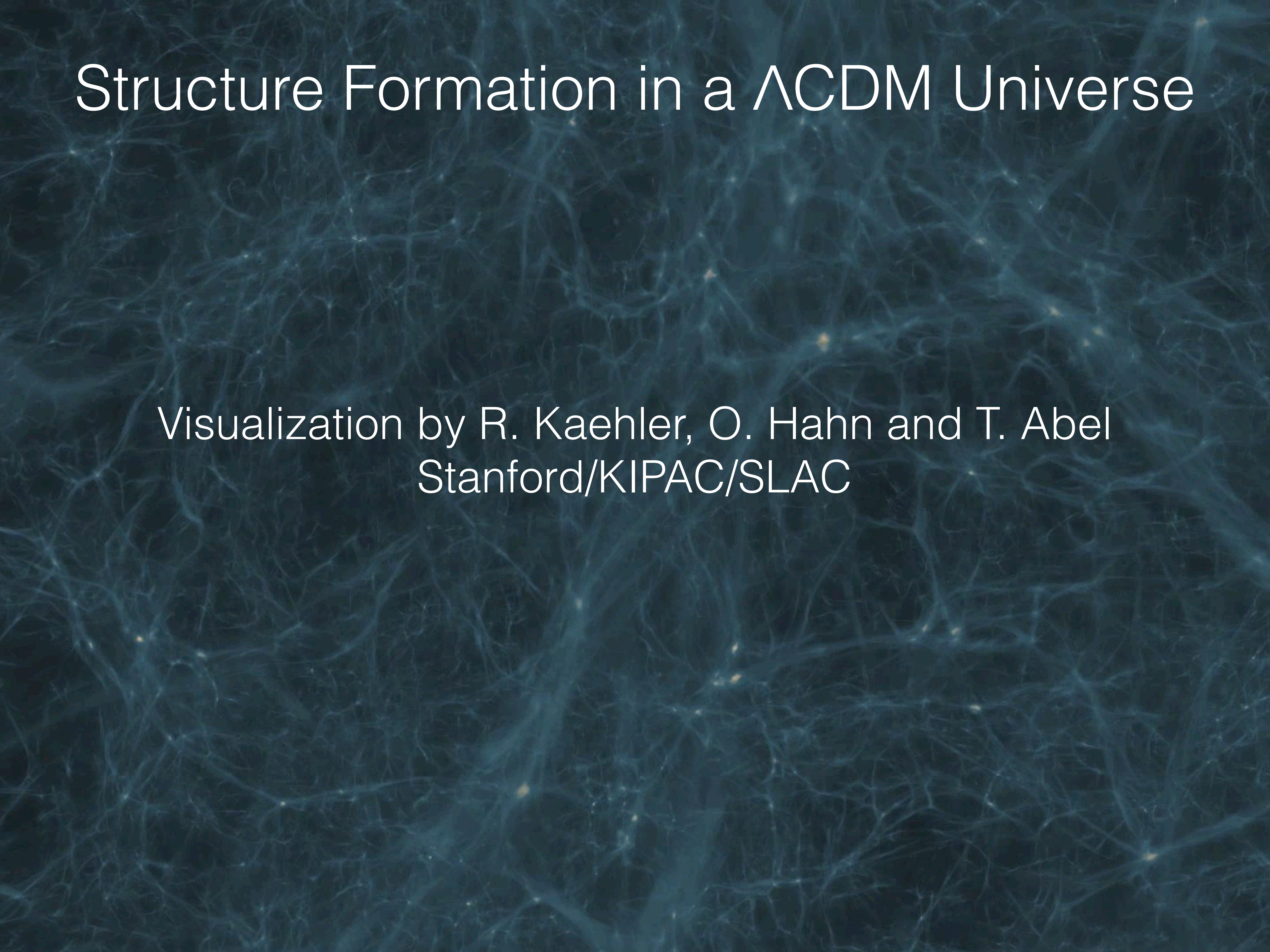
Cosmic Shear Measurements with Dark Energy Survey Science Verification Data

Matthew R. Becker
Stanford/KIPAC/SLAC

On behalf of the Dark Energy Survey Collaboration and the DES Weak Lensing Working Group (deswl.github.io)

Jarvis et al. (arXiv:astro-ph/1507.05603)
Bonnett et al. (arXiv:astro-ph/1507.05909)
Becker et al. (arXiv:astro-ph/1507.05998)
The DES Collaboration et al. (arXiv:astro-ph/1507.05552)

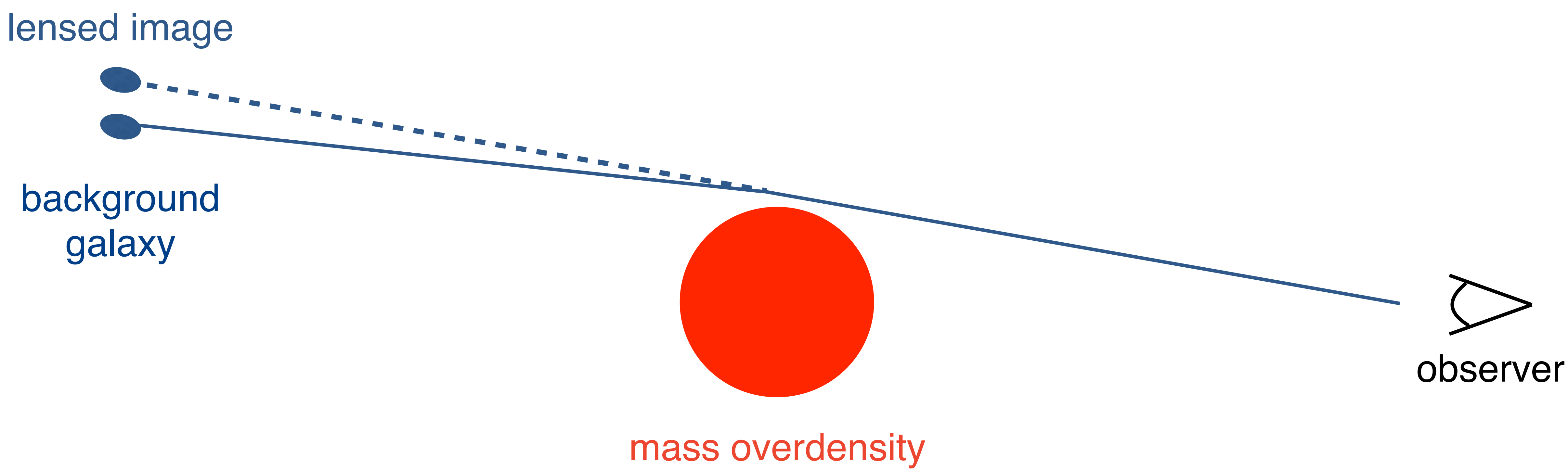
Structure Formation in a ΛCDM Universe



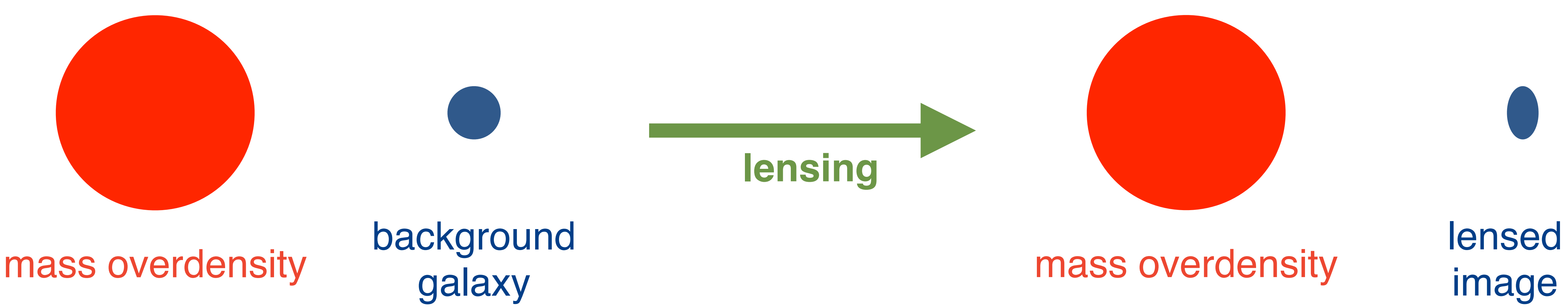
Visualization by R. Kaehler, O. Hahn and T. Abel
Stanford/KIPAC/SLAC

Weak Gravitational Lensing

side view:



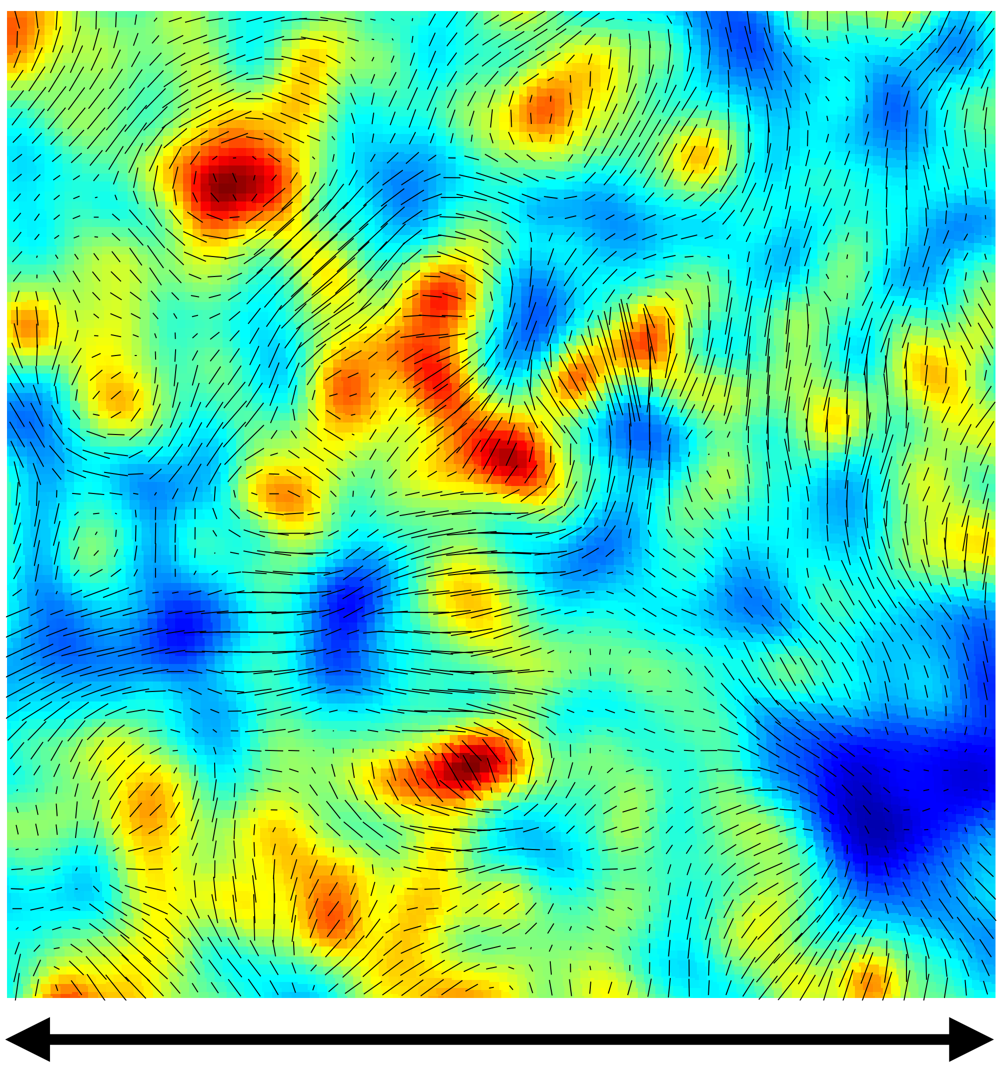
front view:



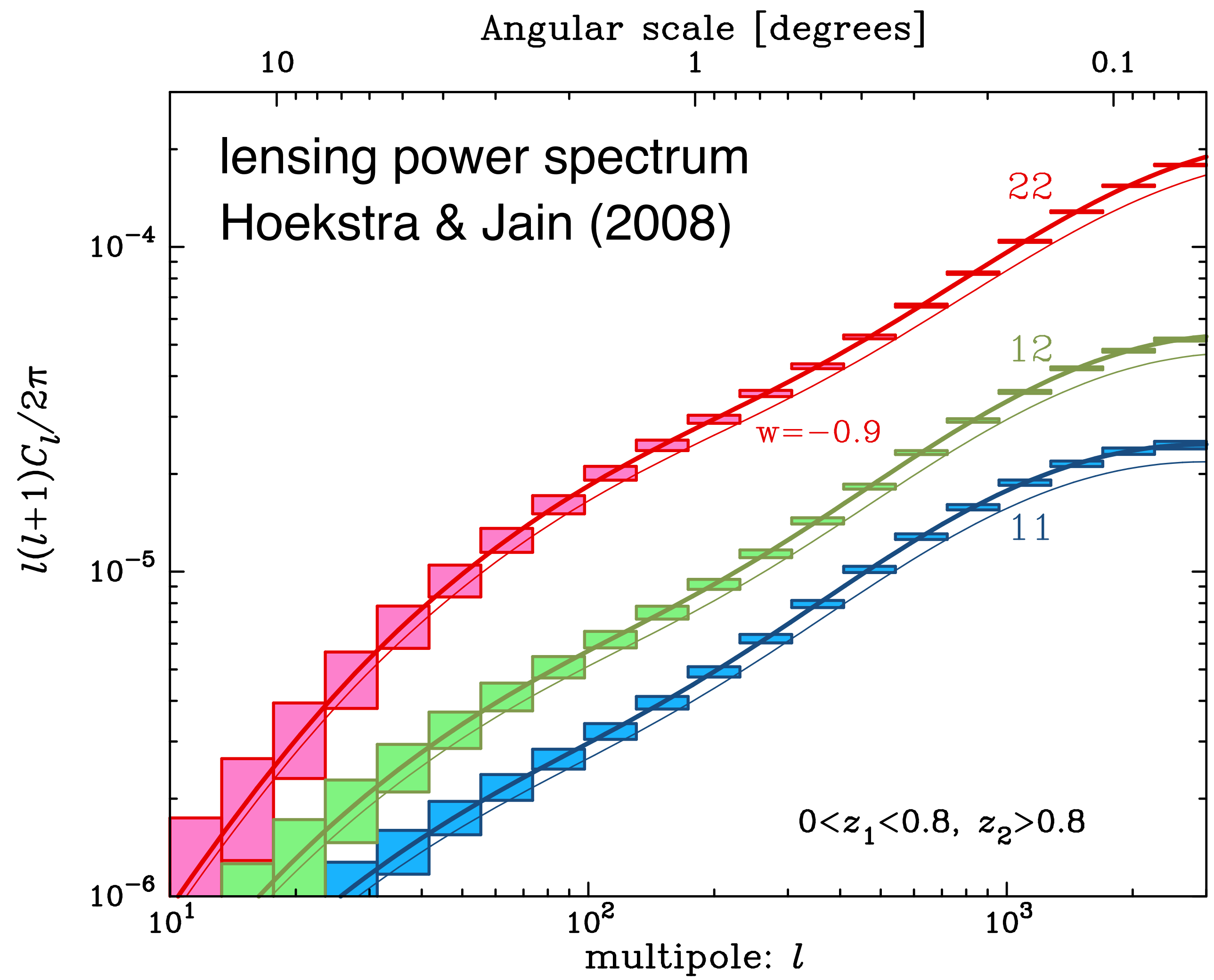
Cosmic Shear

In cosmic shear, you measure the auto- and cross-correlations of galaxy shapes in different redshift bins.

Convergence and shear fields at z=0.57



12.5 degrees



$$C_{\gamma_i\gamma_j}(\ell) = \int_0^\infty dz\, \frac{W_i(z)\, W_j(z)}{\chi(z)^2\, H(z)}\, P_\delta\left(\frac{\ell}{\chi(z)}, z\right)$$

$W_i(z)$: lensing kernel

$P_\delta(k,z)$: matter power spectrum

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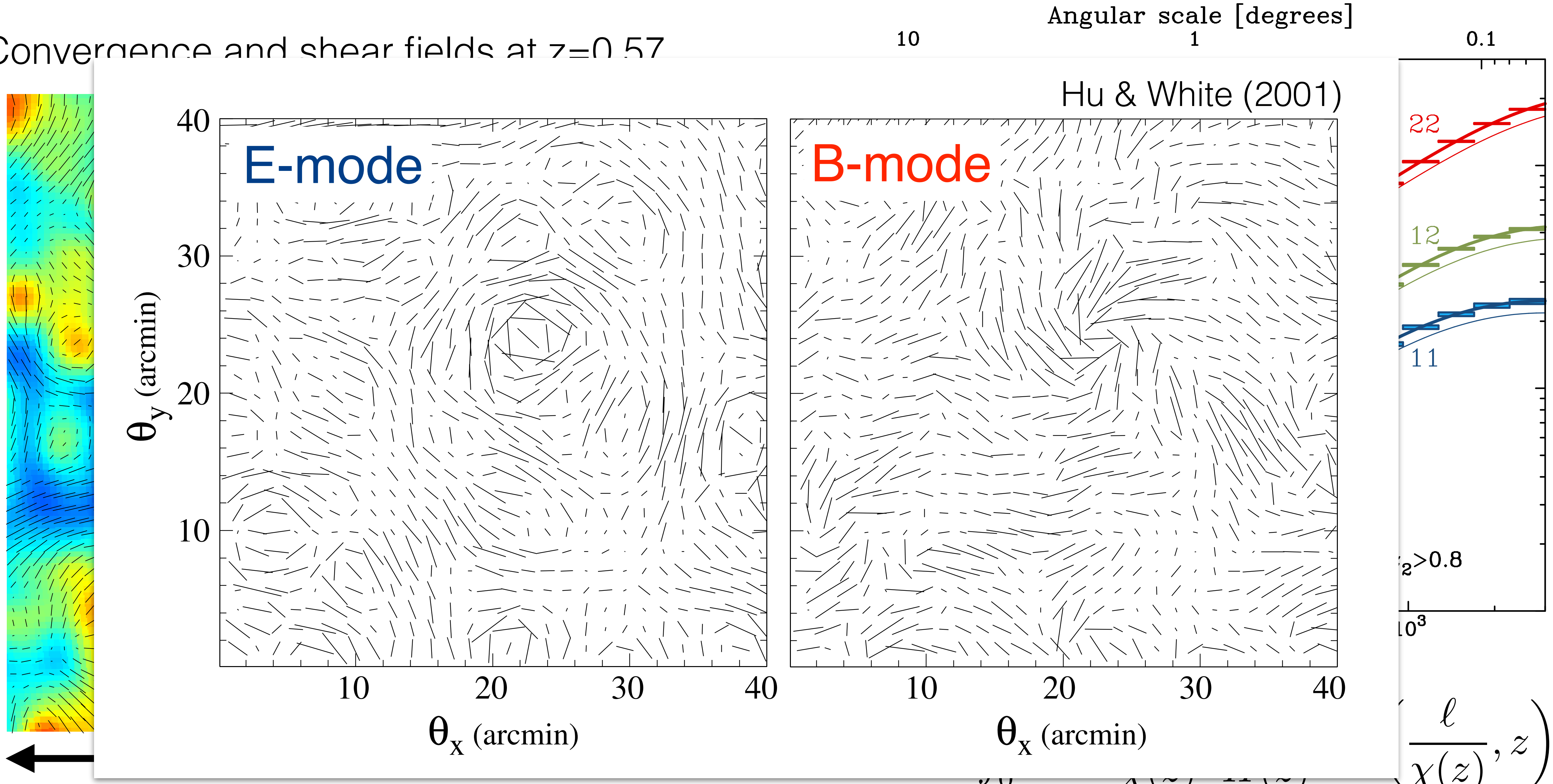
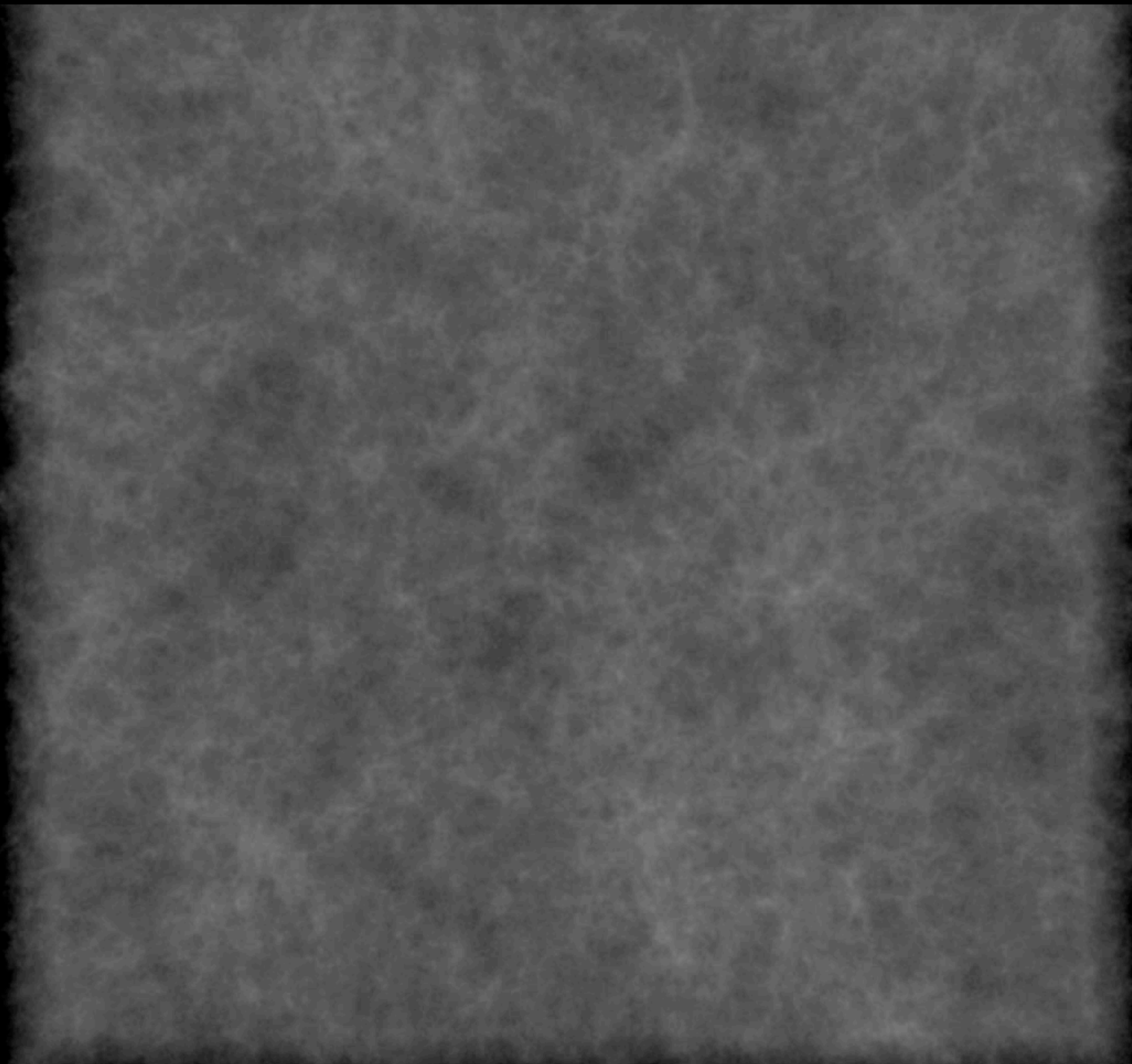


12.5 degrees

Wi(z): lensing kernel

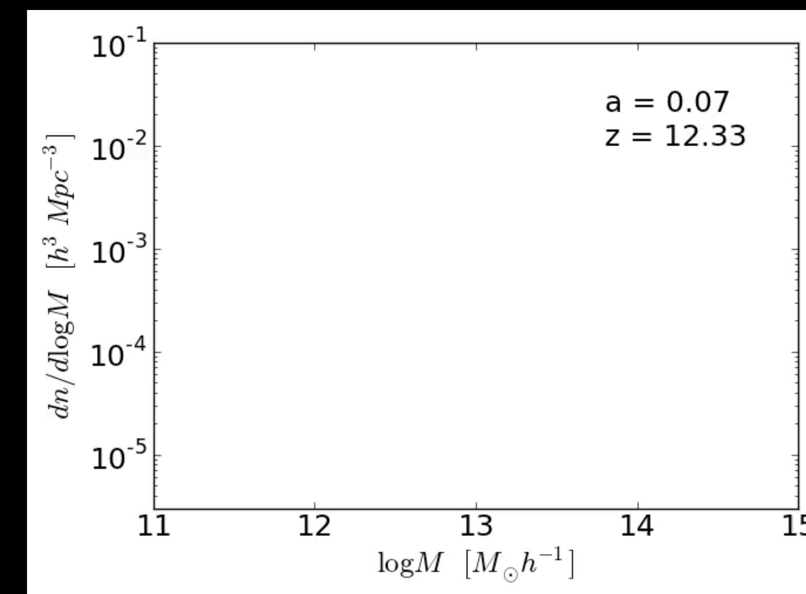
Pδ(k,z): matter power spectrum

matter distribution (125 Mpc/h)

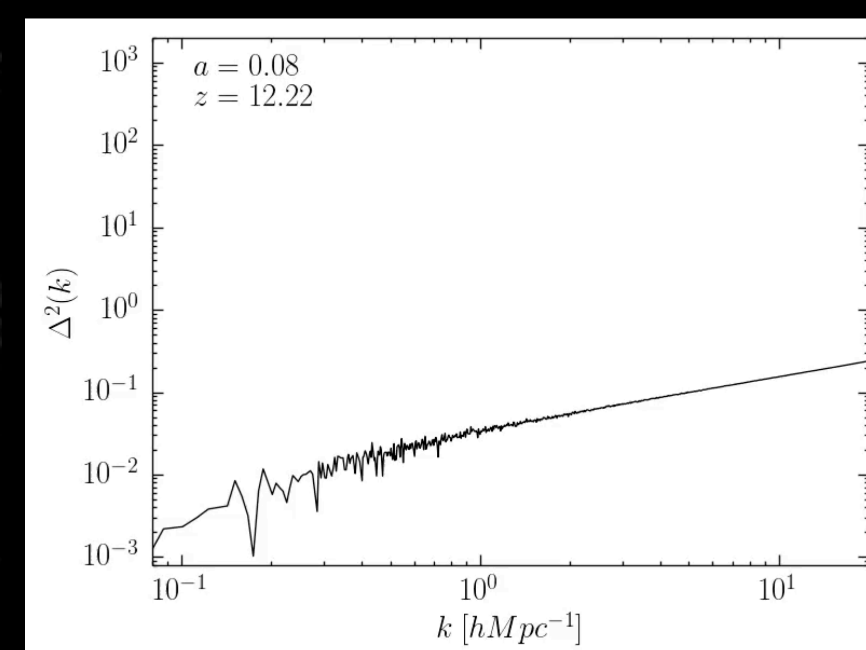


example statistics:

halo mass function

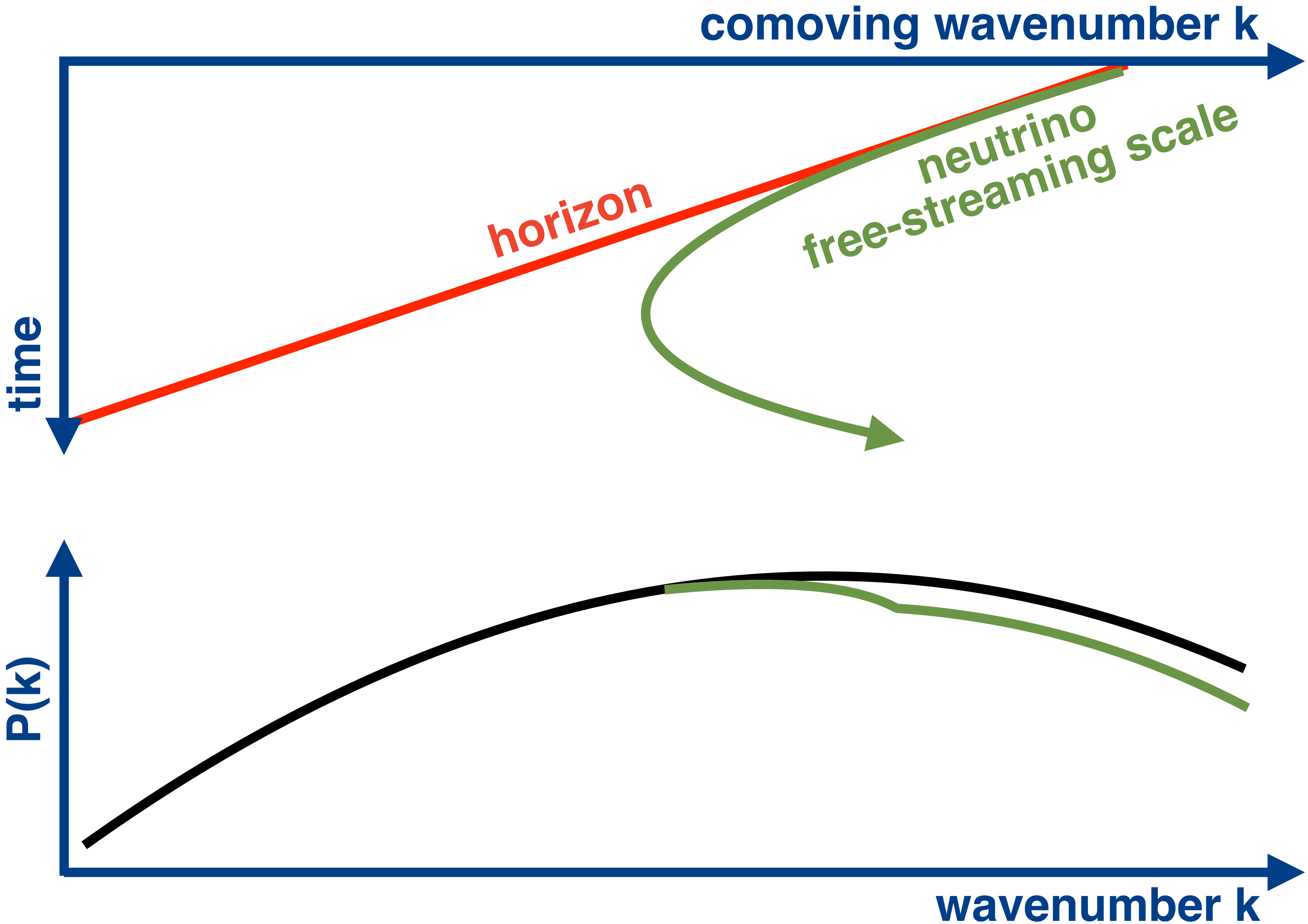


matter power spectrum



movie, simulation, statistics: Matt Becker, Ralf Kaehler, Yao-Yuan Mao, Rachel Reddick, Risa Wechsler (Stanford/SLAC)

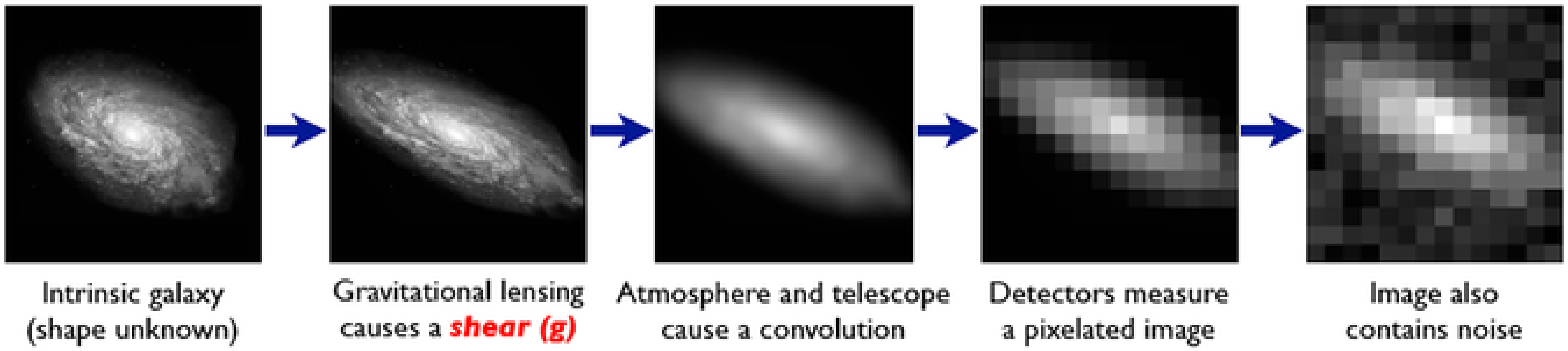
Neutrinos and Large-scale Structure



Some Practicalities

We observe galaxies with telescopes!

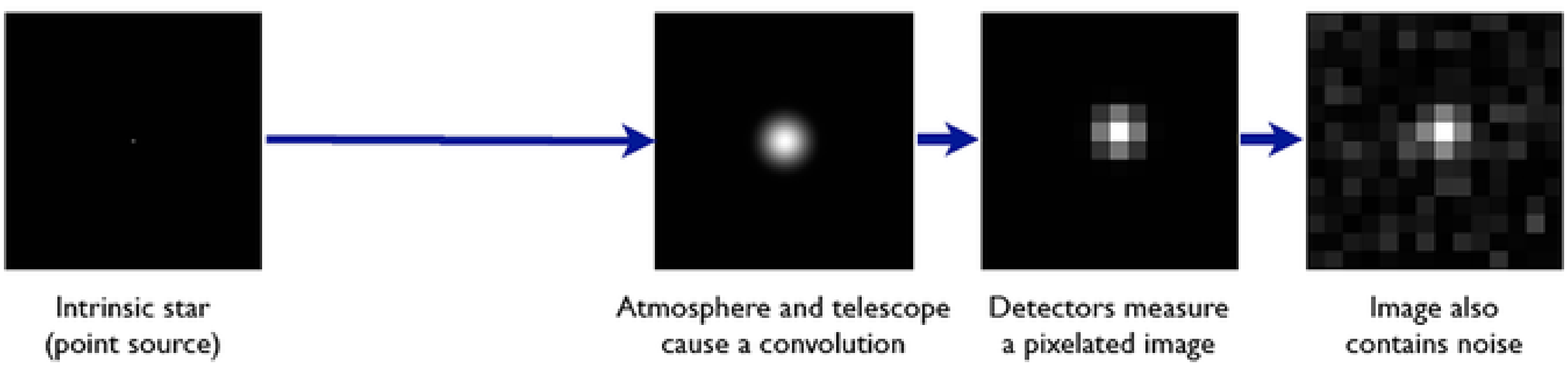
galaxies:



convolution with point spread function (PSF)

stars provide measurements of the PSF

stars:



graphic from the GREAT08 handbook (arXiv:astro-ph/0802.1214)

Measuring shears is hard!

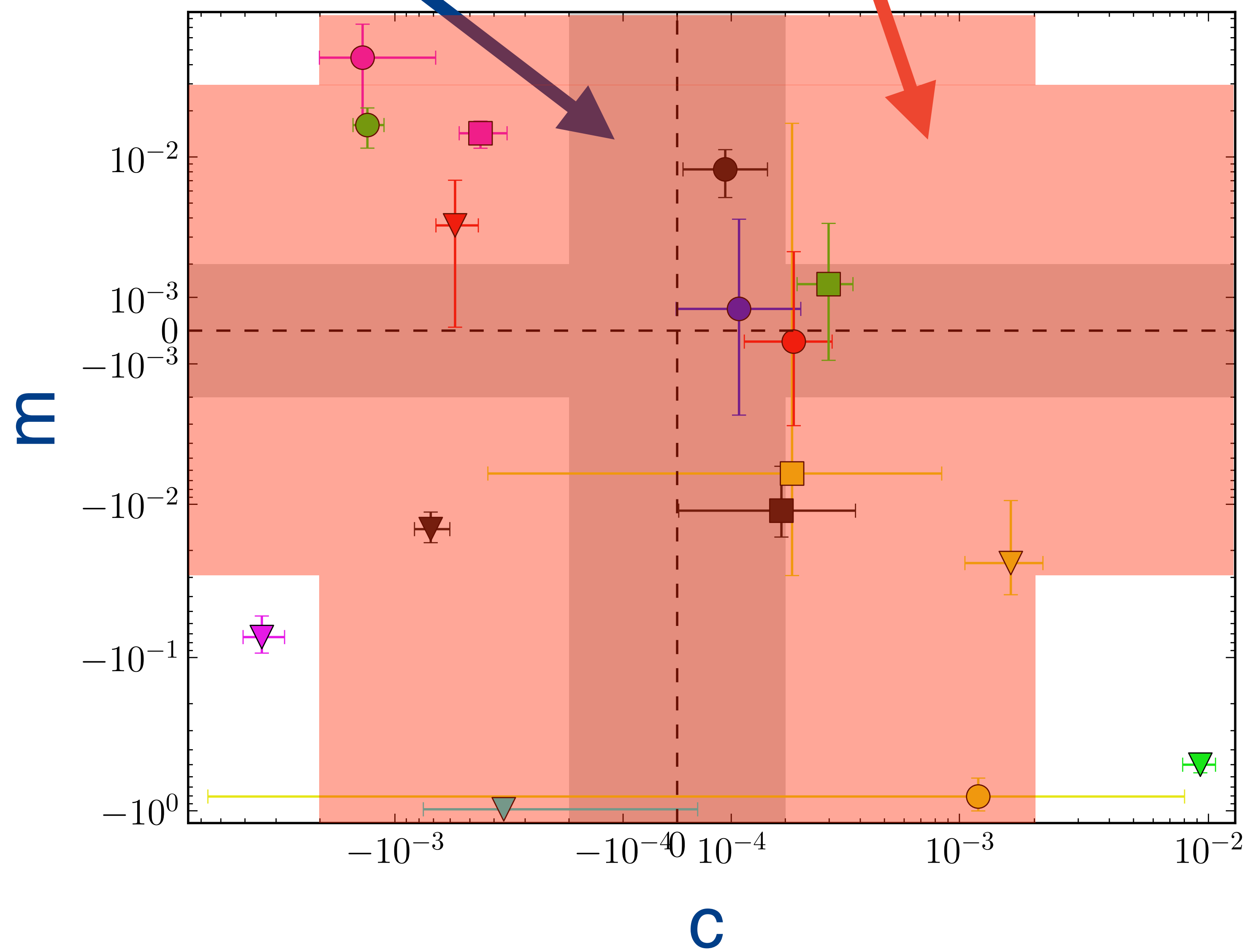
additive errors

$$g_i^{\rm obs} - g_i^{\rm true} = m_i g_i^{\rm true} + c_i$$

multiplicative errors

space-based lensing requirements

DES SV requirements!

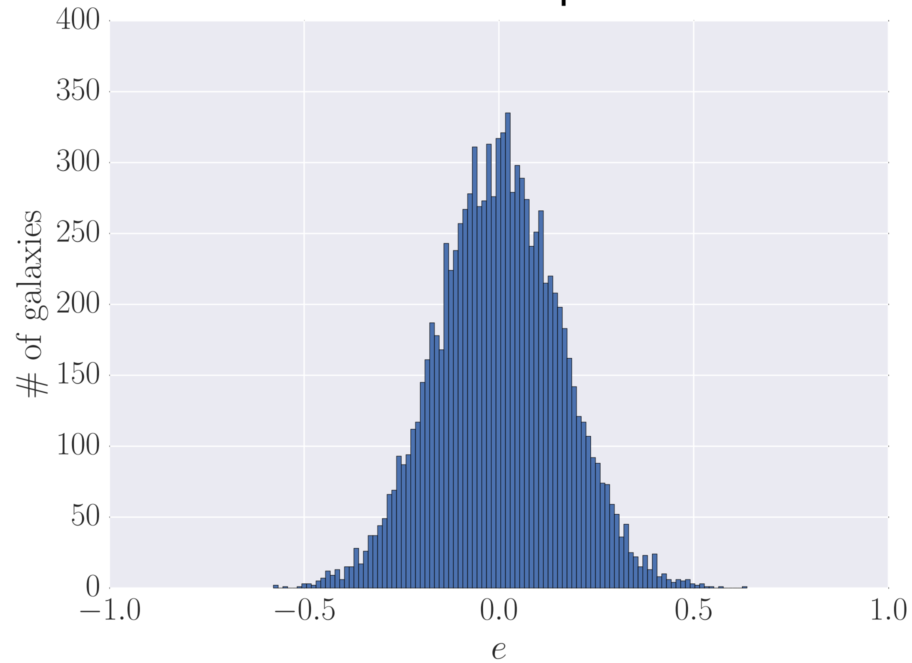


Results from GREAT3 Challenge (arXiv:astro-ph/1412.1825)

Lensfit 101

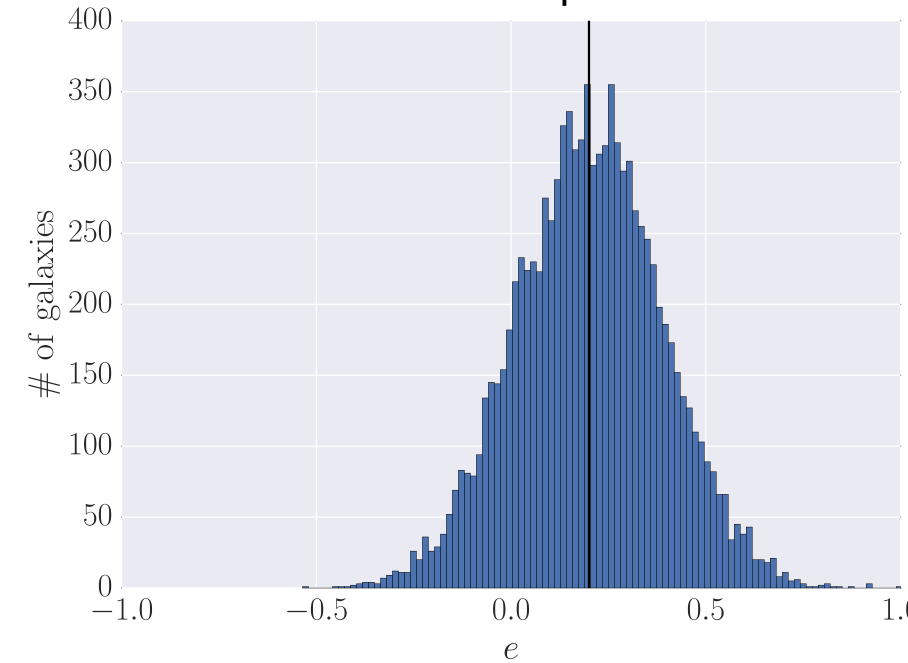
See Miller et al. 2007!

intrinsic shape dist.



lensing + noise

lensed shape dist.



shear estimate defined by posterior mean:

$$\langle e\rangle = \frac{1}{N}\sum_i \int e\; p_i(e|x_i)de = \frac{1}{N}\sum_i \langle e\rangle_i$$

$$p_i(e|x_i) \propto \mathcal{L}(x_i|e)P(e)$$

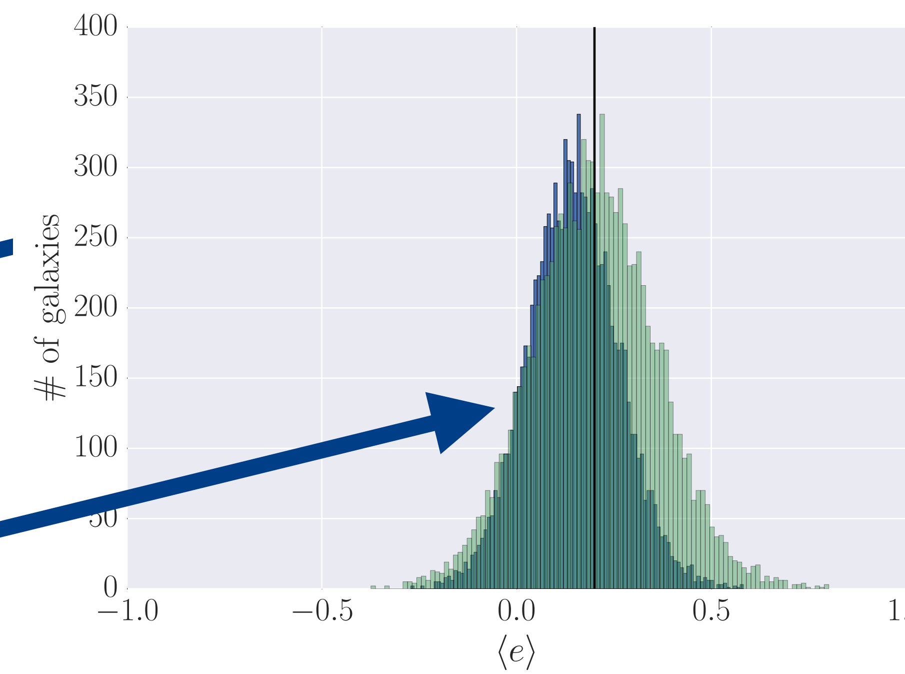
bias due to zero shear prior P(e)

correct for bias via. Taylor expansion at g = 0:

$$\langle e\rangle_i \approx e_i^s + g\,\partial\langle e\rangle_i/\partial g + \ldots$$

$$\sum_i \langle e\rangle_i \approx g\sum_i \partial\langle e\rangle_i/\partial g + \ldots$$

shear sensitivity



Two-point Function Estimators

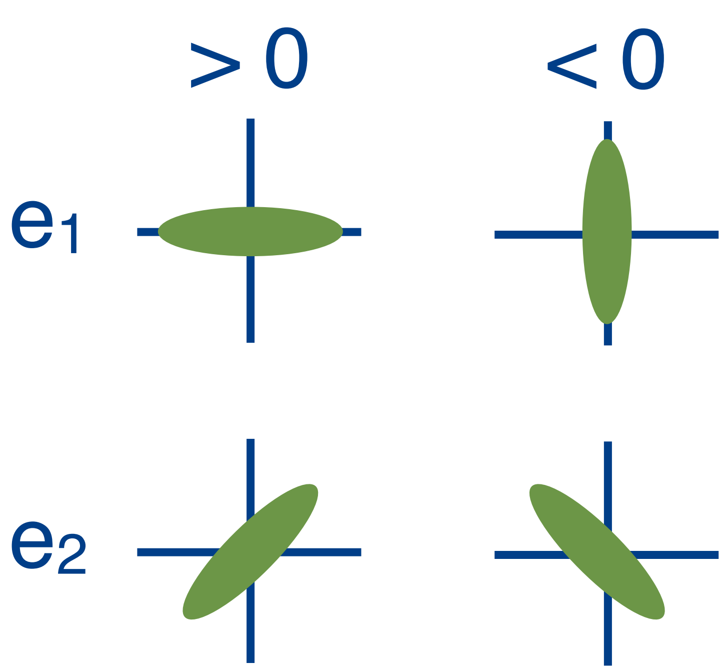
weights

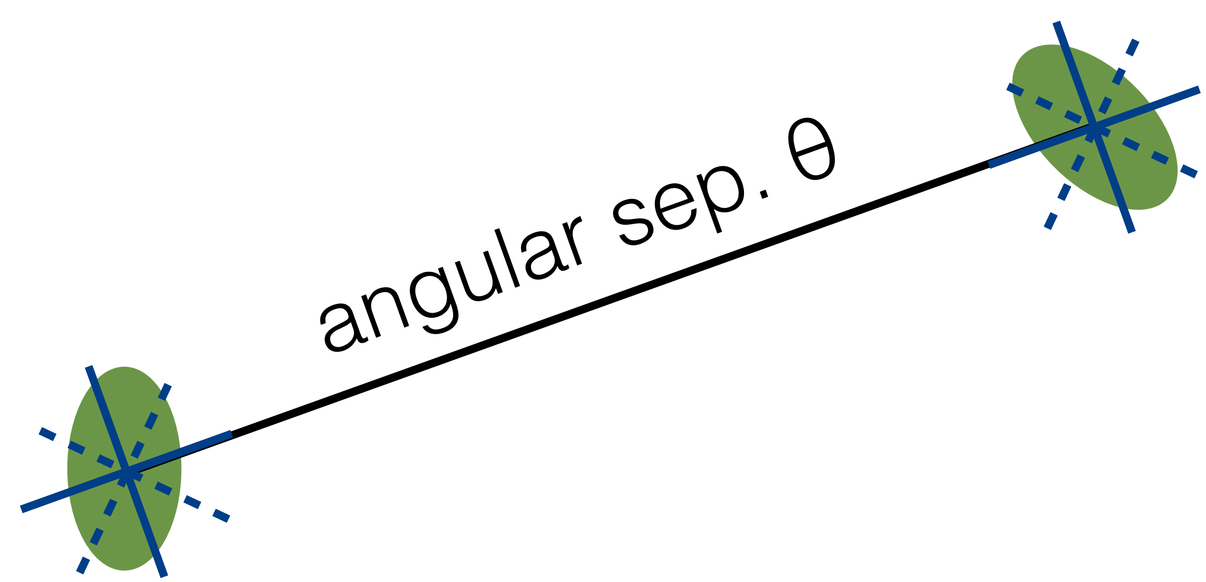
$$
\begin{aligned}
\xi_{\pm} &= X_{+} \pm X_{\times} \\
X_{+/\times} &= \frac{\sum_{i,j} w_i w_j (e-c)^i_{+/\times} (e-c)^j_{+/\times}}{\sum_{i,j} w_i w_j s^i s^j}
\end{aligned}
$$

im3shape additive corrections

sensitivities

Shears and measurement geometry:





Cosmic Shear w/ the Dark Energy Survey

So how does this actually go?

1) a survey (e.g., the Dark Energy Survey)
2) data reduction/calibrations (DES Data Management)
3) shear measurements (e.g., ngmix and im3shape)
4) estimate photometric redshifts
5) estimate covariances of the two-point functions
6) lots of tests, simulations and analysis

The rest of the talk will be about all of these different things with more detail on some than others.

The Dark Energy Survey

The DES aims to constrain the nature of Dark Energy with four probes: clusters (growth), weak lensing (growth), BAO (distance) and supernovae (distance).

Some basic facts about the DES:

- on the Blanco 4-meter telescope at the Cerro Tololo Inter-American Observatory
- survey goes from 2013-2018 w/ 525 nights
- DECam: 570 Mpix, 3 deg^2 FOV, grizY filters
- 5,000 deg^2 survey to 24th mag (10 tilings per band)
- 30 deg^2 deep SN fields

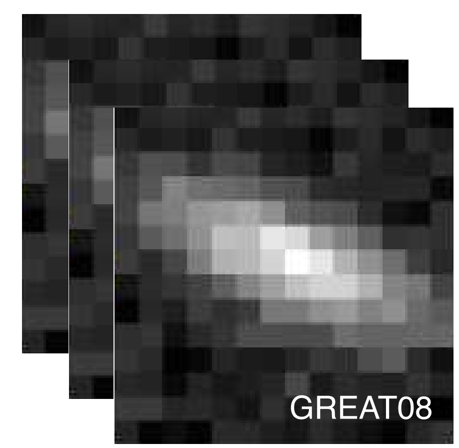
Here I will focus on the analysis of DES Science Verification data. This dataset (for cosmic shear) consists of ~139 deg^2 to approximate full DES depth. It covers the eastern portion of the overlap with the SPT survey, and so has been dubbed informally “SPT East.”

DES SV Shear Measurements

Jarvis et al. (2015; arXiv:astro-ph/1507.05603)

The shape estimation codes use a full likelihood over all of the individual images of each source to measure shears.

DESDM makes coadds and final-cut images → DES WLWG makes MEDS data containing all images of all sources →



→ shear $\{g_1, g_2\}$

$$\mathcal{L}_{tot} = \prod_i \mathcal{L}_i$$

Additional Notes:

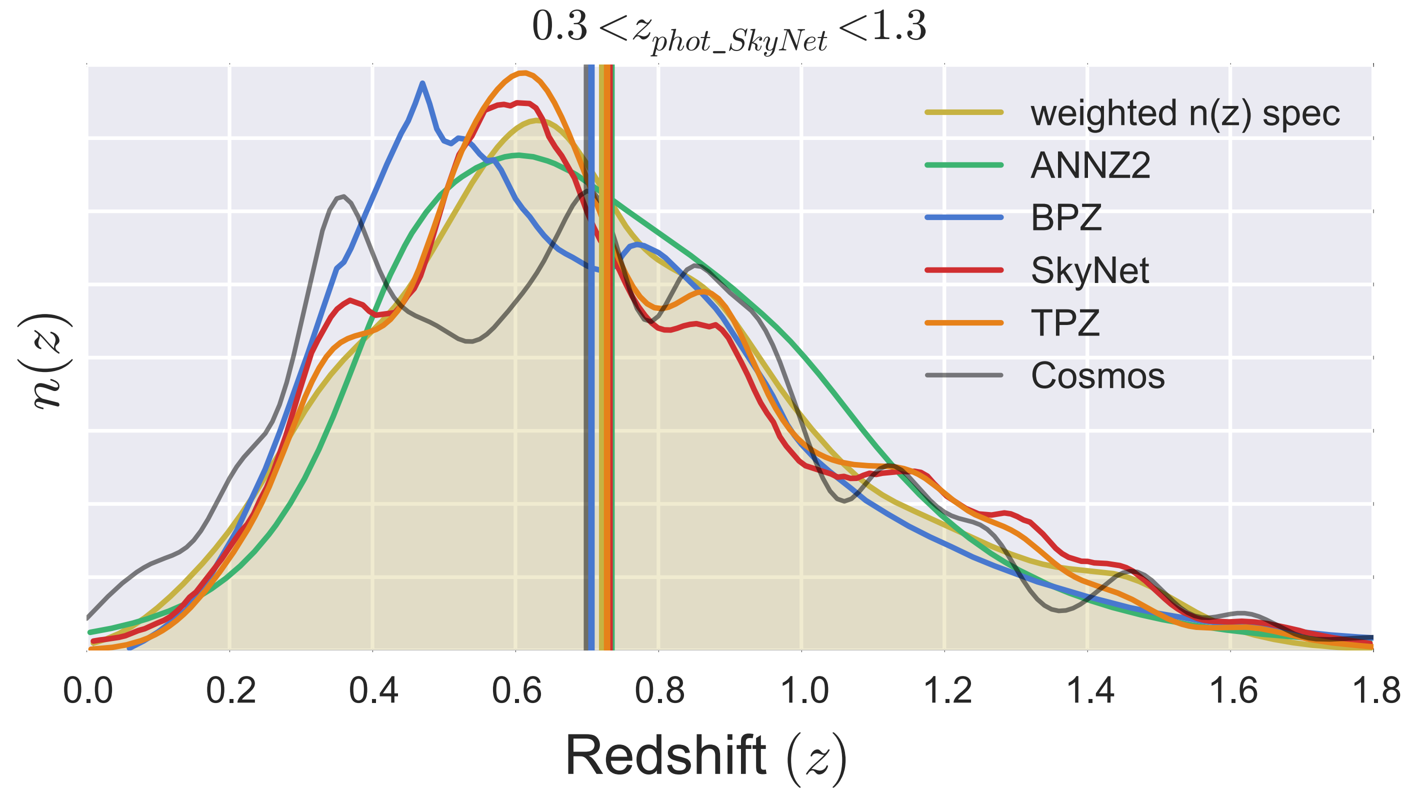
- the DES currently uses two substantially different shear estimation codes (ngmix and im3shape)
- PSF is interpolated with PSFEx (Bertin) excluding brightest stars
- masking of neighboring galaxies in postage stamps is done on-the-fly (but the most blended things are cut)

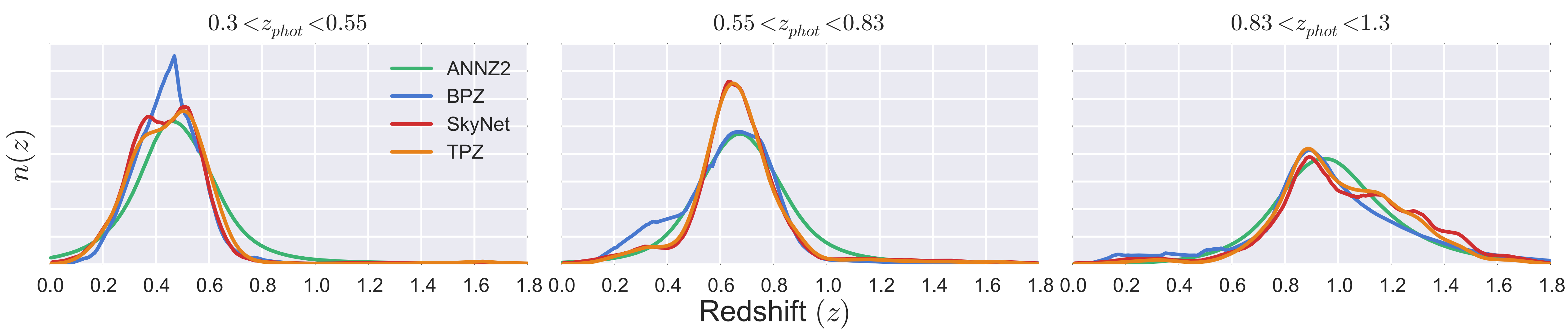
DES Photo-z's for WL

Bonnett et al. (2015; arXiv:astro-ph/1507.05909)

Details:

- used only *griz* magnitudes
- template code: BPZ
- machine learning codes: ANNZ2, SkyNet, TPZ
- marginalize over error of 0.05 in mean redshift of each tomographic bin



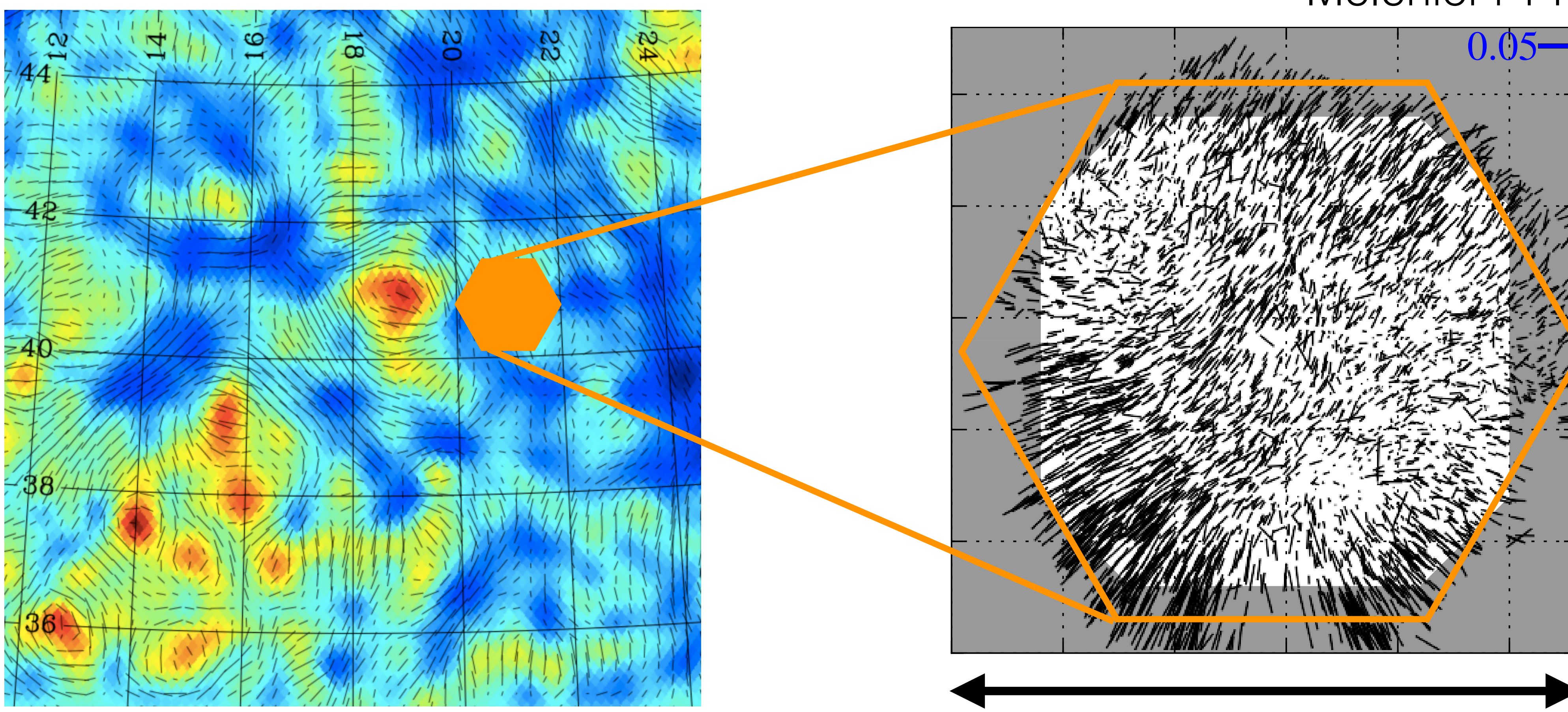


Null Tests

Correlations with the PSF?

Correctly measured shears exhibit no correlation with the PSF on average, but there can be variance due to random alignments of the true shear and the PSF pattern of the telescope.

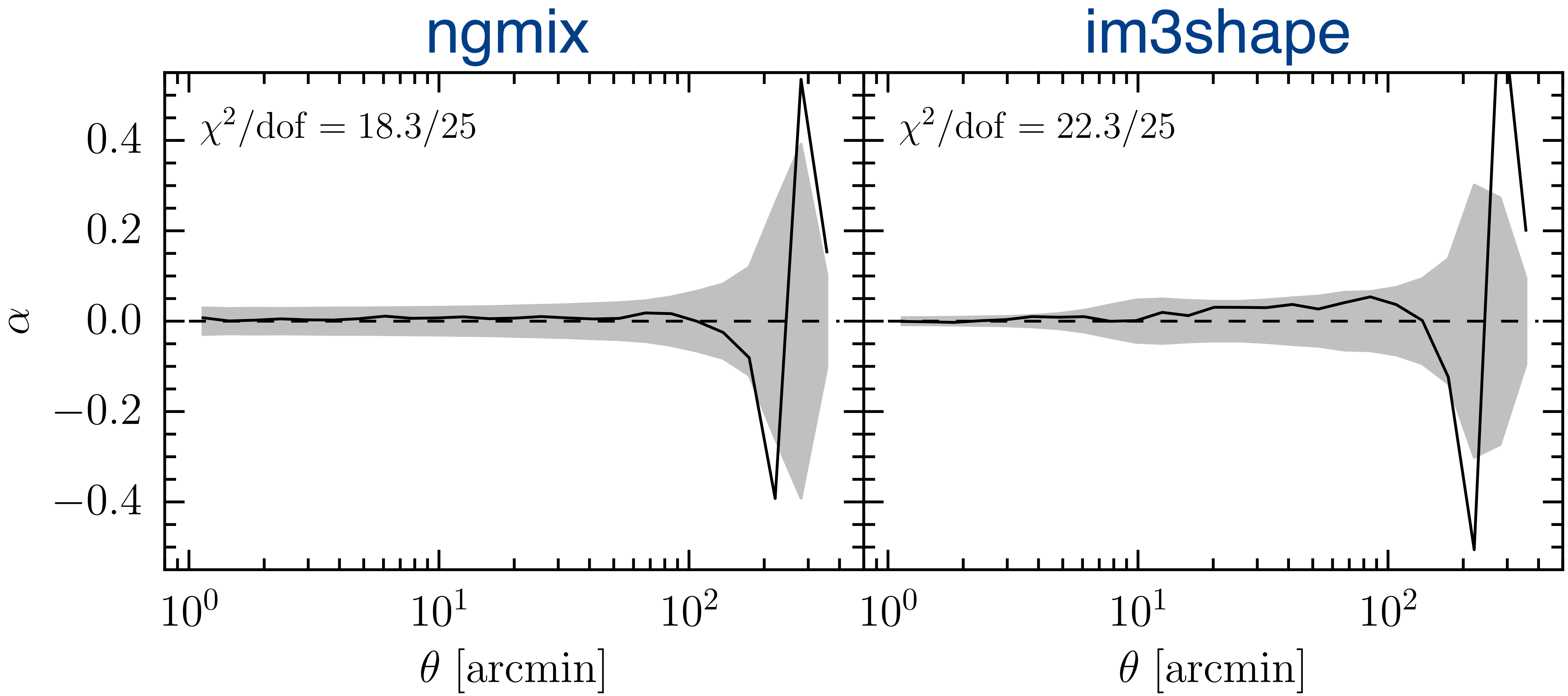
Melchior+14



$$\gamma_{\rm measured} = \gamma_{\rm true} + \epsilon + \alpha\,\gamma_{\rm PSF}$$

No Correlations with the PSF

Jarvis et al. (2015; arXiv:astro-ph/1507.05603)

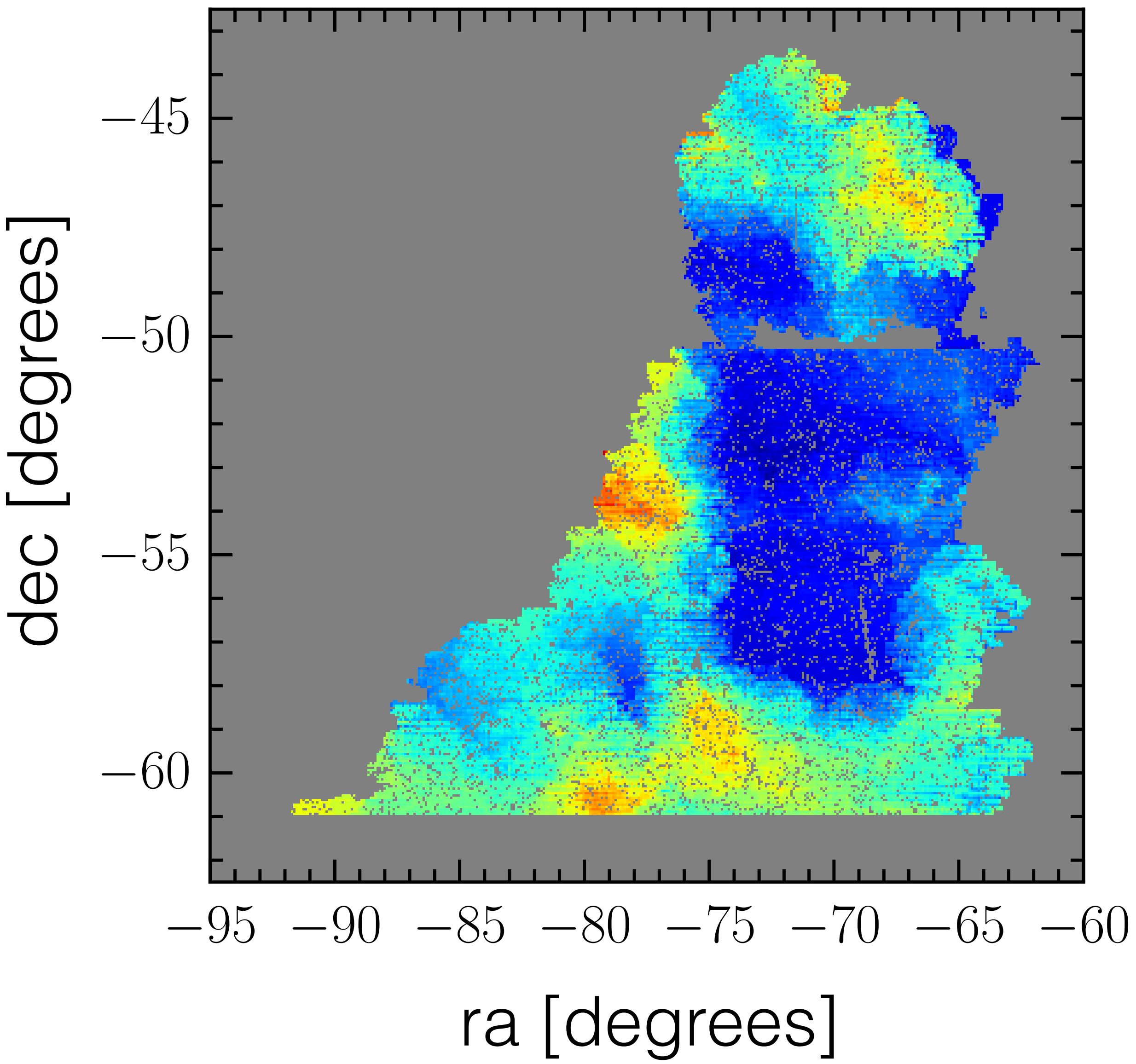


$$\gamma_{\text{measured}} = \gamma_{\text{true}} + \epsilon + \alpha\,\gamma_{\text{PSF}}$$

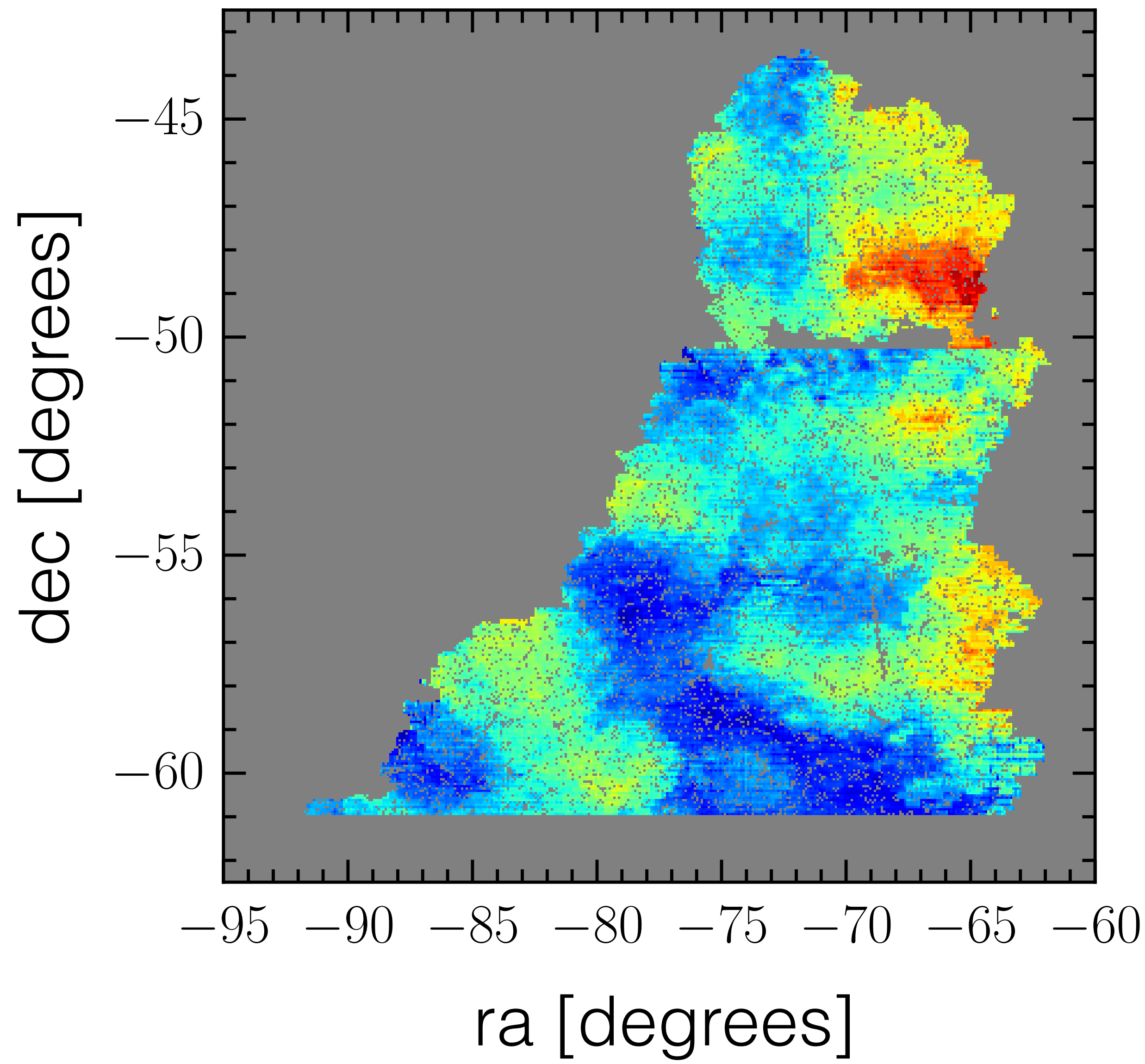
Two-point Function Null Tests

Lots of things vary over the survey.

airmass

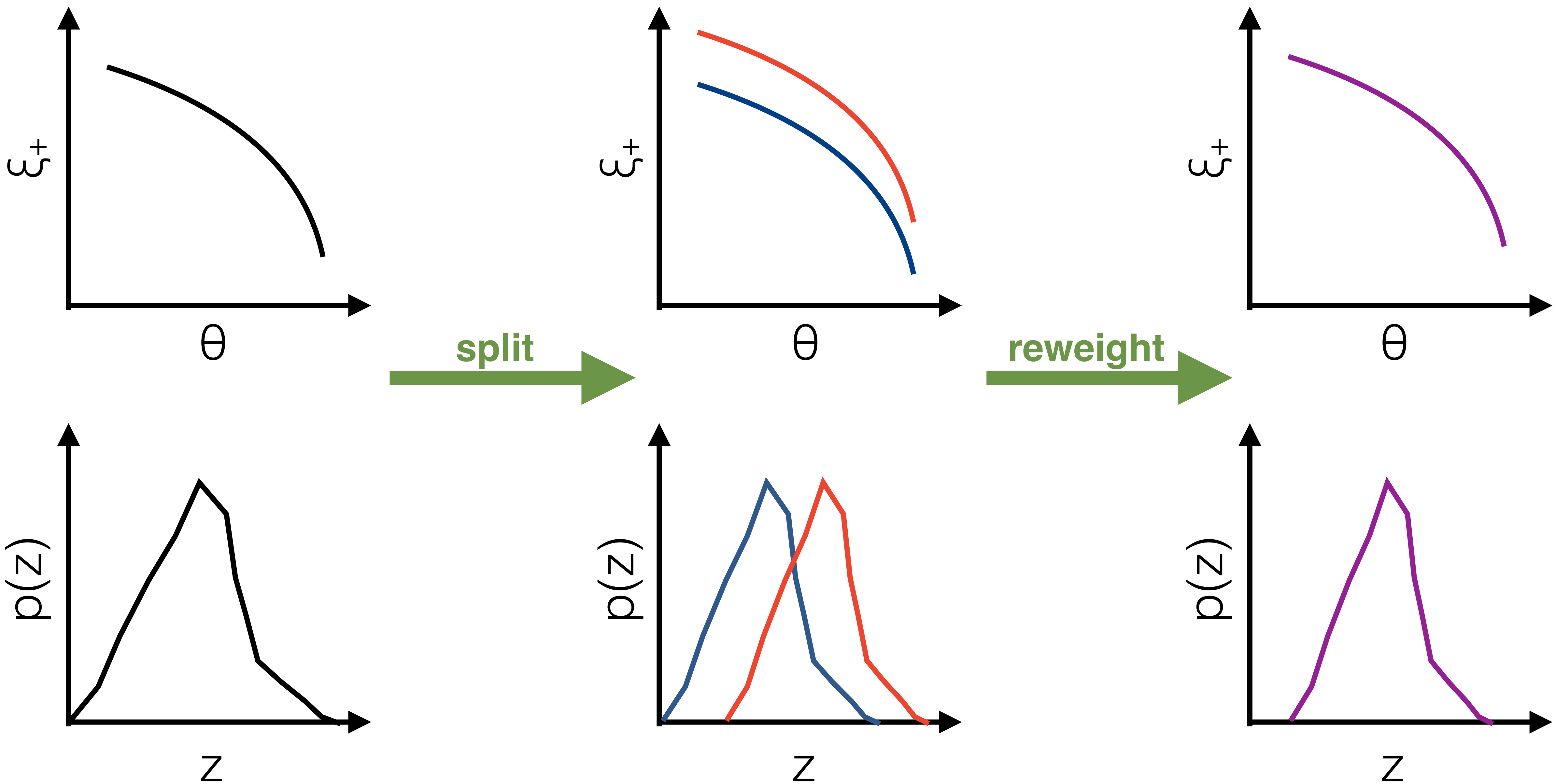


PSF FWHM



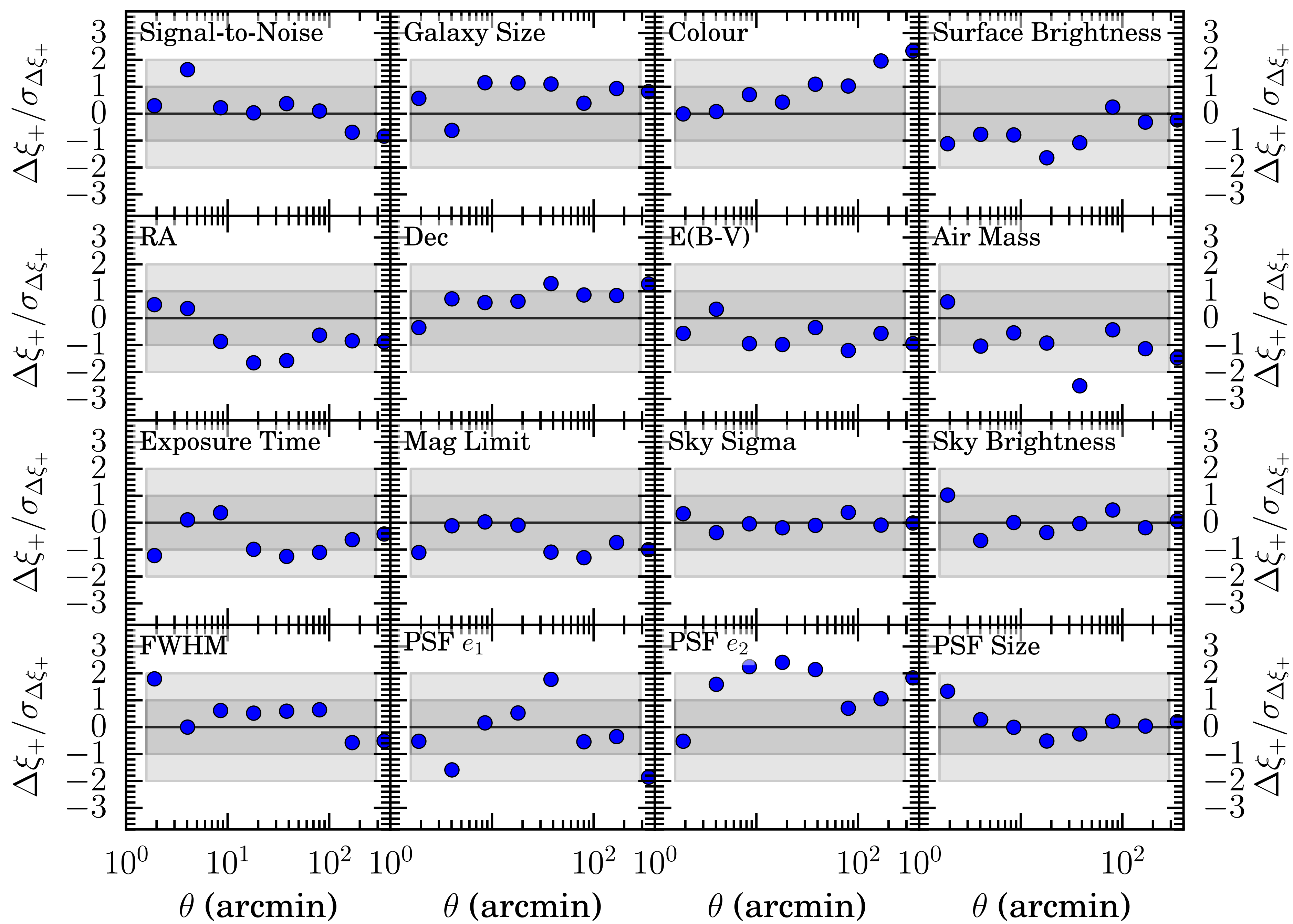
Two-point Function Null Tests

These tests are of both the photo-z's and the shear measurements!

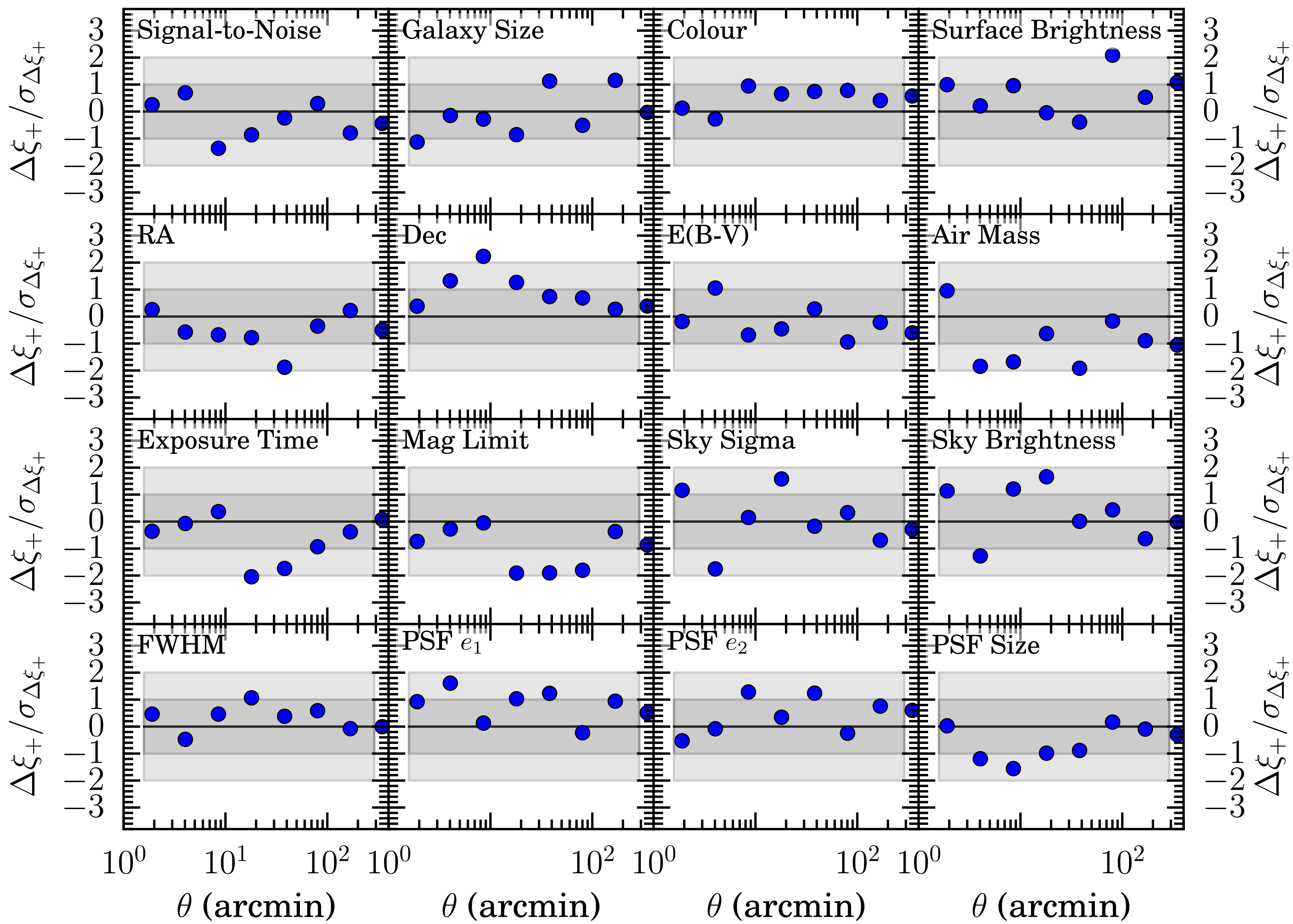


red = upper half blue = lower half purple = reweighted

Null Test Results for ngmix



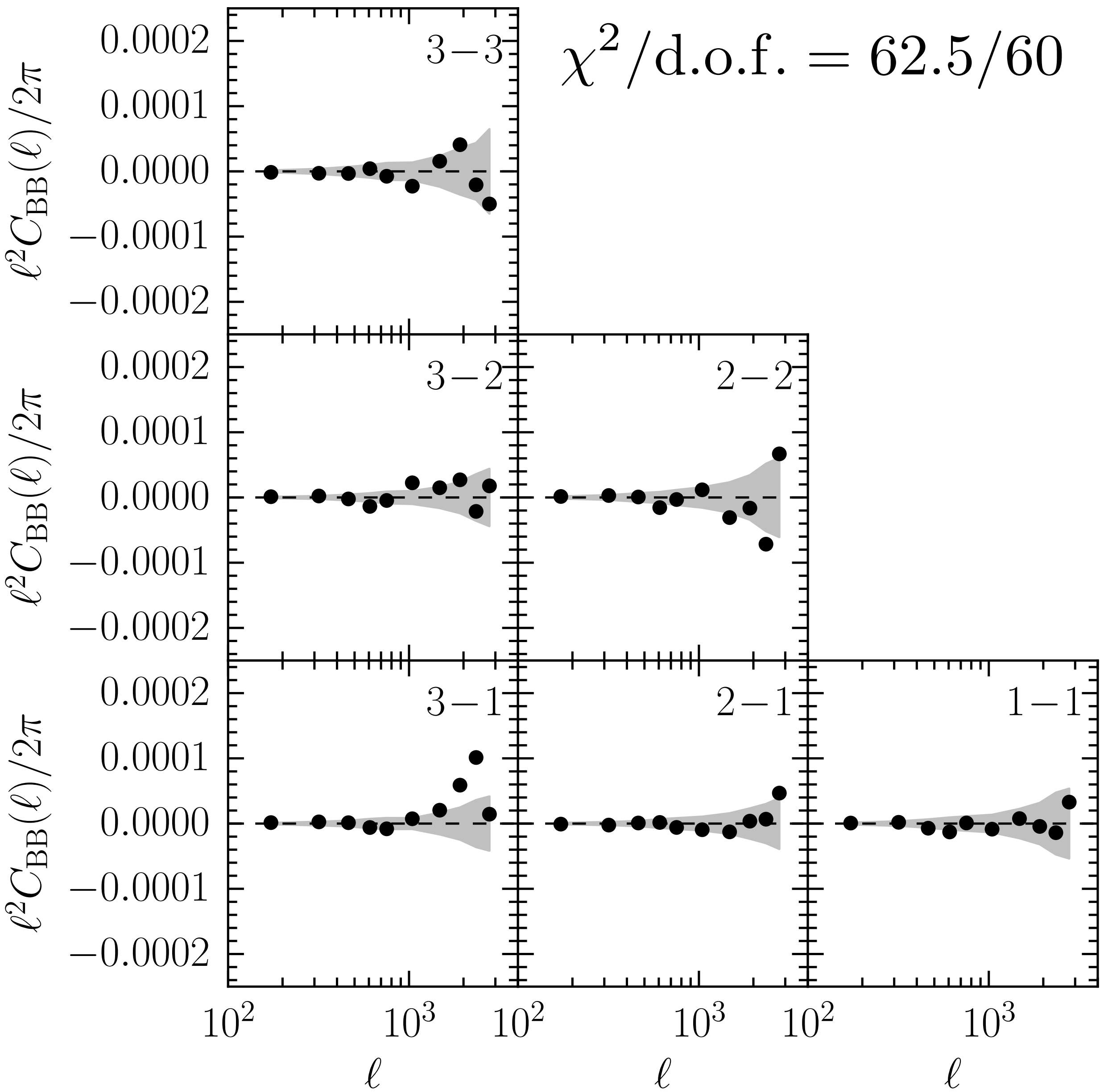
Null Test Results for im3shape



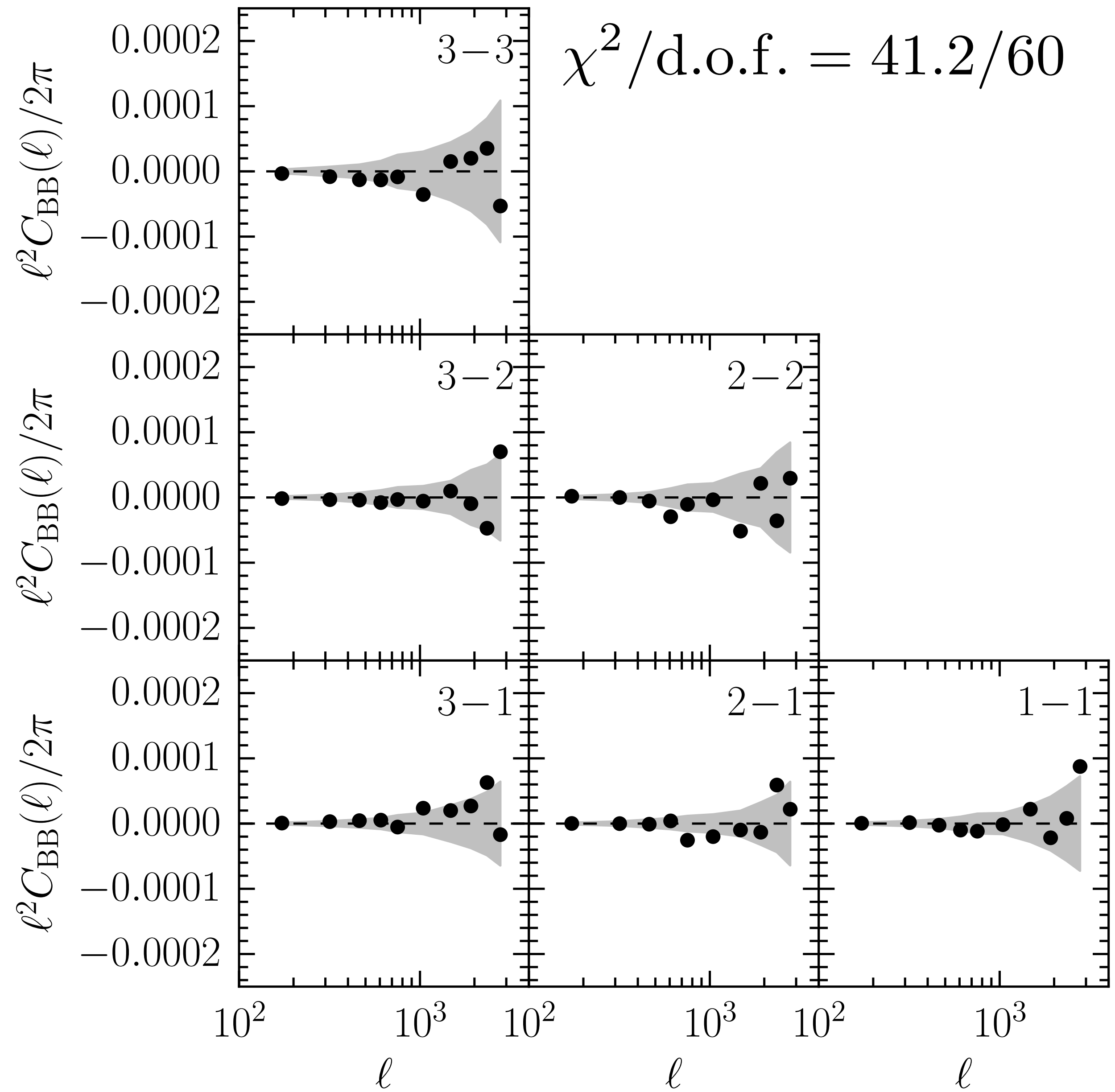
B-modes

Tomographic B-modes

ngmix

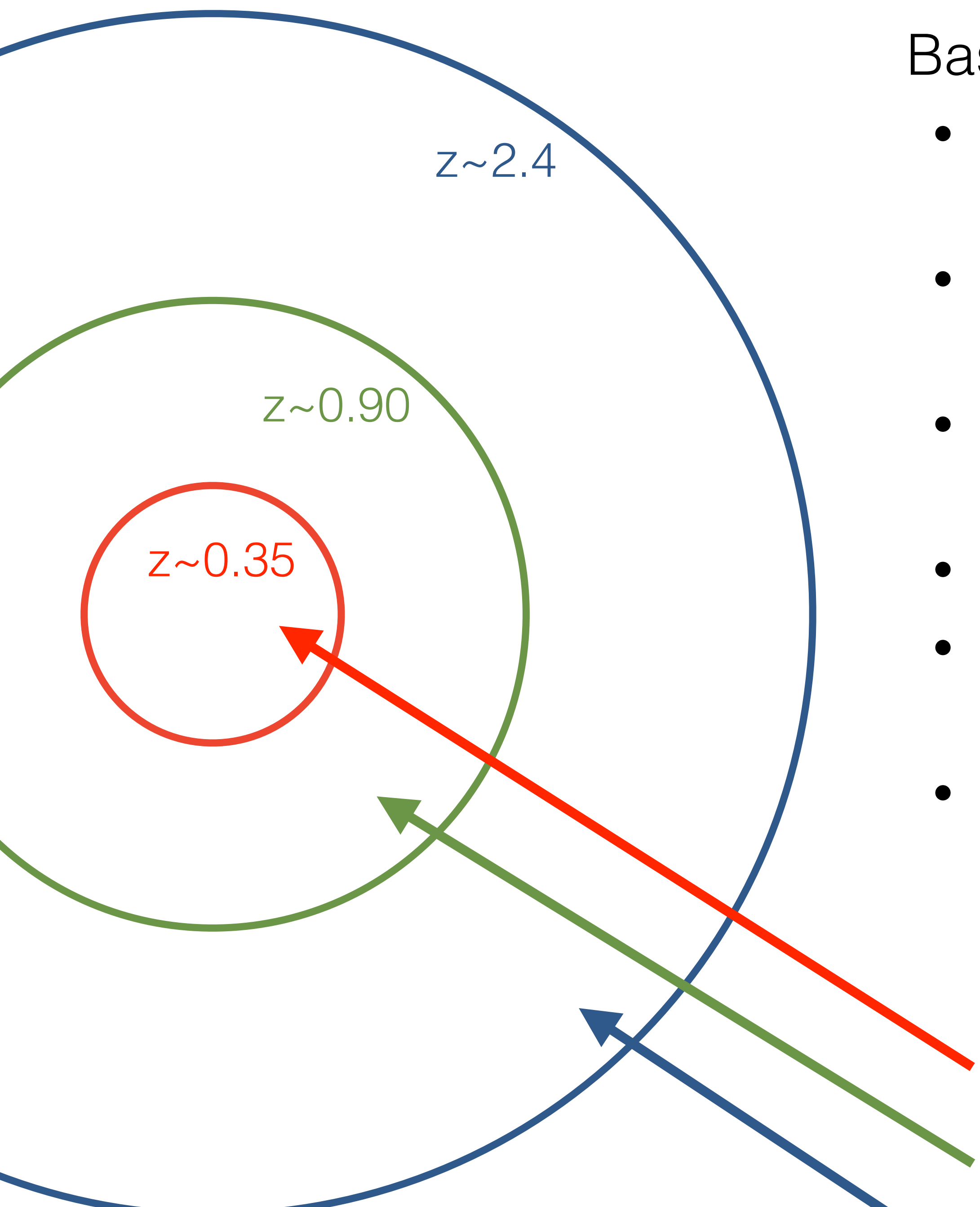


im3shape



Covariances
(for everything)

Simulations for DES SV Data

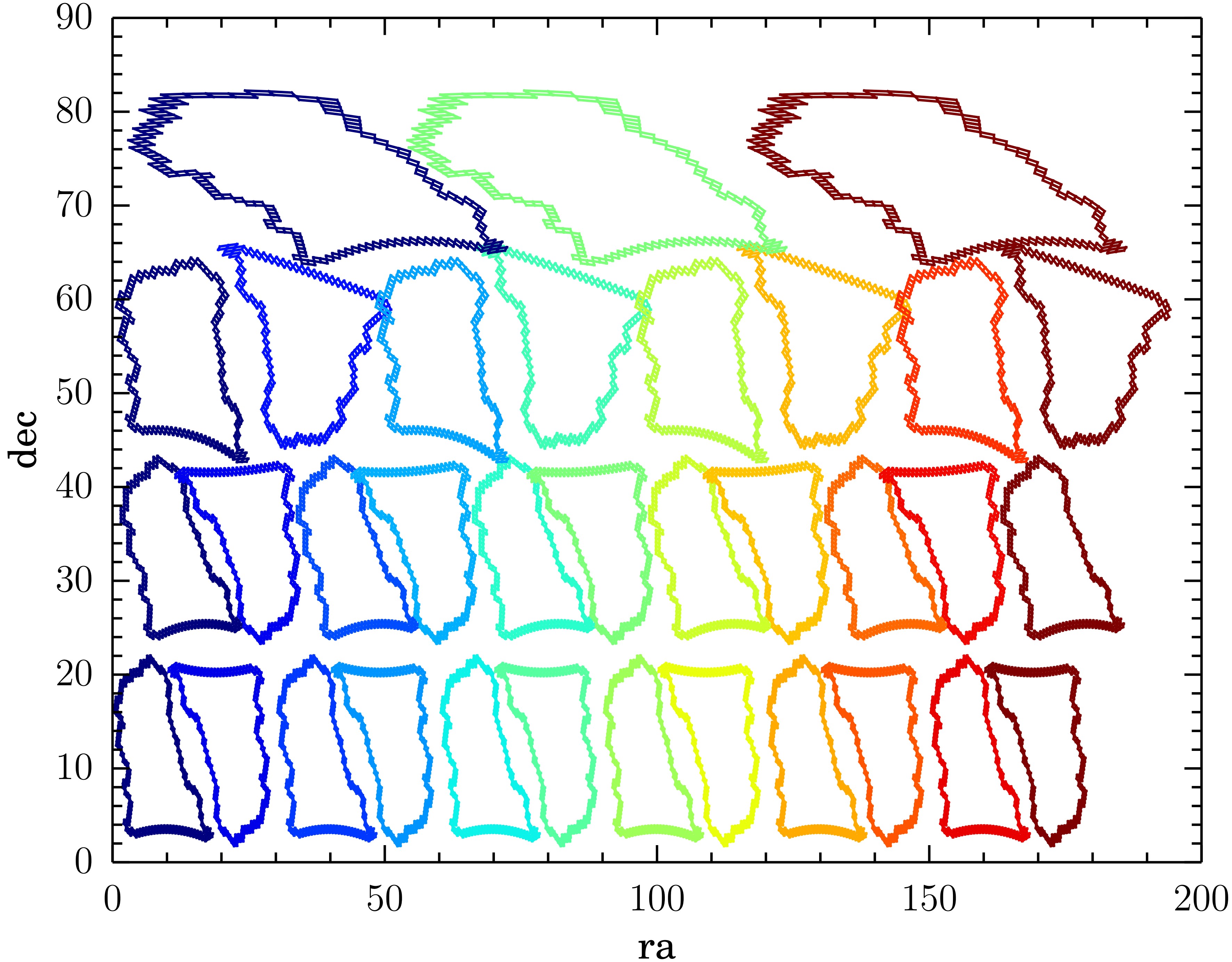


Basic ingredients:

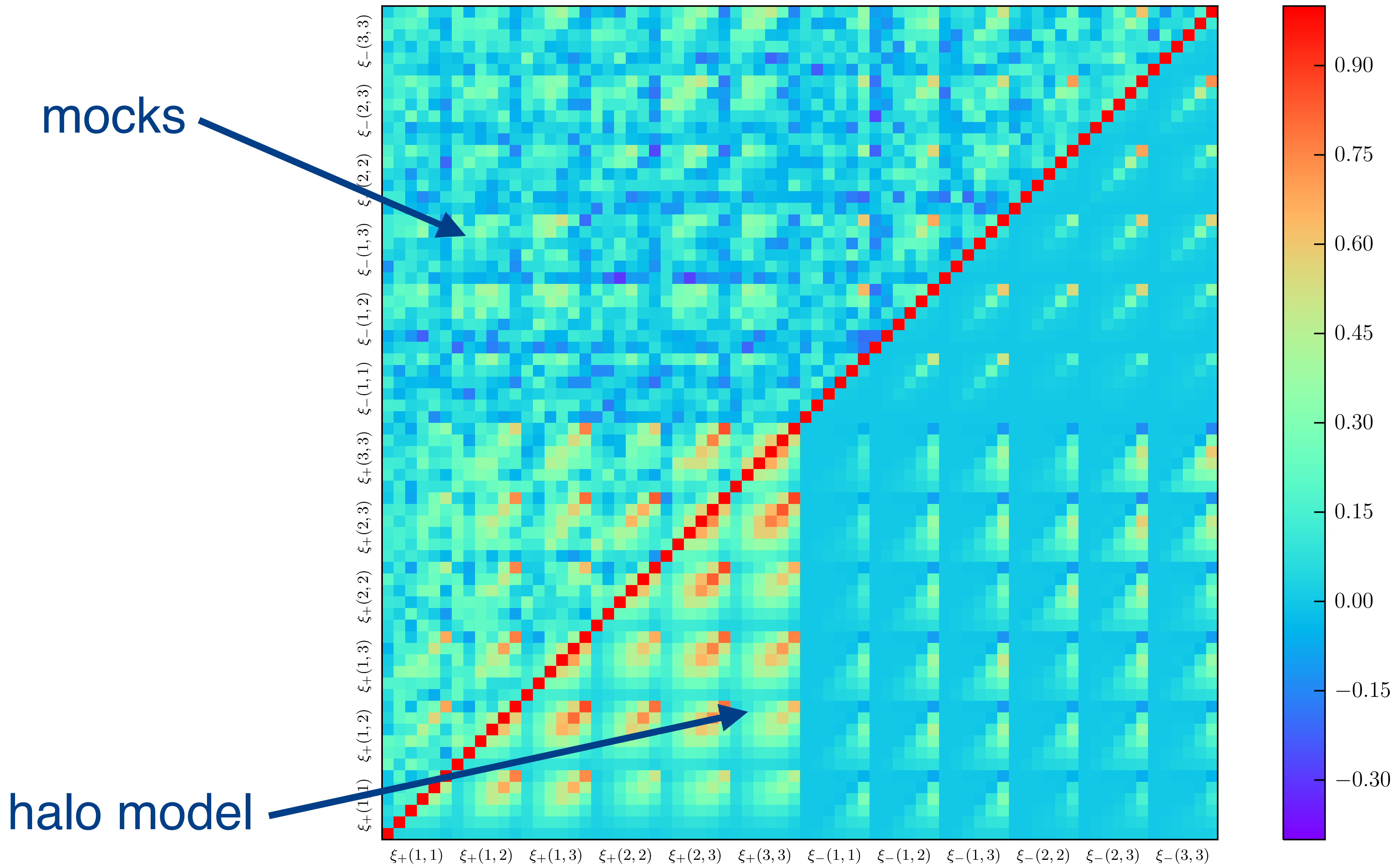
- initial conditions w/ CAMB (Lewis et al.) & 2LPTic (Croccee et al.)
- simulations run with LGadget-2 (Springel et al.) w/ a custom light cone generator
- ray traced to produce WL shear maps (CALCLENS; Becker 2013)
- apply observational masks
- add shape noise and other props. by drawing from the data
- select "galaxy" sample w/ obs. redshift distribution

Box Size [Mpc/h]	# of particles	Storage	CPU hours
1050	1400^3	0.70 TB	12.3k
2600	2048^3	2.2 TB	36.9k
4000	2048^3	2.2 TB	38.8k

Cutting out DES SV's



Tomographic Halo Model Comparison

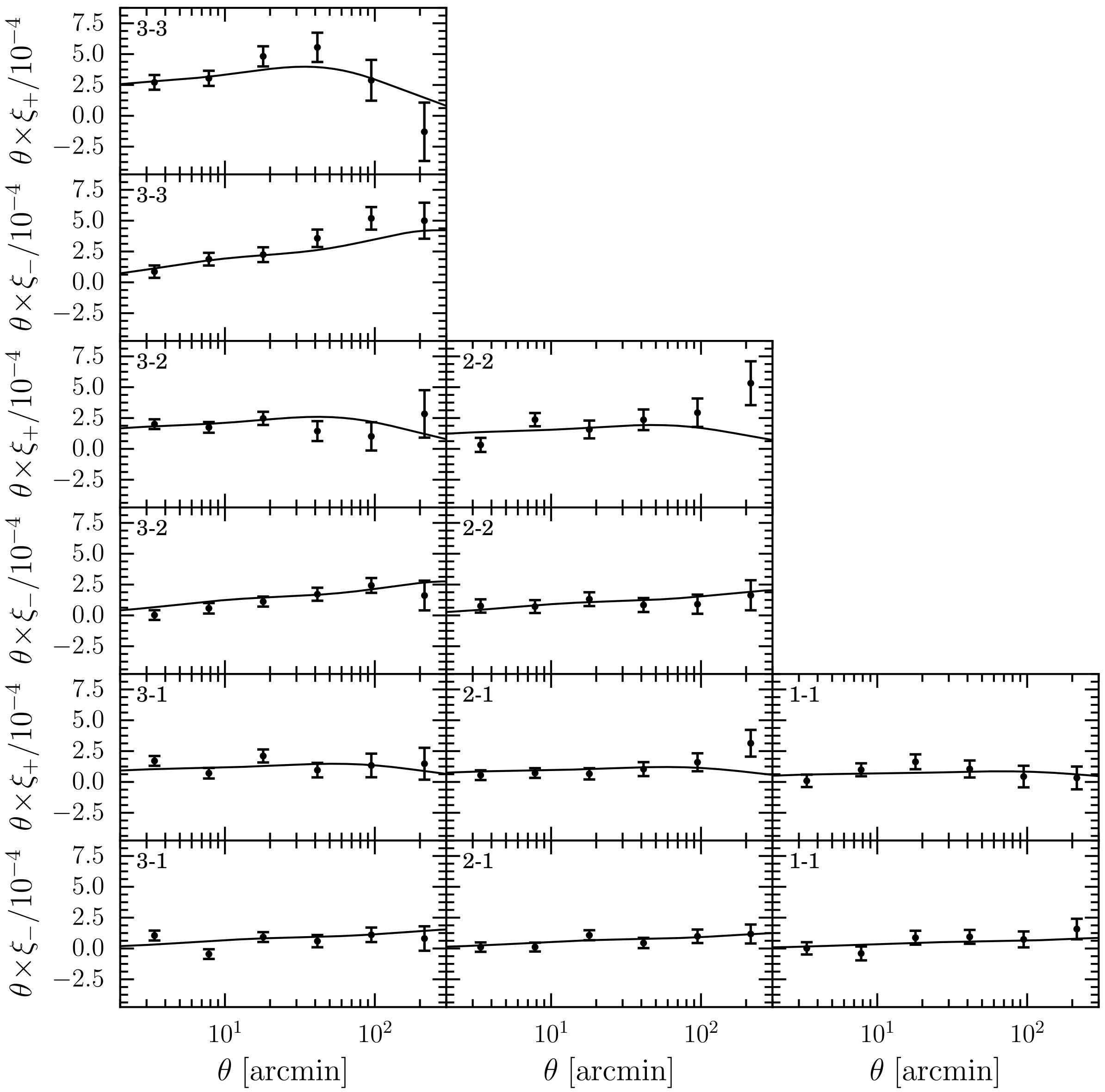


3 tomographic and 6 angular bins from 2' to 300'

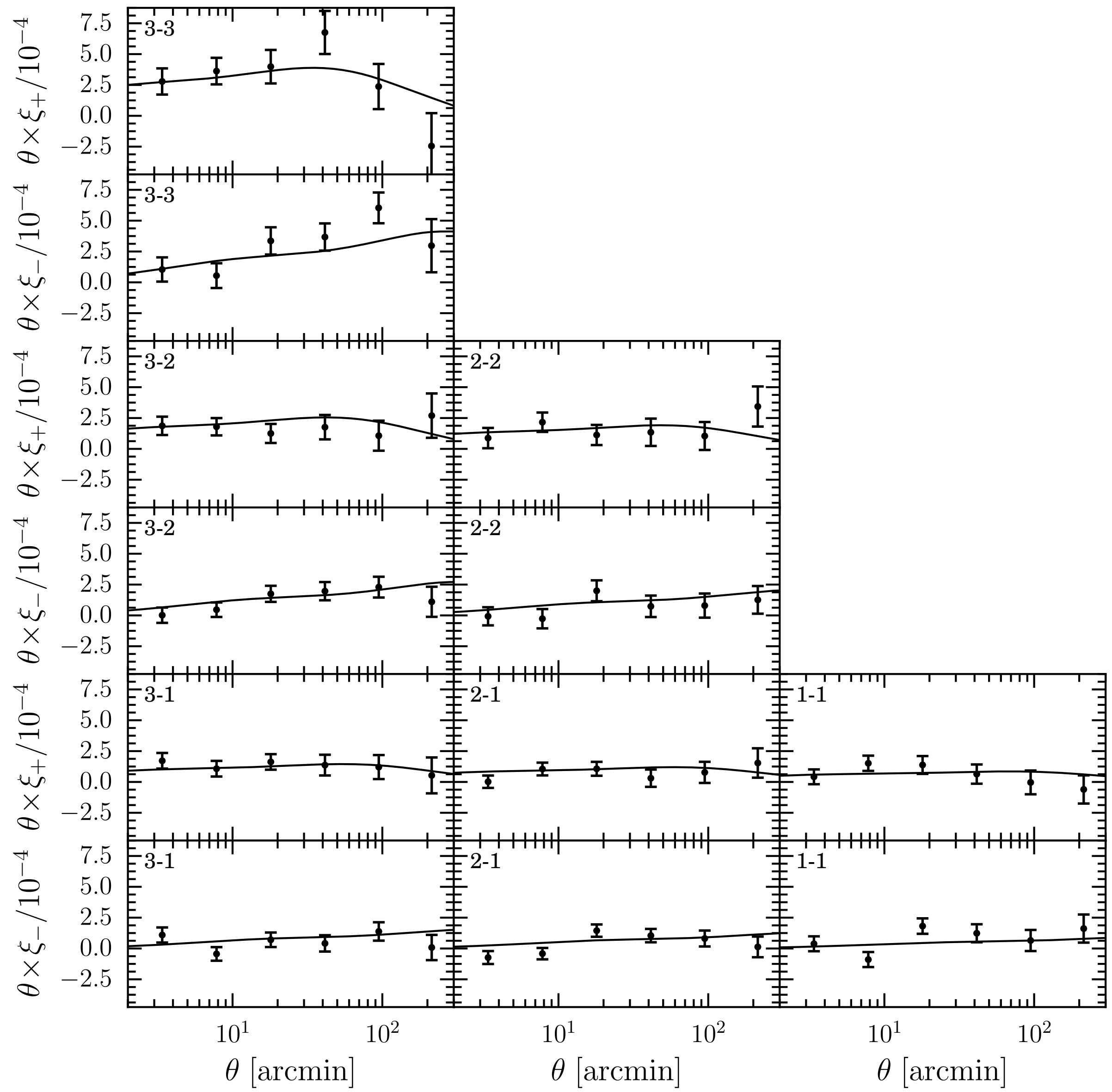
and finally…

Cosmic Shear!

ngmix

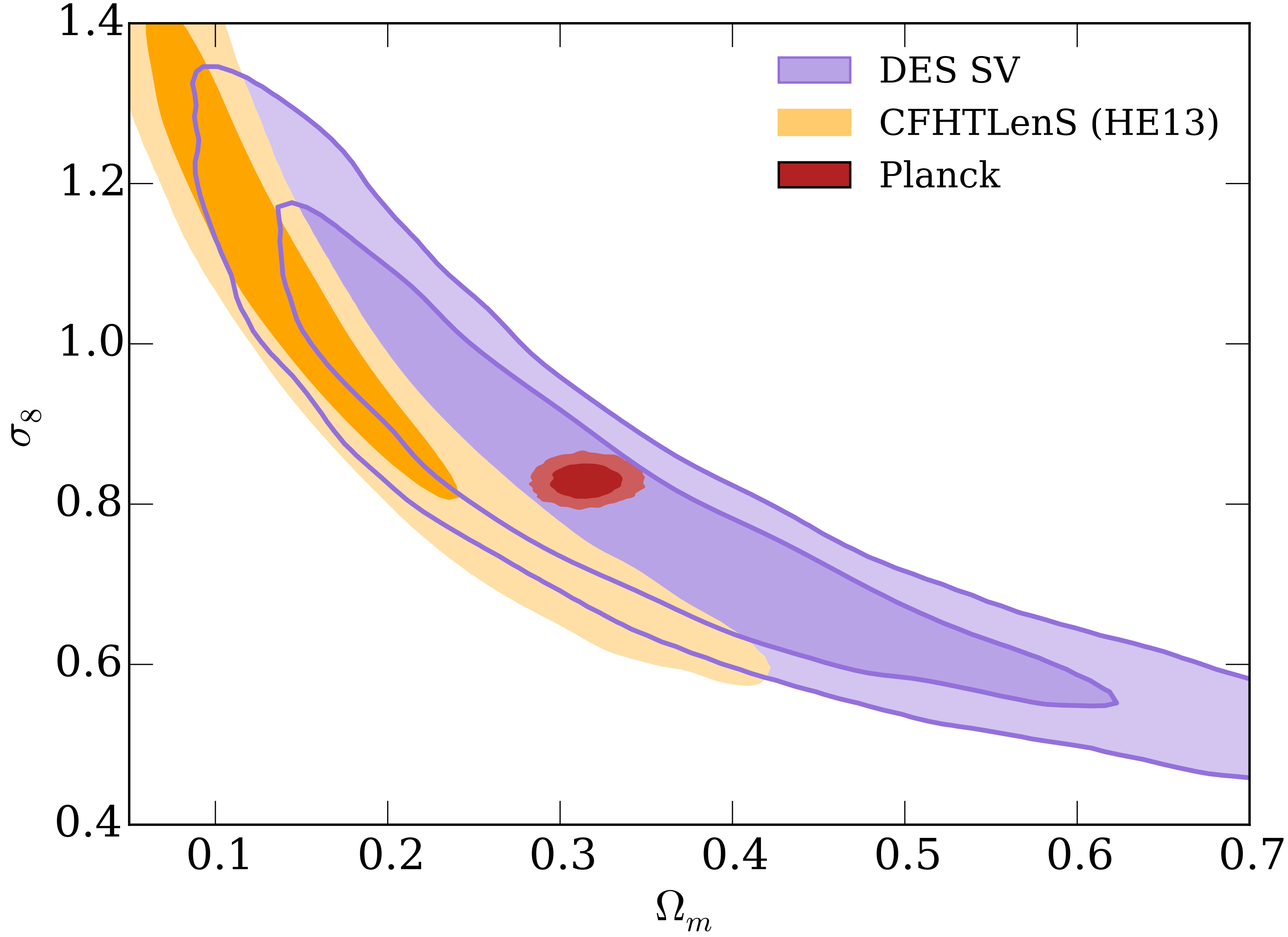


im3shape



Cosmological Constraints

The DES Collaboration (2015; arXiv:astro-ph/1507.05552)



Recap and Outlook

We have a 9.7σ measurement of cosmic shear with six tomographic correlation functions.

We have developed a large suite of null tests and comparisons to theoretical models in order to verify the components of the cosmic shear likelihood.

Lots of improvements to all aspects of the analysis are ongoing, from pixels to the simulations.

The next few years of DES weak lensing science will be exciting!