Image Credit: Marco Gatti

Cosmology from the Dark Energy Survey

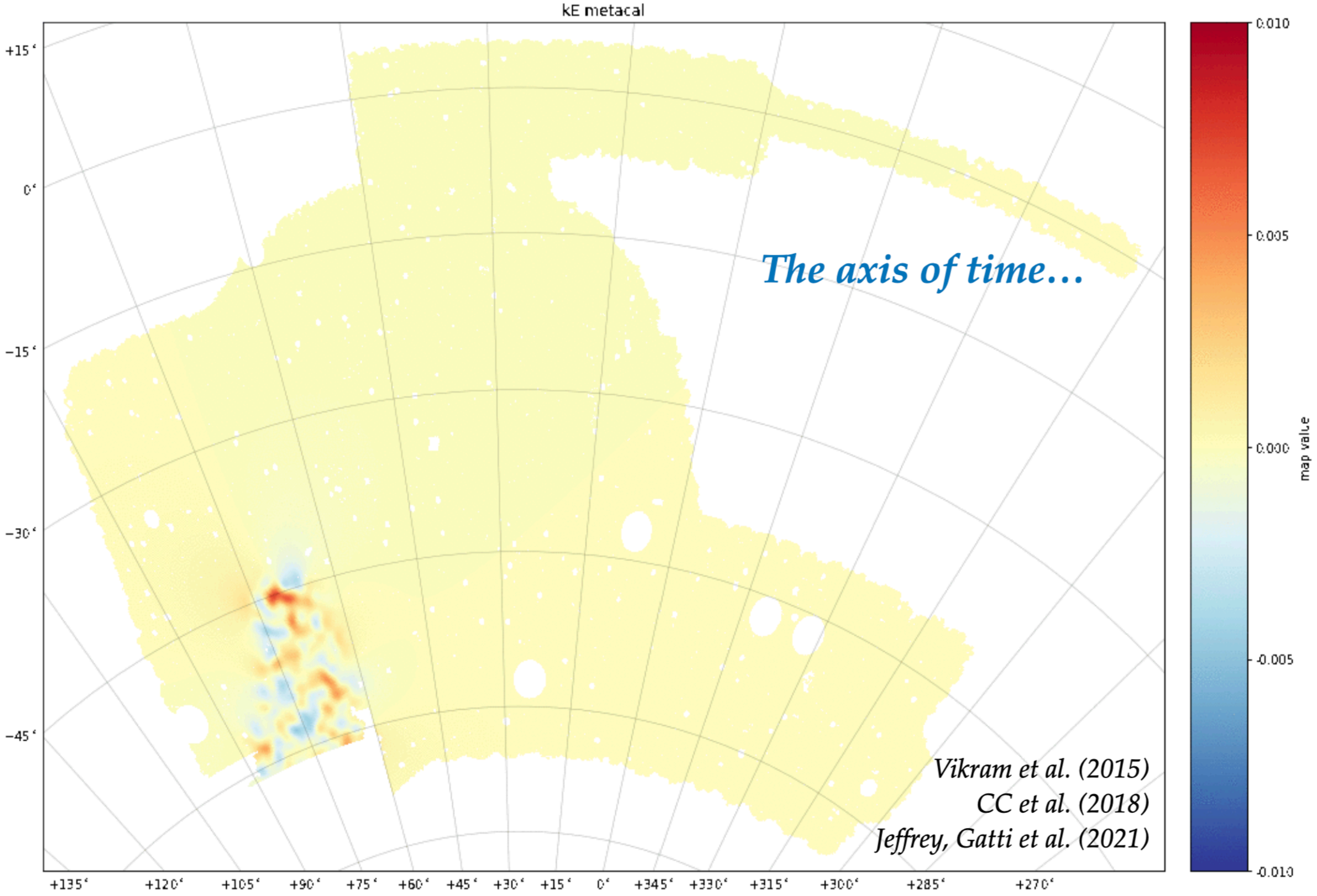
pushing boundaries, setting standards, and shaping the community

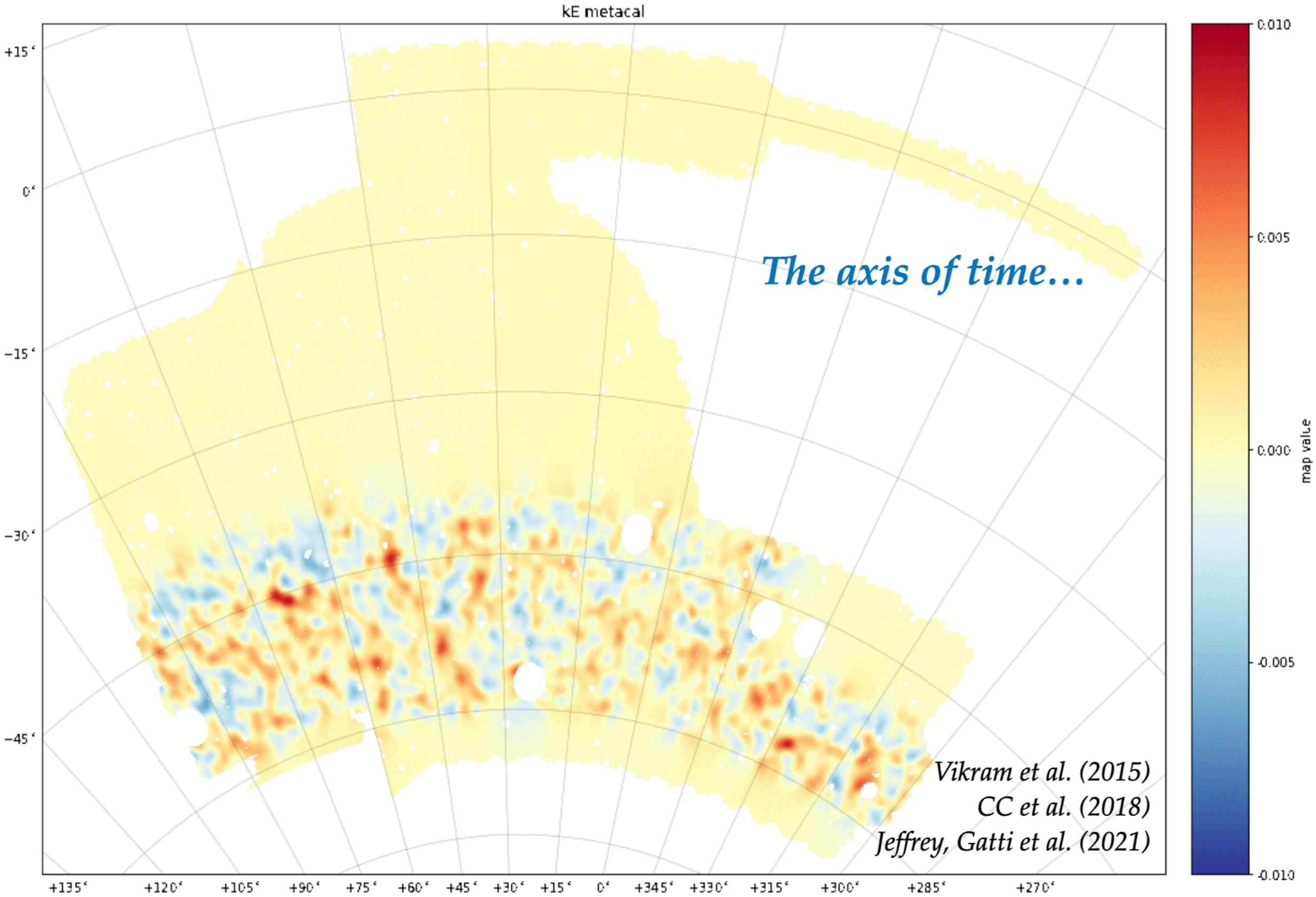
Chihway Chang (UChicago/KICP)
on behalf of the Dark Energy Survey Collaboration

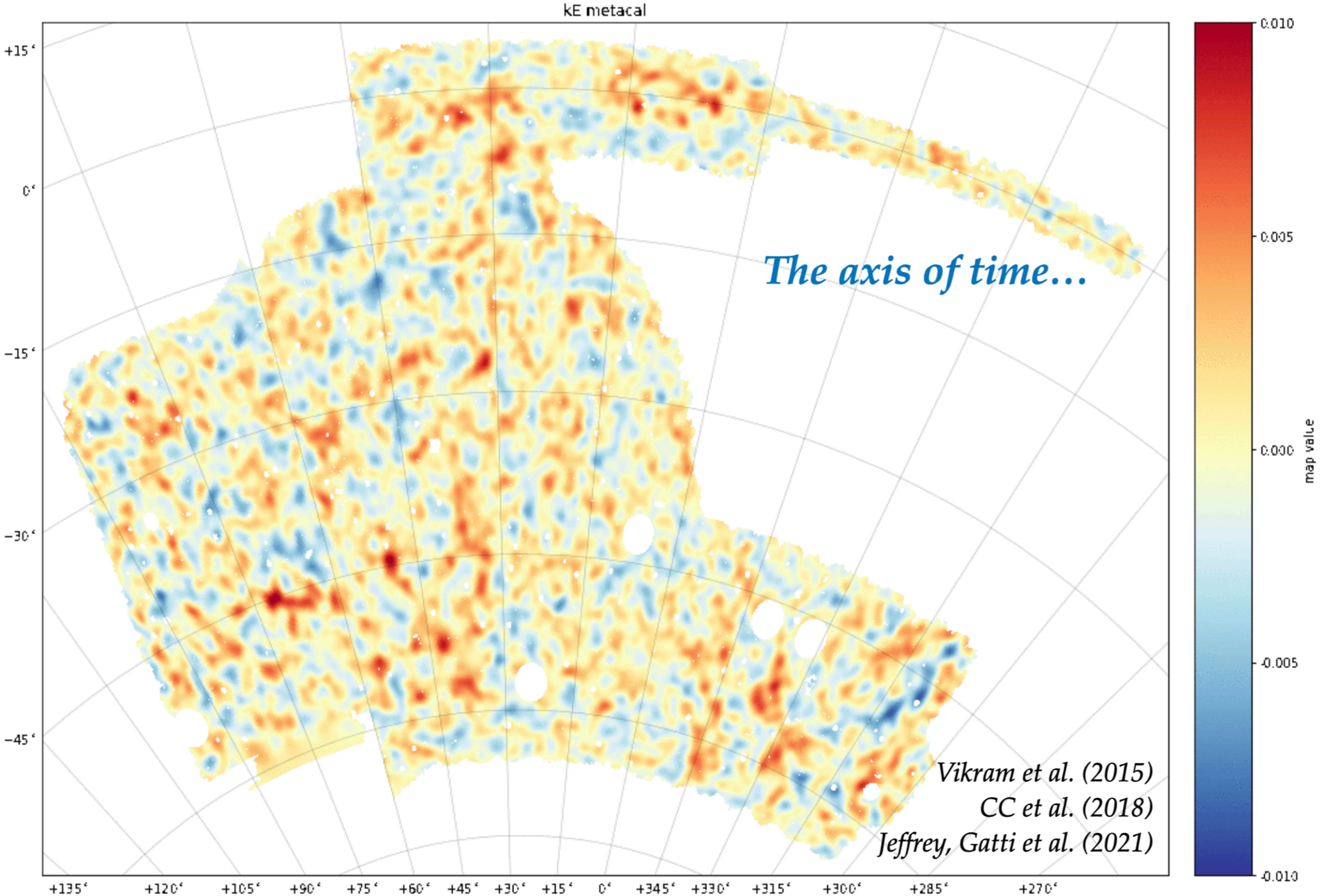
July 2011 Portsmouth

The axis of time…

May 2022 Duke


kE metacal
+15‘
0‘
−15‘
−30‘
−45‘
+135‘
+120‘
+105‘
+90‘
+75‘
+60‘
+45‘
+30‘
+15‘
0‘
+345‘
+330‘
+315‘
+300‘
+285‘
+270‘
0.010
0.005
0.000
-0.005
-0.010
map value
The axis of time…
Vikram et al. (2015)
CC et al. (2018)
Jeffrey, Gatti et al. (2021)

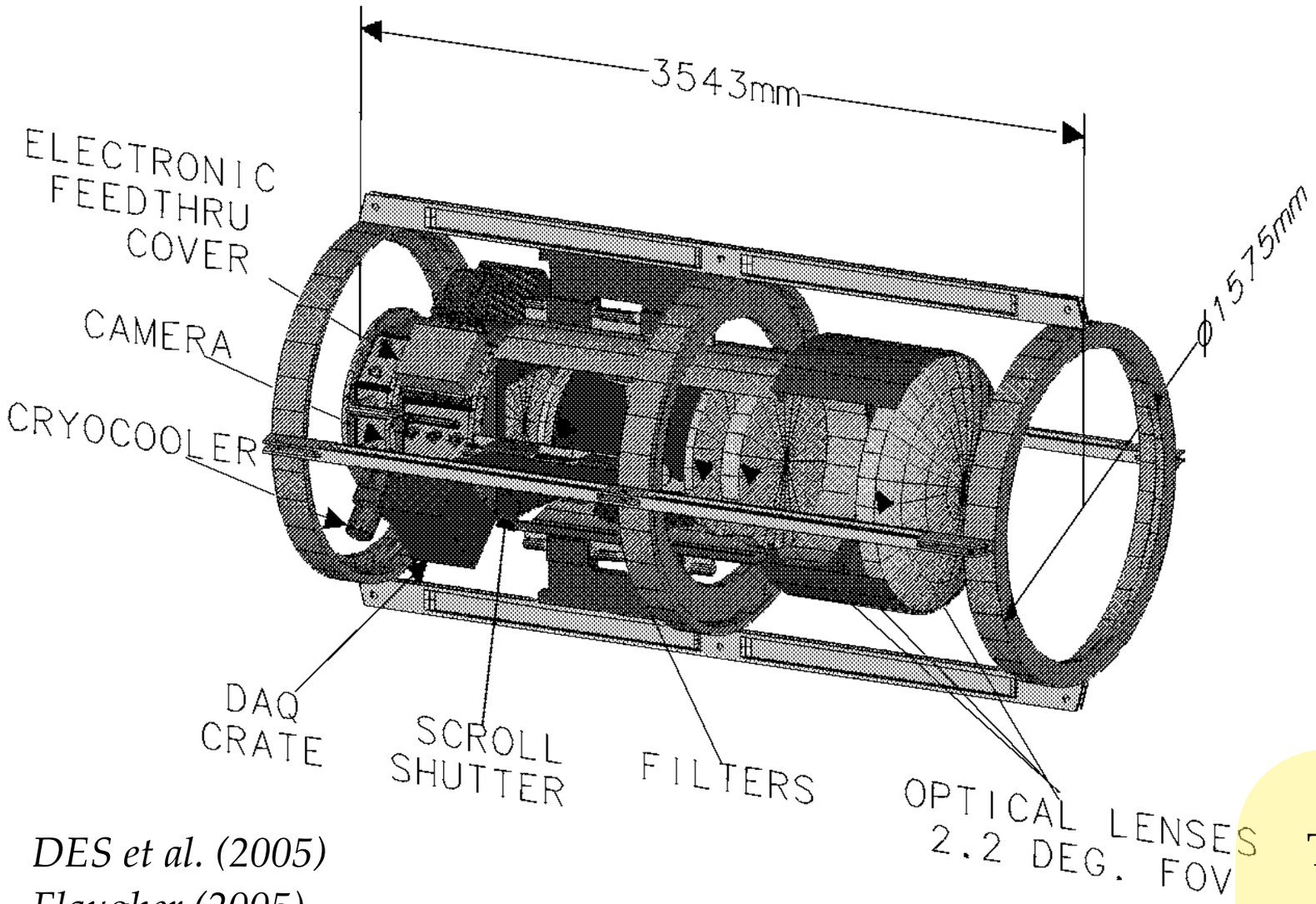

kE metacal
+15°
0°
−15°
−30°
−45°
+135°
+120°
+105°
+90°
+75°
+60°
+45°
+30°
+15°
0°
+345°
+330°
+315°
+300°
+285°
+270°
0.010
0.005
0.000
-0.005
-0.010
map value
The axis of time…
Vikram et al. (2015)
CC et al. (2018)
Jeffrey, Gatti et al. (2021)


kE metacal
+15‘
0‘
−15‘
−30‘
−45‘
+135‘
+120‘
+105‘
+90‘
+75‘
+60‘
+45‘
+30‘
+15‘
0‘
+345‘
+330‘
+315‘
+300‘
+285‘
+270‘
0.010
0.005
0.000
-0.005
-0.010
map value
The axis of time…
Vikram et al. (2015)
CC et al. (2018)
Jeffrey, Gatti et al. (2021)

Outline

- The Dark Energy Survey — the original plan
- Lightning Round of **Baseline** DES Cosmology Results
- Lightning Round of **Extended** DES Cosmology Results
- Taking the DES experience into the next decade
- Summary

DECam is designed to study dark energy



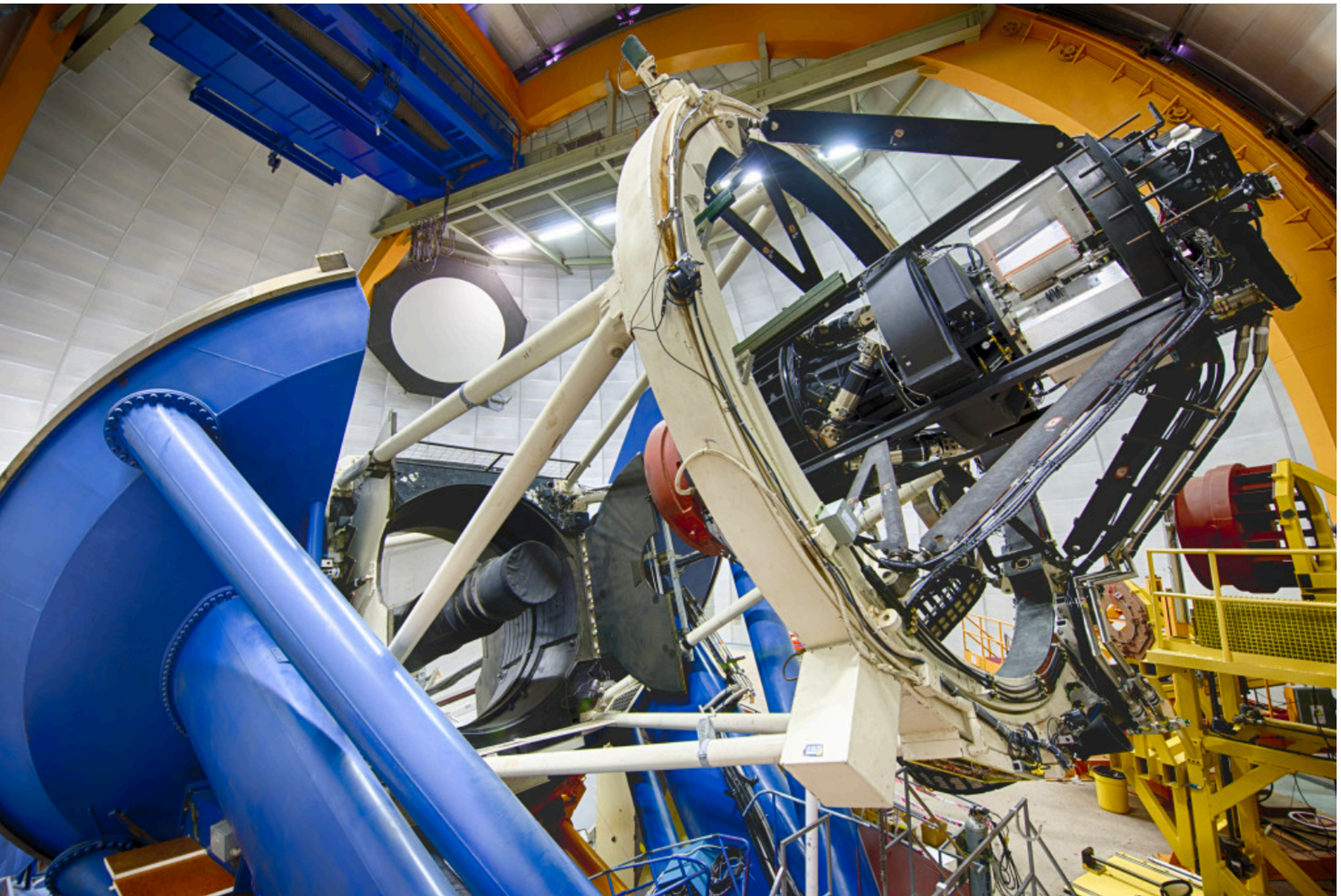
DES et al. (2005)
Flaugher (2005)

This means:

- wide field-of-view (2.2 deg^2)
- high resolution (0.27" pixels)
- high QE, red-sensitive CCDs
- 5000 deg^2 wide-field survey
- 40 deg^2 time-domain survey
- 4000 deg^2 overlap with SPT-SZ

DECam is designed to study dark energy

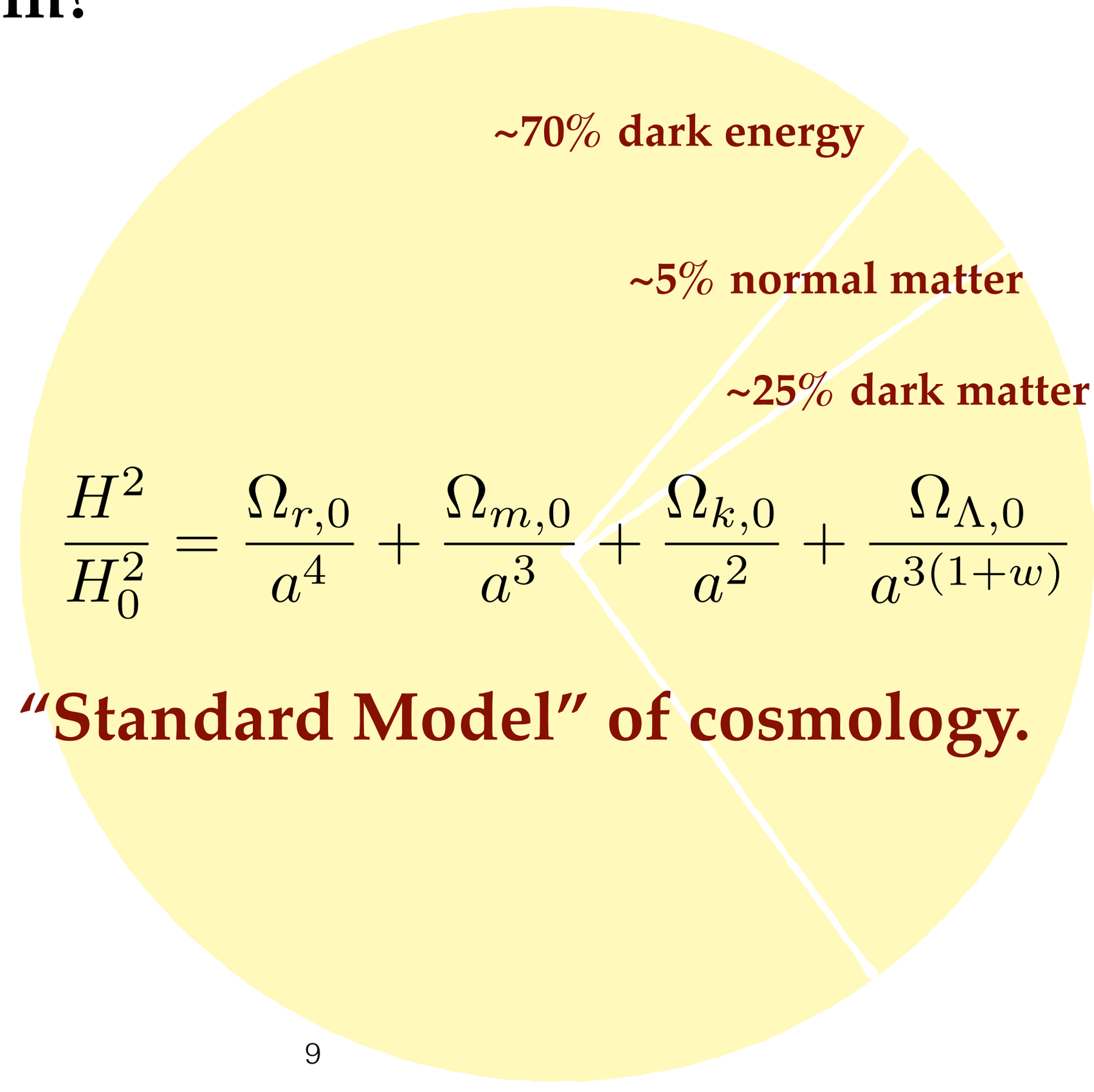
The Dark Energy Survey (DES) is proposed[a] in response to the NOAO Announcement of Opportunity for the Blanco Instrumentation Partnership that offered up to 30% of the observing time over a five year period in exchange for a new instrument. The primary scientific goal of the DES is to measure w using four independent and complementary techniques: galaxy cluster counting, measurement of the galaxy angular power spectrum, weak lensing, and using Type Ia supernovae.



Since 2005, the camera was built, data was collected, the Universe continued to expand and the world continued to change…

17 years later, DES has measured so much more than w

What is w again?

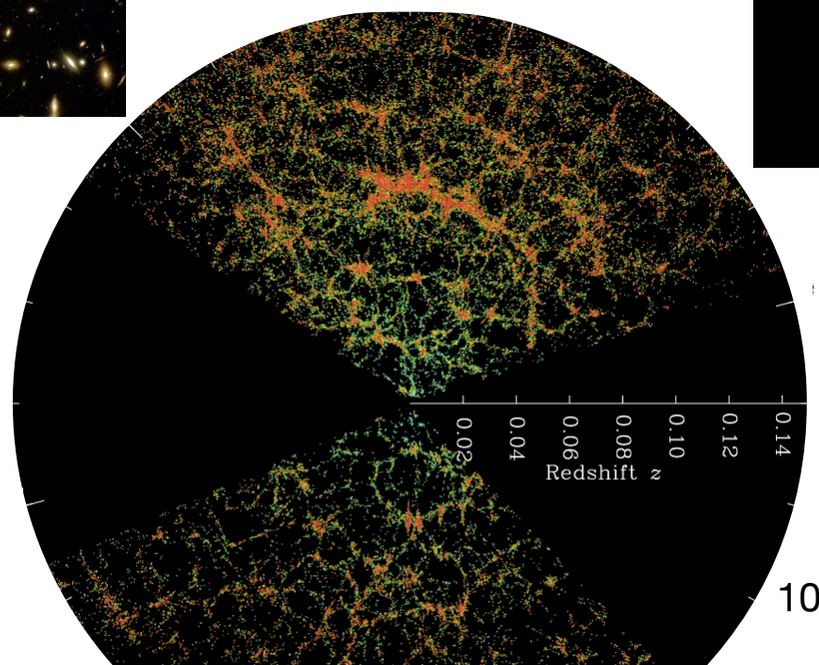


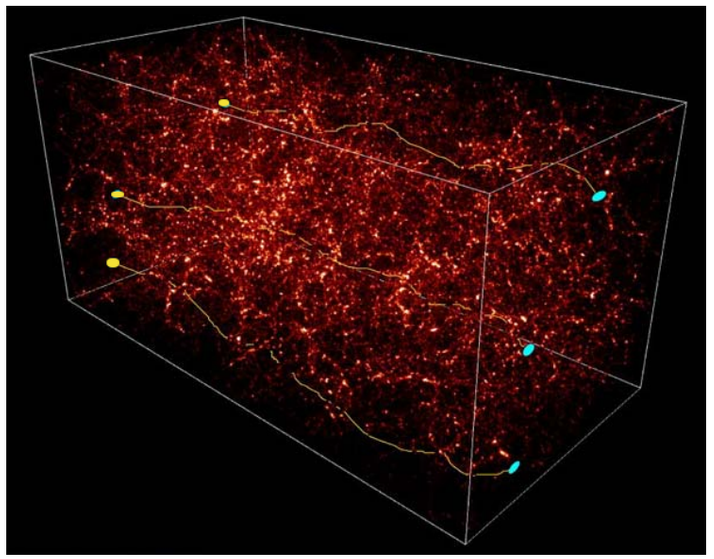
$$\frac{H^2}{H_0^2} = \frac{\Omega_{r,0}}{a^4} + \frac{\Omega_{m,0}}{a^3} + \frac{\Omega_{k,0}}{a^2} + \frac{\Omega_{\Lambda,0}}{a^{3(1+w)}}$$

The "Standard Model" of cosmology.

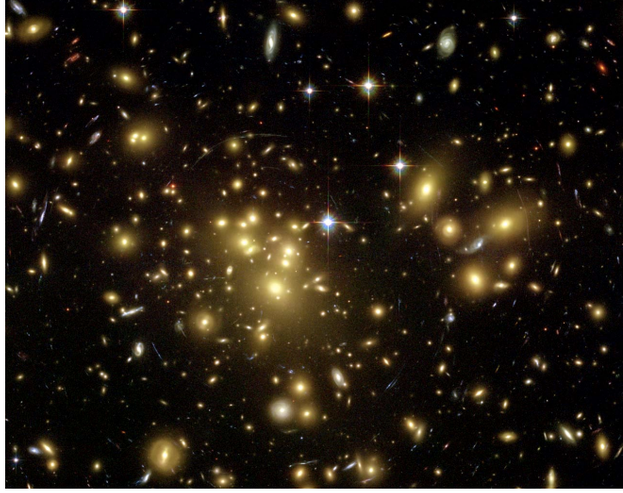
Probes for dark energy

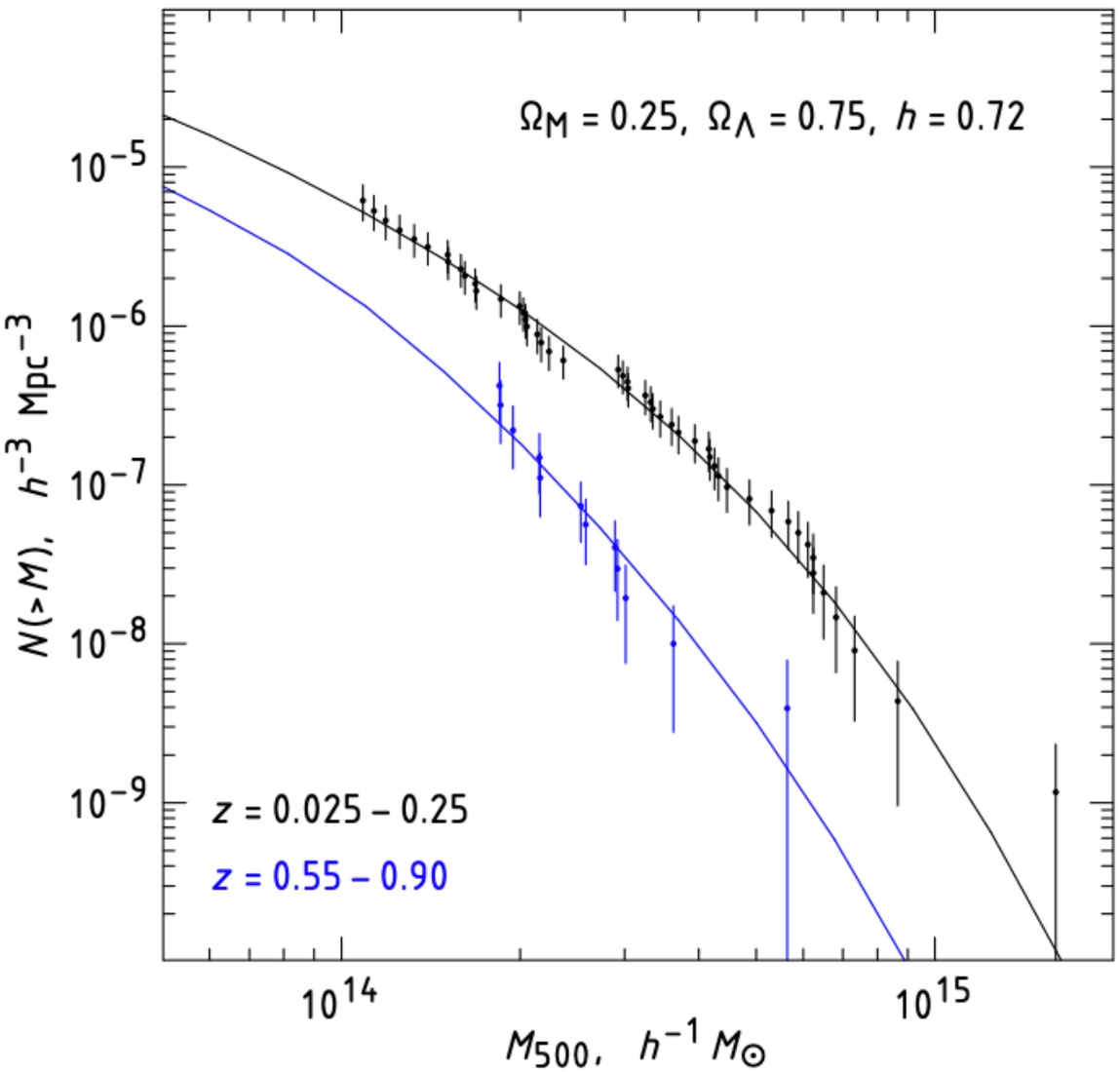
The Dark Energy Survey (DES) is proposed[a] in response to the NOAO Announcement of Opportunity for the Blanco Instrumentation Partnership that offered up to 30% of the observing time over a five year period in exchange for a new instrument. The primary scientific goal of the DES is to measure w using four independent and complementary techniques: galaxy cluster counting, measurement of the galaxy angular power spectrum, weak lensing, and using Type Ia supernovae.

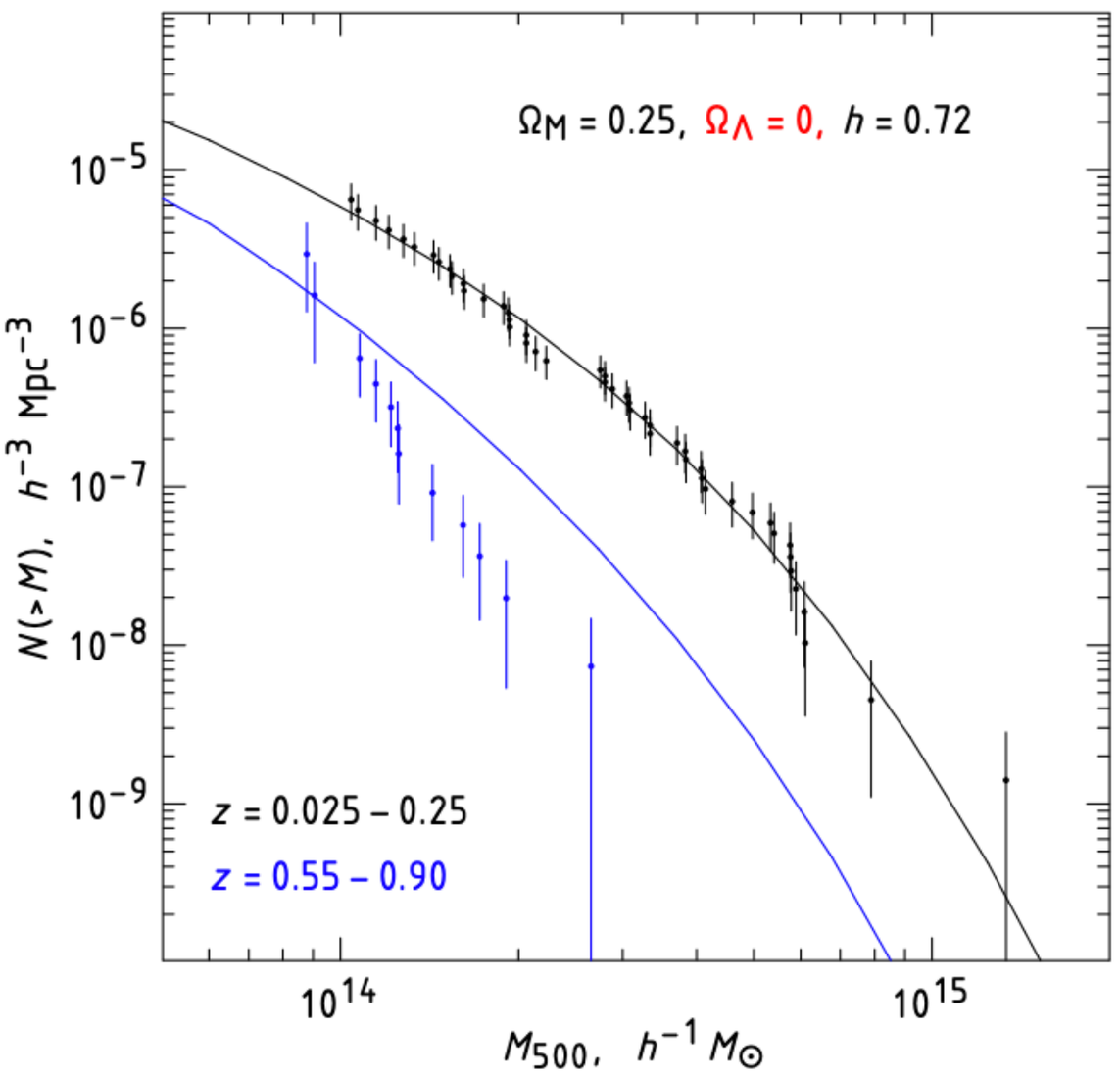




1. Galaxy Cluster Counts

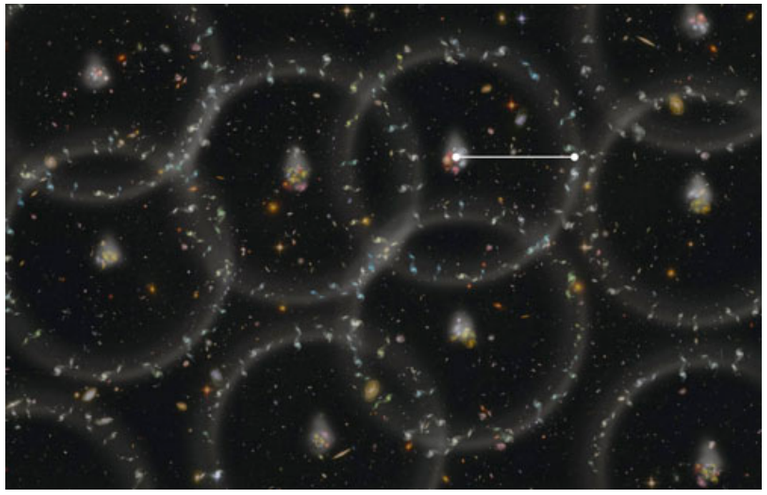


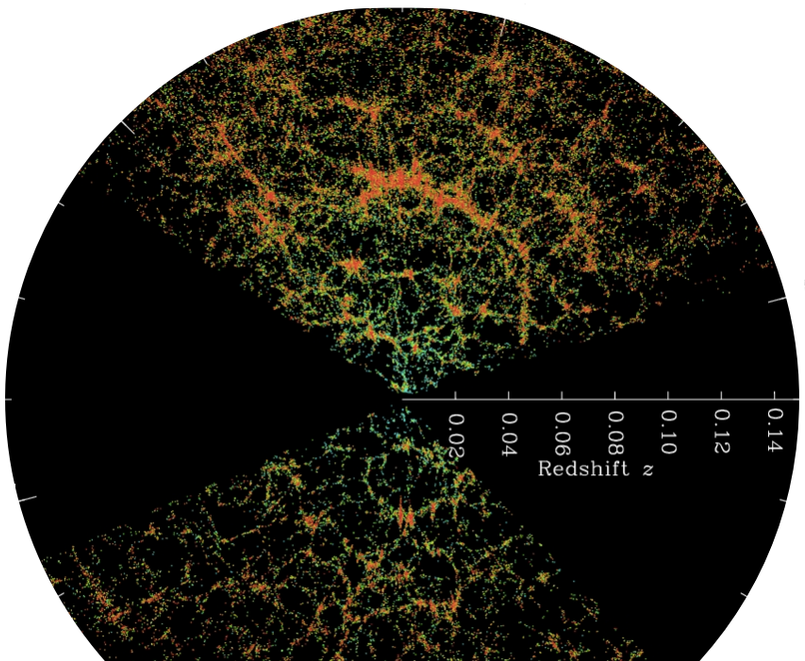


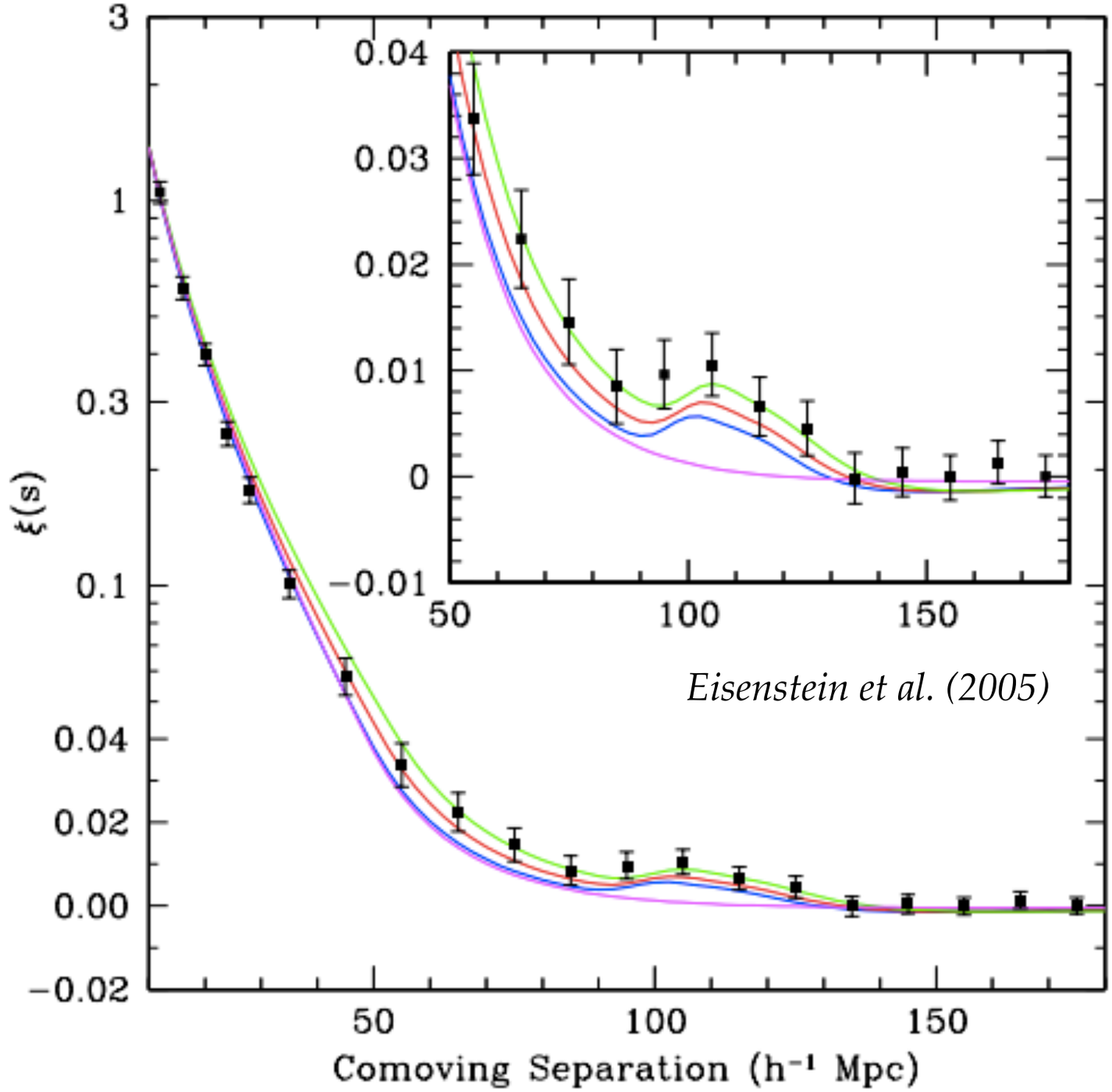


Vikhlinin et al. (2009)

2. Baryon Acoustic Oscillation (BAO)







Eisenstein et al. (2005)

3. Weak Lensing (⇒ 3x2pt)

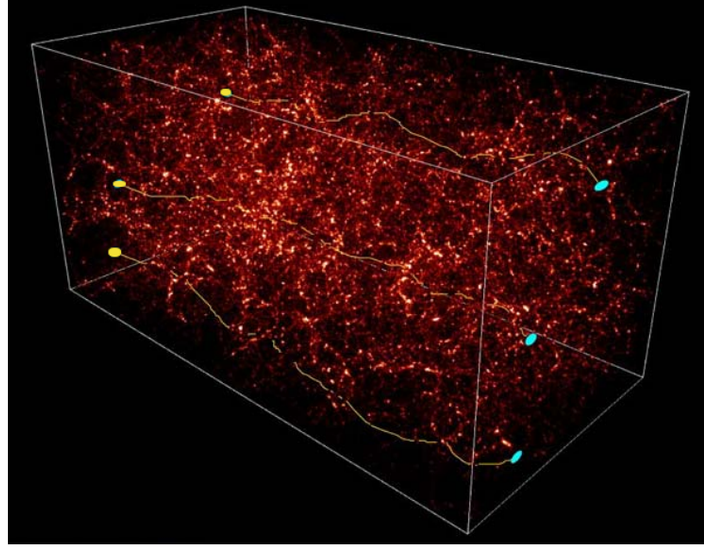
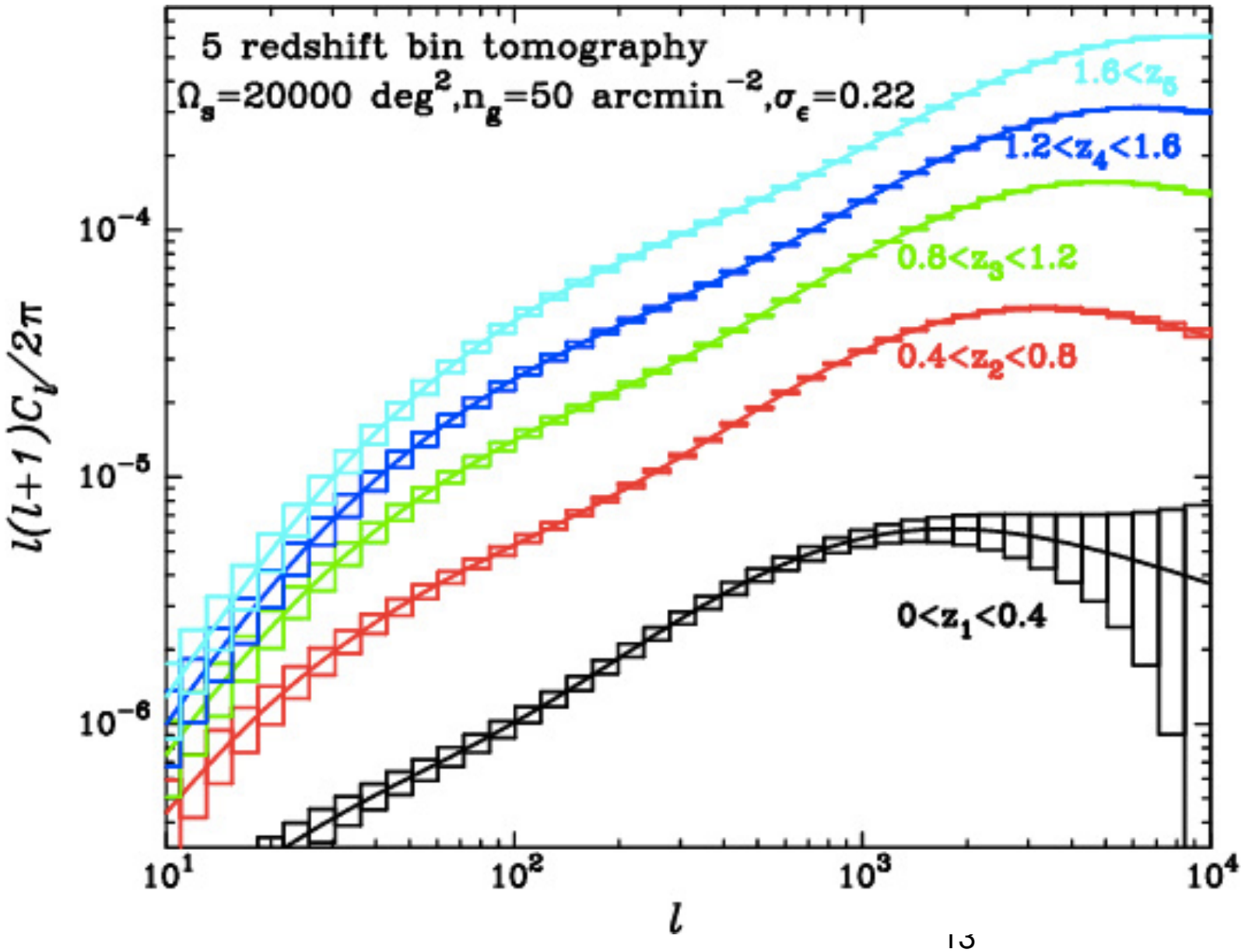


Image Credit: LSST



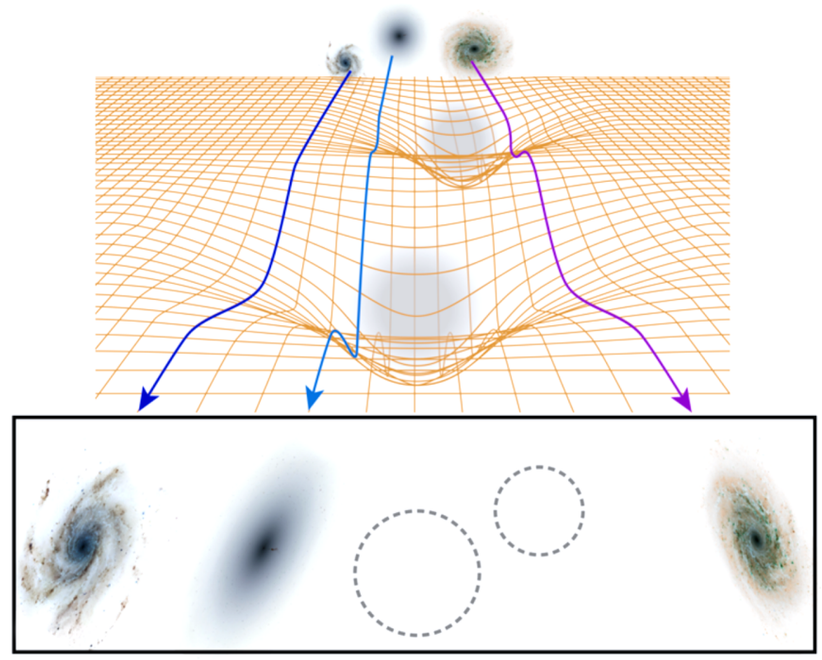
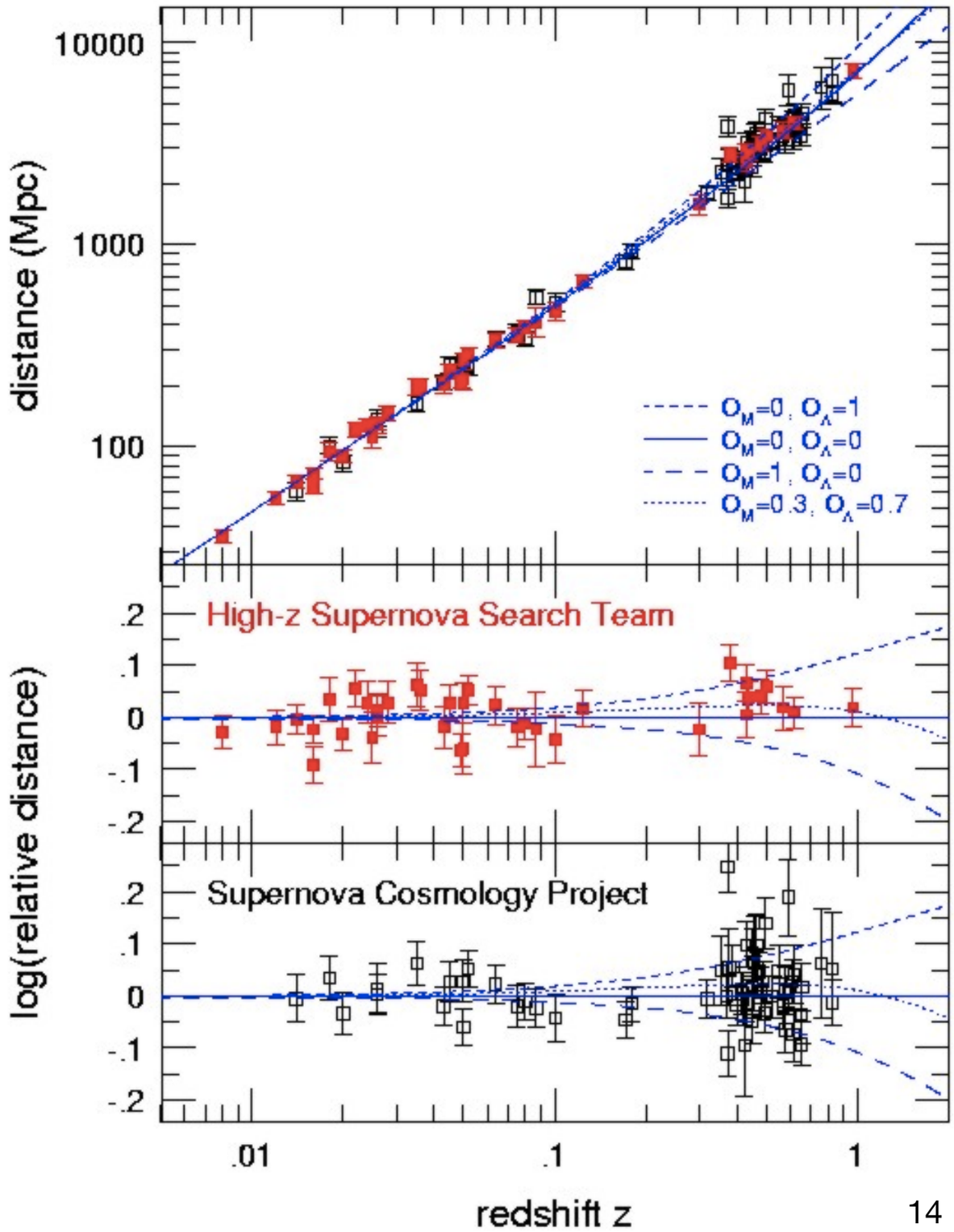


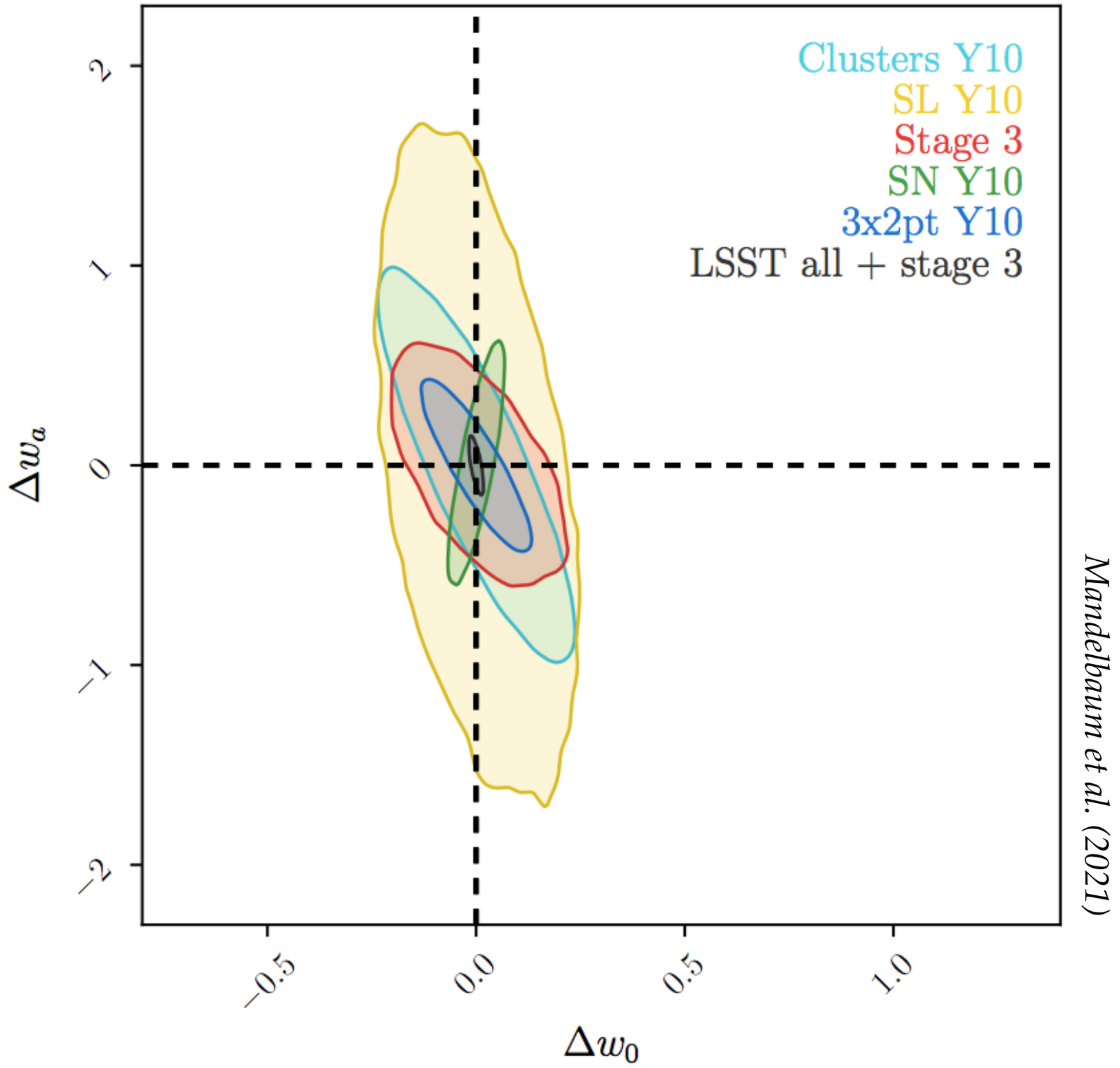
Image Credit: APS

4. Type Ia Supernova



Perlmutter et al (1998)
Riess et al. (1998)

1+2+3+4 = ??

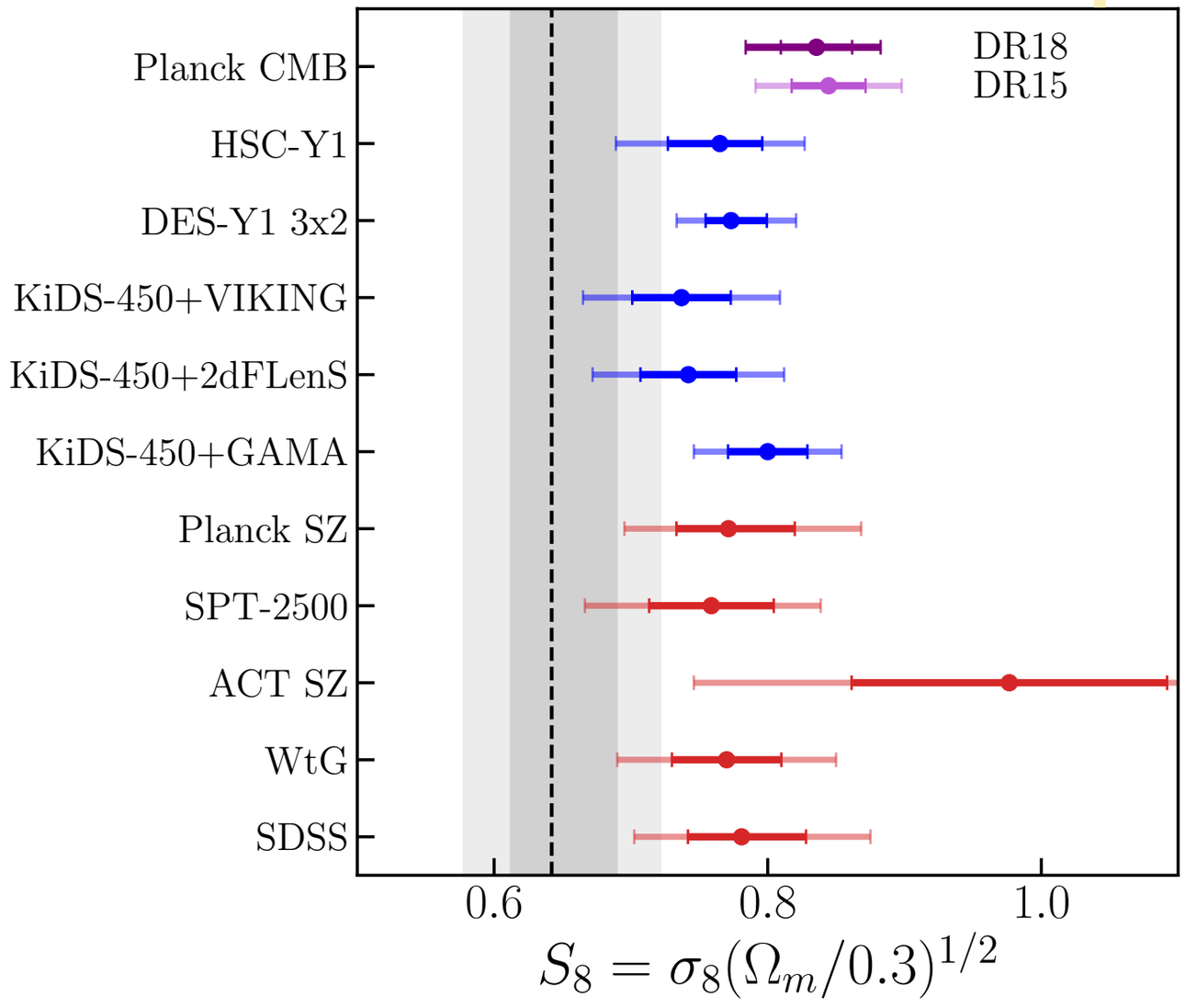

Clusters Y10
SL Y10
Stage 3
SN Y10
3x2pt Y10
LSST all + stage 3
Δw_a
Δw_0
2
1
0
−1
−2
−0.5
0.0
0.5
1.0
Mandelbaum et al. (2021)

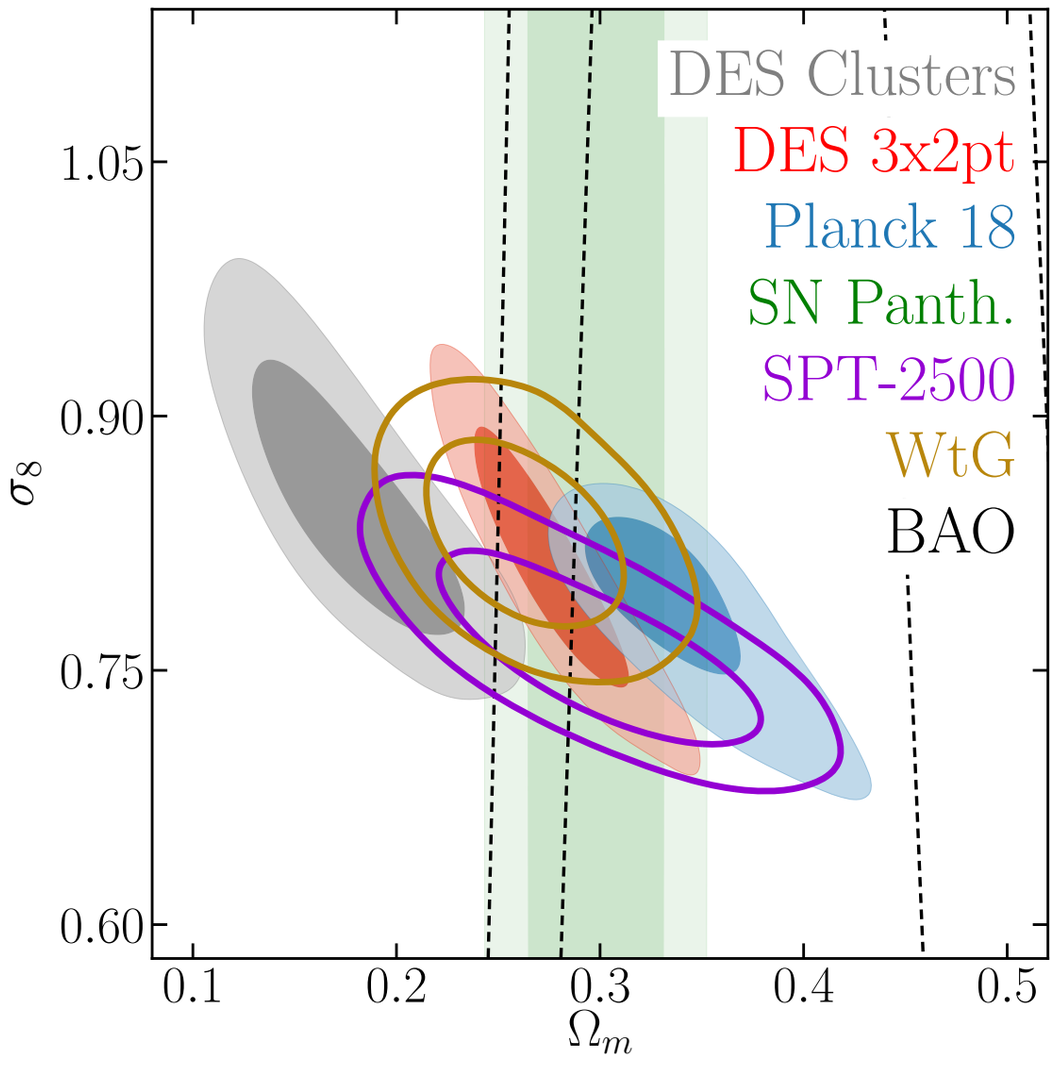
Lightning Round of Baseline DES Cosmology Results (so far)

DES Y1 Cluster Cosmology

2.4 σ tension with DES Y1 3x2pt cluster selection and modeling on small scales turns out extremely challenging!

DES et al. (2020)
Costanzi et al. (2018a, 2018b)
McClintock et al. (2018)
Zhang et al. (2019)
Varga et al. (2018)
Farahi et al. (2019)

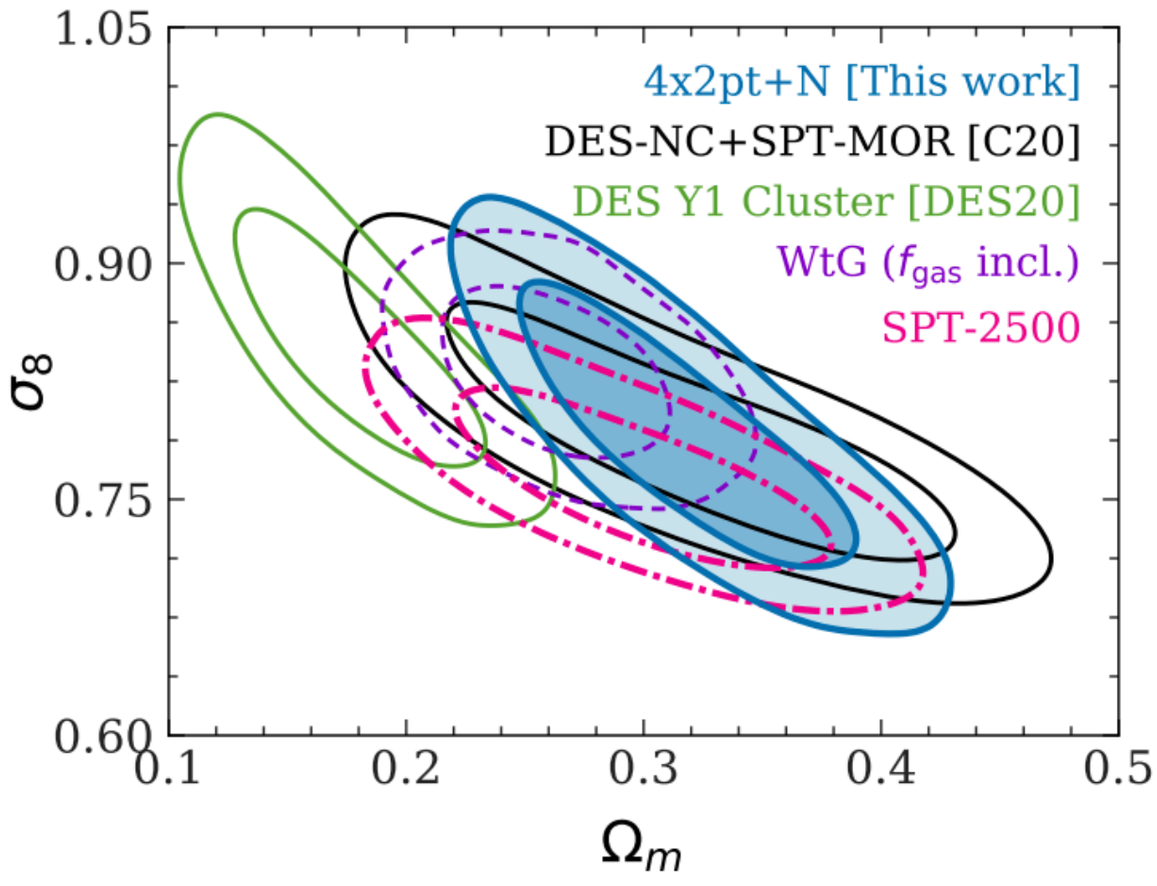


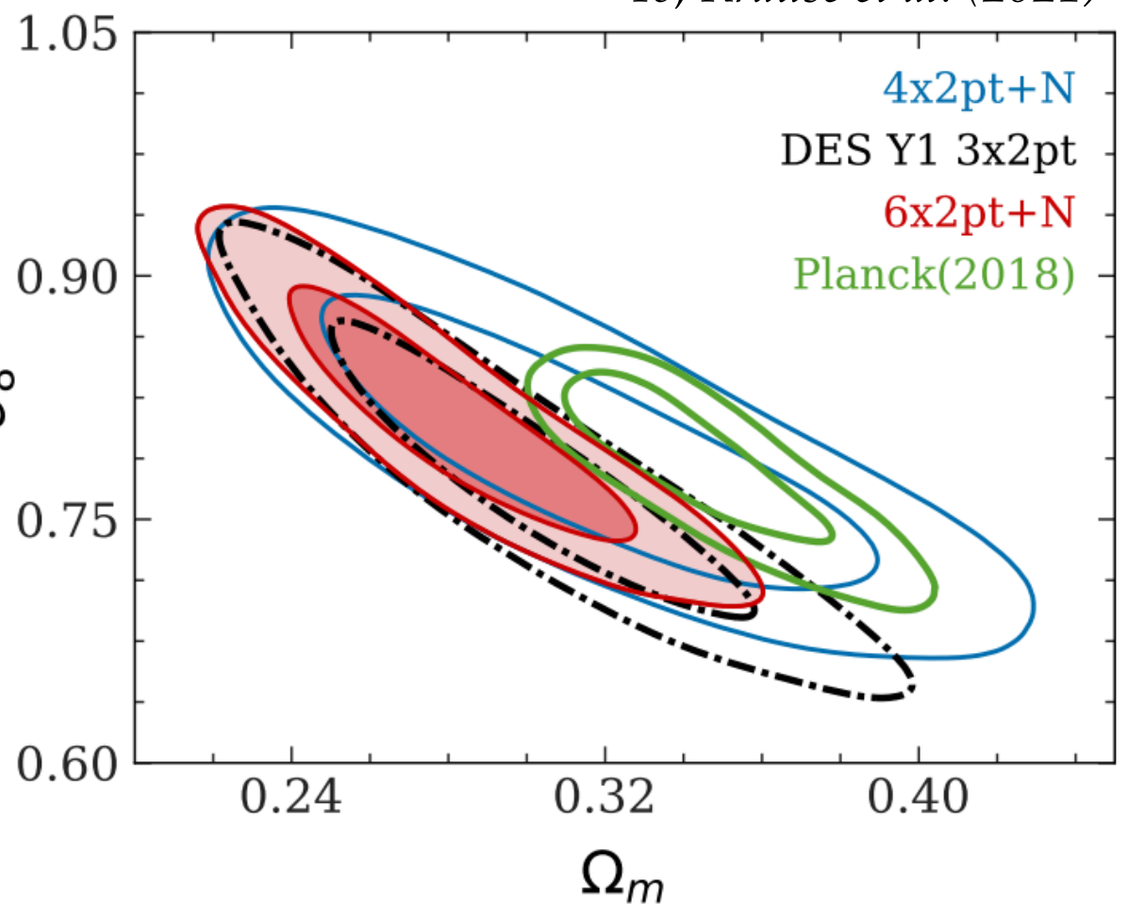


Towards DES Y3/6 Cluster Cosmology

The high potential of cluster cosmology comes with many challenges. The Y1 results are instrumental in creating more rigorous analyses and alternative creative routes.

Costanzi et al. (2021)
To, Krause et al. (2021)



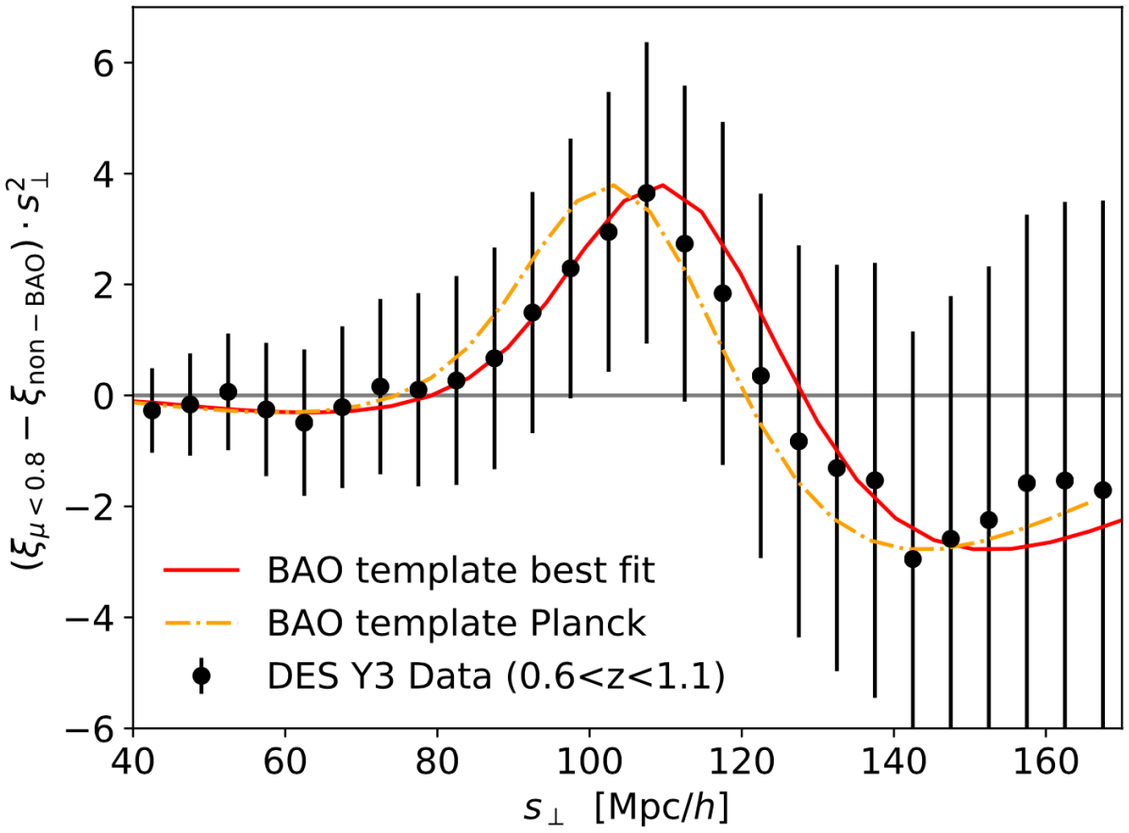


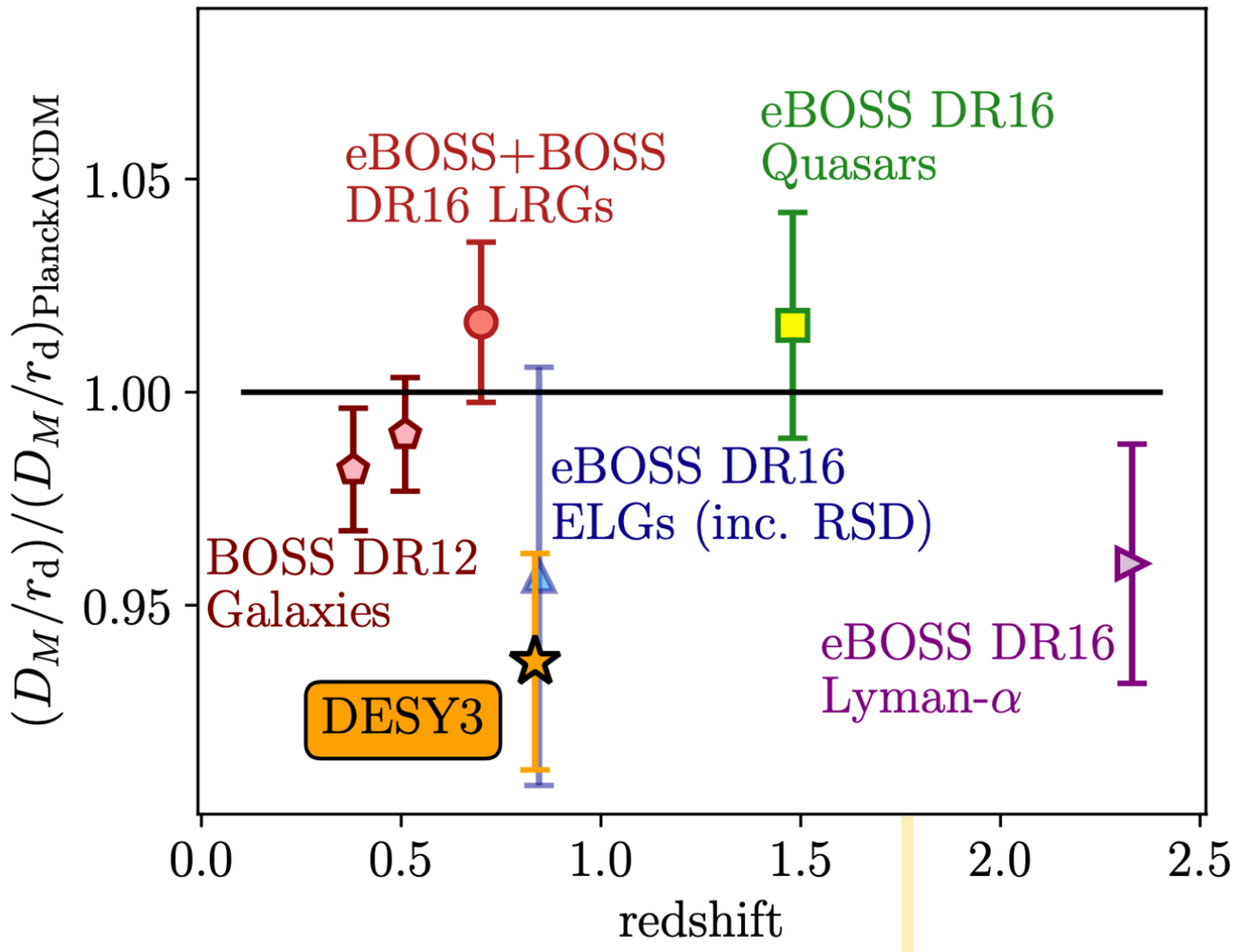
DES Y3 BAO

DES et al. (2021b)

Carnero Rossel et al. (2021)

Ferraro et al. (2021)





7 million galaxies, at z~0.835, 2.7% measurement on the BAO shift, 2.3 σ from *Planck*.

Best measurements from photometric data!

DES Y3 3x2pt Cosmology

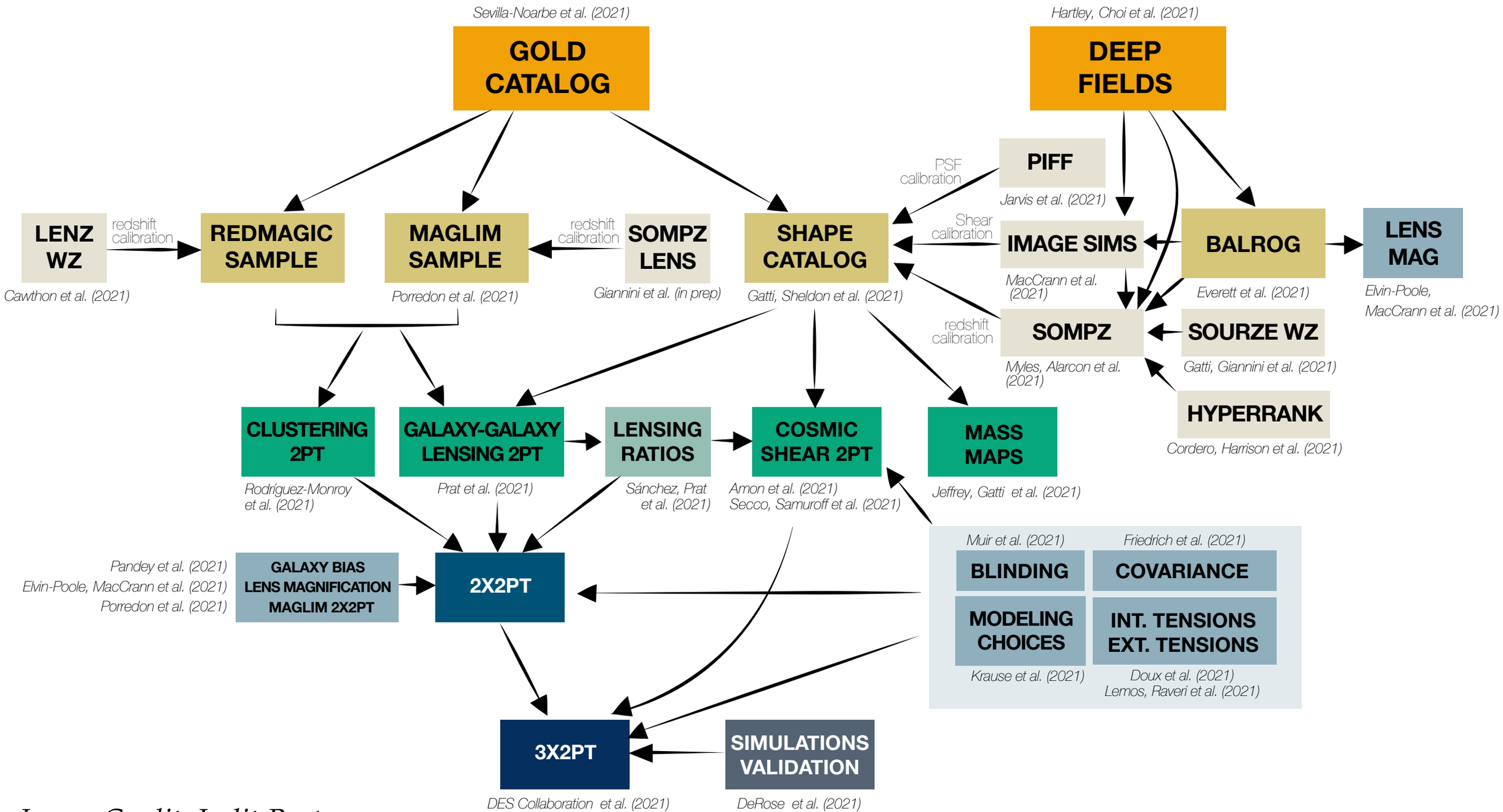


Image Credit: Judit Prat

also see summary webinar on YouTube

DES Y3 3x2pt Cosmology

ΛCDM

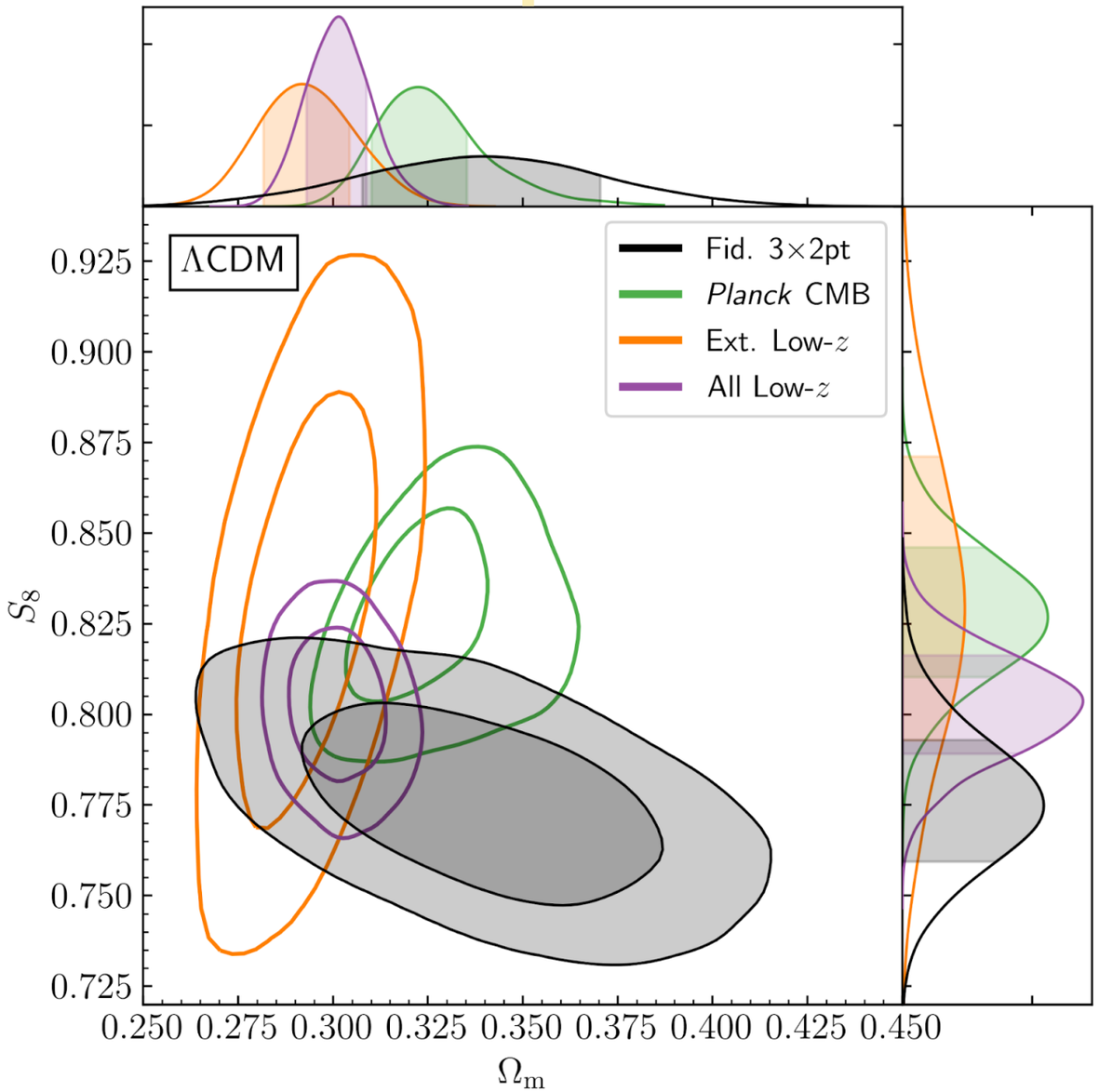
$S_8 = 0.776^{+0.017}_{-0.017}$

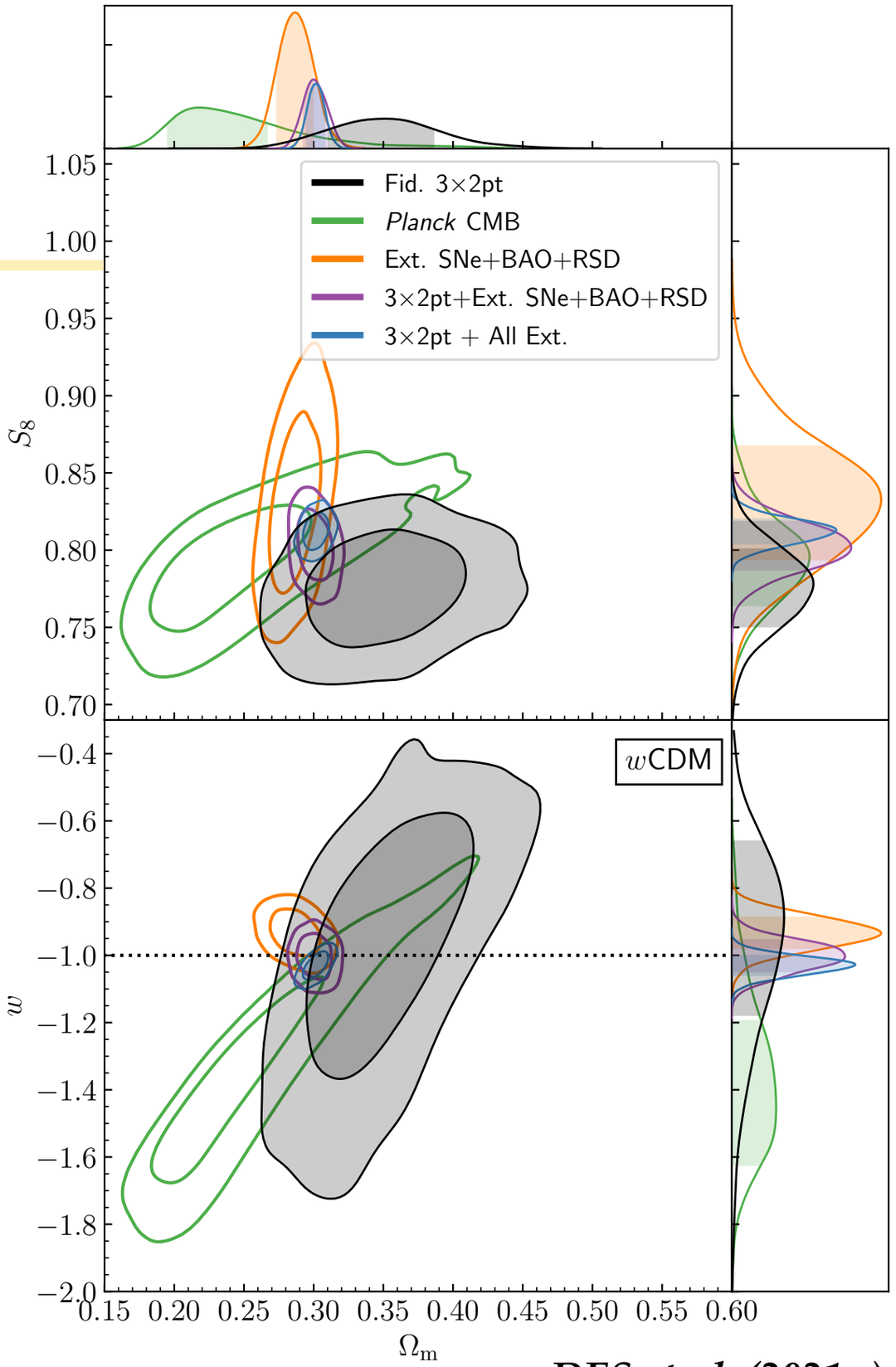
$\Omega_\mathrm{m} = 0.339^{+0.032}_{-0.031}$

wCDM

$\Omega_\mathrm{m} = 0.352^{+0.035}_{-0.041}$

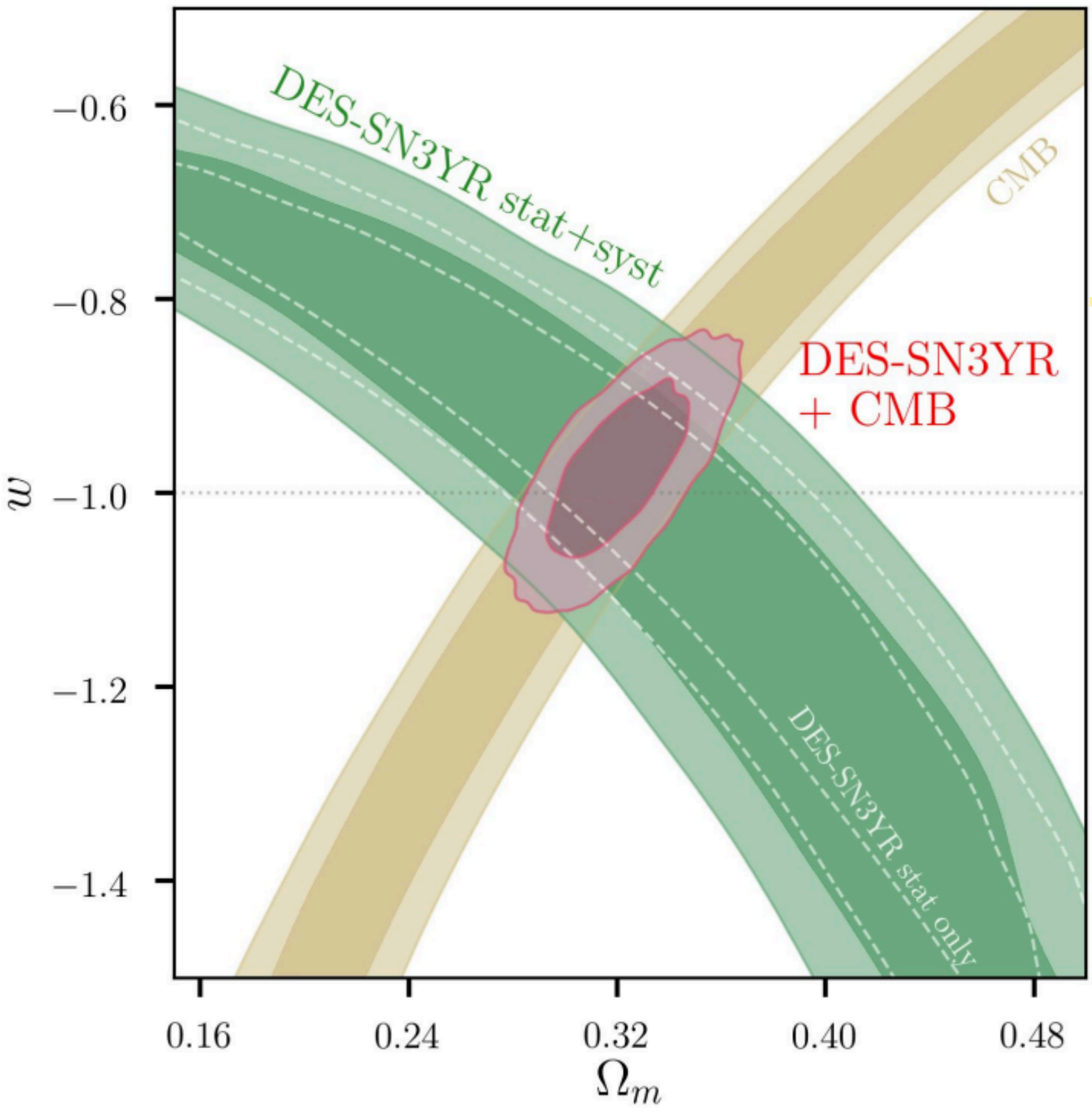
$w = -0.98^{+0.32}_{-0.20}$





DES et al. (2021a)

DES Y3 Supernova



207 spec-confirmed DES SNe Ia

+ 122 spec confirmed low-z SNe Ia

wCDM

$\Omega_{\rm m} = 0.321^{+0.018}_{-0.018}$

$w = -0.978^{+0.059}_{-0.059}$

(with CMB priors)

DES et al. (2019)

Macauley et al. (2018)

Brout et al. (2018a, 2018b)

Kessler et al. (2018)

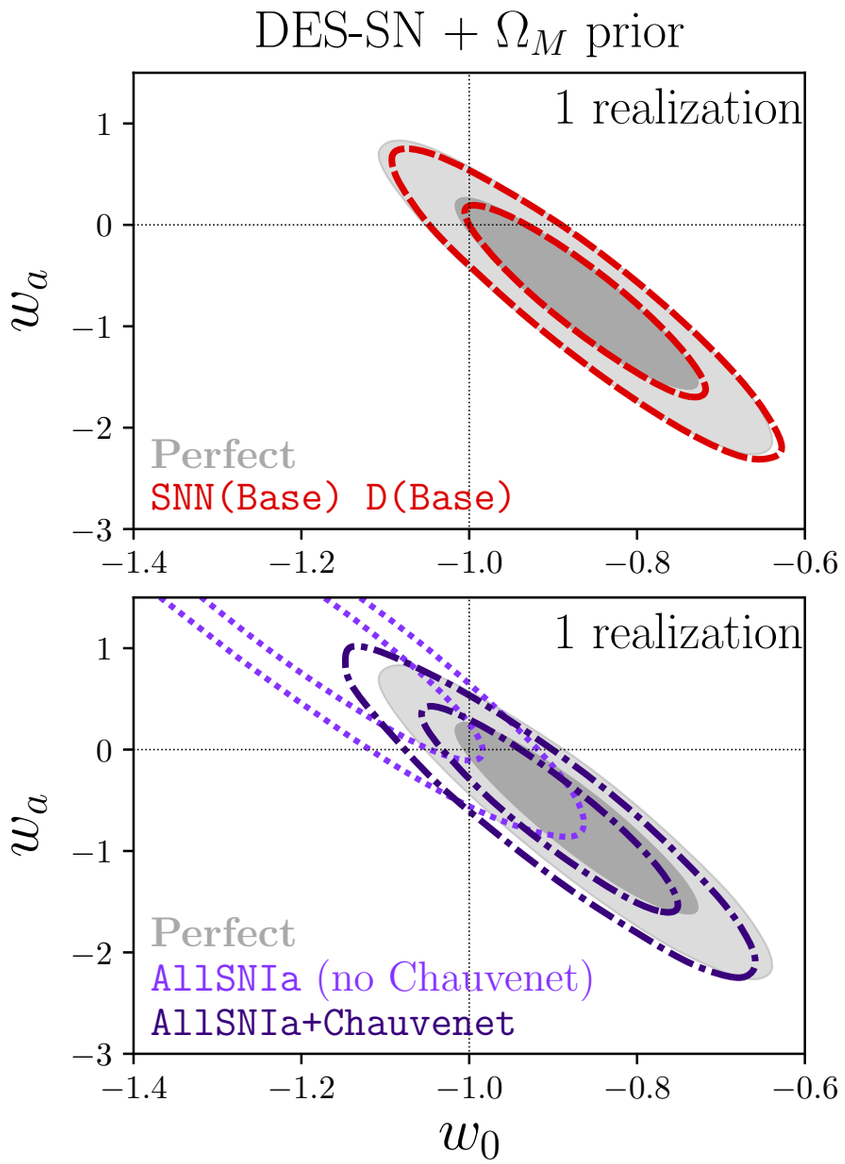
D'Andrea et al. (2018)

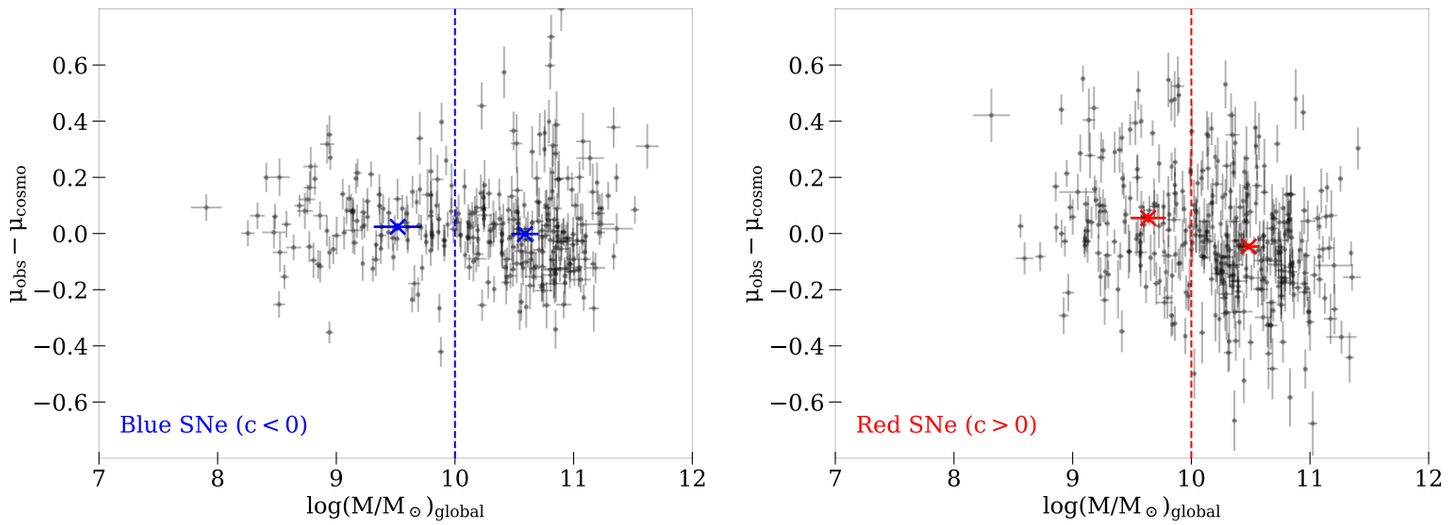
Lasker et al. (2018)

Hinton et al. (2018)

Towards DES Y5 Supernova

Y5 (final) SN analysis is well under way. It will include 5x more SNe Ia and the sample will be photometric instead of spectroscopic. Many many technological advances!

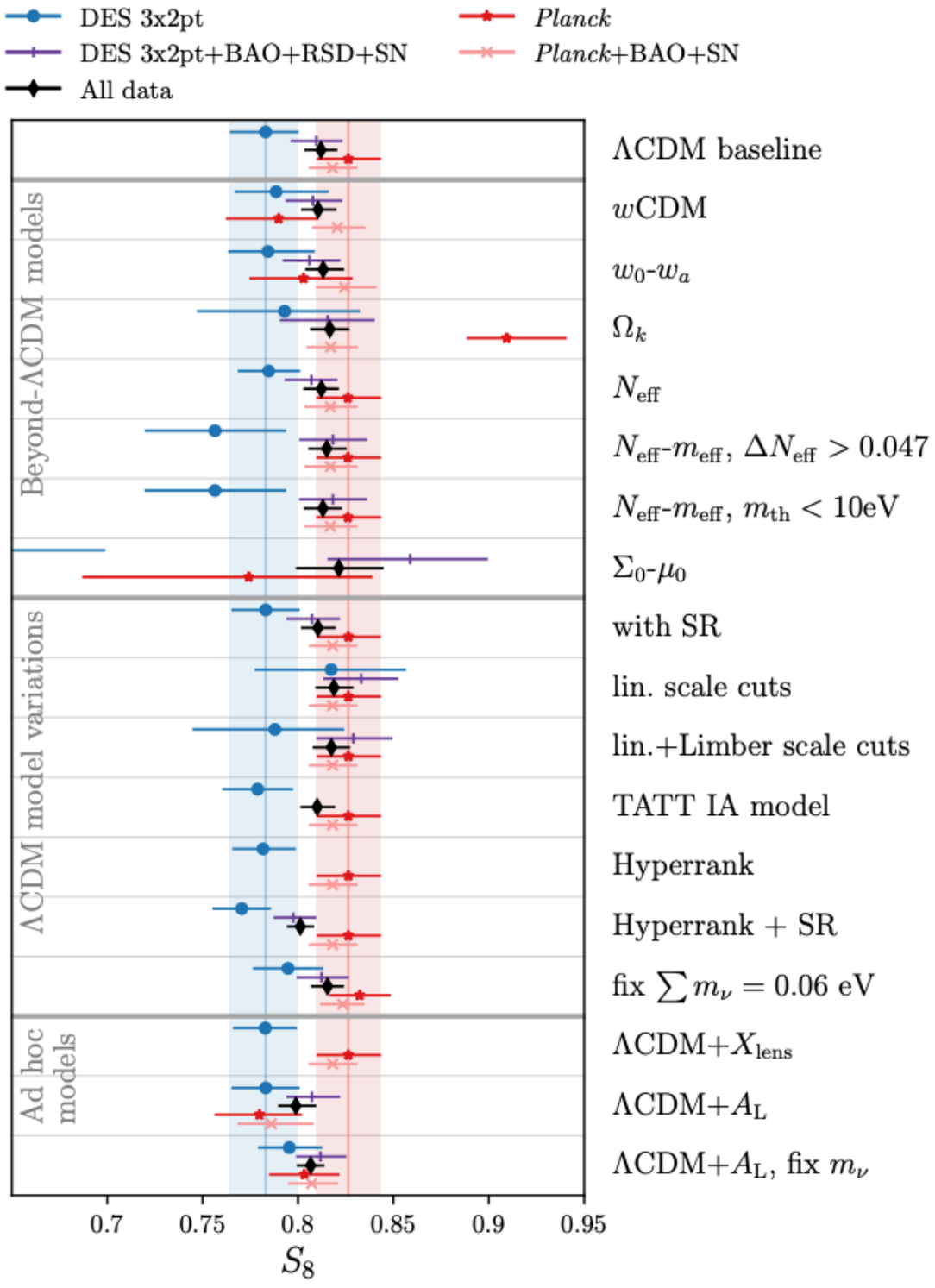




Vincenzi et al. (2021a, 2021b)
Wiseman et al. (2021, 2022)
Grayling et al. (2022)
Moller et al. (2022)
Chen & Scolnic et al. (2022)
Kelsey et al. (2022)
Meldorf, Palmese, Brout et al. (2022)

Lightning Round of Extended DES Cosmology Results (so far)

DES Y3 3x2pt Extension



DES et al. (2022)

Ferté, Muir et al. (in prep.)

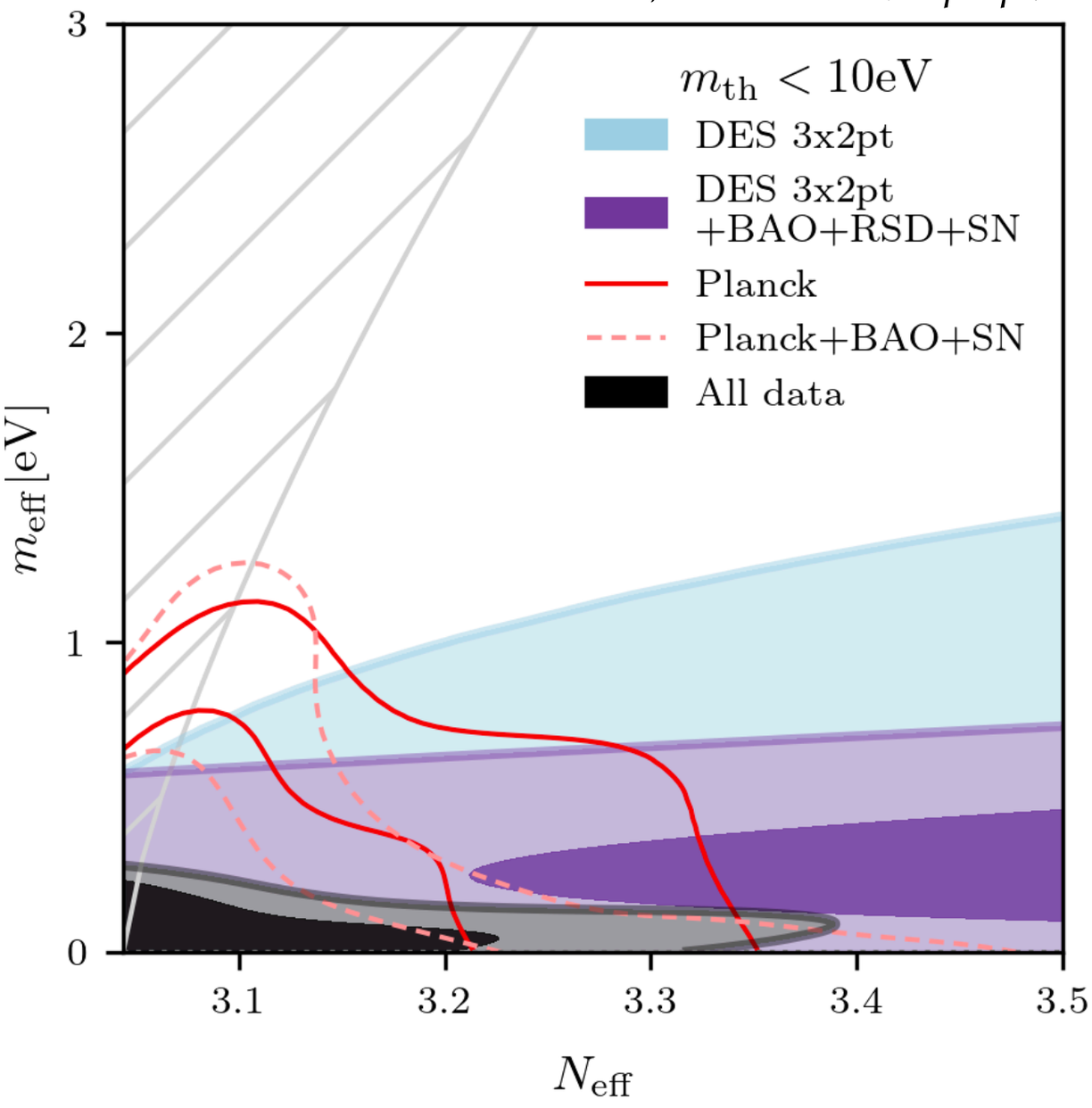
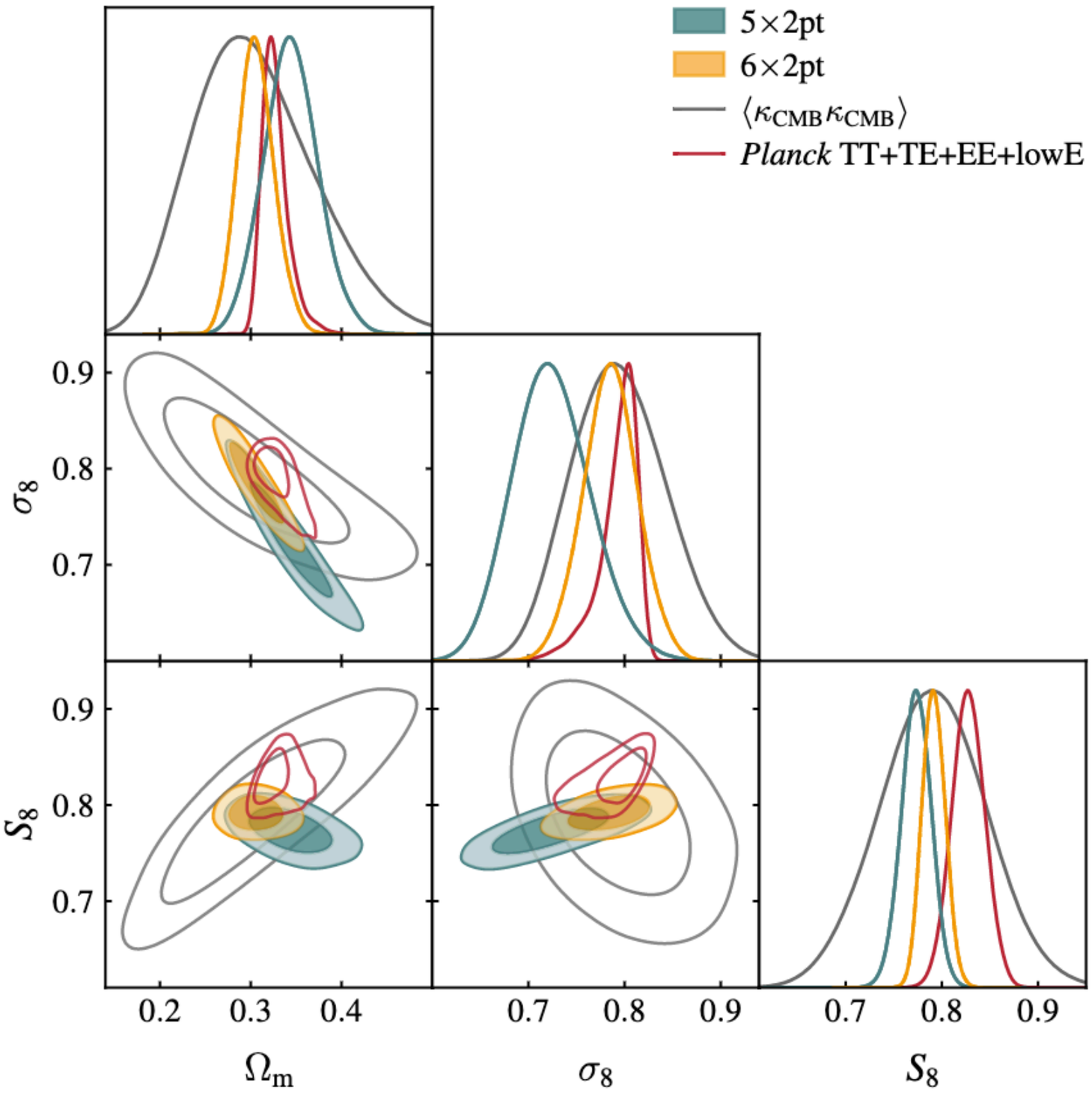
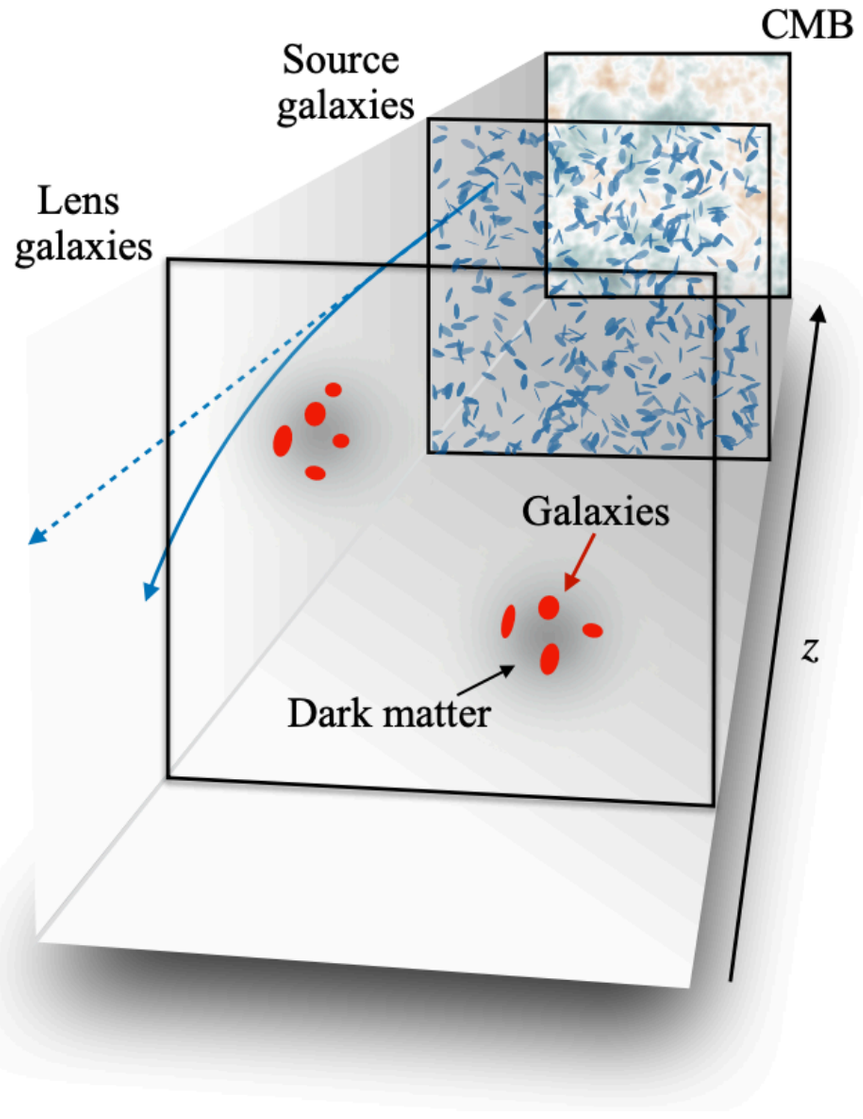


Image Credit: Yuuki Omori

DES Y3 x CMB Lensing

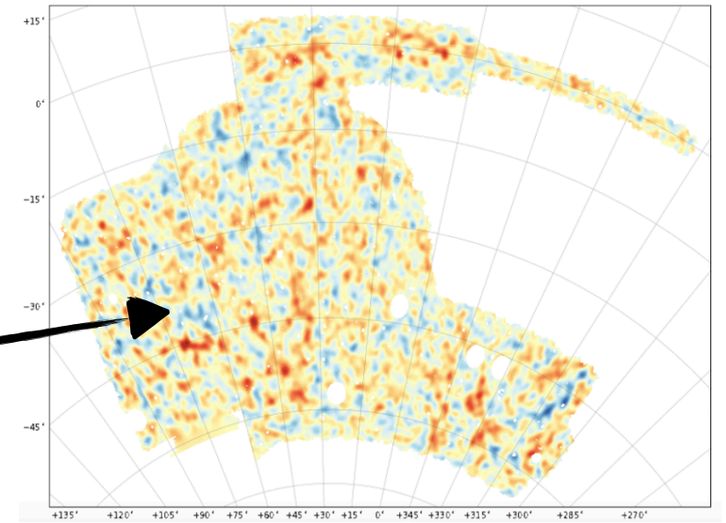


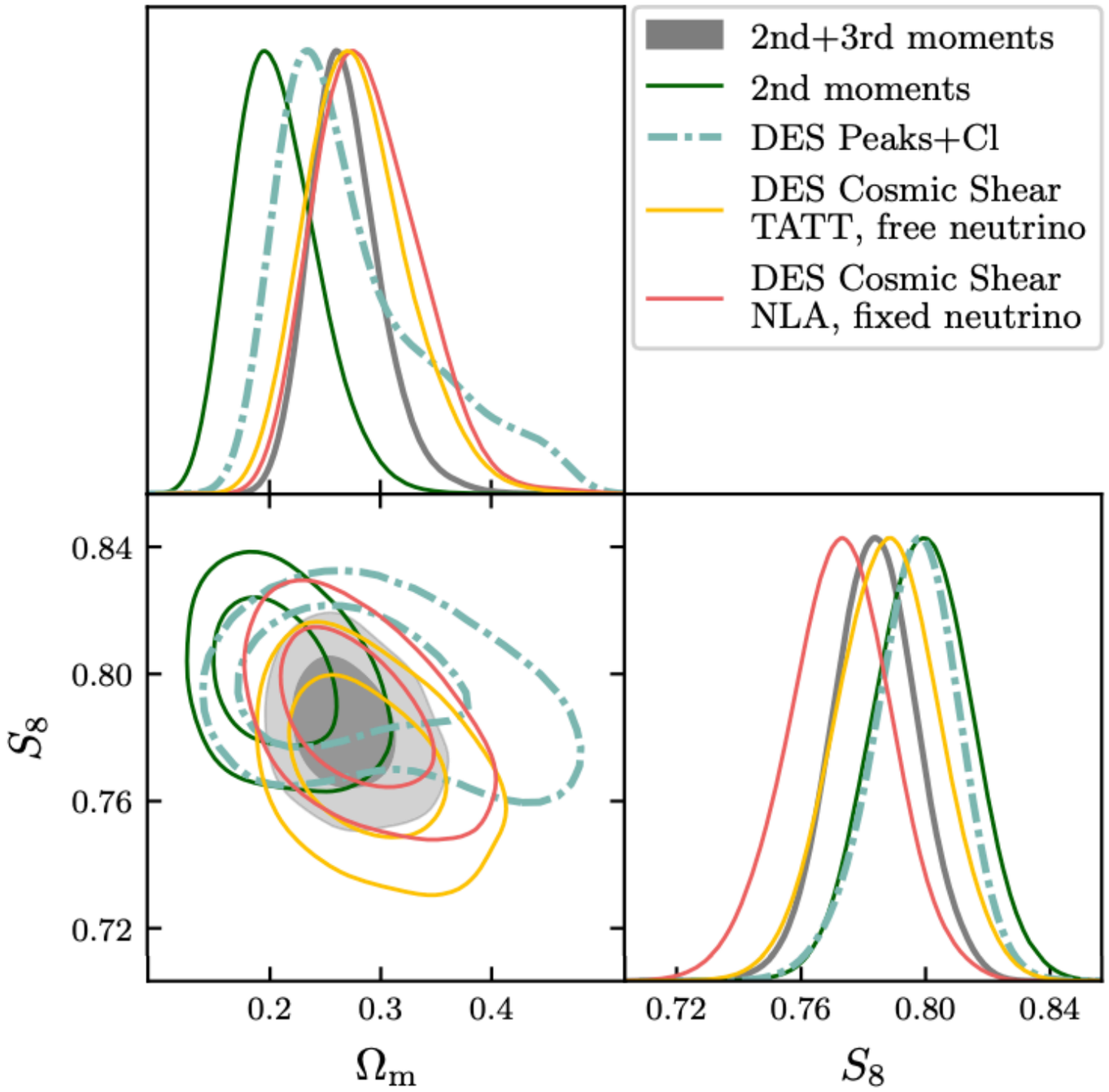


DES, SPT et al. (2022)
Omori, Baxter, CC et al. (2021)
CC, Omori, Baxter et al. (2021)

DES Y3 Higher-order Statics

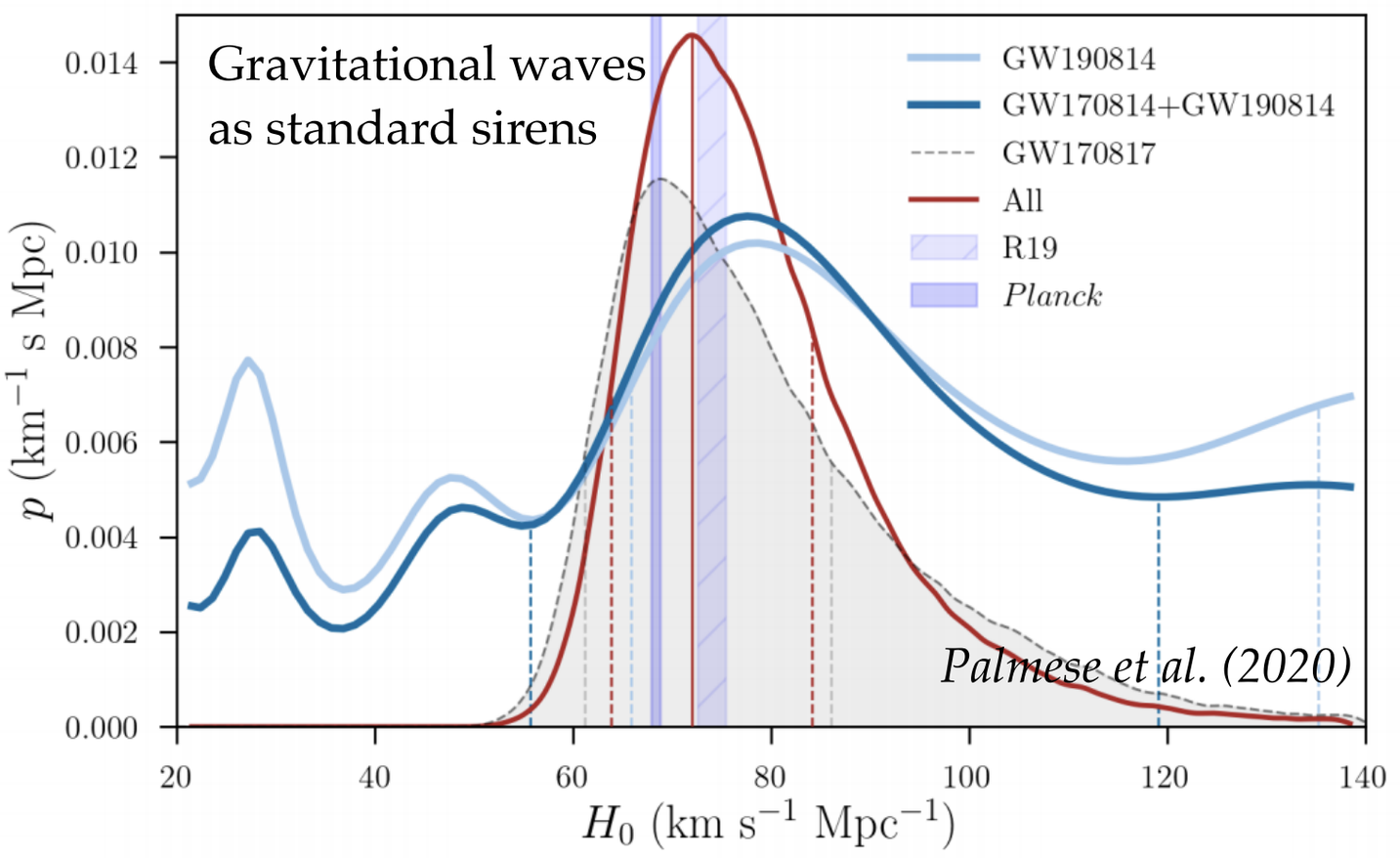
There is a lot of information in this map we are not using yet!





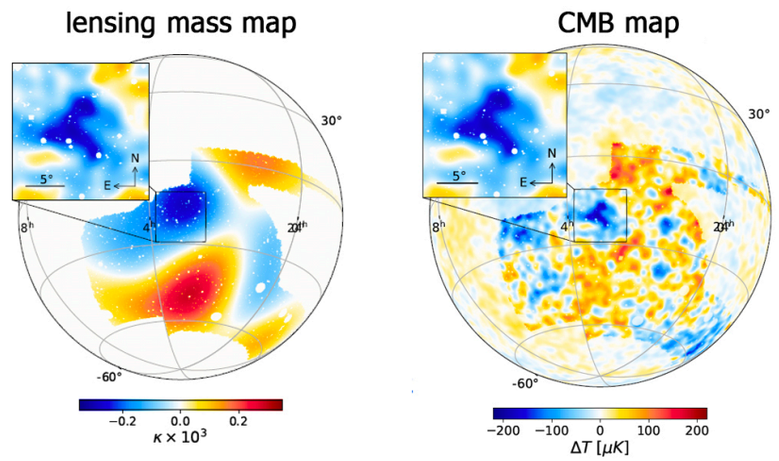
Gatti, Jeffrey et al. (2022)
Zücher et al. (2022)
Halder et al. (In prep)

Other Cosmological Probes



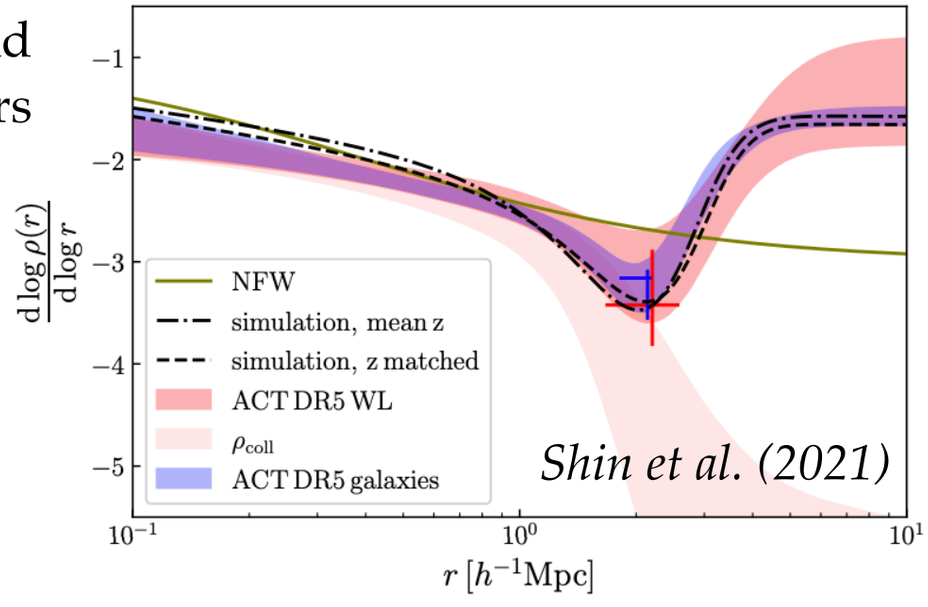
Palmese et al. (2020)

Kovacs et al. (2020)

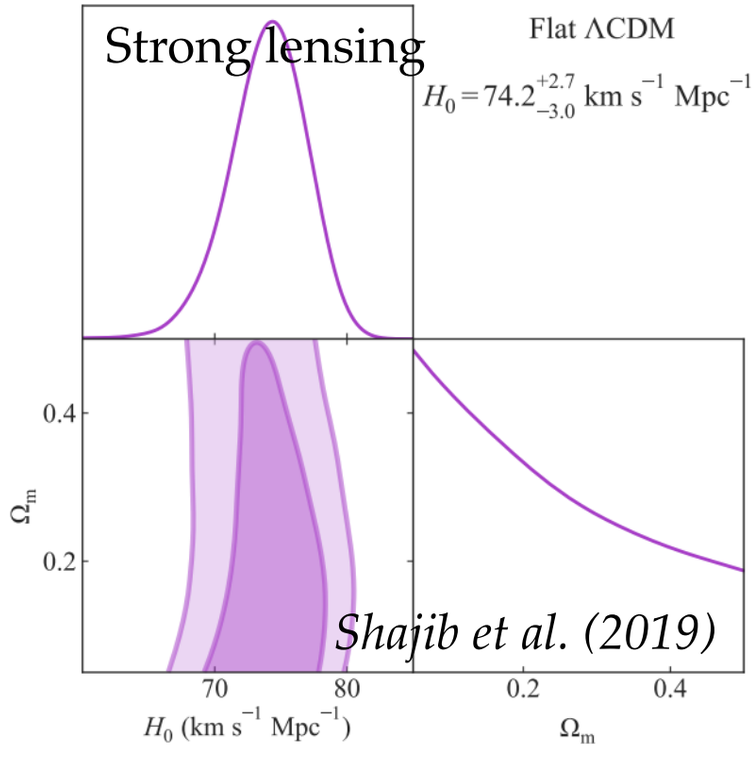


"Cold spot" in lensing maps

Splashback around galaxy clusters

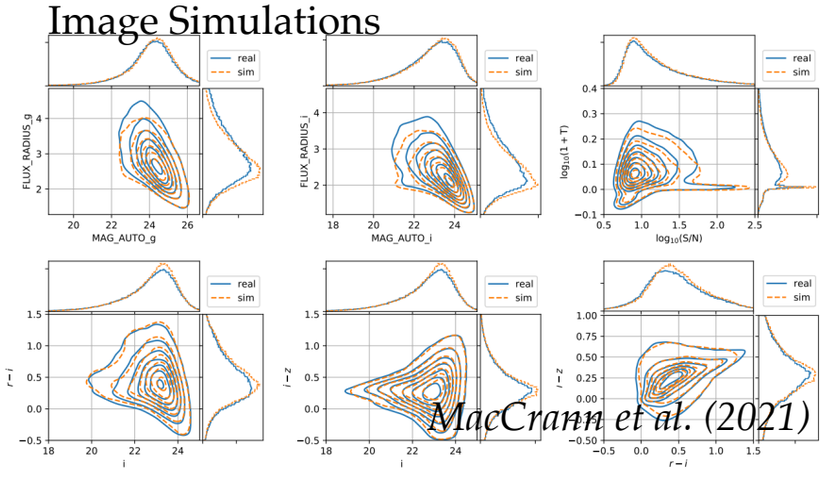


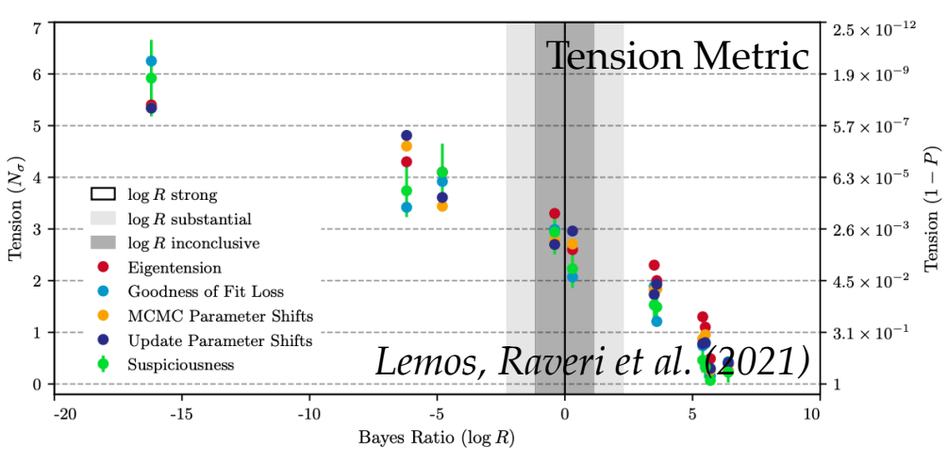
Shin et al. (2021)

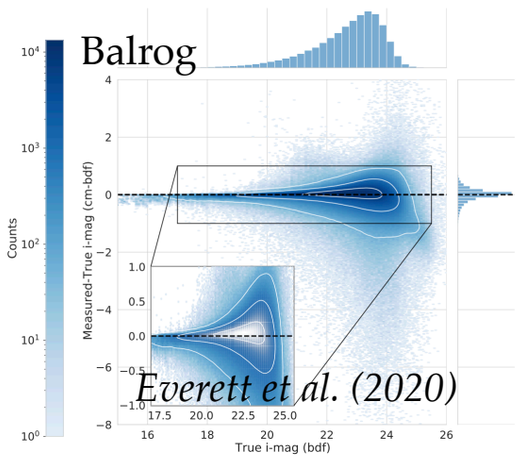


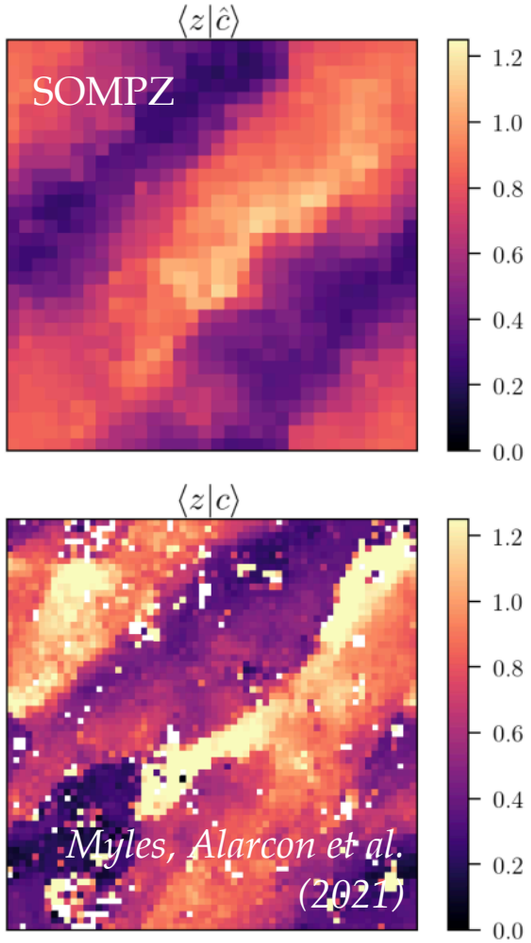
Shajib et al. (2019)

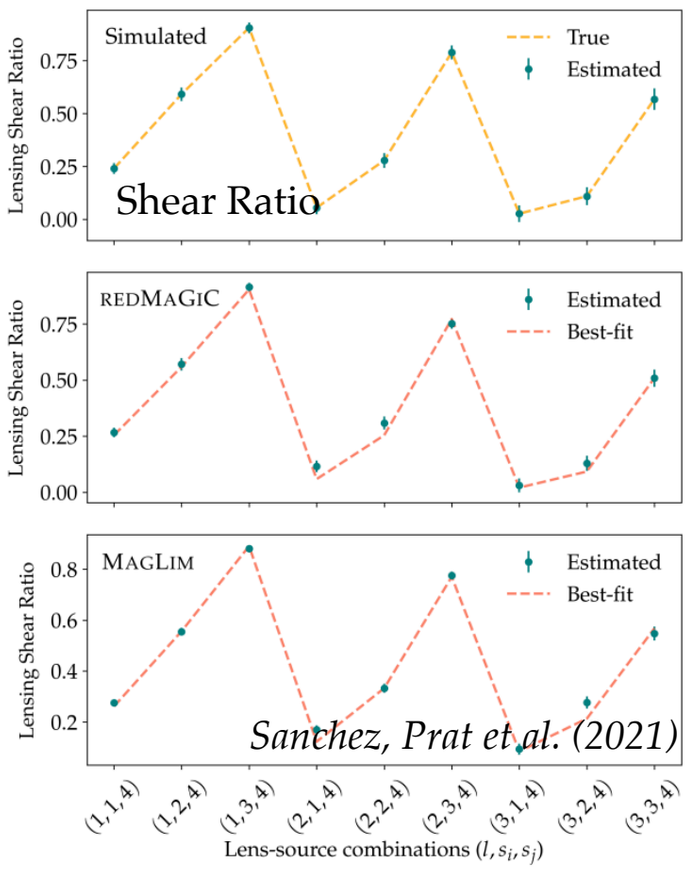
Devil's in the details:
all the technical advances that make DES a *great* survey…







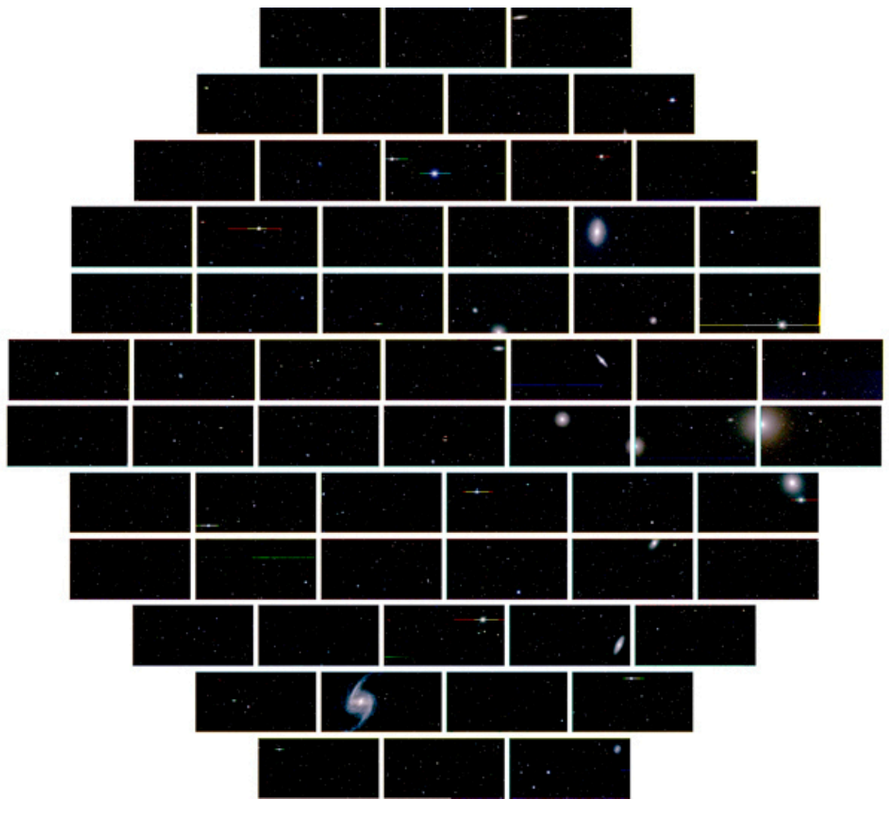




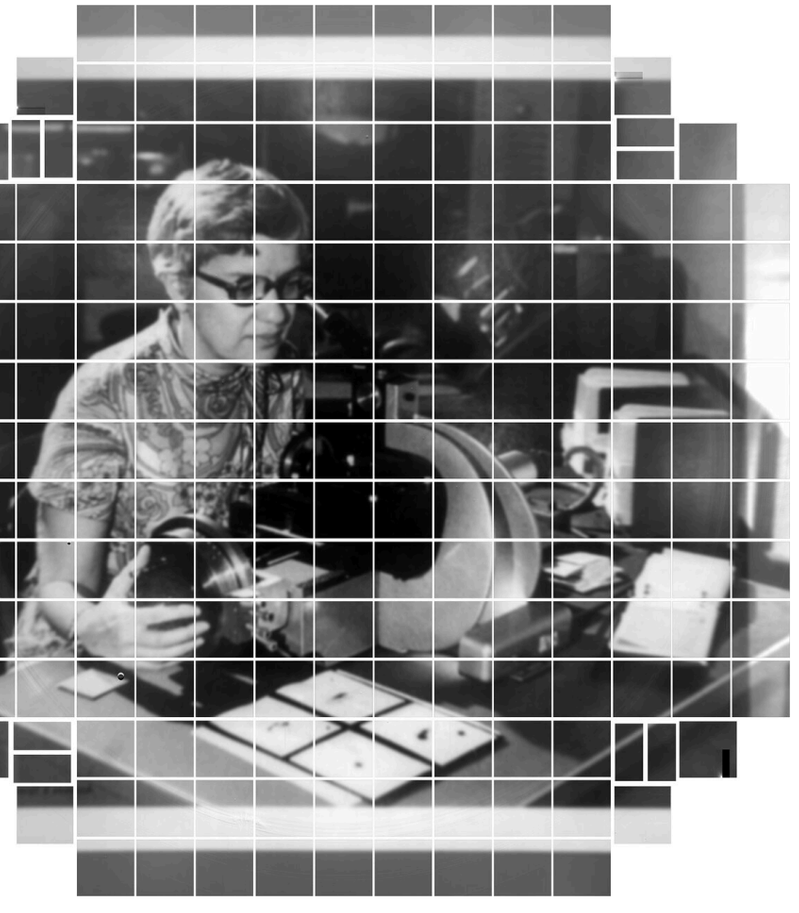
Taking the DES experience into the next decade: Rubin, Roman, Euclid++

Lessons learned

- Preparation is good, but expect (a lot of) surprises
- When people are happy the science is almost guaranteed to be good
- Practically, we should make sure the tools and experiences built are efficiently channeling into the next big experiment, so that the field continues to move on



Dark Energy Camera

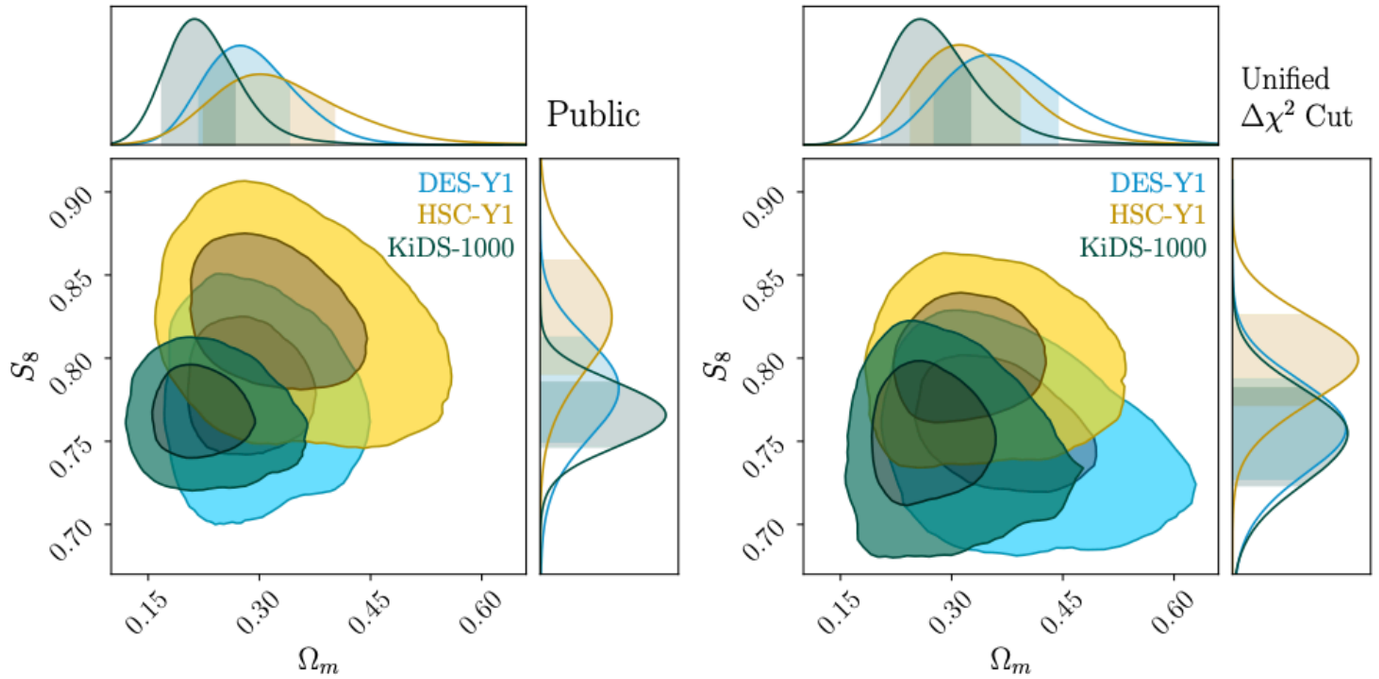


Rubin Observatory LSST Camera

Lessons learned

- Preparation is good, but expect (a lot of) surprises
- When people are happy the science is almost guaranteed to be good
- Practically, we should make sure the tools and experiences built are efficiently channeling into the next big experiment, so that the field continues to move on

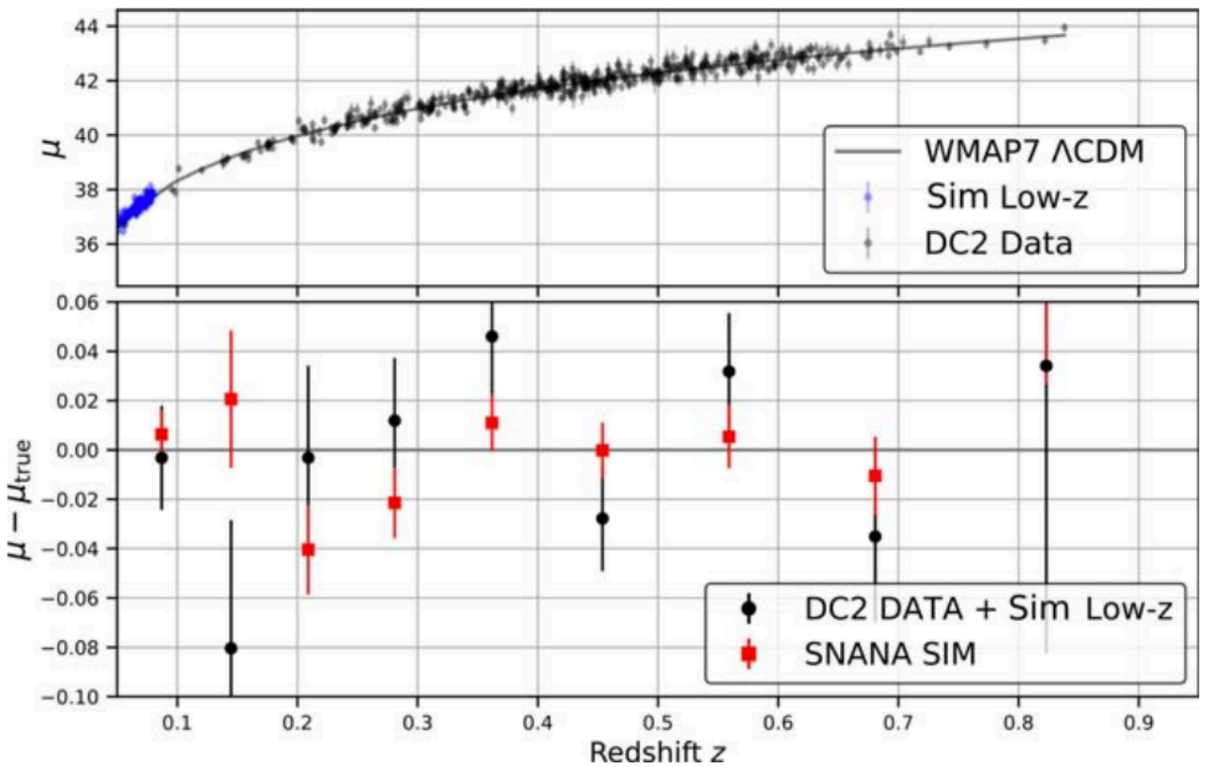
Some example: knowledge transfer



Using LSST DESC tools to reanalyze DES, KiDS, HSC data to perform a unified cosmic shear analysis.

Phillips-Longley et al. (2022)

Testing the LSST Difference Image Analysis pipeline on simulations. Demonstrate we can recover the input within statistical uncertainty.



Sanchez et al. (2022)

Summary

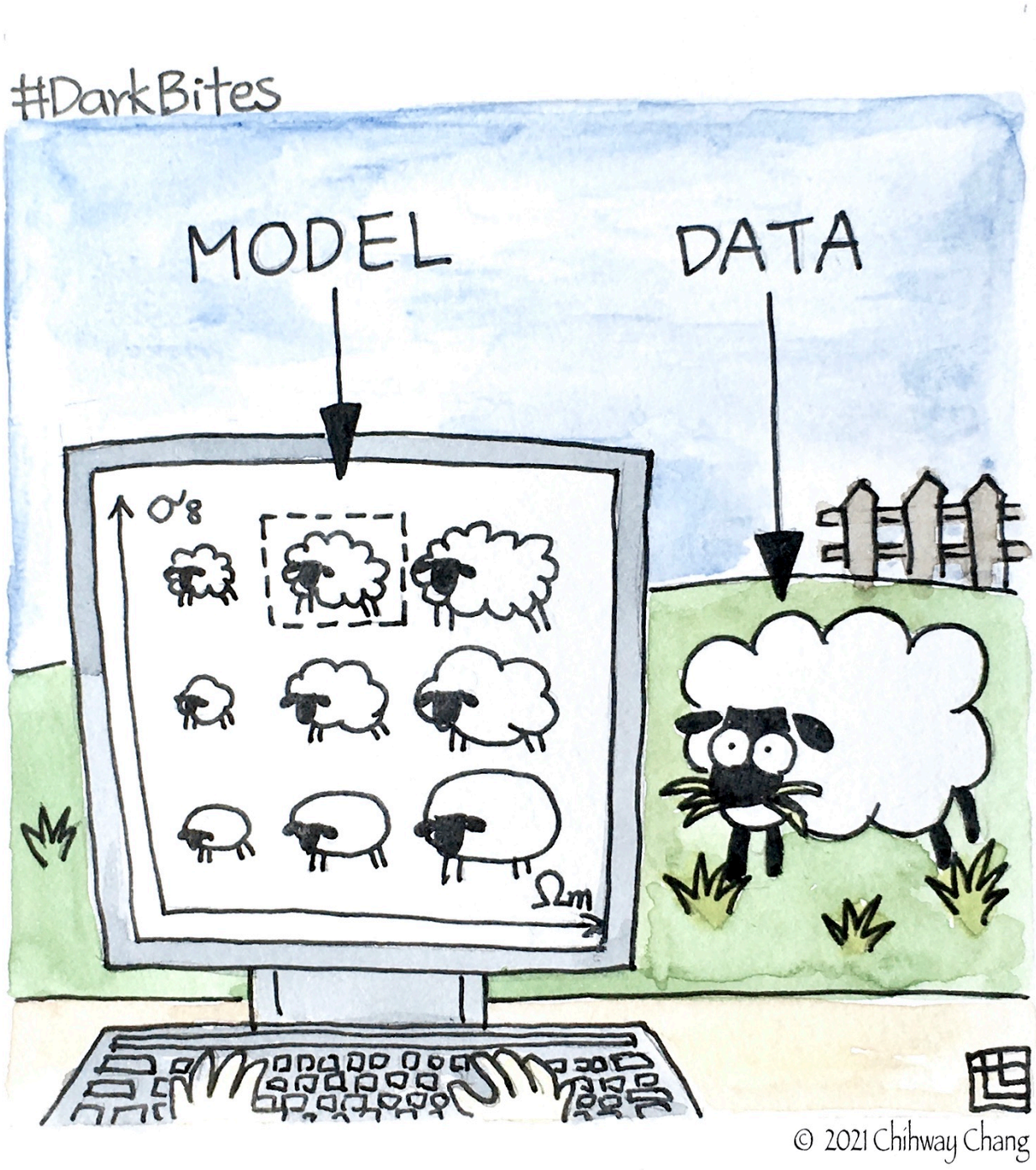
DES was designed to constrain dark energy with 4 cosmological probes. We have many results already (and much beyond the 4 probes), and are working hard towards the final Y6 analysis as we speak.

On the way to measuring dark energy, we learned so much more about our Universe and how we are observing it.

The DES experience provides a good foundation for many of the future cosmology experiments to come.

Happy 10th DECam!

Questions?



Backup

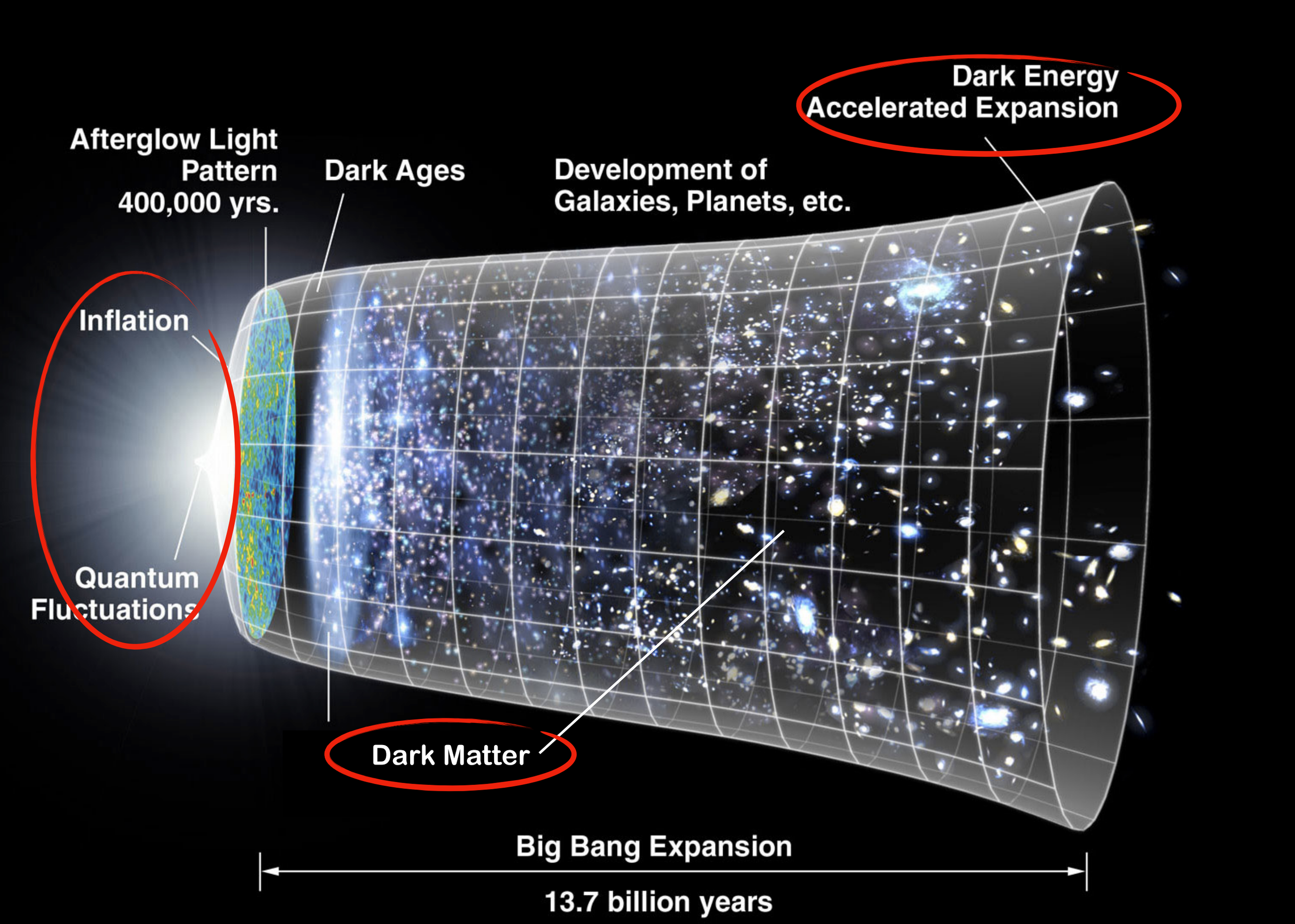
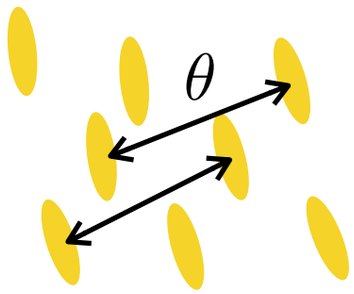


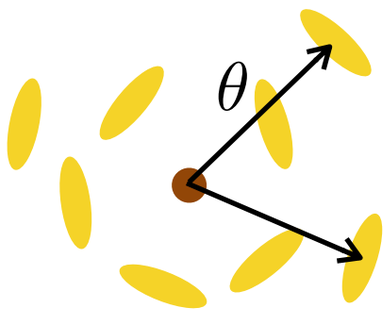
Image credit: NASA/WMAP

3x2pt: Three Two-point Functions

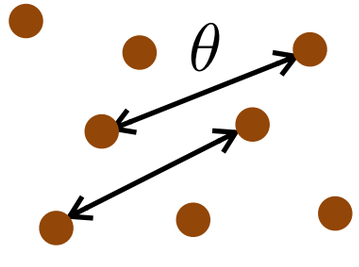
1) Cosmic shear

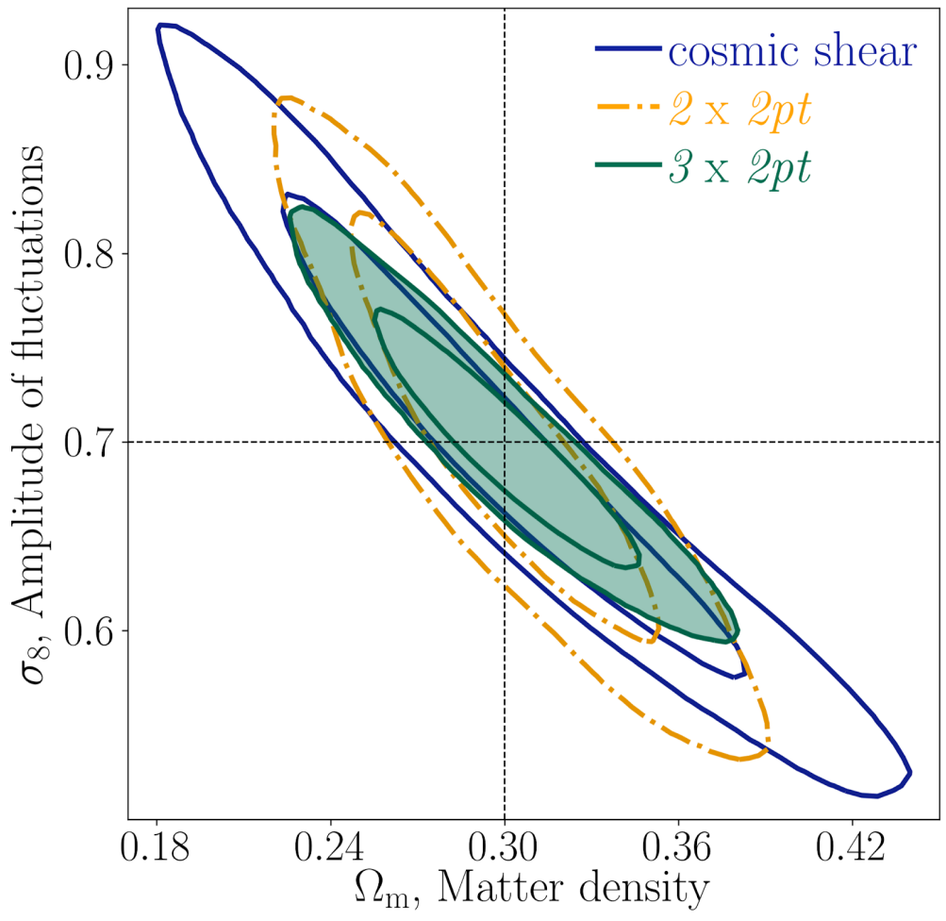


2) Galaxy-galaxy lensing



3) Galaxy clustering

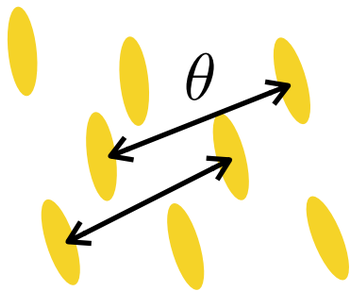




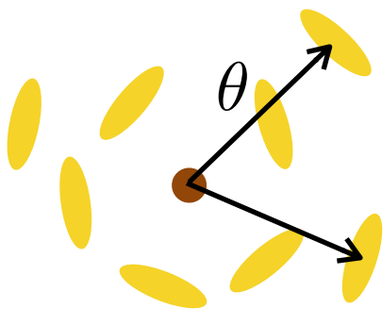
"3x2pt": A joint analysis maximizes the cosmological information and robustly constrains astrophysical & observational systematic priors in the analysis!

3x2pt: Three Two-point Functions

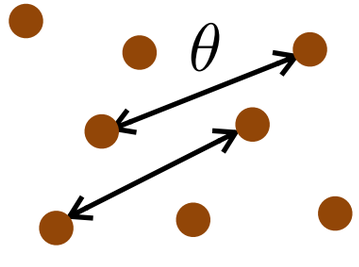
1) Cosmic shear

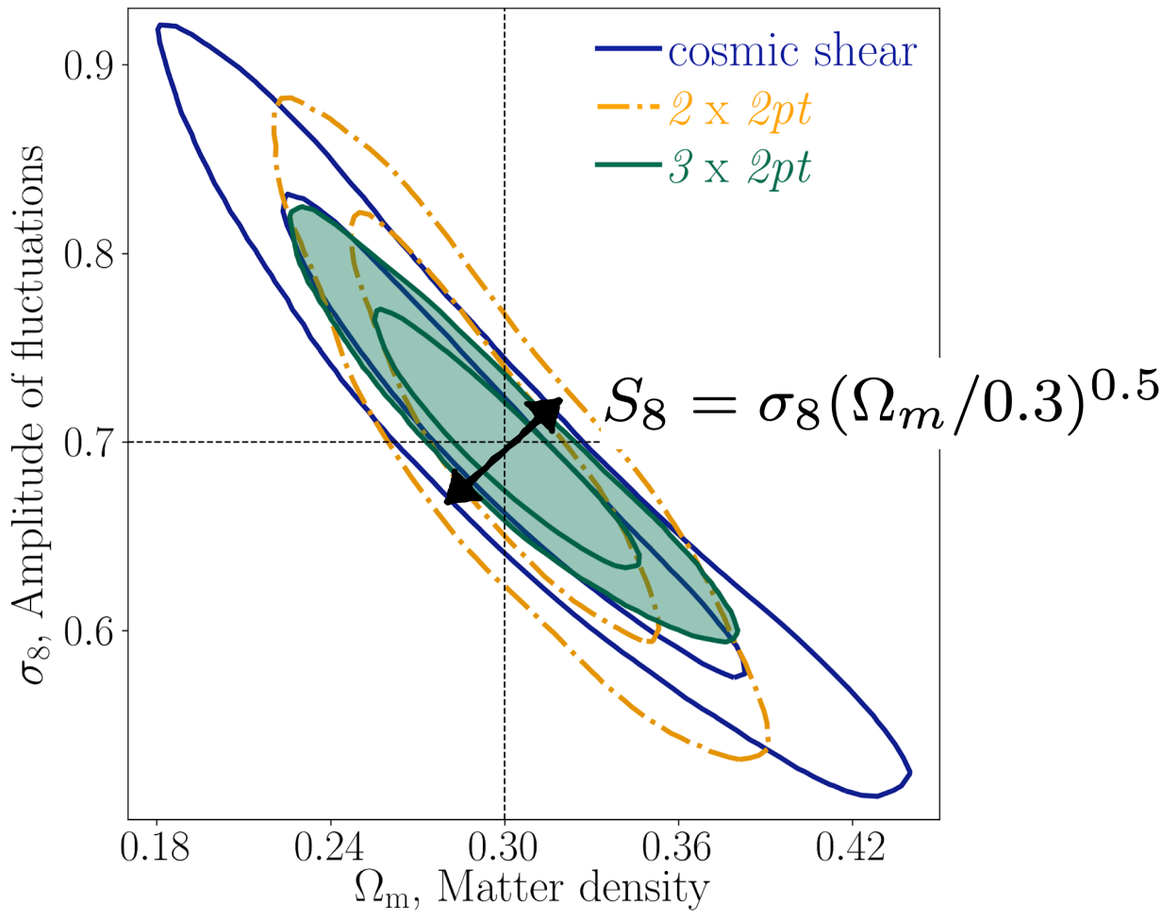


2) Galaxy-galaxy lensing



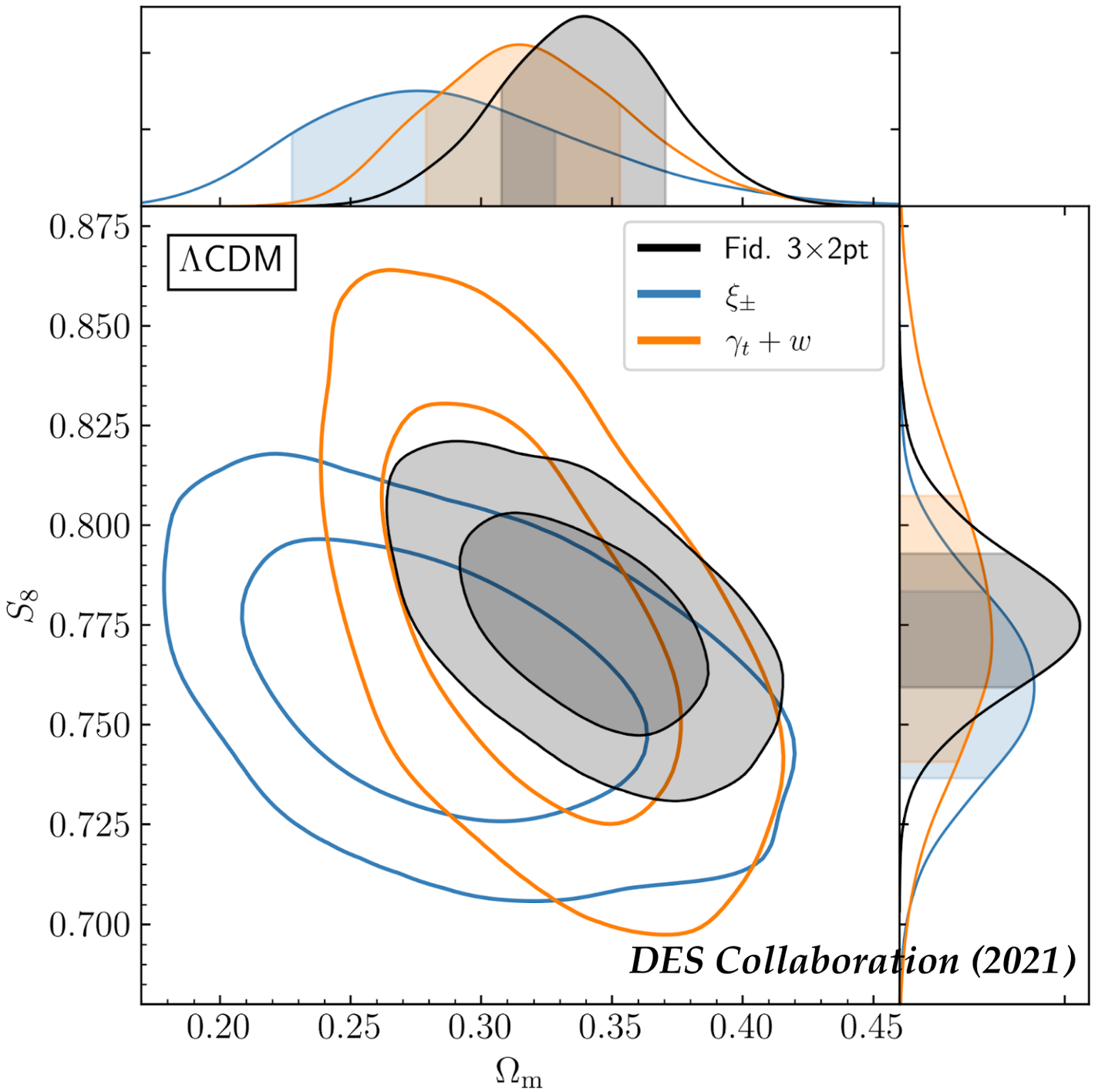
3) Galaxy clustering





"3x2pt": A joint analysis maximizes the cosmological information and robustly constrains astrophysical & observational systematic priors in the analysis!

Headline Results from DES Y3 3x2pt



In ΛCDM:

$$S_8 = 0.776^{+0.017}_{-0.017} \quad (0.776)$$

$$\Omega_\mathrm{m} = 0.339^{+0.032}_{-0.031} \quad (0.372)$$

$$\sigma_8 = 0.733^{+0.039}_{-0.049} \quad (0.696)$$

In wCDM:

$$\Omega_\mathrm{m} = 0.352^{+0.035}_{-0.041} \quad (0.339)$$

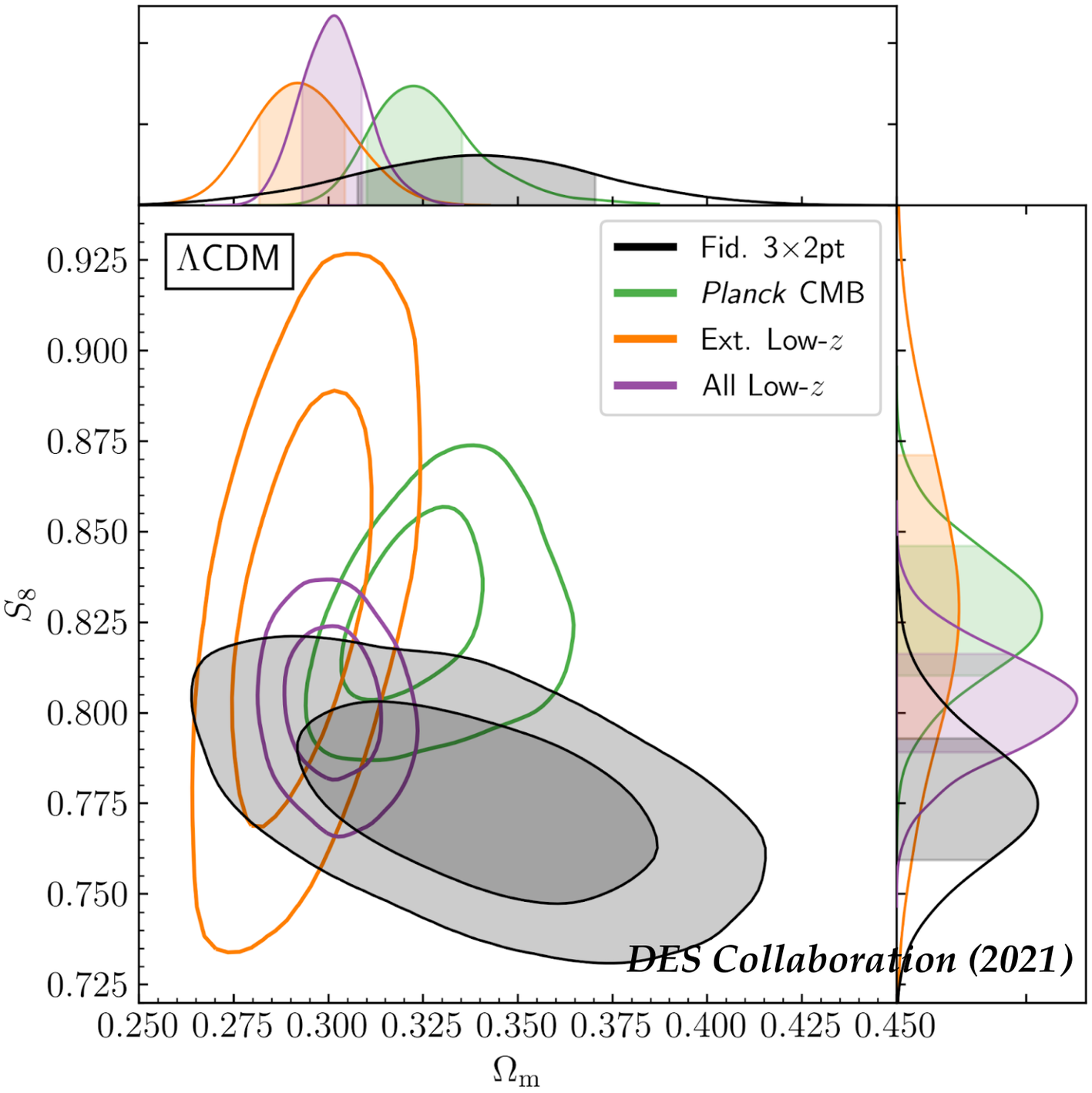
$$w = -0.98^{+0.32}_{-0.20} \quad (-1.03)$$

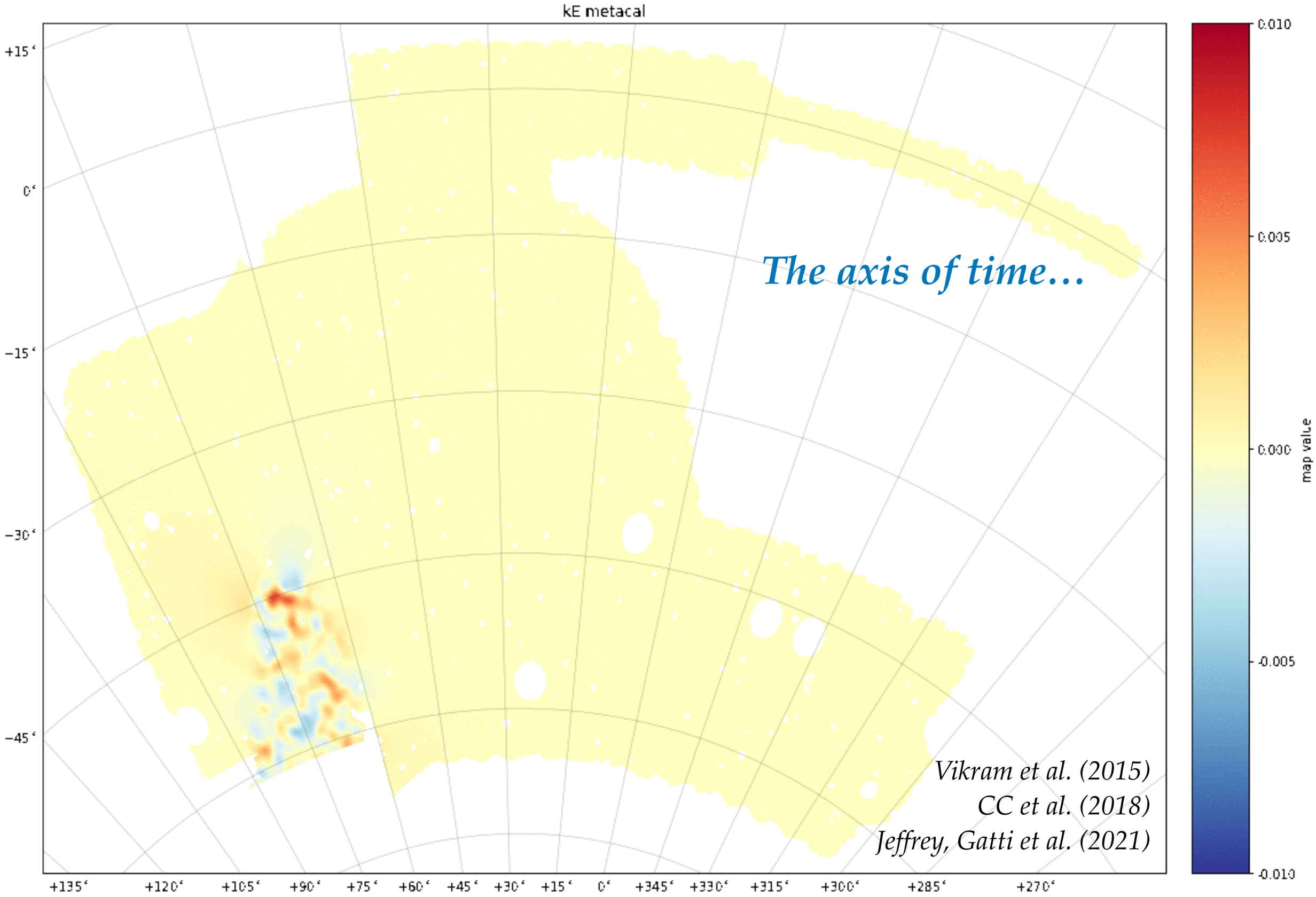
Headline Results from DES Y3 3x2pt

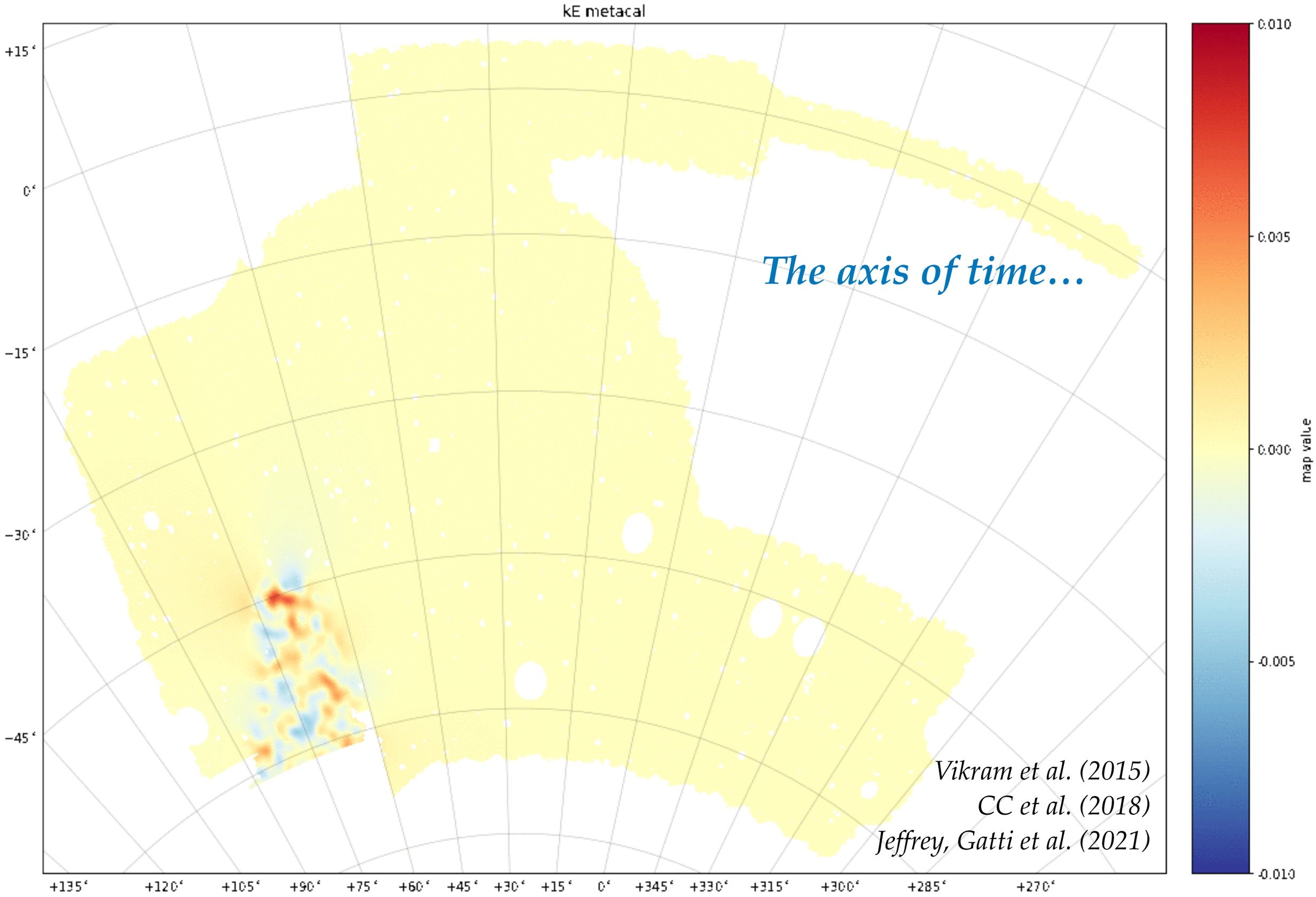
DES Y3 cosmic shear is consistent with Planck at ~2σ

DES Y3 3x2pt is consistent with Planck at ~1σ

Combined with other Low-z probes (SNe Ia, BAO, RSD), we are consistent with Planck at~1σ




kE metacal
+15‘
0‘
−15‘
−30‘
−45‘
+135‘
+120‘
+105‘
+90‘
+75‘
+60‘
+45‘
+30‘
+15‘
0‘
+345‘
+330‘
+315‘
+300‘
+285‘
+270‘
0.010
0.005
0.000
-0.005
-0.010
map value
The axis of time…
Vikram et al. (2015)
CC et al. (2018)
Jeffrey, Gatti et al. (2021)


kE metacal
+15‘
0‘
−15‘
−30‘
−45‘
+135‘
+120‘
+105‘
+90‘
+75‘
+60‘
+45‘
+30‘
+15‘
0‘
+345‘
+330‘
+315‘
+300‘
+285‘
+270‘
0.010
0.005
0.000
-0.005
-0.010
map value
The axis of time…
Vikram et al. (2015)
CC et al. (2018)
Jeffrey, Gatti et al. (2021)