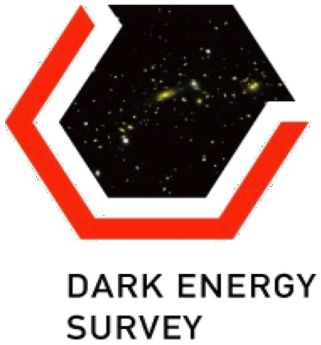


Cosmology from structure

in the Dark Energy Survey

Daniel Gruen, Einstein Fellow @ Stanford / SLAC
on behalf of the DES Collaboration

KIAS Workshop on Cosmology and Structure Formation 2018

Cosmology from structure, geometry, and joint probes in the Dark Energy Survey

9 DES papers released today

sneak peek now

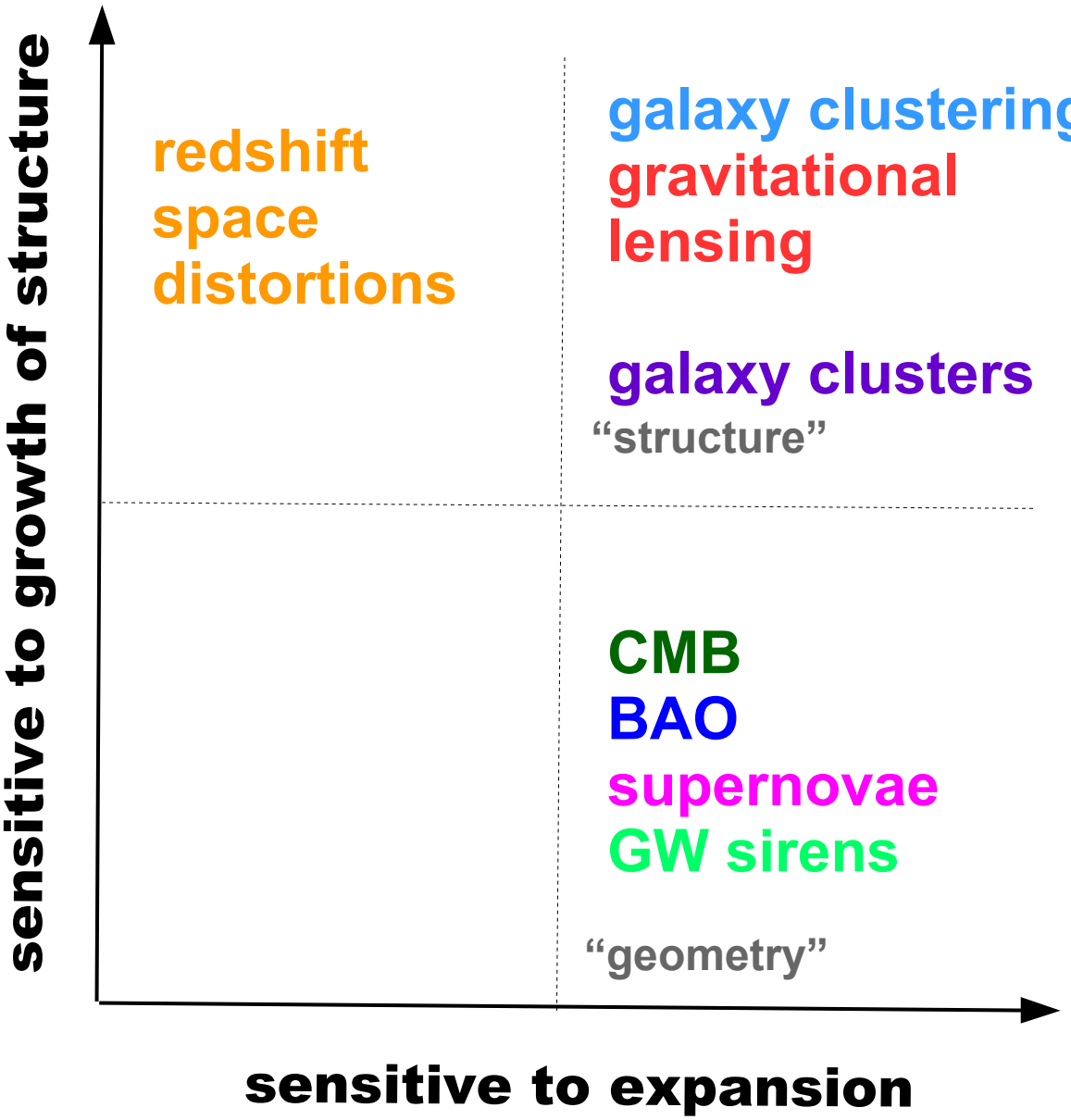
Daniel Gruen, Einstein Fellow @ Stanford / SLAC
on behalf of the DES Collaboration

KIAS Workshop on Cosmology and Structure Formation 2018

Agenda

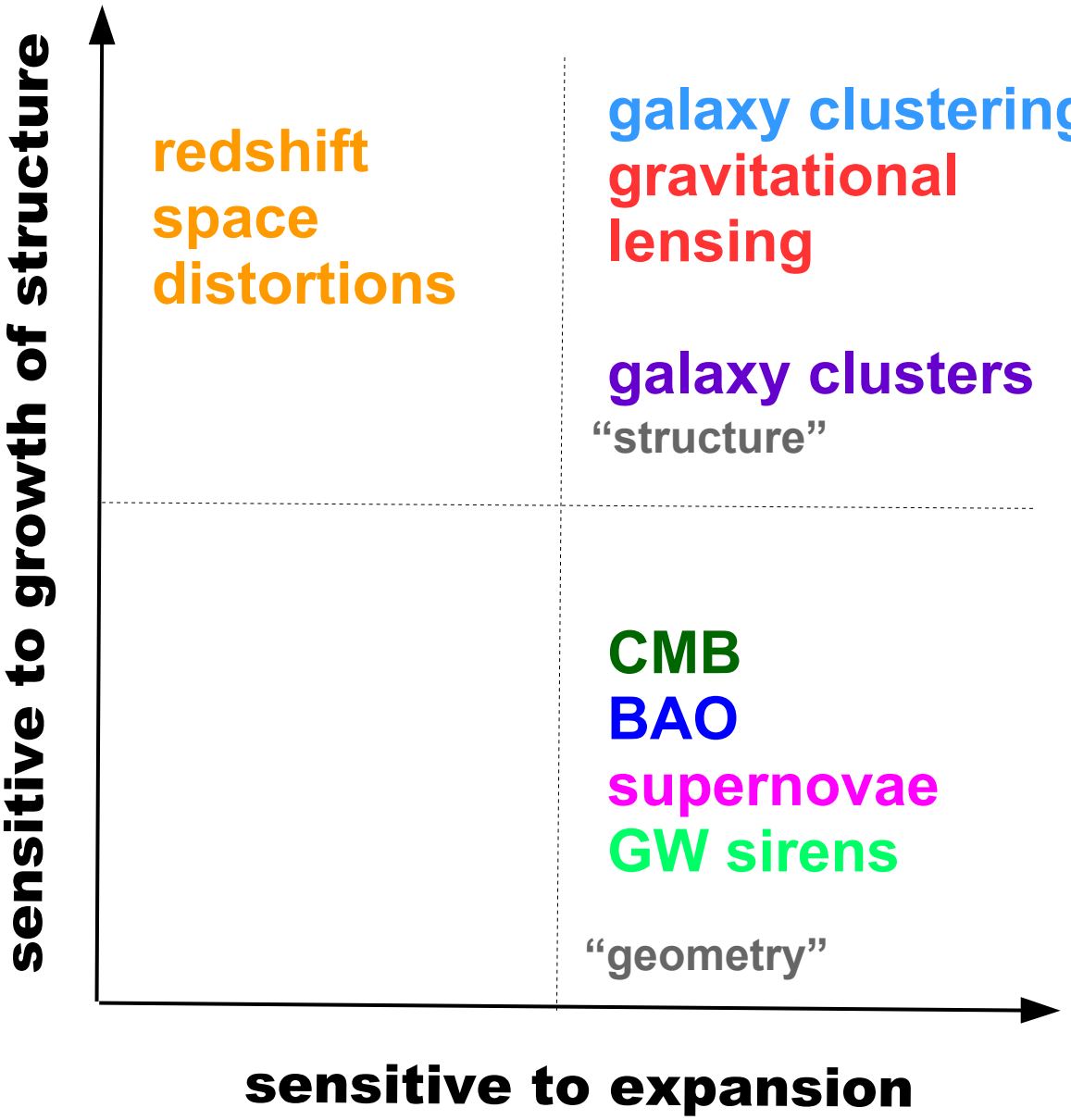
- Introduction [thanks to Myungkook!]
- Joint cosmological constraints from DES structure and geometry
- Views of the matter density field for cosmology
  - lensing/galaxy two-point functions
  - matter/galaxy density PDF
  - clusters of galaxies

How to survey Dark Energy



Q: Is everything we observe consistent with the same parameters in a ΛCDM universe?

How to survey Dark Energy



DES results

Elvin-Poole+2018

Prat, Sanchez+2018

Gruen+2018, Troxel+2018

DES 2018a

McClintock, Varga+2018

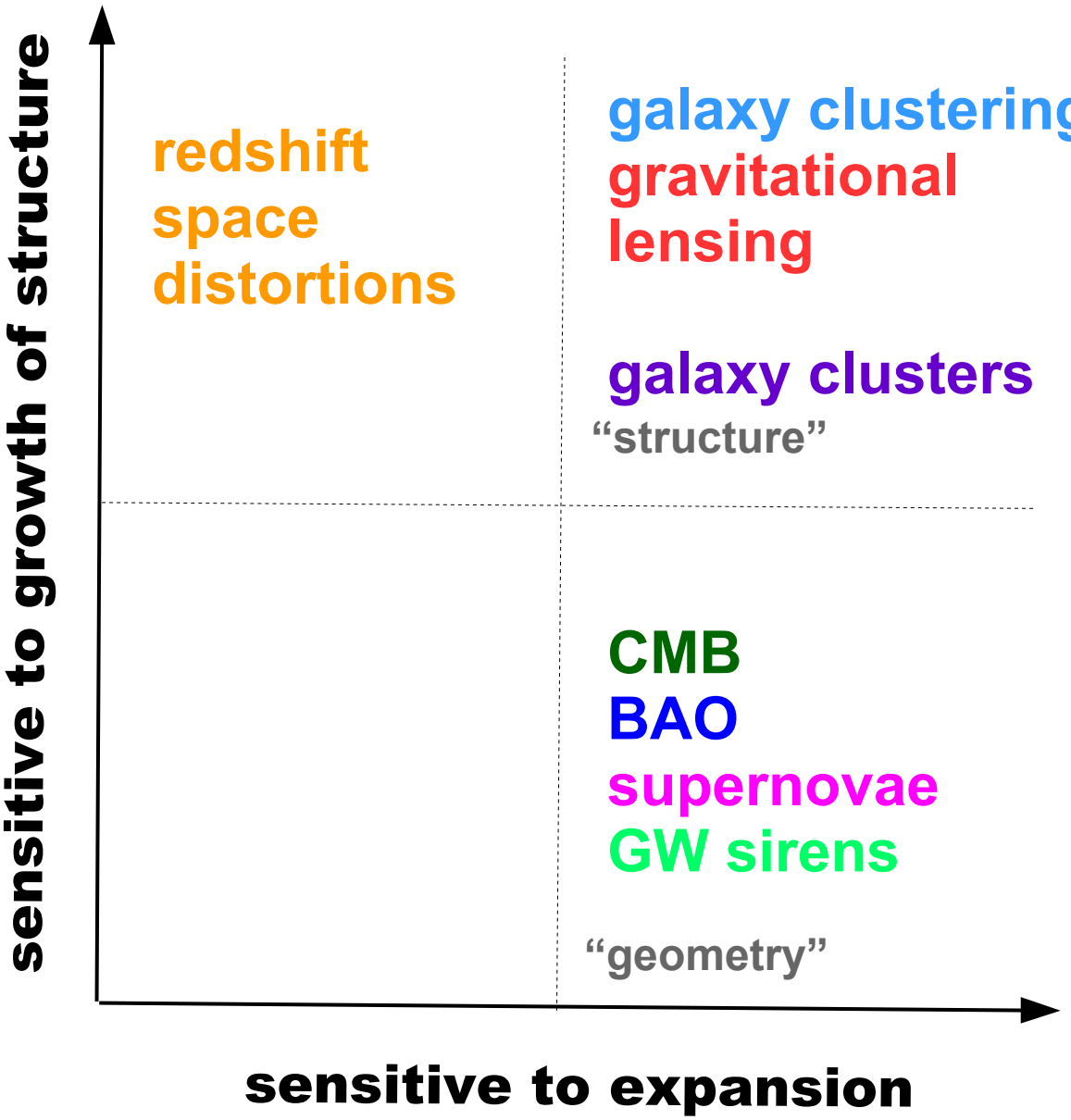
DES in prep.

DES 2018b

DES out today

LIGO-VIRGO-DES+2018

How to survey Dark Energy



Elvin-Poole+2018

Prat, Sanchez+2018

Gruen+2018, Troxel+2018

DES 2018a

McClintock, Varga+2018

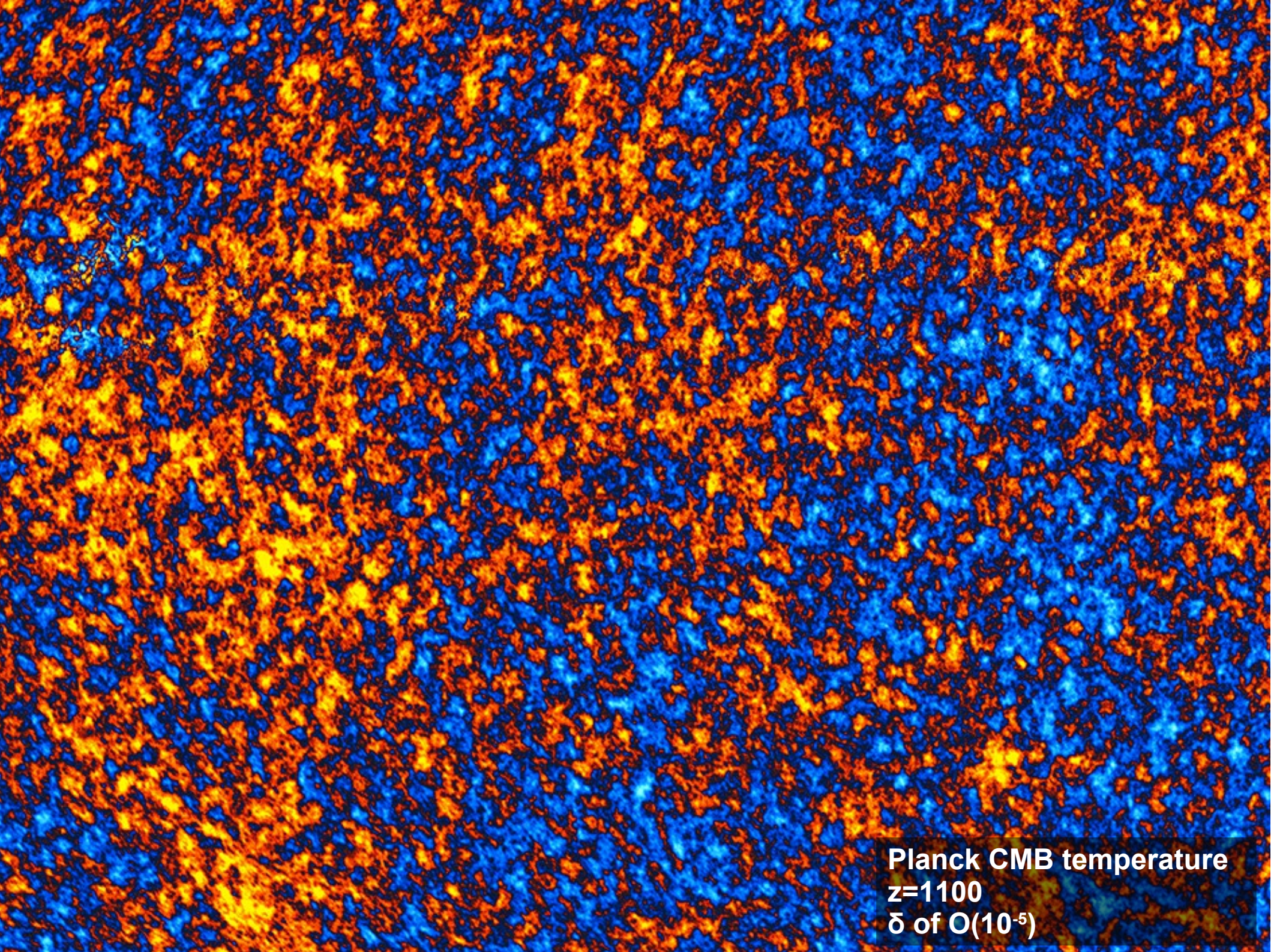
DES in prep.

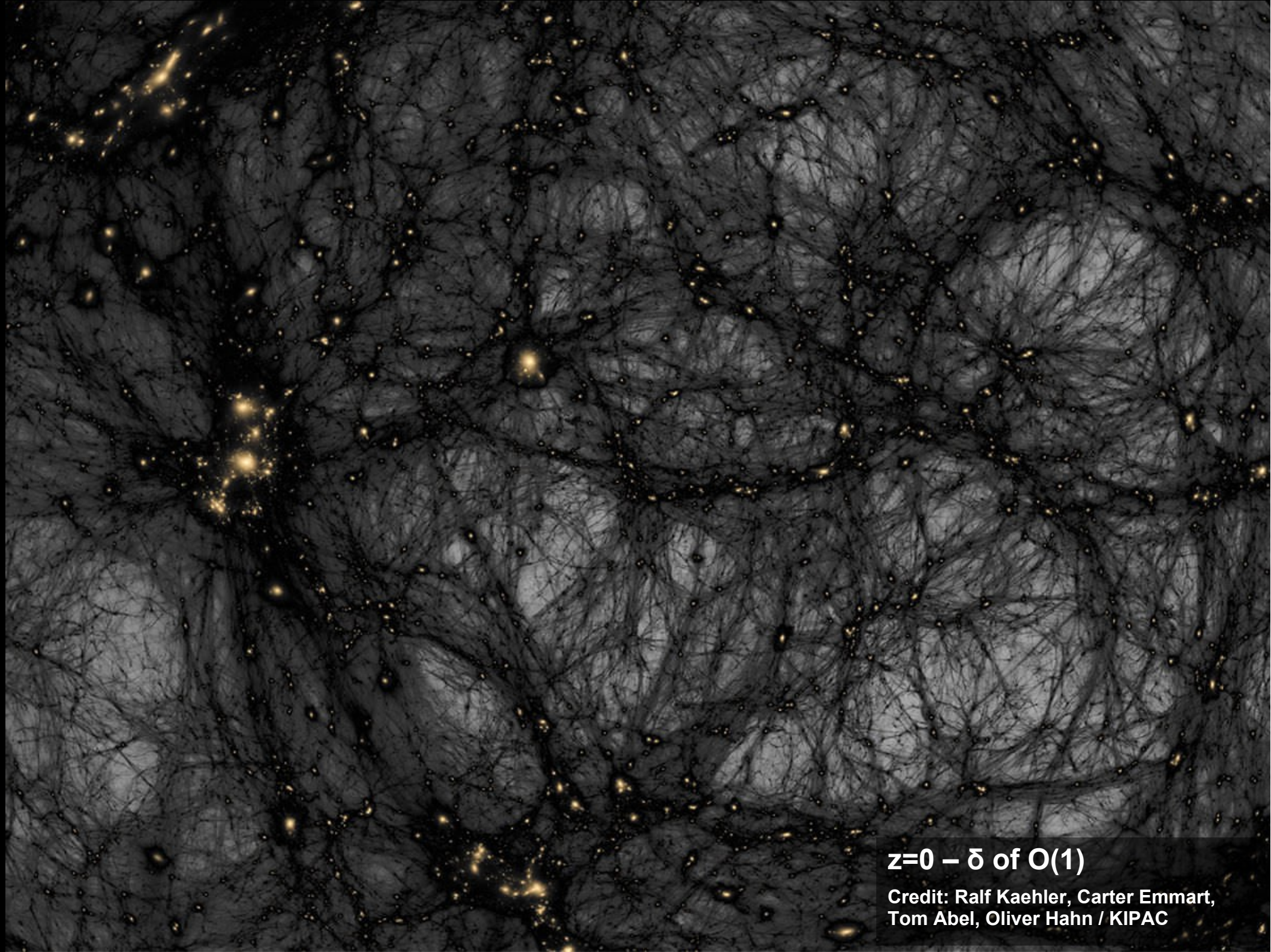
DES WL+clustering
+BAO+SNe out today

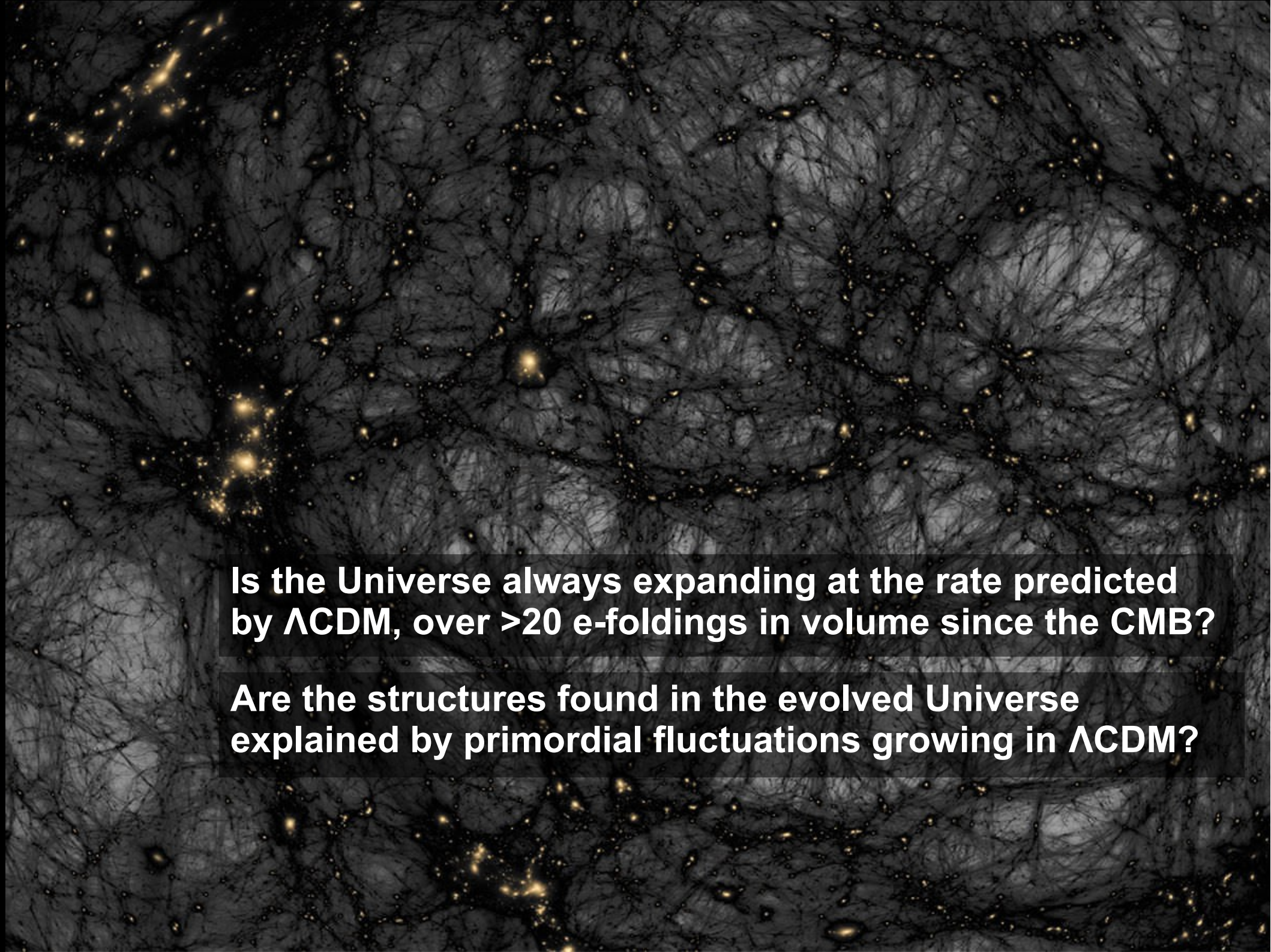
DES 2018b

DES out today

LIGO-VIRGO-DES+2018

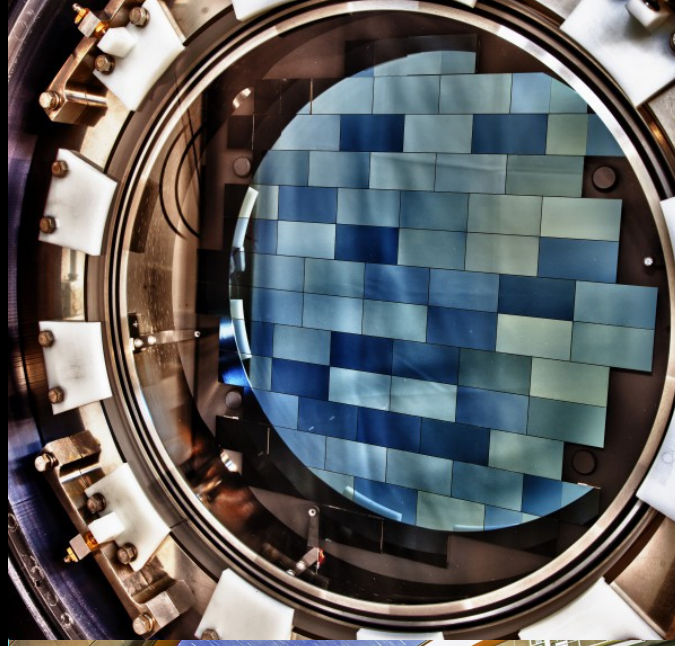

Planck CMB temperature
z=1100
δ of O(10-5)

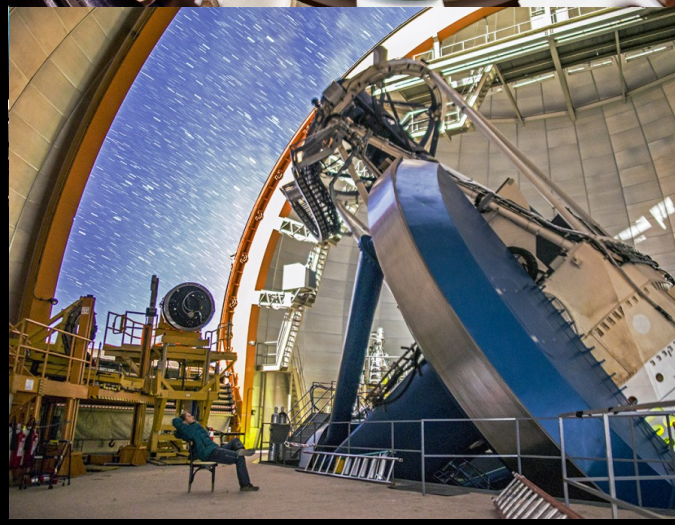

z=0 – δ of O(1)
Credit: Ralf Kaehler, Carter Emmart,
Tom Abel, Oliver Hahn / KIPAC

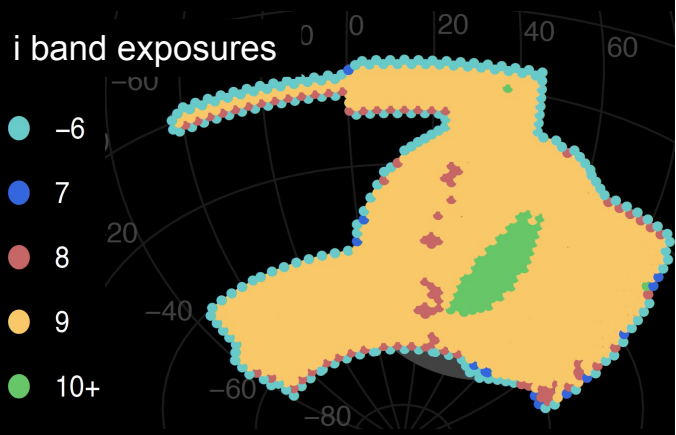

Is the Universe always expanding at the rate predicted by ΛCDM, over >20 e-foldings in volume since the CMB?
Are the structures found in the evolved Universe explained by primordial fluctuations growing in ΛCDM?

The Dark Energy Survey

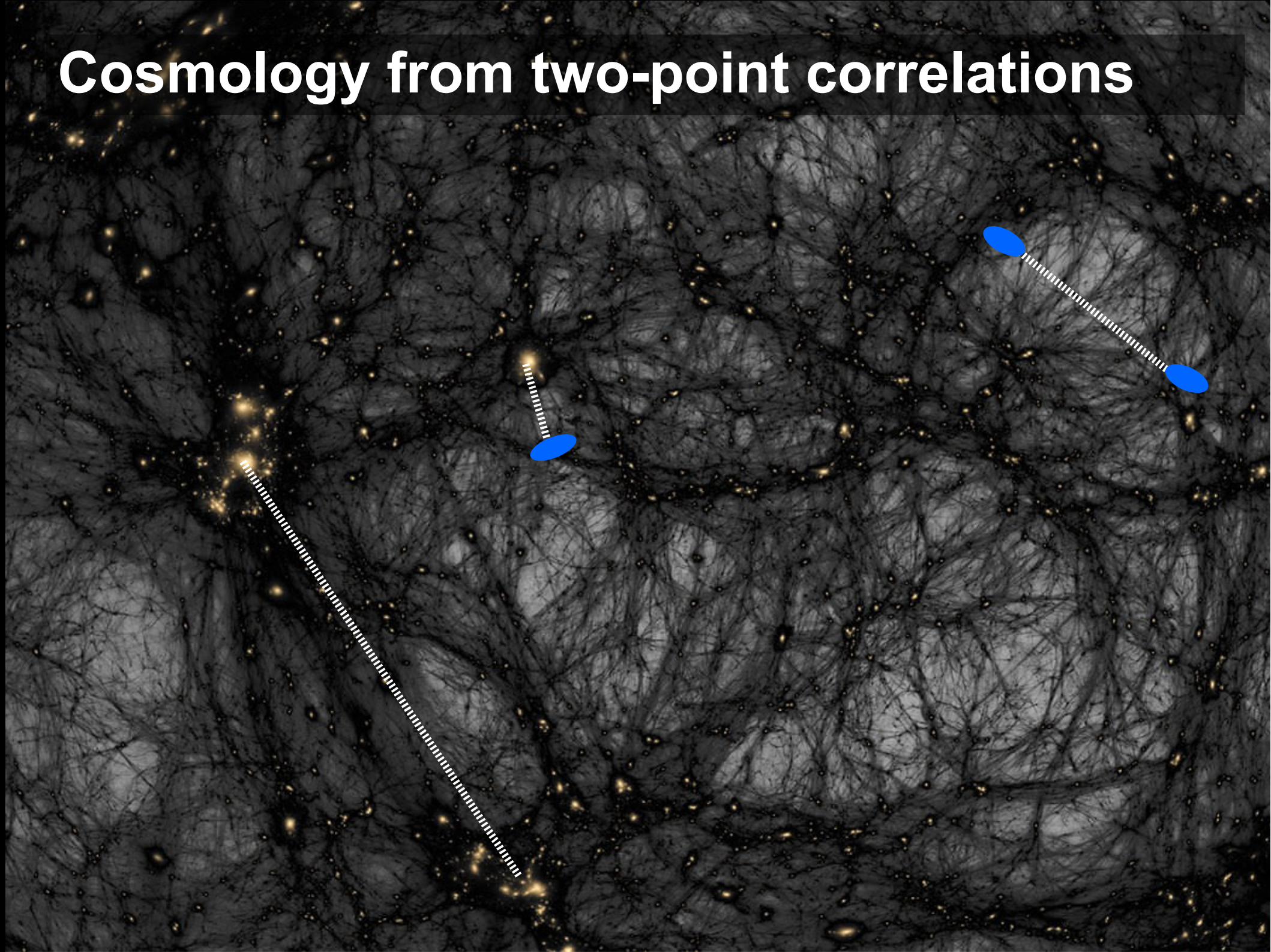
- 5000 sq. deg. survey in grizY from Blanco @ CTIO, 10 exposures, 5.5 years, >400 scientists
- Primary goal: dark energy equation of state
- Probes: Large scale structure, Supernovae, Cluster counts, Gravitational lensing
- Status:
  - Y1 (1500 sq. deg, 40% depth):
    key results published / in internal review
    https://des.ncsa.illinois.edu/releases/y1a1
  - Y3 (5000 sq. deg, 50% depth):
    data processed, vetting catalogs
    https://des.ncsa.illinois.edu/releases/dr1
  - Y5: data taking finished (90% depth)
  - Y6: homogeneous survey at planned depth



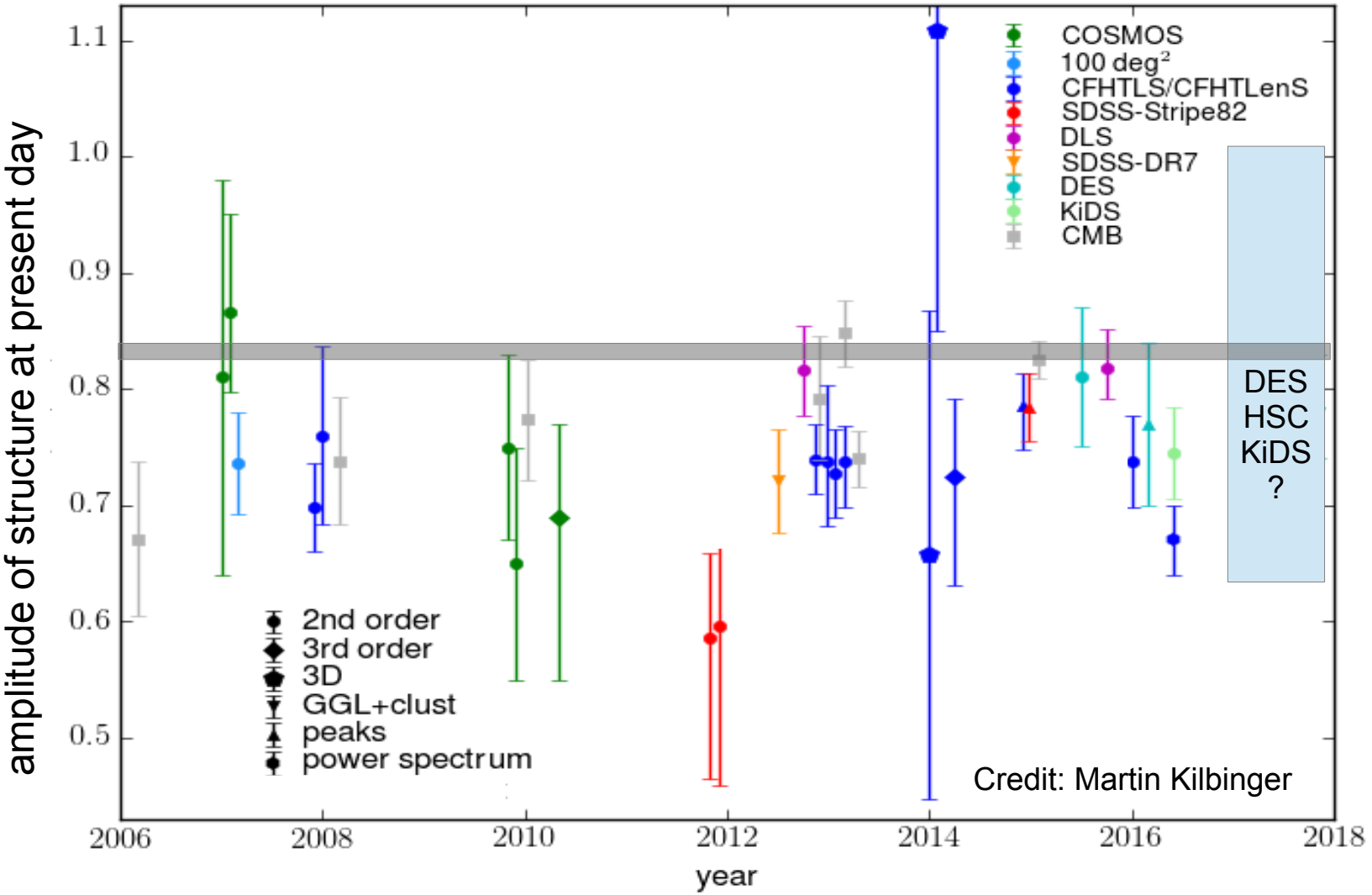




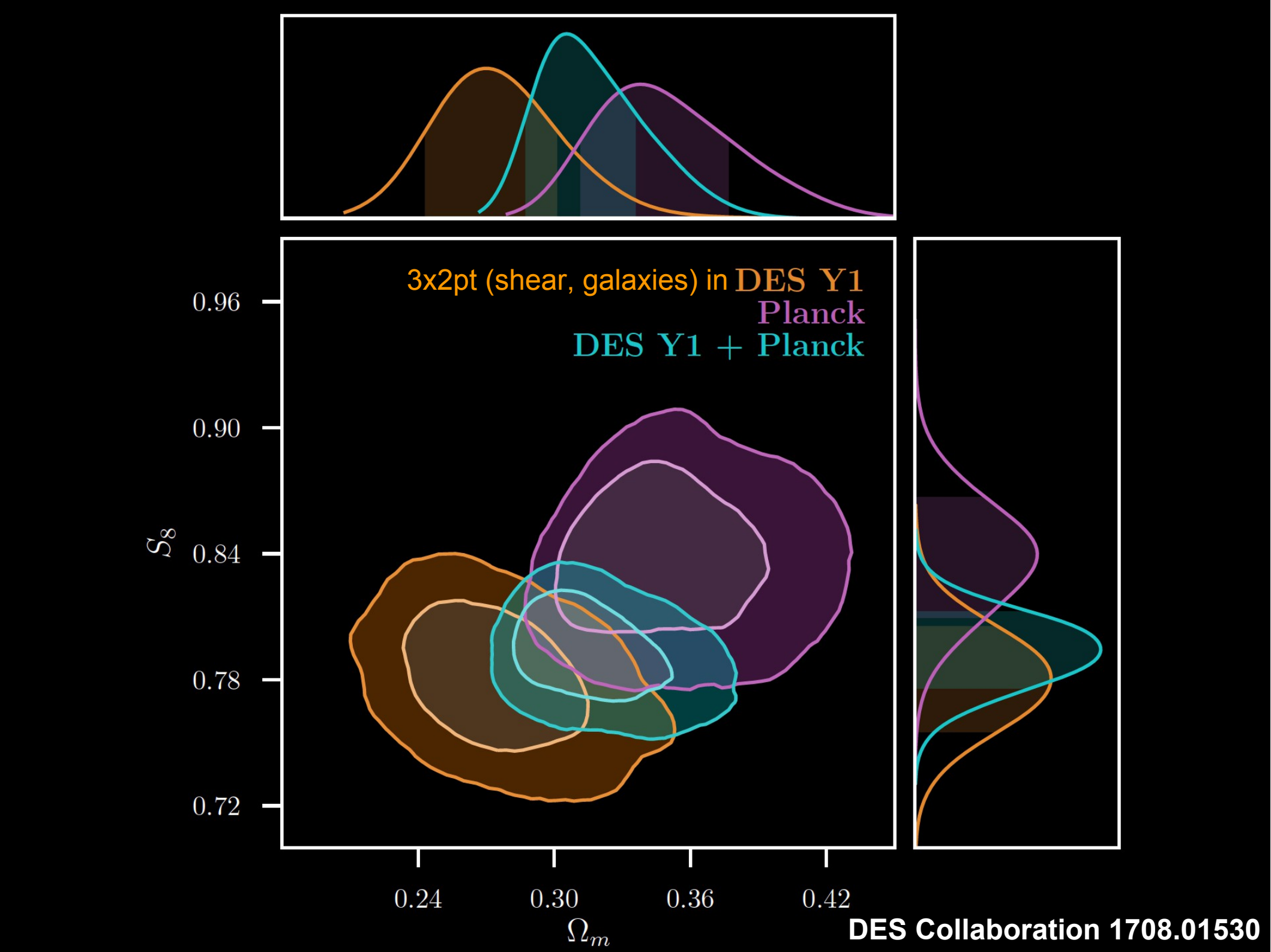
Cosmology from two-point correlations



Are lensing measurements of structure low?



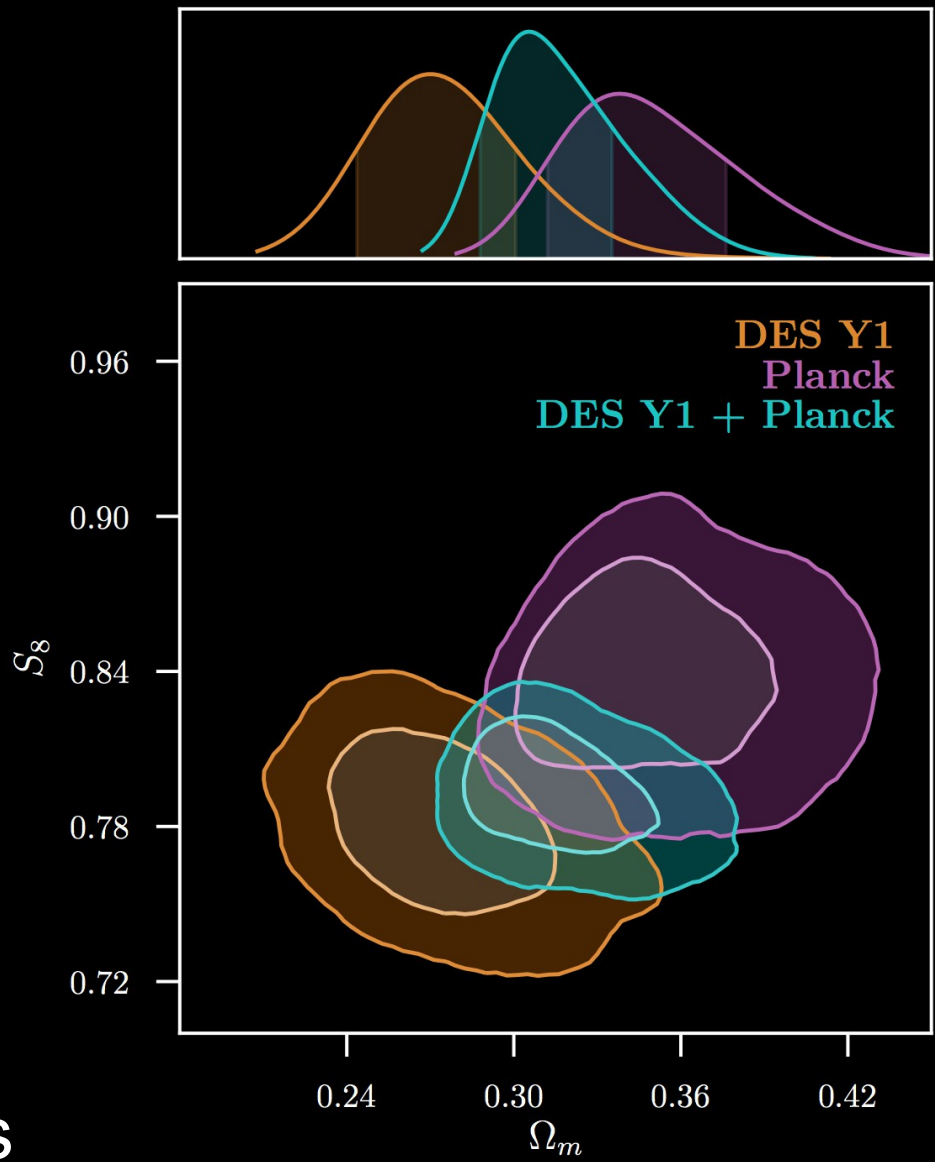
- recent studies have claimed 2-3σ offset from Planck CMB in Ω_m-σ_8
  but see Troxel&Krause, DG+ 1804.10663
- interpretations differ – statistical fluke, systematics, crack in ΛCDM?

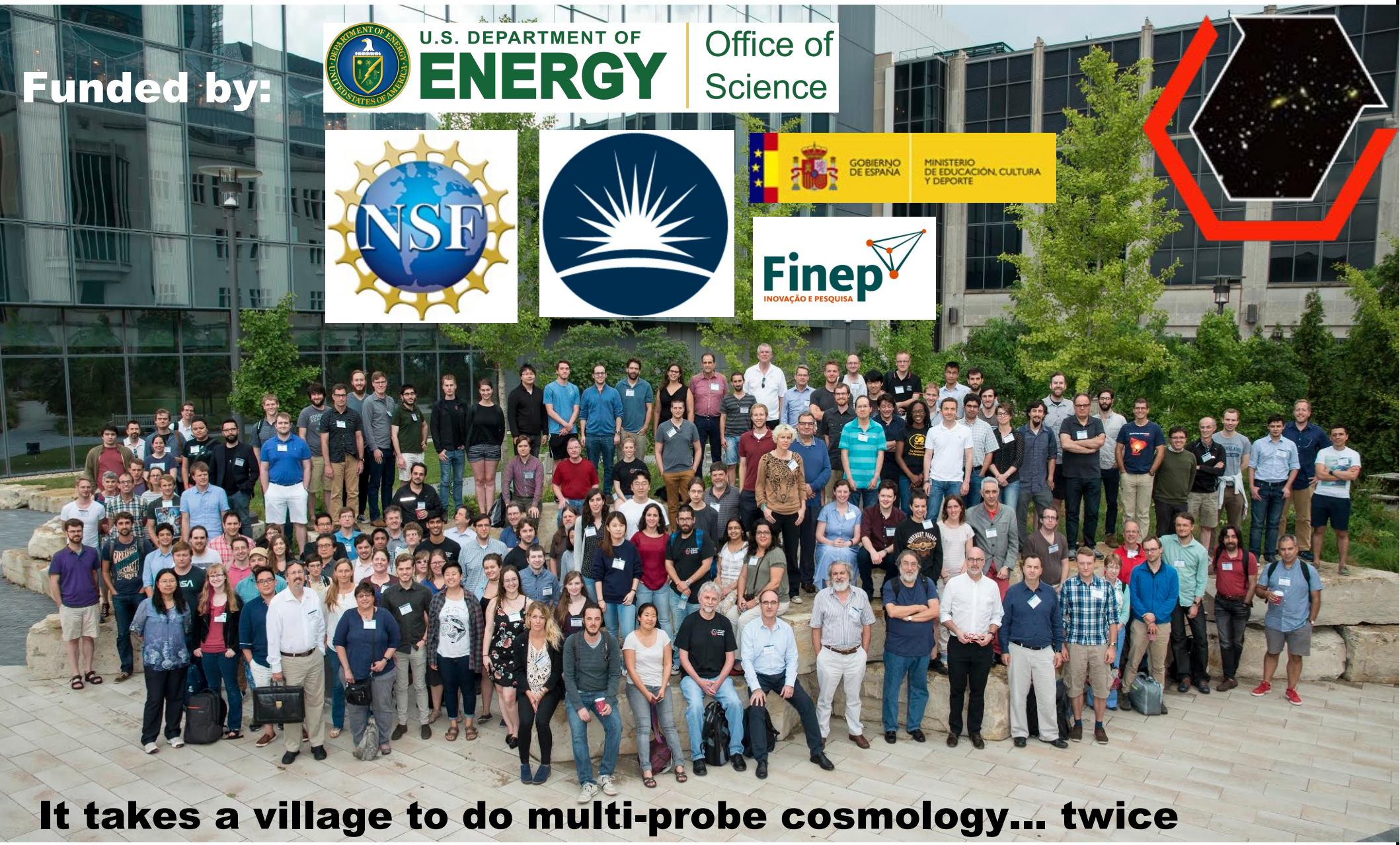


DES Collaboration 1708.01530

Key result: Consistency of late structure with Planck in ΛCDM

- DES and Planck constrain matter density and S_8 with equal strength
- Difference in central values 1-2σ in the same direction as other lensing results
- Bayes Factor shows no evidence for inconsistency
- Combination with CMB/BAO/SNe yields consistent, tightest constraints





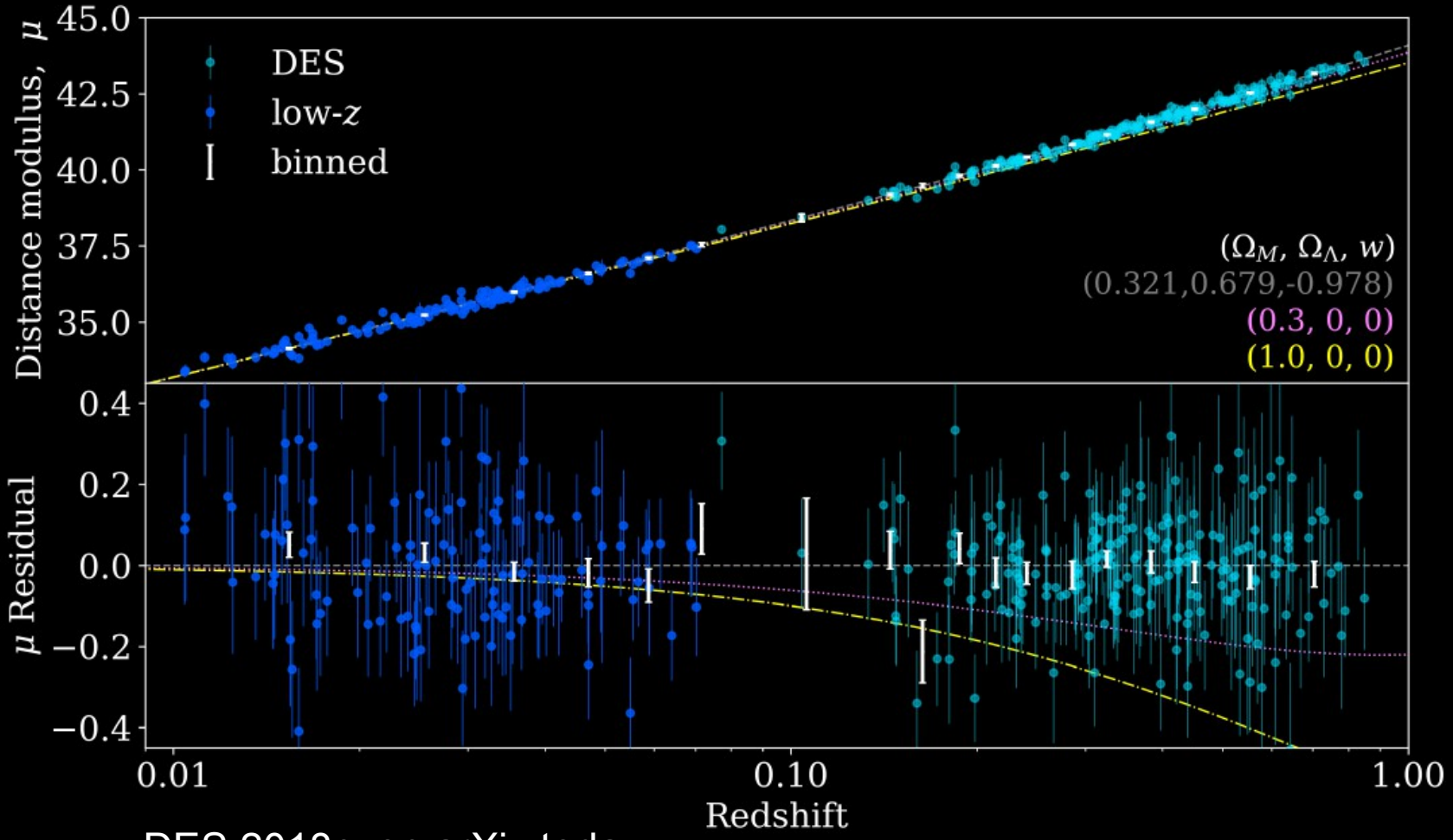
Collaborating institutions:

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

Released today:
Cosmology from DES Supernovae

207 SNe Ia, w/ spectroscopic confirmation from three years of DES

$w = -0.978 \pm 0.059$ w/ Planck, 1.4x the uncertainty of Pantheon



DES 2018c, on arXiv today

On arXiv today:

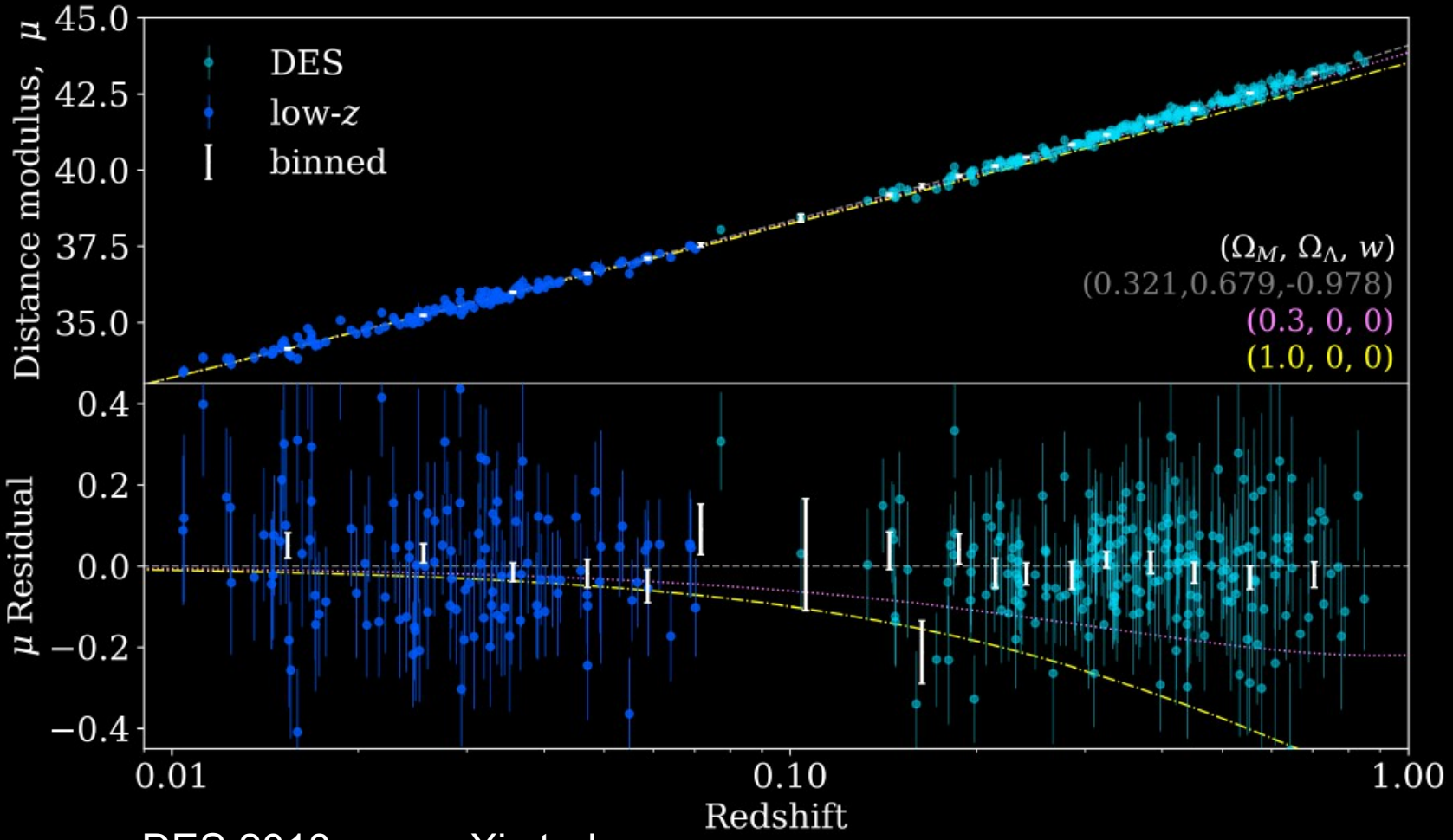
DES 2018d

Brout+ a&b
D'Andrea+
Hinton+
Kessler+
Lasker+

Released today:
Cosmology from DES Supernovae

207 SNe Ia, w/ spectroscopic confirmation from three years of DES

$w = -0.978 \pm 0.059$ w/ Planck, 1.4x the uncertainty of Pantheon



DES 2018c, on arXiv today

On arXiv today:

DES 2018d

Macaulay+
H_0 from inverse distance ladder w/ BOSS BAO

67.77 ± 1.30

DES 3x2pt + BAO + BBN:

67.2±1.2 km/s/Mpc

(DES 2018c)

Released today:
Cosmology from DES 2pt+BAO+SNe

First joint constraint from structure + geometry in an imaging survey

SNe Ia:
207 DES SNe
(no low-z)

Phot. BAO:
angular clustering
of 1.6m DES Y1
galaxies at z=0.6-1

DES 3x2pt:
DES Y1
galaxy/shear 2pt
functions

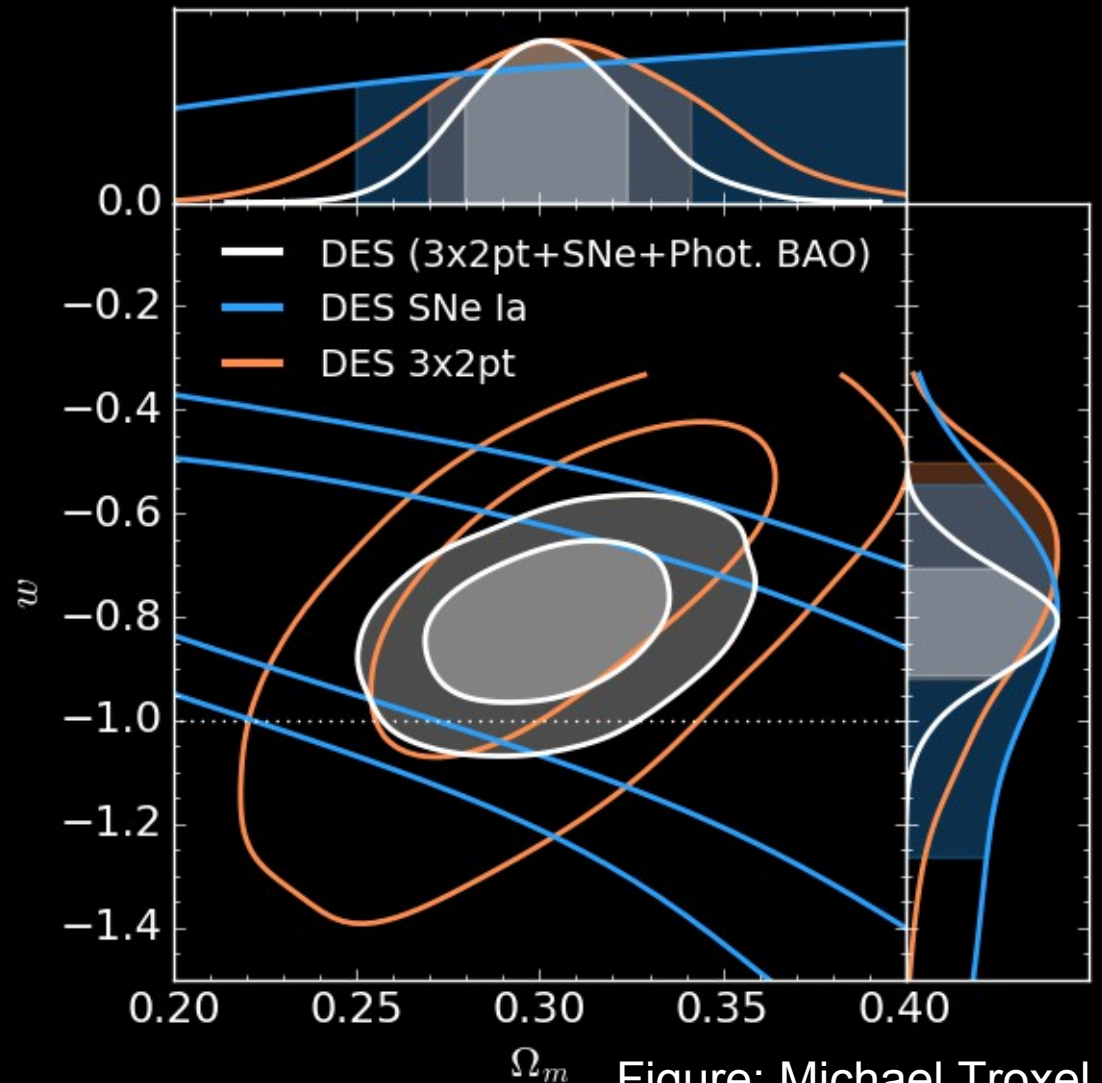


Figure: Michael Troxel

On arXiv today:

DES 2018d
DES 2018e

see also:

DES 2018ab
(3x2pt + BAO)

Released today:
Cosmology from DES 2pt+BAO+SNe

First joint constraint from structure + geometry in an imaging survey

DES against the rest:

consistent in wCDM

Parameter	wCDM
Ω_m	$0.300^{+0.023}_{-0.021}$
Ω_b	$0.064^{+0.013}_{-0.009}$
Ω_k	0
Ω_Λ	$0.700^{+0.021}_{-0.023}$
w	$-0.80^{+0.09}_{-0.11}$
S_8	$0.786^{+0.029}_{-0.019}$

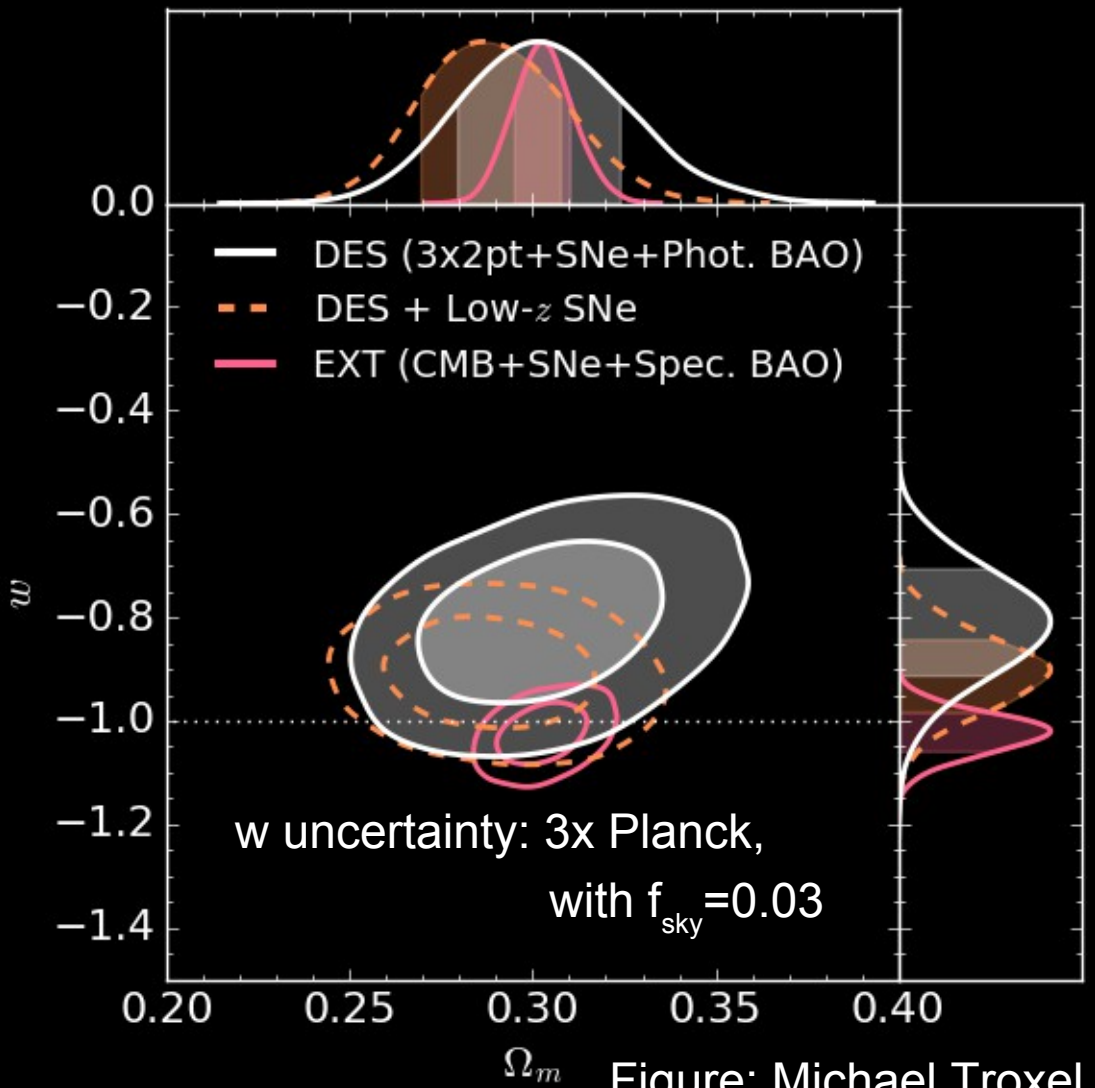


Figure: Michael Troxel

On arXiv today:

DES 2018d
DES 2018e

see also:

DES 2018ab
(3x2pt + BAO)

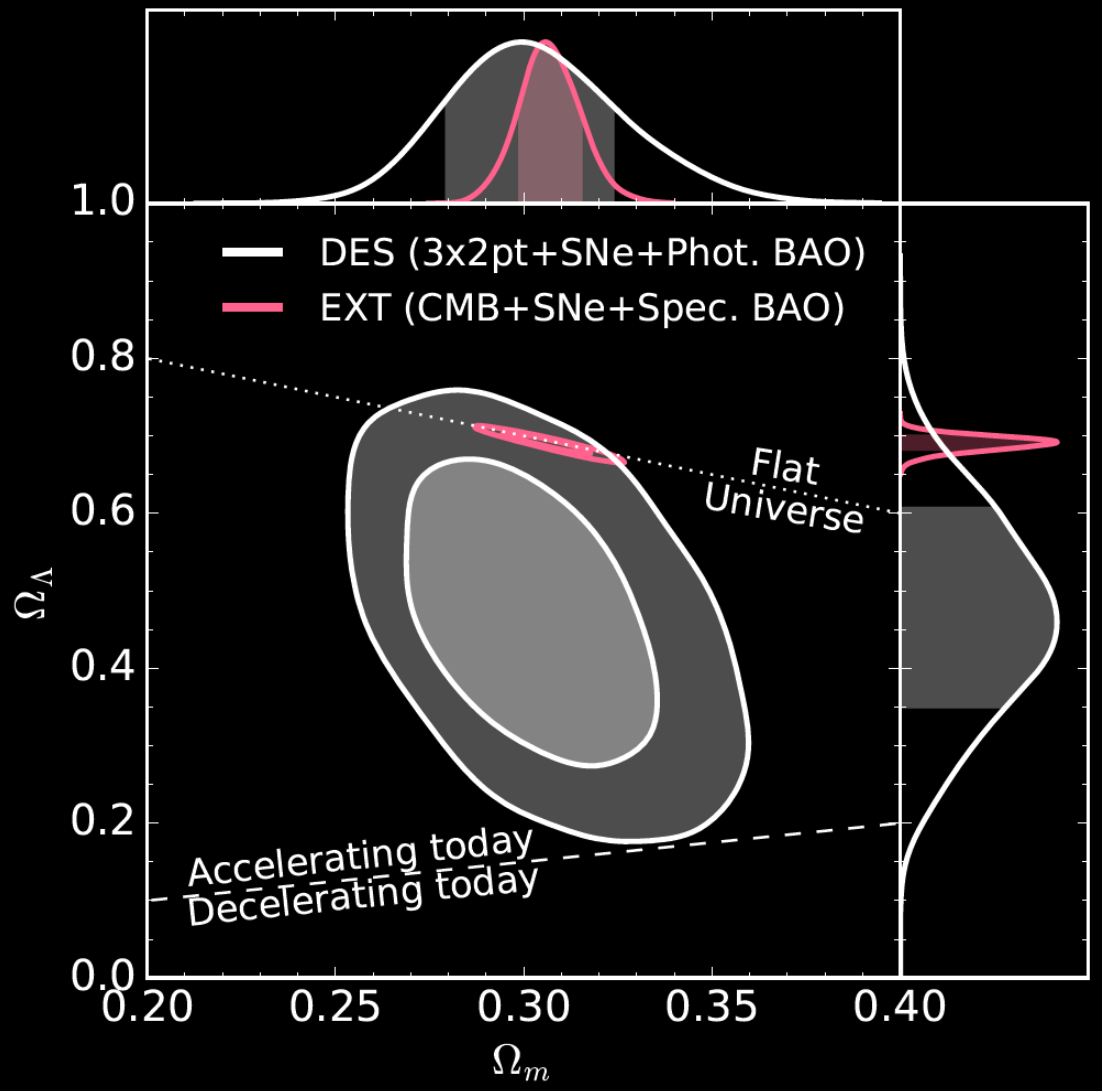
Released today:
Cosmology from DES 2pt+BAO+SNe

First joint constraint from structure + geometry in an imaging survey

DES against the rest:

consistent in open ΛCDM

Parameter	oCDM
Ω_m	$0.299^{+0.024}_{-0.020}$
Ω_b	$0.069^{+0.009}_{-0.012}$
Ω_k	$0.252^{+0.095}_{-0.14}$
Ω_Λ	$0.47^{+0.14}_{-0.12}$
w	-1
S_8	$0.801^{+0.028}_{-0.026}$

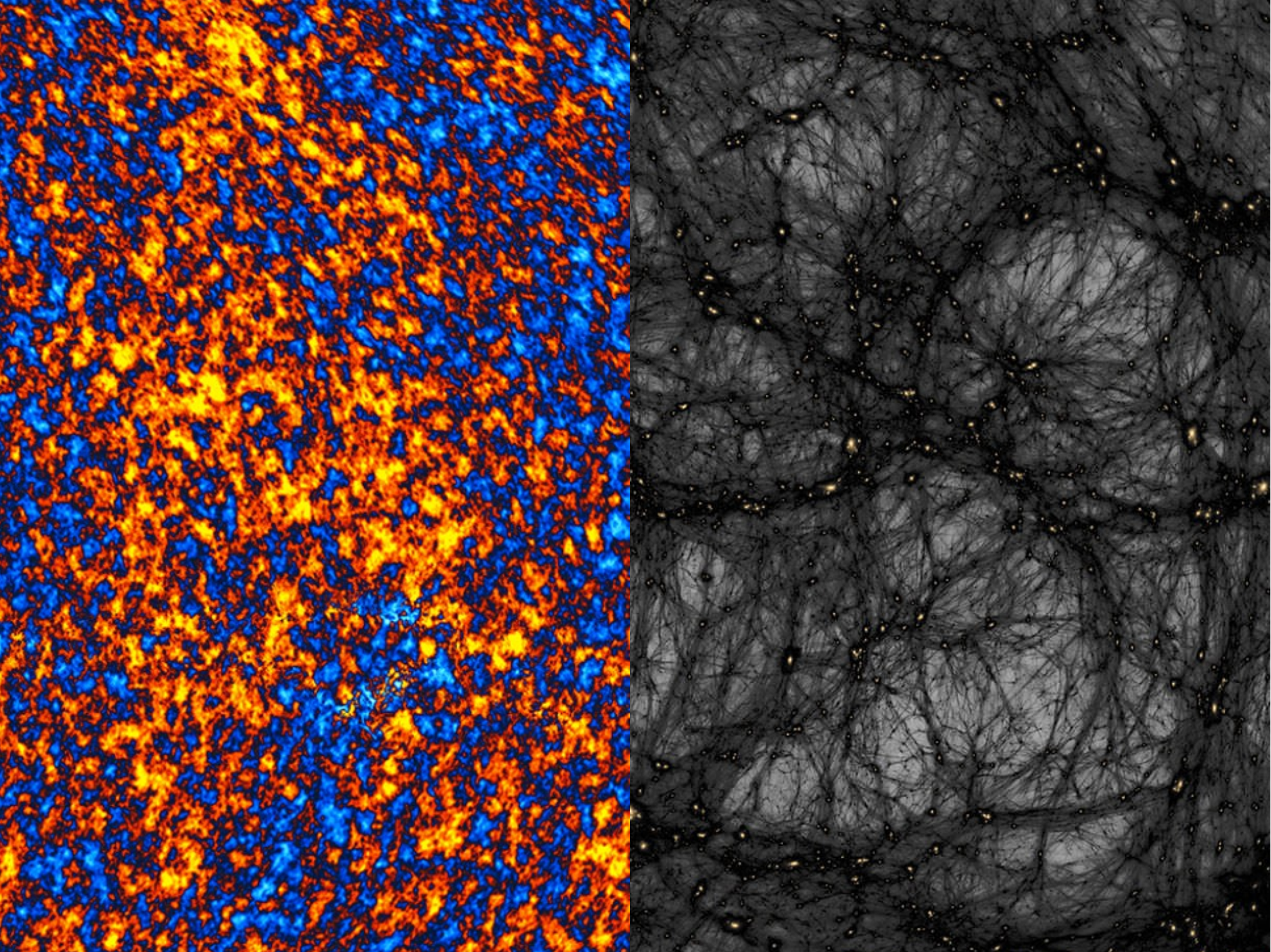


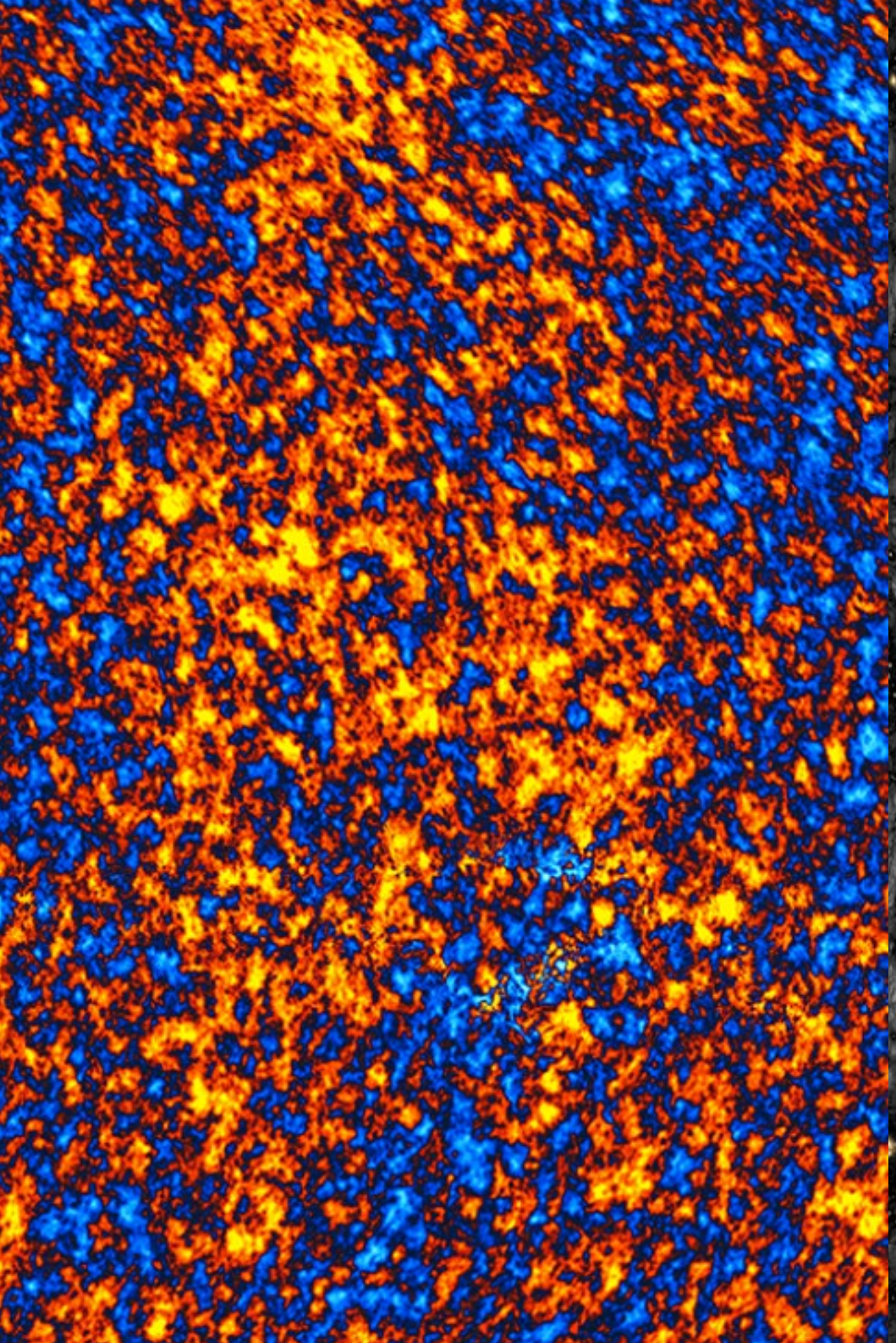
On arXiv today:

DES 2018d
DES 2018e

see also:

DES 2018ab
(3x2pt + BAO)

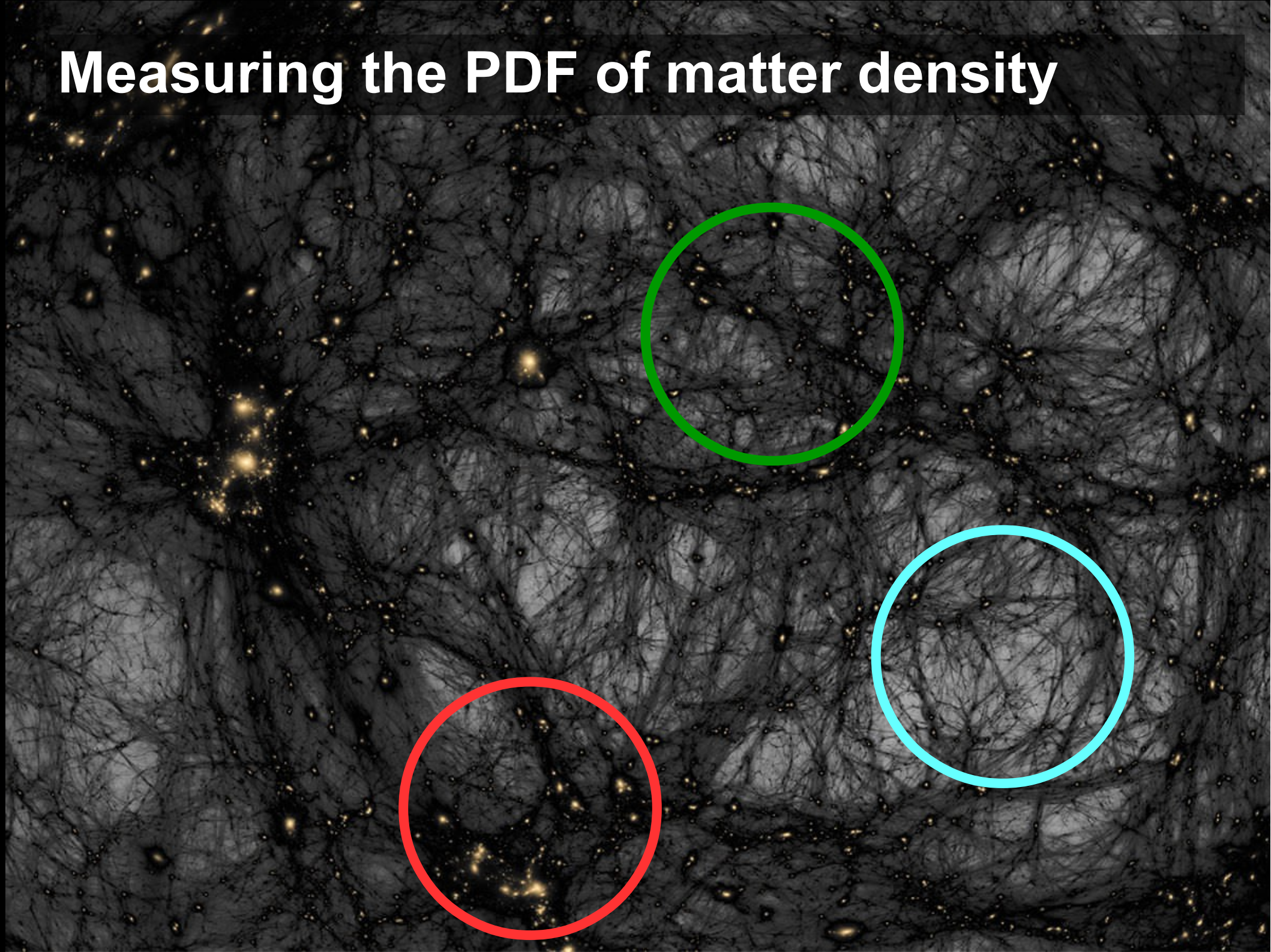




Non-Gaussian properties of structure at least double the cosmological information

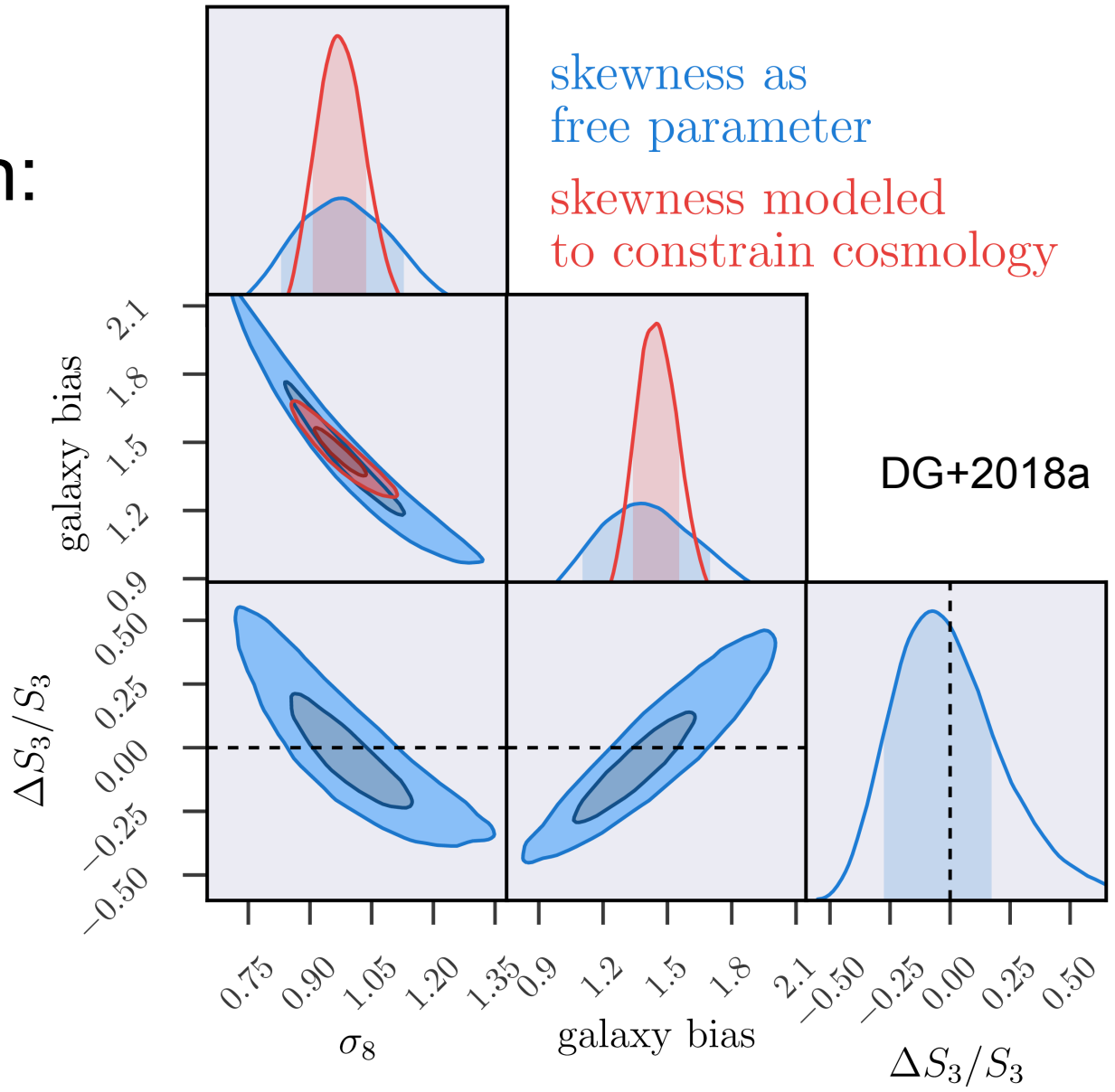
They also at least double the complexity of modeling and simulation-based validation

Measuring the PDF of matter density

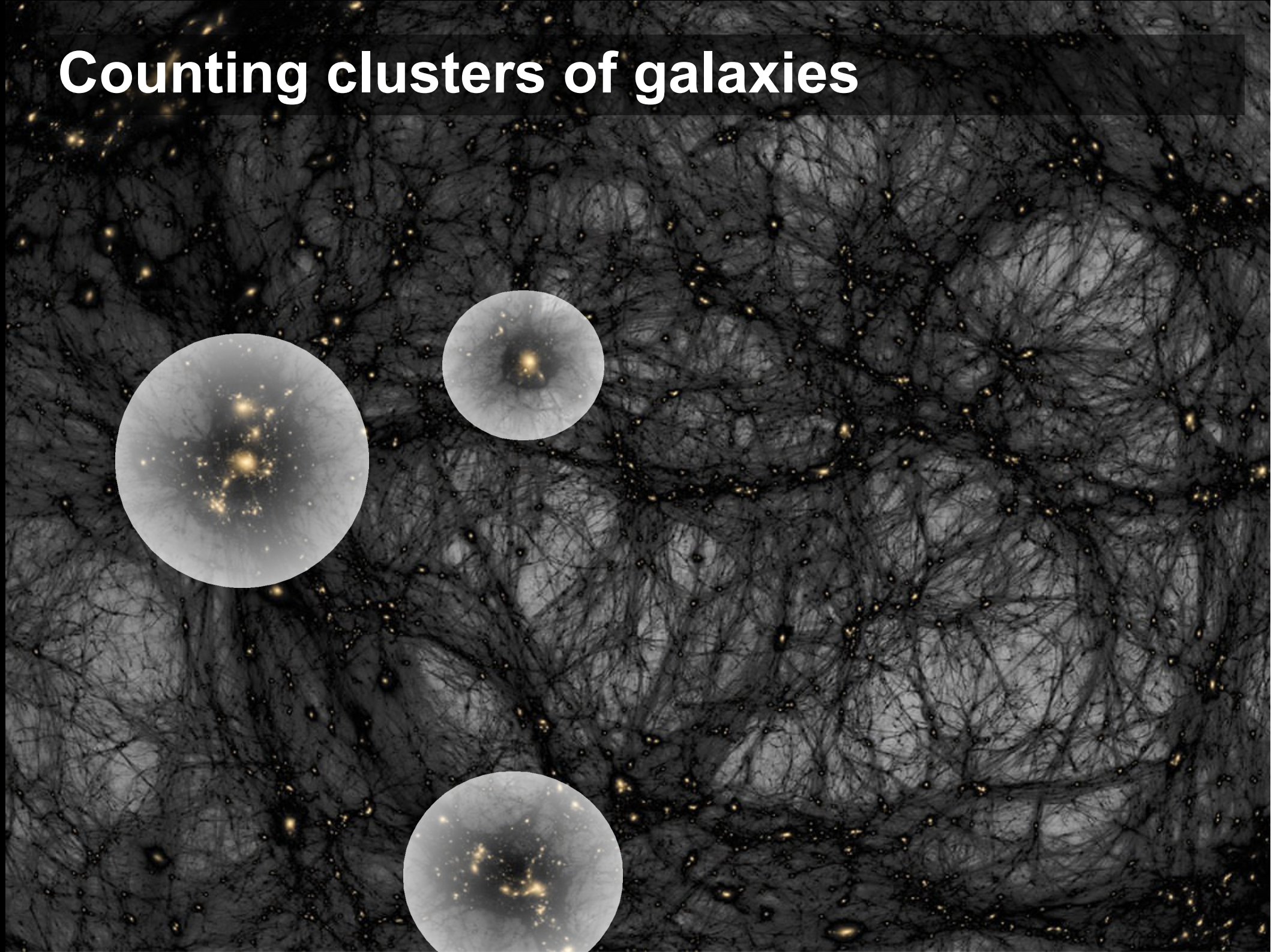


Cosmology from matter/galaxy PDF: skewness of matter density

- Lensing + counts in cells jointly constrain:
  - Cosmology
  - Bias + Stochasticity
  - Skewness of matter density: $S_3 \equiv \frac{\langle \delta^3 \rangle}{\langle \delta^2 \rangle^2}$
- Skewness adds significant constraining power



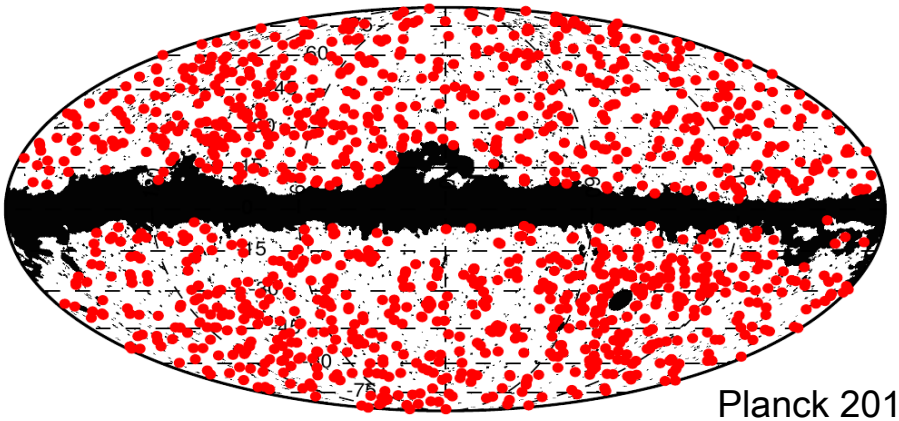
Counting clusters of galaxies



Cosmology with clusters of galaxies

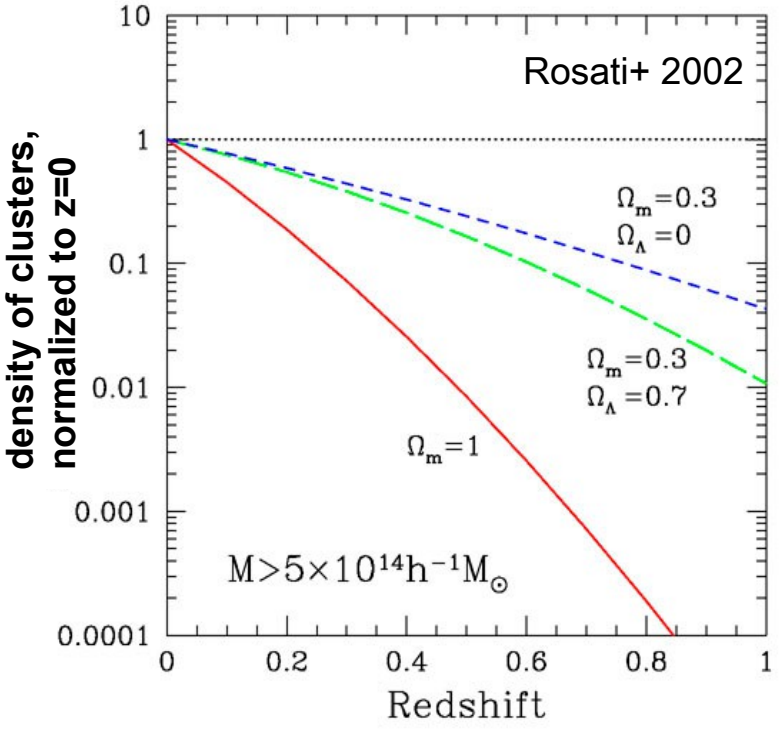
Simply ...

- Count clusters in an optical / X-ray / SZ survey



Planck 2015

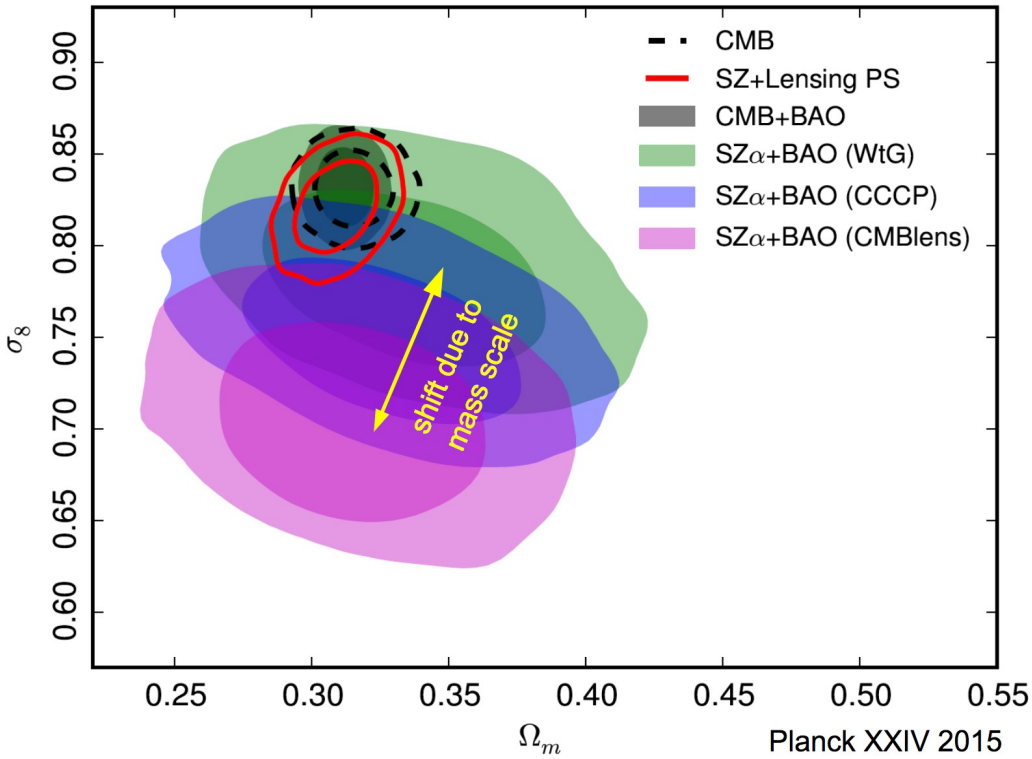
- Compare count to predictions as function of cosmology
  - M dependence: S_8, new physics
  - z dependence: Dark Energy



Cosmology with clusters of galaxies: Mass-observable relation is key

Simply ...

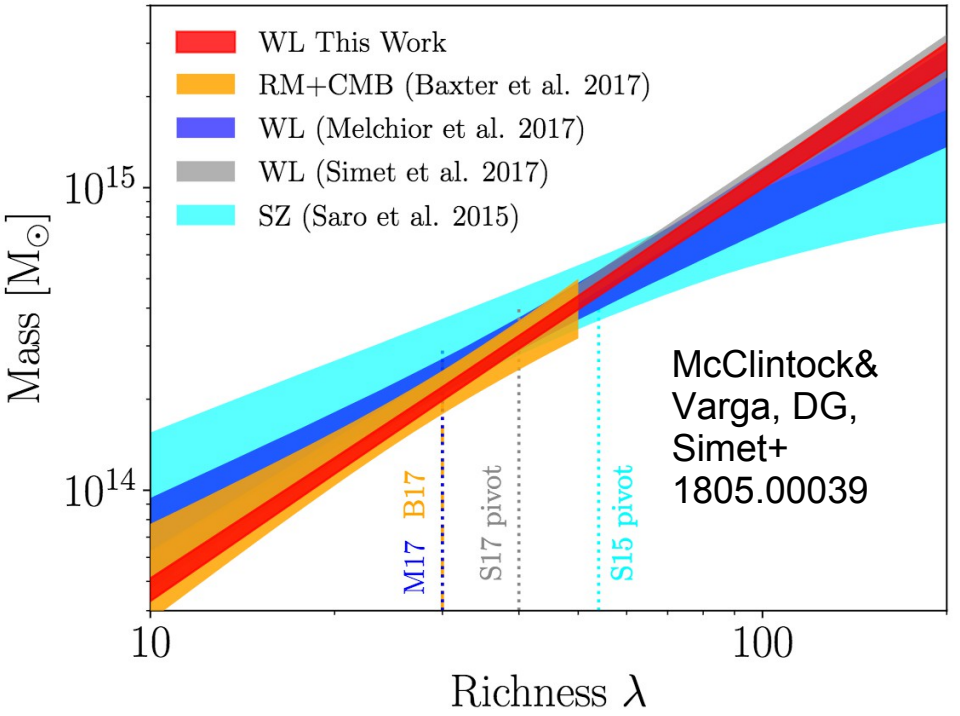
- Count clusters in an optical / X-ray / SZ survey
- Calibrate MOR, including scatter
- Compare count to predictions as function of cosmology
  - M dependence: S_8, new physics
  - z dependence: Dark Energy



see also DG+2014 for first lensing calibration of Planck SZ MOR

Mass-observable relation: Weak lensing is key for mean mass

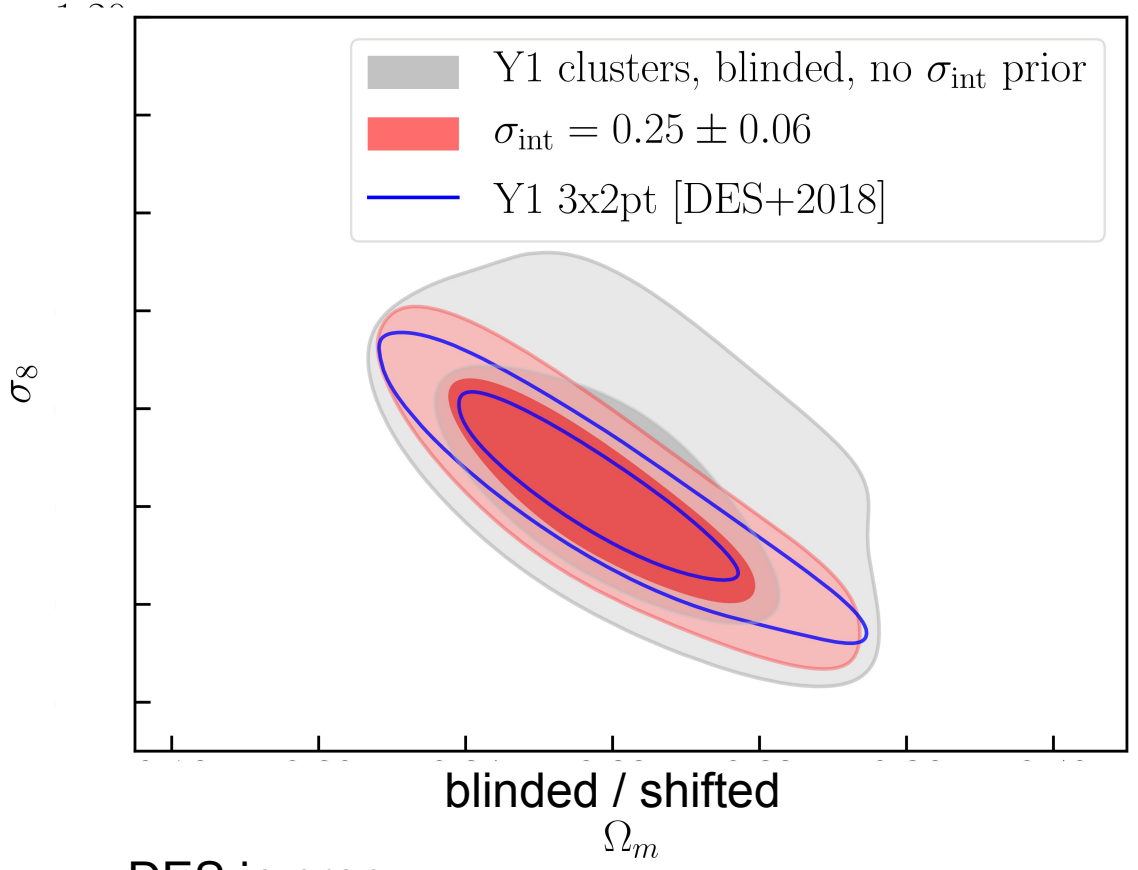
- Large area lensing surveys are now by far the best calibrator of mean mass of cluster samples
- Uncertainties are now limited by modeling – we need (hydro) simulations



Source of systematic	SV Amplitude uncertainty	Y1 Amplitude Uncertainty
Shear measurement	4%	1.7%
Photometric redshifts	3%	2.6%
Modeling systematics	2%	0.73%
Cluster triaxiality	2%	2.0%
Line-of-sight projections	2%	2.0%
Membership dilution + miscentering	$\leqslant$ 1%	0.78%
Total Systematics	6.1%	4.3%
Total Statistical	9.4%	2.4%
Total	11.2%	5.0%

Mass-observable relation: We are limited by scatter prior

- greatly improved model for scatter due to projection effects [Costanzi&Rozo+2018a]
- intrinsic scatter is a free parameter
- prior motivated by dedicated&archival X-ray and SZ data
- daily telecons, unblinding this week
- DES Y1 clusters will significantly add to S_8 issue – we need to get this right



DES in prep.

see also Costanzi&Rozo+2018ab, McClintock&Varga, DG+2018, DG+2018b, Zhang+2018, Farahi+in prep., von der Linden&Mantz+in prep.

Summary

- The Dark Energy Survey tests cosmology competitively, with lensing-empowered measurements of structure.
  - Consistency with Planck CMB, but intriguingly low S_8
  - Different, almost fully independent, views of Gaussian and non-Gaussian properties of density field.

- Geometry and growth of structure are complementary. DES is the first photometric survey to join them. Both are consistent with the simple yet crazy ΛCDM.
- Stay tuned for 5x more DES and next generation surveys.