Accelerated Cosmic Expansion and the Dark Energy Survey

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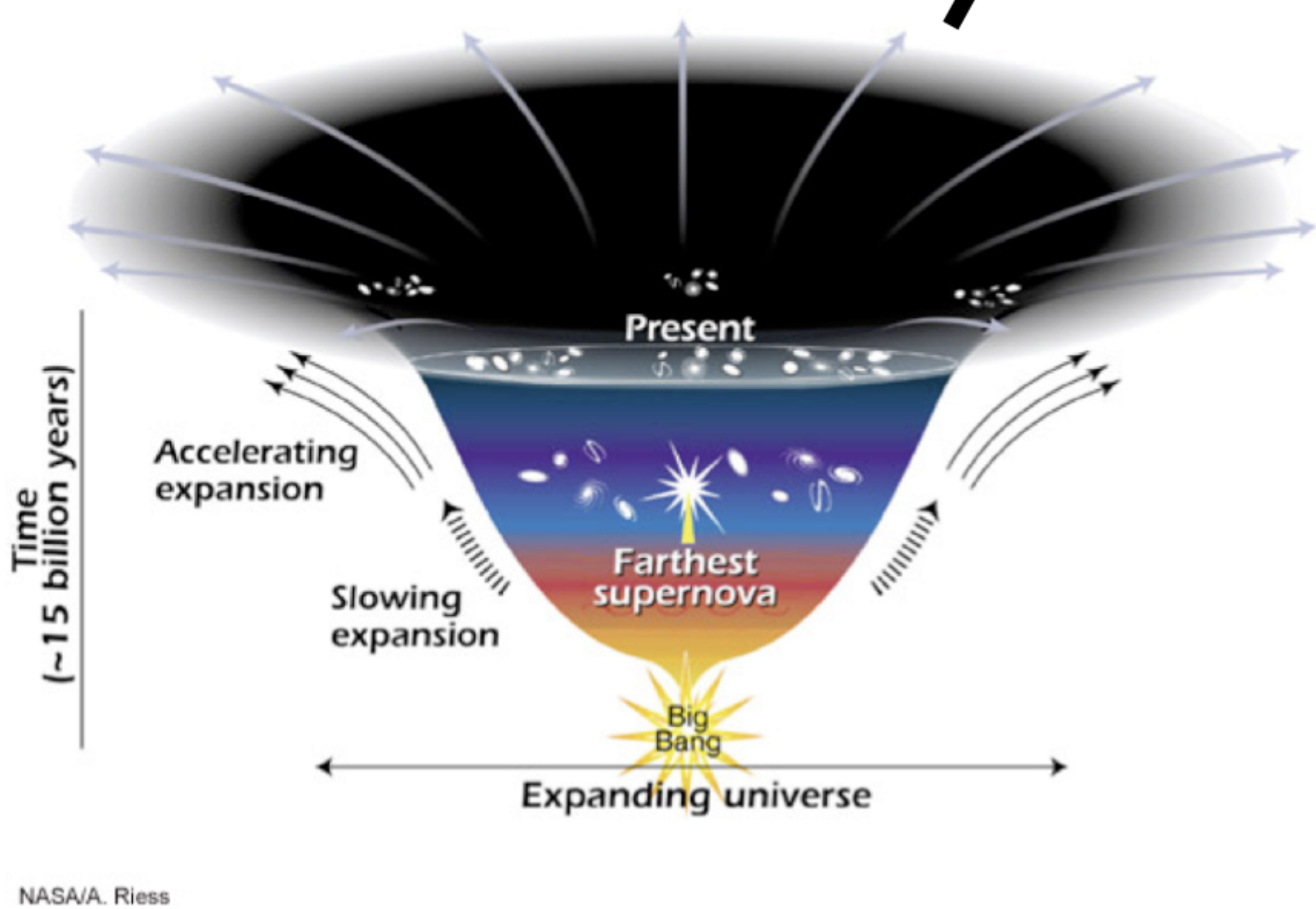
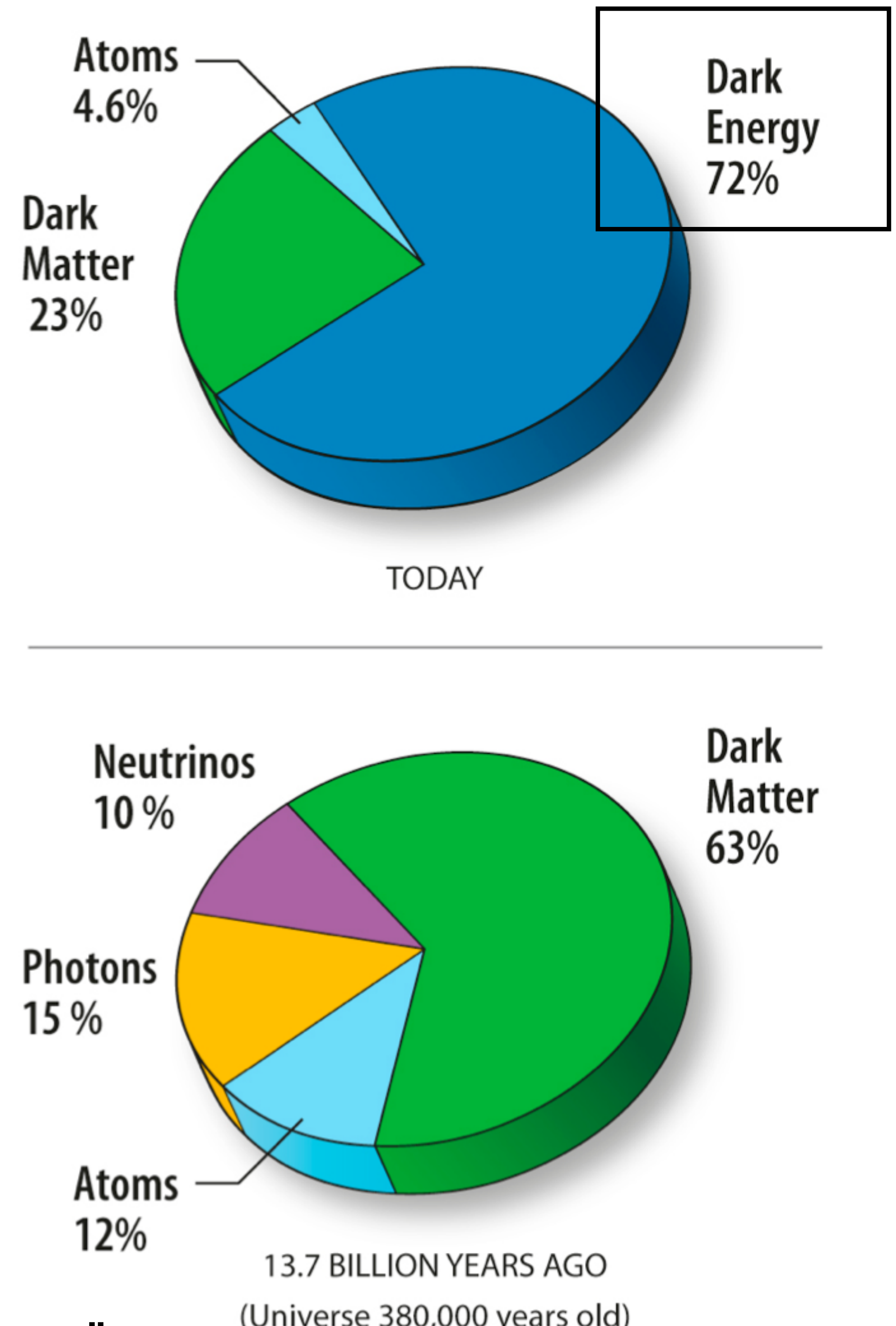
Current cosmological model

$$\frac{H^2}{H_0^2} = \Omega_R a^{-4} + \Omega_M a^{-3} + \Omega_k a^{-2} + \Omega_\Lambda$$





- It is a “concordance” model although with some “tensions”

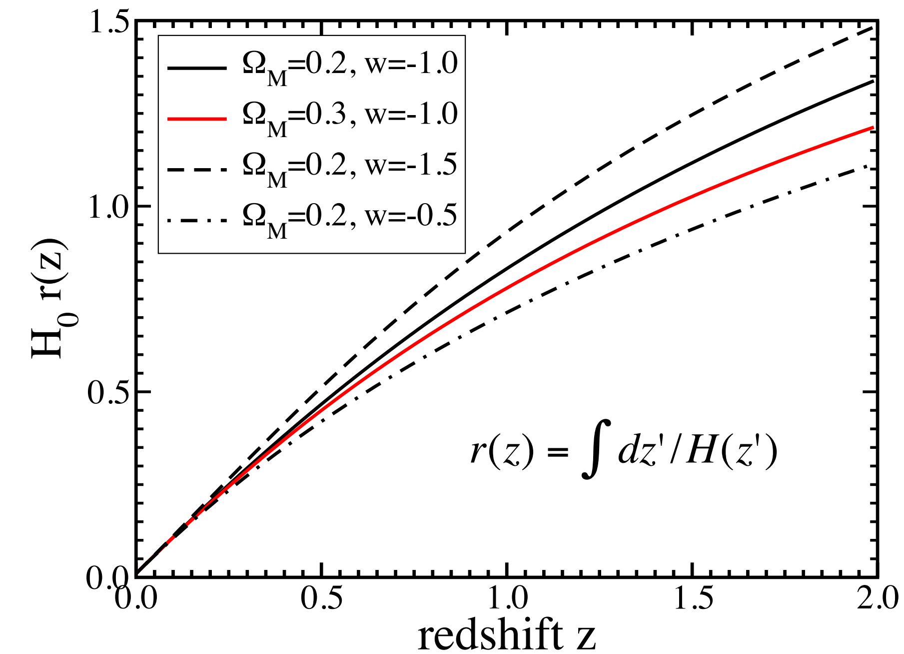
credit : NASA

Measuring Dark Energy

➡ Geometry: distance vs. redshift

(expansion history = SNIa, BAO)

- ✦ redshift tells degree of expansion
- ✦ light-travel distance = time

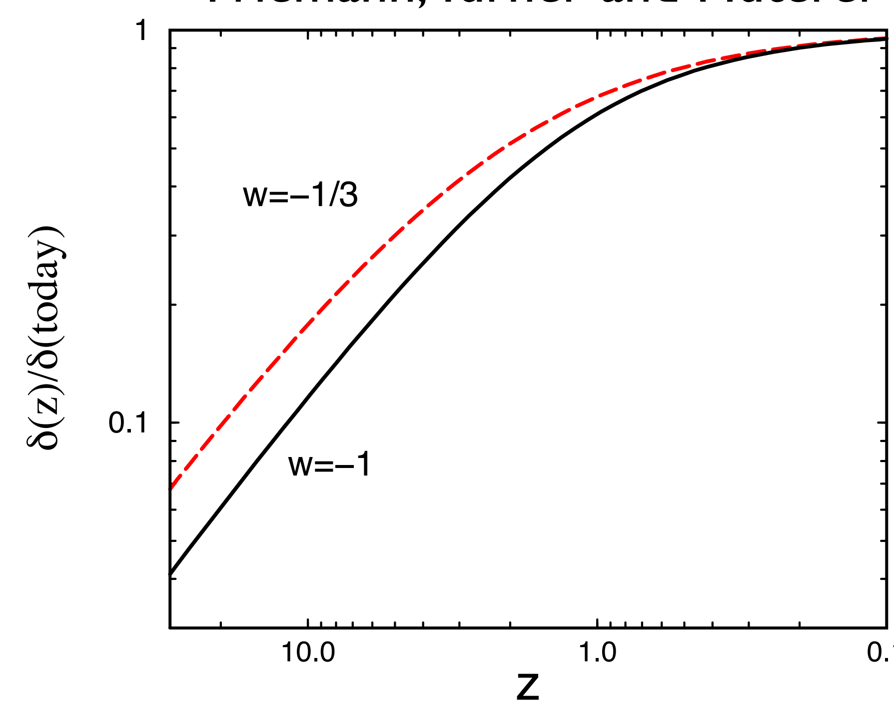


➡ Dynamics: structure growth

(growth history = Weak Lensing, Clusters, RSD)

- ✦ growth rate depends on matter density
- ✦ evolution in matter density ⟷ evolution in dark energy density

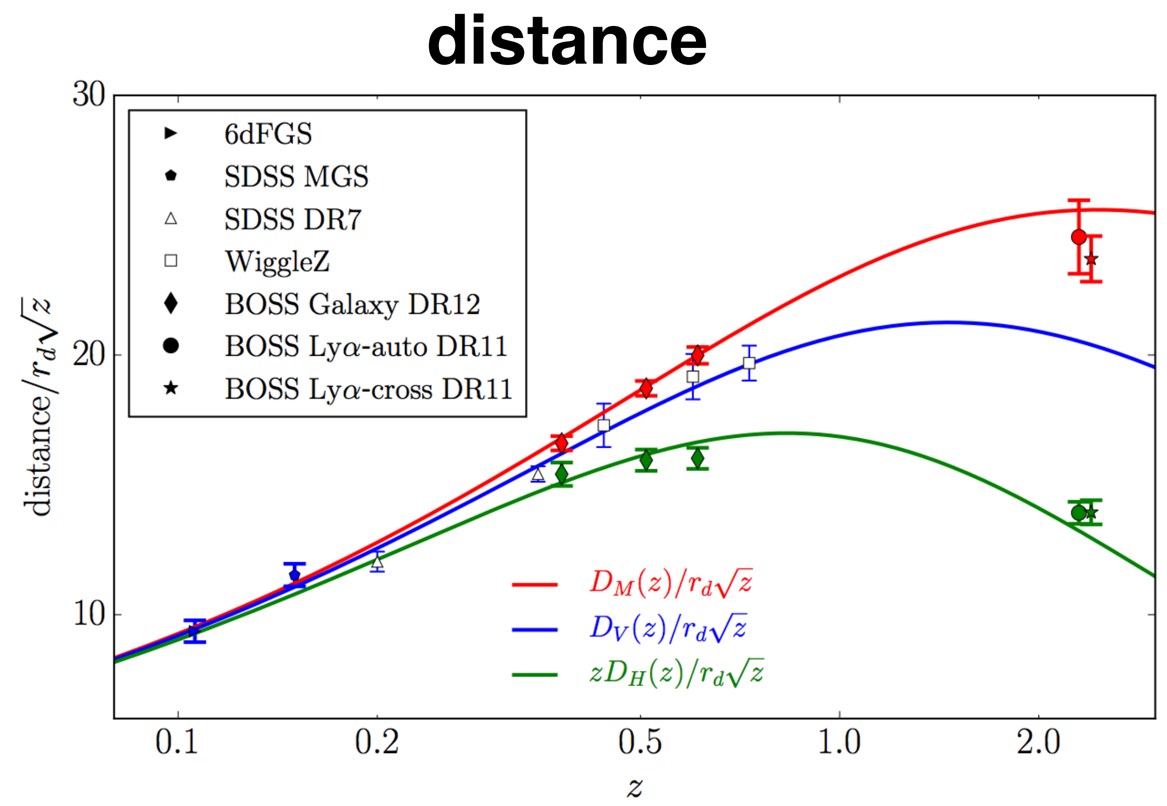
Friemann, Turner and Huterer



we need both to disentangle GR vs DE !

Galaxy redshift surveys (measuring & correlating galaxy positions) have been very successful over the past decade or so

2dFGRS, SDSS, BOSS, VIPERS



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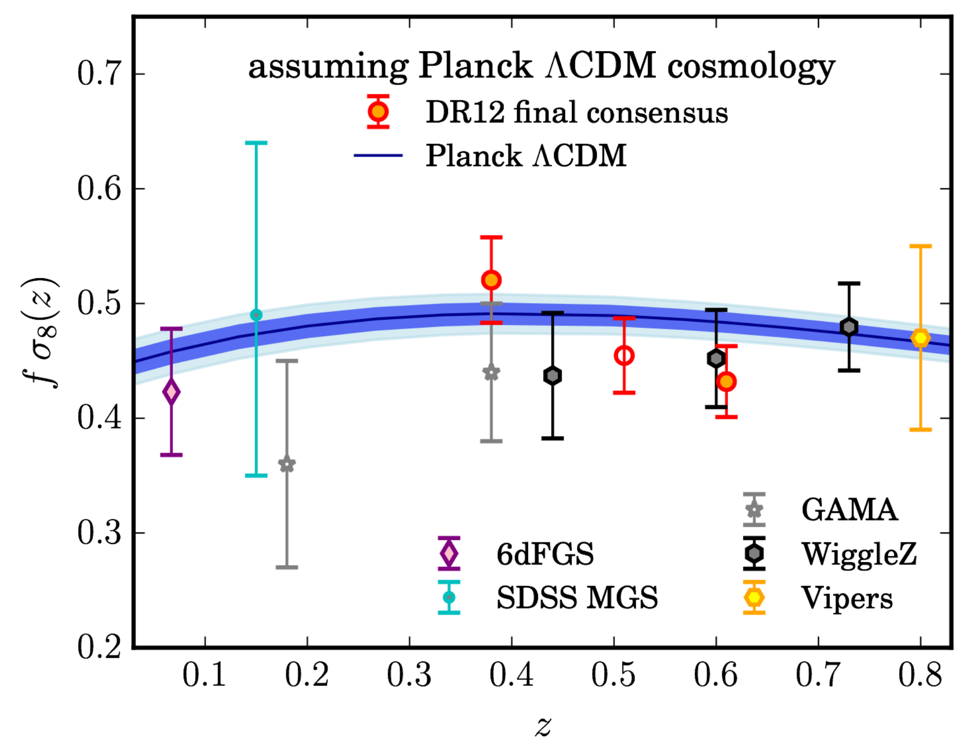
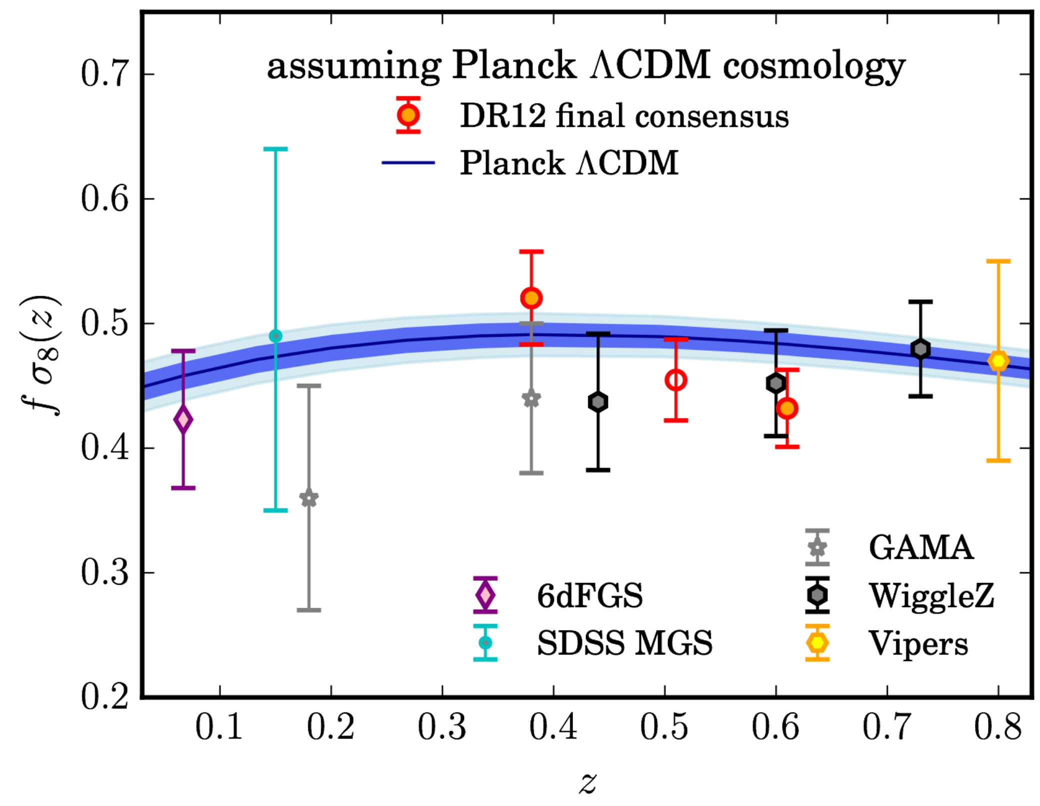
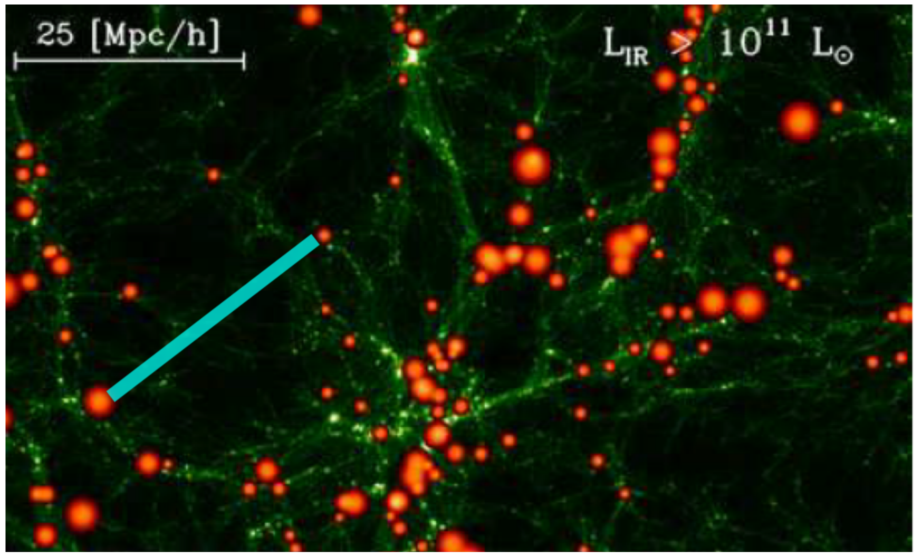
growth

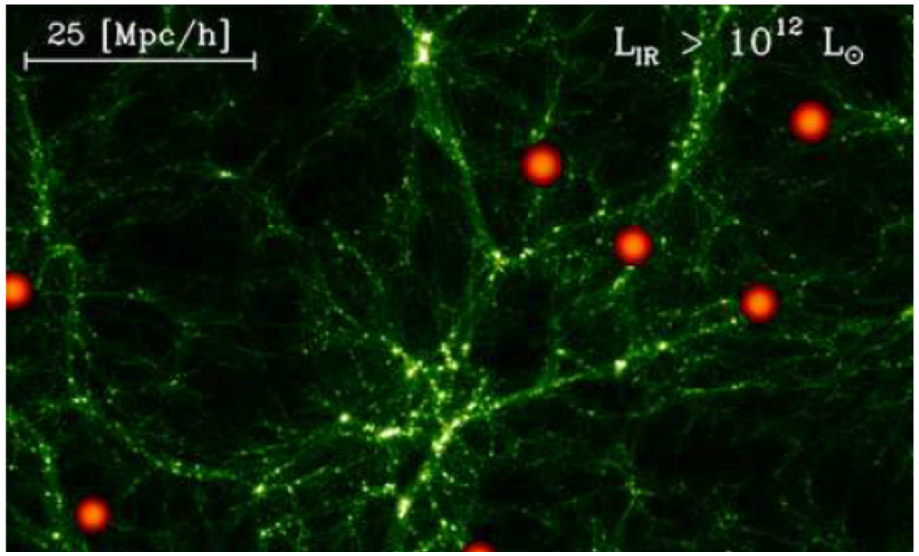


Galaxy redshift surveys (measuring & correlating galaxy positions) have been very successful over the past decade or so



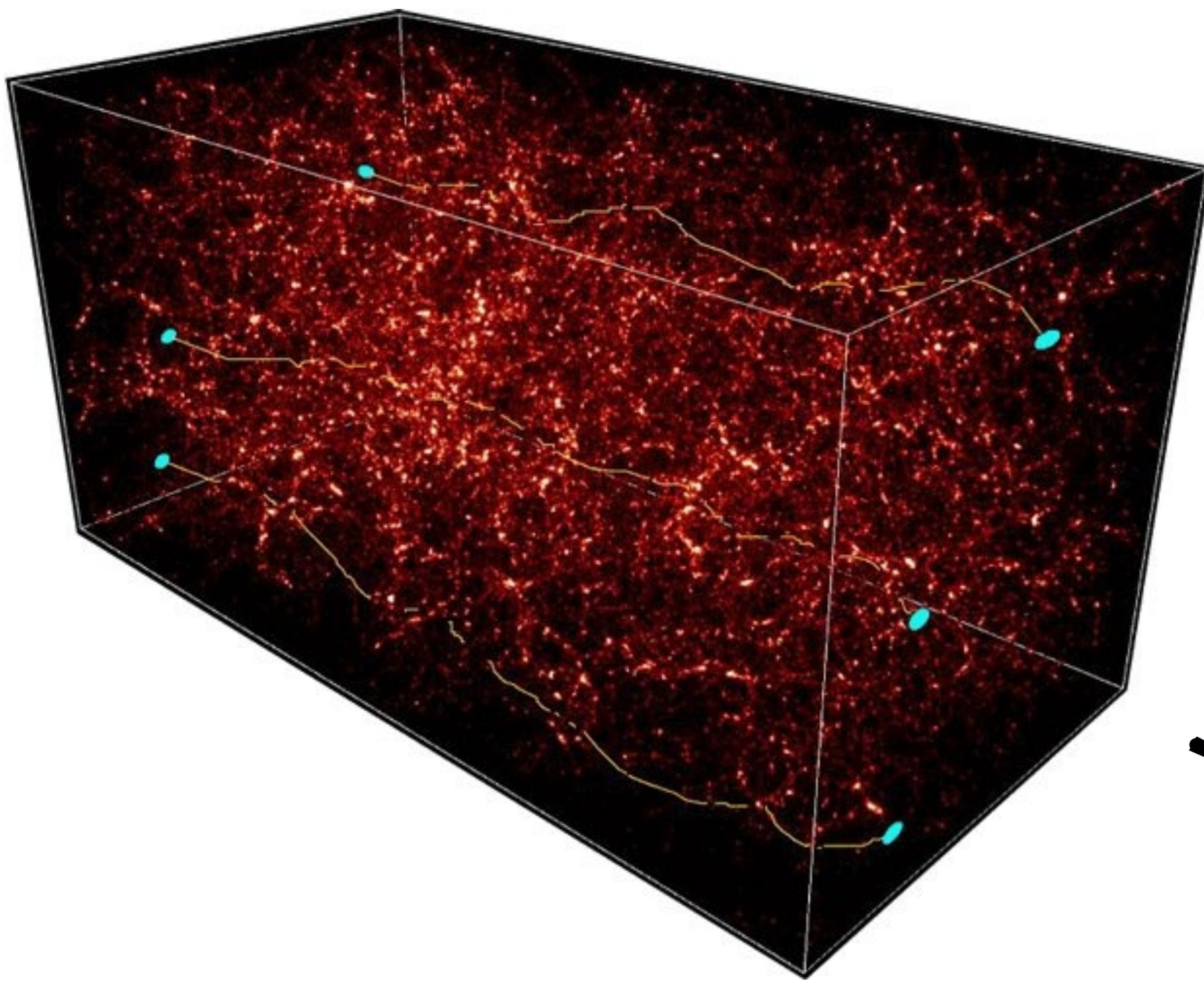
Limitation —> galaxies are not perfect tracers of the matter field : galaxy bias <—> degenerate with σ_8 or D(z)





Weak Lensing

source galaxies at
z ~ 1



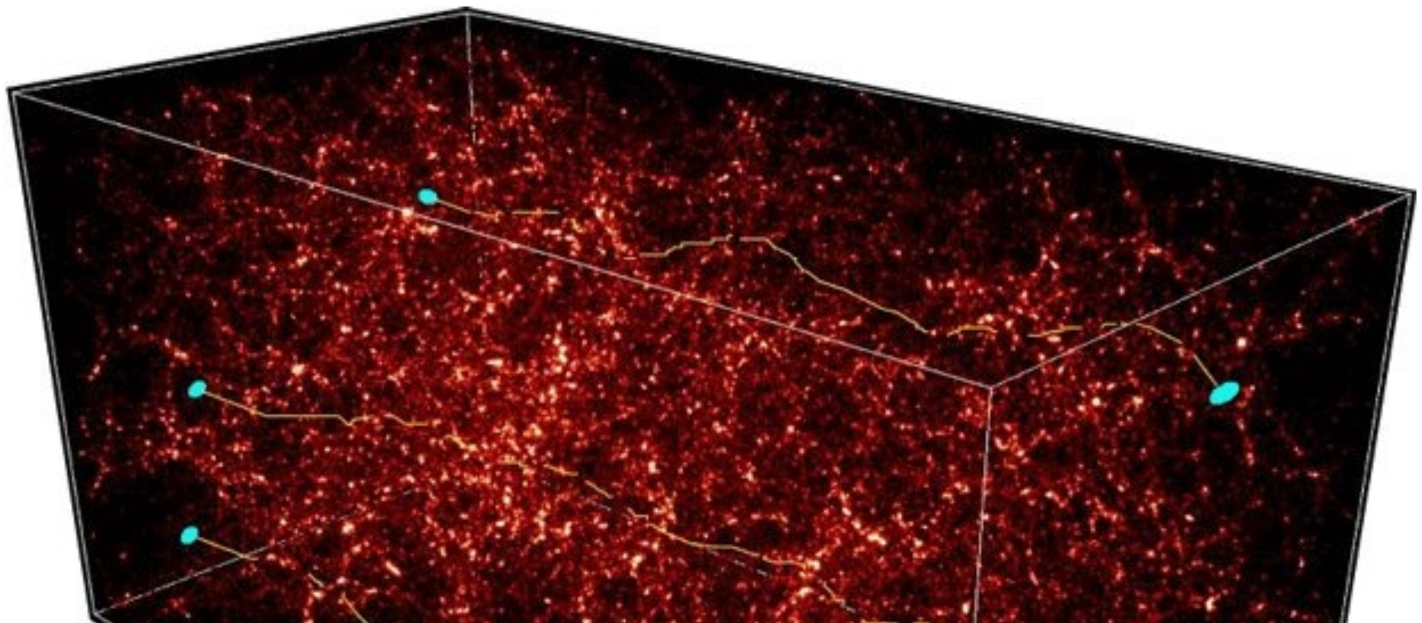
- Matter distorts back-ground galaxy shapes
- Measure shapes to obtain "shear" catalog
- Shear-shear correlations is an unbiased tracer of matter distribution

Observer : shapes have been "sheared" coherently by the large-scale structure

- **Problems** – Intrinsic Alignments, Baryon Physics, Shapes biases

Weak Lensing

technology has enabled accurate shape measurements



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The "cosmic-shear" era

2003-2008: Canada-France-Hawaii Legacy Survey: 154 deg^2

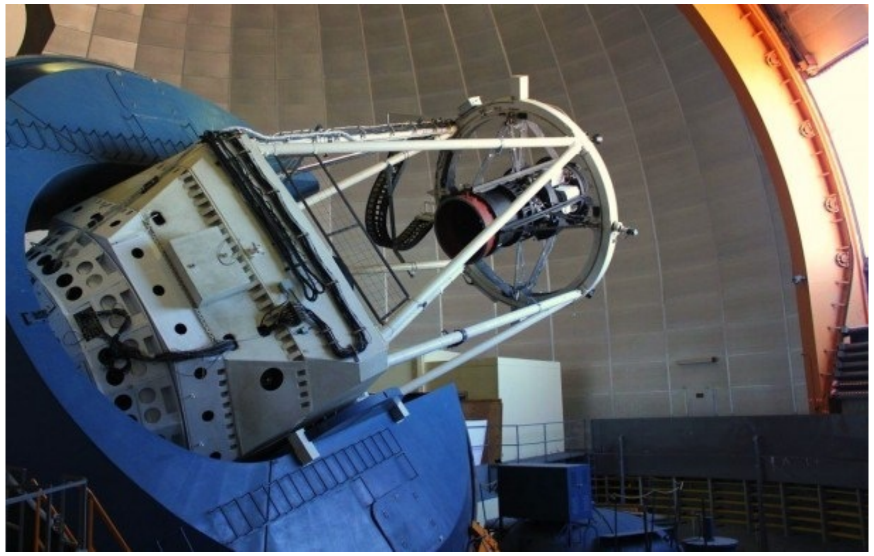
2014-2019: **Hyper-Suprime Cam Survey**, 1400 deg^2

2013-2018: **Dark Energy Survey**, 5000 deg^2

2011-2018: **Kilo-Degree Survey**, 1350 deg^2

Dark Energy Survey

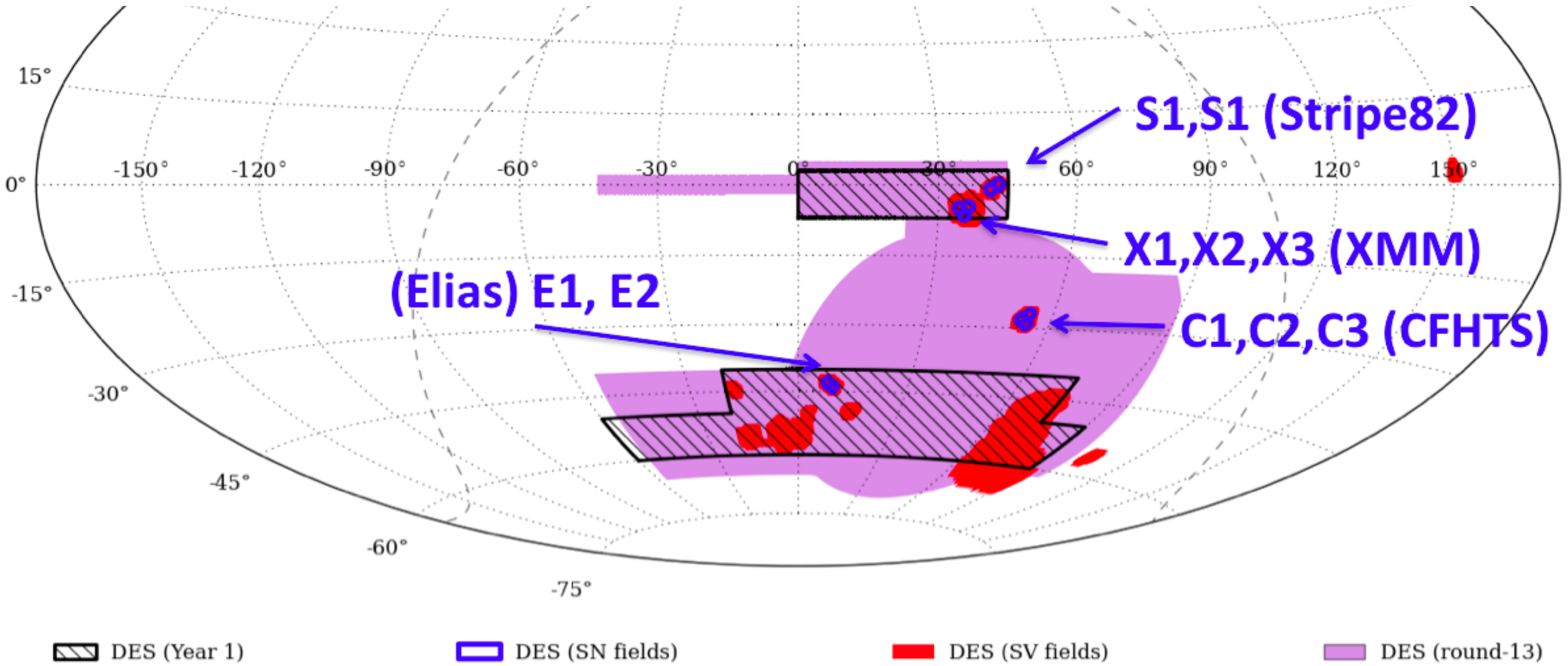
overview



- Wide Optical and near IR survey (grizY bands)
- 525 nights over 5 seasons in 5 imaging bands
- 5000 deg2 of which 2500 overlap with South Pole Telescope
- i-band magnitud limit ~24 at S/N=10, largest survey at this sensitivity
- 30 deg^2 in time domain, SN fields visited at least once per week

Observations will finish by end of this year

Cosmology from Y1 (hash regions) published



Dark Energy Survey

Weak lensing (distance, structure growth)
shapes of 200 millions galaxies

Baryonic acoustic oscillations (distance)
300 millions galaxies to z=1 and beyond

Galaxy clusters (distance, structure growth)
hundred of thousands of clusters up to z~1
synergies with SPT, VHS

Type Ia supernovae (distance)
30 sq. deg. SN fields
3000 SNIa to z~1

robust combination of probes

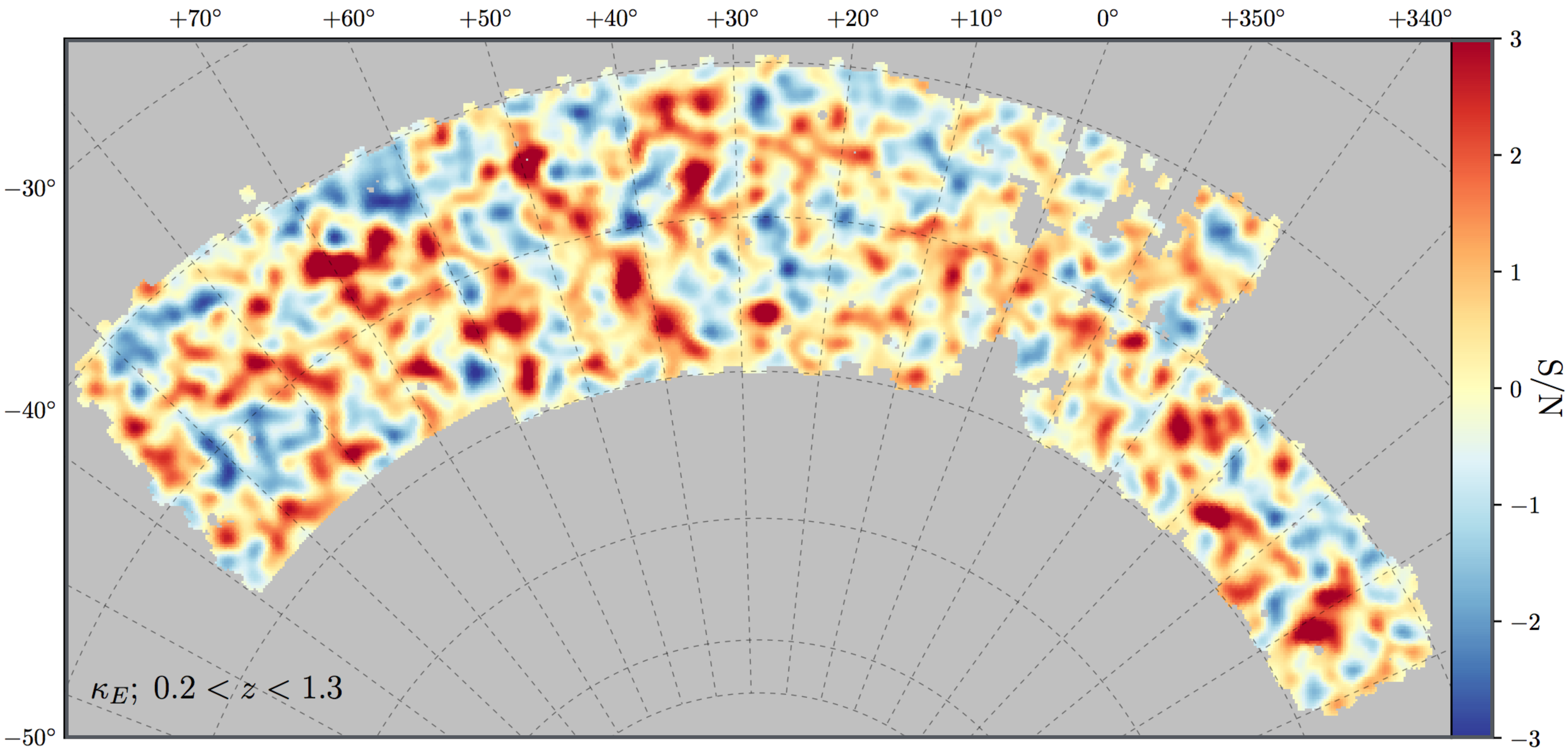
→ shared photometry/footprint
→ shared analysis of systematics
→ shared galaxy redshift estimates

Cross-correlations
Galaxies and WL x CMB lensing

Strong Lensing (distance)
30 QSO lens time delays
Arcs with multiple source redshifts

Chang et al (arxiv 1708.01535)

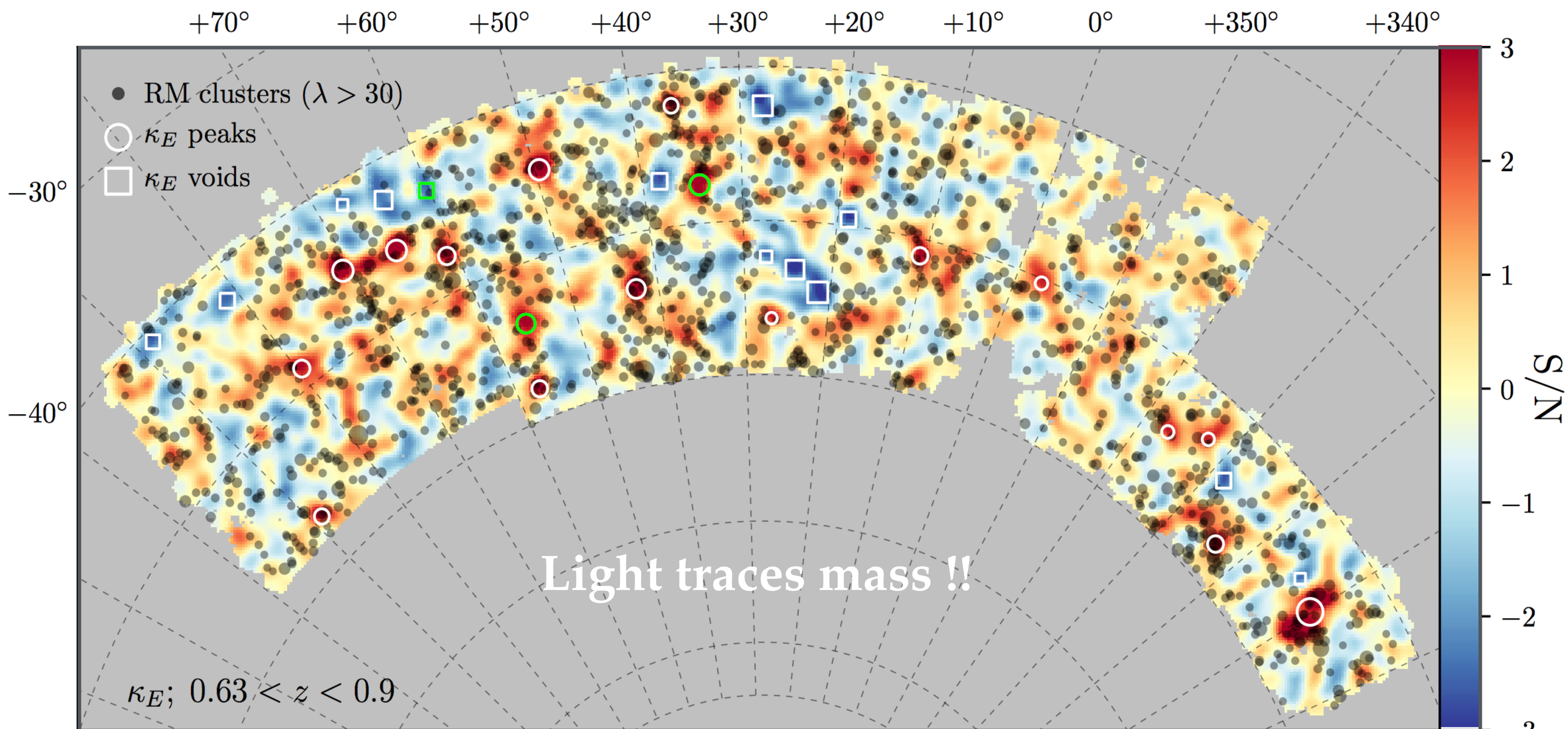
DES Year 1 Projected Dark-Matter



from 23 million galaxy shapes measured over 1300 deg²

Chang et al (arxiv 1708.01535)

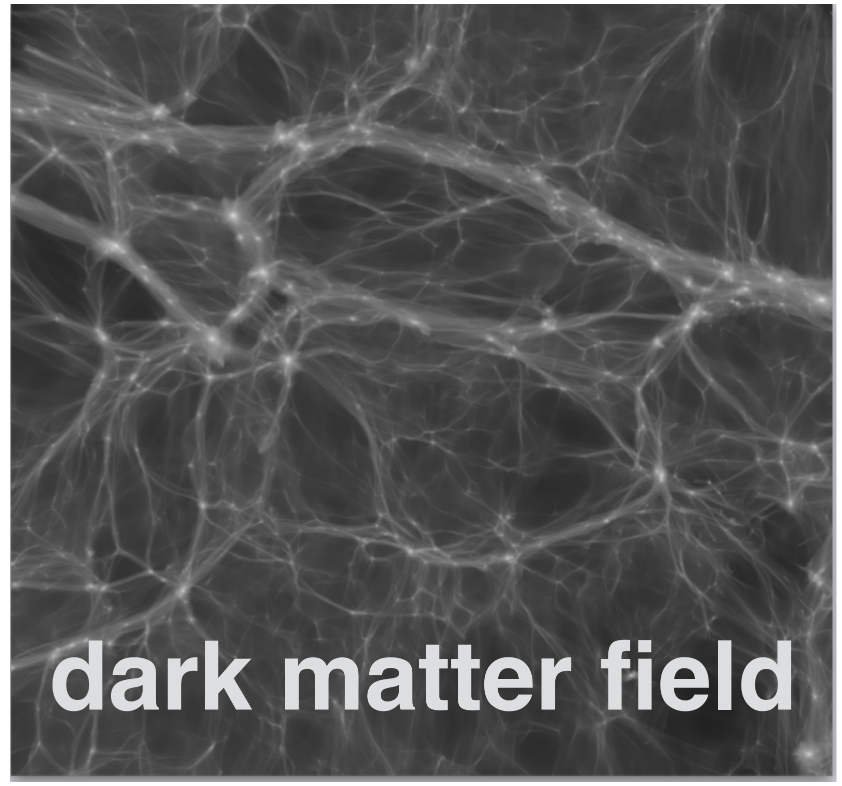
DES Year 1 Projected Dark-Matter



+ Clusters over-imposed

from 23 million galaxy shapes measured over 1300 deg^2

LSS $\delta_{gal} \sim b \times \delta_m$



WL $\delta_{gal\,shapes} \sim \delta_m$

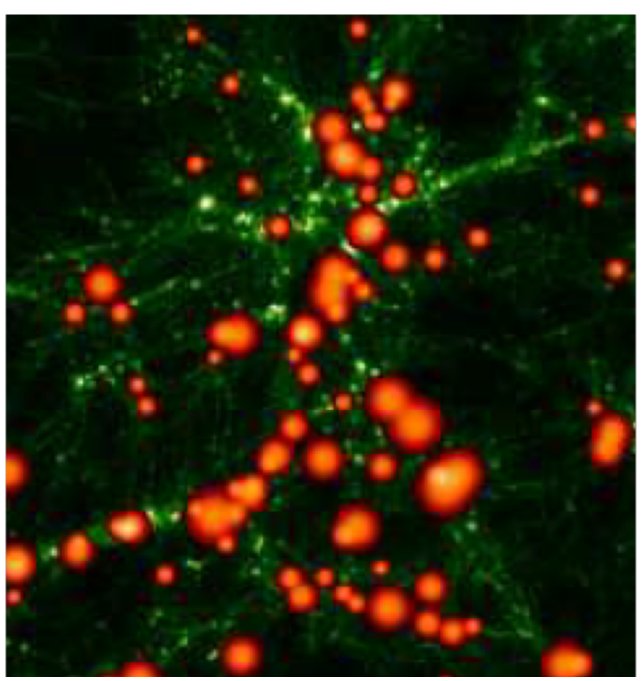
galaxy clustering

$w_{gal-gal} \sim b^2 \times D^2(z)$

3x2pt

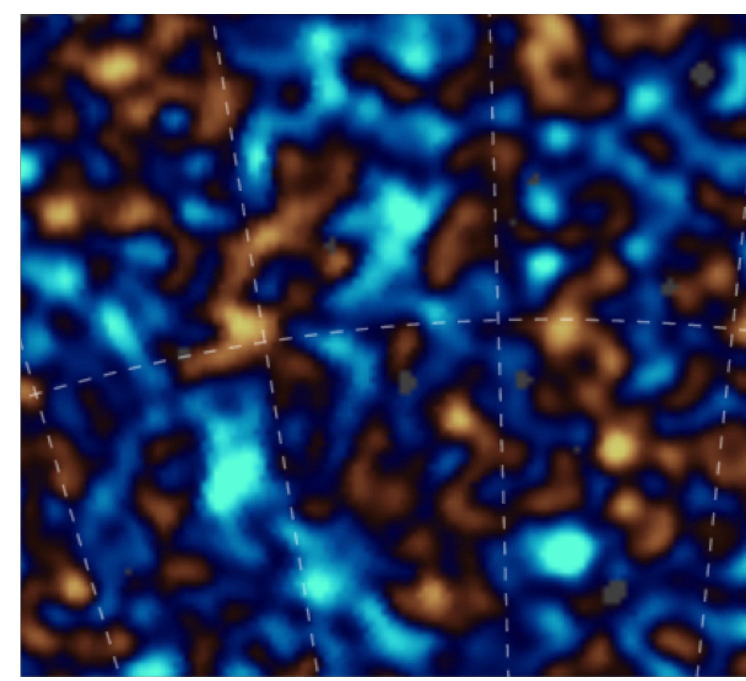
cosmic shear

$w_{shear-shear} \sim D^2(z)$



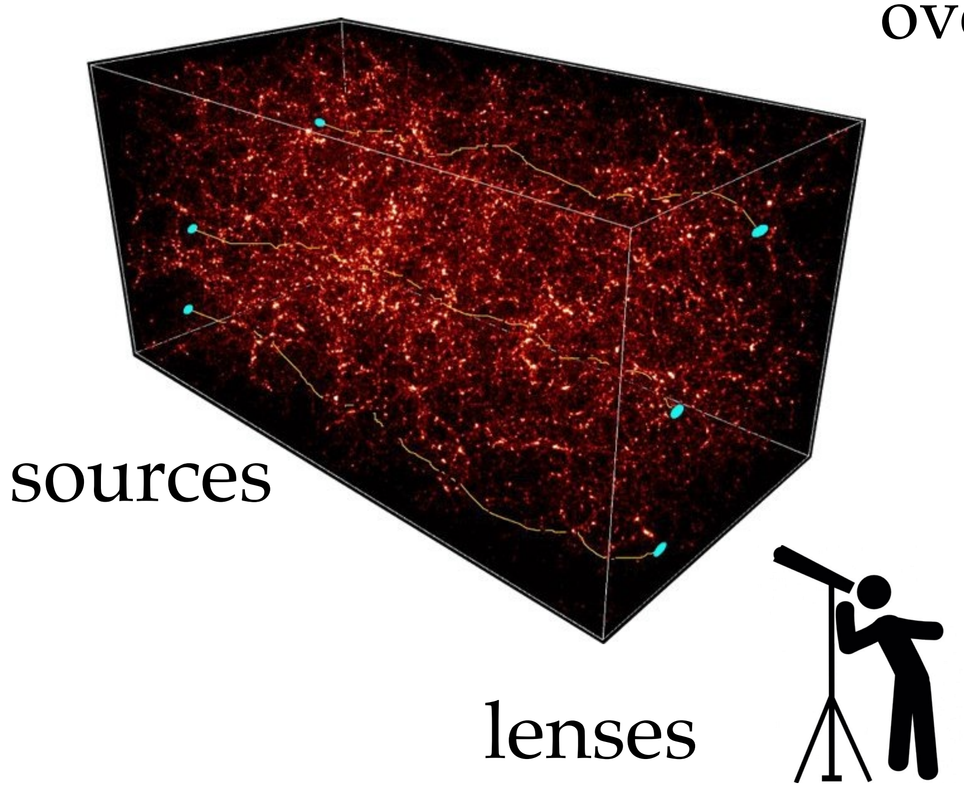
gal-gal lensing

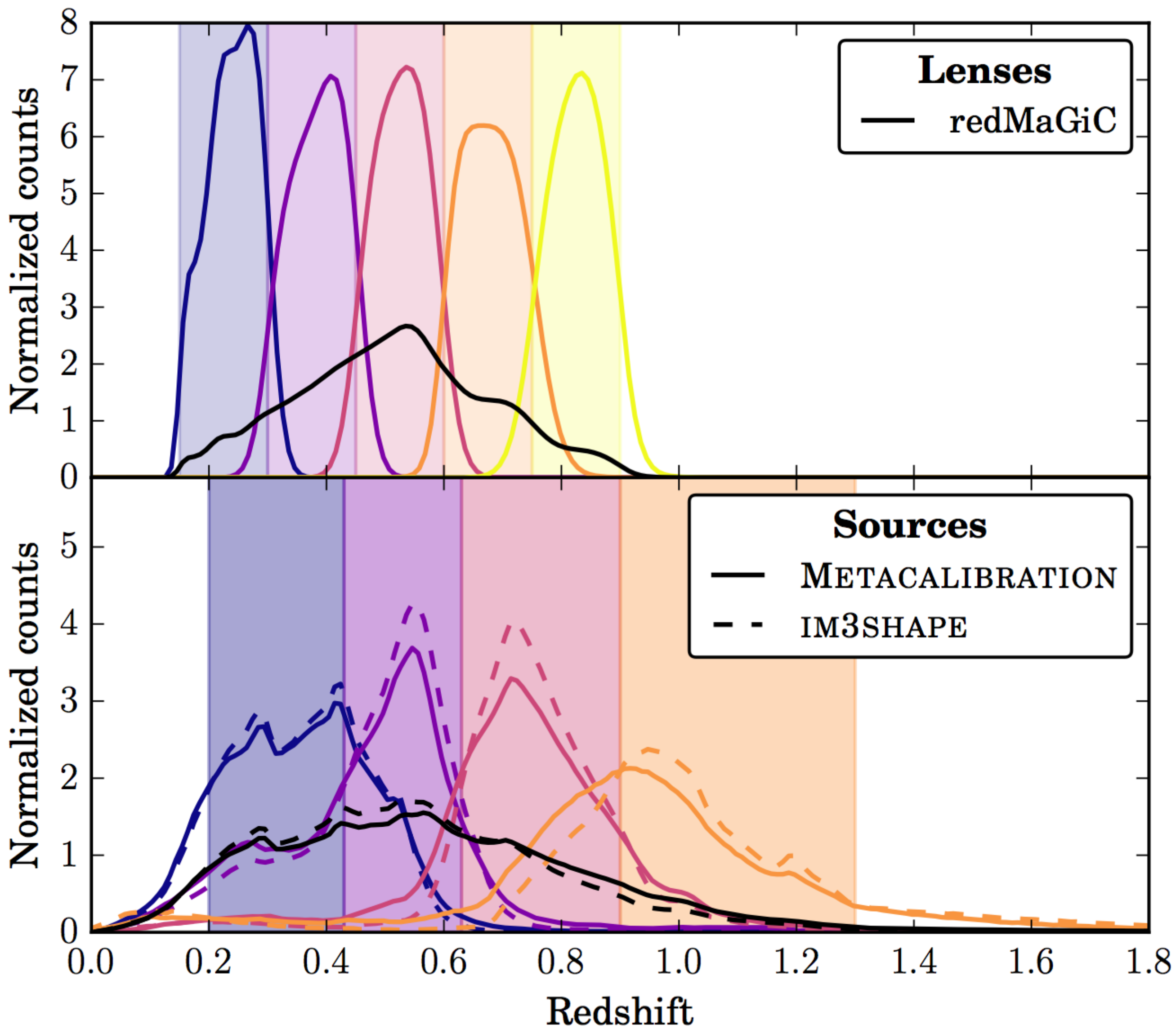
$w_{gal-shear} \sim b \times D^2(z)$



DES Y1 cosmology

over 1321 deg^2





Lens sample

- 600,000 red sequence galaxies

Accurate photo-z, optimal for clustering

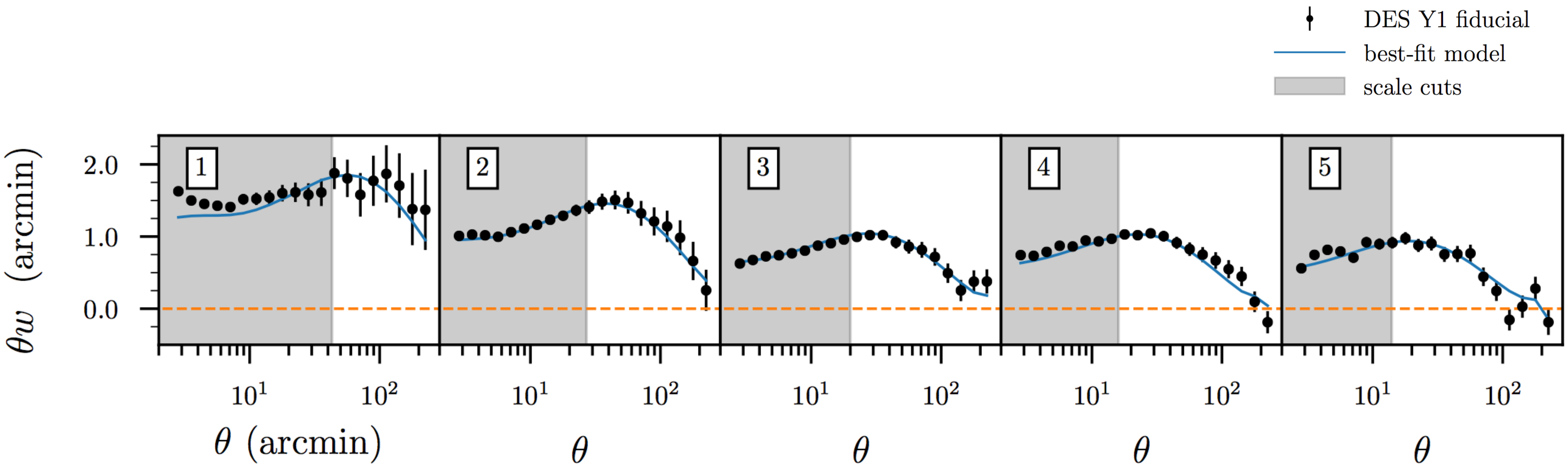
Source Sample

- Metacalibration 26 Millon shapes
- Im3shape 18 M. shapes

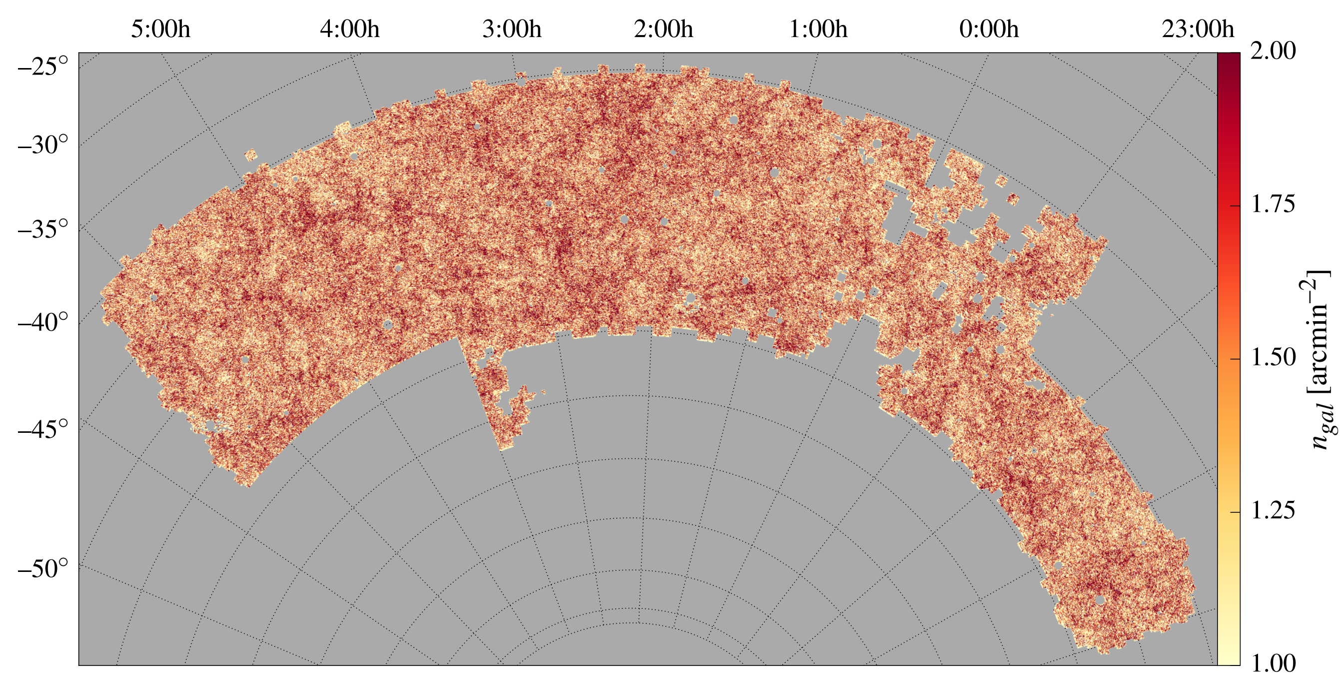
Two independent shape measurements pipelines (different systematics & assumptions)

DES Y1 gal-gal clustering

- **5 lens bins** (660,000 red galaxies with ~ 1%~2% redshift error),



$$w^i(\theta) = (b^i)^2 \int \frac{dl}{l} 2\pi J_0(l\theta) \int d\chi \times \frac{[n^i_{\rm g}(z(\chi)]^2}{\chi^2 H(z)} P_{\rm NL}\left(\frac{l+1/2}{\chi}, z(\chi)\right)$$



Elvin-Poole, Crocce, Ross et al 2017
(arxiv 1708.01536)

DES Y1 shear-shear correlations

$$\xi_+(\theta) = \langle\gamma\gamma^*\rangle(\theta) \qquad = \langle\gamma_t\gamma_t\rangle(\theta) + \langle\gamma_\times\gamma_\times\rangle(\theta);$$
$$\xi_-(\theta) = \Re\left[\langle\gamma\gamma\rangle(\theta)e^{-4i\phi}\right] = \langle\gamma_t\gamma_t\rangle(\theta) - \langle\gamma_\times\gamma_\times\rangle(\theta).$$

Shapes of galaxies are Spin-2 quantities. Sum and difference of the product of the tangential and cross components of the shear (ellipticity) w.r.t line connecting pairs of galaxies.

$$\hat{\xi}^{ij}_{\pm}(\theta) = \frac{1}{2\pi}\int d\ell\ell J_{0/4}(\theta\ell)P^{ij}_{\kappa}(\ell)$$

amplitude and growth rate of structure

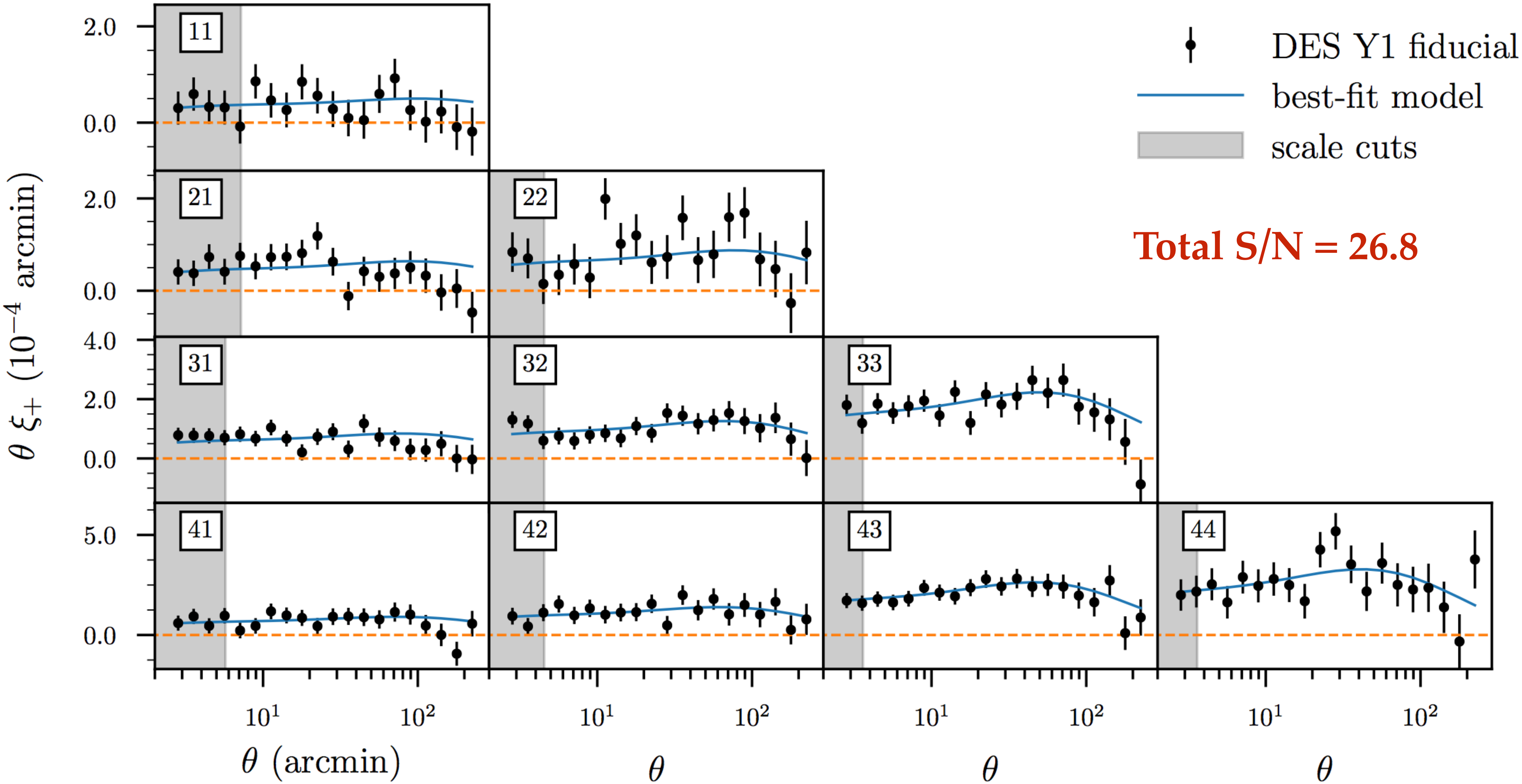
$$P^{ij}_{\kappa}(\ell) = \int_0^{\chi_H} d\chi \frac{q^i(\chi)q^j(\chi)}{\chi^2} P_{\rm NL}\left(\frac{\ell+1/2}{\chi}, \chi\right)$$

$$q^i(\chi) = \frac{3}{2}\Omega_m\left(\frac{H_0}{c}\right)^2 \frac{\chi}{a(\chi)}\int_\chi^{\chi_H} d\chi' n^i(\chi')\frac{dz}{d\chi'}\frac{\chi'-\chi}{\chi'}.$$

Geometry (distances or expansion)

DES Y1 shear-shear correlations

- **10 two-point correlations (26 million sources)**



Total S/N = 26.8

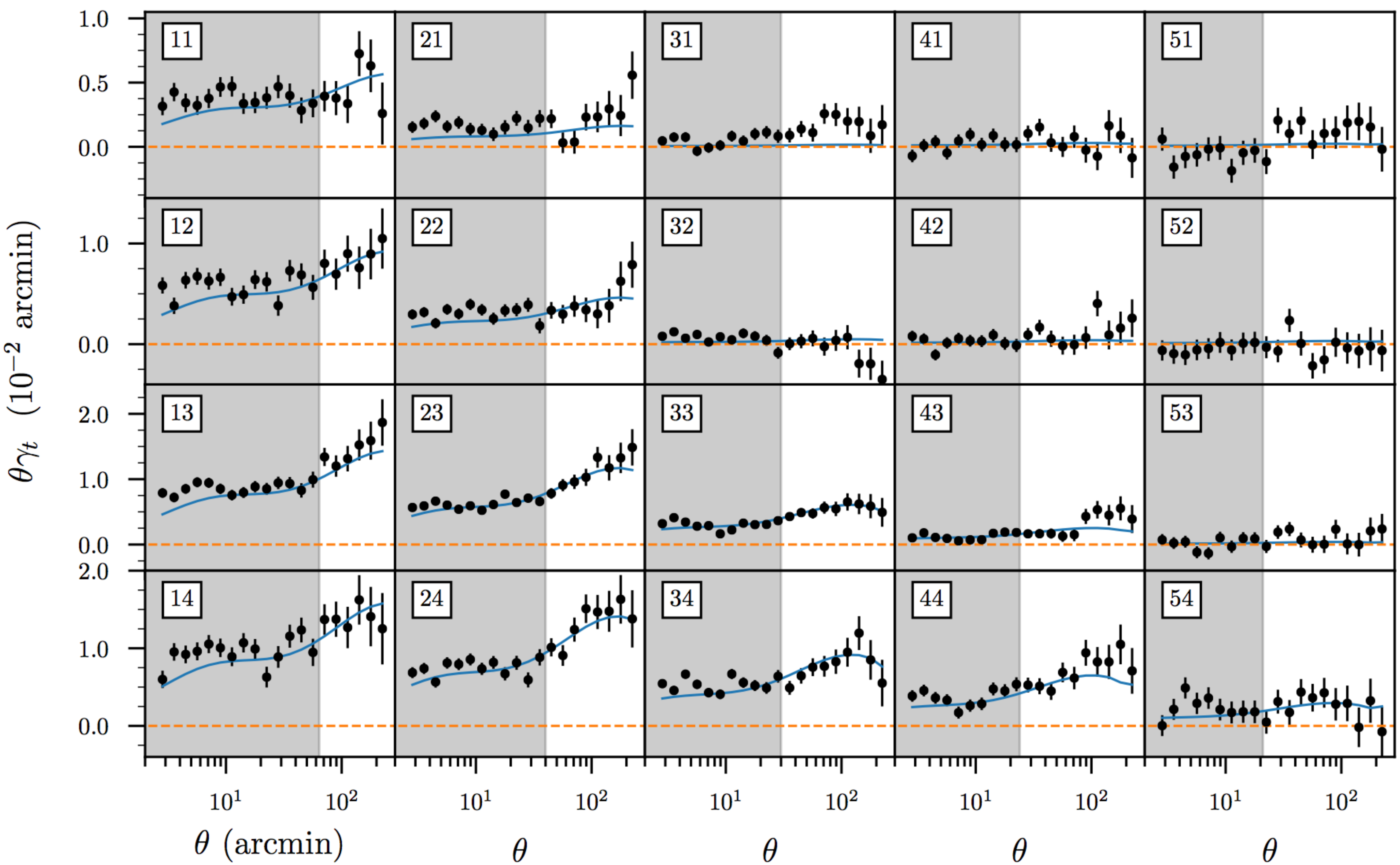
Troxel et al 2017 (arxiv 1708.01538)

- **Another 10 for xi_minus**

DES Y1 gal-gal lensing

- **20 correlations**

Prat, Shanchez et al 2017 (arxiv 1708.01537)



+ similar with im3shape

3x2 Y1 DES Cosmological Analysis

45 different 2-pt correlations, 457 data-points

[1] Marginalizing over

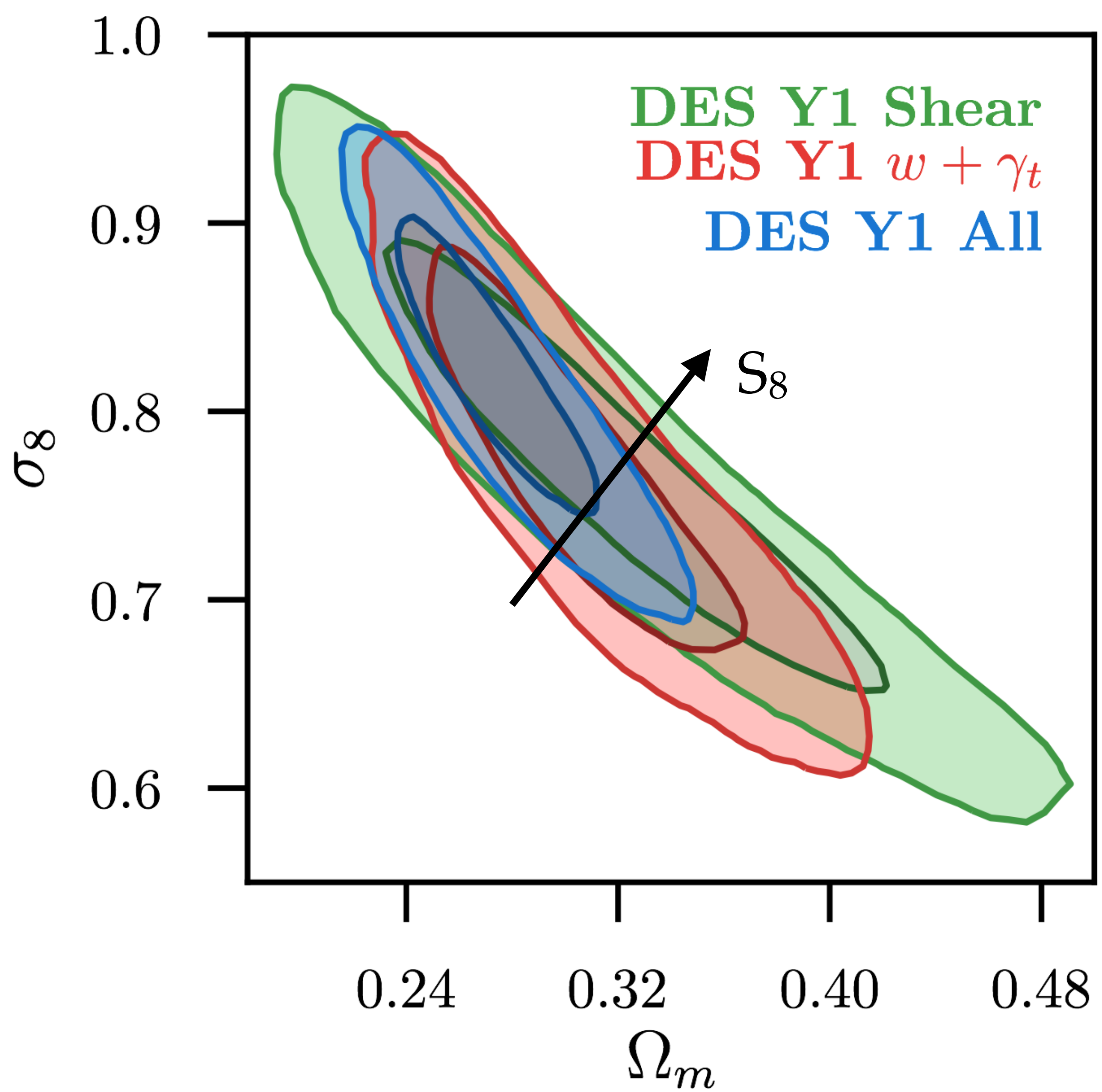
- 6 (+w) cosmological parameters
  - including neutrino mass
- 7 astrophysical parameters (bias, IA)
- 13 systematic parameters (shear and photo-z calibration)

[2] Data and analysis validation extended over two years (blinded)

[3] Almost every step is doubled implemented (two shear pipelines, two analysis pipelines, two photo-z calibrations, two simulations sets, two likelihood samplers)

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	
$A_{\rm IA}(z) = A_{\rm IA}[(1 + z)/1.62]^{\eta_{\rm IA}}$	
$A_{\rm IA}$	flat $(-5, 5)$
$\eta_{\rm IA}$	flat $(-5, 5)$
Lens photo-z shift (red sequence)	
$\Delta z^1_{\rm l}$	Gauss $(0.008, 0.007)$
$\Delta z^2_{\rm l}$	Gauss $(-0.005, 0.007)$
$\Delta z^3_{\rm l}$	Gauss $(0.006, 0.006)$
$\Delta z^4_{\rm l}$	Gauss $(0.000, 0.010)$
$\Delta z^5_{\rm l}$	Gauss $(0.000, 0.010)$
Source photo-z shift	
$\Delta z^1_{\rm s}$	Gauss $(-0.001, 0.016)$
$\Delta z^2_{\rm s}$	Gauss $(-0.019, 0.013)$
$\Delta z^3_{\rm s}$	Gauss $(+0.009, 0.011)$
$\Delta z^4_{\rm s}$	Gauss $(-0.018, 0.022)$
Shear calibration	
$m^i_{\rm METACALIBRATION}(i = 1, 4)$	Gauss $(0.012, 0.023)$
$m^i_{\rm IM3SHAPE}(i = 1, 4)$	Gauss $(0.0, 0.035)$

[1] Internal consistency : 3x2pt



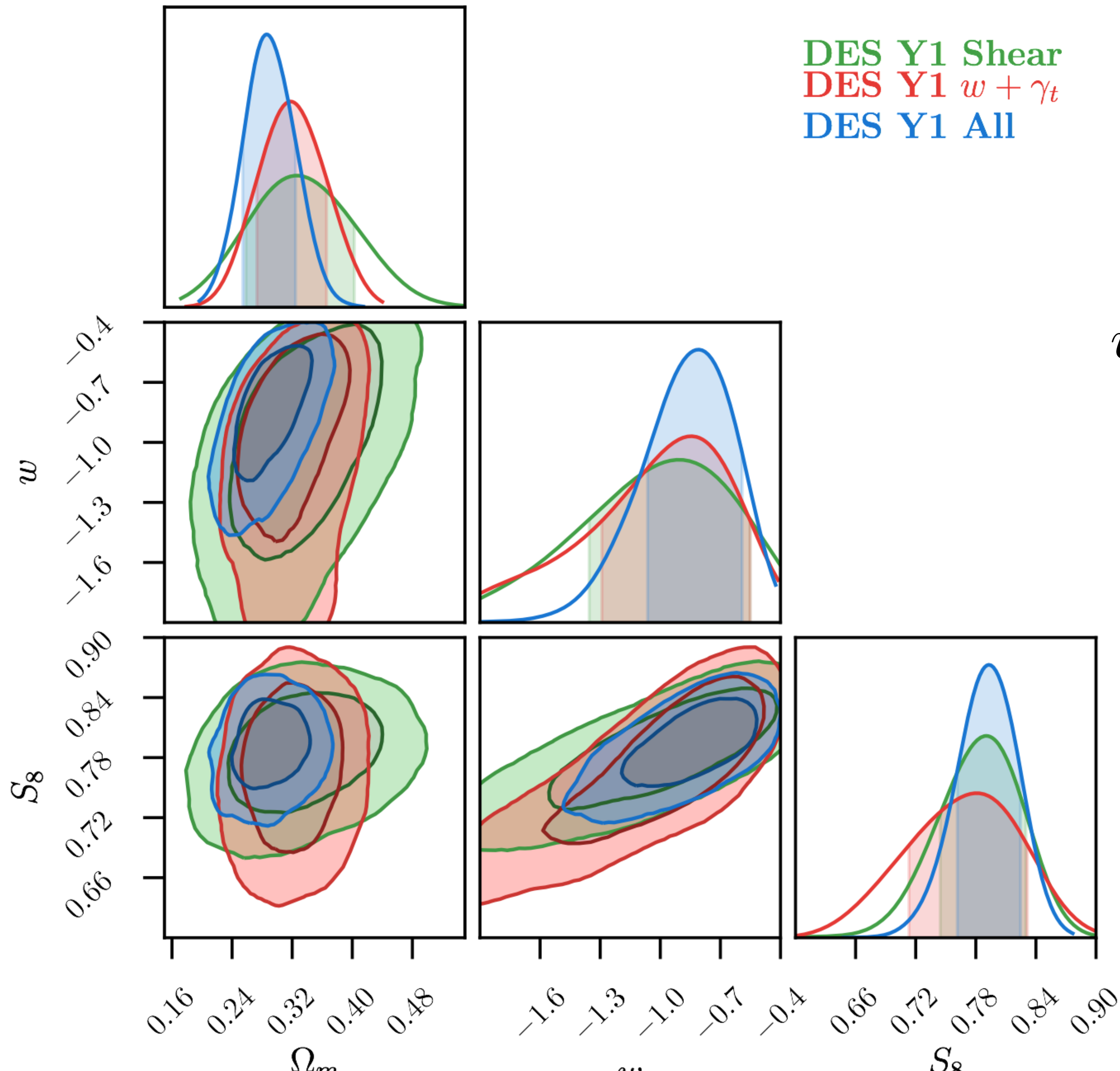
- Remarkable agreement of lensing and galaxy clustering
- Most precise cosmology from LSS alone to date
- Combination of clustering and weak lensing (3x2pt) improves constrains from them alone (~ factor 2)

- First constrain on Intrinsic Alignments Amplitude from optical data, and galaxy bias ~10 % even fully marginalised

DES Collaboration (arxiv 1708.01530)

[2] wCDM

- **DES alone does not favor wCDM**

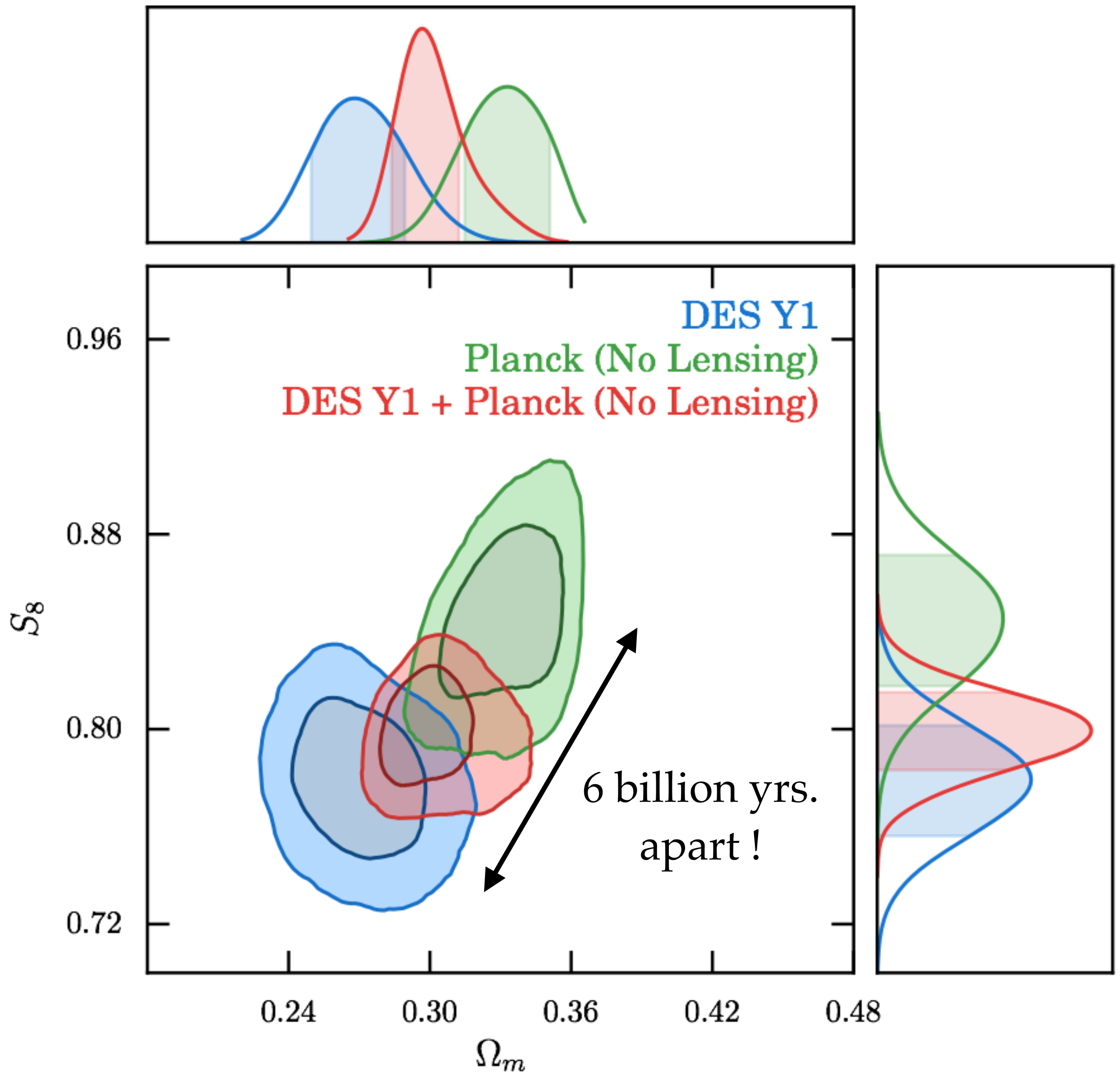


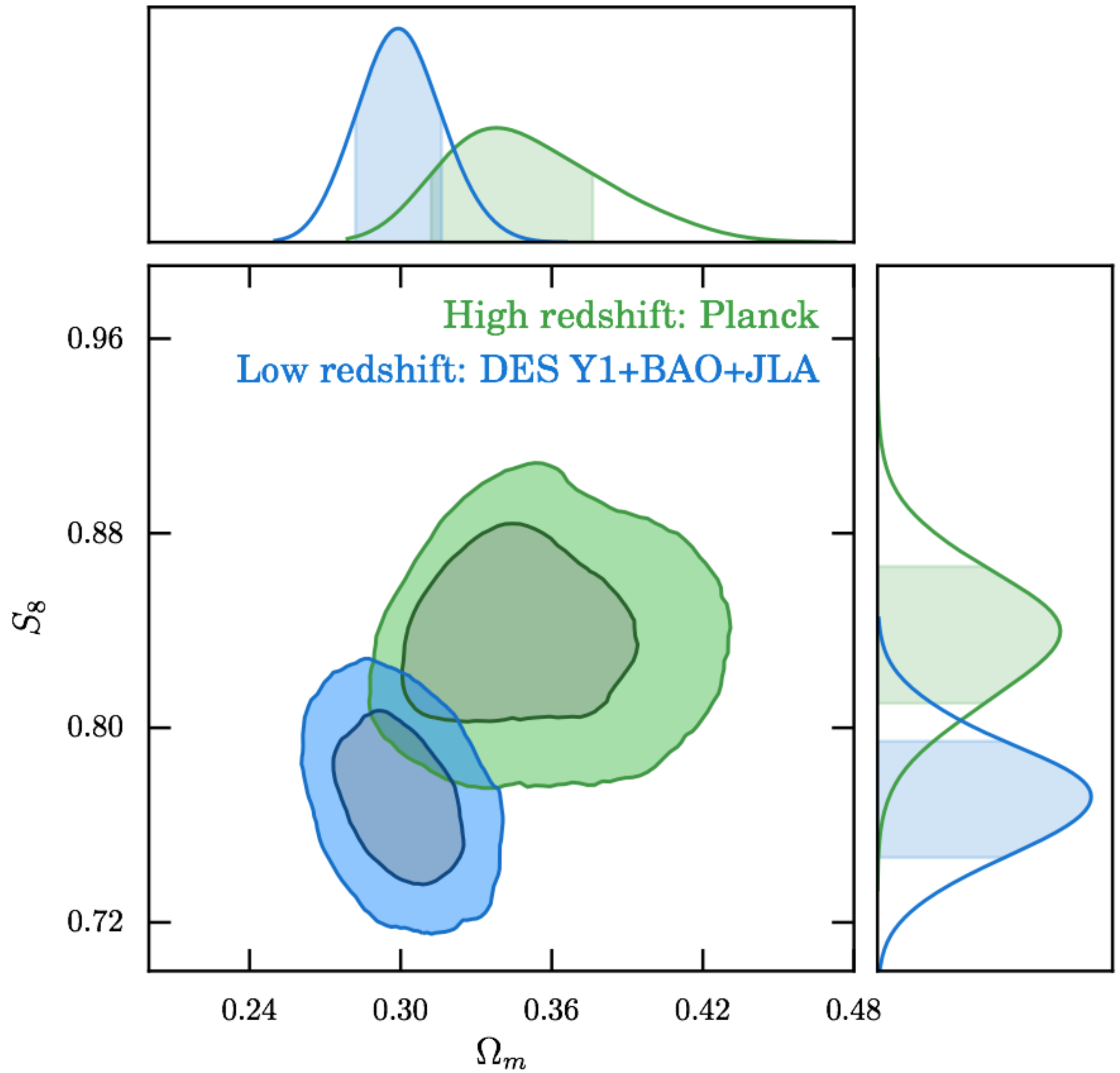
$$w = -0.80^{+0.20}_{-0.22} \quad (68\%\,\mathrm{CL})$$

$$R_w = \frac{P(\mathbf{D}|w\mathrm{CDM})}{P(\mathbf{D}|\Lambda\mathrm{CDM})} = 0.36$$

[3] From high-z to low-z
the Universe at its two extremes

Consistent and comparable constrains between LSS and CMB





[3] From high-z to low-z

the Universe at its two extremes

Combining DESY1 + Planck (w/lensing) + BAO + JLA —> most stringent constrains so far of large-scale structure related parameters

$$\Omega_m = 0.298 \pm 0.007.$$

$$\sigma_8 = 0.808^{+0.009}_{-0.017}$$

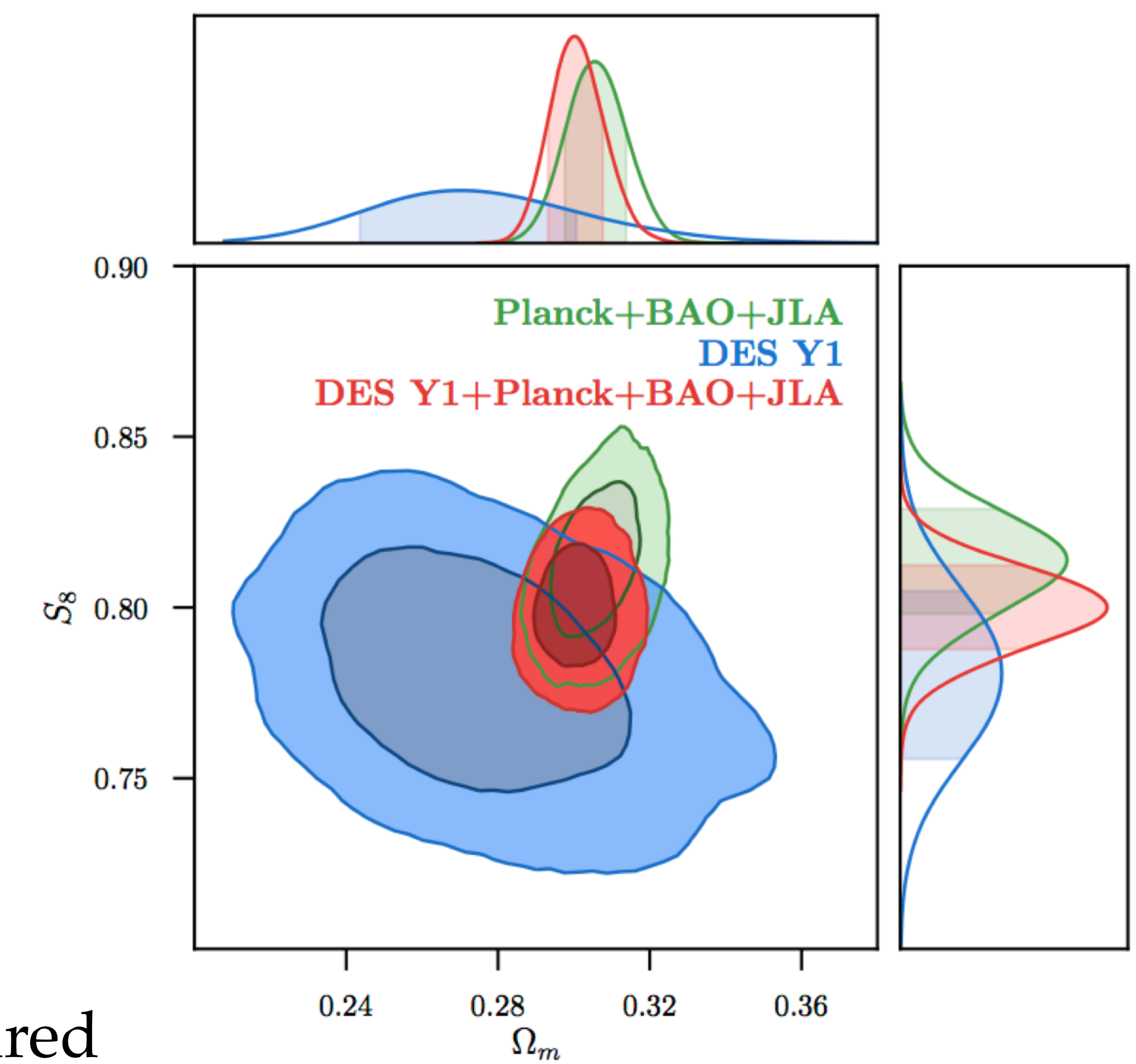
$$S_8 = 0.802 \pm 0.012.$$

$$h = 0.685^{+0.005}_{-0.007}$$

wCDM :

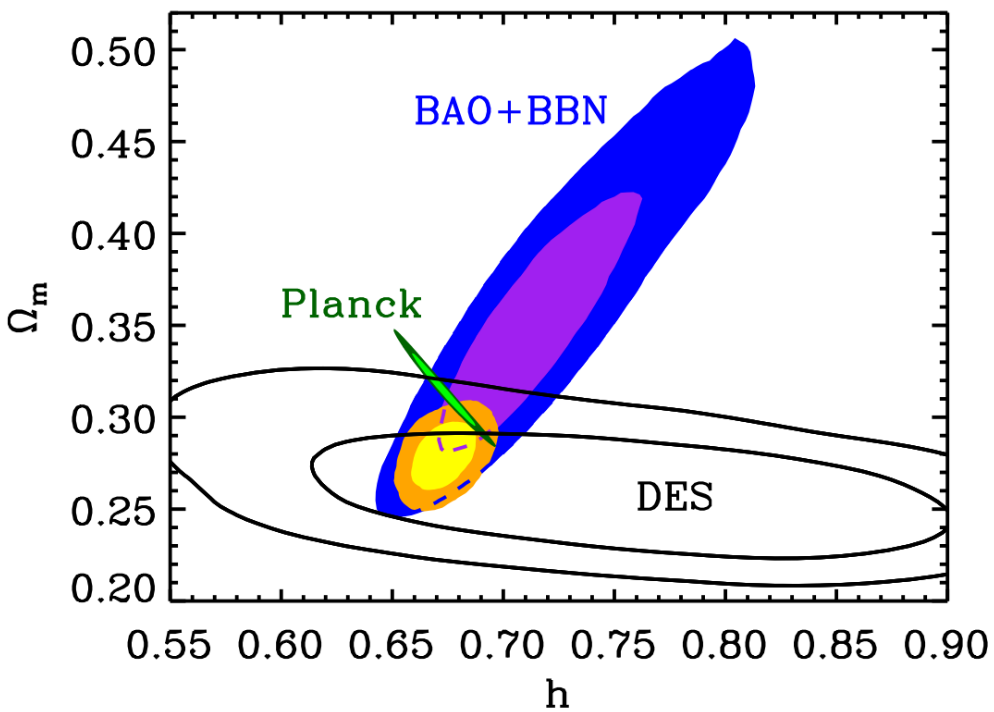
$$w = -1.00^{+0.05}_{-0.04}.$$

Introducing w is not formally favoured

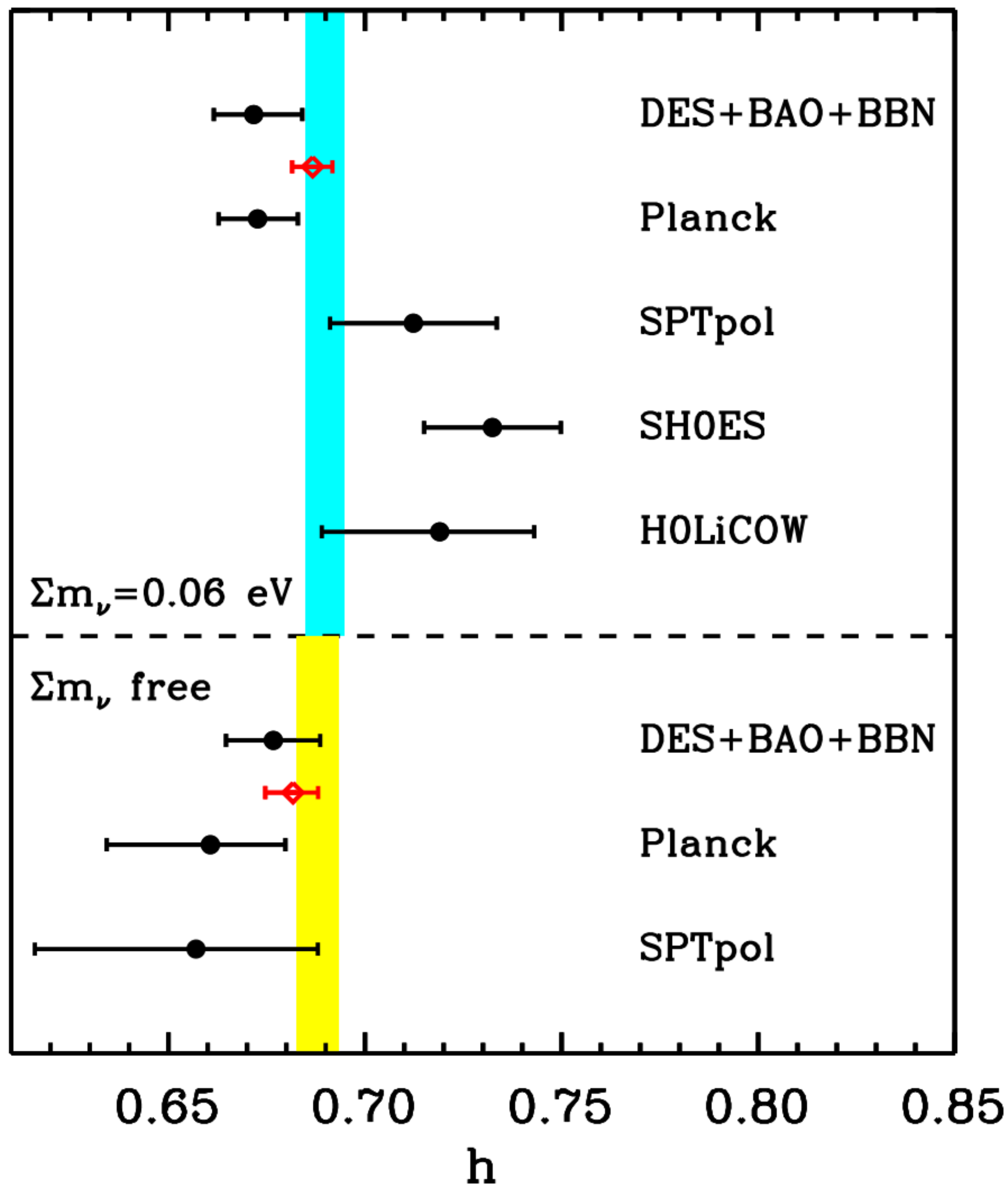


DES Collaboration (arxiv 1711.00403)

[4] H0 tension



DES+BAO+BBN $H_0 = 67.2^{+1.2}_{-1.0}$ km/s/Mpc

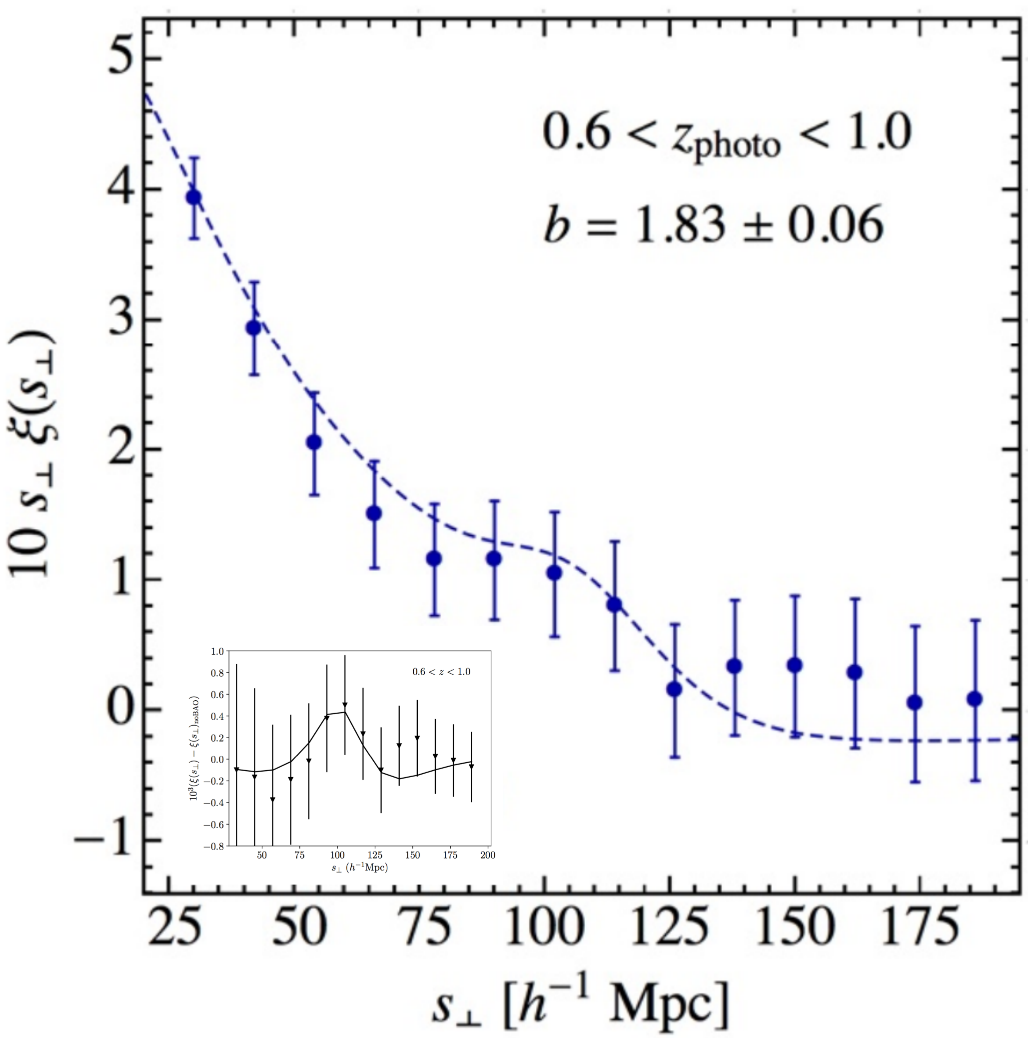


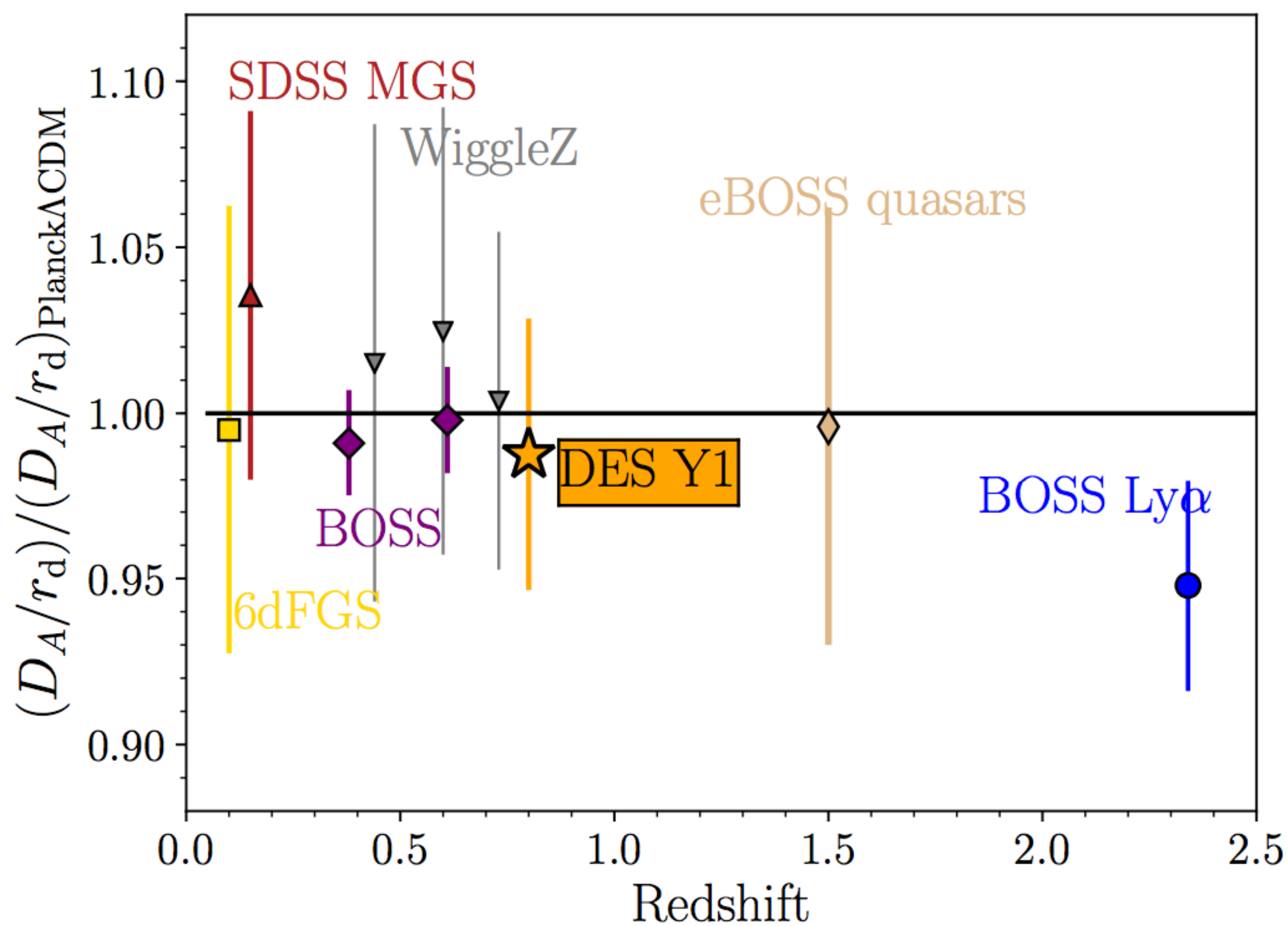
- DES constrains on Om combined with BAO and BBN can constrain H_0
- 5 totally independent measurements of H0
- As such the distribution is consistent at 2.1 sigma

BAO in DES-Y1

- Measuring galaxy clustering on the largest scales, optimised sample (1380 sq deg)
- 4% measurement of angular diameter distance to z ~ 0.8
- Expect a 2% in Y3 (early next year)

DES Collaboration (arxiv 1712.06209)





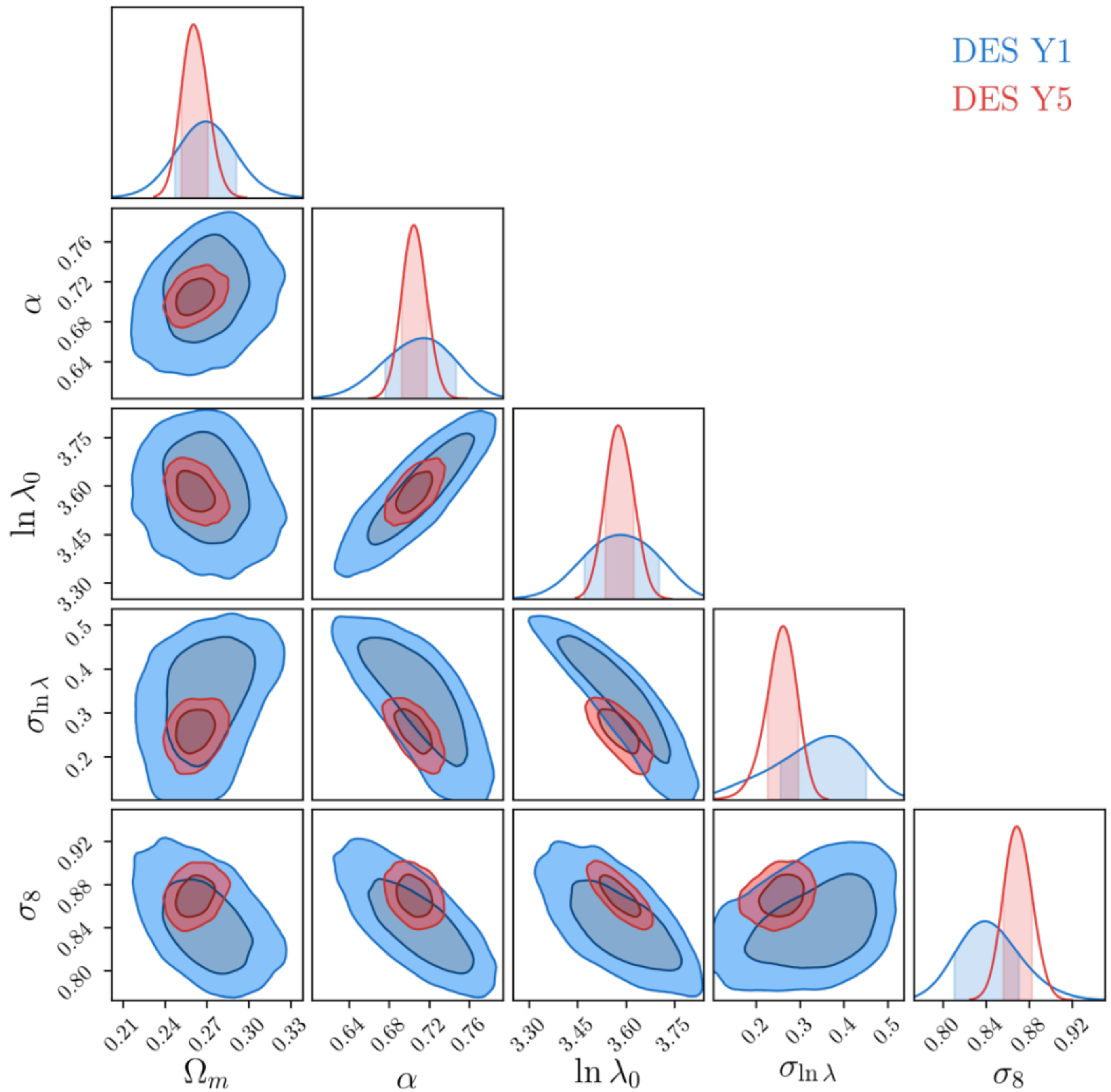
Cluster cosmology in DES-Y1

results coming soon

Cluster abundance sensitive to dark energy. Challenge is mass / obs relation

Cluster counts probe structure growth & expansion history:

1. masses calibrated with weak lensing
2. systematics include mis-centering, constrained by X-ray data
3. as the statistical errors get smaller, more careful treatment of systematics becomes essential



Summary

results coming soon

- Weak lensing surveys are here to stay, robust and consistent results together with galaxy clustering
- DES have stress tested Planck's LCDM, two extreme moments of the universe
- Some tensions remaining (H_0), stay tuned of DES Y3 results next year