Weak lensing simulations

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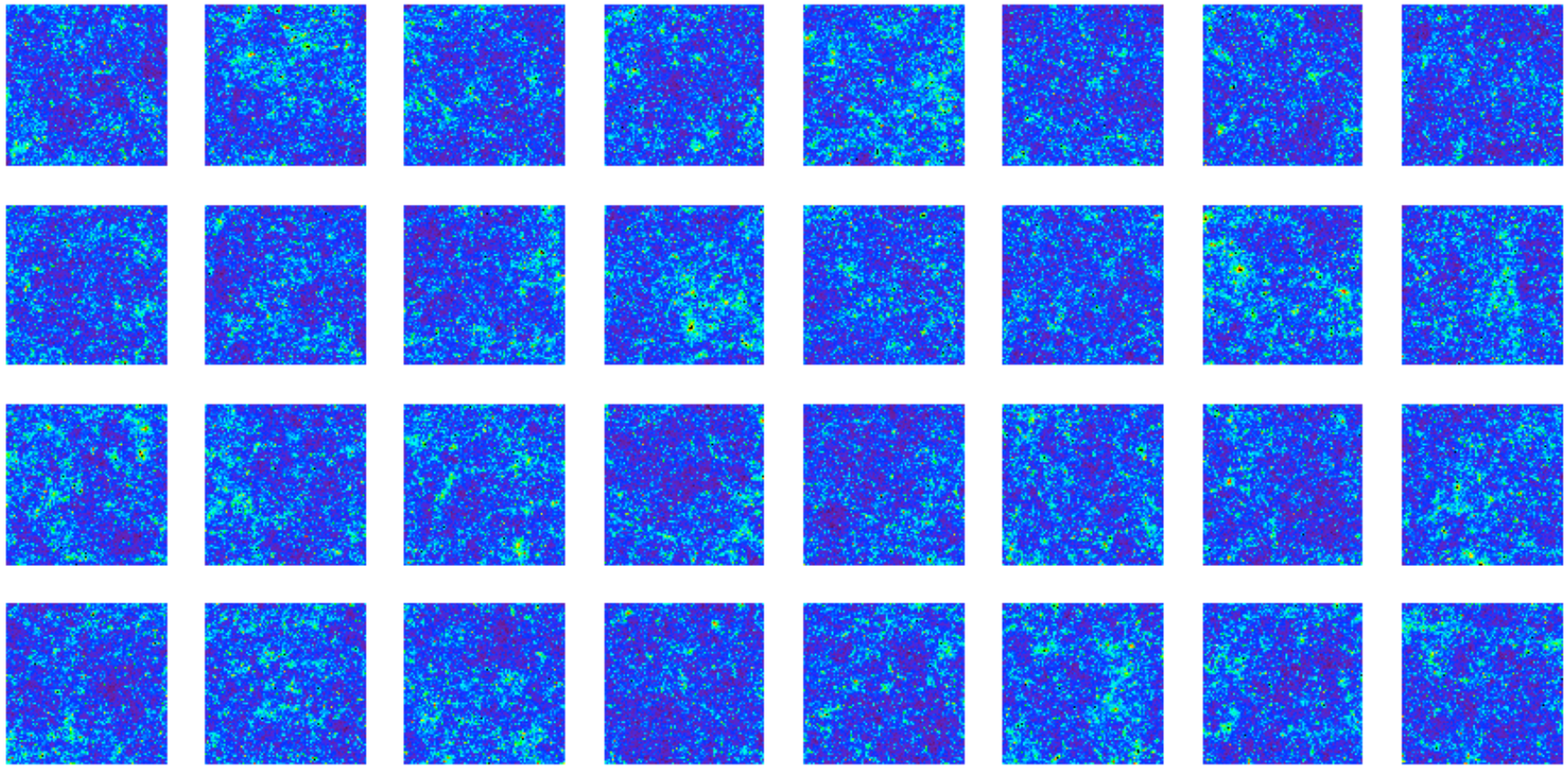
Theory & Analysis

- Using the code described in Vale & White (2003) we have produced simulated weak lensing maps for a number of cosmological models.
  - These maps are very useful for investigating higher order functions and higher order effects.
  - The maps make good tests of algorithms.
  - The maps can be used to model systematic errors and their removal or estimate error bars from sample variance.
- Available
  - Convergence and shear maps [different $p(z_s)$]
  - Halo catalogs
  - Sheared "galaxy" catalogs
  - Power spectra, …
- Recent run: maps of one cosmology covering 1000 sq. deg.

http://mwhite.berkeley.edu/Lensing/

$\Omega_m = 0.357$ $w = -0.8$ $h = 0.64$ $n = 1.00$ $\sigma_8 = 0.88$ $\tau = 0.15$

Tracing light rays through a simulation of structure formation…



32 convergence maps, 3^o on a side

http://mwhite.berkeley.edu/Lensing/

Next steps

- For the 2-pt function we need to know the non-linear power spectrum in the range $0.1<k<10 Mpc^{-1}$ to 1-2% accuracy, with the requirement at k~1 being the most stringent.
- Current state of the art is ~3%.
- For gravity only, there is no known obstacle to reaching the above requirement.

Beyond gravity

- Non-gravitational physics becomes important on small scales, becoming dominant beyond l~3000.
  - —White (2005), Zhan & Knox (2005)
- Dramatic progress in modeling extra physics!
  - —Expect small # of simulations including relevant physics will be available within 5-10 years.
  - —Can mock up some of the physics in gravity-only simulations
    - Put gas in hydrostatic equilibrium with known DM potential.
    - Apply adiabatic contraction to halos where gas would have cooled.
- Use photo-z to apply “nulling tomography”.
  - —Huterer & White (2005)

Lessons from what we have now

- We already have a large number of high-fidelity simulations in hand.
- What can we do with these?
  - These maps are very useful for investigating higher order functions and higher order effects.
  - The maps make good tests of algorithms.
  - The maps can be used to model systematic errors and their removal or estimate error bars from sample variance.

Reduced shear

- Unless we have a measurement of the intrinsic size or magnification of a galaxy we cannot measure γ but only $g=\gamma/(1-\kappa)$

$$\frac{\partial\theta^{\rm src}}{\partial\theta^{\rm img}} = \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix}$$
$$= (1-\kappa)\begin{pmatrix} 1-g_1 & -g_2 \\ -g_2 & 1+g_1 \end{pmatrix}$$

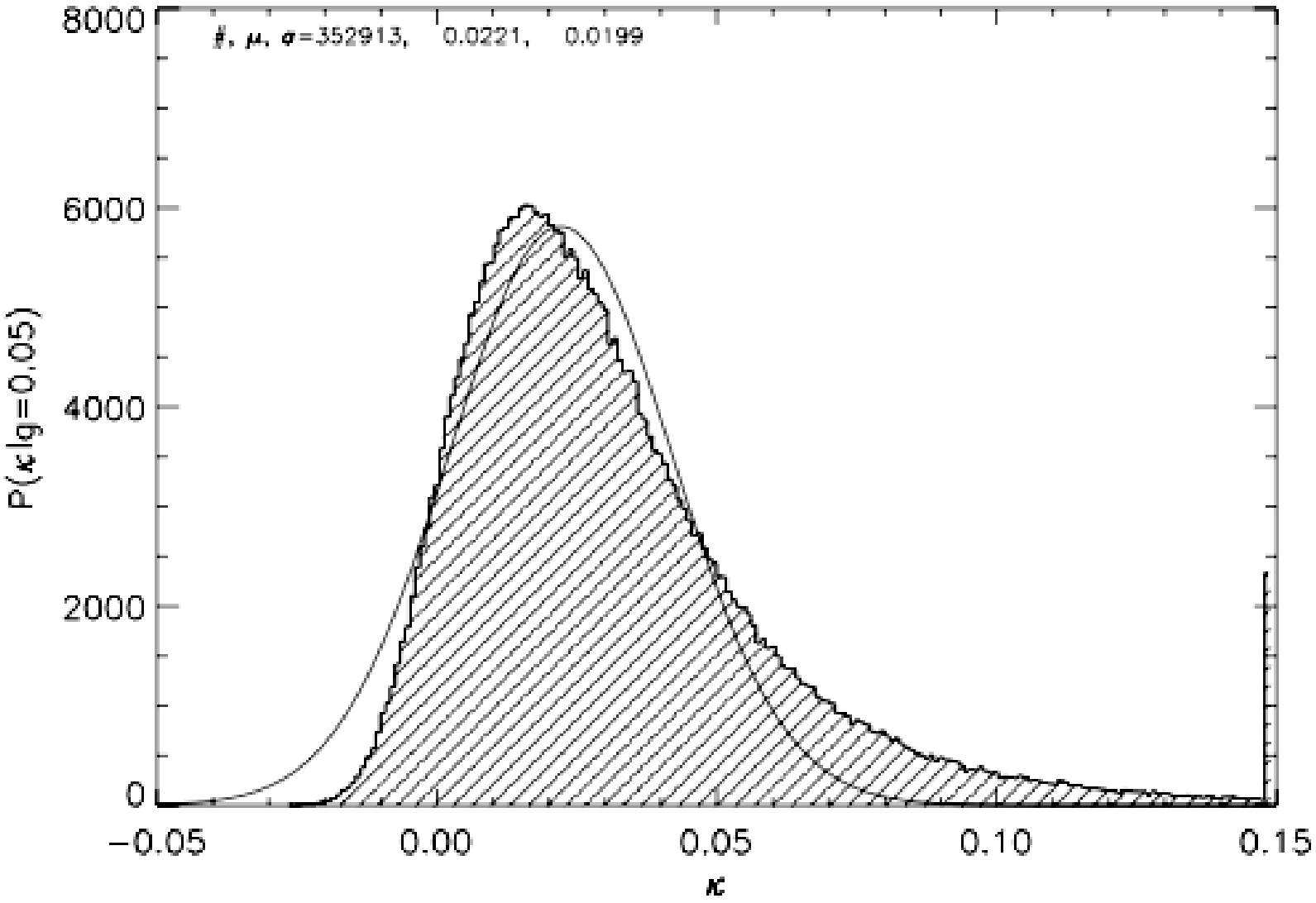
- Since γ and κ are usually small this difference is often neglected (except around clusters).
- Can be a few percent effect on arcminute scales!

Reducing shear enhances shear

- On small scales κ can be quite large, and spatial smoothing does not commute with the "reducing" operation.

- Generally g has larger fluctuations than γ because κ is skew positive.
  - —Excess small-scale power compared to naïve predictions.
- The effect is different for different estimators
  - —A signal of "reduced shear" vs. e.g. intrinsic alignments or systematics.
- The effect is non-linear
  - —Provides cross-check on shear calibration

Conditional probability



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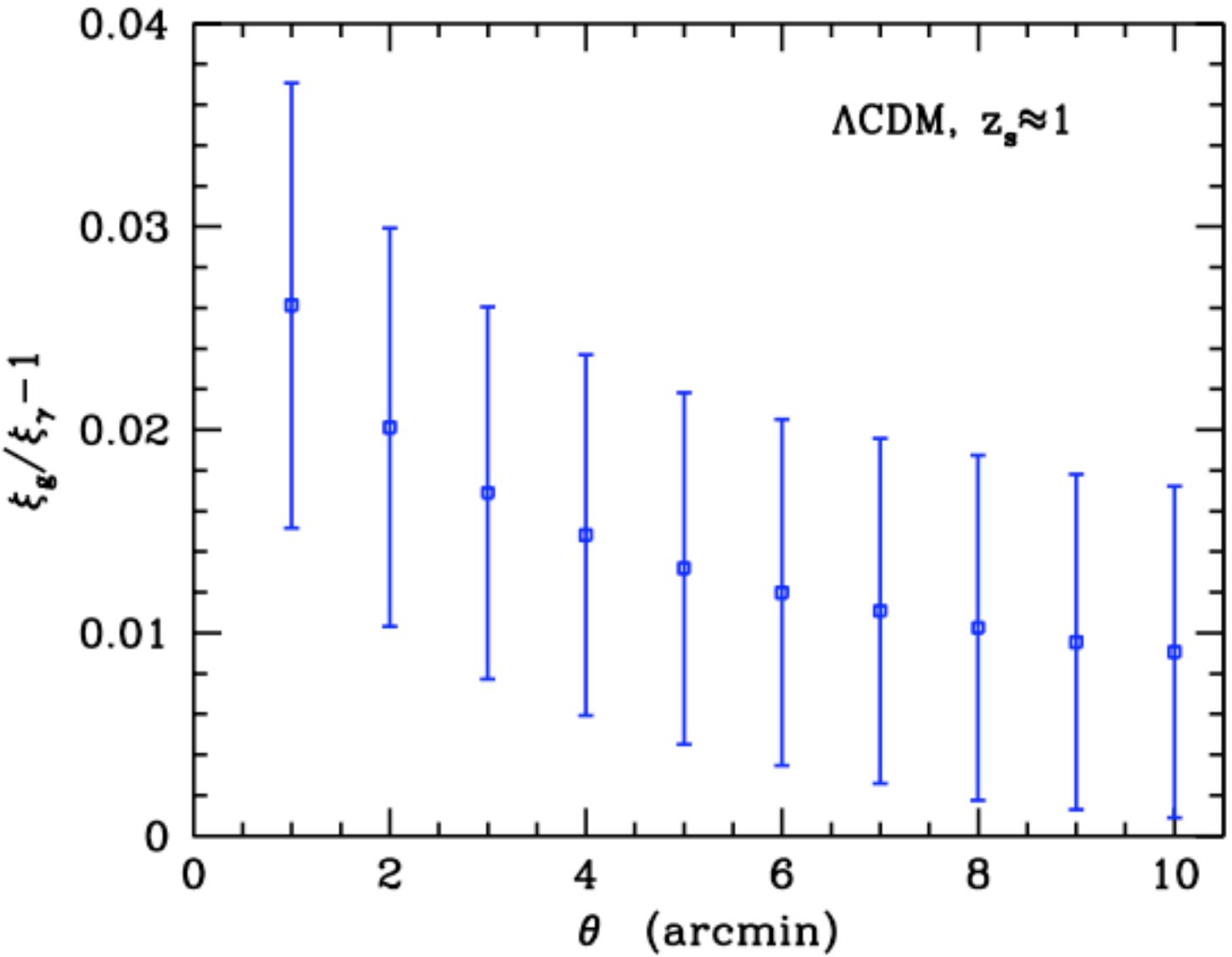
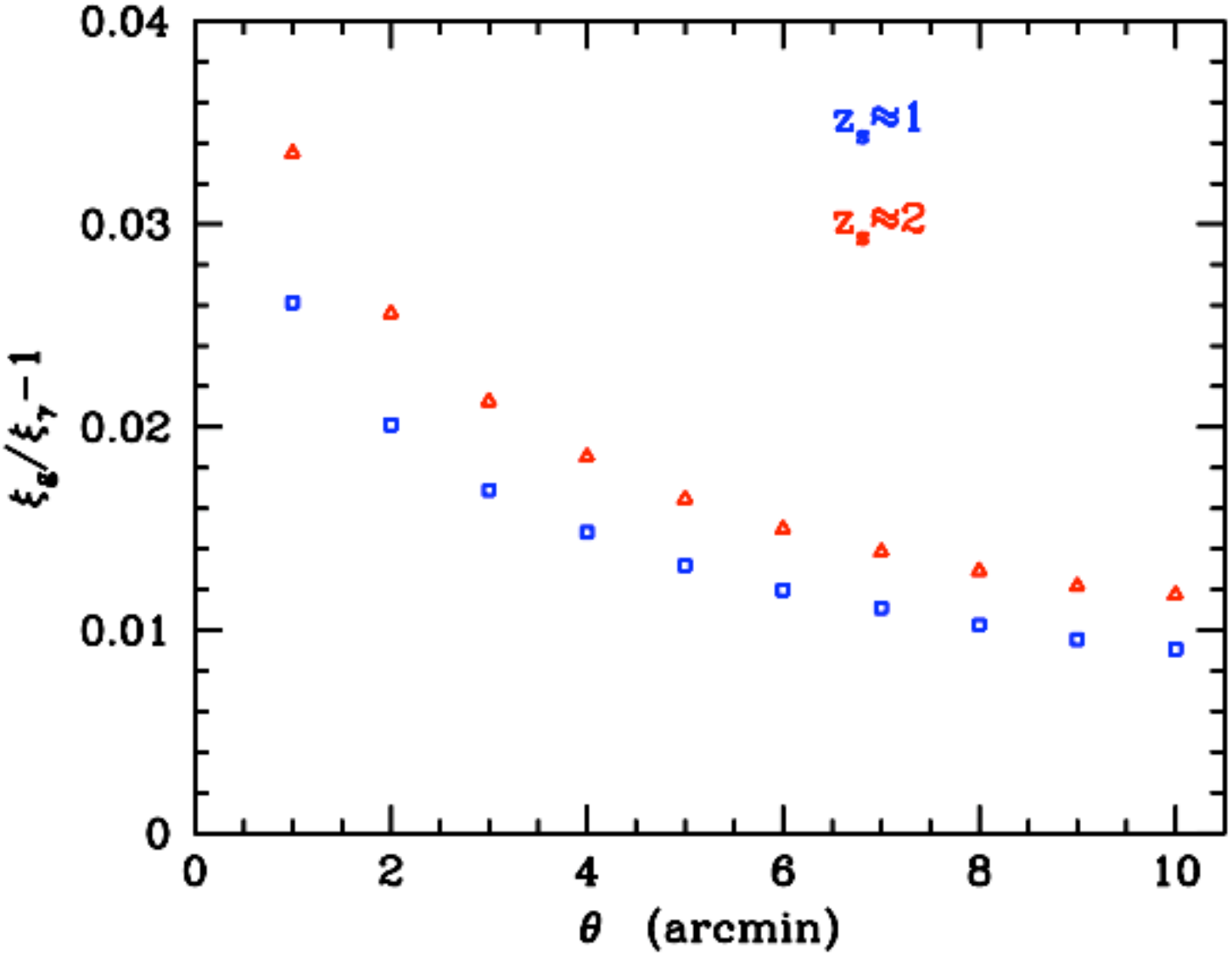
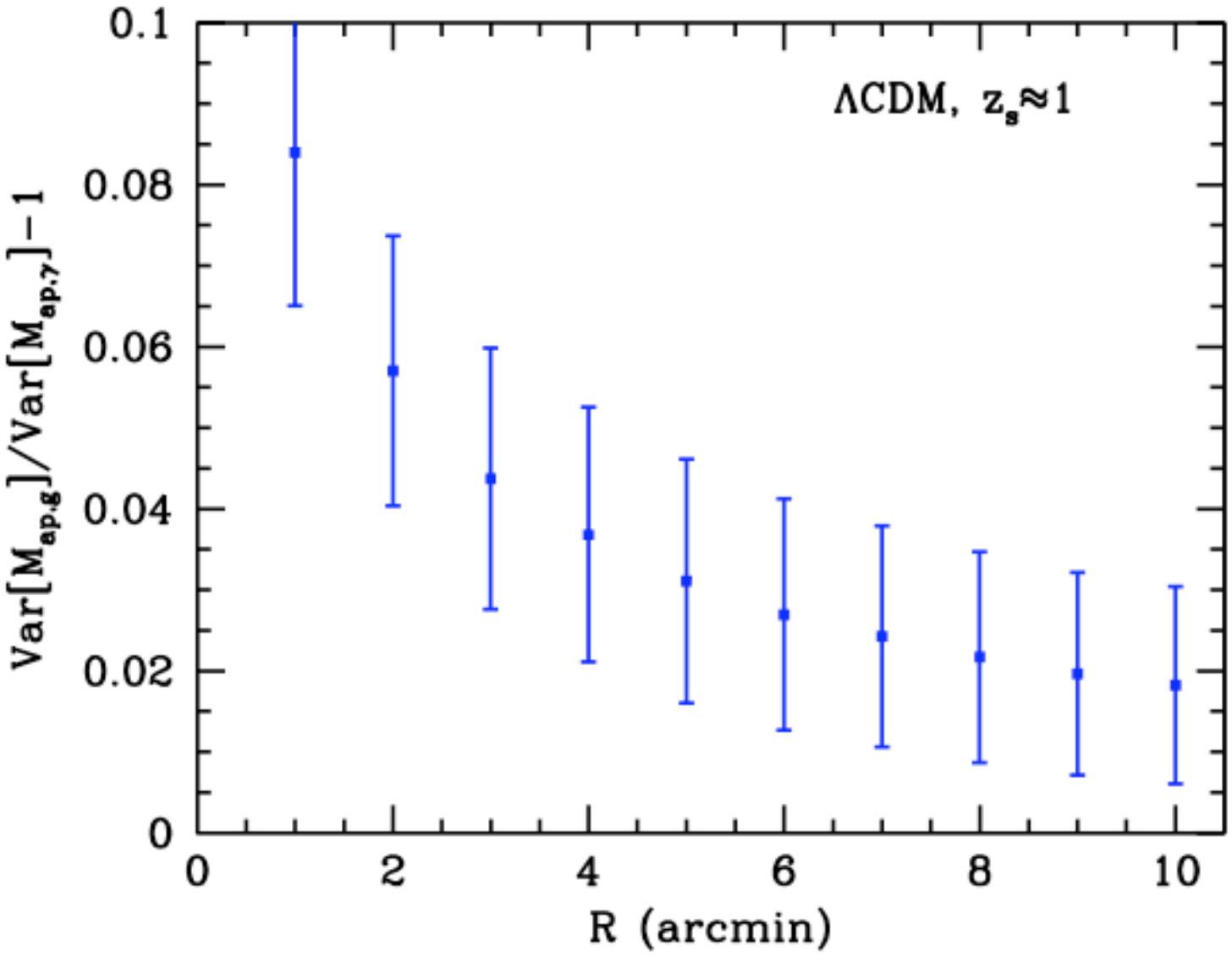
Effect on correlation function



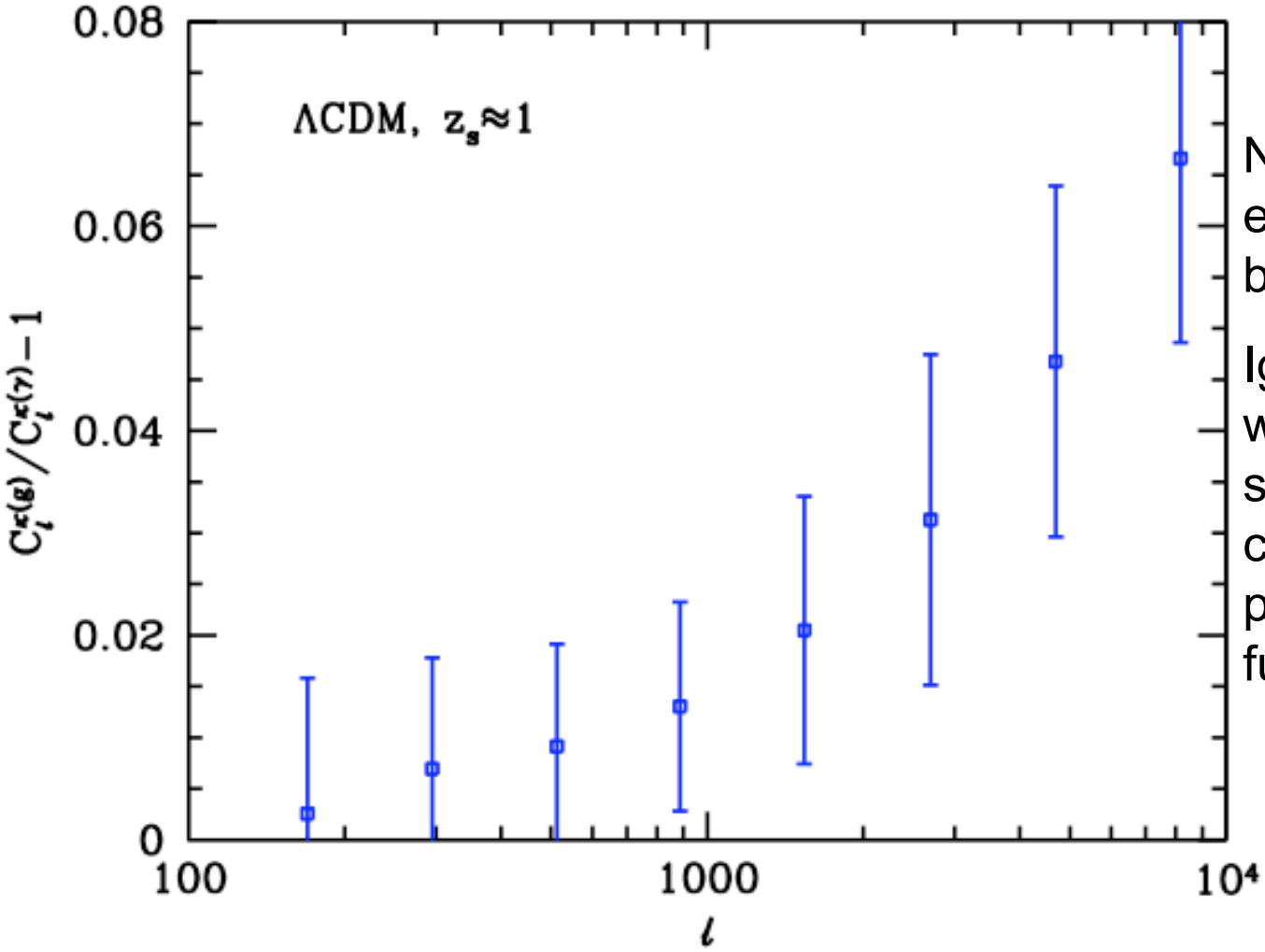
… increases to higher redshift



Effect on aperture mass variance



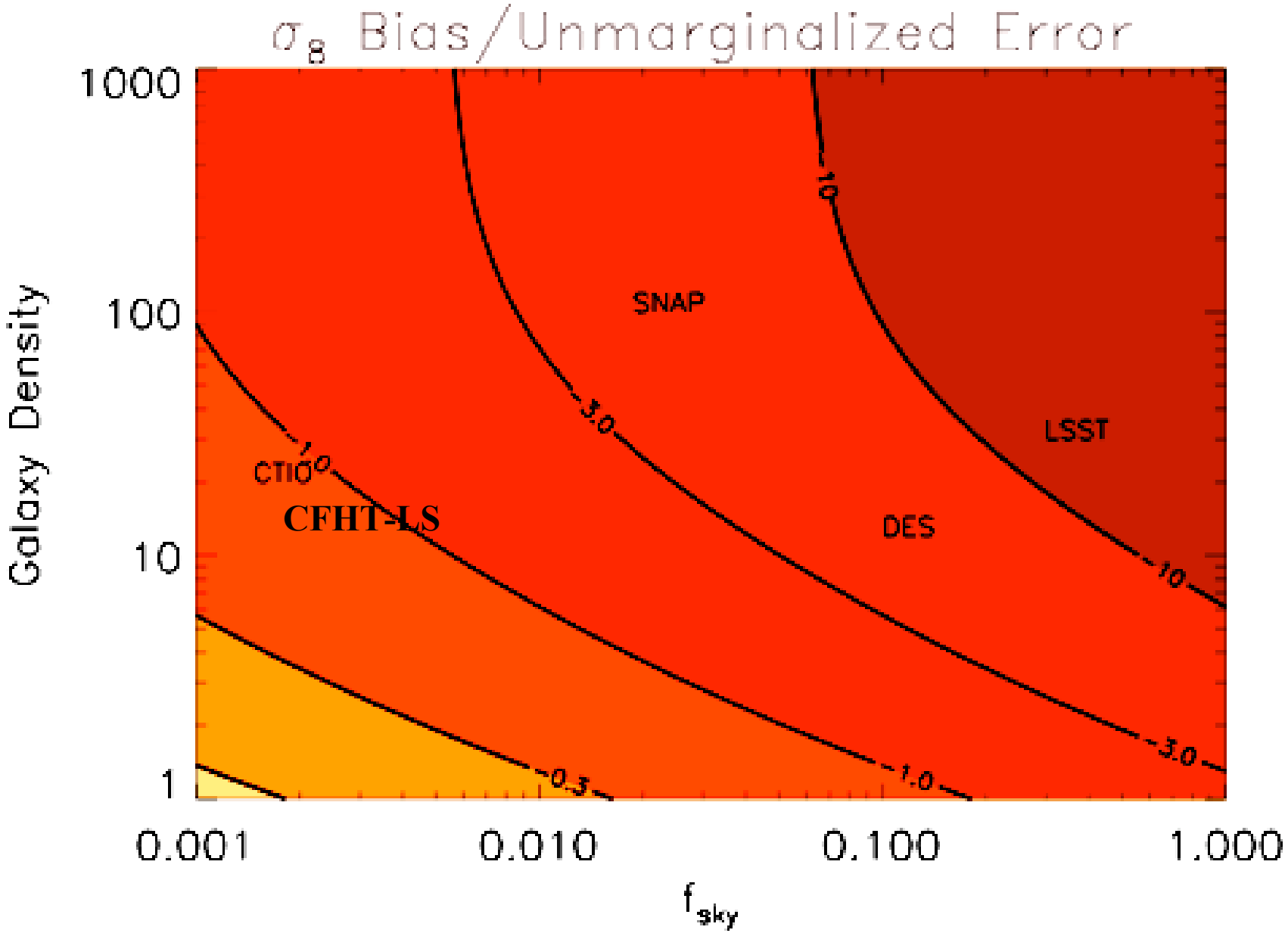
Effect on the power spectrum



Not a problem for existing surveys, but …

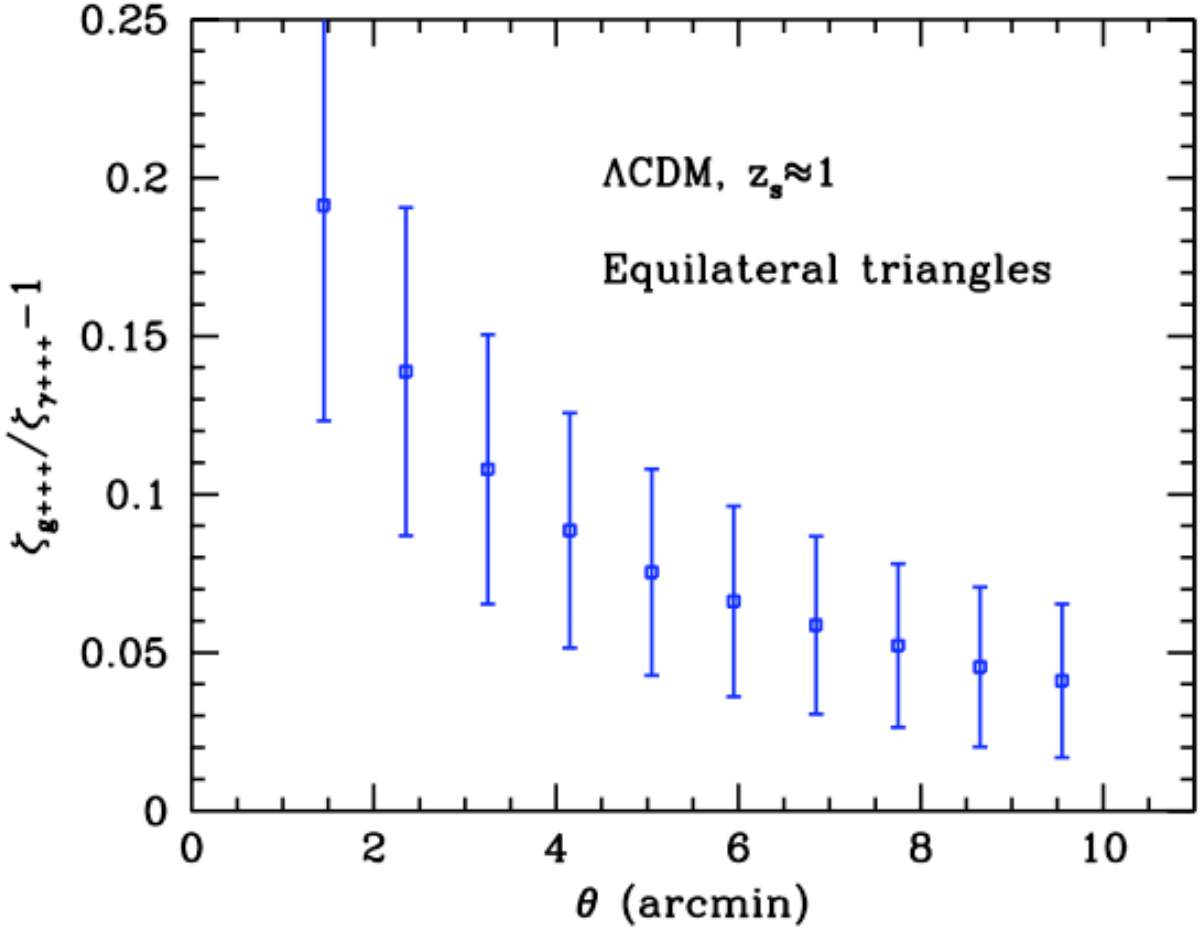
Ignoring this effect would lead to a significant bias in cosmological parameters for future surveys.

Bias in parameters



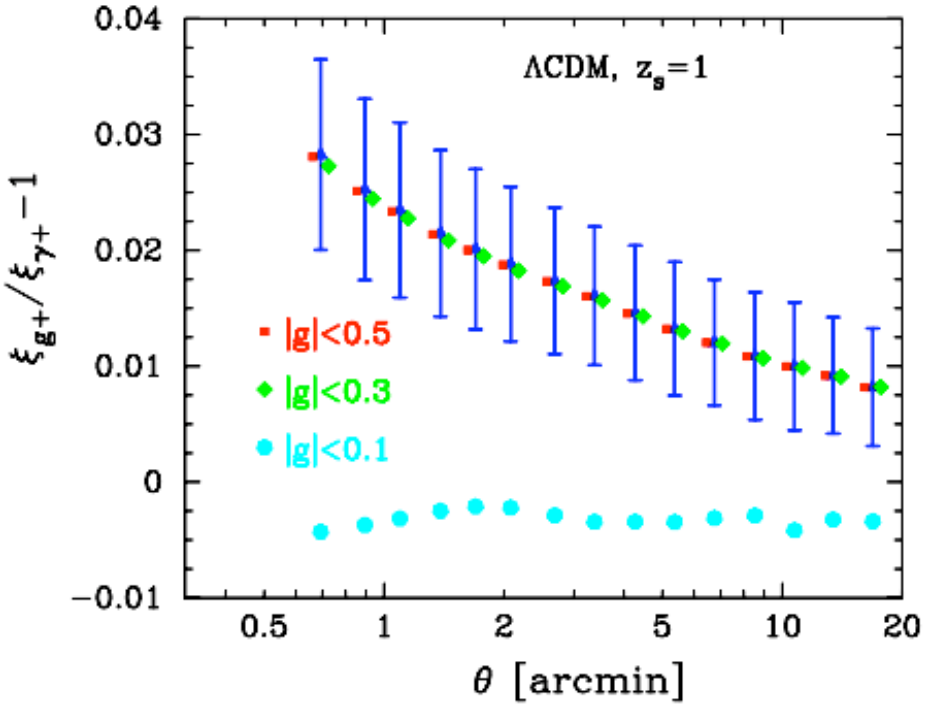
Effect on higher-order functions

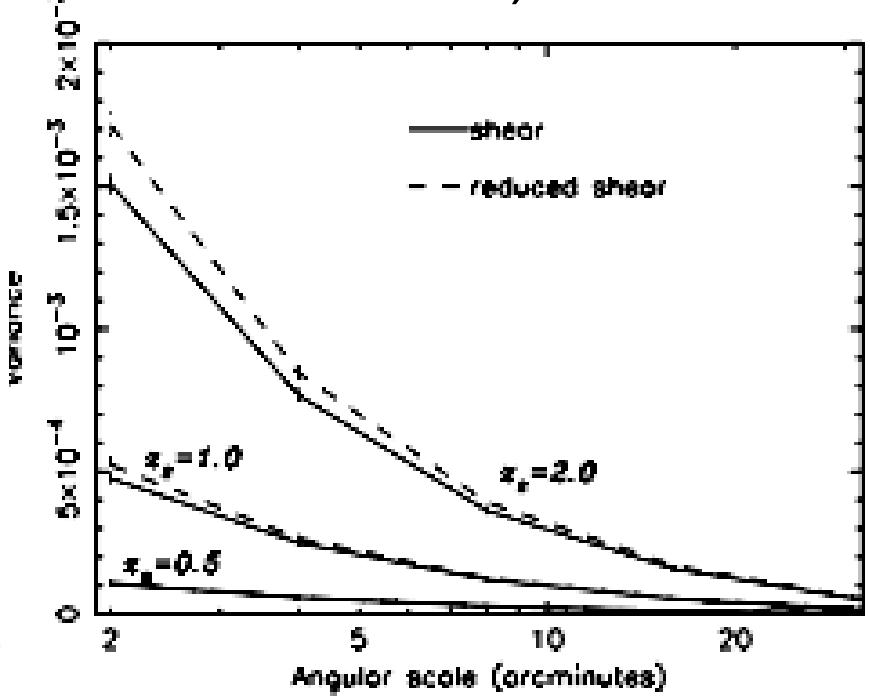
Might think that difference would be much larger for higher order functions - but it is not. It *does* however change the configuration dependence of the 3-pt function slightly.



Robust across simulations

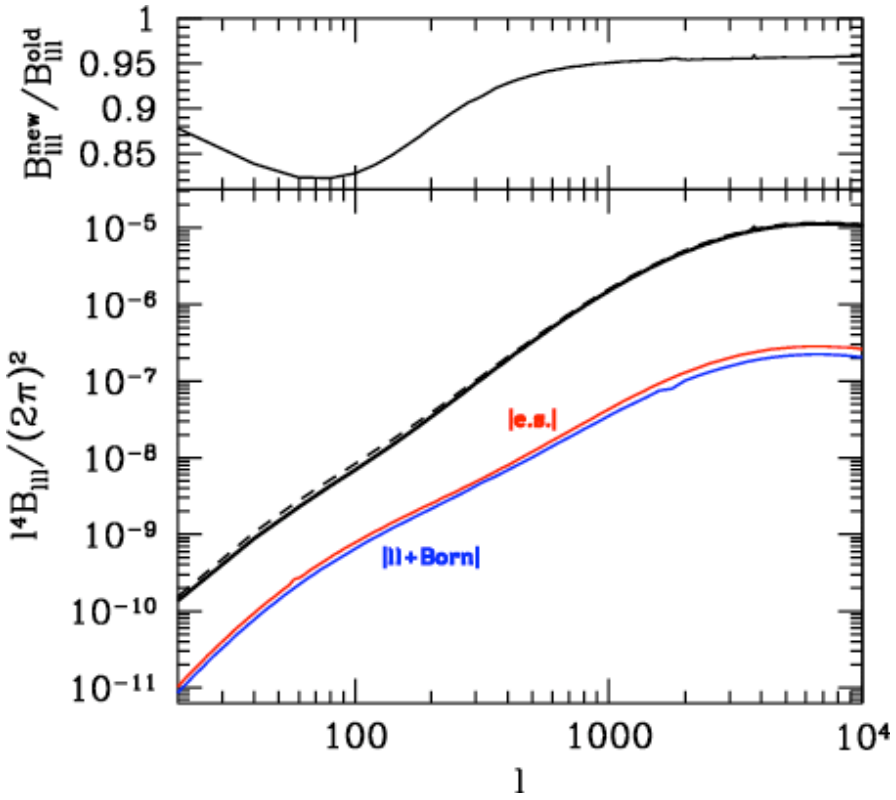
- Comparison of these results with other ray-tracing simulations (where available) shows good agreement.
  - —M. Takada ($\xi(r)$, private communication)
  - —A. Barber (Var[γ], MNRAS, 335, 909, 2002)





Analytic work

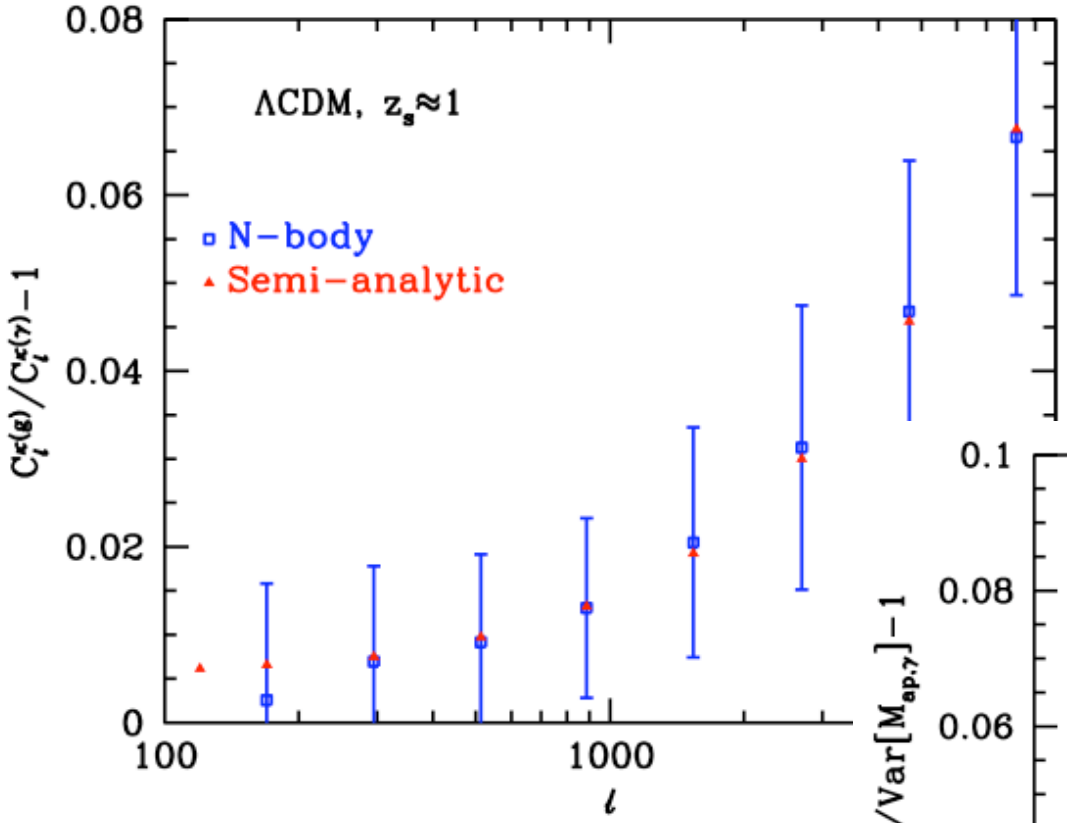
Dodelson, Zhang et al. have computed corrections to the 2- and 3-point functions using an analytic approach. They find roughly comparable results, though some quantitative disagreements with simulations and previous analytic estimates remain.

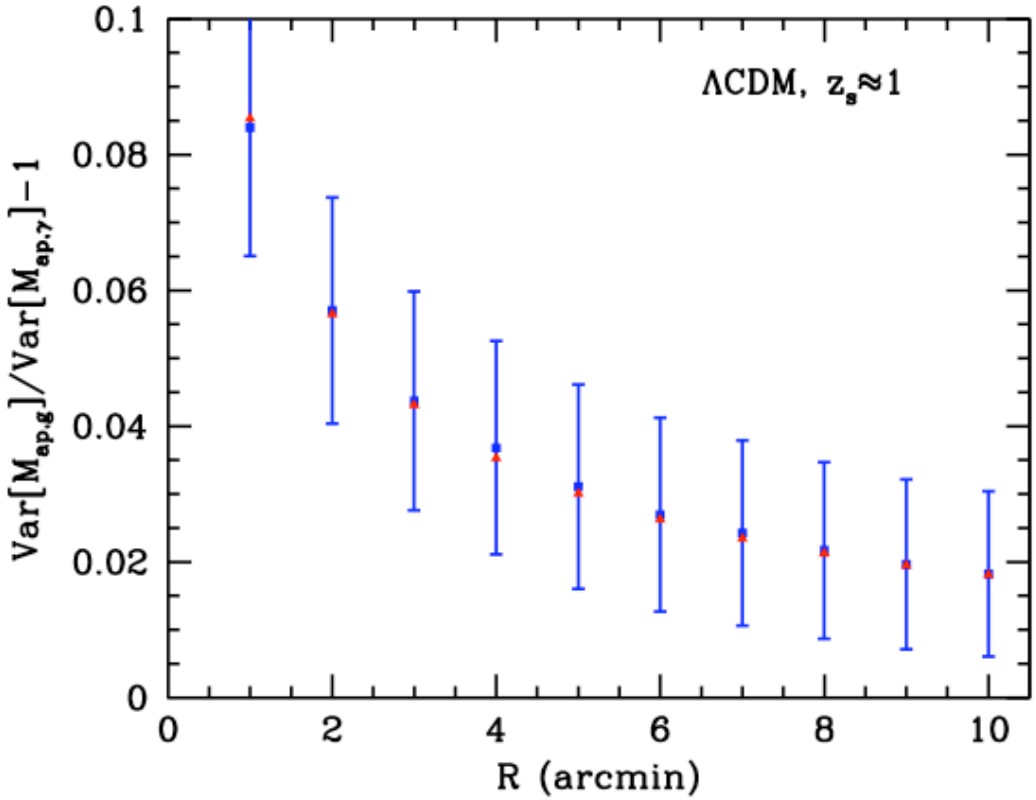


Work currently in progress to assess agreement: Charles Shapiro, Scott Dodelson, MW.

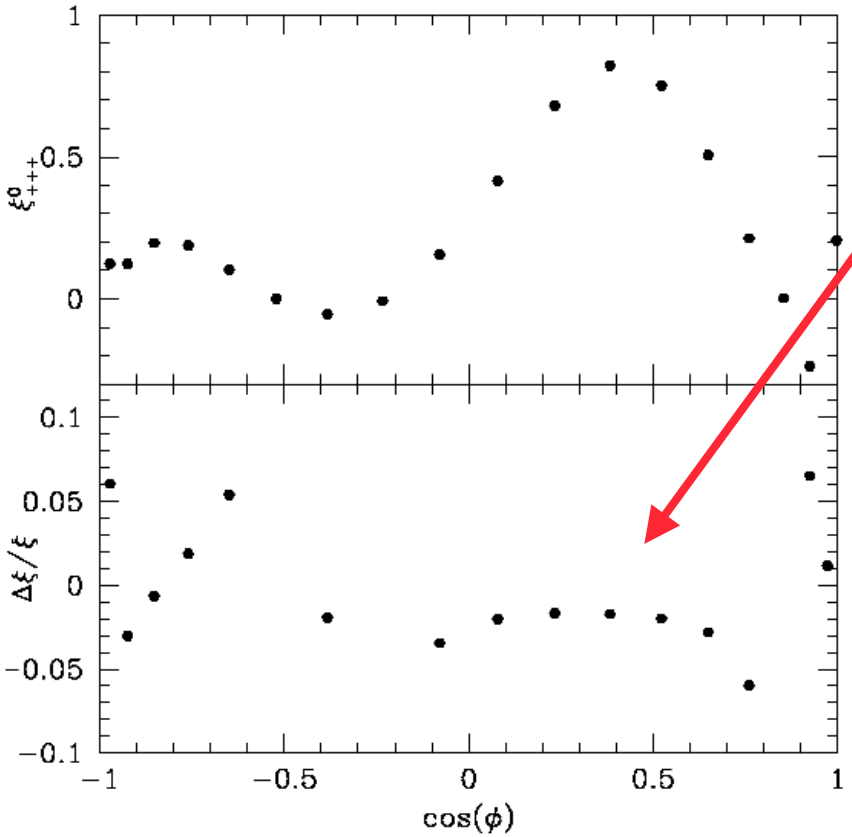
An analytic model would allow us to incorporate the results into Fisher matrix calculations.

2-point functions: agreement





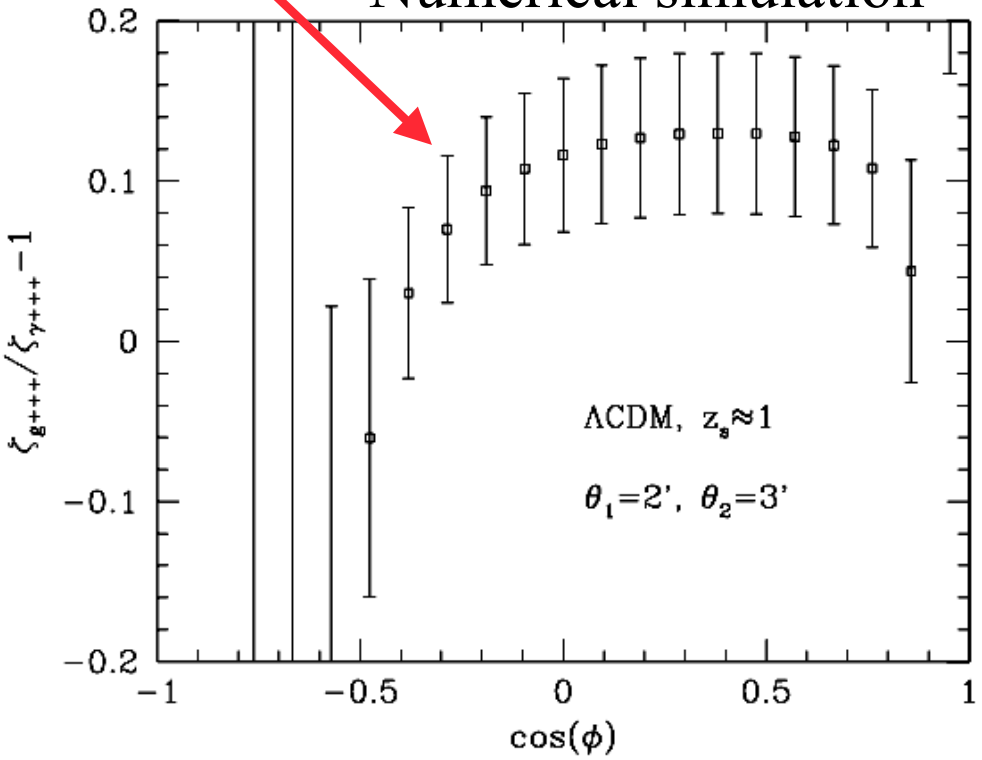
Real Space 3-point function



Analytic calculation

Compare

Numerical simulation

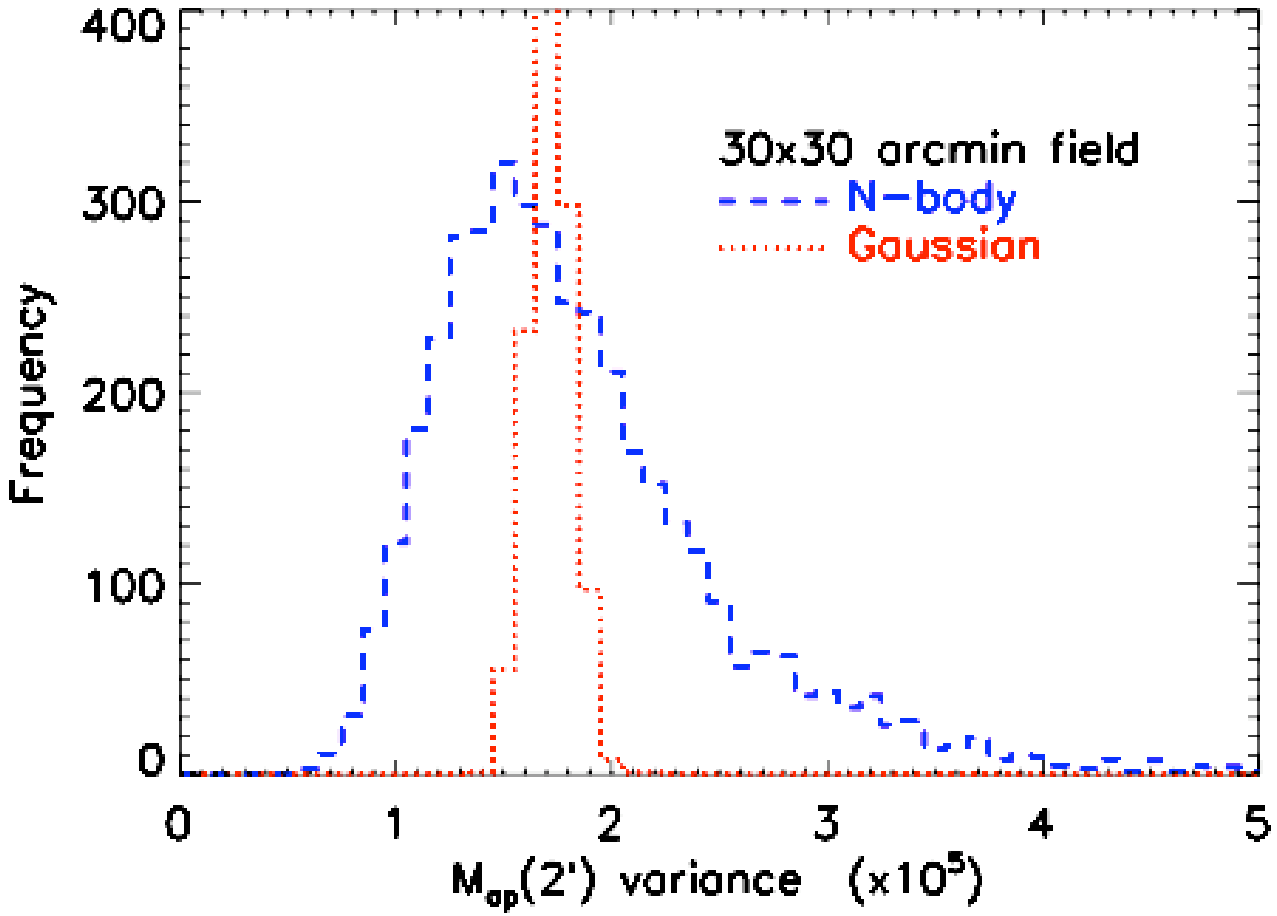


Clustering statistics

- With the 1000 sq. deg run we are now in a position to look at the distribution of these statistics.
- Moving from central values to error bars!

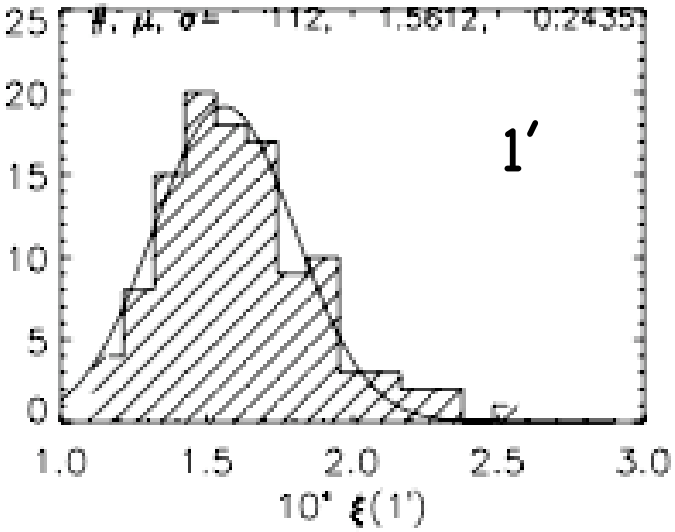
  —See also Kilbinger & Schneider (2005)

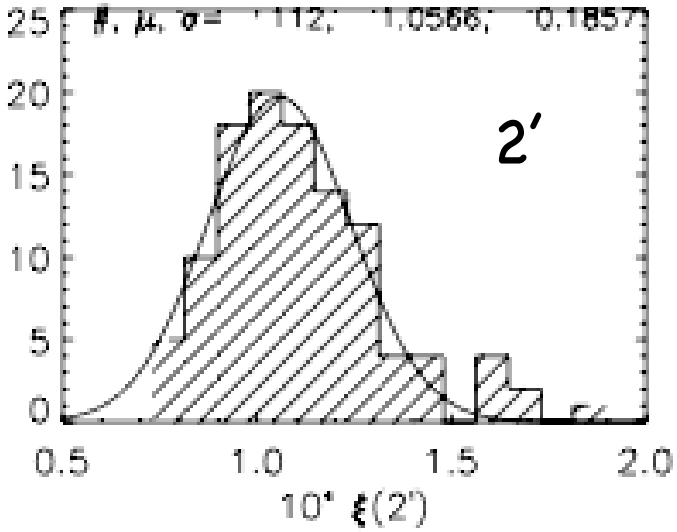
Non-Gaussianity & sample variance



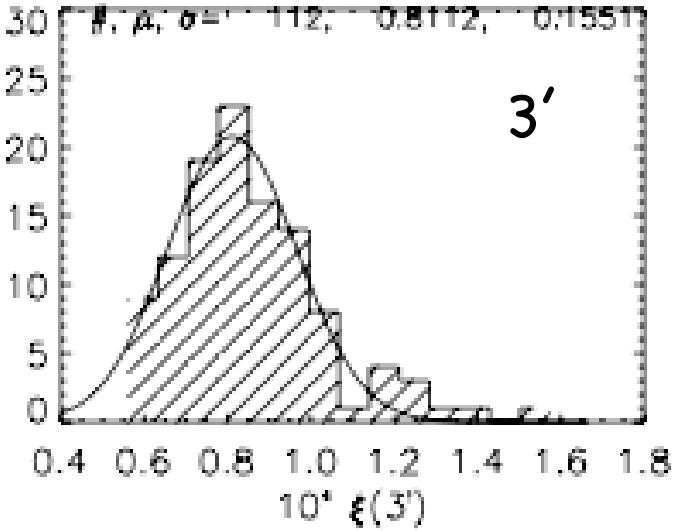
The distribution of variances is not well approximated by a Gaussian on small scales. Sample variance is a larger effect than a naïve calculation would indicate.

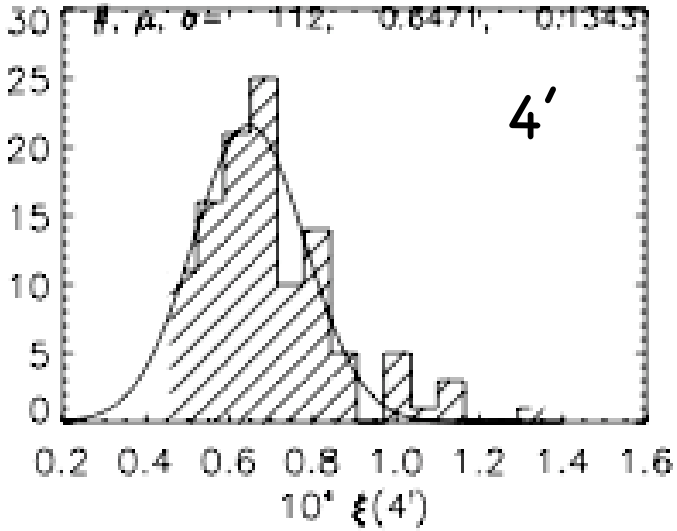
Correlation function errors



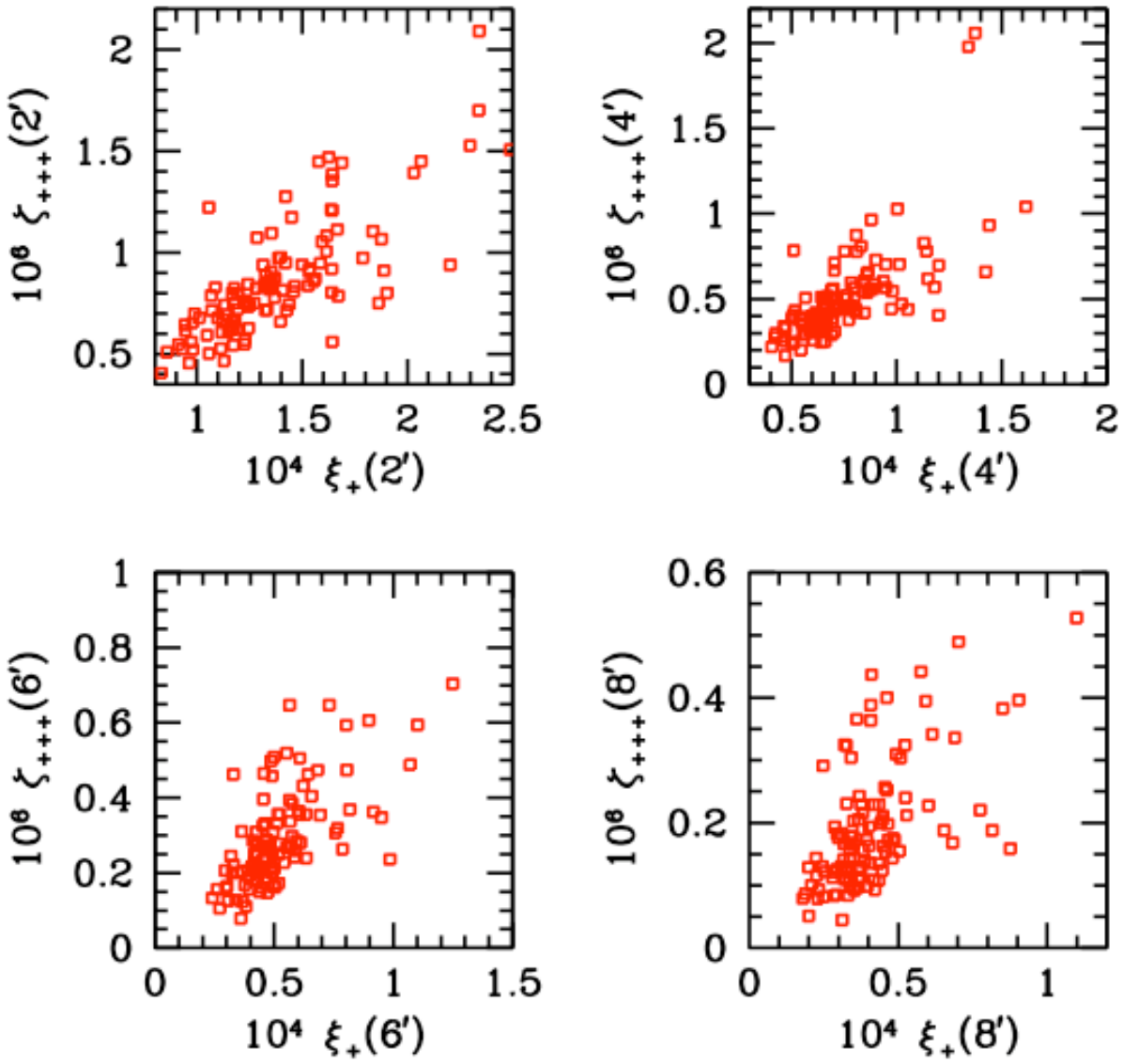


ξ(θ) from 112 maps, each 3x3 degrees





Correlations in clustering

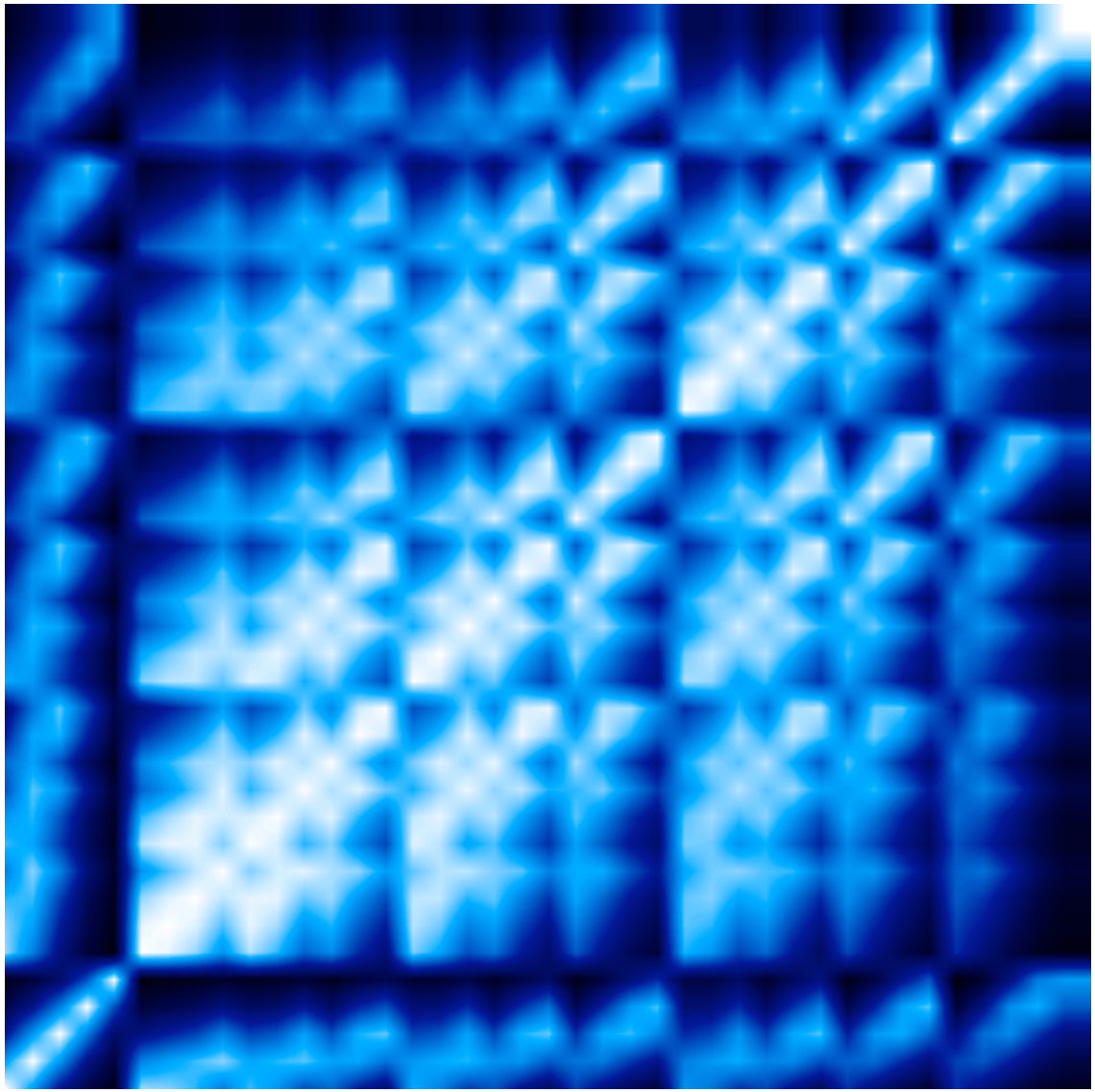


Find that the 2-point and 3-point functions are highly correlated on small scales.

This is not too surprising when thought of from an "object" perspective but is not often assumed.

Correlations contd.

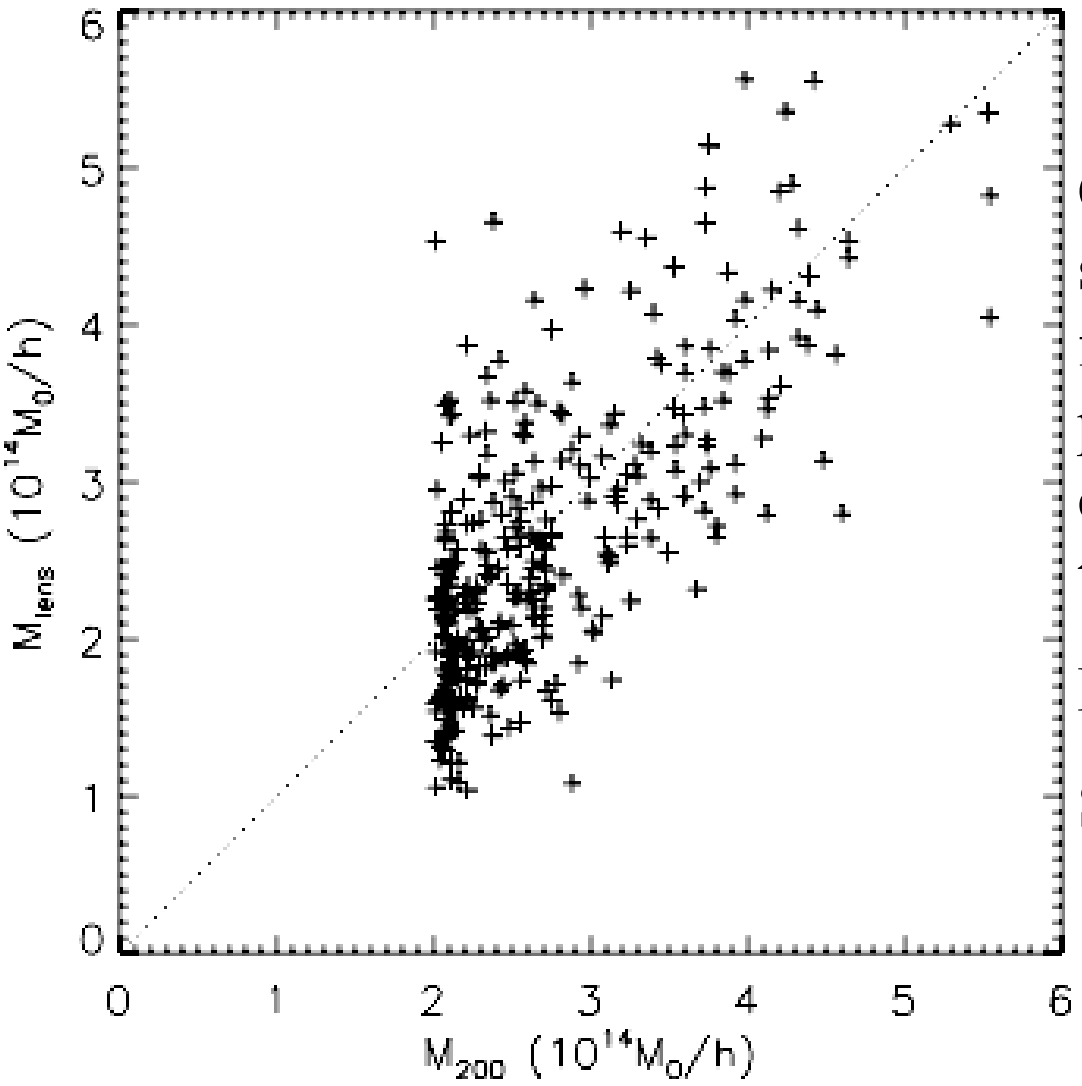
- Correlation matrix for 2nd and 3rd order M_{ap} statistics (computed from κ maps).
- Uses Mexican hat filter with scales 1, 2, 4, 8 & 16 arcmin (40 measures: 5x 2-pt and 35x 3-pt).



Scatter in lensing “masses”

- Lots of confusion about lensing mass, bias and scatter.
- Just measuring projected mass will lead to generally overestimated 3D masses since clusters live in overdense regions.
- One can correct for this statistically by assuming a model for the contamination
  - —This can be thought of as an extension of the halo profile beyond the virial radius
- The resulting scatter can bias mass function estimates unless it is included in the analysis.

Scatter in mass estimator

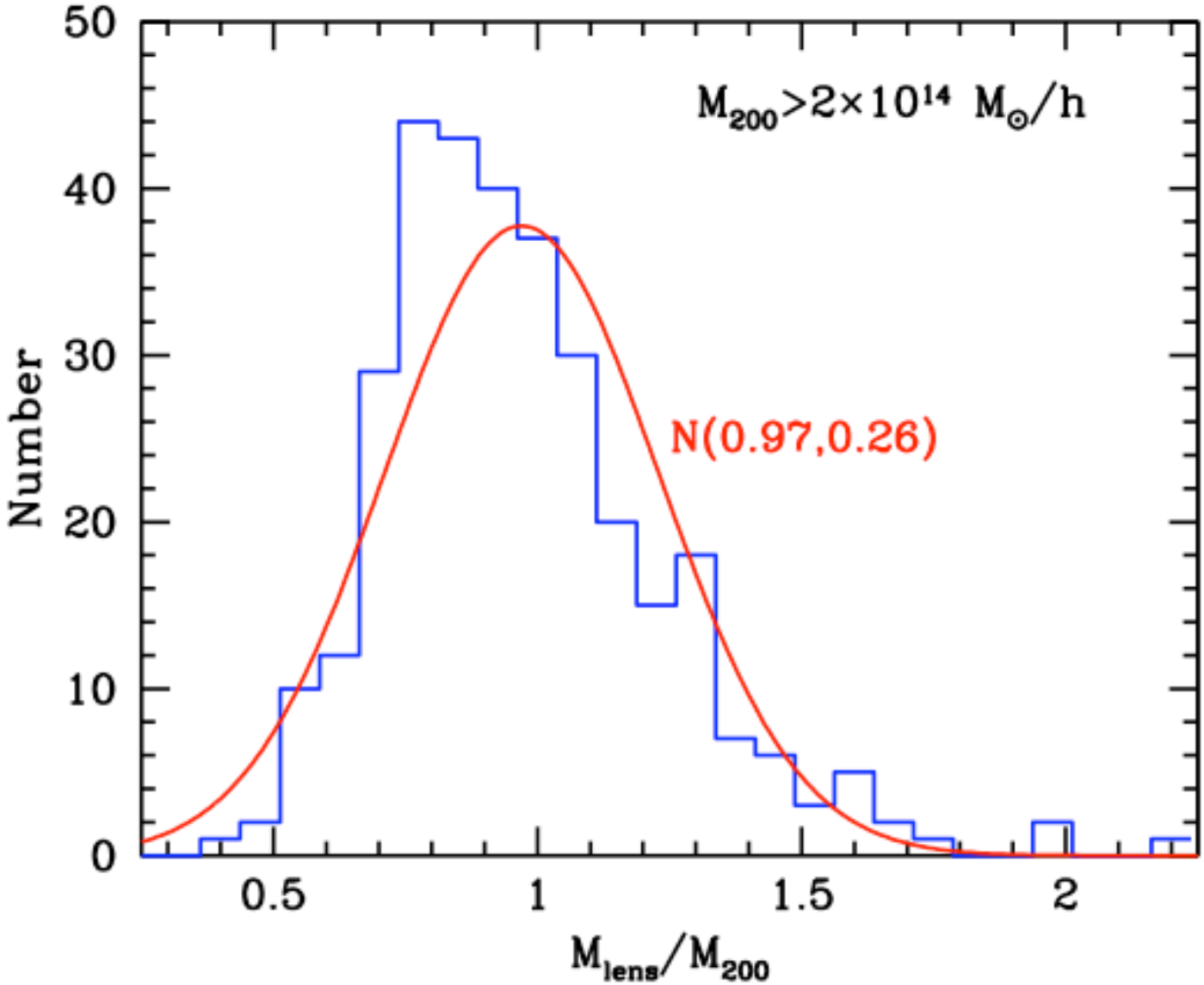


Correction for line-of-sight contamination by fitting a projected NFW profile to the shear and computing M_{200} from the fit.

Bias is a few percent.

Scatter is ~25%.

Distribution of errors



The End