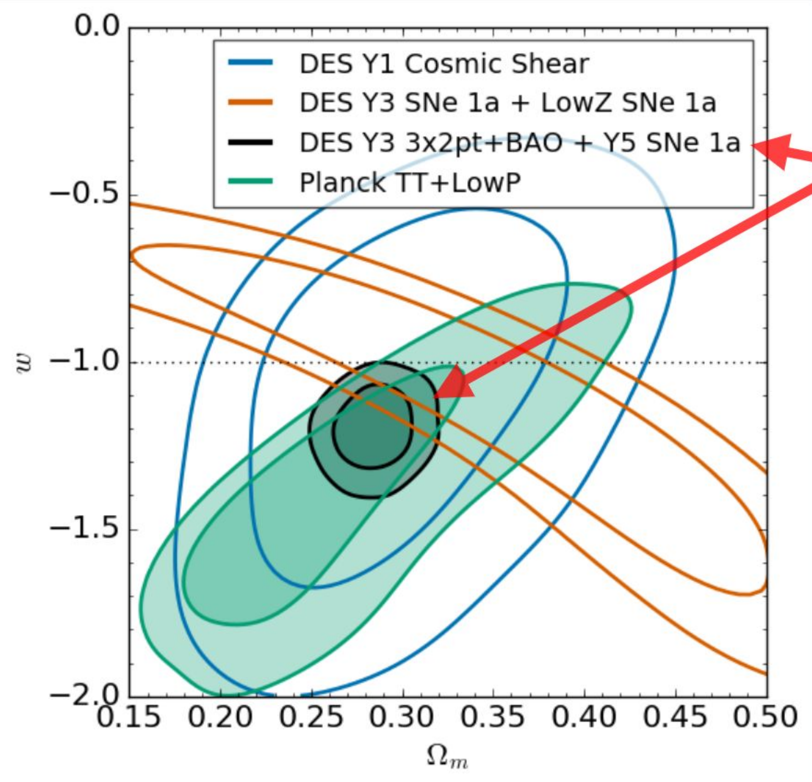
The one most curious thing in three years of DES lensing



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

(contour position is artificial)

The *three* most curious things in *one* year~~s~~ of DES lensing

Introduction:

Cosmology
Structure
Gravitational Lensing

The curious case of low-mass galaxy clusters

A first detection of γ_t around γ_{Fermi}

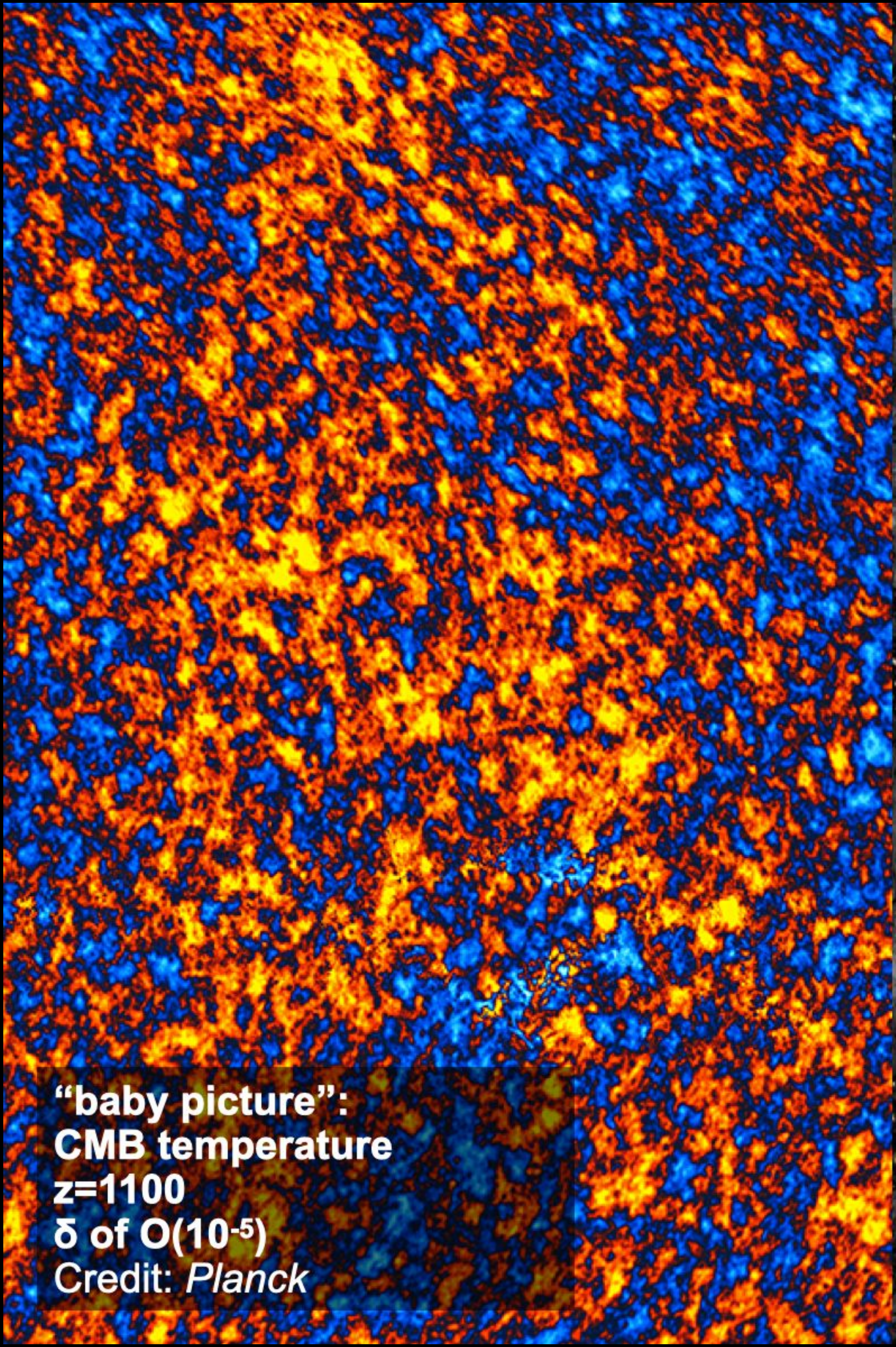
Nobody knew photo-z

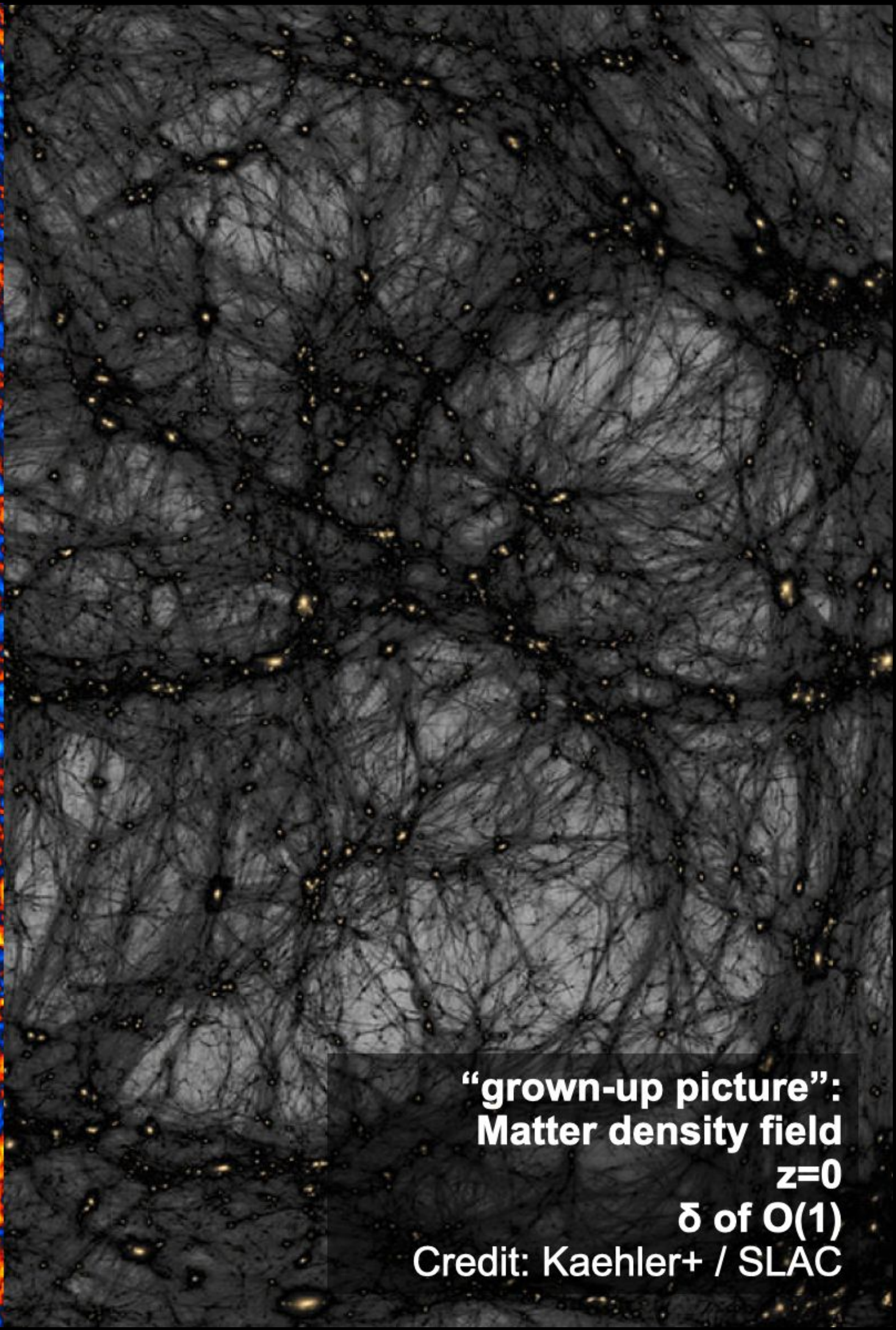
could be so complicated

Daniel Gruen (Panofsky Fellow, SLAC)
and the DES WL WG

April 28, 2020, Berkeley, virtually

Where are you joining from today?


"baby picture":
CMB temperature
z=1100
δ of O(10^-5)
Credit: *Planck*

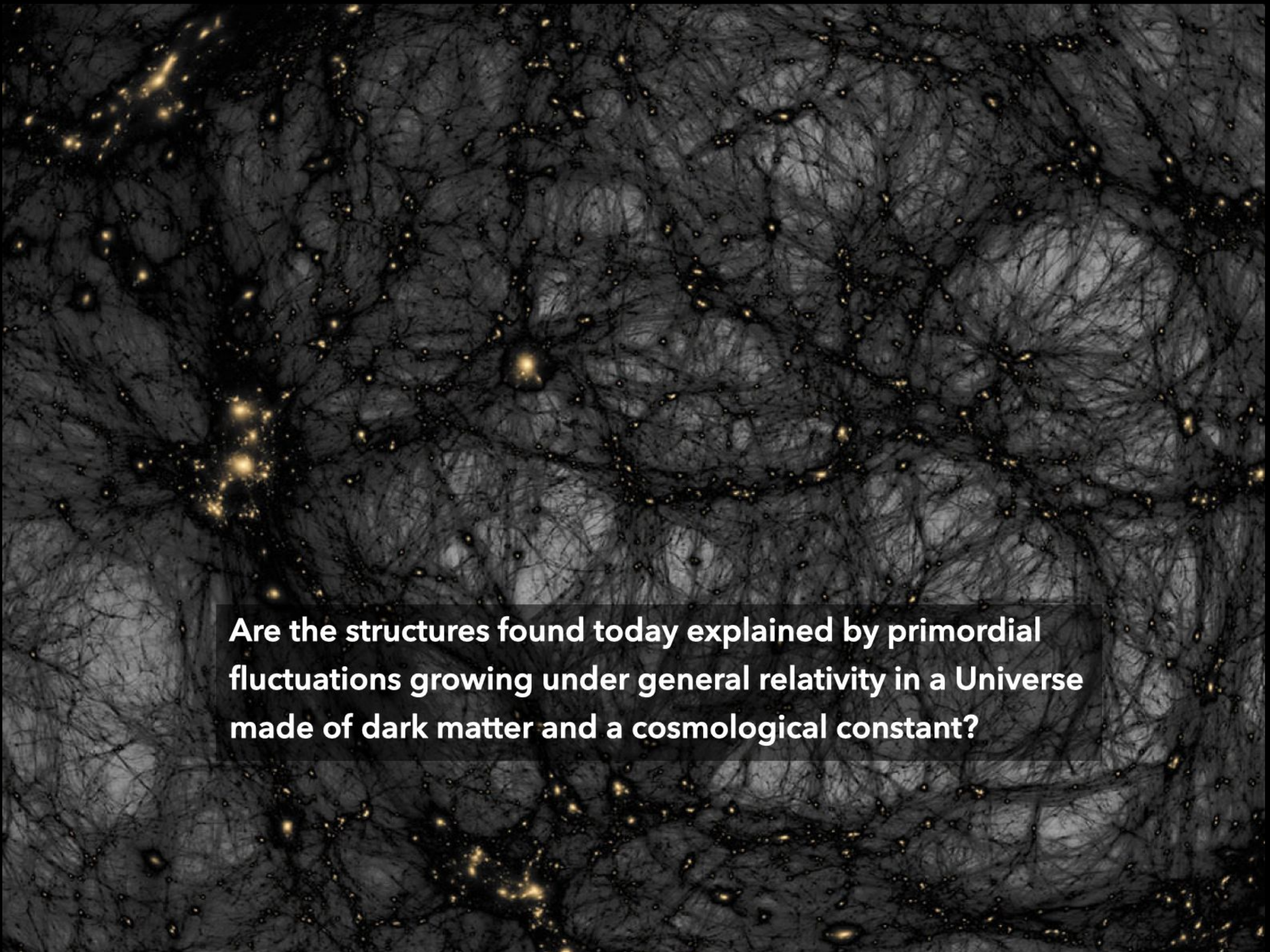

"grown-up picture":
Matter density field
z=0
δ of O(1)
Credit: Kaehler+ / SLAC

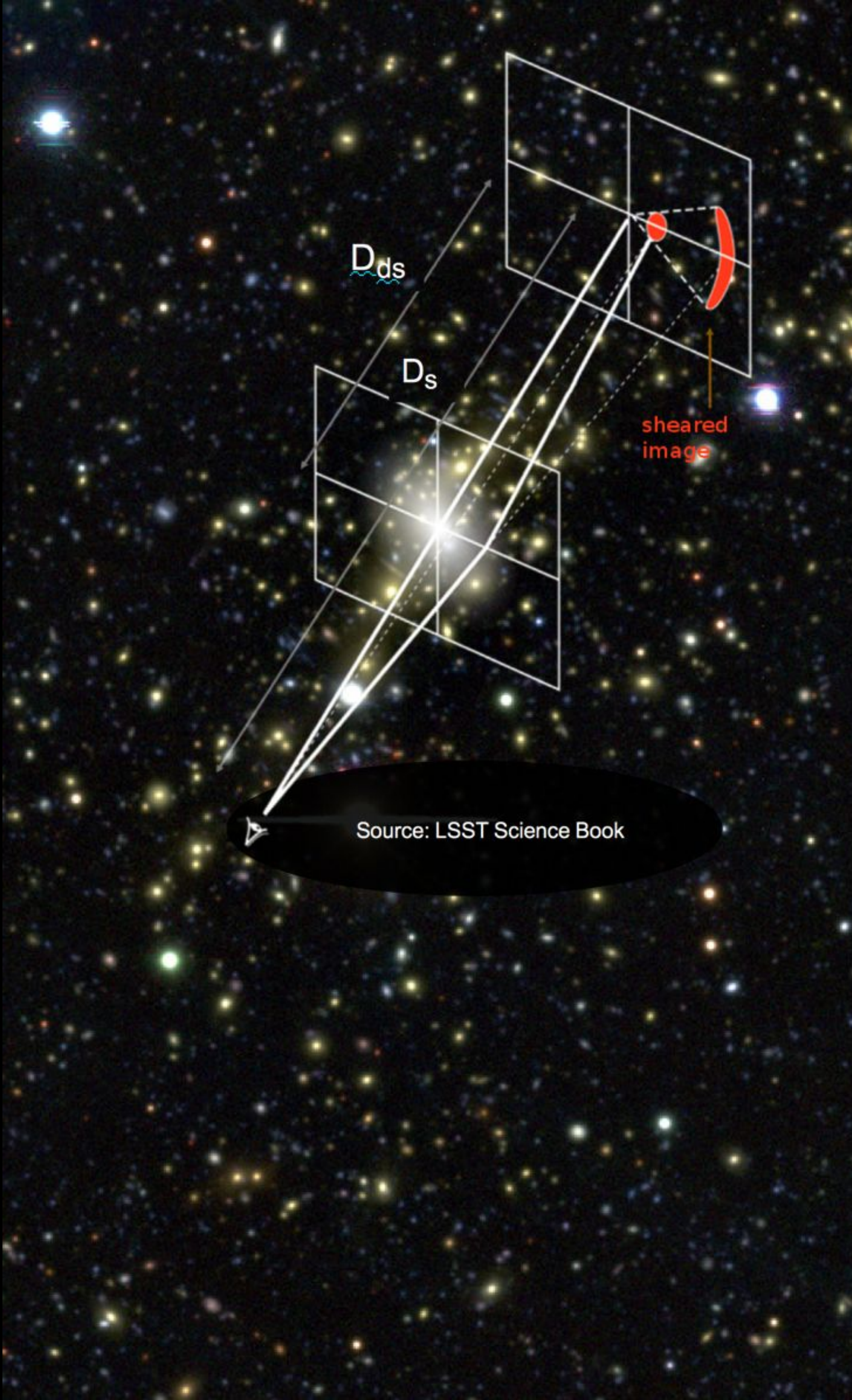
To explain the biography of the cosmos, we need:

An **acceleration** mechanism:
e.g. 70% of energy today in vacuum (**Λ**)

A mechanism for **extra gravity** in addition to visible matter:
e.g. 25% **C**old **D**ark **M**atter and 5% standard model particles

ΛCDM is a successful model, but has no foundation in theory.


Are the structures found today explained by primordial fluctuations growing under general relativity in a Universe made of dark matter and a cosmological constant?

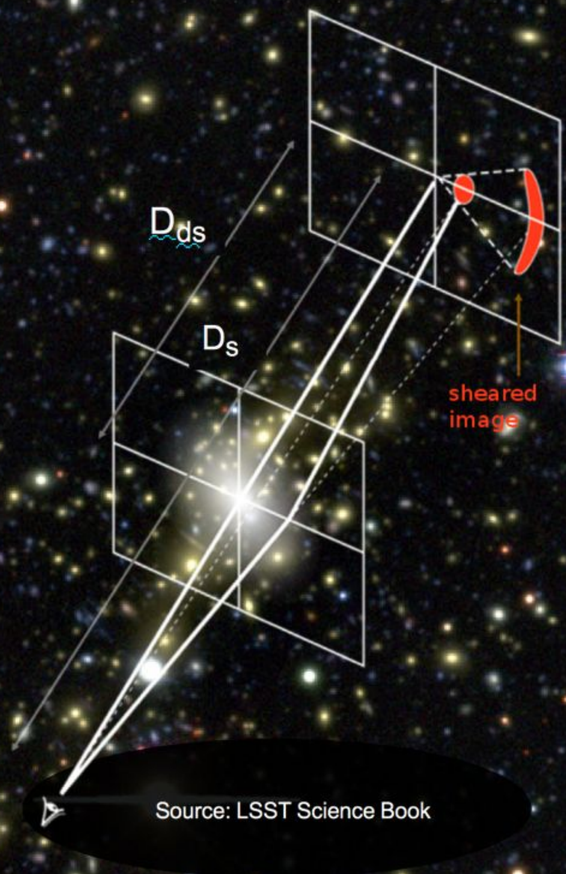


Gravitational lensing

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

$$\begin{aligned} \gamma_t(\theta) &= \langle \kappa(\theta') \rangle_{\theta' < \theta} - \kappa(\theta) \\ \kappa &= \Sigma / \left[\frac{c^2}{4\pi G} \frac{D_\mathrm{s}}{D_\mathrm{d} D_\mathrm{ds}} \right] \end{aligned}$$

- Enables study of structure by connecting observed images to matter density



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

galaxy shapes

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

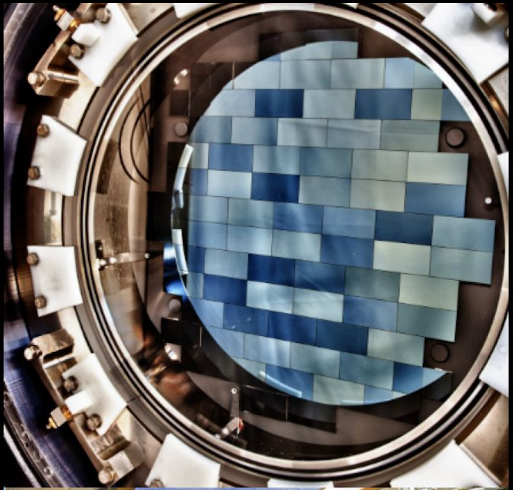
galaxy redshifts

- Enables study of structure by connecting observed images to matter density

The Dark Energy Survey

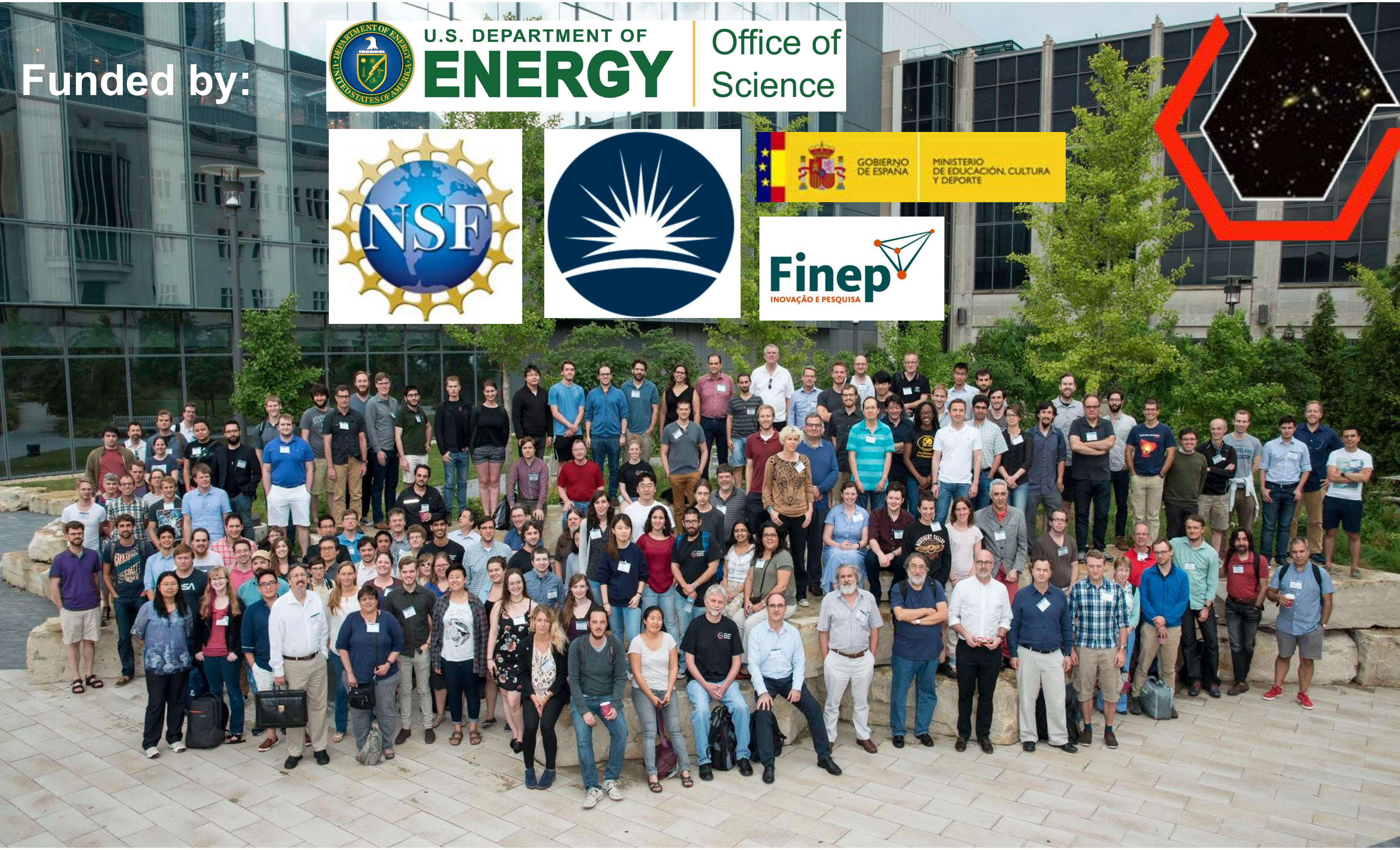
- 5000 sq. deg. survey in grizY from Blanco @ CTIO, 10 exposures, 5.5 years, >400 scientists
- Primary goal: dark energy equation of state
- Probes: Large scale structure, Supernovae,
  Cluster counts, Gravitational lensing
- Status:
  - Y1 (1500 sq. deg, 40% depth):
    all key results published
  - Y3 (5000 sq. deg, 50% depth):
    data processed, blinded analyses)
  - Y6: homogeneous survey at planned depth

    basic Y3 & Y1 value added data released
    www.darkenergysurvey.org

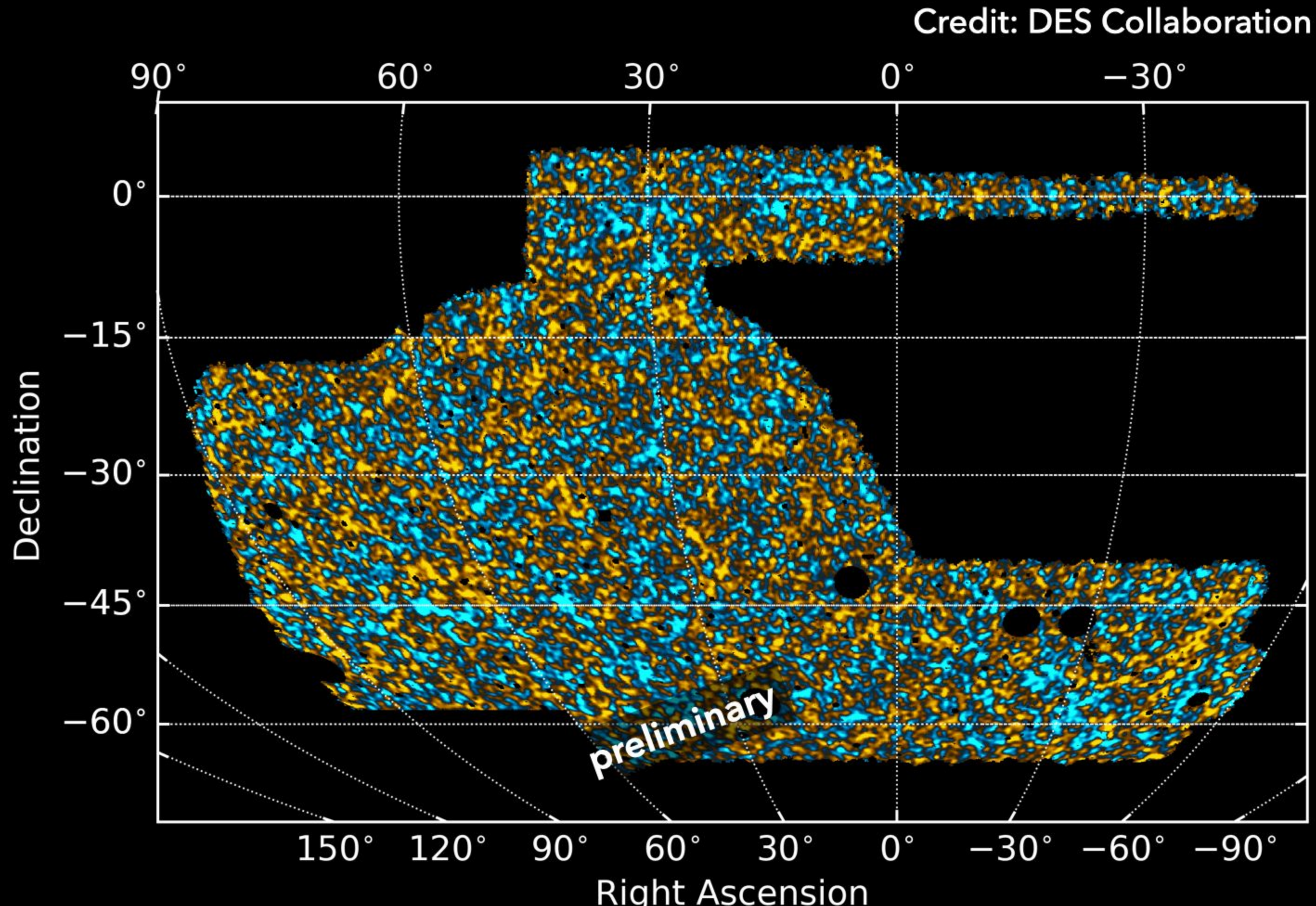


Much more than just Dark Energy / Weak Lensing!

Funded by:



Collaborating institutions:



DES Y3 weak lensing mass map

4800 deg^2 from 100M galaxies in 4100 deg^2 effective survey area (after masking)

What would you most be worried about when inferring cosmology from O(10^8) lensed galaxies?

Systematics in detection / shape measurement of galaxies **A**

Assigning distance = redshift distributions to samples of galaxies **B**

Modeling of signals **C**

Covariance and sampling **D**

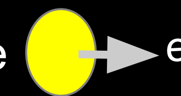
With great statistical power comes great systematic responsibility

- Y1: two independent galaxy shape measurements, including metacalibration algorithm, bias<1.3% (68 c.l.) (Zuntz & Sheldon+2018)

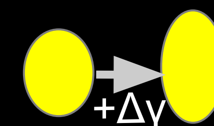
Update for Y3:
realistic + modular image simulations to constrain the effect of blending on metacalibration + redshift estimation.
[N. MacCrann, M. Becker, J. McCullough, A. Choi, A. Amon, DG, …]

Metacalibration:

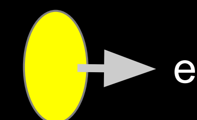
i. apply biased estimator to image



ii. manipulate image to include artificial (shear) signal



iii. apply biased estimator to manipulated image
→ derivative w.r.t. signal



$$\text{response} = \frac{e' - e}{\Delta\gamma}$$

iv. related tricks to also correct selection bias

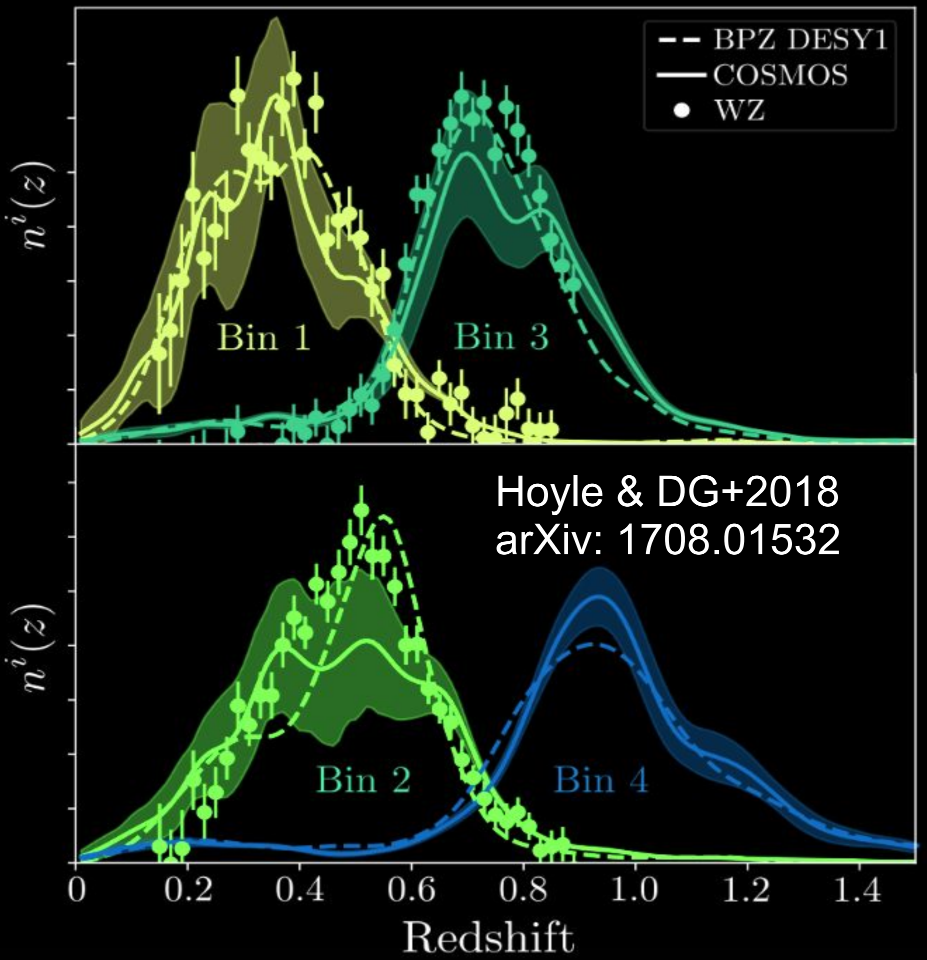
35 million galaxy shapes with systematic error <1.3% (68% C.L.)

Huff & Mandelbaum, Sheldon & Huff 2017; Zuntz & Sheldon+2018

With great statistical power comes great systematic responsibility

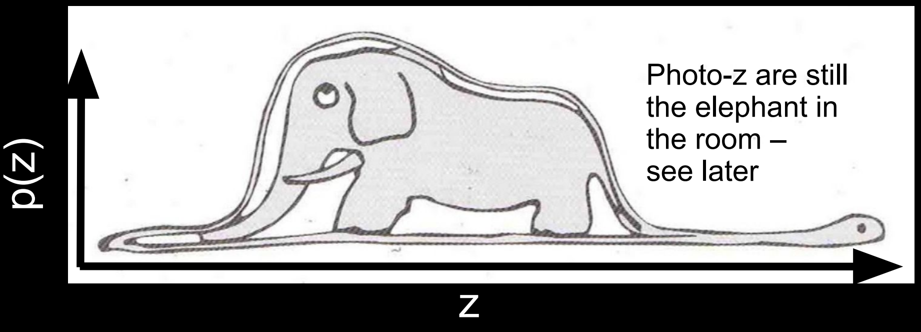
- Y1: two independent calibrations of photometric redshifts of four source bins (Hoyle & DG+2018)

COSMOS + clustering methods agree, ~0.015 uncertainty on <z>



Update for Y3: substantially extended methodology that allows to use deep field photometry + spectroscopy consistently.

[A. Amon, J. Myles, J. McCullough, A. Alaron, C. Sanchez, G. Bernstein, S. Dodelson, G. Giannini, DG, …]

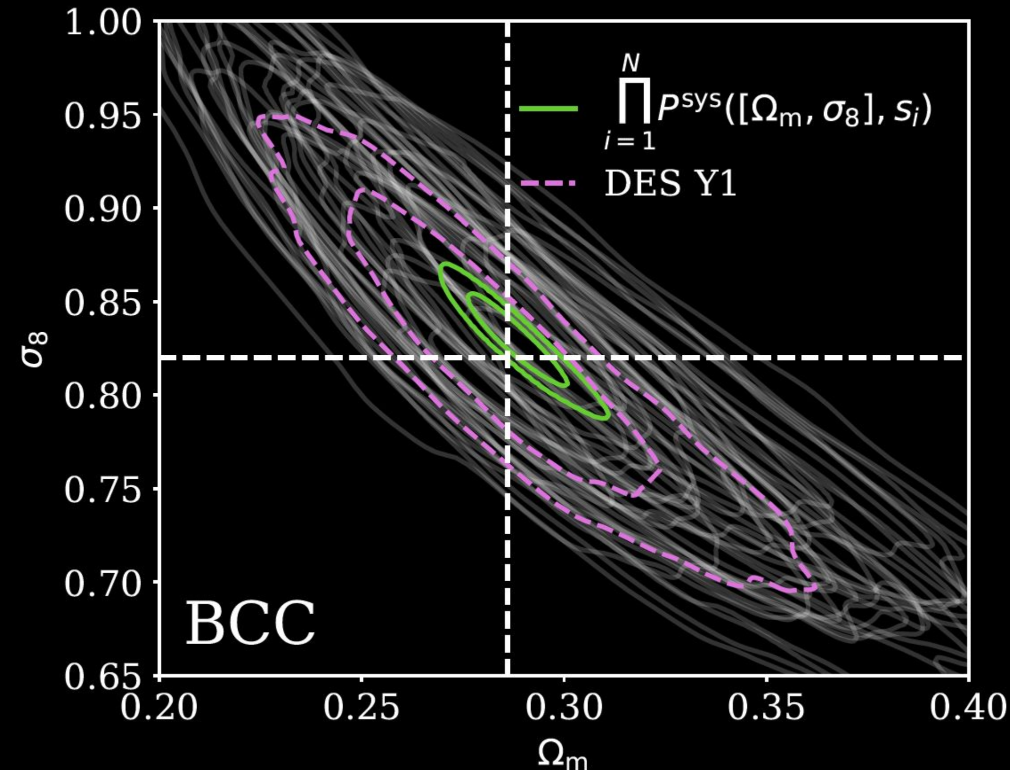


With great statistical power comes great systematic responsibility

- Y1: two independent cosmological inference pipelines, tested with simulations

Update for Y3: substantially improved models of smaller-scale effects (bias, intrinsic alignment, magnification) ++

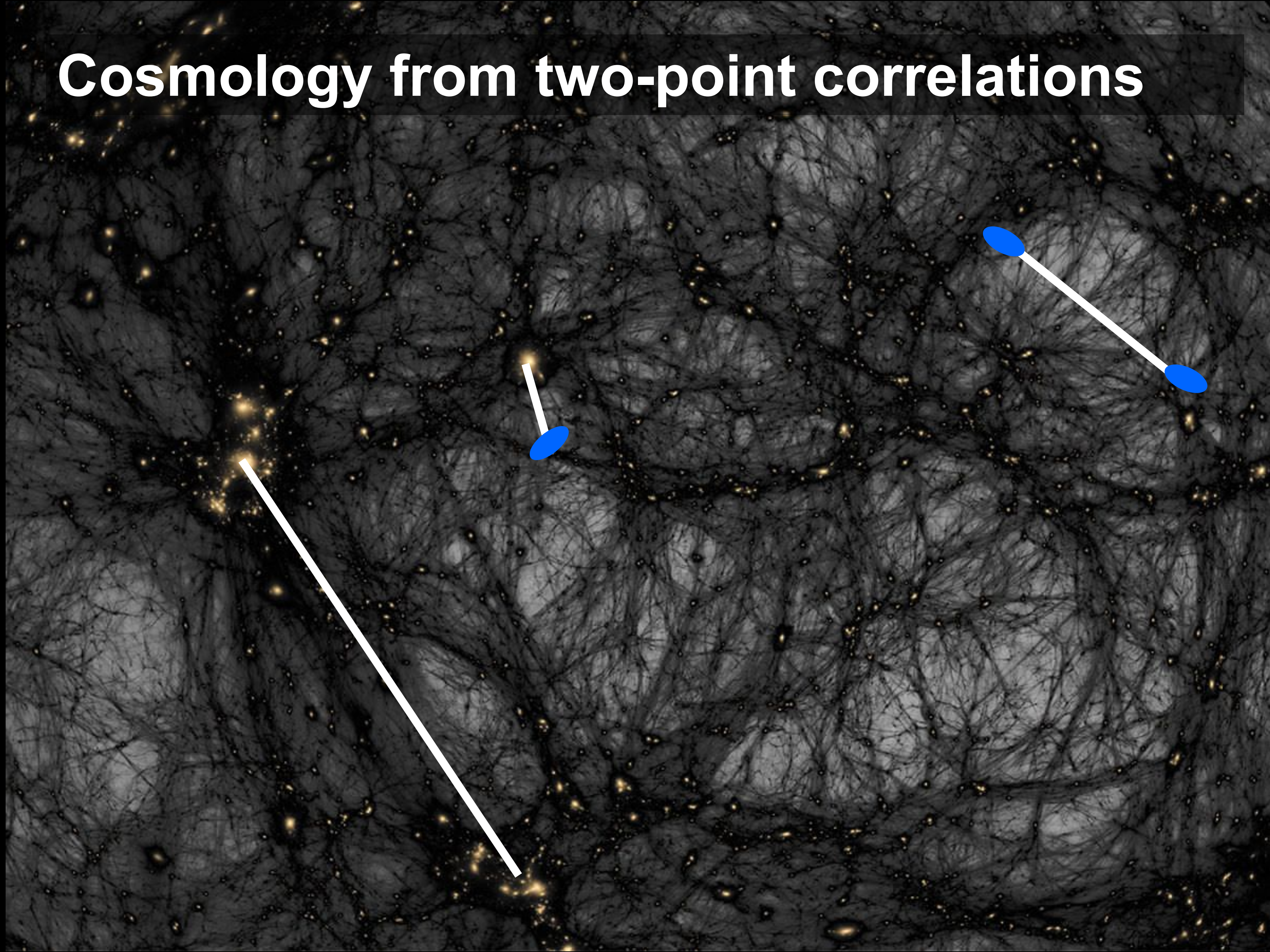
[J. DeRose, S. Pandey, L. Secco, J. Elvin-Poole, J. Blazek, E. Krause, M. Troxel, N. MacCrann, A. Porredon, J. Prat, O. Friedrich, T. Eifler, D. Huterer, J. Muir, B. Jain, ...]

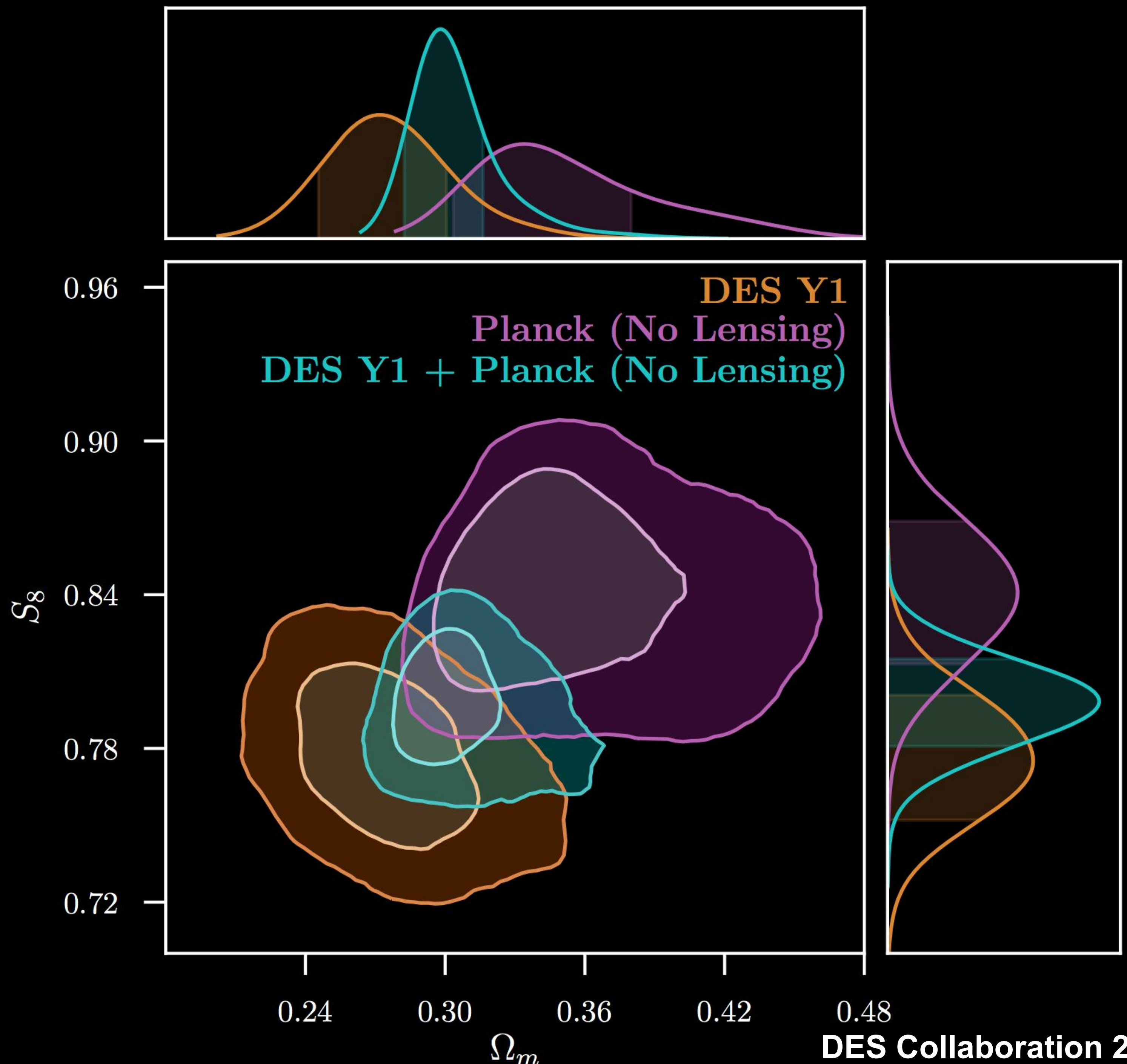


MacCrann & DeRose+2018:
DES likelihoods accurate enough for 18x the (simulated) Y1 volume

(Krause &Eifler+2018; MacCrann & DeRose+2018)

Cosmology from two-point correlations



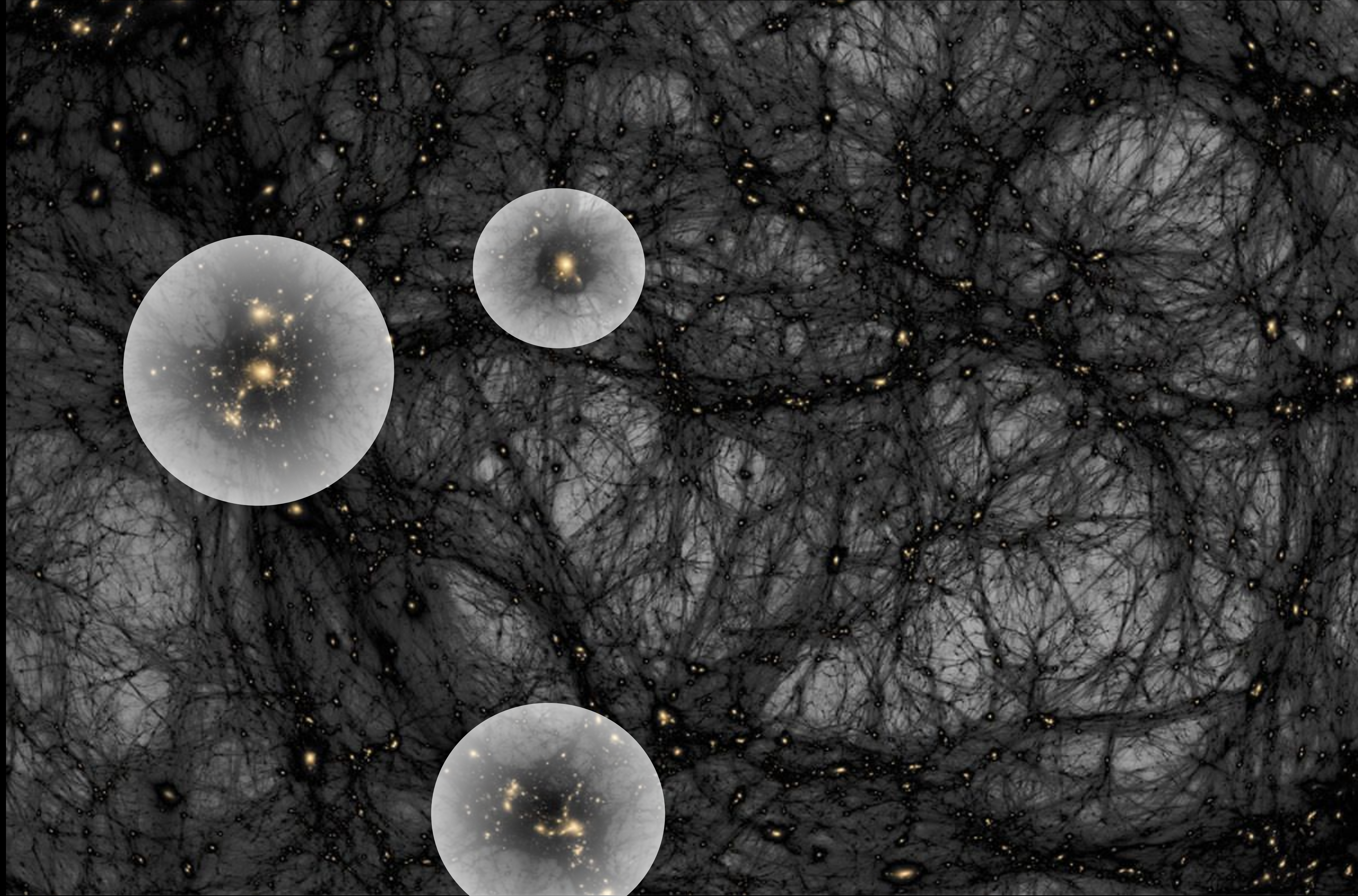


DES Collaboration 2018

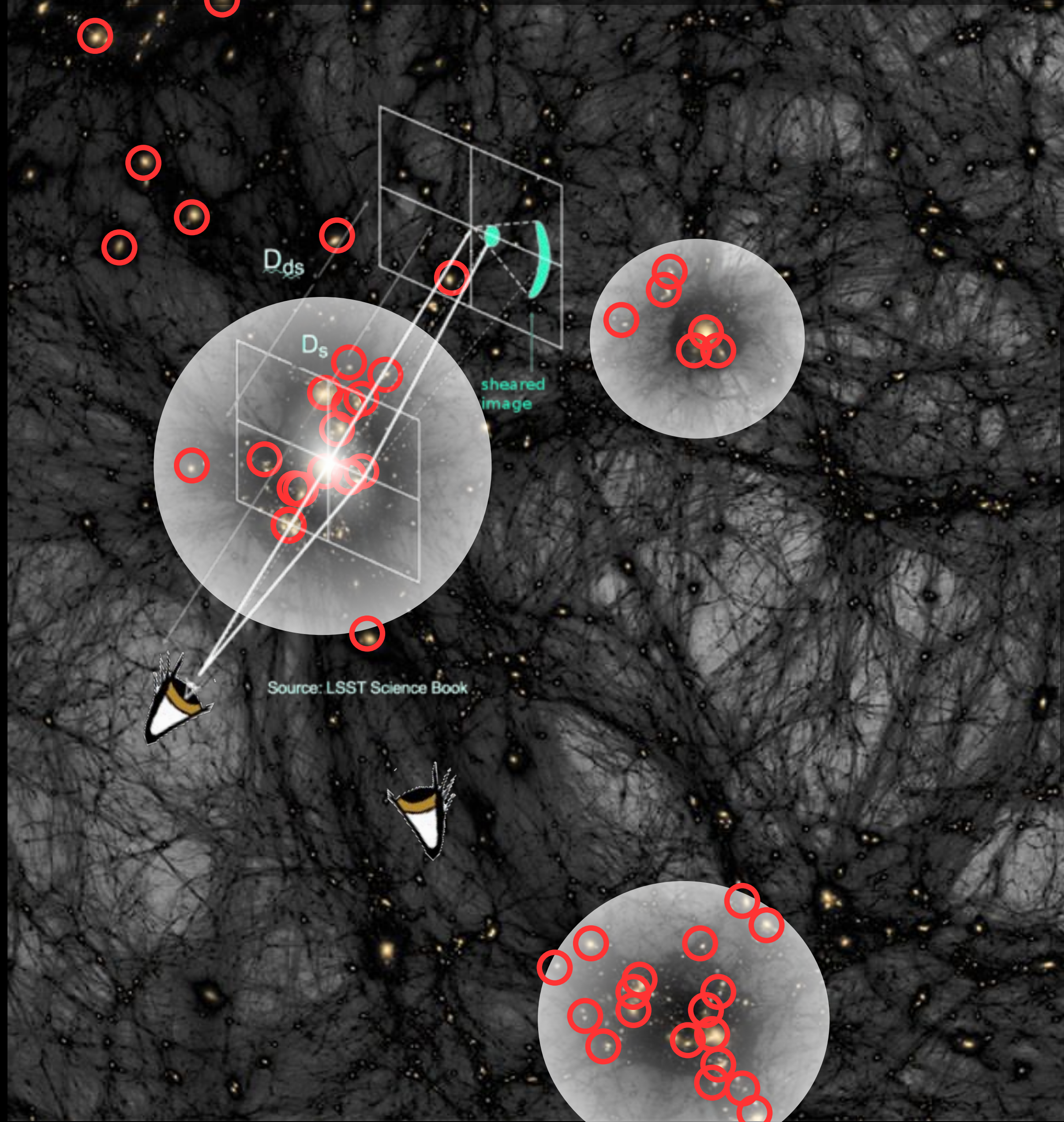
I. The curious case of low-mass clusters

DES 2020; McClintock&Varga+2018; Varga+2019; Zhang+2019; Costanzi+2018,2019;
Rykoff&Rozo&Rozo&Rykoff++; ...

Clusters of galaxies



Counting clusters of galaxies

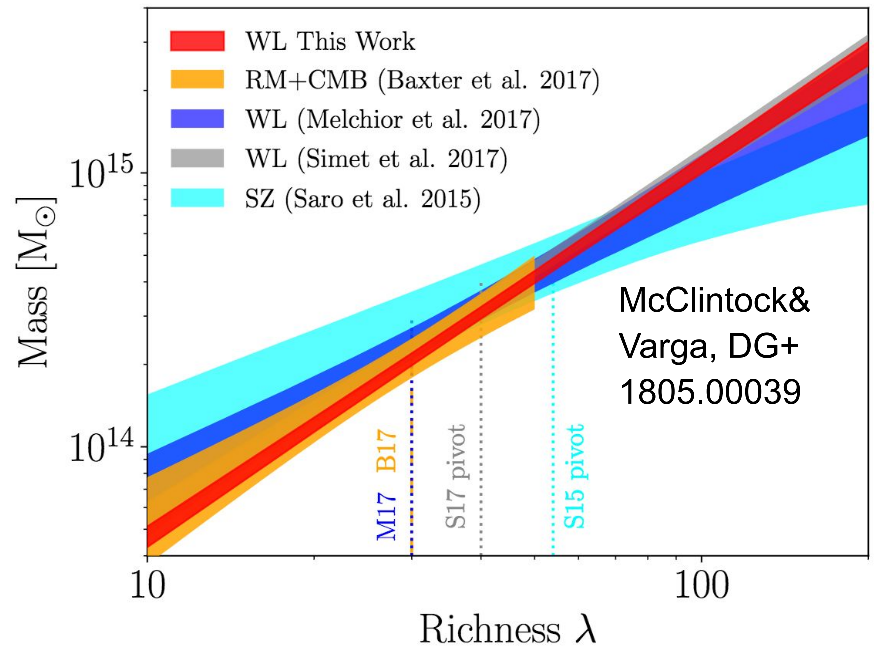


richness =
count of bright
elliptical galaxies

Caveat:
projection effects

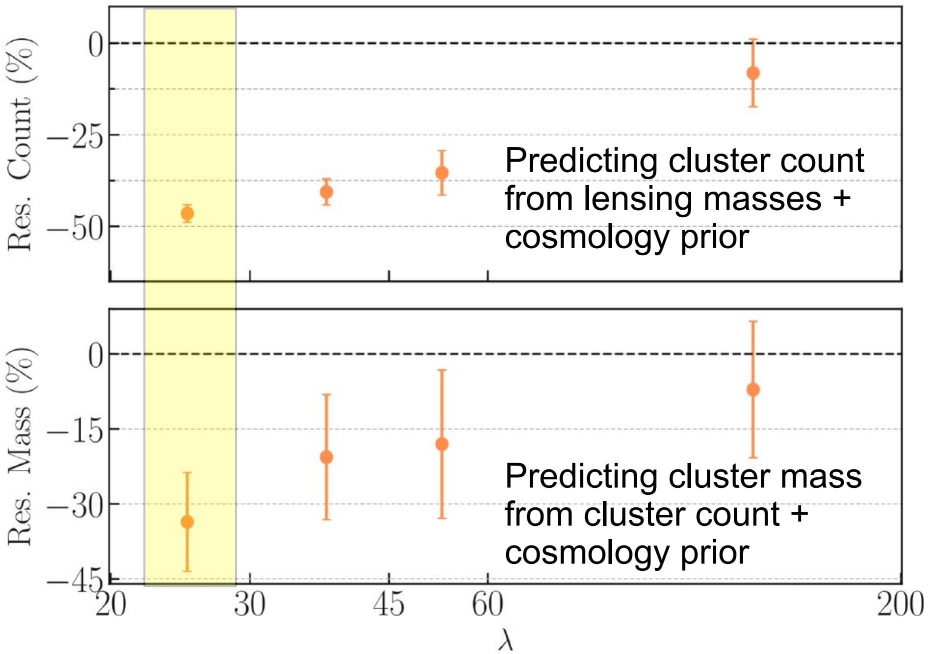
Cosmology with clusters of galaxies: MOR calibration with lensing surveys

- Large area lensing surveys are now by far the best way of calibrating the mean mass of cluster samples



Cosmology with clusters of galaxies: DES Y1 shows something is 'off'

- Large area lensing surveys are now by far the best way of calibrating the mean mass of cluster samples
- The DES Y1 analysis revealed that something is off



DES 2020

Cosmology with clusters of galaxies: DES Y1 shows something is 'off'

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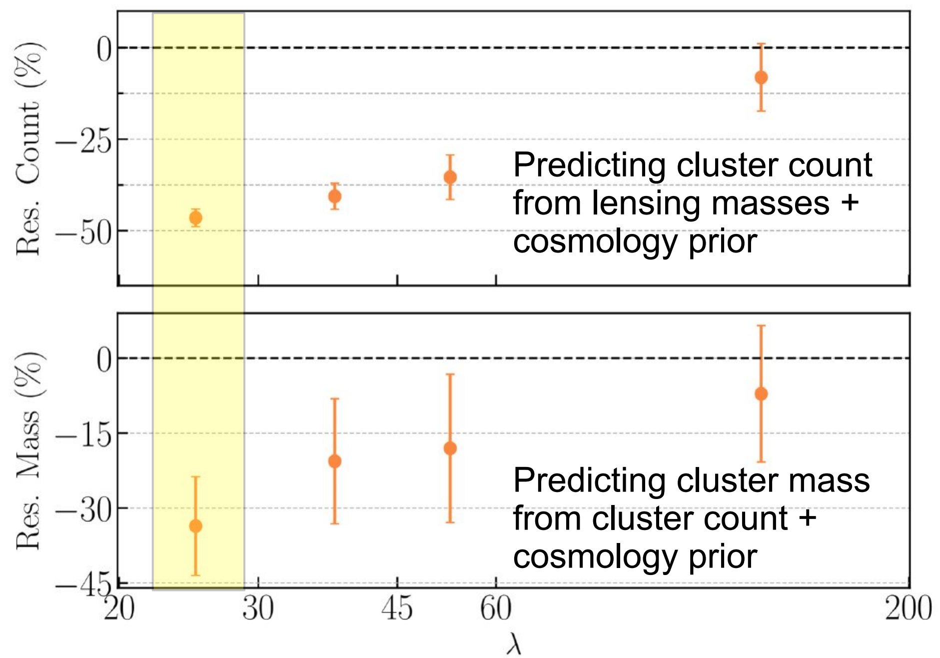


If we use a plausible cosmology prior and fit MOR models to the lensing masses of clusters in bins of richness, we find that there are way fewer than our model predicts at small to intermediate richness.

If we use a plausible cosmology prior and fit MOR models to the counts of clusters in bins of richness, we find that small-richness clusters show way smaller lensing signal than our model predicts.

What's your hypothesis?

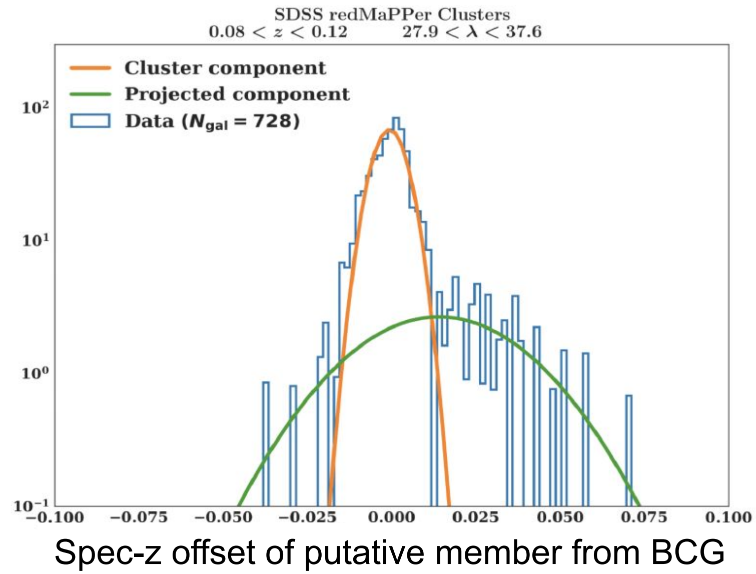
Hypotheses wanted: what causes low counts and low masses of low-richness clusters?

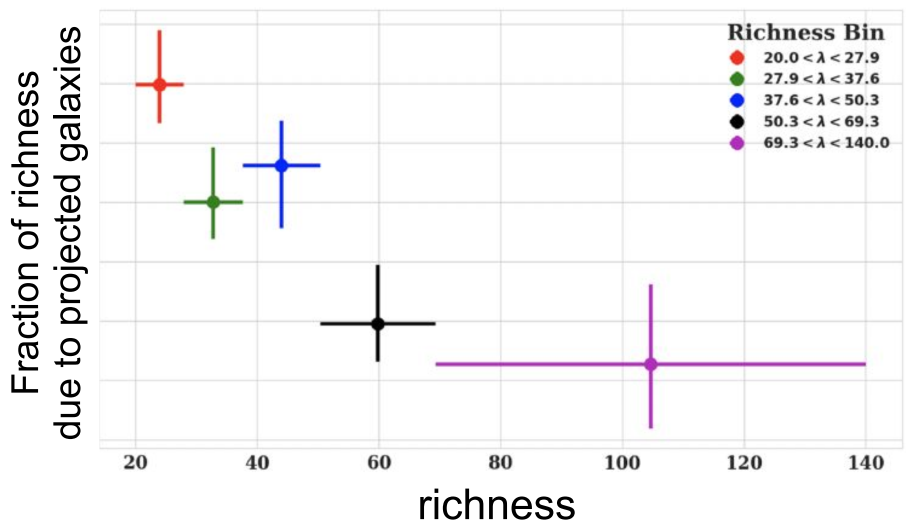
Top

Ways forward:
MOR calibration with lensing++

- Large area lensing surveys are now by far the best way of calibrating the mean mass of cluster samples
- The unblinded DES Y1 analysis is revealing that a piece of the picture is off
- We will have to probe the pieces individually: e.g. with spectroscopic follow-up and individual X-ray masses

Spectroscopic study of projection effects:
Myles, DG+ in prep.;
spec-z campaign, including A. Kremin



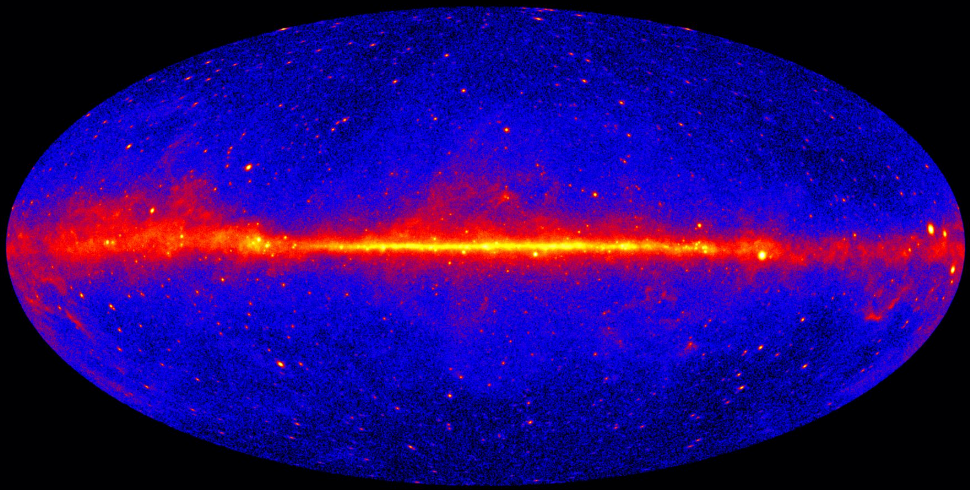


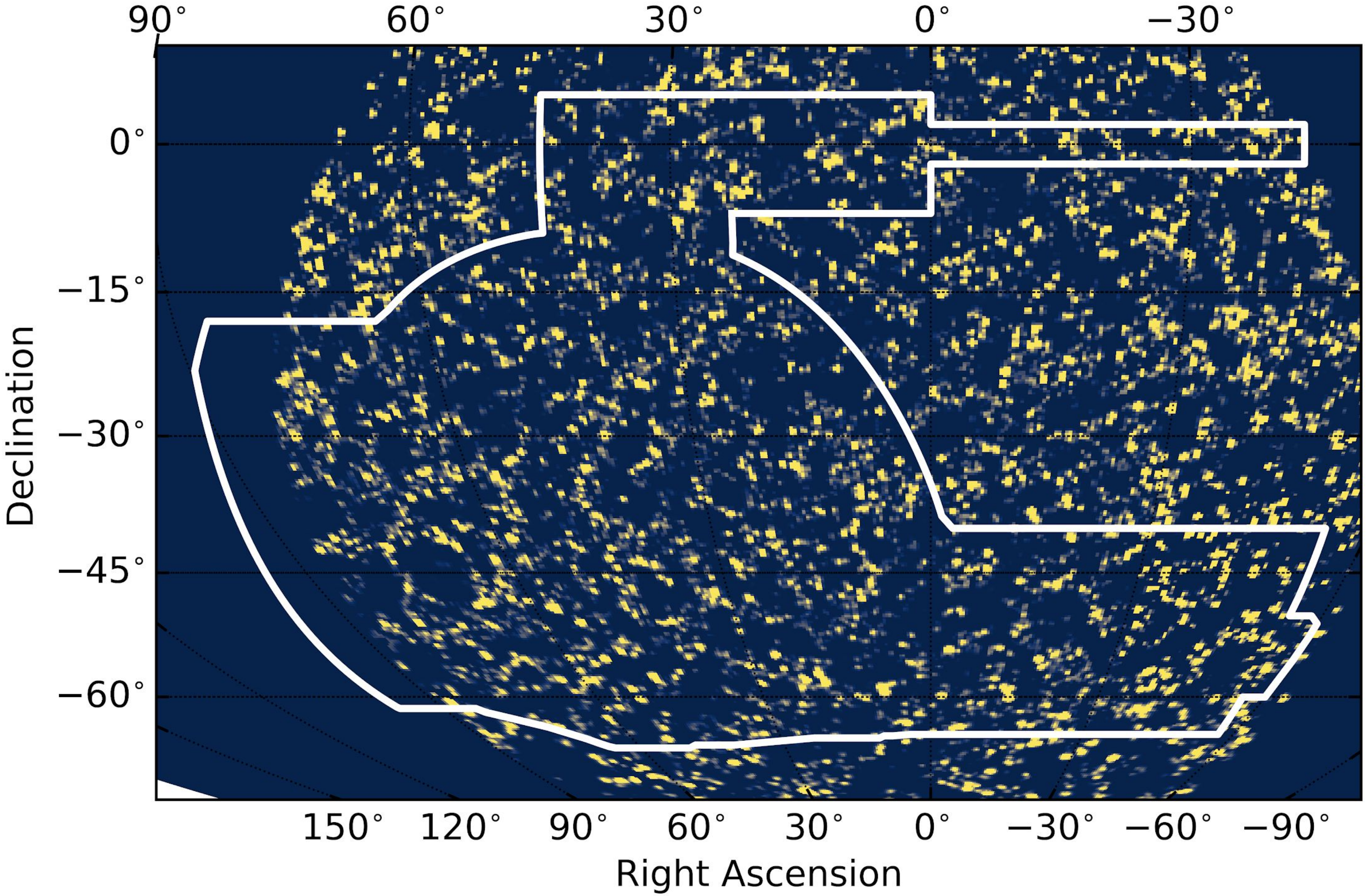
II. First detection of γ around γ

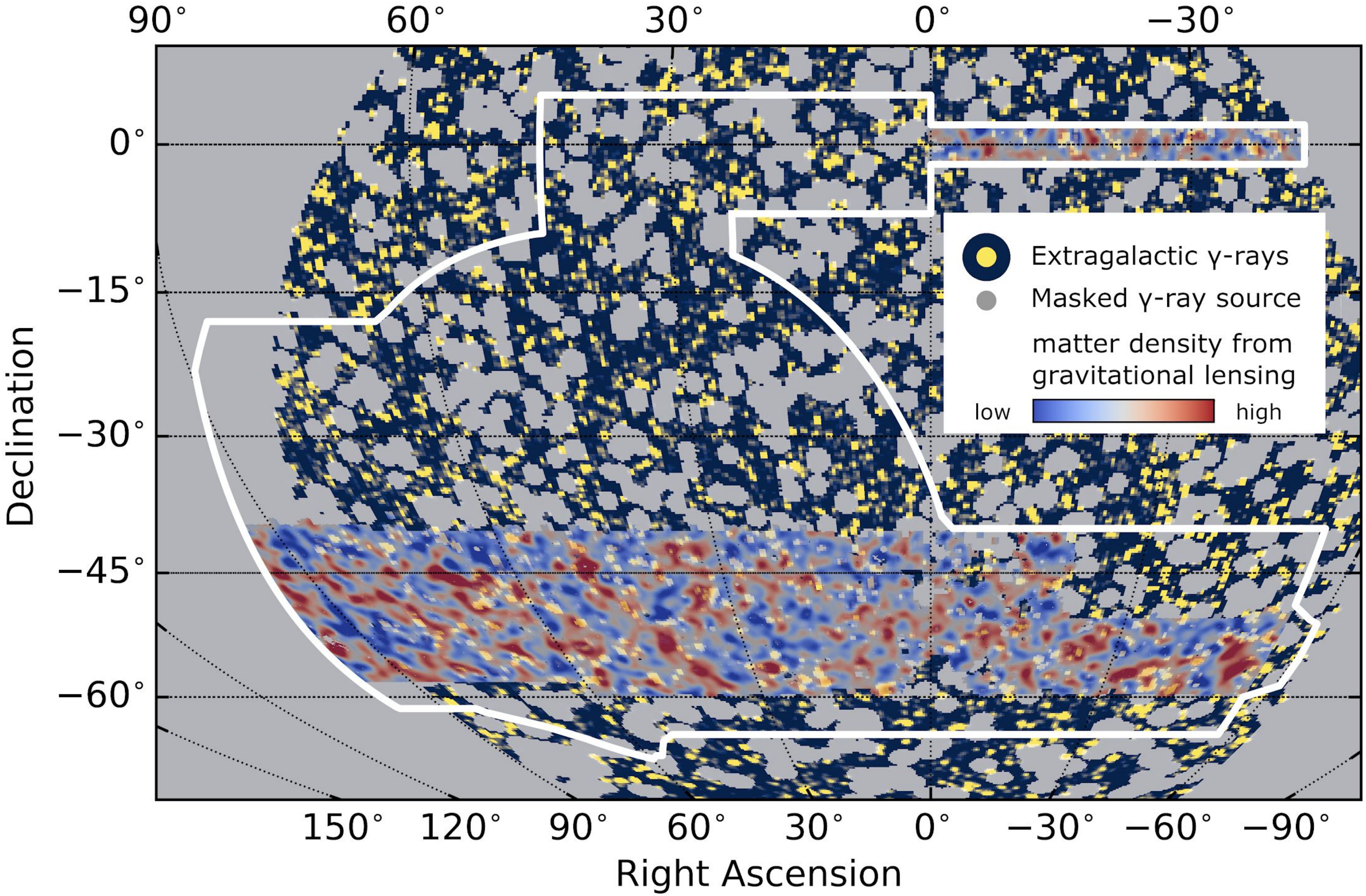
Ammazzalorso&Gruen+2020

Fermi Large Area Telescope

- Space mission by DOE+NASA to map gamma-ray sky
- 20% of the sky observed at any time
- 20 MeV - 1 TeV
- 1deg … 10arcmin PSF from low to high energy
- Counting photons since 2008

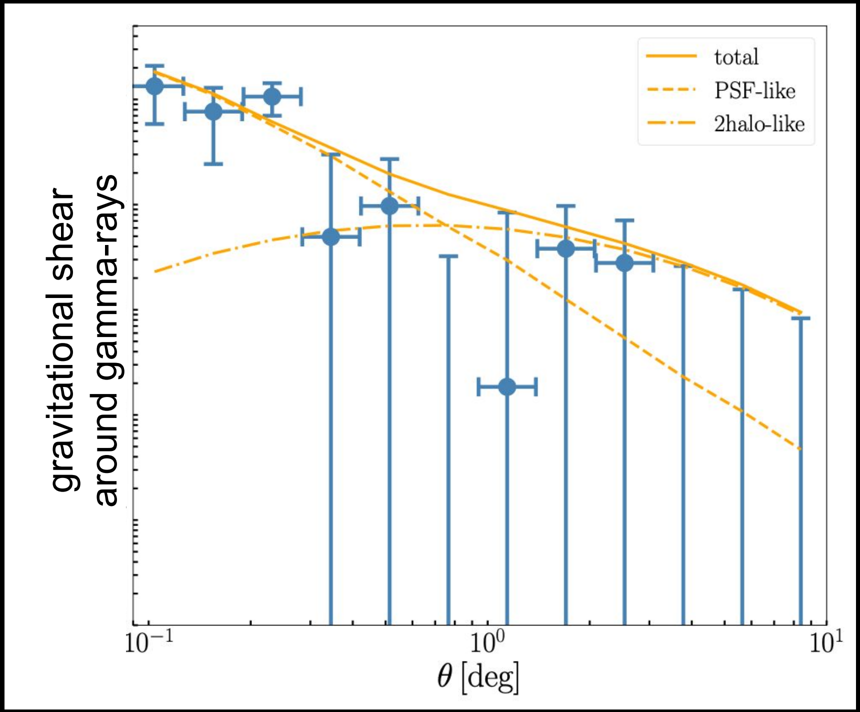


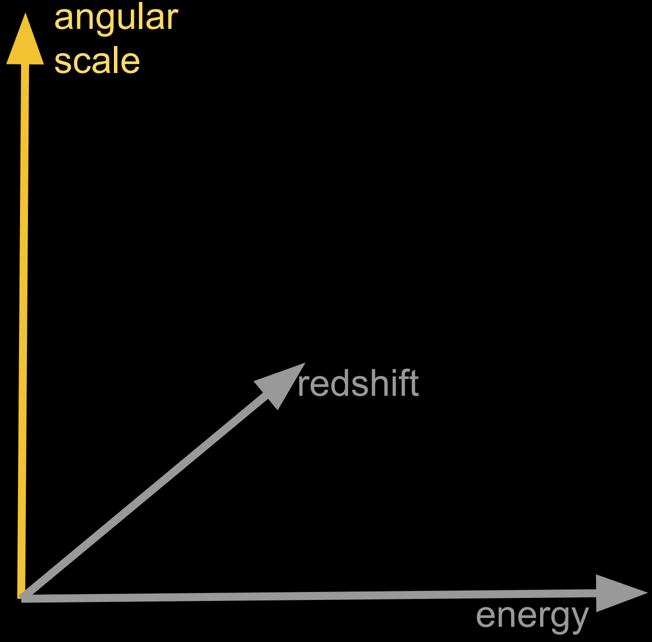

90°
60°
30°
0°
−30°
0°
−15°
−30°
−45°
−60°
Declination
150°
120°
90°
60°
30°
0°
−30°
−60°
−90°
Right Ascension



90°
60°
30°
0°
−30°
0°
−15°
−30°
−45°
−60°
150°
120°
90°
60°
30°
0°
−30°
−60°
−90°
Declination
Right Ascension
Extragalactic γ-rays
Masked γ-ray source
matter density from gravitational lensing
low
high

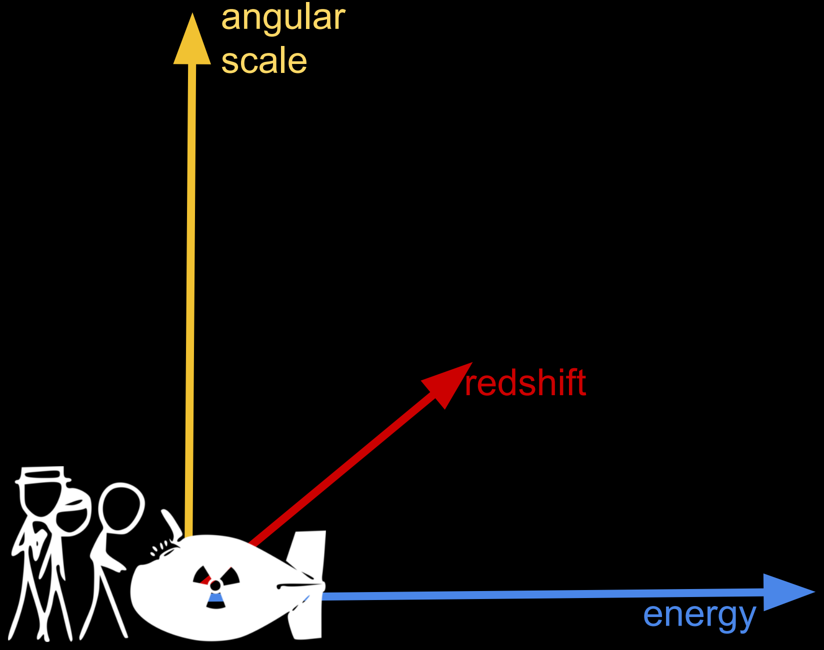
Detecting cross-correlation of γ-rays with gravitational lensing





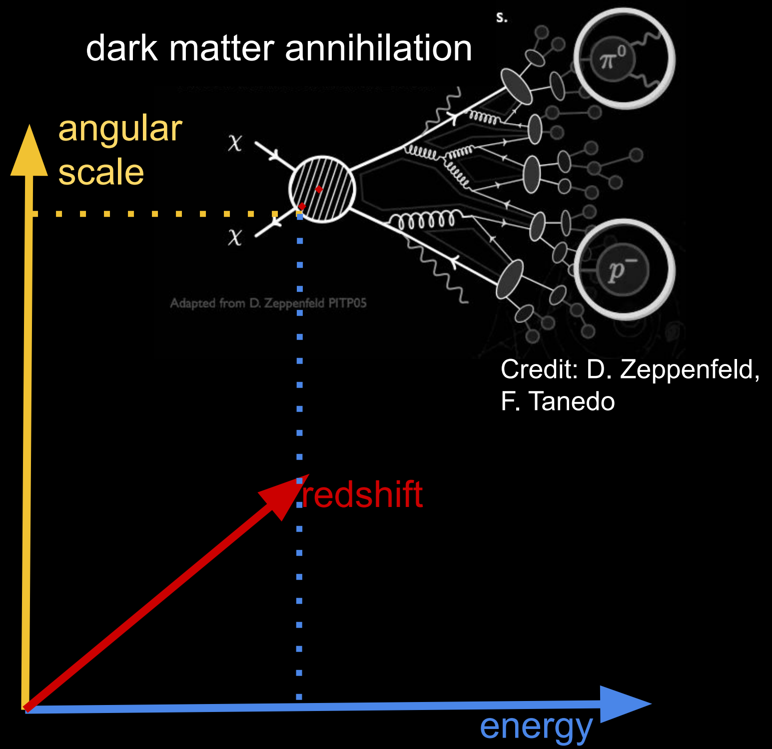
Discriminating sources of γ-rays with gravitational lensing

- Cross-correlation is a 3D data vector: angular scale, γ-ray energy, redshift
- Components have characteristic signatures



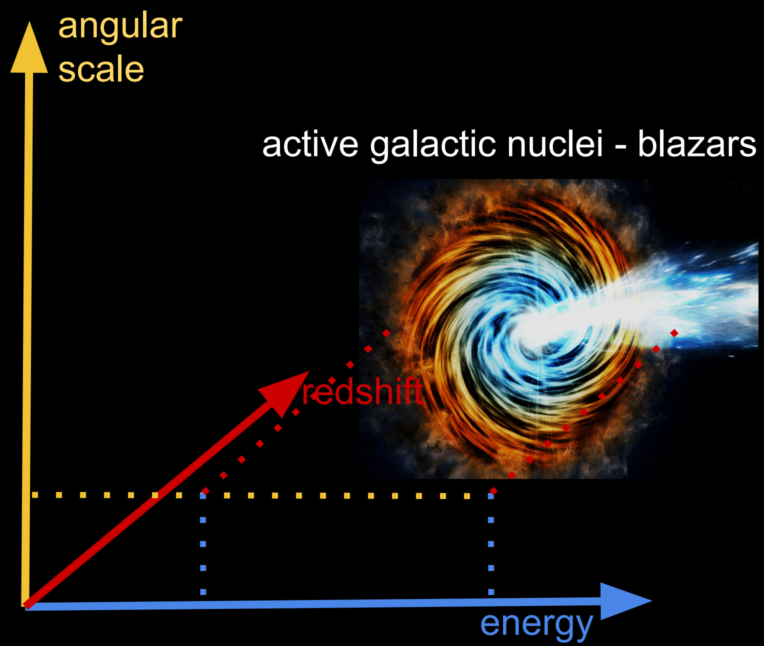
Discriminating sources of γ-rays with gravitational lensing

- Cross-correlation is a 3D data vector: angular scale, γ-ray energy, redshift
- Components have characteristic signatures:
    - Dark matter annihilation: low redshift, bump in energy related to particle mass, large two-halo/one-halo ratio



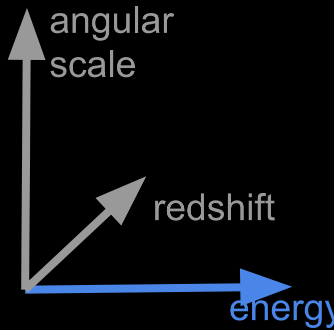
Discriminating sources of γ-rays with gravitational lensing

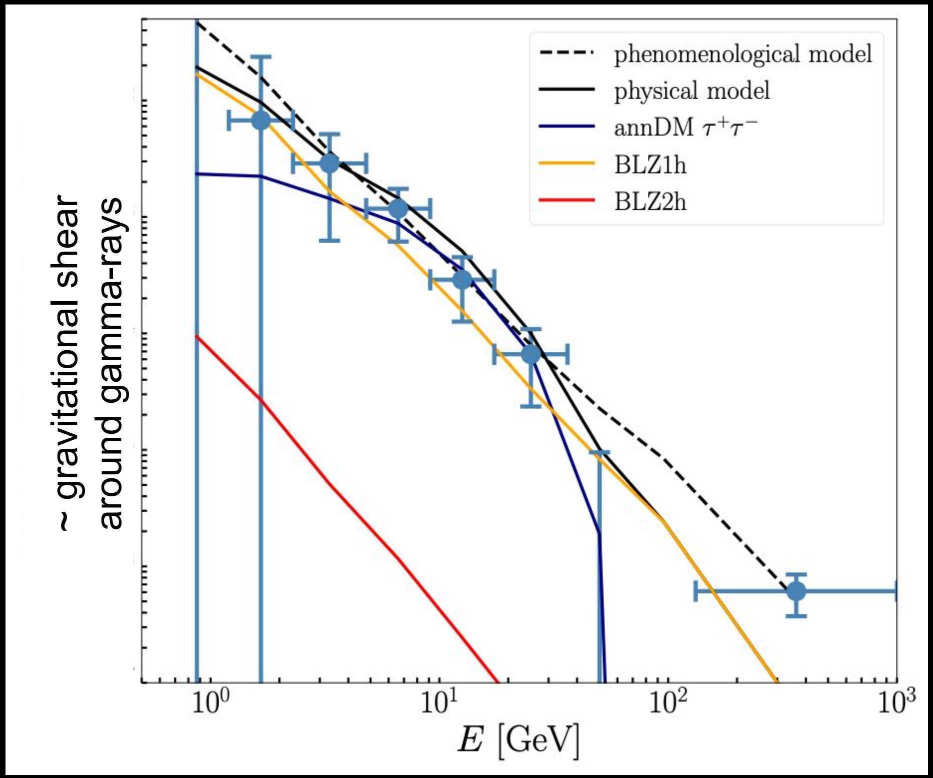
- Cross-correlation is a 3D data vector: angular scale, γ-ray energy, redshift
- Components have characteristic signatures:
  - Dark matter annihilation: low redshift, bump in energy related to particle mass, large two-halo/one-halo ratio
  - Blazars: higher redshift, dominate at higher/lower energies than bump, small one-halo/two-halo ratio



Discriminating sources of γ-rays with gravitational lensing

- Cross-correlation is a 3D data vector: angular scale, γ-ray energy, redshift
- Components have characteristic signatures:
  - Dark matter annihilation: low redshift, bump in energy related to particle mass, large two-halo/one-halo ratio
  - Blazars: higher redshift, dominate at higher/lower energies than bump, small two-halo/one-halo ratio
- Fit improves (with 2-3σ significance) when adding DM component





What do you think this fit indicates?

The excess correlation is caused by dark matter particles annihilating.

The excess correlation is caused by more complex astrophysical components.

The excess correlation is noise.

Something else.

III. Direct redshift calibration

Hoyle&Gruen+2018; Gruen+2017; Joudaki+2019; Buchs&Davis+2019; Hartley+2020

A redshift calibration algorithm

sample of galaxies with wide-field few-band photometry —match to, by (g)riz→ **sample of galaxies with known redshift**

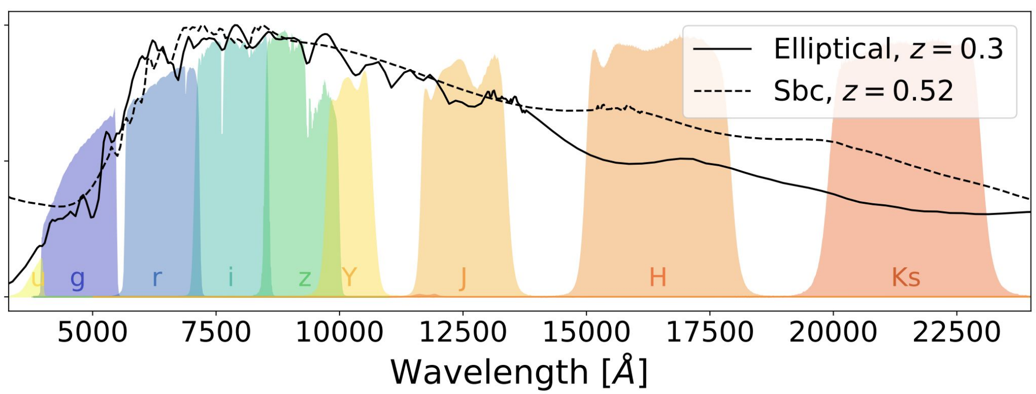
OK if and only if:

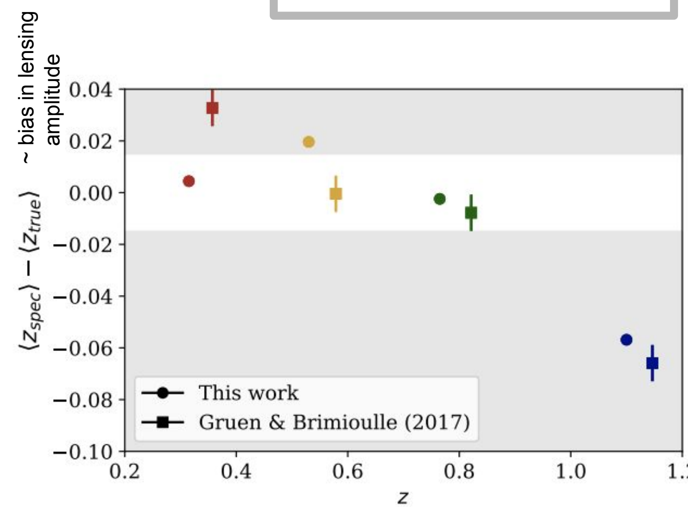
- 'known redshifts' are actually correct redshifts
- redshift sample is complete + representative of all types/redshifts of wide field galaxies
- matching is done in a consistent fashion

For all we know, COSMOS30 redshifts at Y1 depth and the Y1 methodology check these boxes

A redshift calibration algorithm with large bias

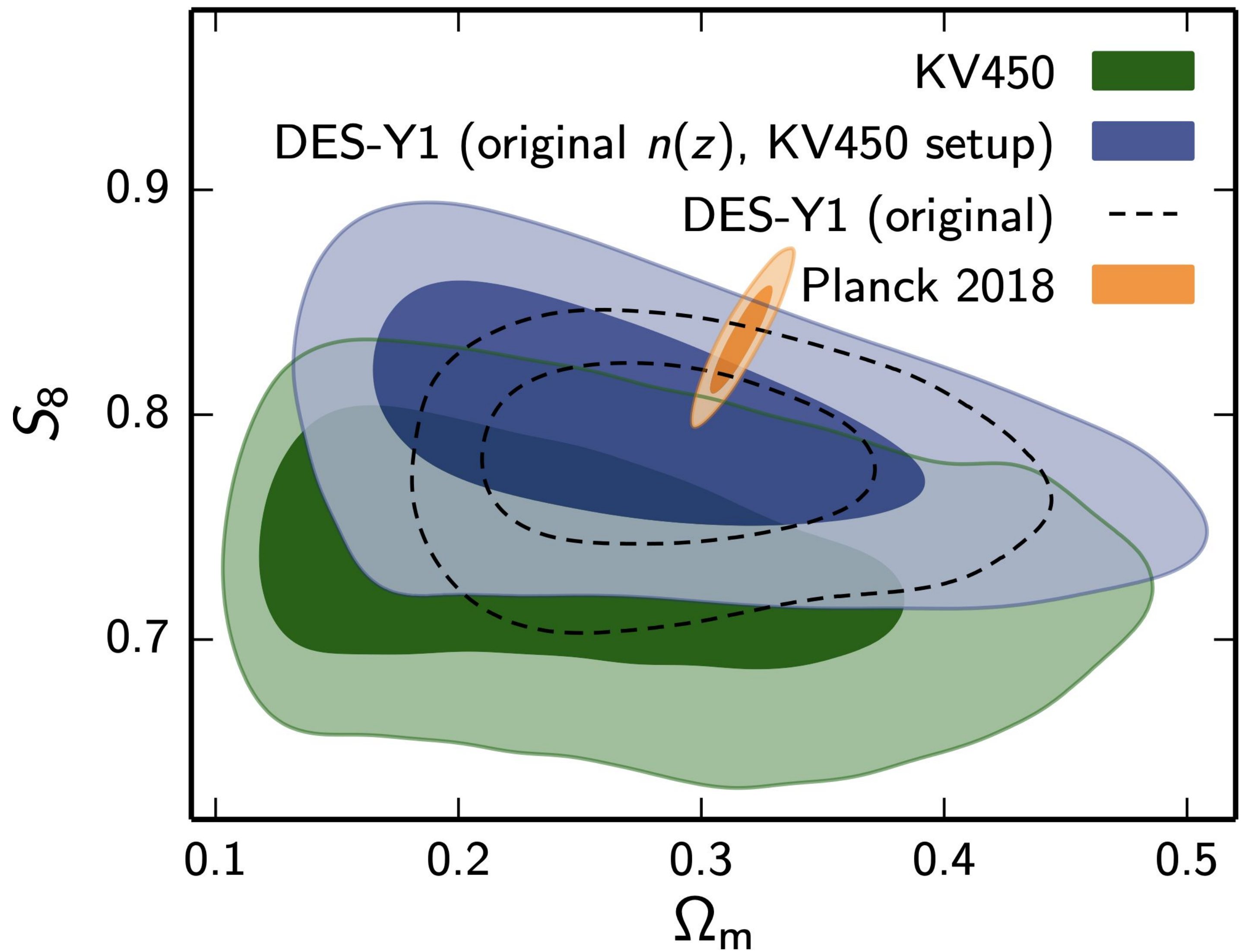
sample of galaxies with wide-field few-band photometry → match to, by (g)riz → **sample of galaxies with spectroscopic redshift**

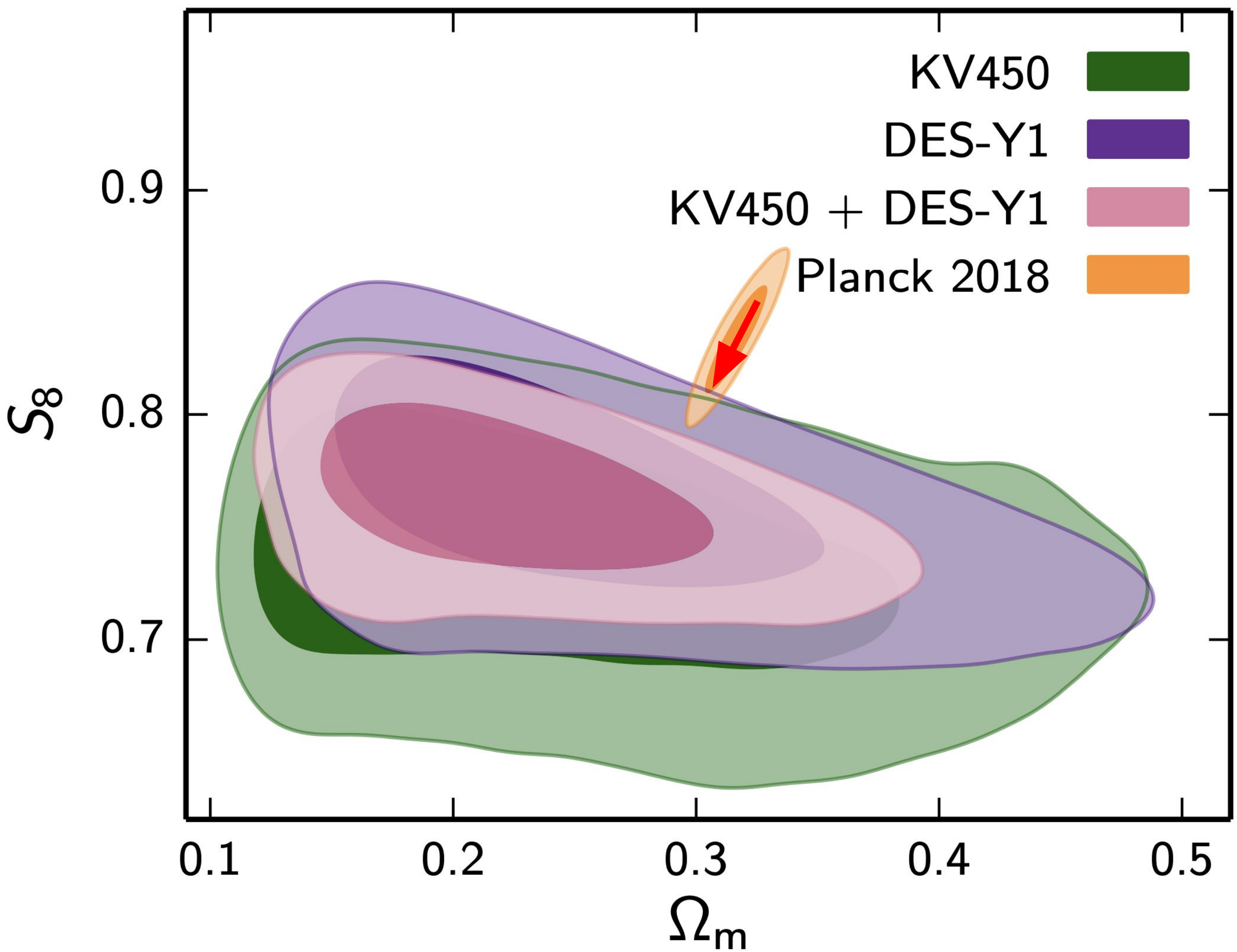




Explicit selection bias: spec-z sample selected by colors not observed by wide-field survey
Implicit selection bias: spec-z success rate depends on type/redshift of galaxy

Bonnett+2016; DG & Brimioulle 2017; Buchs & Davis+ 2019; Hartley+ 2020


KV450
DES-Y1 (original n(z), KV450 setup)
DES-Y1 (original)
Planck 2018
0.9
0.8
0.7
0.1
0.2
0.3
0.4
0.5
S_8
Ω_m



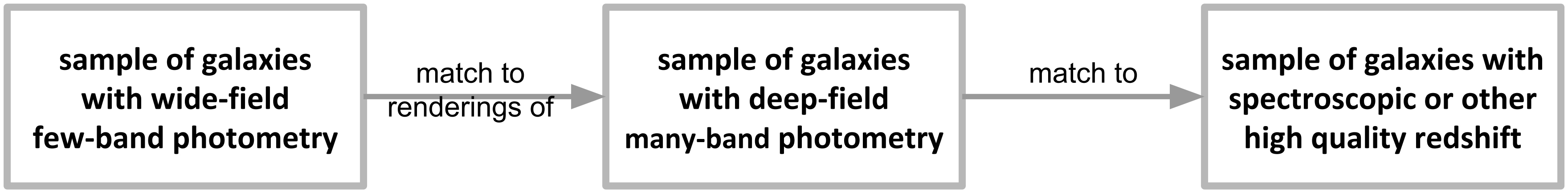
KiDS reanalysis of DES Y1 with 'direct spectroscopic calibration' Joudaki+2019

Table A.1: KV450 and DES-Y1 changes in the mean redshift for each tomographic bin informed by the MICE2 mock catalogues (i.e. Truth − $\mathrm{DIR}_{\mathrm{MICE2}}$).

Tom. bin	KV450 $\Delta < z >$	DES-Y1 $\Delta < z >$
1	-0.048 ± 0.010	-0.026 ± 0.016
2	-0.026 ± 0.008	-0.021 ± 0.014
3	-0.033 ± 0.012	-0.033 ± 0.010
4	0.005 ± 0.008	-0.012 ± 0.012
5	0.013 ± 0.008	—

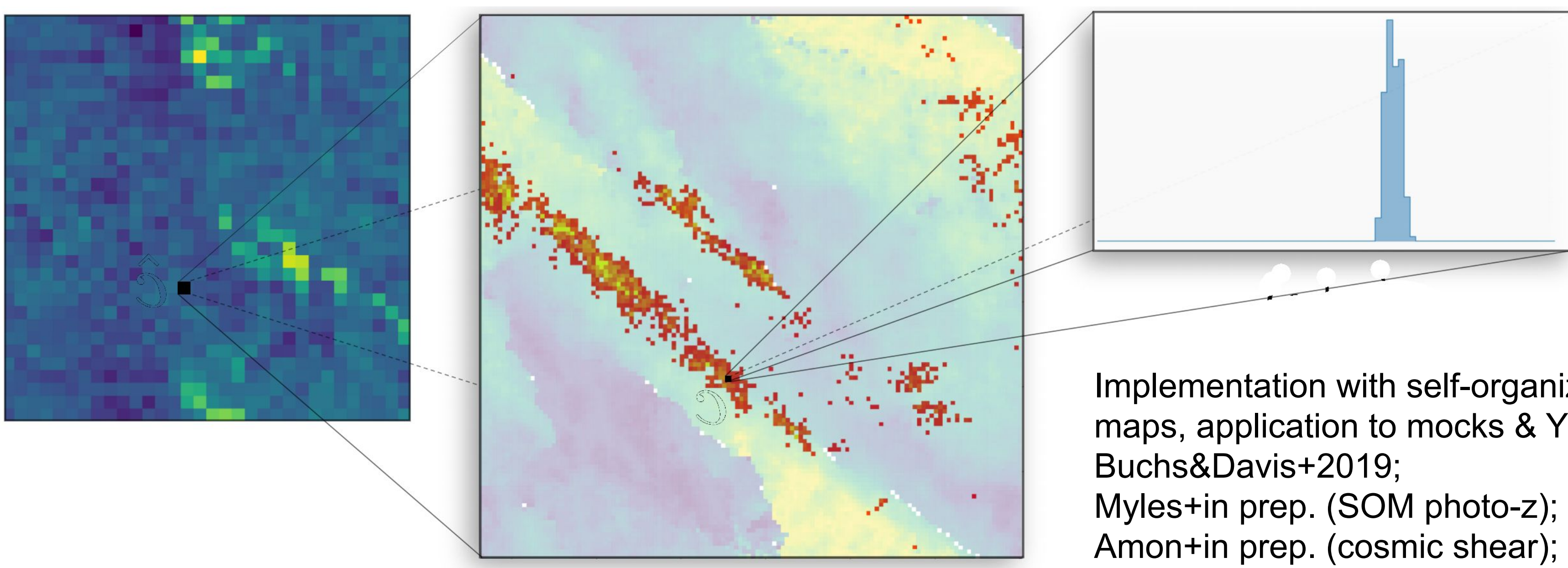
revised version of Joudaki et al.:
-0.05 to 0.02 bias on mean redshift with ‘direct spectroscopic calibration’ on mocks,
cf. their -0.05 to -0.02 revision of the original DES Y1 calibration

An updated redshift calibration algorithm for DES Y3



An updated redshift calibration algorithm for DES Y3

sample of galaxies with wide-field few-band photometry → match to renderings of → **sample of galaxies with deep-field many-band photometry** → match to → **sample of galaxies with spectroscopic or other high quality redshift**



Implementation with self-organizing maps, application to mocks & Y3:
Buchs&Davis+2019;
Myles+in prep. (SOM photo-z);
Amon+in prep. (cosmic shear);
J. McCullough: (photo-z & blending)

Summary

- When you look at the sky for a long time with a big camera and telescope, sometimes you find something you didn't expect.
- Personal selection from one year of DES lensing data:
  - The anomalously small count and lensing signal of low-richness galaxy clusters
  - The not-quite-as-expected tomographic cross-correlation signal of gamma rays and lensing
  - The trials and tribulations of direct spectroscopic calibration
- Three years of DES data and our improved methods
  - have the power to provide answers to these questions (this year!)
  - will test cosmological model with late-time structure better than ever

When poll is active, respond at **PollEv.com/dgru**

Text **DGRU** to **22333** once to join

Questions?