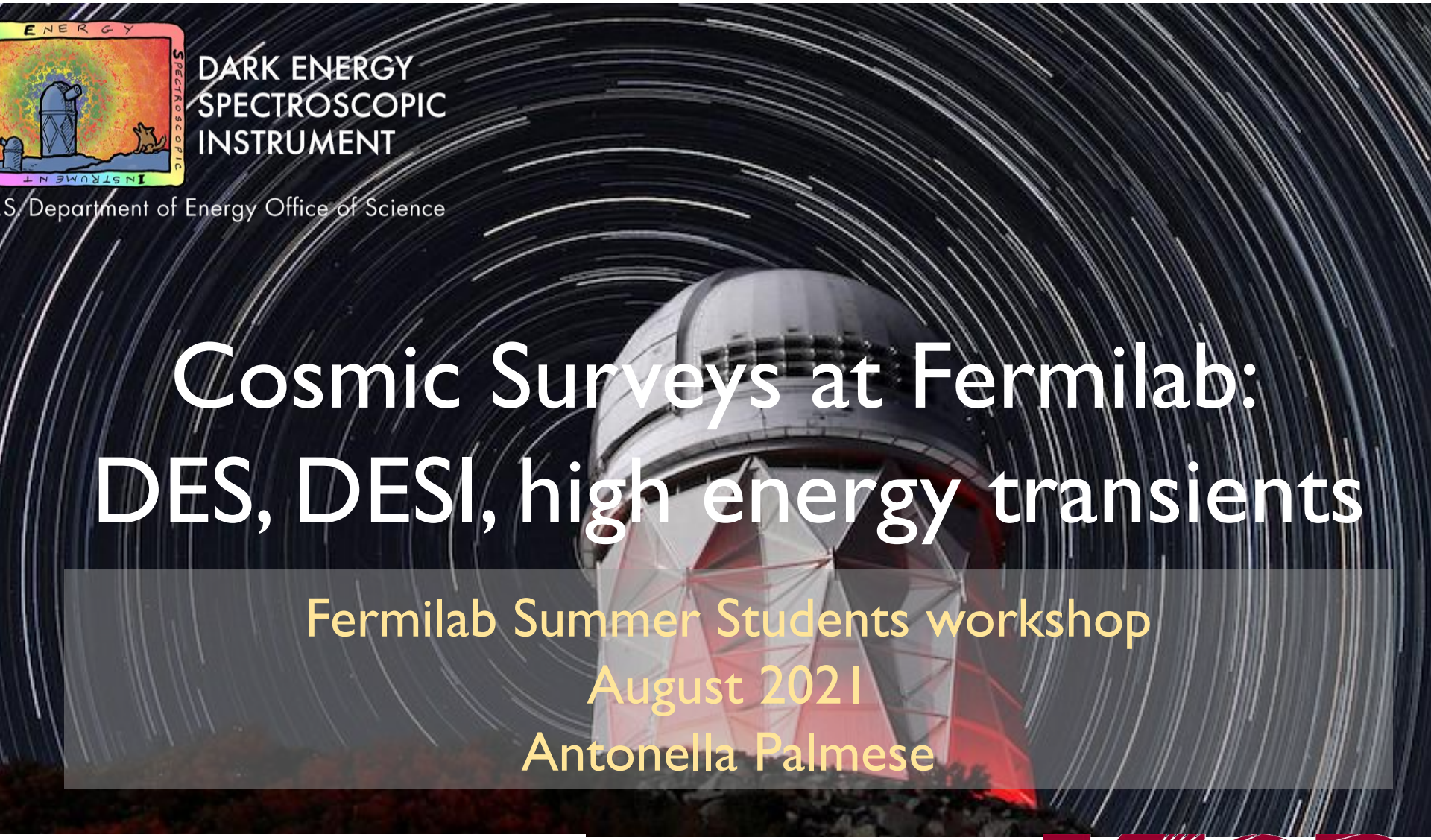


Cosmic Surveys at Fermilab: DES, DESI, high energy transients

Fermilab Summer Students workshop

August 2021

Antonella Palmese

Fermilab

KICP

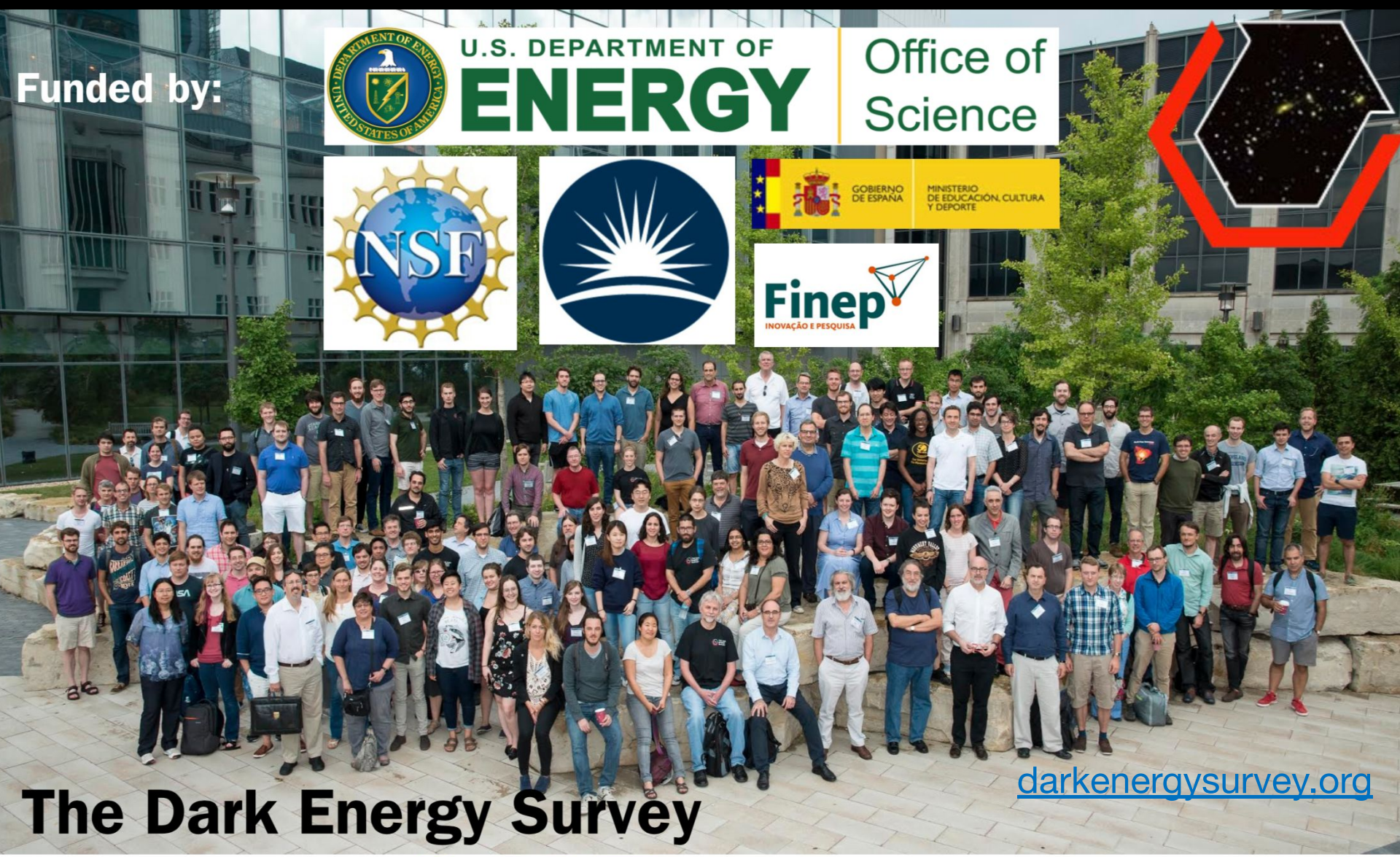
Fermilab CPC

Cosmic Physics Center (CPC) includes several activities:

- Dark matter direct detection experiments
- Astroparticle Theory
- Cosmic Surveys
  - Growing effort on Cosmic Microwave Background (CMB): SPT, CMB-S4
  - Long-term involvement in optical sky surveys: SDSS, DES, DESI, Rubin LSST, LS4, DELVE

April 2021 CPC meeting


Dark Energy Survey
Fermilab-led experiment - Operations completed
Last night - January 8th 2019
NGC1365

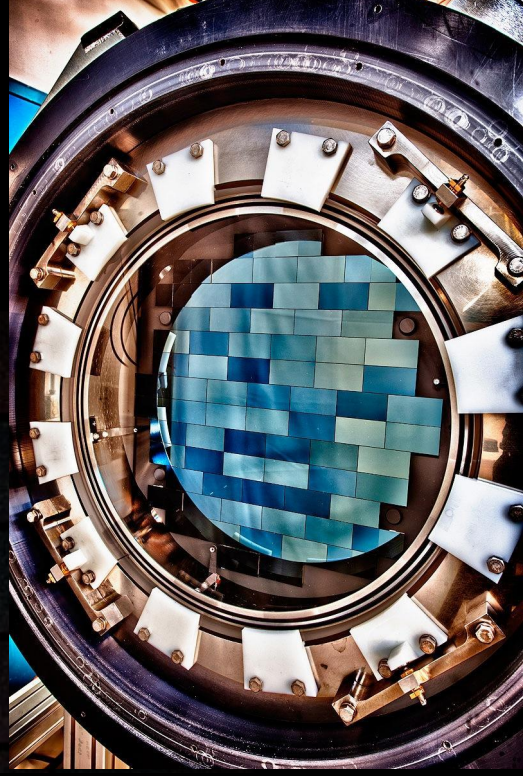


~450 scientists from 25 institutions in 7 countries

facebook.com/darkenergysurvey

NCSA
OHIO STATE UNIVERSITY
BERKELEY LAB
LMU
SLAC
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Dark Energy Survey



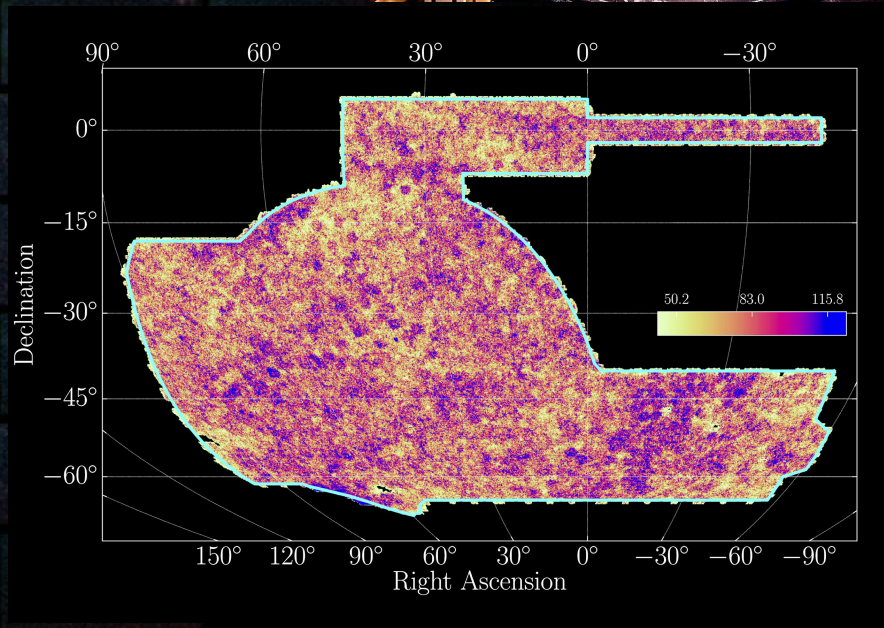
DECam

3 sq deg FOV, 570 Mpix optical CCD camera
Built at Fermilab
Blanco telescope (Chile)

DES programs

Wide: 5000 sq deg (**1/8 of the sky & data for 300 Million galaxies**)
SNe: 30 sq deg ~every week
Neutrinos: followup of Icecube events
GW: followup of LIGO/Virgo events

DES-GW effort continues

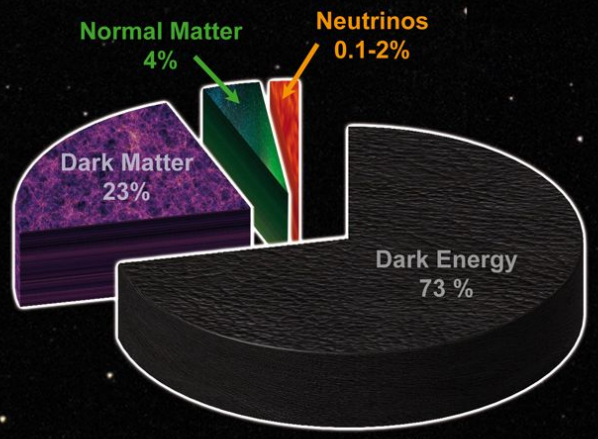


Datasets

Year 1 (Y1): <2000 sq deg, not full depth
Year 3 (Y3): Full area, not full depth (DR1, https://des.ncsa.illinois.edu/home)
Year 5 (Y5): DR2

Dark Energy

- Makes up ~70% of the mass-energy of the Universe, causes the observed accelerated expansion
- DE equation of state parameter w: Pressure=w*density
- **Cosmological constant** Lambda: energy density constant in time, w=-1.
- **Most successful cosmological model - flat LambdaCDM** spatially flat expanding Universe governed by GR, where Lambda and CDM (Cold Dark Matter) are the main components at times close to present. Works well with just 6 parameters!
- Dynamical DE (CPL): w(a)=w0+wa(1-a)



Content of the Universe

How do you measure DE?

DE leaves 2 observable imprints:

Geometry of the Universe

Increases distances and volumes

Supernovae (SNe) ★
Standard candles

Gravitational wave (GW) ★
Standard sirens

Baryon Acoustic Oscillations (BAO)
Standard ruler

Cosmic Microwave Background (CMB)

Growth of cosmic structure

Suppresses the growth

Galaxy clustering

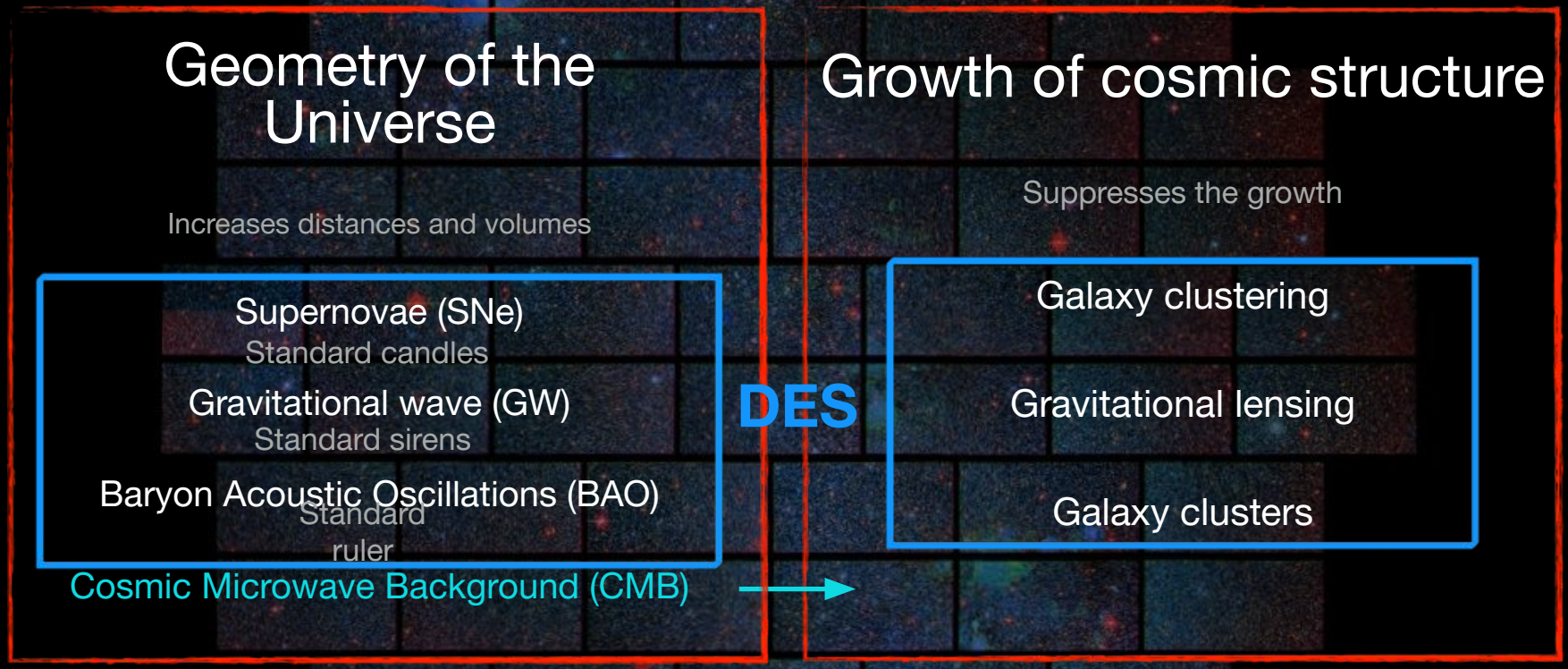
Gravitational lensing

Galaxy clusters

See Jim's talk

★ Transients

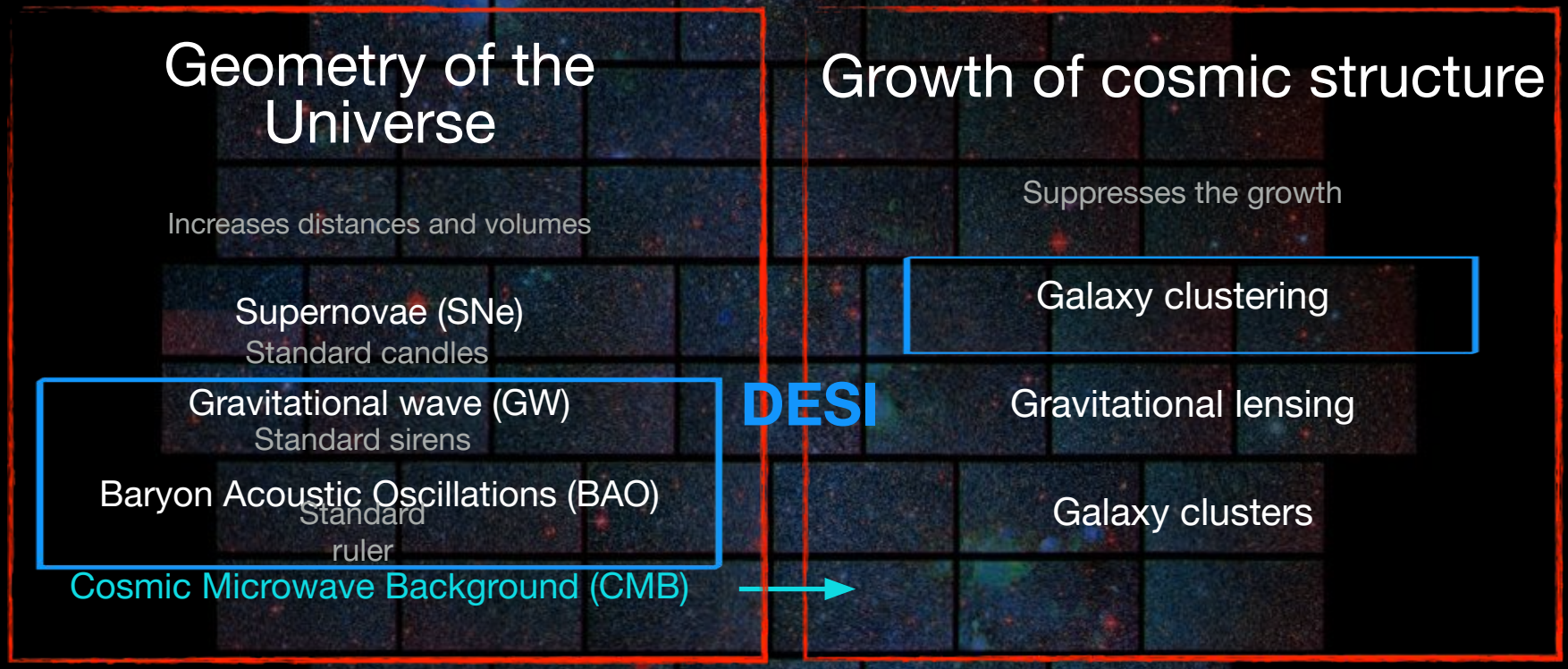
How do you measure DE?



The effects of DE can also be mimicked by variations in other cosmological components, other physical models, and systematics

With DE experiments, we are interested in **a set of cosmological parameters**, measured by **combining different, complementary probes/experiments**

How do you measure DE?



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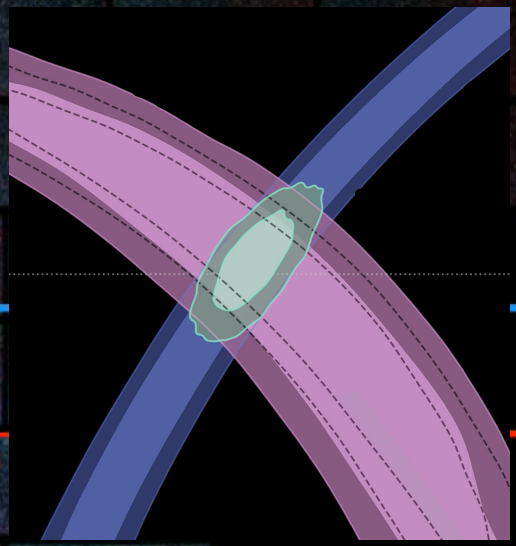
Suppresses the growth



The effects of DE can also be mimicked by variations in other cosmological components, other physical models, and systematics

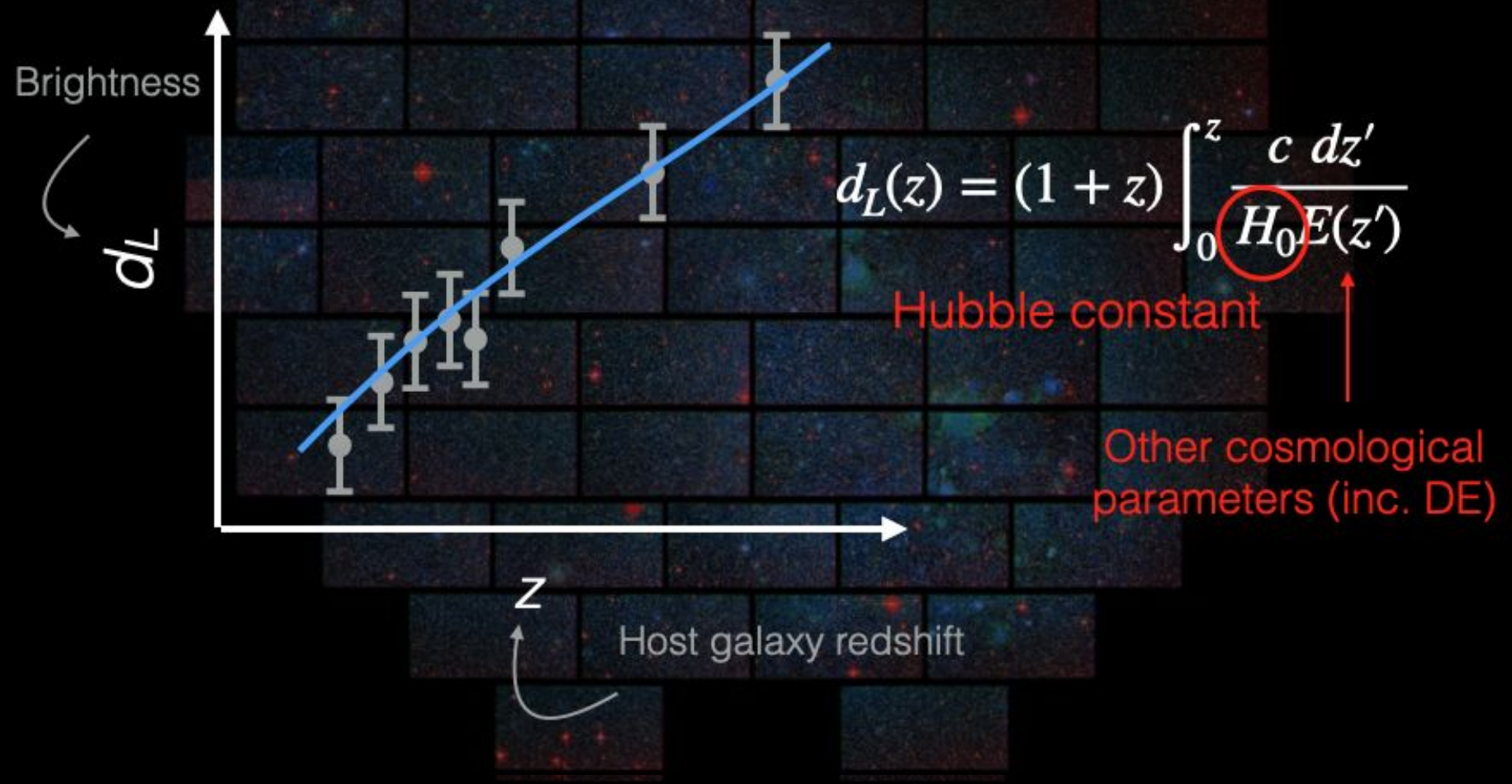
With DE experiments, we are interested in **a set of cosmological parameters**, measured by **combining different, complementary probes/experiments**

SNe as standard candles

SNe as standard candles

SNe as standard candles

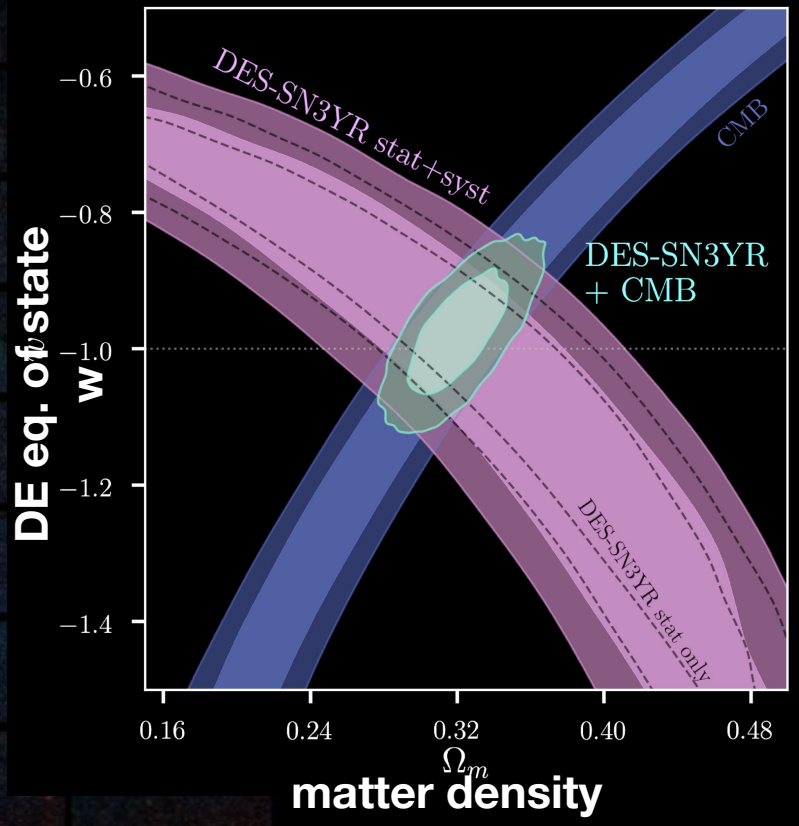
SNe as standard candles



First DES Supernovae results

DES 2019
Brout+2019
Hinton+2019
Macaulay+2019
....

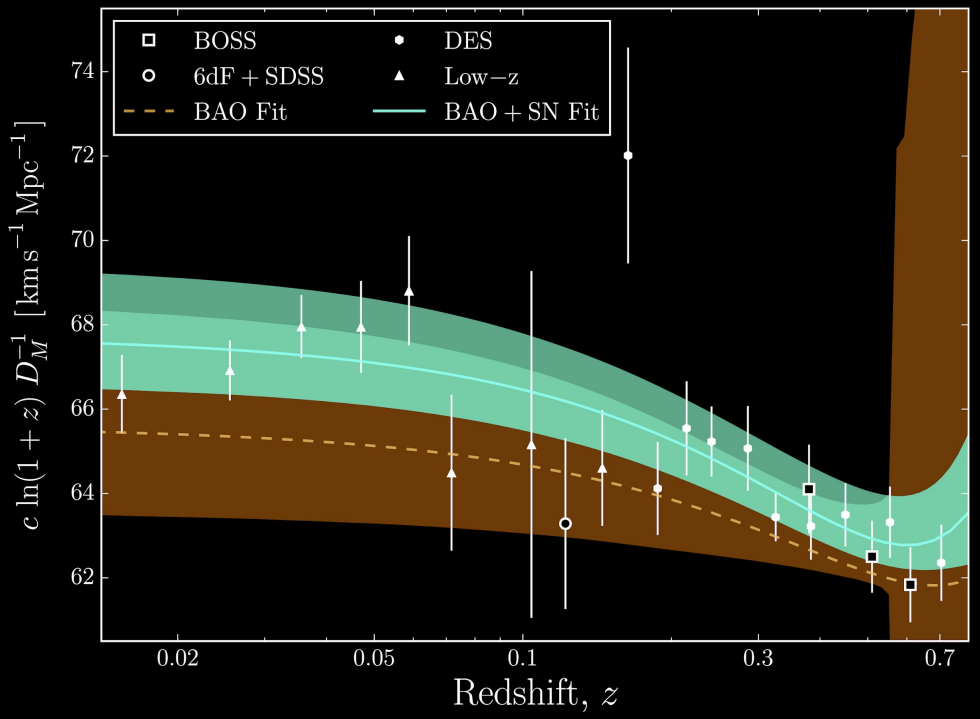
- 207 DES Y3 spectroscopically confirmed SN
- ~10% of final DES sample
- Size <1/3 state-of-the-art combined SN sample, *W* constraints only 1.4x larger: excellent DES data quality
- Consistent with flat LCDM



DES 2019 1811.02374

First DES Supernovae results: H_0

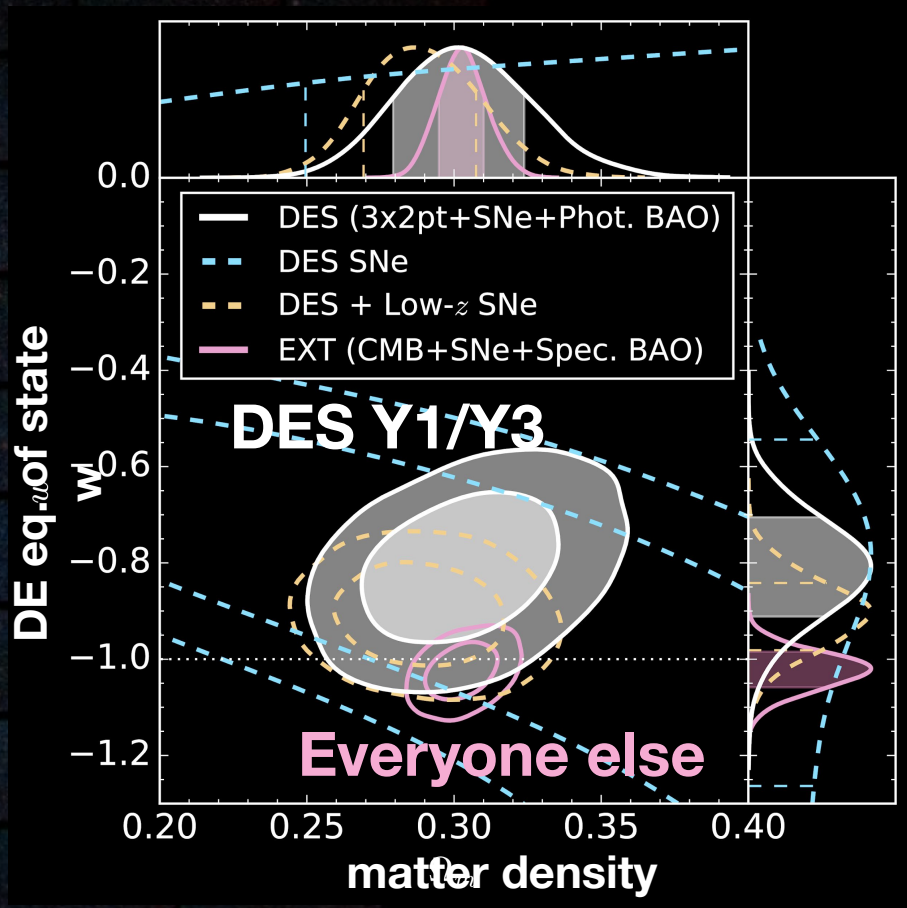
- Need a “distance ladder”
- DESY3 + low-z + BAO + Planck CMB prior on sound horizon
- Minimal assumptions about cosmological model
- Consistent with CMB measurements of H_0



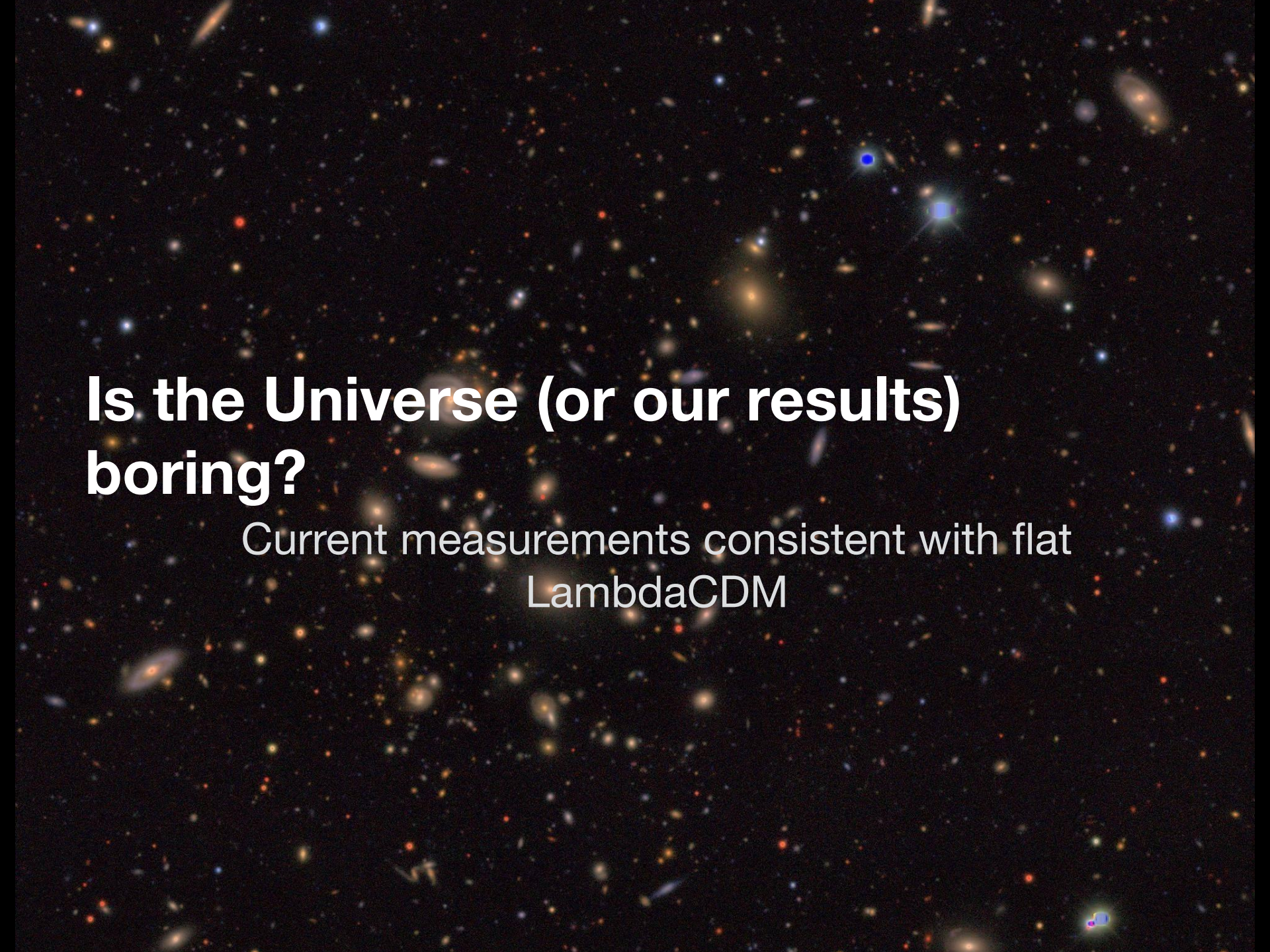
Macaulay+DES 2019 1811.02376

DES Y1/Y3 combined probes

- DES Y1 3x2pt (weak lensing+clustering) & BAO + Y3 SNe
- Consistently validated analysis across all probes
- Probes from this single photometric experiment **rule out a Universe with no Dark Energy**



DES 2019 1811.02375

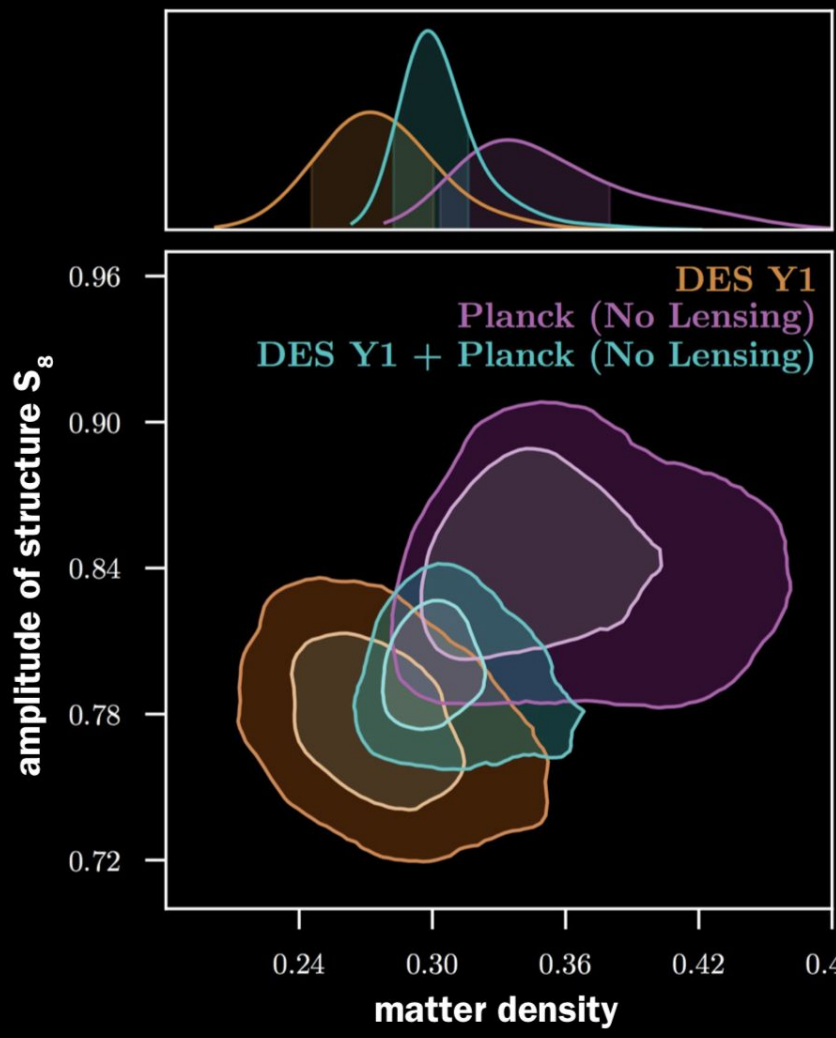


Is the Universe (or our results) boring?

Current measurements consistent with flat LambdaCDM

Game of tensions pt 1

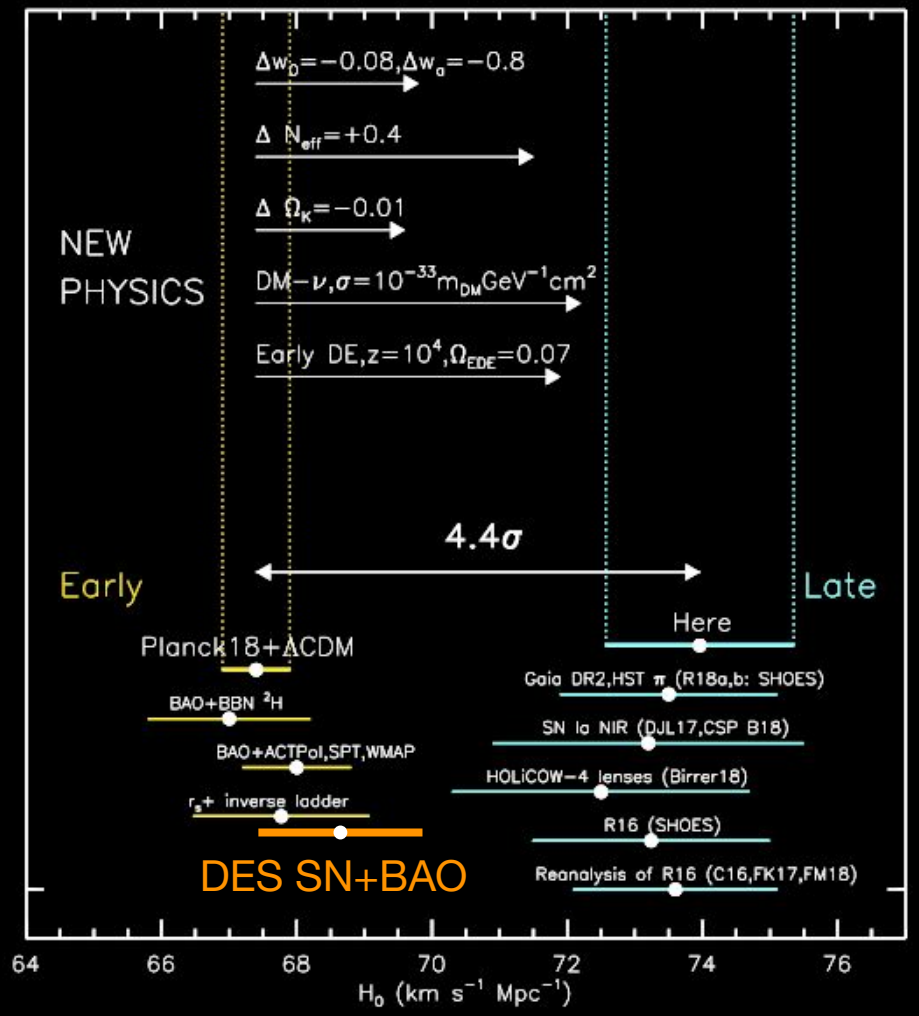
- DES Y1 constraints on clustering amplitude and matter density
- **Mild visual tension**: Bayesian evidence shows consistency
- Worse for KiDS
- **Future DES measurements** will be able to confirm consistency or show tension



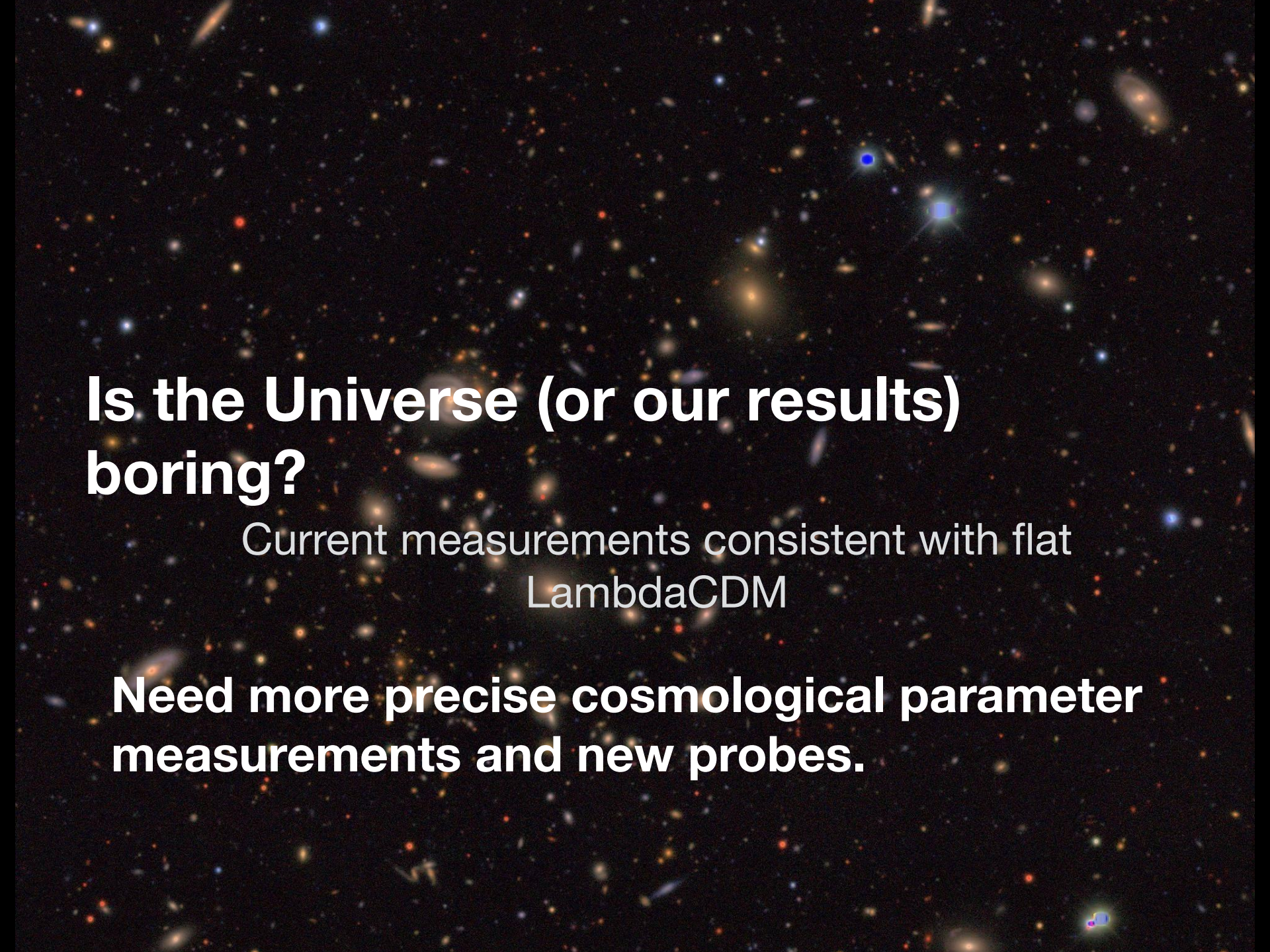
DES 2019 1708.01530

Hubble constant tension

- **4.4 sigma discrepancy** between early and late time Universe measurements
- Systematics or new physics?



Riess+2019



Is the Universe (or our results) boring?

Current measurements consistent with flat LambdaCDM

Need more precise cosmological parameter measurements and new probes.

GW Standard sirens

Schutz 1986

Holz & Hughes 2005

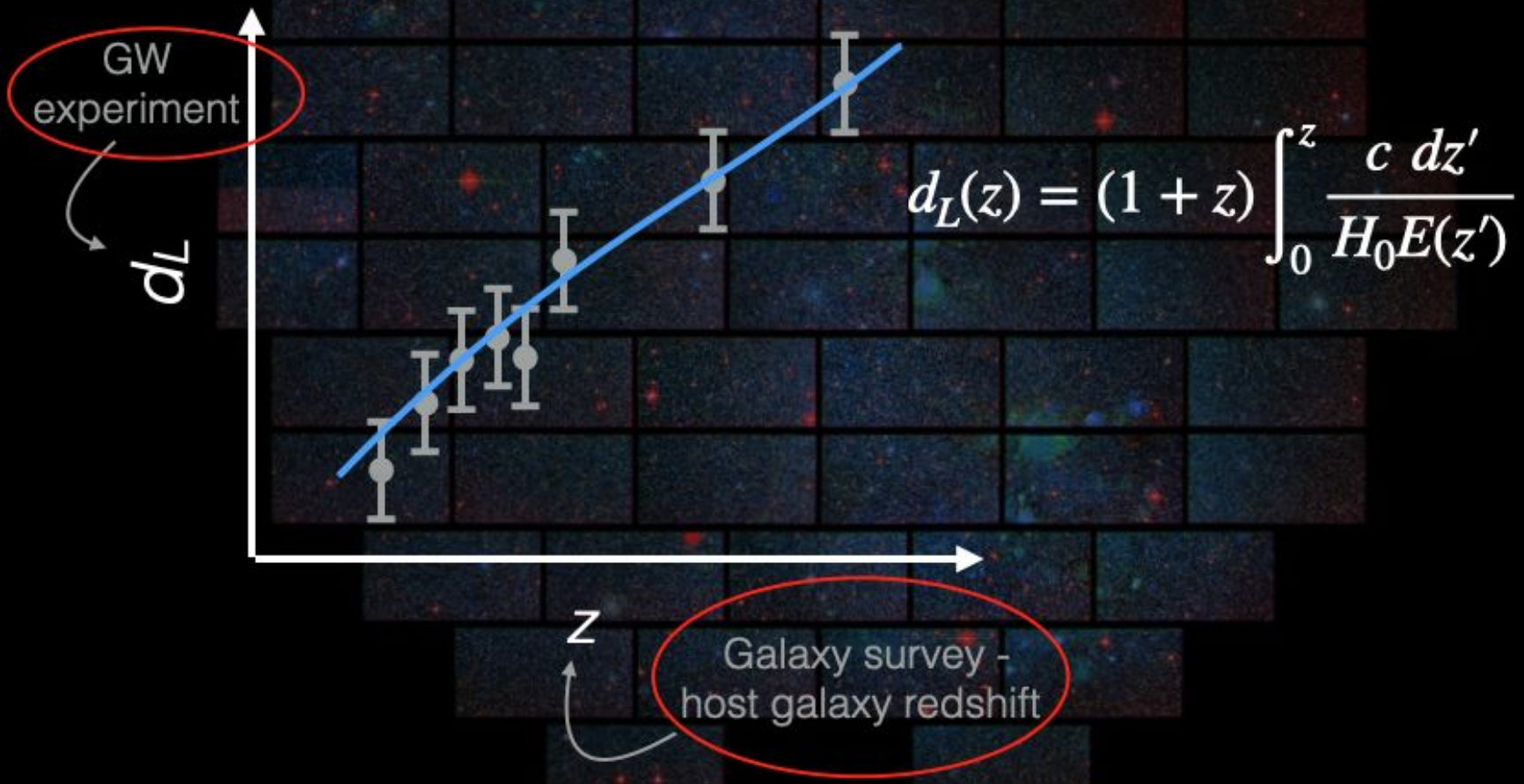
MacLeod & Hogan 2008

Nissanke+2010

Del Pozzo 2012

- Similar to SN cosmology:

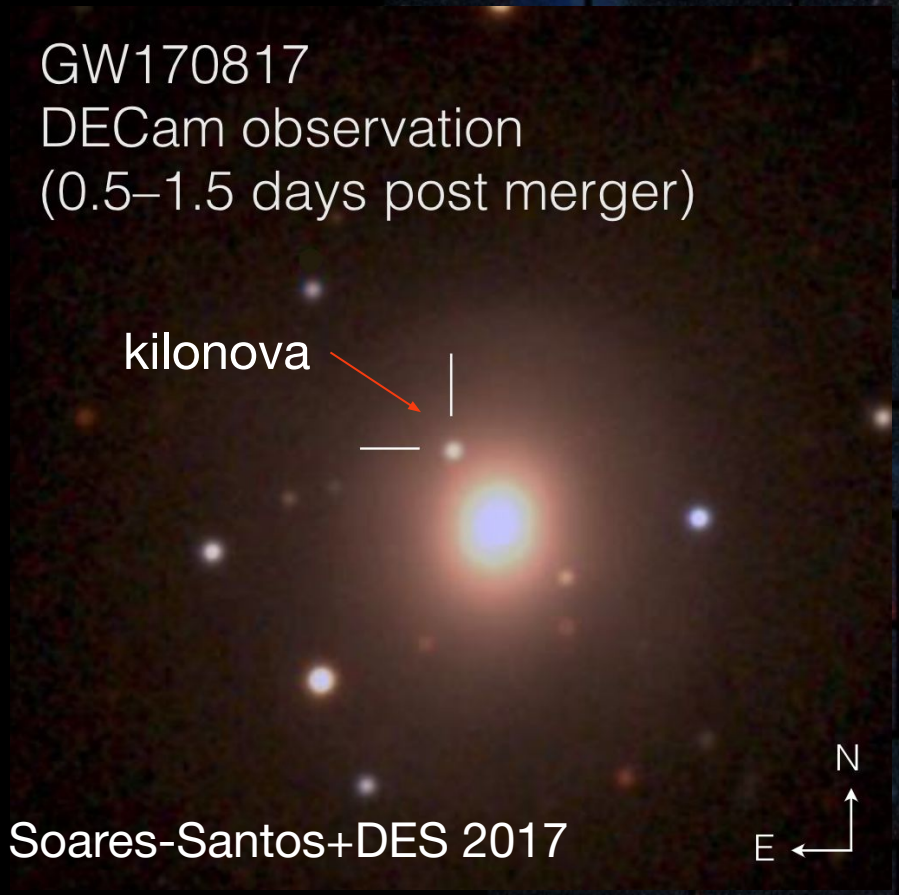
Self-calibrating: No distance ladder



$$d_L(z) = (1+z)\int_0^z \frac{c\,dz'}{H_0 E(z')}$$

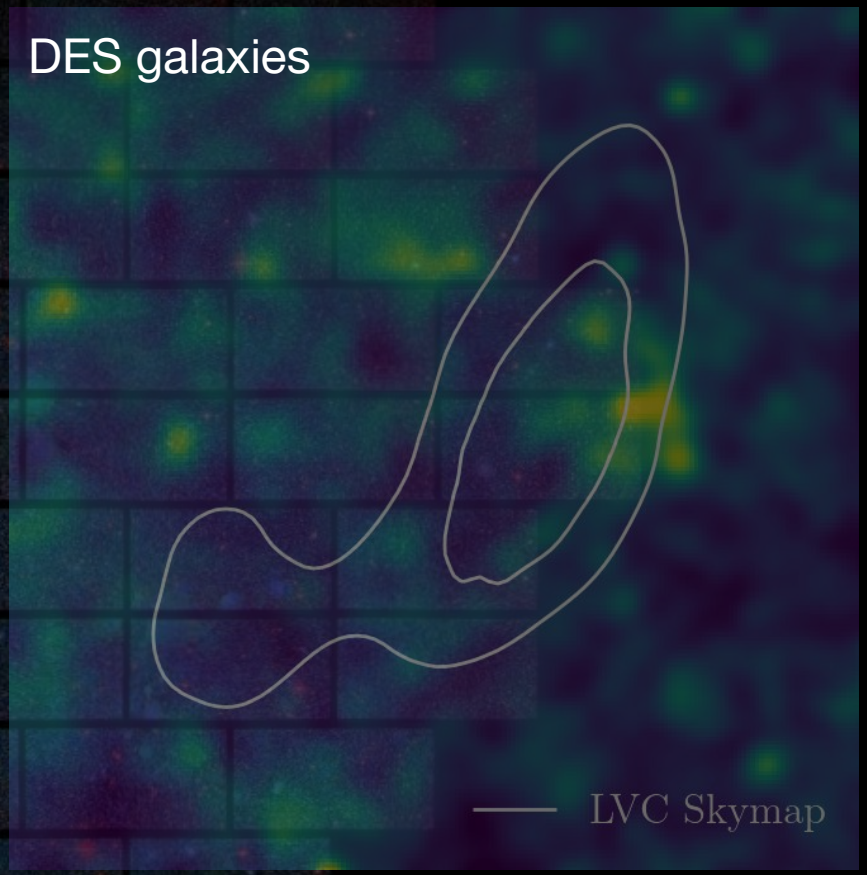
GW+EM standard siren methods

Unique host galaxy



Bright standard sirens

No EM counterpart: potential host galaxies



Dark standard sirens / statistical method

GW+EM standard siren methods

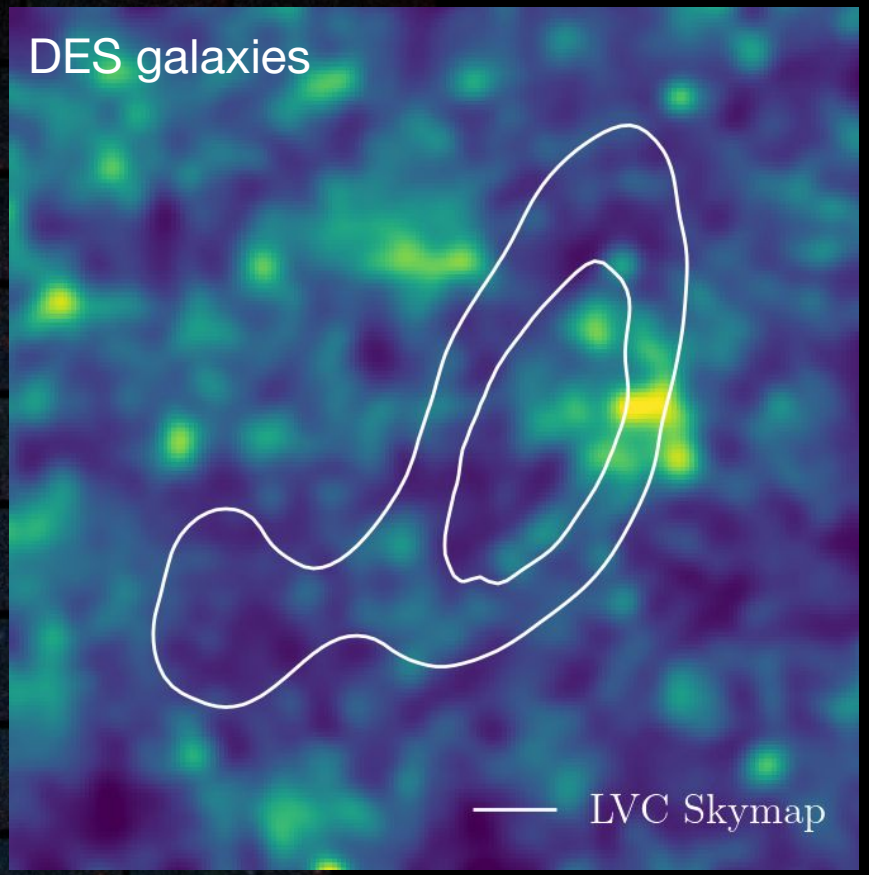
Unique host galaxy

GW170817
DECam observation
(0.5–1.5 days post merger)

N
E

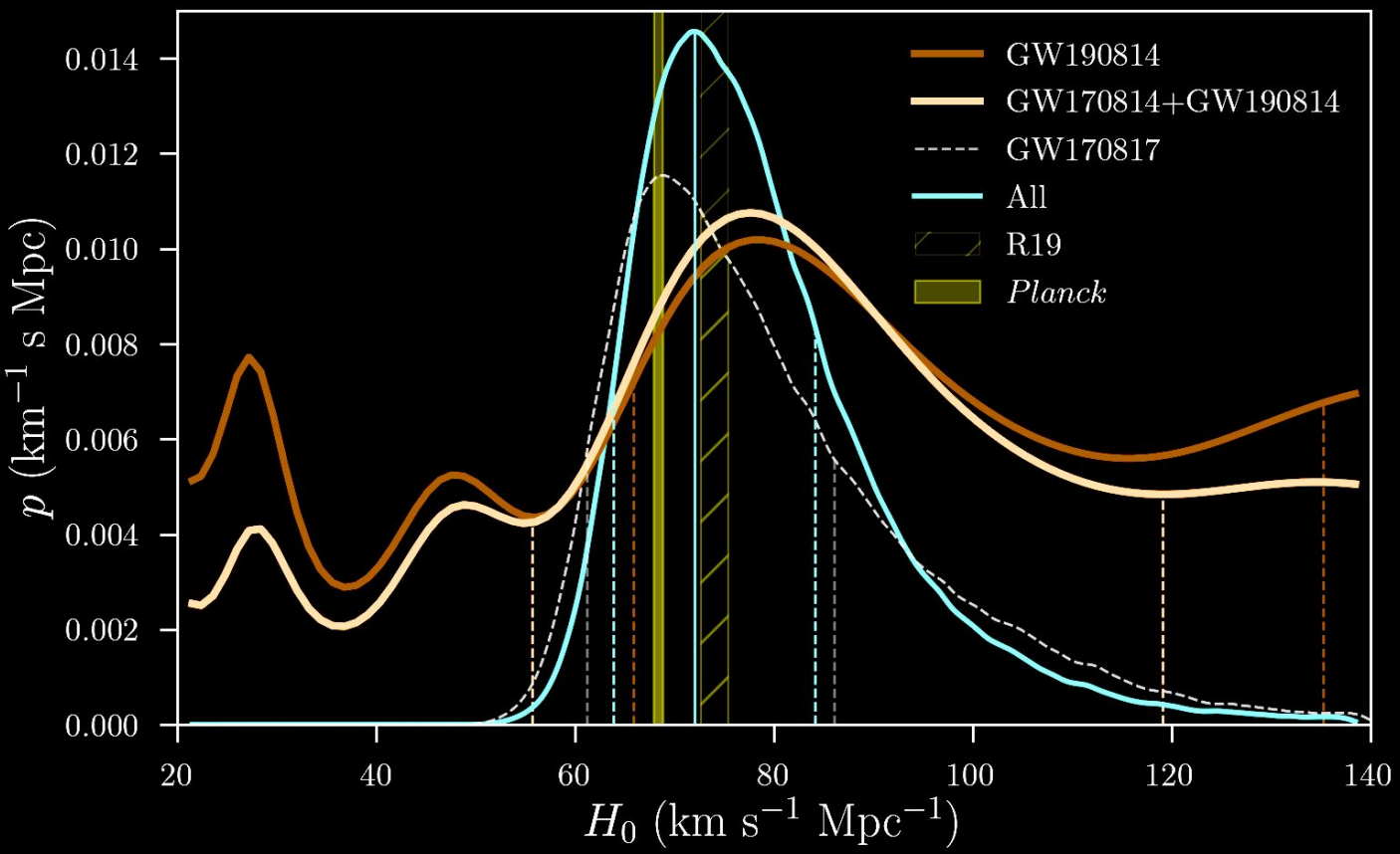
Bright standard sirens

No EM counterpart: potential host galaxies



Dark standard sirens

DES standard sirens results



Palmese et al 2020

DES at FNAL

AI, Machine Learning: Aleksandra Ciprijanovic, Alex Drlica-Wagner, Antonella Palmese, Brian Nord, Brian Yanny, Yuanyuan Zhang

Data Management, Simulations and Validation: Alex Drlica-Wagner, Brian Yanny, Doug Tucker, Nikolay Kuropatkin, Sahar Allam, William Wester

Dark Matter, Milky Way: Alex Drlica-Wagner, Eric Nielsen, Josh Frieman

Transients (including gravitational waves and Supernovae): Antonella Palmese, Jim Annis, Ken Herner, William Wester

Galaxy Clusters: Antonella Palmese, Huan Lin, Jim Annis, Marc Paterno, Tom Diehl, Yuanyuan Zhang,

Galaxy evolution: Alex Drlica-Wagner, Antonella Palmese, Yuanyuan Zhang

Redshift: Huan Lin

Strong lensing: Brian Nord, Liz Buckley-Geer, Huan Lin, Tom Diehl

Weak lensing and large scale structures: Brian Yanny, Javier Sanchez, Gaston R. Gutierrez, Ken Herner, Michael Wang

Operations, instrument, observations: Brenna Flaugher, Eric Nielsen, Josh Frieman, Steve Kent, Tom Diehl

Dark Energy Spectroscopic Instrument (DESI): Telescope

Fiber-fed spectrograph at Kitt Peak (KP):

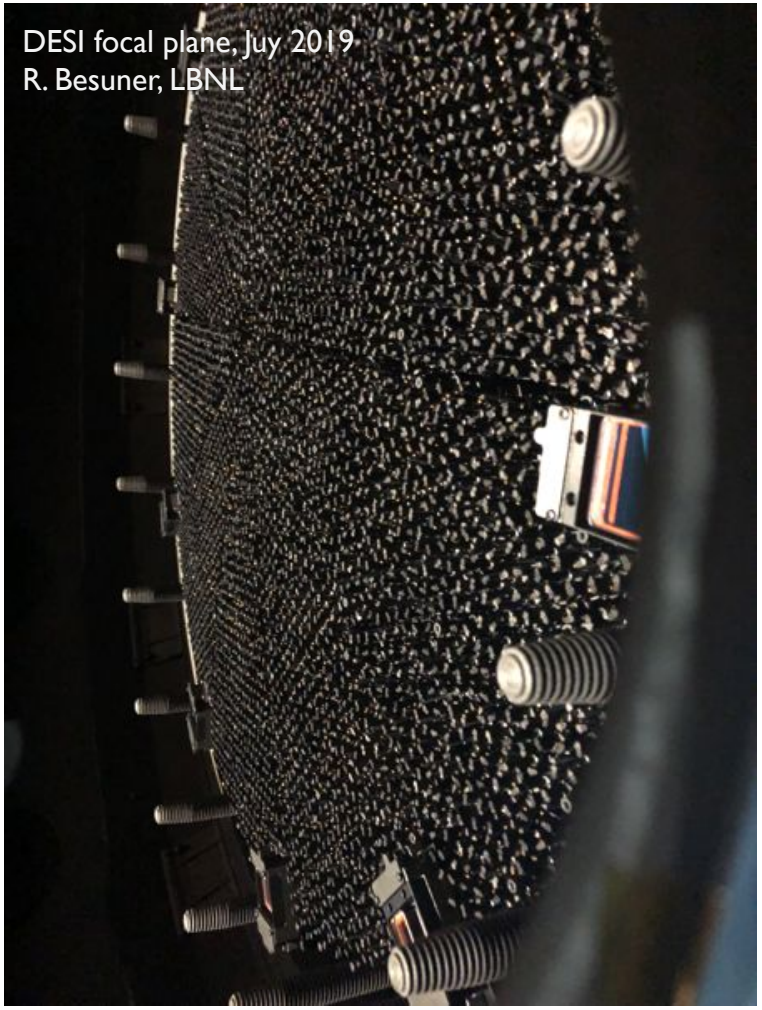
- 5,000 fibers
- Focal plane: 8 deg^2 field of view
- ~160-500 deg^2/night.

2021 - 2025: ~30M galaxies and QSOs

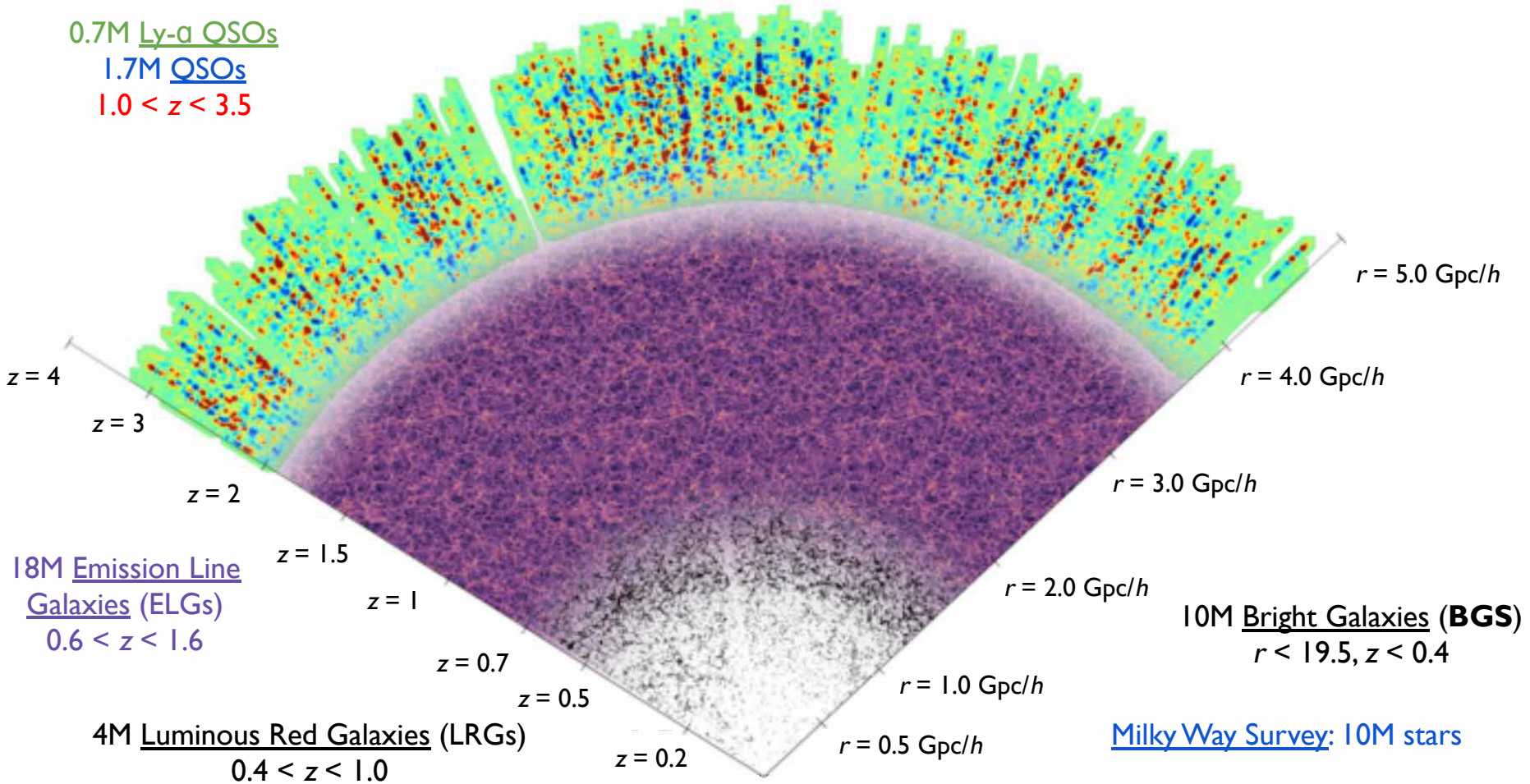
to measure BAO and RSD to $z \sim 3.5$.

Science Verification - done

Year 1 operations - began May 2021



Dark Energy Spectroscopic Instrument (DESI): Survey



DESI at FNAL

Early involvement of FNAL in DESI (**Juan Estrada, Gaston Gutierrez**,...)

Steve Kent - Platemaker (code that puts positioner fibers onto targets)

Elizabeth Buckley-Geer - Lead Observer. Support of the online database and web tools. Working on improvements for the Membership Database. Supporting DESI PubDB.

Antonella - Continuing Time Domain WG co-chair. Ombudsperson.

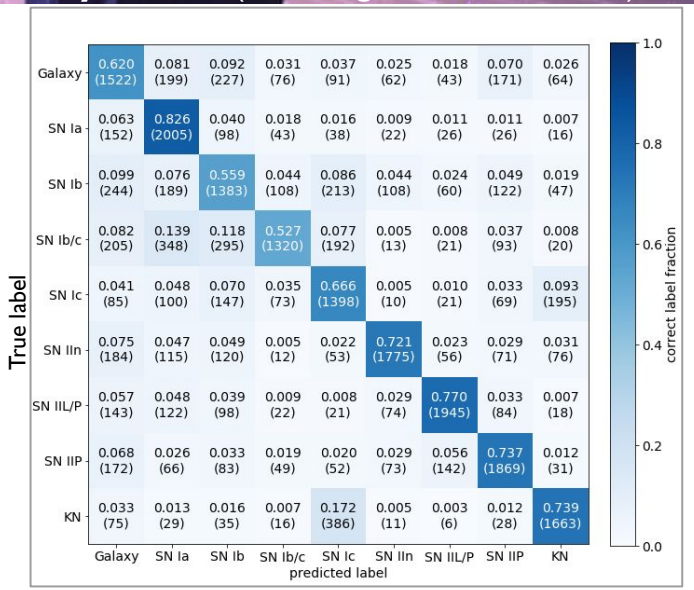
- CNN classification of DESI spectra
- Follow up of external transients and Multi-messenger (archival GW+ high energy neutrinos)
- External telescope proposals: DECam shadowing (AP co-PI)

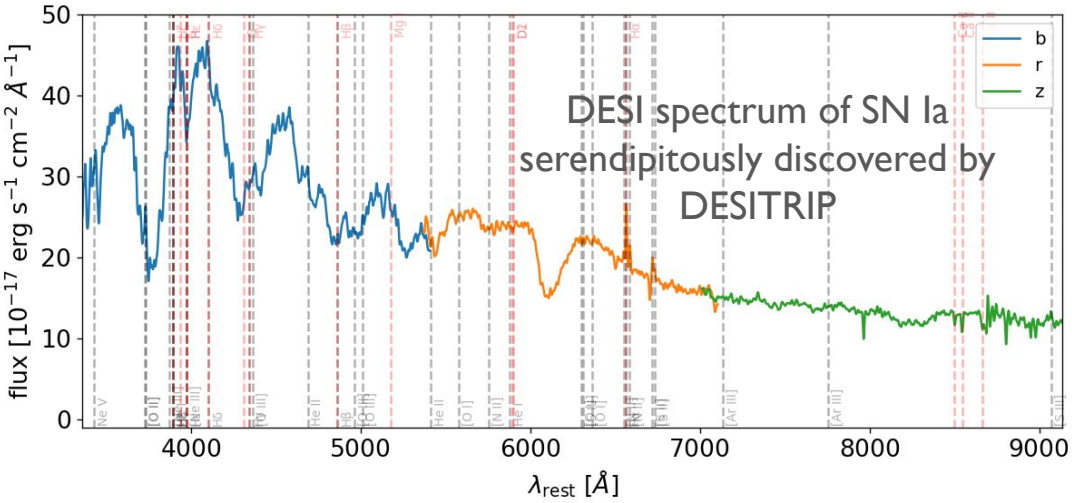
Serendipitous Discoveries of Transients (DESITRIP)

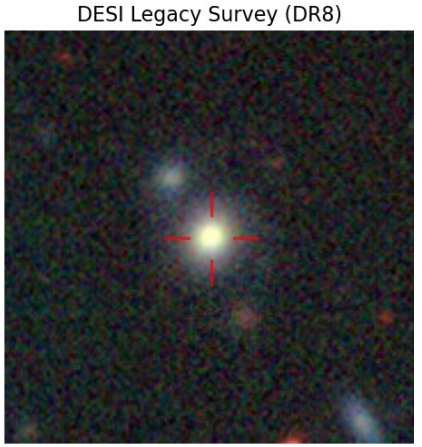
Lily Eshani (UChicago summer intern)

Automatic daily Machine Learning transient classification pipeline searching all DESI spectra for supernovae and kilonovae in host galaxy emission

- Thousands of candidates identified from few months of SV+Year 1, dozens confirmed by imaging





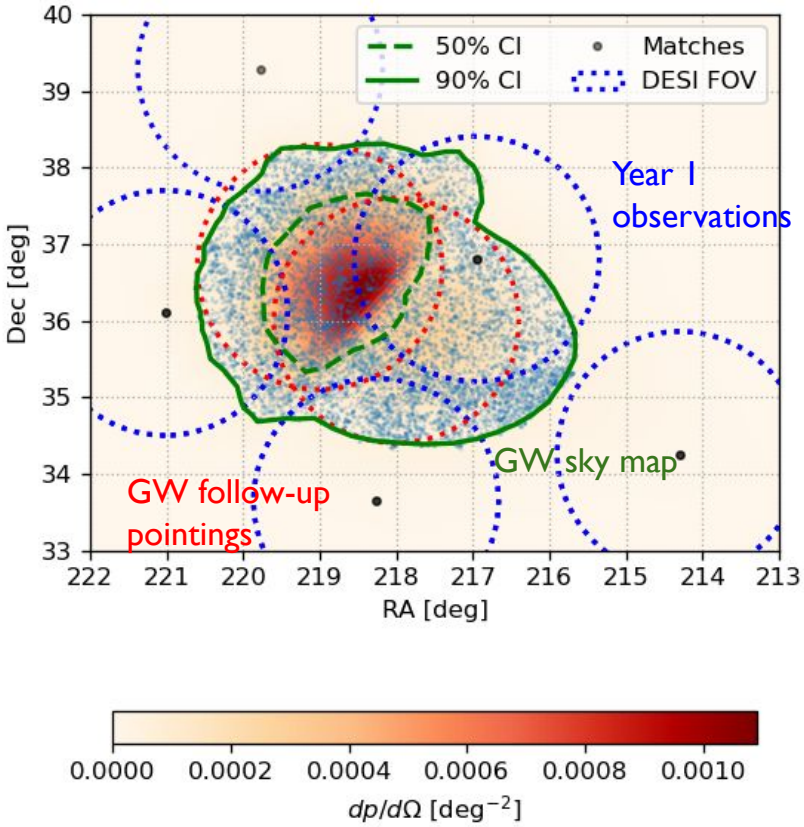


GW Follow-up and standard sirens

Archival GW190412 follow-up successfully performed:

- Pull active transients from other surveys
- Compare galaxy targets in GW skymap with existing observations
  - ~40% of BGS targets already observed

Perform **dark siren analysis** and understand **binary black hole formation** mechanisms



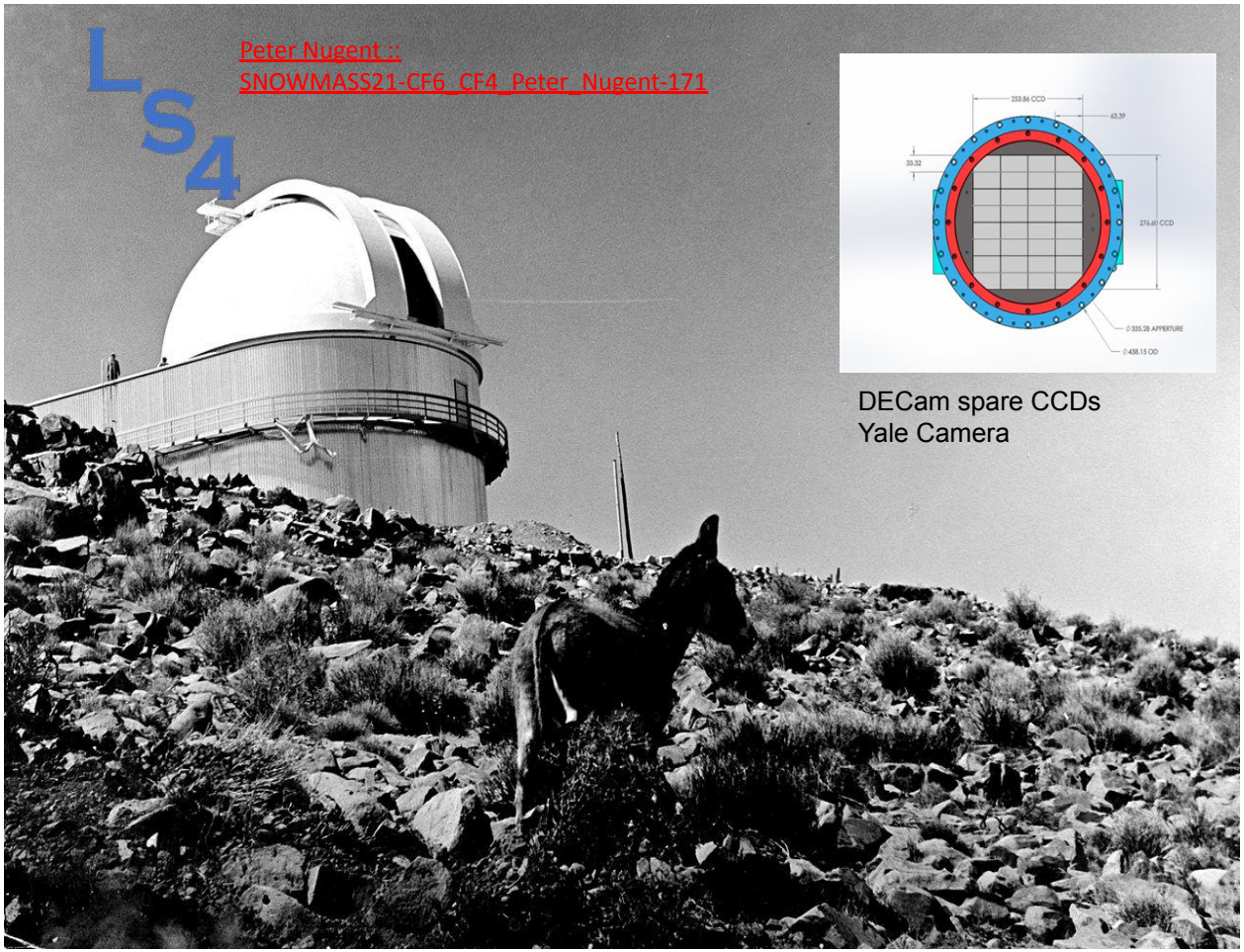
DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

Thanks to our sponsors and 69 Participating Institutions!

La Silla Schmidt Survey (LS4)

Slide from P. Nugent (PI)



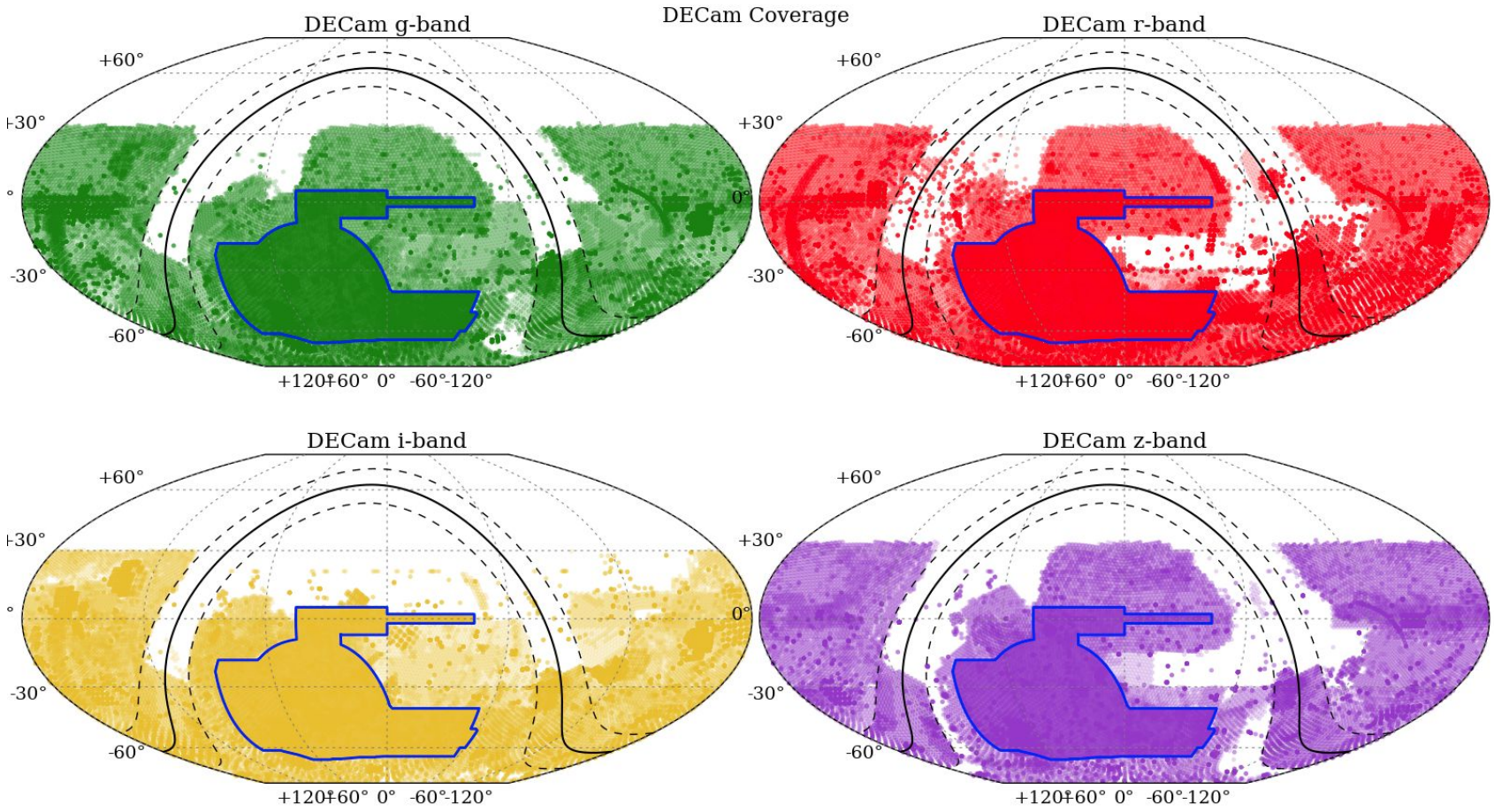
DECam spare CCDs
Yale Camera

Recycling Fermilab's DECam leftover CCDs to build a new camera. CCDs currently being tested at Fermilab, will be sent to Yale to build the camera. To be mounted on existing telescope.

Quick facts:

- **20 sq. deg. fov**
- **2 fixed filters (g+z)**
- 45s exp; 15s read+slew
- g-band: 21.0+/- 0.5
- z-band: 20.0
- **2k-4k sq.deg./night**
- **90% Survey mode**
- **10% MMA ToO's**
- **Real-time public data**
- **First light summer 2022**

DECam Local Volume Survey



DELVE (https://delve-survey.github.io)

126 nights of DECam time to complete contiguous coverage in g,r,i,z

International collaboration with ~80 members

First Data Release in January

FNAL Members:

- Drlica-Wagner (PI)
- Kuropatkin
- Neilsen
- Sánchez
- Tucker
- Yanny

- Mau et al. (2020) - Two Ultra-faint Milky Way Stellar Systems Discovered in Early Data from the DECam Local Volume Exploration Survey
- Cerny et al. (2021) - Discovery of an Ultra-Faint Stellar System near the Magellanic Clouds with the DECam Local Volume Exploration Survey
- Drlica-Wagner et al. (2021) - The DECam Local Volume Exploration Survey: Overview and First Data Release
- Ferguson et al. (2021) - DELVE-ing into the Jet: a thin stellar stream on a retrograde orbit at 30 kpc

Summary

- Dark energy and cosmology
- Current experiments at Fermilab: DES, DESI, LS4, DELVE
- Some of the DES and DELVE recents results - stay tuned for Y3/Y5 DES results and DESI results!
- Activities where students can get involved:
  - Searches for optical counterparts to gravitational waves
  - Cosmology (GW, galaxy clustering, galaxy clusters - see next talk)
  - AI applications
  - Search for transients in all surveys, study of their properties, use for cosmology
  - Stellar systems in our own Milky Way
- There are a lot of activities I have not covered in this talk:
  - Strong gravitational lensing
  - Search for ultra-diffuse galaxies: how did they form and what are their properties?
  - Dark matter constraints from local Universe observations
  - Galaxy evolution: galaxy properties, their evolution over cosmic time
  - Photometric redshifts techniques
  - Instrumentation
  - Infrastructure work, software development, observing...
- Feel free to get in touch: palmese@fnal.gov antonella.palmese@gmail.com


Thank you!