Probing Dark Energy
with DES and Other Imaging Surveys

Jonathan Blazek
Northeastern University

Simonyi-NSF

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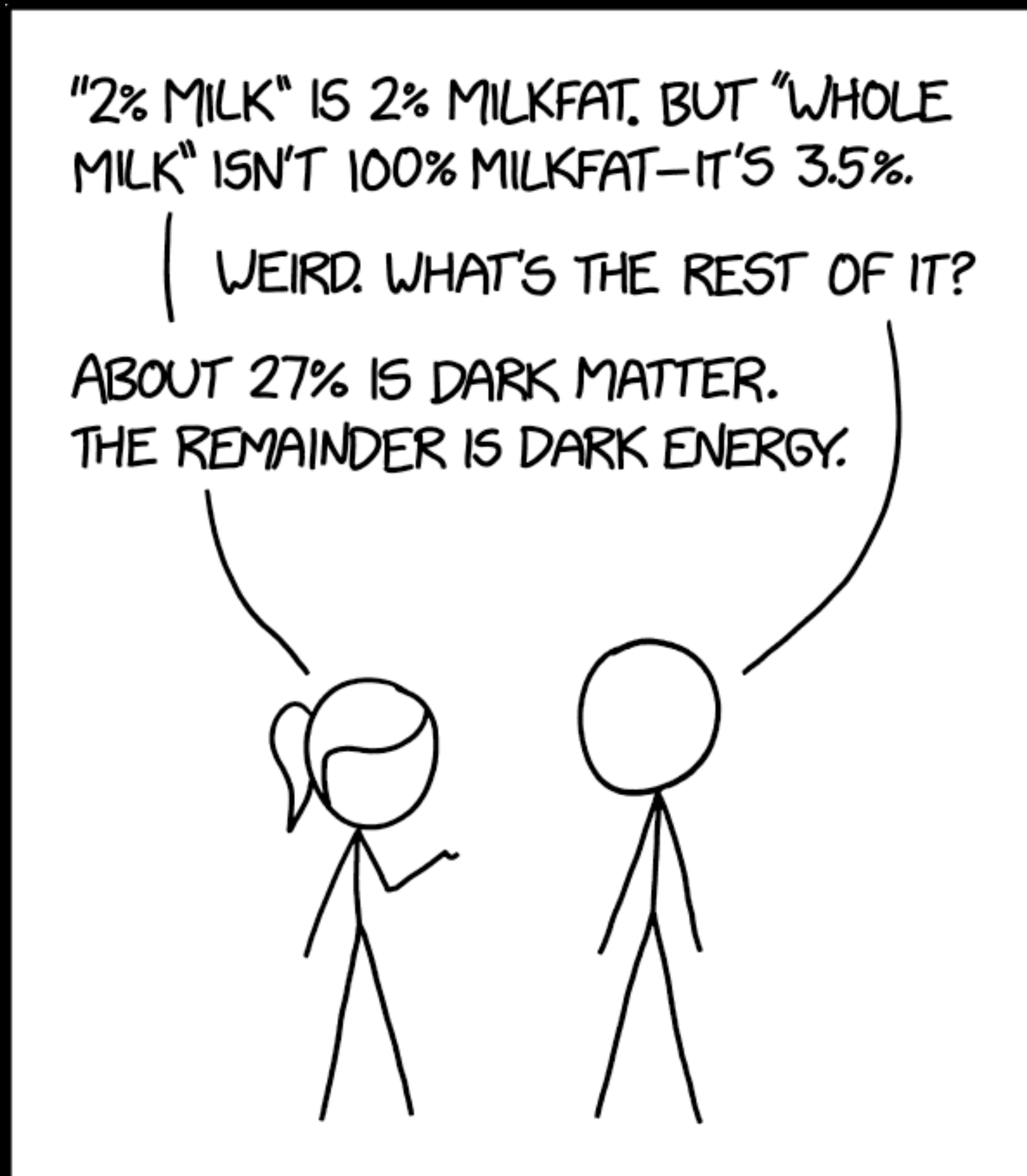
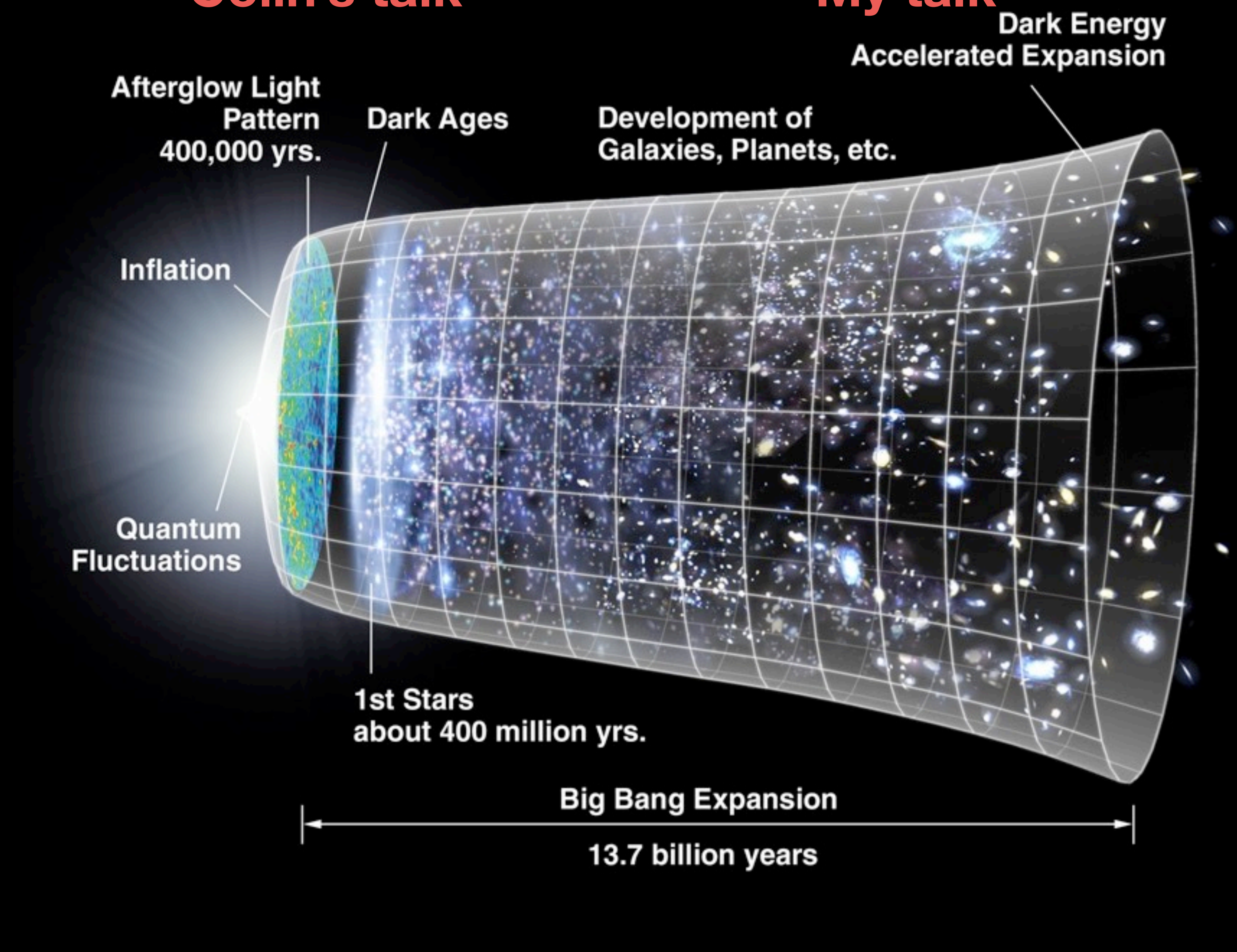
The state of cosmology



xkcd

ΛCDM: Concordance Cosmology

Colin's talk **My talk**



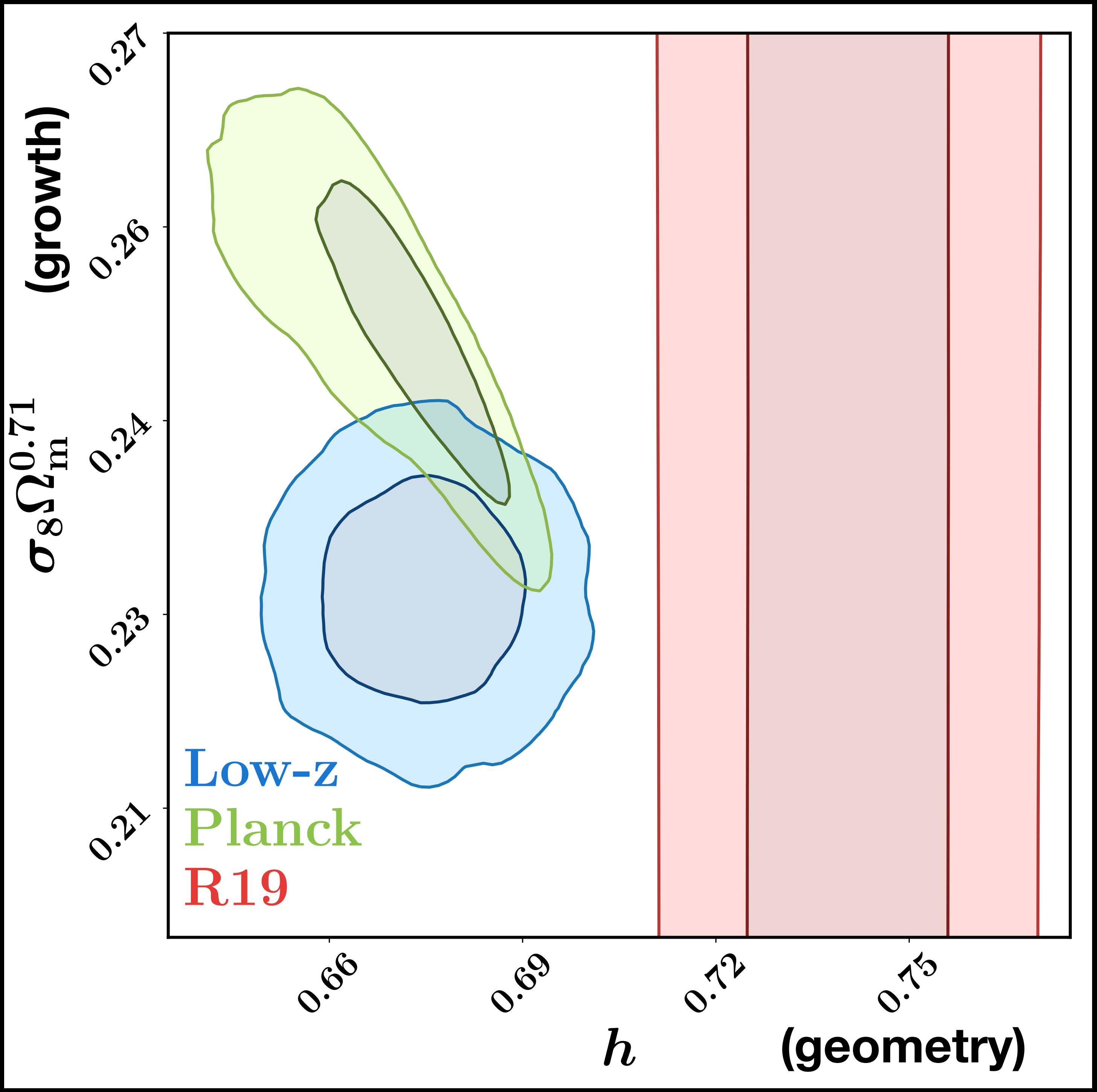
Geometry and Growth

- Baryon acoustic oscillations (BAO)
- Type Ia supernovae
- Distance ladder and local measurements of H_0
- Strong lensing time delays
- Gravitational wave standard sirens
- CMB

- Weak gravitational lensing
- Galaxy clustering (amplitude)
- Redshift-space distortions
- Galaxy clusters
- CMB (anchor)

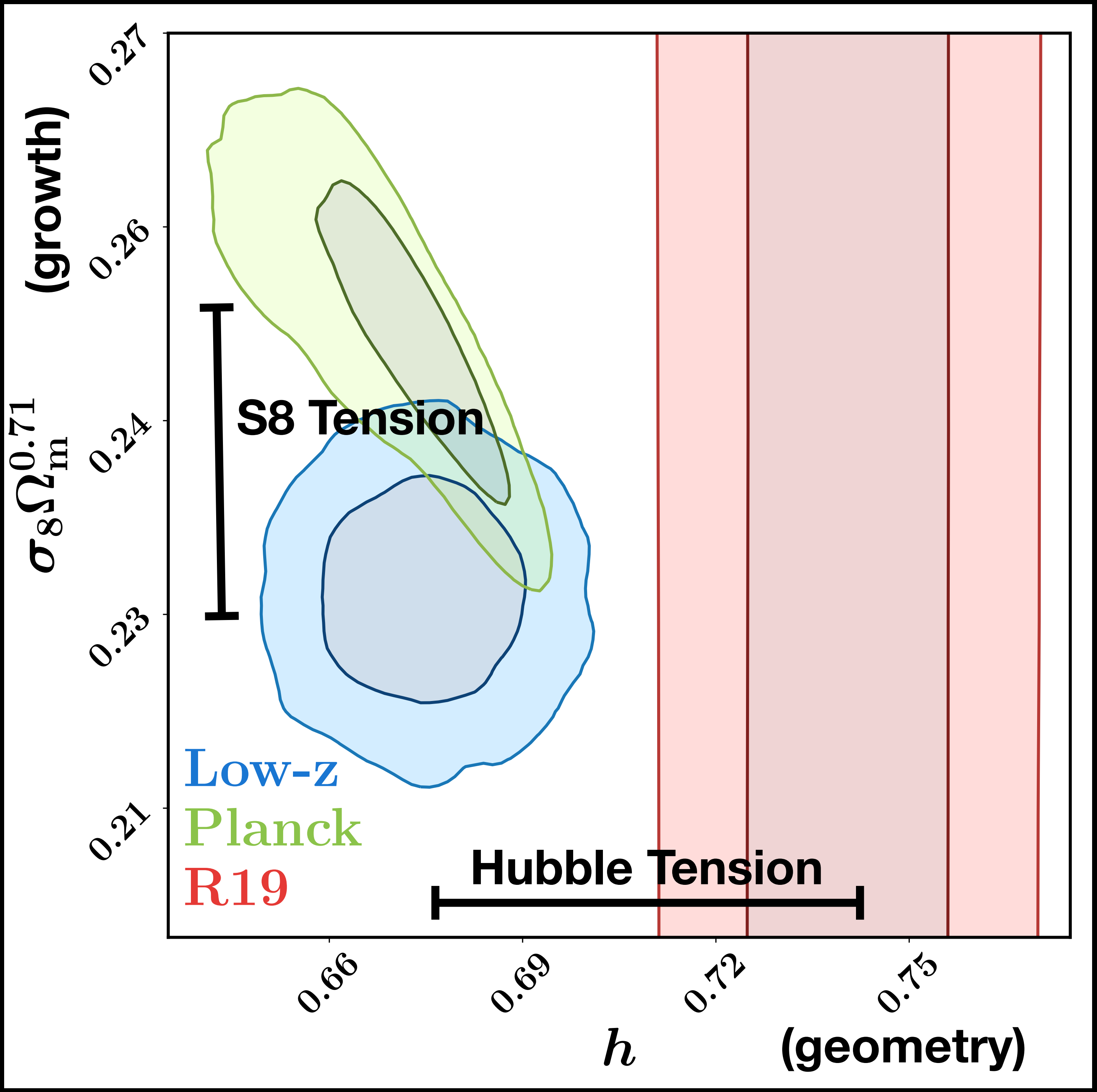
Note: List is not complete, and division is not always clean.

Concordance Cosmology?



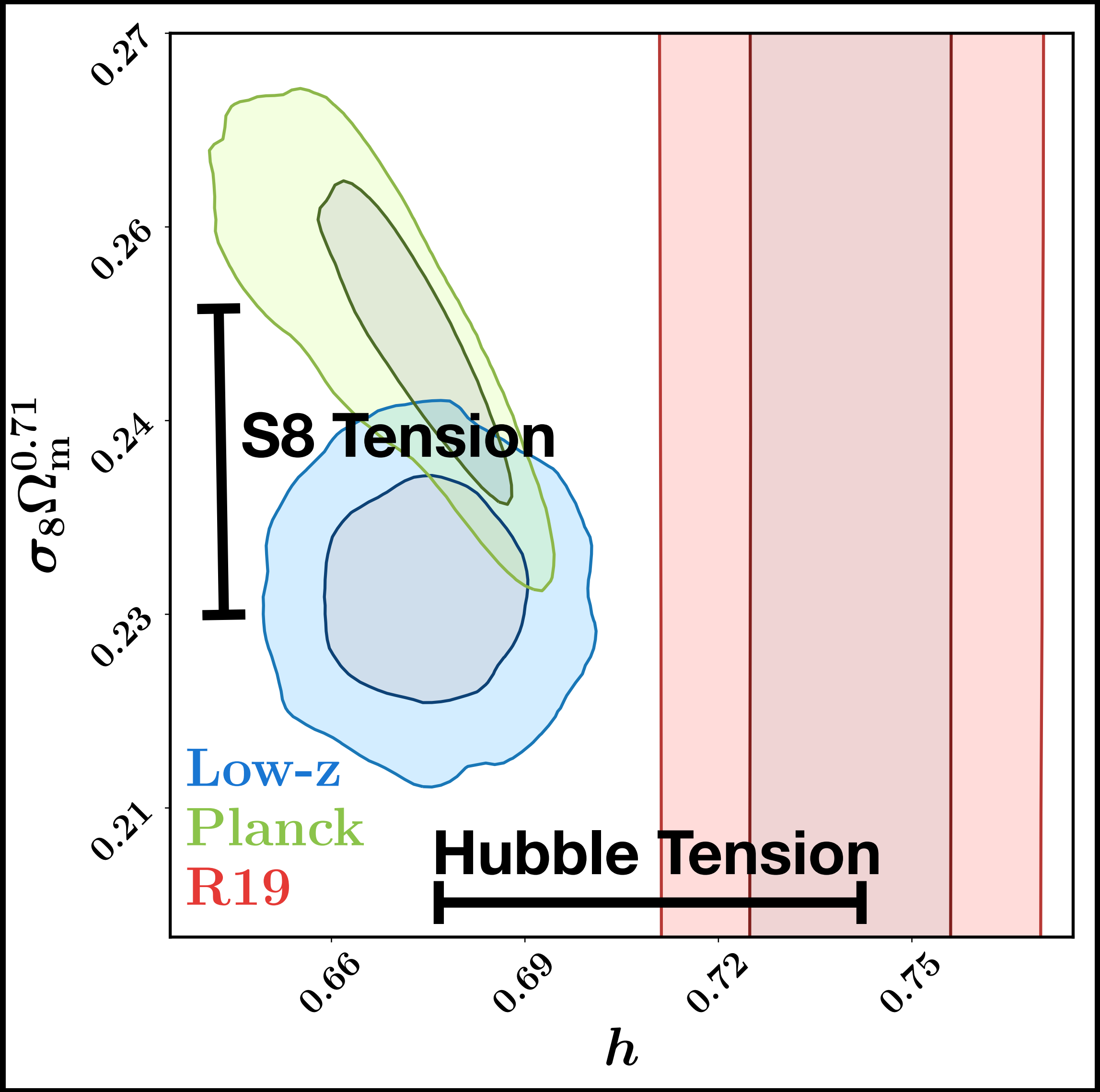
Park & Rozo 2019

A Tale of Two Tensions

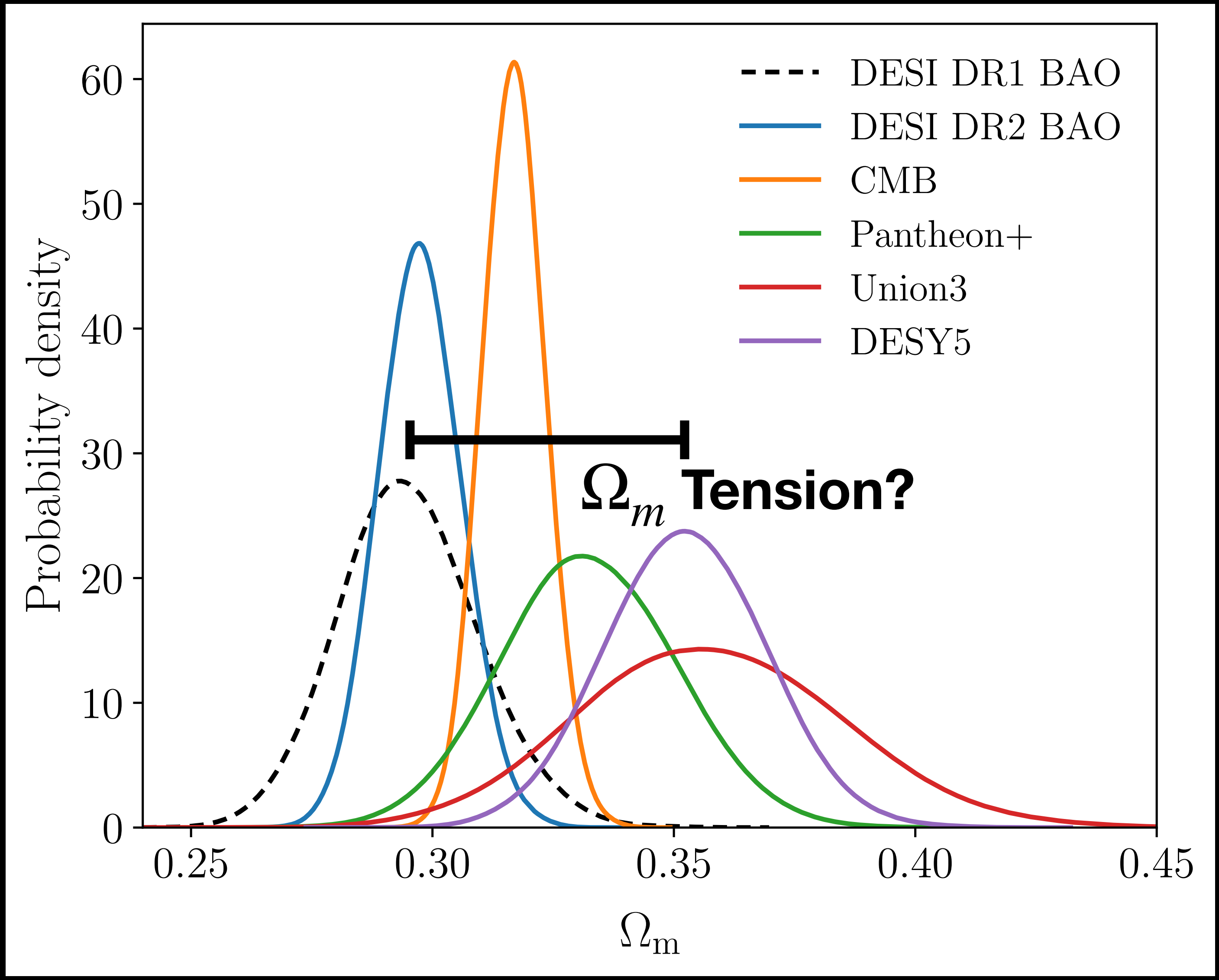


Park & Rozo 2019

A Tale of ~~Two~~ Three Tensions

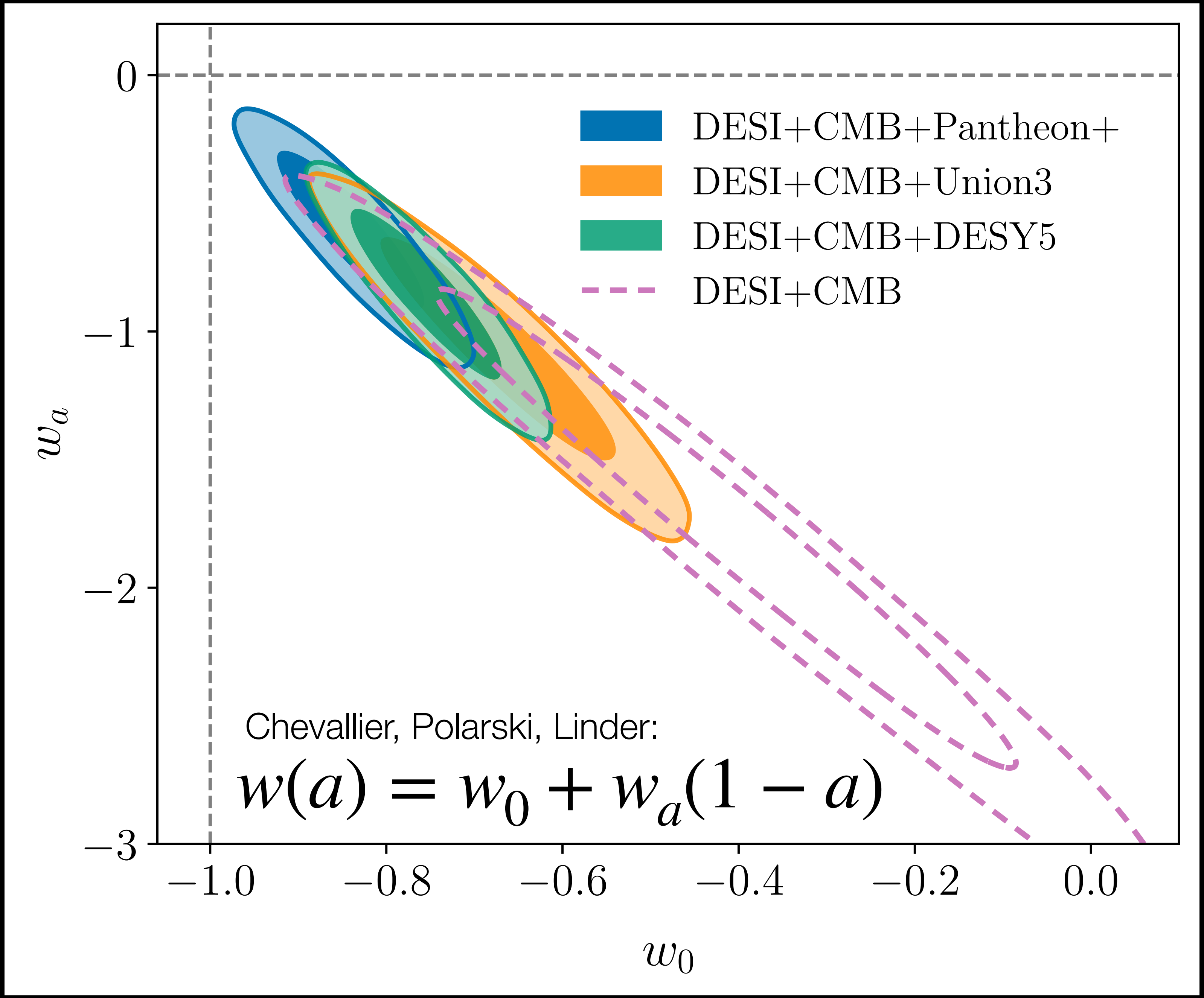


Park & Rozo 2019



DESI DR2 2025

Evolving Dark Energy?



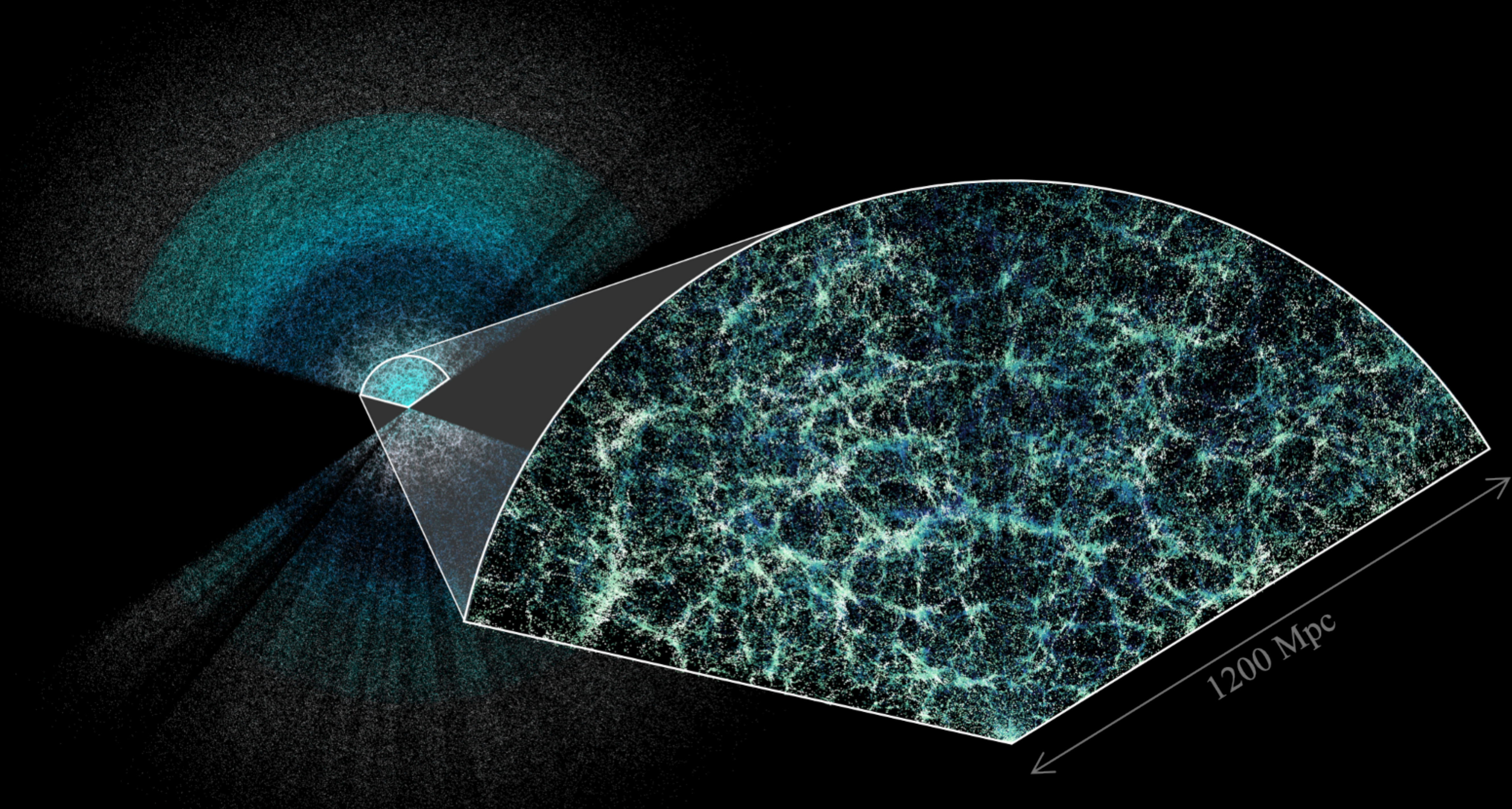
DESI DR2 (2025)

Note: DESY5 —> DESY5-Dovekie (Popovic, DES+ 2025); 3.2σ vs 4.2σ

Outline and Takeaways

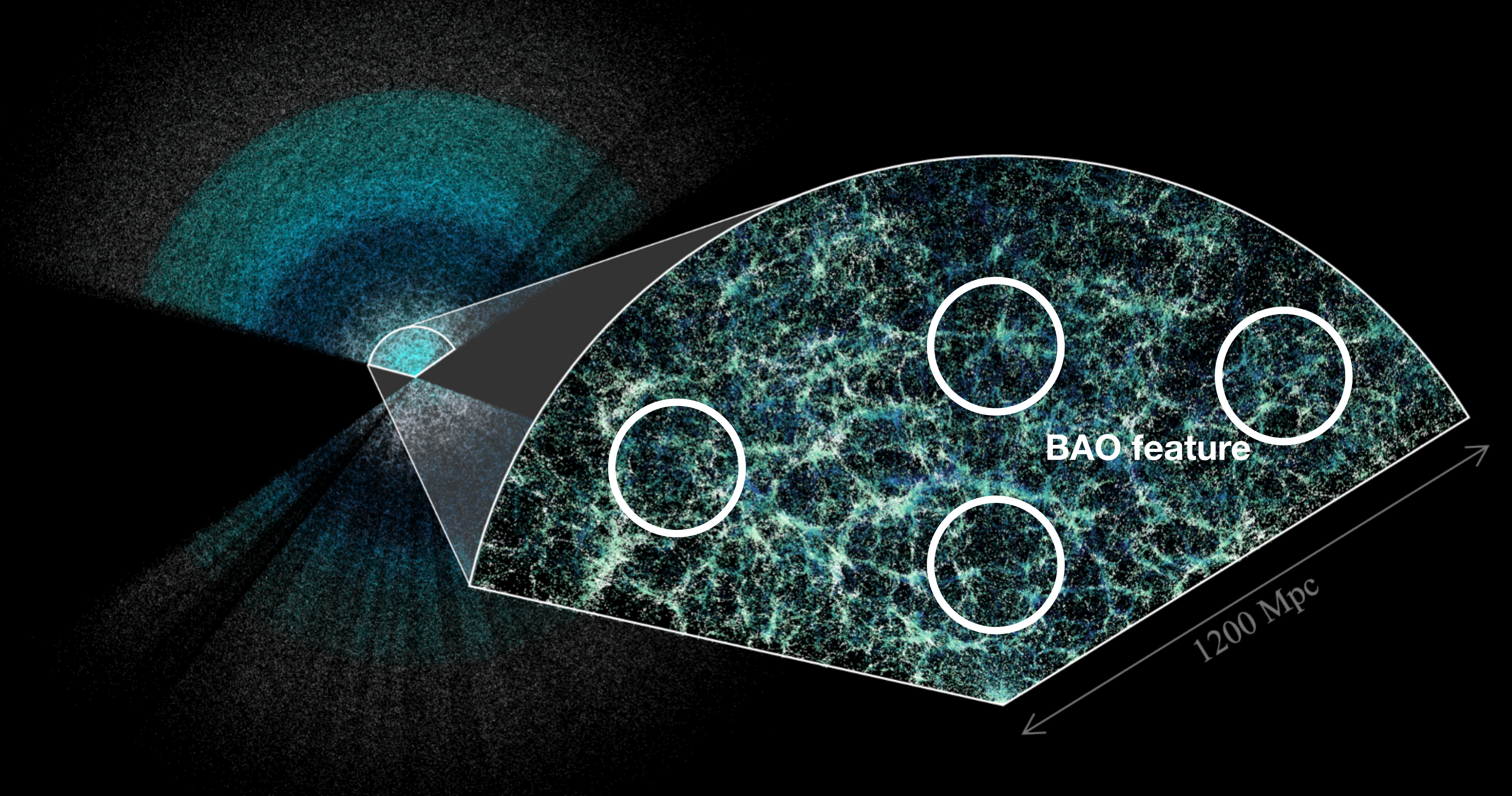
- Combining weak lensing and galaxy clustering is a powerful probe of cosmic structure and dark energy.
- DES has been a successful, decades-long effort to probe dark energy and much more.
- Results from completed DES (Year 6): 2.8σ tension with CMB in ΛCDM, 2.2σ (3.0σ) preference for evolving dark energy from DES alone (all combined).
- Rubin Observatory LSST, the Roman Space Telescope, and Euclid will provide unprecedented cosmological data sets.

“Spectroscopic” surveys



Claire Lamman | The DESI Collabortation

“Spectroscopic” surveys



Claire Lamman | The DESI Collabortation

“Photometric” (imaging) surveys

Dark Energy Survey (DES)

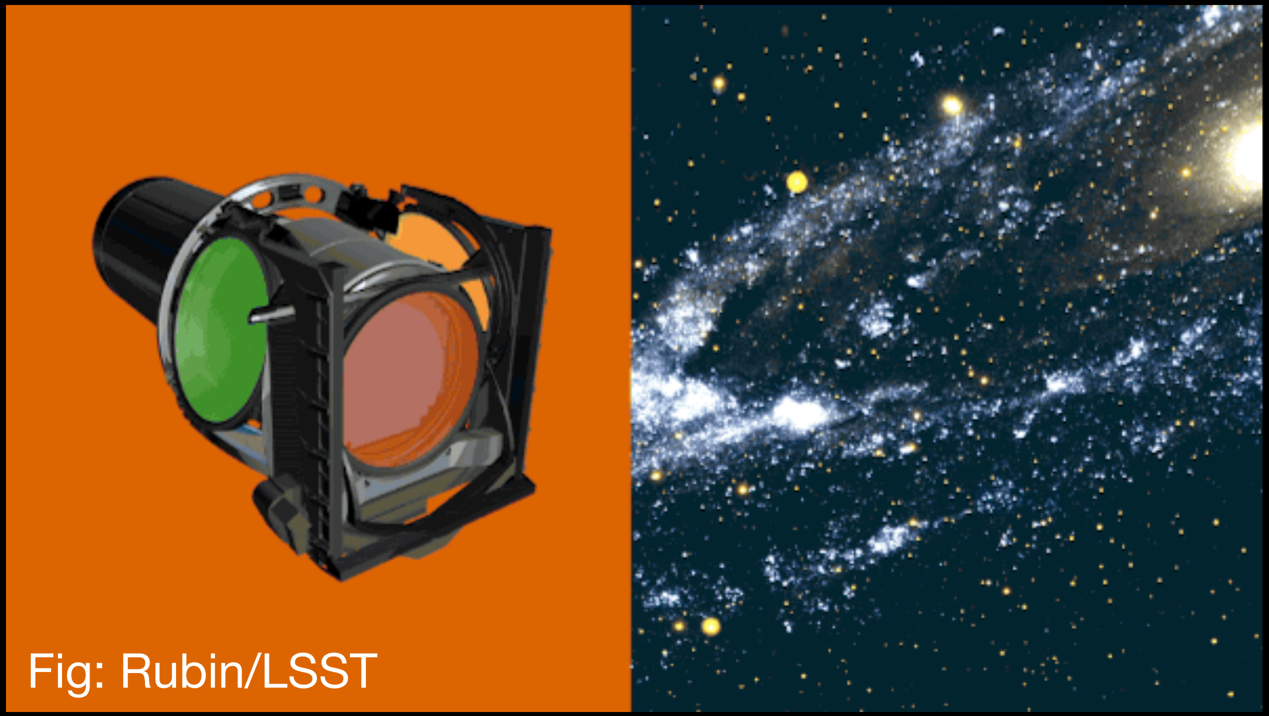


Fig: Rubin/LSST

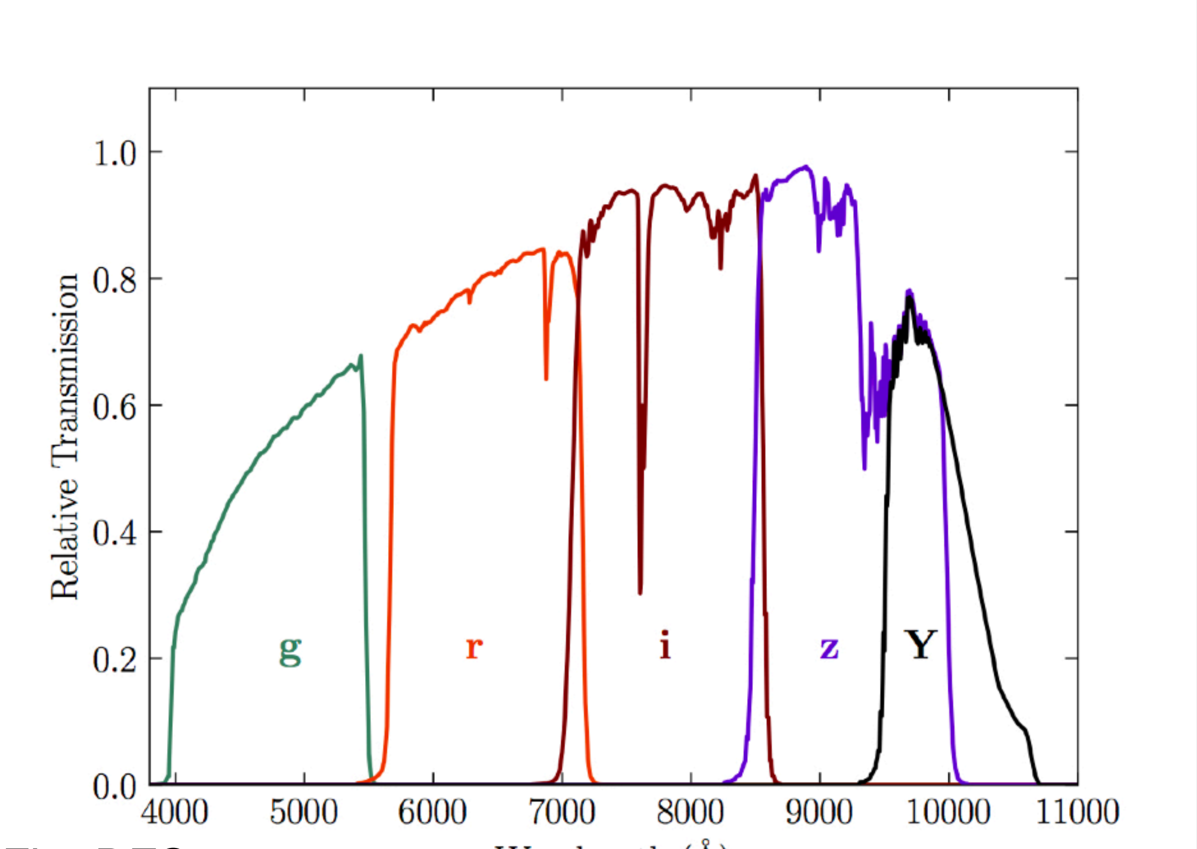
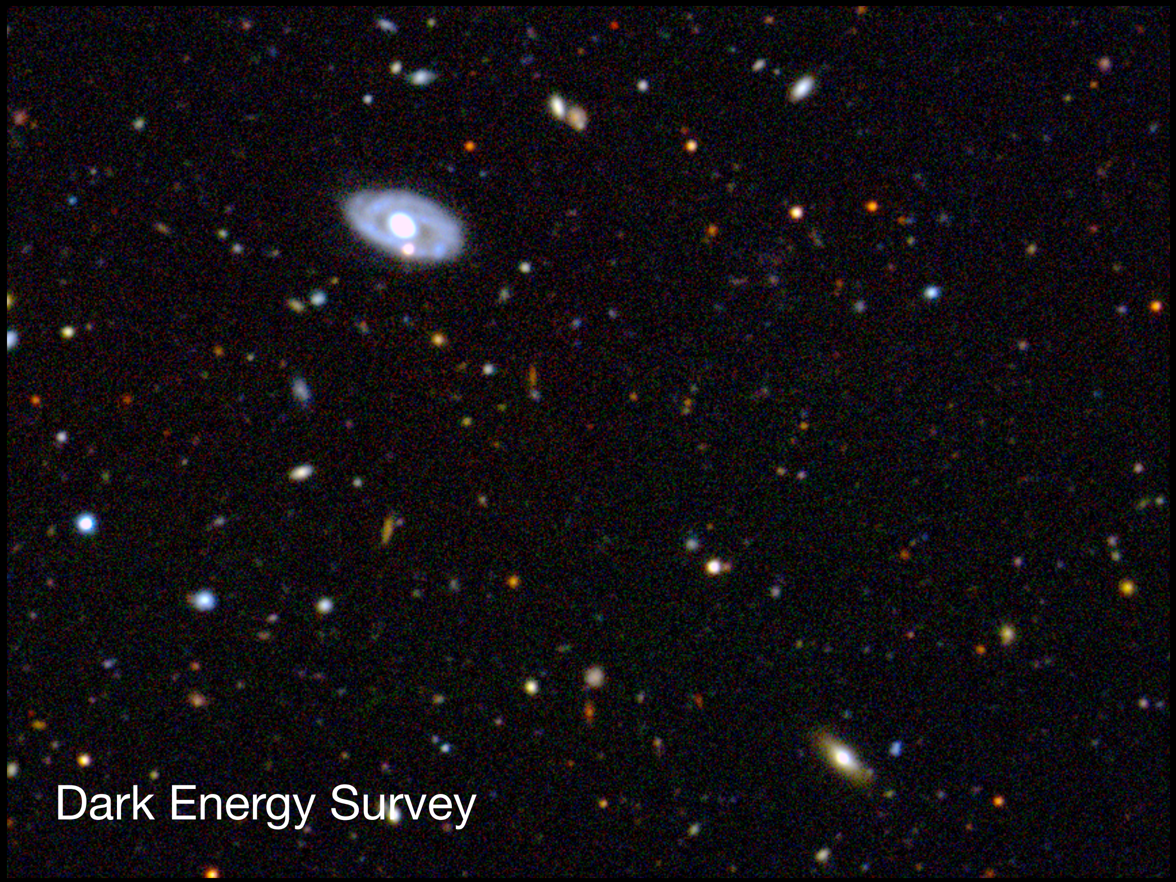
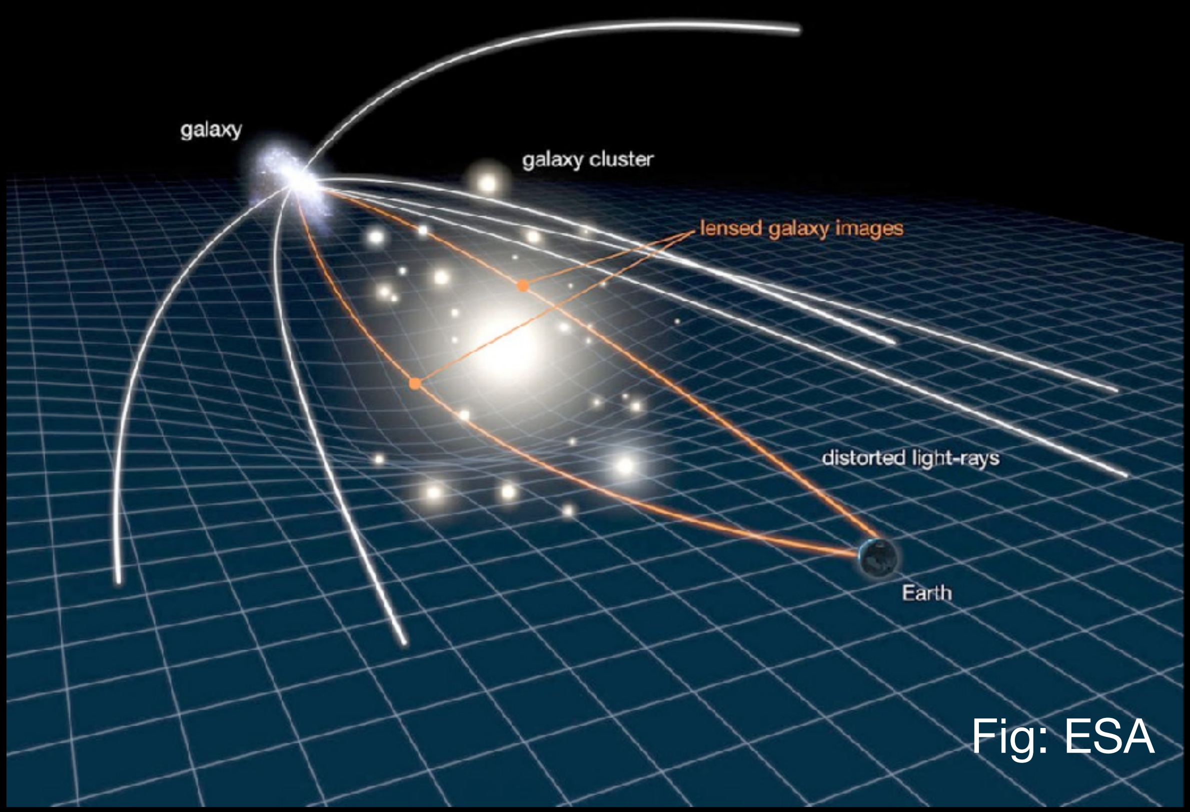


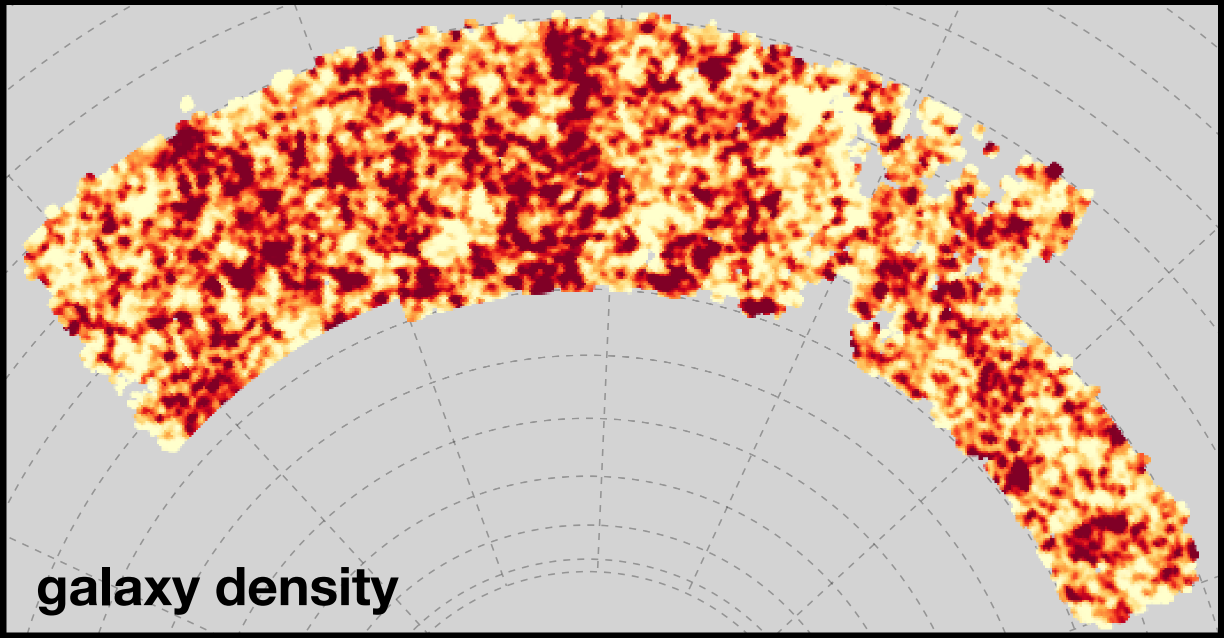
Fig: DES

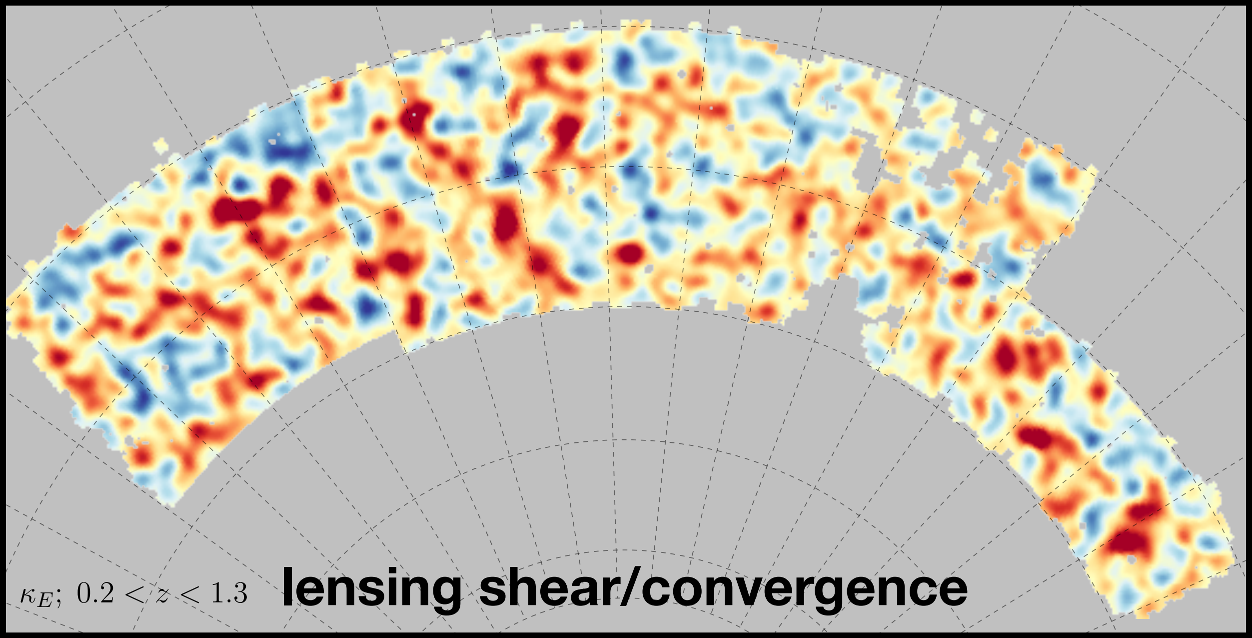
Lensing and large-scale structure



(Weak) Gravitational Lensing

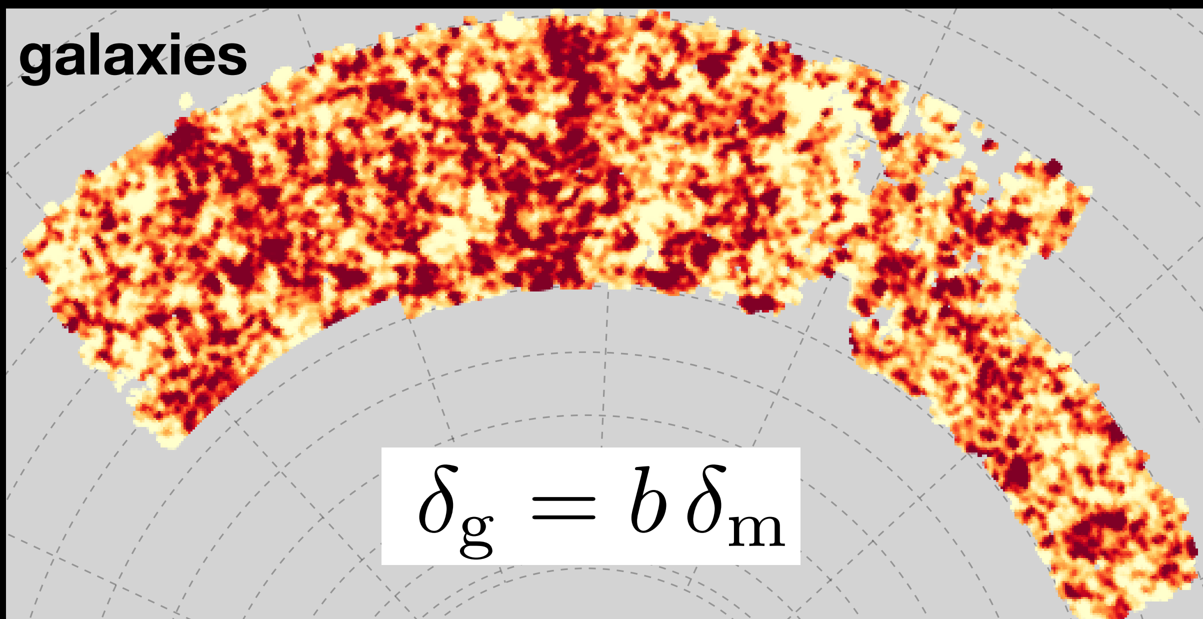


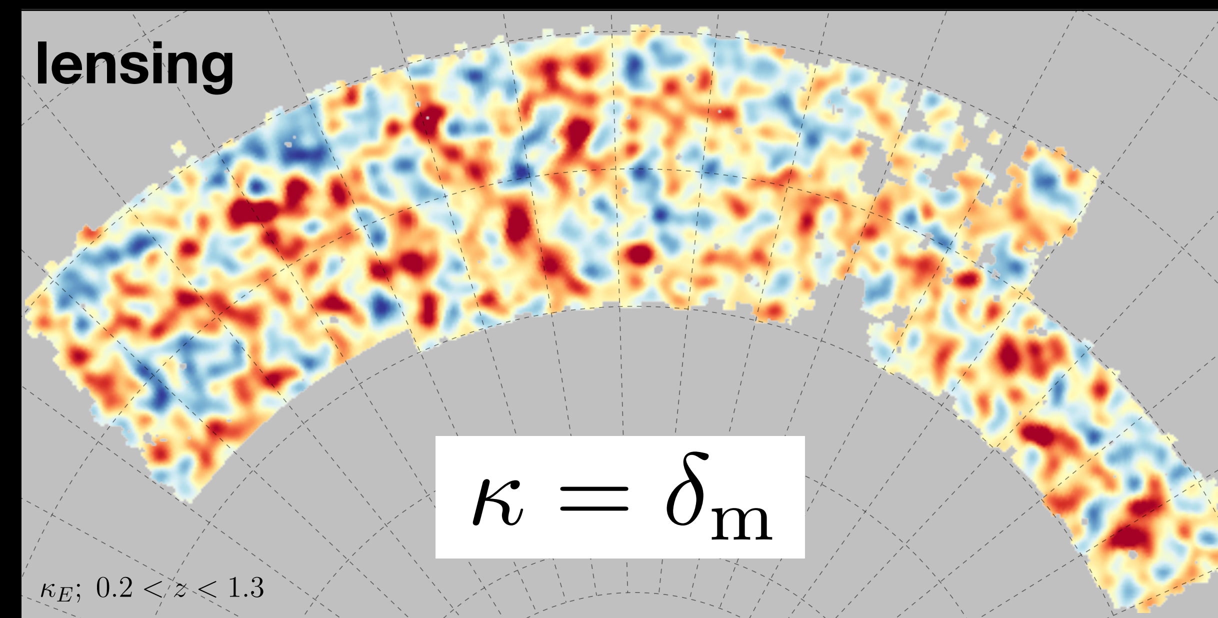




DES Year 1: Elvin-Poole+ 2018; Chang+ 2018

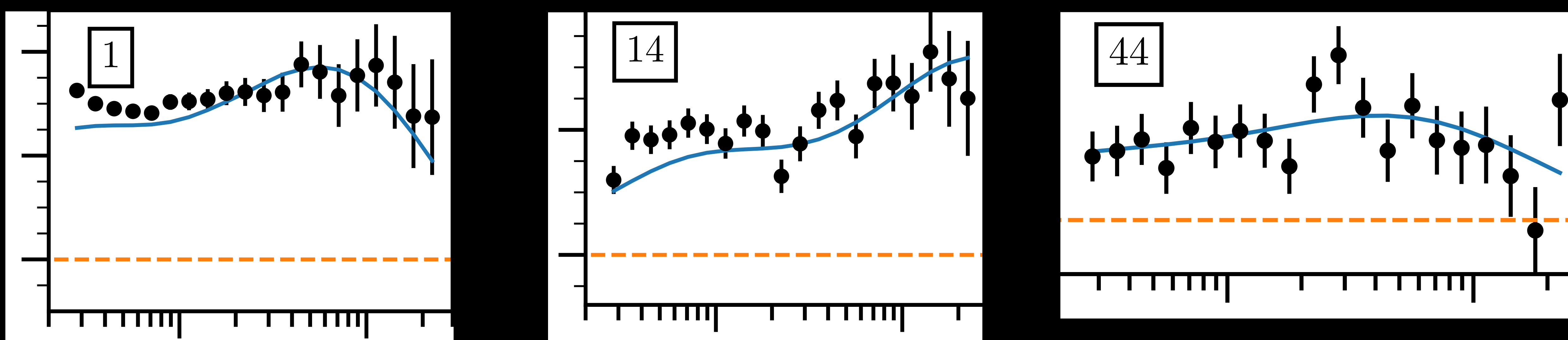
Combining probes





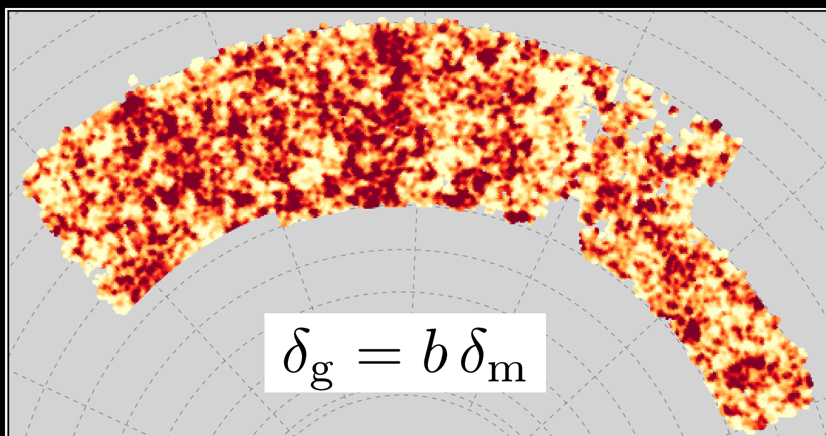
$\delta_g = b\,\delta_m$ $\kappa = \delta_m$

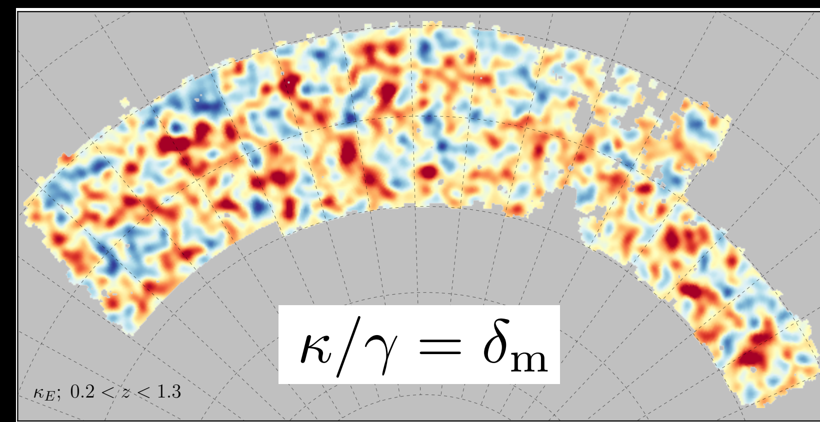
$\langle\delta_g|\delta_g\rangle = \xi_{gg} \sim b^2\sigma_8^2$ $\langle\delta_g|\kappa\rangle = \xi_{gm} \sim b\sigma_8^2$ $\langle\kappa|\kappa\rangle = \xi_{mm} \sim \sigma_8^2$

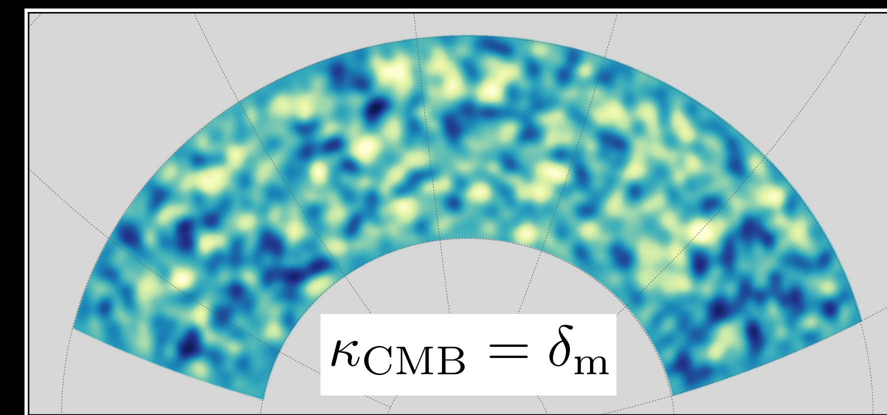


"3x2 analysis"

Combining probes







SPT+Planck; Omori+ 2017

“3x2”

“6x2”

self-calibration and improved statistics

e.g. DES Y3 2023; Krolewski+ 2021 (unWISE + Planck); Farren+ 2025 (unWISE + ACT)

Dark Energy Survey: A brief timeline

- ~1998: discovery of "dark energy" (Riess+, Perlmutter+).
- ~2000: first detection of cosmic shear (Van Waerbeke+, Bacon+, Witmann+, Kaiser+).
- 2003-2004: NOAO call for new instruments on the Blanco telescope; "Dark Energy Survey" submits response.

Overview

DES+ 2005

We describe the Dark Energy Survey (DES), a proposed optical-near infrared survey of 5000 sq. deg of the South Galactic Cap to ~24th magnitude in SDSS *griz*, that would use a new 3 deg^2 CCD camera to be mounted on the Blanco 4-m telescope at Cerro Telolo Inter-American Observatory (CTIO). The survey data will allow us to measure the dark energy and dark matter densities and the dark energy equation of state through four independent methods: galaxy clusters, weak gravitational lensing tomography, galaxy angular clustering, and supernova distances. These methods are doubly complementary: they constrain different combinations of cosmological model parameters and are subject to different systematic errors. By deriving the four sets of measurements from the same data set with a common analysis framework, we will obtain important cross checks of the systematic errors and thereby make a substantial and robust advance in the precision of dark energy measurements.

Dark Energy Survey: A brief timeline

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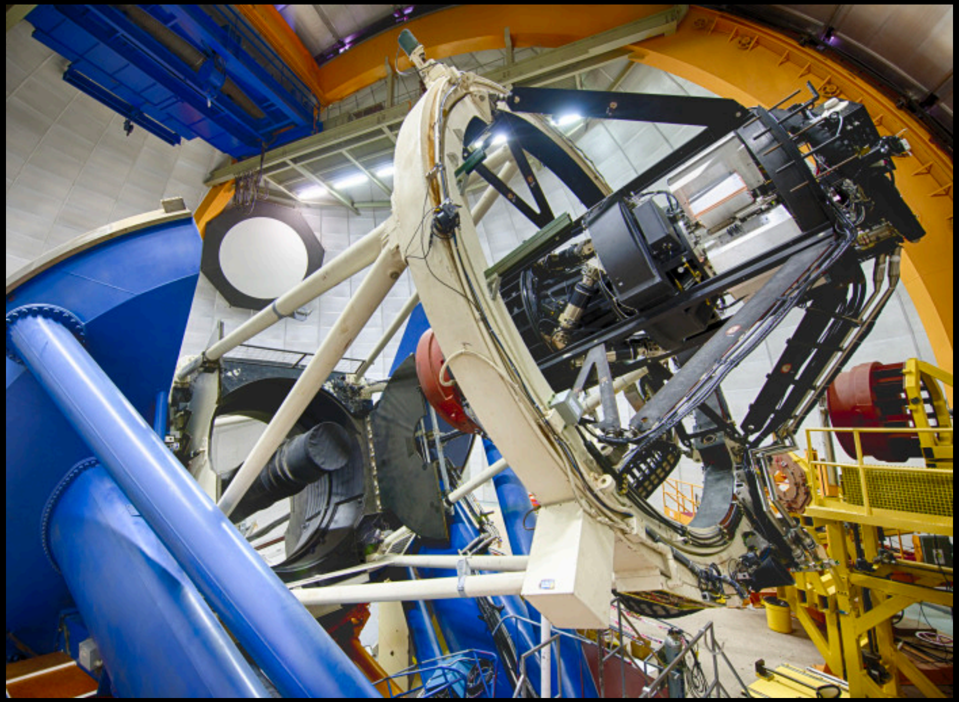
- ~2000: first detection of cosmic shear (Van Waerbeke+, Bacon+, Witmann+, Kaiser+).
- 2003-2004: NOAO call for new instruments on the Blanco telescope; “Dark Energy Survey" submits response.
- 2005: Dark Energy Task Force solidifies consensus on approaches for studying dark energy and the classification into “Stages.” DOE establishes need for ground-based DE experiment.
- May 2008: DES Collaboration formally created.
- 2012: First light for DECam, start of Science Verification (SV) survey.
- 2013-2019: DES Survey, providing SV, Y1, Y3, Y5/6 data sets.
- ~2026: Final collaboration cosmology analyses.

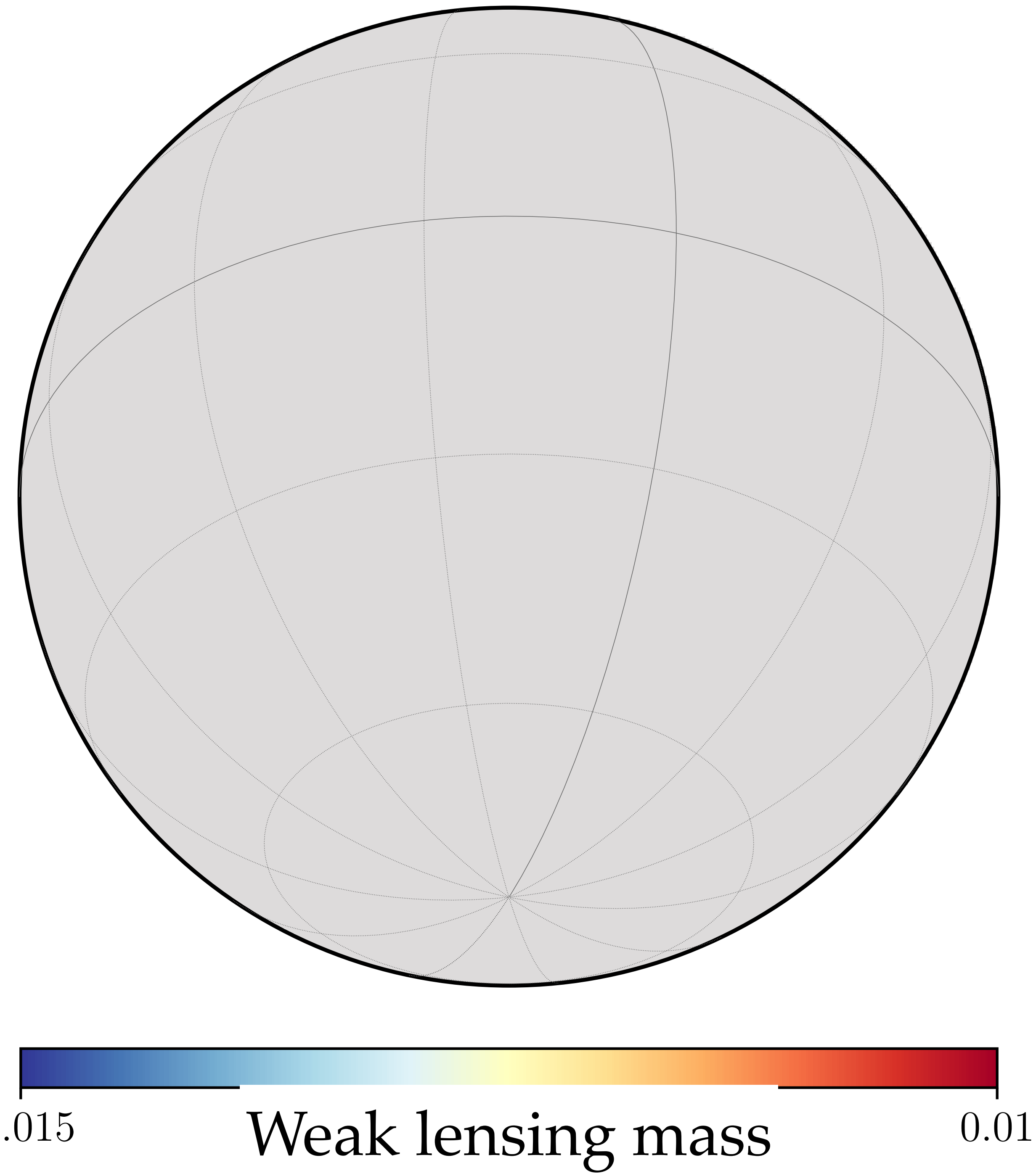
Dark Energy Survey

- DECam (520 Mpix) on 4m Blanco Telescope, Cerro Tololo, Chile
- 1/8 of sky (5000 deg^2)
- 6 year mission, 525 nights, completed 2019. Y3 and Y6 are full area. Final (Y6) analyses out starting Jan 2026
- *grizY* filters (photometric redshifts)
- 300-450 million galaxies ($0 < z < 2$)
  Y3: 100 million with WL shapes
  Y6: 140 million with WL shapes
- Y5 SNe: 1635 Type Ia



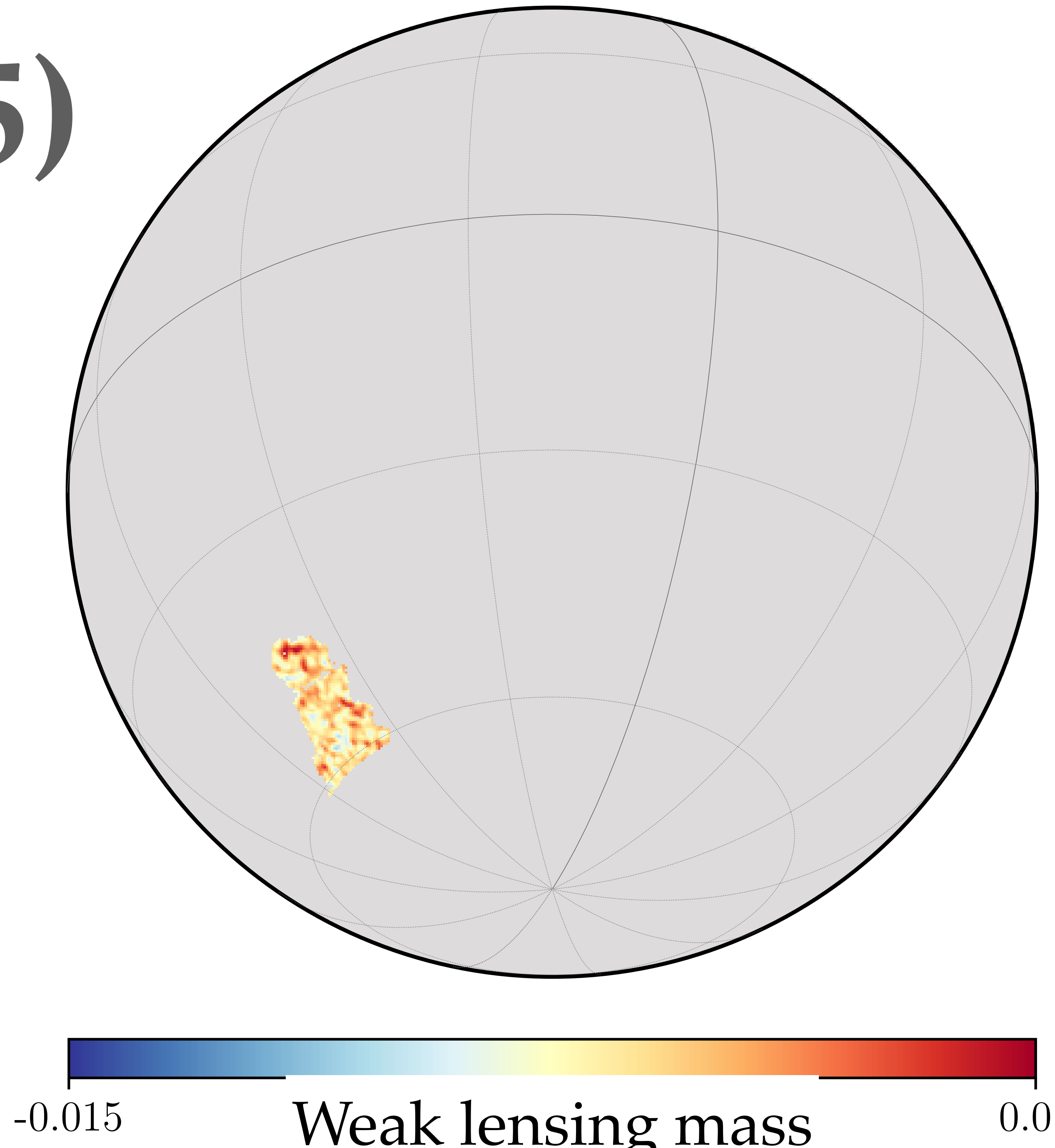
Support for DES provided by

- U.S. Department of Energy & U.S. National Science Foundation
- Ministry of Science and Education of Spain
- Science and Technology Facilities Council of the United Kingdom & Higher Education Funding Council for England
- National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign
- Kavli Institute of Cosmological Physics at the University of Chicago
- Center for Cosmology and Astro-Particle Physics at the Ohio State University
- Mitchell Institute for Fundamental Physics and Astronomy at Texas A&M University
- Financiadora de Estudos e Projetos, Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro, Conselho Nacional de Desenvolvimento Científico e Tecnológico & Ministério da Ciência, Tecnologia e Inovação
- Deutsche Forschungsgemeinschaft
- the Collaborating Institutions in the Dark Energy Survey



Credit: M. Gatti,
C. Chang, and the
DES Collaboration

SV (2015)



150 deg^2

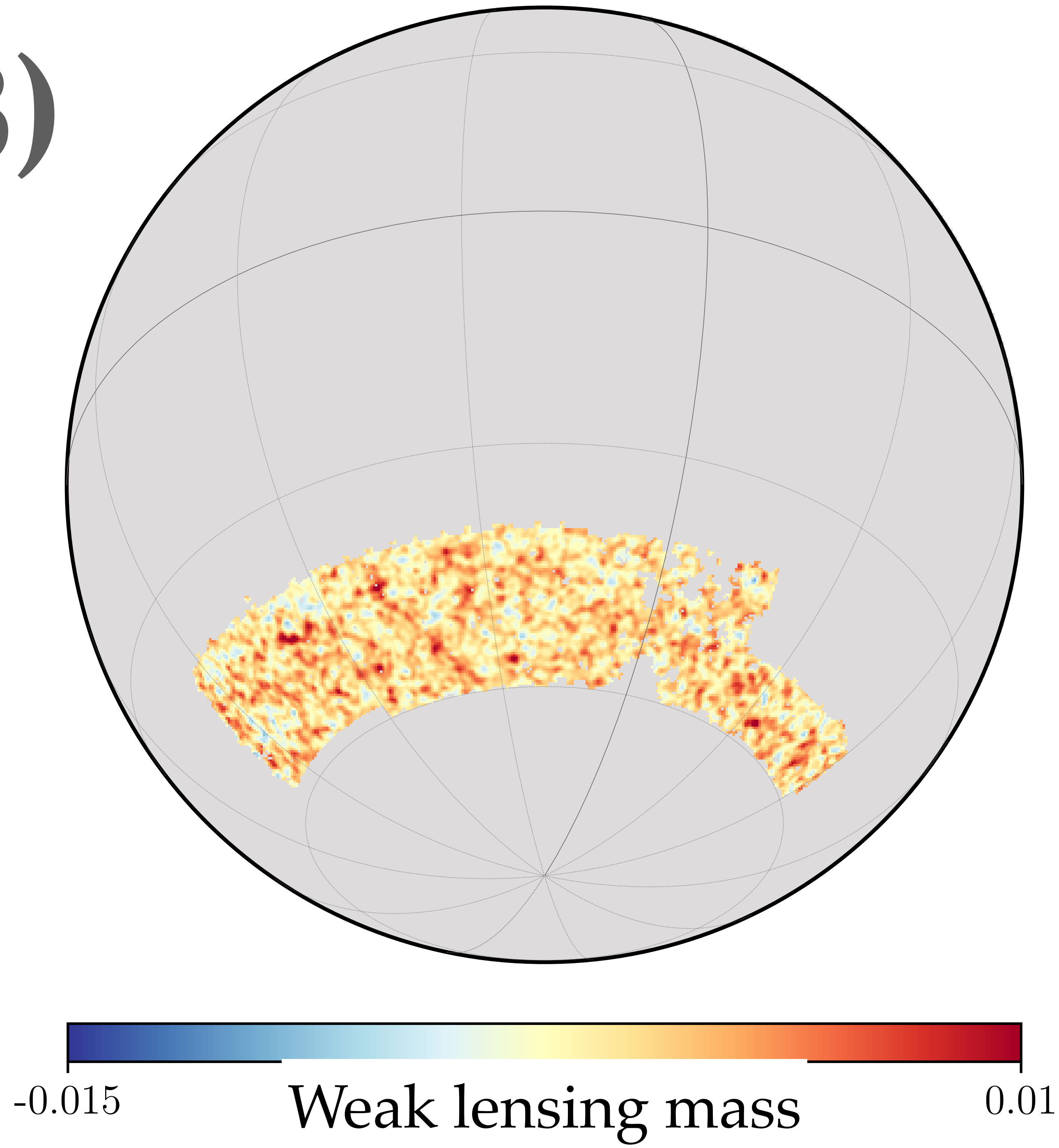
3.4 M galaxies

Vikram, Chang, Jain et al. (201

Chang, Vikram, Jain et al. (201

DES Collaboration

Y1 (2018)

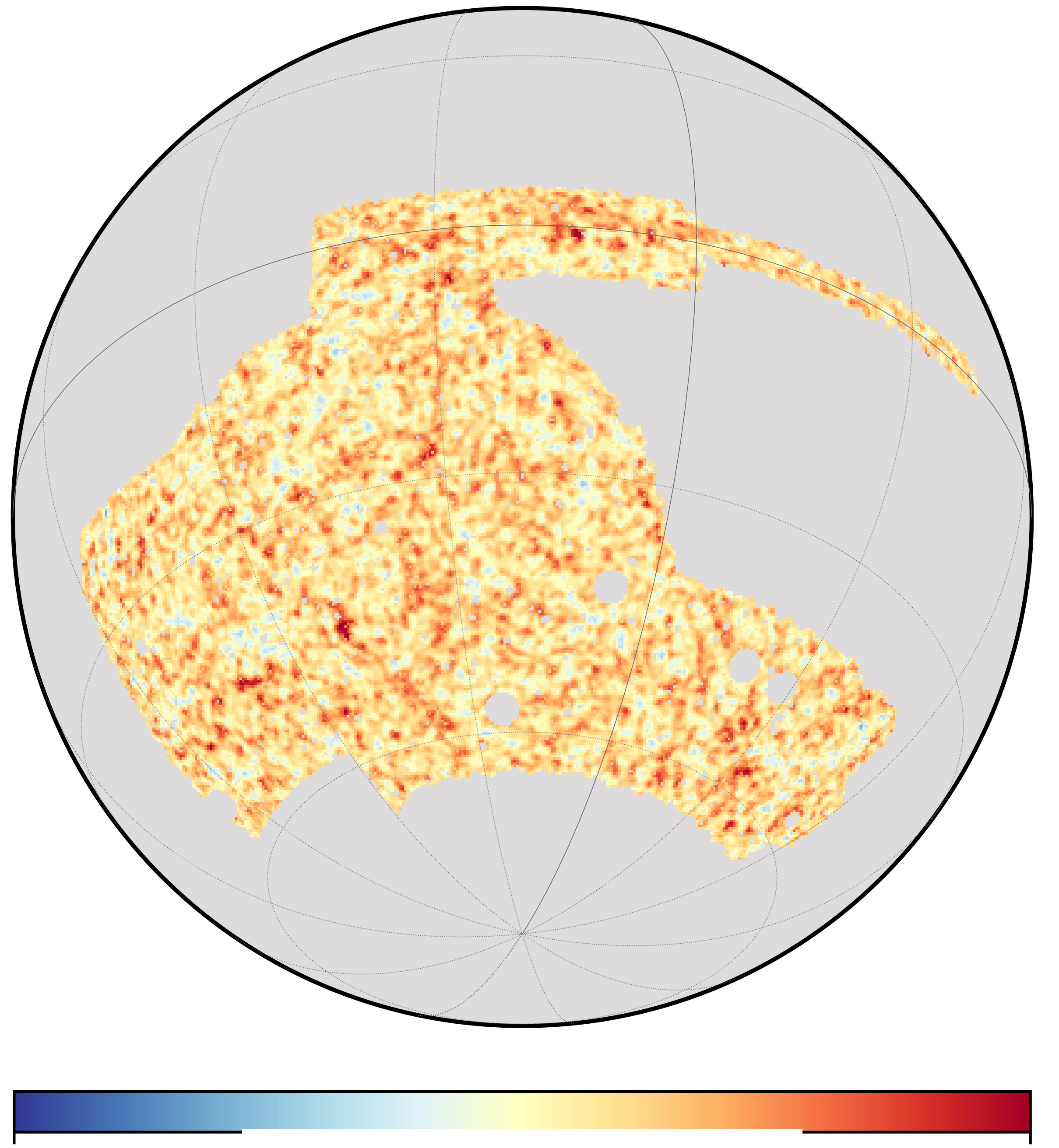


1,300 deg²

35 M galaxies

Chang et al. (2018)
DES Collaboration

Y3 (2021)

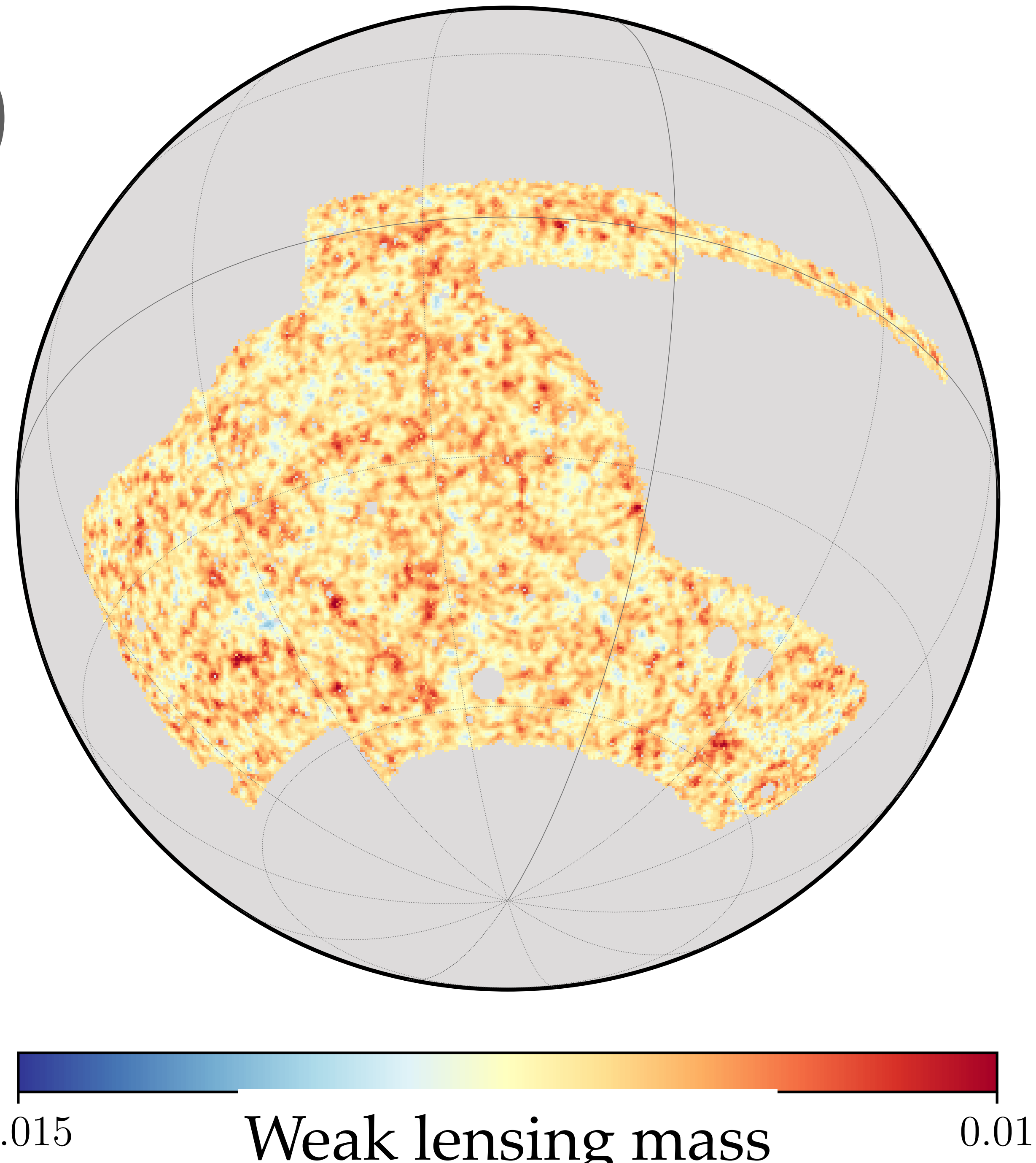


4,200 deg²

100 M galaxies

Jeffrey, Gatti, Chang et al. (202
DES Collaboration

Y6 (2026)



4,400 deg^2
140 M galaxies

DES Collaboration

Results and Webinar

THE DARK ENERGY SURVEY

THE DES PROJECT ▾ RESULTS & PAPERS ▾ DATA ACCESS ▾ NEWS & MEDIA ▾ EDUCATION ▾

INICIO (OVERVIEW IN SPANISH) ▾ CONTACT US

DES Y6 Cosmology Papers

Webinar from Jan 22, 2026: DES Y6 3x2pt results webinar – January 22, 2026

Our Year 6 cosmology analysis of galaxy clustering and gravitational lensing is a massive effort from more than one hundred scientists. There will be more than 20 interconnected papers in all, with the main cosmology analysis, and an 'extended models' analysis, at the bottom of the page. We provide links to papers that are public.

Key paper: 3×2 cosmology result arXiv: arXiv:2601.14559

Dark Energy Survey Year 6 Results: Photometric Dataset for Cosmology

Authors: K. Bechtol (kbechtol@wisc.edu), I. Sevilla-Noarbe (ignacio.sevilla@ciemat.es), A. Drlica-Wagner (kadrlica@fnal.gov) et al.

Link to paper: https://arxiv.org/abs/2501.05739

Link to Y6 Cosmology data products: https://des.ncsa.illinois.edu/releases/y6a2

DES Year 6 Authors

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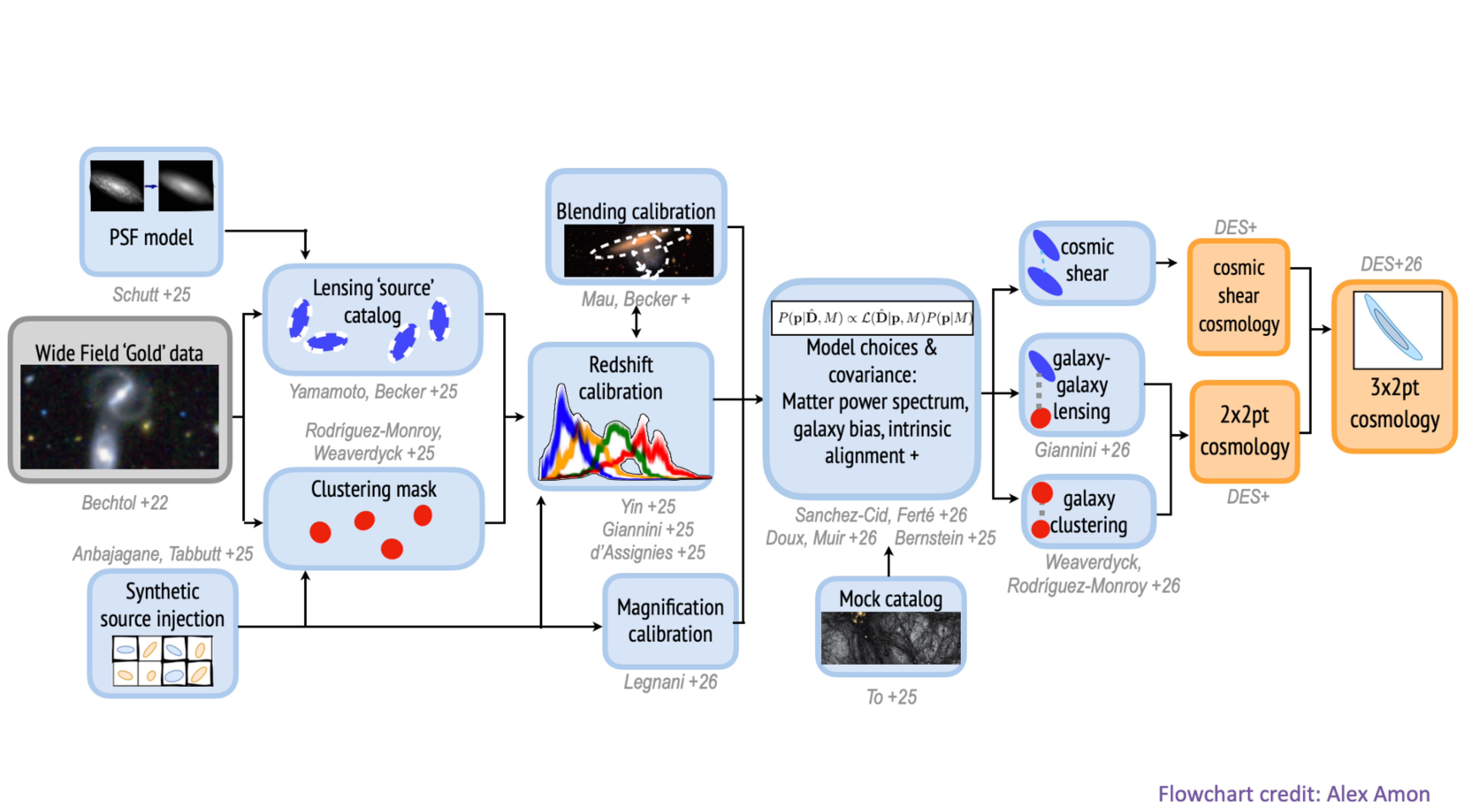
T. M. C. Abbott, **M. Adamow**, **M. Aguena**, **A. Alarcon**, S. S. Allam, **O. Alves**, **A. Amon**, **D. Anbajagane**, **F. Andrade-Oliveira**, **S. Avila**, D. Bacon, **E. J. Baxter**, **J. Beas-Gonzalez**, **K. Bechtol**, **M. R. Becker,** G. M. Bernstein, E. Bertin, **J. Blazek, S. Bocquet**, D. Brooks, **D. Brout**, **H. Camacho**, **G. Camacho-Ciurana**, **R. Camilleri**, **G. Campailla**, **A. Campos**, A. Carnero Rosell, M. Carrasco Kind, J. Carretero, P. Carrilho, F. J. Castander, **R. Cawthon**, **C. Chang, A. Choi,** **J. M. Coloma-Nadal**, **M. Costanzi, M. Crocce**, **W. d'Assignies**, L. N. da Costa, **M. E. da Silva Pereira**, T. M. Davis, **J. De Vicente**, **J. DeRose** H. T. Diehl, S. Dodelson, **C. Doux, A. Drlica-Wagner**, **T. F. Eifler**, **J. Elvin-Poole**, J. Estrada, **S. Everett**, A. E. Evrard, J. Fang, **A. Farahi**, **A. Ferte**, B. Flaugher, P. Fosalba, J. Frieman, J. Garcia-Bellido, **M. Gatti**, E. Gaztanaga, **G. Giannini**, **P. Giles**, K. Glazebrook, **M. Gorsuch**, **D. Gruen**, R. A. Gruendl, **J. Gschwend**, G. Gutierrez, **I. Harrison**, **W. G. Hartley**, E. Henning, K. Herner, S. R. Hinton, D. L. Hollowood, K. Honscheid, **E. M. Huff**, D. Huterer, B. Jain, D. J. James, M. Jarvis, **N. Jeffrey**, T. Jeltema, **T. Kacprzak**, S. Kent, **A. Kovacs**, **E. Krause**, R. Kron, K. Kuehn, O. Lahav, **S. Lee**, **E. Legnani**, C. Lidman, H. Lin, **N. MacCrann**, M. Manera, T. Manning, **R. Marco**, J. L. Marshall, **S. Mau**, **J. McCullough**, **J. Mena-Fernandez**, F. Menanteau, R. Miquel, J. J. Mohr, **J. Muir**, **J. Myles**, R. C. Nichol, **B. Nord**, **J. H. O'Donnell**, **R. L. C. Ogando**, **A. Palmese**, M. Paterno, J. Peoples, W. J. Percival, D. Petravick, A. Pieres, **A. A. Plazas Malagon**, **A. Porredon**, A. Pourtsidou, **J. Prat**, **C. Preston**, **M. Raveri**, **W. Riquelme**, **M. Rodriguez-Monroy**, **P. Rogozenski**, A. K. Romer, A. Roodman, R. Rosenfeld, **A. J. Ross**, **E. Rozo**, **E. S. Rykoff**, **S. Samuroff**, **C. Sanchez**, **E. Sanchez**, **D. Sanchez Cid**, **T. Schutt**, **I. Sevilla-Noarbe**, **E. Sheldon**, **N. Sherman**, **T. Shin**, M. Smith, **M. Soares-Santos**, **E. Suchyta**, M. E. C. Swanson, **M. Tabbutt**, G. Tarle, D. Thomas, **C. To**, **A. Tong**, **L. Toribio San Cipriano**, **M. A. Troxel**, M. Tsedrik, D. L. Tucker, **V. Vikram**, A. R. Walker, **N. Weaverdyck**, R. H. Wechsler, D. H. Weinberg, J. Weller, **V. Wetzell**, **A. Whyley**, R.D. Wilkinson, **P. Wiseman**, **H.-Y. Wu**, **M. Yamamoto**, B. Yanny, **B. Yin**, **G. Zacharegkas**, **Y. Zhang**, **J. Zuntz**

bold: early career scientists

blue: mid-career scientists (at least partially) trained in DES

The (long) path to cosmology



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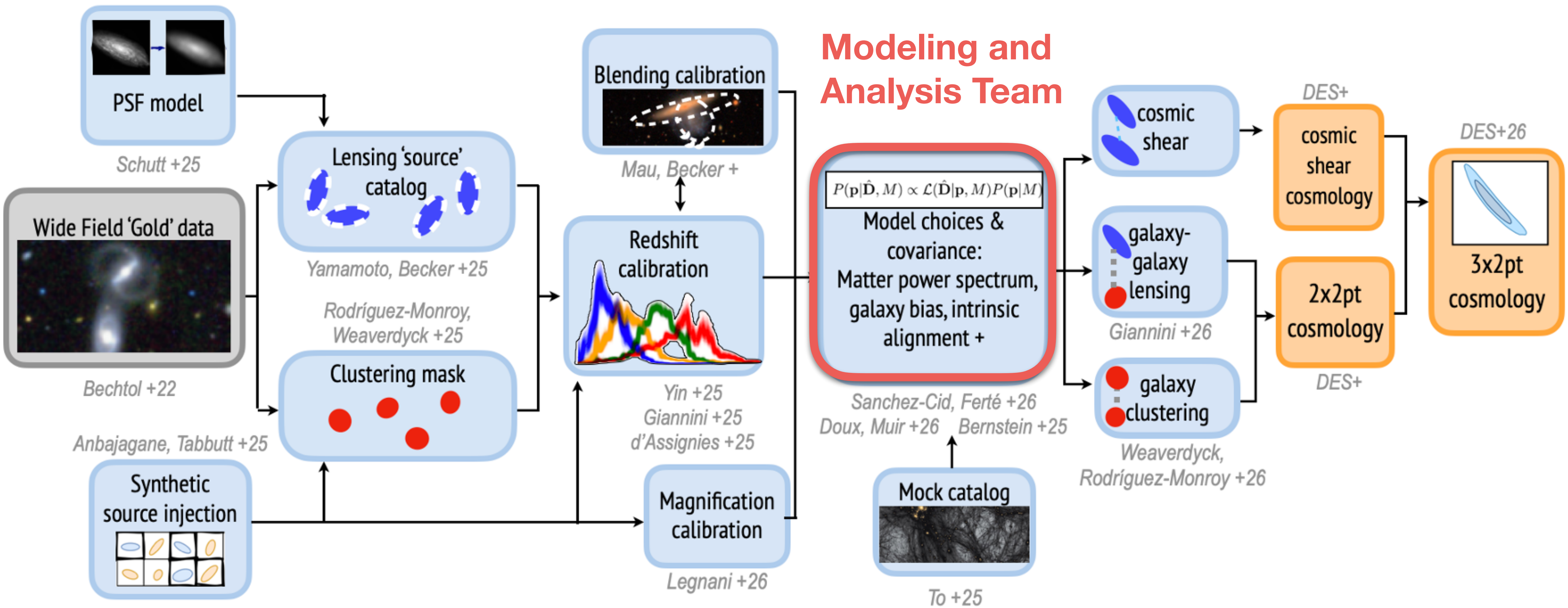
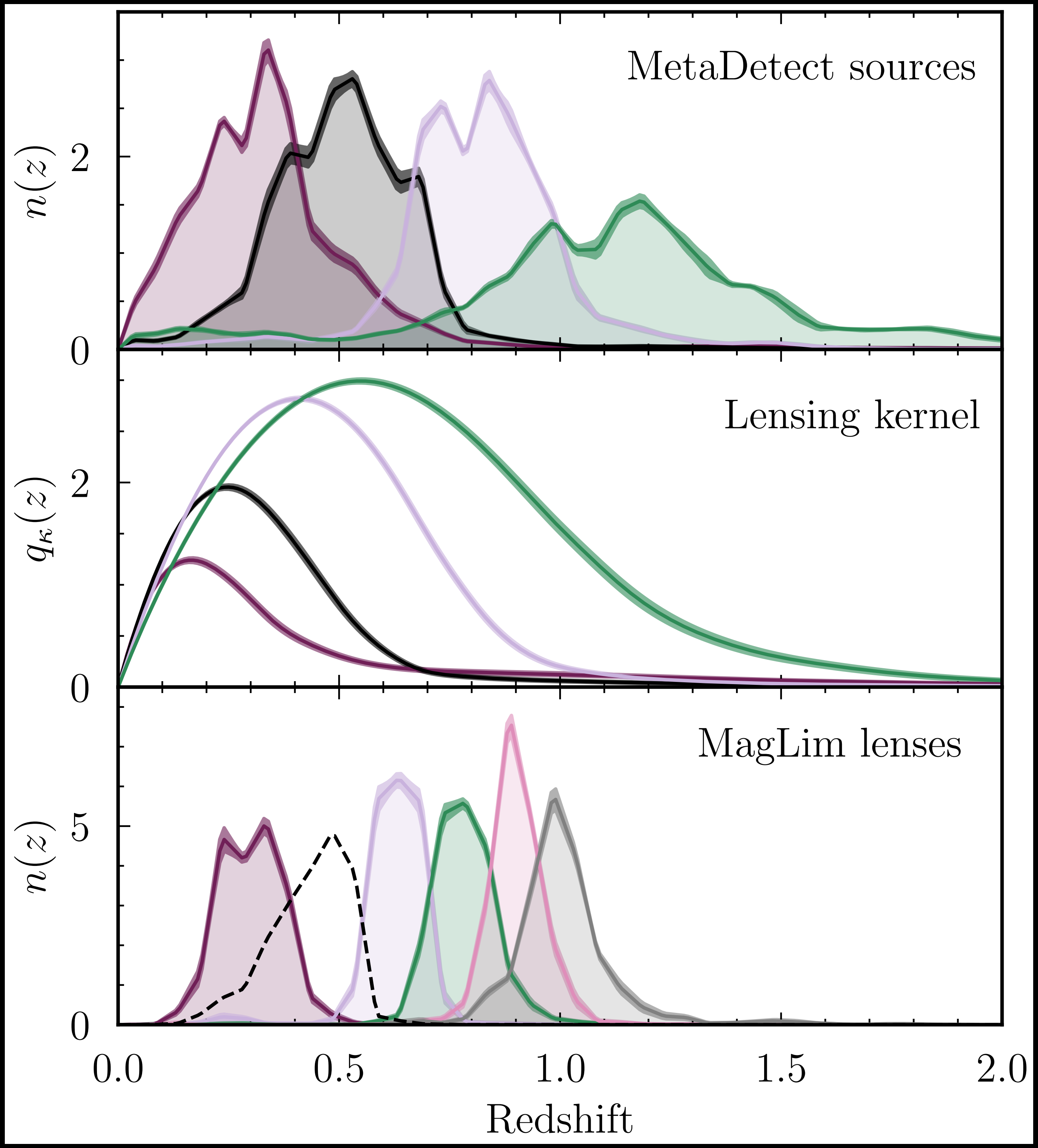
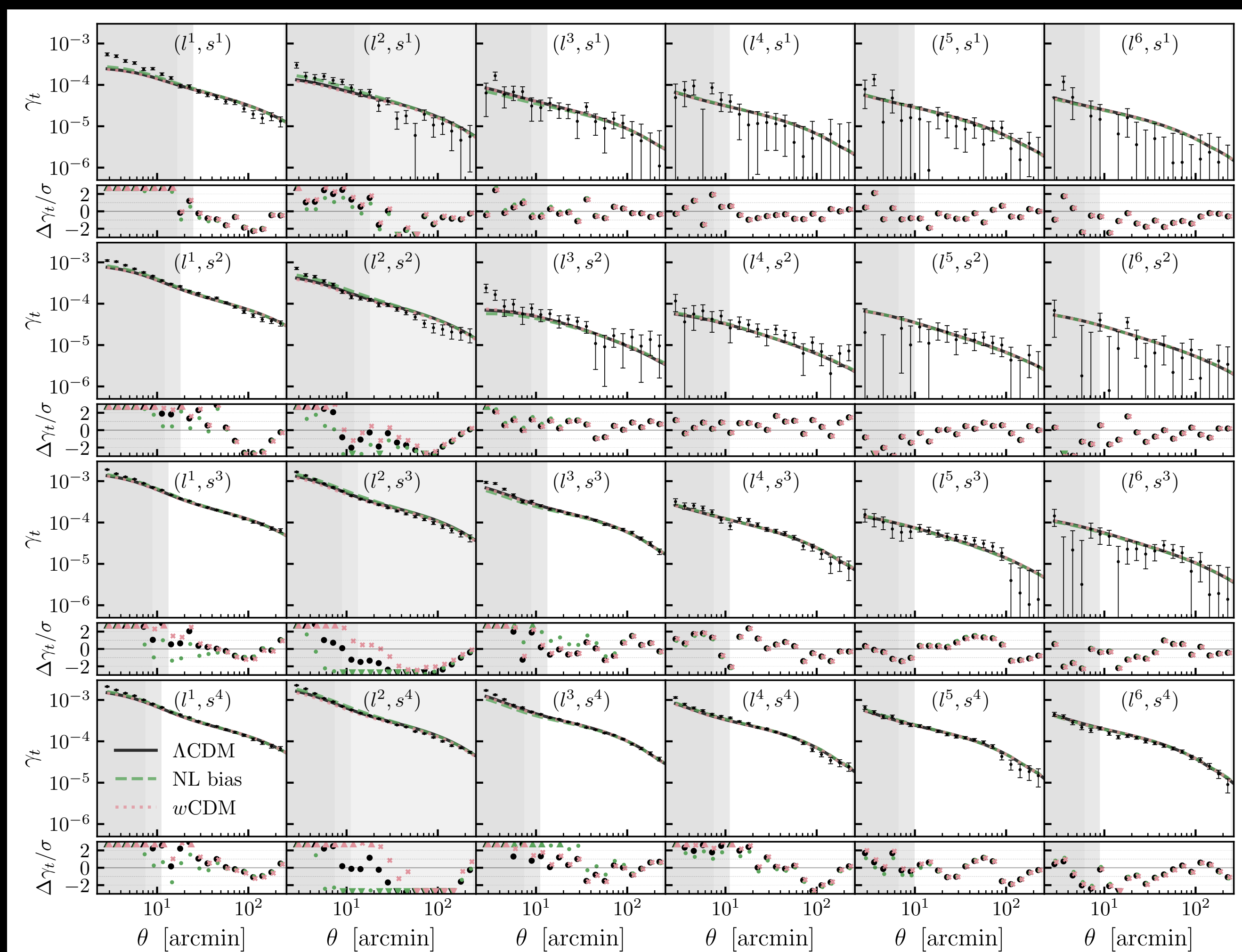


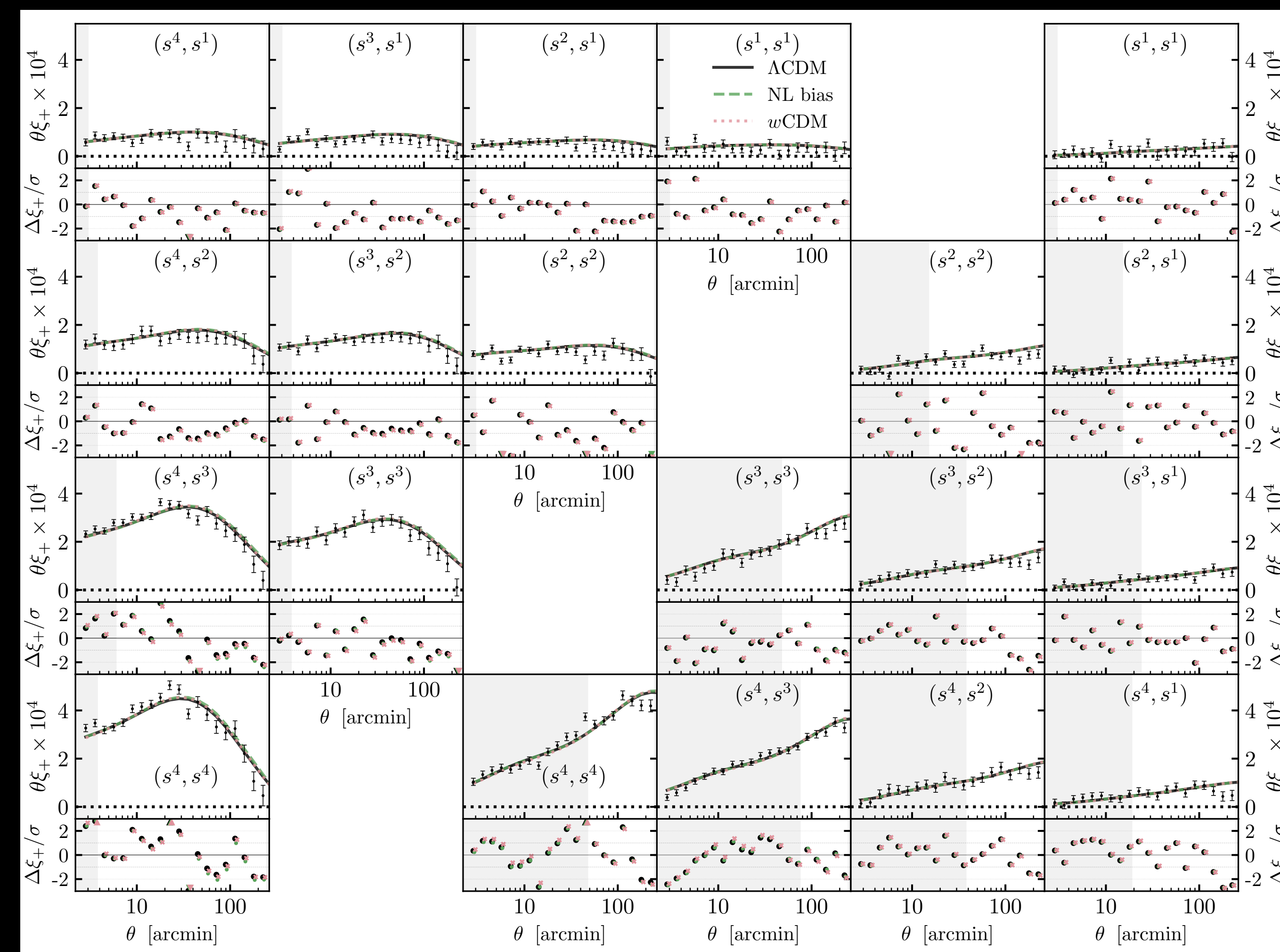
Flowchart credit: Alex Amon

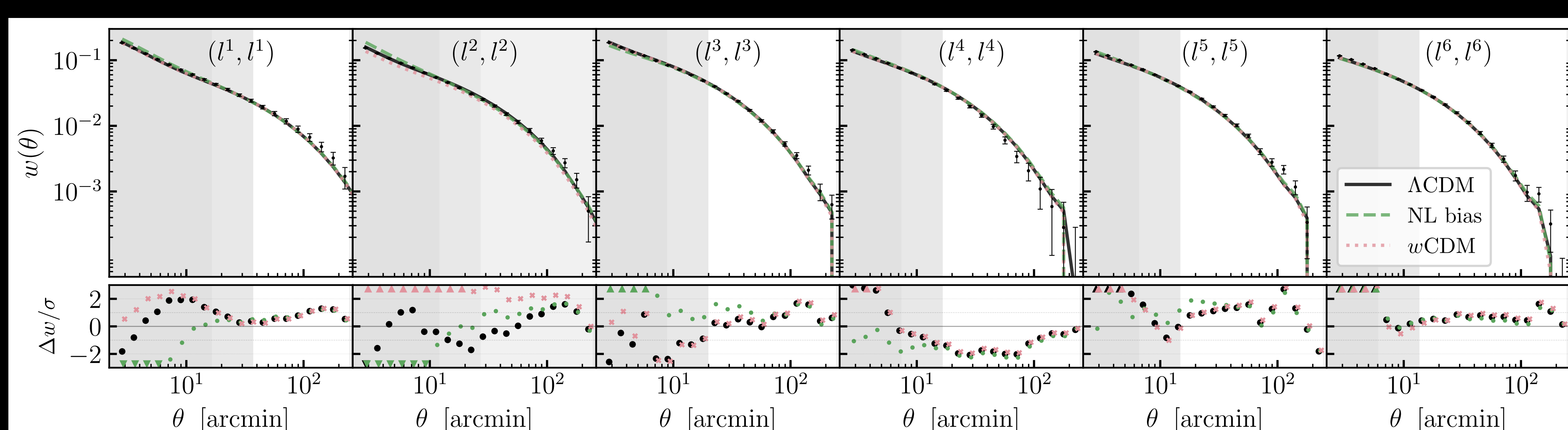
DES Y6 samples



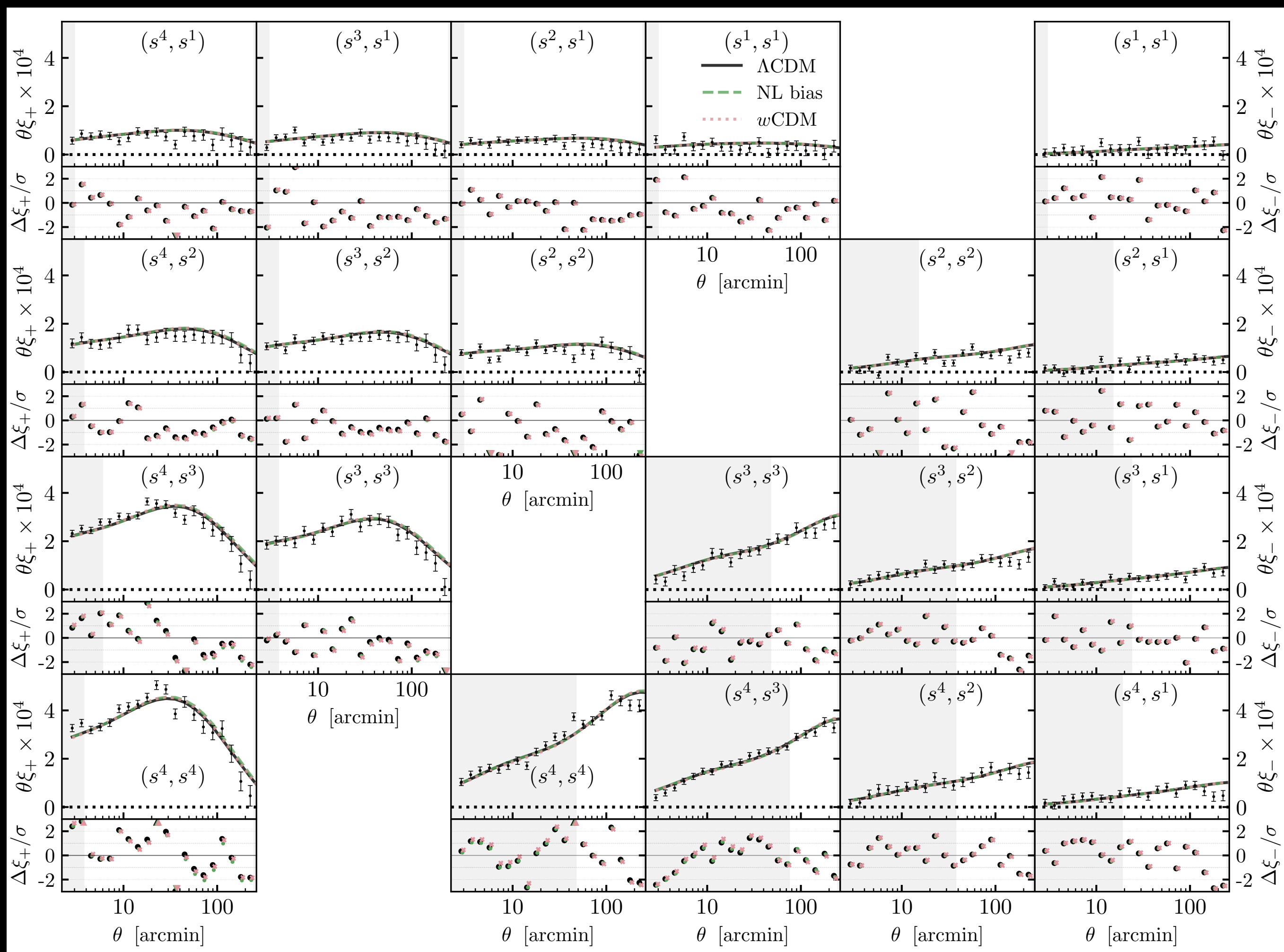
DES Y6 correlation functions

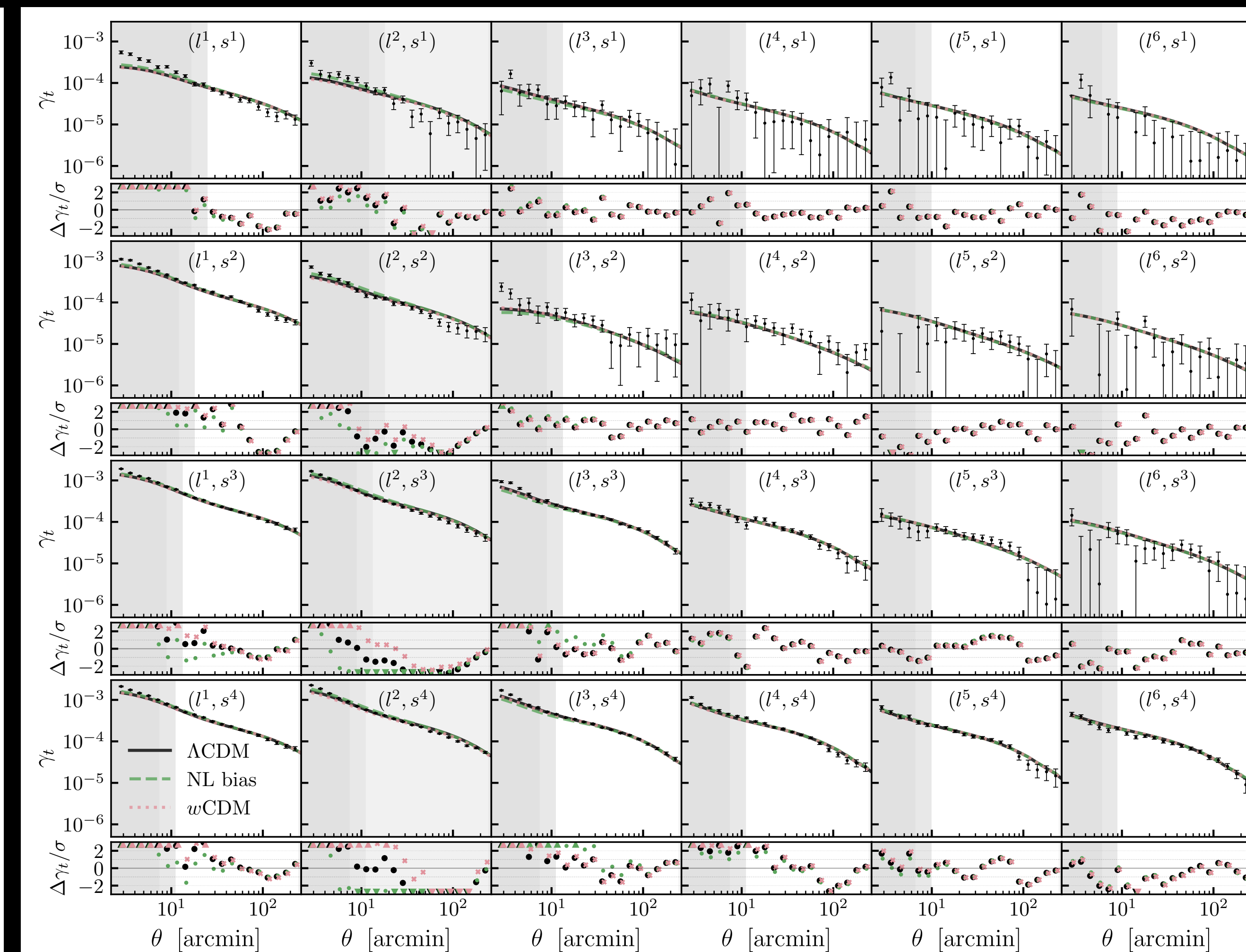


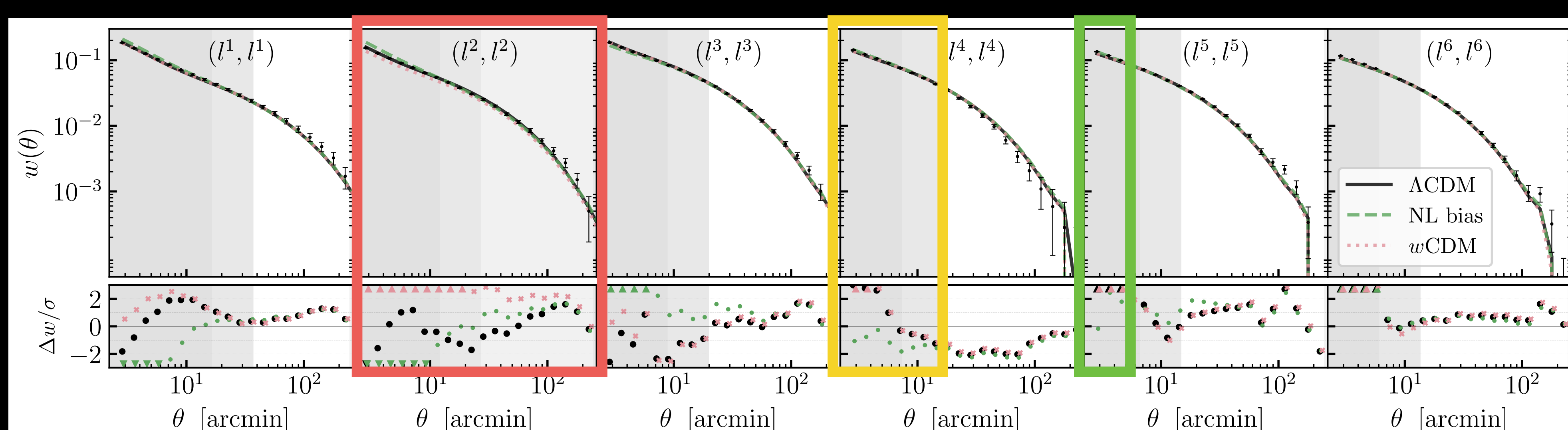




DES Y6 correlation functions







Y6 fiducial model

(7+33 = 40 free parameters)

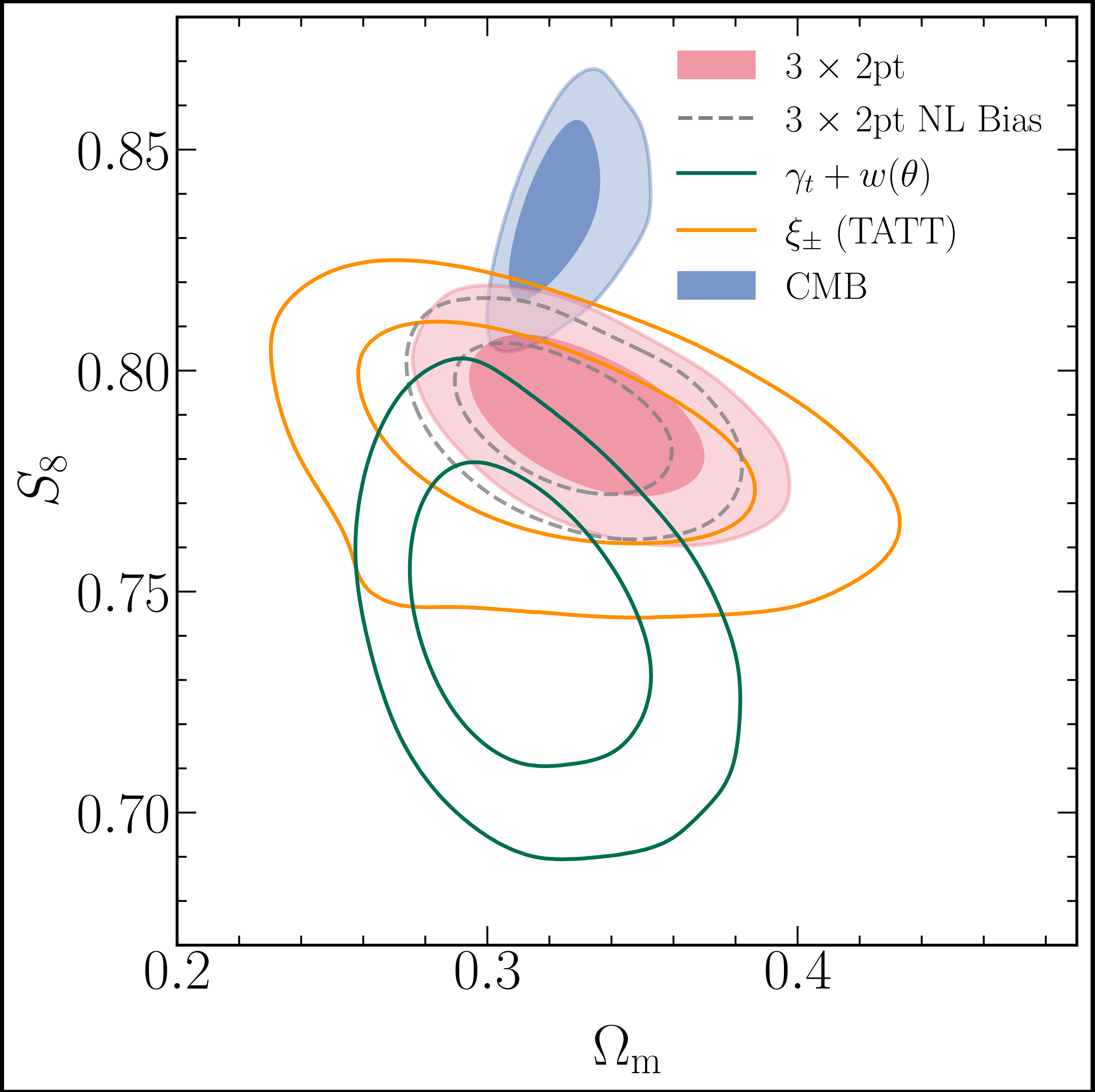
Parameter	Prior
Cosmology	
Ω_m	[0.1, 0.6]
$A_\mathrm{s} \times 10^9$	[0.5, 5]
h	[0.58, 0.8]
Ω_b	[0.03, 0.07]
n_s	[0.93, 1.00]
w	[-2, -1/3]
m_ν [eV]	[0.06, 0.6]
Intrinsic alignment	
A_1	[-1, 3]
A_2	[-3, 3]
η_1	$\mathcal{N}(0.0, 3.0) \in [-5, 5]$
η_2	$\mathcal{N}(0.0, 3.0) \in [-5, 5]$
b_TA	1, fixed
z_0	0.3, fixed
Lens galaxy bias	
$b_1^i (i \in [1, 6])$	[0.8, 3]
$b_2^i (i \in [1, 6])$	[-3, 3]

Lens magnification	
α^1	$\mathcal{N}(1.58, 0.04)$
α^2	$\mathcal{N}(1.38, 0.11)$
α^3	$\mathcal{N}(2.04, 0.08)$
α^4	$\mathcal{N}(2.21, 0.08)$
α^5	$\mathcal{N}(2.45, 0.14)$
α^6	$\mathcal{N}(2.42, 0.13)$
Lens n(z) modes	
$u_1^{i,\beta}$ $(i \in [1, ..., 6],\ \beta \in [1, 2, 3])$	$\mathcal{N}(0, 1) \in [-3, 3]$
Source n(z) modes	
u_s^β $(\beta \in [1, ..., 7])$	$\mathcal{N}(0,\ 1) \in [-3, 3]$
Shear calibration	
m^1	$\mathcal{N}(-0.0034, 0.0058)$
m^2	$\mathcal{N}(0.0065, 0.0066)$
m^3	$\mathcal{N}(0.0159, 0.0059)$
m^4	$\mathcal{N}(0.0017, 0.0122)$
Baryonic feedback	
$\log_{10} T_\mathrm{AGN}$	7.7 fixed

ΛCDM

Y6 3x2 results

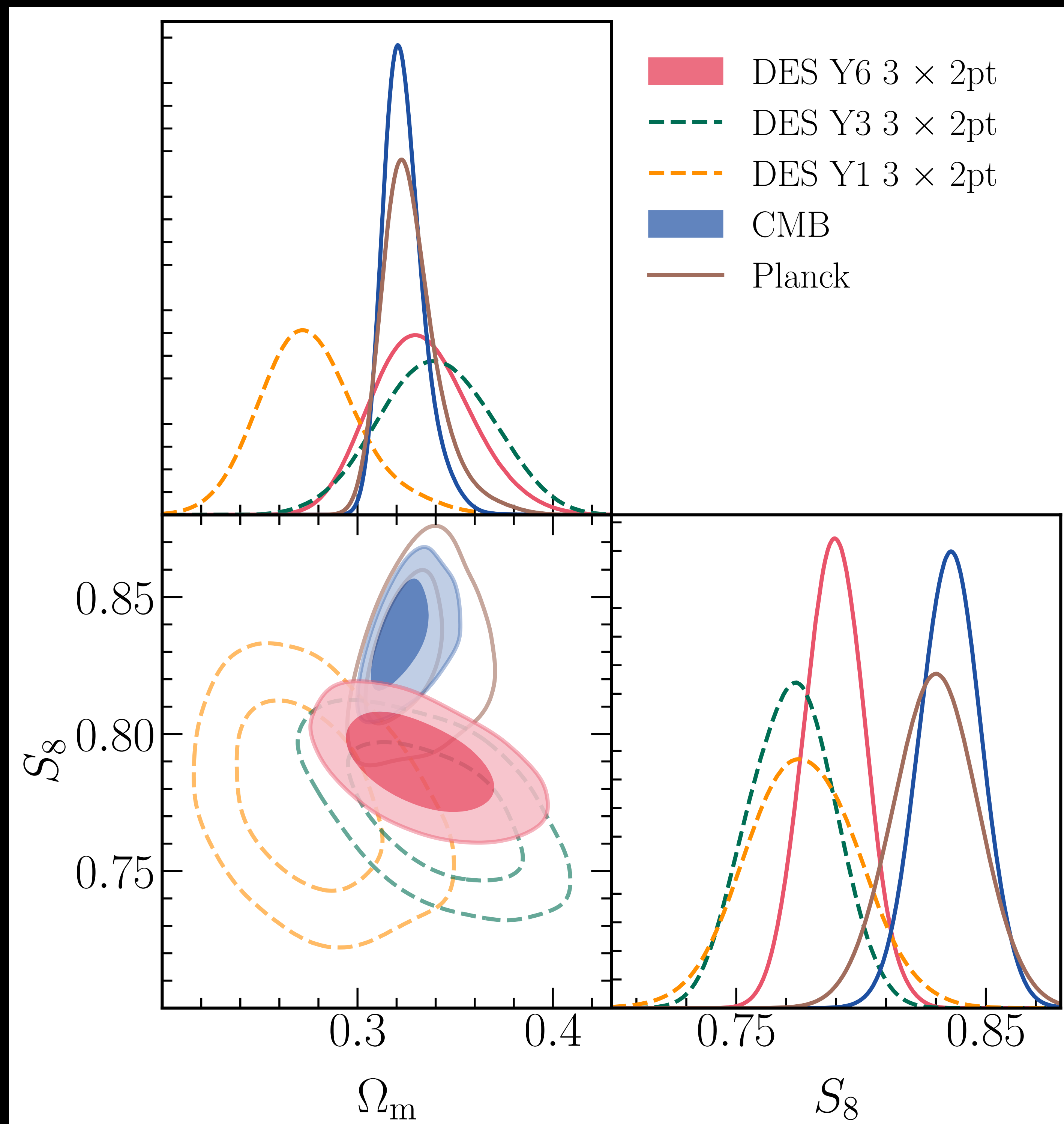
factor of ~2 more constraining power than Y3



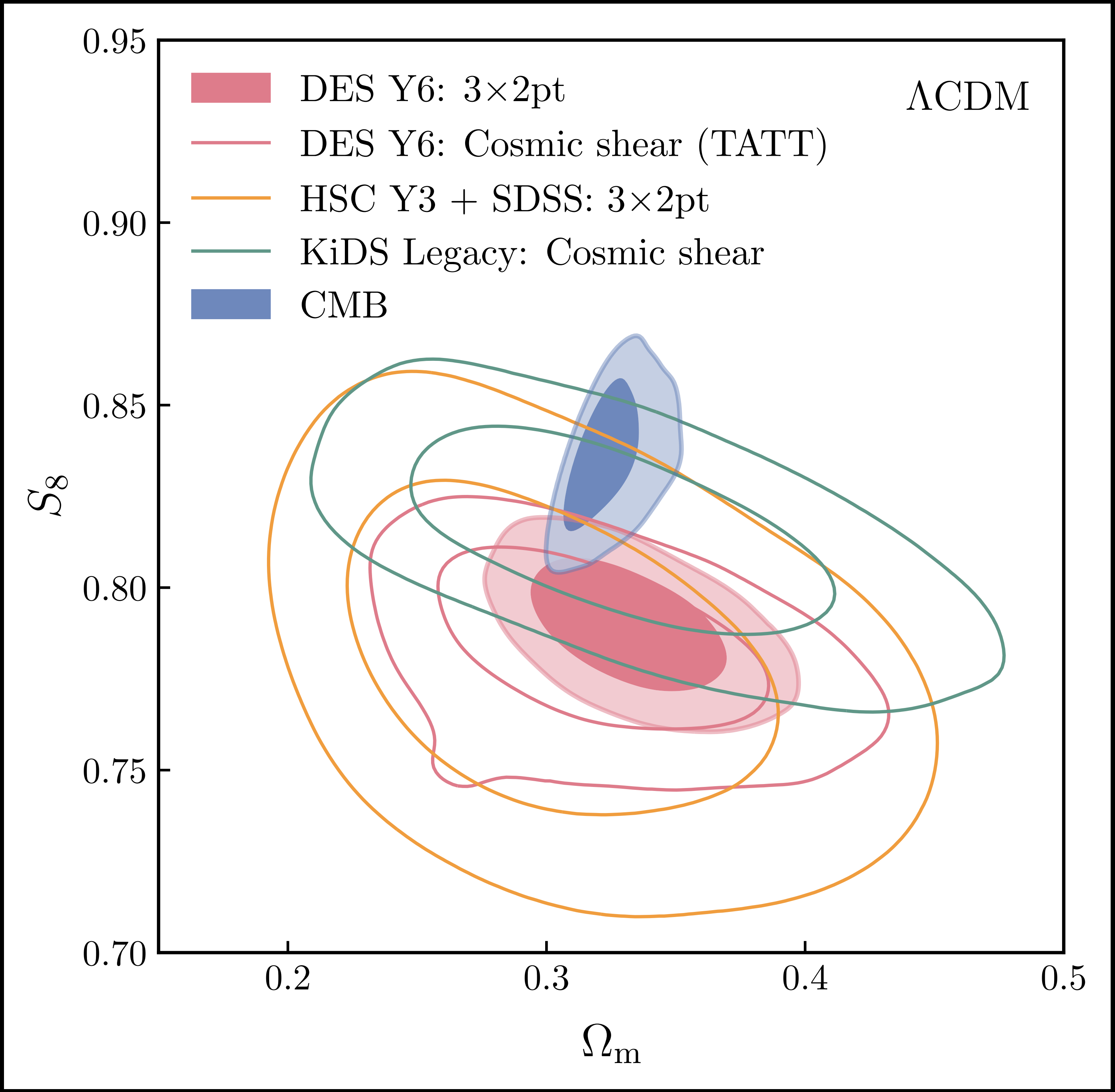
Y6 results vs CMB

1.0**σ** parameter tension with Planck (vs. 1.5**σ** in Y3)

1.8**σ** tension with Planck + ACT + SPT

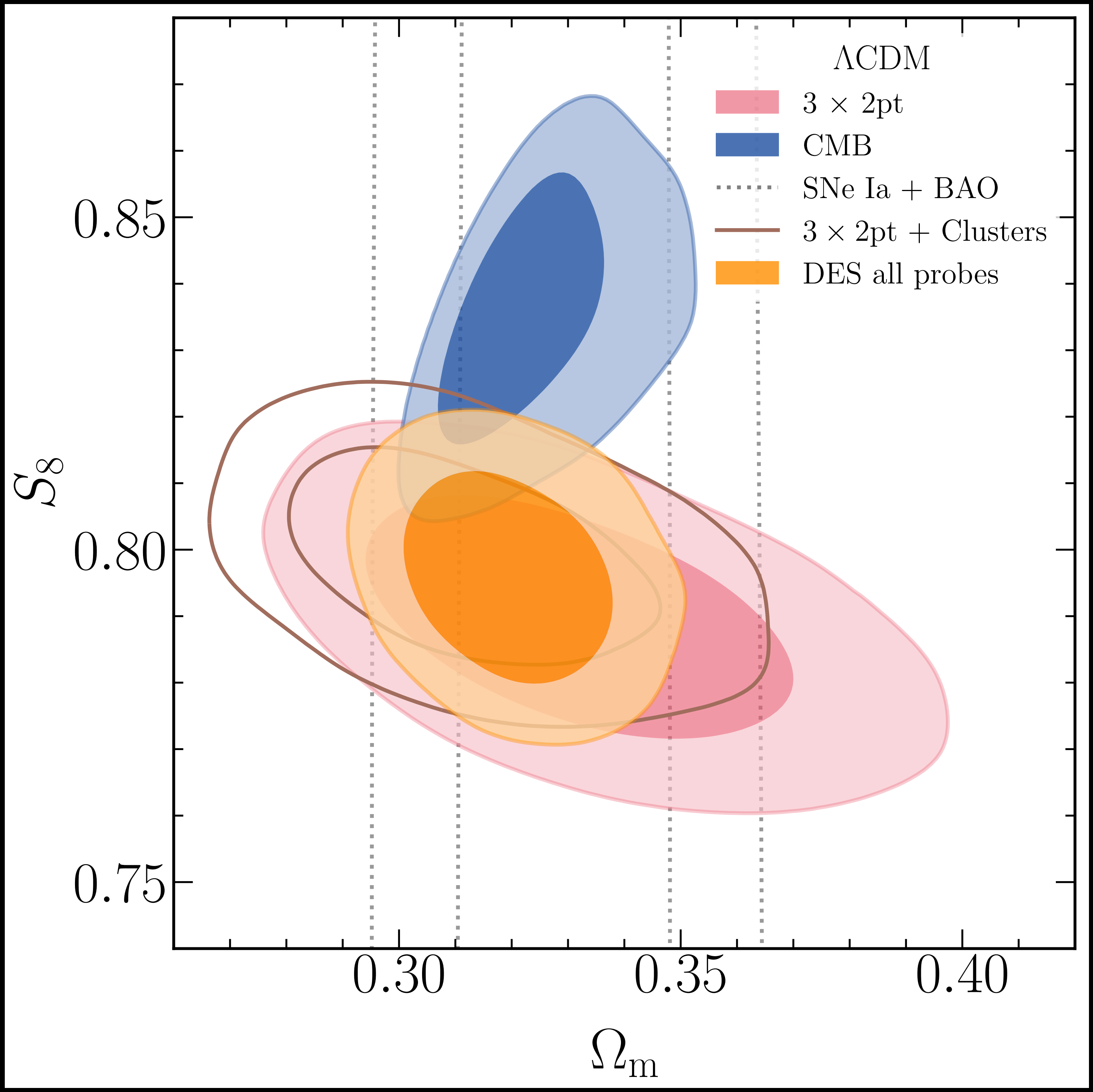


Y6 results vs other surveys



All DES Probes

2.8σ tension with Planck + ACT + SPT

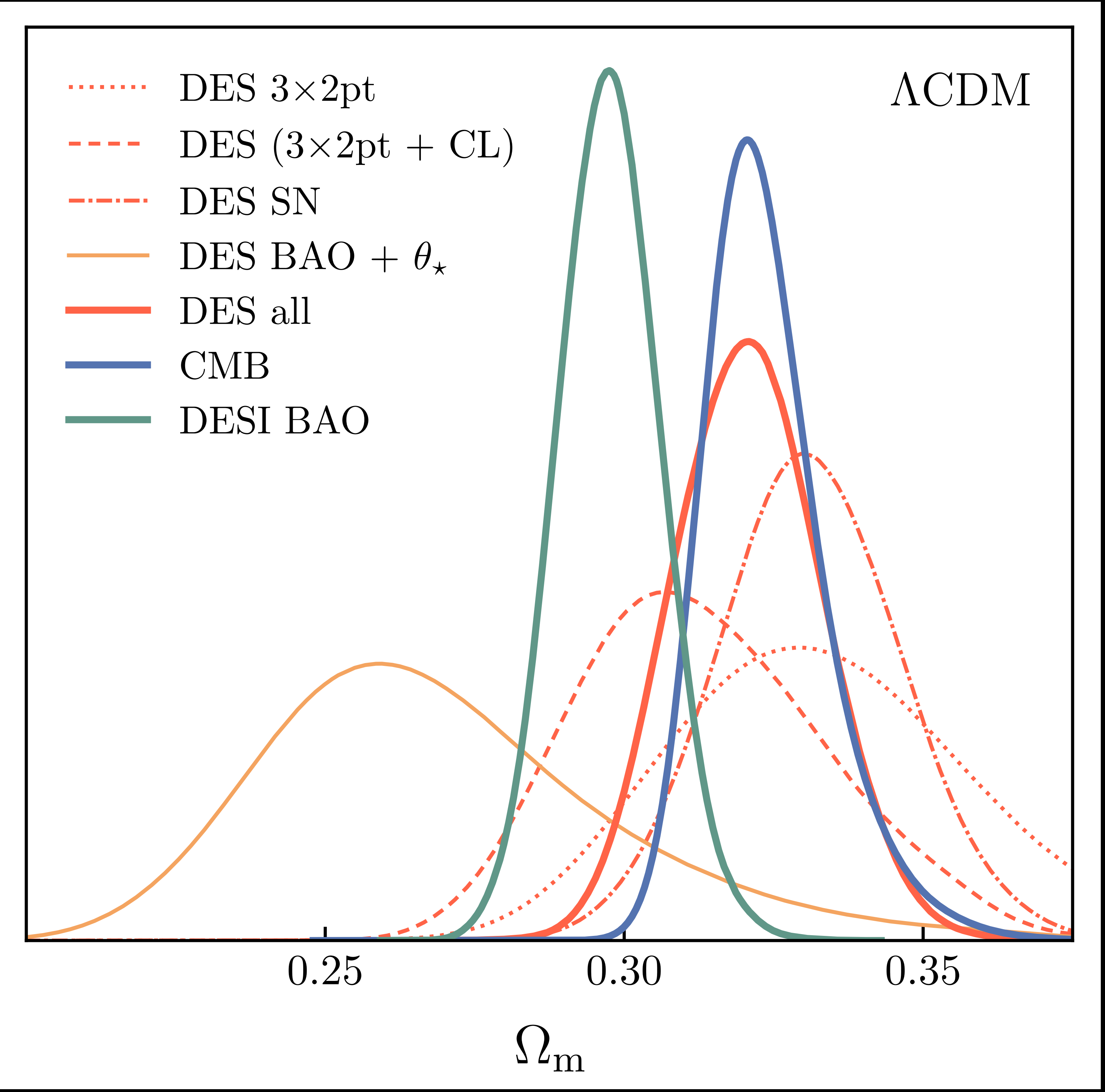


Evolving Dark Energy

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

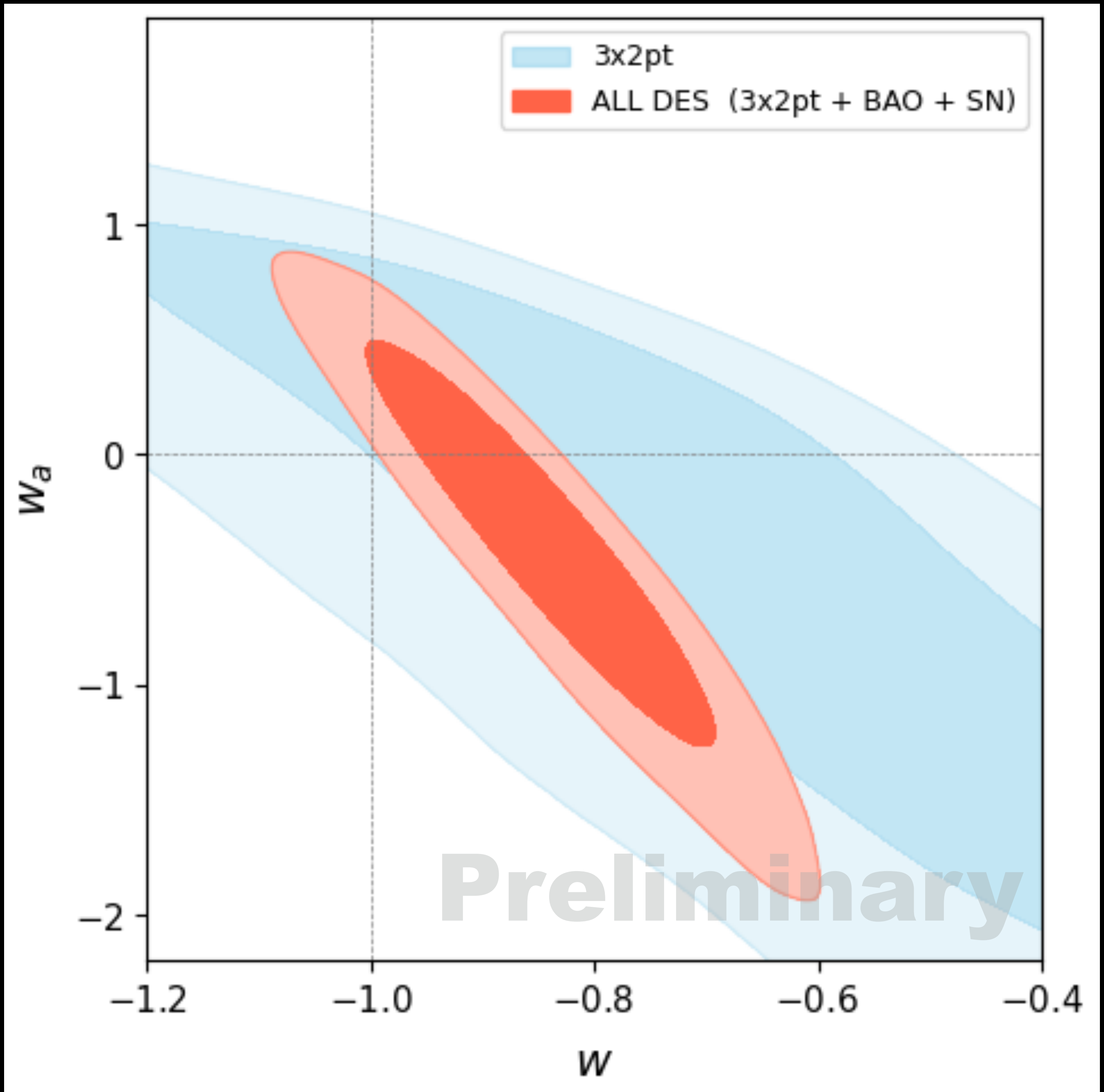
Preliminary, but out soon.
Stay tuned for “extensions” analysis.

Ω_m tension?



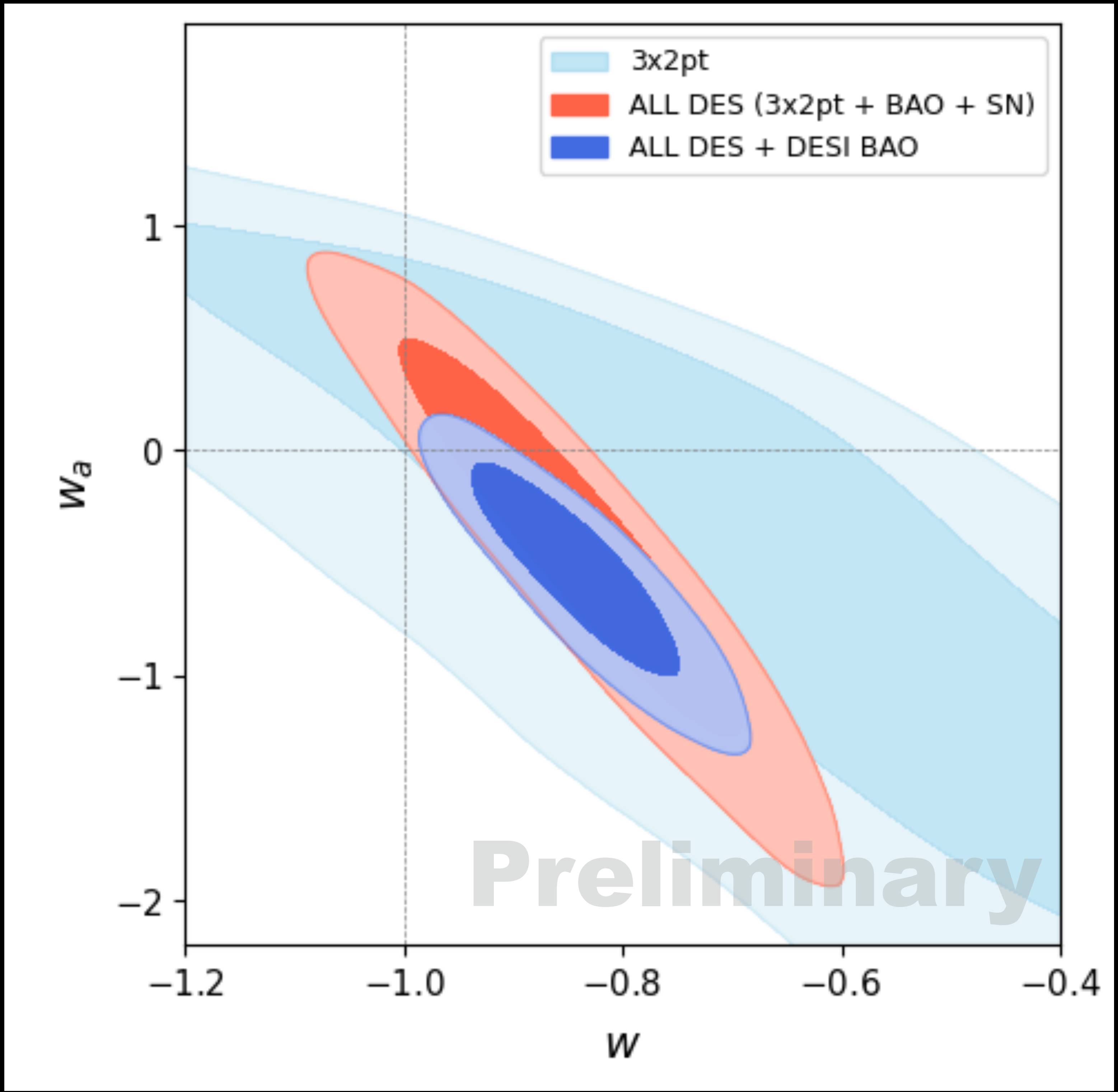
DES only

~2.2**σ** (first single-survey constraint)



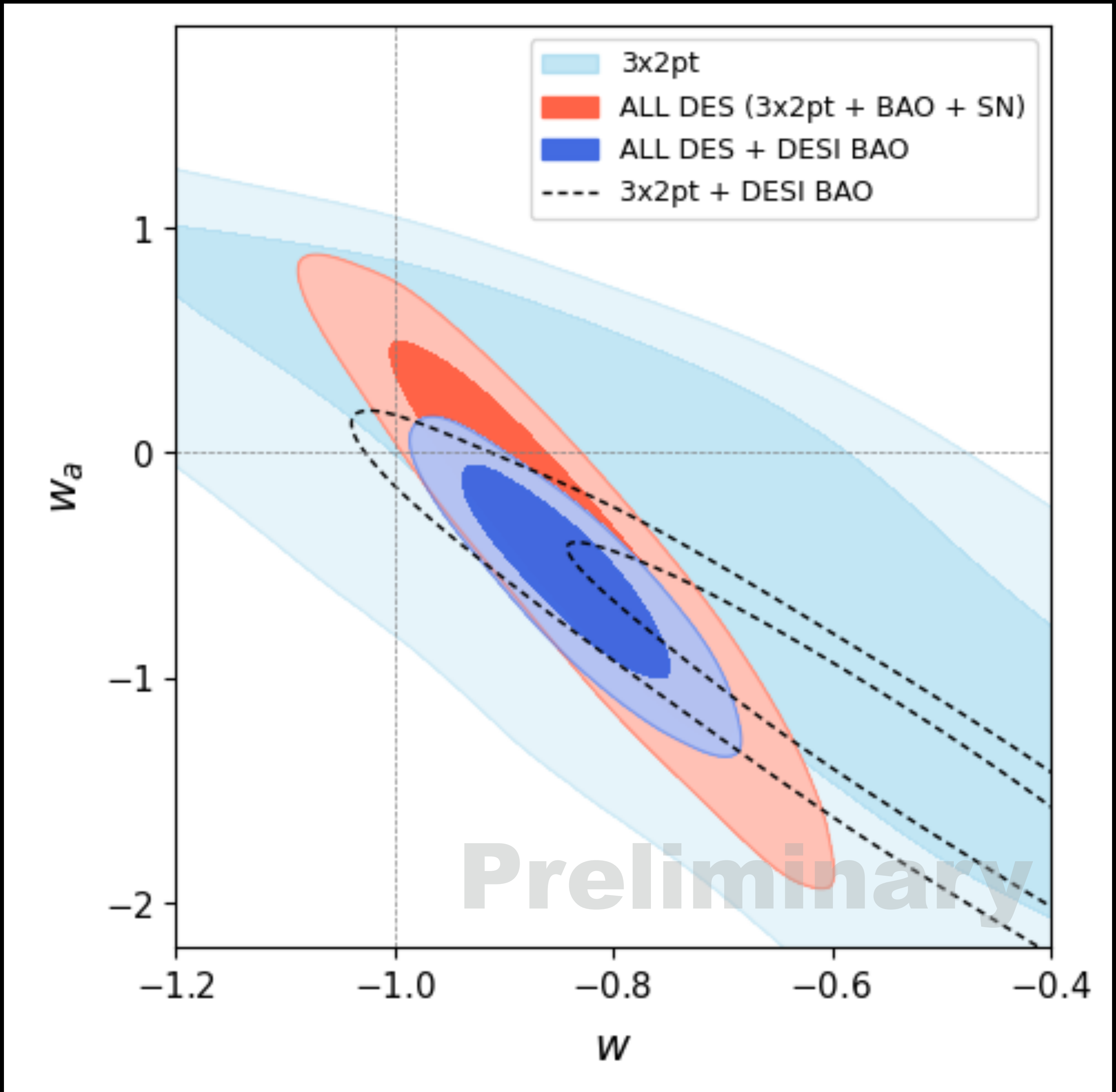
DES + DESI BAO

~2.3**σ** (No CMB! 3x2 ~doubles constraining power)



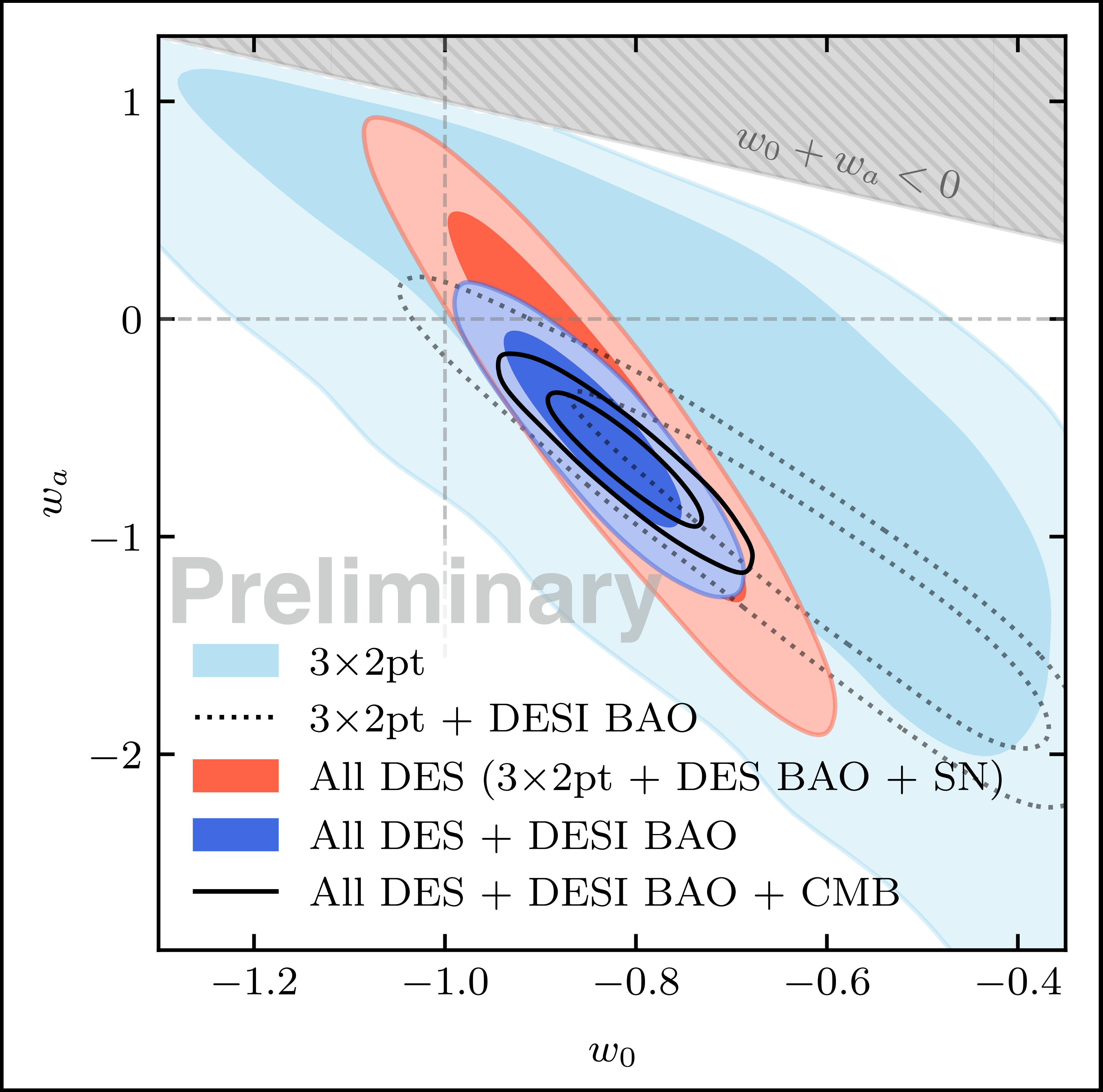
No SNe or CMB

~1.7σ



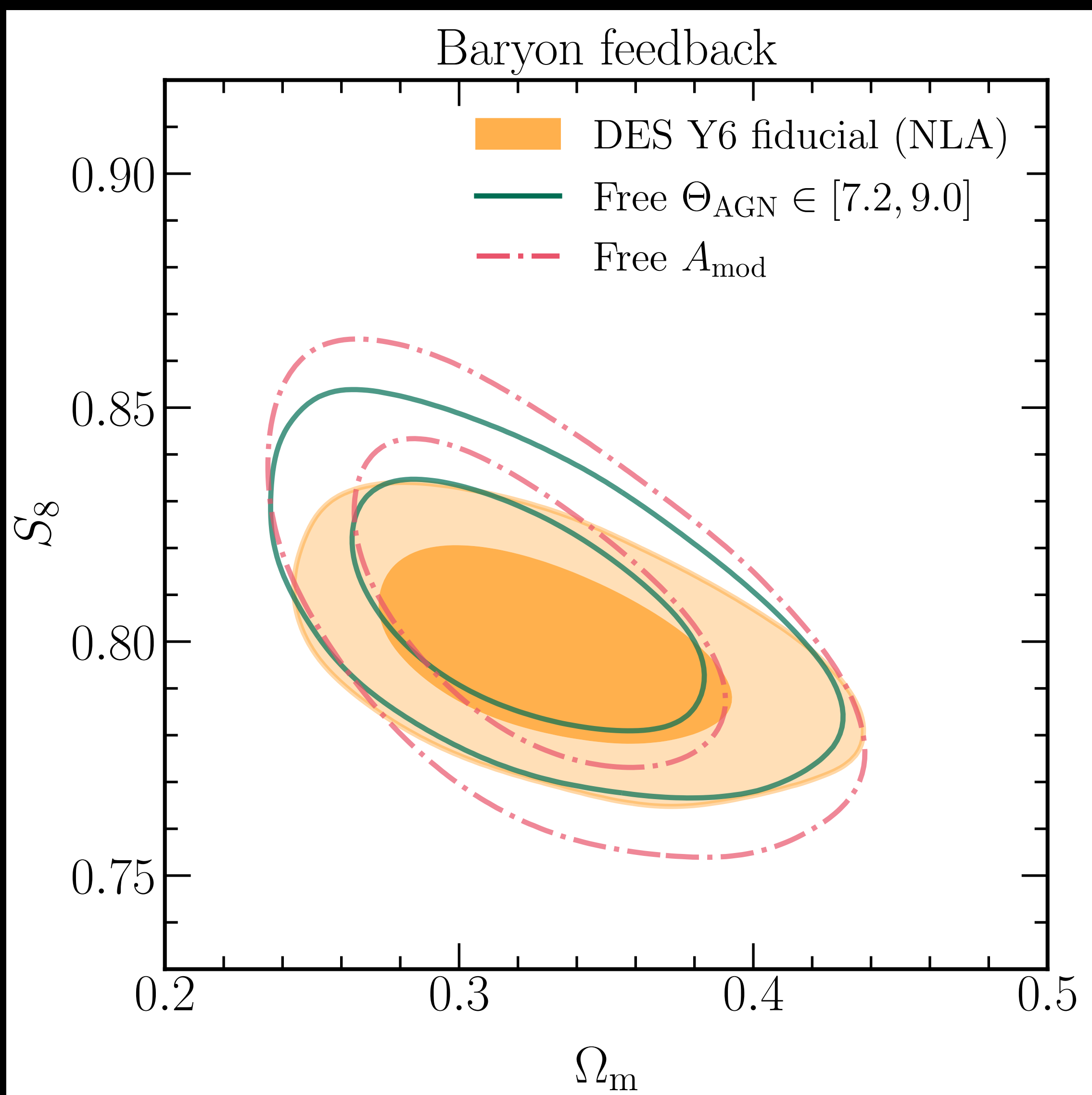
DES + DESI BAO + CMB

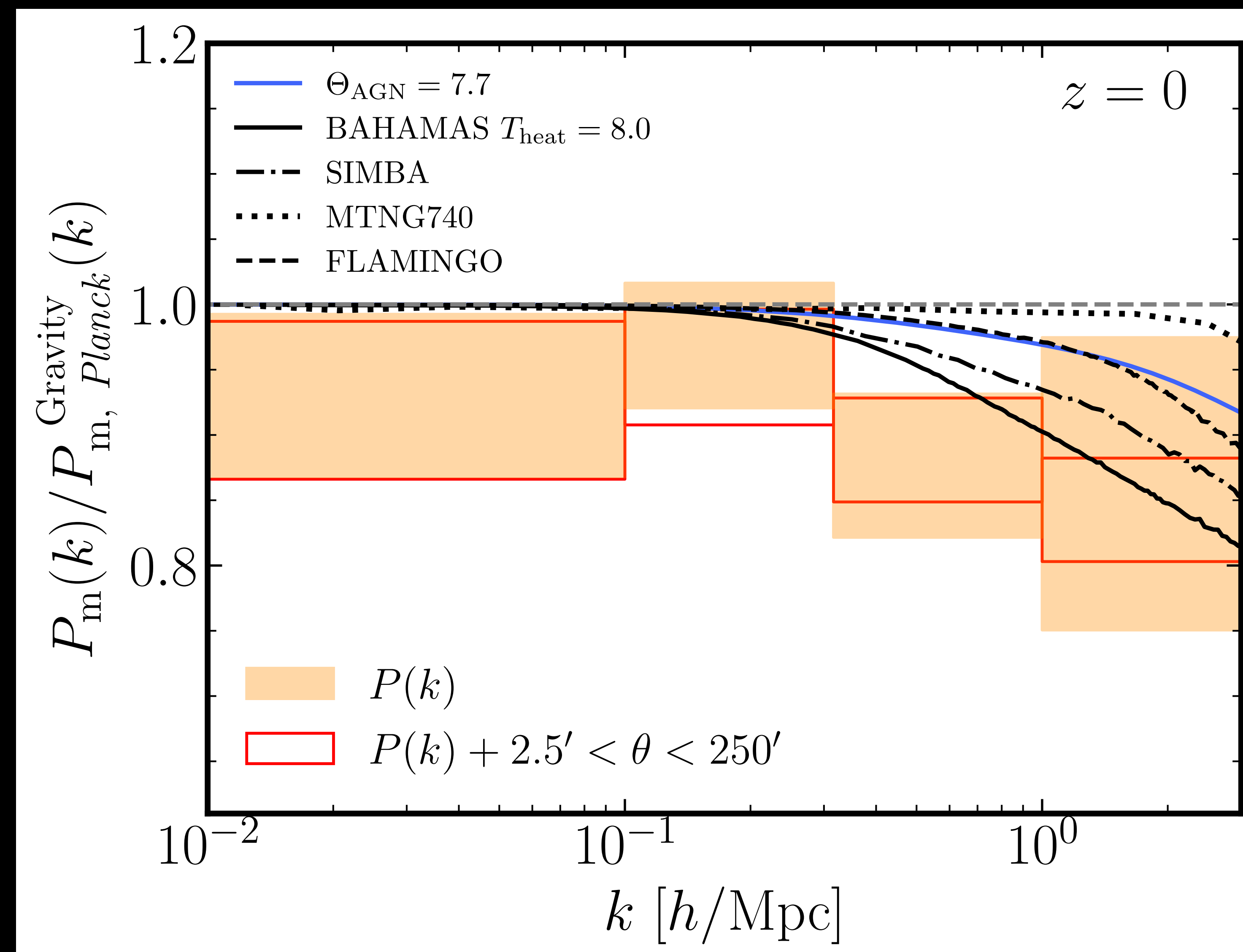
~3.0**σ**



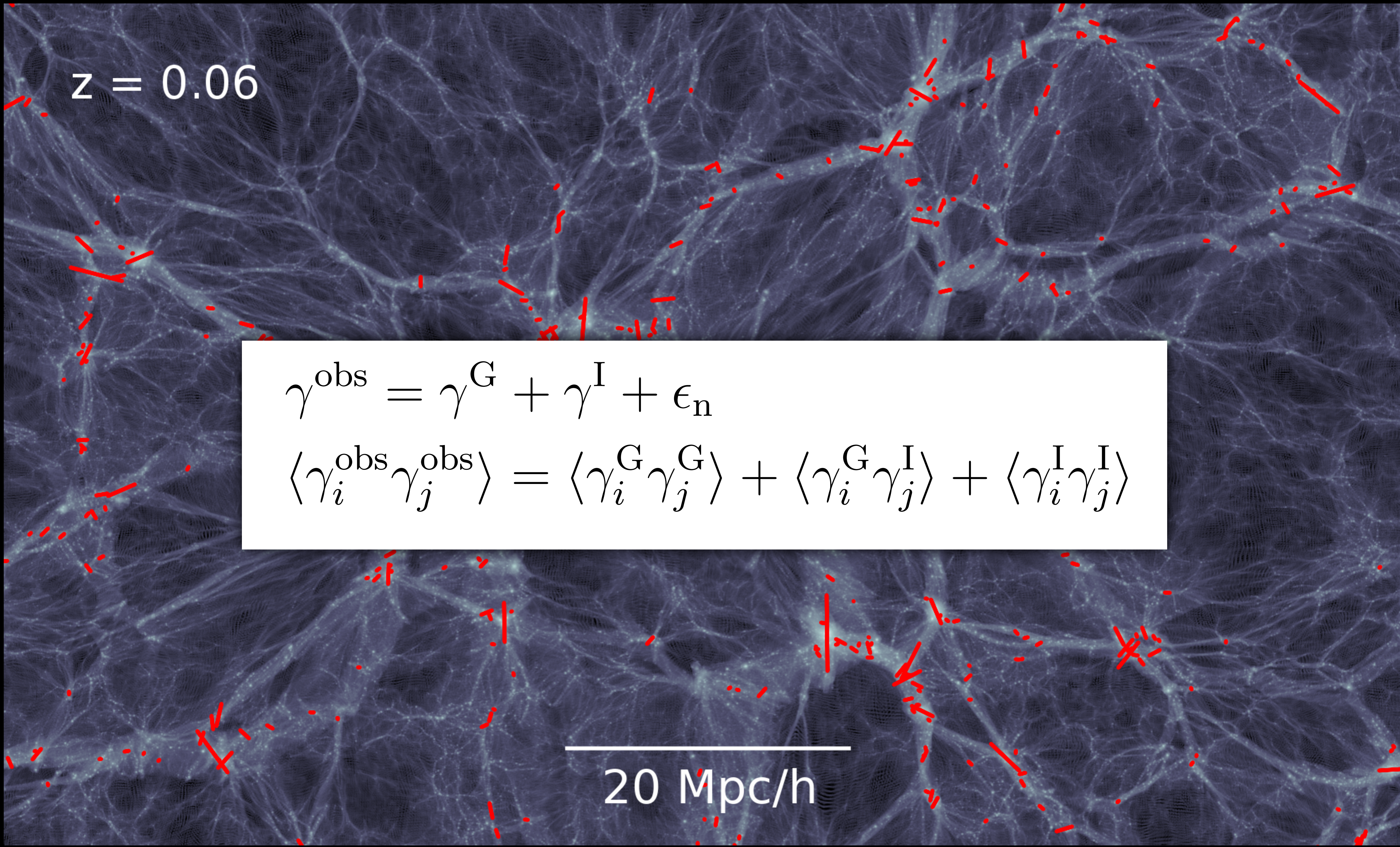
Important “systematics” (Astrophysics!)

Baryonic feedback
(cosmic shear only)





Galaxy intrinsic alignments (IA)

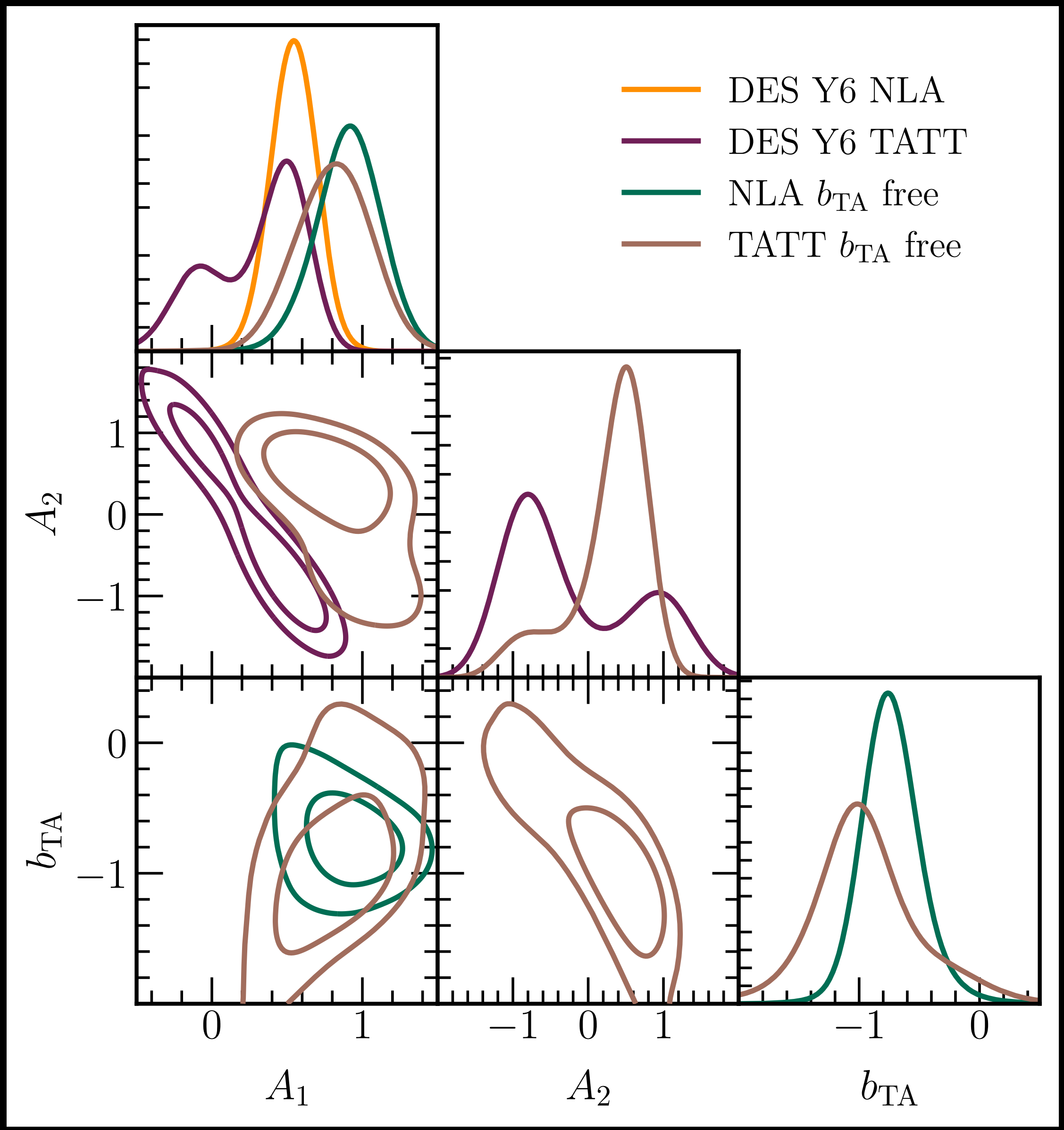


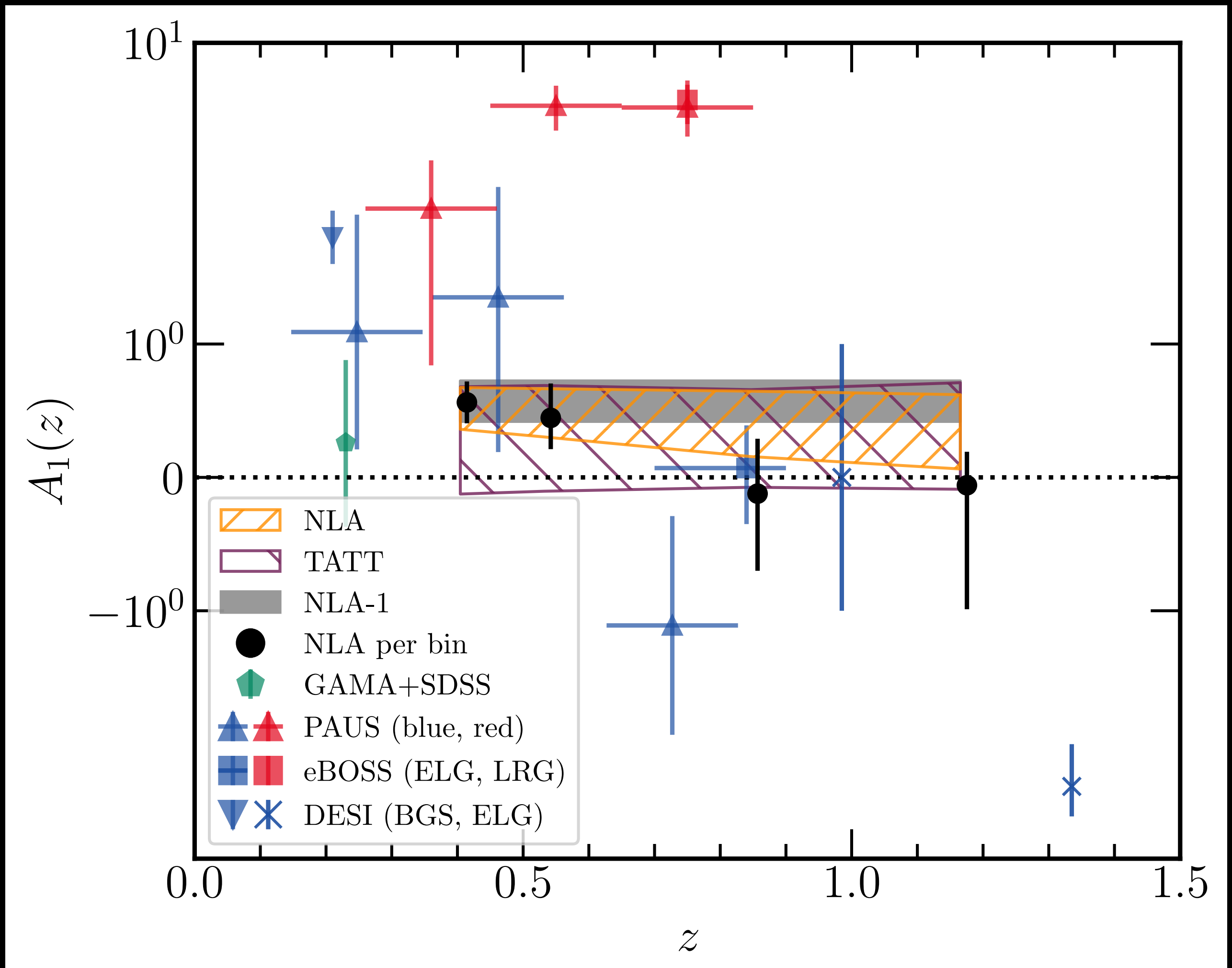
$$\gamma^{\mathrm{obs}} = \gamma^{\mathrm{G}} + \gamma^{\mathrm{I}} + \epsilon_{\mathrm{n}}$$

$$\langle \gamma_i^{\mathrm{obs}} \gamma_j^{\mathrm{obs}} \rangle = \langle \gamma_i^{\mathrm{G}} \gamma_j^{\mathrm{G}} \rangle + \langle \gamma_i^{\mathrm{G}} \gamma_j^{\mathrm{I}} \rangle + \langle \gamma_i^{\mathrm{I}} \gamma_j^{\mathrm{I}} \rangle$$

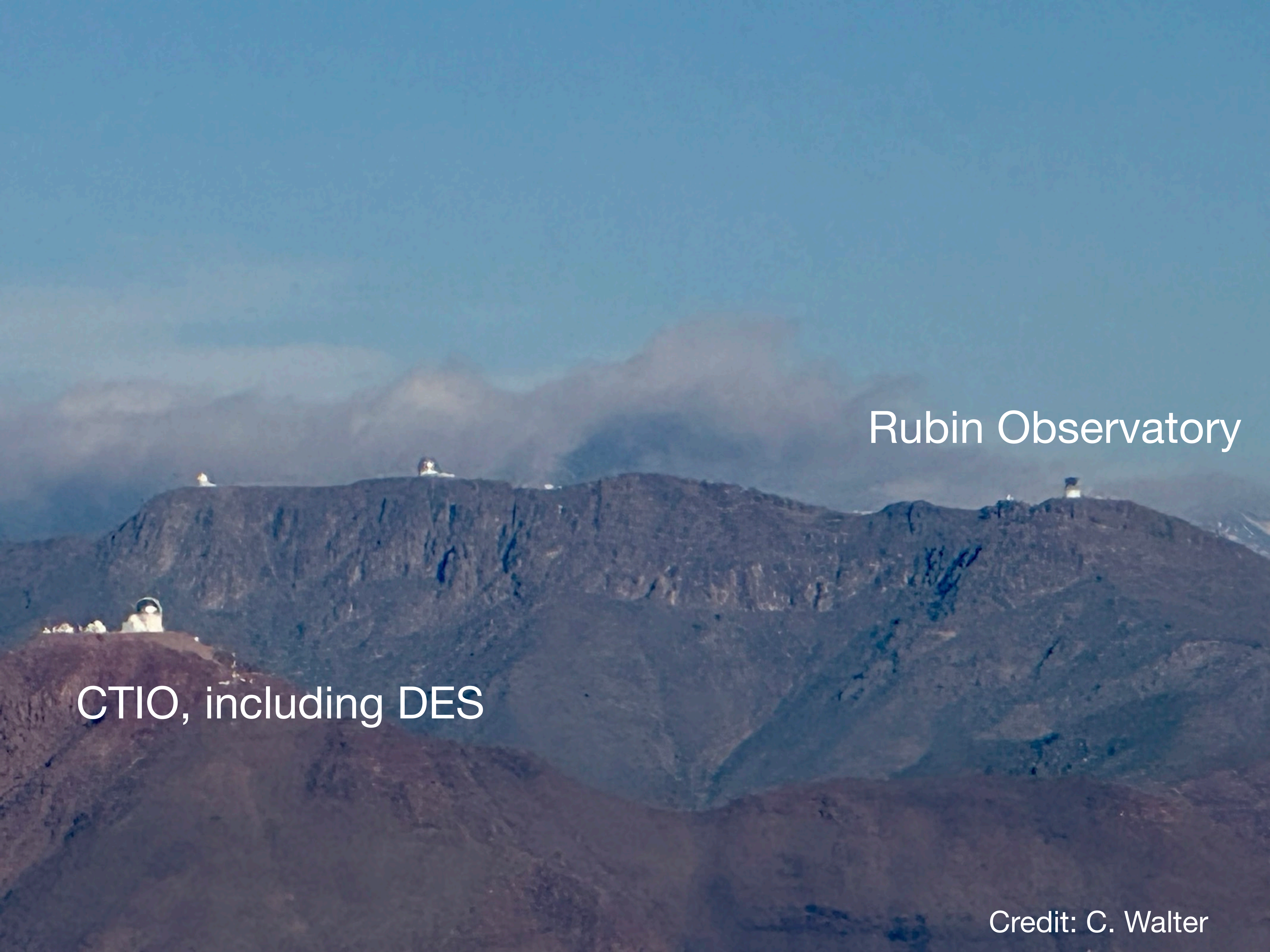
Intrinsic alignments

(cosmic shear only)

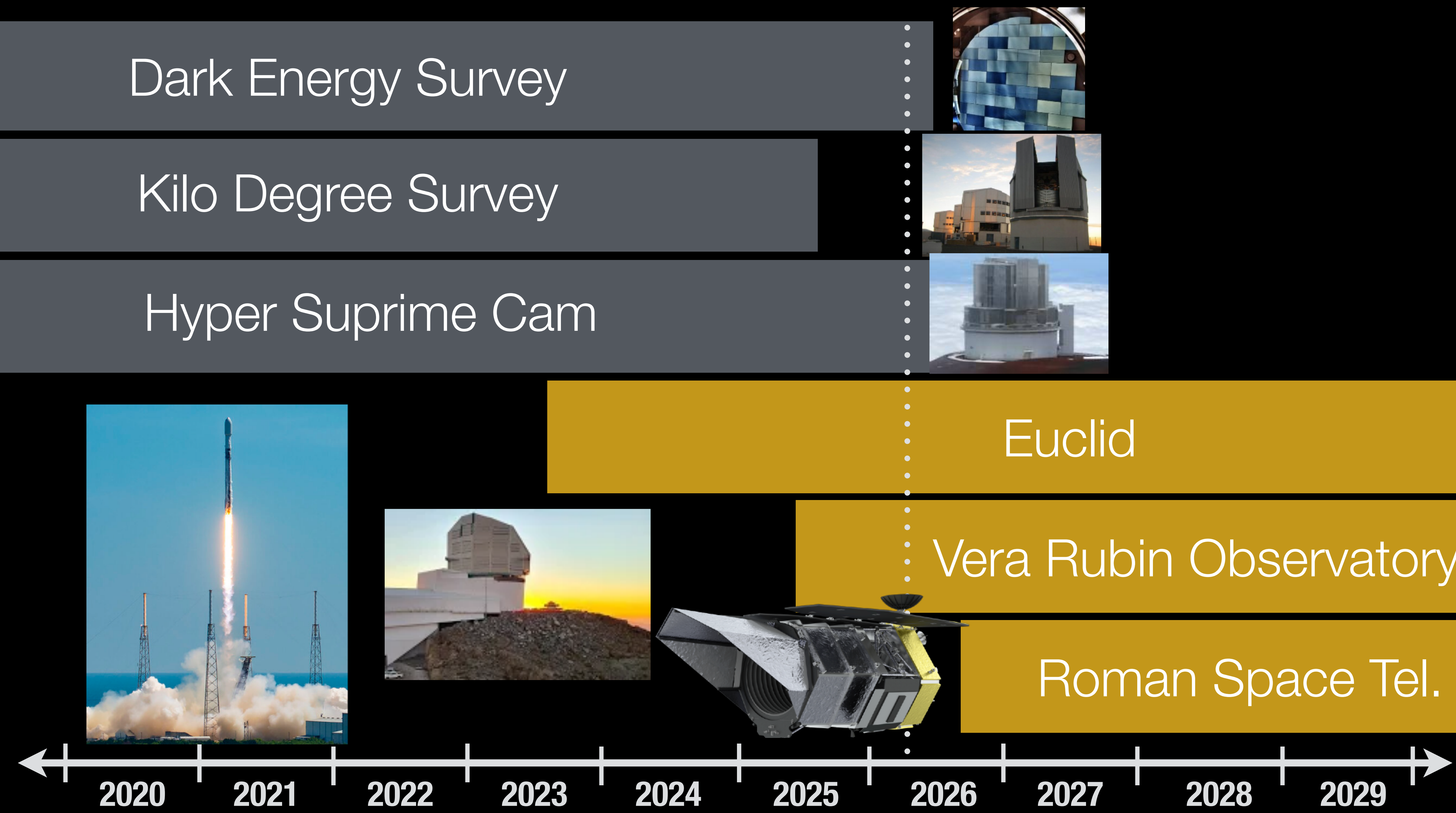





Credit: C. Walter


Rubin Observatory
CTIO, including DES
Credit: C. Walter

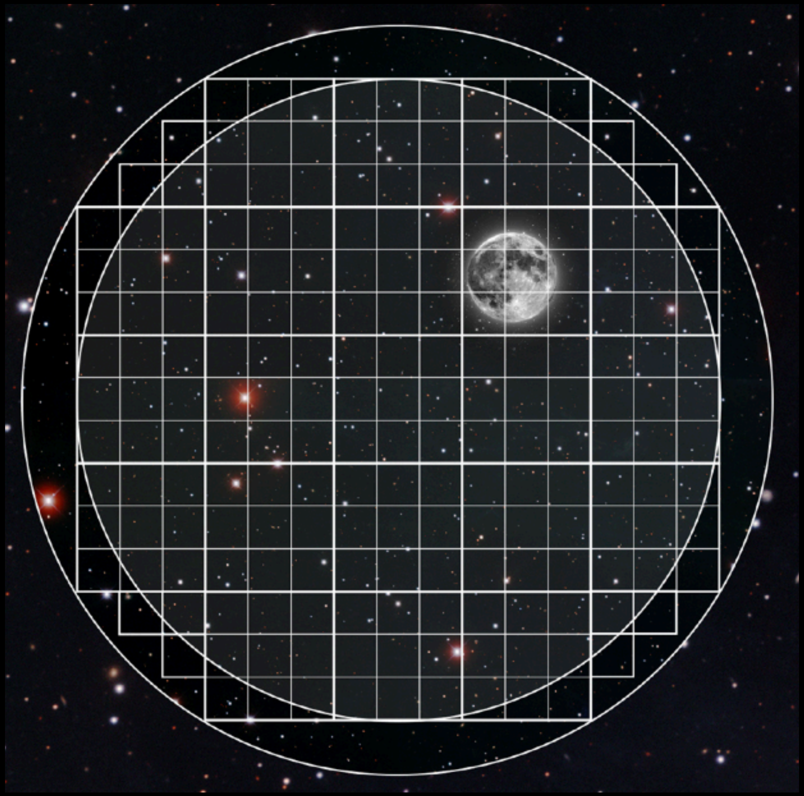
The “next generation” is now



Vera C. Rubin Observatory

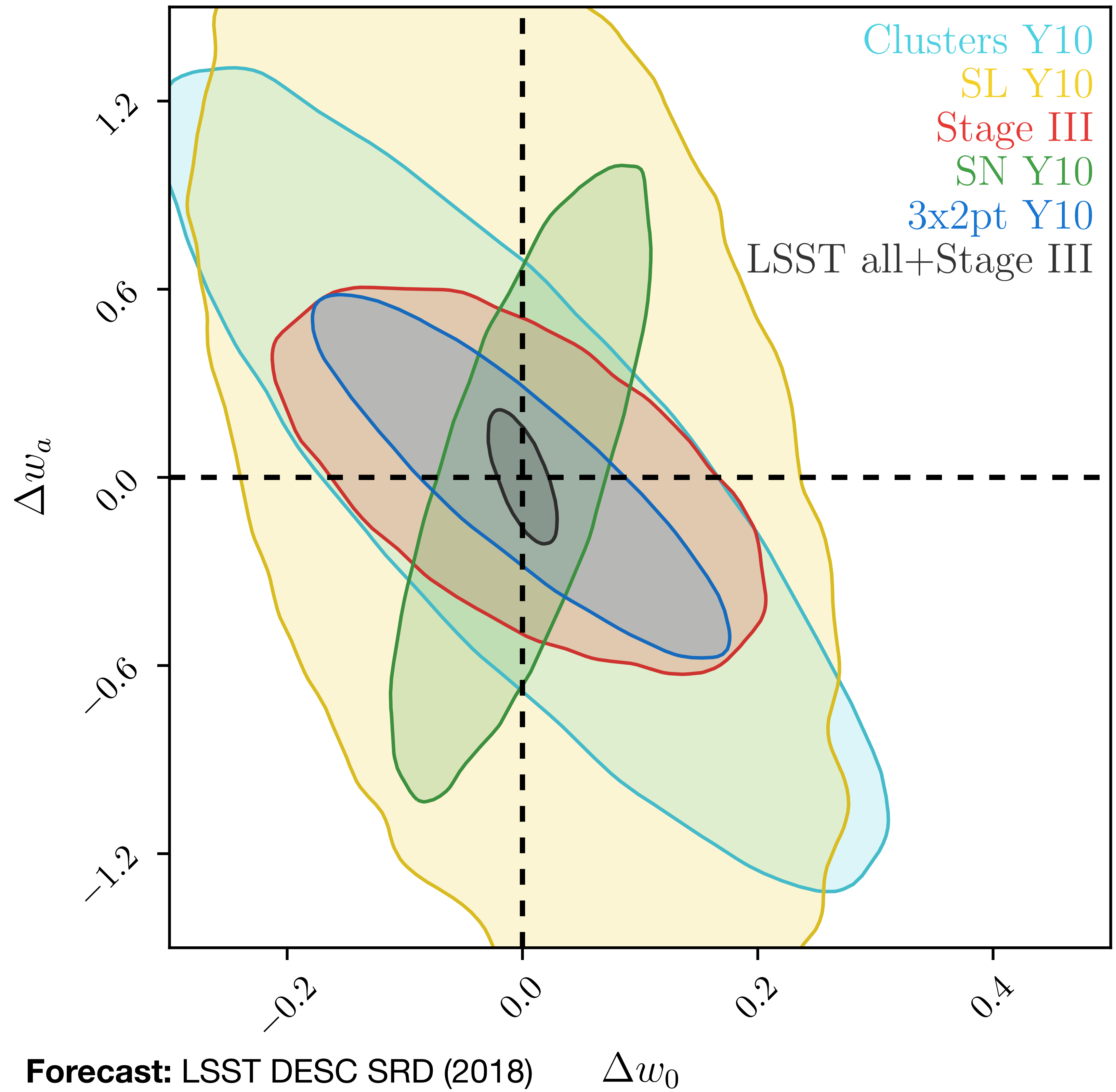
Vera C. Rubin Observatory

- Legacy Survey of Space and Time (LSST)
- LSSTCam (3.2 Gpix) on 8.4m telescope, Cerro Pachón, Chile
- ~1/2 of sky (18-25k deg^2)
- 10 year dedicated survey (2026-2036)
- 20 billion galaxies
- 8 science collaborations. “Dark Energy” (DESC) also includes dark matter, gravity, inflation, neutrinos, …



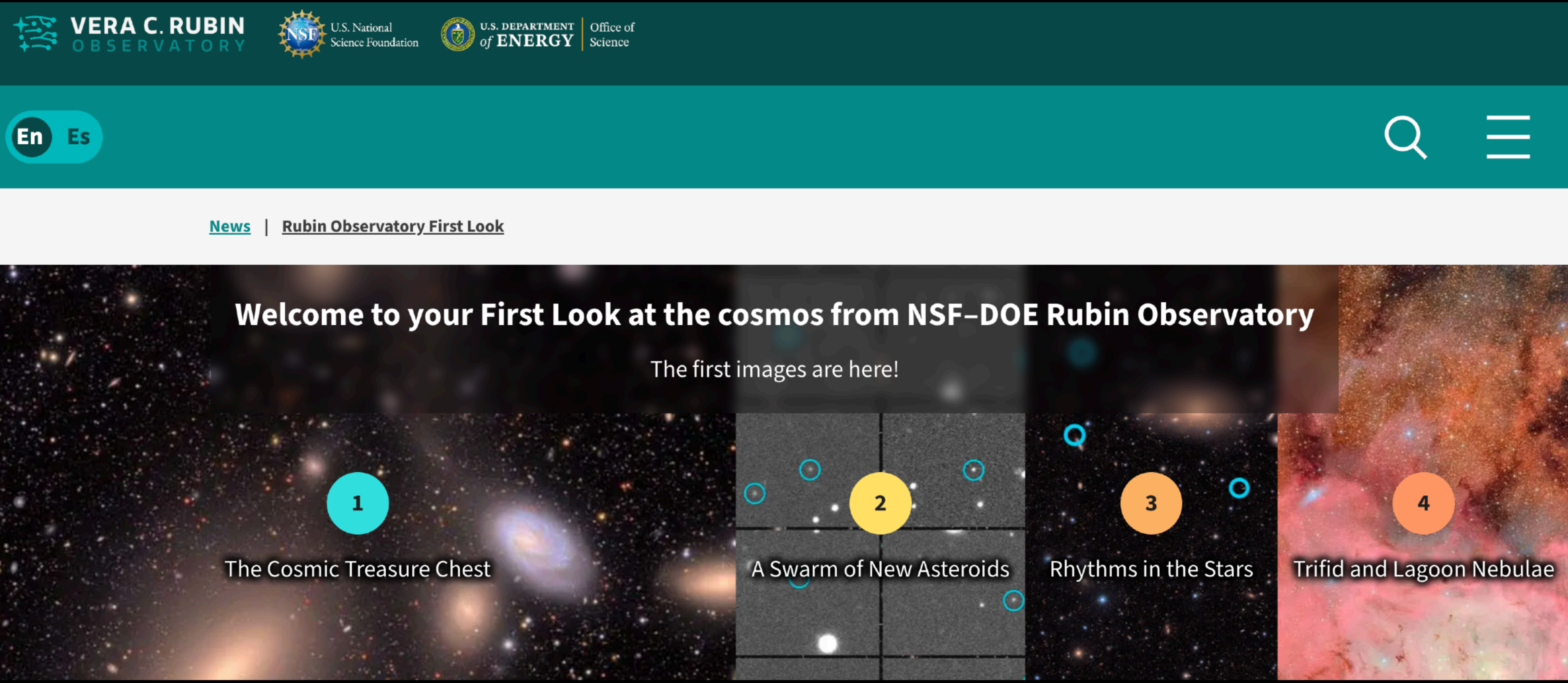
~10 deg^2 field-of-view

Dark Energy with Rubin LSST



Forecast: LSST DESC SRD (2018)

It is happening!



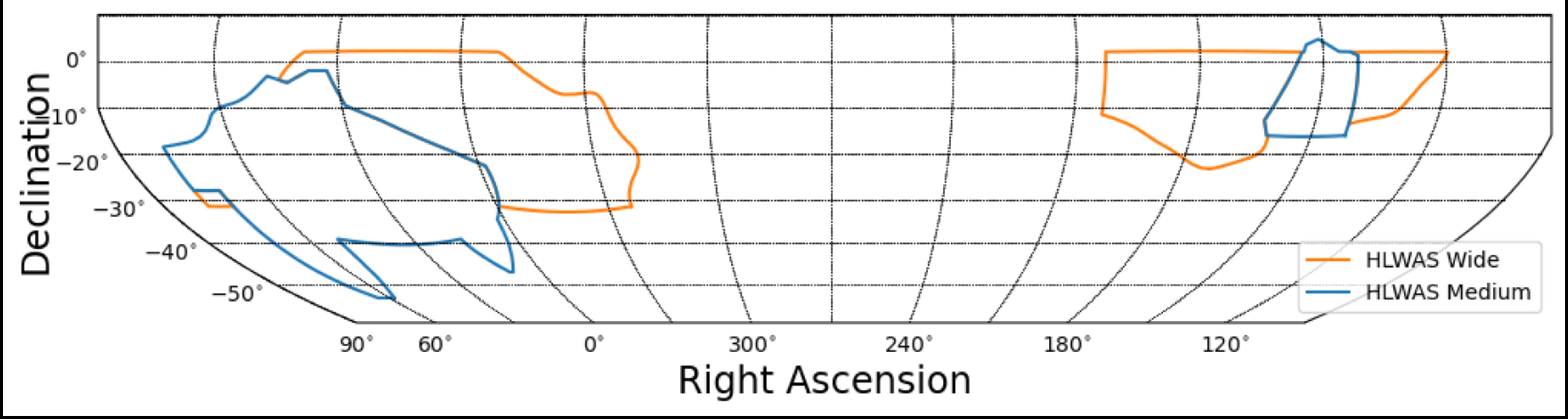
- Data taking started in 2025. “First Look” event June 2025.
- Some amazing images. 2100 new asteroids in 7 nights.
- Commissioning complete, now in Early Science Operations. LSST to begin soon. We will first analyze “Data Preview 2.”

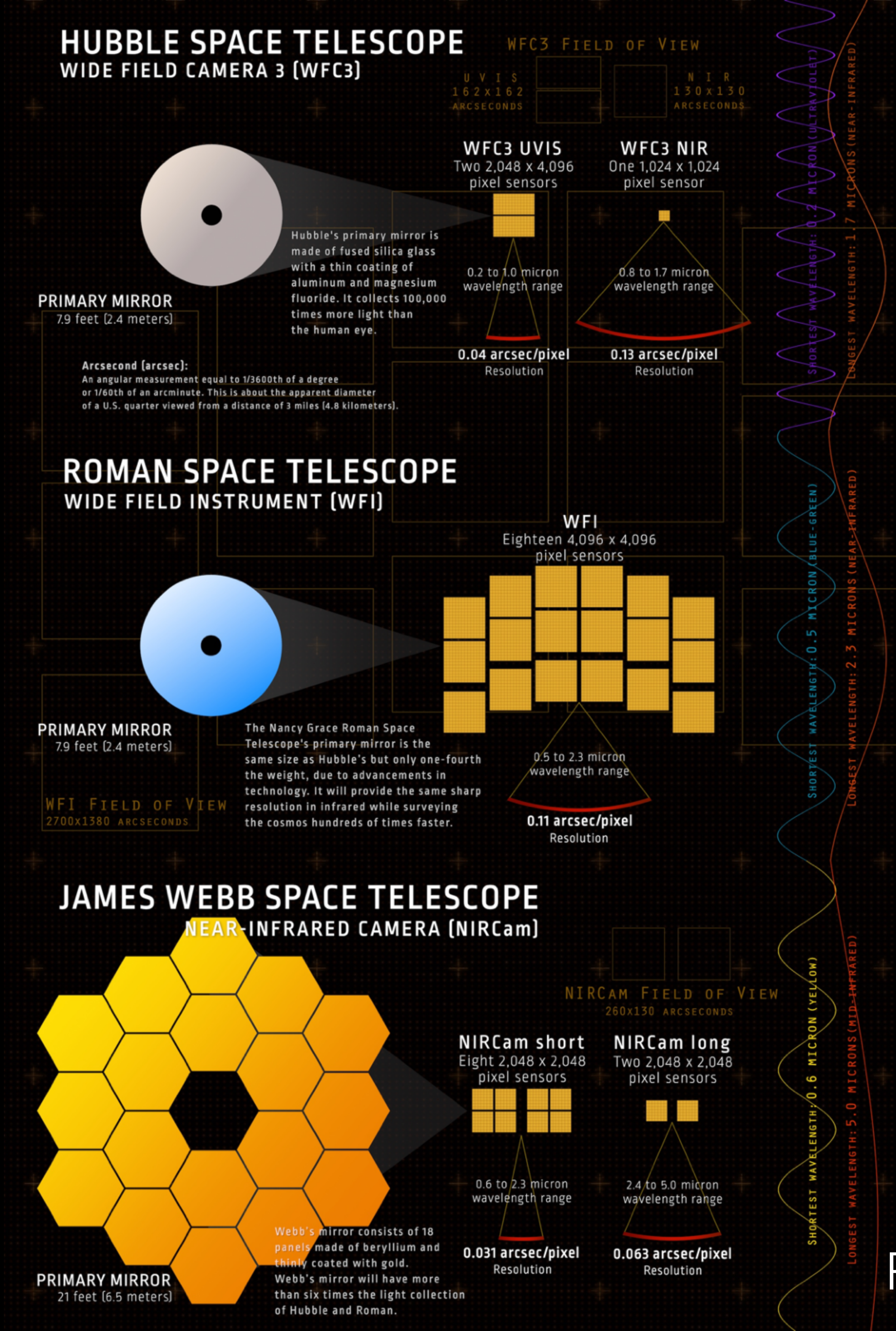
Roman Space Telescope

- Nancy Grace Roman: NASA's first Chief of Astronomy
- 2.4m mirror (same as Hubble)
- Field of view ~100x larger than Hubble
- Amazing image quality over unprecedented area of the sky
- Will do imaging, spectroscopy, and coronagraph
- Launch ~August 30, 2026! (Ahead of schedule and under budget)

Roman Space Telescope

- High-latitiude wide-area survey (HLWAS)
- Wide, medium, deep, and ultra-deep tiers
- Wide (~2700 deg^2, single band) + deep (~2400 deg^2, multi-band + grism spectroscopy) combine for ~600 million galaxy shapes (>4x DES)
- Enabling multi-probe cosmology with excellent control of systematics




HUBBLE SPACE TELESCOPE
WIDE FIELD CAMERA 3 (WFC3)
WFC3 FIELD OF VIEW
UVIS 162x162 ARCSECONDS
NIR 130x130 ARCSECONDS
WFC3 UVIS
Two 2,048 x 4,096 pixel sensors
WFC3 NIR
One 1,024 x 1,024 pixel sensor
Hubble's primary mirror is made of fused silica glass with a thin coating of aluminum and magnesium fluoride. It collects 100,000 times more light than the human eye.
PRIMARY MIRROR
7.9 feet (2.4 meters)
0.2 to 1.0 micron wavelength range
0.8 to 1.7 micron wavelength range
0.04 arcsec/pixel
Resolution
0.13 arcsec/pixel
Resolution
Arcsecond (arcsec):
An angular measurement equal to 1/3600th of a degree or 1/60th of an arcminute. This is about the apparent diameter of a U.S. quarter viewed from a distance of 3 miles (4.8 kilometers).
ROMAN SPACE TELESCOPE
WIDE FIELD INSTRUMENT (WFI)
WFI
Eighteen 4,096 x 4,096 pixel sensors
PRIMARY MIRROR
7.9 feet (2.4 meters)
WFI FIELD OF VIEW
2700x1380 ARCSECONDS
The Nancy Grace Roman Space Telescope's primary mirror is the same size as Hubble's but only one-fourth the weight, due to advancements in technology. It will provide the same sharp resolution in infrared while surveying the cosmos hundreds of times faster.
0.5 to 2.3 micron wavelength range
0.11 arcsec/pixel
Resolution
JAMES WEBB SPACE TELESCOPE
NEAR-INFRARED CAMERA (NIRCam)
NIRCAM FIELD OF VIEW
260x130 ARCSECONDS
NIRCam short
Eight 2,048 x 2,048 pixel sensors
NIRCam long
Two 2,048 x 2,048 pixel sensors
0.6 to 2.3 micron wavelength range
2.4 to 5.0 micron wavelength range
0.031 arcsec/pixel
Resolution
0.063 arcsec/pixel
Resolution
Webb's mirror consists of 18 panels made of beryllium and thinly coated with gold. Webb's mirror will have more than six times the light collection of Hubble and Roman.
PRIMARY MIRROR
21 feet (6.5 meters)
SHORTEST WAVELENGTH: 0.2 MICRON (ULTRAVIOLET)
LONGEST WAVELENGTH: 1.7 MICRONS (NEAR-INFRARED)
SHORTEST WAVELENGTH: 0.5 MICRON (BLUE-GREEN)
LONGEST WAVELENGTH: 2.3 MICRONS (NEAR-INFRARED)
SHORTEST WAVELENGTH: 0.6 MICRON (YELLOW)
LONGEST WAVELENGTH: 5.0 MICRONS (MID-INFRARED)

Roman, STScI

Roman - Nov 2025

Credit: A. Choi

Roman - April 15, 2026

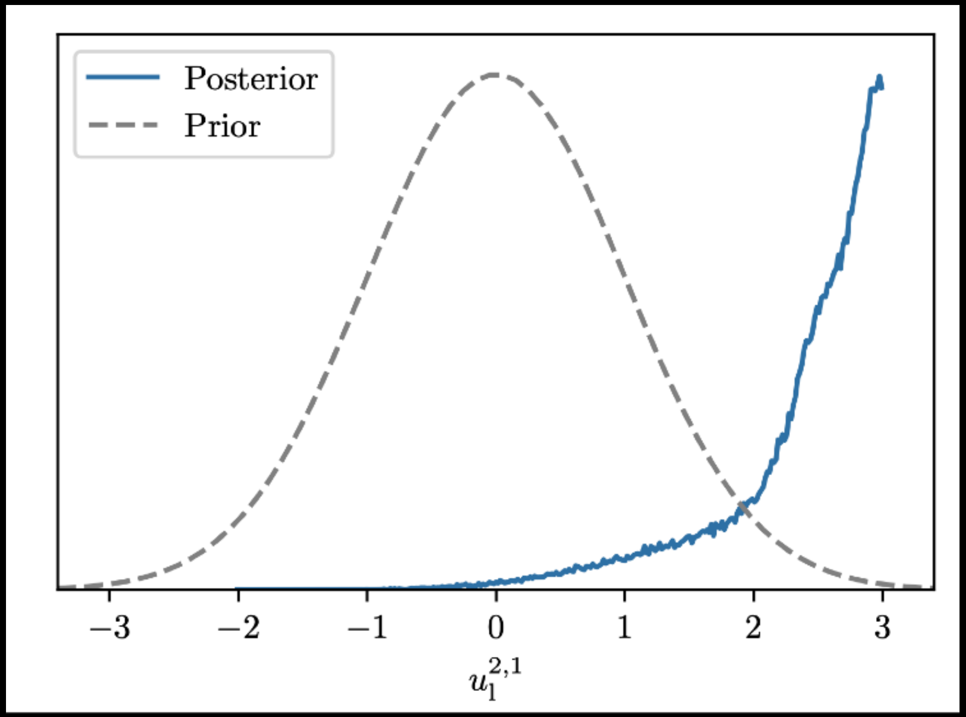
Takeaways

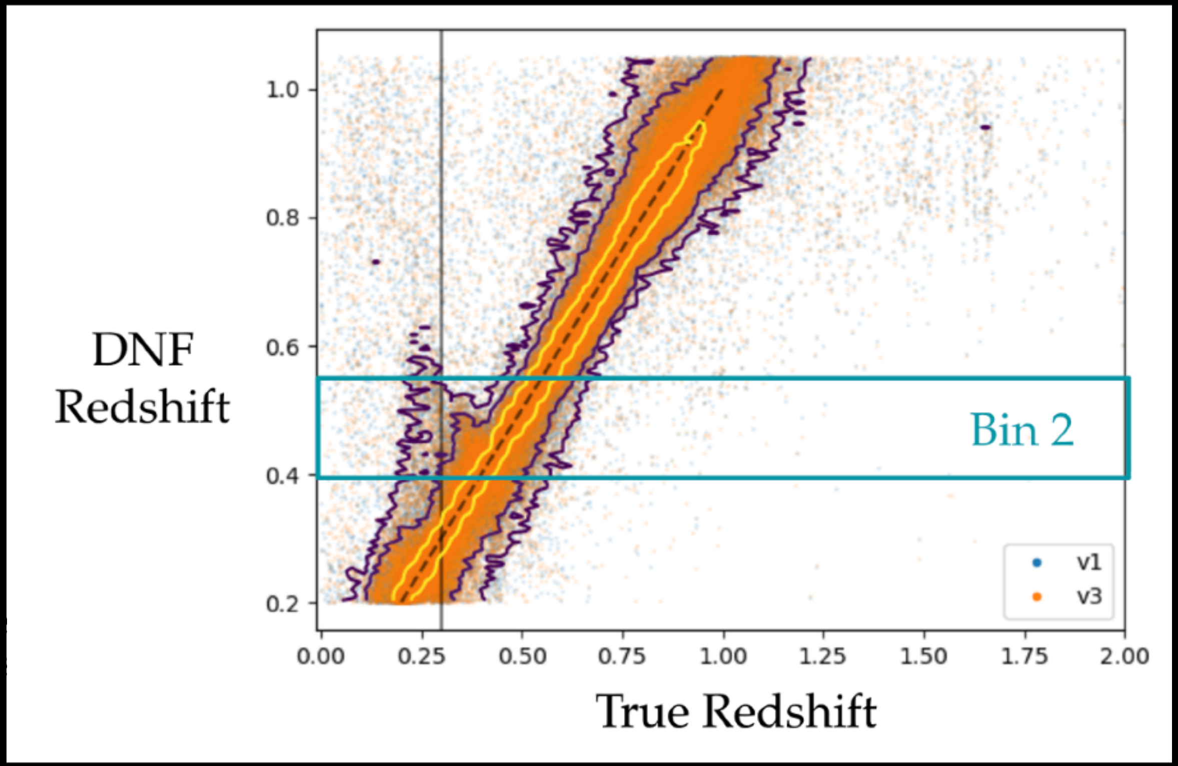
- Combining weak lensing and galaxy clustering is a powerful probe of cosmic structure and dark energy.
- DES has been a successful, decades-long effort to probe dark energy and much more.
- Results from completed DES (Year 6): 2.8σ tension with CMB in ΛCDM, 2.2σ (3.0σ) preference for evolving dark energy from DES alone (all combined).
- Rubin Observatory LSST, the Roman Space Telescope, and Euclid will provide unprecedented cosmological data sets.

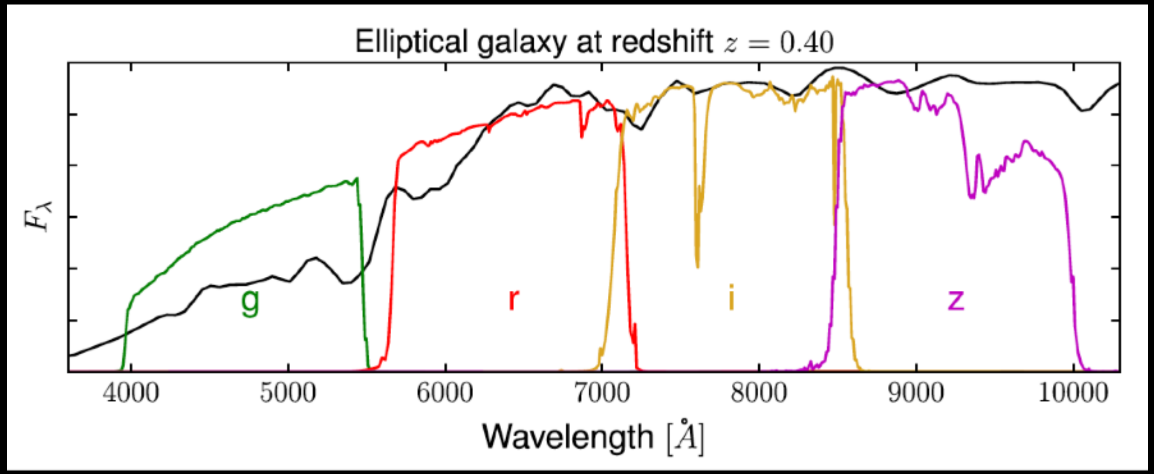

Thank you!

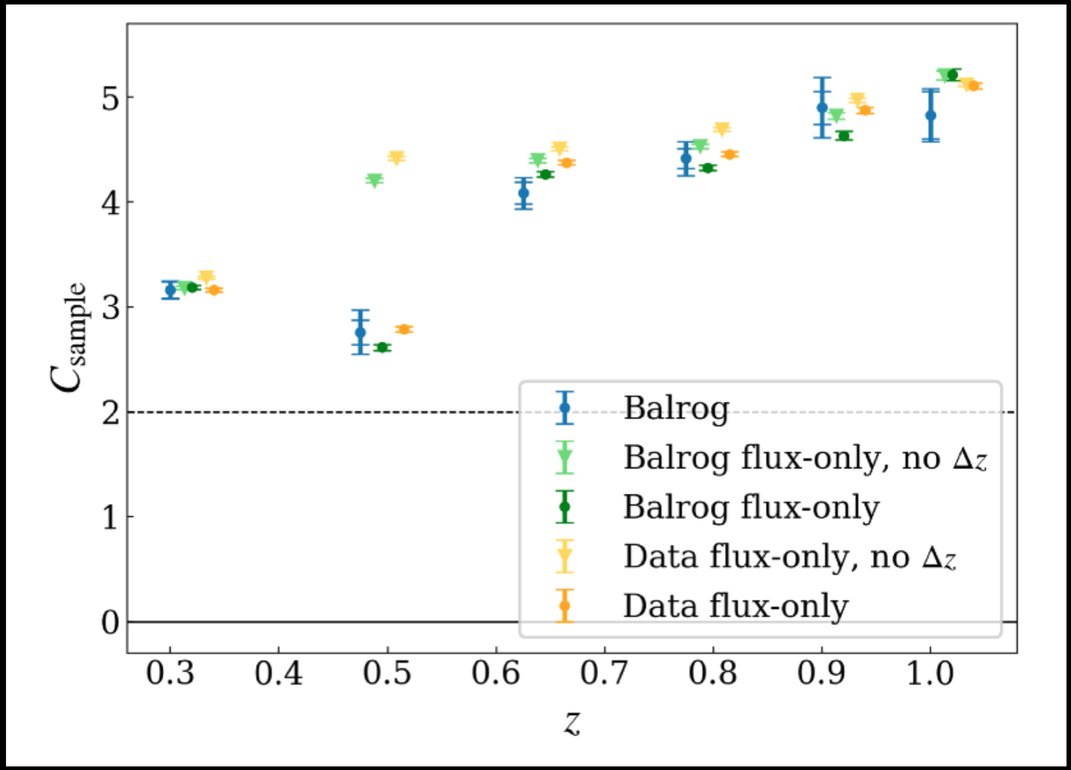
Backup slides

Maglim (lens) Bin 2

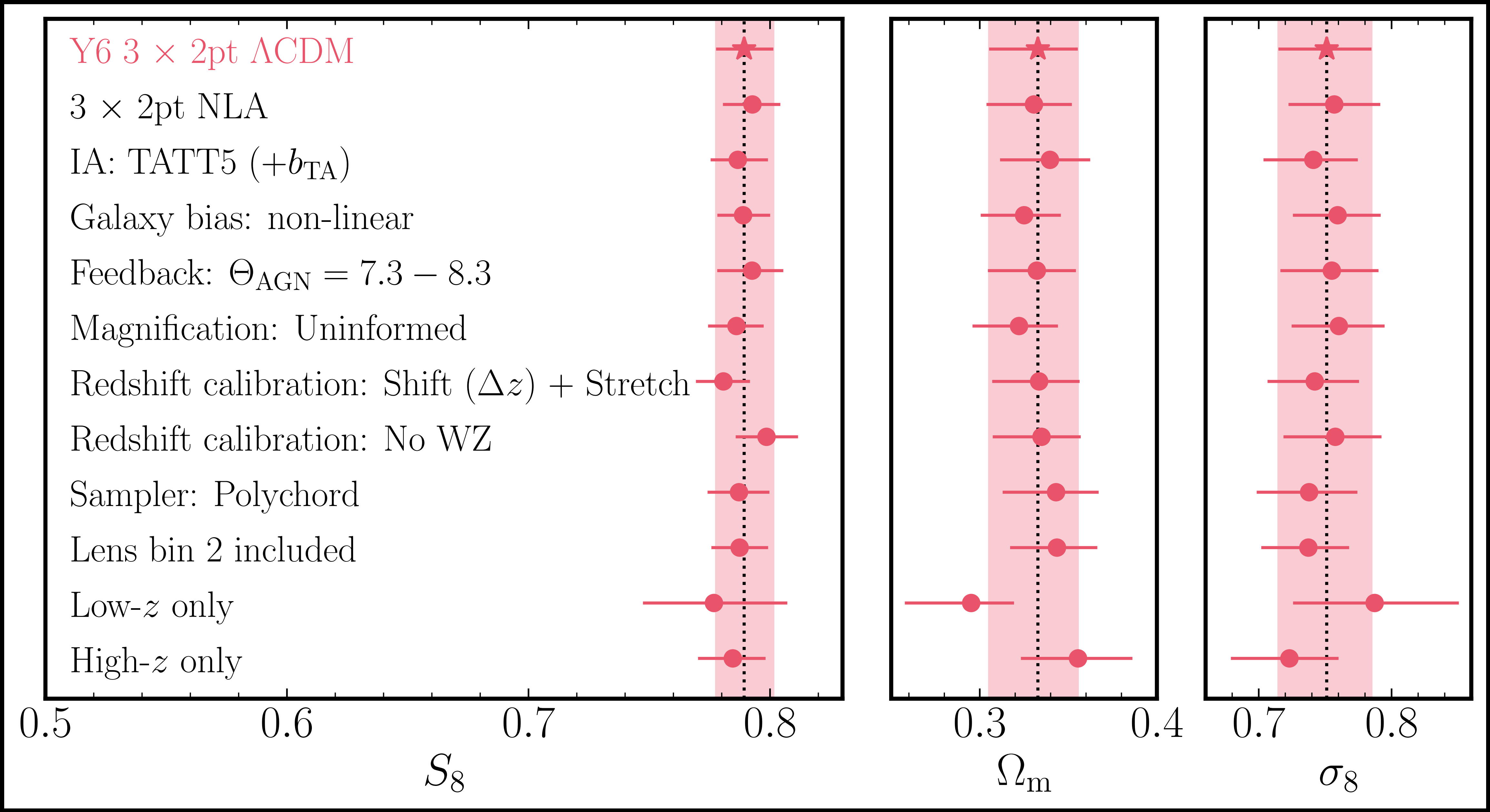




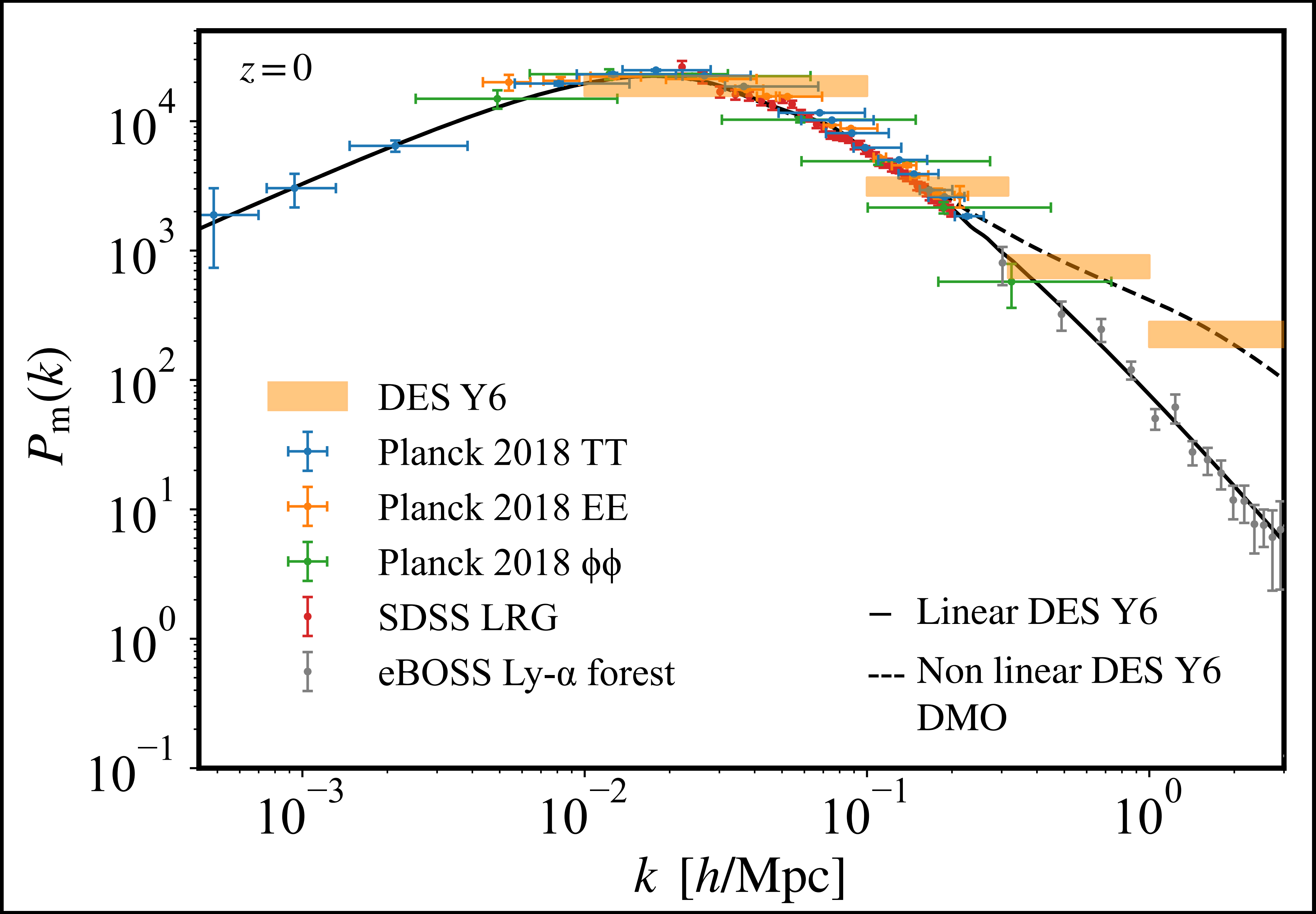




Model testing and systematics



Matter Power Spectrum

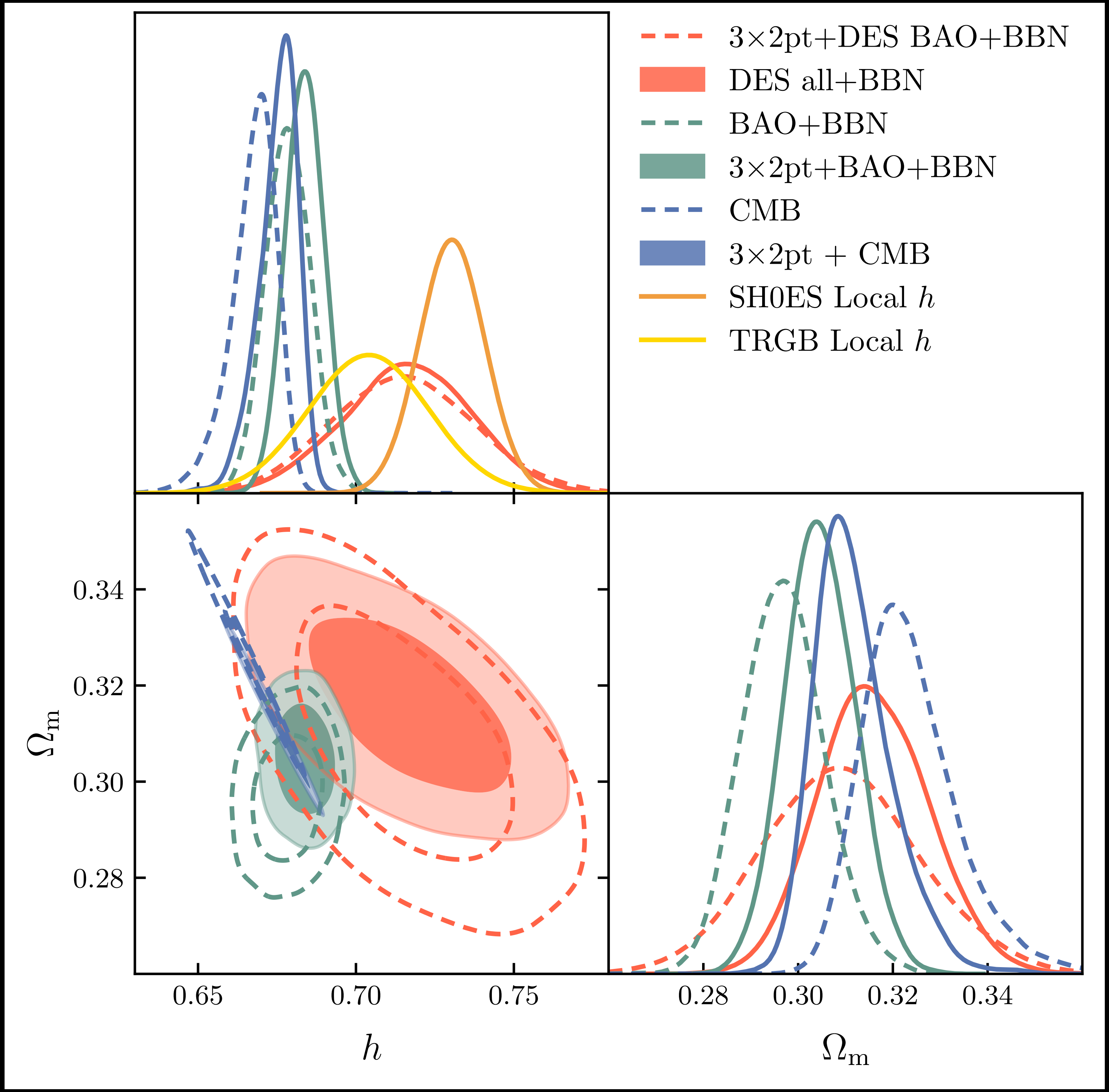


Intrinsic alignments

(cosmic shear only)

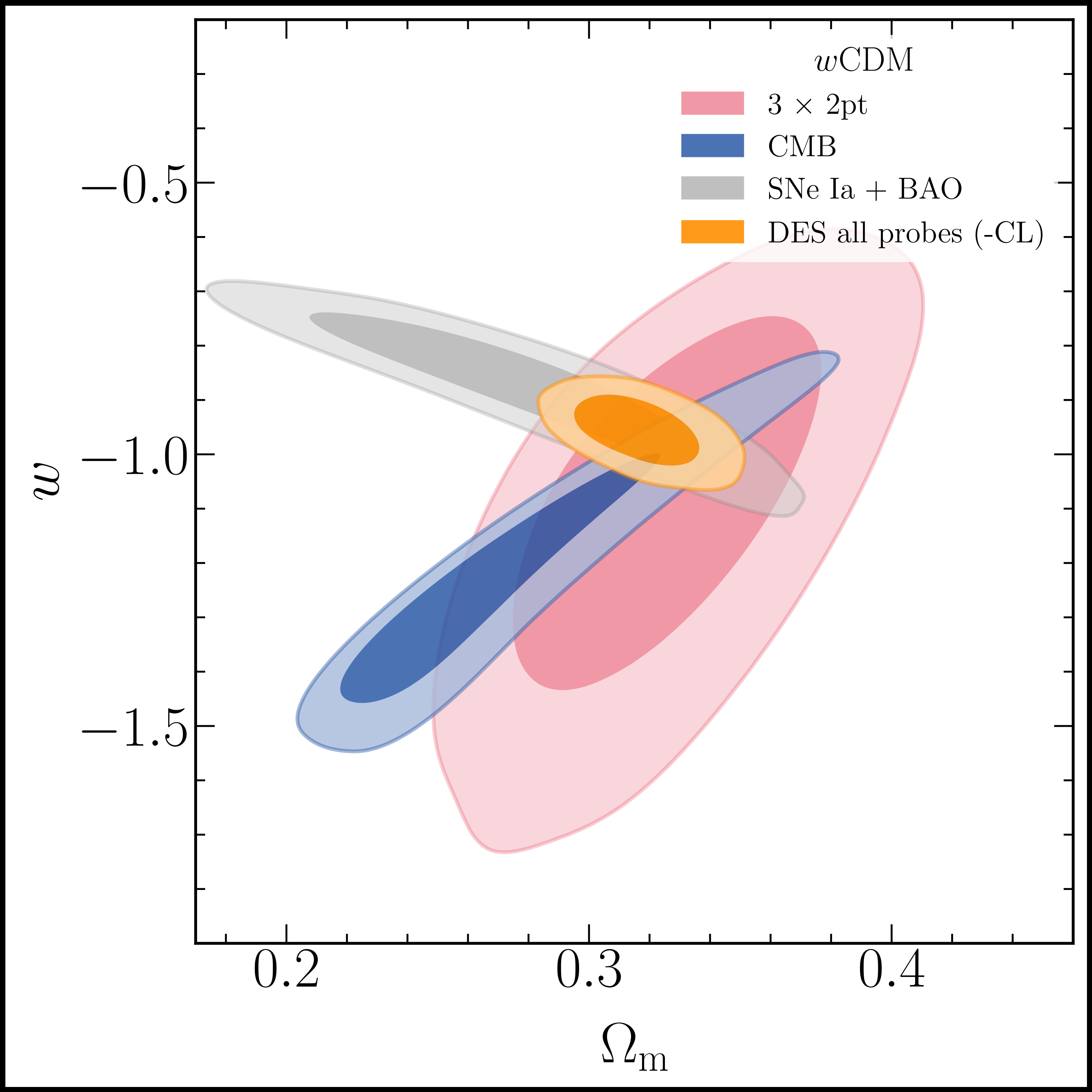
IA Model	$b_{\rm TA}$	$\Delta\chi^2/\Delta$dof	$p-$val.	R	S_8
None	0	0/0	0.06	1	$0.792^{+0.013}_{-0.013}$
NLA-1 (A_1)	0	$3.8/0.3$	0.07	71	$0.799^{+0.014}_{-0.014}$
NLA* (A_1, η_1)	0	$3.5/0.6$	0.07	41	$0.798^{+0.014}_{-0.015}$
TA (A_1, η_1)	1	$0.24/0.7$	0.05	1	$0.802^{+0.014}_{-0.014}$
TA no z (A_1, $b_{\rm TA}$)	[-2,2]	$11.9/0.7$	0.13	143	$0.788^{+0.014}_{-0.015}$
TA-3 (A_1, η_1, $b_{\rm TA}$)	[-2,2]	$13.9/1.9$	0.15	232	$0.782^{+0.014}_{-0.015}$
TATT-3 (A_1, A_2, η_1)	1	$6.6/1.2$	0.08	3	$0.789^{+0.017}_{-0.016}$
TATT no z (A_1, A_2)	1	$5.0/1.1$	0.08	4	$0.792^{+0.015}_{-0.015}$
TATT no z (A_1, A_2)	0	$11.9/0.9$	0.13	95	$0.787^{+0.015}_{-0.015}$
TATT*	1	$5.3/1.5$	0.07	2	$0.786^{+0.018}_{-0.018}$
TATT	0	$14.0/1.5$	0.14	114	$0.779^{+0.016}_{-0.016}$
TATT + $b_{\rm TA}$	[-2,2]	$15.4/2.7$	0.14	104	$0.782^{+0.016}_{-0.016}$
NLA per bin	0	$5.0/2.1$	0.07	5	$0.790^{+0.015}_{-0.017}$
NLA linear z	0	$4.0/0.9$	0.07	31	$0.795^{+0.016}_{-0.014}$
TATT linear z	1	$6.0/1.6$	0.08	2	$0.773^{+0.023}_{-0.018}$

DES and H_0

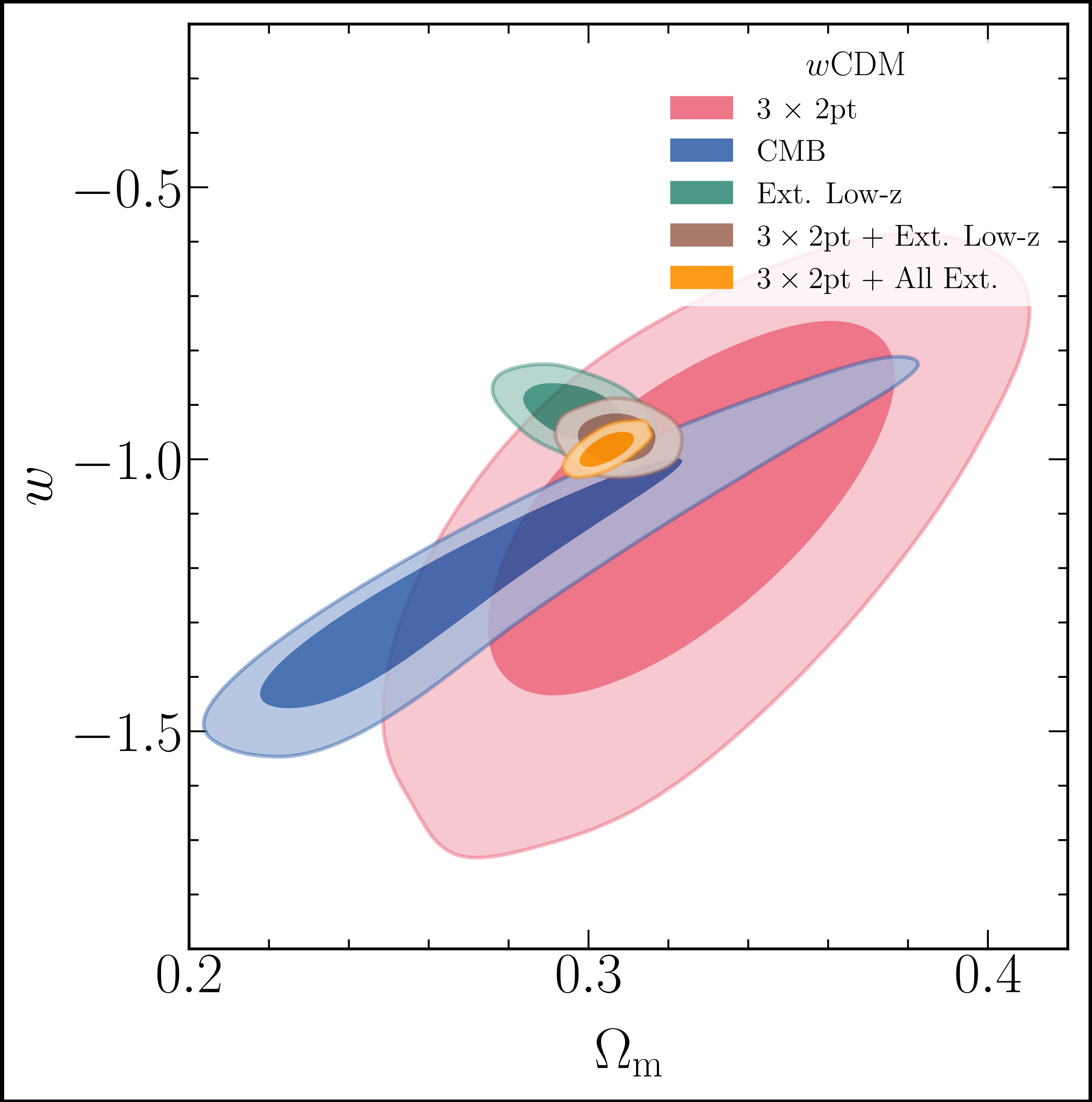


3×2pt+DES BAO+BBN
DES all+BBN
BAO+BBN
3×2pt+BAO+BBN
CMB
3×2pt + CMB
SH0ES Local h
TRGB Local h
0.34
0.32
0.30
0.28
Ωm
0.65
0.70
0.75
h
0.28
0.30
0.32
0.34
Ωm

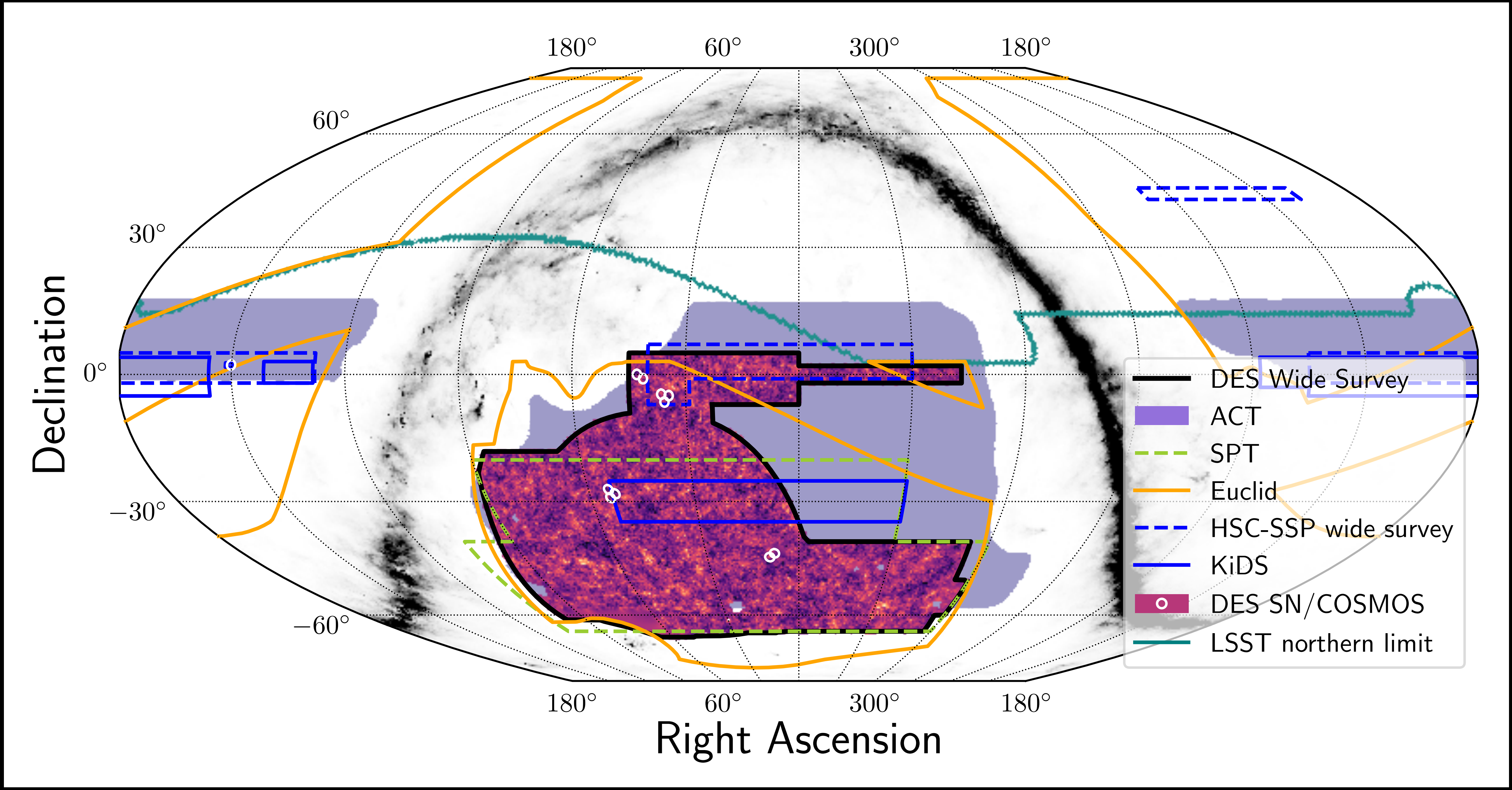
DES probes (no CL)



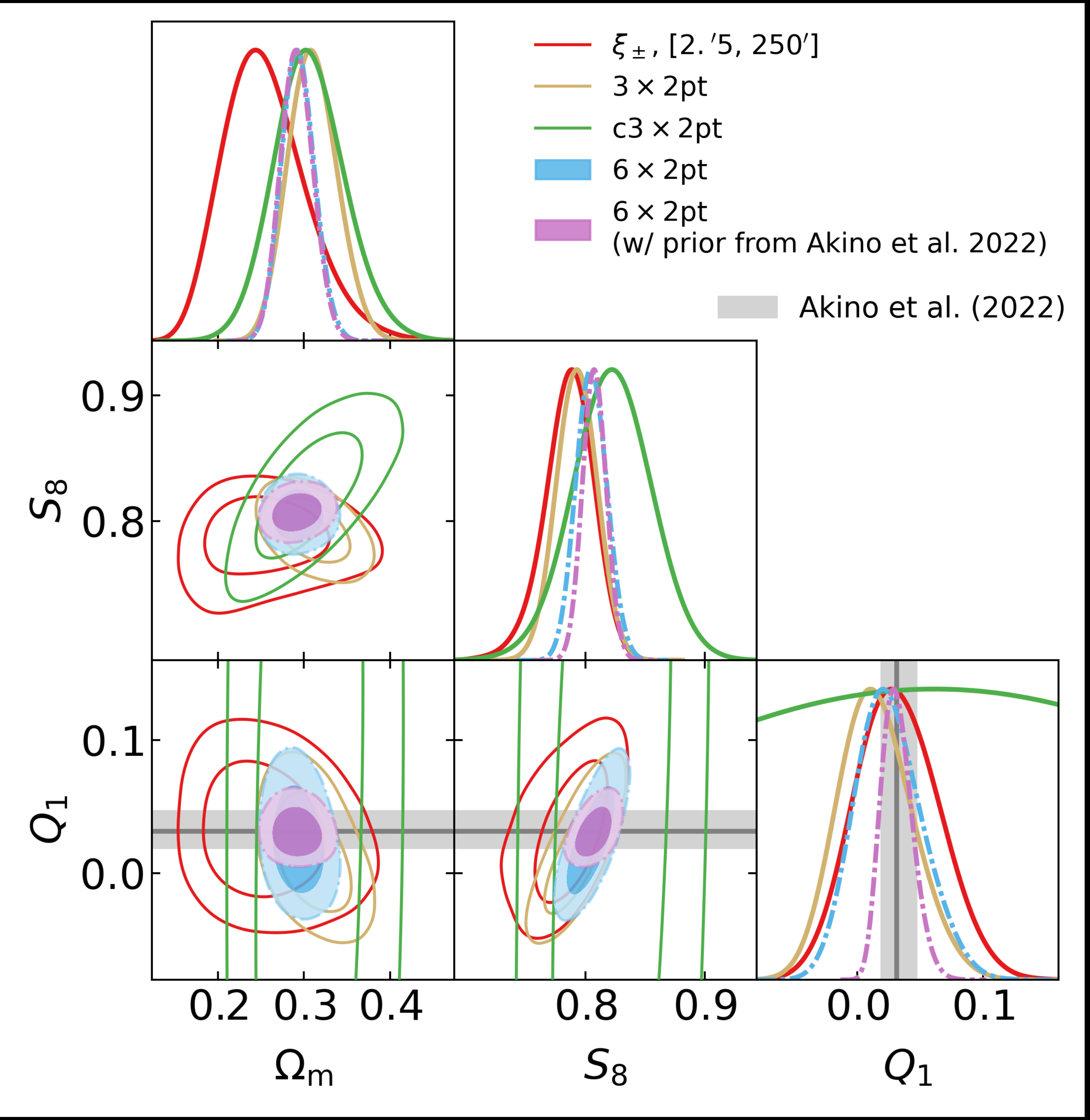
DES + external data



DES Footprint



Y3 re-analysis:
Improved baryonic treatment and AI acceleration



J. Xu+ 2025, arXiv:2510.25596

Perturbation theory for galaxy bias and IA

galaxy biasing

$$\delta_g(x) = b_1 \delta_m(x) + b_2 \delta_m^2(x) + b_s s^2(x) + \cdots$$

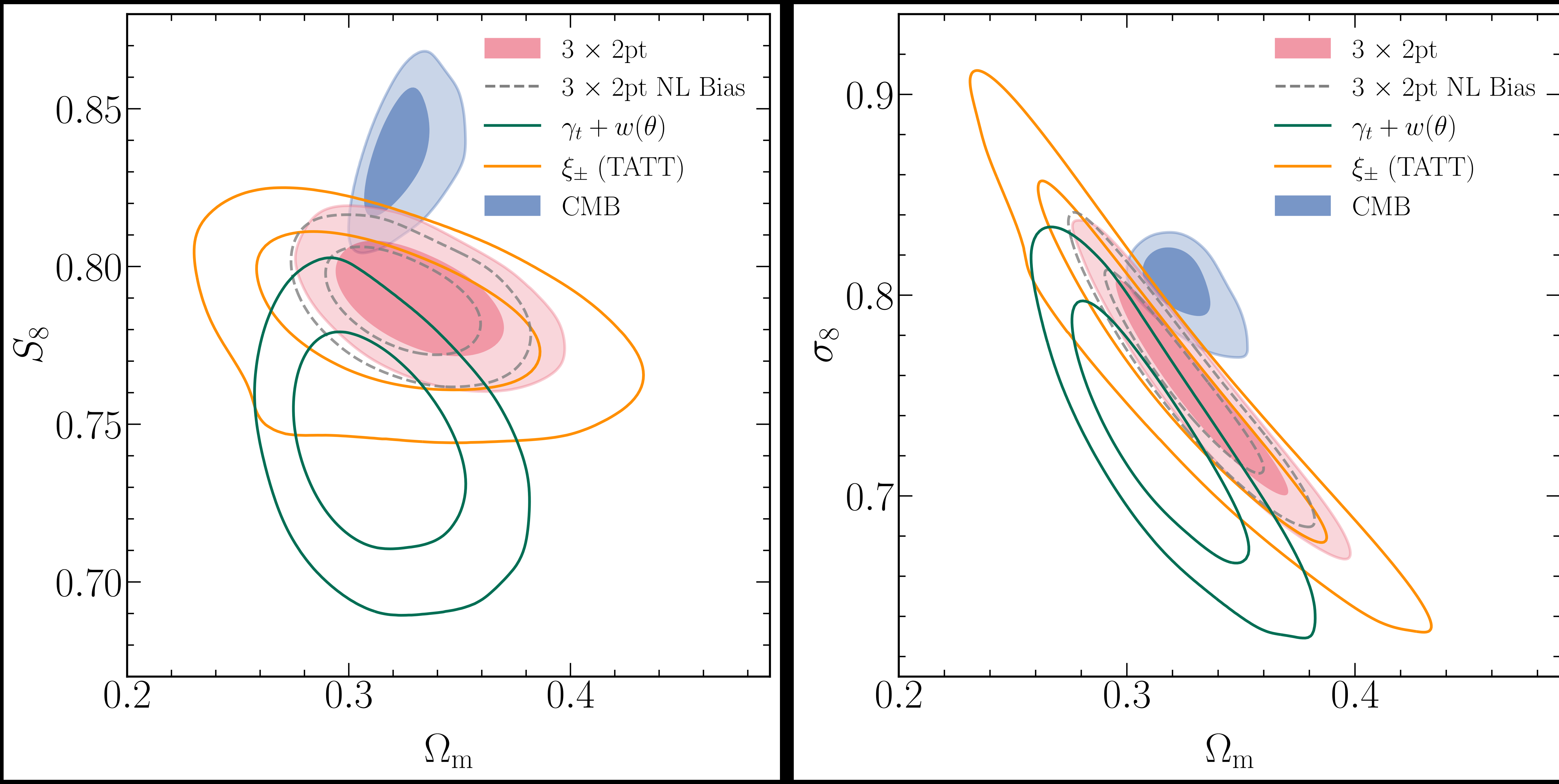
$$\gamma_{ij}^I = C_1 s_{ij} + C_2 (s_{ik} s_{kj}) + C_\delta (\delta s_{ij}) + C_t t_{ij} + \cdots$$

galaxy intrinsic alignments: e.g. **TATT model**, EFT of IA

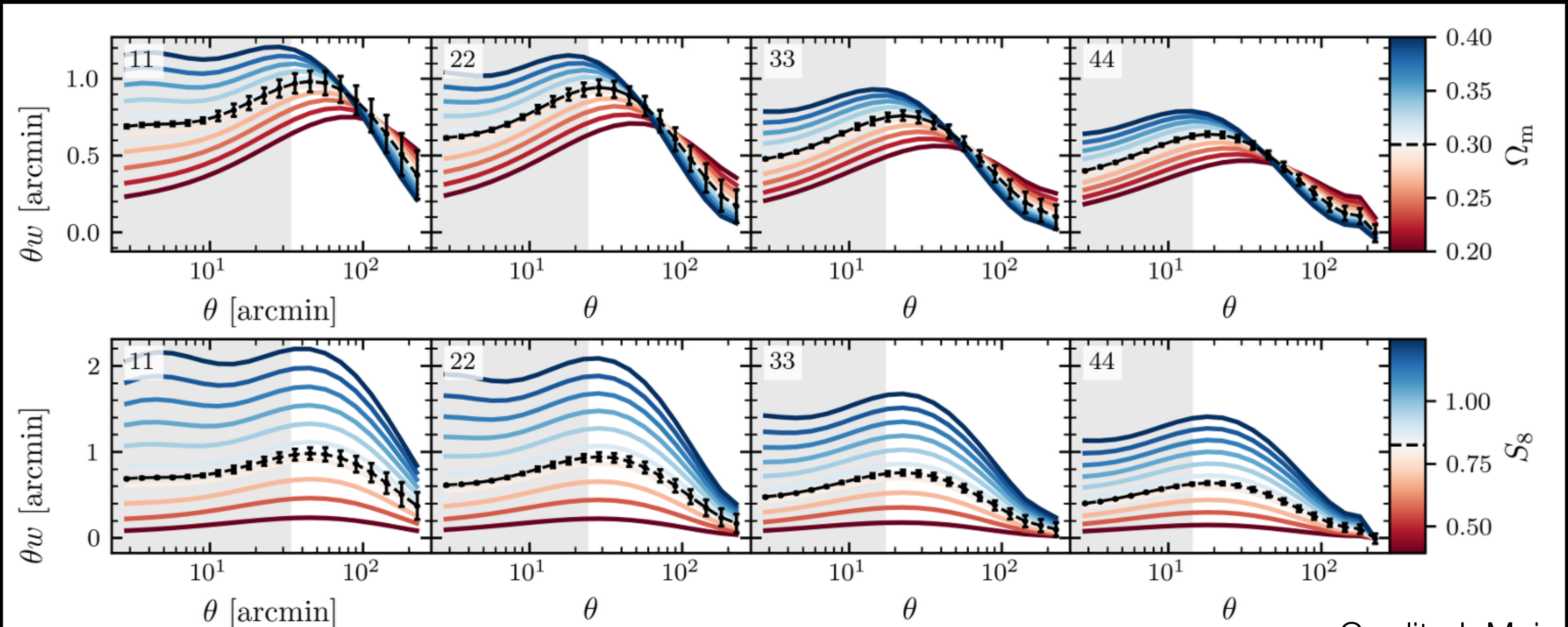
- EPT: JB, Vlah, Seljak 15; Schmidt, Chisari, Dvorkin 15; JB, MacCrann, Troxel, Fang 19; Schmitz, Hirata, JB, Krause 19; Akitsu+ 23
- EFT: Vlah, Chisari, Schmidt 20, 21; Bakx+ 23
- (Hybrid) Lagrangian: Maion, Angulo+ 24; Chen & Kokron 24
- Halo model: Schneider, Bridle 2010; Fortuna+ 21

Y6 results vs CMB

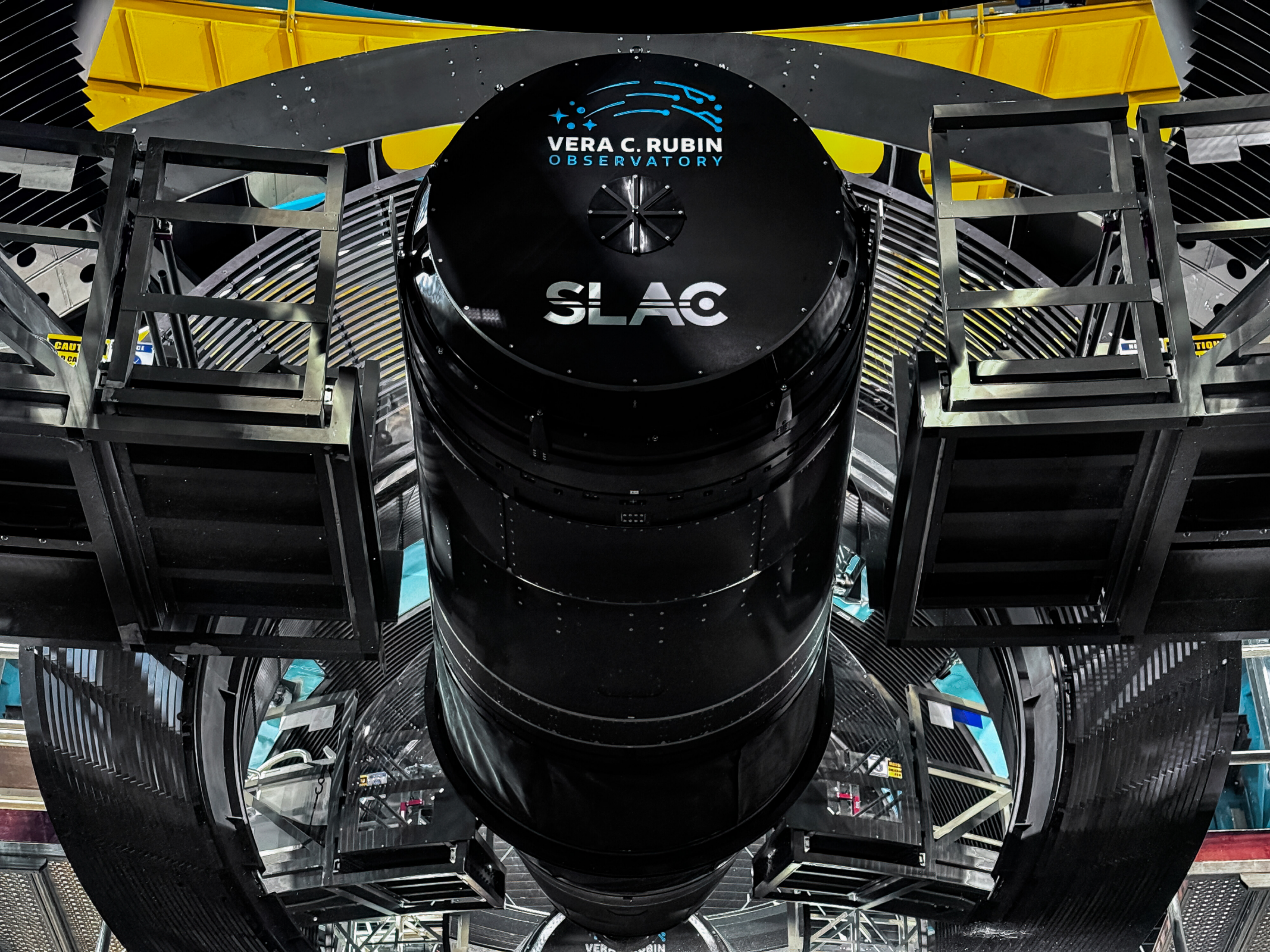
factor of ~2 more constraining power than Y3



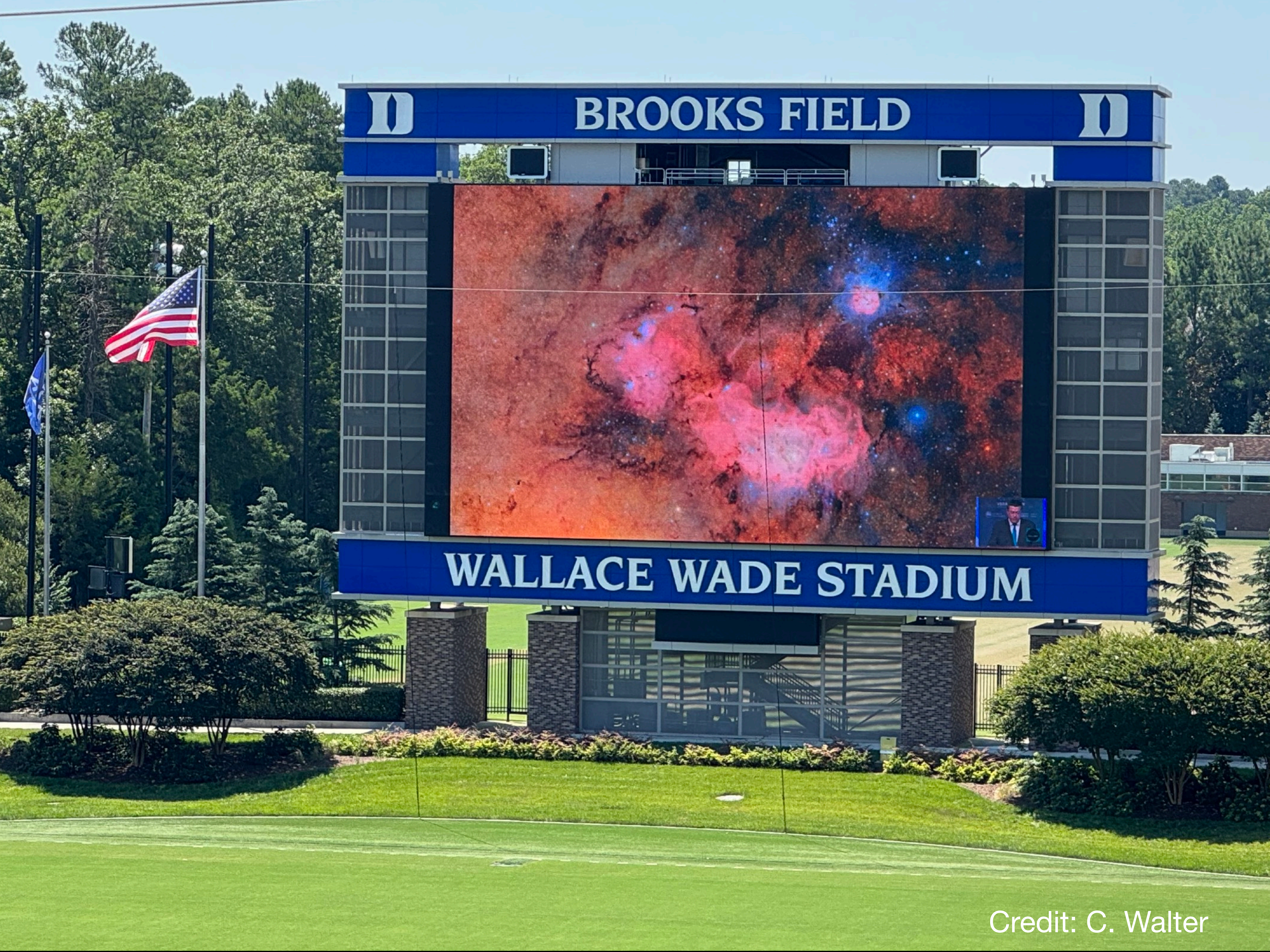
Cosmological parameters from observables



Credit: J. Muir


VERA C. RUBIN
OBSERVATORY
SLAC

Credit: E. Urbach



Credit: C. Walter