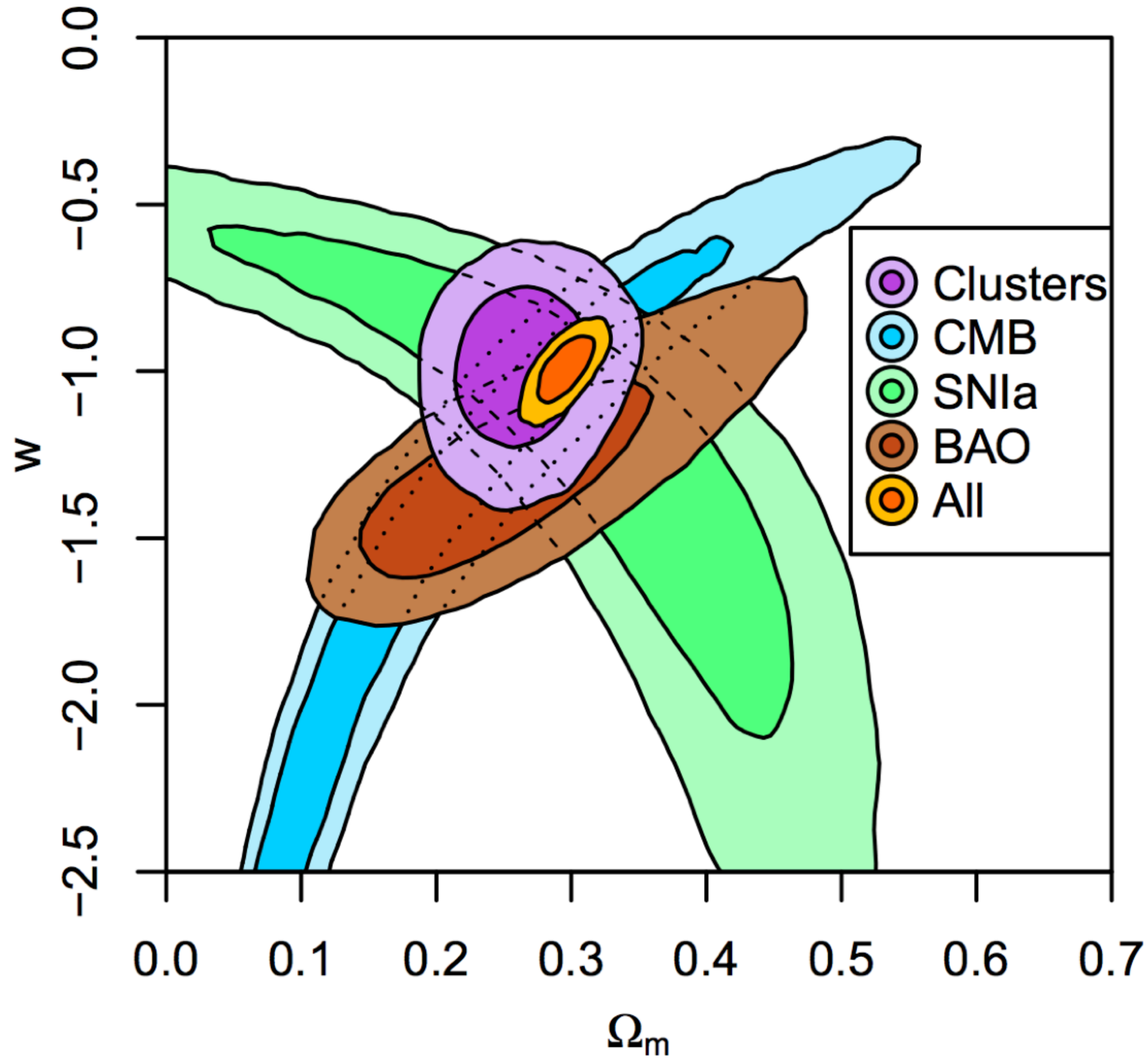
New results from the Dark Energy Survey

Eric Baxter, University of Pennsylvania
with the Dark Energy Survey collaboration

DARK ENERGY SURVEY

The Success of LCDM

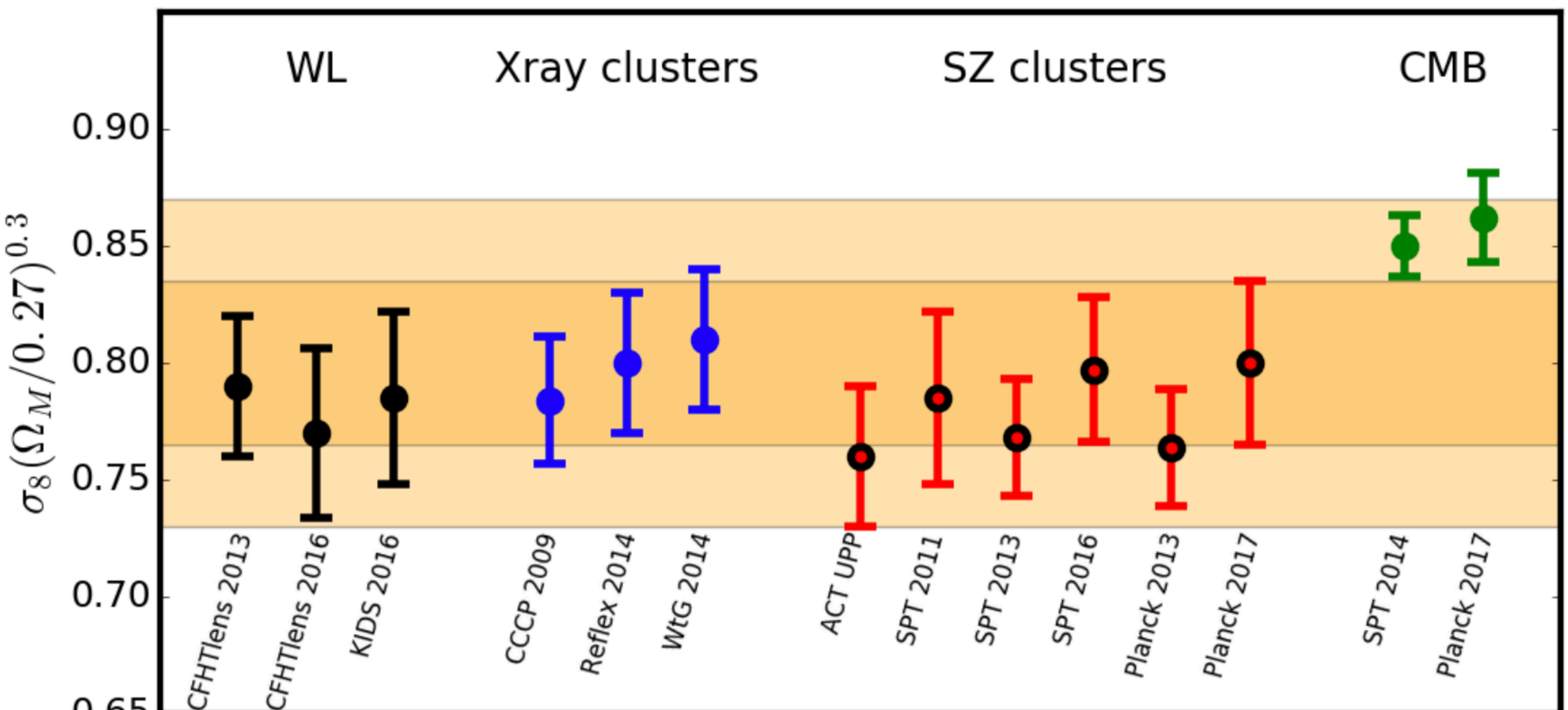
LCDM model explains many observations amazingly well



Mantz et al. 2014

The beginning of tension?

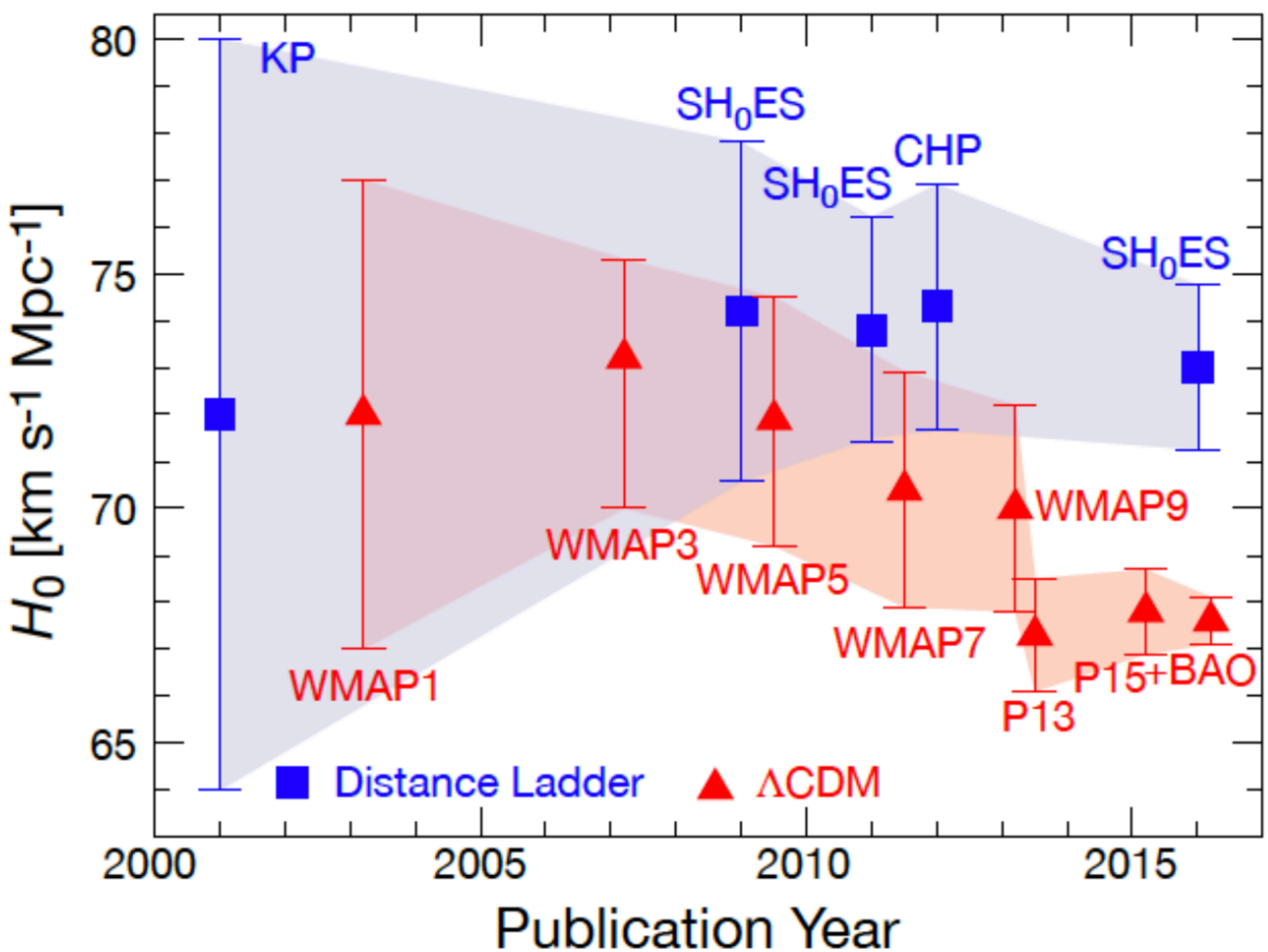
σ_8: lensing (+clusters) vs. CMB



Douspis et al.

The beginning of tension?

H_0: local vs. CMB (+BAO)



Freedman, 2017

What do you when model tension is at the 2-4σ level?

What do you when model tension is at the 2-4σ level?

Collect more data!

The Dark Energy Survey

5.5 year survey of 5000 sq. deg. of southern sky in optical wavelengths

4 meter mirror

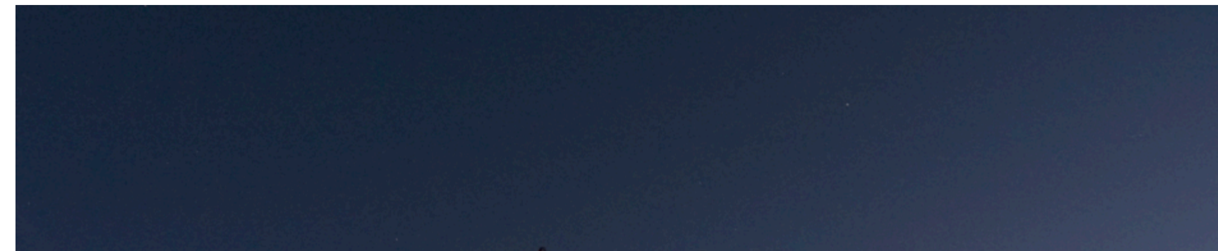
Dark energy camera (DECam)
Wide field of view, 62 CCDs, red optimized

Year 5 data already collected

Many probes: weak lensing, galaxy clustering, clusters, supernovae

The Dark Energy Survey

5.5 year survey of 5000 sq. deg. of southern sky in optical



Many probes: weak lensing, galaxy clustering, clusters, supernovae

Outline

1. Year one two-point function analysis
2. DES + BAO constraint on Hubble constant
3. Going to small scales: splashback

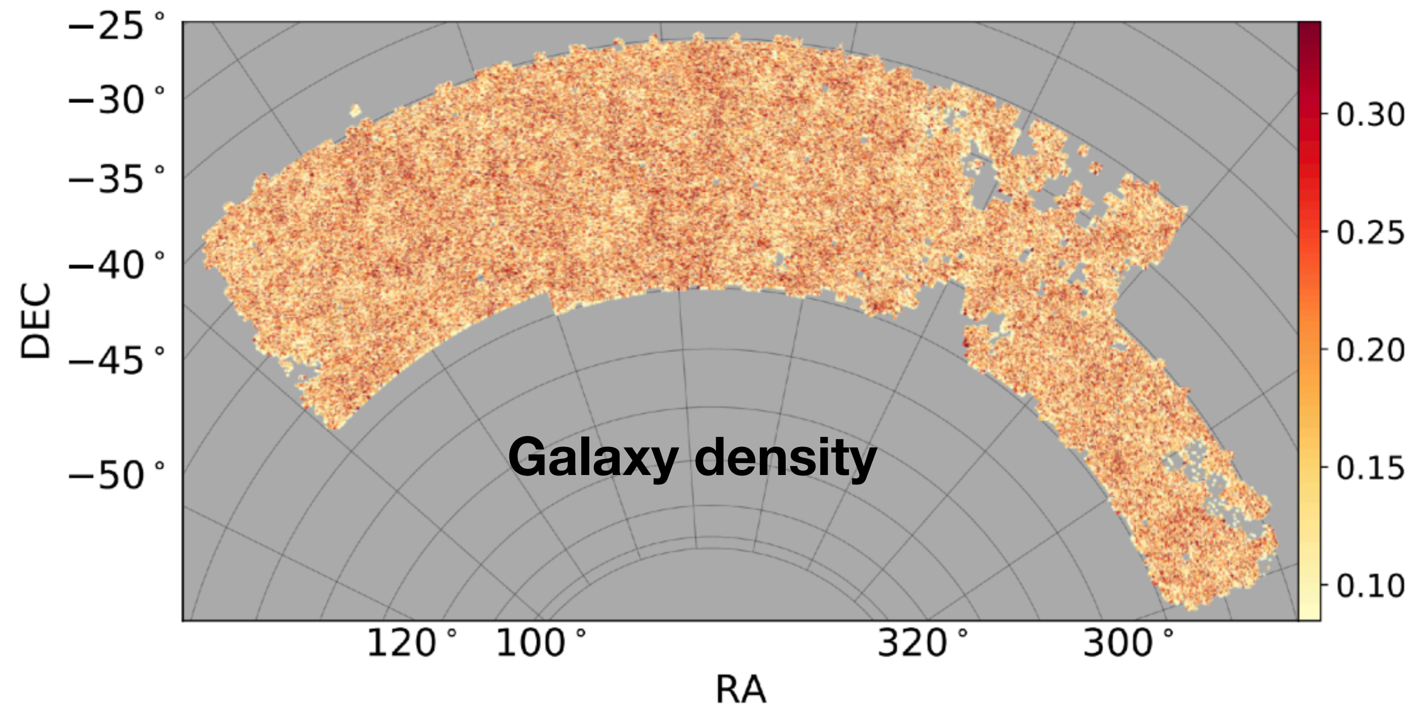
DES year one joint two-point correlation function analysis a.k.a. 3x2pt

Two-point correlations between galaxies and lensing

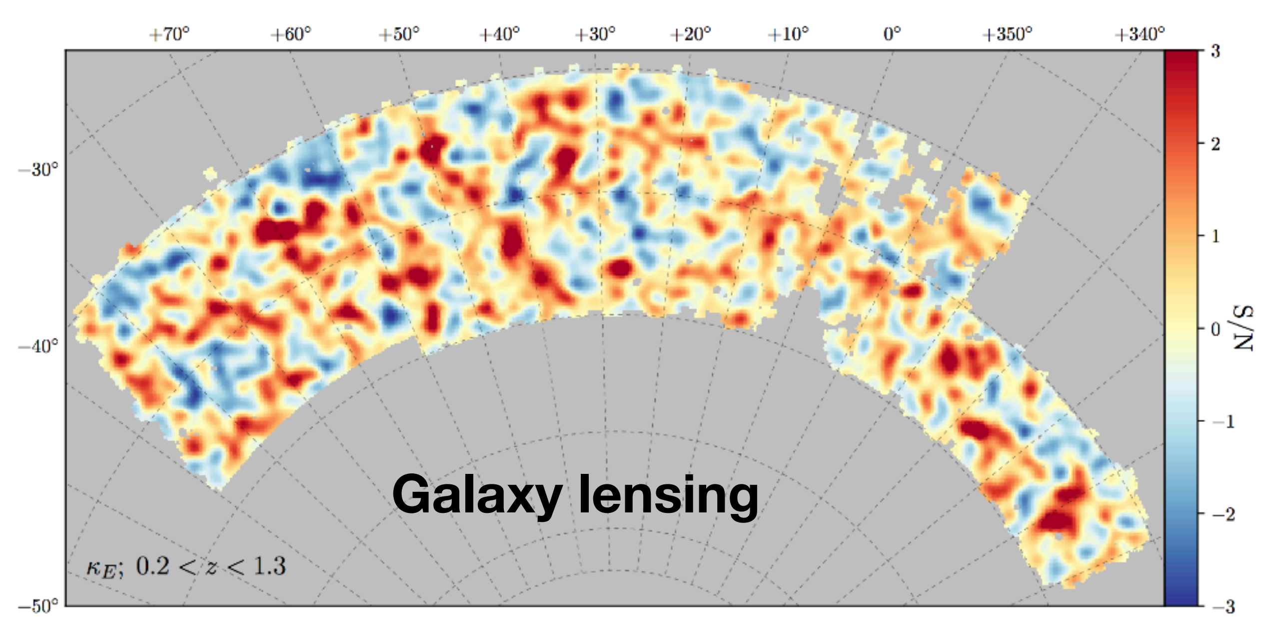
Correlations between galaxies and gravitational lensing are sensitive to cosmology

For a Gaussian random field, two-point functions contain all information*

*But…large scale structure is non-Gaussian



Elvin-Poole et al. 2017



Chang et al. 2017

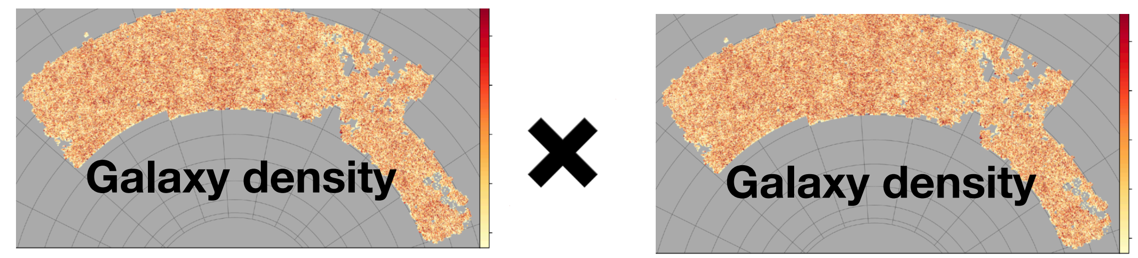
The three 2pt functions

Joint measurement of three two-point functions:

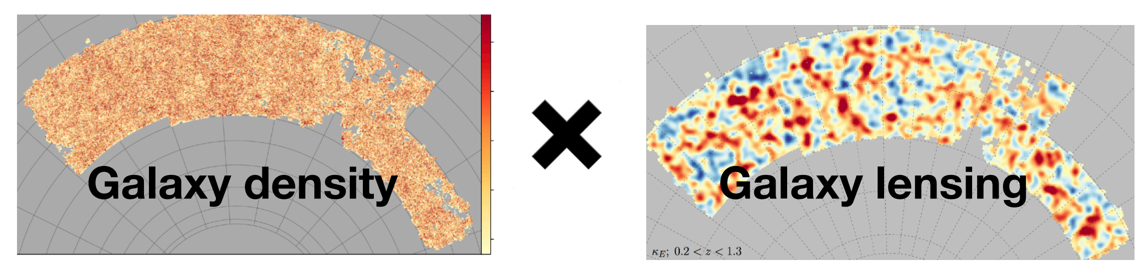
- < galaxies x galaxies >
- < galaxies x lensing >
- < lensing x lensing >

Multiple probes make 3x2pt very robust to systematics

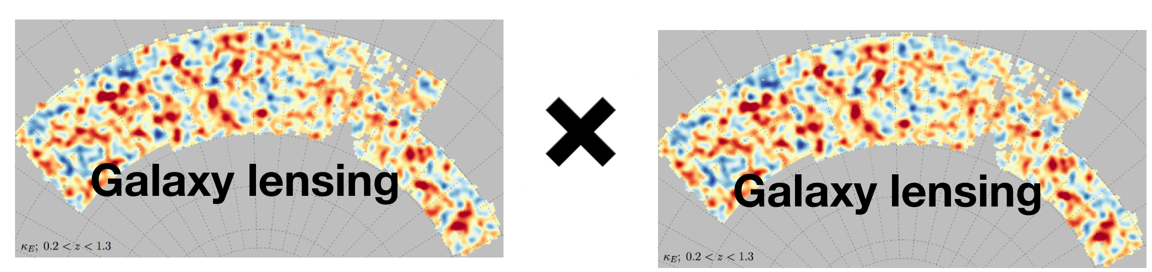
Main measurement ingredients are galaxy positions, redshifts, and shapes



Elvin-Poole et al. 2017



Prat et al. 2017



Troxel et al. 2017

Measuring galaxy redshifts

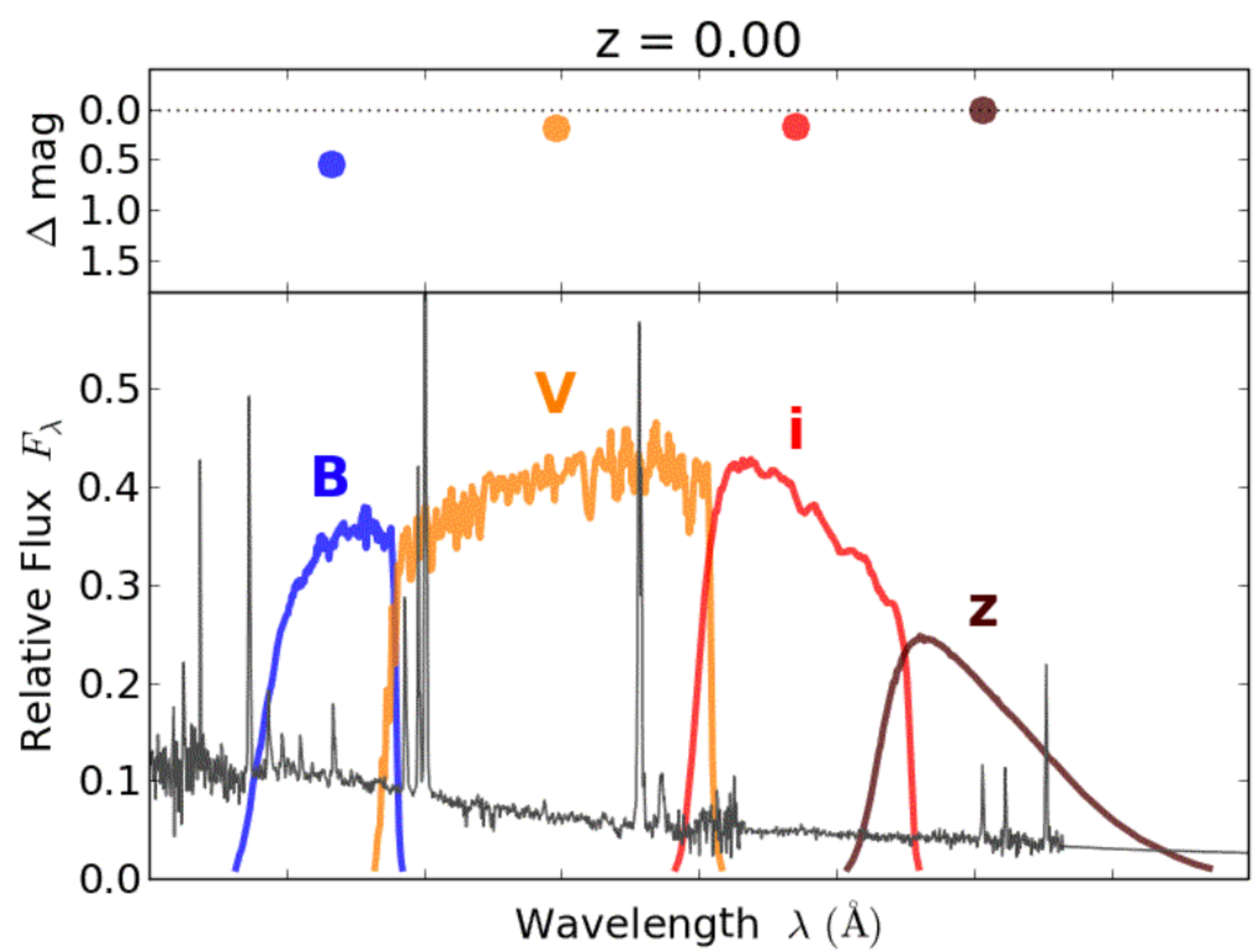
Galaxy redshift estimates are needed for modeling 3x2pt

For source galaxies, use standard template fitting approach

- Use other techniques to constrain potential systematics

For lens galaxies, use redMaGiC (Rozo et al. 2016)

- Only include galaxies that are good match to a template



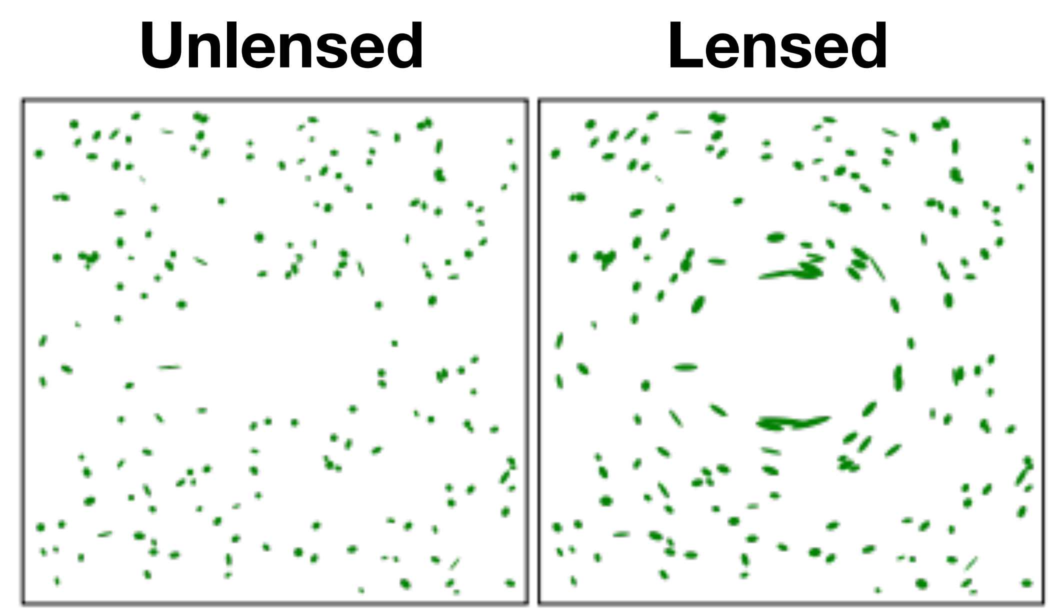
Credit: http://www.stsci.edu/~dcoe/BPZ

Measuring galaxy lensing

DES uses images of galaxy shapes to infer gravitational lensing

DES Y1 approach: metacal (Sheldon & Huff 2017)

- Calibrate response of a shear estimator by applying artificial shear to actual image



Modeling 3x2pt

DES year one philosophy: keep it "simple"

The model:

- Constant linear galaxy bias in each redshift bin
- Ignore baryonic effects
- Basic intrinsic alignment model
- One parameter photo-z and shear systematic models

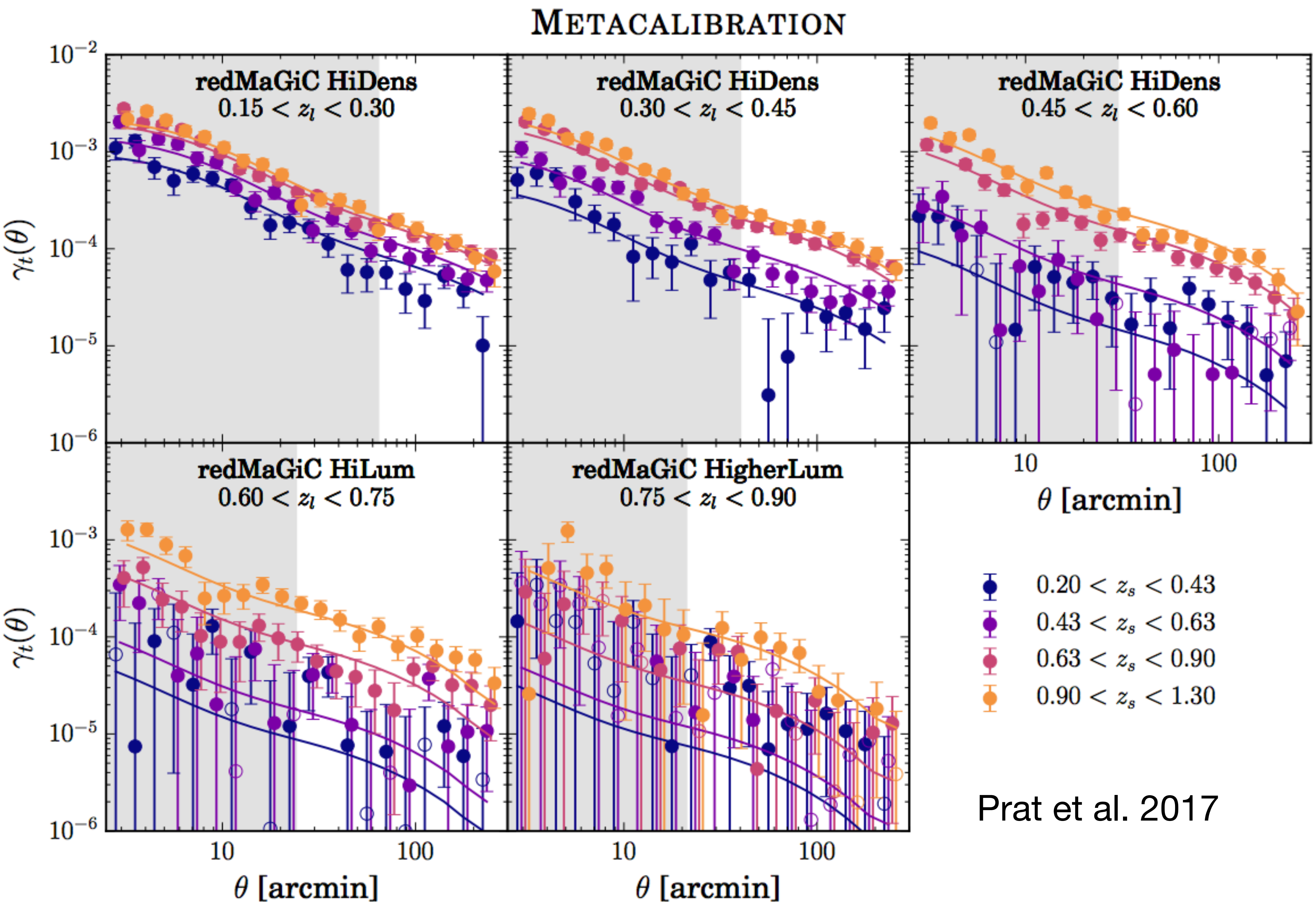
Cut out scales that we don't know how to model

- Unfortunately, this means throwing out lots of signal!

Parameter	Prior
Cosmology	
Ω_m	flat (0.1, 0.9)
A_s	flat $(5 \times 10^{-10}, 5 \times 10^{-9})$
n_s	flat (0.87, 1.07)
Ω_b	flat (0.03, 0.07)
h	flat (0.55, 0.91)
$\Omega_\nu h^2$	flat$(5 \times 10^{-4}, 10^{-2})$
w	flat $(-2, -0.33)$
Lens Galaxy Bias	
$b_i (i = 1, 5)$	flat (0.8, 3.0)
Intrinsic Alignment	
$A_{\text{IA}}(z) = A_{\text{IA}}[(1+z)/1.62]^{\eta_{\text{IA}}}$	
A_{IA}	flat $(-5, 5)$
η_{IA}	flat $(-5, 5)$
Lens photo-z shift (red sequence)	
Δz_l^1	Gauss $(0.001, 0.008)$
Δz_l^2	Gauss $(0.002, 0.007)$
Δz_l^3	Gauss $(0.001, 0.007)$
Δz_l^4	Gauss $(0.003, 0.01)$
Δz_l^5	Gauss $(0.0, 0.01)$
Source photo-z shift	
Δz_s^1	Gauss $(-0.001, 0.016)$
Δz_s^2	Gauss $(-0.019, 0.013)$
Δz_s^3	Gauss $(+0.009, 0.011)$
Δz_s^4	Gauss $(-0.018, 0.022)$
Shear calibration	
$m^i_{\text{METACALIBRATION}} (i = 1, 4)$	Gauss $(0.012, 0.023)$
$m^i_{\text{IM3SHAPE}} (i = 1, 4)$	Gauss $(0.0, 0.035)$

Abbot et al. 2017

Scale cuts

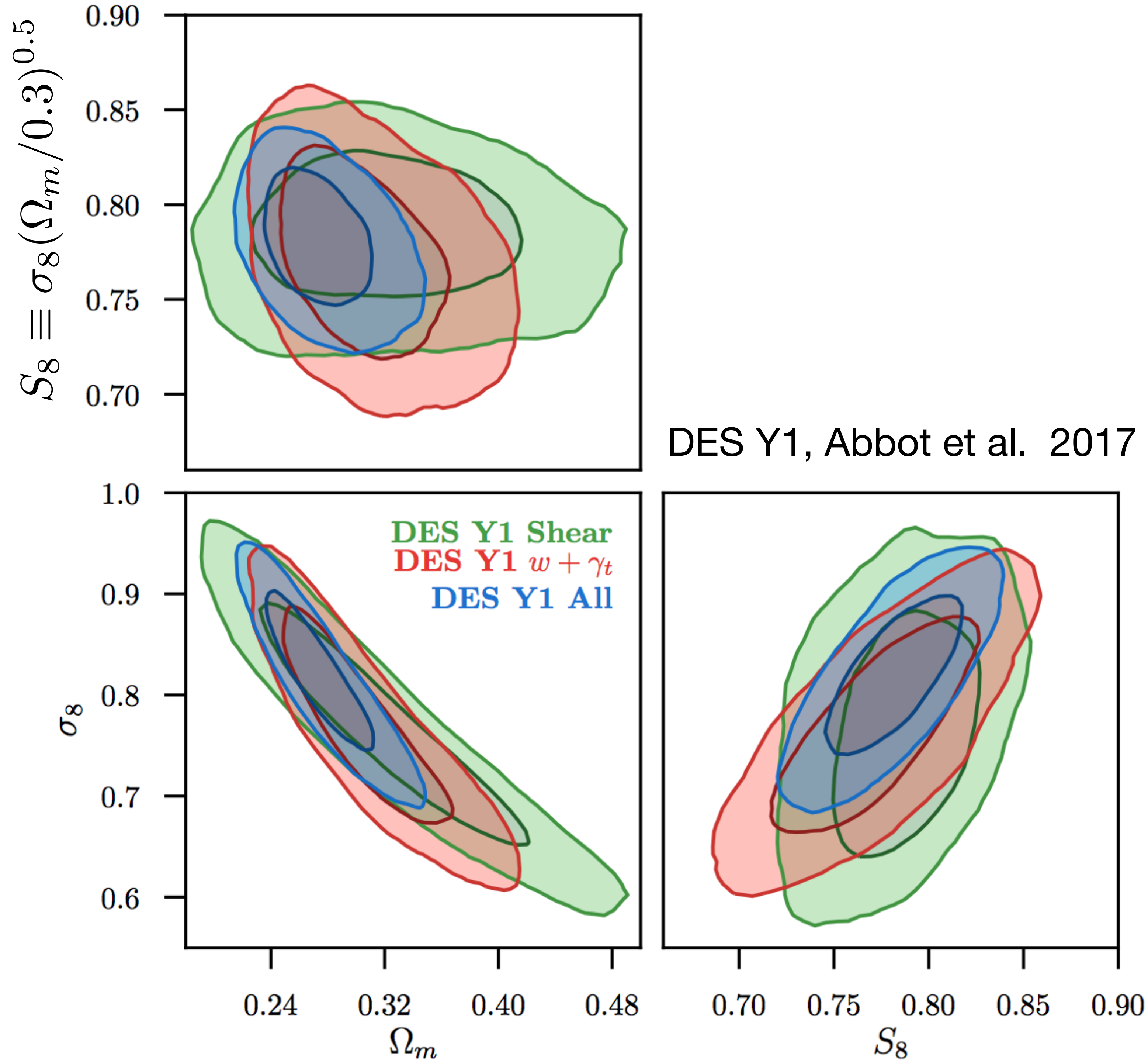


Prat et al. 2017

3x2pt results

The different DES two-point functions are consistent with each other

Tight cosmological constraints



DES Y1, Abbot et al. 2017

3x2pt results

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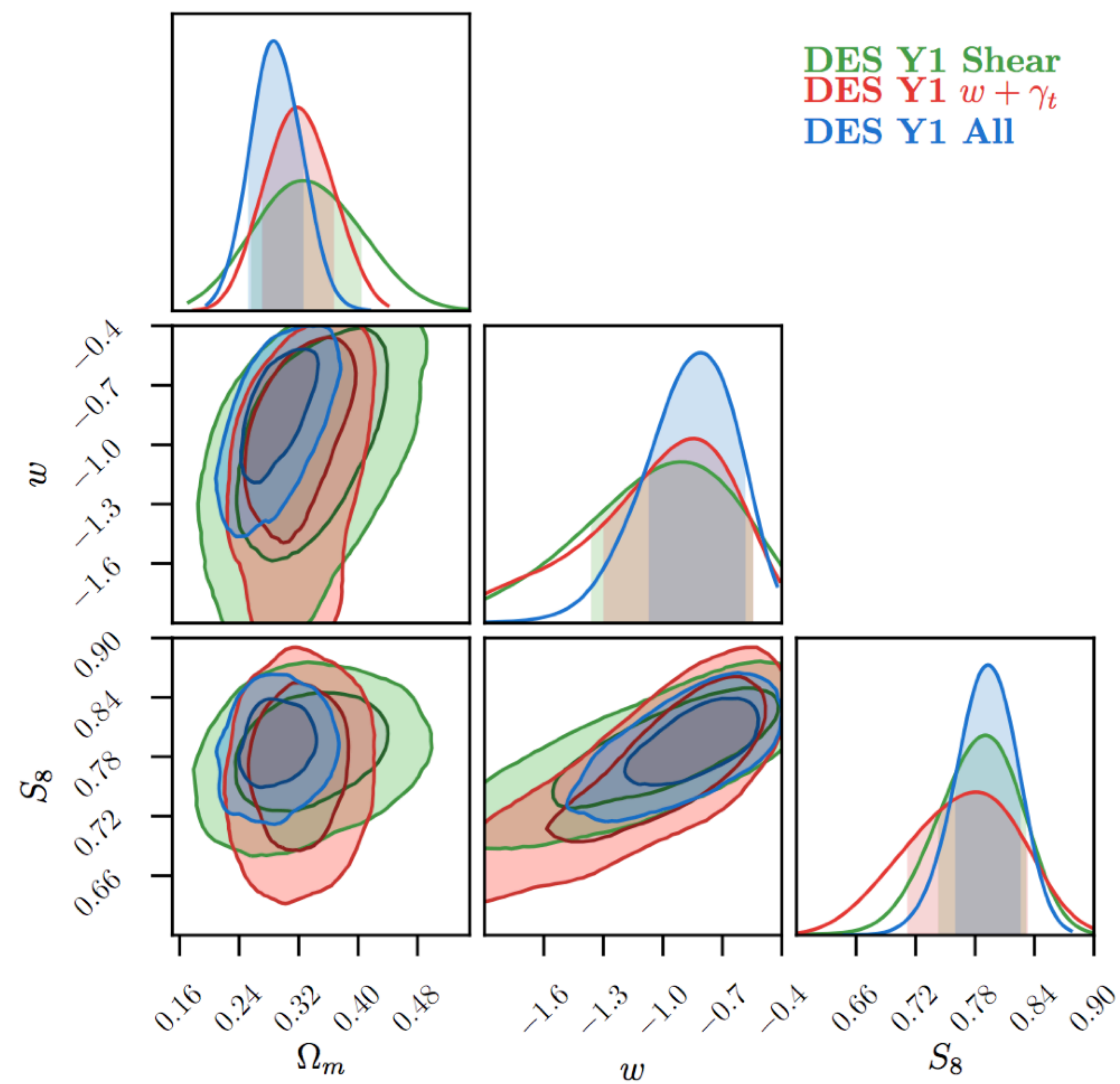
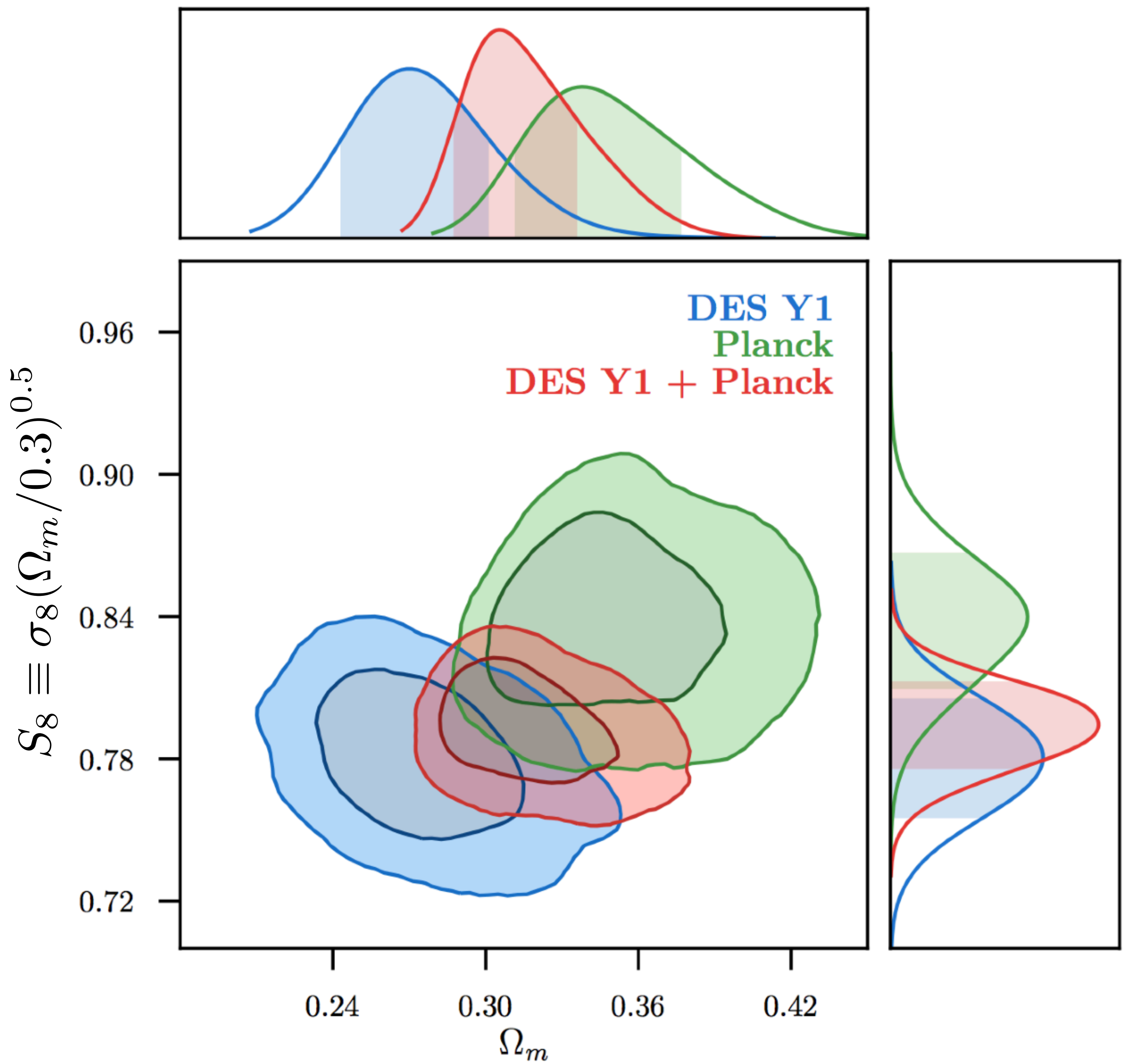


DES Y1, Abbot et al. 2017

3x2pt results vs. Planck

DES 3x2 prefers low S_8 and matter density relative to Planck (similar to other previous weak lensing measurements)

Statistically consistent with Planck

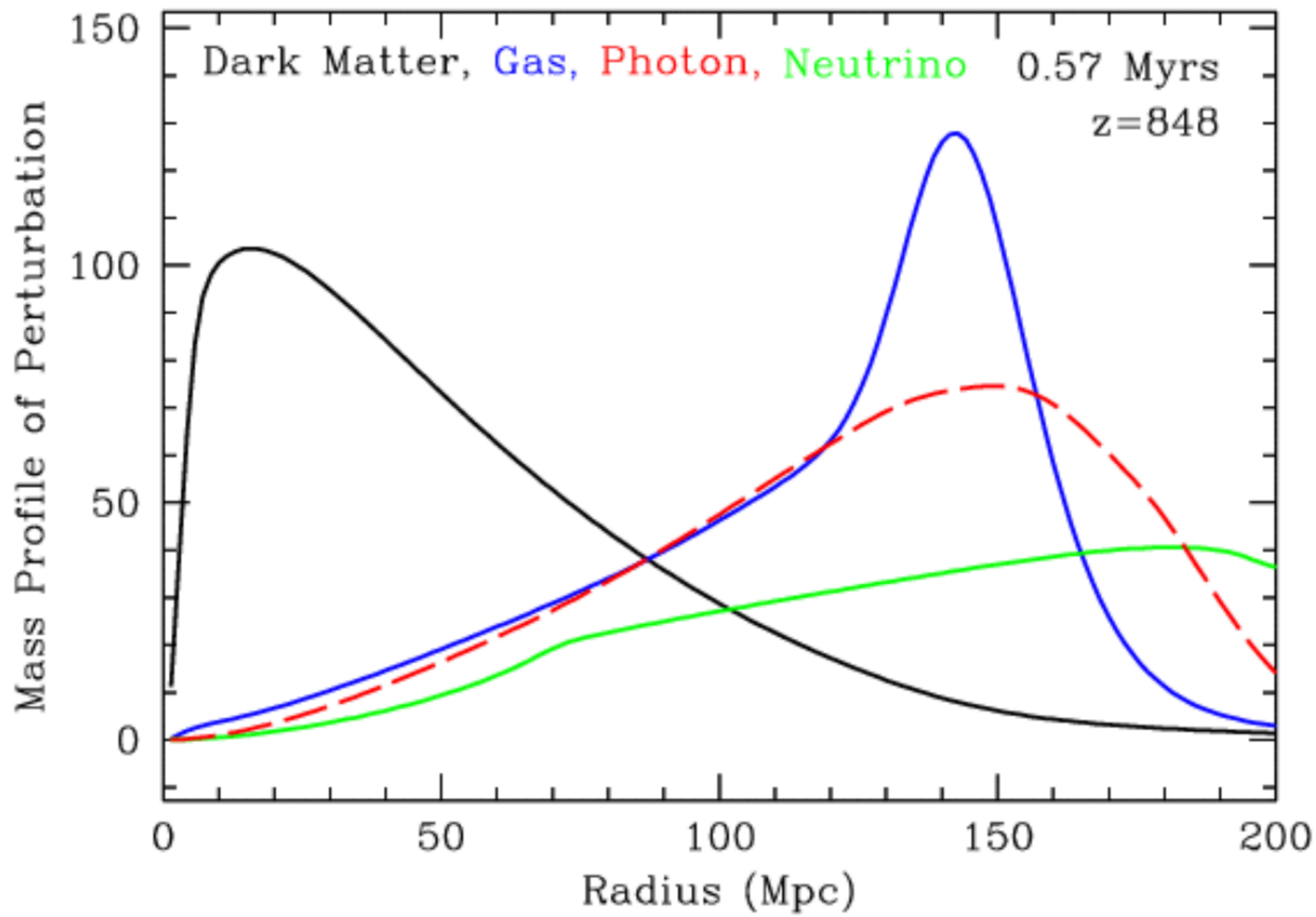


DES Y1, Abbot et al. 2017

Using DES and baryon acoustic oscillations to constrain the Hubble constant

Baryon acoustic oscillations

Same photon-baryon oscillations that give rise to CMB power spectrum also lead to characteristic scales in galaxy distribution



Credit: D. Eisenstein

Predicting the BAO scale

Angular scale of BAO feature is r_s/D_M

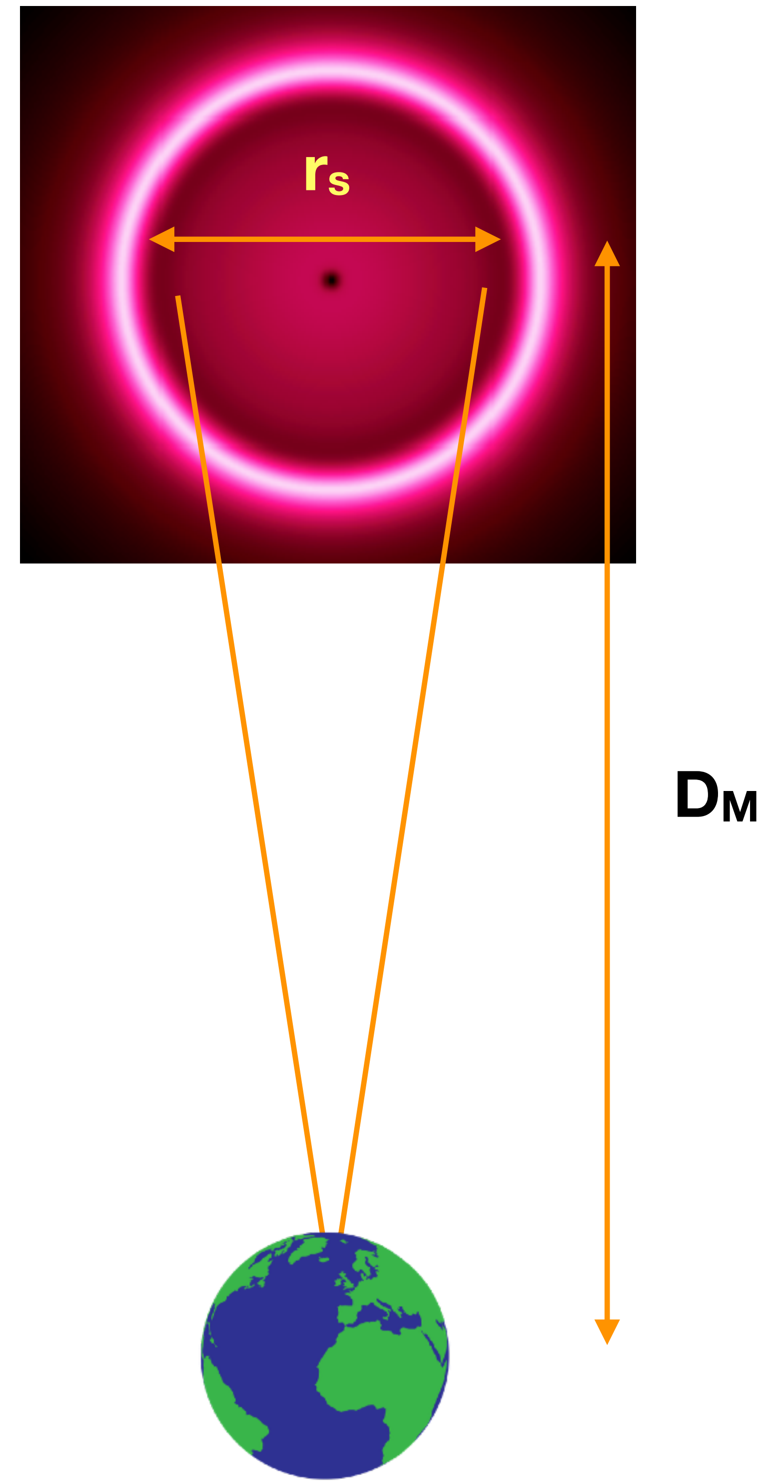
- r_s is sound horizon at photon-baryon decoupling
- DM is angular diameter distance to galaxies

In flat LCDM, D_M is fixed by H_0 and Ω_m
r_s depends on T_{CMB}, $\Omega_\mathrm{m} h^2$, $\Omega_b h^2$

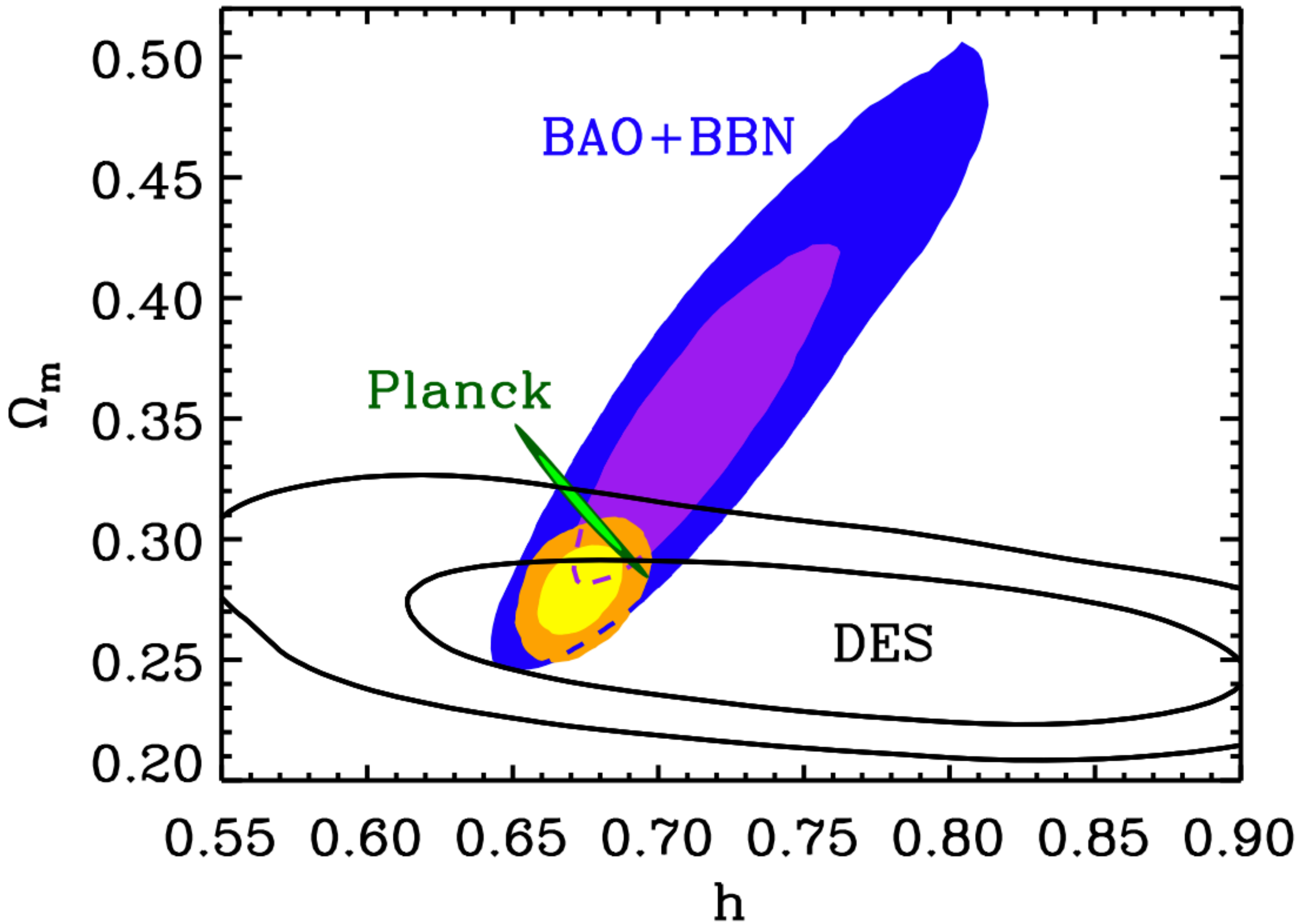
Can get constraint on Hubble with:

- BAO measurement of r_s/D_M
- COBE measurement of T_{CMB}
- big bang nucleosynthesis constraints on $\Omega_b h^2$
- **DES measurement of Ω_m**

Completely independent of CMB power spectrum and distance ladder measurements



Constraints on the Hubble constant

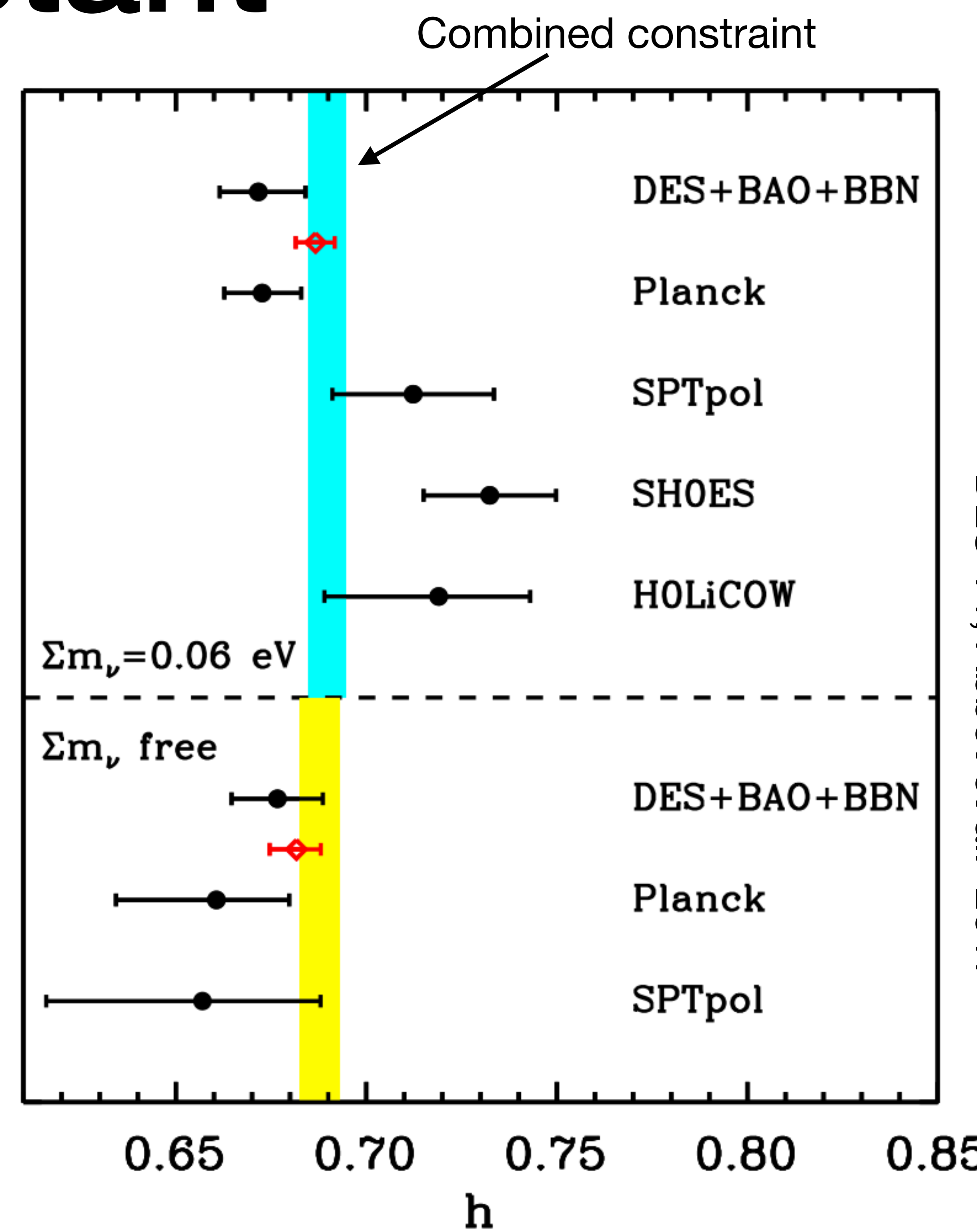


Abbot et al. 2017

Constraints on the Hubble constant

Many different measurements of H_0

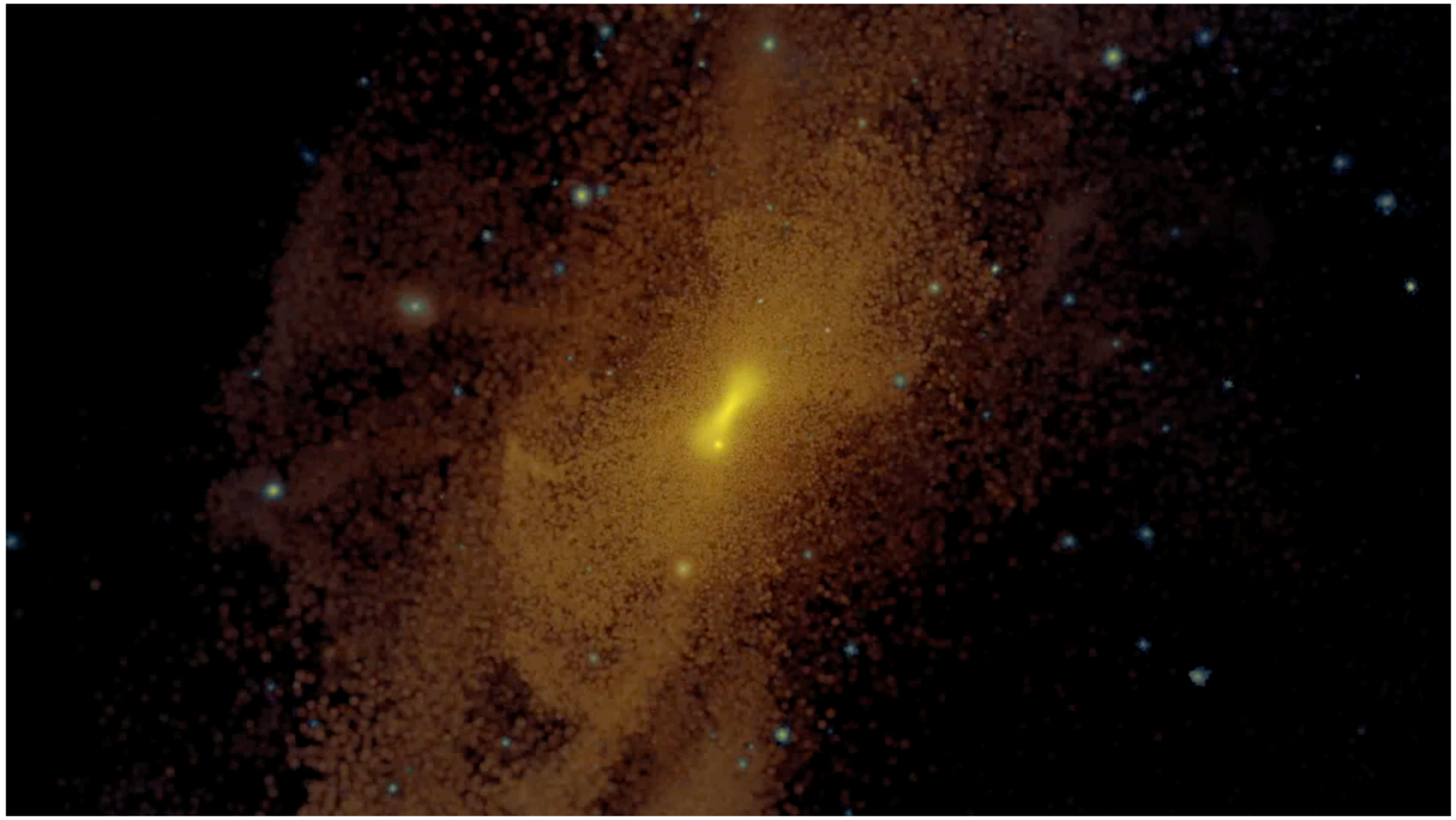
Considering all measurements, evidence for tension only at the ~2σ level



DES Y1, Abbot et al. 2017

Small scales with DES

Going to small scales



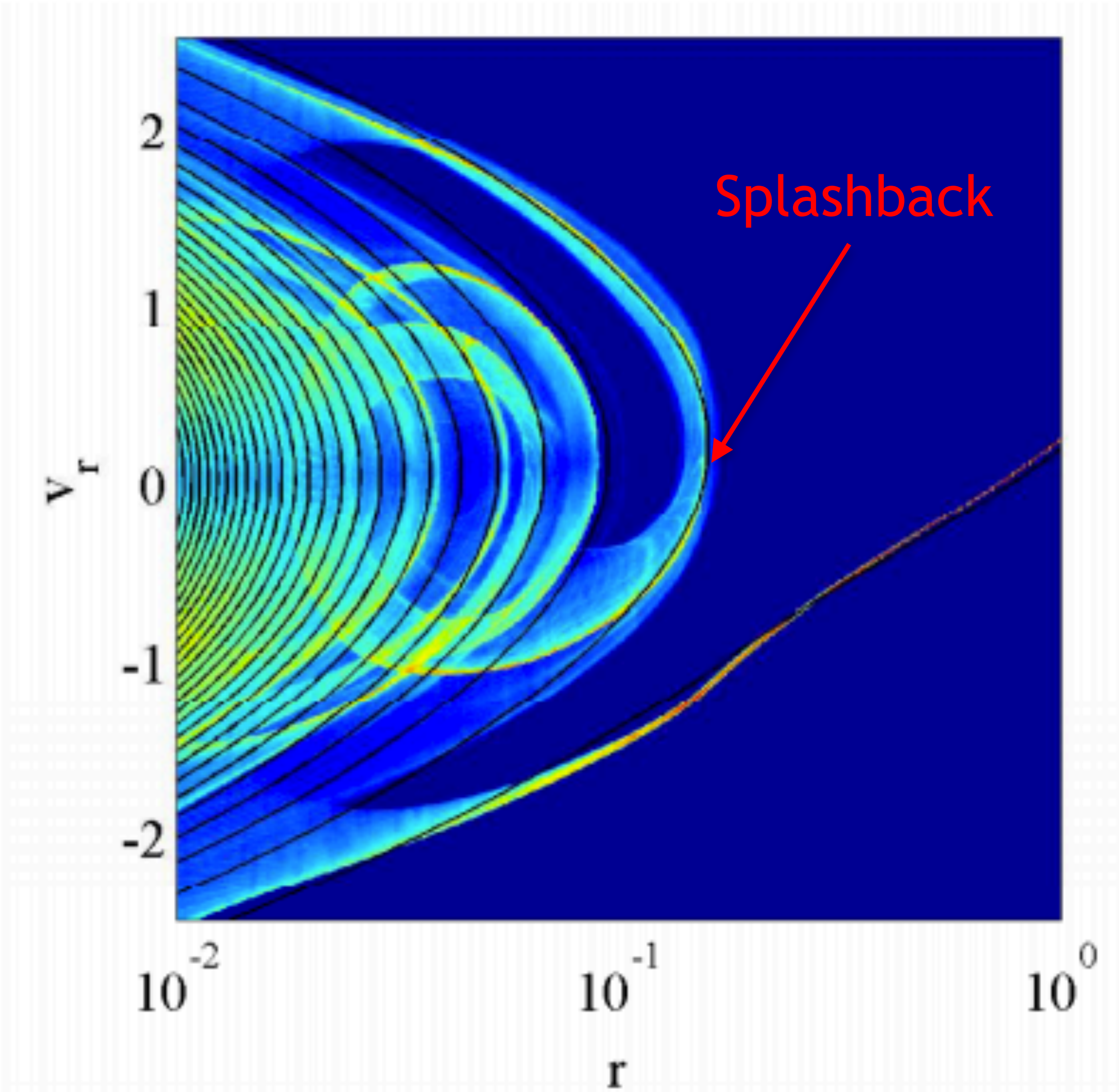
Helly, Cooper, Cole & Frenk, Institute for Computational Cosmology

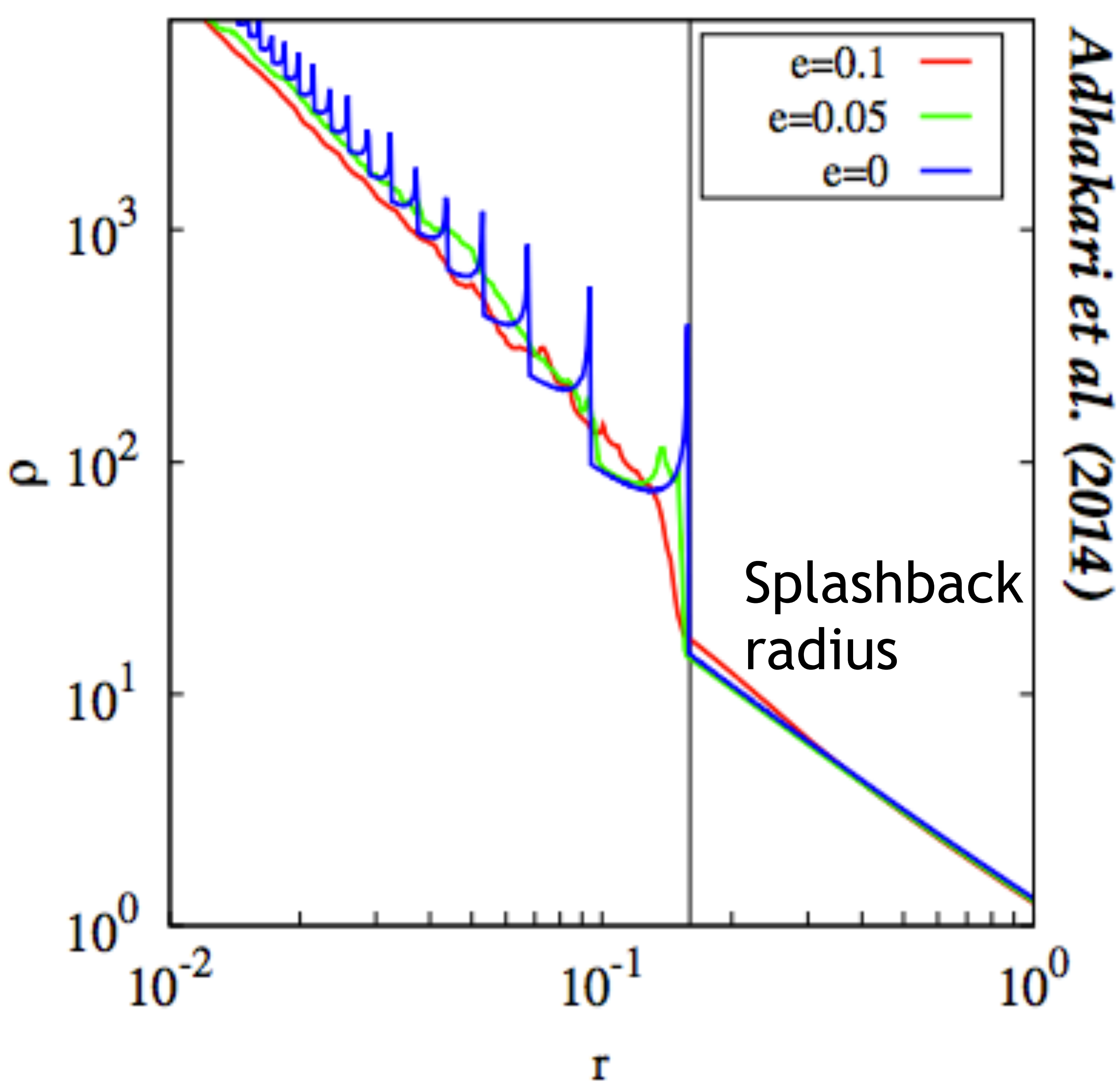
Lots of interesting physics and signal-to-noise at smaller scales

However: small scales are more difficult to model

Splashback

Self similar collapse models predict that accreted matter piles up at first apoapsis after collapse (e.g. Fillmore & Goldreich 1984)





Splashback

Splashback feature seen in N-body simulations, even after averaging over many halos (Diemer & Kravtsov 2014)

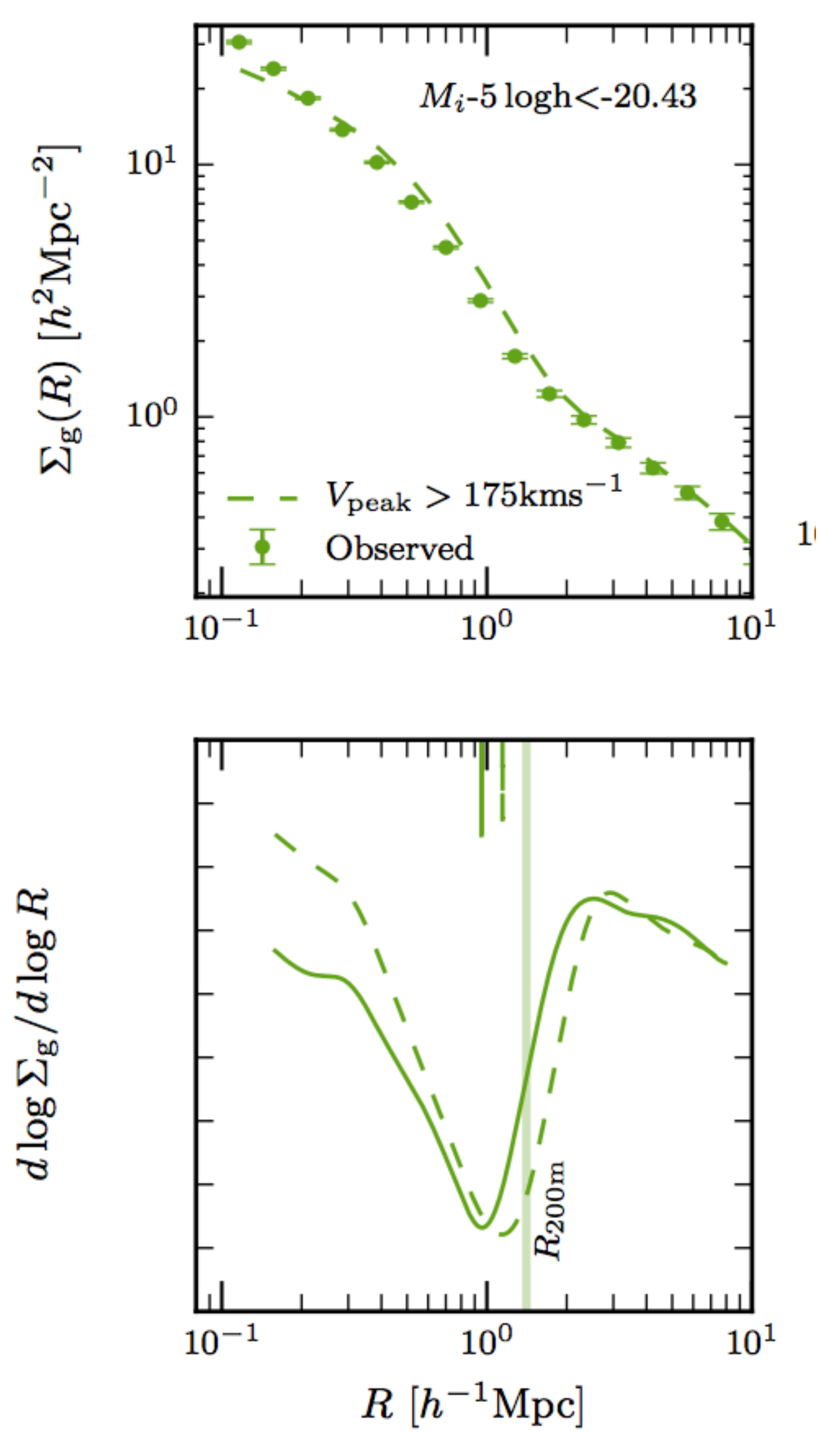
Can measure in data by correlating galaxy clusters with galaxies

- Use galaxies as tracers of mass

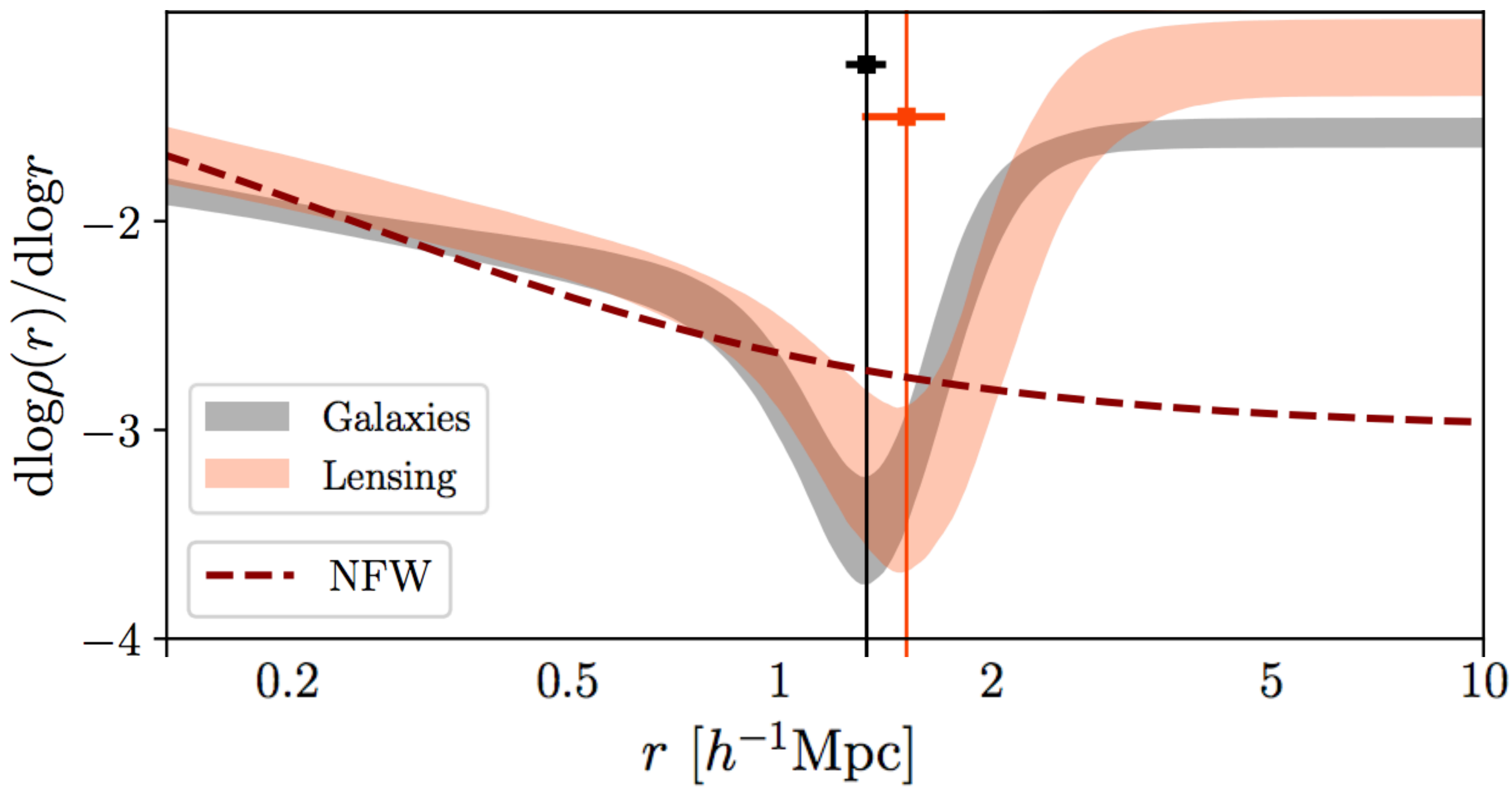
However, predictions for splashback radius do not agree with observations

- Modified gravity? Dark matter-baryonic interactions? (Adhikari, Jain, Sakstein, Dalal…)

More, S. et al.



Splashback with DES



Chang, Baxter et al. 2017

For the first time we measure this feature using gravitational lensing

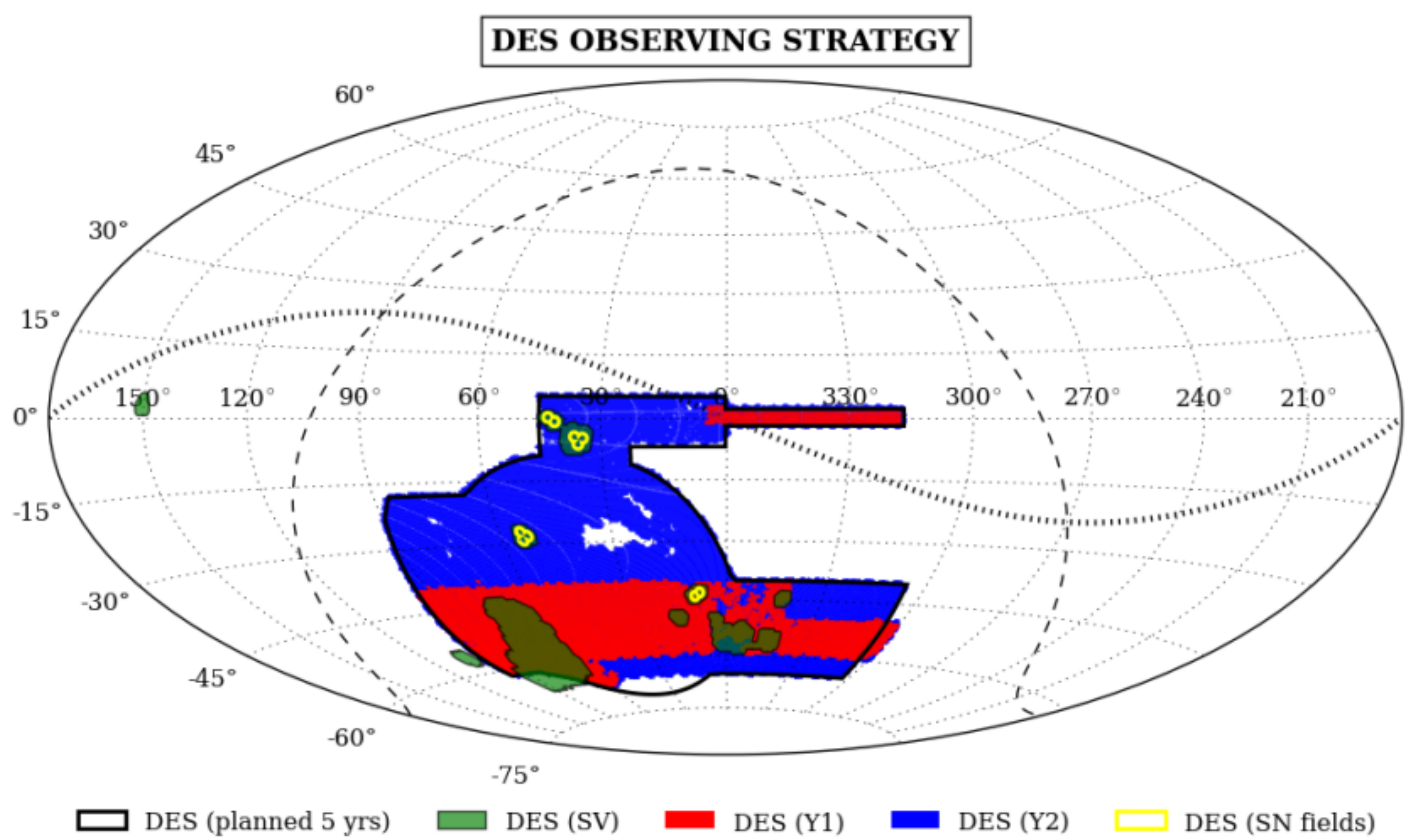
Find similar level of tension (several sigma) with simulations using galaxy distribution

The future of DES

Data: ~4.5x more data to be analyzed

Measurements: new shape measurement algorithms, new galaxy catalogs

Analysis: improved modeling of small scales



Summary

With first year data, **DES has already yielded tightest cosmological constraints from a single galaxy survey**

Weak lensing and galaxy clustering are now competitive with Planck

Lots of science beyond two-point function cosmology

Significant near term improvements due to more data and better analysis

Hopeful that situation with various tensions will be clarified in near future