

COSMIC SHEAR IN DES-Y3: 2-POINT AND 3-POINT CORRELATIONS

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Cosmic Shear with DES-Y3

- The Dark Energy Survey & weak lensing
- Cosmology with shear-2pt correlations
 - *PSF errors*
 - *Intrinsic alignments*
- Pursuing a measurement of shear-3pt correlations
- Conclusion: what to expect from DES-Y3

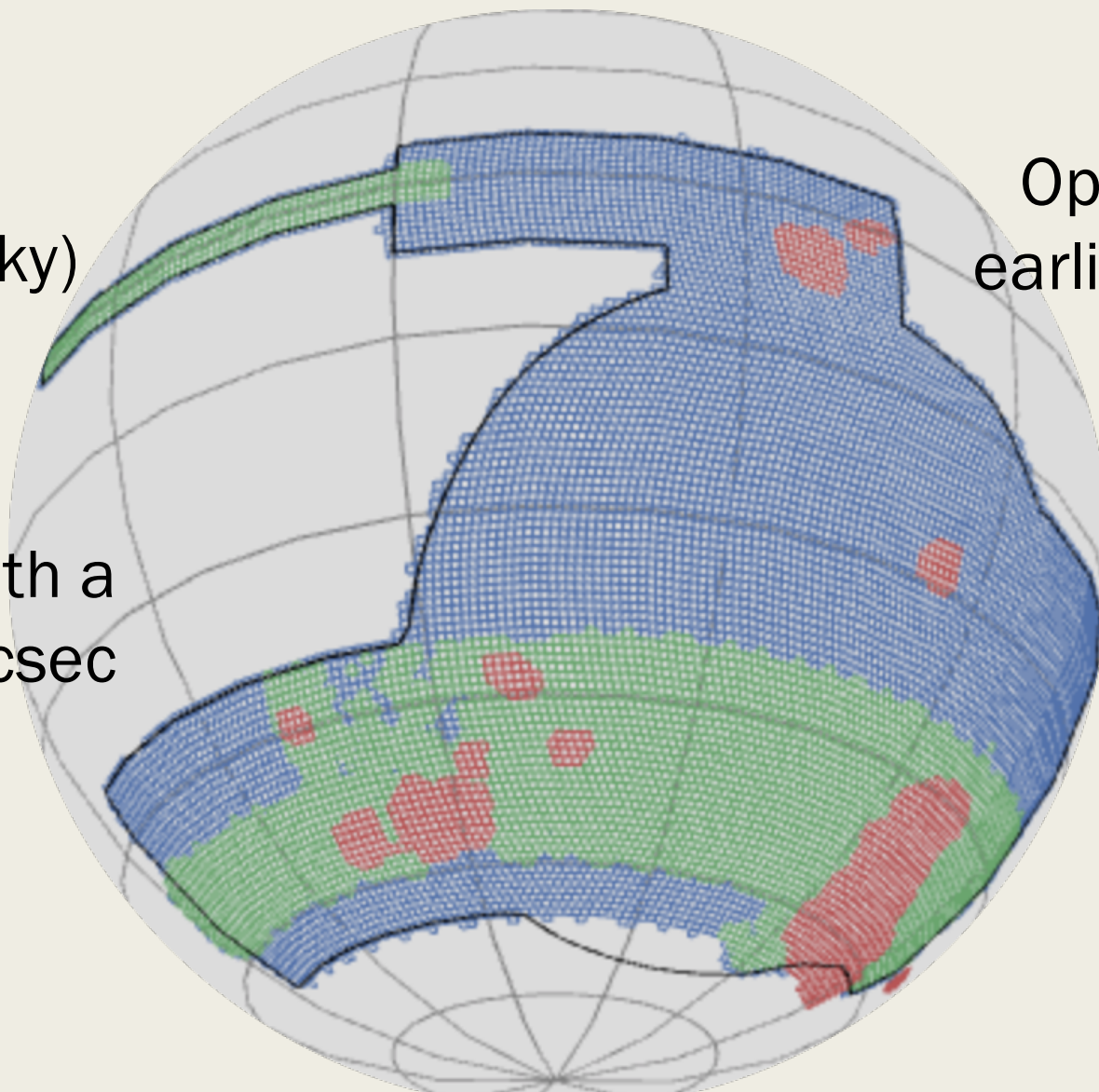
The Dark Energy Survey

~5000 sq. deg
(1/8th of the full sky)

g,r,i,z,(Y) bands with a
seeing of ~0.9 arcsec

Operations finalized
earlier this year (~5.5y)

~120M objects
make the final
cuts of the weak
lensing sample



Credit: Nacho Sevilla (DES)

The Dark Energy Survey

>400 people

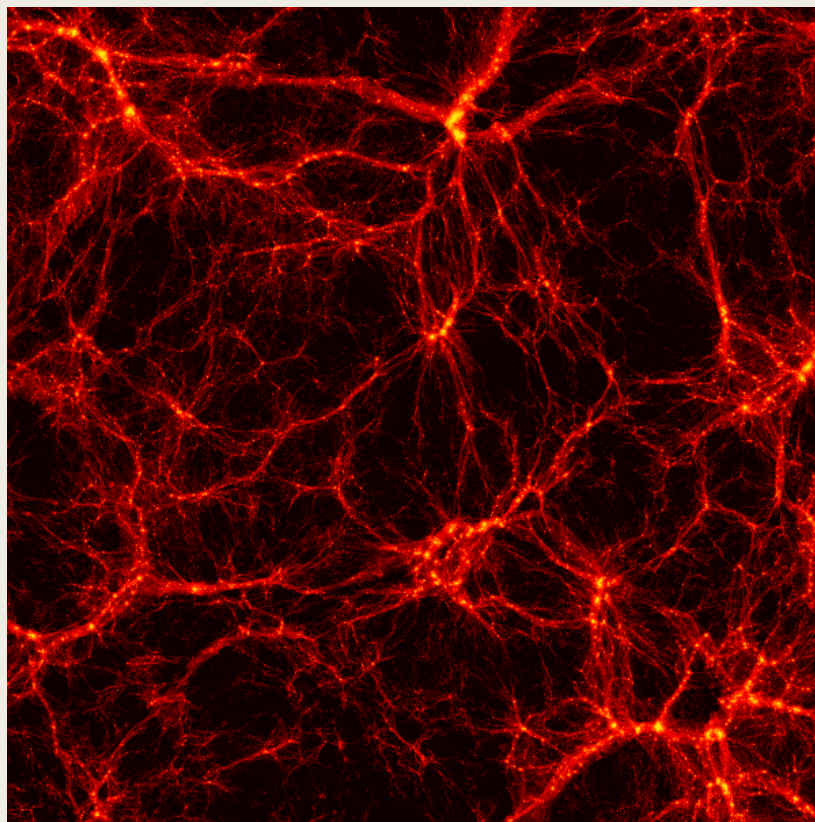


Blanco Telescope @
CTIO Chile

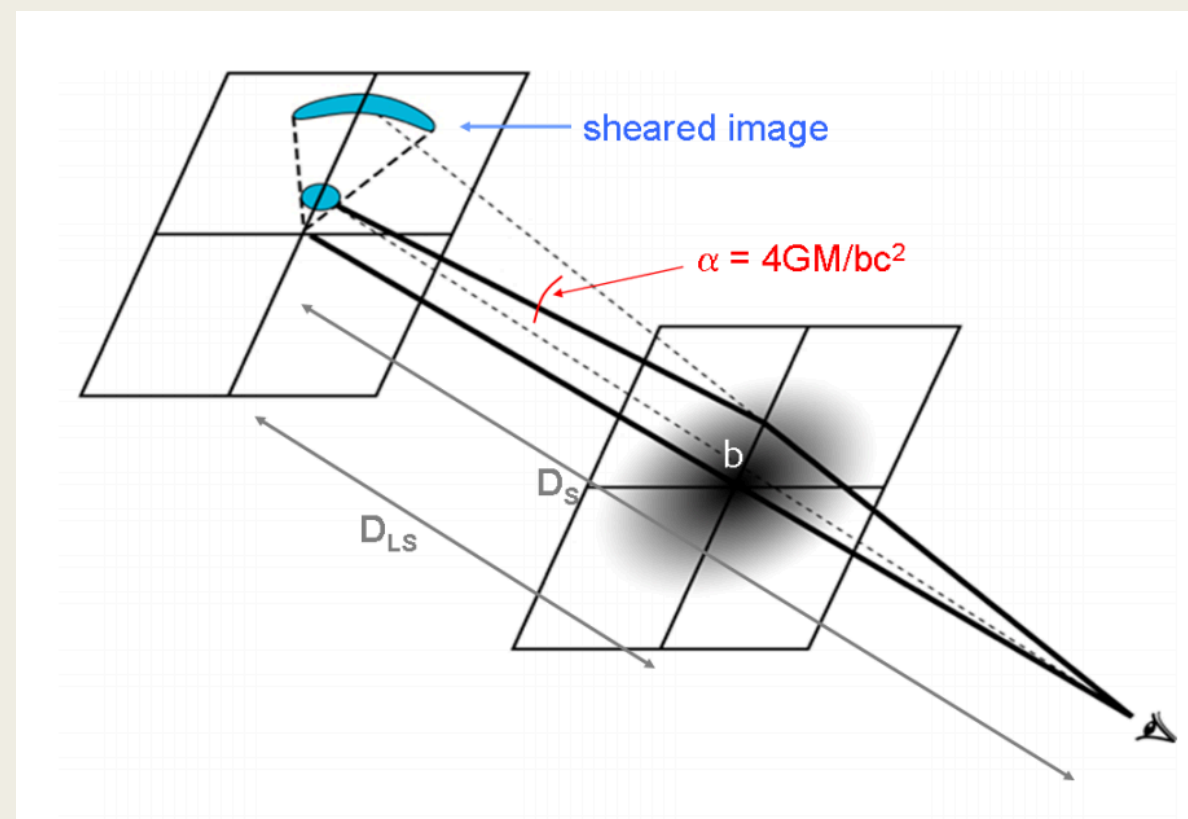
From shapes to cosmology

Evolution under gravity: the matter distribution in the universe is **not random** (uniform)

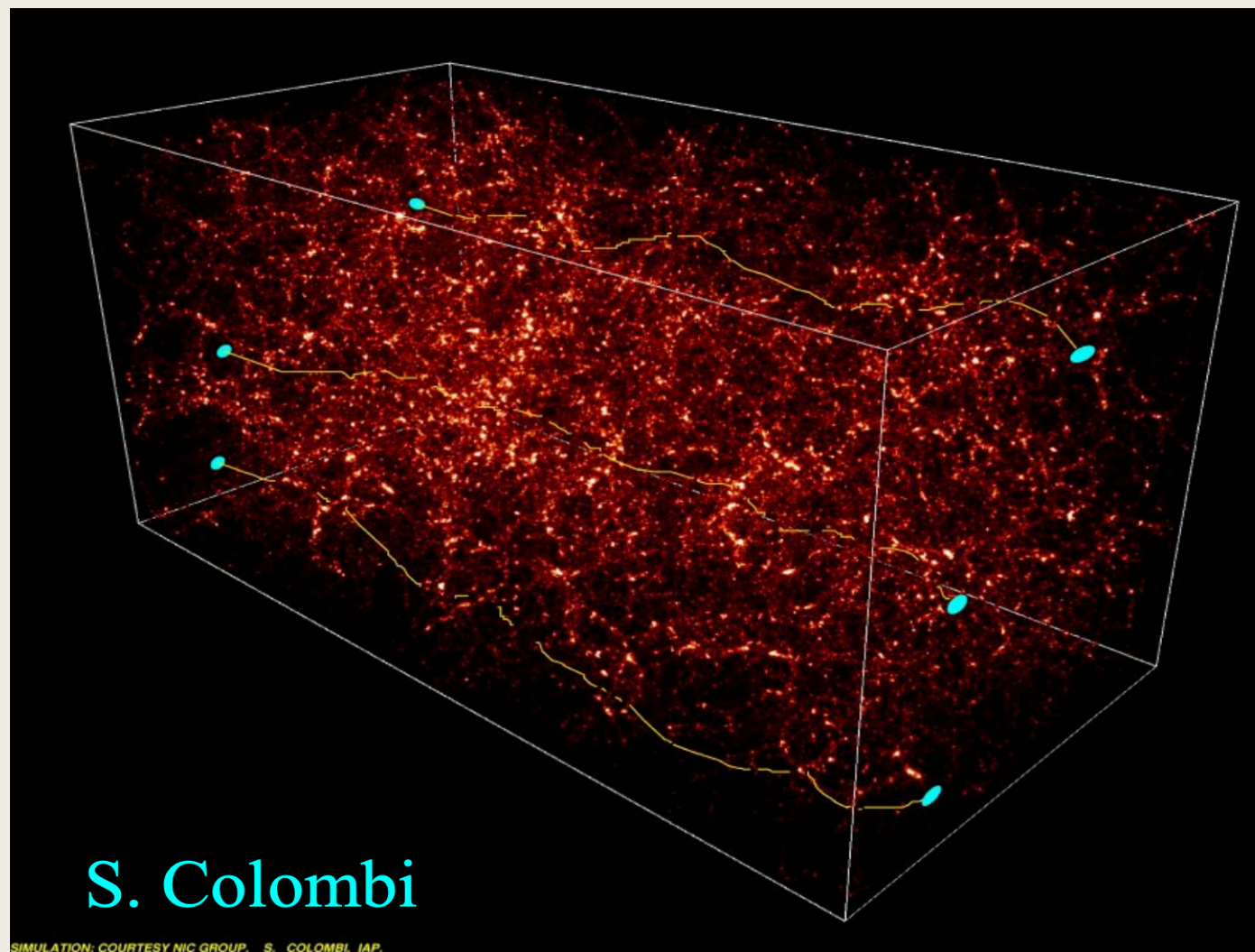
[Quijote, Villaescusa-Navarro et al 2019]



Intervening matter **deflects** light bundles and imprint shapes (shear)



[LSST science book]

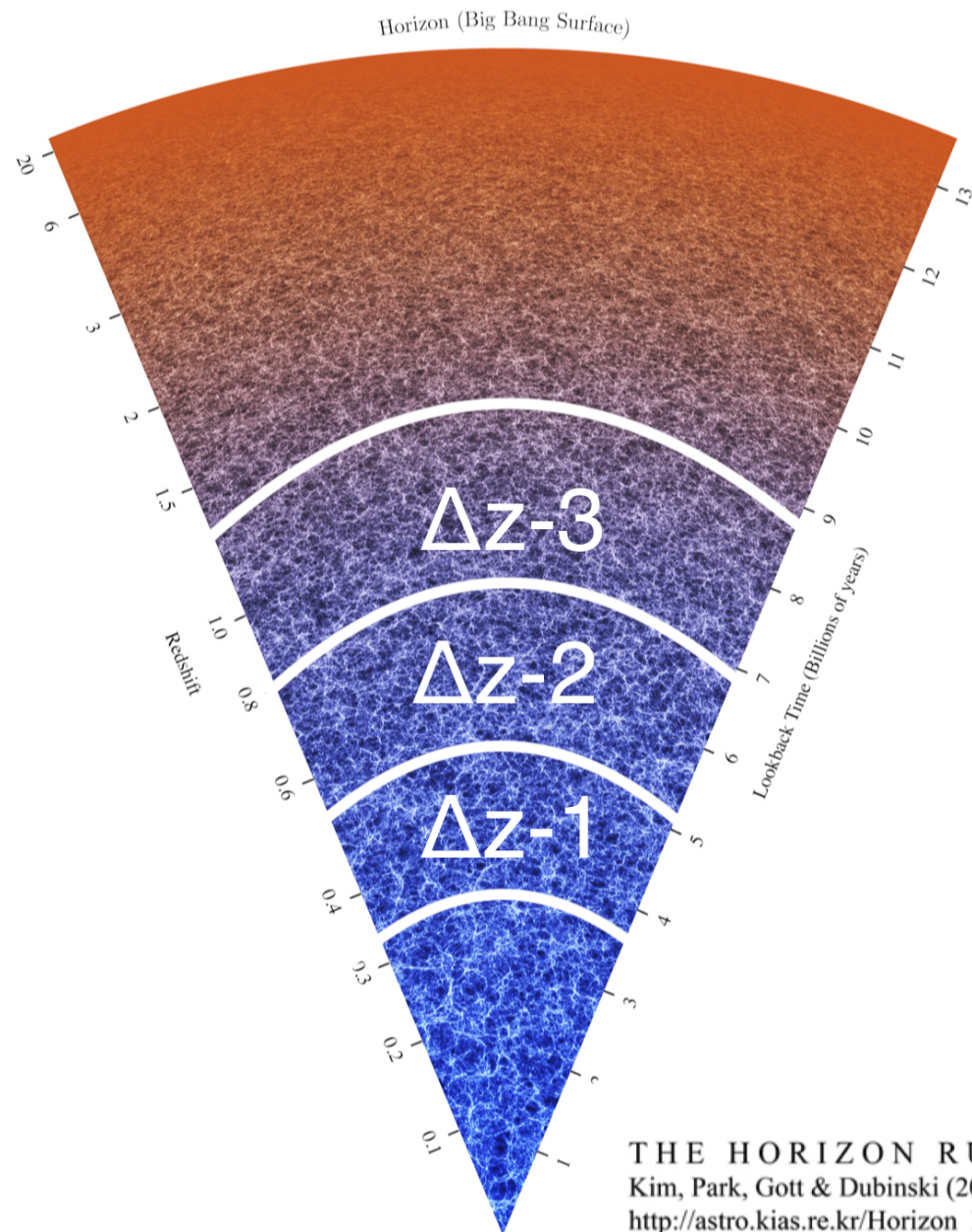


Matter clustering in the universe
as a function of Ω , Λ , h , ...



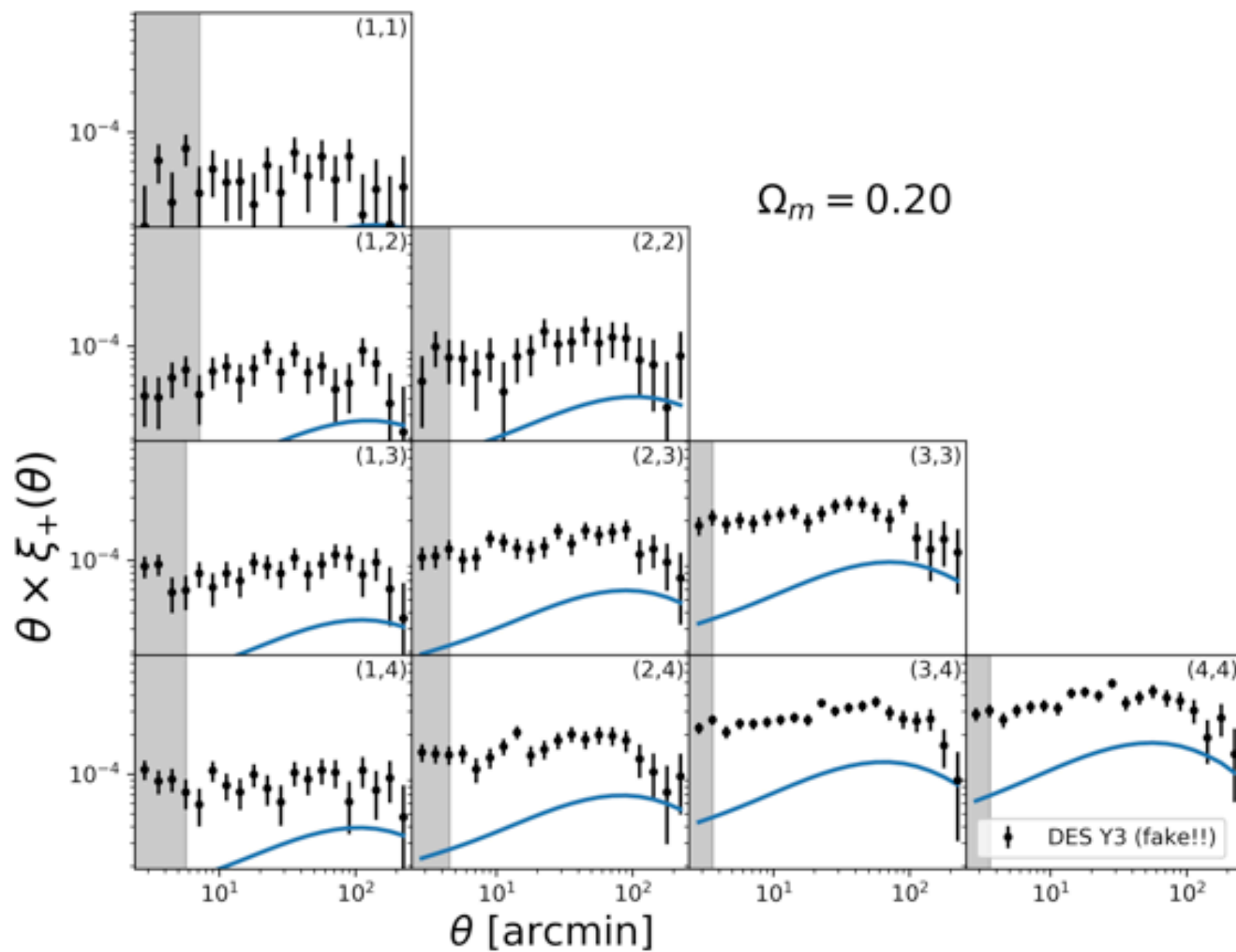
Galaxy shape correlations
as a function of Ω , Λ , h , ...

Make
measurements
tomographically

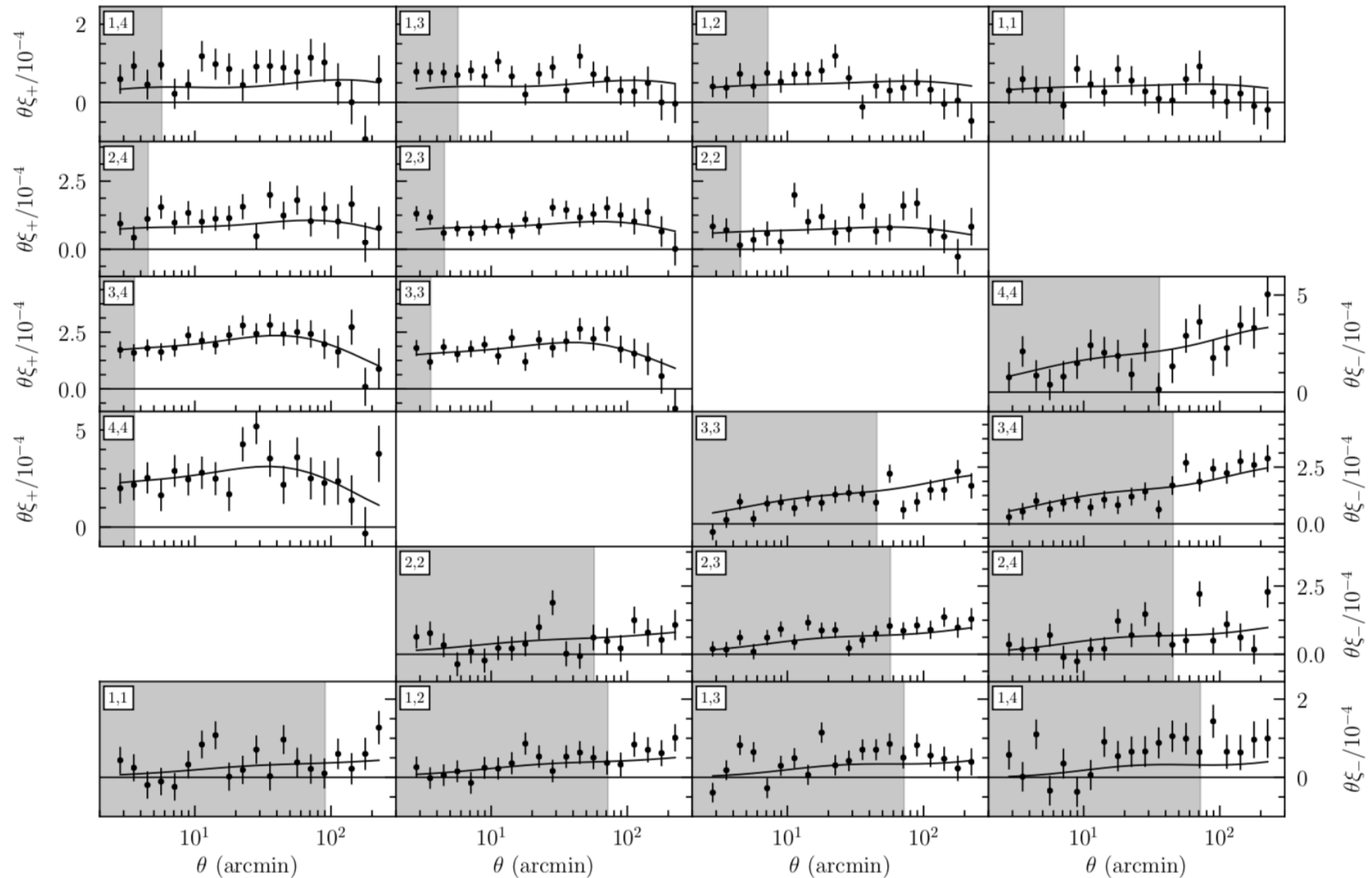


Distance ratios
contain information
[Hu 1999]

Cosmic shear as a function of Ω_m



Cosmic shear in DES-Y1



[Troxel, ..., LS et al 2018]

Cosmic shear in DES-Y1

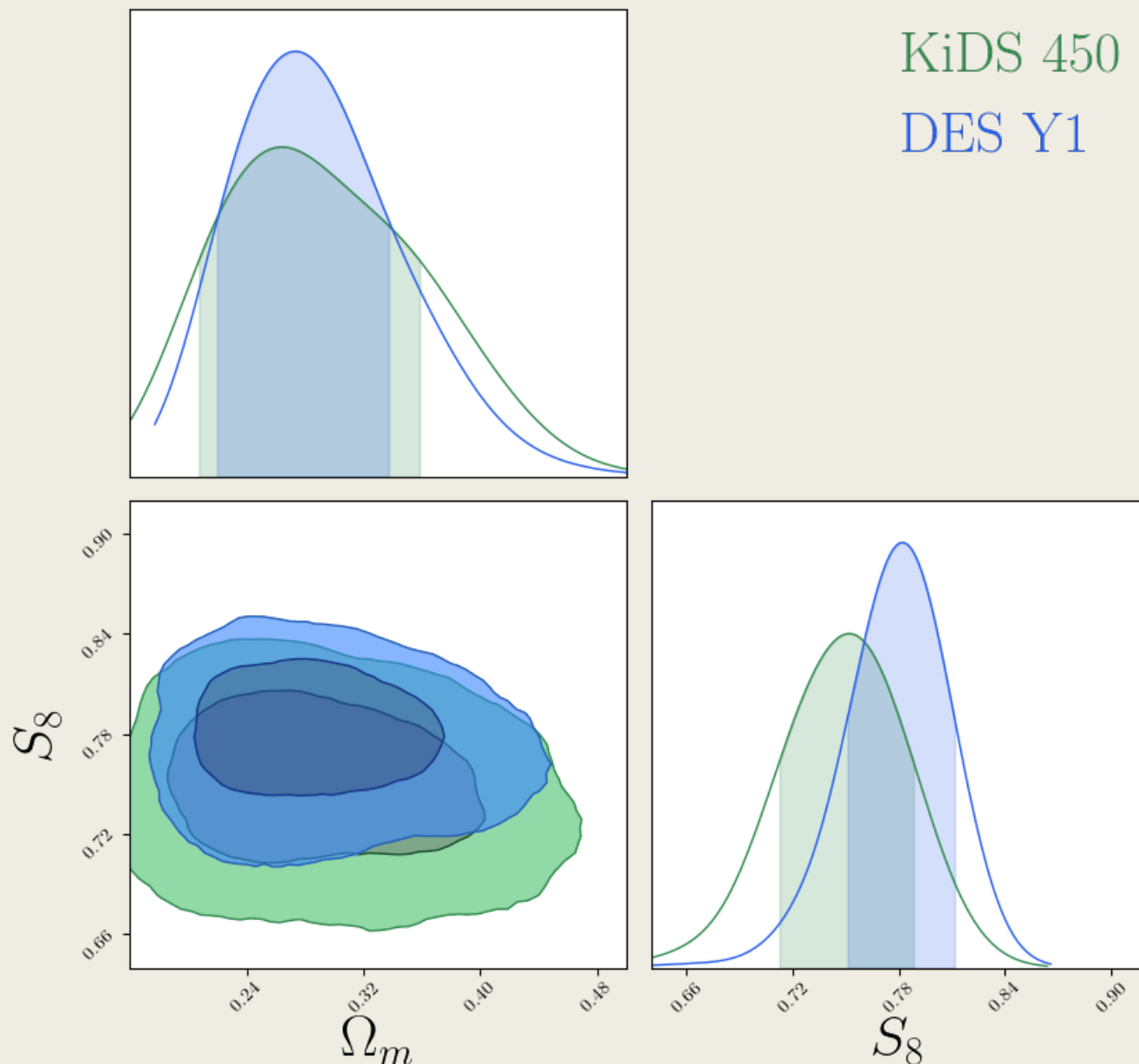
Cosmology = 6D (in Λ CDM)

Nuisance = 10+D

3.5% fractional uncertainty
in the amplitude of the
lensing signal (S_8)

$$\sigma_8(\Omega_m/0.3)^{0.5} = 0.782^{+0.027}_{-0.027}$$

Upcoming in Year-3:
a **3-fold increase**
in survey area



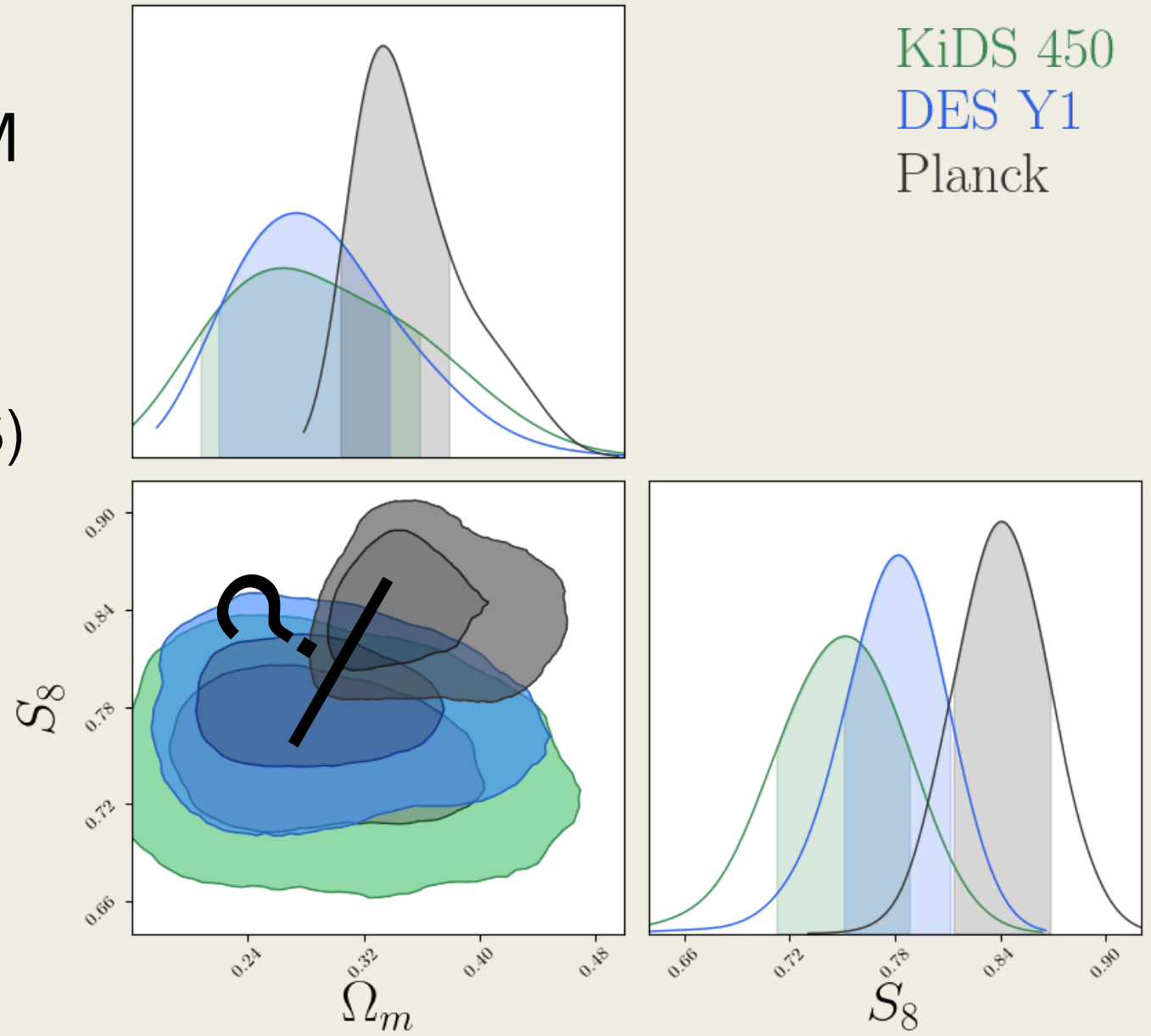
Cosmic shear in DES-Y1

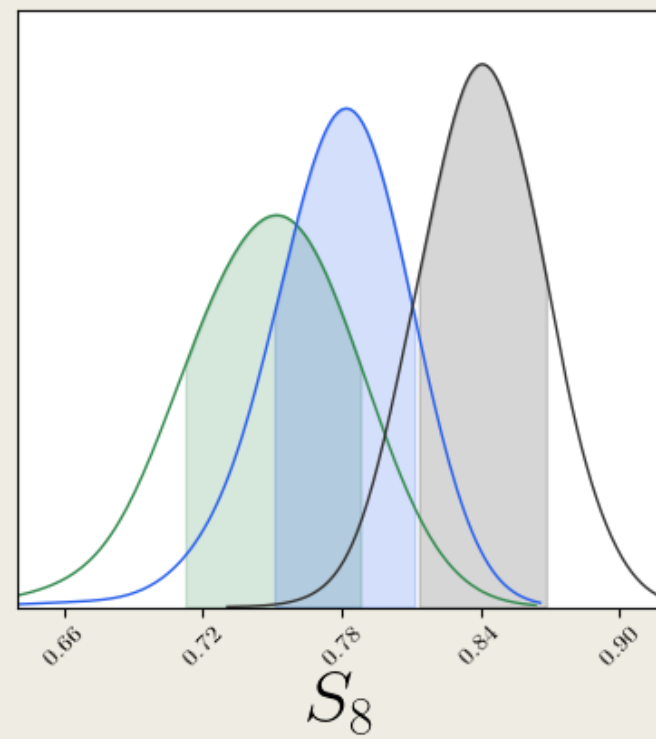
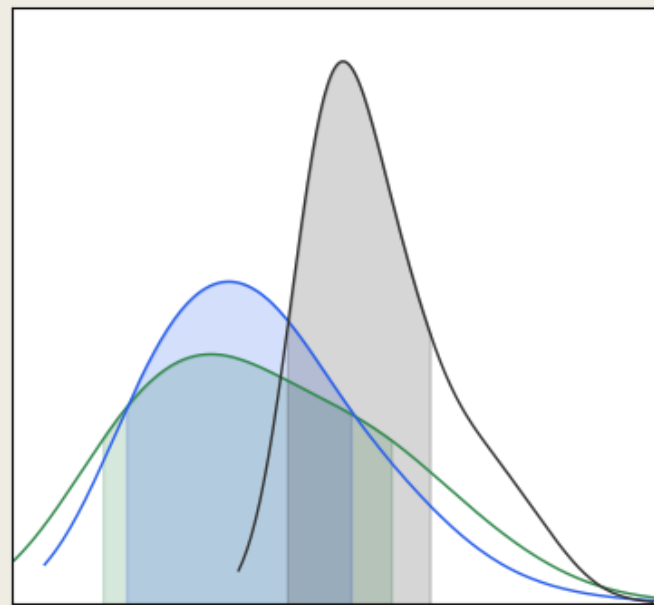
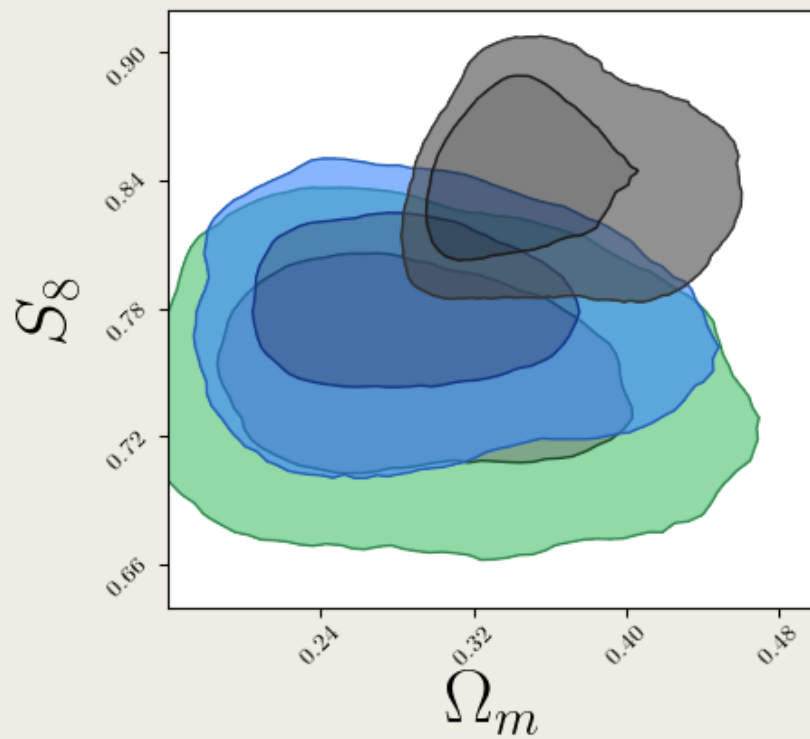
CMB vs. low-z probes:
an **end-to-end test** of Λ CDM

Also seen by other weak
lensing surveys (2.3σ in KiDS)

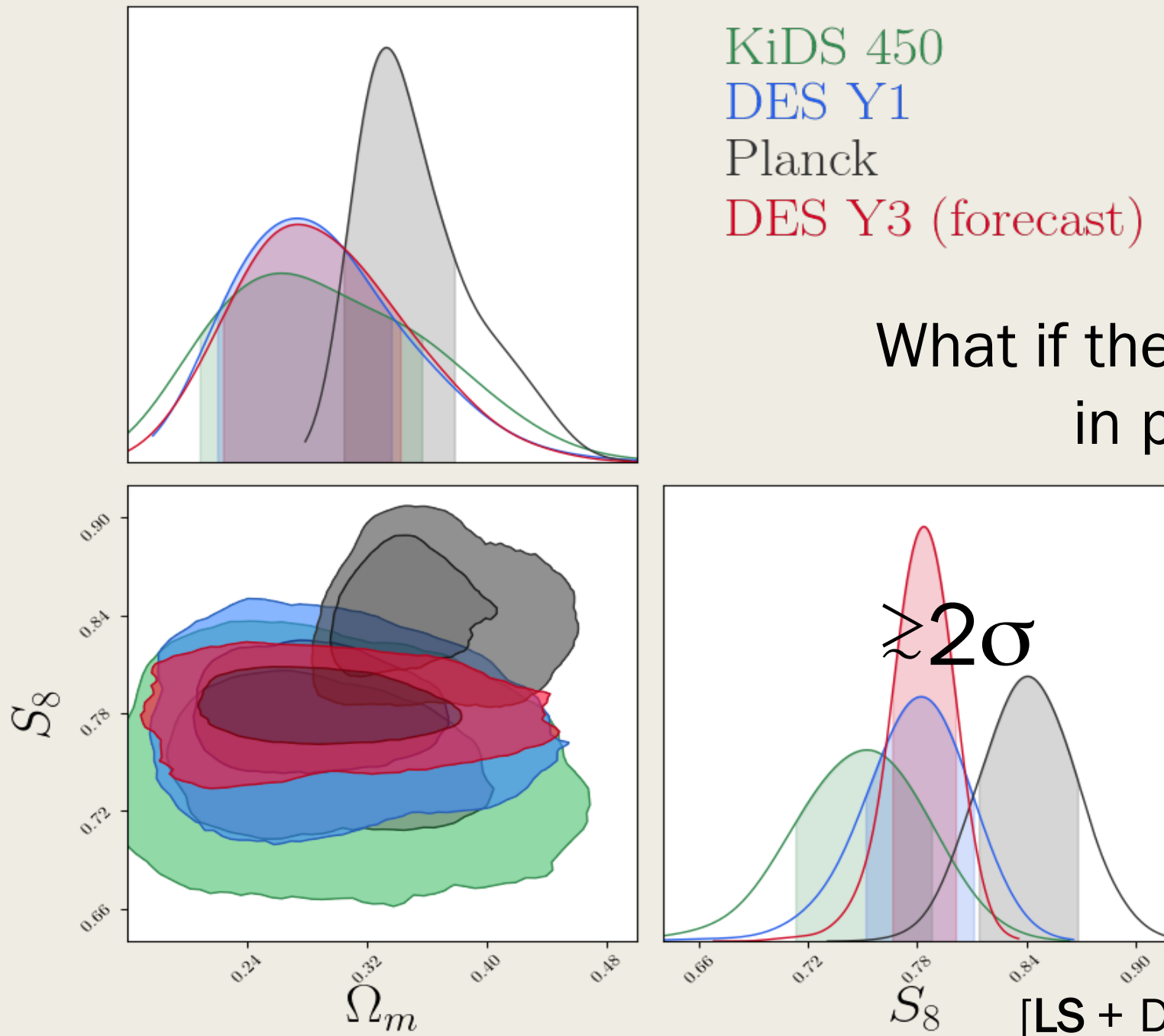
[Hildebrandt et al. (2018), Hikage et al.
(2019); Joudaki et al. (2017); Jee et al.
(2016)]

Could this become an
alarming discrepancy?





KiDS 450
DES Y1
Planck

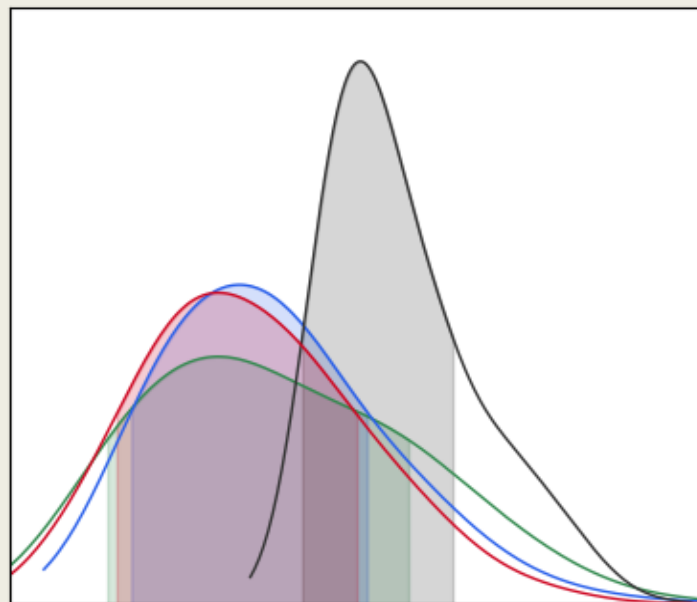


KiDS 450
DES Y1
Planck
DES Y3 (forecast)

What if the DES shrinks
in place?

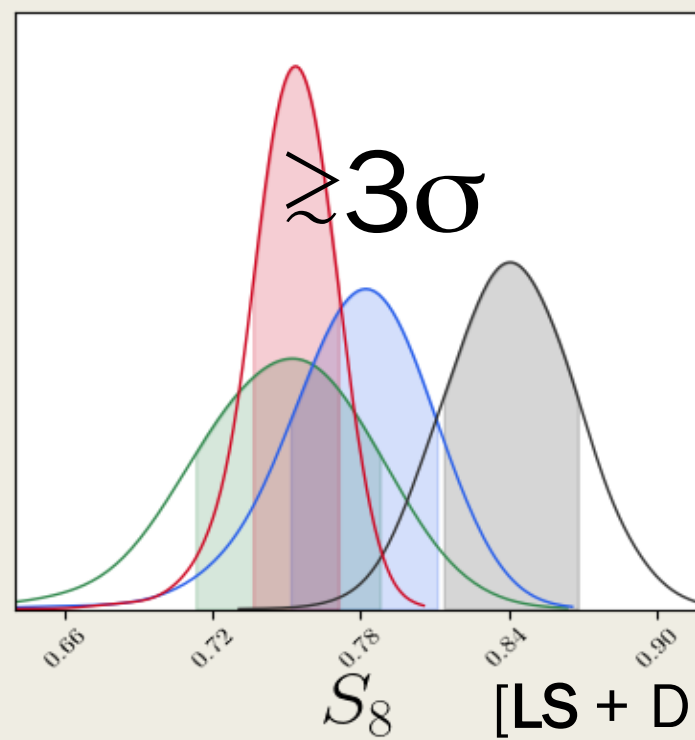
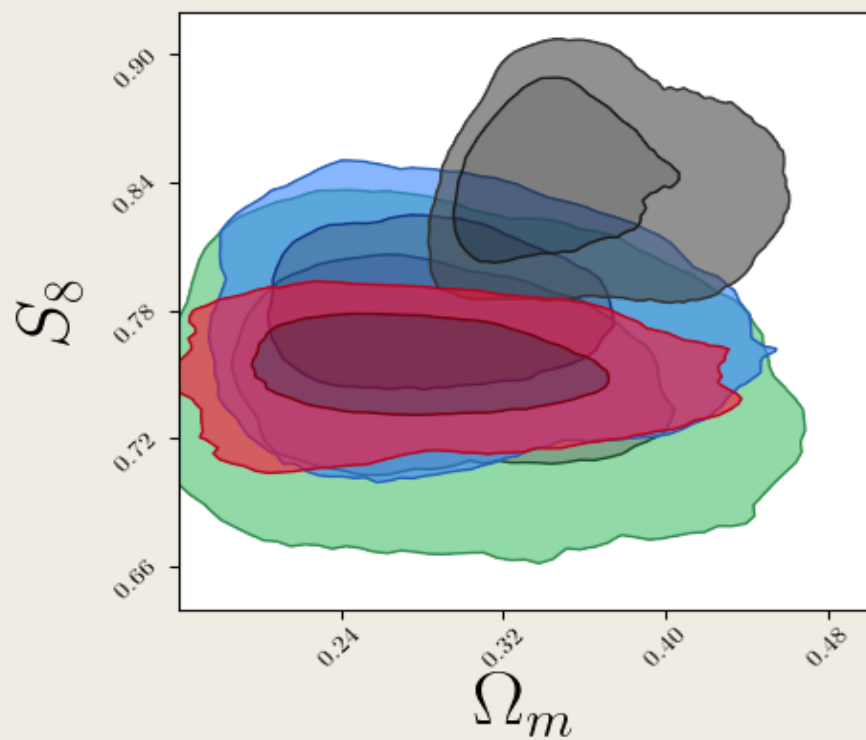
$\gtrsim 2\sigma$

[LS + DES et al. (in prep)]



KiDS 450
DES Y1
Planck
DES Y3 (forecast)

What if the DES shrinks
on KiDS?



[LS + DES et al. (in prep)]

Cosmic Shear Systematics

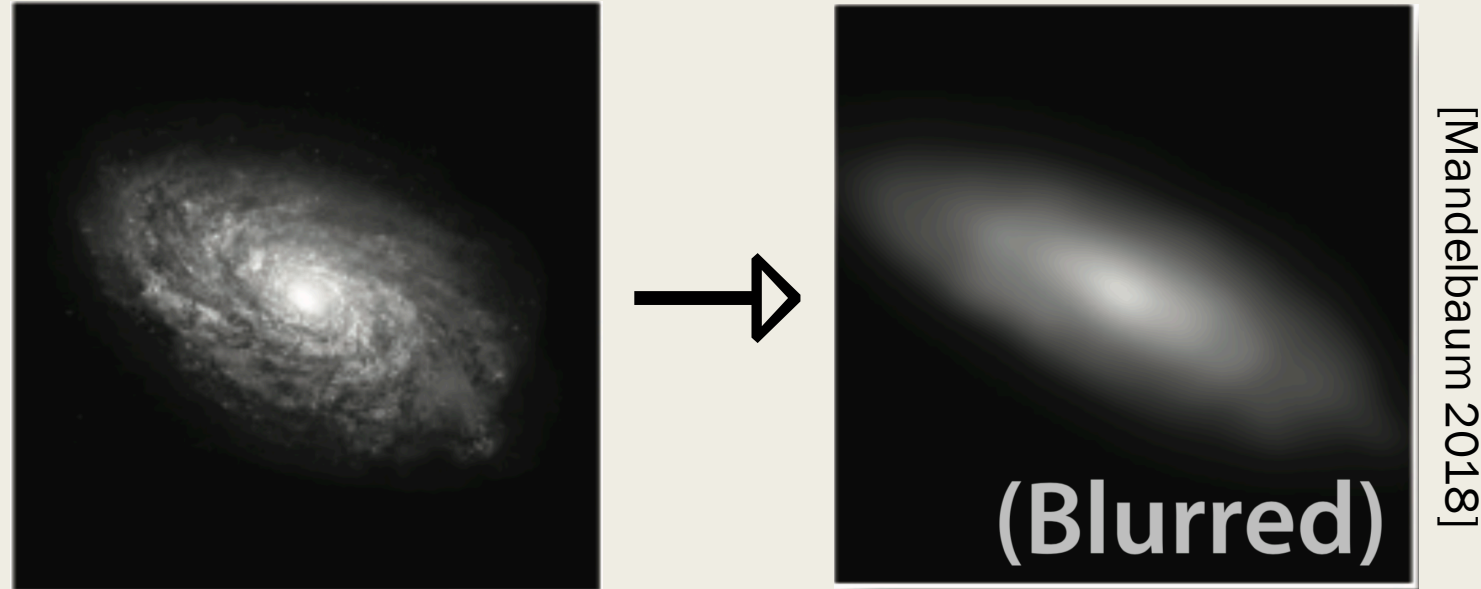
With great constraining power comes great responsibility:
we're currently testing for **shear systematics**

- 1) Generate synthetic 2pt data with some added complexity
- 2) With a likelihood model that does not include that added effect, obtain cosmological constraints

[Krause, ..., LS et al. 2018]

Is the model unbiased if there is extra complexity in the data?

Cosmic Shear Systematics: PSF modeling errors



PSFs are only known on stars, but we need to deconvolve them **from galaxies**

Using stars in the field, **interpolate** the PSF at the location of each a galaxy

Cosmic Shear Systematics: PSF modeling errors

To estimate whether the galaxy PSF is trustworthy, use **reserved stars** that did not go into the PSF modeling

[Rowe 2010, Jarvis et al 2016]

$$e^{gal} = \gamma + \delta e^{sys}$$

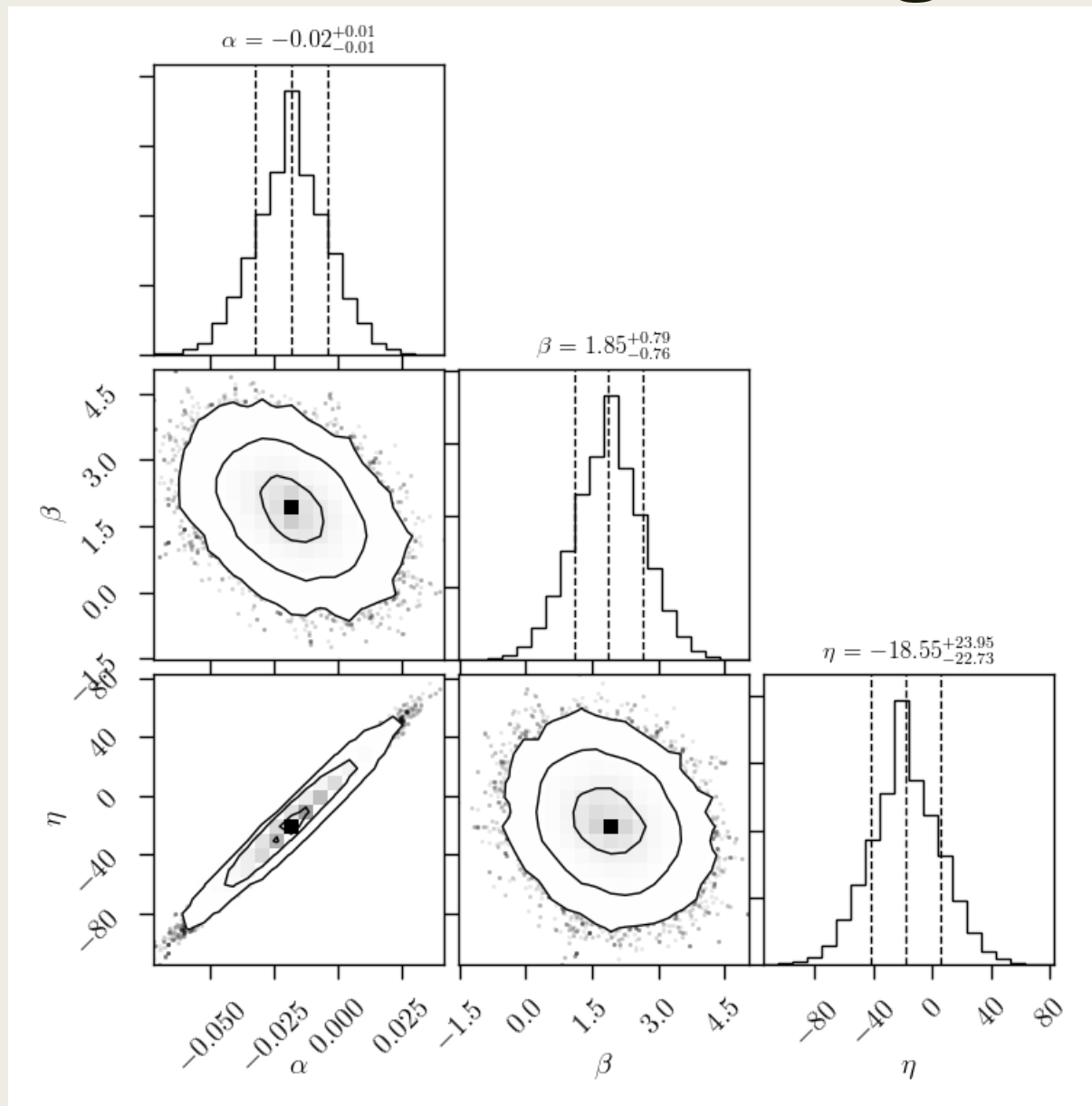
$$\delta e^{sys} = \alpha e^p + \beta \left(e^* - e^p \right) + \eta \left(e^p \frac{T^* - T^p}{T^*} \right)$$

Cosmic Shear Systematics: PSF modeling errors



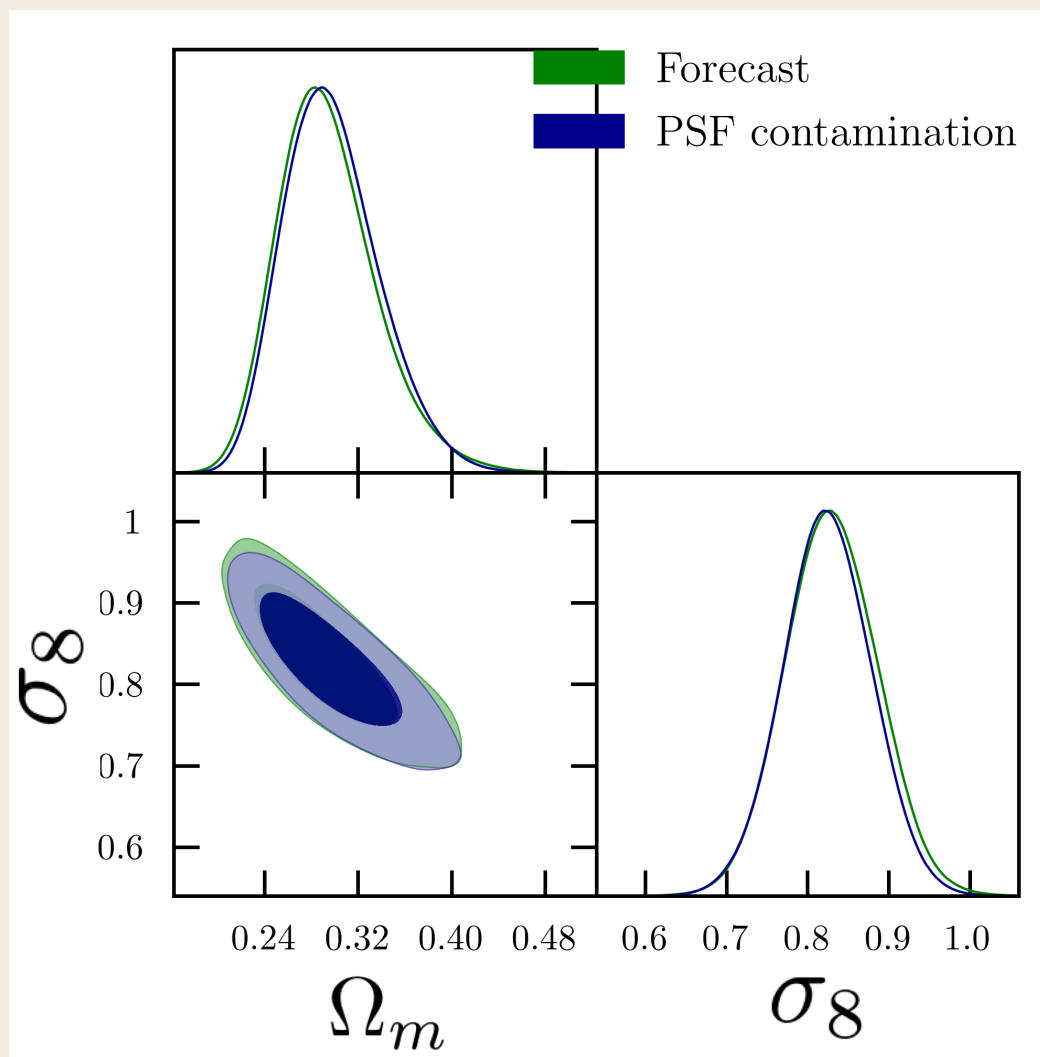
(w/ Andrés Alsina and the DES)

α, β, η
estimated from
cross-correlations



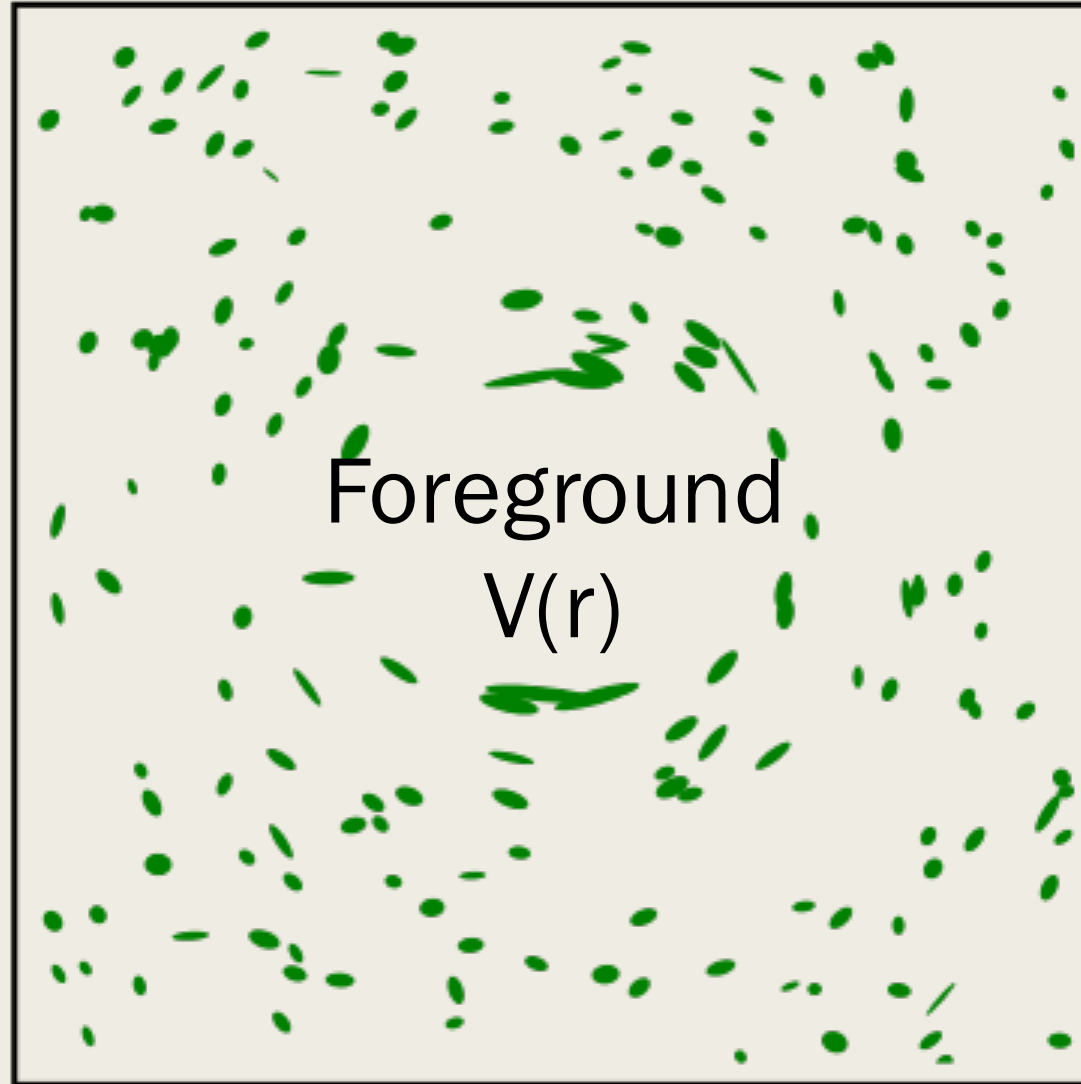
[Sheldon, ..., LS et al (in prep)]

Cosmic Shear Systematics: PSF modeling errors



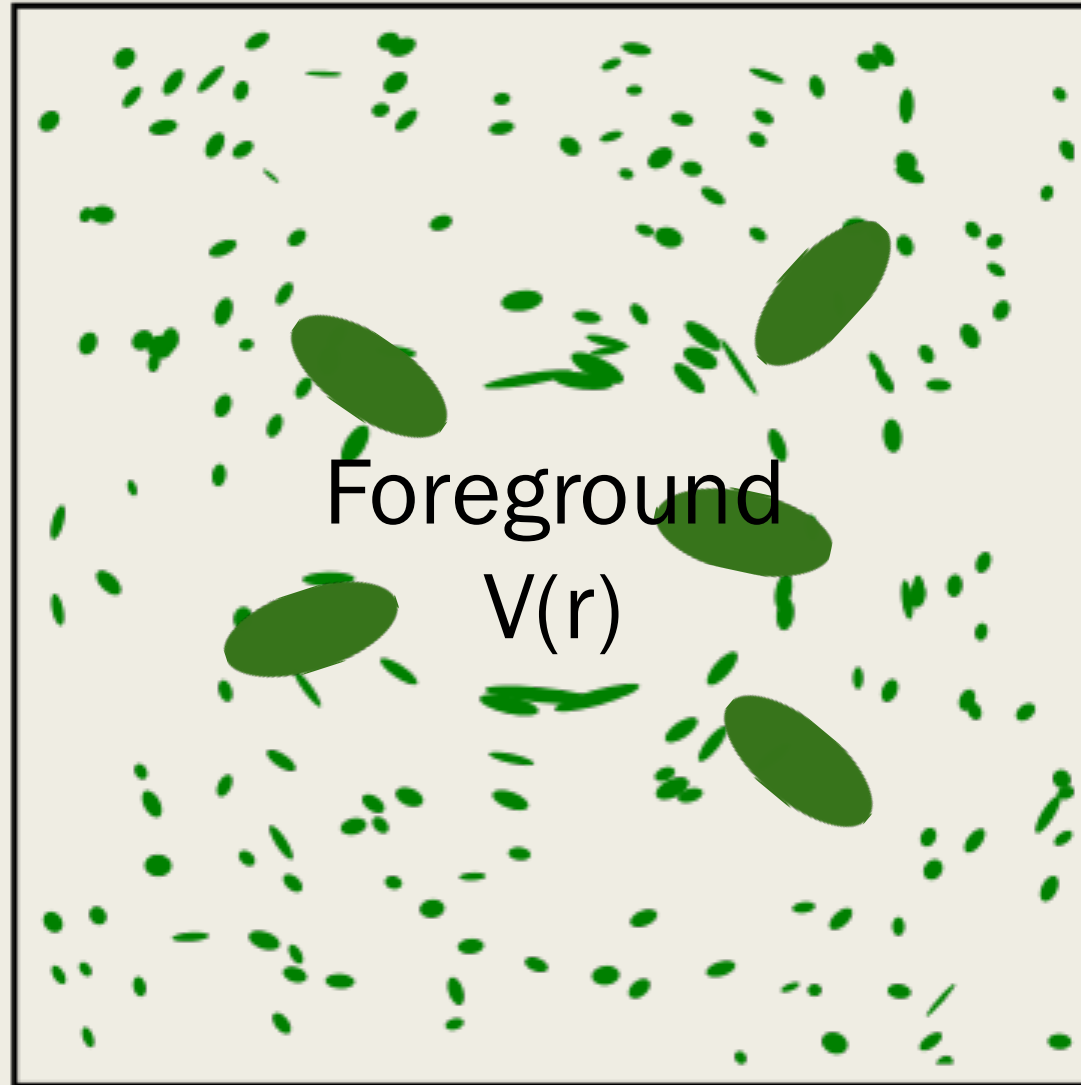
Can **PSF modeling errors** impact cosmology in DES-Y3? **No.**

Cosmic Shear Systematics: Intrinsic Alignments



Cosmic Shear Systematics: Intrinsic Alignments

Galaxies
respond to the
tidal potential
around to
them



To linear order,
the effect
opposes the
GR shear

[Catelan et al 2001]

Cosmic Shear Systematics: Intrinsic Alignments

The widely used model for IA: **linear** in the tidal field with a nonlinear power spectrum (NLA)

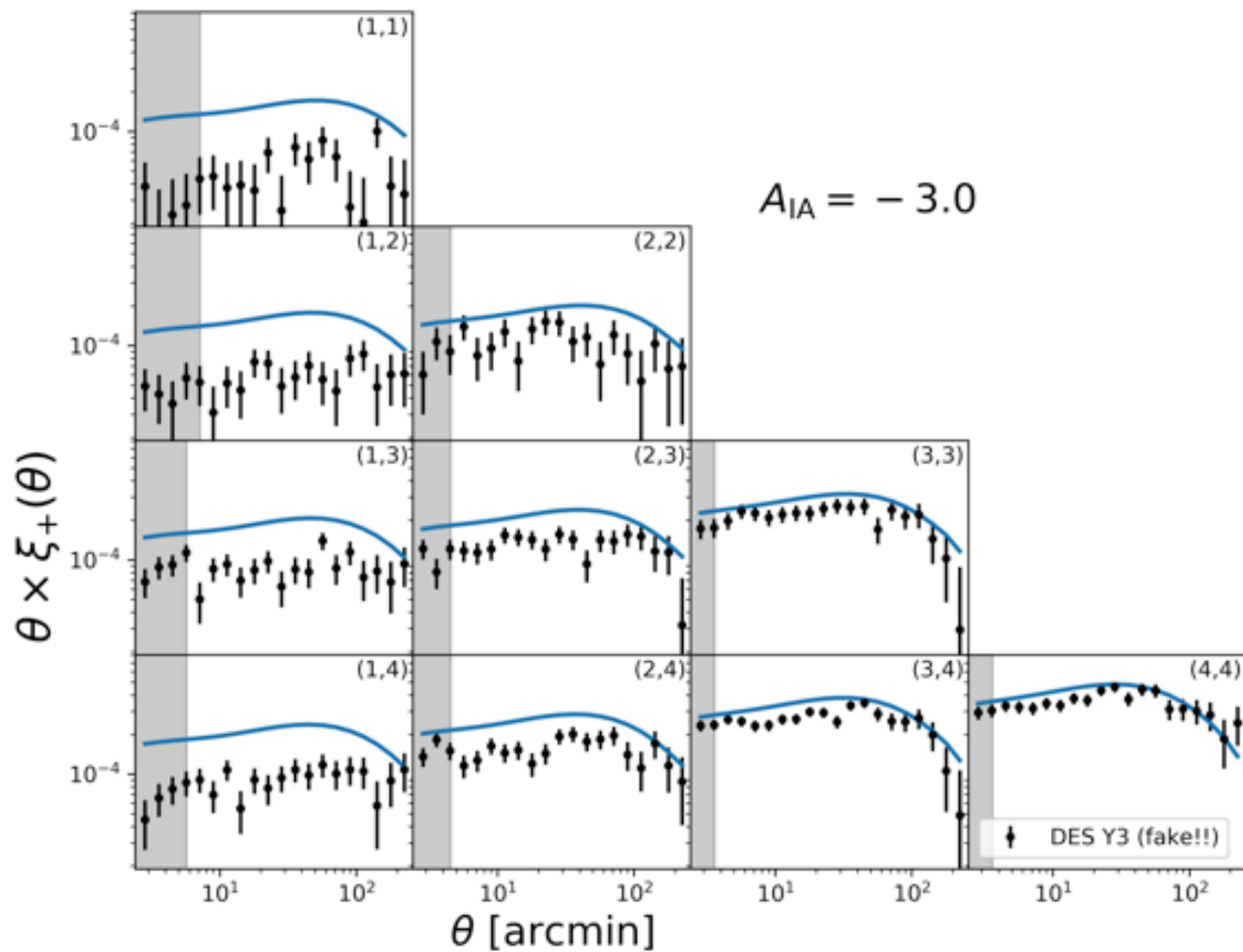
[Catelan et al 2001; Hirata & Seljak 2004]

$$\gamma = \gamma_G + \gamma_I$$

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

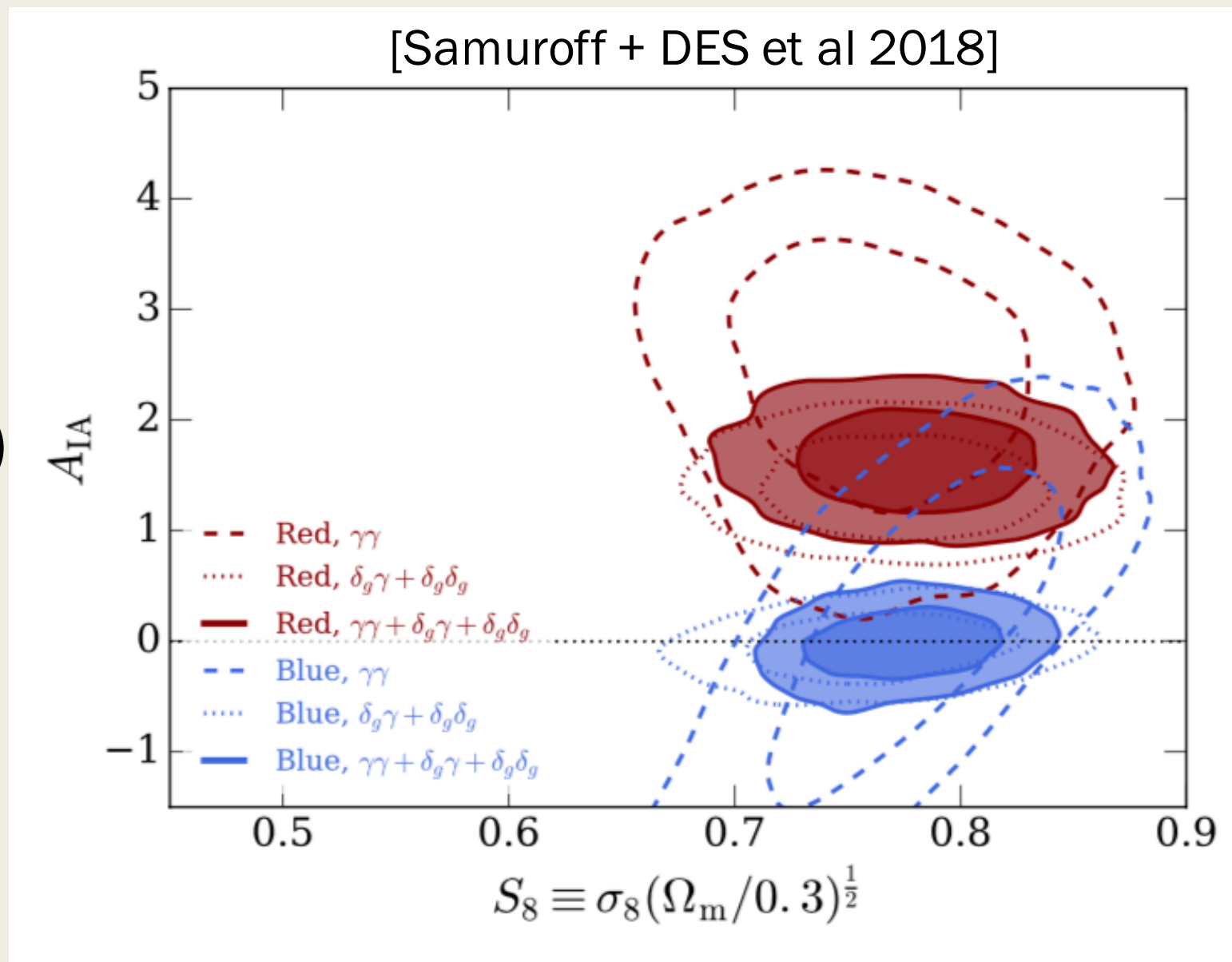
$$q_{\kappa}^i(\chi) \longrightarrow q_{\kappa}^i(\chi) - A(z(\chi)) \frac{n_{\kappa}^i(z(\chi))}{\bar{n}_{\kappa}^i} \frac{dz}{d\chi}$$

Cosmic shear as a function of IA amplitude



Cosmic Shear Systematics: Intrinsic Alignments

However, ~80% of weak lensing samples (late-type) are **not well described** by this tidal framework (“NLA”)



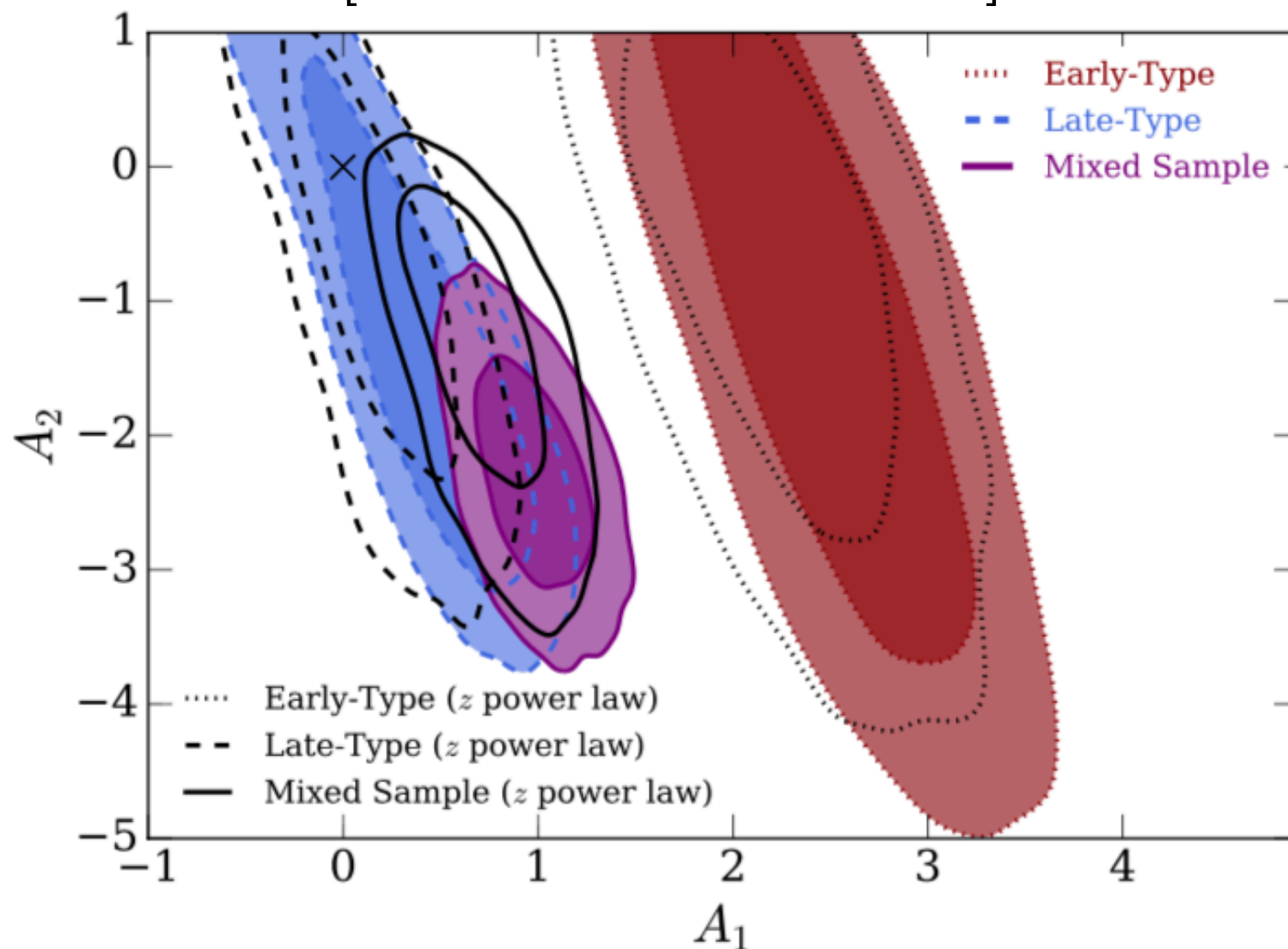
Cosmic Shear Systematics: Intrinsic Alignments

[Samuroff + DES et al 2018]

Incorporate the orientation of late-types

(e.g. Chisari et al 2015)
with a model that
accounts for **tidal
torquing** (“TATT”)

[Blazek et al 2017]



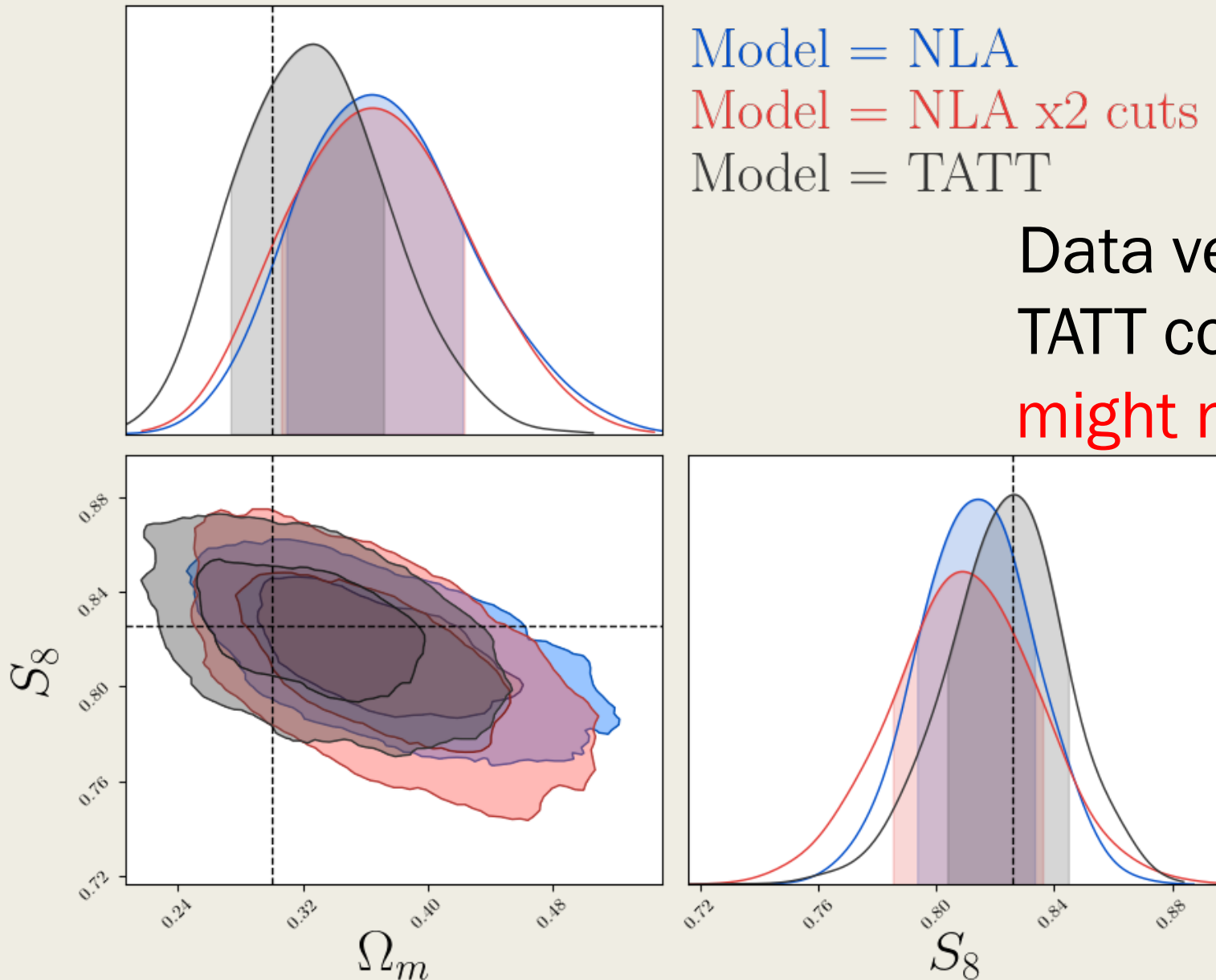
Cosmic Shear Systematics: Intrinsic Alignments

Model = NLA

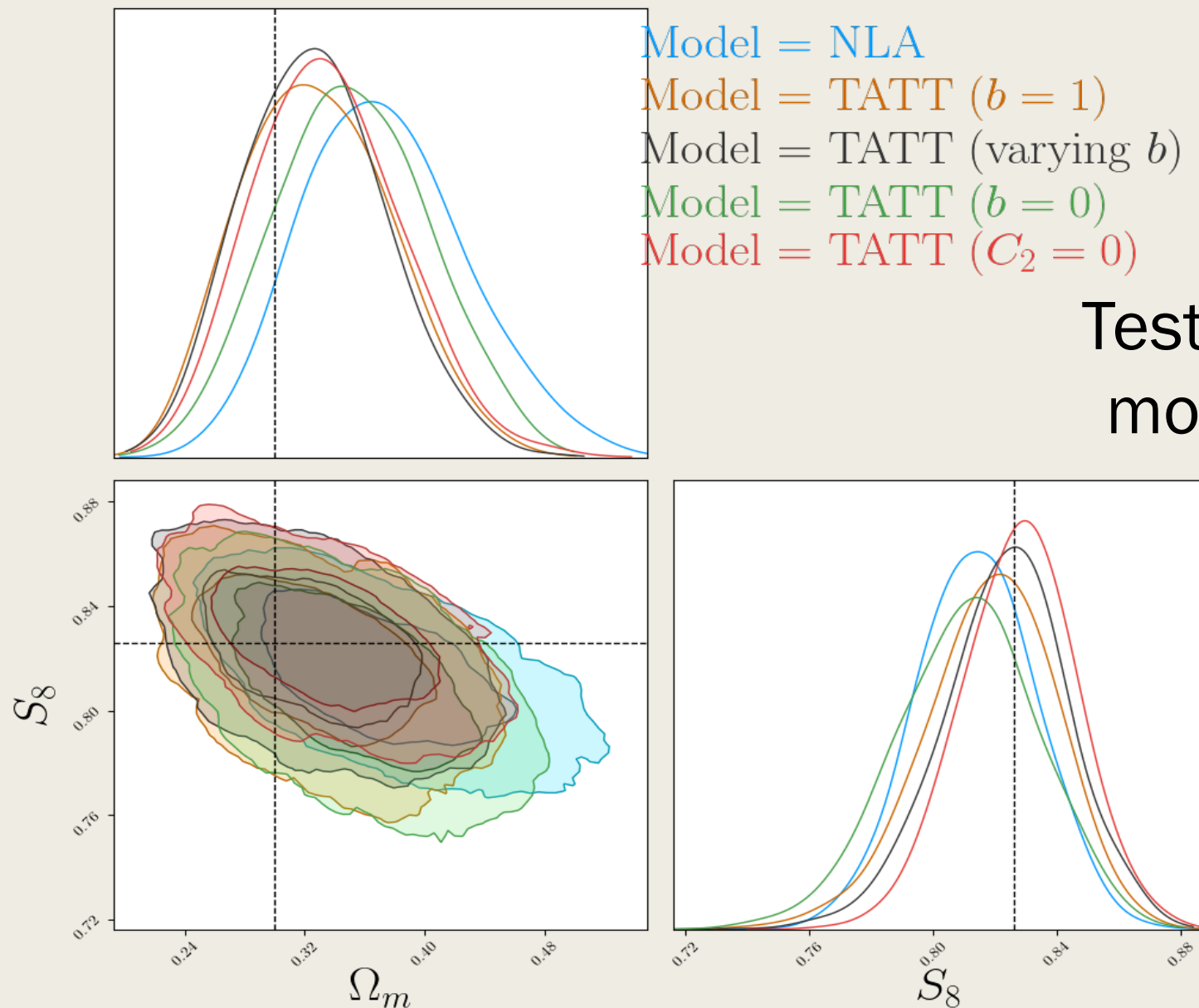
Model = NLA x2 cuts

Model = TATT

Data vector includes a
TATT contribution, NLA
might not be unbiased



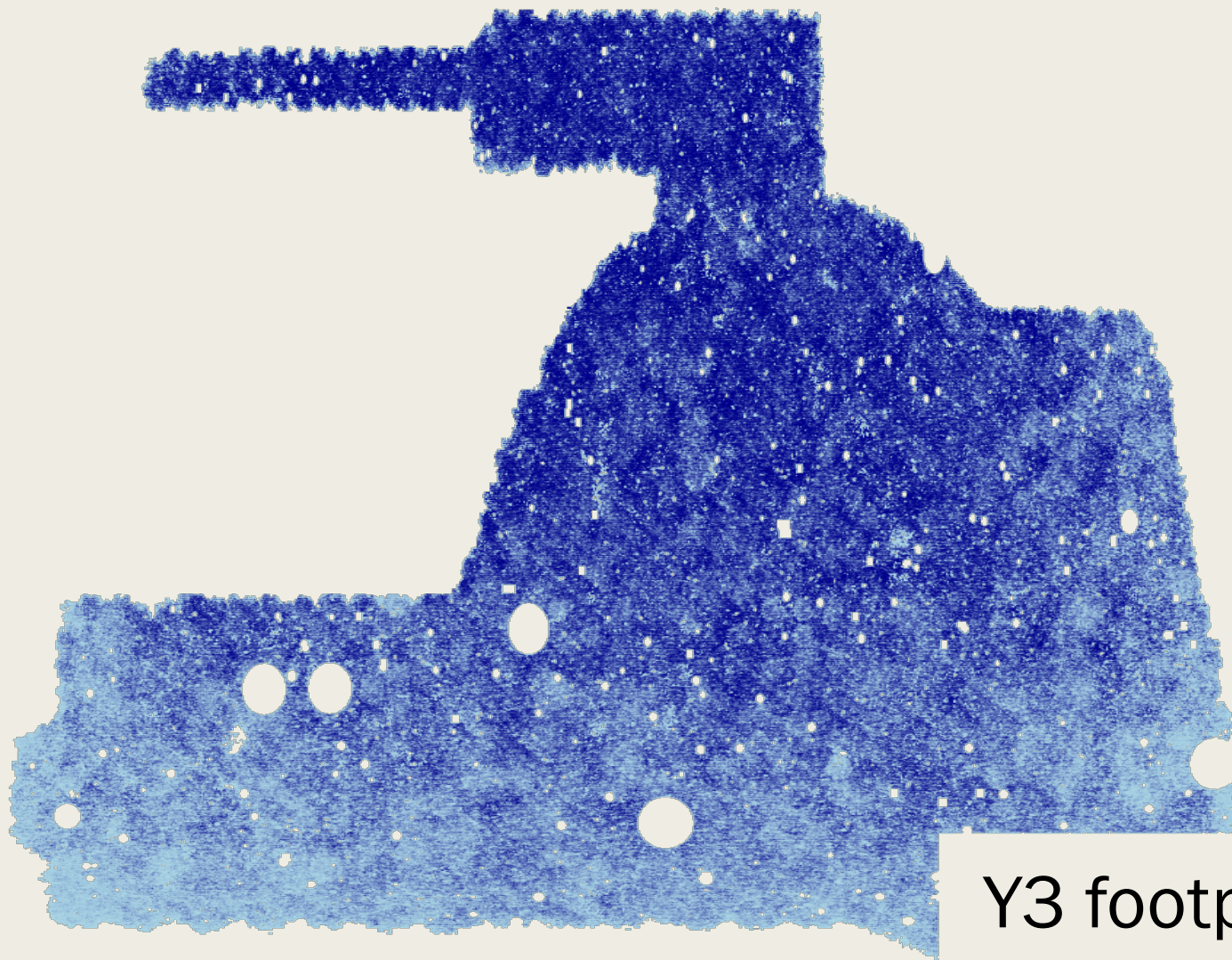
Cosmic Shear Systematics: Intrinsic Alignments



Summarizing

- DES-Y3 **cosmic shear** will have unprecedented constraining power
 - “Systematics” is the name of the game:
 - *PSF errors? No worries, the model is good*
 - *Intrinsic alignments? Tests underway*
 - *Many other effects being tested!*

What else can you do with the largest weak lensing catalog to date?



Y3 footprint

How about looking for 3pt correlations on data?

(with Mike Jarvis, Bhuv Jain @ Penn)

Vast literature on the matter & lensing Bispectrum

The B/P ratio can help break cosmological degeneracies

$$\frac{B(\mathbf{k}_1, \mathbf{k}_2, \mathbf{k}_3)}{P(k_1)P(k_2) + P(k_2)P(k_3) + P(k_3)P(k_1)} \sim \frac{1}{\Omega_m}$$

[Bernardeau et al. 1997]

Primordial non-gaussianities? Neutrino masses? ...

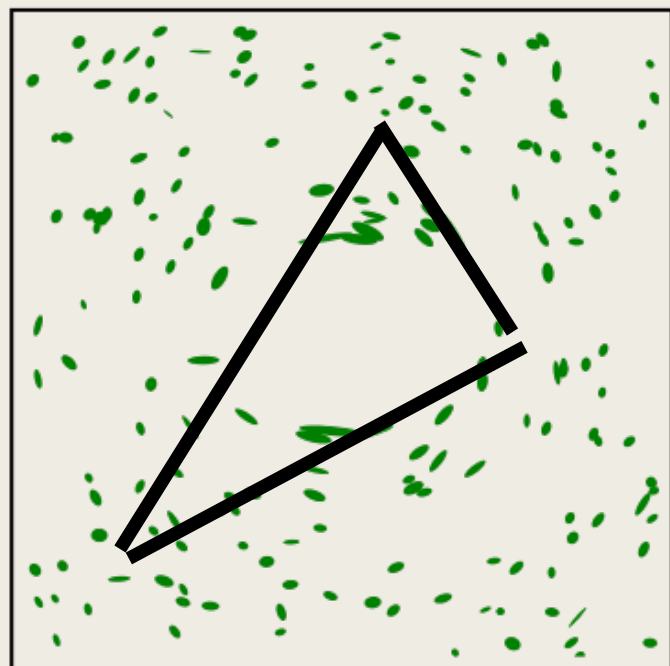
Wide applications!

How about looking for 3pt correlations on data?

(with Mike Jarvis, Bhuv Jain @ Penn)

1) Computationally expensive: is it feasible?

2) $\langle \gamma\gamma\gamma \rangle$ has 8 total independent components, do you know where to find the signal?



3) Is there a way to “compress” the information?

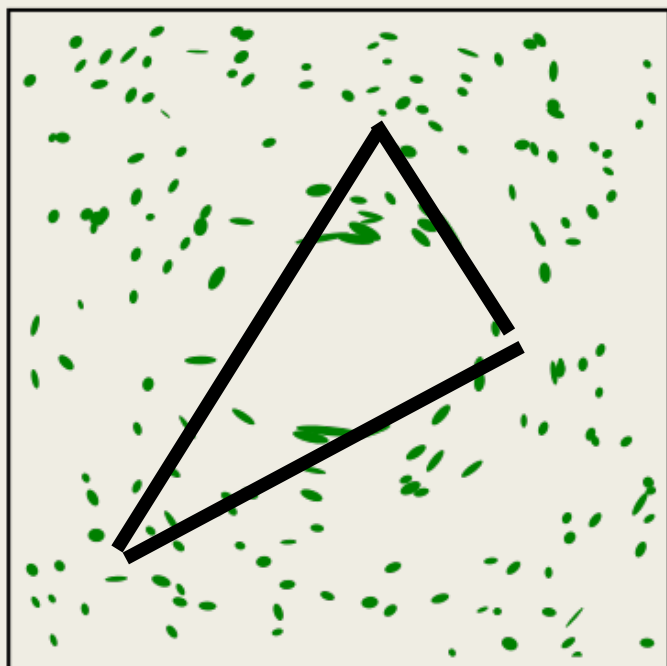
4) Do you even have enough S/N?

How about looking for 3pt correlations on data?

(with Mike Jarvis, Bhuv Jain @ Penn)

1) Computationally expensive: is it feasible? **YES**

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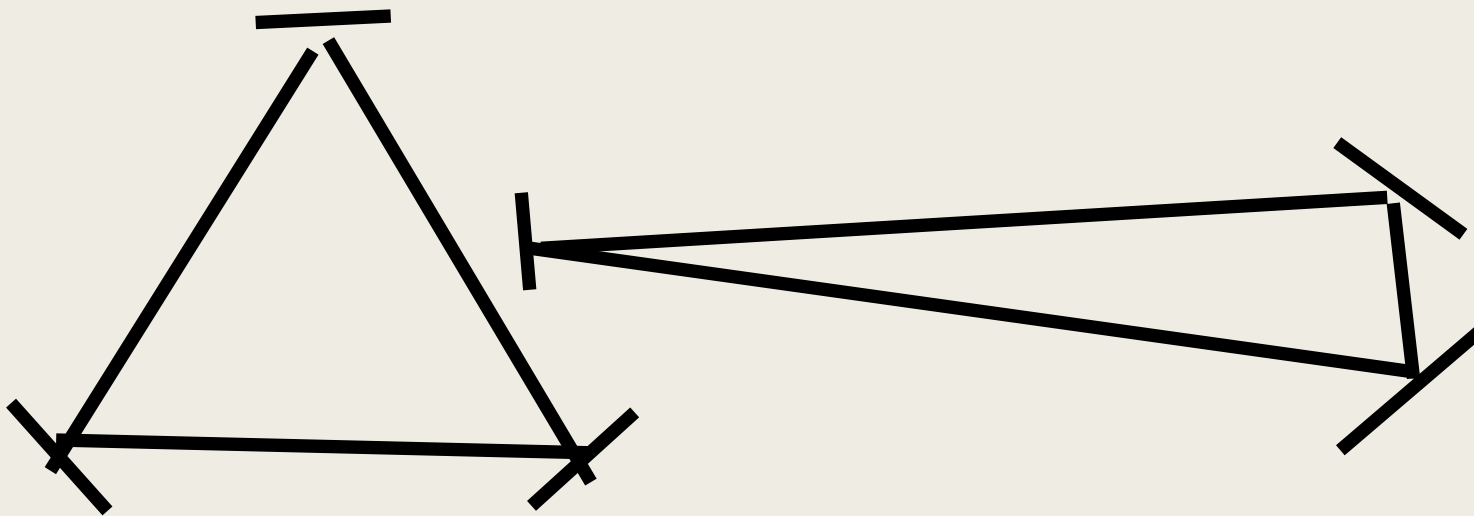
3) Is there a way to “compress” the information? **YES**

4) Do you even have enough S/N?
YES!

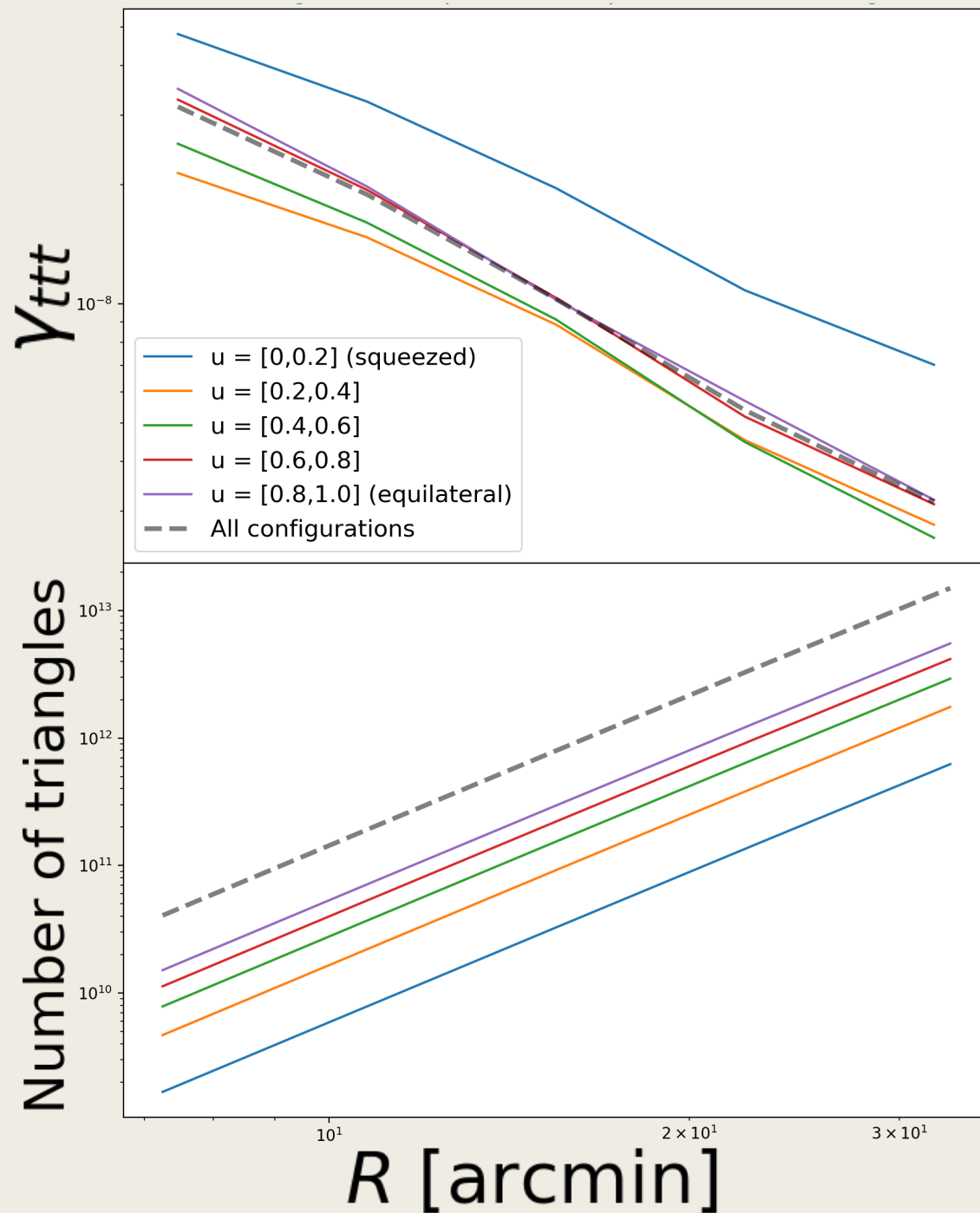
Detecting shear-3pt

1) Efficient code: Treecorr (<https://github.com/rmjarvis/TreeCorr>)

2) Look first at the projection, **triangle configuration** and scales where most of the signal should be: [Takada & Jain 2003]



In the shape noise regime, triangle **counts** will also affect the actual S/N



Tests on noiseless simulations

[Fosalba et al 2015]

Solution:

combine configurations
(sacrifices configuration sensitivity, but compresses the signal)

Detecting shear-3pt

- 3) Collect more triangles by looking at the 3rd moment of the **Mass Aperture** (Map)

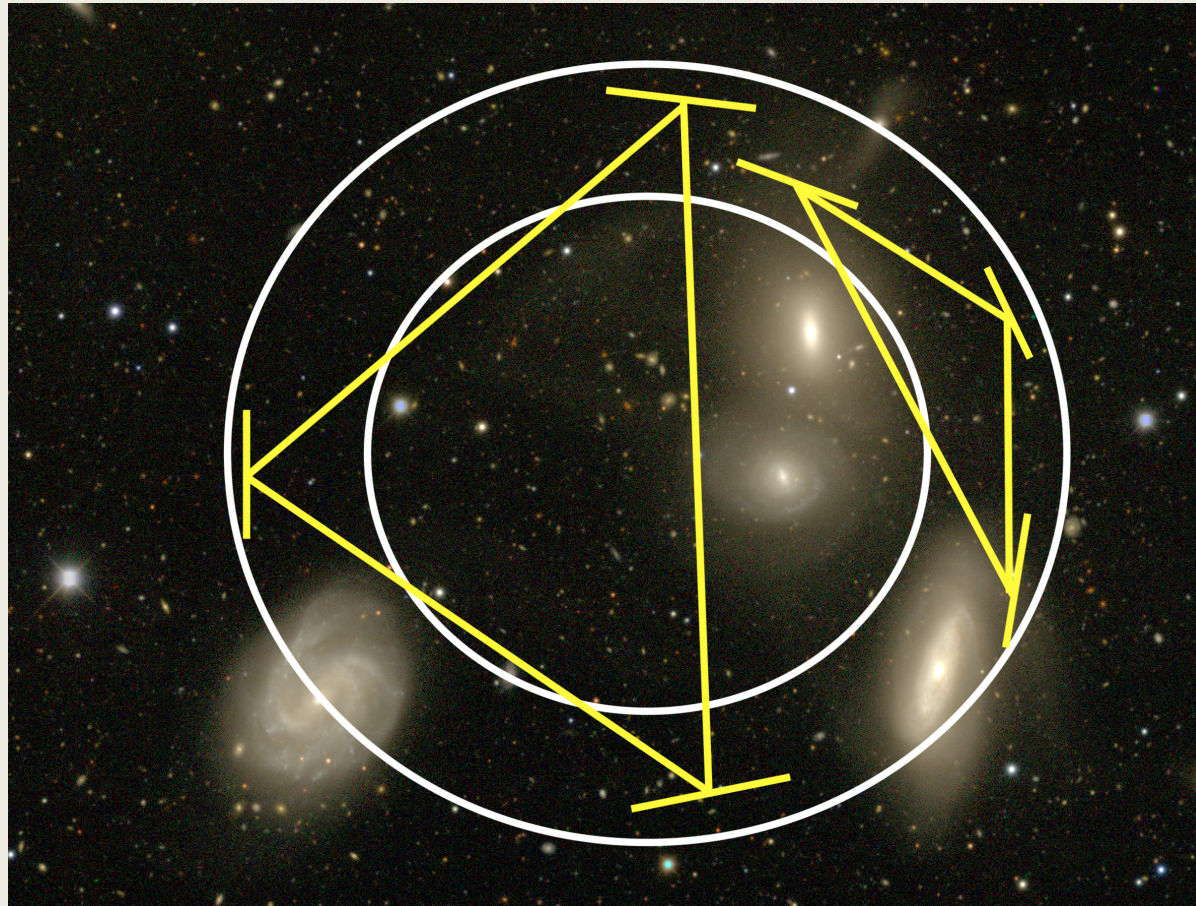
$$\langle M_{\text{ap}}^2 \rangle (\theta) = \int_0^\infty d\ell \ell P_\kappa(\ell) \times W(\ell\theta)$$

$$\langle M_{\text{ap}}^2 \rangle (\theta) = \frac{1}{2} \int ds \frac{s}{\theta^2} \left[\xi_+(s) T_+ \left(\frac{s}{\theta} \right) + \xi_-(s) T_- \left(\frac{s}{\theta} \right) \right]$$

3pt version: [Jarvis, Bernstein, Jain 2004]

Detecting shear-3pt

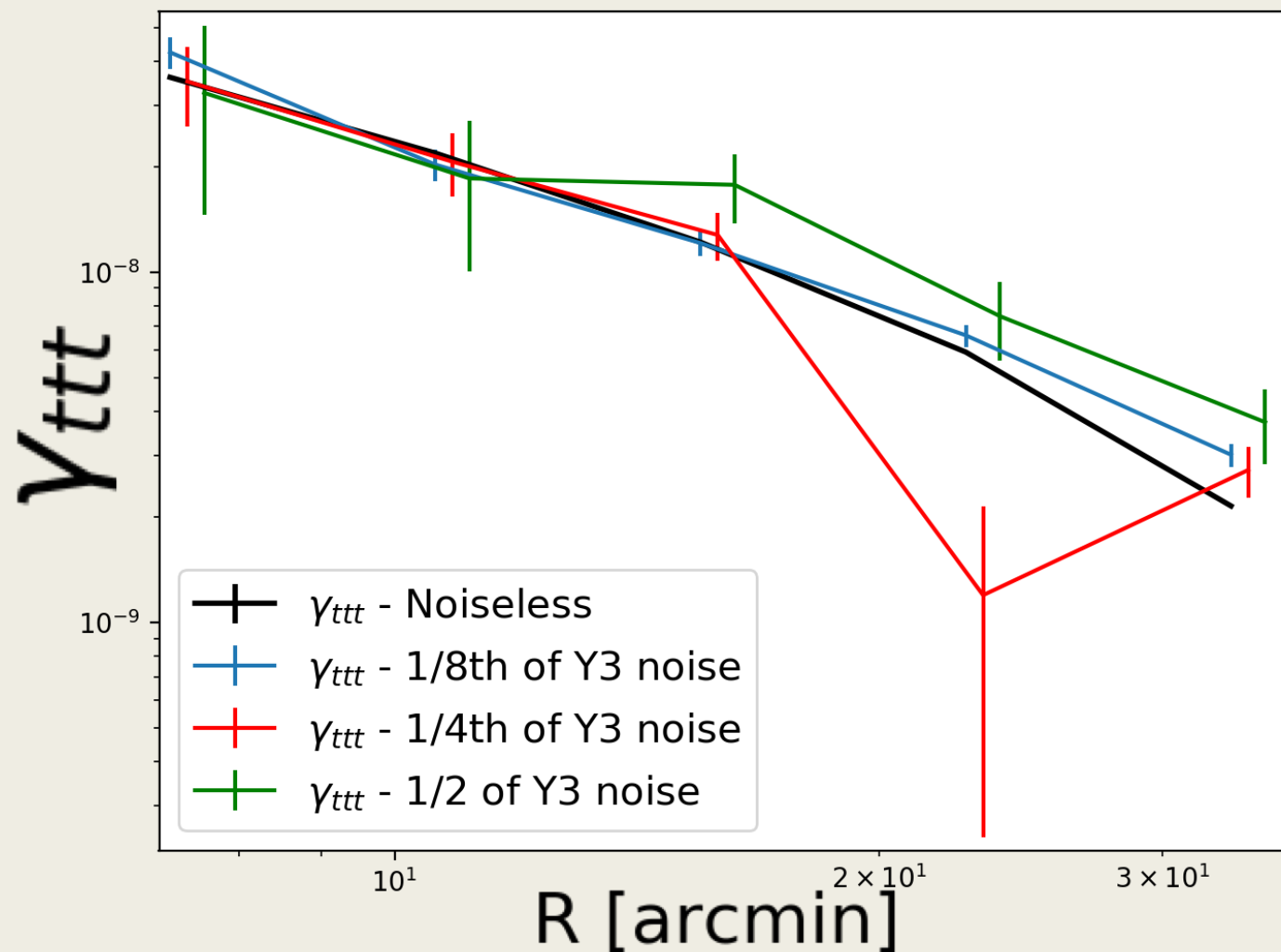
3) Collect more triangles by looking at the 3rd moment of the **Mass Aperture** (Map)



Detecting shear-3pt

4) Tests with N-body sims

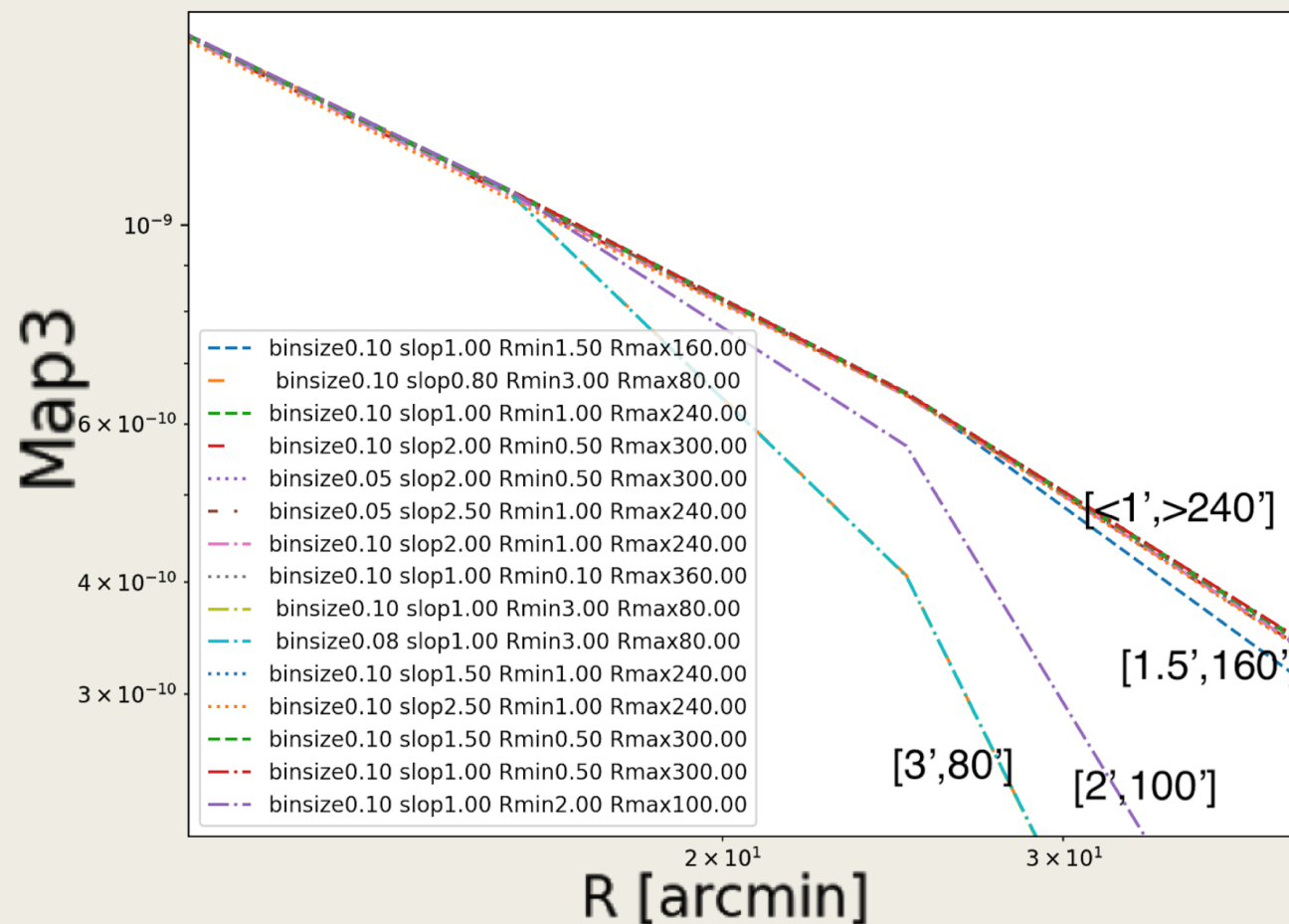
Start from the noiseless shears (pure gravity), crank up the **noise** to match DES-Y3



Detecting shear-3pt

4) Tests with N-body sims

Test binning schemes,
estimator configurations
for $\langle \text{Map}^3 \rangle$



Detecting shear-3pt

Based on N-body sims, the detection significance in DES-Y3 is:

Detecting shear-3pt

Based on N-body sims, the detection significance in DES-Y3 is:

$$\langle \gamma\gamma\gamma \rangle \gtrsim 4\sigma$$

$$\langle \text{Map}^3 \rangle \gtrsim 9\sigma$$

Detecting shear-3pt

Based on N-body sims, the detection significance in DES-Y3 is:

$$\langle \gamma\gamma\gamma \rangle \gtrsim 4\sigma$$

$$\langle \text{Map}^3 \rangle \gtrsim 9\sigma$$

Confirmed on data with preliminary shape catalogs

[LS + DES et al. (in prep)]

Summarizing

- DES-Y3 data can provide **high S/N** detections of shear-3pt correlations (first ever $\langle\gamma\gamma\gamma\rangle$)
- Cosmic shear in upcoming DES will help test Λ CDM with **unprecedented precision**
- Mitigating **systematics** is only getting more important

Outlook and other interests

Think of DES as a testing ground for LSST and Stage-IV science, both in terms of **systematics** and **statistical power**

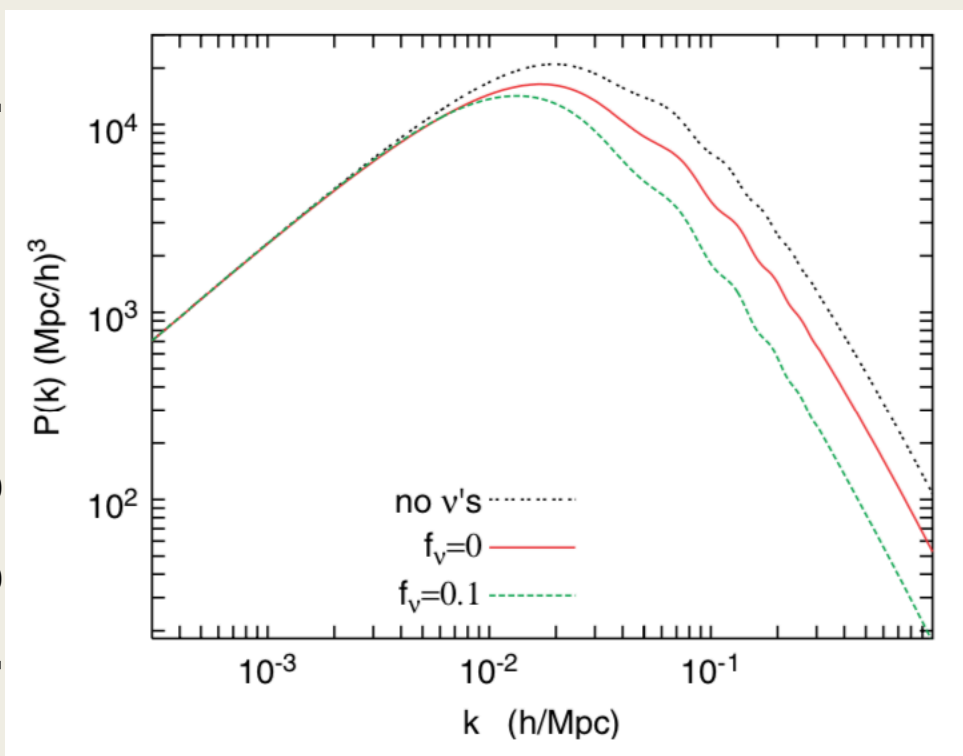
W O'Mullane/LSST Project/NSF/AURA



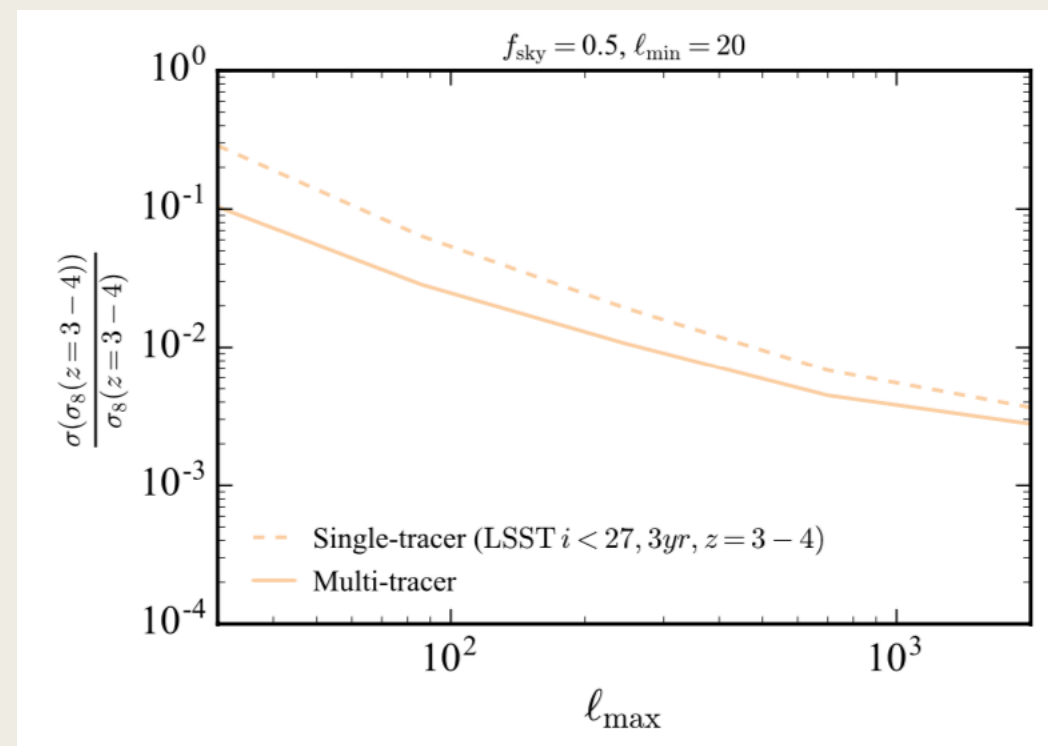
Outlook and other interests

Lots of **astrophysics** to learn from 2pt + 3pt lensing observables & wide imaging surveys

[Lesgourges & Pastor 2006]



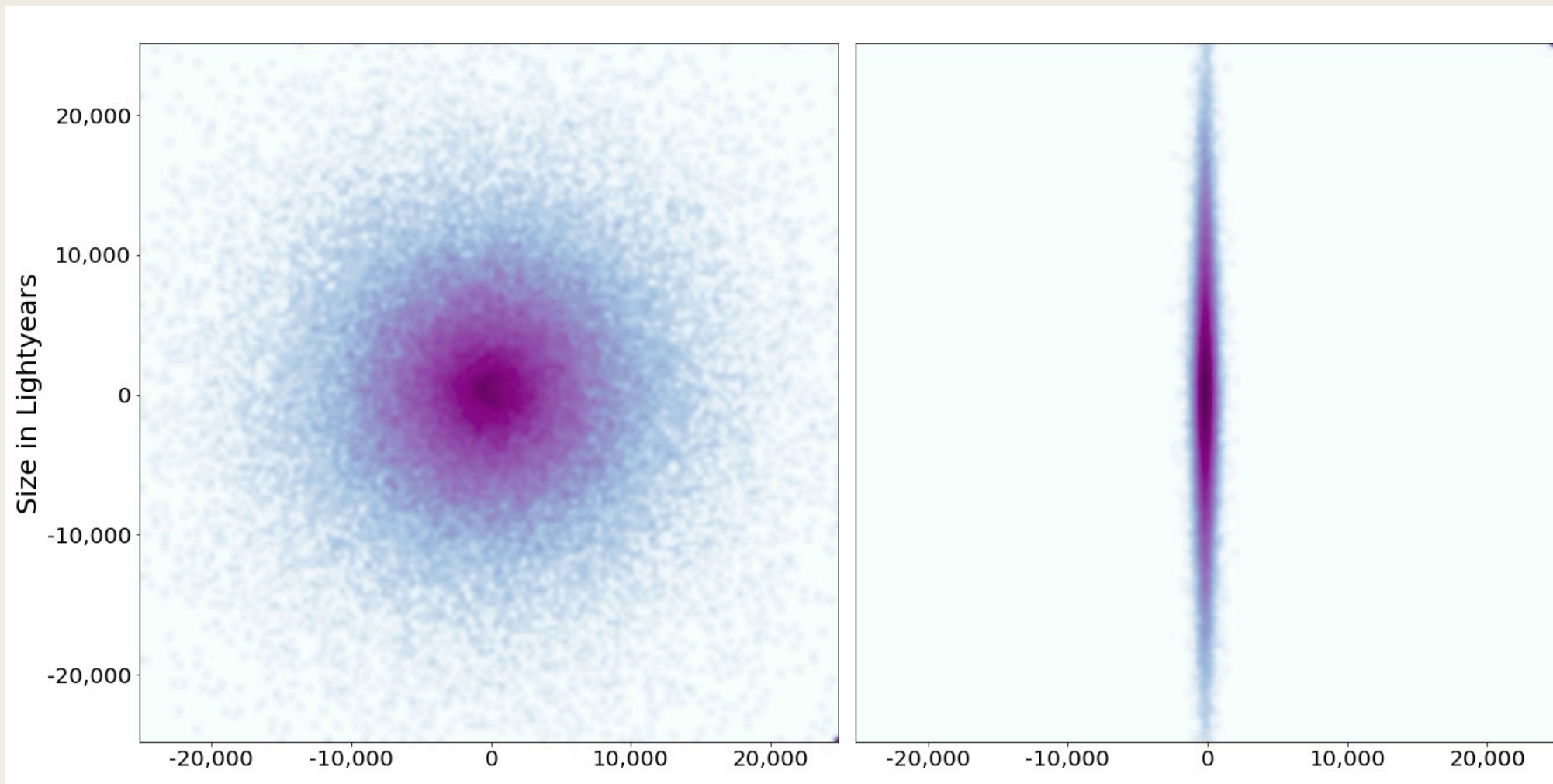
Neutrino masses



Multi-tracer tricks in LSS

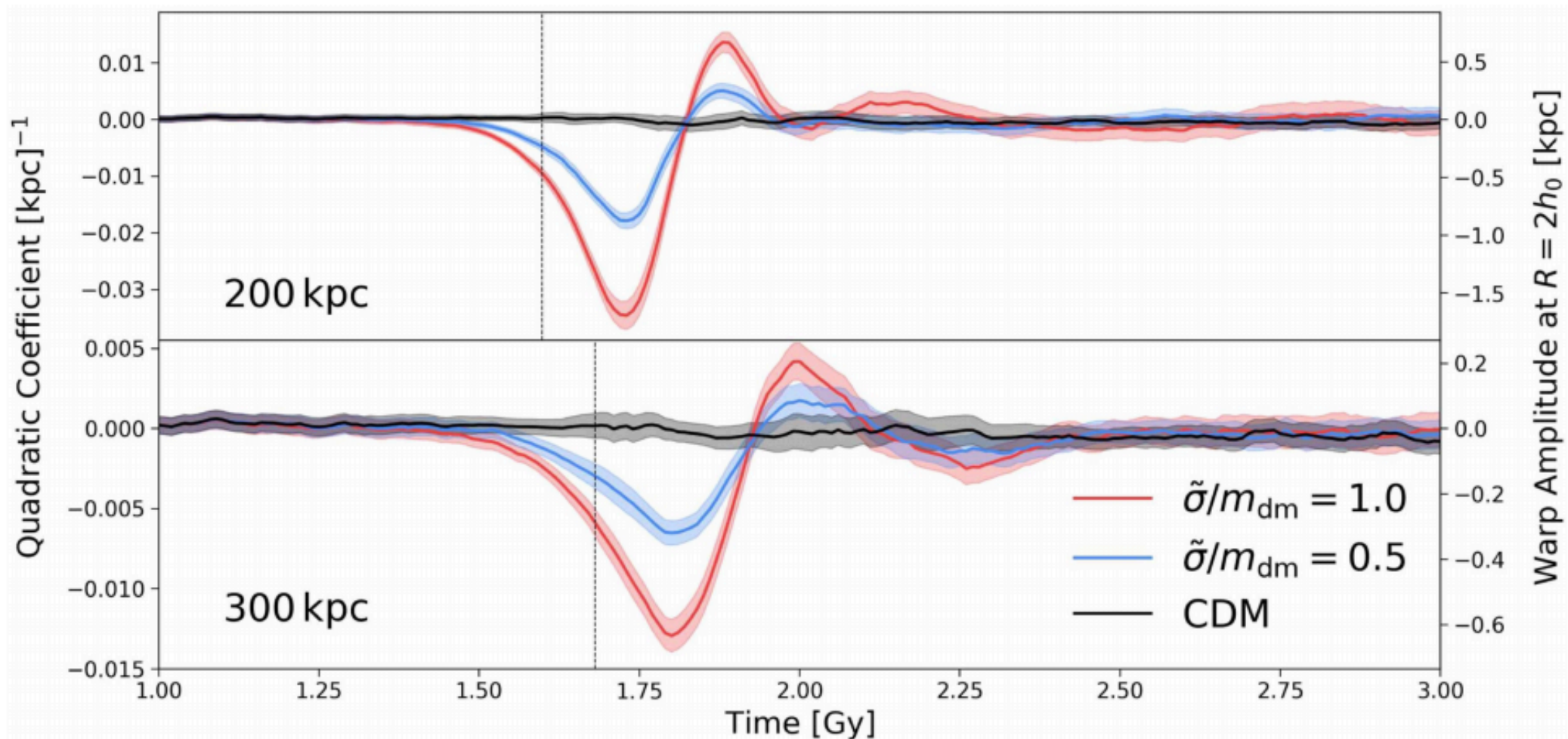
[Schmittfull & Seljak 2018]

Outlook and other interests



LS et al 1712.04841 – SIDM in disk galaxies

Outlook and other interests



LS et al 1712.04841 – SIDM in disk galaxies

Thank you!