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

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Cosmic Shear with DES-Y3

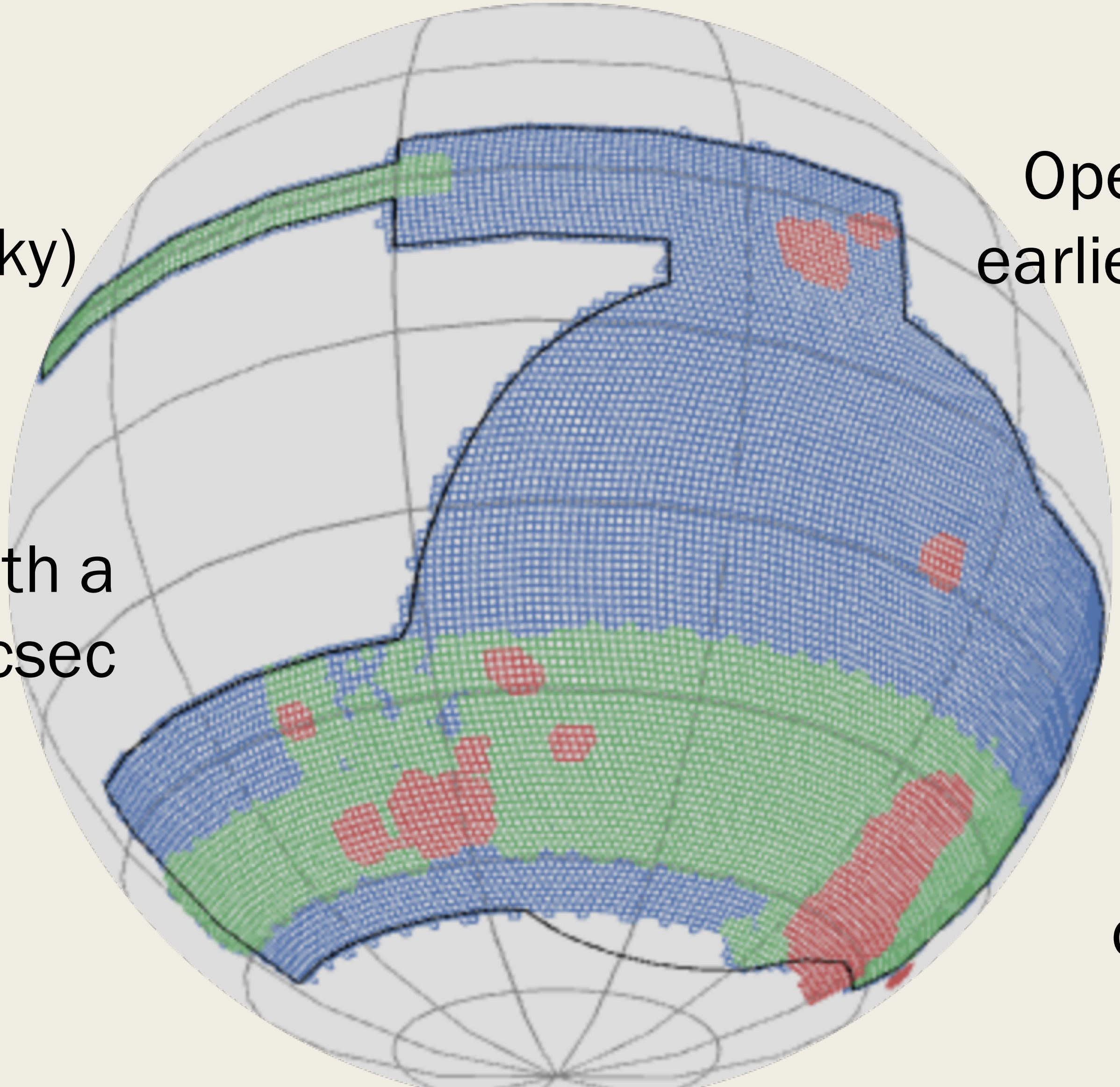
- The Dark Energy Survey & weak lensing
- Cosmology with shear-2pt correlations
  - *PSF errors*
  - *Intrinsic alignments*
- Pursuing a measurement of shear-3pt correlations
- Conclusion: what to expect from DES-Y3

The Dark Energy Survey

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

Operations finalized
earlier this year (~5.5y)

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



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

Credit: Nacho Sevilla (DES)

The Dark Energy Survey

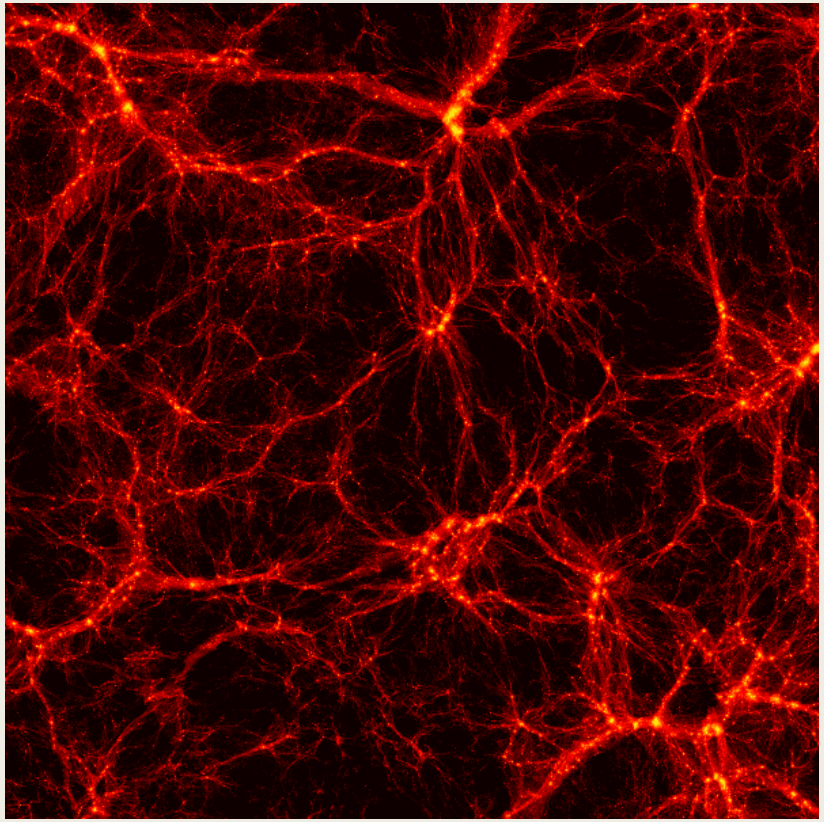
>400 people

Blanco Telescope @ CTIO Chile

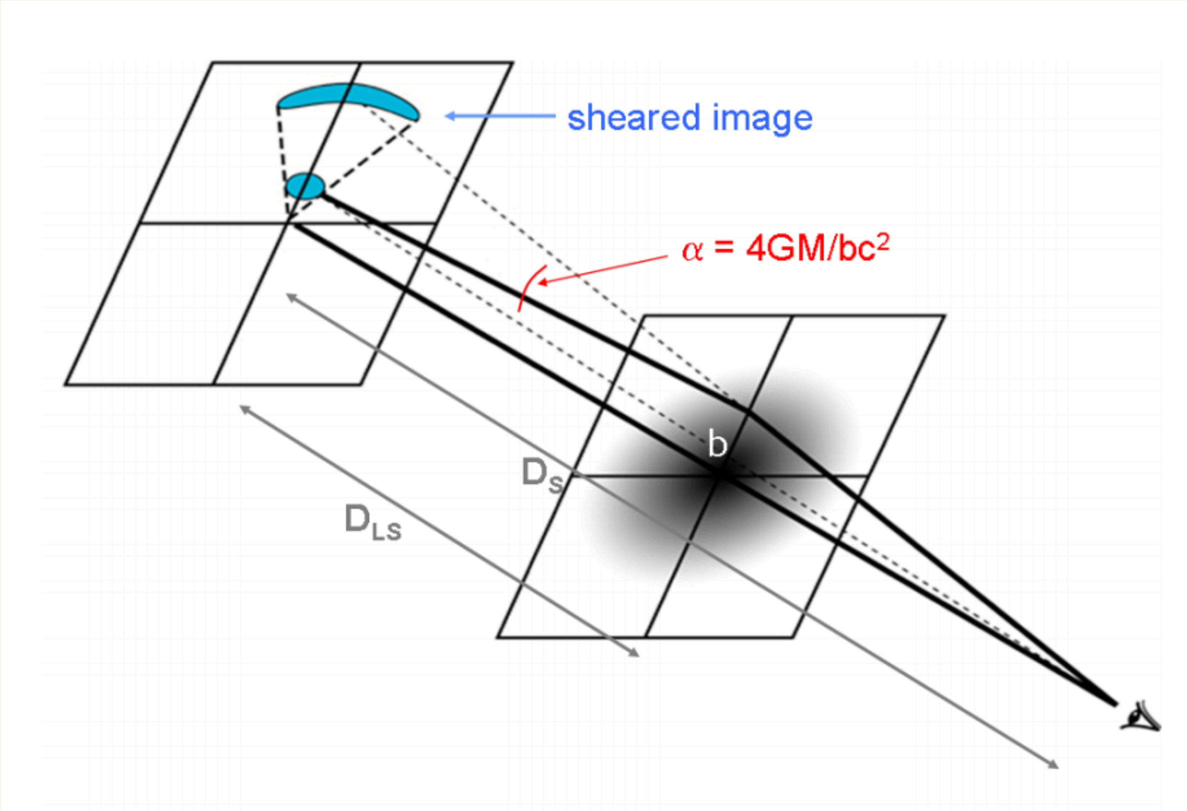
From shapes to cosmology

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

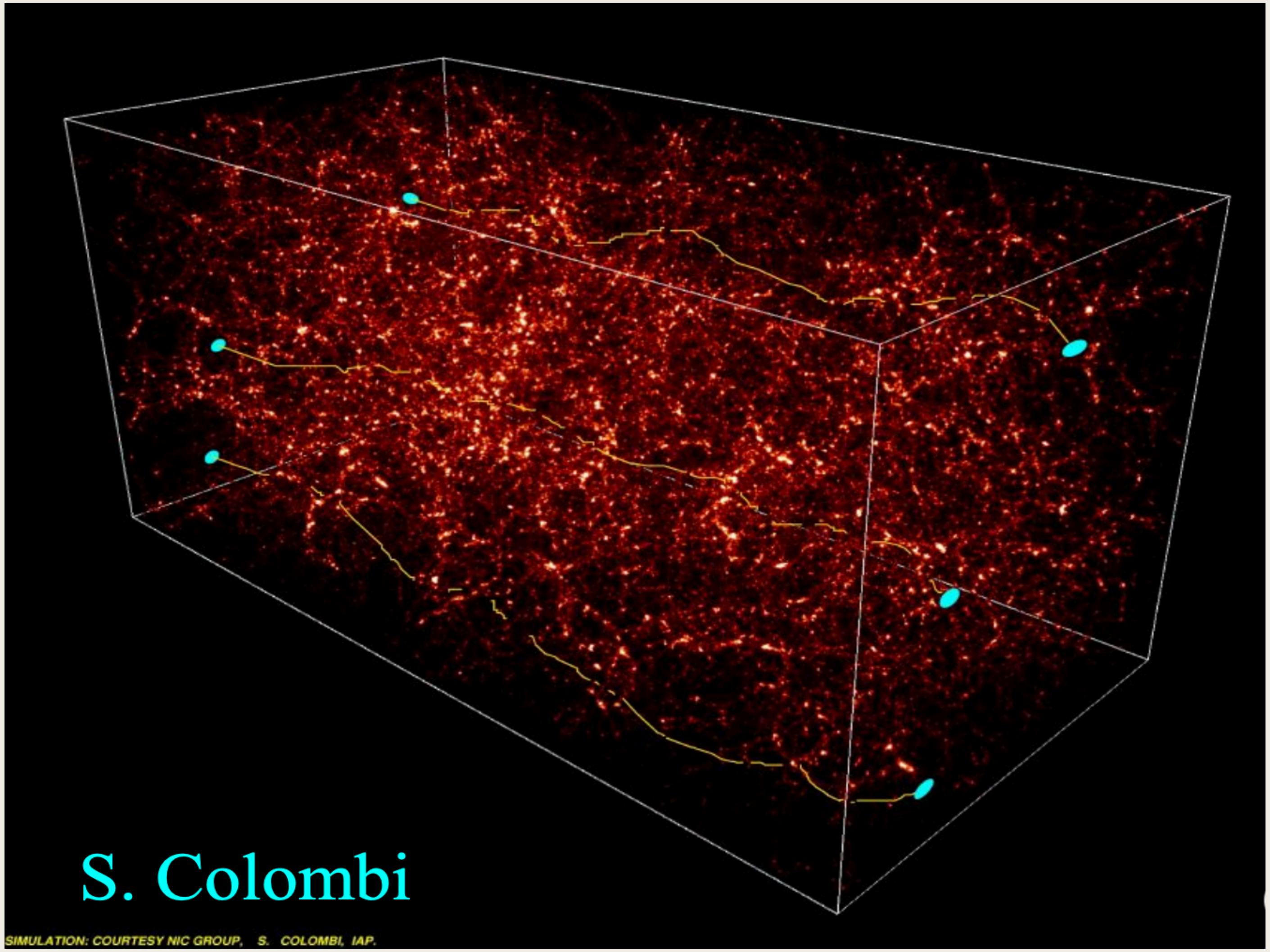
[Quijote, Villaescusa-Navarro et al 2019]



Intervening matter deflects light bundles and imprint shapes (shear)

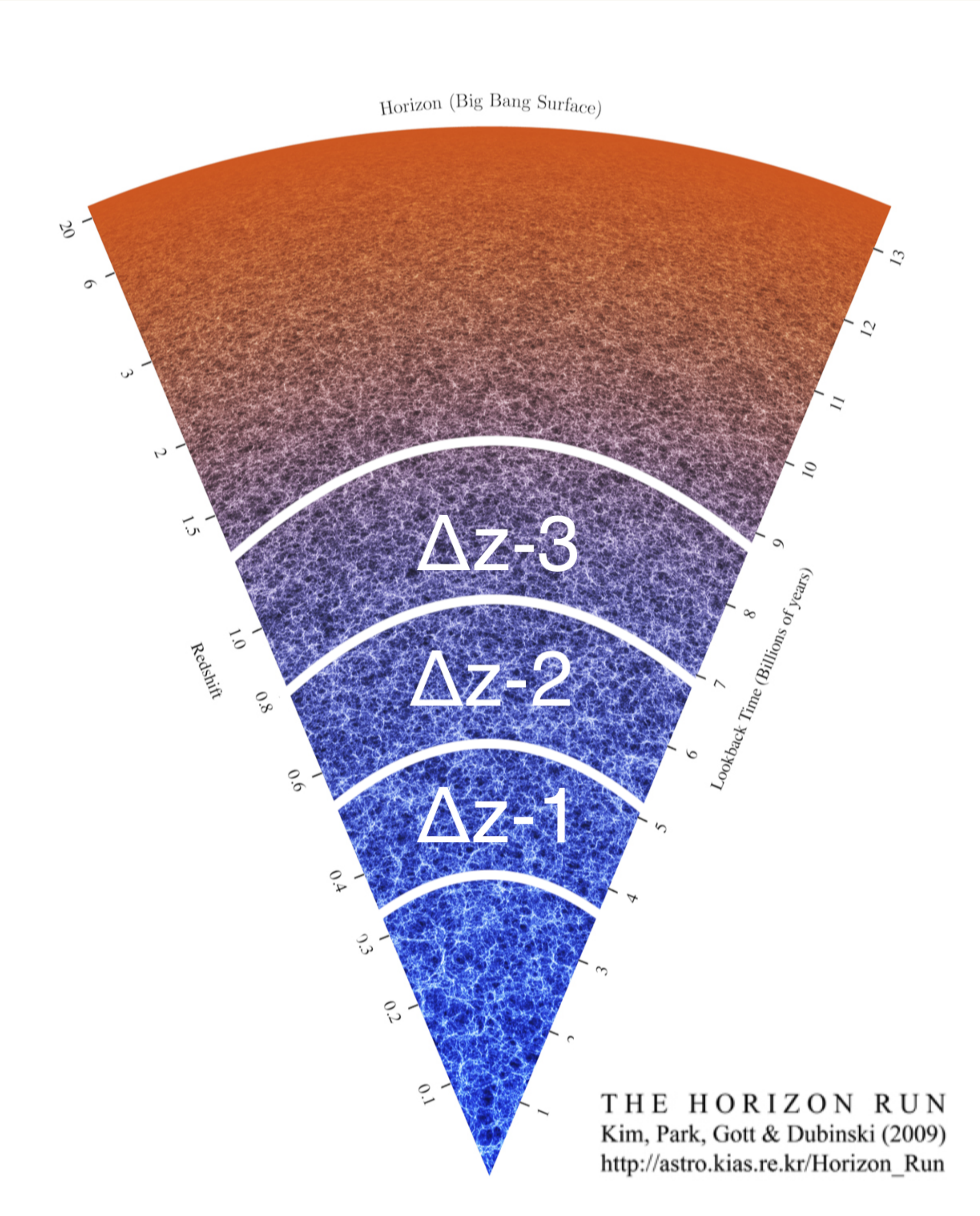


[LSST science book]



Matter clustering in the universe as a function of Ω, $\boldsymbol{\Lambda}$, $\boldsymbol{h}$, … → Galaxy shape correlations as a function of Ω, $\boldsymbol{\Lambda}$, $\boldsymbol{h}$, …

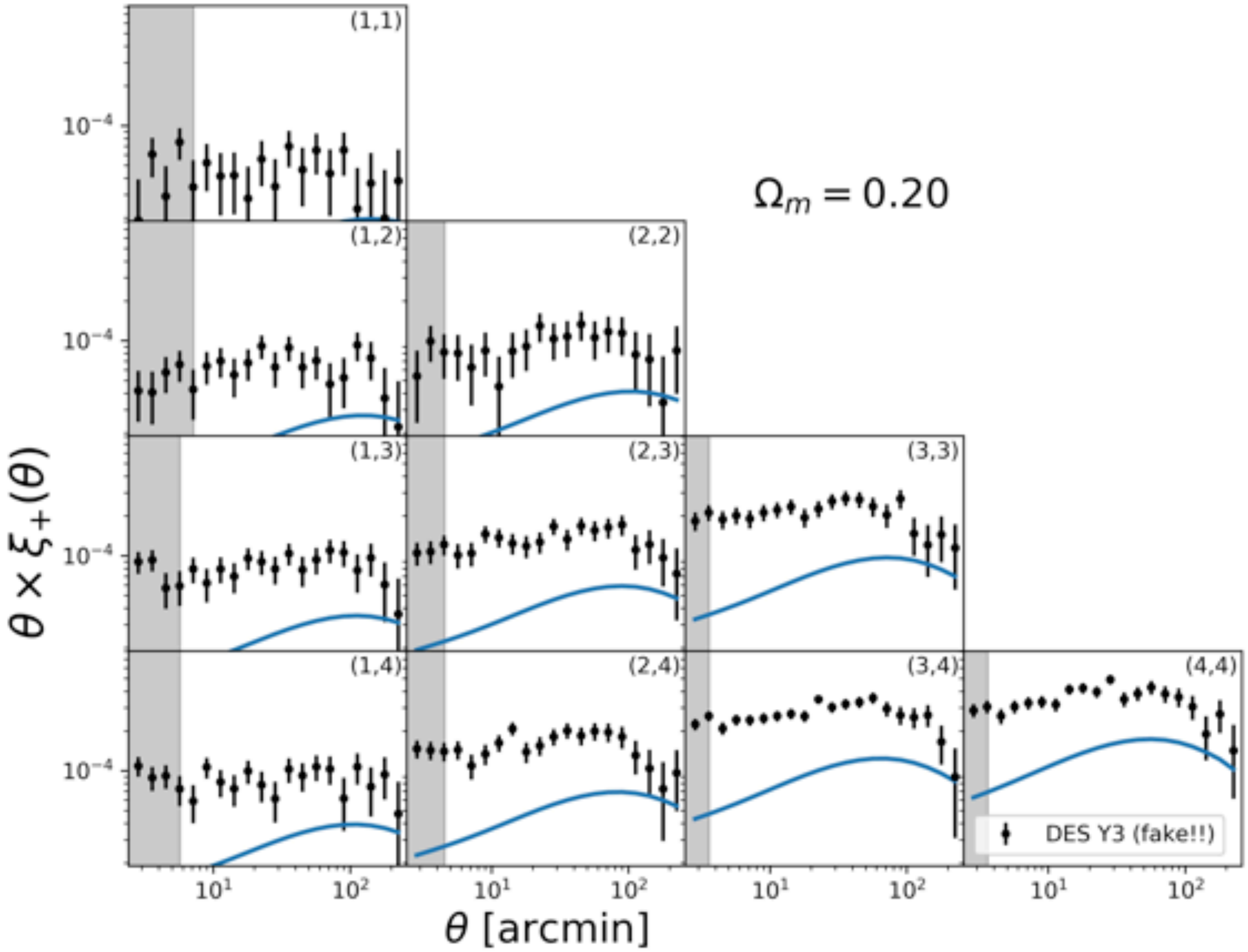
Make measurements tomographically



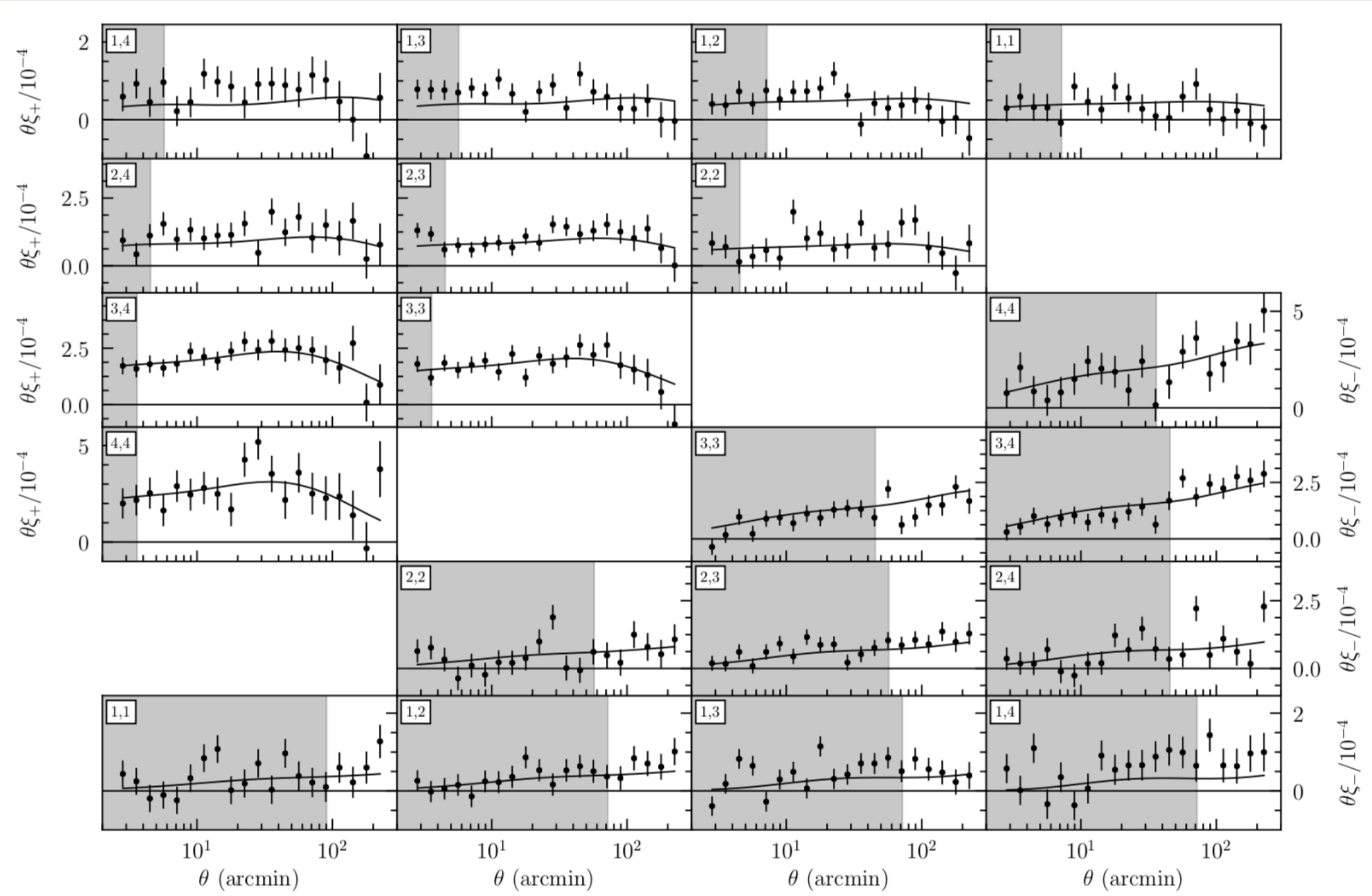
Distance ratios contain information

[Hu 1999]

Cosmic shear as a function of Ω_m



Cosmic shear in DES-Y1



[Troxel, …, LS et al 2018]

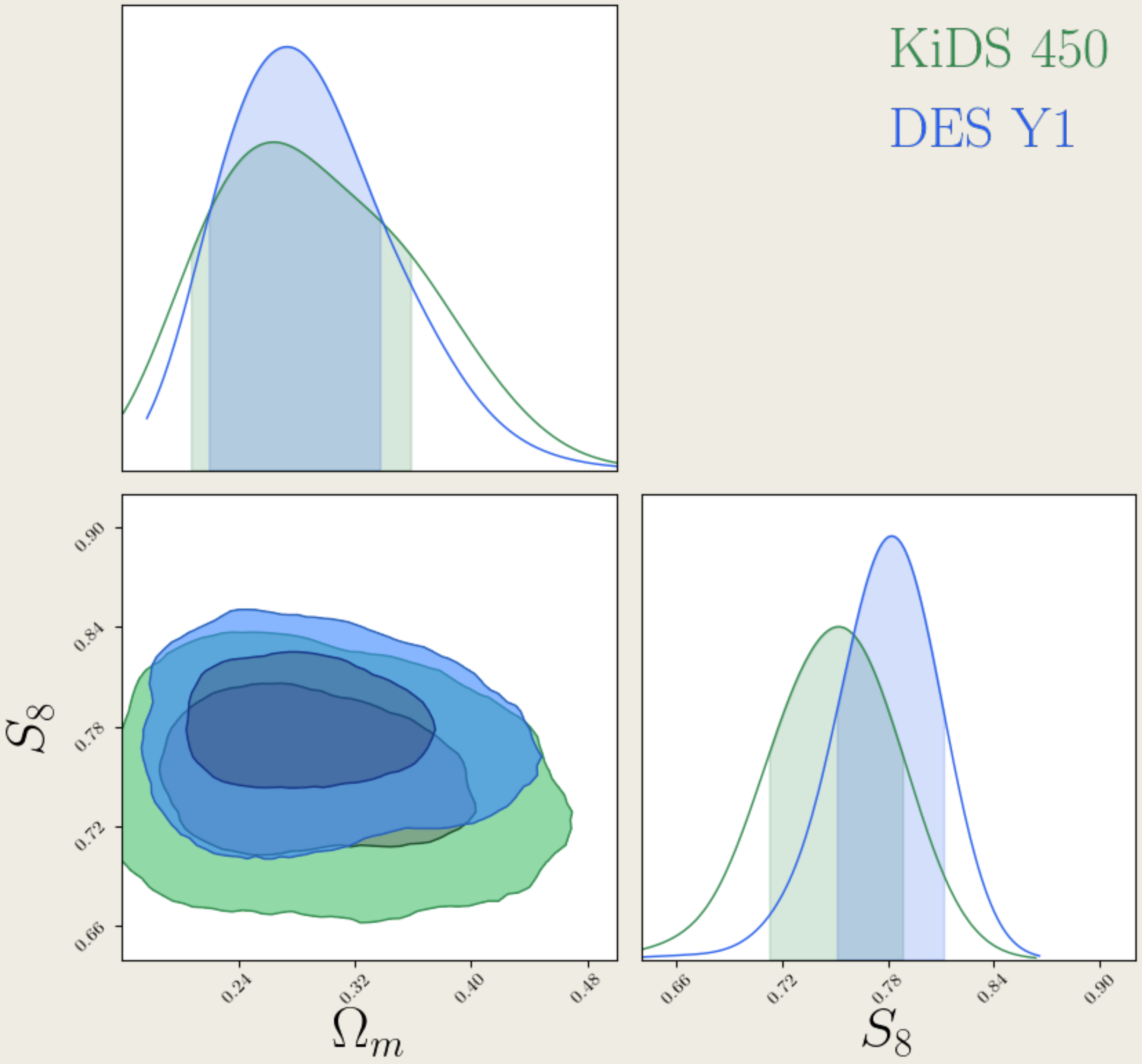
Cosmic shear in DES-Y1

Cosmology = 6D (in ΛCDM)
Nuisance = 10+D

3.5% fractional uncertainty in the amplitude of the lensing signal (S8)

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

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

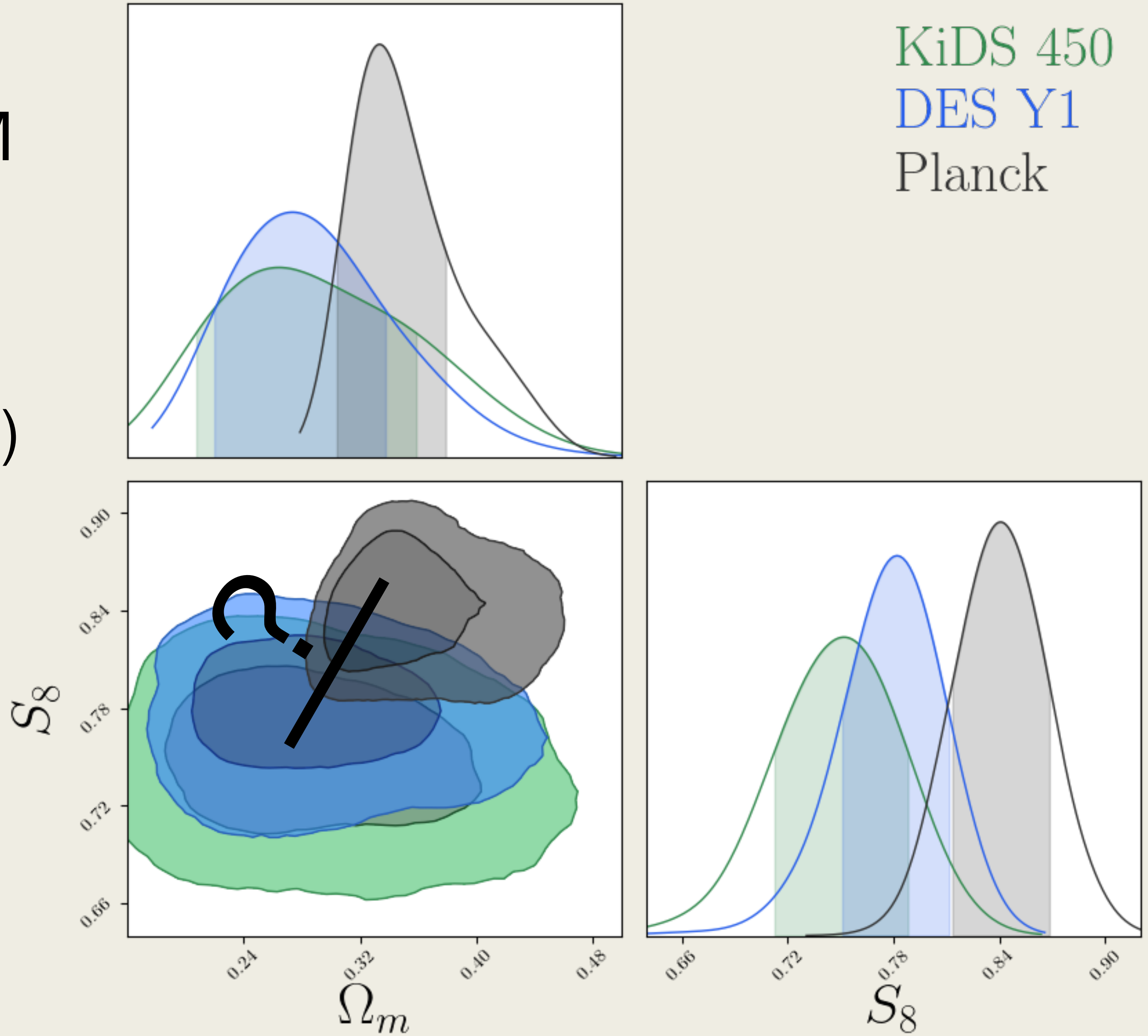


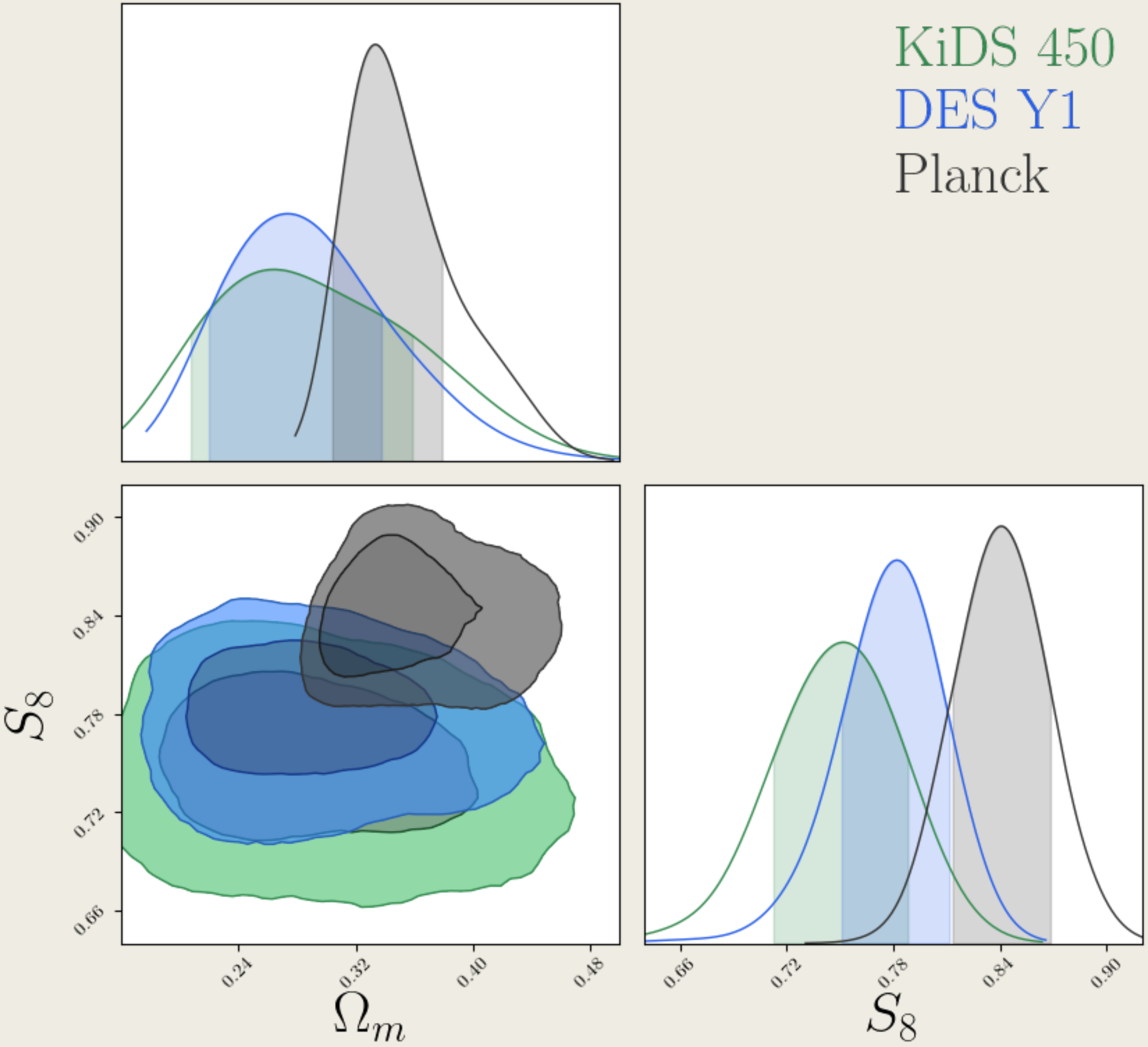
Cosmic shear in DES-Y1

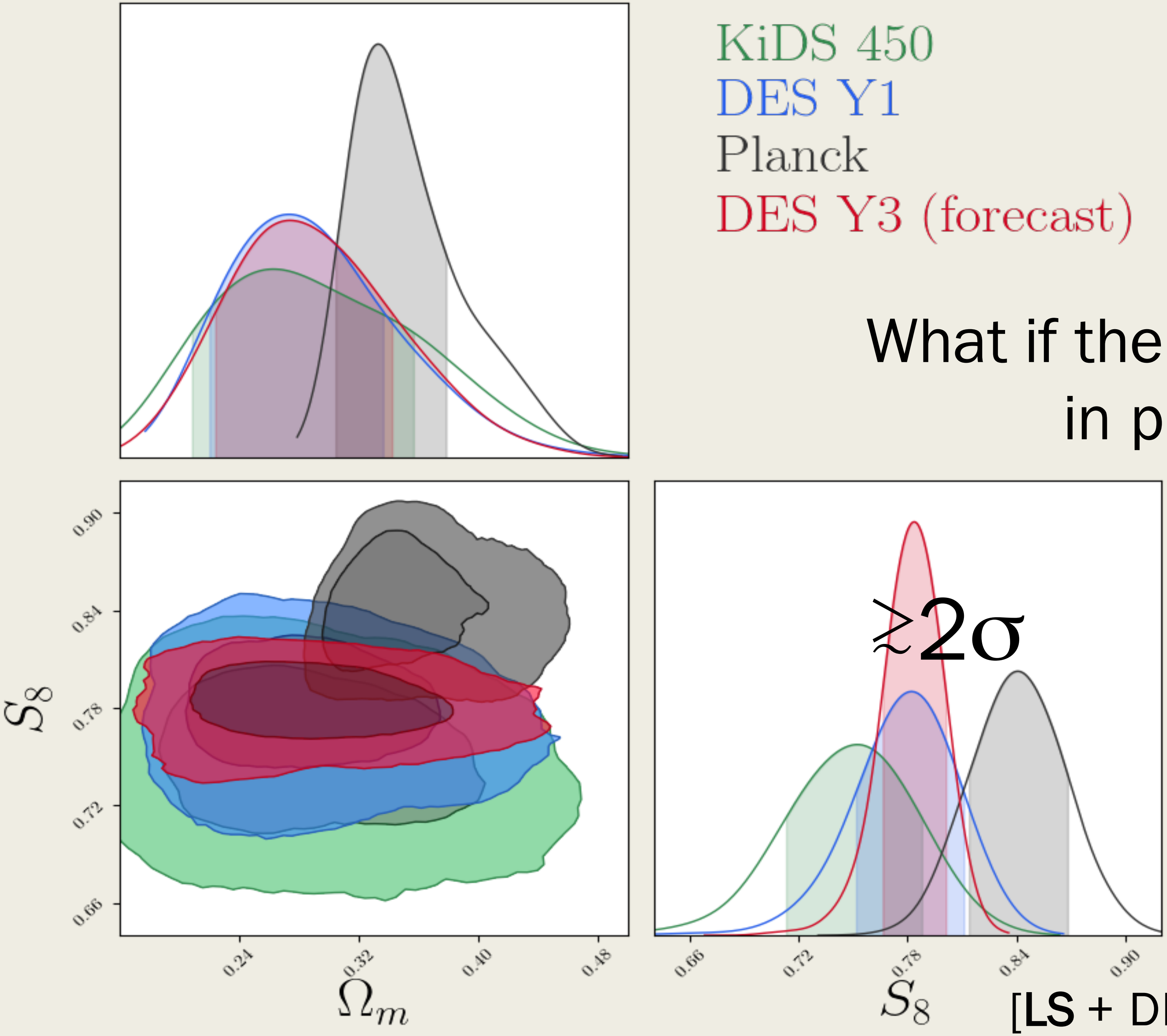
CMB vs. low-z probes:
an end-to-end test of ΛCDM

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?

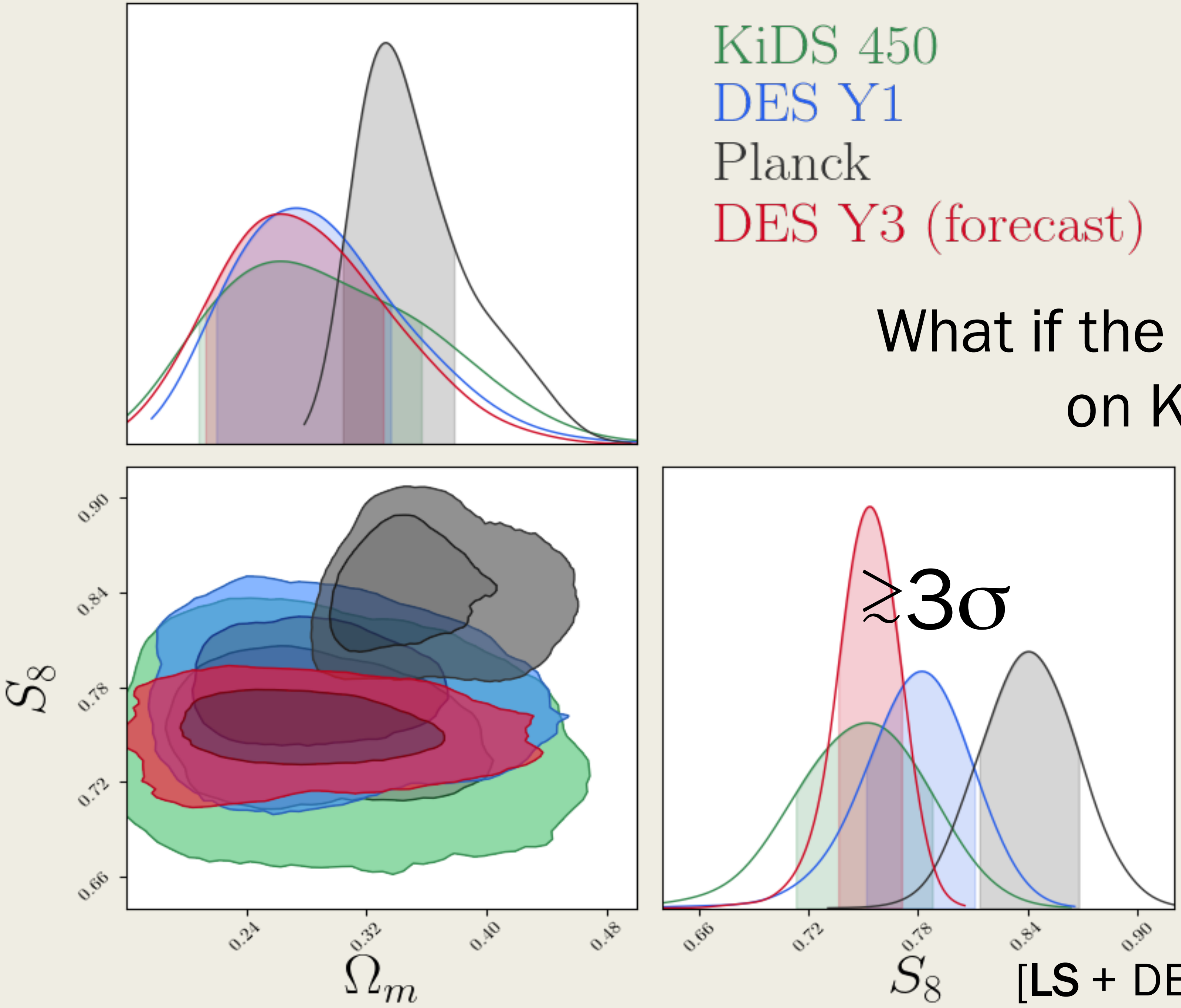



KiDS 450
DES Y1
Planck
0.90
0.84
0.78
0.72
0.66
S_8
0.24
0.32
0.40
0.48
Ω_m
0.66
0.72
0.78
0.84
0.90
S_8



What if the DES shrinks in place?

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



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

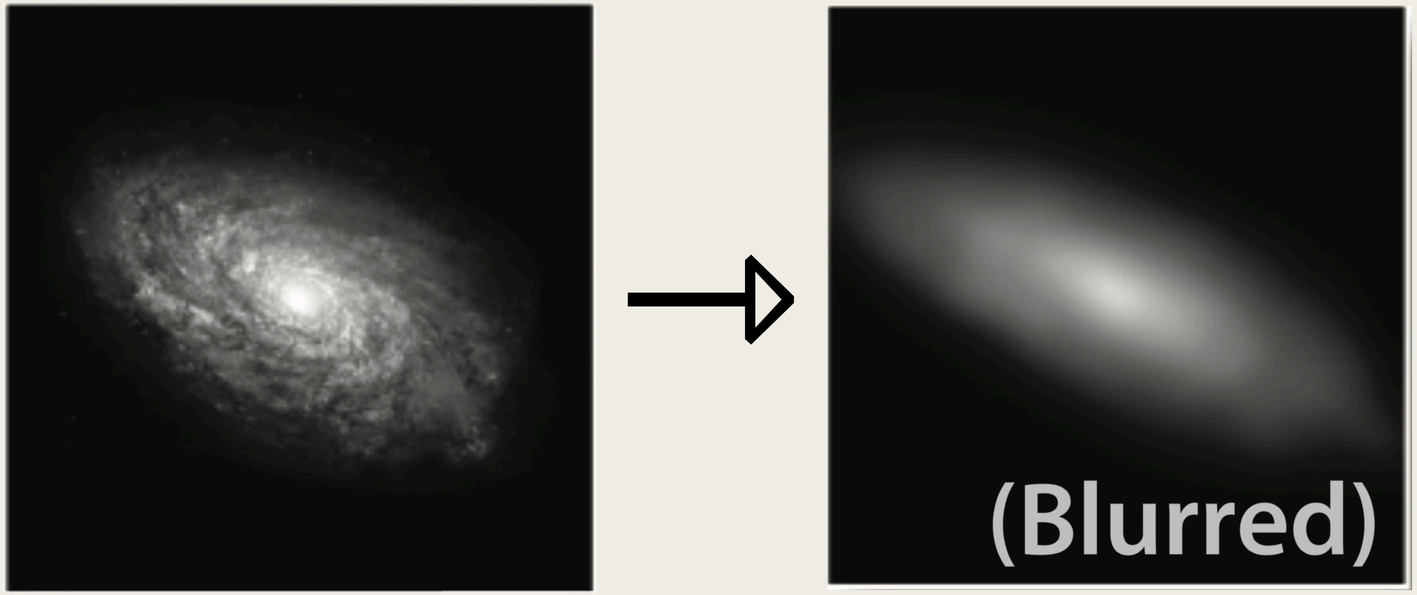
1) Generate synthetic 2pt data with some added complexity

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



[Mandelbaum 2018]

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]

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

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

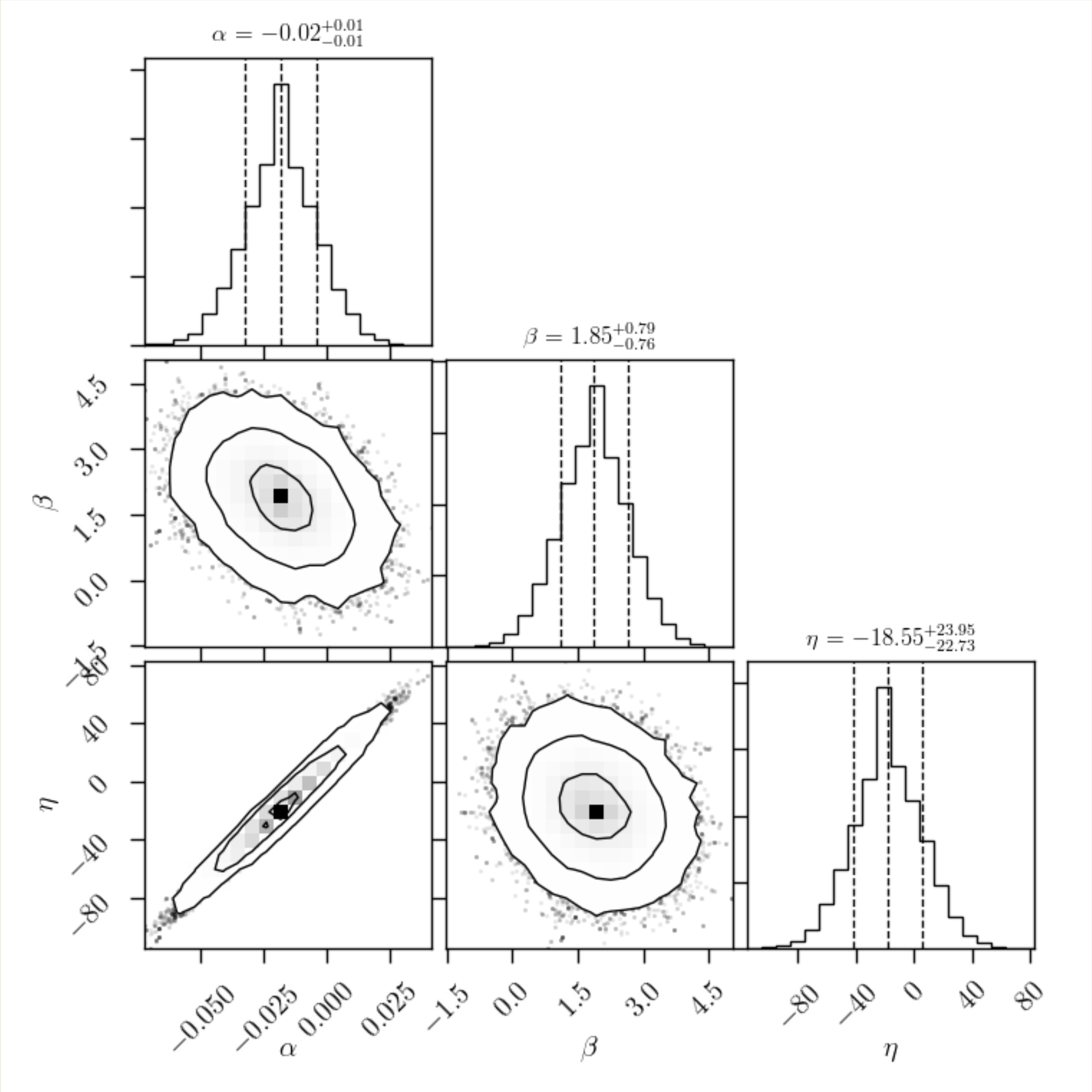
Cosmic Shear Systematics: PSF modeling errors

(w/ **Andrés Alsina** and the DES)

$$\alpha, \beta, \eta$$

estimated from

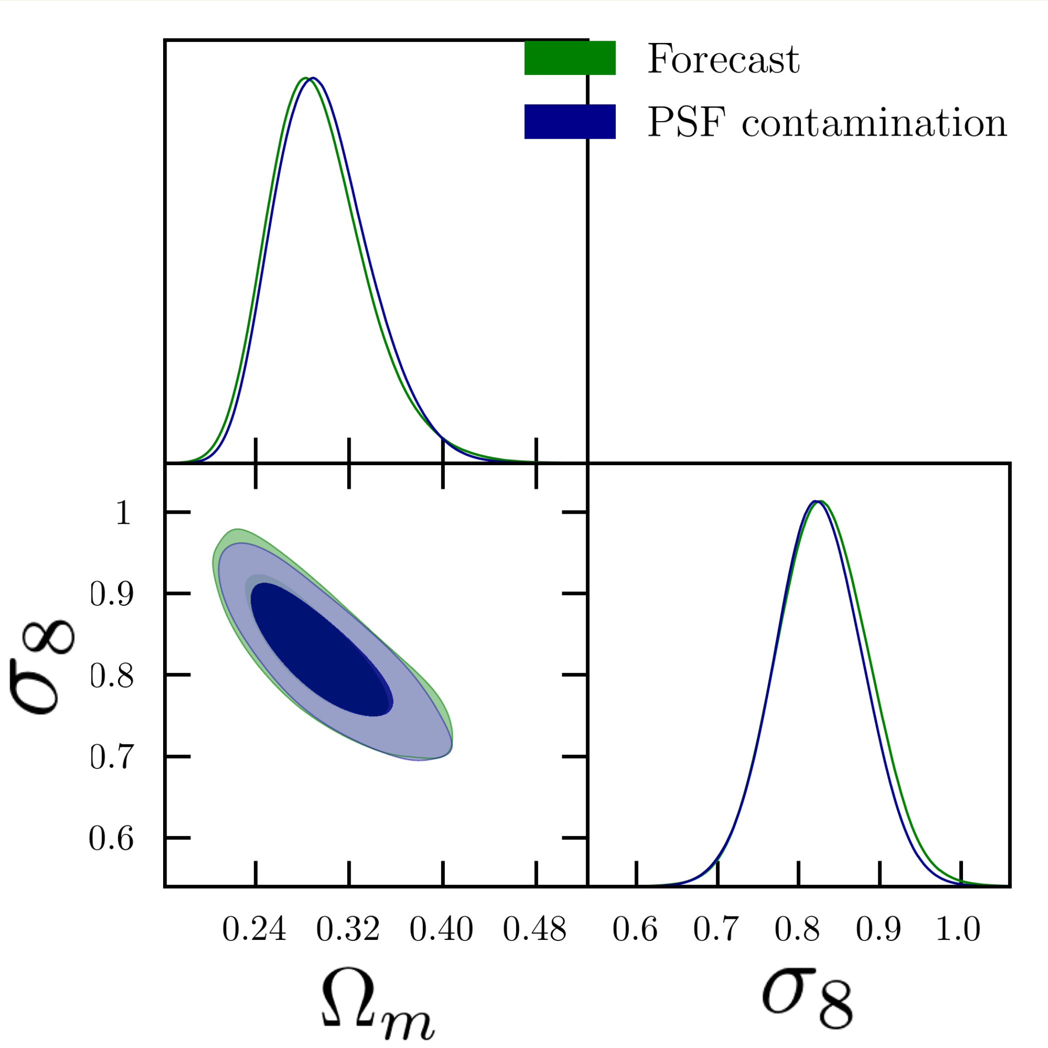
cross-correlations



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

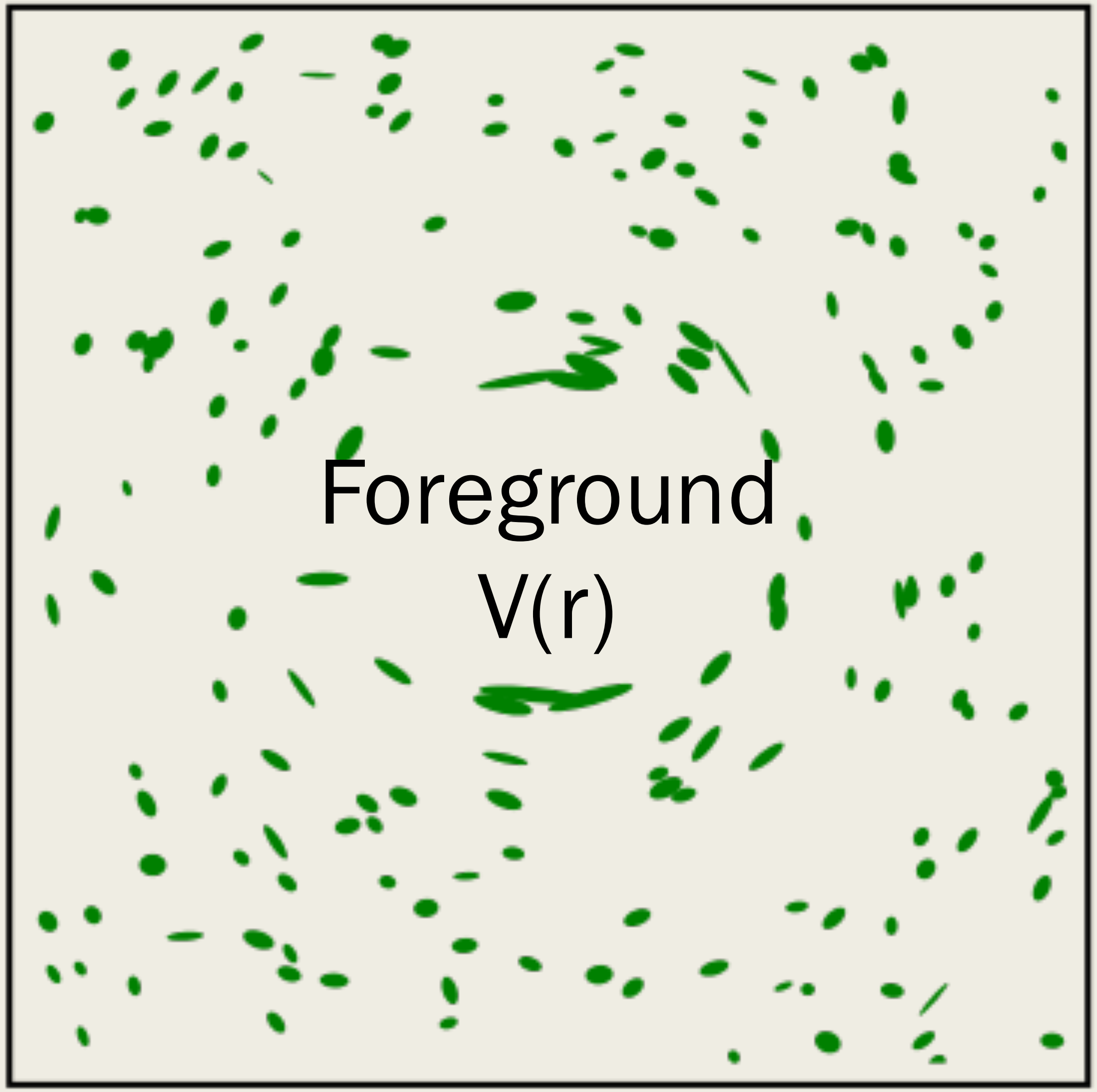
Lucas Secco – DES Y3 Cosmic Shear

Cosmic Shear Systematics: PSF modeling errors



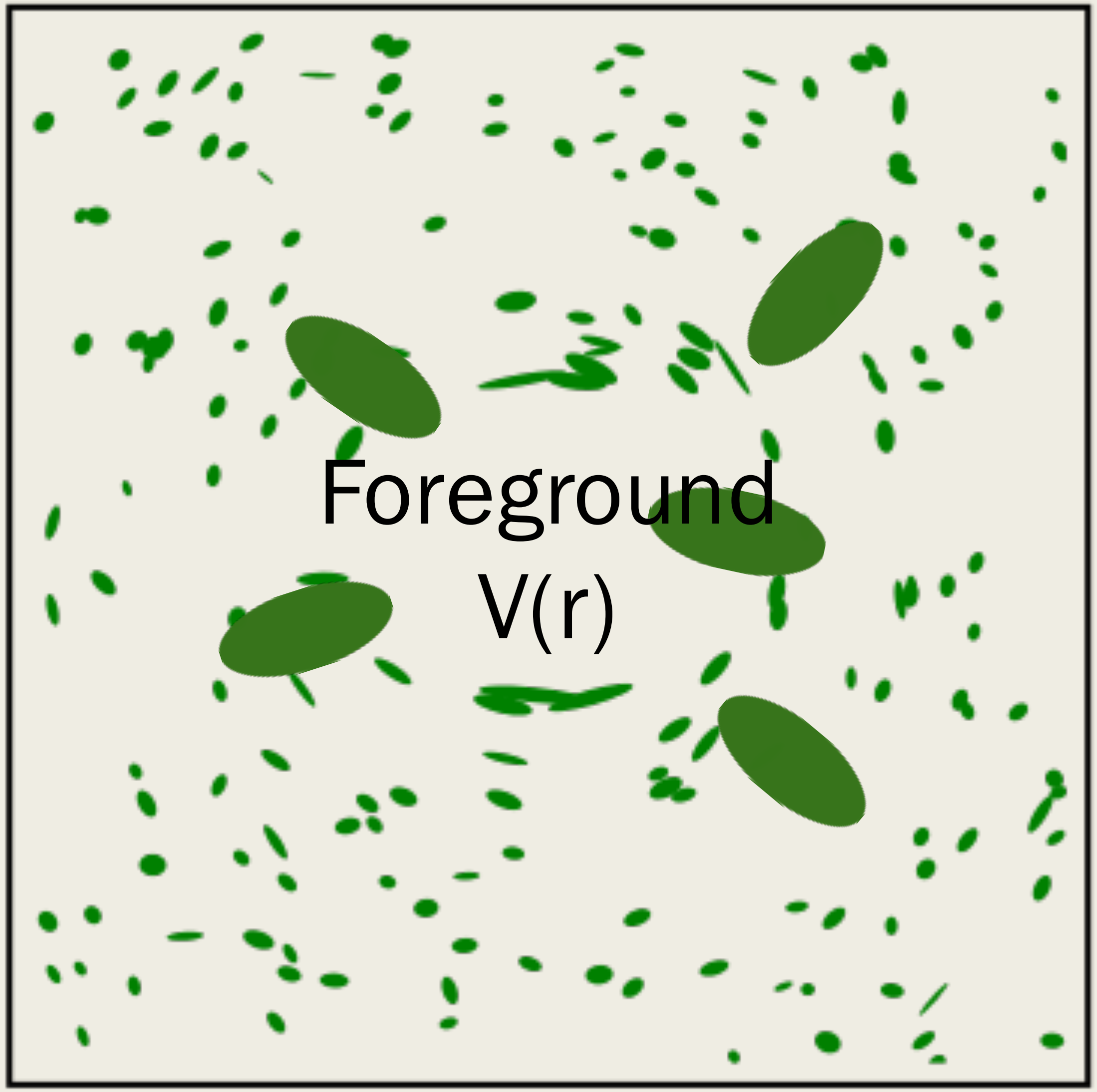
Can PSF modeling errors impact cosmology in DES-Y3? No.

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)

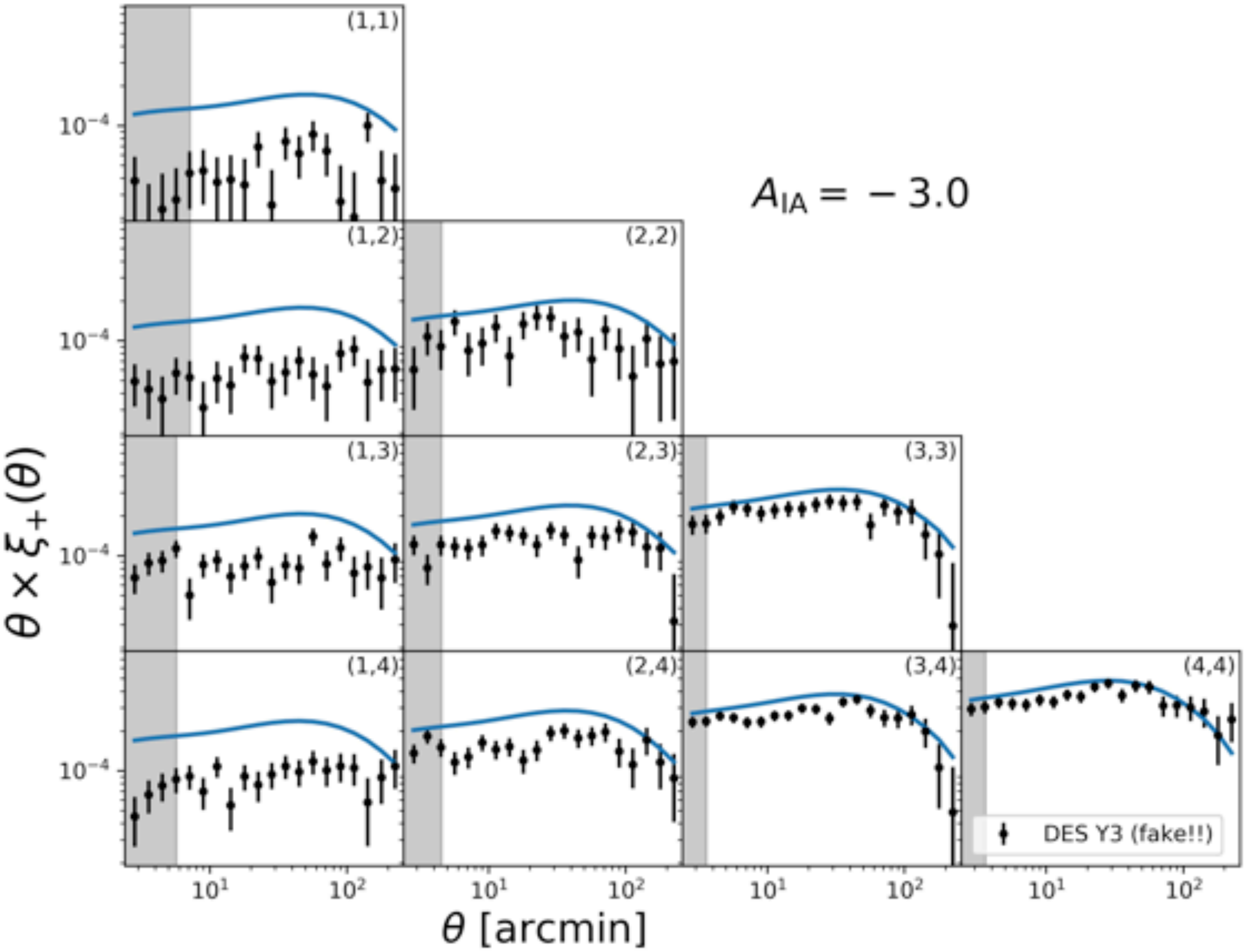
[Catelan et al 2001; Hirata & Seljak 2004]

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

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

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

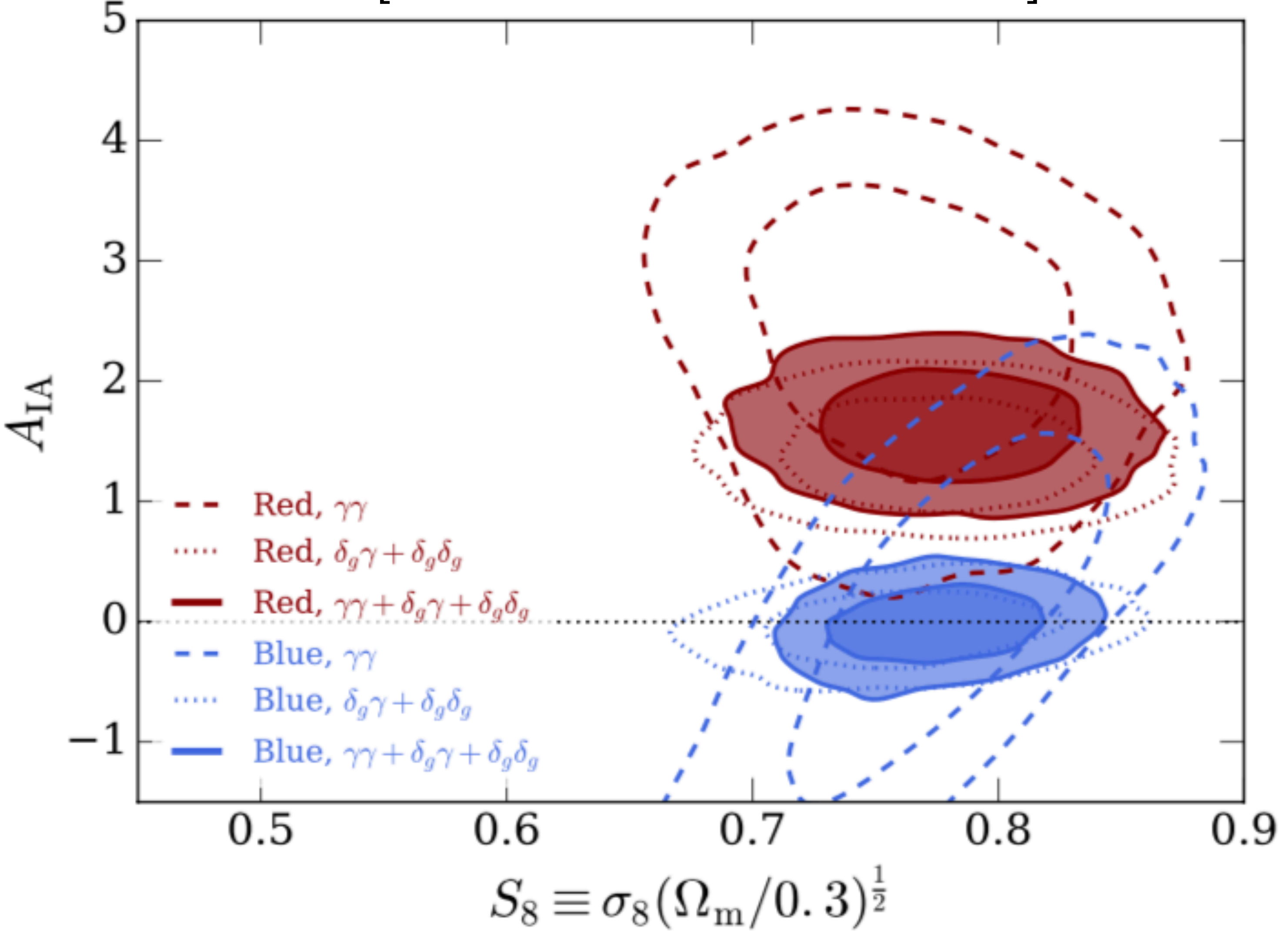
Cosmic shear as a function of IA amplitude



Cosmic Shear Systematics: Intrinsic Alignments

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

[Samuroff + DES et al 2018]



Cosmic Shear Systematics: Intrinsic Alignments

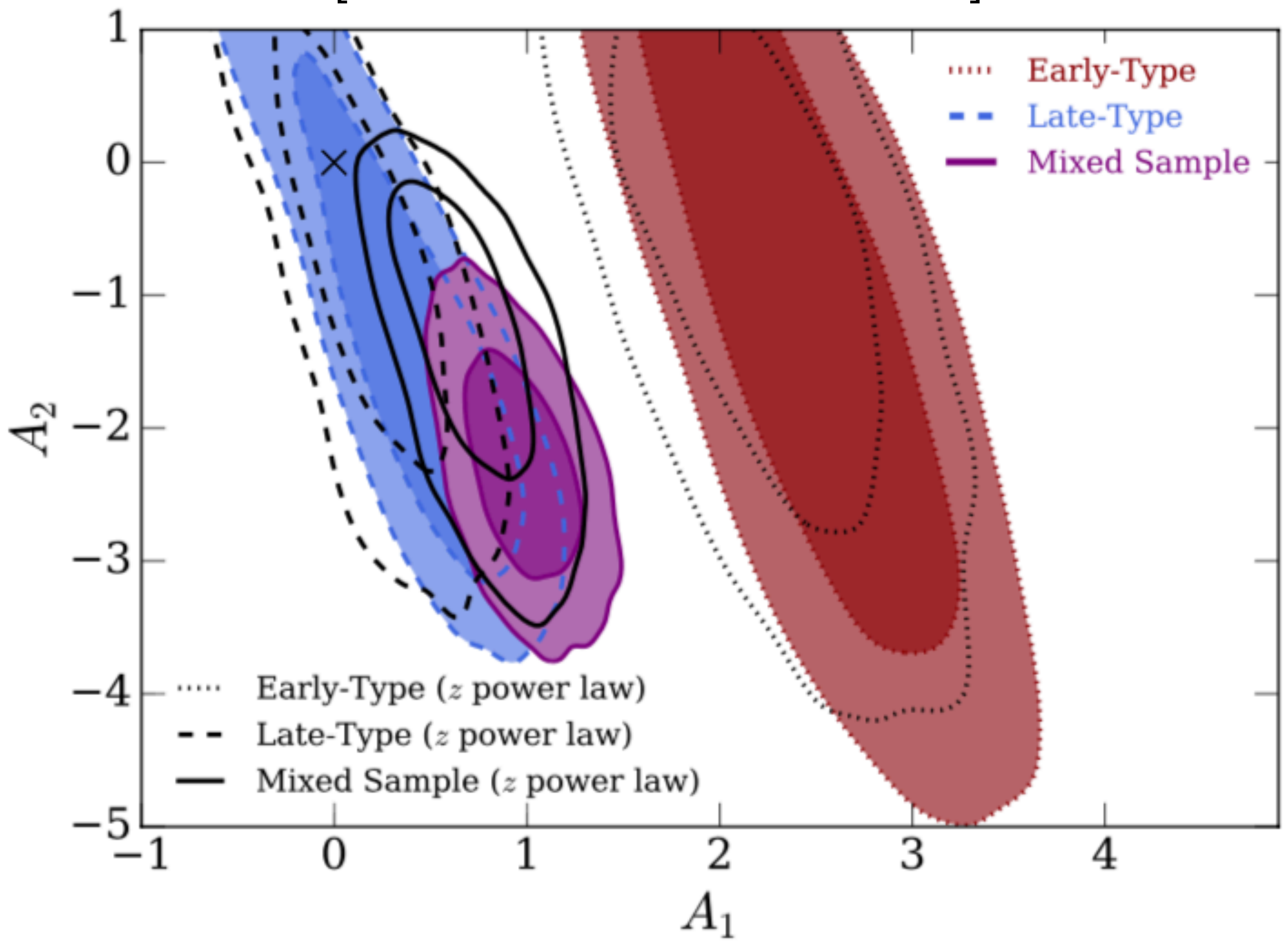
Incorporate the orientation of late-types

(e.g. Chisari et al 2015)

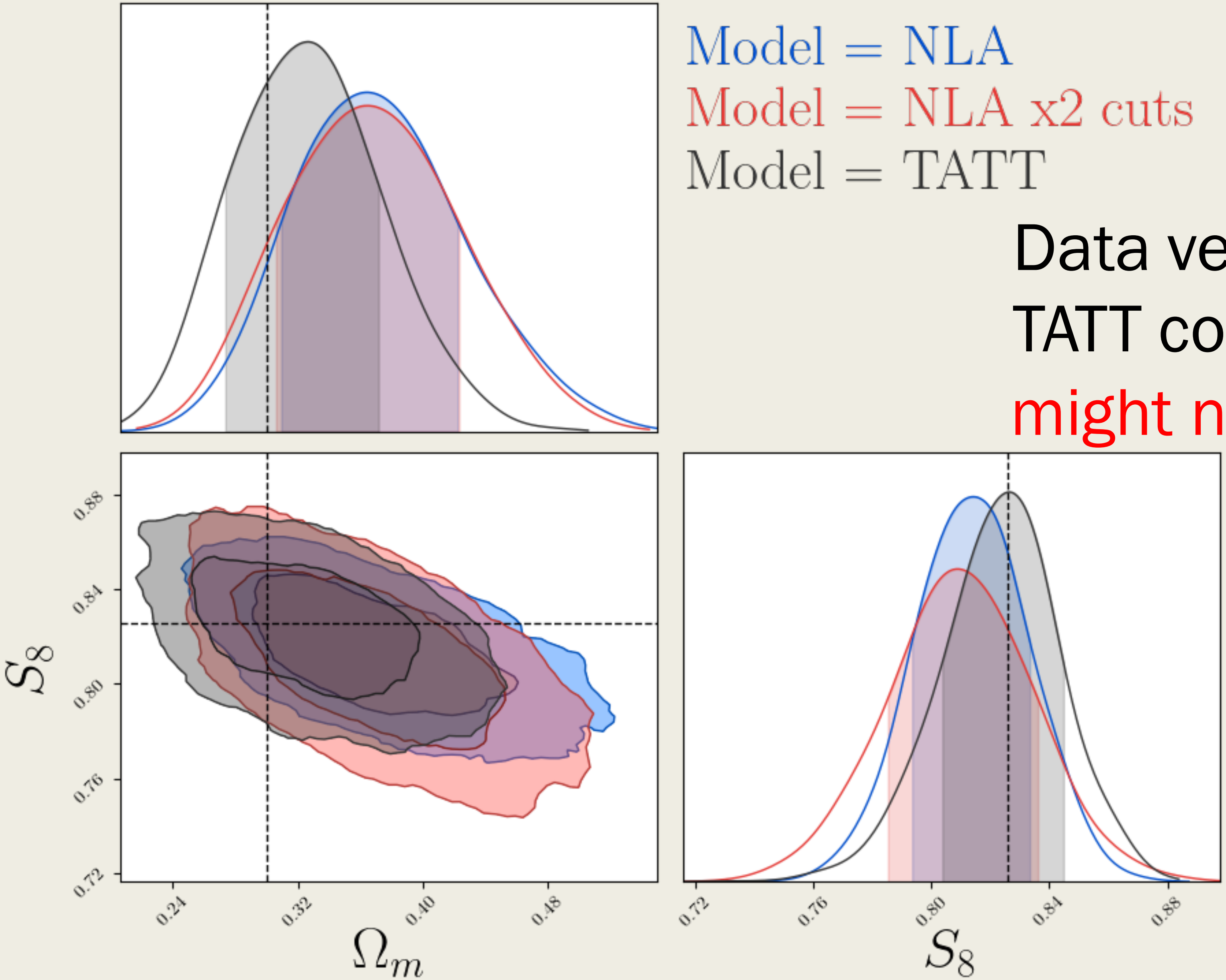
with a model that accounts for tidal torquing ("TATT")

[Blazek et al 2017]

[Samuroff + DES et al 2018]

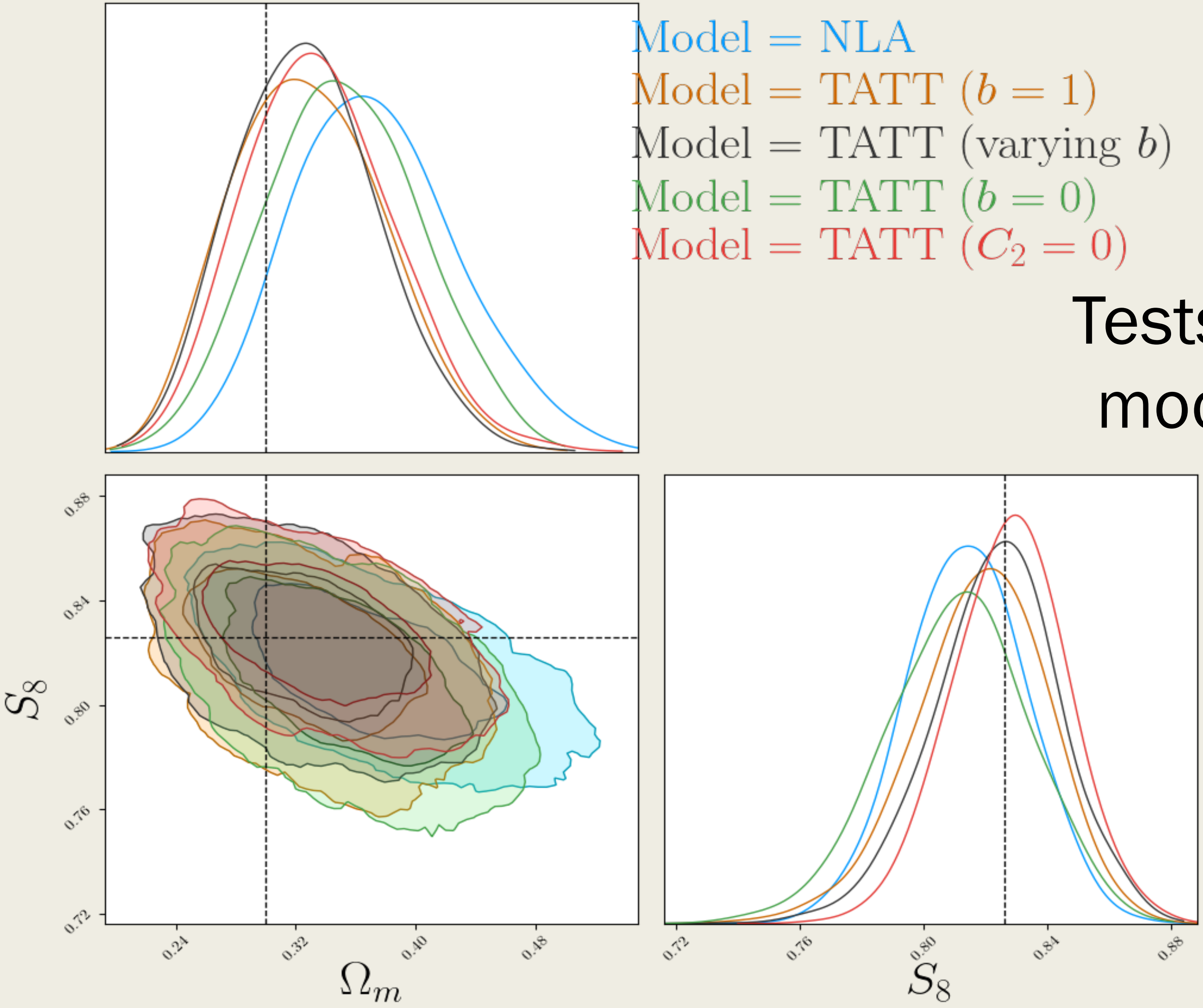


Cosmic Shear Systematics: Intrinsic Alignments



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

Cosmic Shear Systematics: Intrinsic Alignments



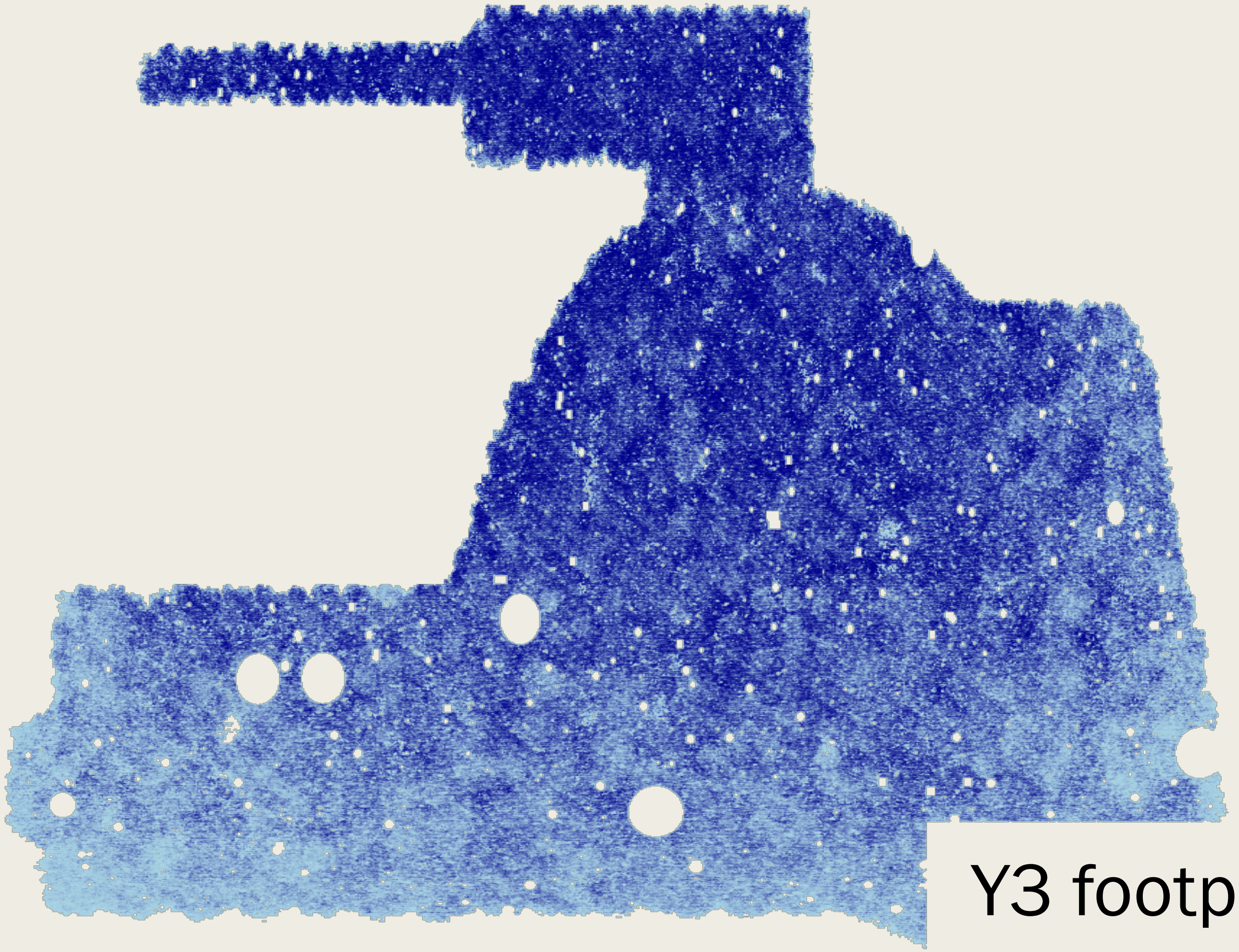
Tests with different modeling choices underway

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

$$\frac{B(\boldsymbol{k}_1,\boldsymbol{k}_2,\boldsymbol{k}_3)}{P(k_1)P(k_2)+P(k_2)P(k_3)+P(k_3)P(k_1)} \sim \frac{1}{\Omega_{\rm m}}$$

[Bernardeau et al. 1997]

Primordial non-gaussianities? Neutrino masses? ...

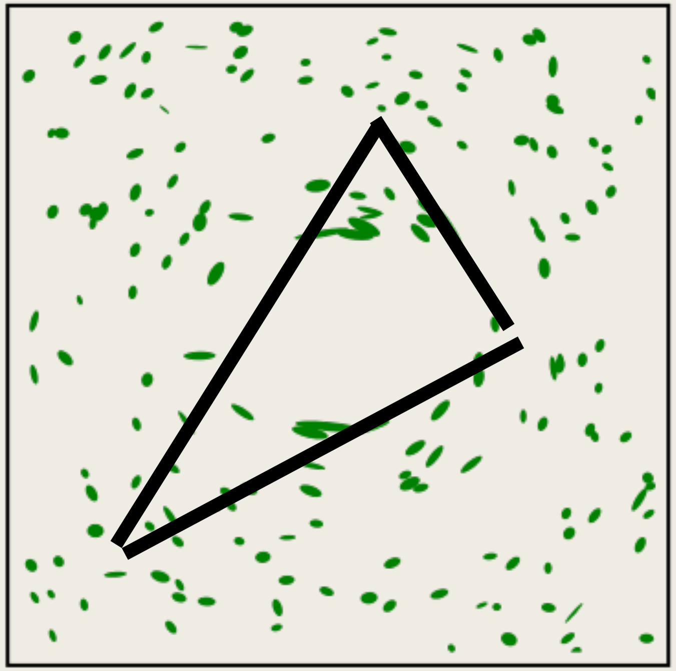
Wide applications!

How about looking for 3pt correlations on data?

(with Mike Jarvis, Bhuv Jain @ Penn)

1) Computationally expensive: is it feasible?

2) $< \gamma\gamma\gamma >$ 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?

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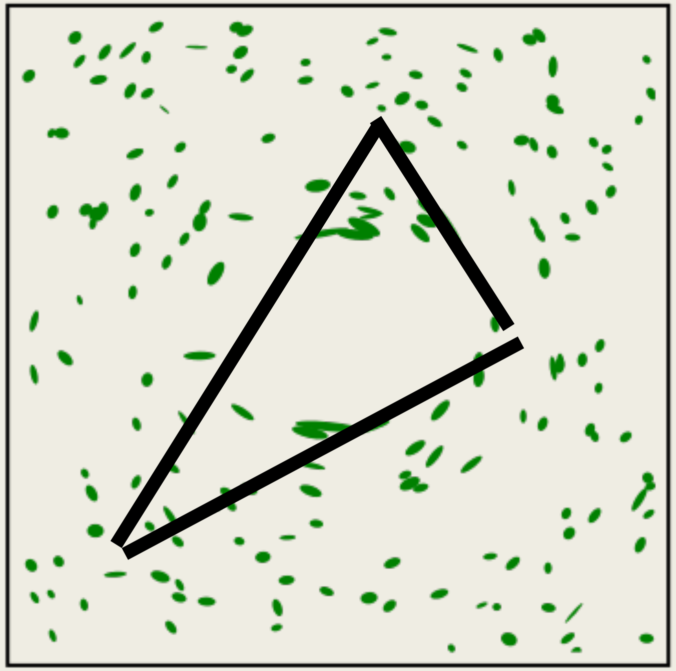


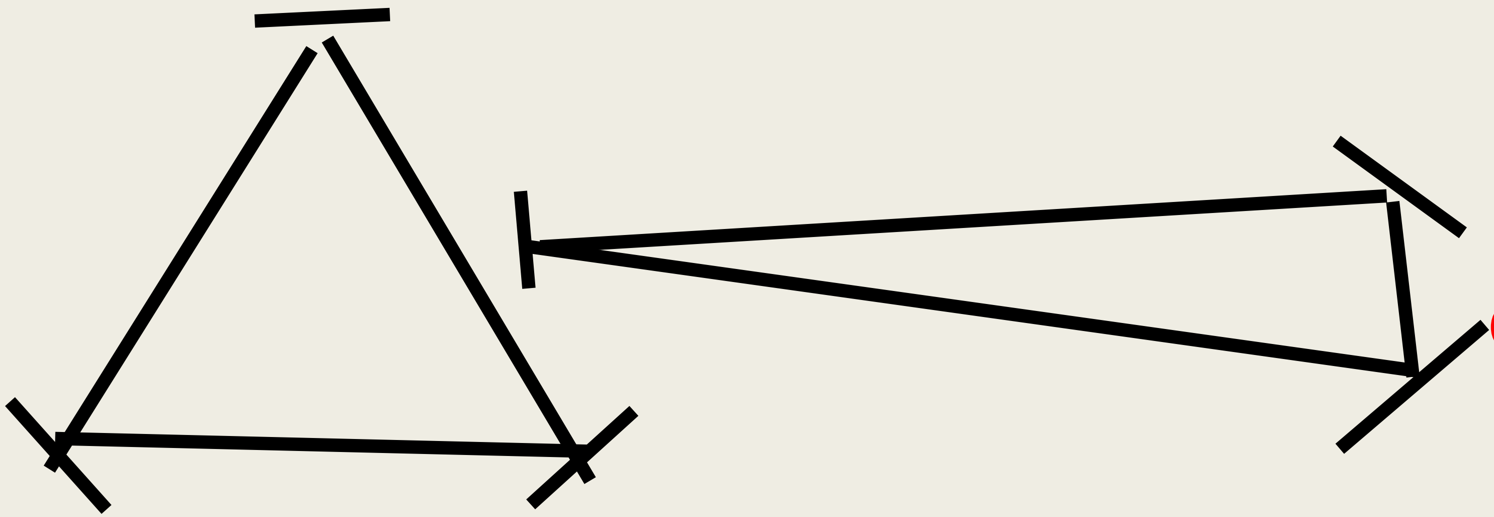
3) Is there a way to "compress" the information? YES

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

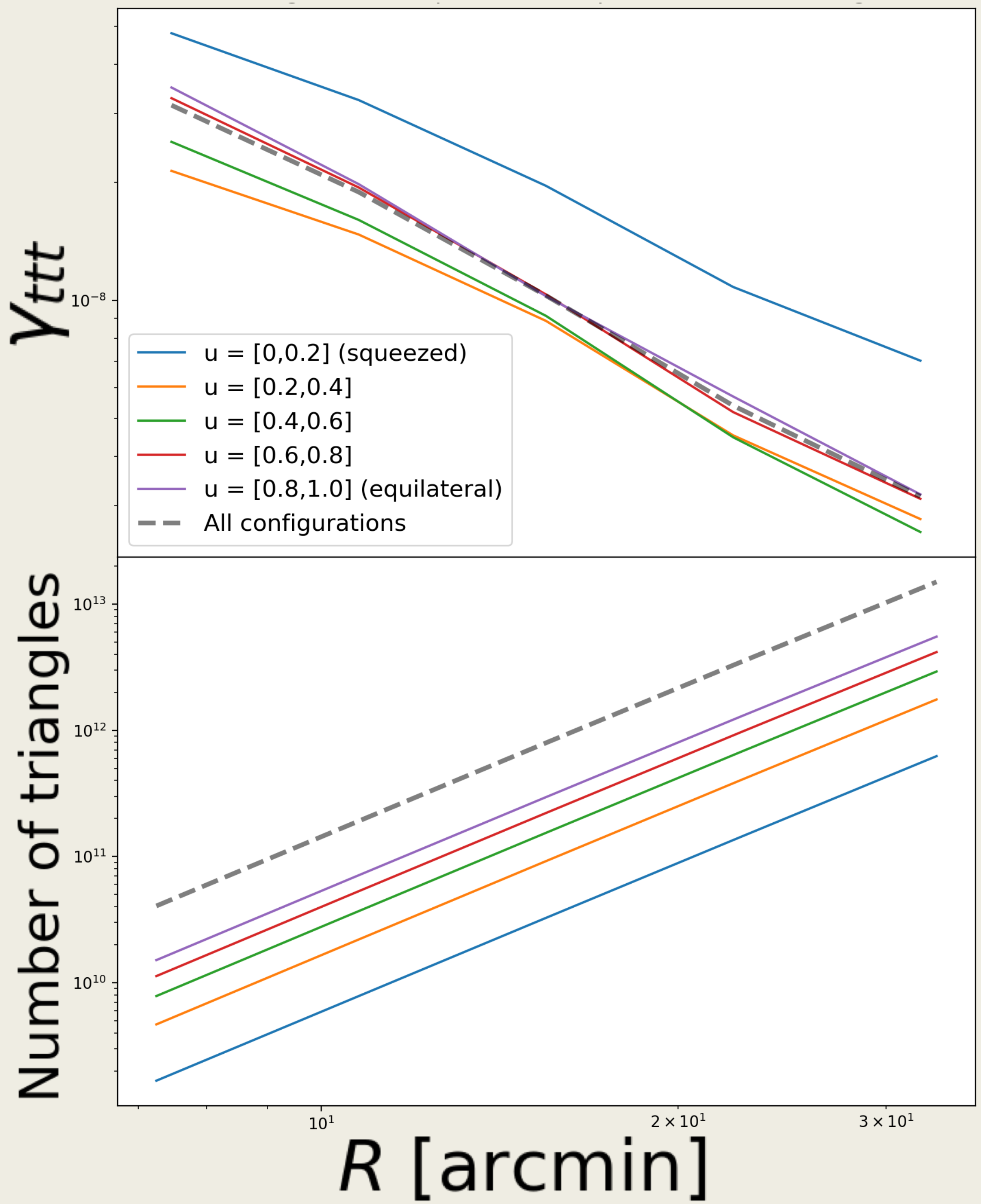
Detecting shear-3pt

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)

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

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

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

Detecting shear-3pt

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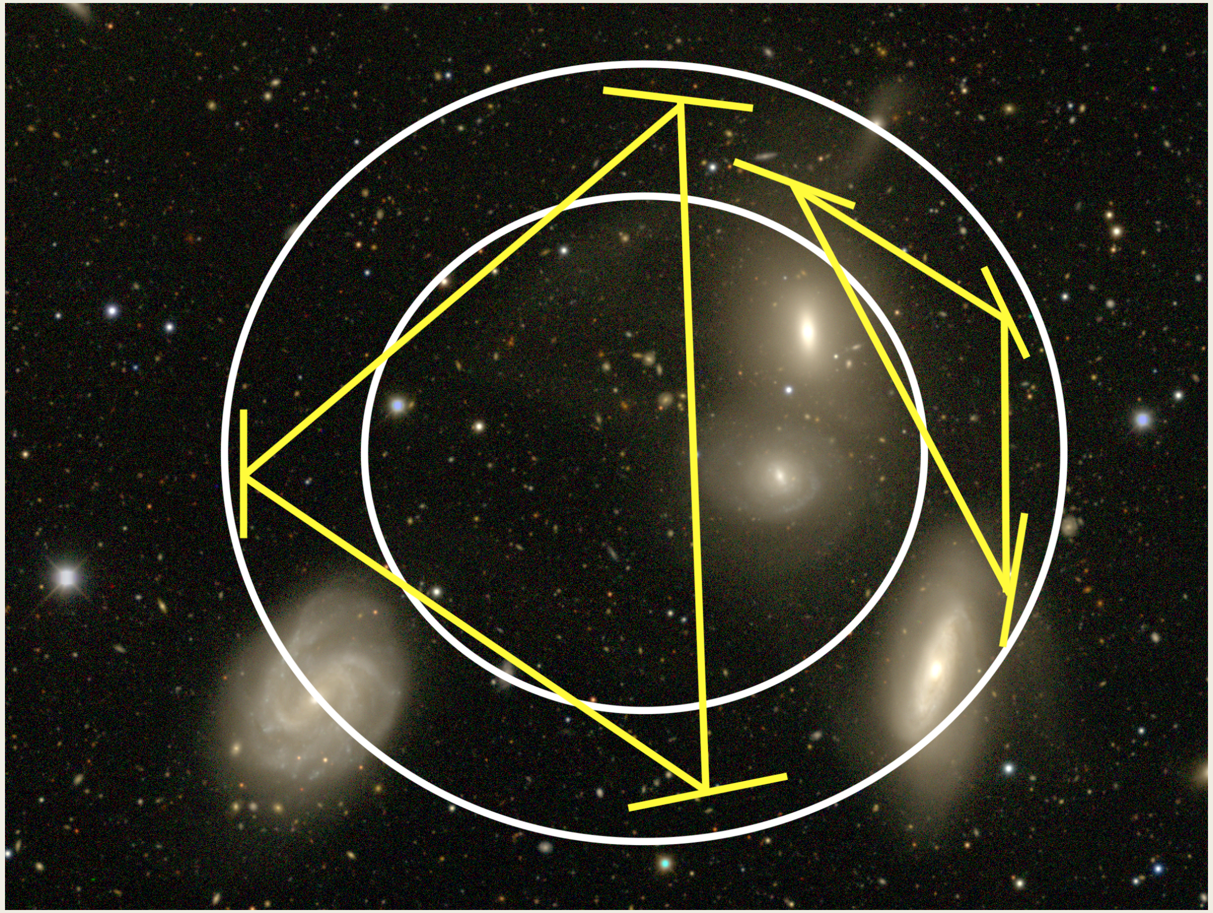
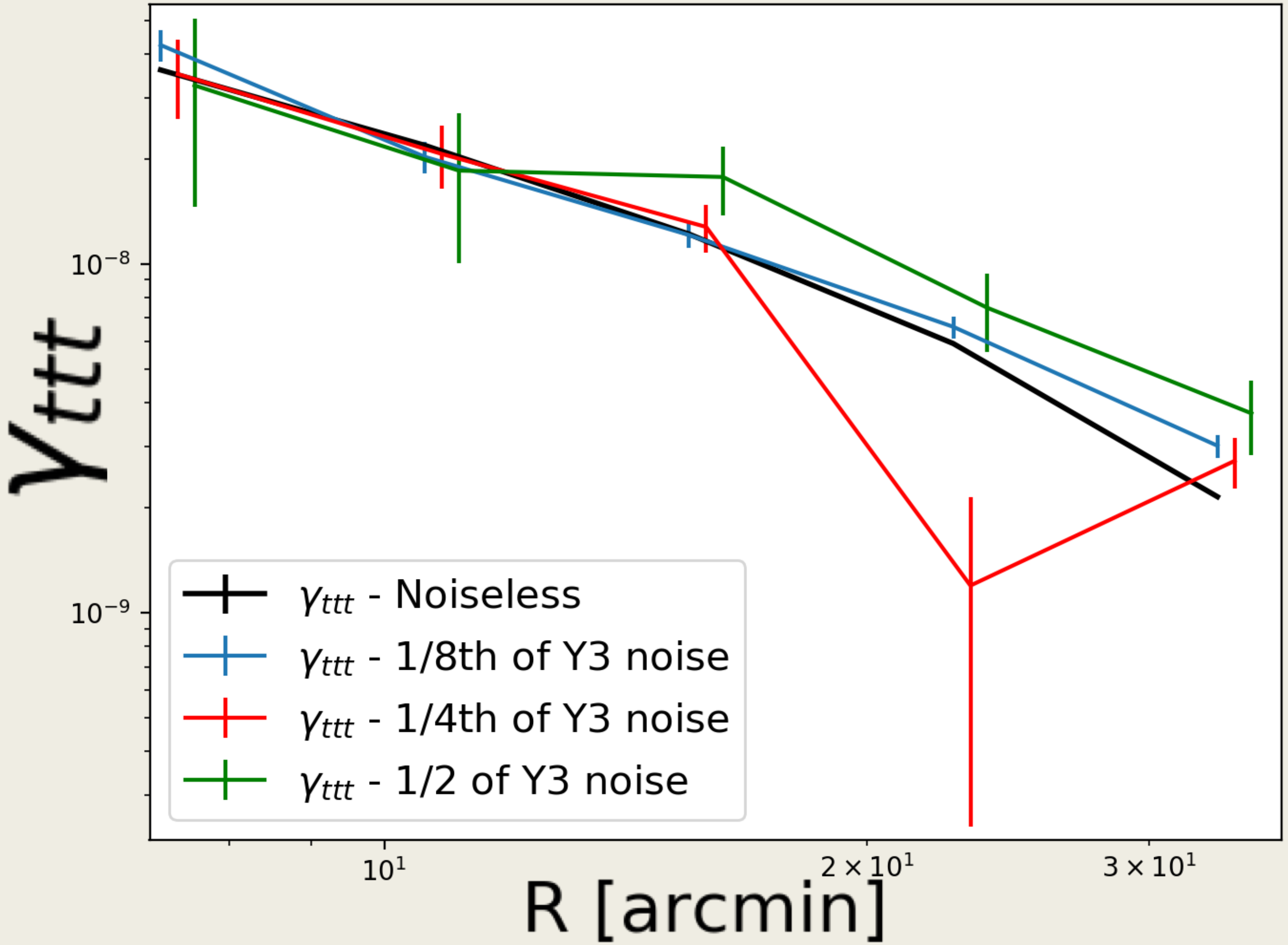


Detecting shear-3pt

4) Tests with N-body sims

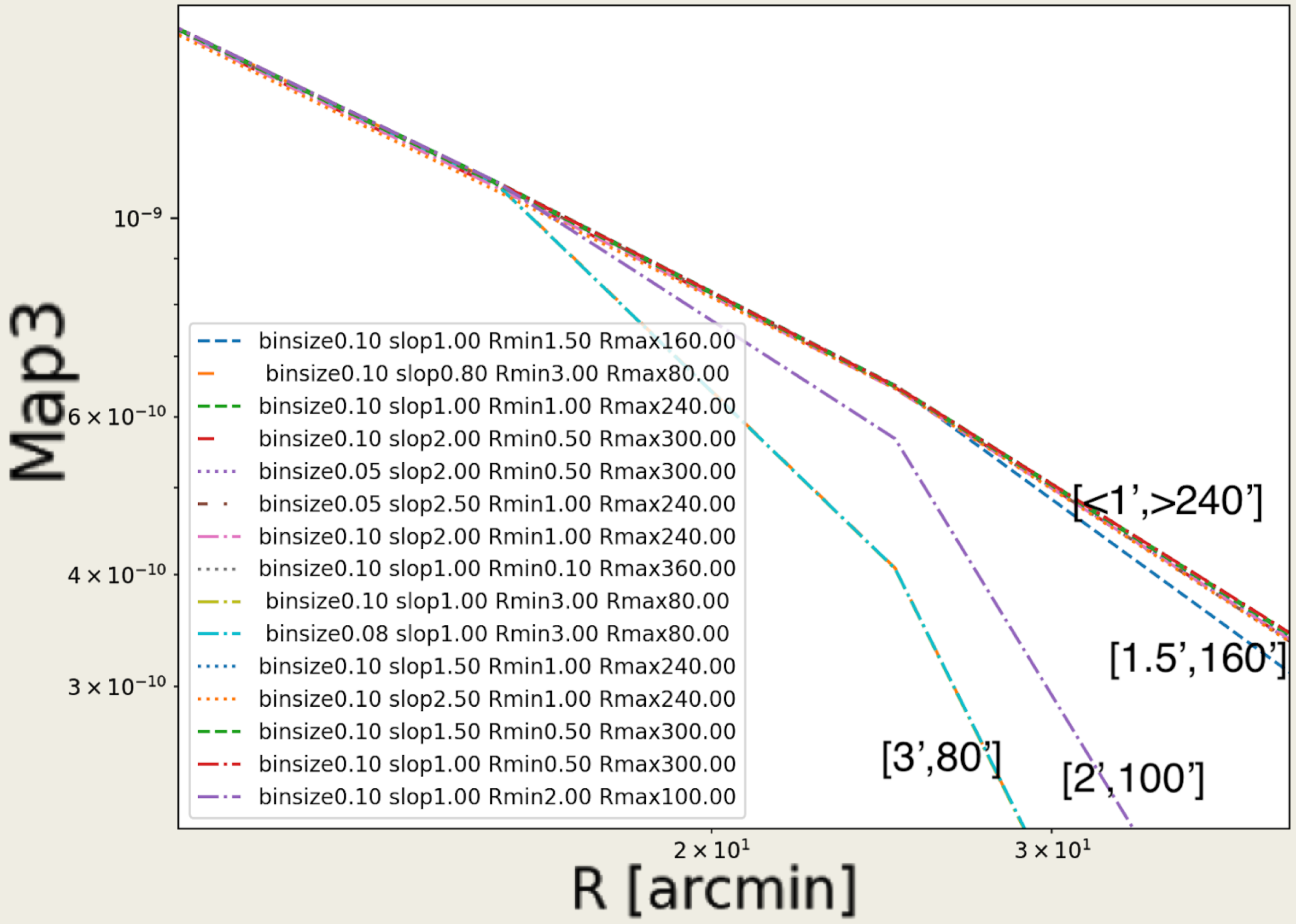
Start from the noiseless shears (pure gravity), crank up the noise to match DES-Y3



Detecting shear-3pt

4) Tests with N-body sims

Test binning schemes, estimator configurations for <Map³>



Detecting shear-3pt

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

Detecting shear-3pt

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

$$\langle Map^3\rangle \gtrsim 9\sigma$$

Detecting shear-3pt

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

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

$$\langle Map^3\rangle \gtrsim 9\sigma$$

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 <γγγ>)
- Cosmic shear in upcoming DES will help test ΛCDM 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

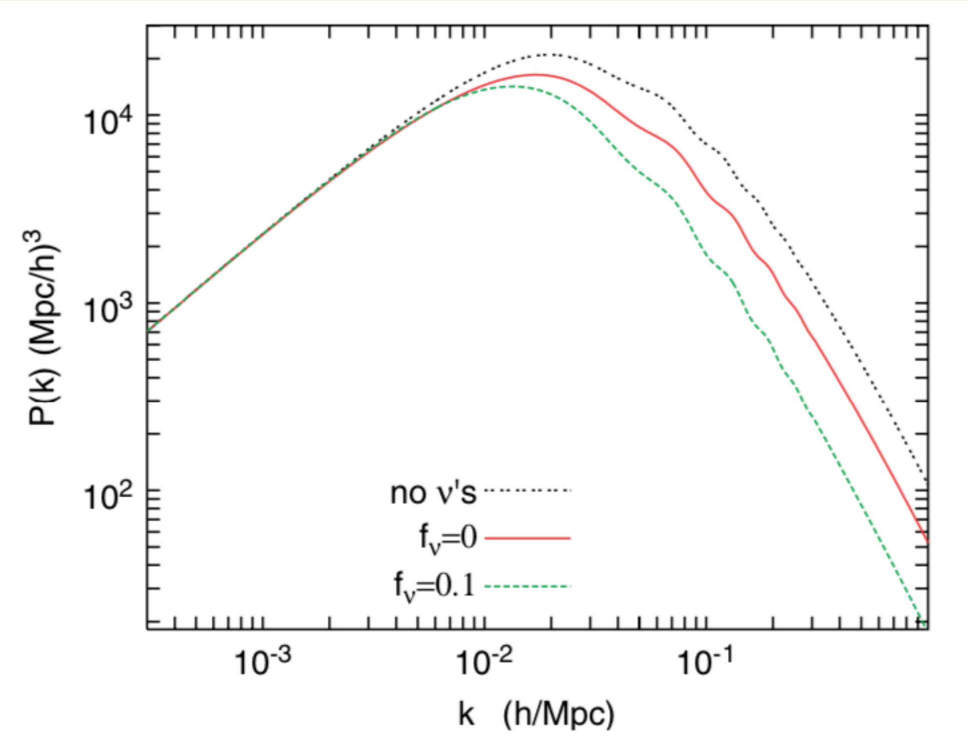
Thank you!

Extra slides

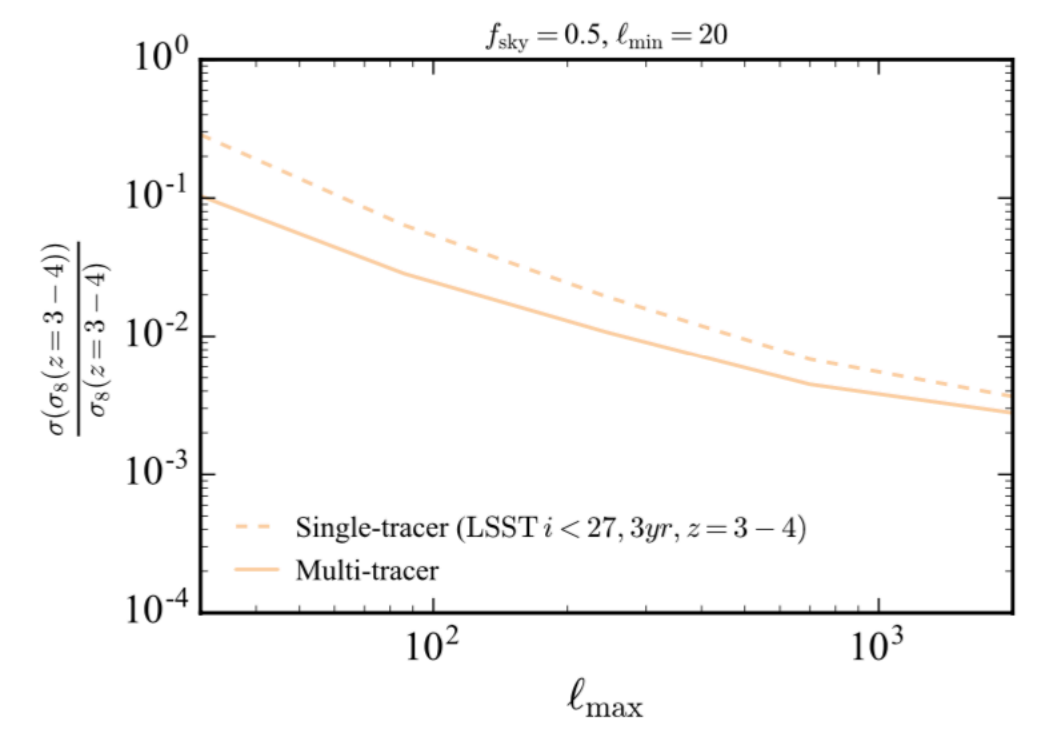
Outlook and other interests

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

[Lesgourges & Pastor 2006]



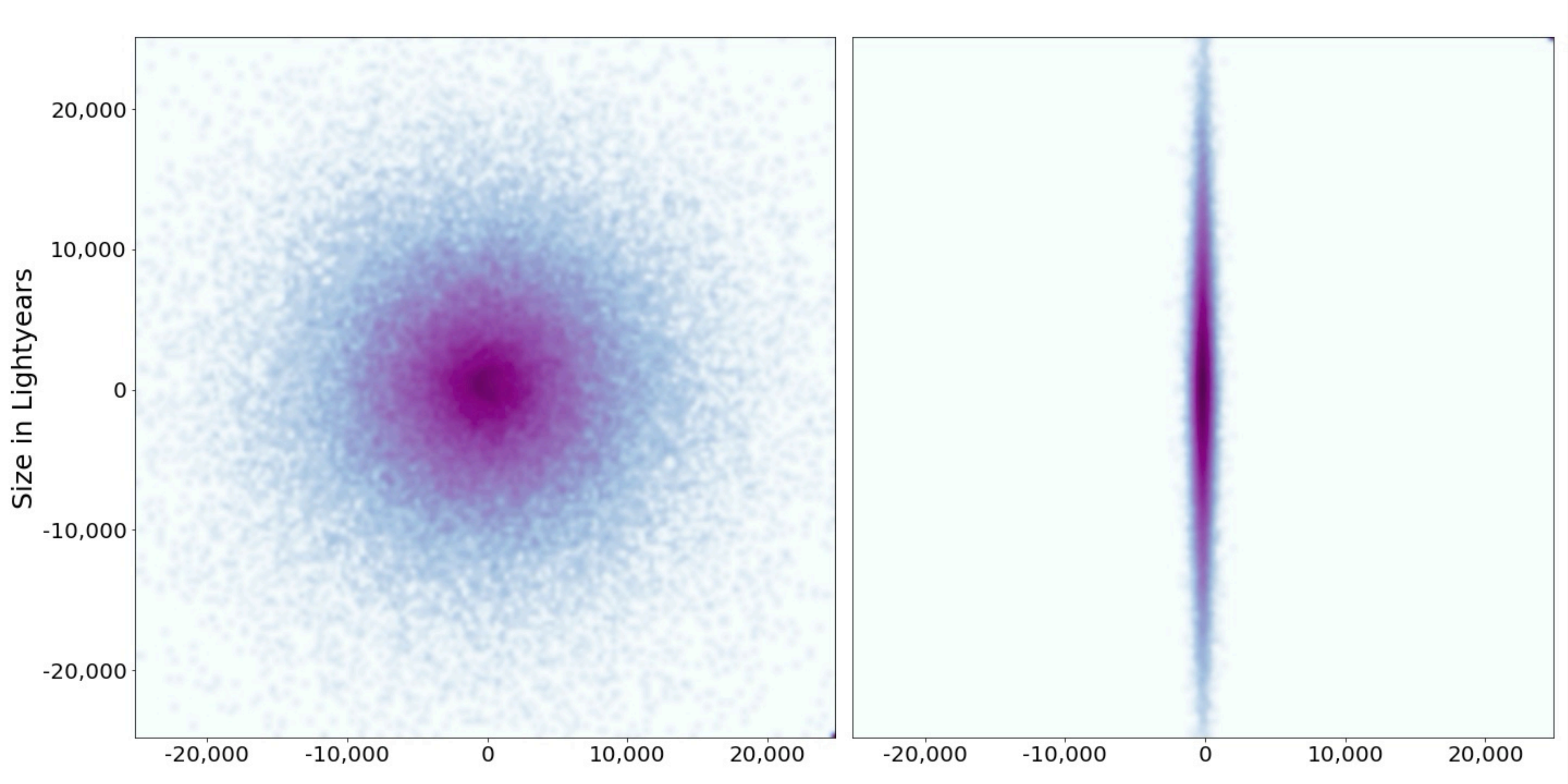
Neutrino masses



[Schmittfull & Seljak 2018]

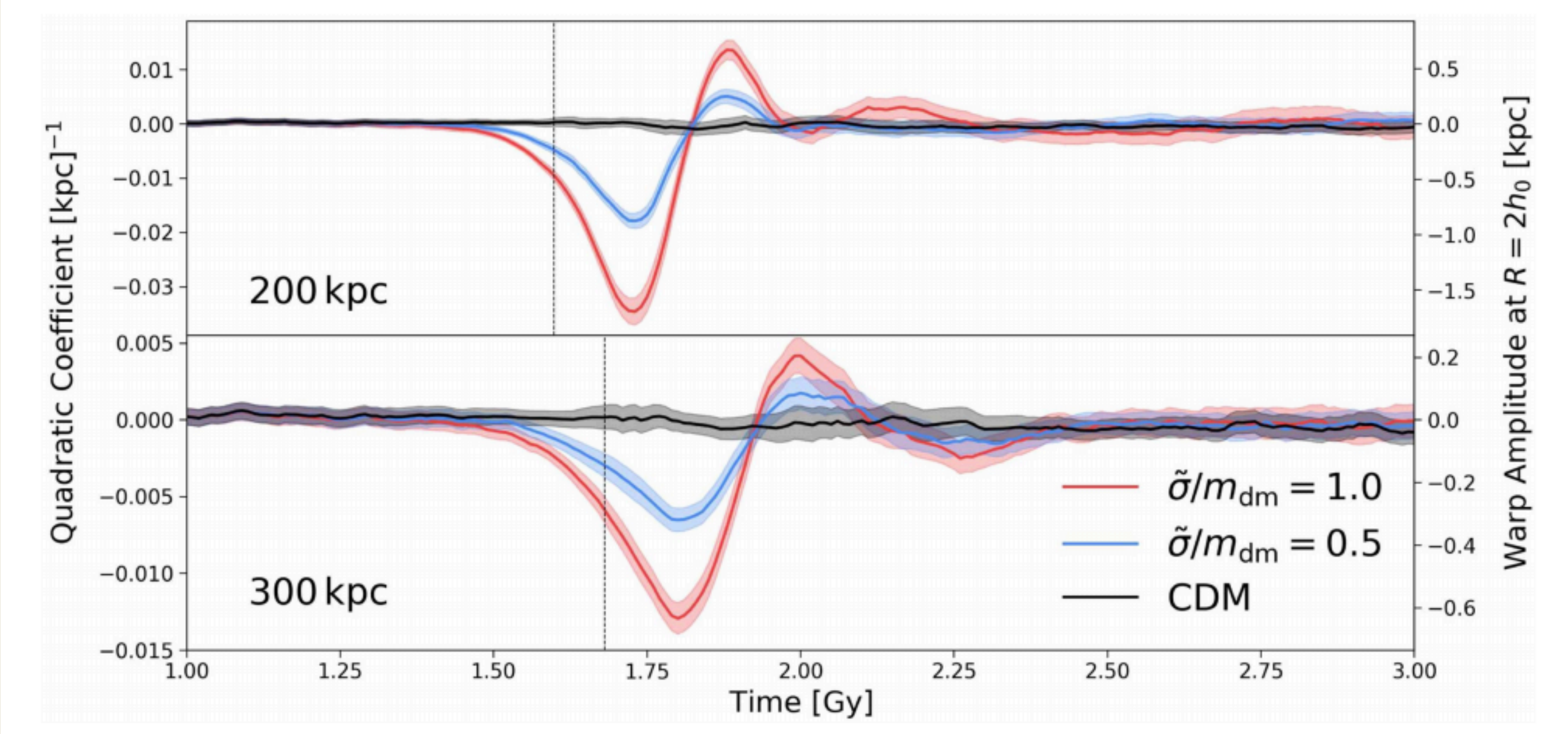
Multi-tracer tricks in LSS

Outlook and other interests



LS et al 1712.04841 – SIDM in disk galaxies

Outlook and other interests



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