Cosmic Acceleration @ KIPMU, Feb 19, 2020

Cosmology in the Era of Galaxy Surveys: from DES to LSST

Chihway Chang (UChicago/KICP)

For

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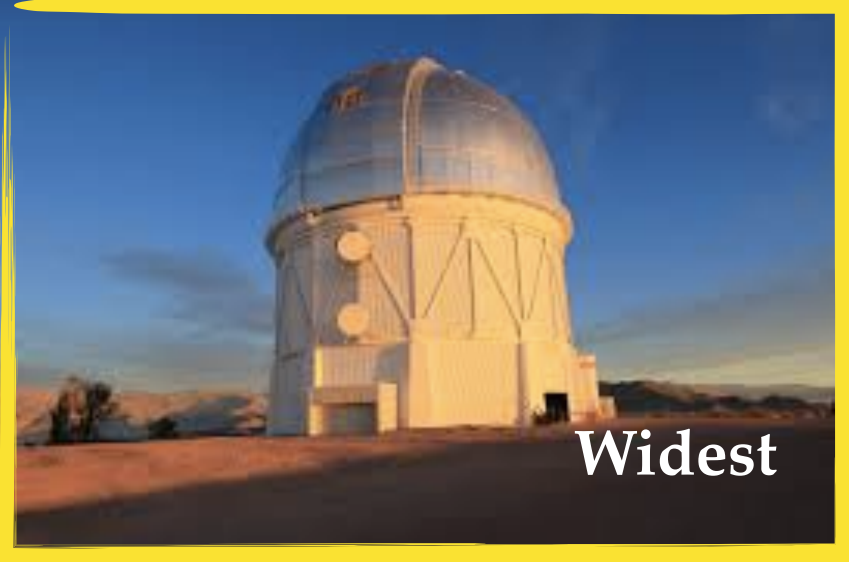
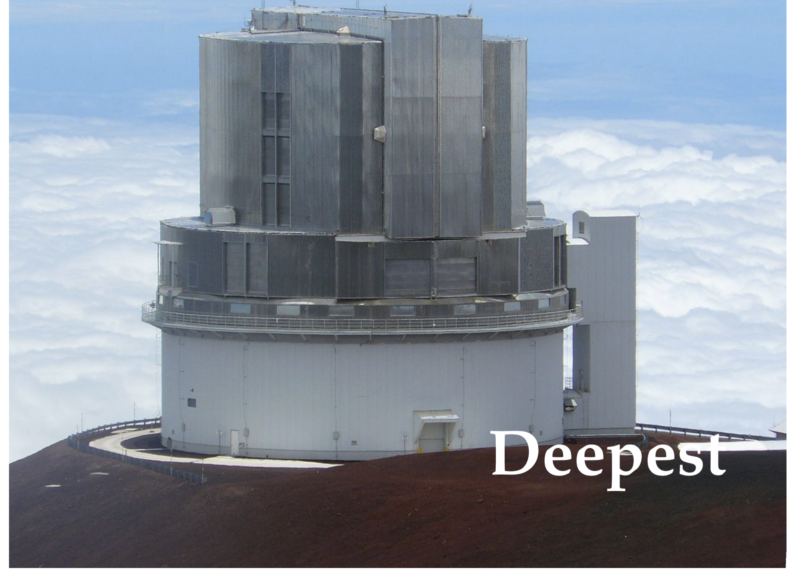
For

LSST DESC Dark Energy Science Collaboration





Cosmic Acceleration @ KIPMU, Feb 19, 2020

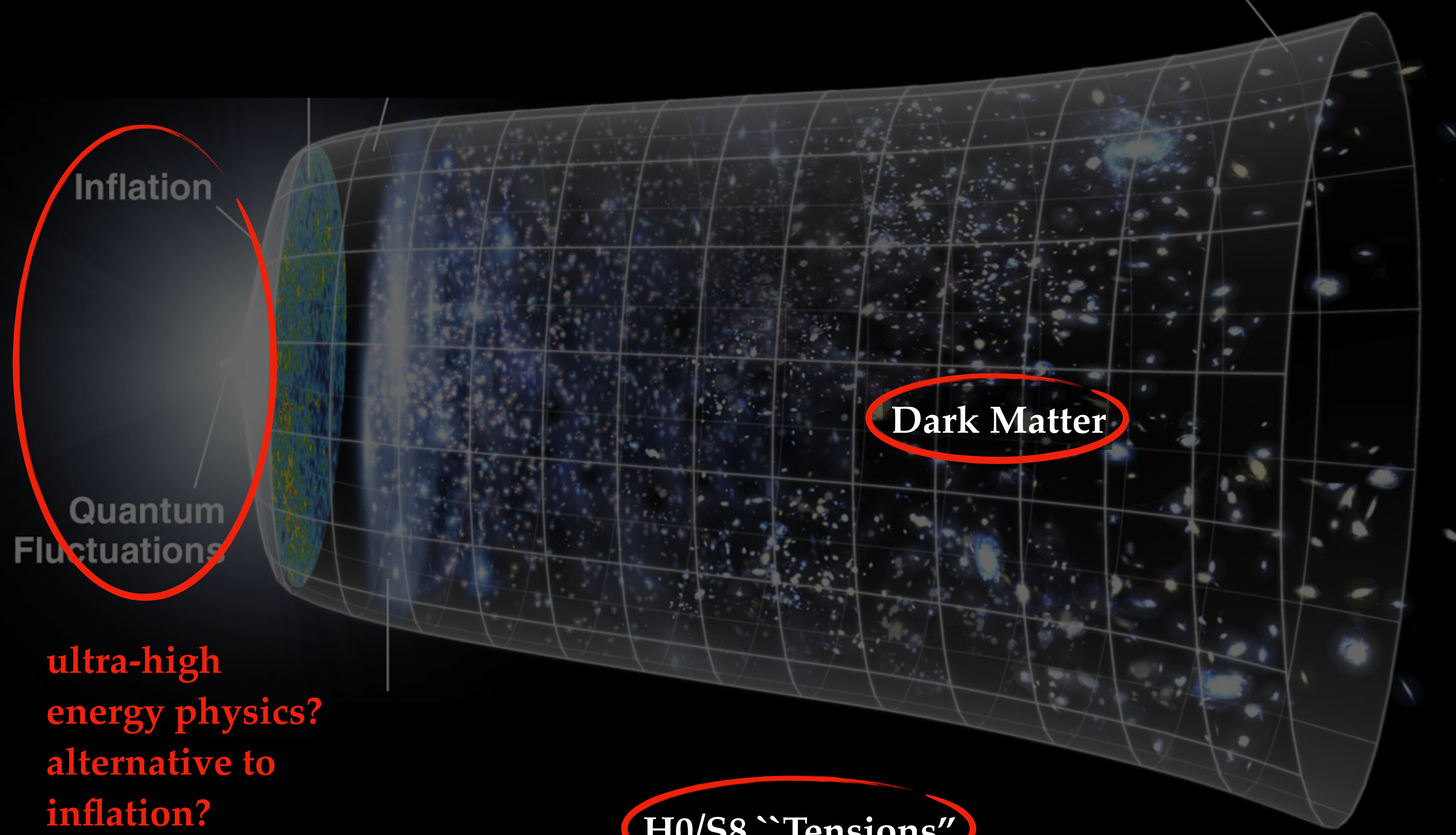
Cosmology in the Era of Galaxy Surveys: from DES to LSST

Chihway Chang (UChicago/KICP)

For

cosmological constant?
Dark Energy? modify gravity?

Key Questions in Cosmology



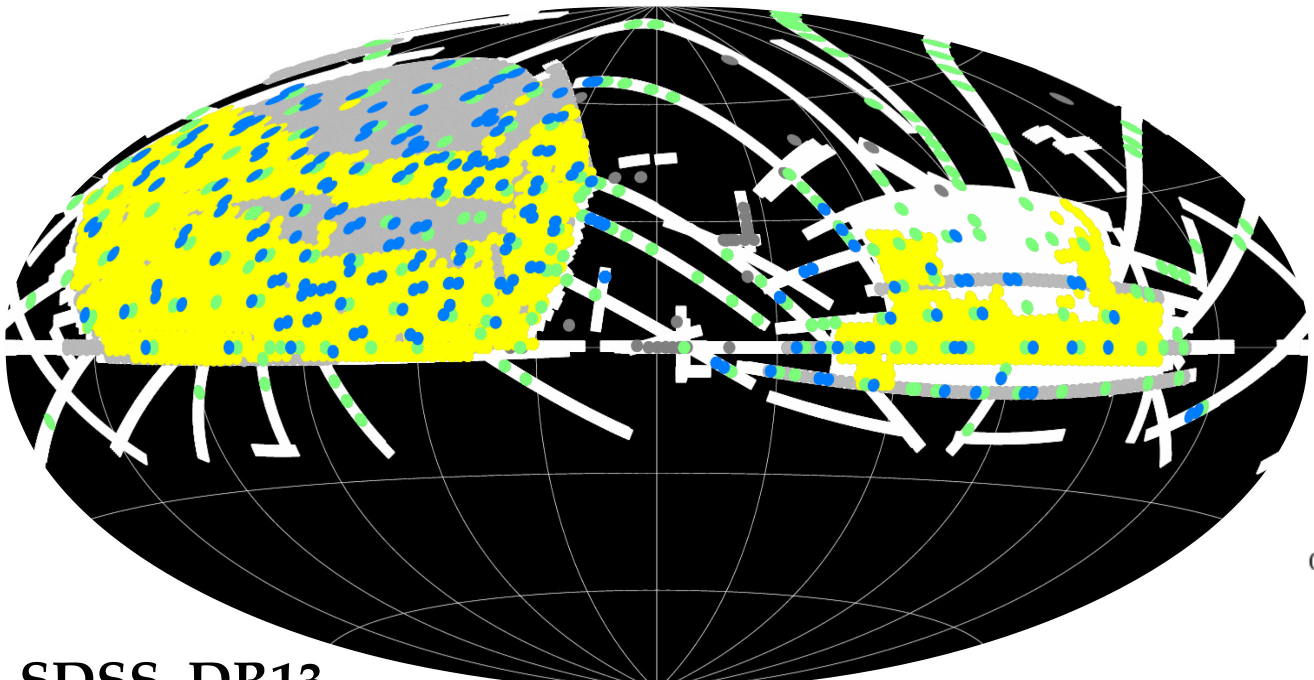
Dark Matter

ultra-high
energy physics?
alternative to
inflation?

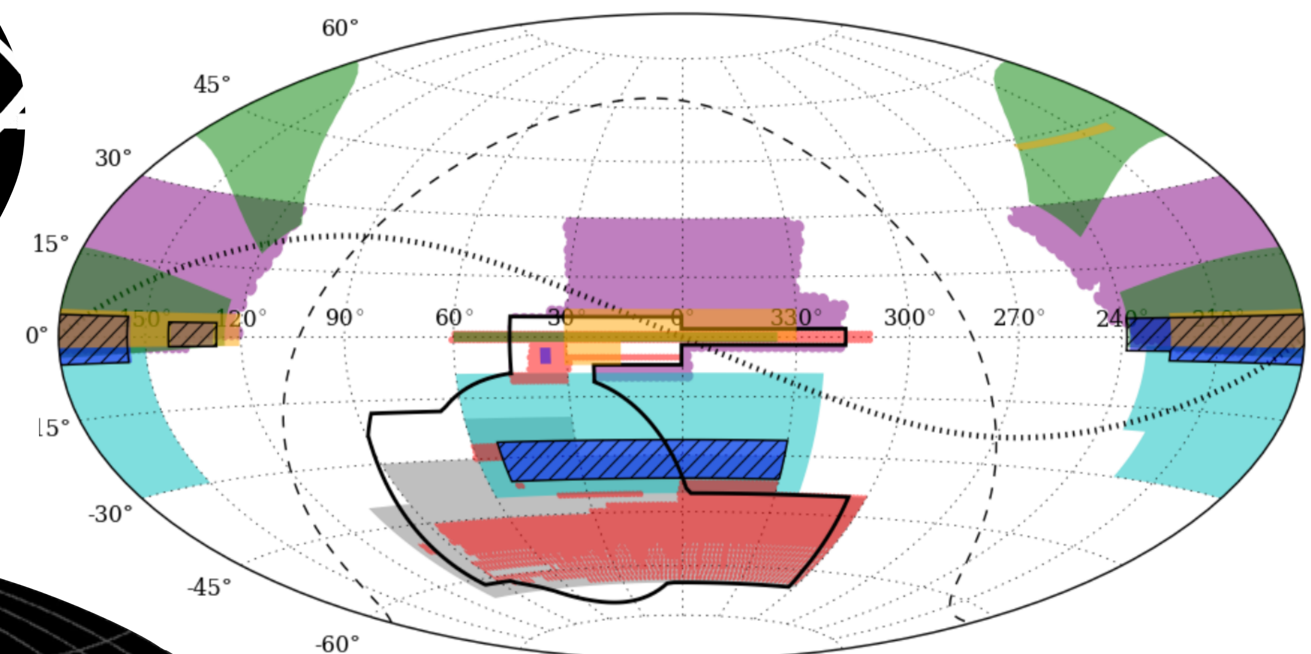
H0/S8 ``Tensions”

Image credit: NASA/WMAP

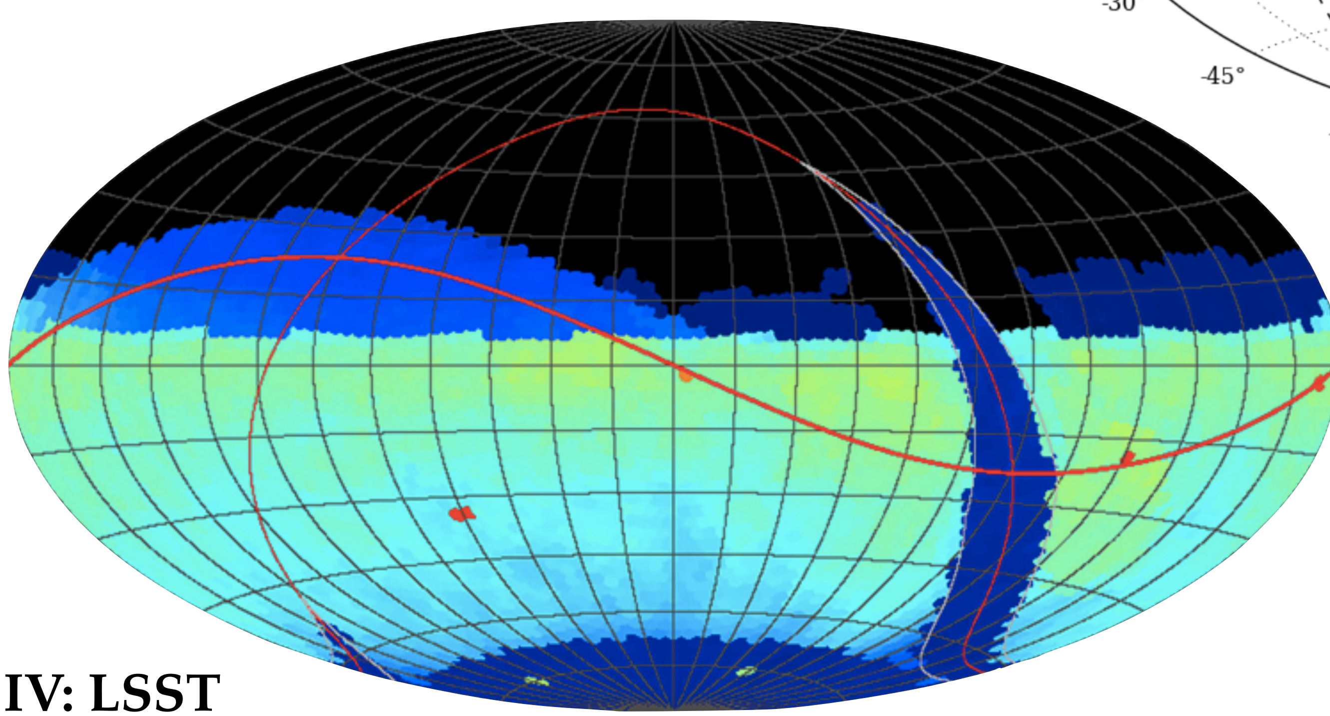
Galaxy Surveys Have a lot to Offer



SDSS DR13



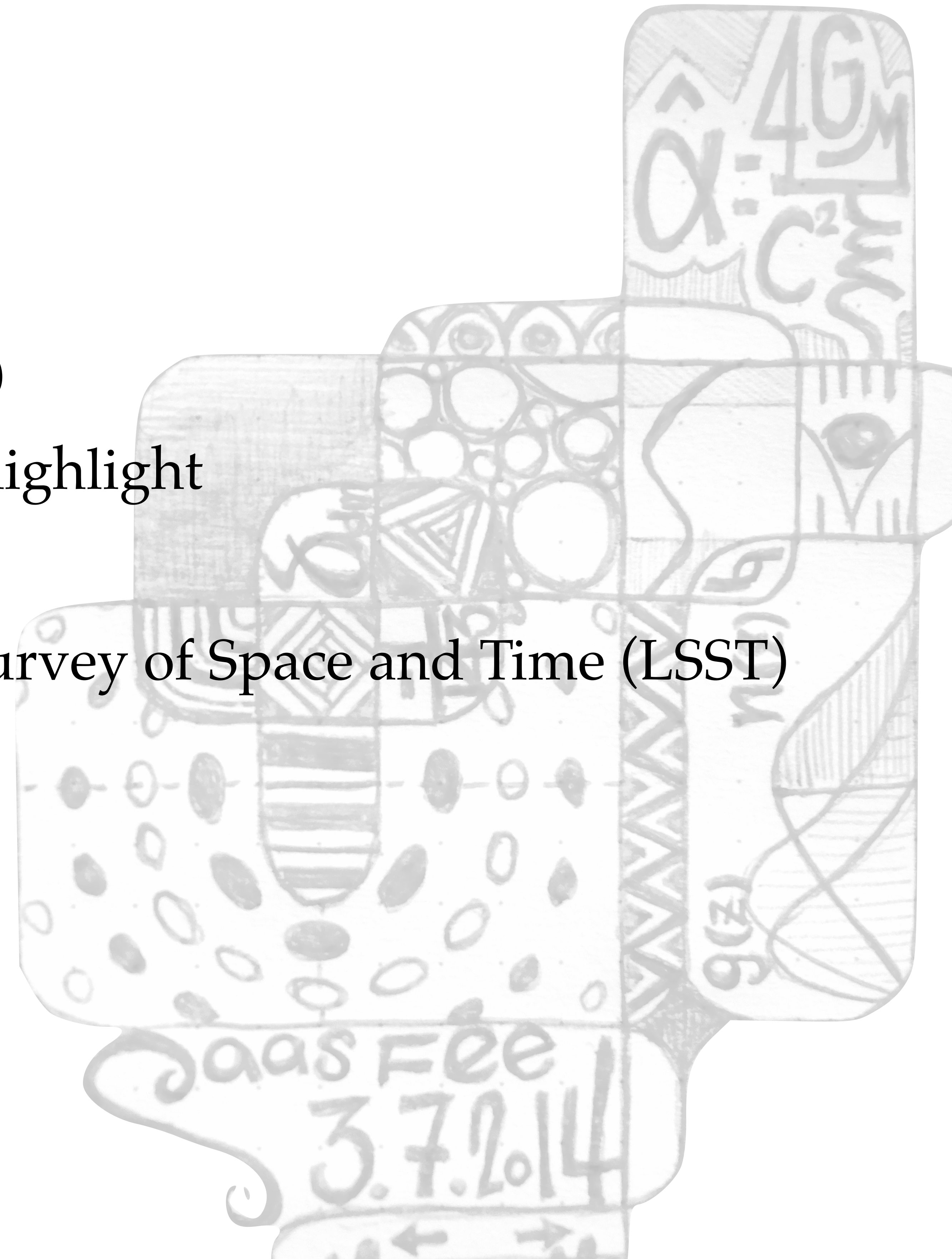
"Stage III": DES, HSC, KiDS etc.



Stage IV: LSST

Outline

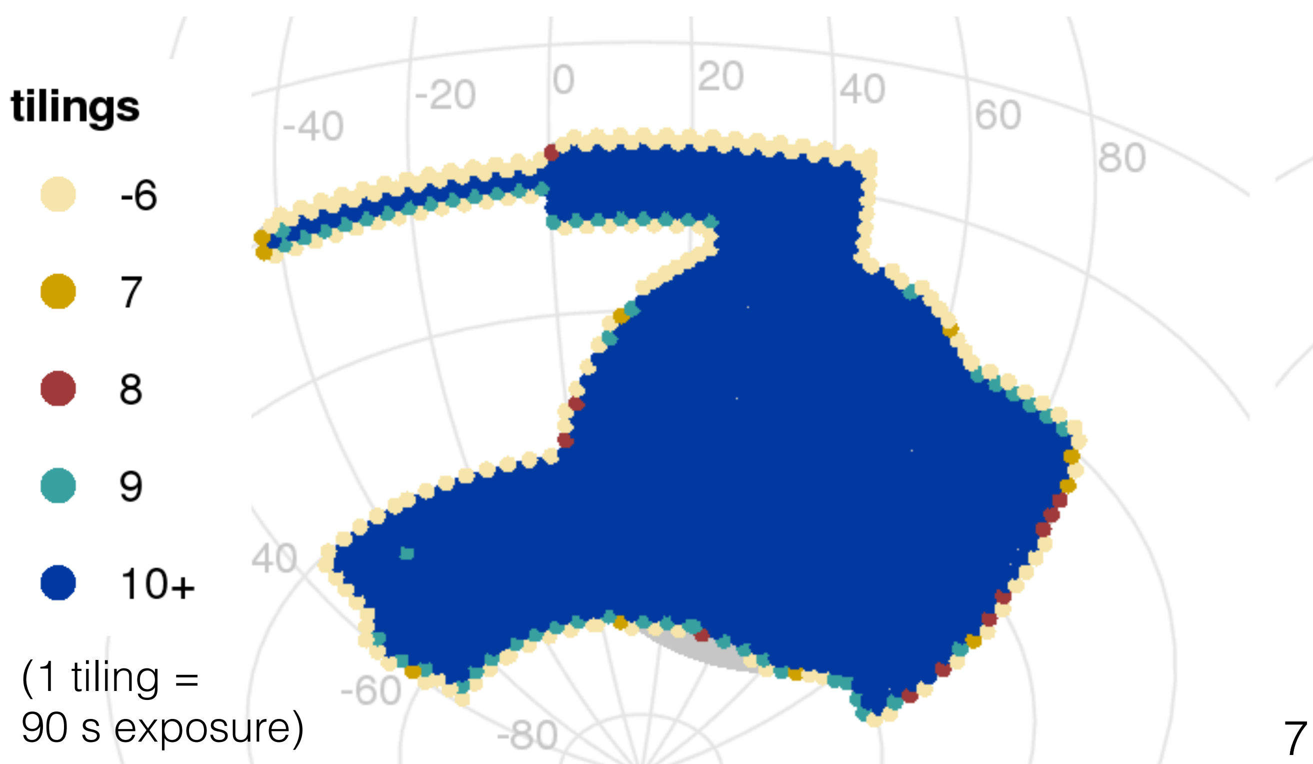
- The Dark Energy Survey (DES)
- Recent DES cosmology result highlight
- DES in the next few months
- Rubin Observatory's Legacy Survey of Space and Time (LSST)



The **D**ark **E**nergy **S**urvey

DES is an imaging survey using the
Dark Energy Camera on the Blanco telescope
SV: 2012-2013, Y1: 2013-2014
Survey finished Jan 9, 2019

5 filter bands (*grizY*), 3 sq. deg FOV,
5.5 years, **5000 sq. deg, i~24**
Wide field and time-domain science



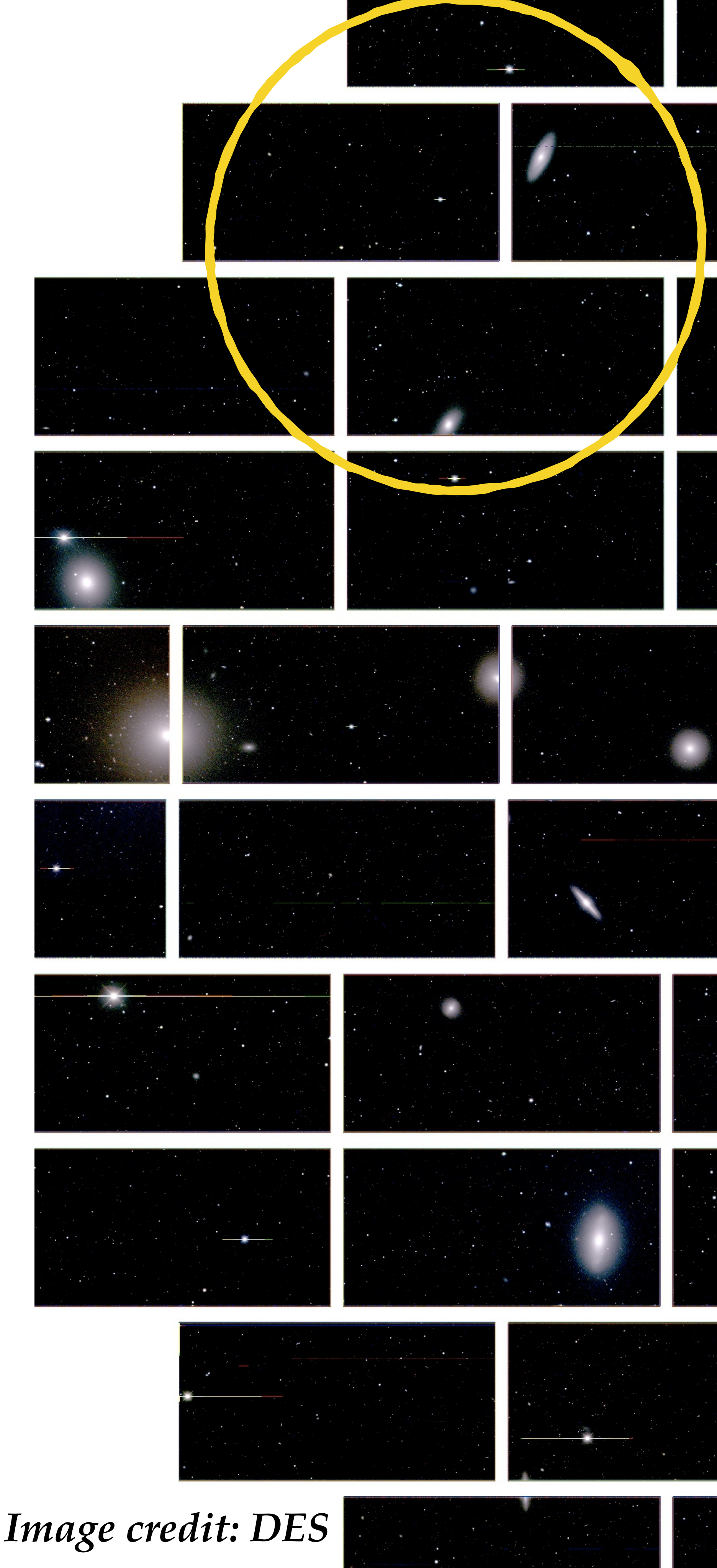


Image credit: DES

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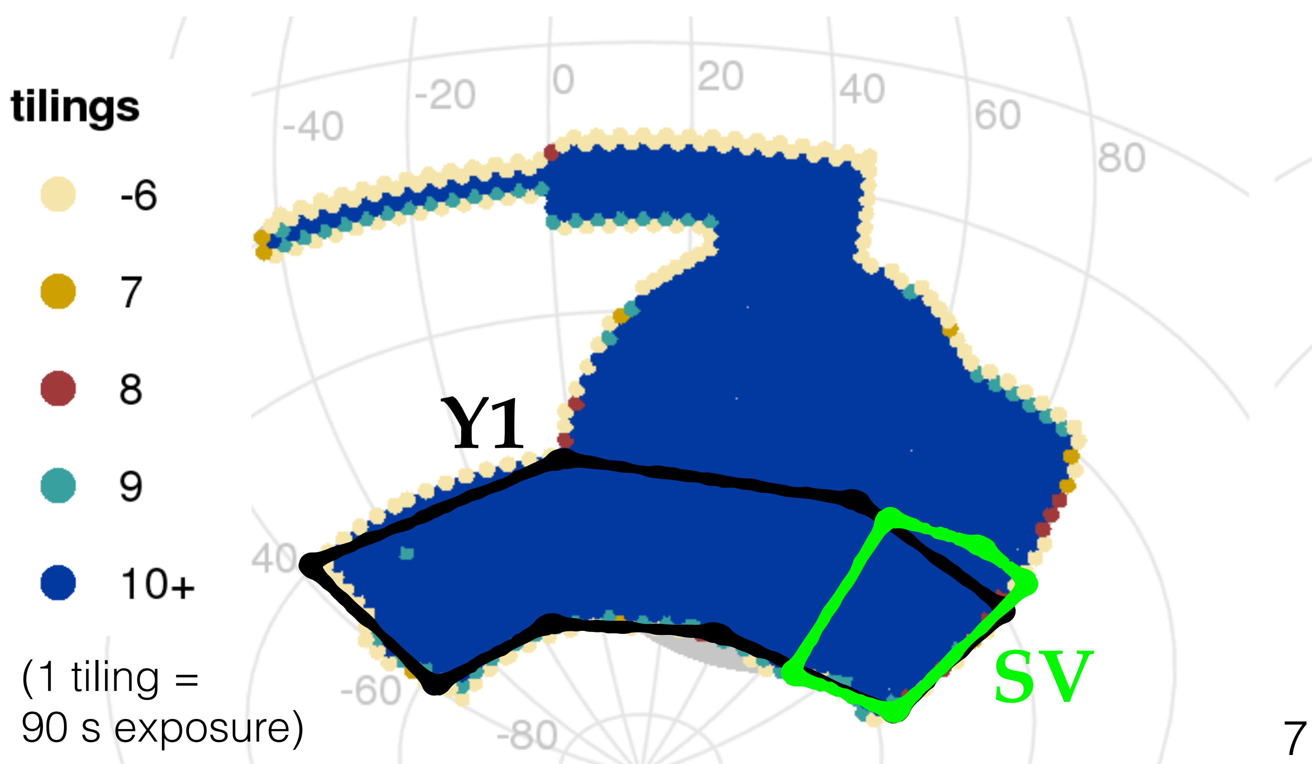


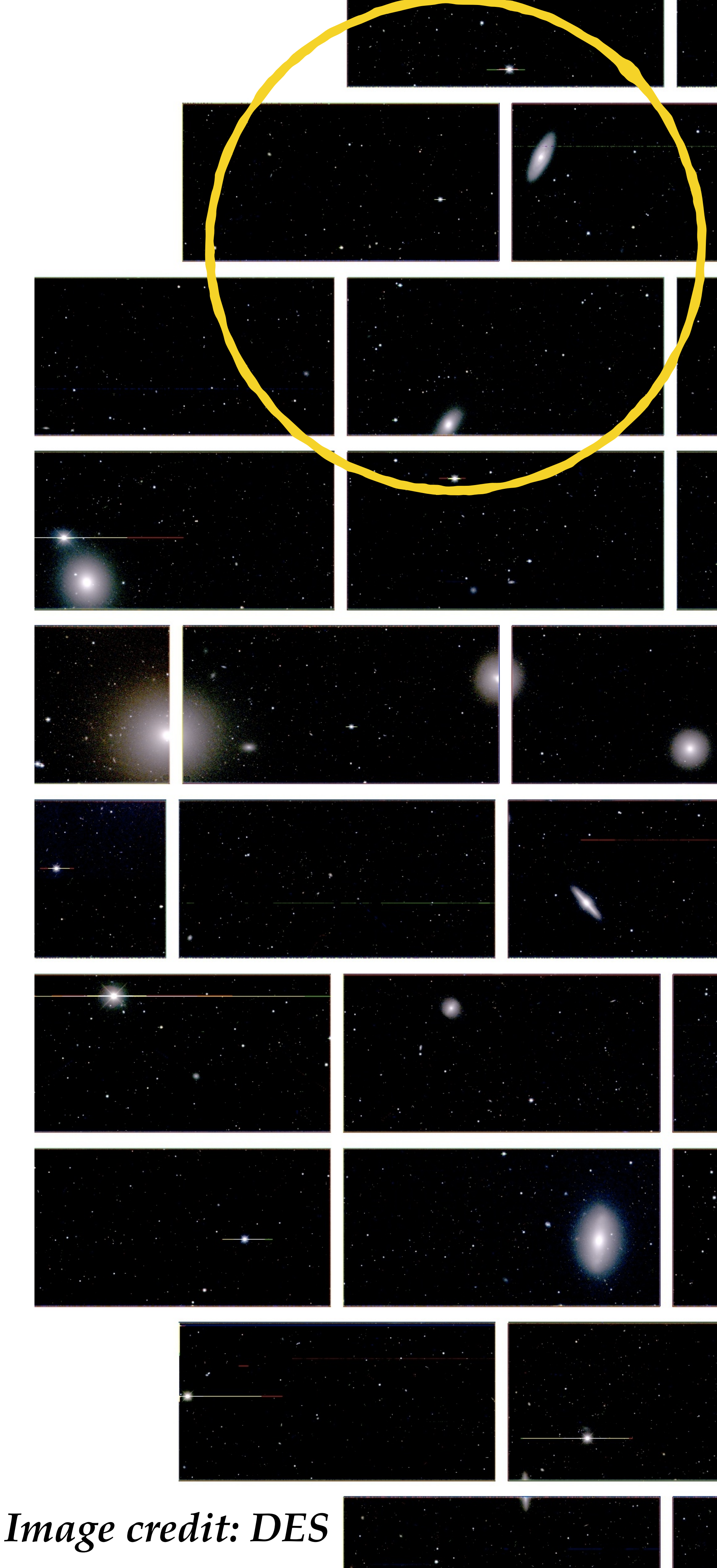
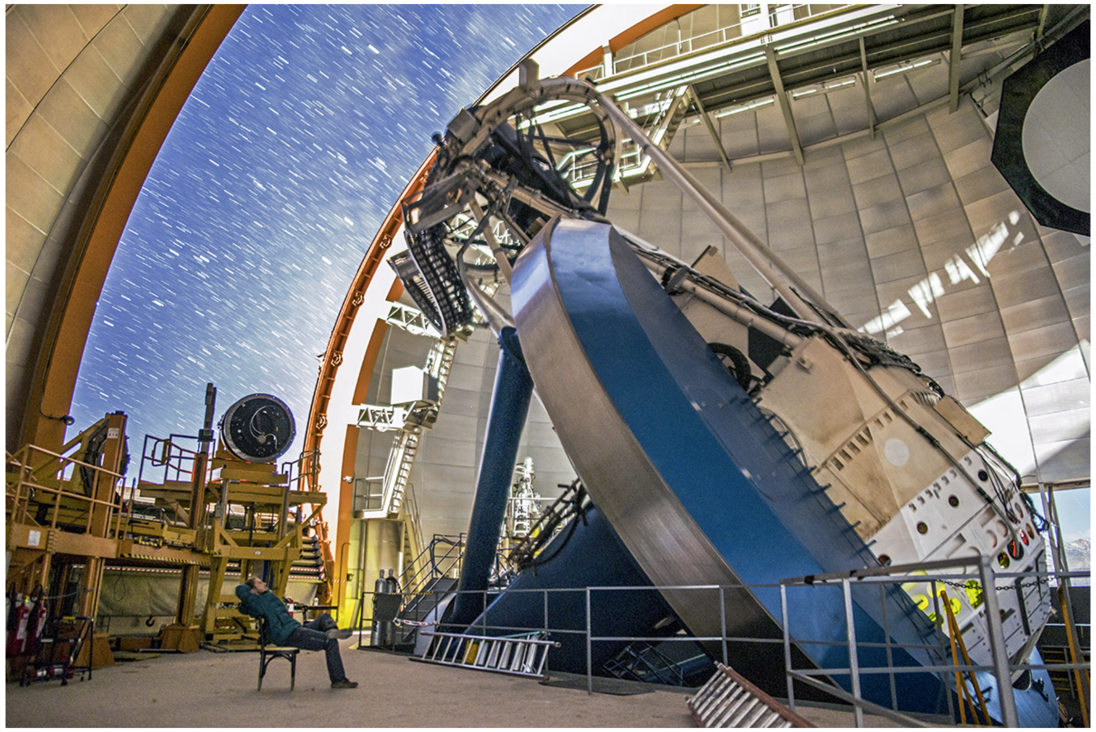


Image credit: DES

The Dark Energy Survey



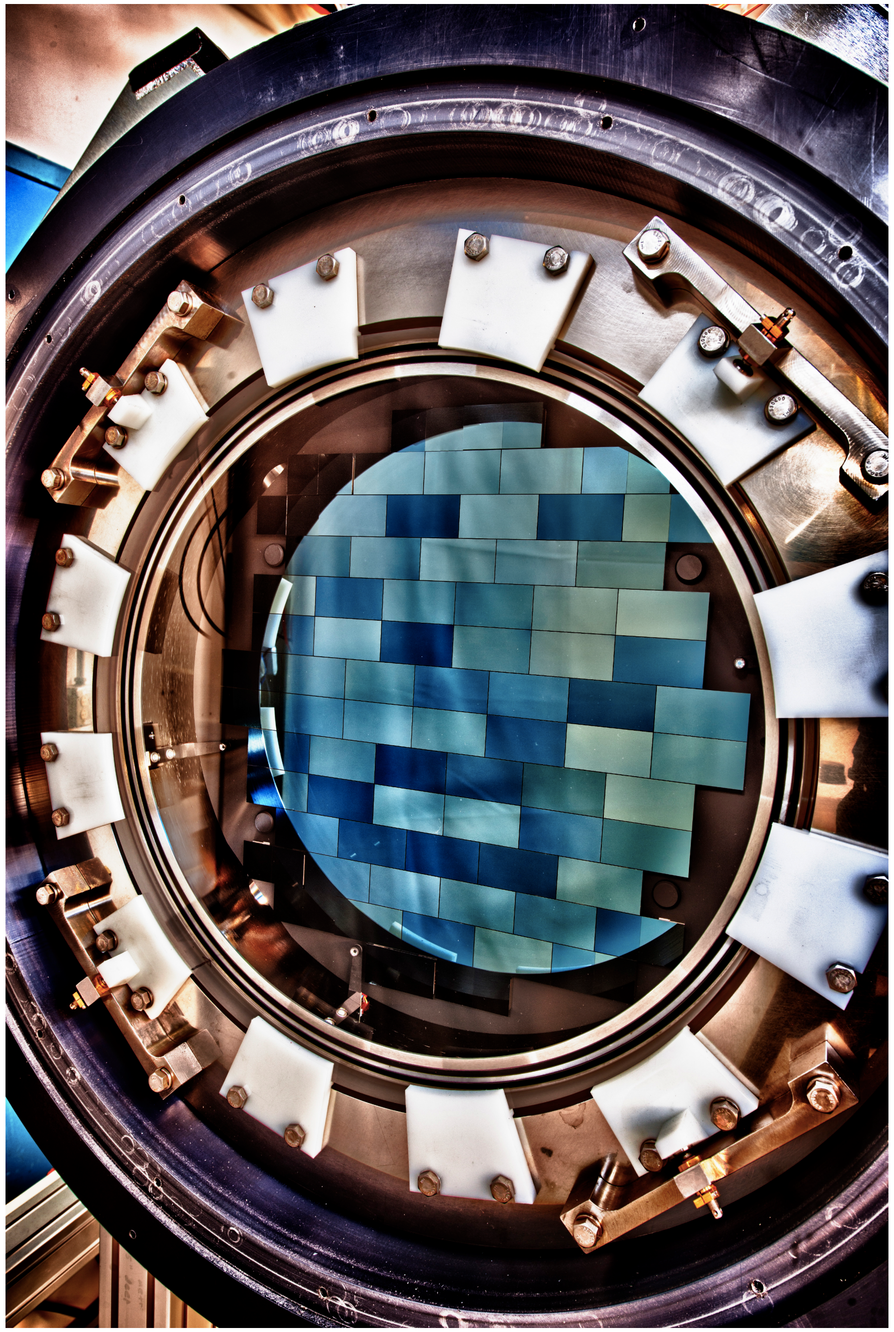


Image credit: DES

Papers are Rolling Out…

List of recent WL-related papers from DES, posted or published since the last DESC meeting:

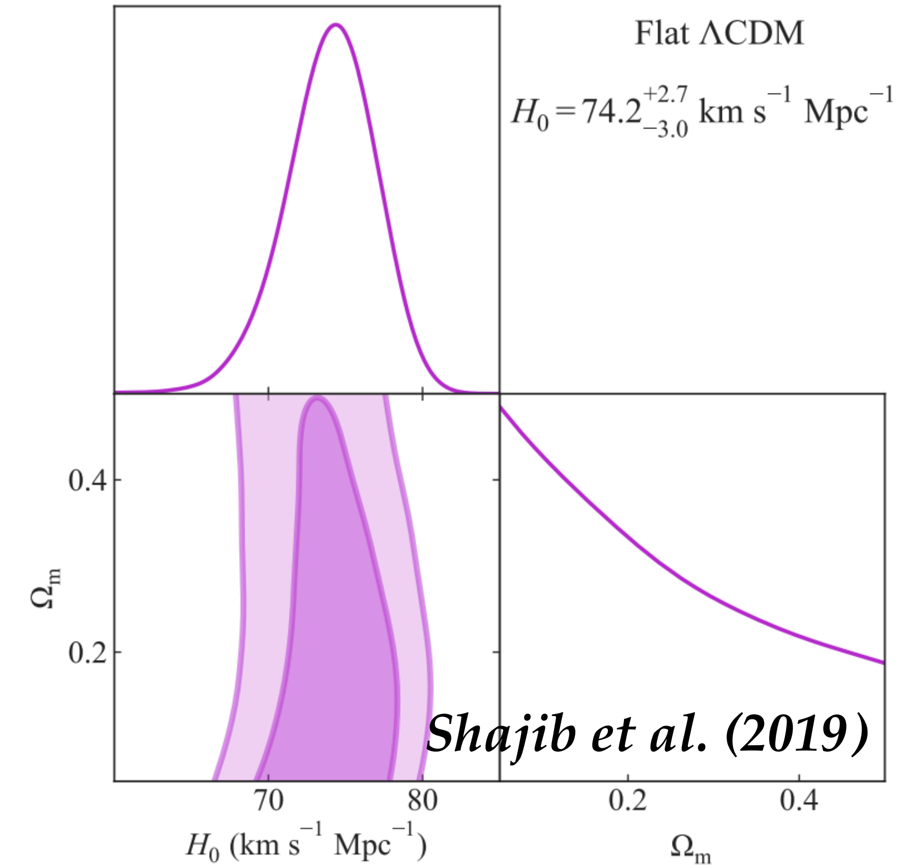
- A Detection of CMB-Cluster Lensing using Polarization Data from SPTpol, S. Raghunathan et al., 1907.08605
- Blinding multi-probe cosmological experiments, J. Muir et al., 1911.05929
- Cosmological Constraints from Multiple Probes in the Dark Energy Survey, DES Collaboration, 1811.02375
- Cosmological lensing ratios with DES Y1, SPT and Planck, J. Prat et al., 1810.02212
- Detection of cross-correlation between gravitational lensing and gamma rays, S. Ammazzalorso, D. Gruen et al., 1907.13484
- DES Y1 results: Calibration of Cluster Mis-centering in the redMaPPer Catalogs, Y. Zhang et al., 1901.07119
- DES Y1 results: Joint Analysis of Galaxy Clustering, Galaxy Lensing, and CMB Lensing Two-point Functions, DES Collaboration et al., 1810.02322
- DES Y1 results: Methodology and Projections for Joint Analysis of Galaxy Clustering, Galaxy Lensing, and CMB Lensing Two-point Functions, E. J. Baxter et al., 1802.05257
- DES Y1 results: Methods for Cluster Cosmology and Application to the SDSS, M. Costanzi et al., 1810.09456
- DES Y1 results: The effect of intra-cluster light on photometric redshifts for weak gravitational lensing, D. Gruen et al., 1809.04599
- DES Y1 results: The relationship between mass and light around cosmic voids, Y. Fang, N. Hamaus et al., 1909.01386
- DES Y1 results: tomographic cross-correlations between DES galaxies and CMB lensing from SPT+Planck, Y. Omori et al.,, 1810.02342
- DES Y1 results: Wide field mass maps via forward fitting in harmonic space, B. Mawdsley et al.,, 1905.12682
- Monte Carlo Control Loops for cosmic shear cosmology with DES Year 1, T. Kacprzak et al., 1906.01018
- Optimising Automatic Morphological Classification of Galaxies with Machine Learning and Deep Learning using Dark Energy Survey Imaging, T.Y. Cheng, et al., 1908.03610
- Producing a BOSS-CMASS sample with DES imaging, S. Lee et al., 1906.01136
- The lensing imprint of DES voids on the Cosmic Microwave Background, P. Vielzeuf et al., 1911.02951
- The SPTpol Extended Cluster Survey, L. E. Bleem et al., 1910.04121

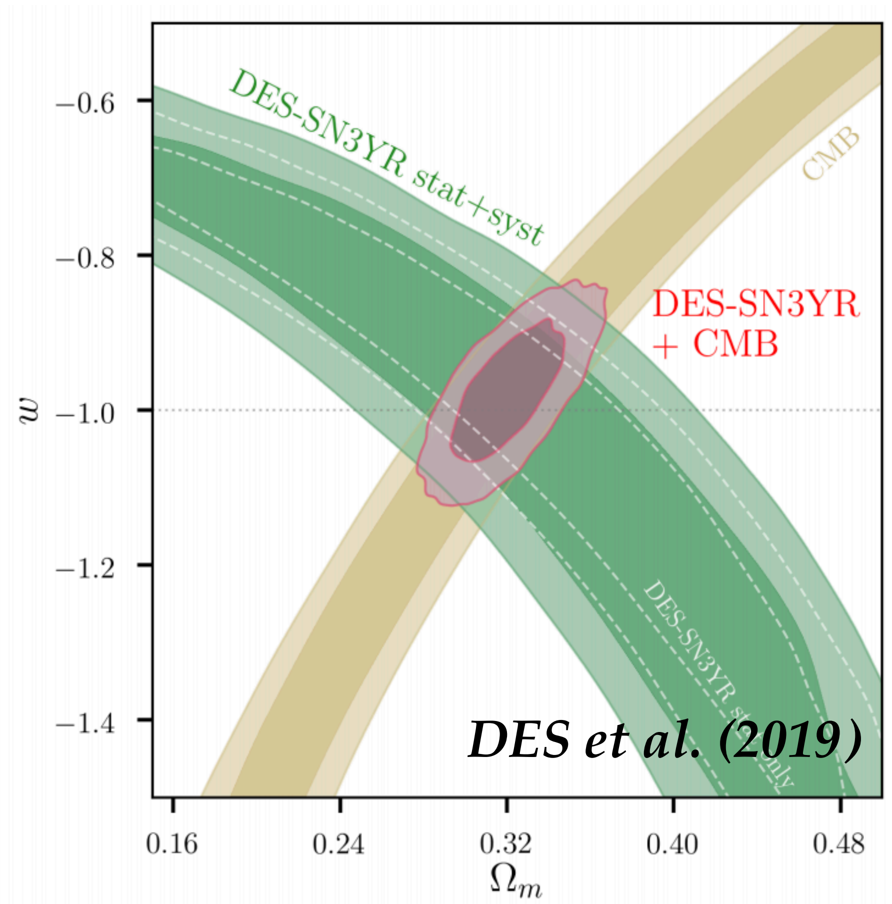
Since Nov 2019

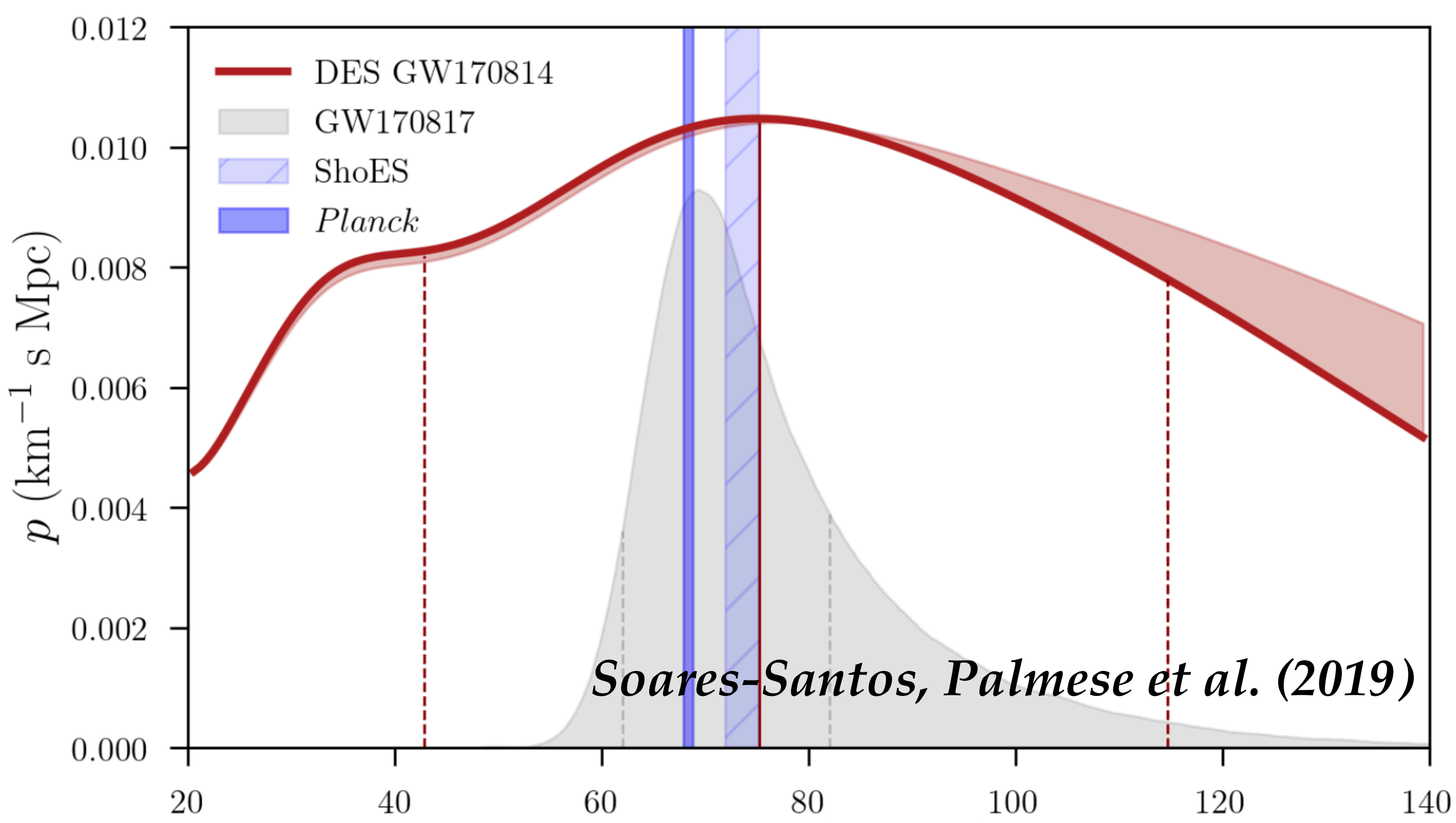
Papers are Rolling Out…

- **3x2pt Cosmology:** 1708.01530
- **5x2pt Cosmology:** 1810.02322
- SN Cosmology: 1811.02374
- Strong Lensing H0: 1910.06306
- GW constraints on H0: 1901.01540

+ lots of non-cosmology papers!

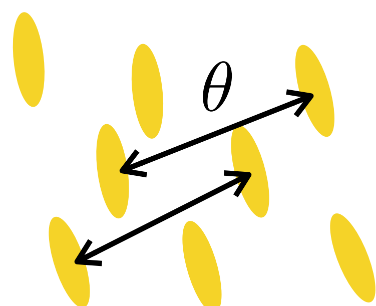




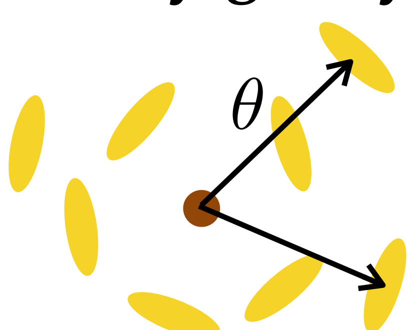


3x2pt Cosmology

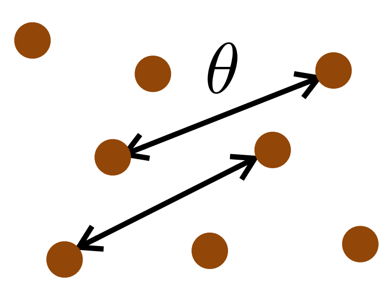
1) Cosmic shear

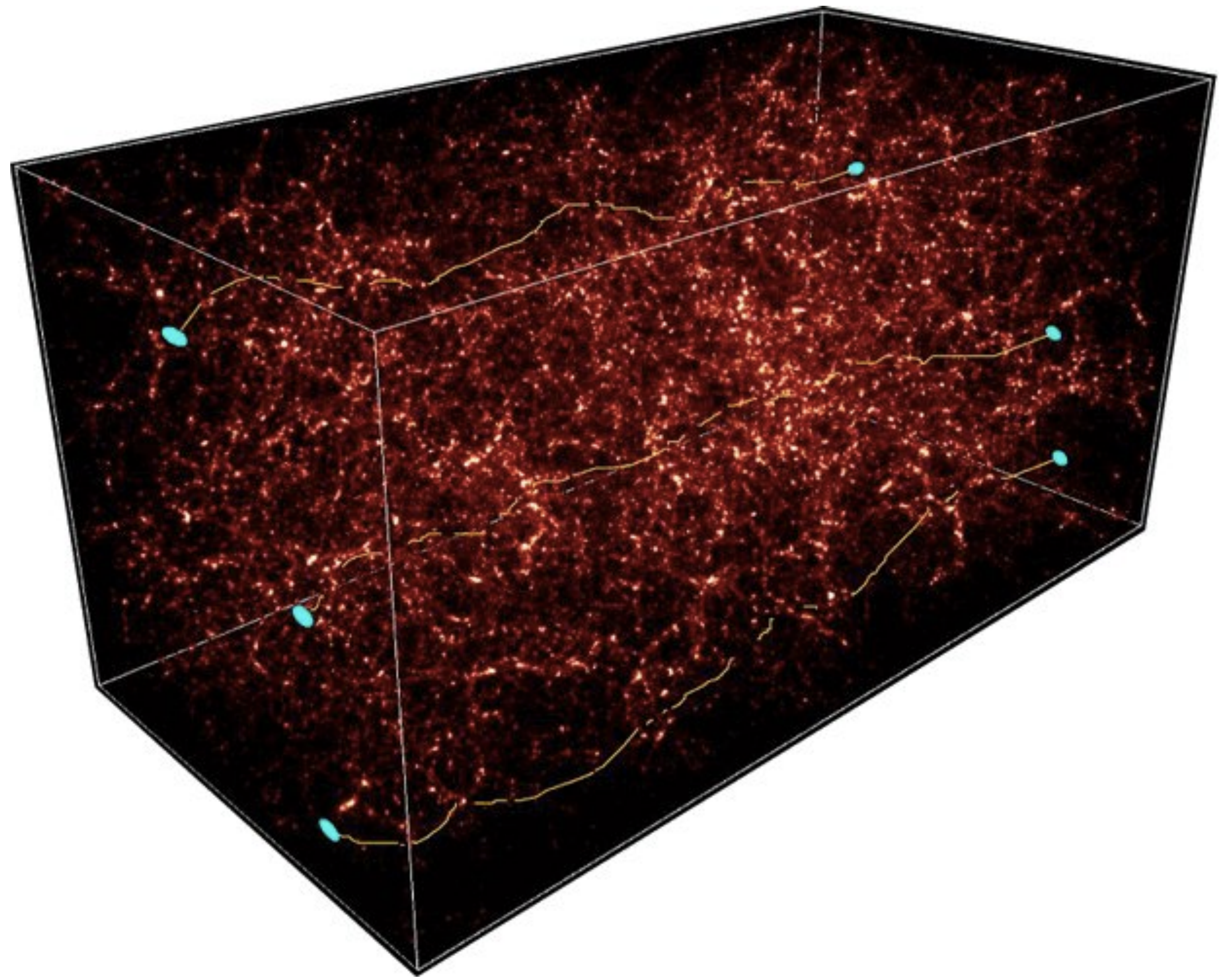


2) Galaxy-galaxy lensing



3) Galaxy clustering

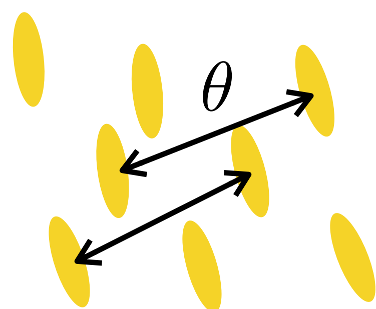




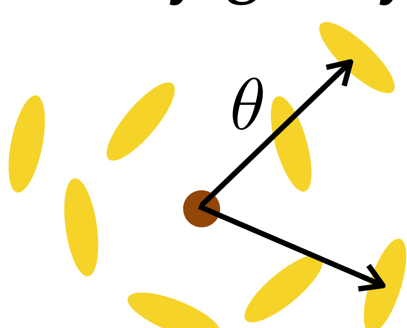
Subsets of 3x2pt have been explored in previous literature. DES sets a new “normal”.

3x2pt Cosmology

1) Cosmic shear

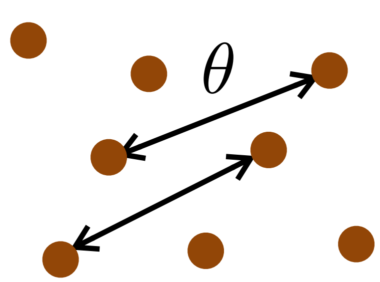


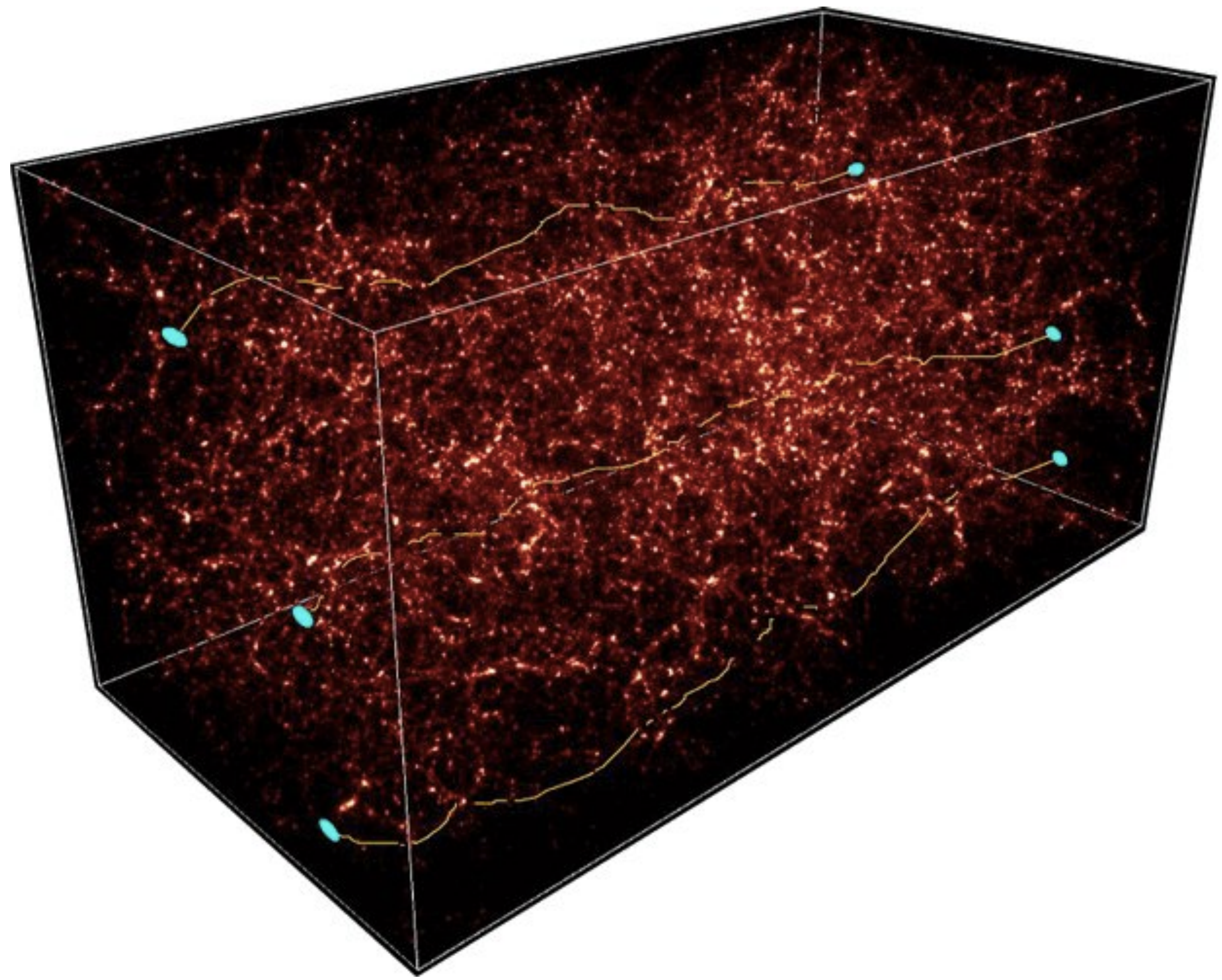
2) Galaxy-galaxy lensing



Hironao's talk

3) Galaxy clustering

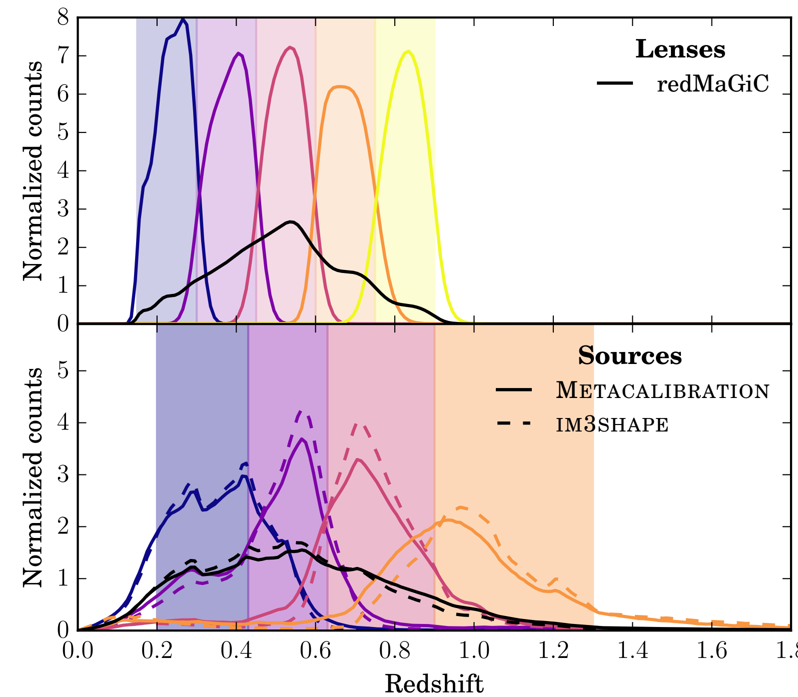




Subsets of 3x2pt have been explored in previous literature. DES sets a new "normal".

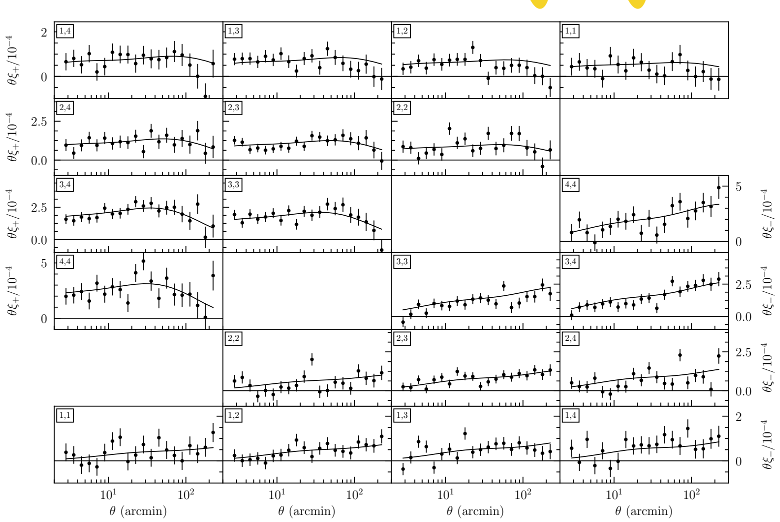
DES Y1 3x2pt Cosmology

Prat et al. (2017)

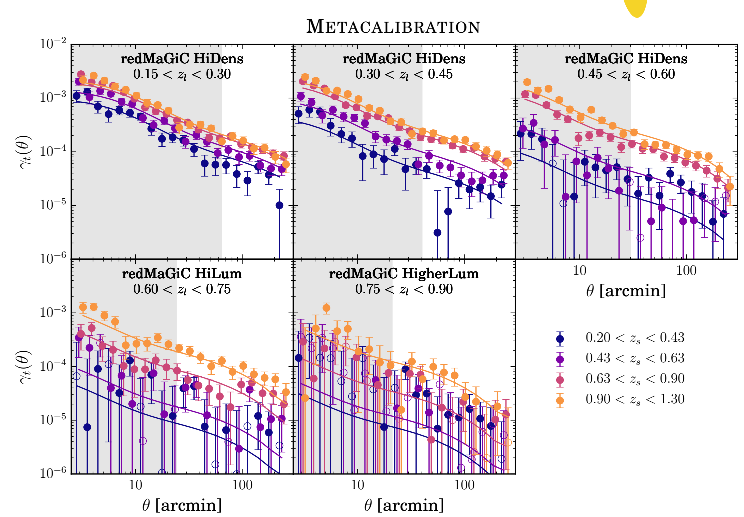


- 2 samples of galaxies: **lens** and **source**
- Each binned into multiple redshift bins
- Consider all auto- and cross-correlations

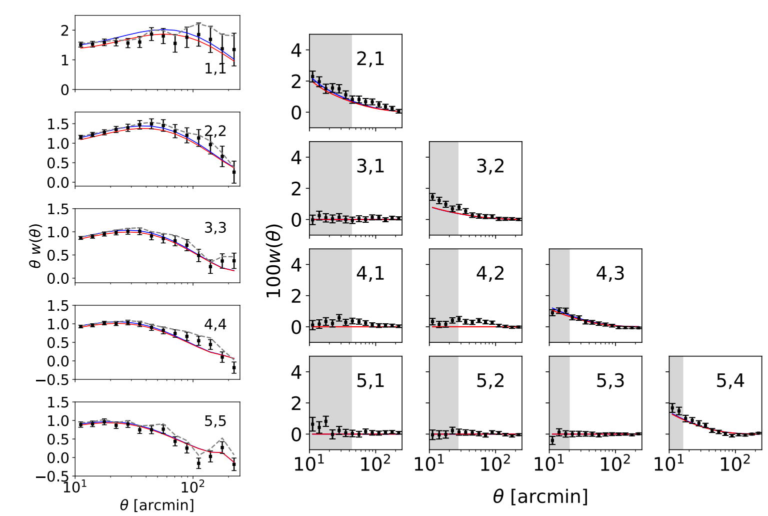
Troxel et al. (2017) –



Prat et al. (2017) –



Elvin-Poole et al. (2017) –



Blinded analysis

3x2pt Cosmology

$$C^{ij}_{\kappa\kappa}(l) = \int d\chi \frac{q^i_\kappa(\chi) q^j_\kappa(\chi)}{\chi^2} P_{\rm NL}\left(\frac{l+1/2}{\chi}, z(\chi)\right)$$

$$C^{ij}_{\delta_{\rm g}\kappa}(l) = \int d\chi \frac{q^i_{\delta_{\rm g}}\left(\frac{l+1/2}{\chi}, \chi\right) q^j_\kappa(\chi)}{\chi^2} P_{\rm NL}\left(\frac{l+1/2}{\chi}, z(\chi)\right)$$

$$C^{ij}_{\delta_{\rm g}\delta_{\rm g}}(l) = \int d\chi \frac{q^i_{\delta_{\rm g}}\left(\frac{l+1/2}{\chi}, \chi\right) q^j_{\delta_{\rm g}}\left(\frac{l+1/2}{\chi}, \chi\right)}{\chi^2} P_{\rm NL}\left(\frac{l+1/2}{\chi}, z(\chi)\right)$$

$$q^i_{\delta_{\rm g}}(k,\chi) = b^i\left(k, z(\chi)\right) \frac{n^i_{\rm g}(z(\chi))}{\bar{n}^i_{\rm g}} \frac{dz}{d\chi}$$

Lens

$$q^i_\kappa(\chi) = \frac{3H_0^2\Omega_m}{2{\rm c}^2} \frac{\chi}{a(\chi)} \int_\chi^{\chi_{\rm h}} {\rm d}\chi' \frac{n^i_\kappa(z(\chi'))dz/d\chi'}{\bar{n}^i_\kappa} \frac{\chi'-\chi}{\chi'}$$

Source

$$\mathrm{Cov}\left(\Xi^{ij}(\theta),\, \Theta^{km}(\theta')\right) = \int \frac{dl\, l}{2\pi} J_{n(\Xi)}(l\theta) \int \frac{dl'\, l'}{2\pi} J_{n(\Theta)}(l'\theta') \left[\mathrm{Cov}^{\rm G}\left(C^{ij}_\Theta(l), C^{km}_\Xi(l')\right) + \mathrm{Cov}^{\rm NG}\left(C^{ij}_\Theta(l), C^{km}_\Xi(l')\right)\right]$$

3x2pt Cosmology

$$C_{\kappa\kappa}^{ij}(l) = \int d\chi \frac{q_\kappa^i(\chi) q_\kappa^j(\chi)}{\chi^2} \boxed{P_{\mathrm{NL}}\left(\frac{l+1/2}{\chi}, z(\chi)\right)}$$

Intrinsic alignment

Shear calibration

$$C_{\delta_{\mathrm{g}}\kappa}^{ij}(l) = \int d\chi \frac{q_{\delta_{\mathrm{g}}}^i\left(\frac{l+1/2}{\chi}, \chi\right) q_\kappa^j(\chi)}{\chi^2} P_{\mathrm{NL}}\left(\frac{l+1/2}{\chi}, z(\chi)\right)$$

$$C_{\delta_{\mathrm{g}}\delta_{\mathrm{g}}}^{ij}(l) = \int d\chi \frac{q_{\delta_{\mathrm{g}}}^i\left(\frac{l+1/2}{\chi}, \chi\right) q_{\delta_{\mathrm{g}}}^j\left(\frac{l+1/2}{\chi}, \chi\right)}{\chi^2} P_{\mathrm{NL}}\left(\frac{l+1/2}{\chi}, z(\chi)\right)$$

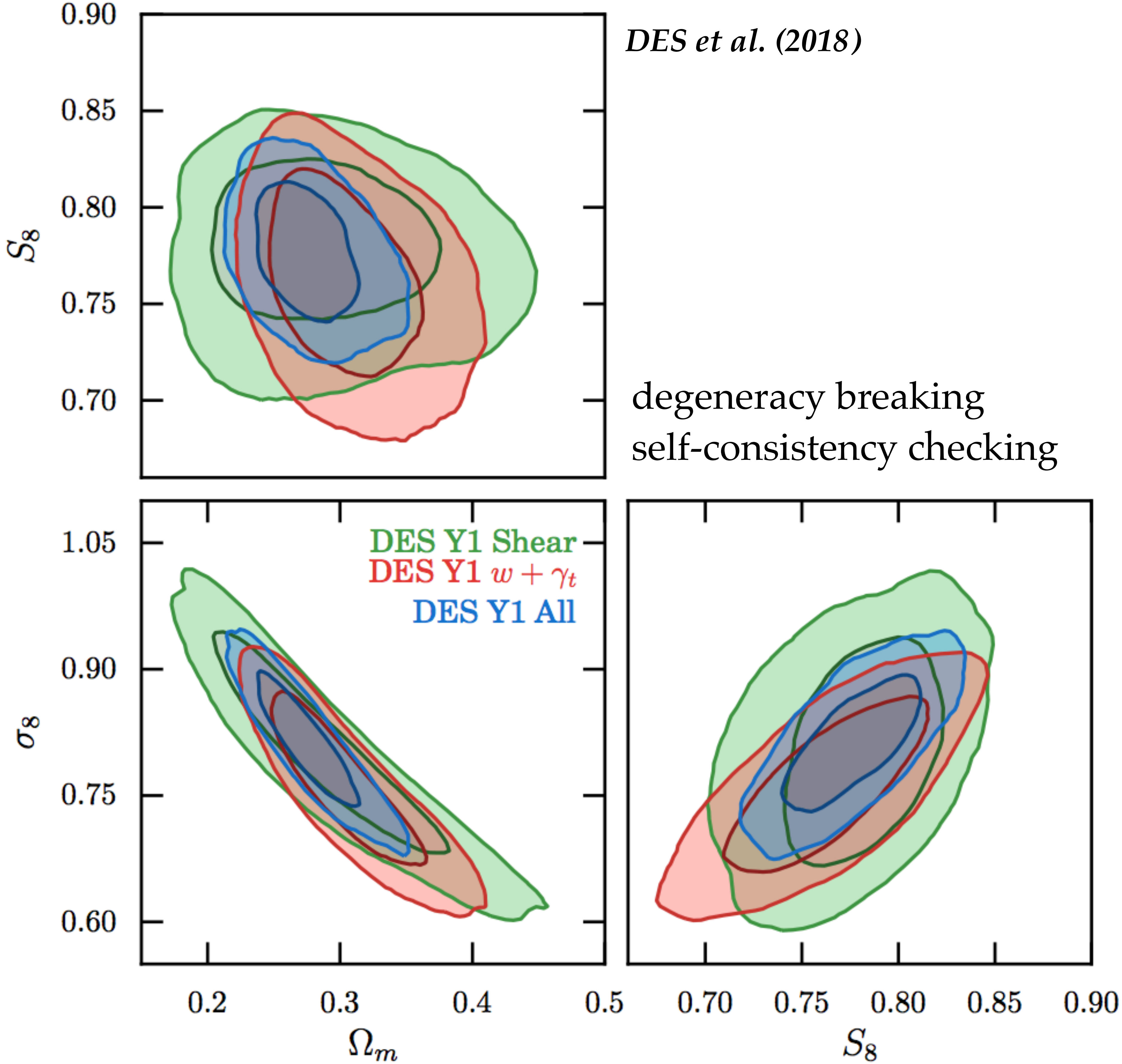
$$q_{\delta_{\mathrm{g}}}^i(k,\chi) = \boxed{b^i\left(k, z(\chi)\right)} \frac{\boxed{n_{\mathrm{g}}^i(z(\chi))}}{\bar{n}_{\mathrm{g}}^i} \frac{dz}{d\chi}$$

Lens

$$q_\kappa^i(\chi) = \frac{3H_0^2 \Omega_m}{2\mathrm{c}^2} \frac{\chi}{a(\chi)} \int_\chi^{\chi_{\mathrm{h}}} \mathrm{d}\chi' \frac{\boxed{n_\kappa^i(z(\chi'))} dz/d\chi'}{\bar{n}_\kappa^i} \frac{\chi' - \chi}{\chi'}$$

Source

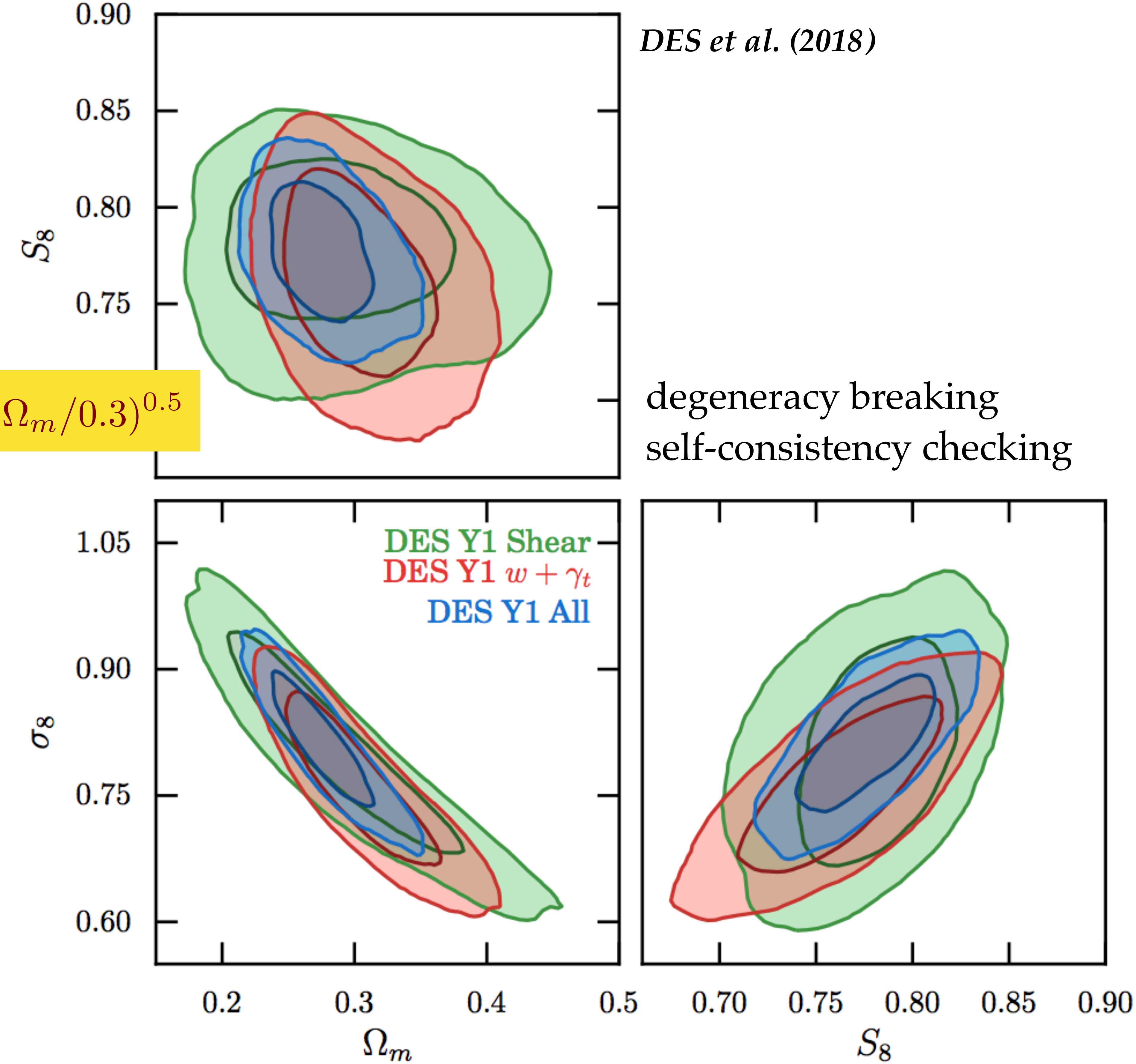
$$\mathrm{Cov}\left(\Xi^{ij}(\theta), \Theta^{km}(\theta')\right) = \int \frac{dl\, l}{2\pi} J_{n(\Xi)}(l\theta) \int \frac{dl'\, l'}{2\pi} J_{n(\Theta)}(l'\theta') \left[\mathrm{Cov}^{\mathrm{G}}\left(C_\Theta^{ij}(l), C_\Xi^{km}(l')\right) + \boxed{\mathrm{Cov}^{\mathrm{NG}}\left(C_\Theta^{ij}(l), C_\Xi^{km}(l')\right)}\right]$$



DES et al. (2018)

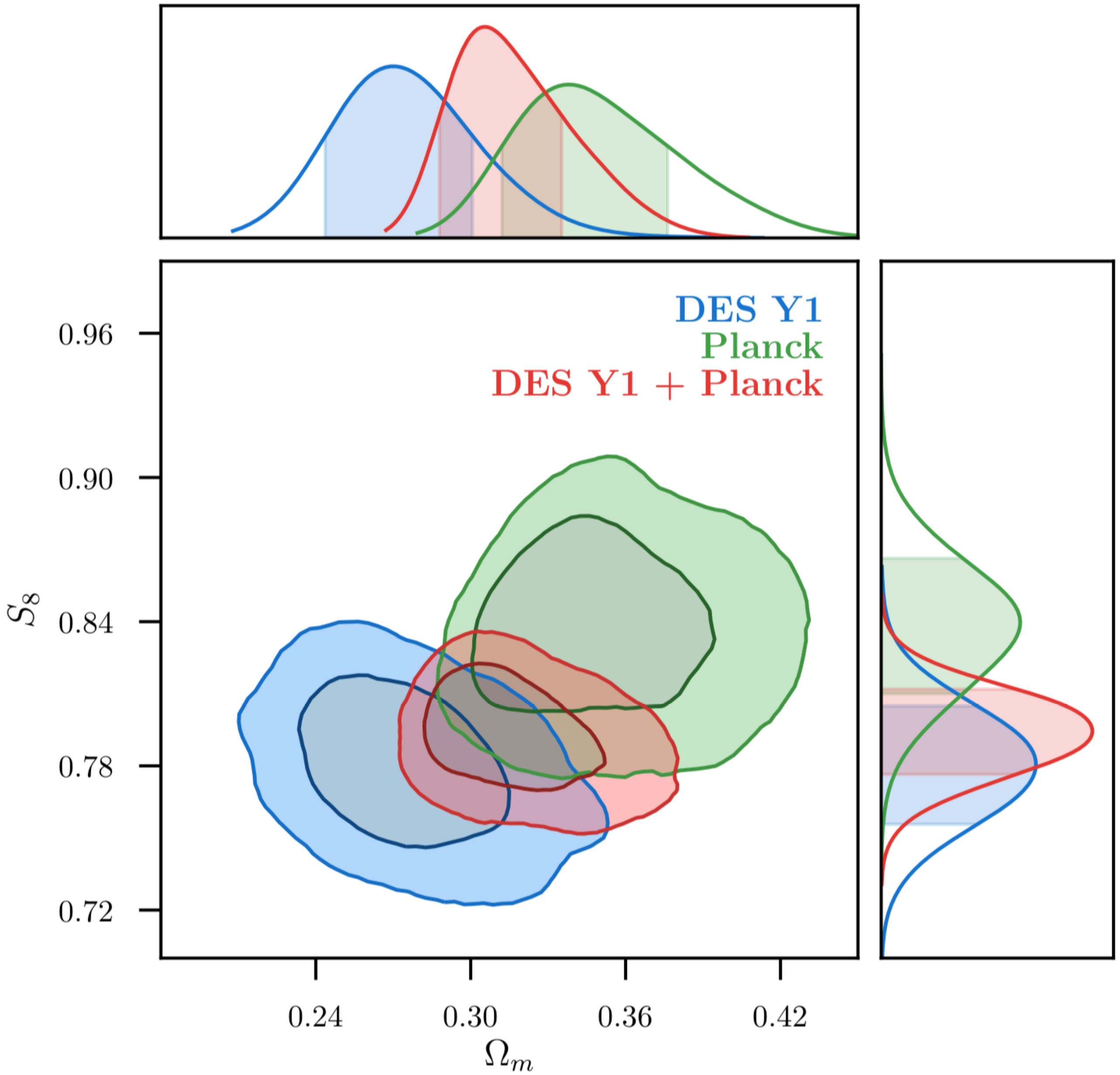
degeneracy breaking
self-consistency checking

DES et al. (2018)

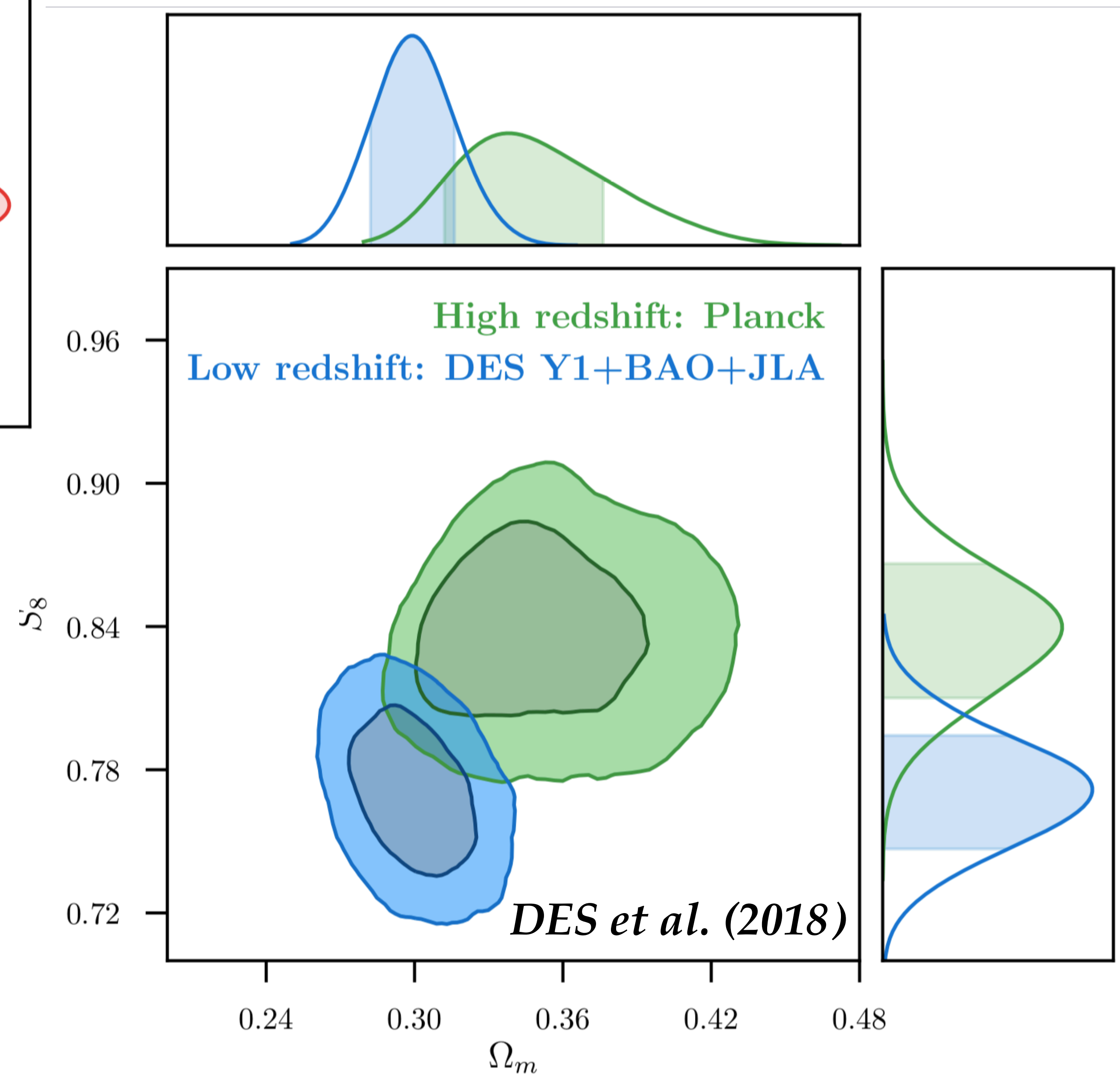


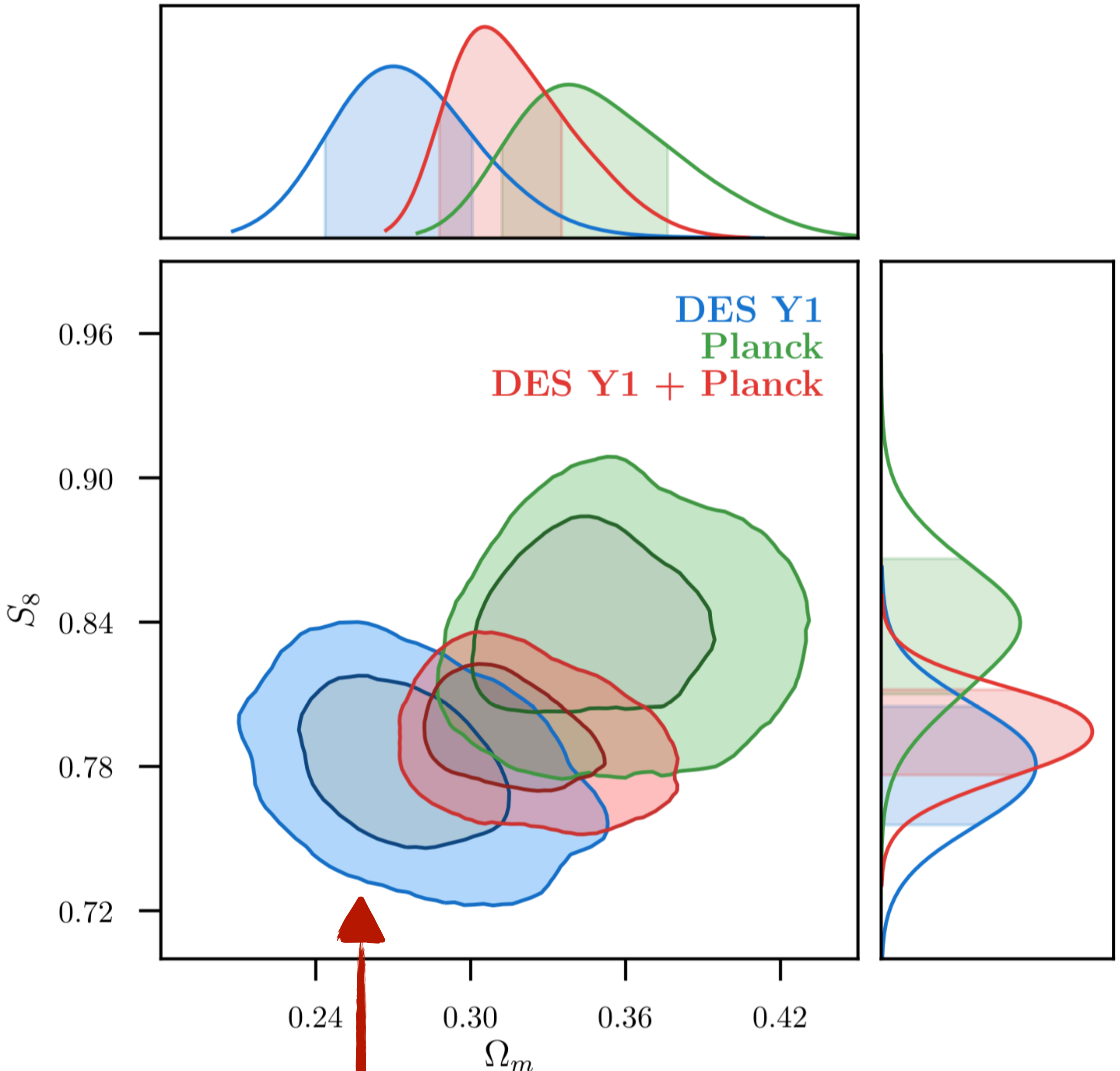
$S_8 \equiv \sigma_8(\Omega_m/0.3)^{0.5}$

degeneracy breaking
self-consistency checking



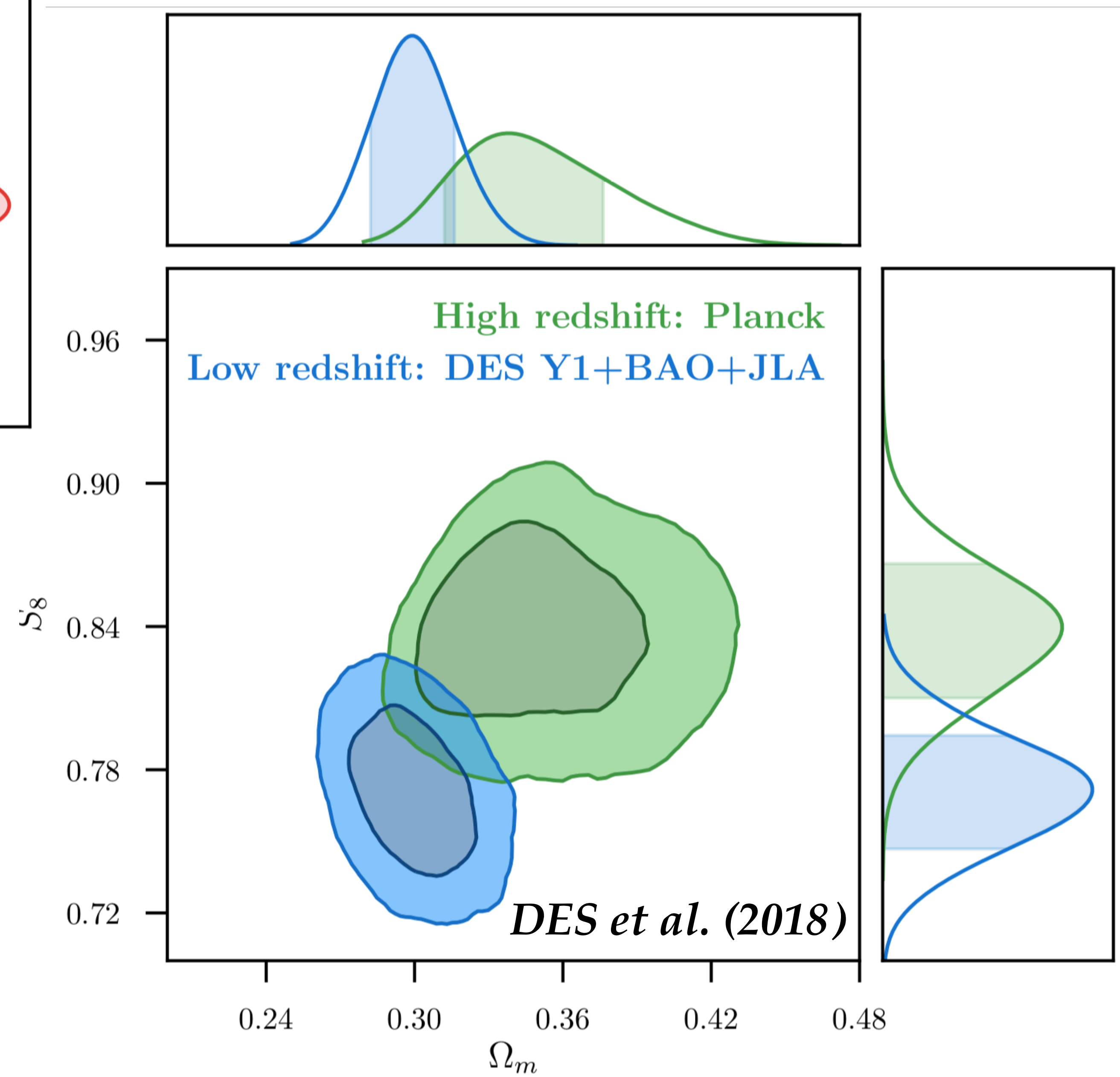
Is the low-redshift Universe in agreement with the high-redshift Universe?



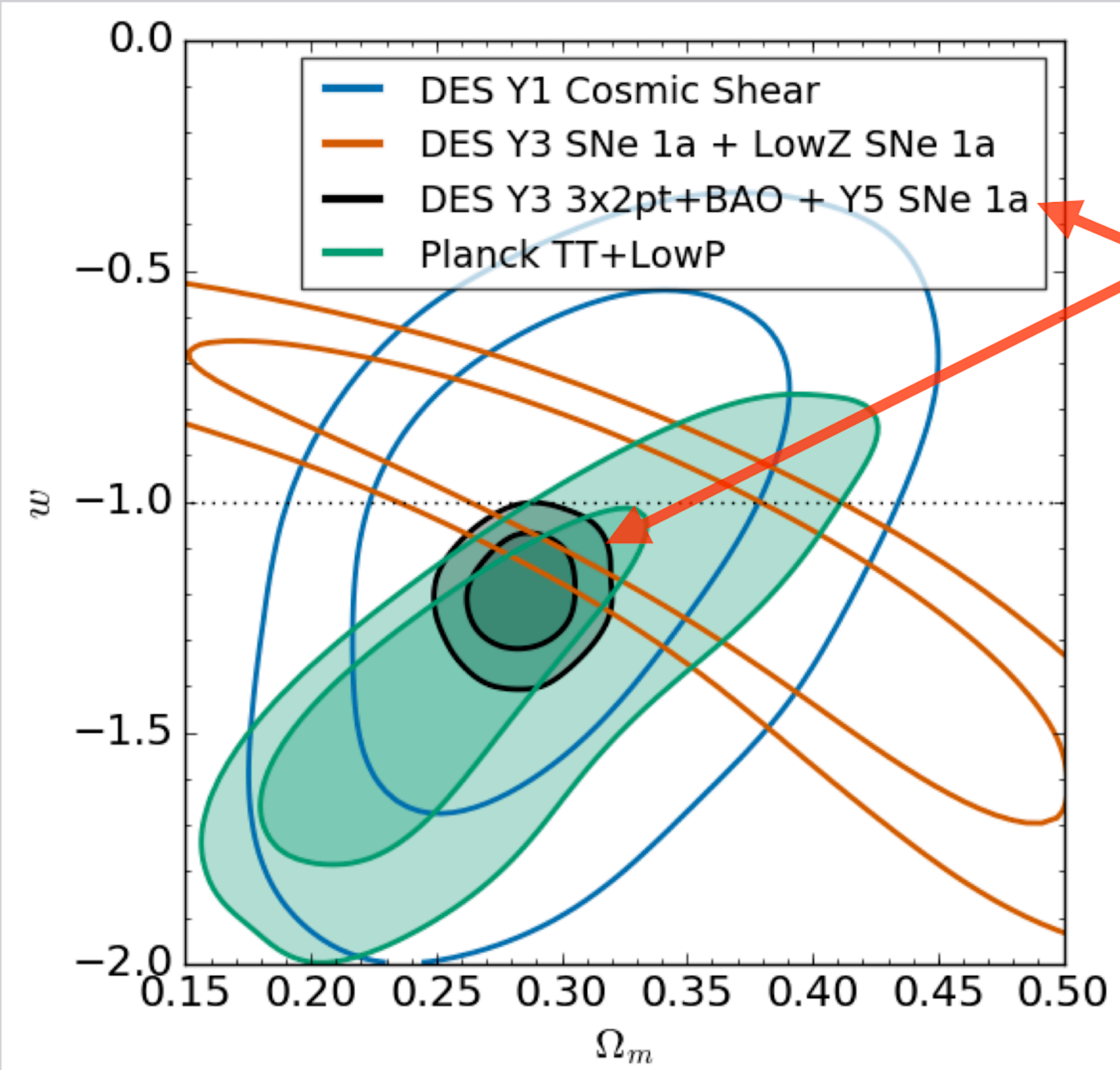


Is the low-redshift Universe in agreement with the high-redshift Universe?

KiDS and HSC also have contours at similar locations



Where we think we'll get in the next round of joint analyses (Y3/Y5).

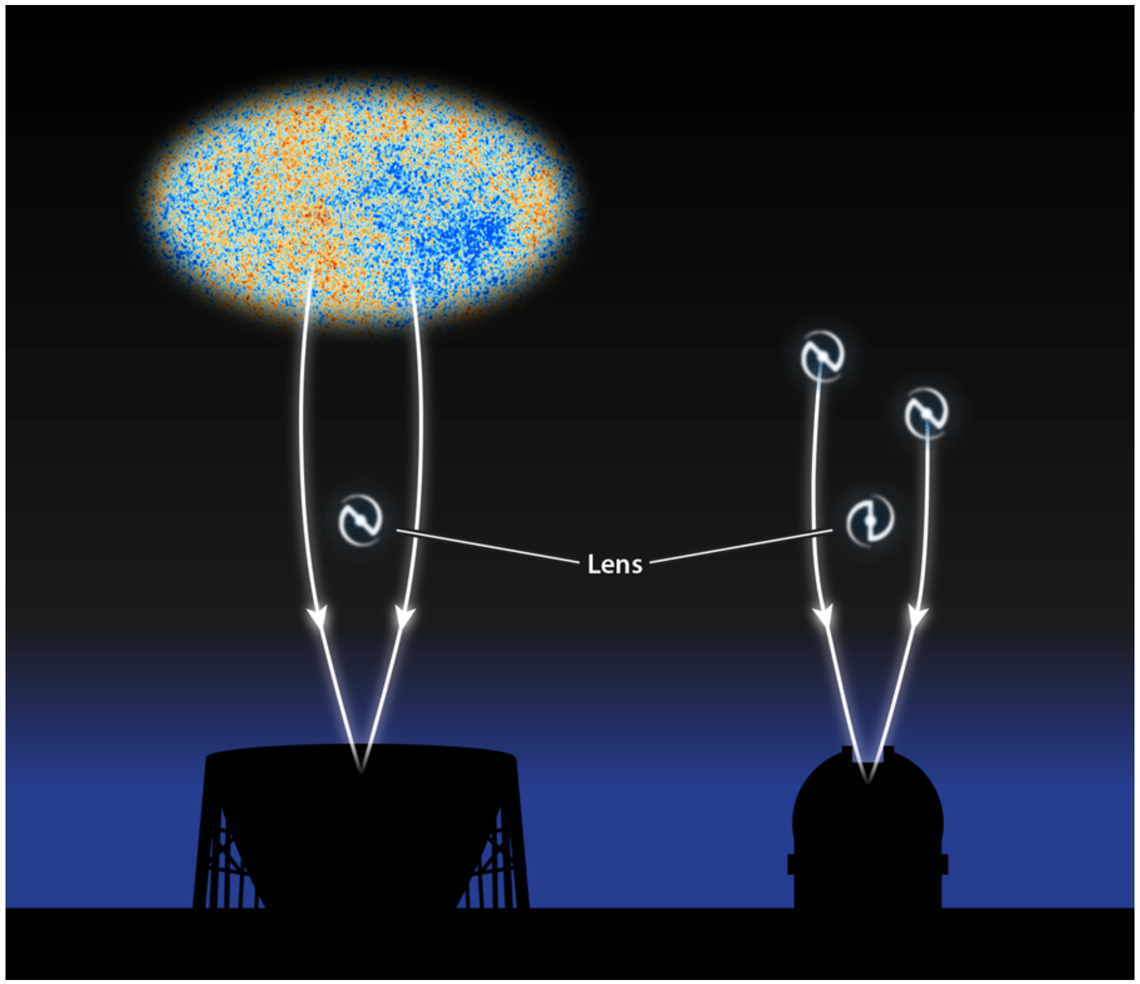


Projection based on expected statistical and analysis improvements - not data!

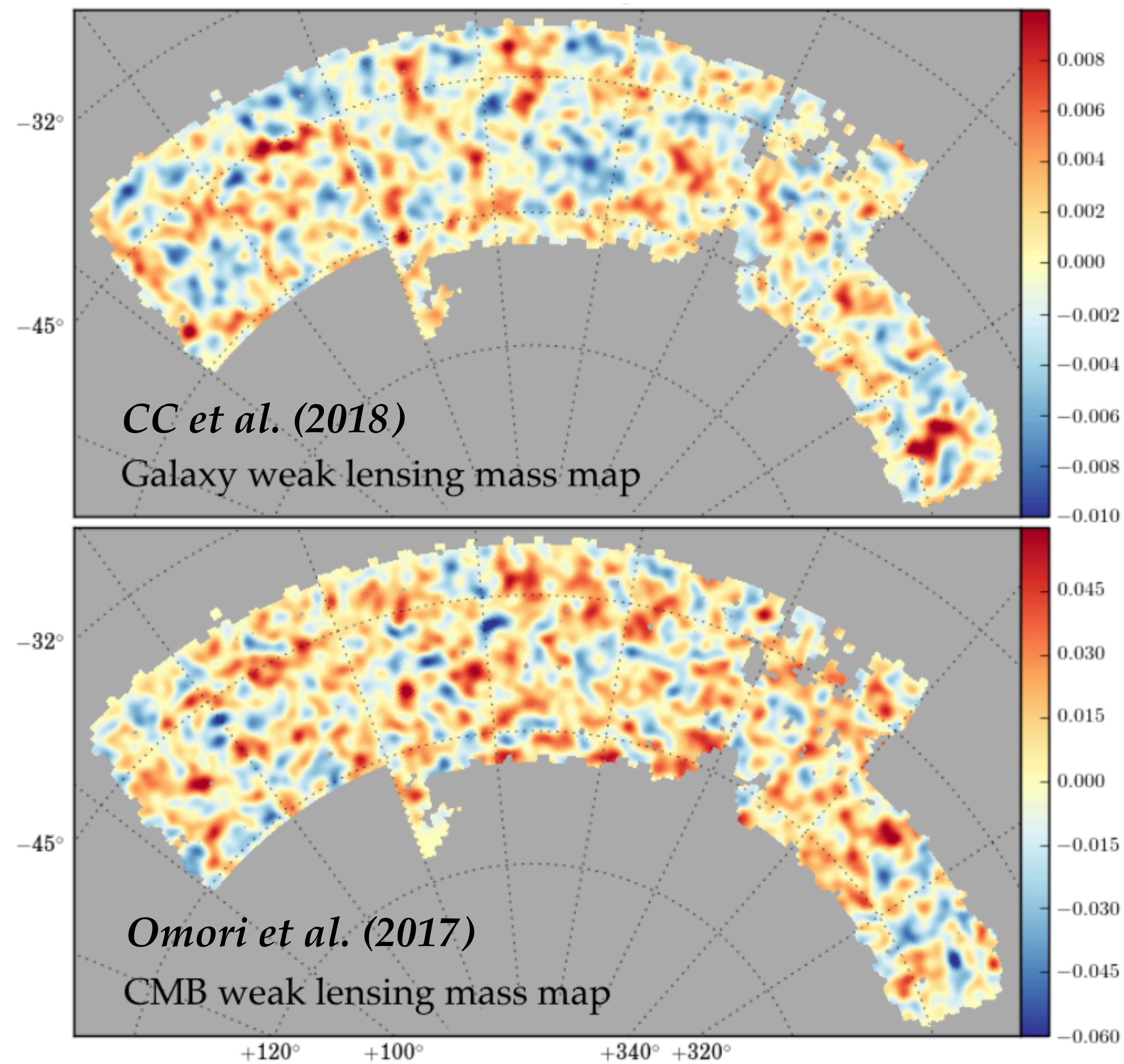
(contour position is artificial)

Slide shamelessly stole from Troxel

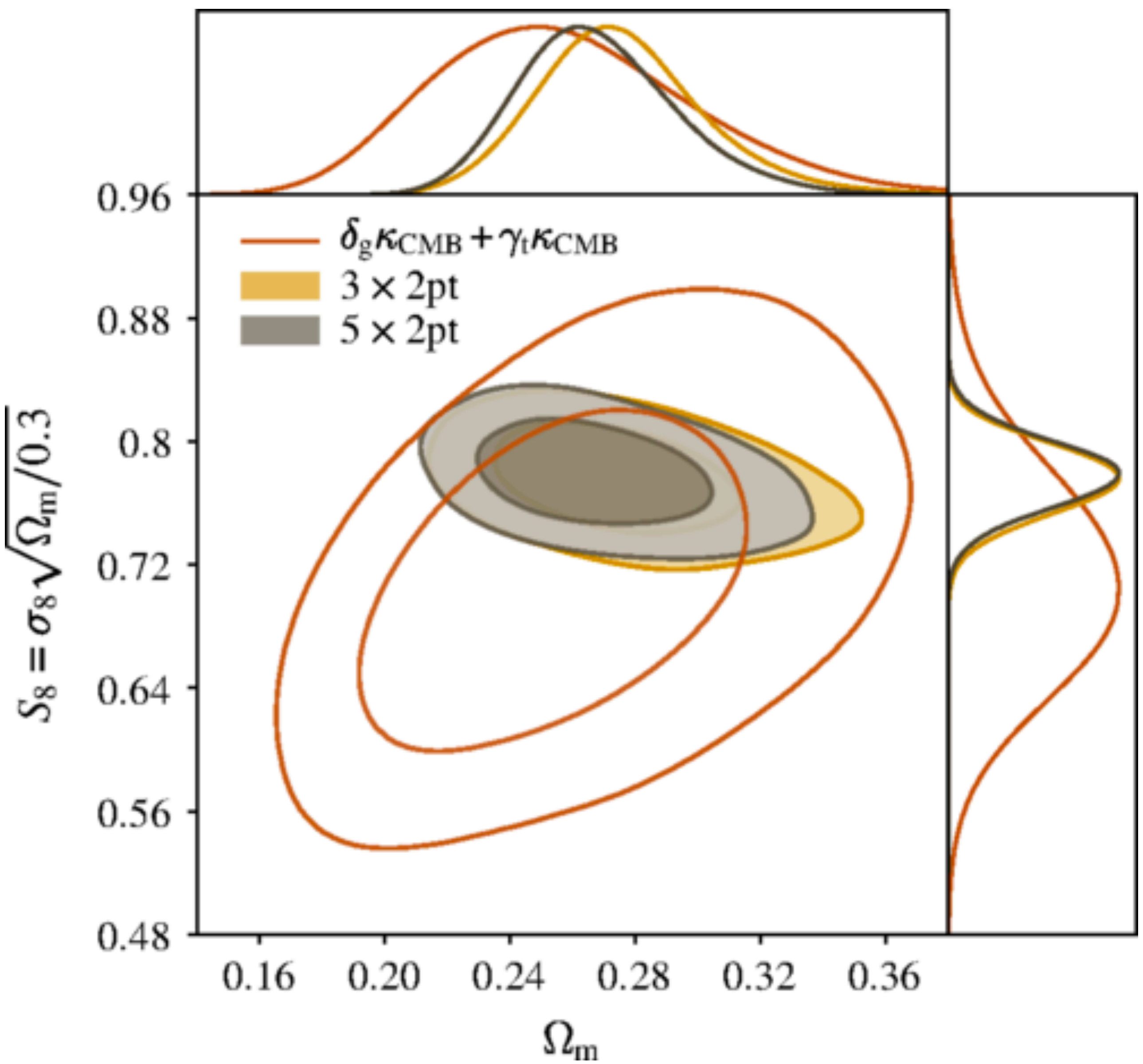
5x2pt Cosmology



with
Eric Baxter (Hawaii)
Yuuki Omori (Stanford)

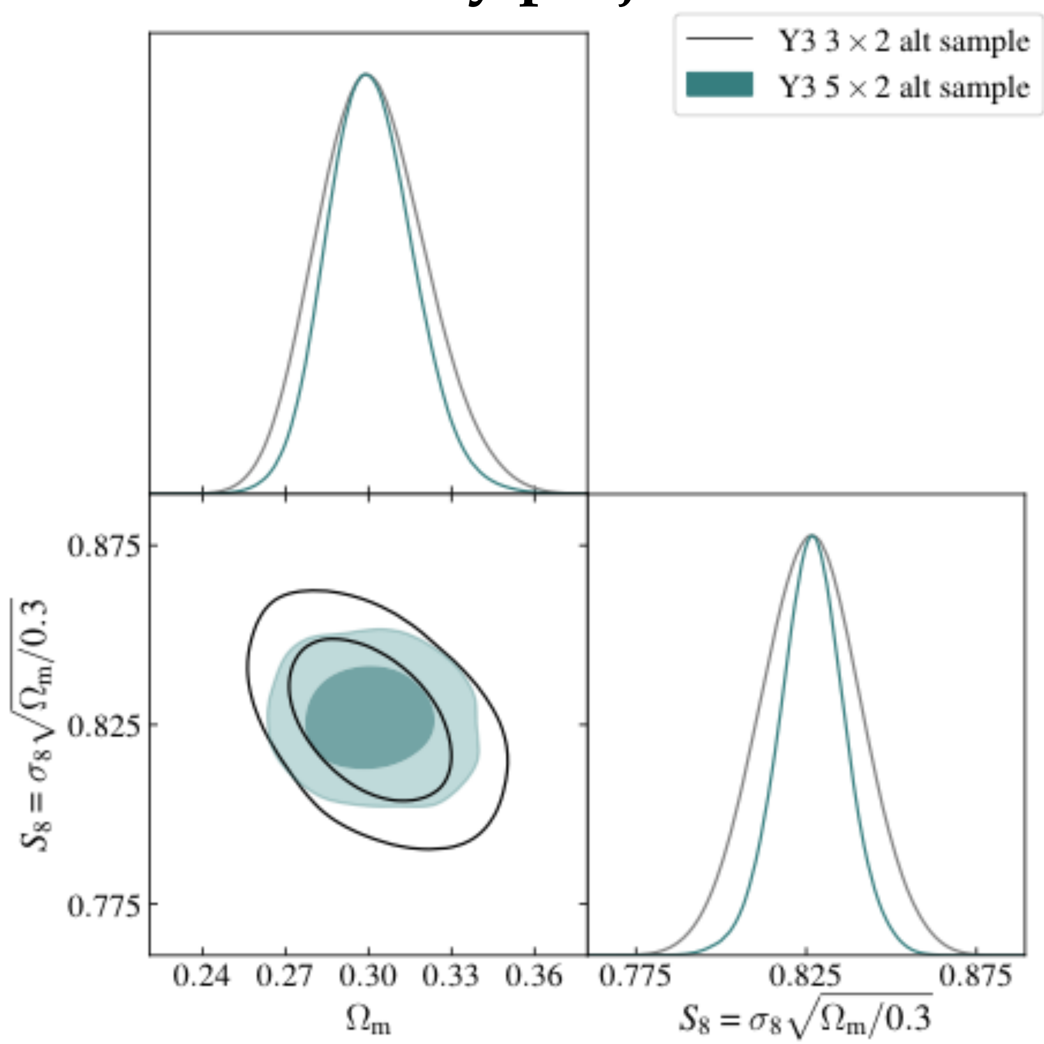


DES Y1 5x2pt Cosmology

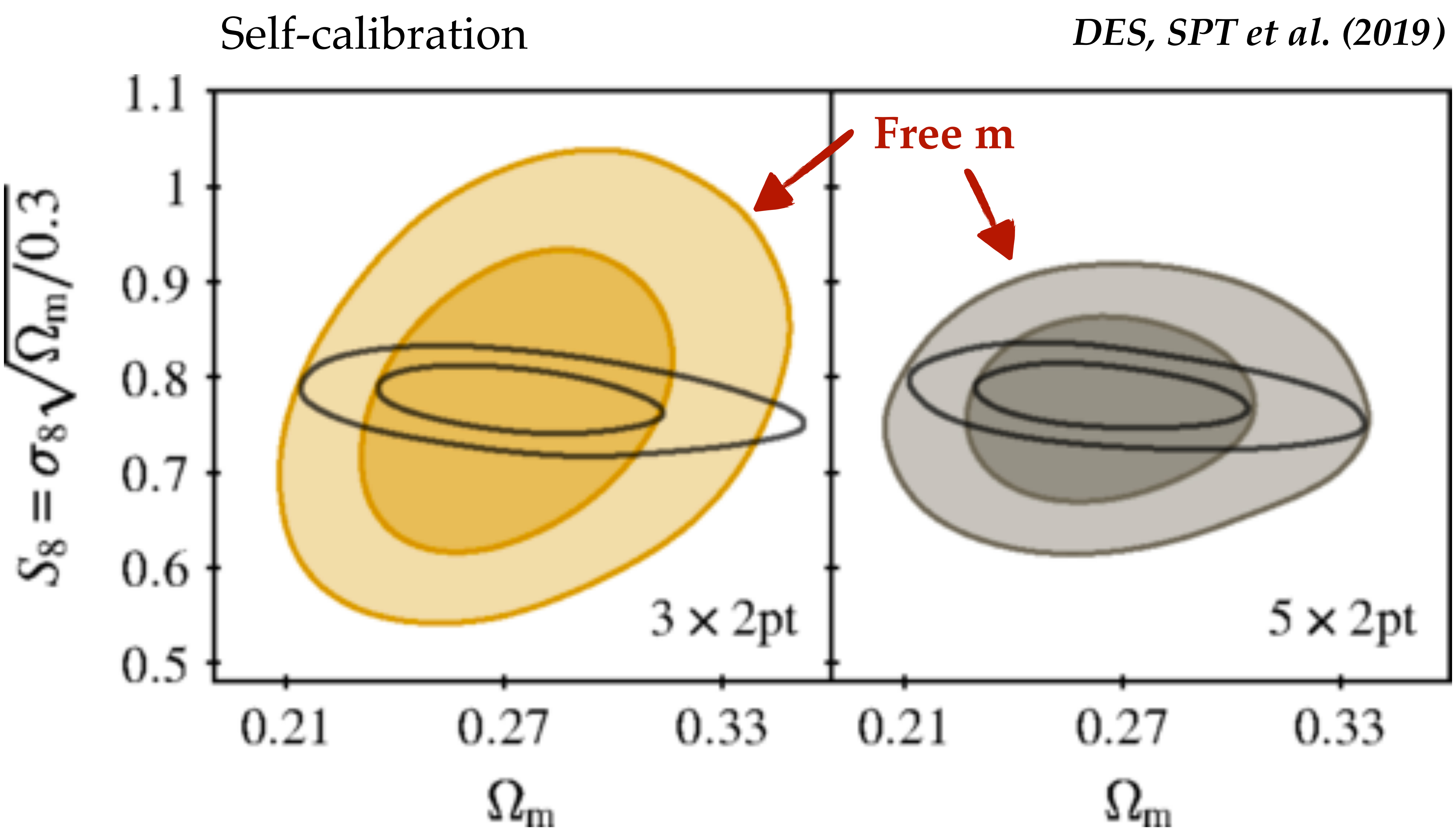


DES, SPT et al. (2018)

Preliminary projection for Y3



DES Y1 5x2pt Cosmology



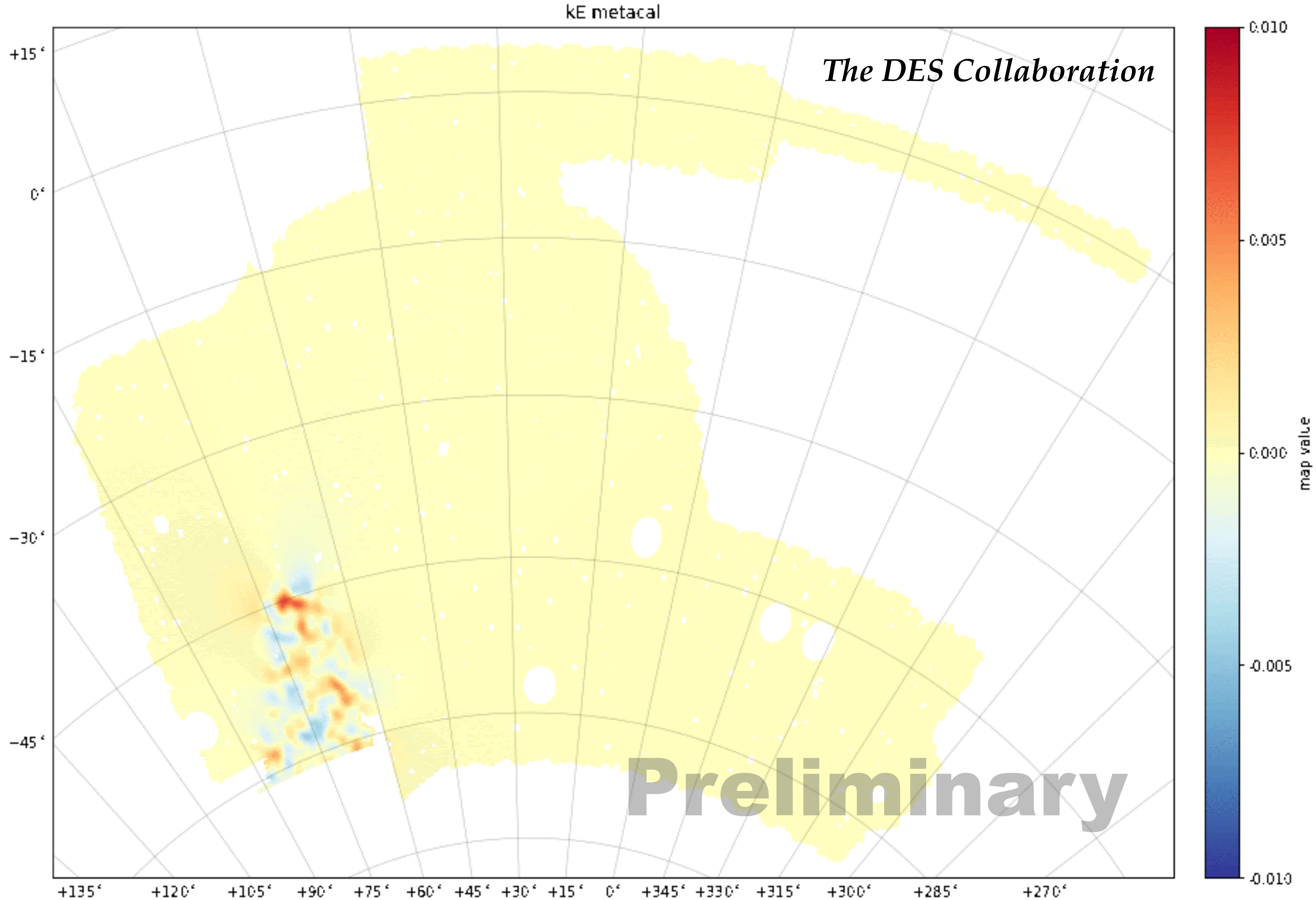
DES in the Next Few Month

DES Y3: 4143 sq deg, 110 million WL objects, order 20 papers in the pipeline.

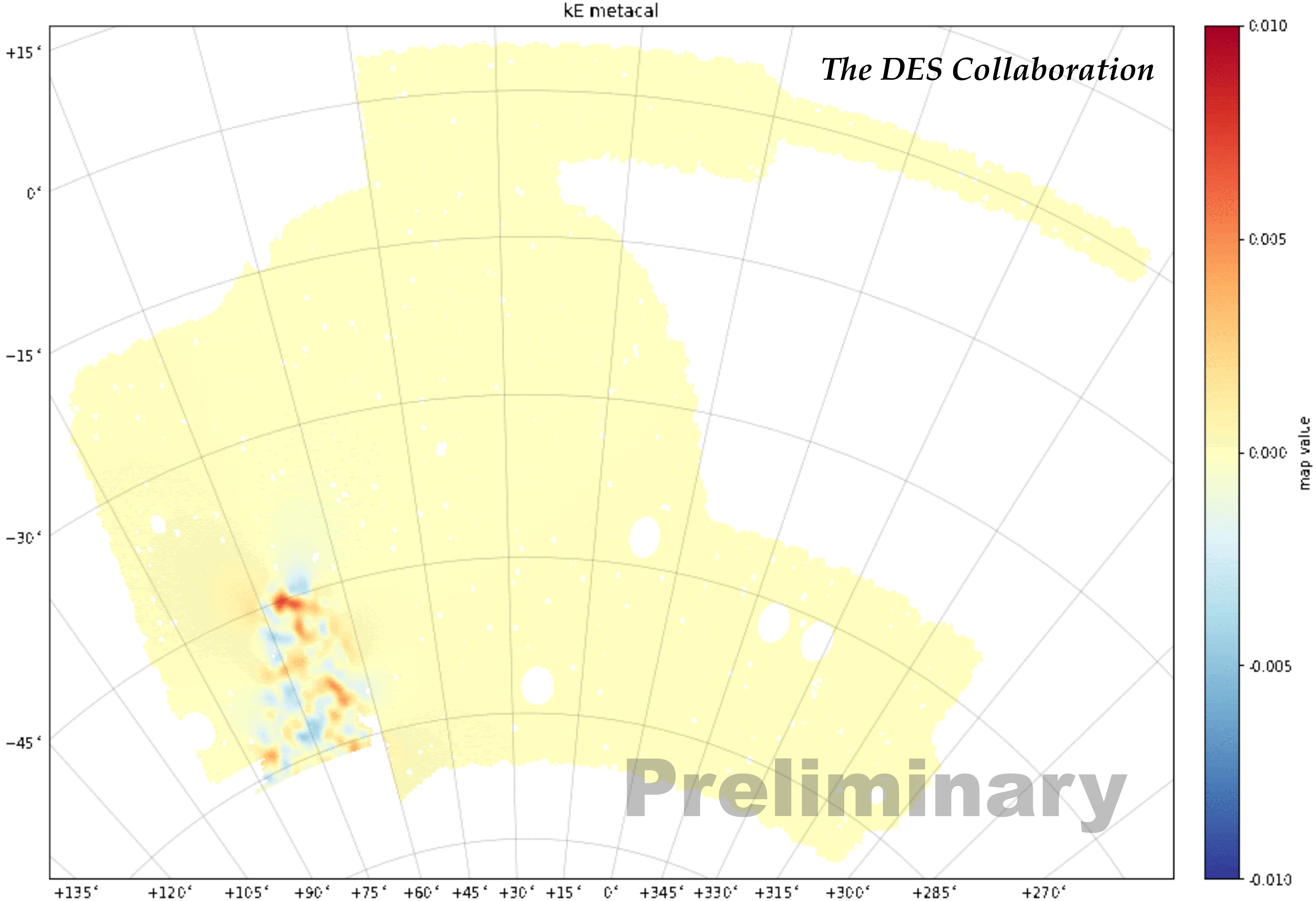
Major changes relative to Y1:

- New PSF model (PIFF)
- Deblending using MOF
- New photo-z methodology bridging deep- (ugrizYJHK) and wide-field (riz) data
- New Balrog simulation to infer survey selection function (via injection)
- Two lens populations (redMaGic and magnitude-limited sample)
- Modelling improvements:
    - Nonlinear galaxy bias modelling
    - Nonlocal tangential shear marginalization
    - Magnification
    - Mixed tidal alignment/tidal torquing intrinsic alignment model

DES in the Next Few Month

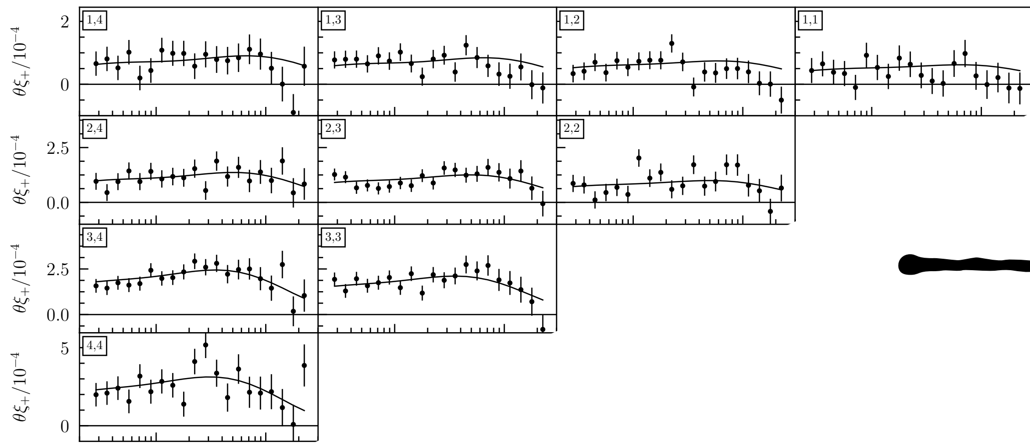


DES in the Next Few Month

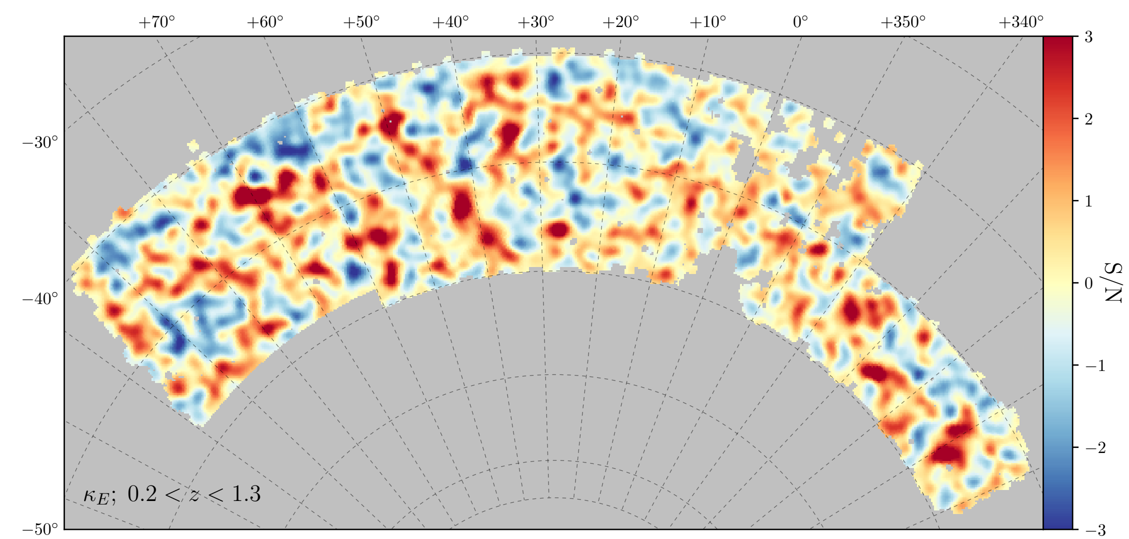


DES Outside-the-Box

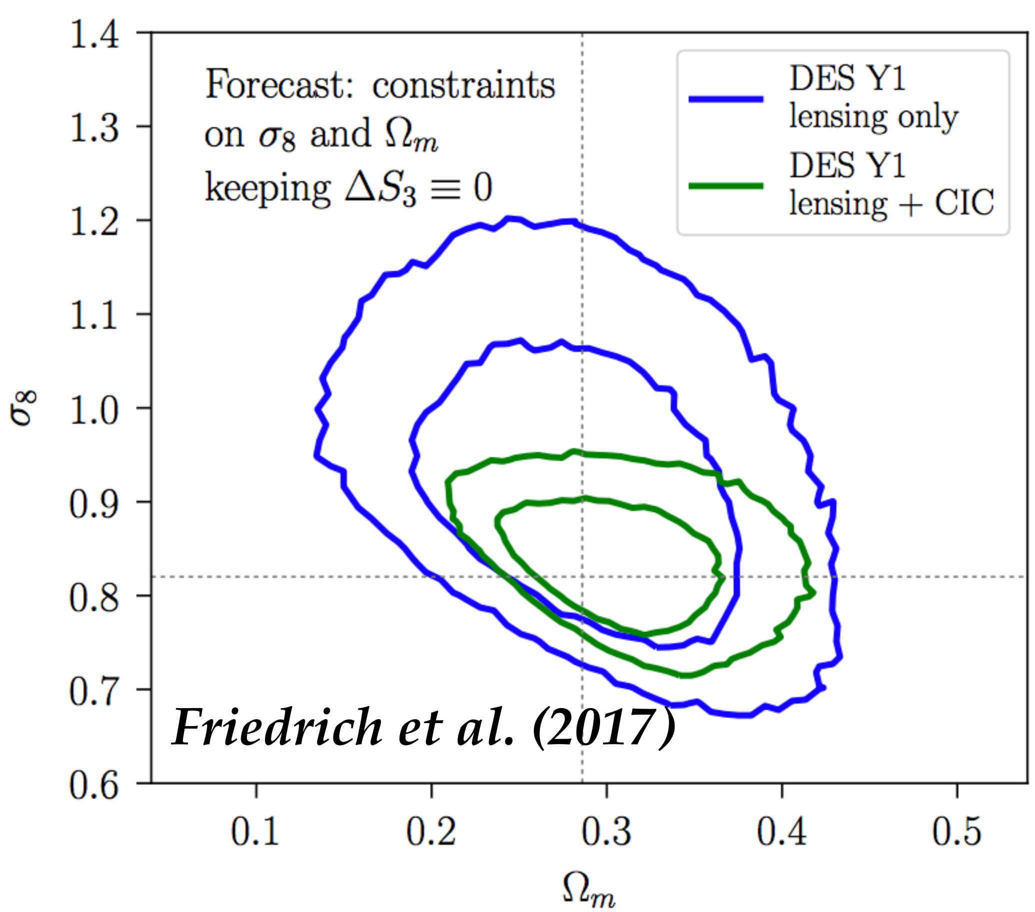
with
Marco Gatti (Barcelona)



Troxel et al. (2018)

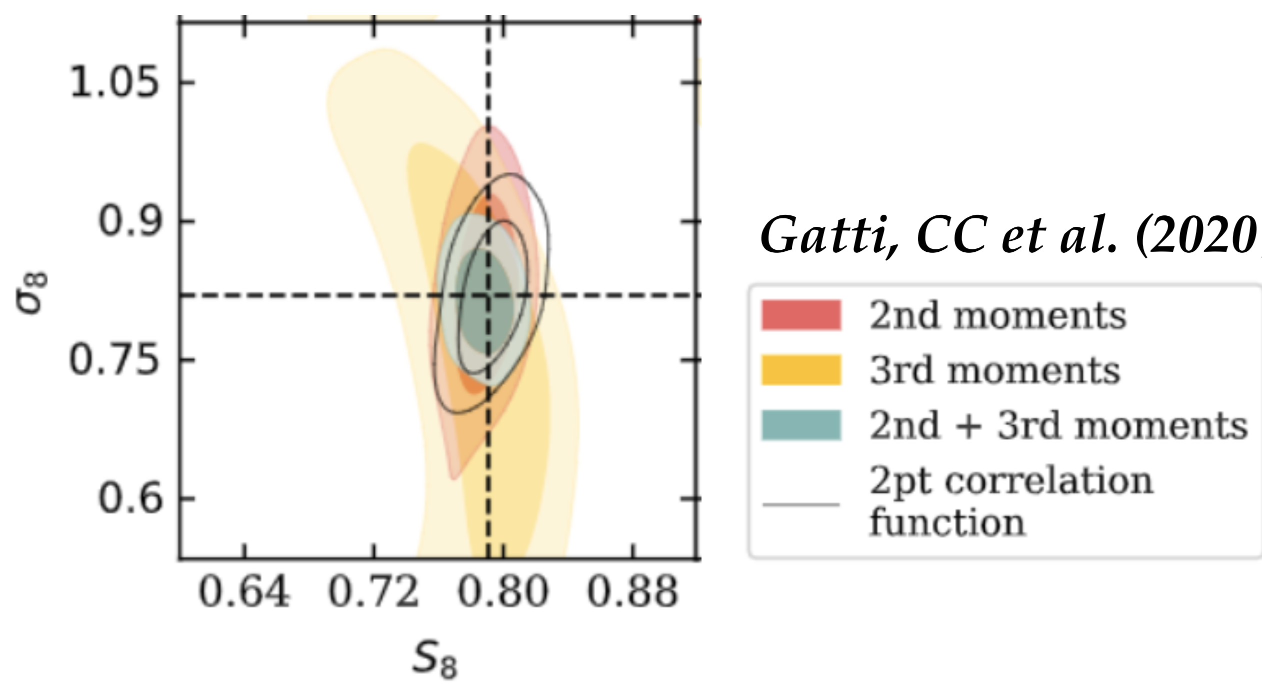


CC et al. (2018)



Friedrich et al. (2017)

The cosmic field contains a lot of information in the **phases** of the structure.

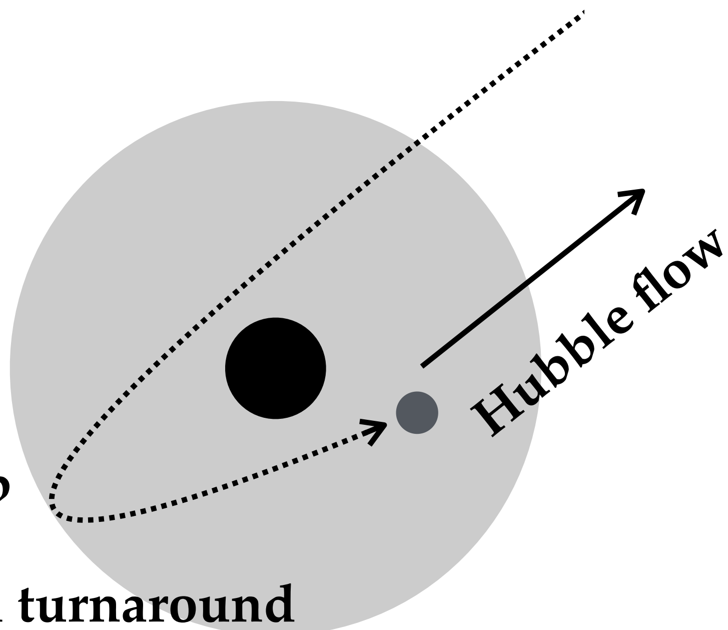


Gatti, CC et al. (2020)

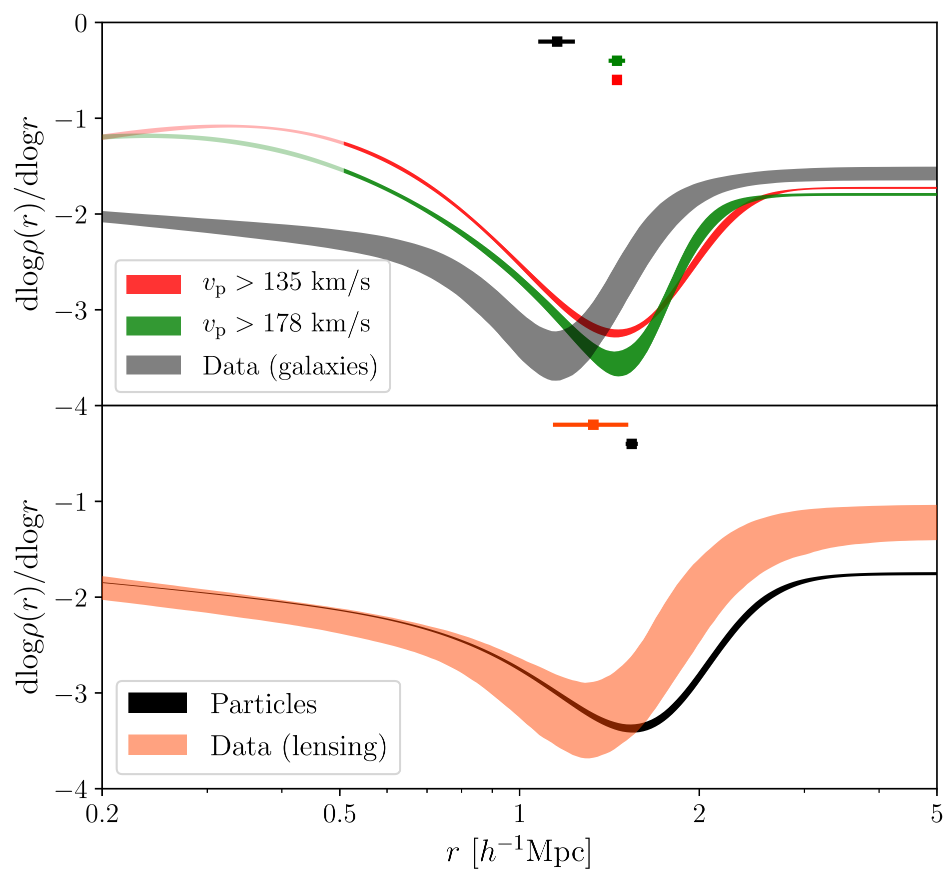
DES Outside-the-Box

with
Tae-Hyeon Shin (UPenn)
Eric Baxter (Hawaii)
Susmita Adhikari (Stanford)
Bhuv Jain (UPenn)

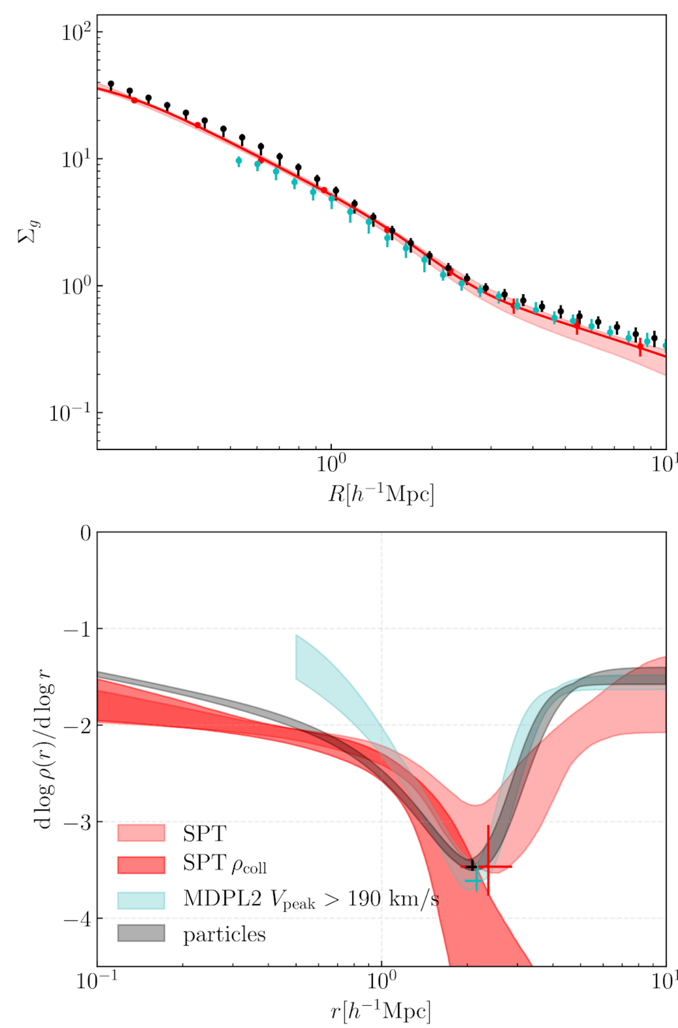
v_r = 0
r = r_sp



Second turnaround
= “Splashback" radius

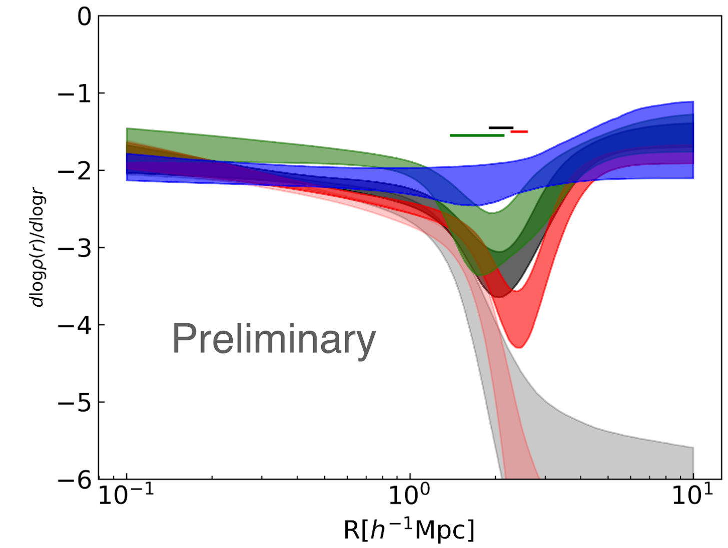


CC et al. (2017)



Shin et al. (2019)

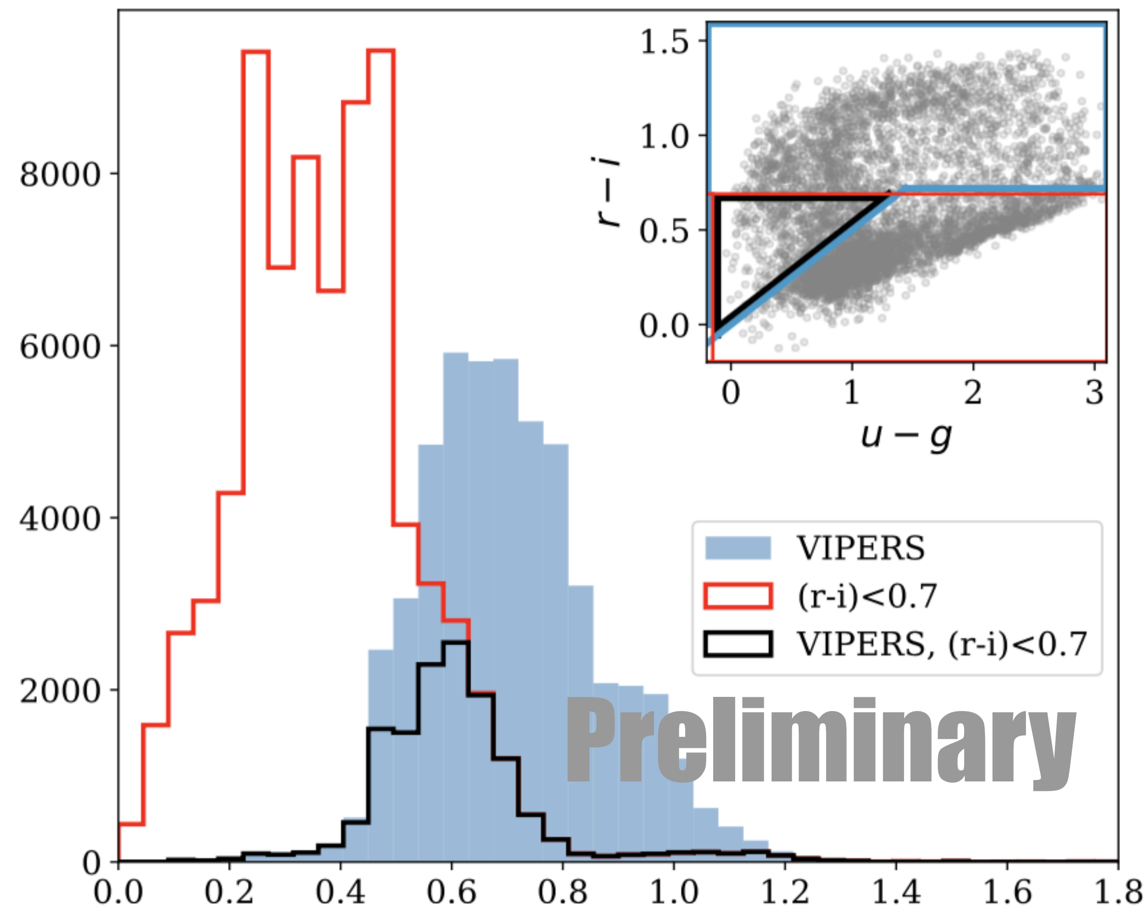
Credit: Tae Shin



400+ AdvACT clusters
—> SZ-selected clusters are starting to have the statistics to say something interesting

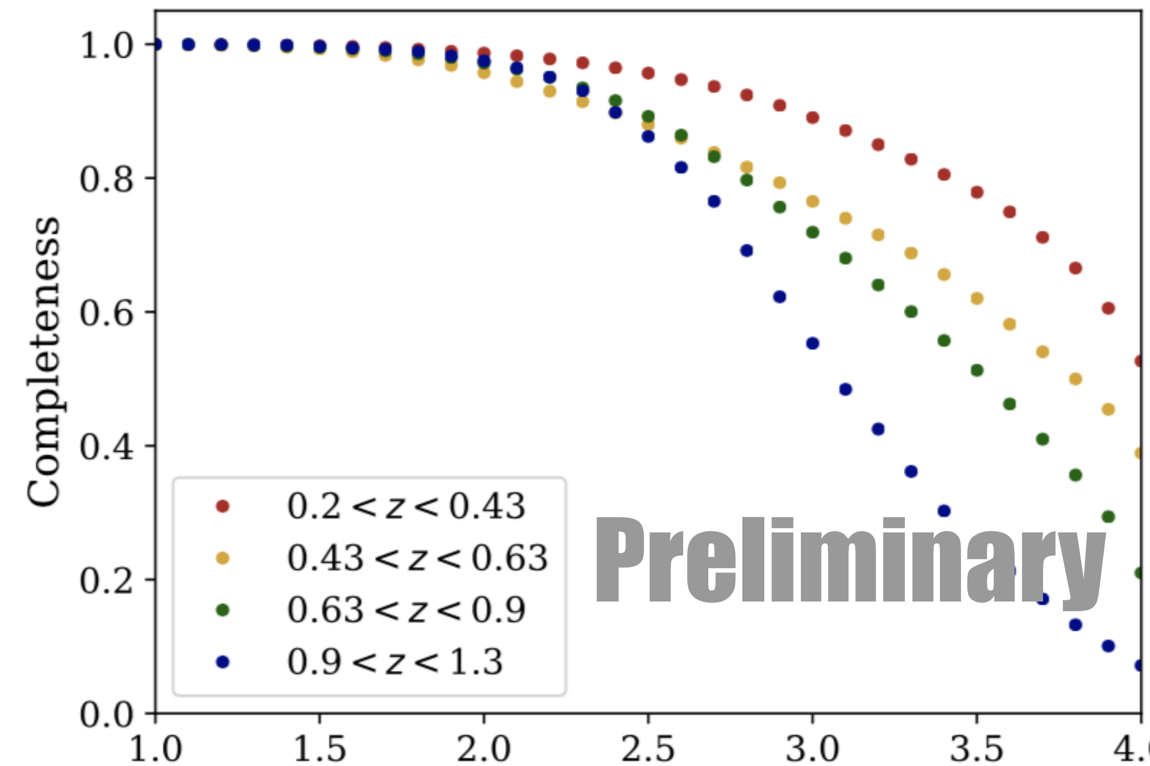
DES Outside-the-Box

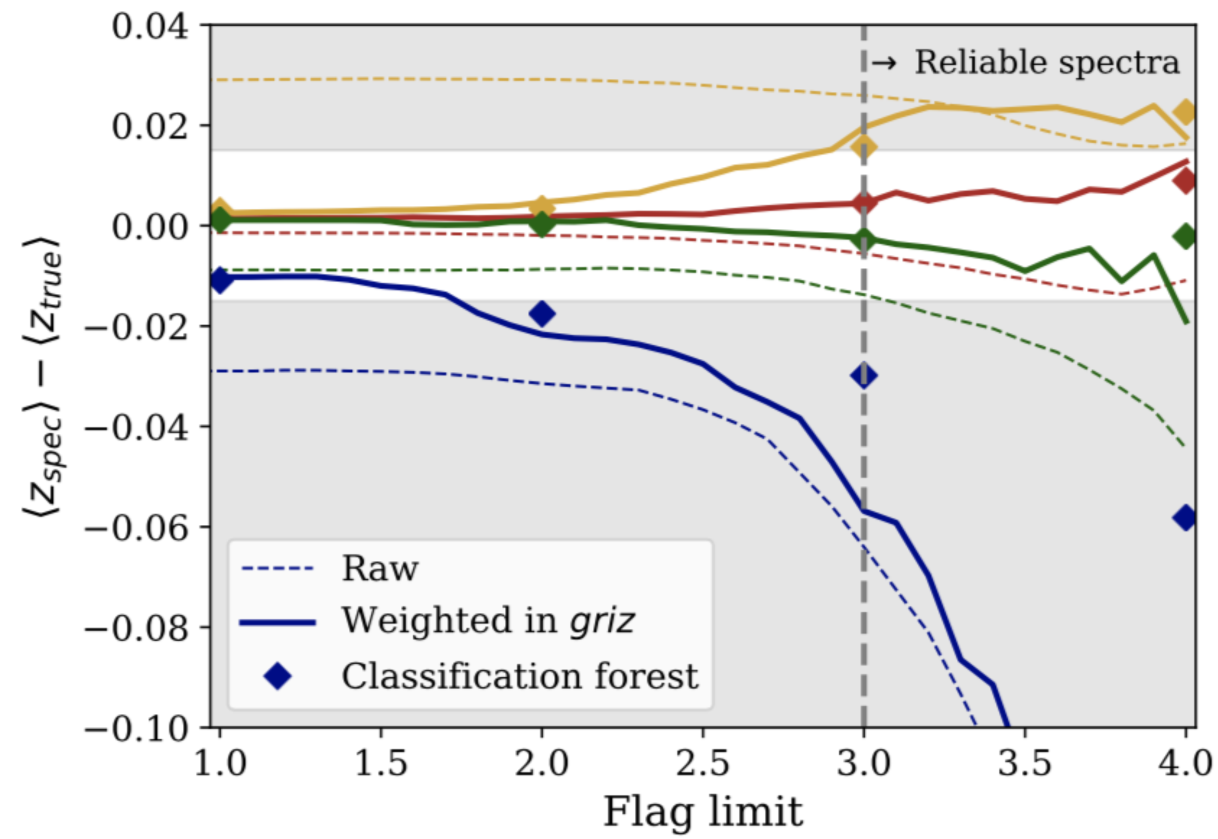
with
Will Hartley (Geneva)



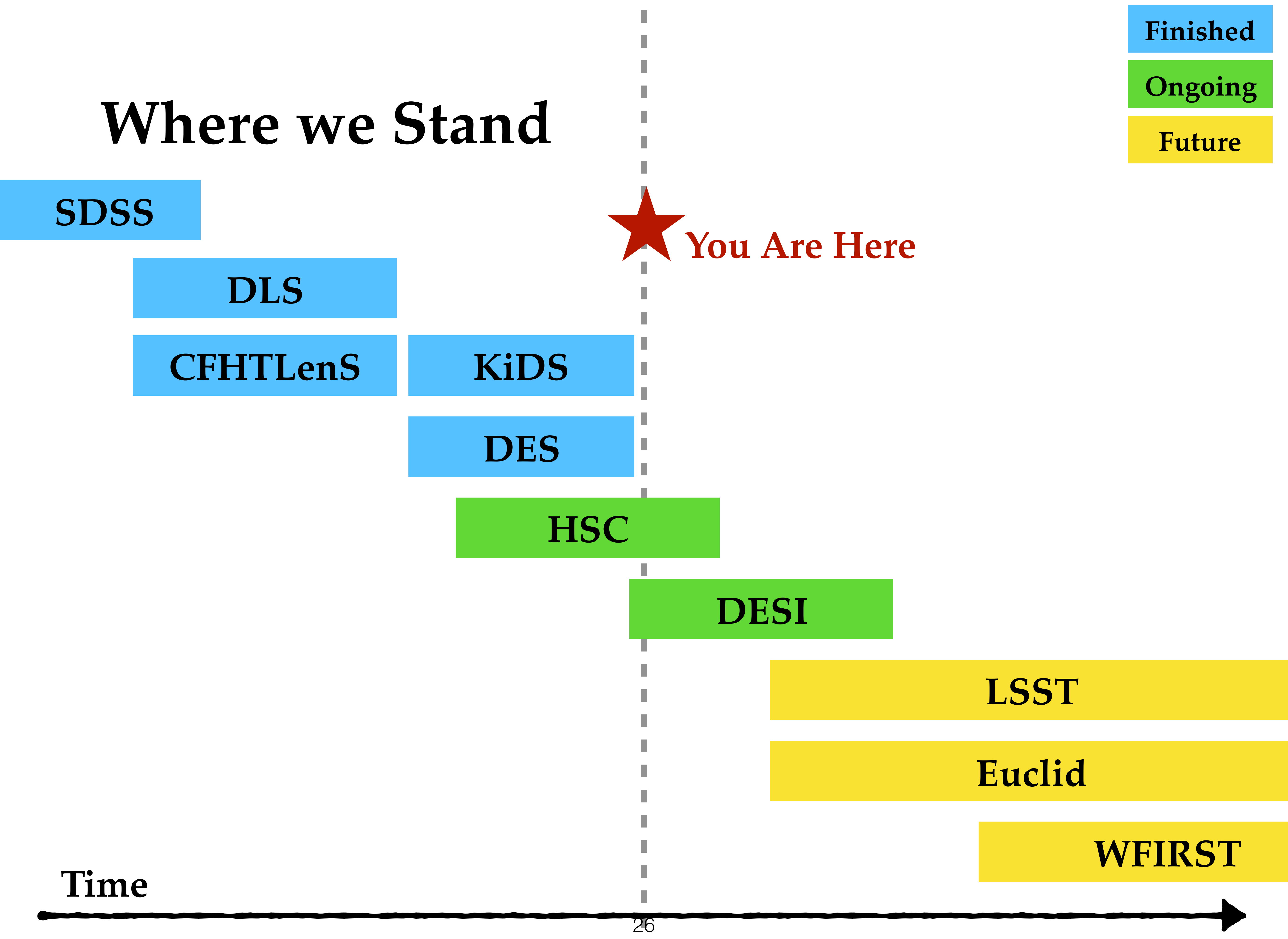
Hartley, CC et al. (in prep)

Investigating the effect of spectroscopic incompleteness in WL experiments



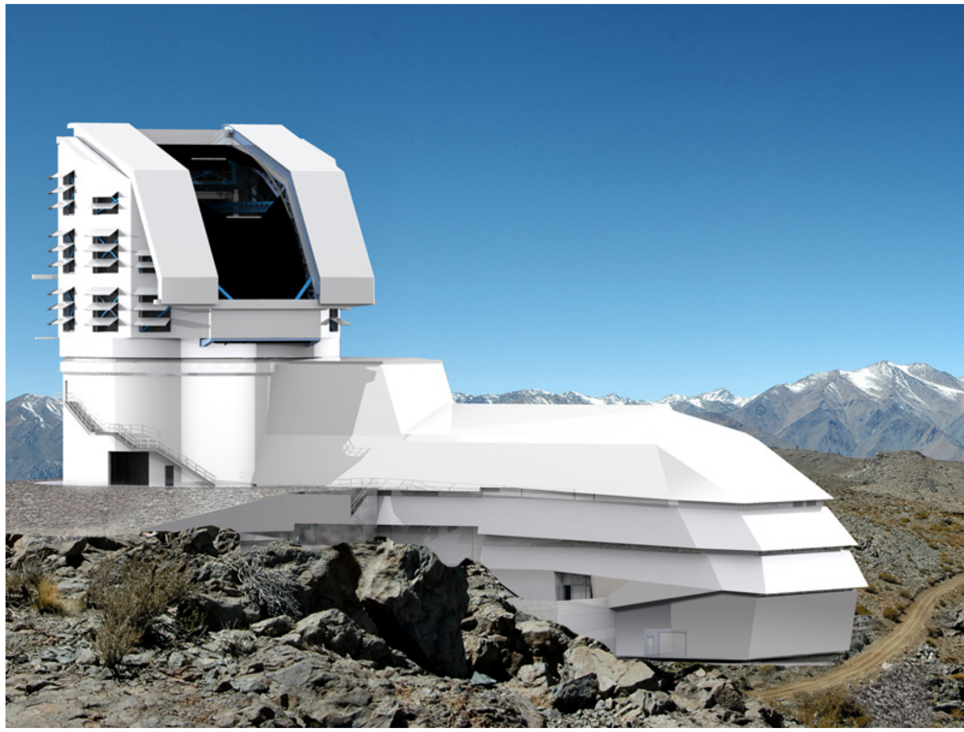


Where we Stand



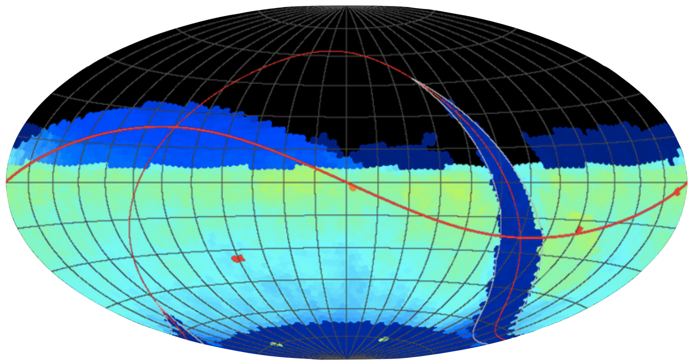
(Vera Rubin's Observatory, Simony Survey Telescope)

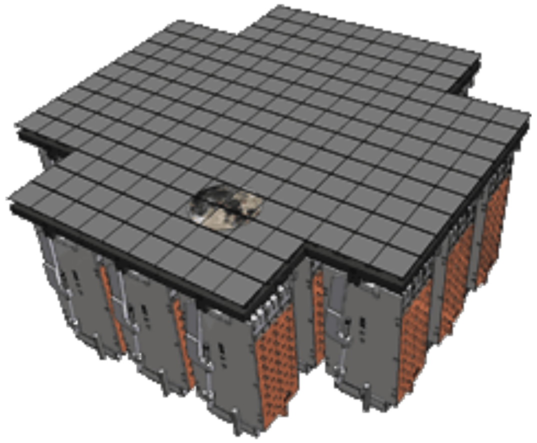
The Legacy Survey of Space and Time

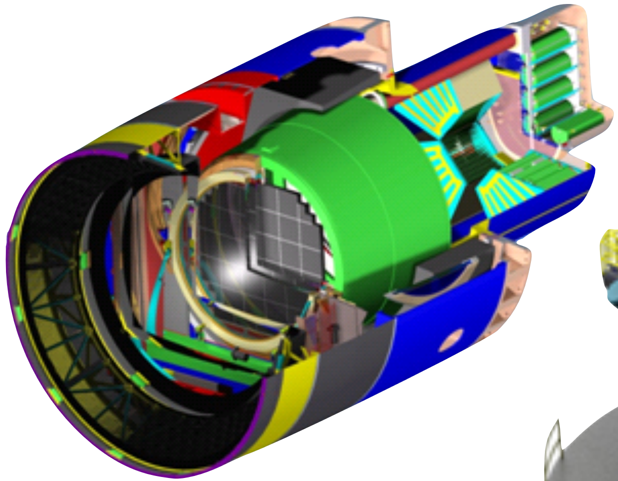


LSST is an imaging survey
scheduled science run ~2022

6 filter bands (u*grizY*), 10 sq. deg FOV,
10 years, ~3 day cadence, **18000 sq. deg, i~27**
Wide field and time-domain science







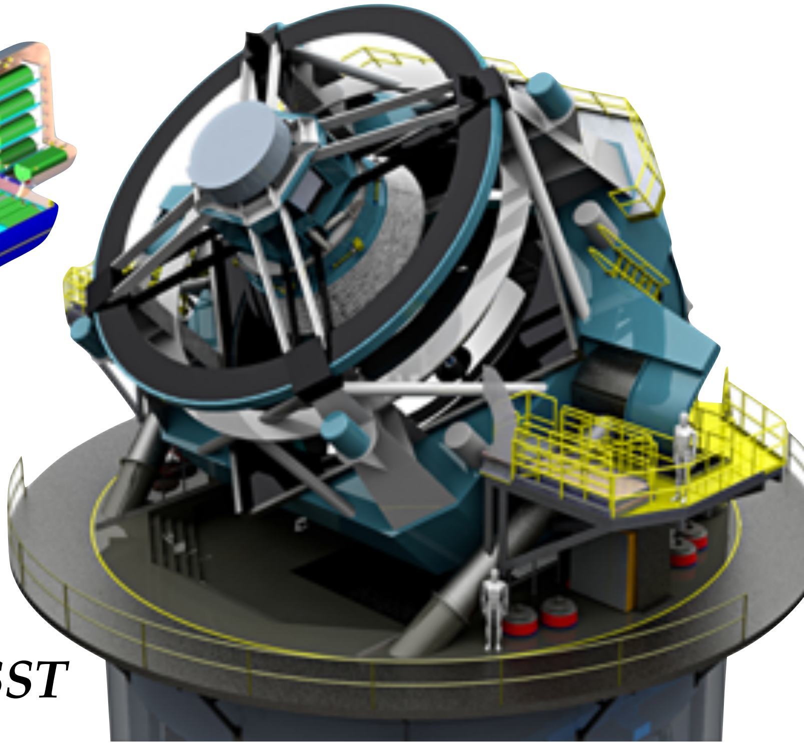


Image credit: LSST

(Vera Rubin's Observatory, Simony Survey Telescope)

The **L**egacy **S**urvey of **S**pace and **T**ime

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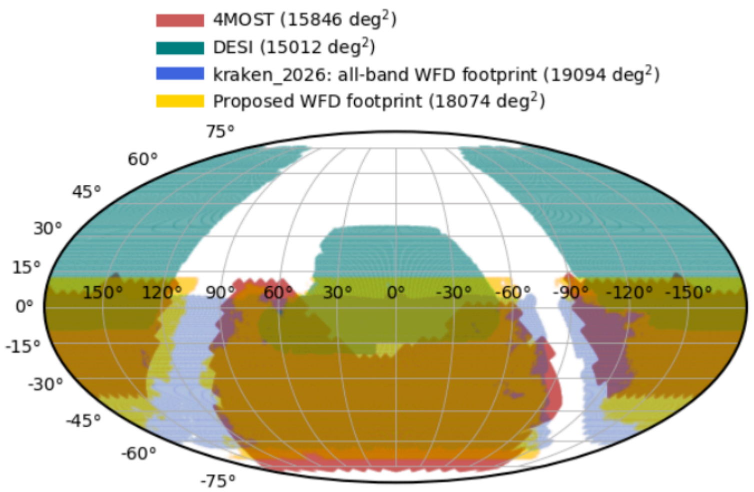


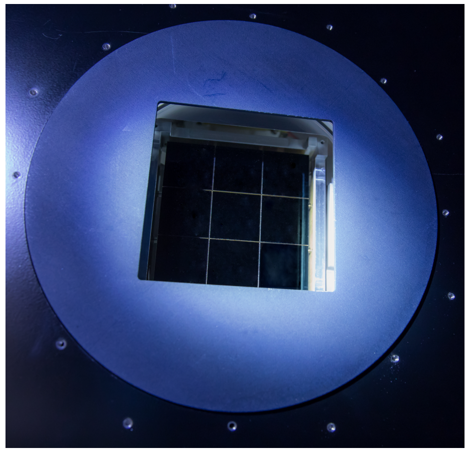
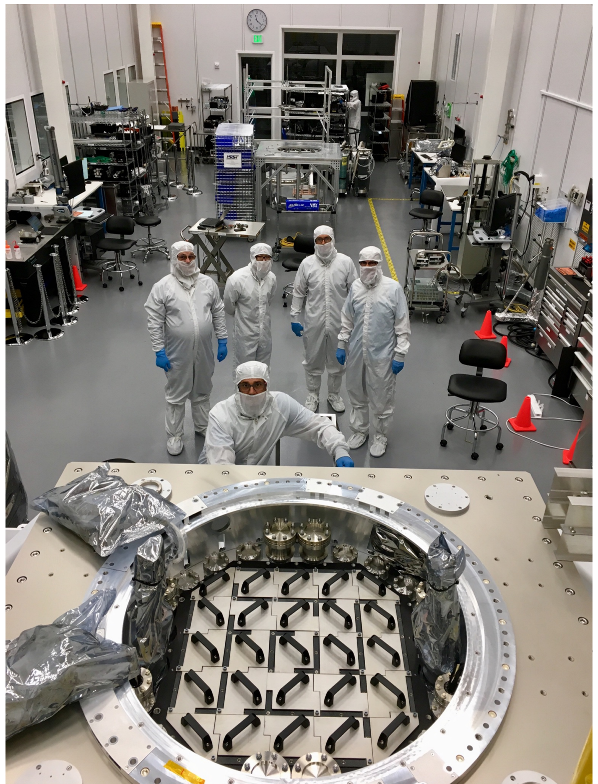
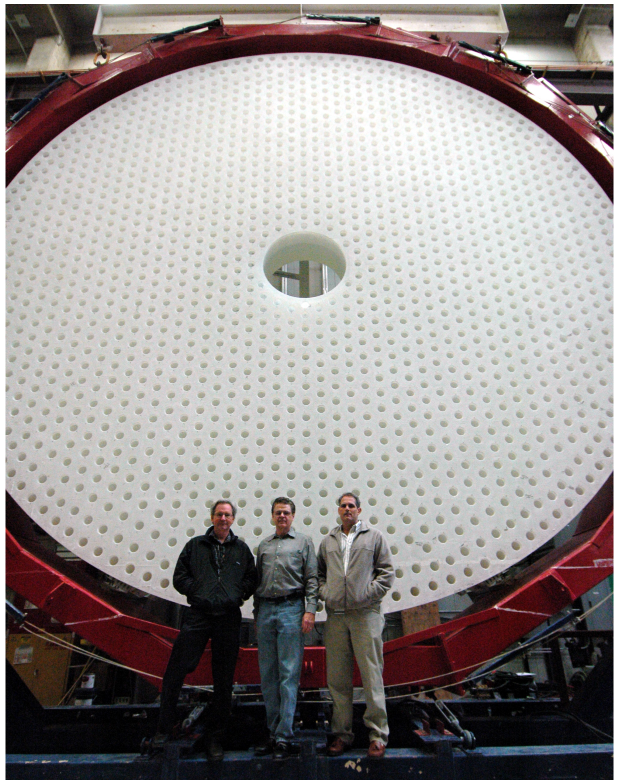


Image credit: LSST





(Vera Rubin's Observatory, Simony Survey Telescope)

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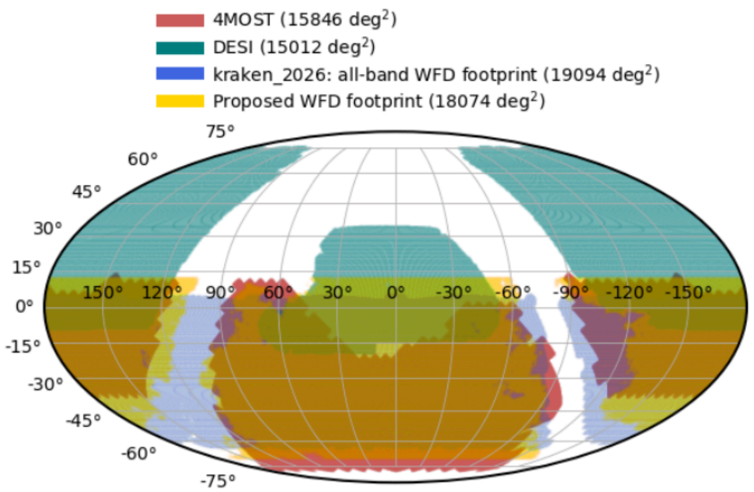


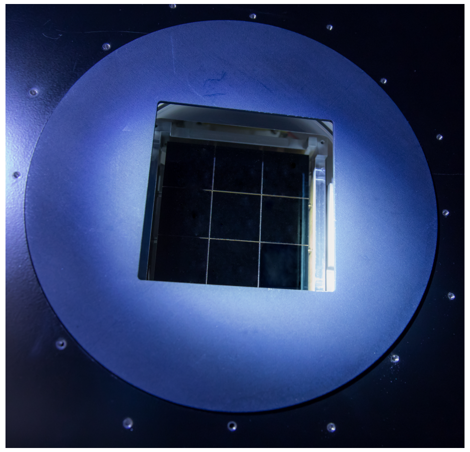
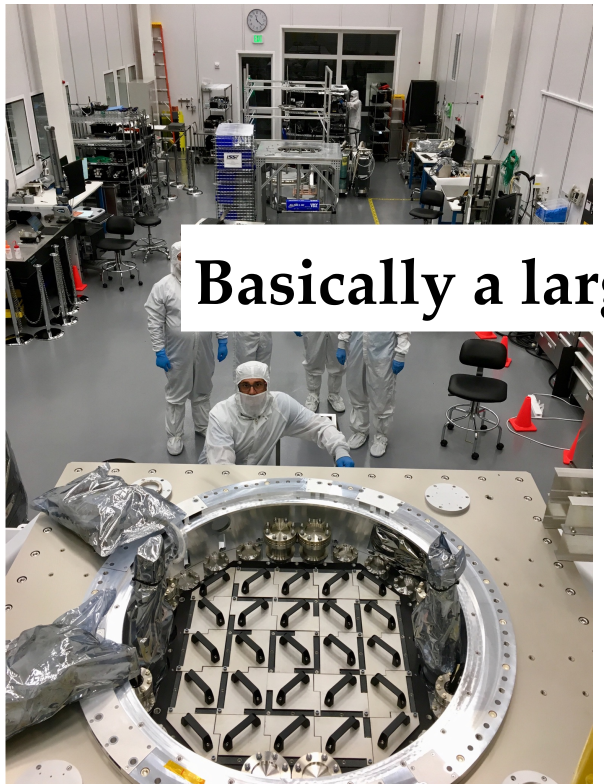
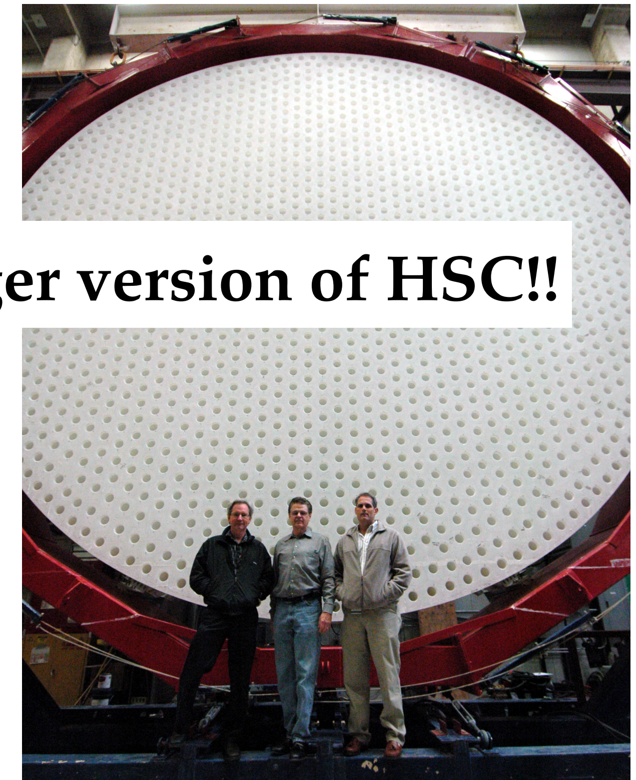


Image credit: LSST

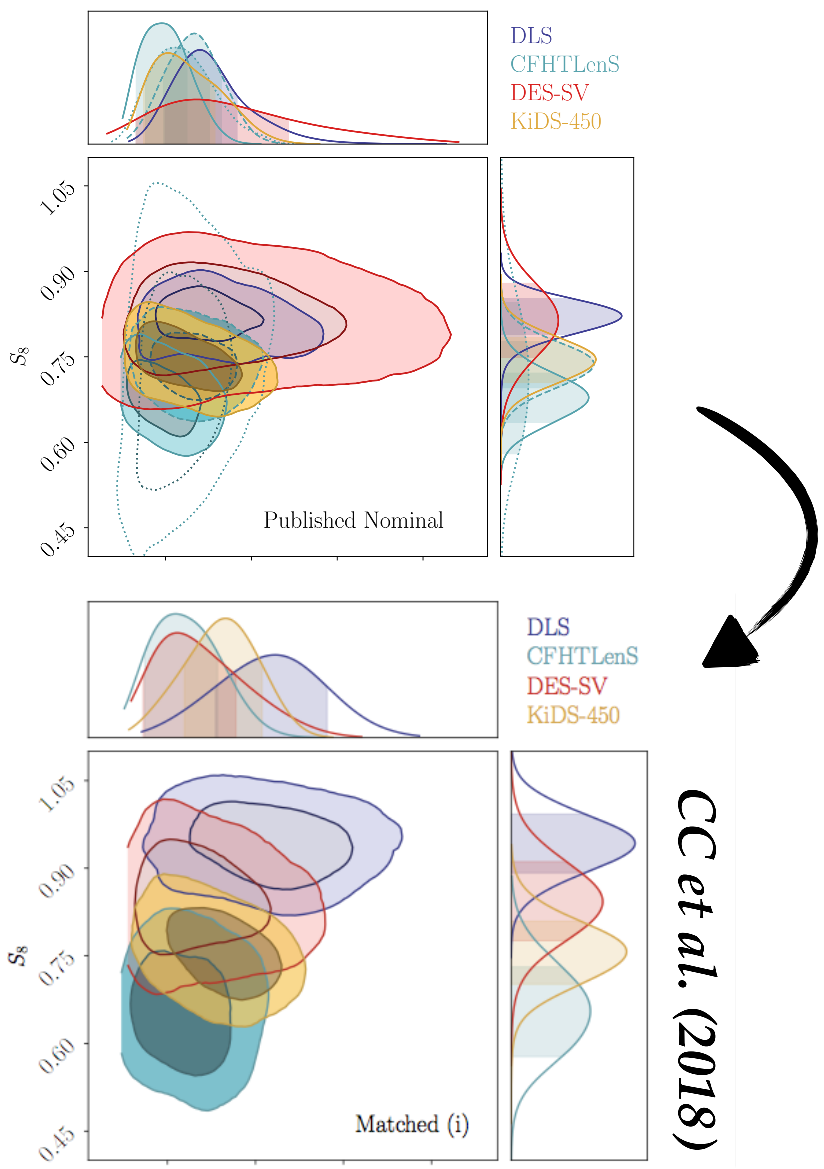




Basically a larger version of HSC!!

The LSST Dark Energy Science Collaboration (DESC)

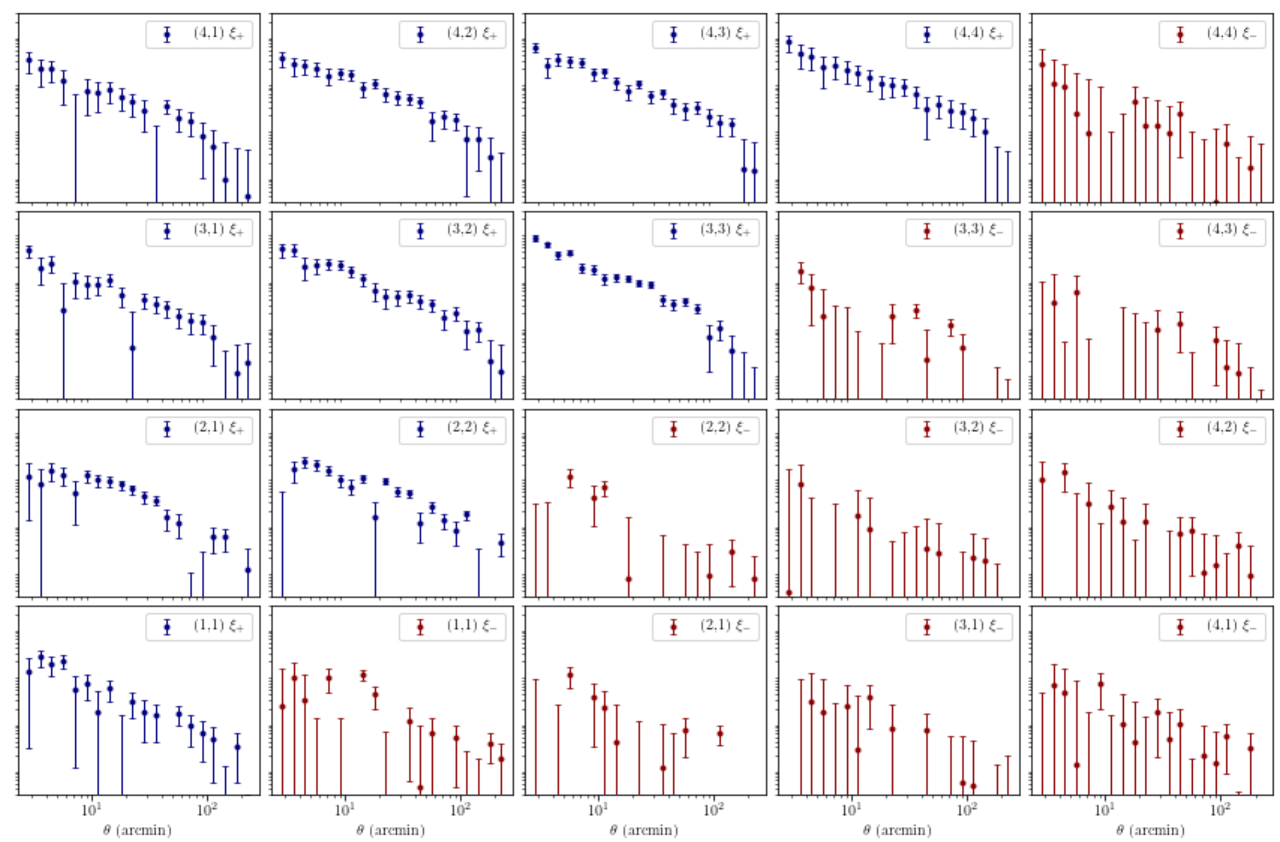
DESC Cosmology Pipelines



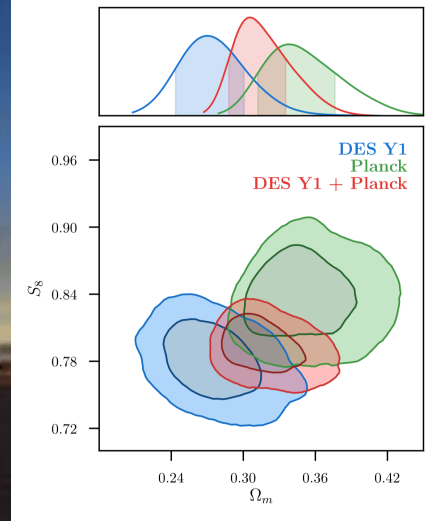
Reanalyzed **DLS, CFHTLenS, DES-SV, KiDS-450** cosmic shear analysis under unified assumption

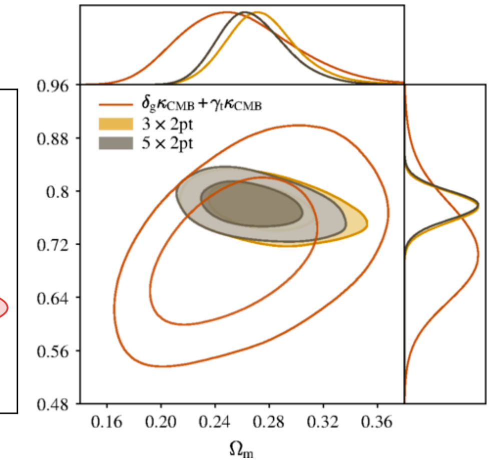
Currently we are using reanalysis of Stage III published data to push the development of DESC pipelines. Example: cosmic shear from **DES-Y1, KV450, HSC Y1**

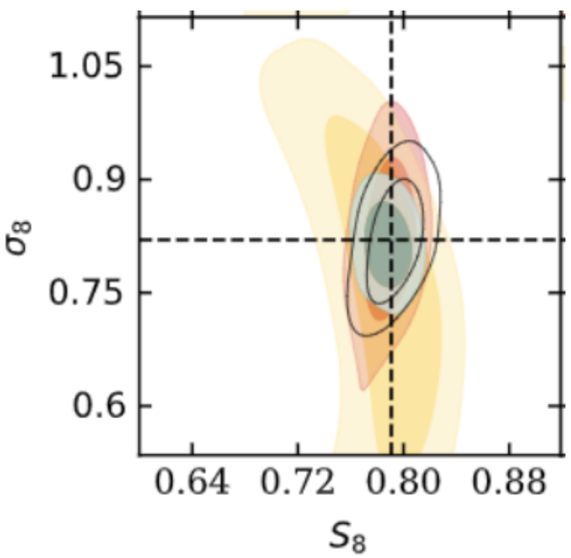
Recall: HSC~LSST

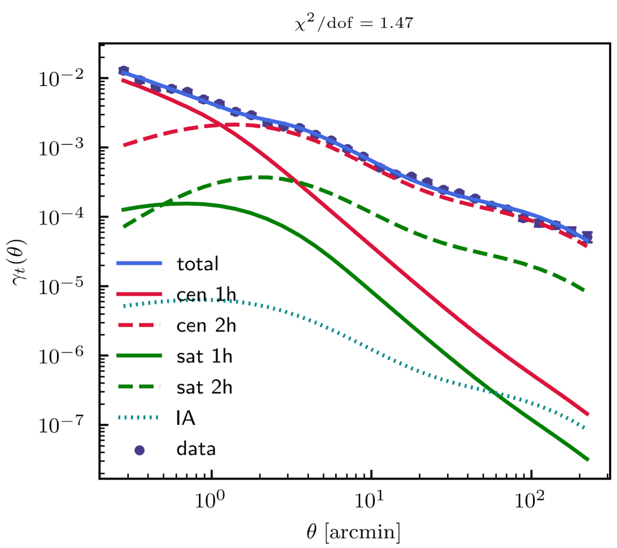


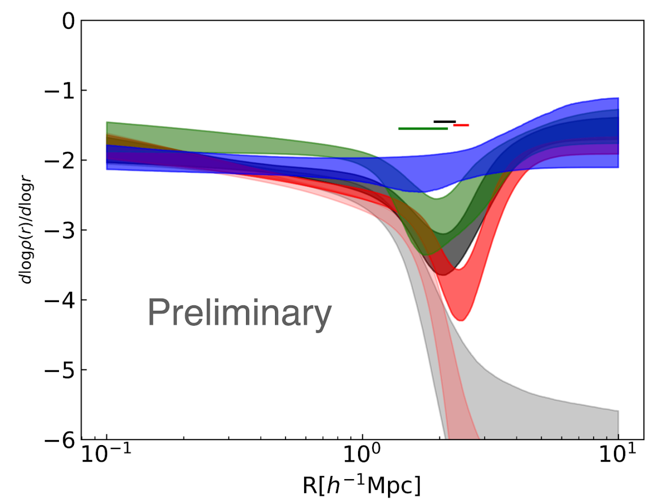
Summary

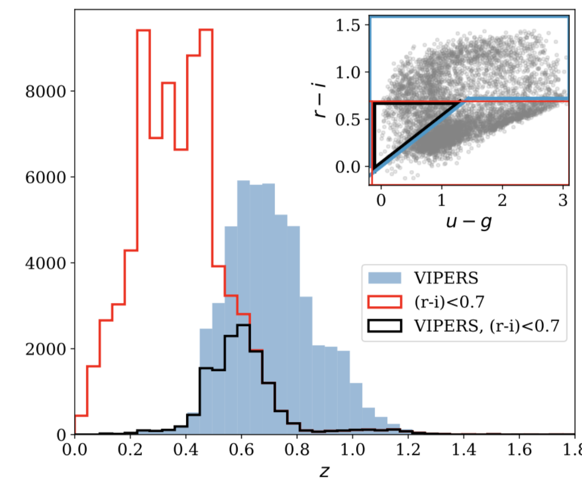

DES Y1
Planck
DES Y1 + Planck
S_8
Ω_m

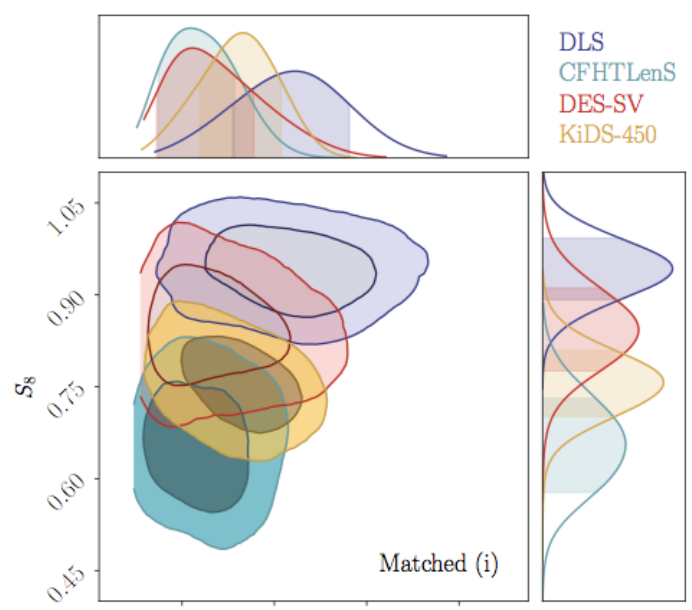

$\delta_g\kappa_{CMB} + \gamma_t\kappa_{CMB}$
3×2pt
5×2pt
Ω_m


σ_8
S_8


$\chi^2/\mathrm{dof} = 1.47$
total
cen 1h
cen 2h
sat 1h
sat 2h
IA
data
$\gamma_t(\theta)$
θ [arcmin]


Preliminary
dlogρ(r)/dlogr
R[h^{-1}Mpc]


VIPERS
(r-i)<0.7
VIPERS, (r-i)<0.7
$r-i$
$u-g$
z


DLS
CFHTLenS
DES-SV
KiDS-450
S_8
Matched (i)