DARK ENERGY SURVEY

DES Overview

Tom Diehl for FNAL/DES

Oct. 30, 2023

Overview

Data

Recent Cosmology Results

More than just cosmology

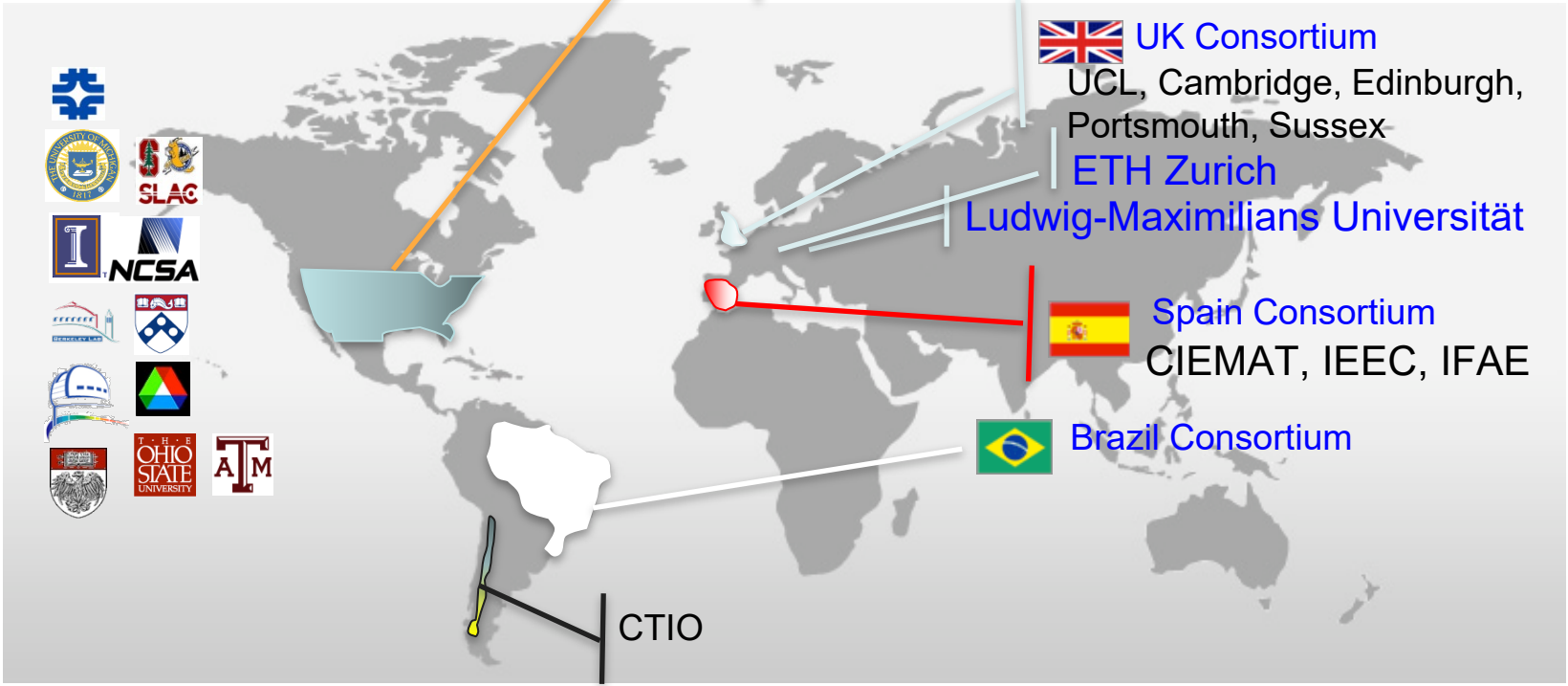
Some slides from FNAL/DES

Plan

DARK ENERGY SURVEY

Started in 2003, DES is now an international collaboration of ~500 scientists from 27 institutions + associates

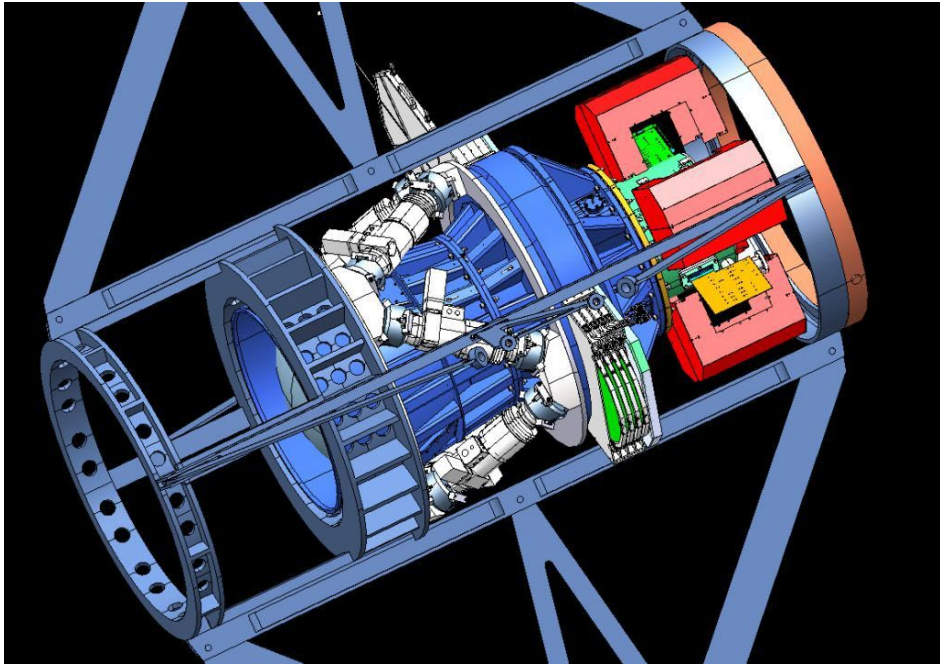
Fermilab, UIUC/NCSA, University of Chicago, LBNL, NOAO, University of Michigan, University of Pennsylvania, Argonne National Laboratory, Ohio State University, Santa-Cruz/SLAC/Stanford Consortium, TAMU



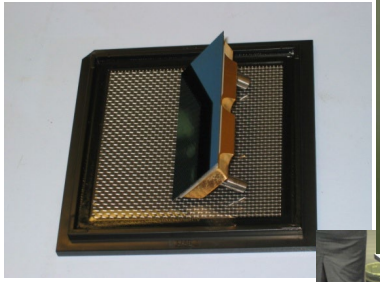
DARK ENERGY SURVEY

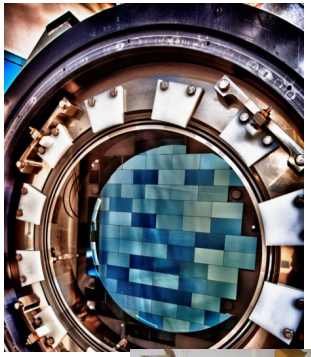
The Dark Energy Camera: Designed and Built at Fermilab

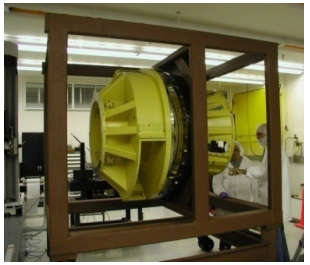
- Spider/Cage
- Barrel
- Optics:Lenses
- Optics:Filters
- Shutter
- Hexapod
- CCDs
- Electronics
- Controls

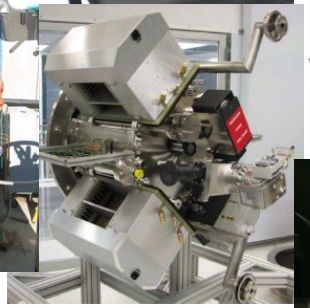


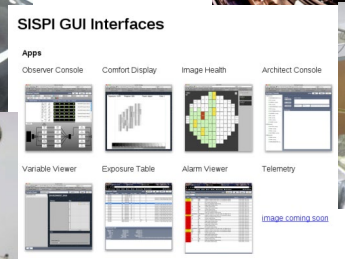
The Dark Energy Camera in Parts







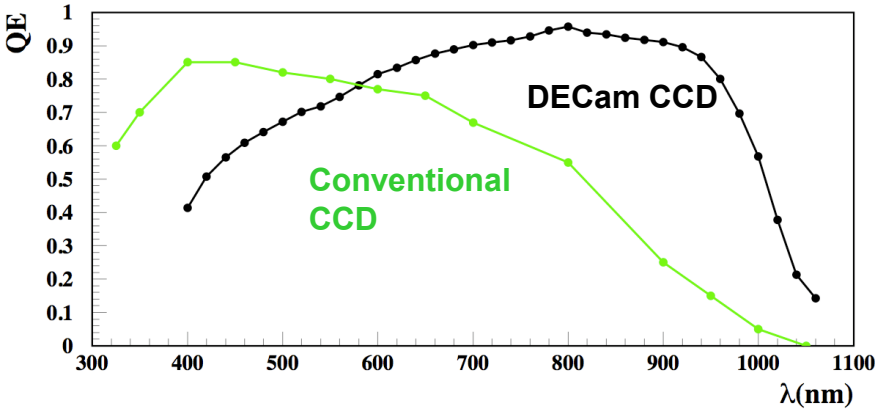


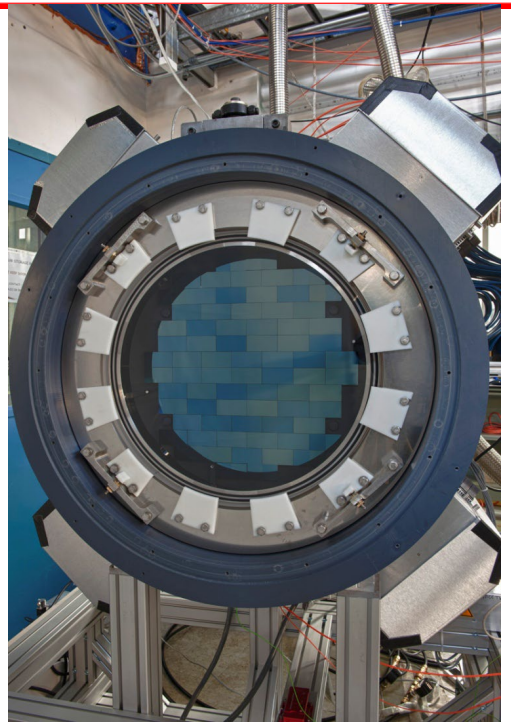


The Dark Energy Camera is powerful

DARK ENERGY SURVEY

- Blanco Telescope w/ 4m primary mirror
- Large (45 cm diameter) Focal Plane, 2 deg across
- 74 High “Quantum Efficiency” CCDs, especially good in the near-infrared wavelengths.
- 570 Mpix readout in 20s.





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- Cerro Tololo is at ~7200 ft near La Serena, Chile
- Home of the Blanco 4m Telescoper

DARK ENERGY SURVEY

DECam

Built 2008 to 2011

Installed on the telescope in 2012

1st Light in September 2012

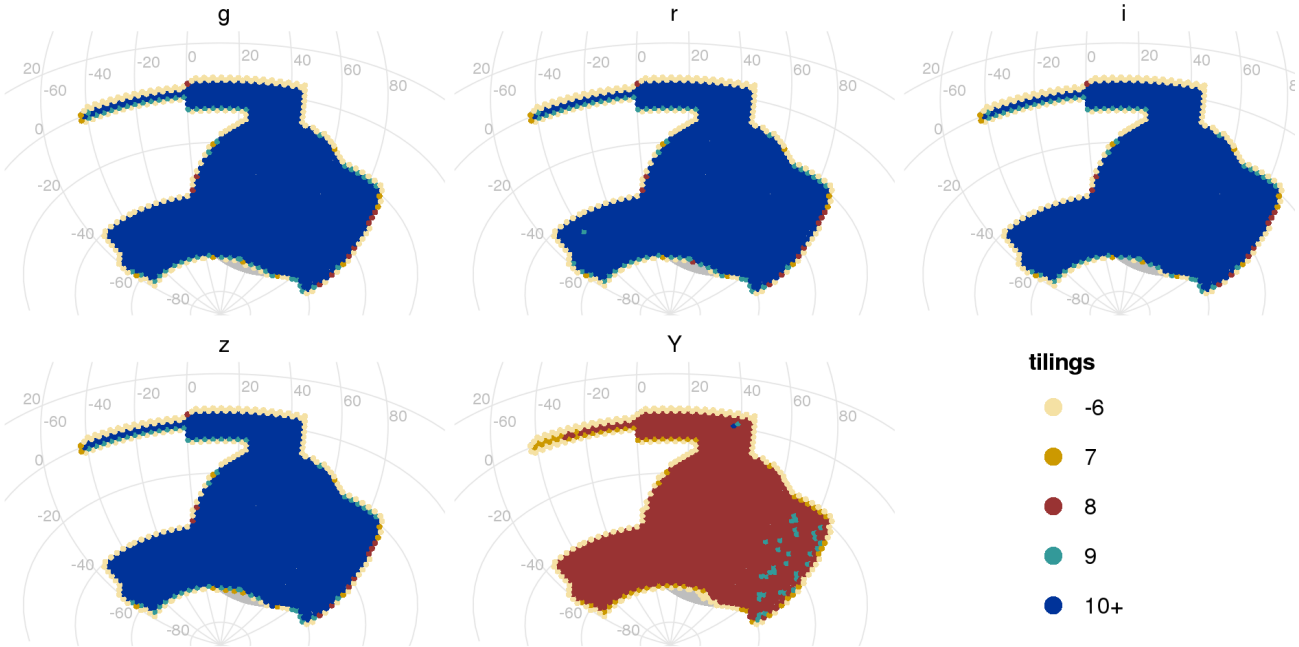
DARK ENERGY SURVEY

DES Widefield Data

Took > 100,000 Images from 2013 to 2019.

“10+” tilings in 5 filter bands.

180 different DES collaborators observed at CTIO



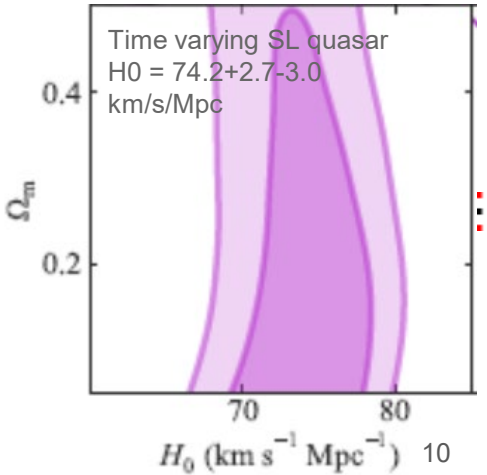
DES: Cosmology 7 Ways

DARK ENERGY SURVEY

Growth rate of structure and Expansion History:
Weak Gravitational Lensing, Galaxy Clustering, Galaxy Cluster Abundance

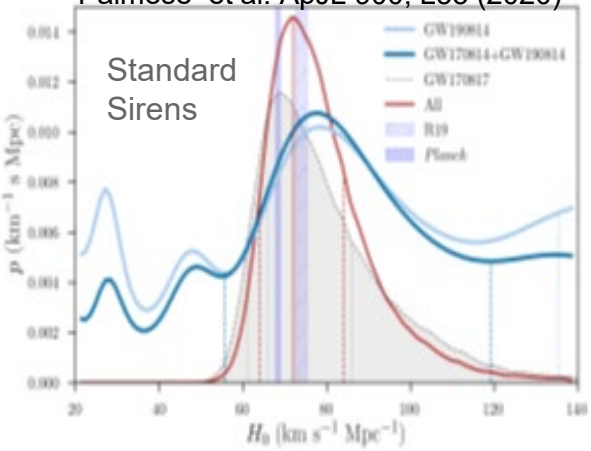
Expansion History:
BAO (standard rulers), SNIa (standard candles),
Gravitational Wave Follow up (standard sirens),
Time delays from Strongly-Lensed Transients.

Some shown here:



Shahib et al., MNRAS 494, 6072 (2020)

Palmese et al. ApJL 900, L33 (2020)

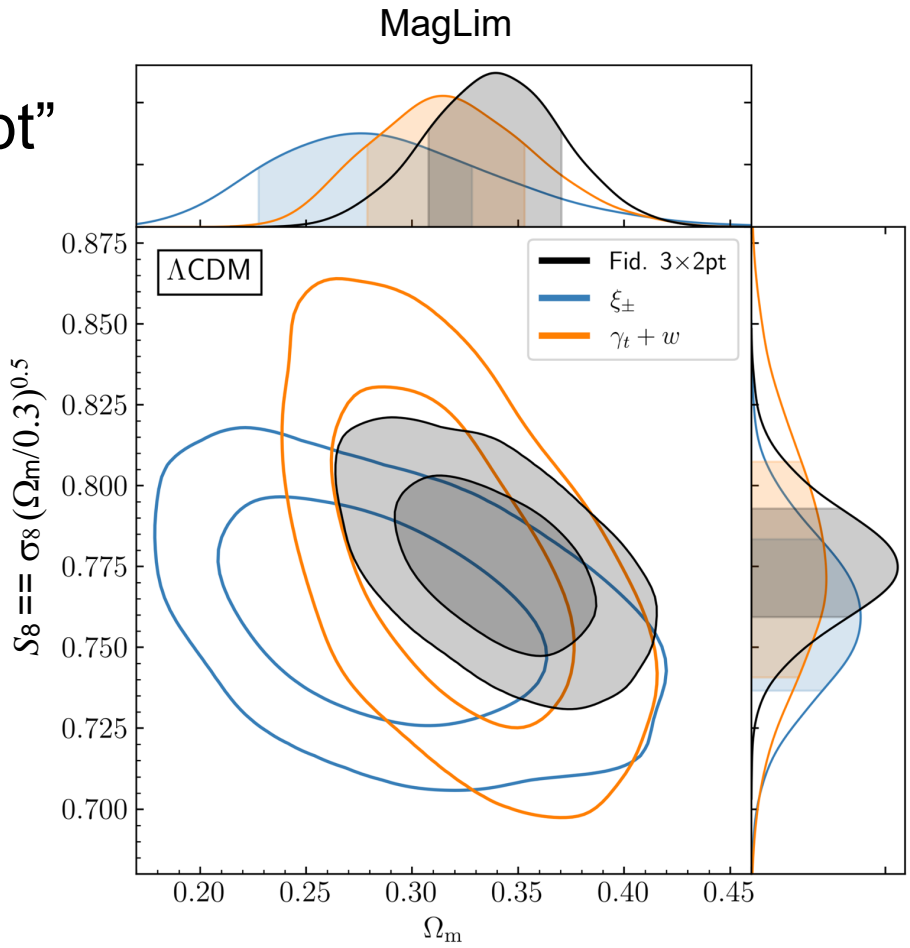


DES Y3 Weak Lensing Cosmology Results “3x2pt”

DARK ENERGY SURVEY

ΛCDM	$S_8 = 0.776^{+0.017}_{-0.017}$ (0.776)
	$\Omega_m = 0.339^{+0.032}_{-0.031}$ (0.372)
	$\sigma_8 = 0.733^{+0.039}_{-0.049}$ (0.696)
*w*CDM	$\Omega_m = 0.352^{+0.035}_{-0.041}$ (0.339)
	$w = -0.98^{+0.32}_{-0.20}$ (−1.03)

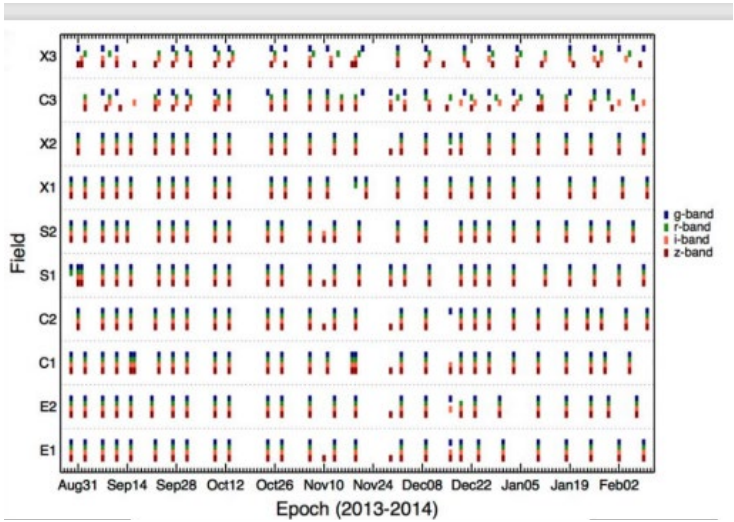
- Lens samples MagLim and redMaGiC 3x2 in perfect agreement
- Evidence for potential systematics in the redMaGiC clustering data vector at all redshifts and above the fiducial lens redshift range for MagLim. *arXiv:2105.13549 DES Collaboration (2021)*

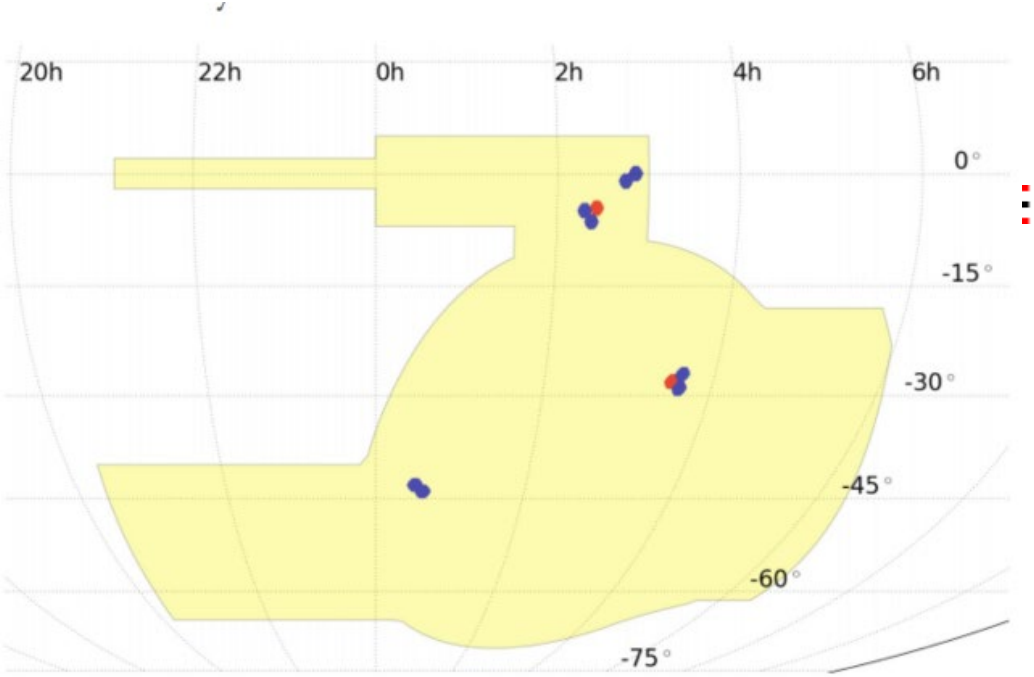


Press Release: https://news.fnal.gov/2021/05/dark-energy-survey-releases-most-precise-look-at-the-universes-evolution/

DES SN Data

DARK ENERGY SURVEY





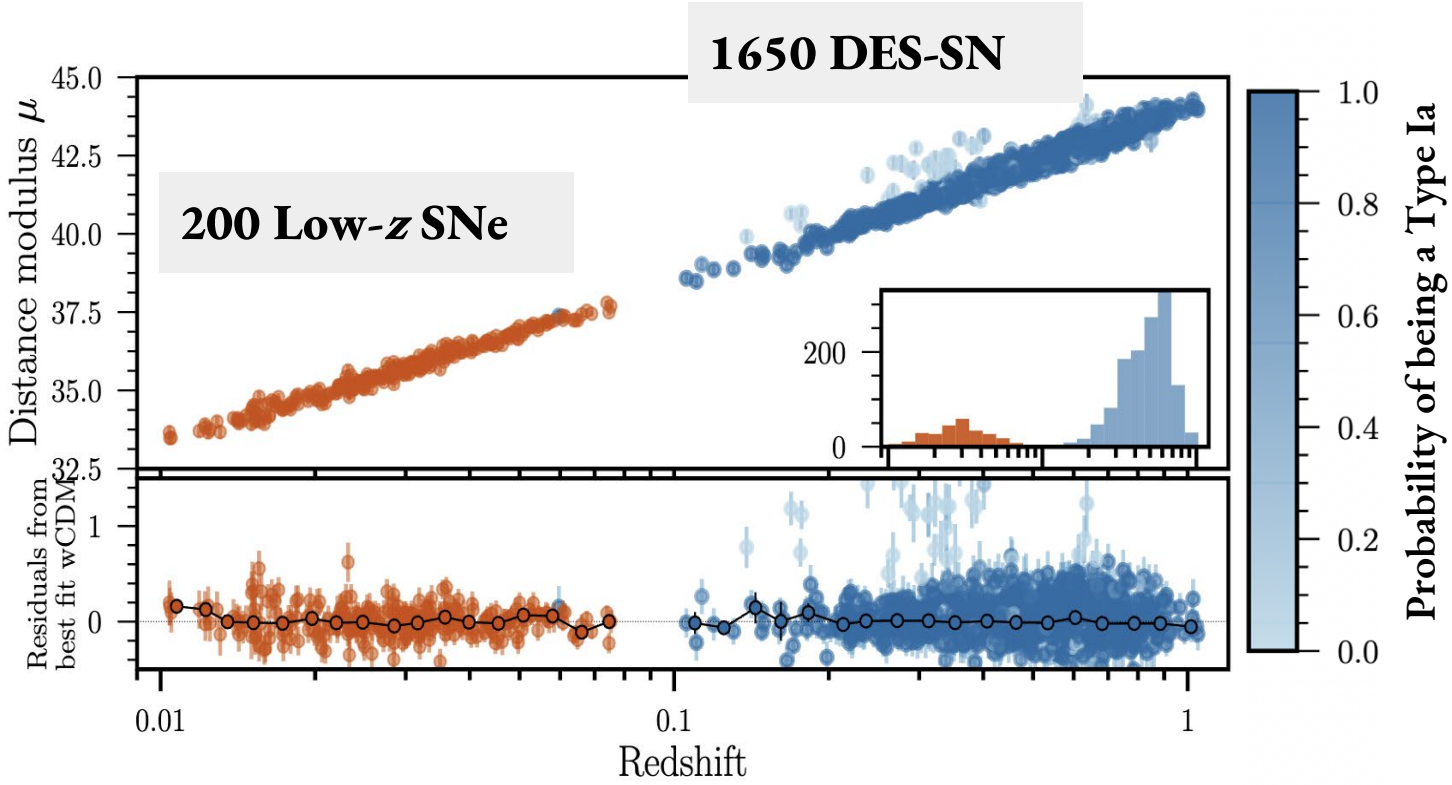
Took Images from 2013 to 2018 on ~ weekly cadence from Aug. to Feb.

RHS: SN Fields

Above: bars represent observations in one of 5 seasons

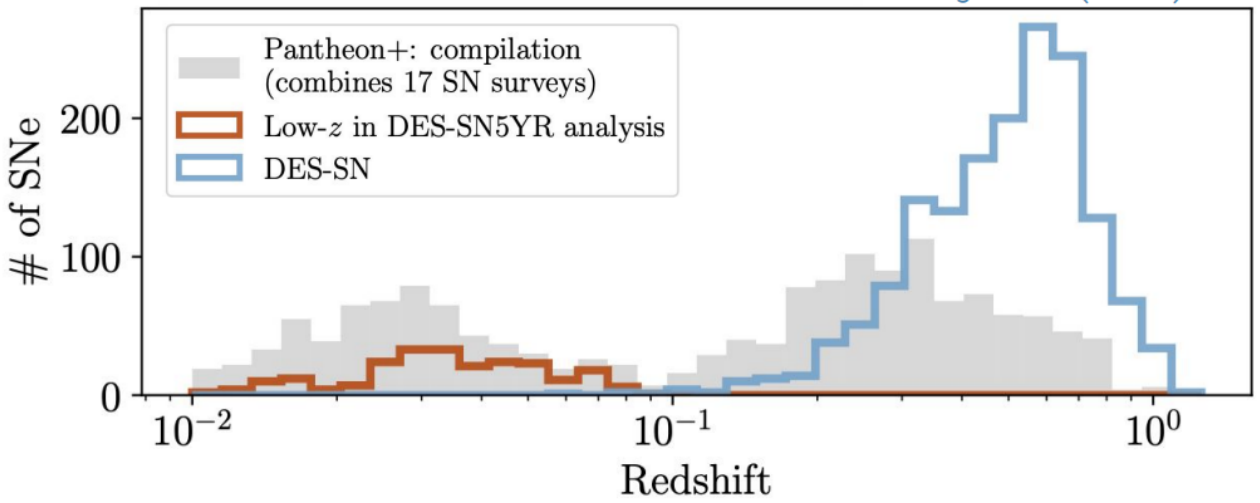
DARK ENERGY SURVEY

SN Sample: Photometrically-typed redshifts from spectroscopy of host galaxies



To illustrate size of DES SN1a sample:

DES contributes 80% of known high-z SNe (z > 0.5)!



The DES SN sample is the **largest** and **deepest** SN sample from a **single telescope ever compiled**

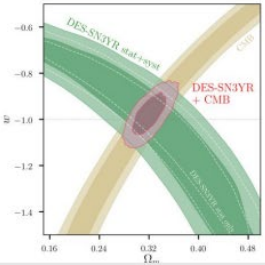
Biggest z>0.5 SN sample by a factor of 4 over all previous combined

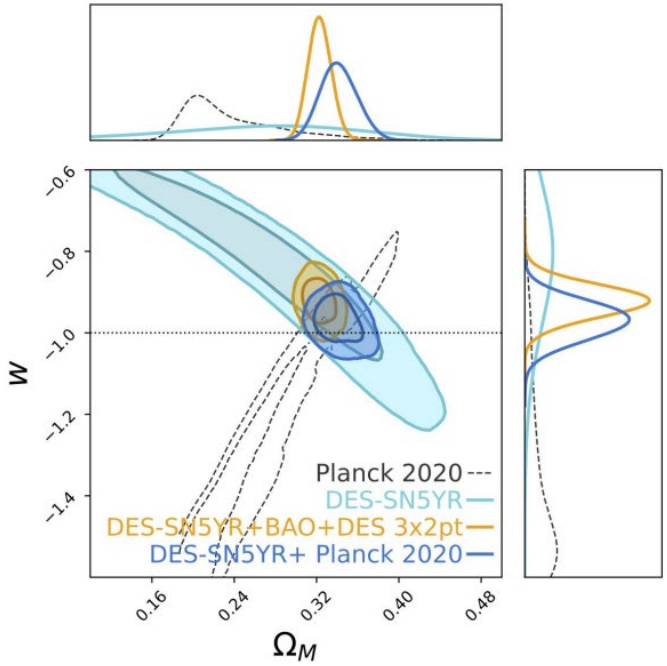
SNIae Cosmology Results

DARK ENERGY SURVEY

Flat-wCDM

	Ω_m	Ω_k	w_0	w_a
DES-SN5YR (no external priors)				
Flat-wCDM	$0.283^{+0.082}_{-0.076}$	-	$-0.80^{+0.14}_{-0.15}$	-
DES-SN5YR + Planck 2020				
Flat-wCDM	$0.337^{+0.017}_{-0.011}$	-	$-0.965^{+0.034}_{-0.038}$	-
DES-SN5YR + eBOSS BAO and DES 3x2pt				
Flat-wCDM	$0.323^{+0.009}_{-0.012}$	-	-0.922 ± 0.037	-
DES SN only (no Low-z)				
Flat-wCDM	$0.397^{+0.026}_{-0.038}$	-	$-1.64^{+0.39}_{-0.20}$	-





- Look for complete set of results on the arxiv soon

DES Publishes more than cosmology
Milky Way Structure, Solar System Objects, transients, Strong Lensing …

Through Sept. 30, 2023, DES has 442 refereed science papers (not counting pre-data technical papers) with 26,000+ citations. **A sample of papers from a couple of years ago**:

Instrumental: *"A Machine Learning Approach to the Detection of Ghosting and Scattered Light Artifacts in Dark Energy Survey Images", "Reducing ground-based astrometric errors with Gaia and Gaussian processes" will both be useful to LSST*

Solar System: *"Testing the isotropy of the Dark Energy Survey's extreme trans-Neptunian objects"*

SN1ae: *"OzDES multifibre spectroscopy for the Dark Energy Survey: Results and implications for future surveys", "The Effect of Environment on Type Ia Supernovae in the Dark Energy Survey Three-Year Cosmological Sample", "The Dark Energy Survey Supernova Program: Modelling selection efficiency and observed core collapse supernova contamination", "Rates and delay times of type Ia supernovae in the Dark Energy Survey"*

Galaxy Clusters: *"Is diffuse intracluster light a good tracer of the galaxy cluster matter distribution?", "μ^* Masses: Weak Lensing Calibration of the Dark Energy Survey Year 1 redMaPPer Clusters using Stellar Masses", "The WaZP galaxy cluster sample of the Dark Energy Survey Year 1"*

Weak Lensing: *"Galaxy Clustering in Harmonic Space from the Dark Energy Survey Year 1 Data: Compatibility with Real Space Results"*

Galaxy Clusters + WL: *"Combination of cluster number counts and two-point correlations: Validation on Mock Dark Energy Survey", "Dark Energy Survey Year 1 Results: Cosmological Constraints from Cluster Abundances, Weak Lensing, and Galaxy Correlations"*

Galaxy Clusters + External Data: *"Cosmological Constraints from DES Y1 Cluster Abundances and SPT Multi-wavelength data", "Probing galaxy evolution in massive clusters using ACT and DES: splashback as a cosmic clock", "The Atacama Cosmology Telescope: A Catalog of > 4000 Sunyaev-Zel'dovich Galaxy Clusters"*

Modified Gravity*: "Probing gravity with the DES-CMASS sample and BOSS spectroscopy", "Galaxy-galaxy lensing with the DES-CMASS catalogue: measurement and constraints on the galaxy-matter cross-correlation"*

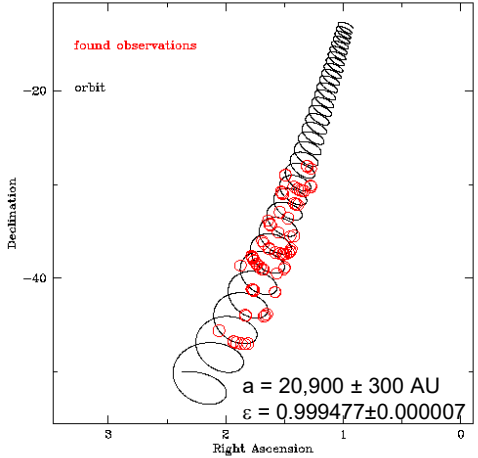
Optical + GW: *"Constraints on the Physical Properties of S190814bv through Simulations based on DECam Follow-up Observations by DES"*

Dark Matter: *"Milky Way Satellite Census. III. Constraints on Dark Matter Properties from Observations of Milky Way Satellite Galaxies", "Constraints on Decaying Dark Matter with DES-Y1 and external data" .*

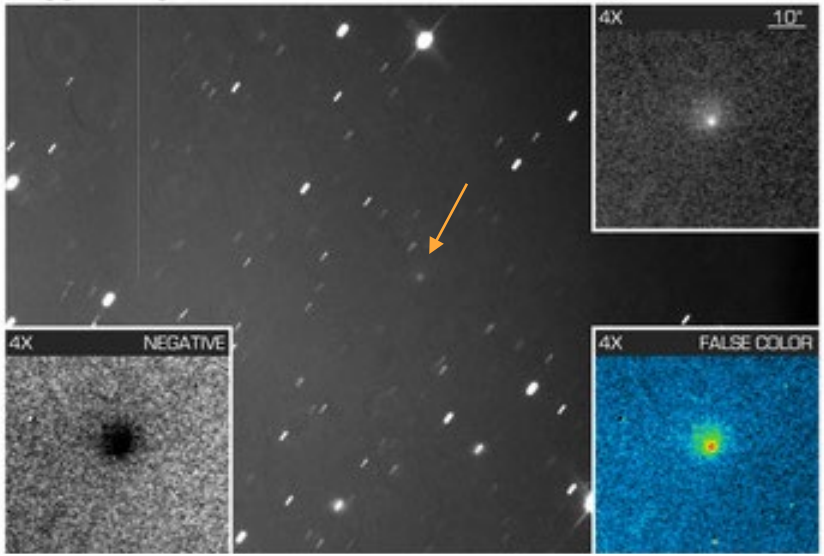
Galaxy Evolution: *"Galaxy Morphological Classification Catalogue of the Dark Energy Survey Year 3 data with Convolutional Neural Networks"*

Most Massive & Most Distant Comet C/2014 UN271 “Bernardinelli-Bernstein”

DARK ENERGY SURVEY



- DES data is great for finding “Transient and Moving Objects”
- 245+ New Trans-Neptunian Objects @ 30 to 100 AU



- C/2014 UN271 was detected as it came in from the Oort cloud at 29 to 23 AU
- Massive (~200 km wide) comet discovered.
- Early studies of the coma show sub-mm sized grains at 7 m/s as well as sublimation of CO
- Perihelion at 11 AU in 2031, so we’ll watch this one “turn on” for a long time

https://www.syfy.com/syfywire/gigantic-comet-is-currently-inbound-toward-the-sun

DARK ENERGY SURVEY

The only observed companion event to a gravitational wave

arXiv:1710.05459, ApJL 848, L16 (2017)

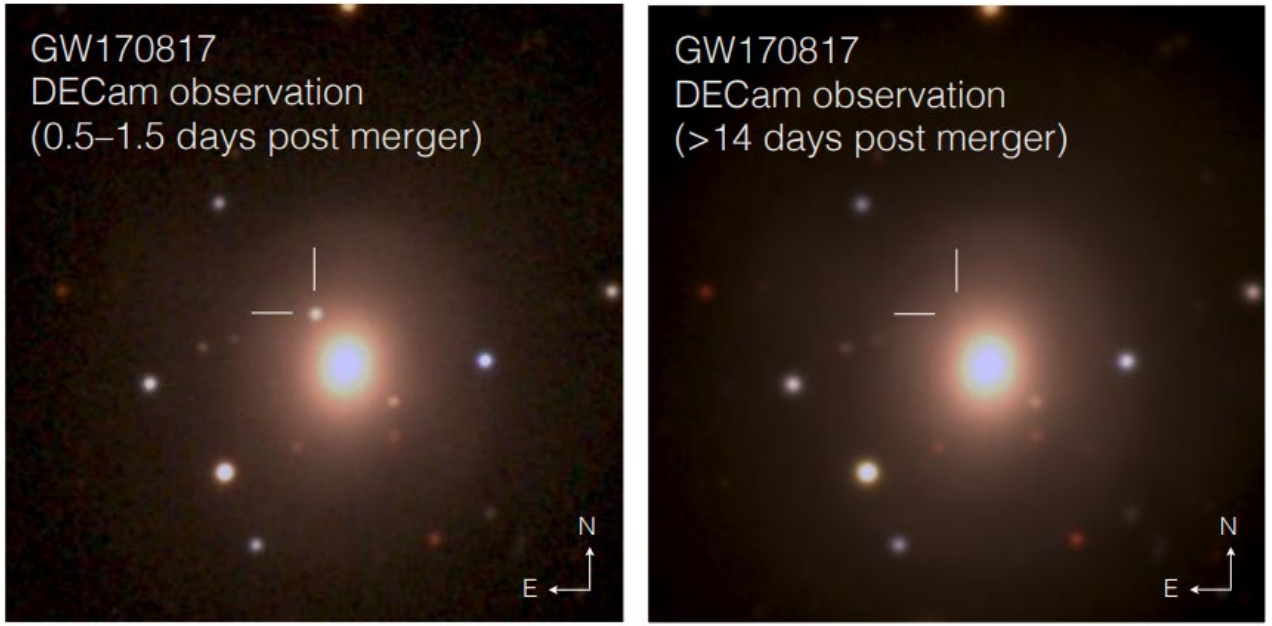


Figure 1. NGC4993 *grz* color composites (1.5'×1.5'). Left: Composite of detection images, including the discovery *z* image taken on 2017 August 18 00:05:23 UT and the g and r images taken 1 day later; the optical counterpart of GW170817 is at RA,Dec = 197.450374, −23.381495. Right: The same area two weeks later.

Things we are doing & The Plan:

- Preparing to move public data service from NCSA to Fermilab
- Preparing to move darkenergysurvey.org website from a private co. to Fermilab
- Finish the Y6 Cosmology Analysis (2024-2025)
- Continue to do great science (… to xy/za/bcde …)

DARK ENERGY SURVEY

STRIDES COLLABORATION: Buckley, Lin et al.

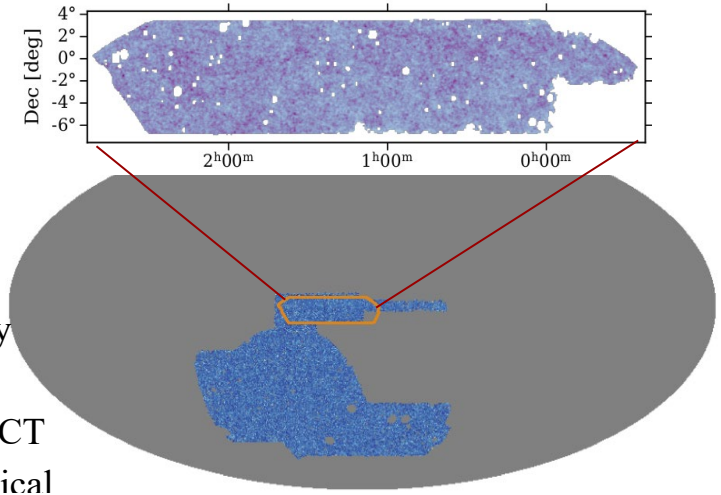
- In 2013 we formed the STRIDES collaboration
  - Fermilab: Liz Buckley-Geer, Huan Lin with people from other surveys
- The goal was to search for lensed QSOs in the DES data and to carry out all the necessary follow-up observations needed to measure H_0.
- So far we have discovered 35 systems from DES (9 quads, 2 triples, 28 doubles). Papers & cosmology!

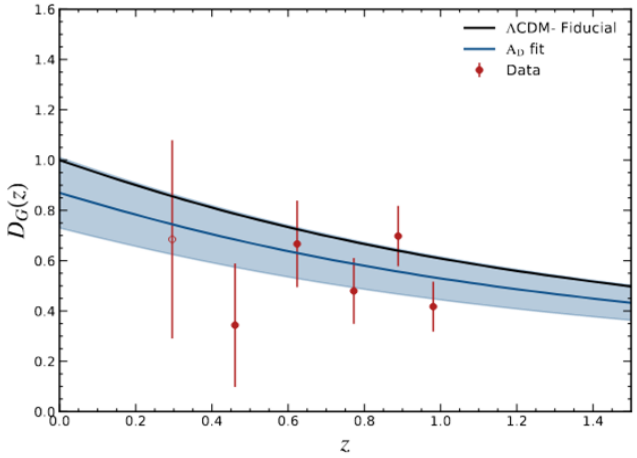
DES Y3 galaxies x ACT CMB lensing And More (see extra slides)!

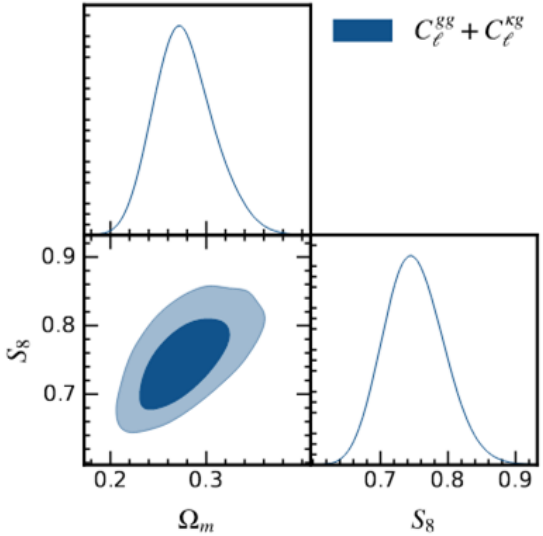
DARK ENERGY SURVEY

***G.A. Marques**, ACT & DES collaborations, 2023 (arxiv: 2306.17268)*

- ACT CMB lensing is signal dominated on large angular scales → very important for cross-correlation studies
- Dark Energy Survey-Y3→ Very dense catalog +Great overlap with ACT
- Constraints on evolution of the growth of the structures and cosmological parameters

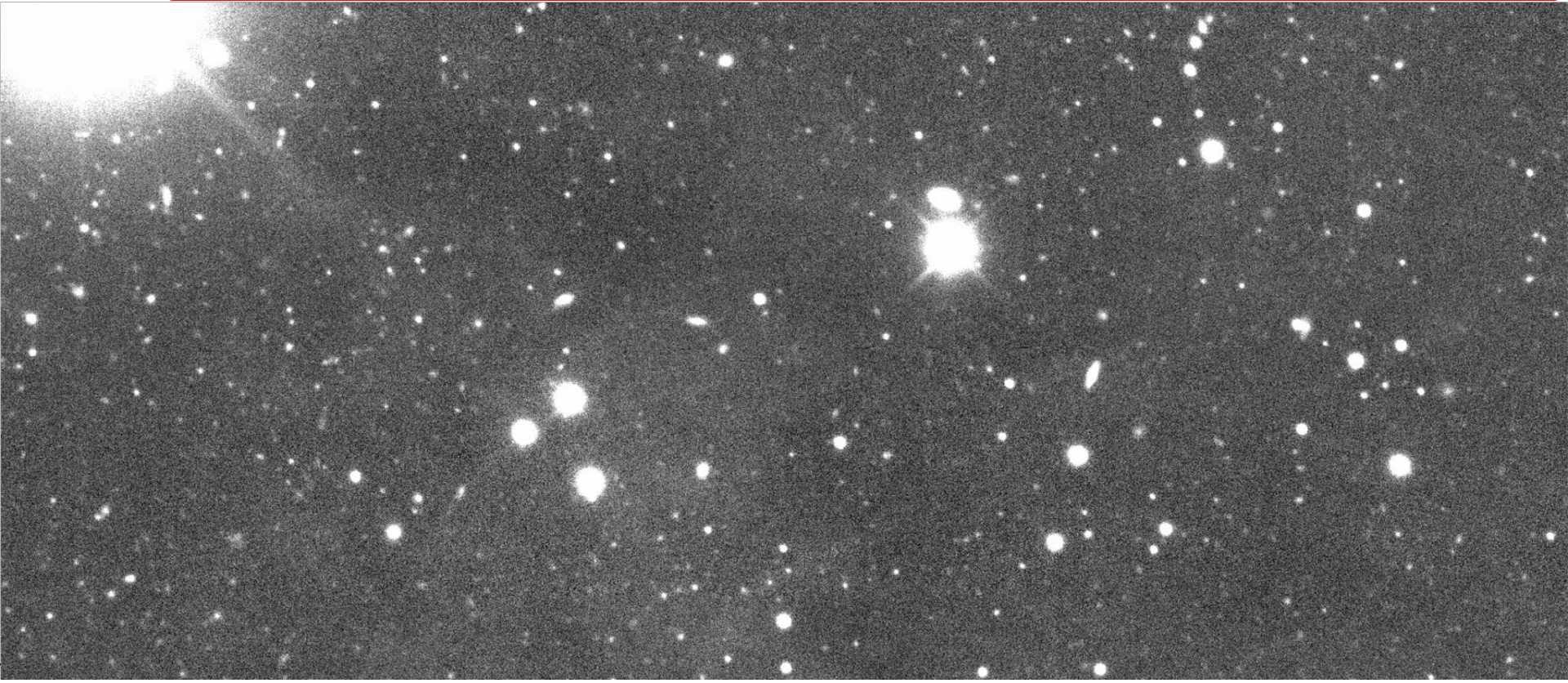






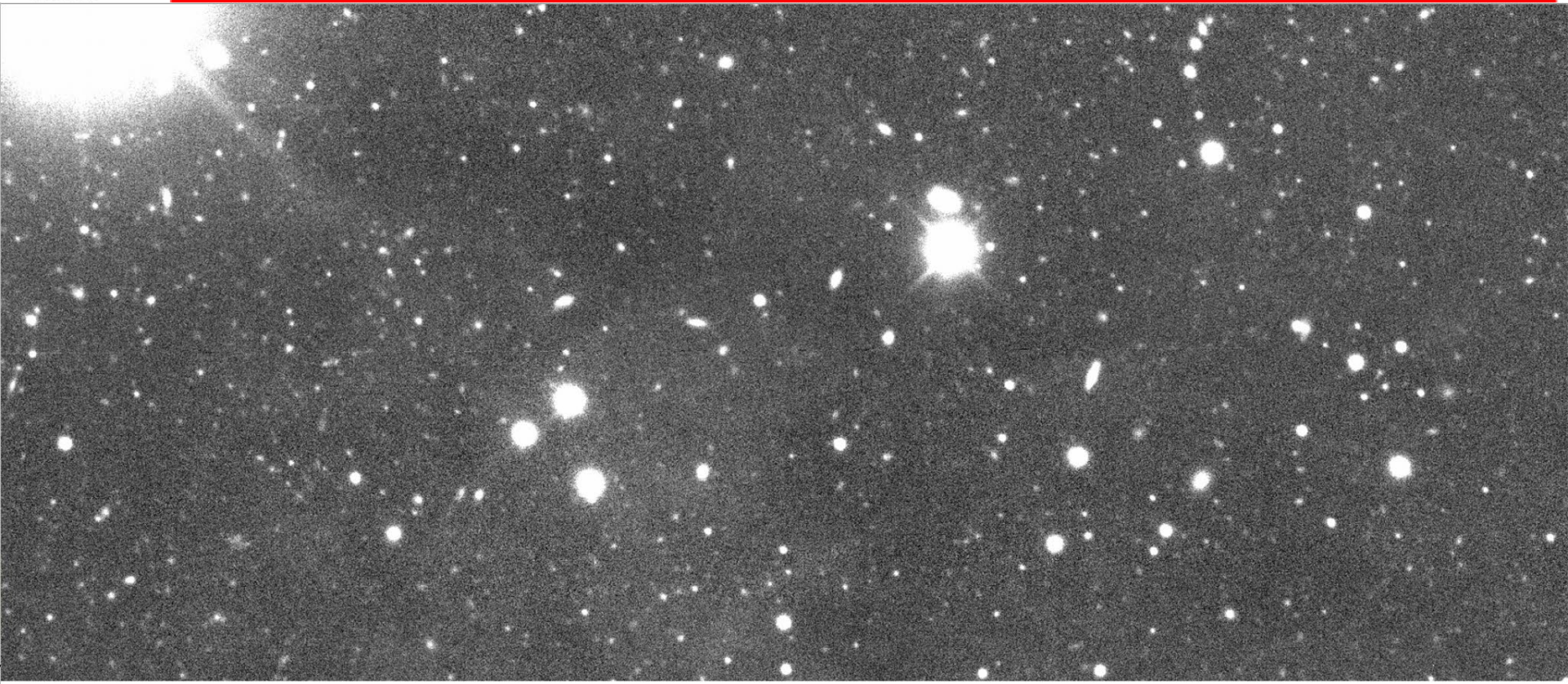
DARK ENERGY SURVEY

BALROG OFF



DARK ENERGY SURVEY

BALROG ON (M. Tabbutt UWisc)

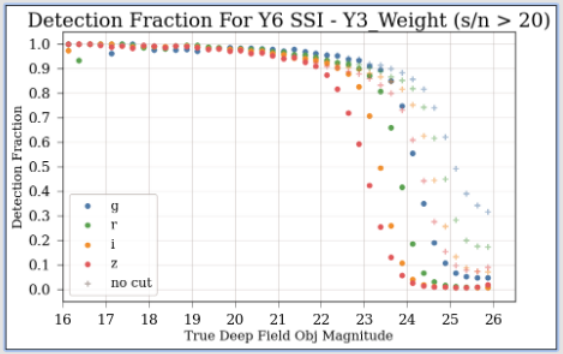


DESDM @ FNAL, Alex Drlica-Wagner (Y6 Gold)

- Not just finding and identifying stars and galaxies (done), the DESDM group runs the key cosmology data processing pipelines on FNAL, NERSC, and UIUC computers
- @ FNAL: WL Shears, Deep Fields, BALROG, & IMSIM … led by Brian Yanny
- Y6 Gold Cosmology Data led by Alex Drlica-Wagner

BALROG is used find precise redshifts, calculate systematic uncertainties

IY6 Completeness – Key science output of Balrog



Detection fraction by band for Balrog injections in the 100 tiles

Only for DF objects randomly chosen "Y3_weight" scheme

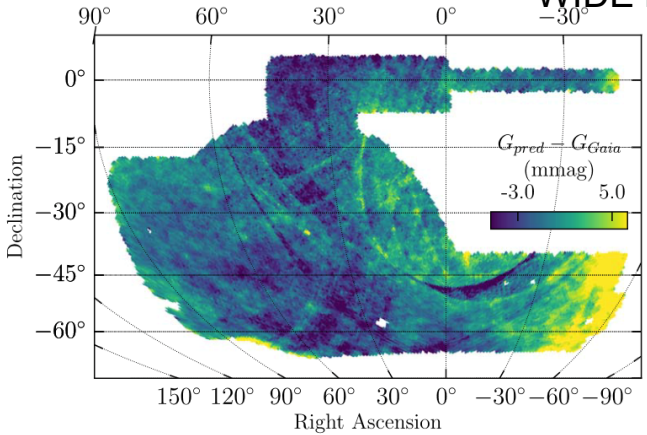
s/n cut of 20 shown in solid dots, all objects (no cut) shown in transparent pluses

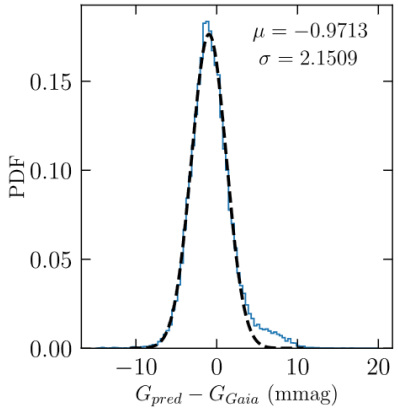
Calibration (Wide Field and Deep Fields)

Doug Tucker w/Drs. M. Wiesner, JA. Smith, and Williger and UG interns

DARK ENERGY SURVEY

WIDE FIELD (Abbott et al. 2021, ApJS, 255, 20; Figure 4)



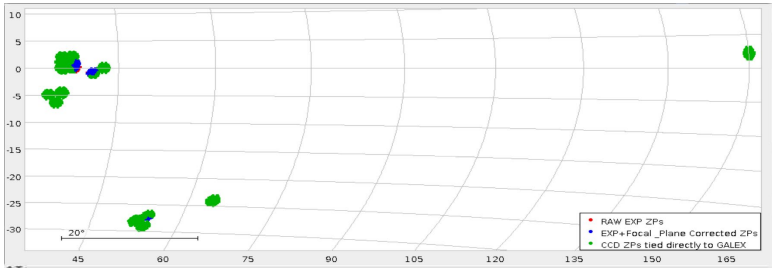


	g	r	i	z	Y
σstat	0.22 %	0.22 %	0.22 %	0.22 %	0.33 %
σsys	1.1 %	1.1 %	1.1 %	1.2 %	1.2 %

- Deep Fields:

g, r, i, z tied to FGCM Standard Stars and to ATLAS-REFCAT (if no FGCM overlap).

u-band tied to GALEX/Gaia DR3, with special effort to calibrate CCD images having no GALEX overlap.



DELVE (led by Alex Drlica-Wagner)

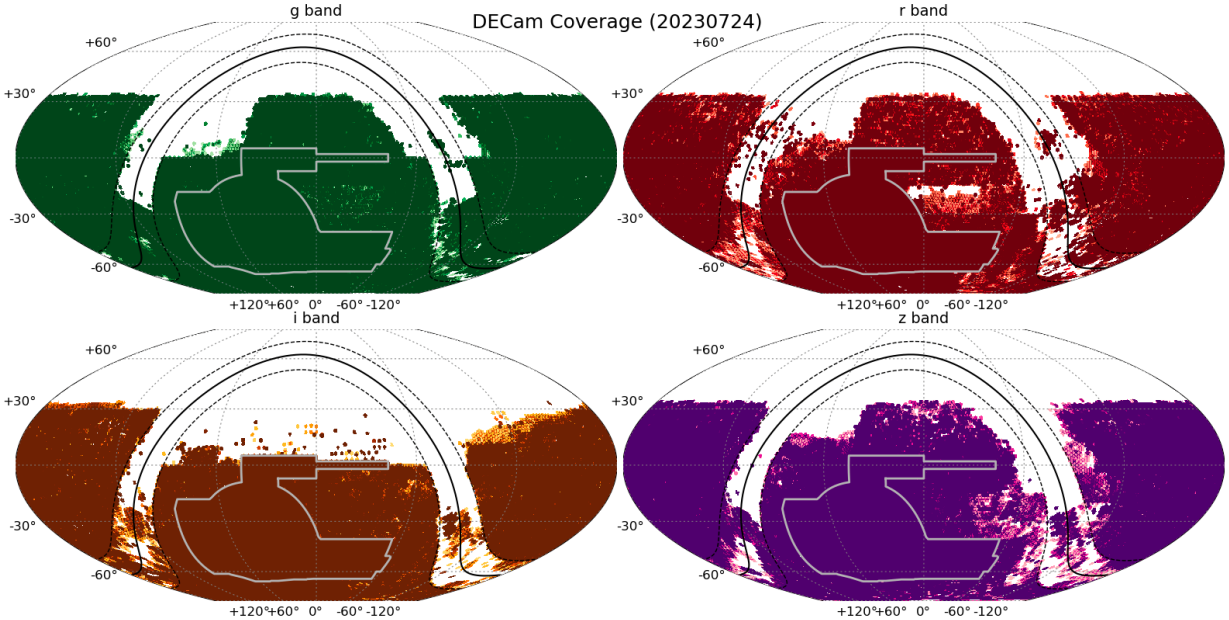
DARK ENERGY SURVEY

3rd largest DECam survey to date.

Observed on 296 distinct nights

Collaboration of ~80 scientist led by Fermilab.

Funded by LDRD, NASA, & NSF.

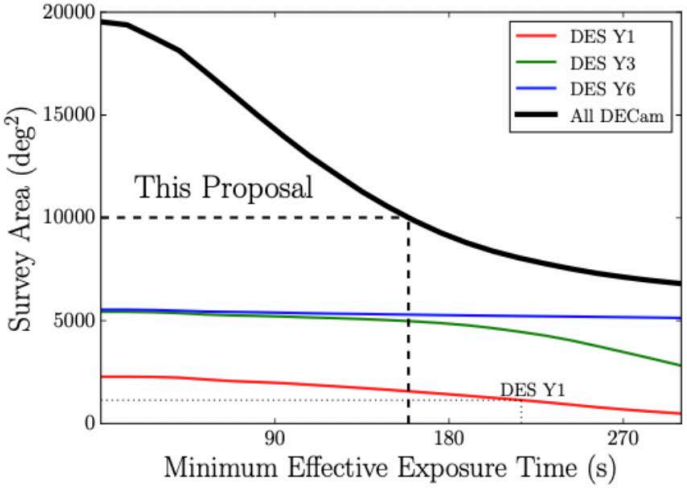


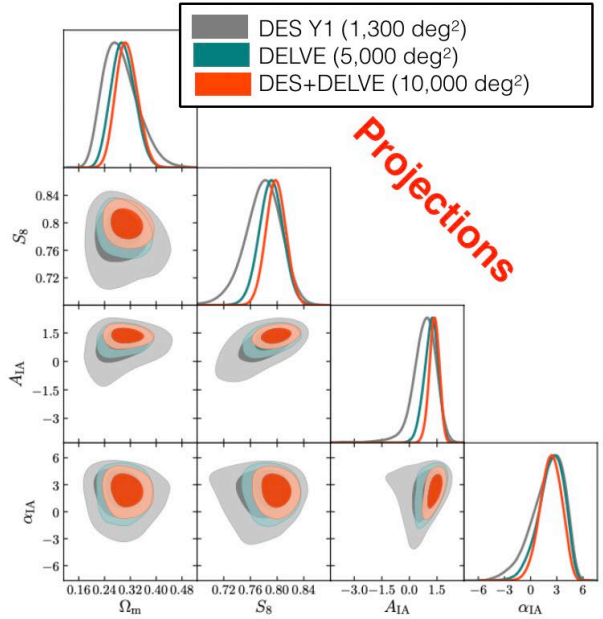
DELVE Cosmic Shear

DARK ENERGY SURVEY

Nathalie Chicoine: DES + DELVE (Fall 2023 & Spring 2024 SULI)
Kai Herron: DES + DELVE (Summer 2022 VFP, Summer 2023 VFP, Spring 2023 SULI)
Dan Suson: DELVE (Summer 2021 VFP, Summer 2022 VFP, Summer 2023 VFP)
Jonah Medoff: DELVE (Summer 2023 SULI)
Caleb Levy: DES (Summer 2021 SIST)
Will Cerny: DELVE (Summer 2021 SULI)
Peter Ferguson: DELVE (Fall 2020 URA Visiting Scholar)

Weak Lensing and LSS



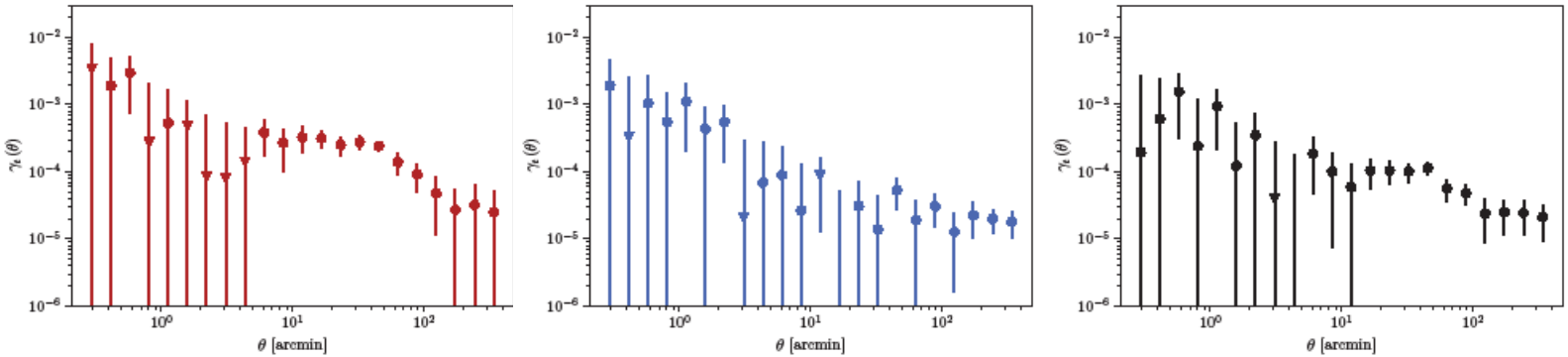


Close collaboration with UChicago and UIUC/NCSA. Funded by LDRD & NSF.

Weak Lensing by Low Surface Brightness Galaxies

From Nathalie Chicoine, working with UC people

- measure weak-lensing shears of ~18,000 blue and 8,000 red LSBGs. These have more than the usual amount of DM vs stars



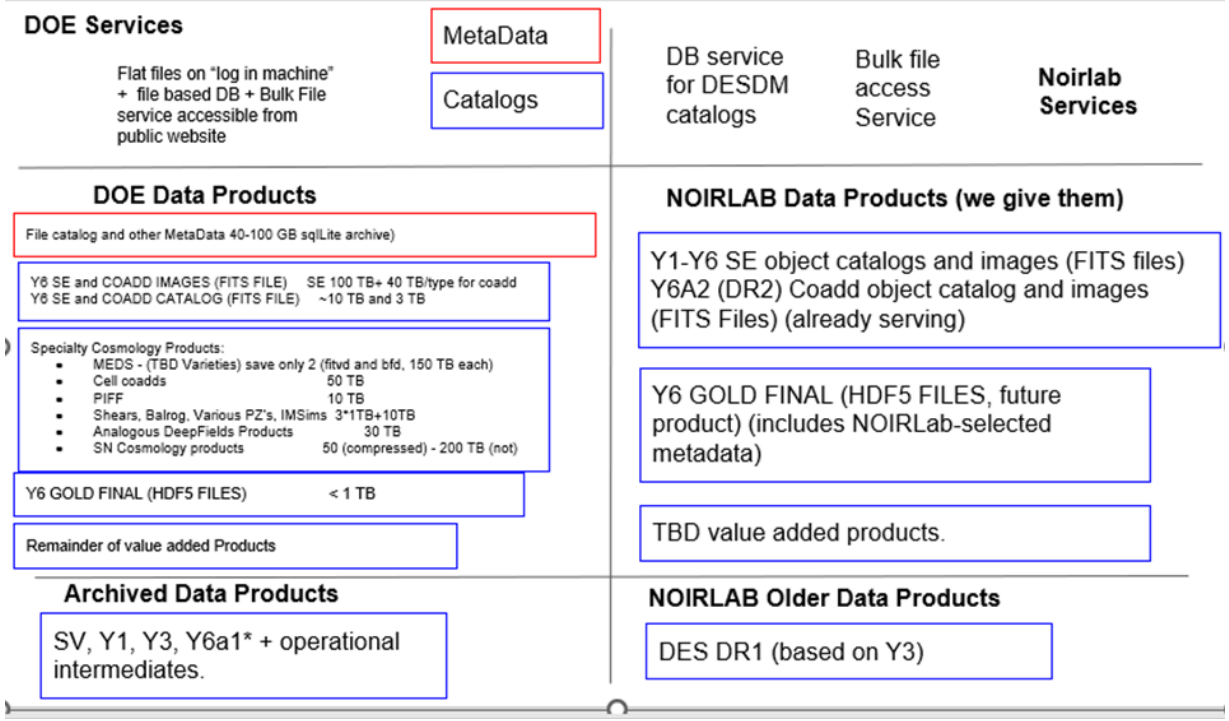
- Compare the stellar mass vs weak lensing mass to get info on the mass distributions

The Big Bangers: Longest Reigning Champs

- Three time champs, the Big Bangers, won the FNAL softball league championship in 2019. Been practicing during summers since 2022.
- Look for announcement of summer practices in mid-spring 2024.

DES Legacy Cosmology Data Plans

The top of the diagram indicates the services. The part beneath indicates the data products. **The LHS is cosmology data products to be made available at Fermilab.** The information includes the estimated size. RHS is NOIRlab. They already serve the upper-most box in “Data Products”. Discussions are underway with NOIRLab for Y6Gold and TBD data products.



DES Web Page to move from a company to Fermilab: darkenergysurvey.org

DES Y3 shear xACT CMB lensing
G. A. Marques

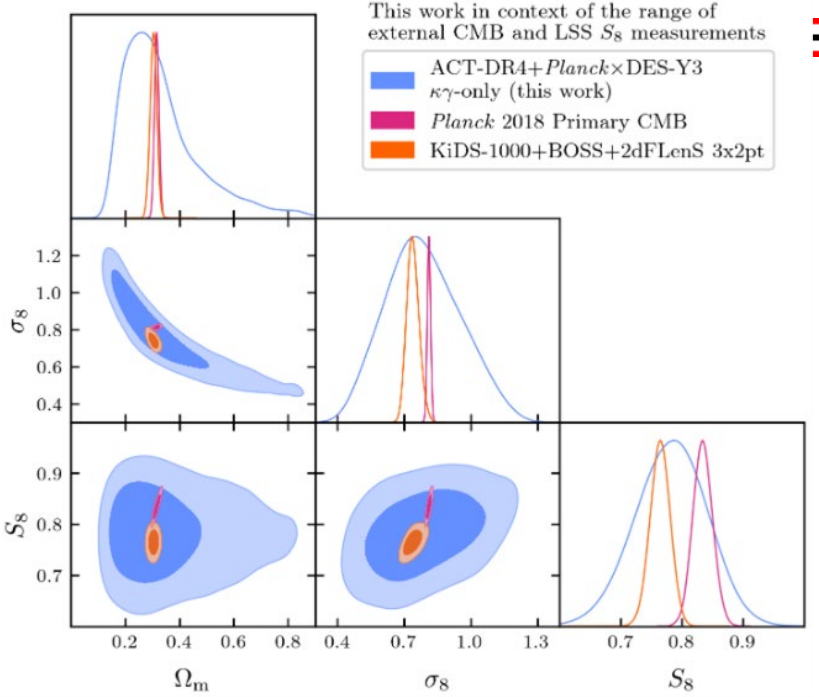
- *Constraints of cosmological parameters purely from cross-correlation →*

and moving towards "6x2" analysis

- *For DES Y6 :*
  - *6x2 pt: CMB lensing + galaxy lensing + galaxy clustering + galaxy lensing x CMB lensing + galaxy x CMB lensing + galaxy-galaxy lensing :*

$$\langle \kappa\kappa \rangle, \langle \gamma\gamma \rangle, \langle gg \rangle, \langle \kappa\gamma \rangle, \langle \kappa g \rangle, \langle \gamma g \rangle$$

Working on individual parts of ACT DR6 x DES Y3
(Chang, Darwish, Harrison, Marques, Pitocco, Shaikh, in prep ++)

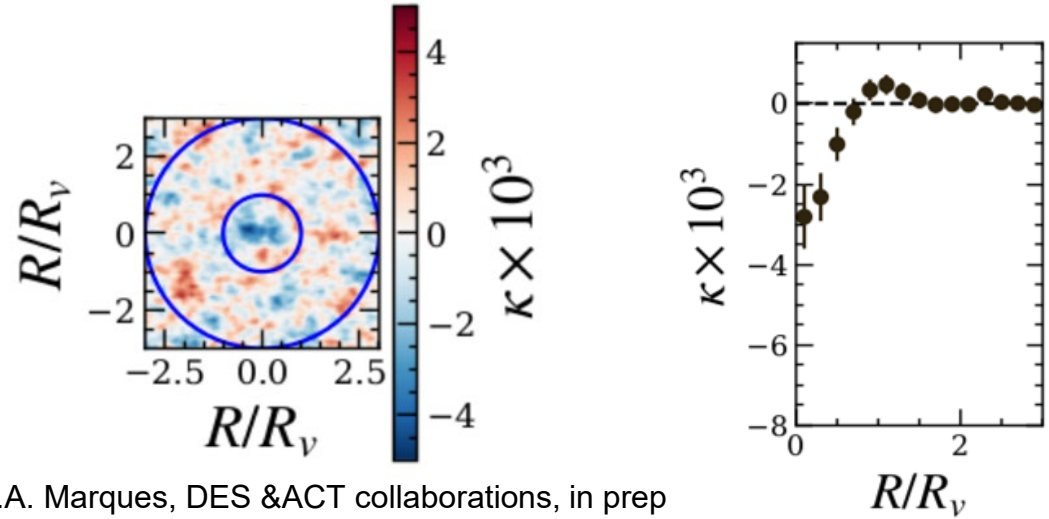


S. Shaik, I. Harrison, A. Engelen, G.A. Marques, and ACT & DES collaborations, 2023 (arxiv: 2309.04412)

Imprints of DES voids on CMB lensing data: G. A. Marques

DARK ENERGY SURVEY

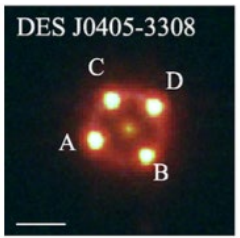
- *Study of the CMB lensing signal associated with DES cosmic voids*
  - *using ACT DR6 lensing map*
    - *signal dominated on large scales and almost ~full overlap with the total DES footprint*
  - *Forecast: 11 sigma detection*
    - *Improvement over the state-of-art (~4 sigma)*

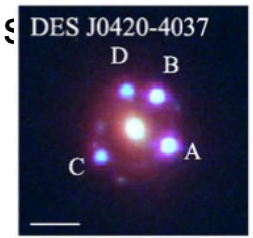


G.A. Marques, DES &ACT collaborations, in prep

STRIDES COLLABORATION: Buckley, Lin et al.

- In 2013 we formed the STRIDES collaboration (ST**R**ong-lensing Insights into **D**ark Energy Survey - PI: Tommaso Treu) between members of the Dark Energy Survey (DES) and a subset of the H0LiCOW and COSMOGRAIL collaborations (Fermilab: Liz Buckley-Geer, Huan Lin)
- The goal was to search for lensed QSOs in the DES data and to carry out all the necessary follow-up observations needed to measure H_0.
- So far we have discovered 35 systems from DES (9 quads, 2 triples, 28 doubles).
- We have ha ucces oposals hed a number of papers.

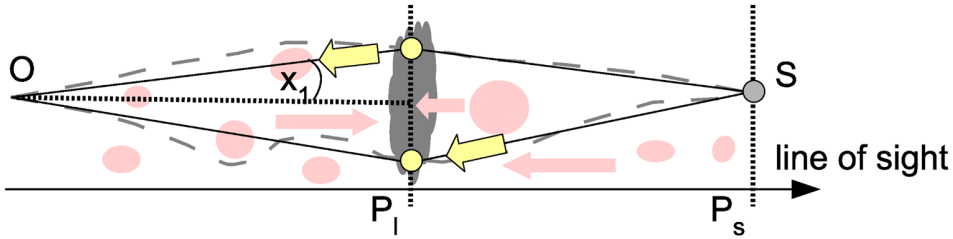




Studying the environment of lensed quasars

DARK ENERGY SURVEY

- The lens model needs to account for massive structures in the vicinity of the lens as well as along the line of sight.



- We use DES or Gemini imaging data around the lens to select objects and then get spectra which allow us to measure the redshifts precisely - required for accurate galaxy group finding
- Eight successful Gemini Proposals since 2021 (Huan Lin, Liz Buckley-Geer + students)