Seeing [in] the Dark: Cosmic Shear from SDSS

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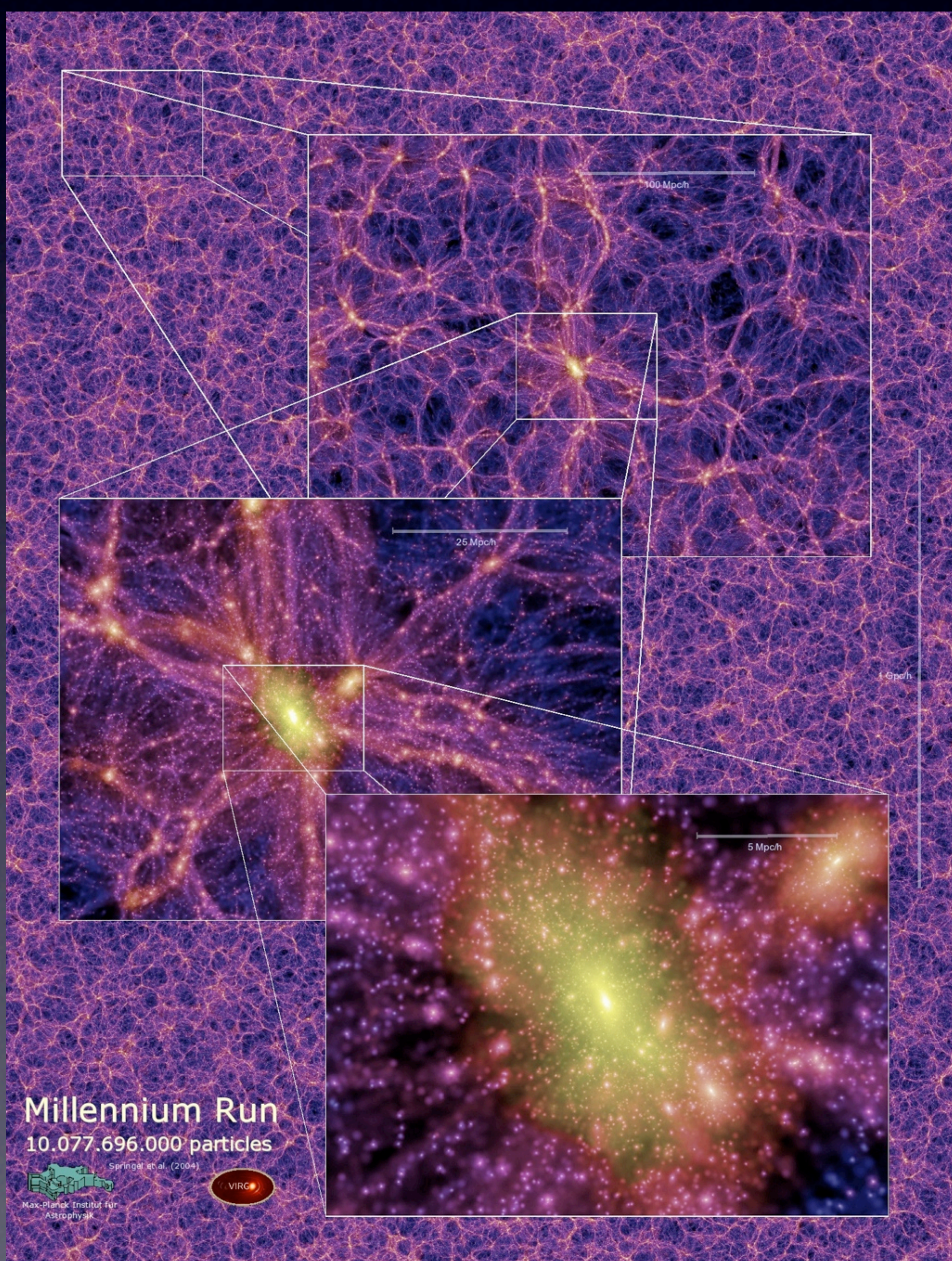
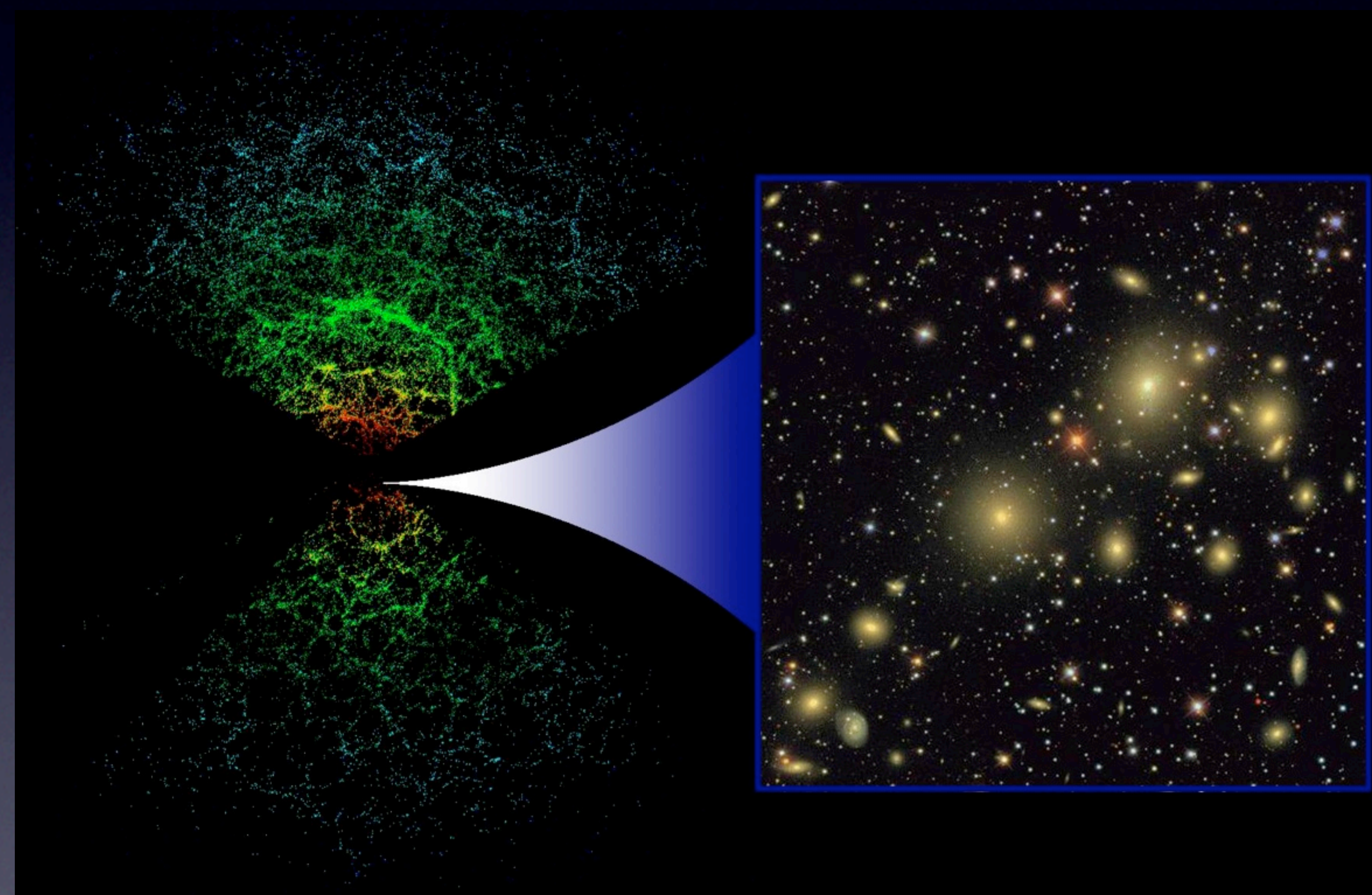
Why we want to measure weak lensing:

We can make very precise predictions about the invisible...

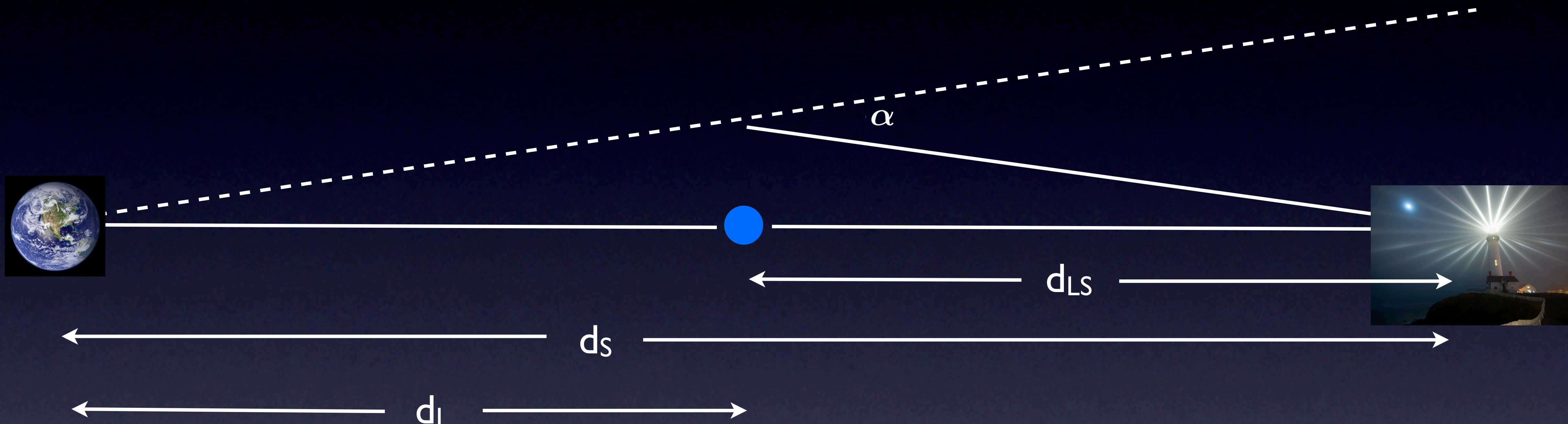




But the visible (baryonic) component is not easy to model.

- Weak Lensing Refresher
- Part I: A Cosmic Shear Measurement
- Part II: A Novel Magnification Measurement

Lensing is the distortion of background images by foreground mass:



$$\kappa\left(\bar{\theta}\right) = \int_0^{z_s} \frac{c}{H_0} \frac{dz}{a} \frac{\rho_m\left(z\right)}{\Sigma_{\rm crit}}$$

$$\Sigma_{\rm crit} = \frac{3H_0^2}{8\pi G} \frac{d_S}{d_L\, d_{LS}}$$

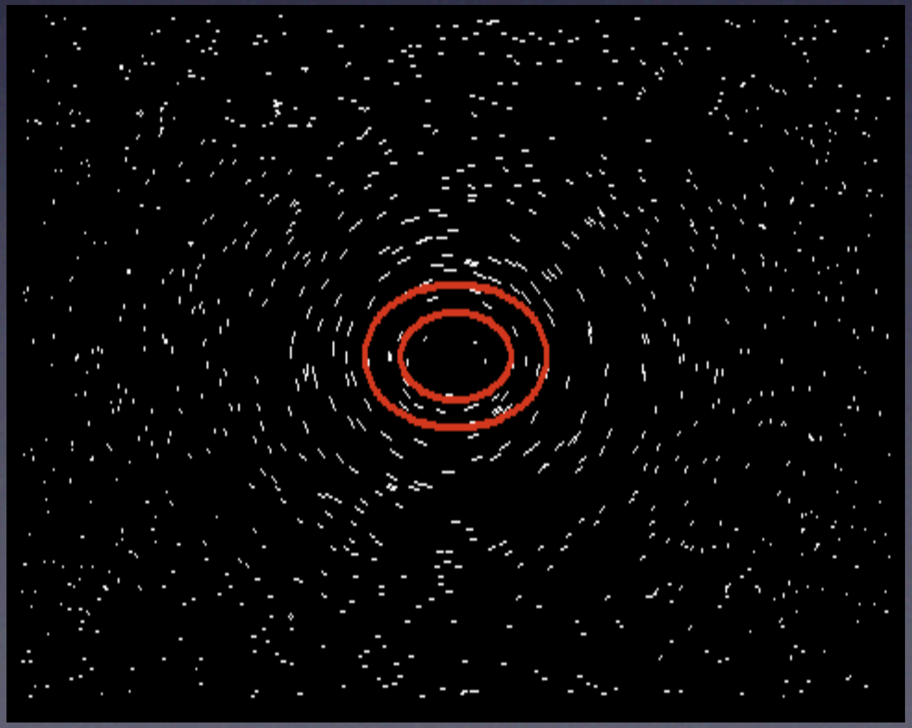
Sensitive to geometry and lens mass

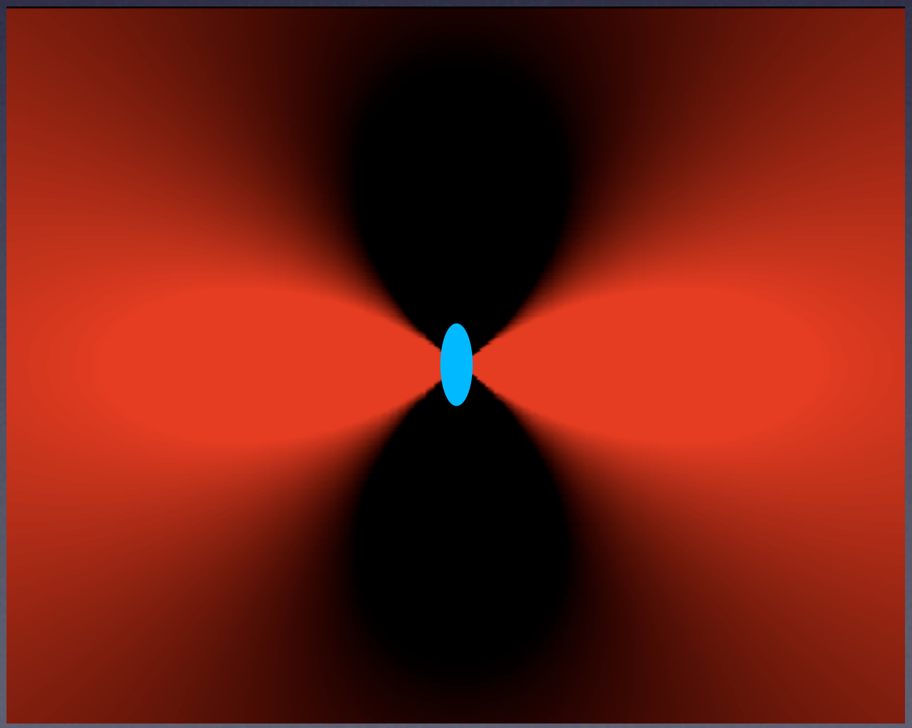
This distortion can be decomposed into shear and magnification:

$$A_{ij} = \frac{\partial \theta^I_i}{\partial \theta^S_j} = \begin{pmatrix} 1+\kappa+\gamma_1 & \gamma_2 \\ \gamma_2 & 1+\kappa-\gamma_1 \end{pmatrix}.$$

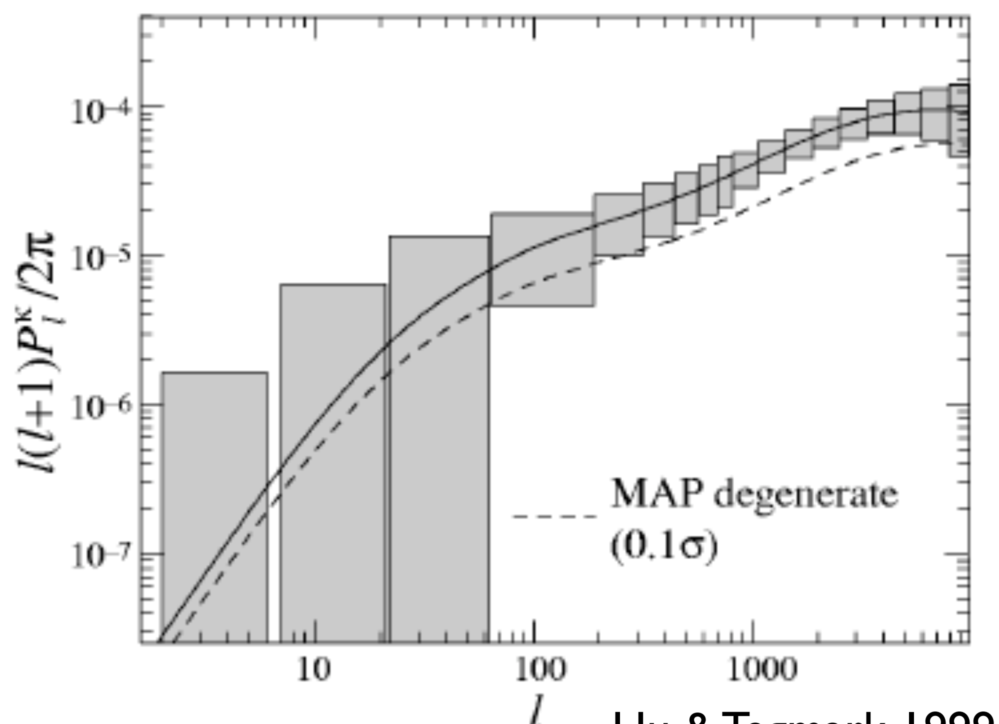
Let's focus on the shear distortion:

$$[\gamma_1 + i\gamma_2](\bar{\theta}) = -\frac{1}{\pi}\int d^2\bar{\phi}\ \frac{\kappa(\bar{\theta}-\bar{\phi})}{|\bar{\theta}-\bar{\phi}|^2} e^{2i\beta}$$





The two-point statistics of the shear are related to the two-point statistics of the matter.



Hu & Tegmark 1999

$$\xi_{\gamma\pm}(\theta) = <\gamma_t\gamma_t> \pm <\gamma_x\gamma_x> = \frac{1}{2\pi}\int_0^\infty d\ell\,\ell P_\kappa(\ell)\,J_{0,4}(\ell\theta)$$

$$P_\kappa(\ell) = \left(\frac{3}{2}\frac{\Omega_m}{d_H^2}\right)^2 \int_0^\infty \frac{d\chi}{a(\chi)^2} P_\delta\left(\frac{\ell}{d(\chi)}\chi\right)\left[\int_\chi^\infty d\chi' n(\chi')\frac{d(\chi'-\chi)}{d(\chi')}\right]^2$$

By measuring galaxy shapes, we can get a bias-free measurement of the clustering of matter.

But the signal to noise is very small.

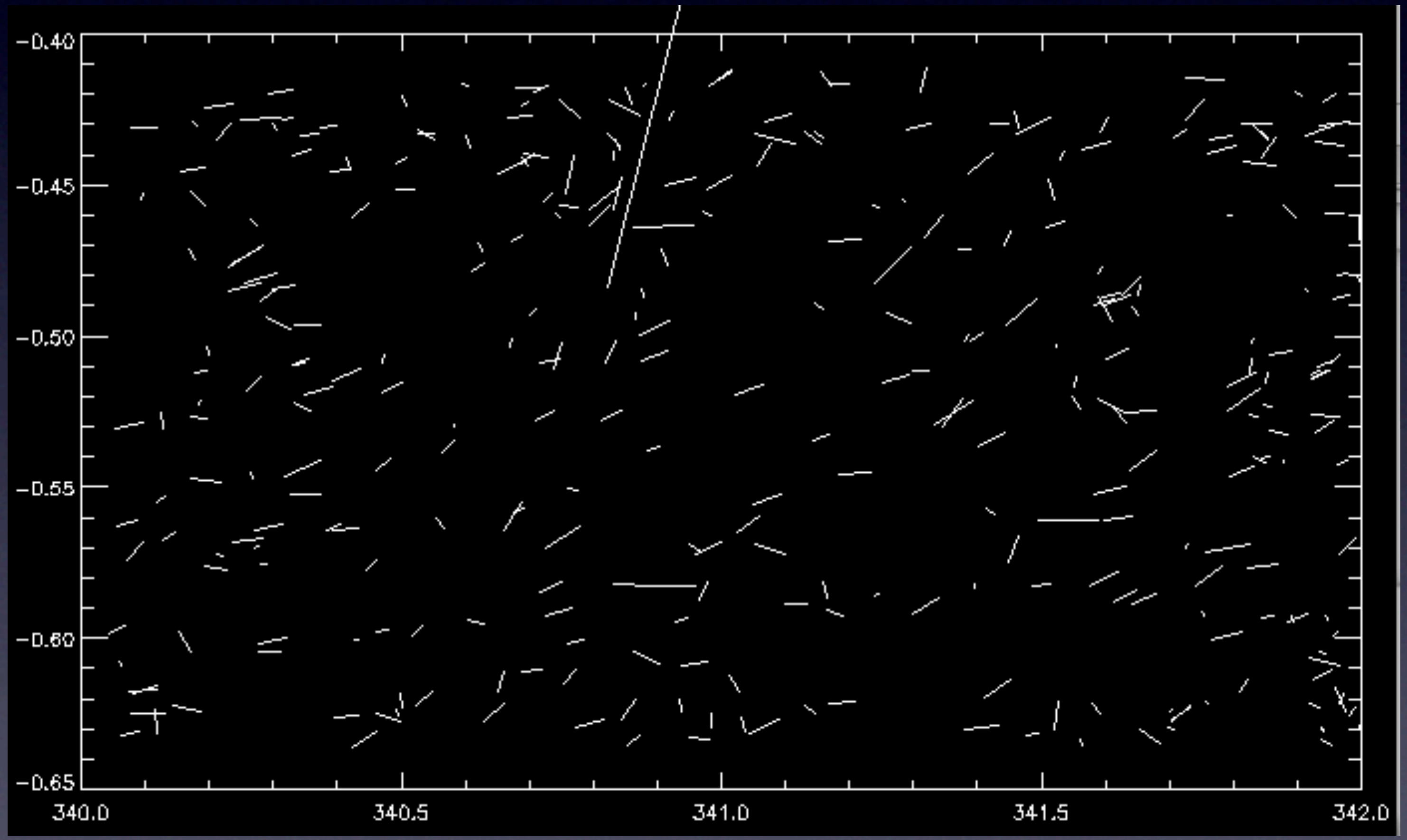
$$< \gamma > \sim 0.001 - 0.01$$

Especially compared to the random noise from galaxy shapes

$$\sigma_\gamma = 0.3$$

Few data sets exist that can measure this at high signal.

and there are many sources of systematic error:



psf ellipticity

photometric redshifts

intrinsic alignments

shear calibration bias

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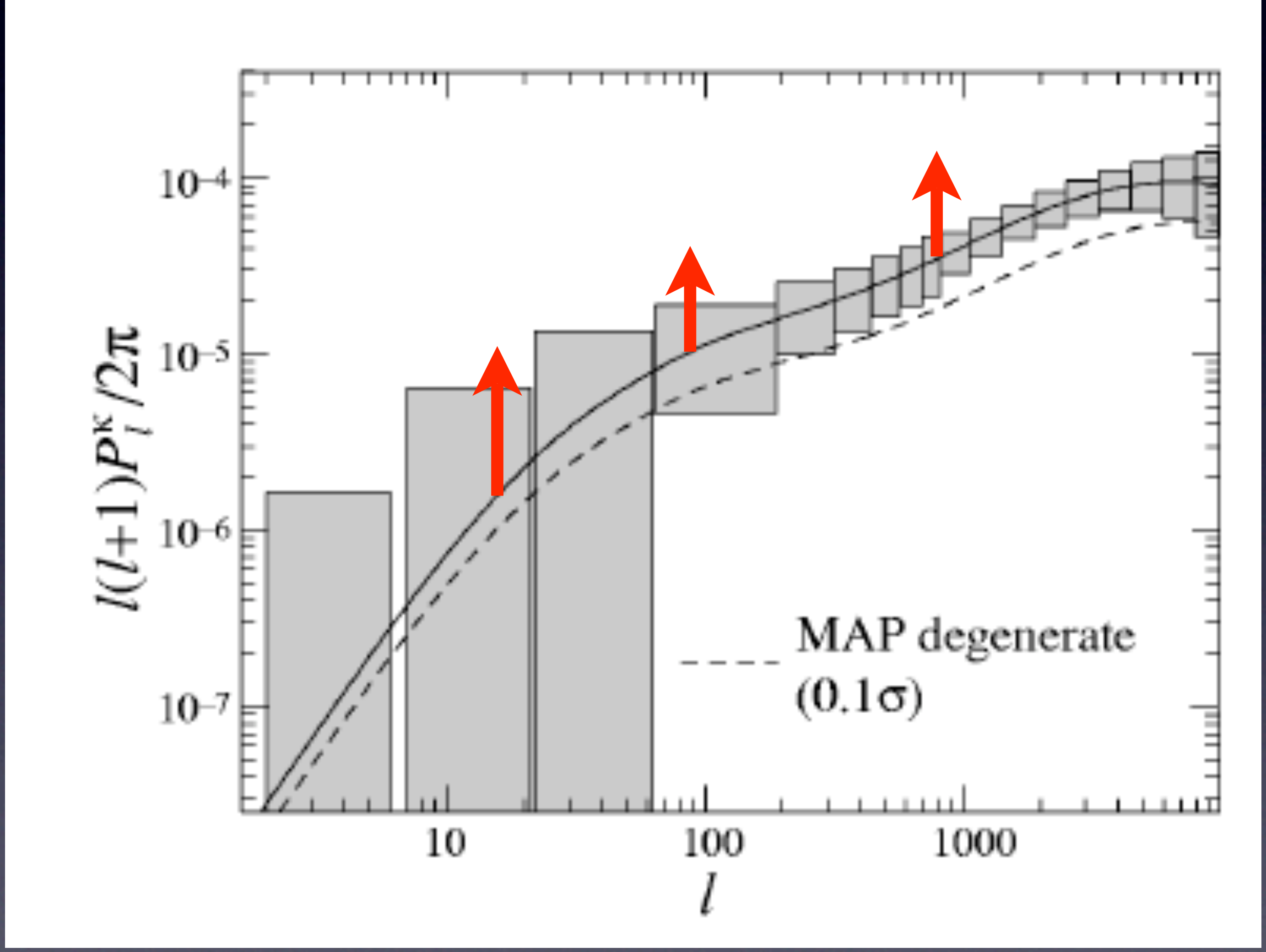

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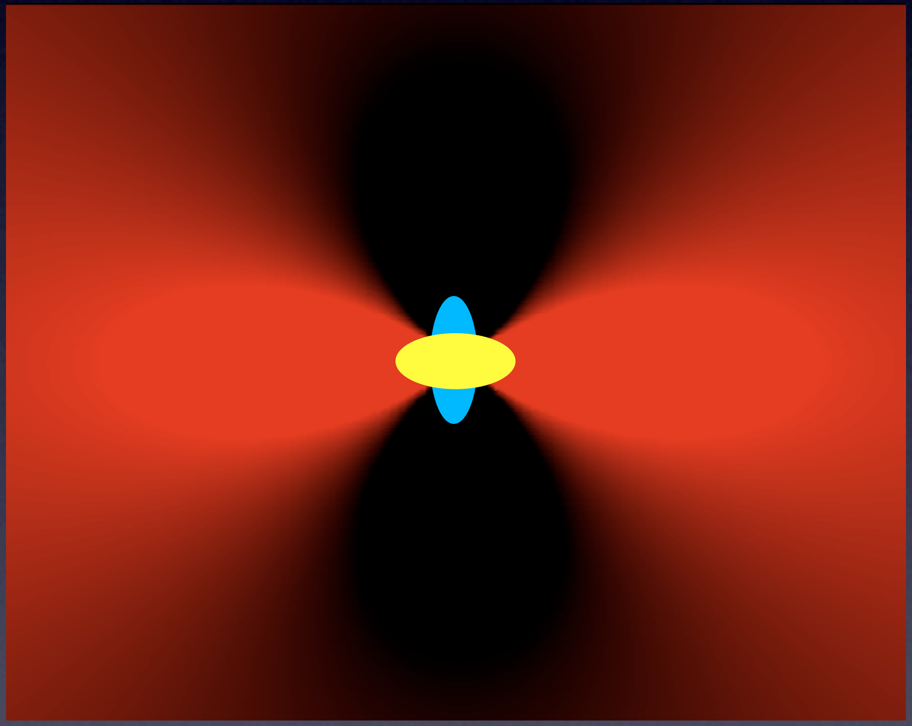

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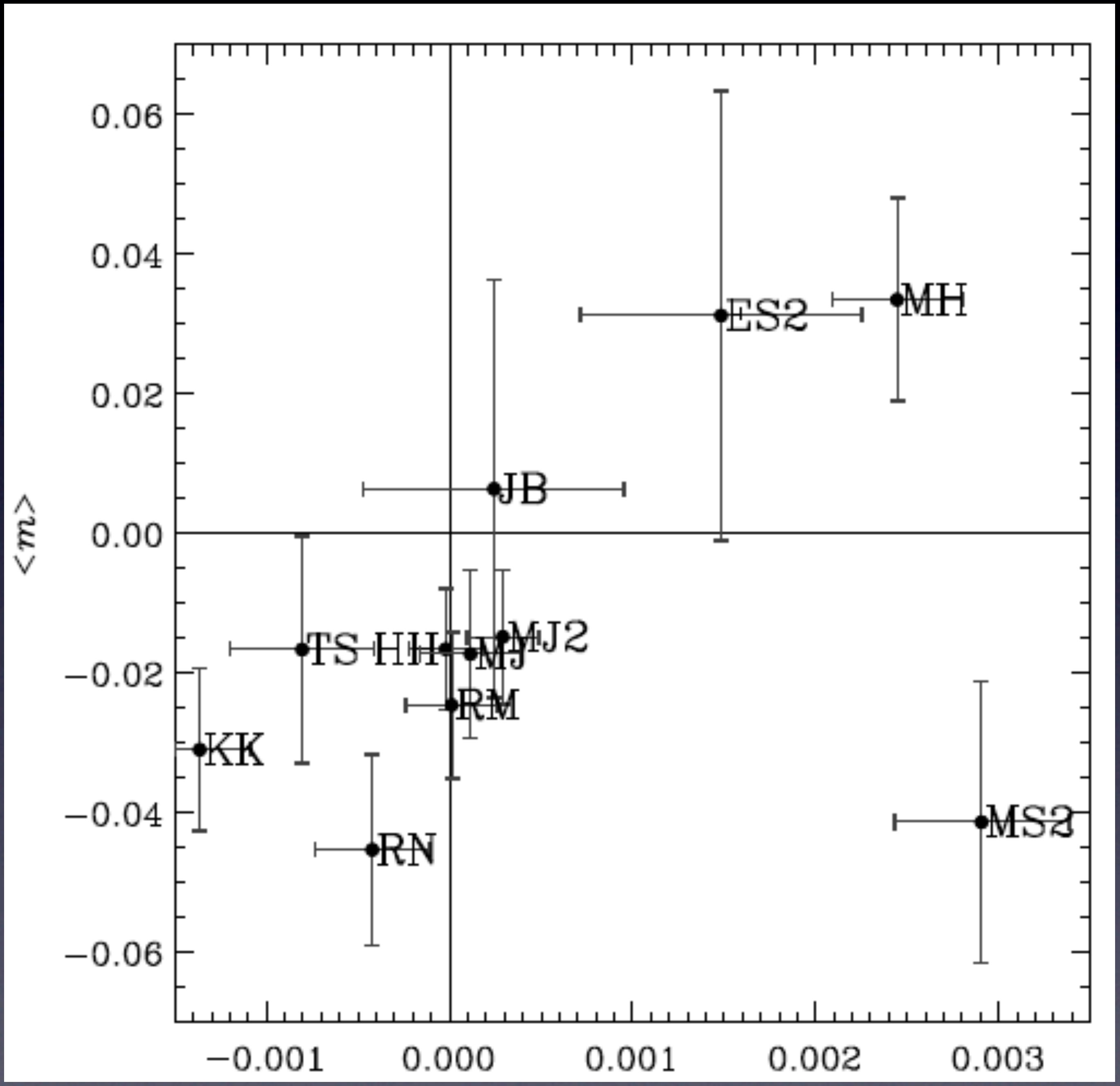


STEP 2: Massey et all 2006

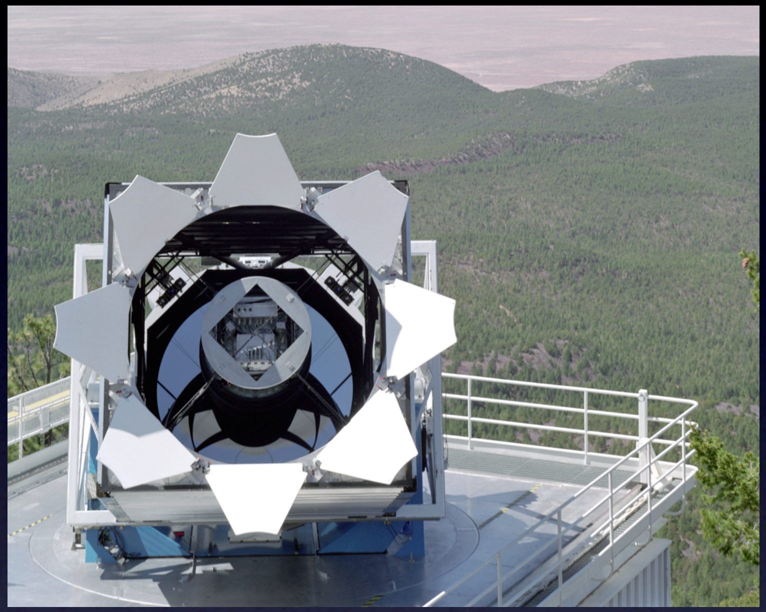
psf ellipticity

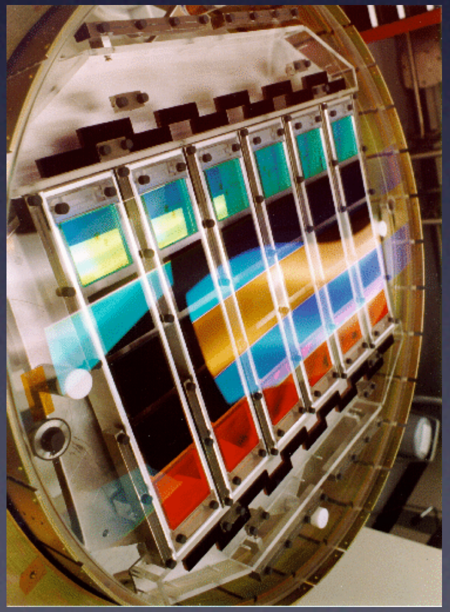
photometric redshifts

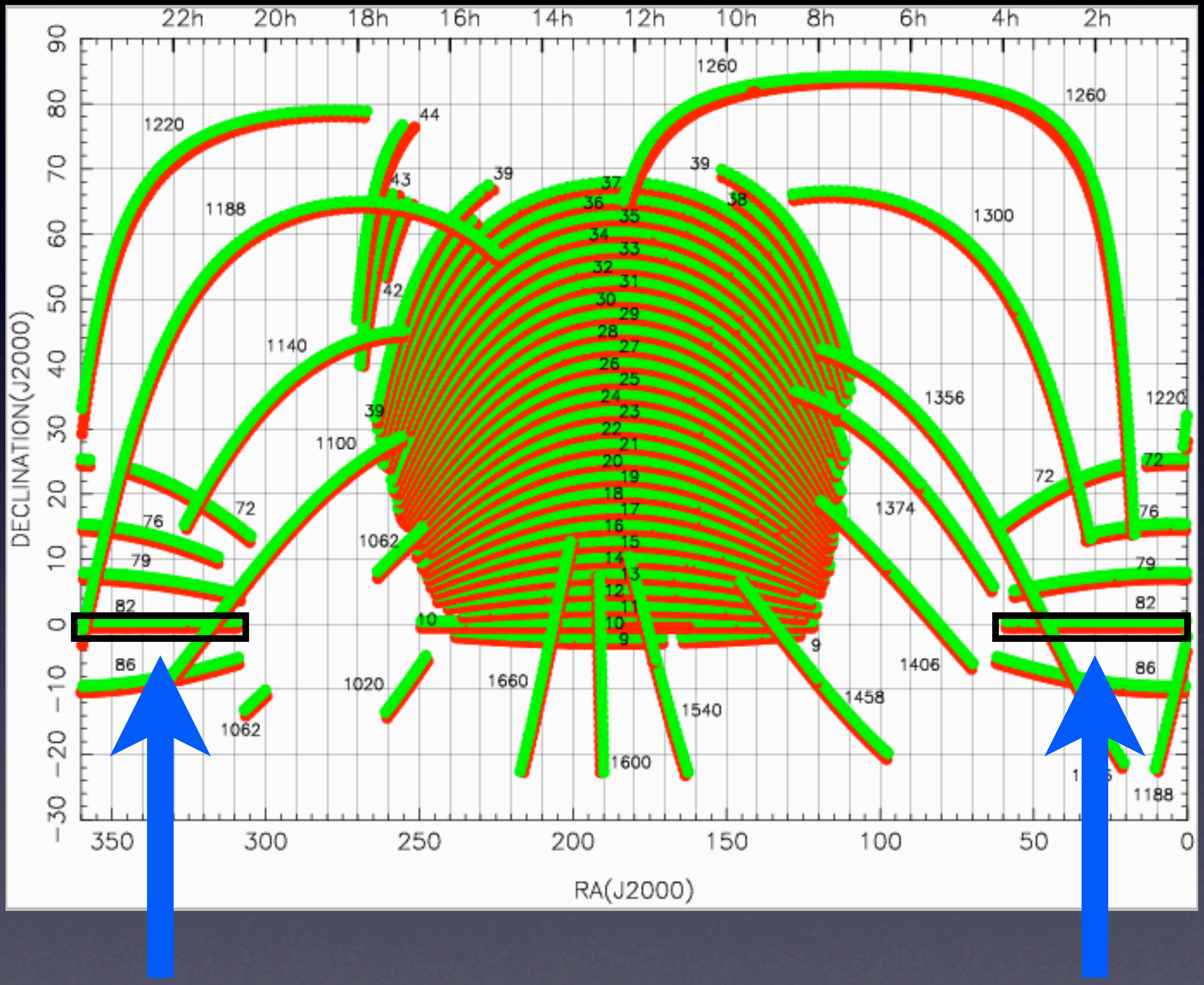
intrinsic alignments

shear calibration bias

We've built a catalog from SDSS data that addresses these problems

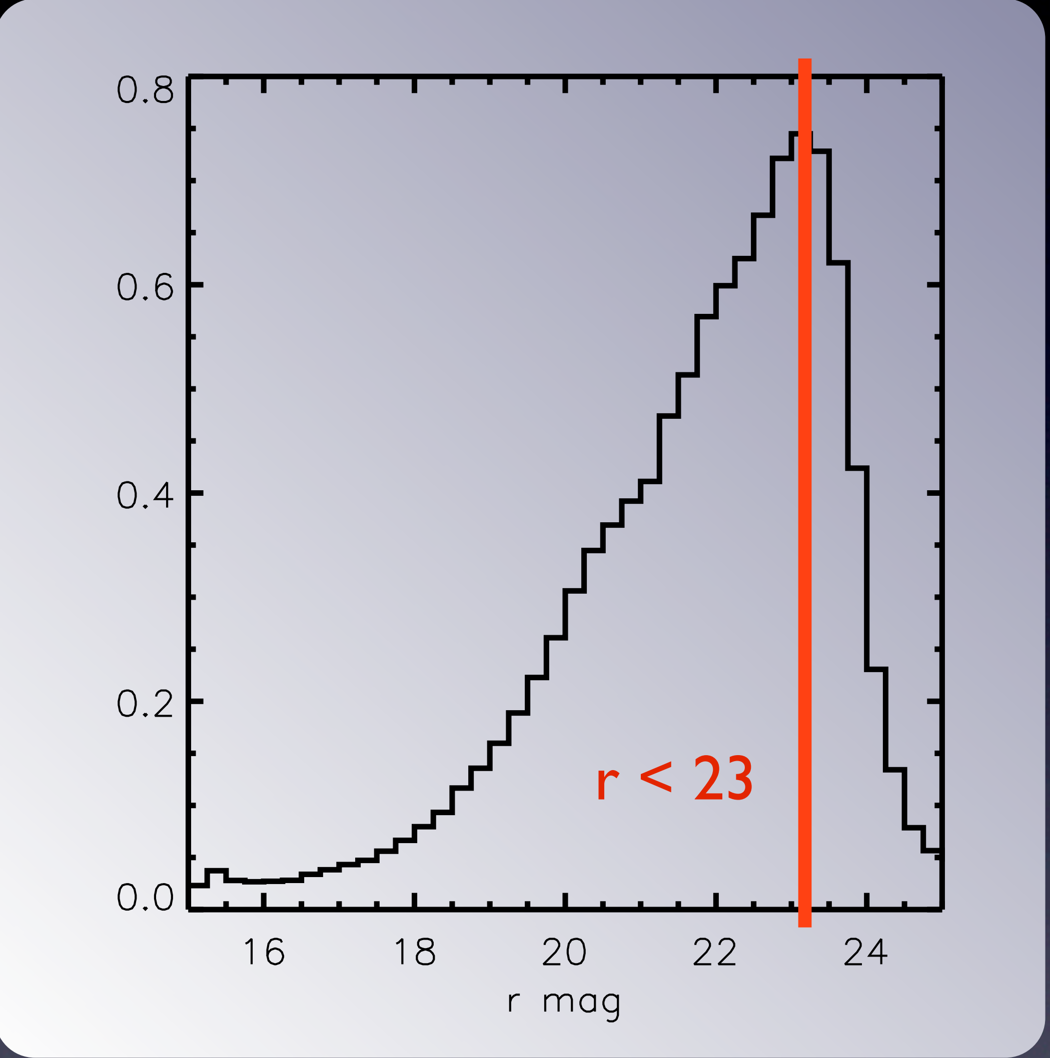






We set out to coadd the 80+ epochs of Stripe 82 data

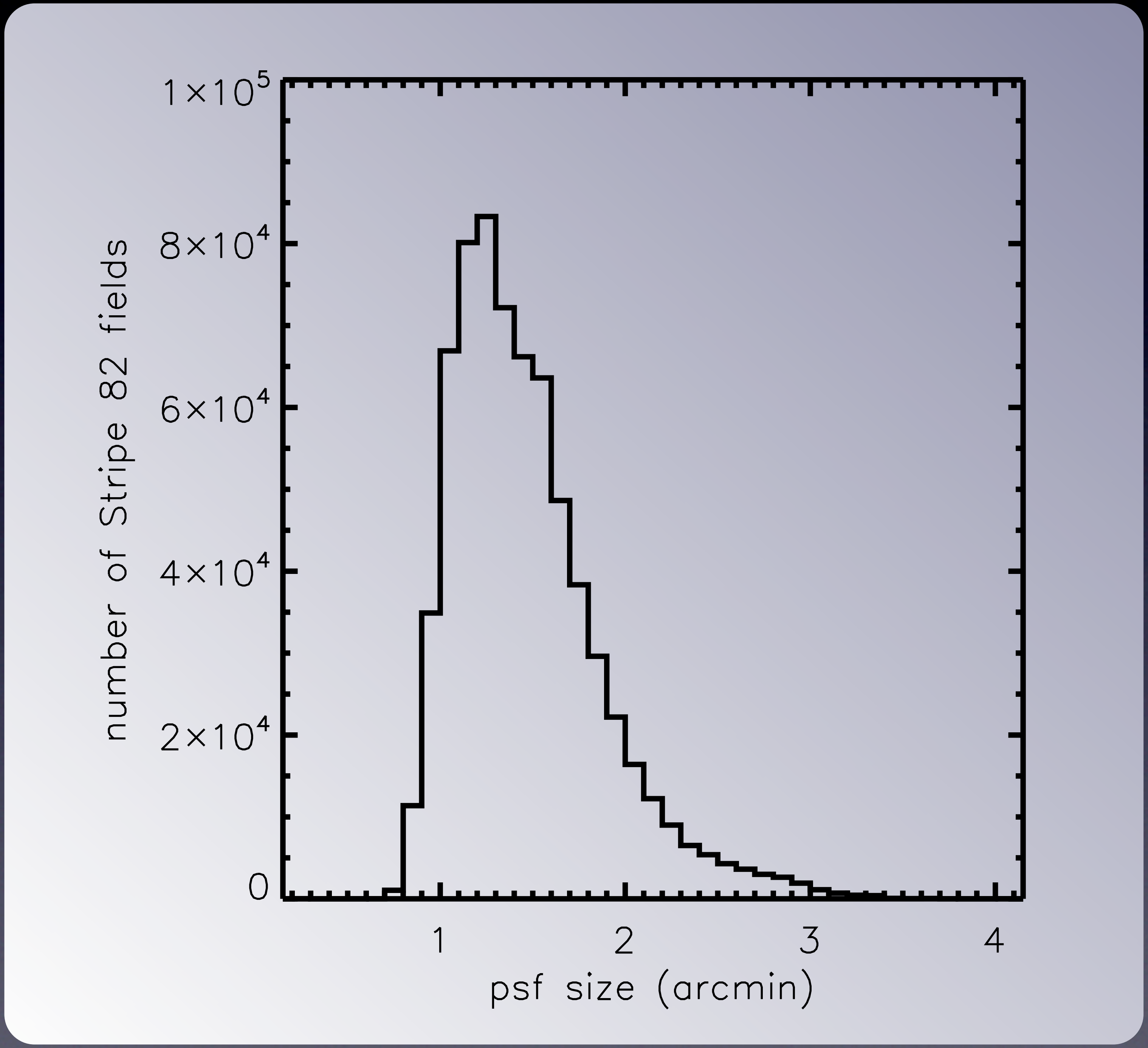
SDSS is not the ideal survey for measuring cosmic shear



Even the SDSS coadds are fairly shallow.

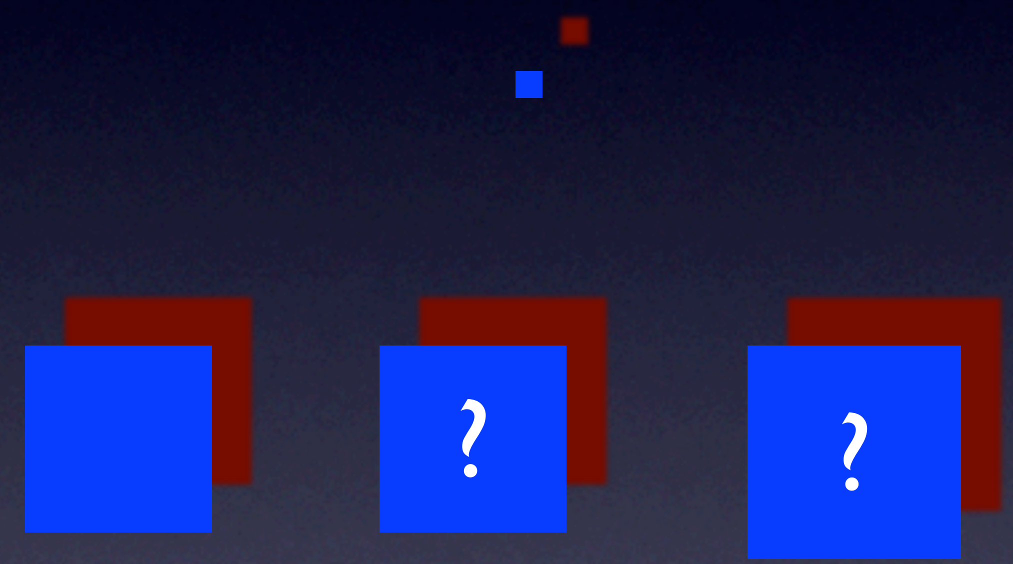
By comparison, CFHTLS has $i < 24.5$

SDSS is not the ideal survey for measuring cosmic shear

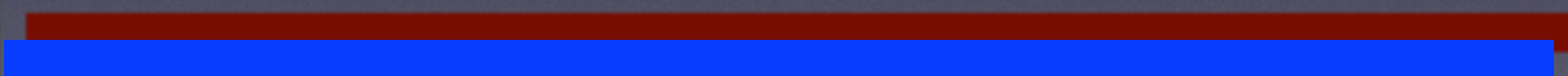


Stripe 82 covers more area than any other cosmic shear survey.

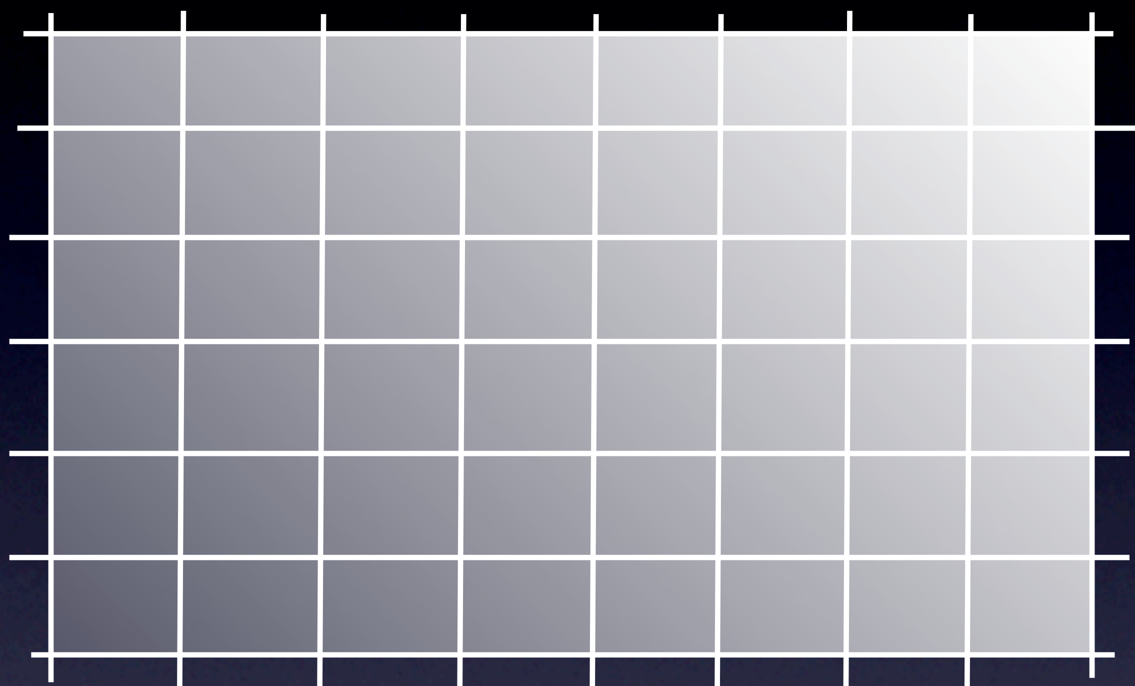
- These are some of the surveys that have been done so far.
  - COSMOS
  - CFHTLS



  - This Work



We use a rounding kernel to homogenize the psf in each image.

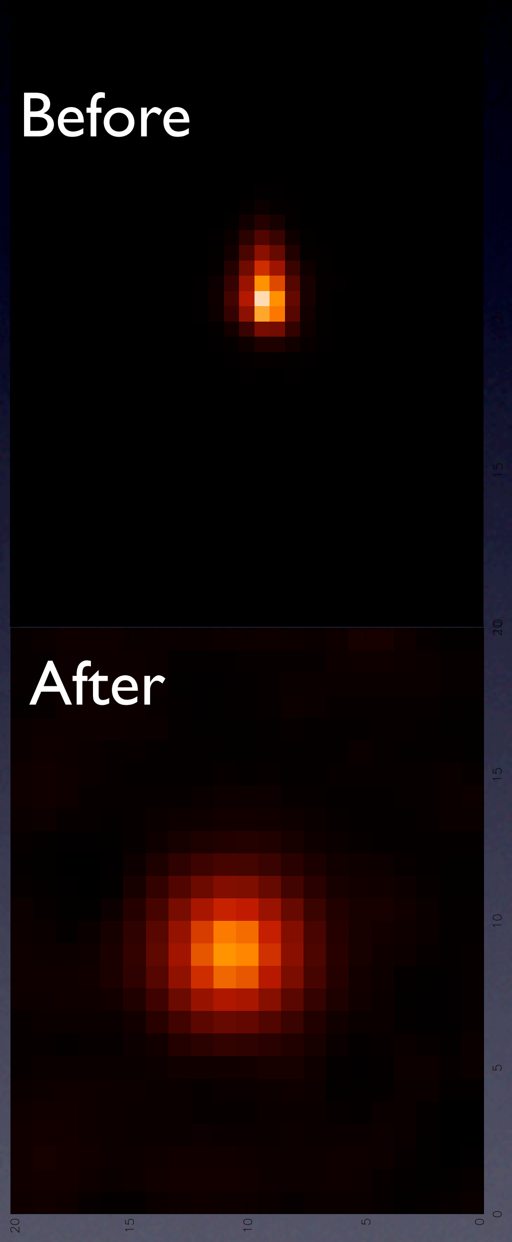


divide each image into 6x8 cells

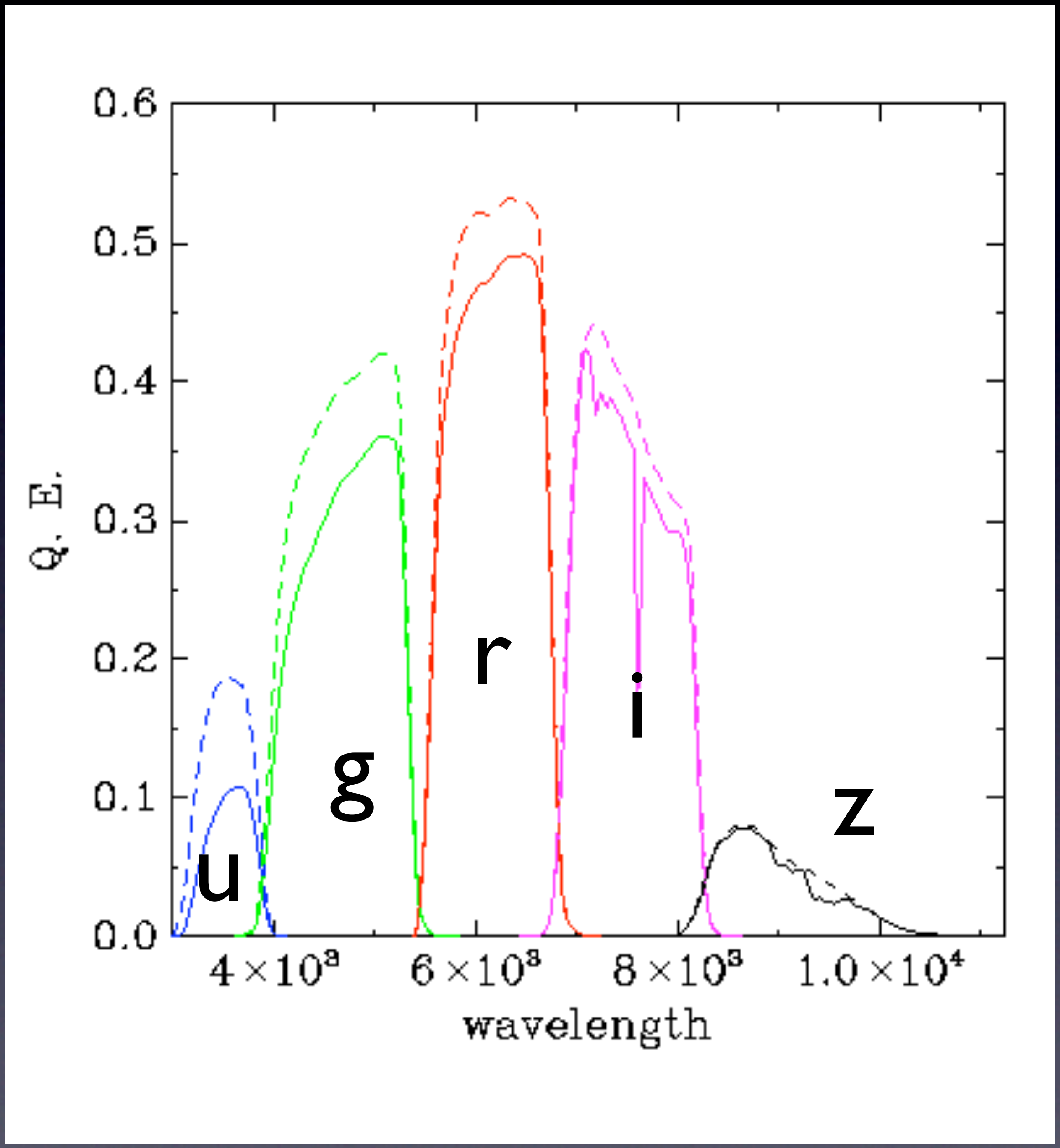
reconstruct SDSS psf in each cell

calculate convolution kernel in each cell

$$\hat{R} = \frac{\hat{G}\hat{T}}{\hat{G}^2 + \lambda}$$

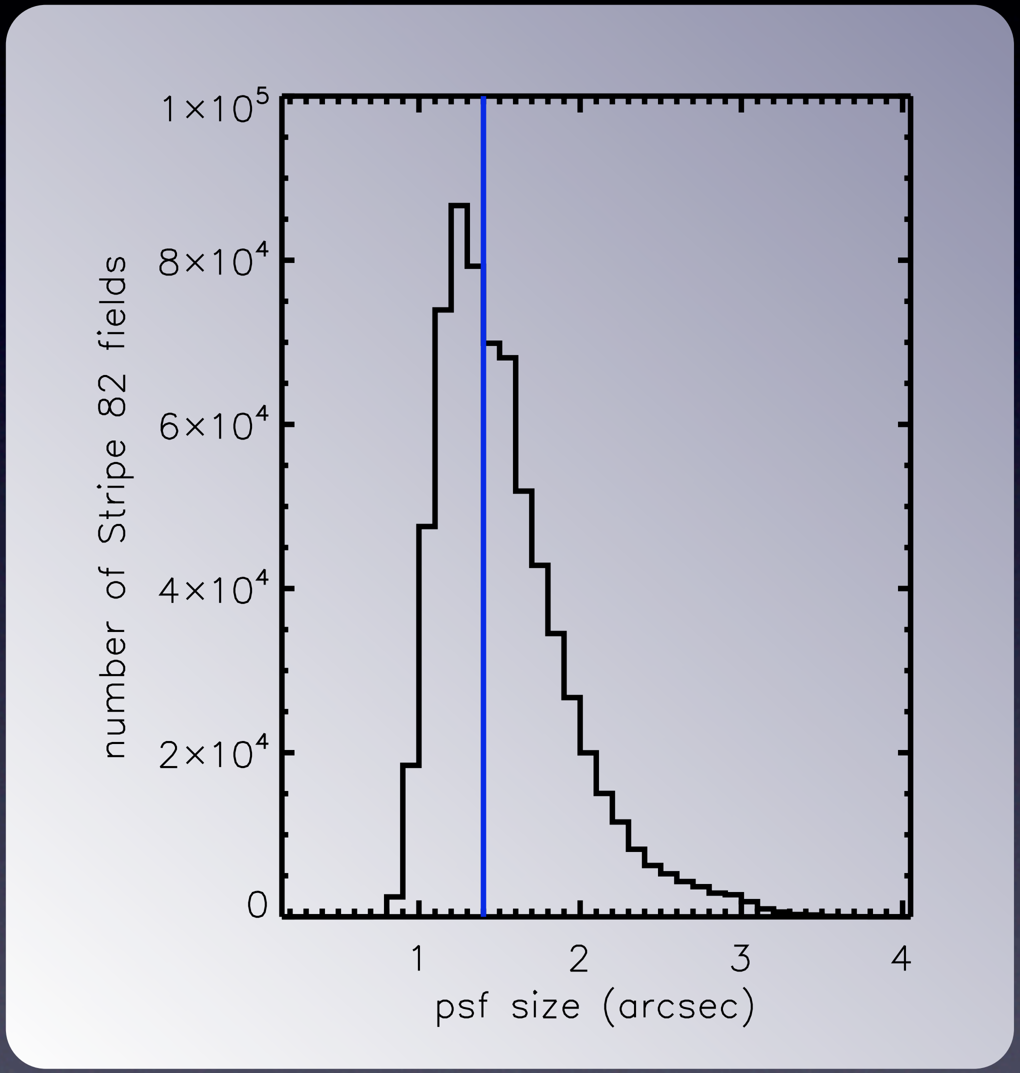


We perform shape measurements in the SDSS r and i bands.

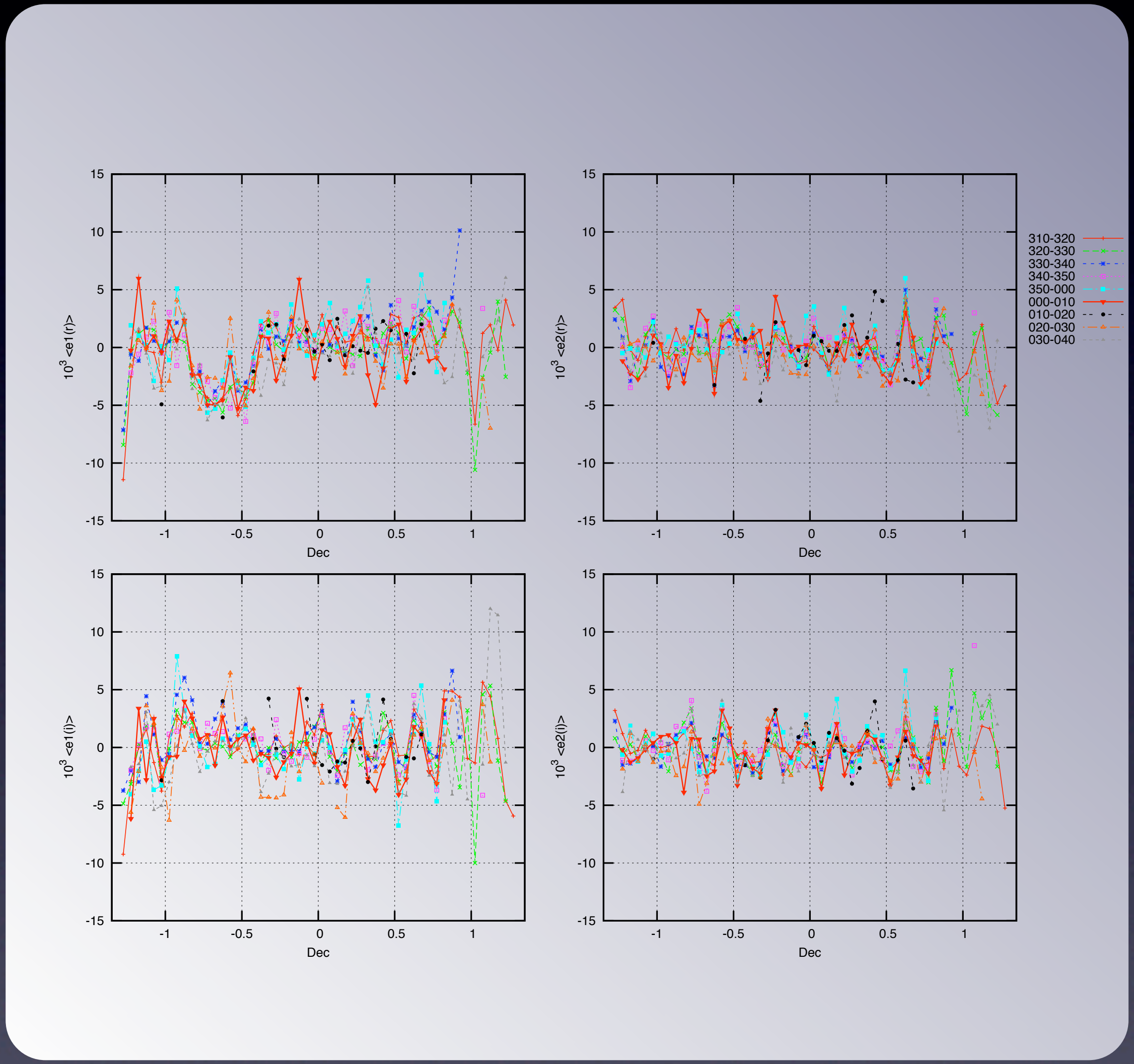


These are the deepest.

We made many cuts on the data products

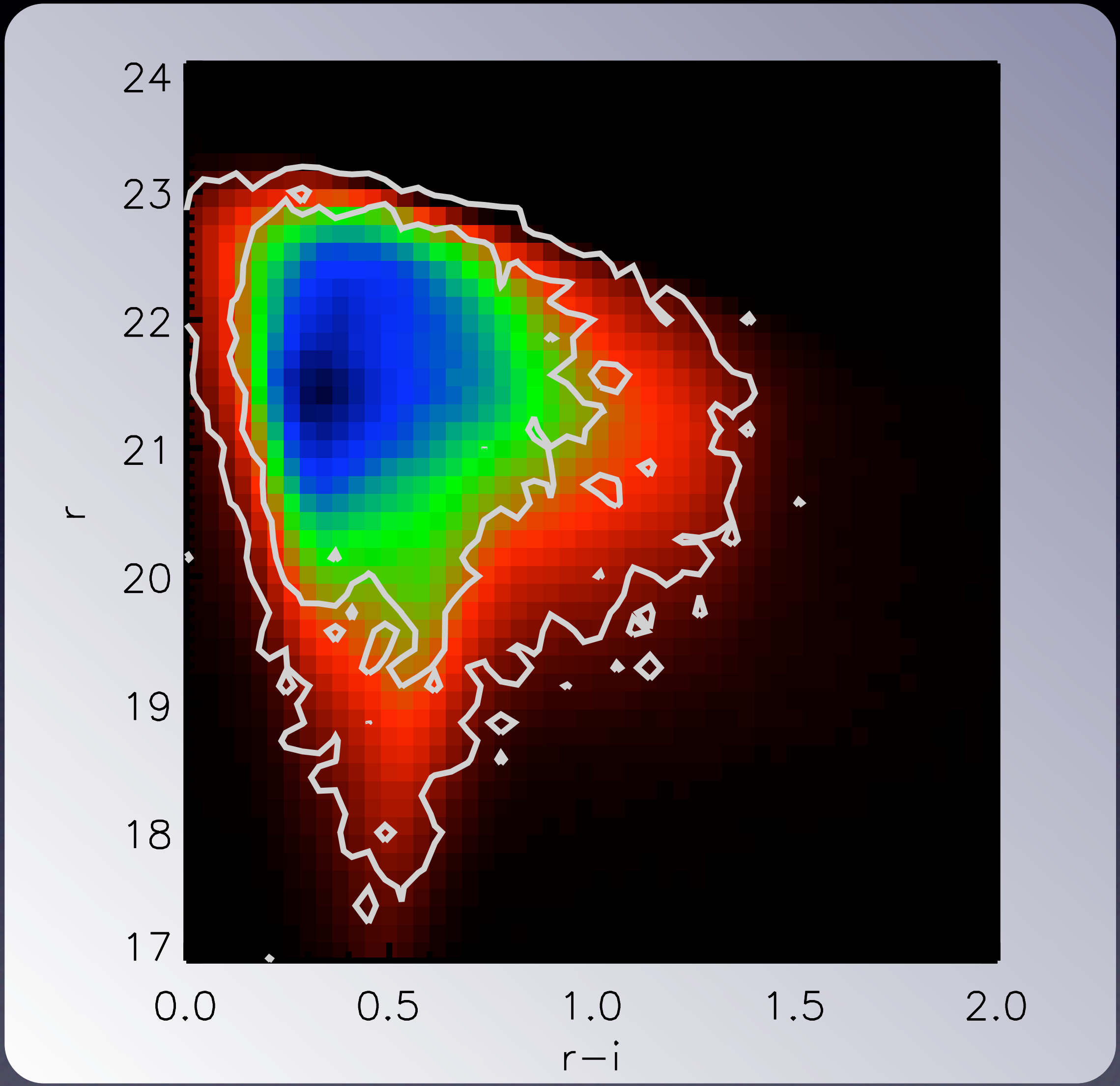


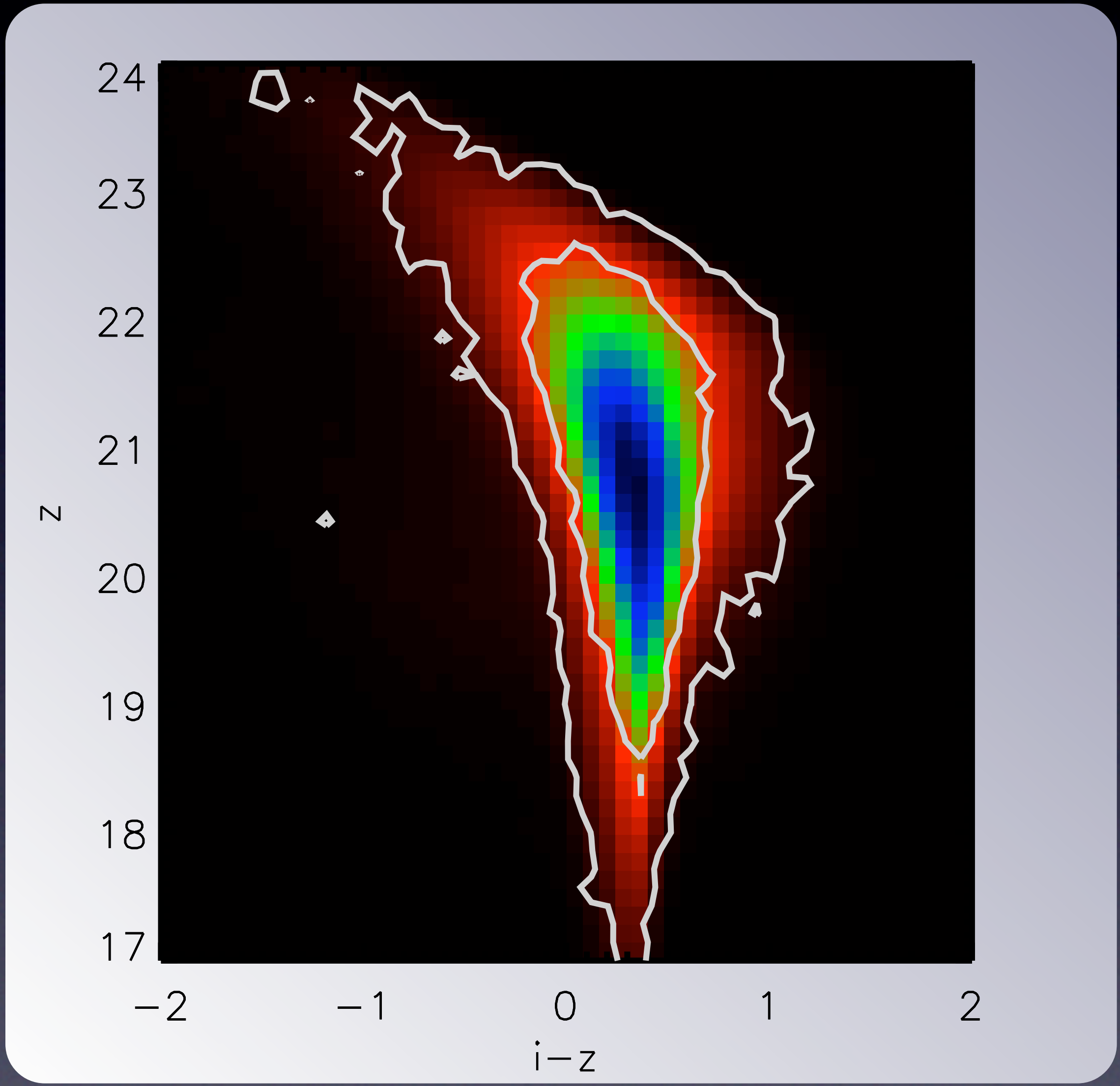
seeing < 1.4 arcsec



exclude r-band camcol 2

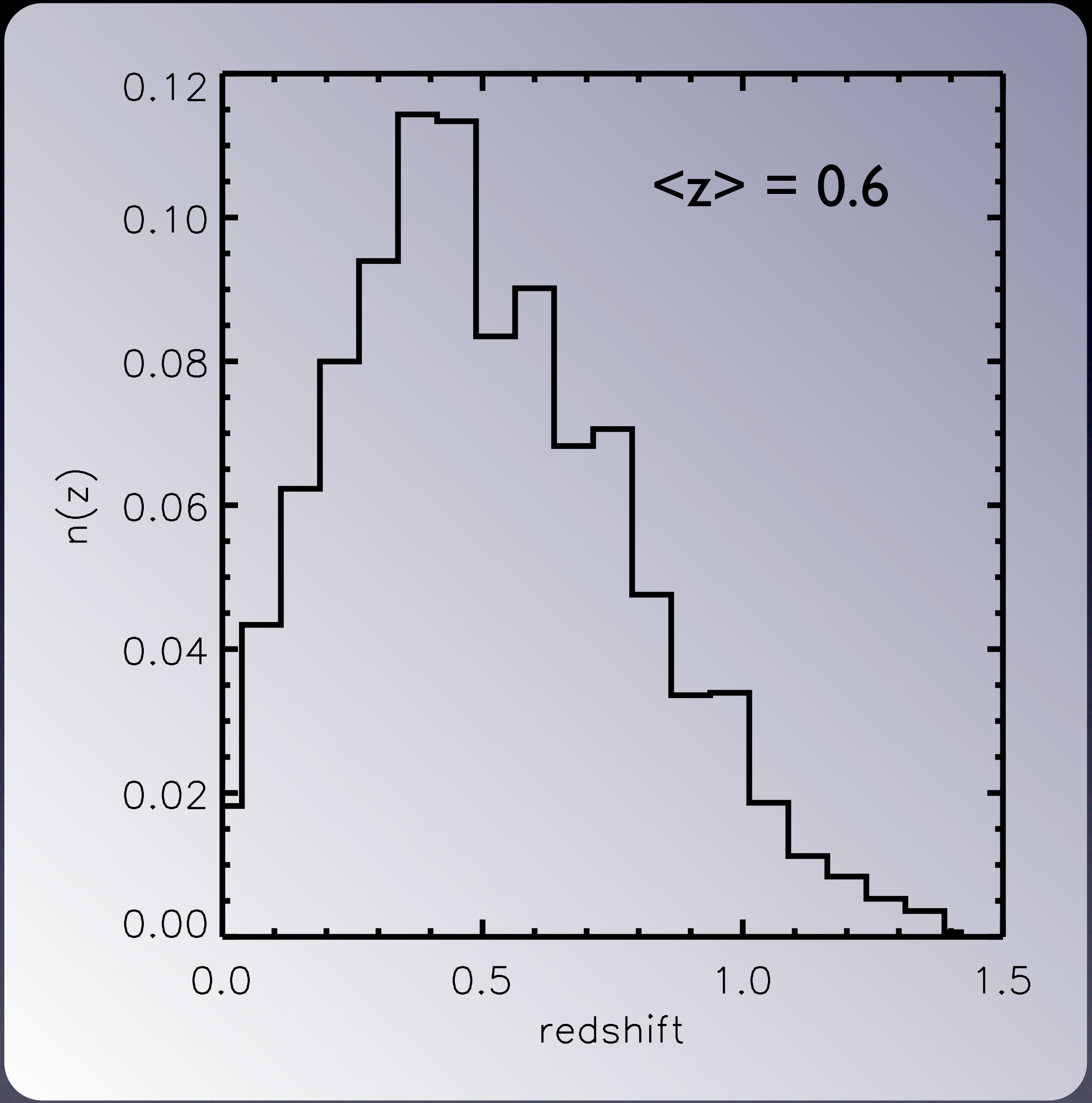
To estimate the redshift distribution:



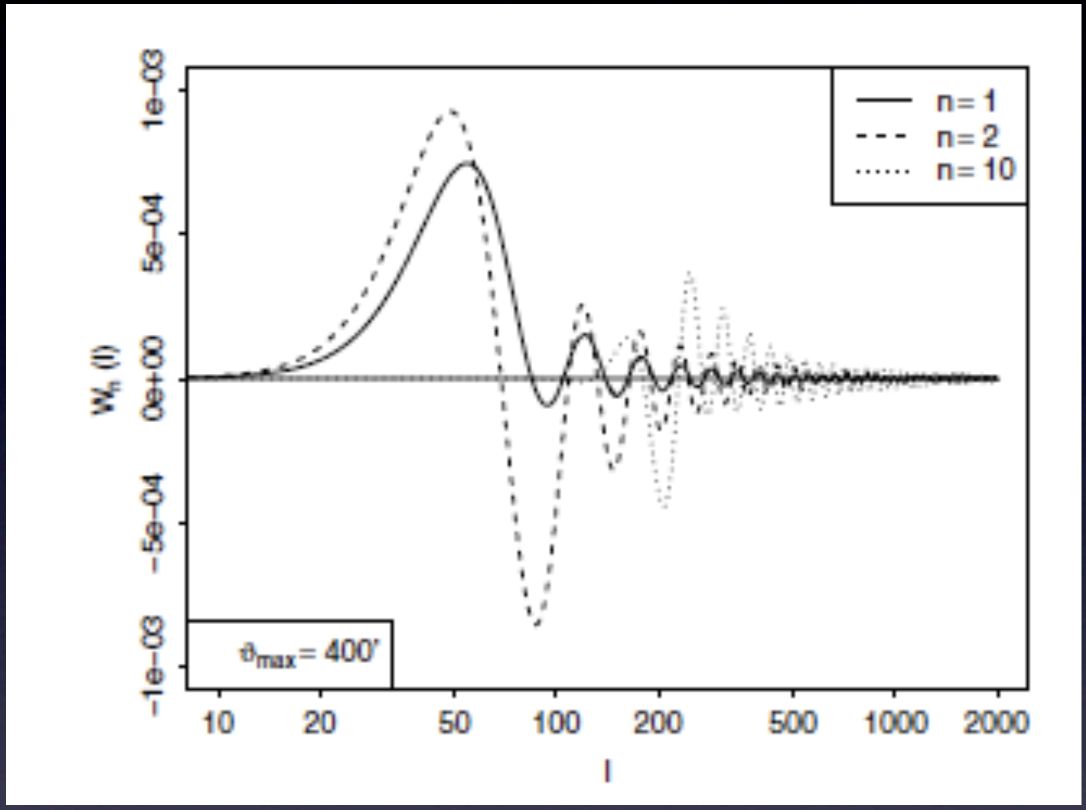


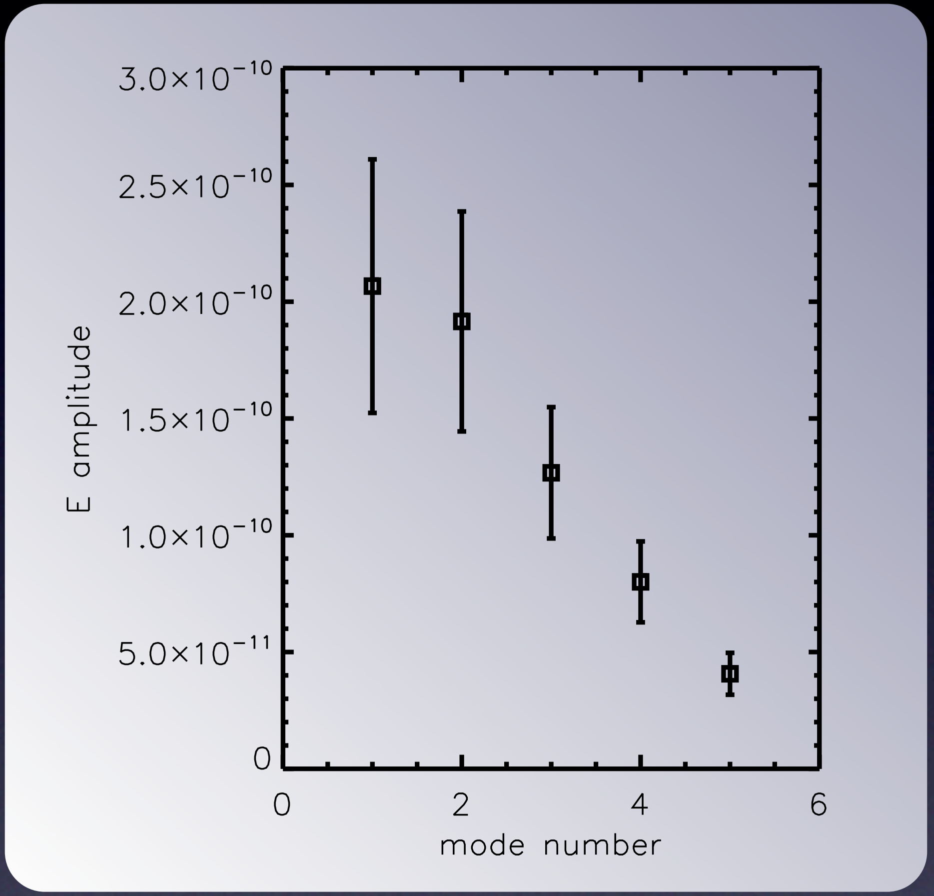
We re-weight the combined calibration sample to match 5-band magnitude distribution

Our redshift distribution:



We use the COSEBI basis to decompose into E and B modes.



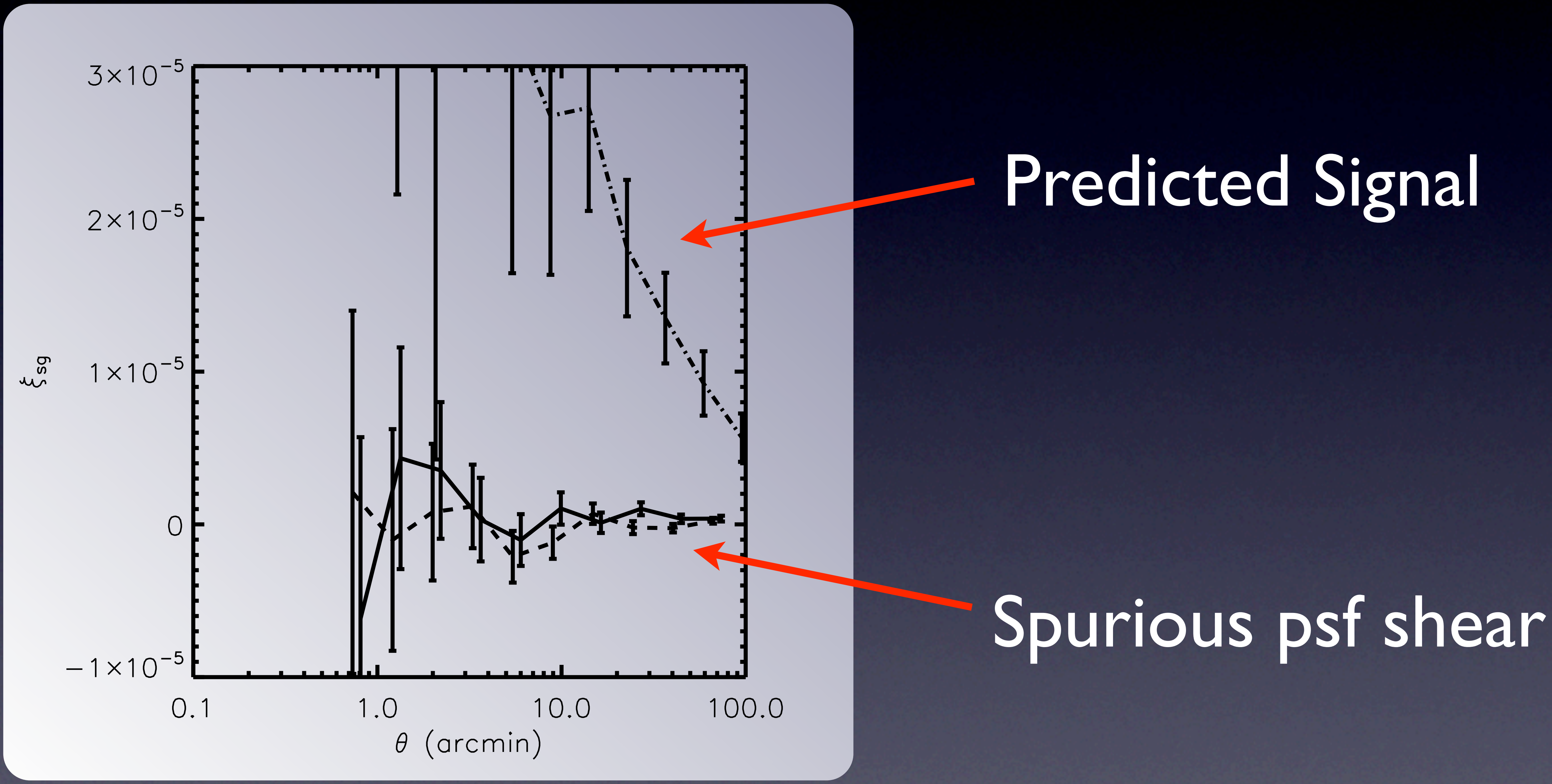


Advantages:

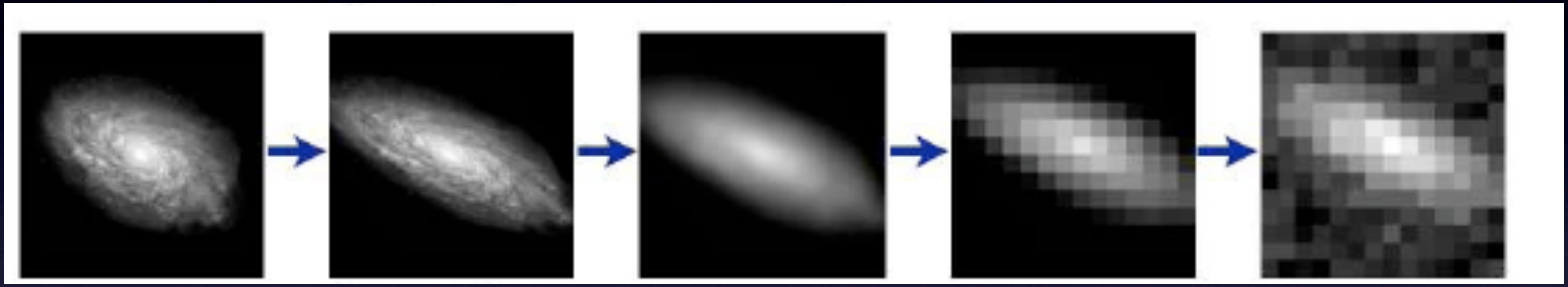
1. small number of bins -- stable inverse covariance matrix
2. Virtually same information content as correlation function
3. Clean E/B decomposition -- removes ambiguous modes

Systematics tests

These coadds have minimal psf shear.



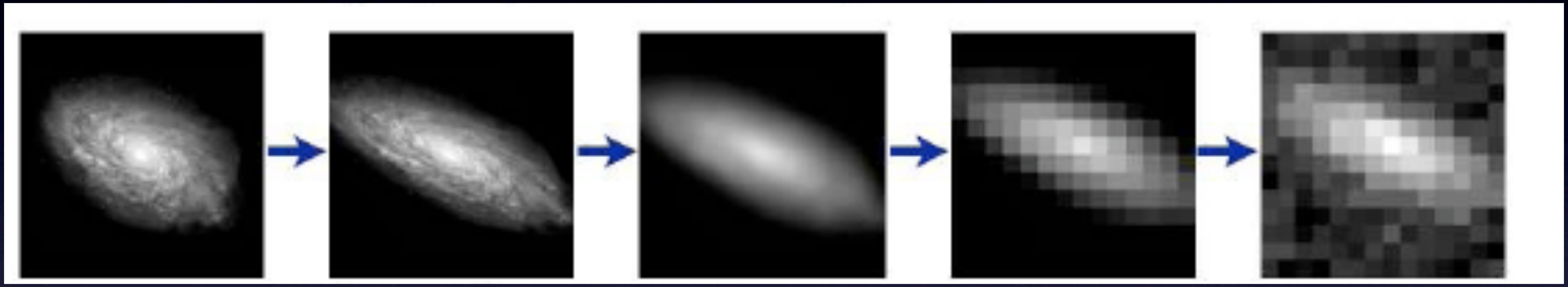
We have tackled shear calibration and photoz errors using simulations.



Credit: Bridle et al, Great08 handbook

Apply a synthetic shear to COSMOS image

We have tackled shear calibration and photoz errors using simulations.



Credit: Bridle et al, Great08 handbook

re-convolve with SDSS PSF

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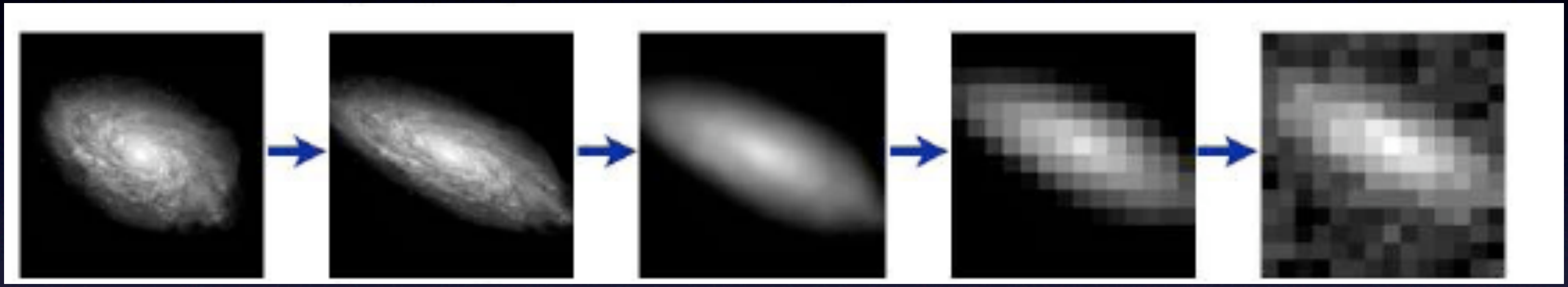

Credit: Bridle et al, Great08 handbook

insert galaxy into coadd image

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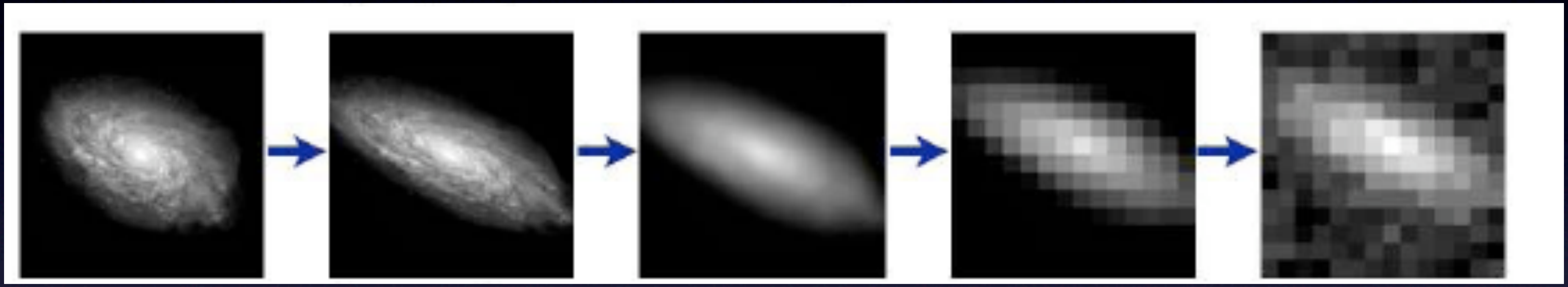
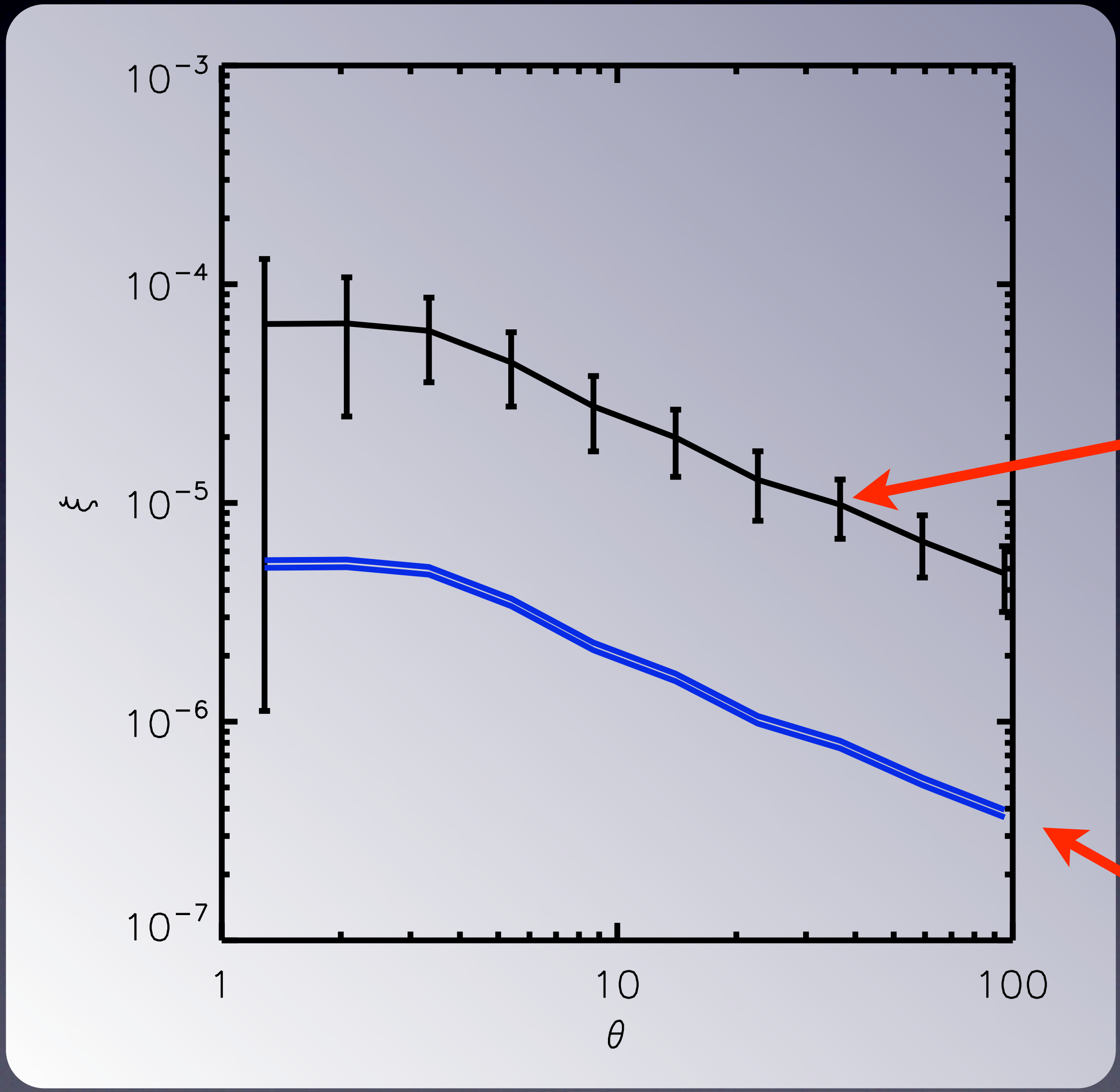


Credit: Bridle et al, Great08 handbook

rerun pipeline, measure shape and selection function

Existing limits on intrinsic alignments add little uncertainty to this measurement

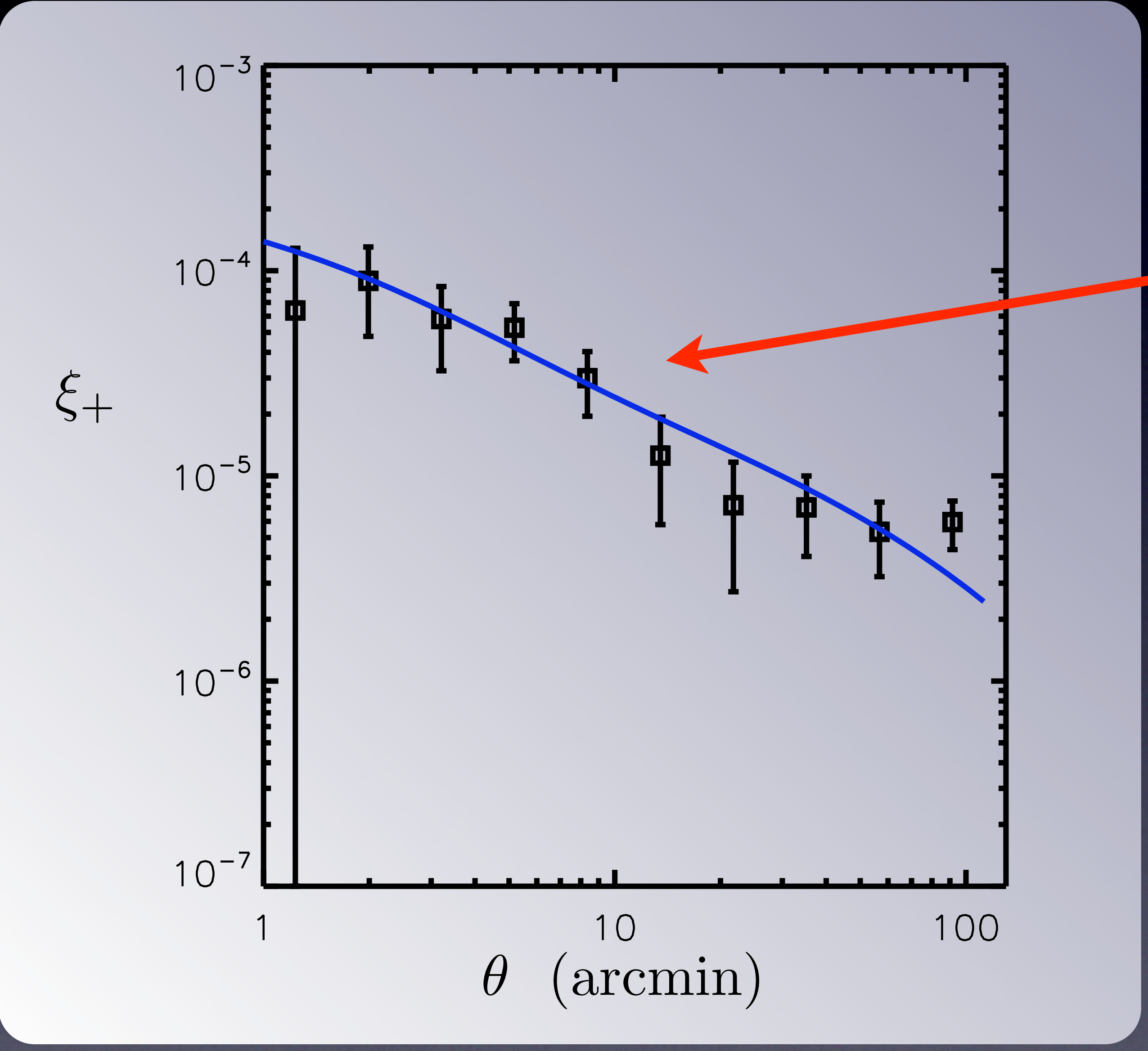


Predicted Signal

Intrinsic alignment from SDSS MegaZ-LRG (Joachimi et al 2011)

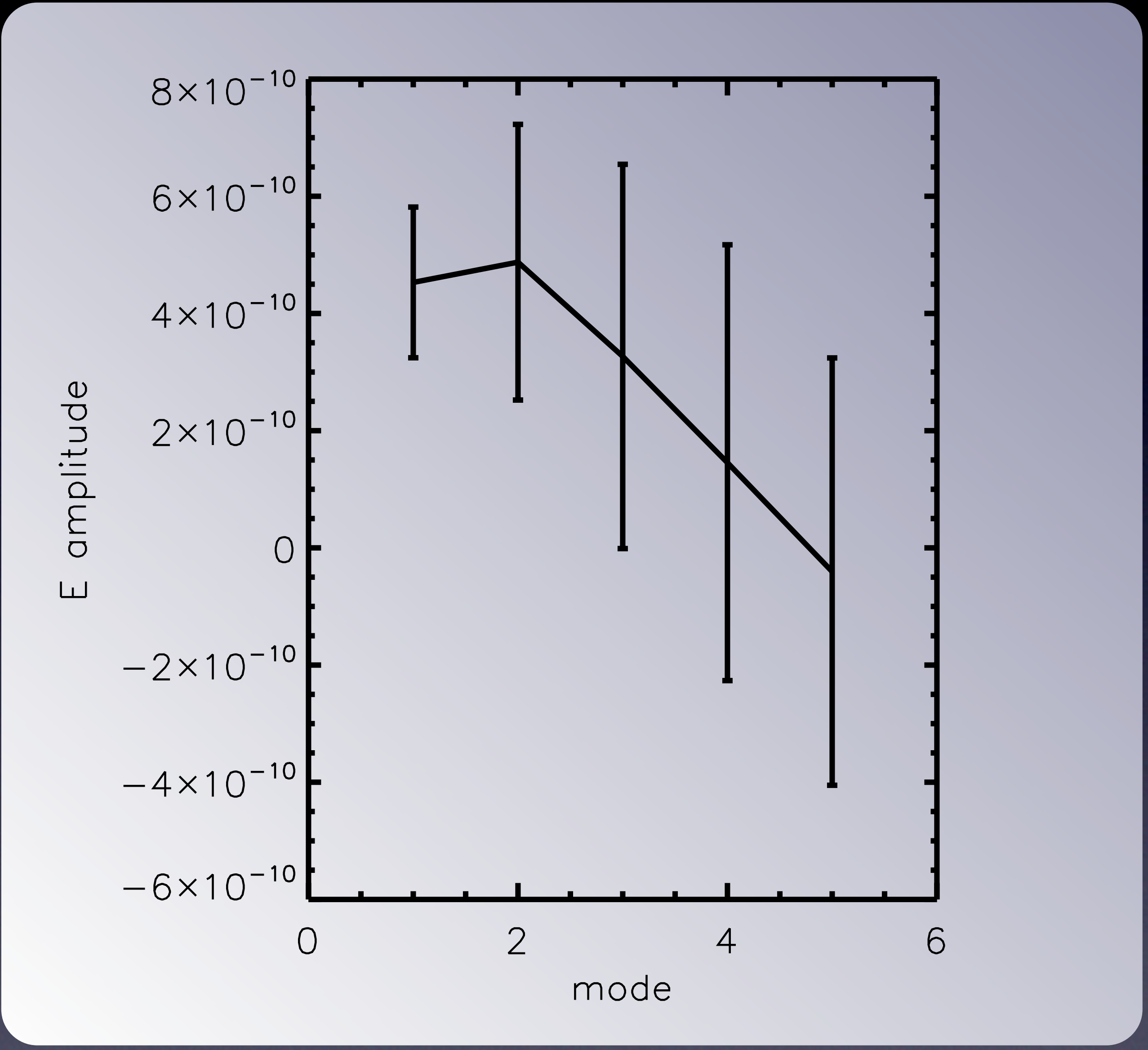
Results

We do detect a cosmic shear signal



WMAP7 prediction

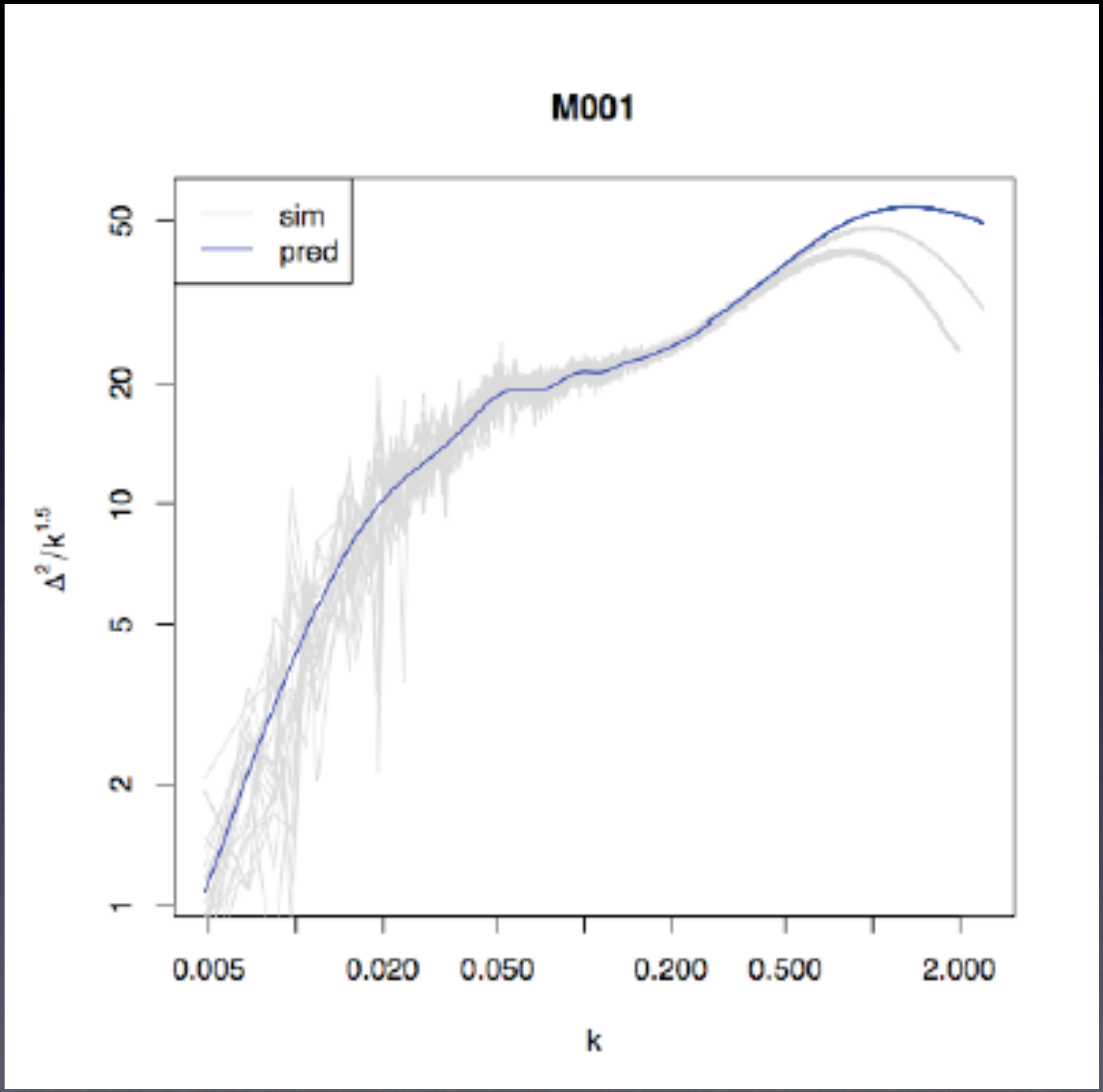
We do detect a cosmic shear signal



We do not detect any B modes.

$$\chi^2\,(B=0)=1.05$$

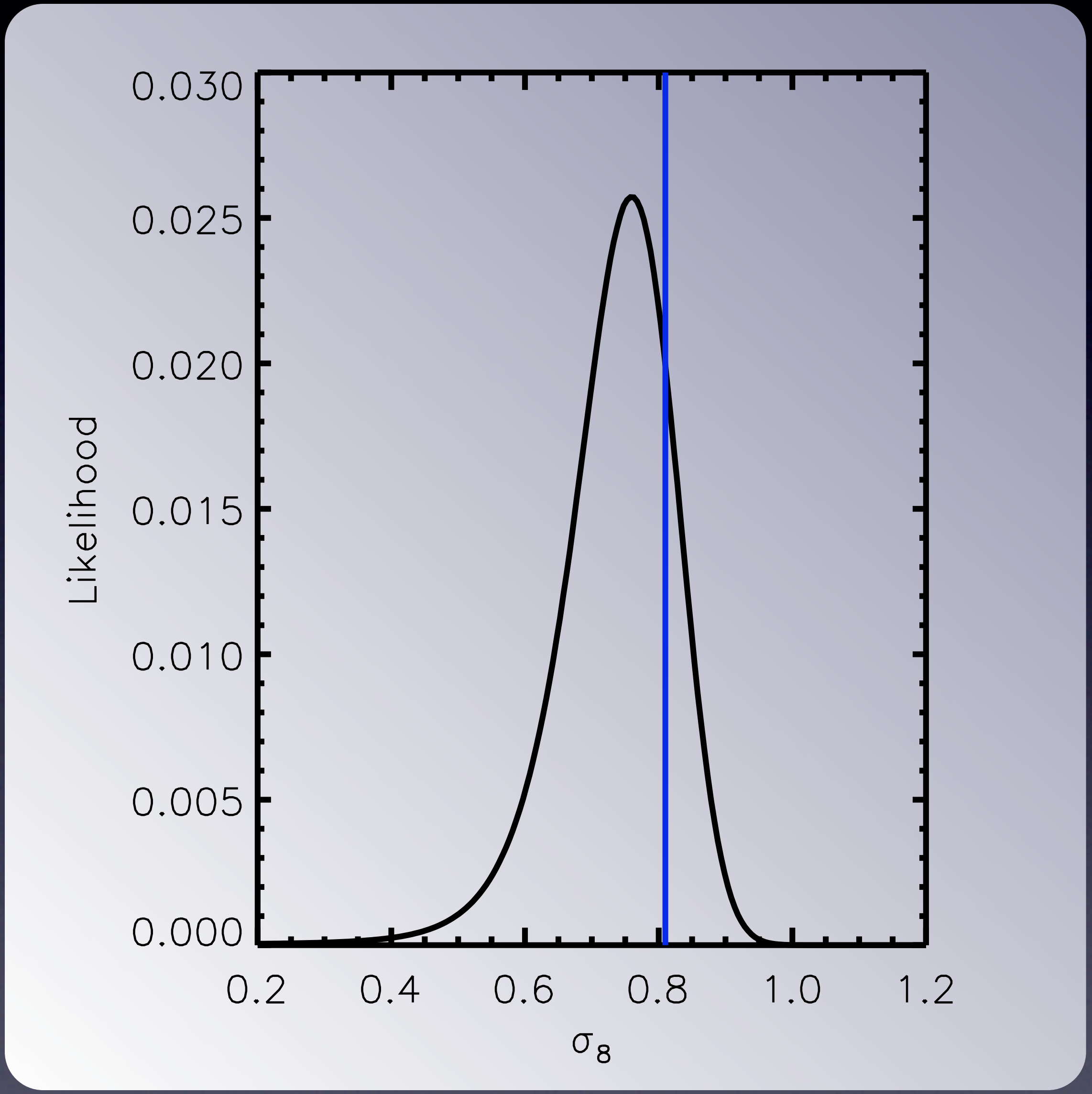
To interpret this, we use the Coyote Universe simulation emulator



We have an interesting constraint on structure.

$$\sigma_8 = 0.7578^{+0.070}_{-0.080}$$

(fixing all other parameters)



Lessons Learned:

0. **It is possible to measure cosmic shear from the ground**.

1. The rounding kernel method is effective if you have the right psf model.

2. Getting the right psf model is not easy.

3. Taking good care of systematics entails throwing away lots of data.

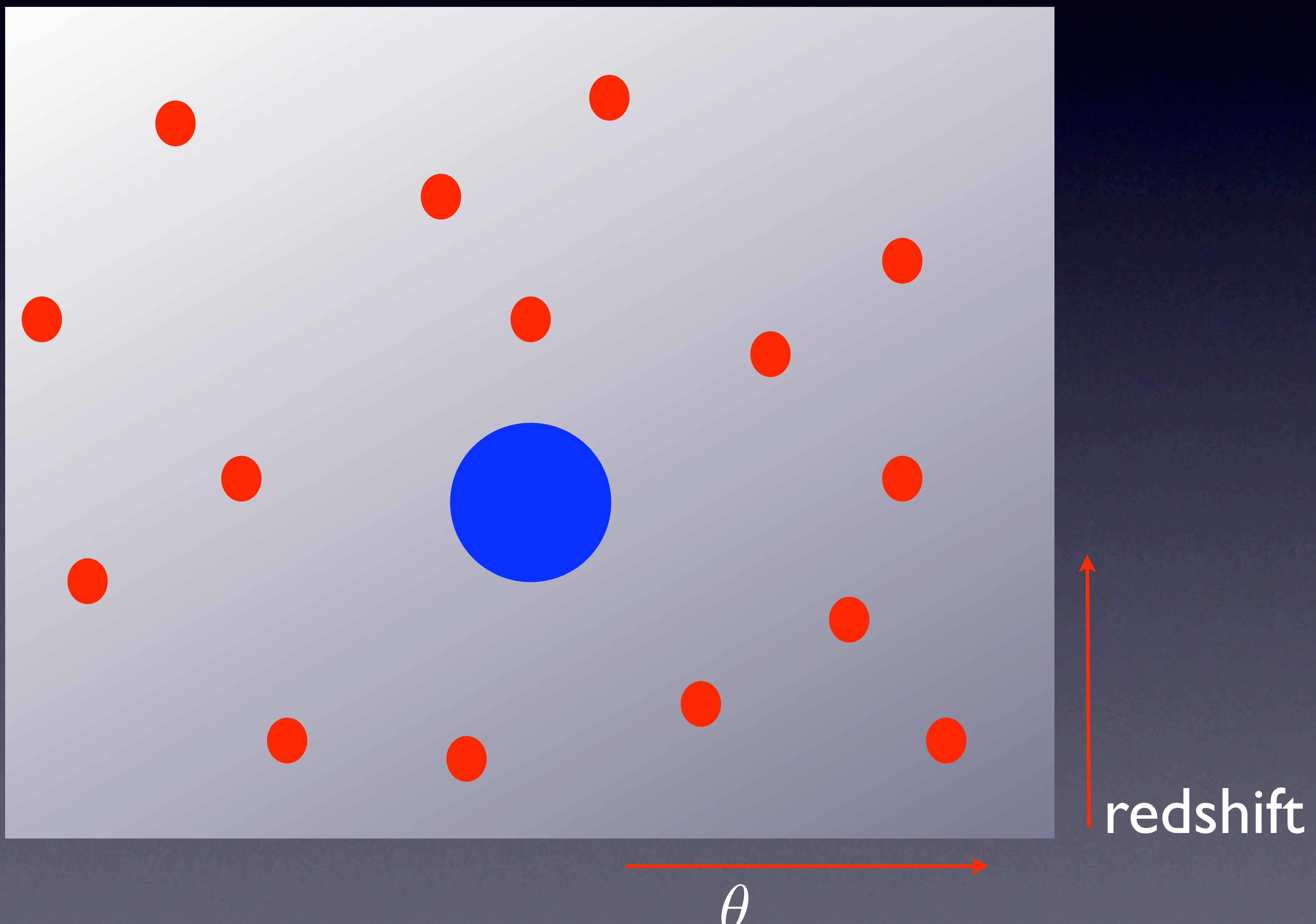
4. Low signal-to-noise is a big problem.

Is there an easier way?

Maybe.

There are other components to the distortion tensor.

The Effect of Magnification on galaxy sizes and luminosities



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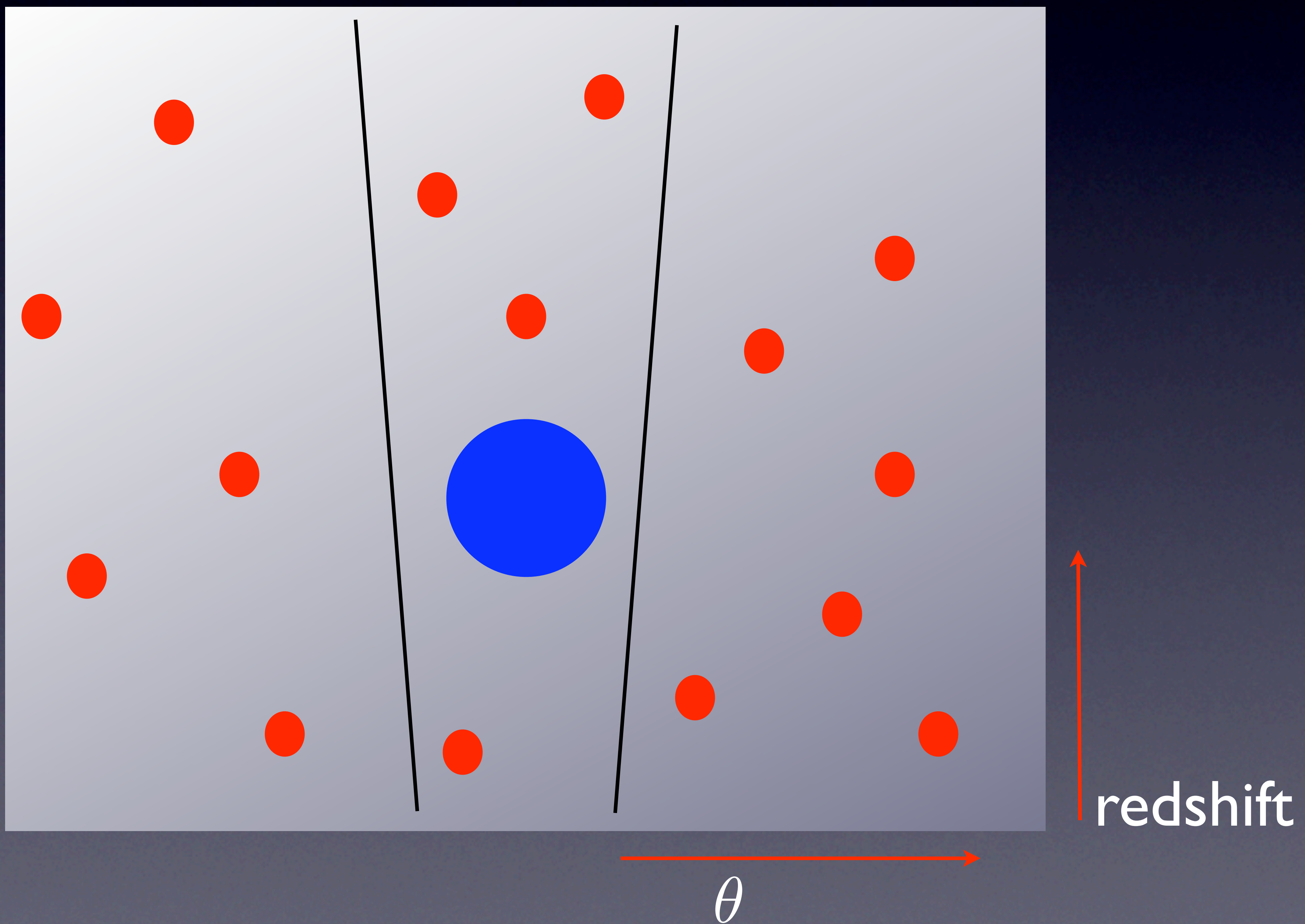

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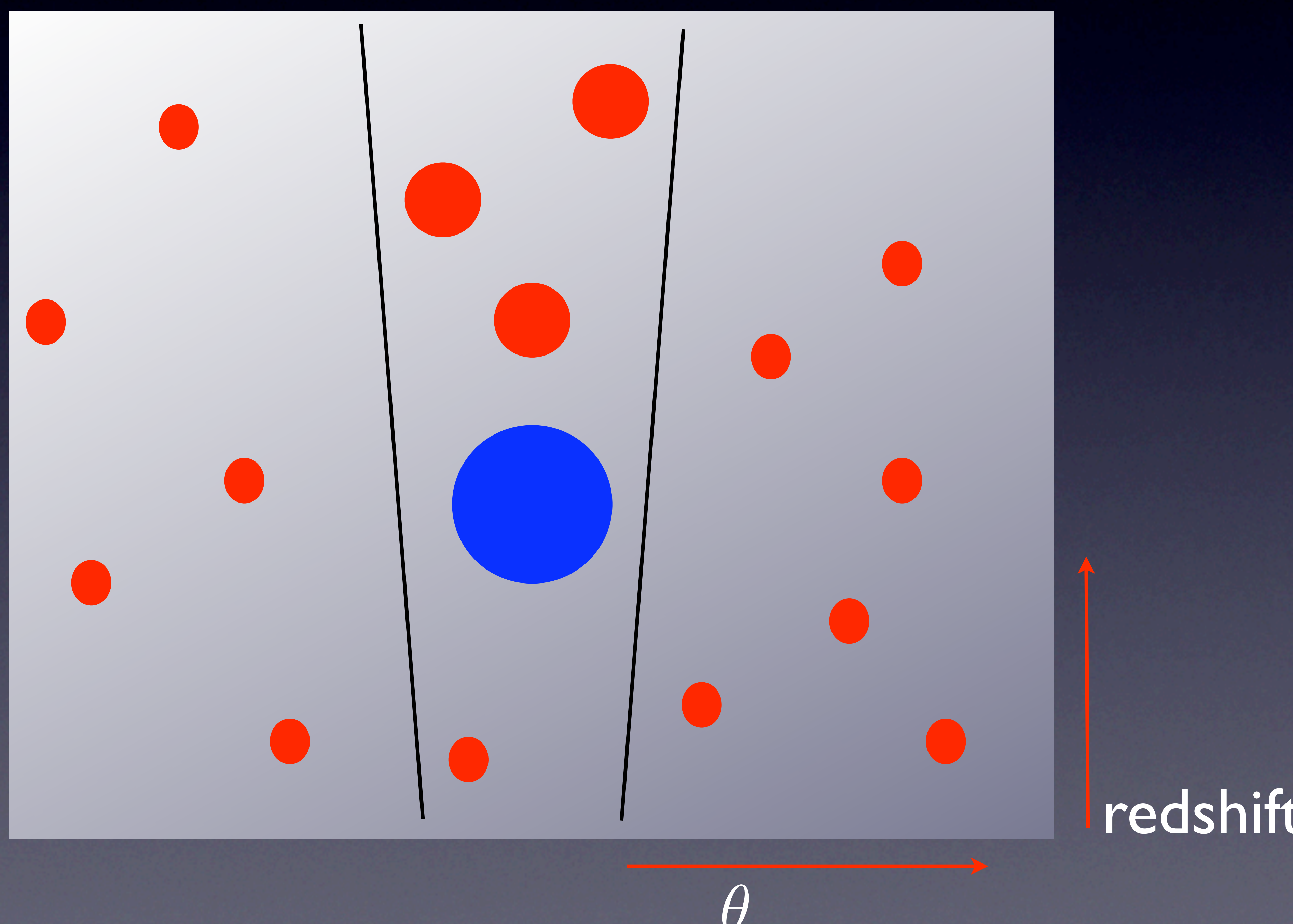

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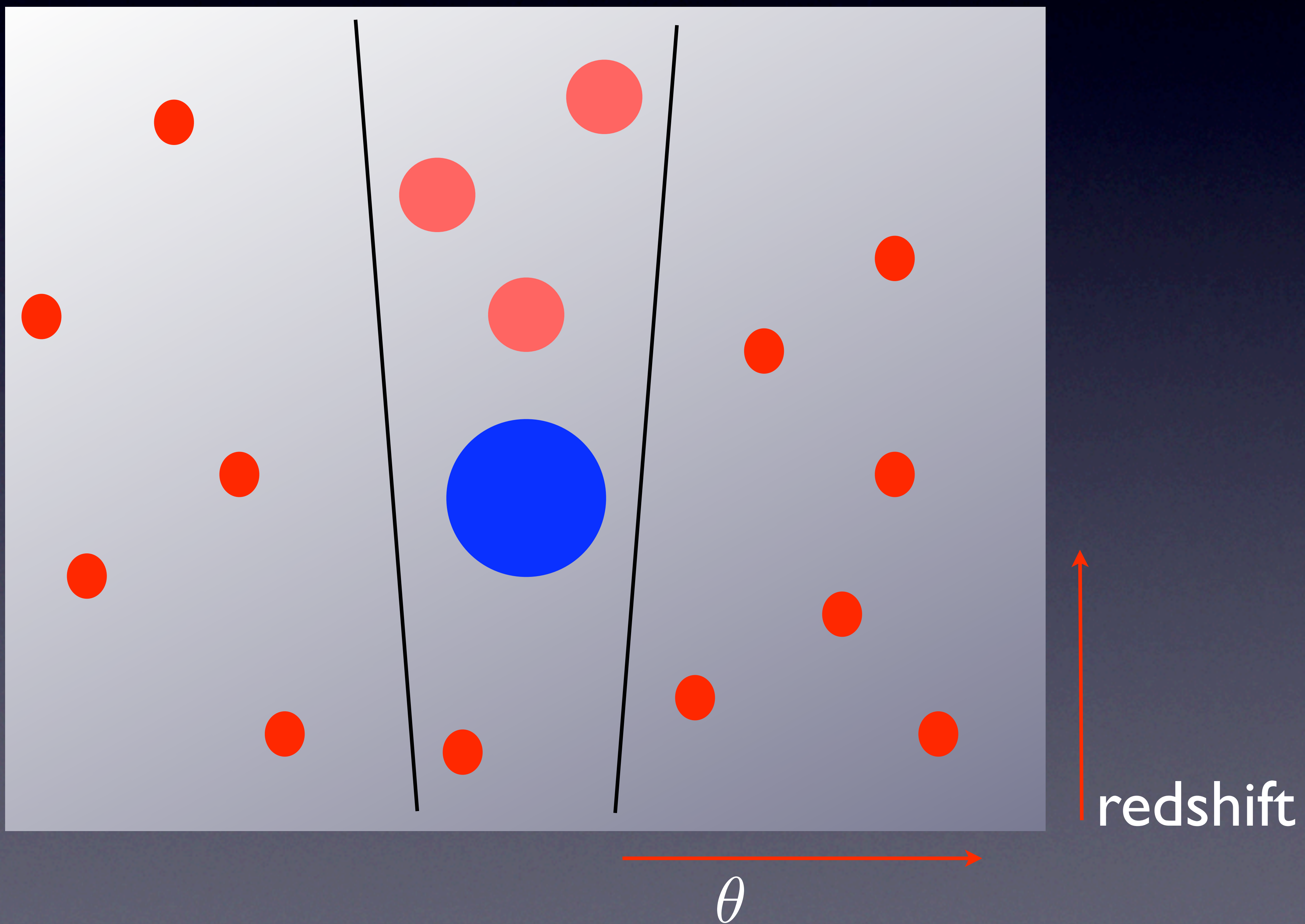
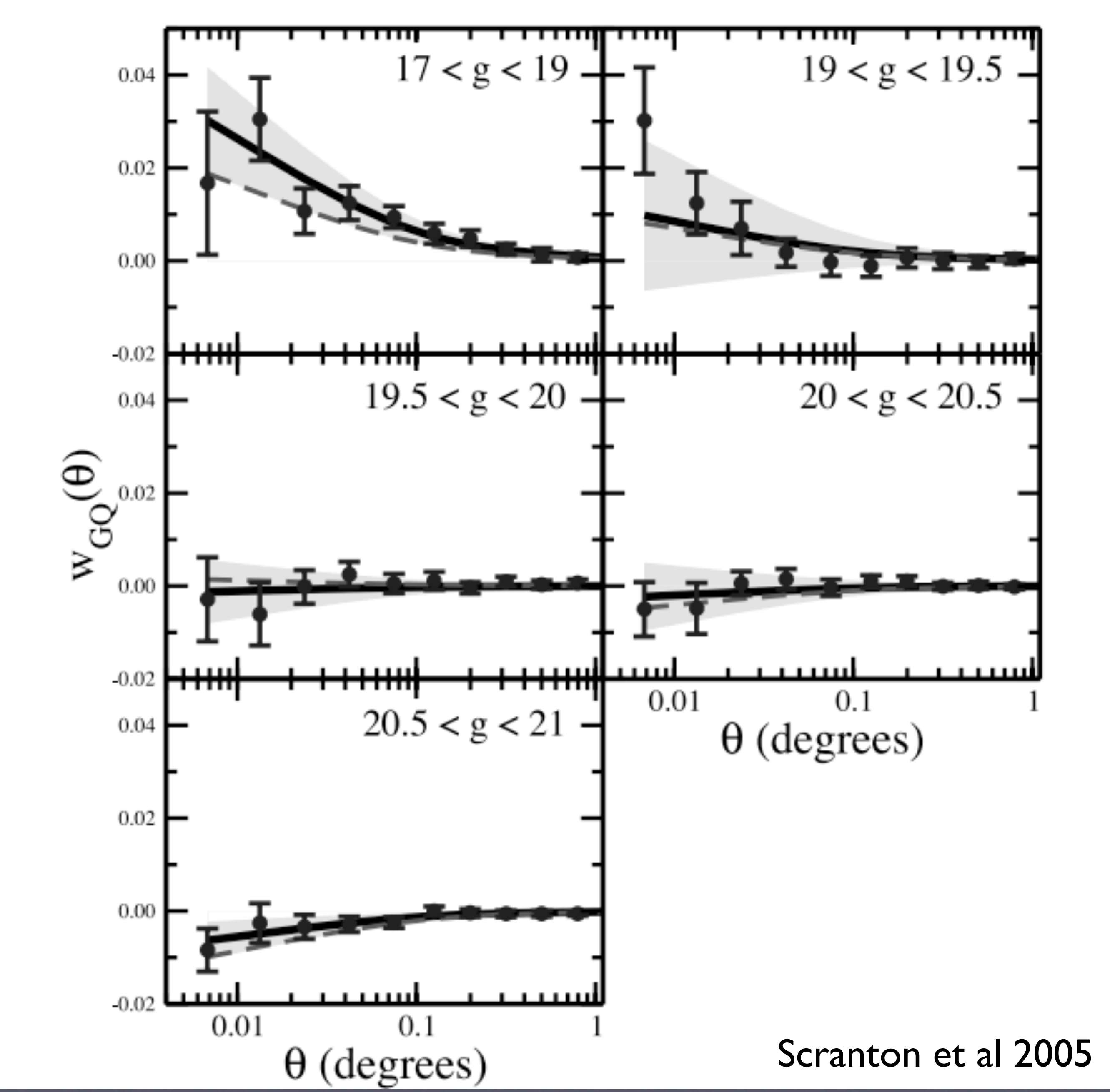


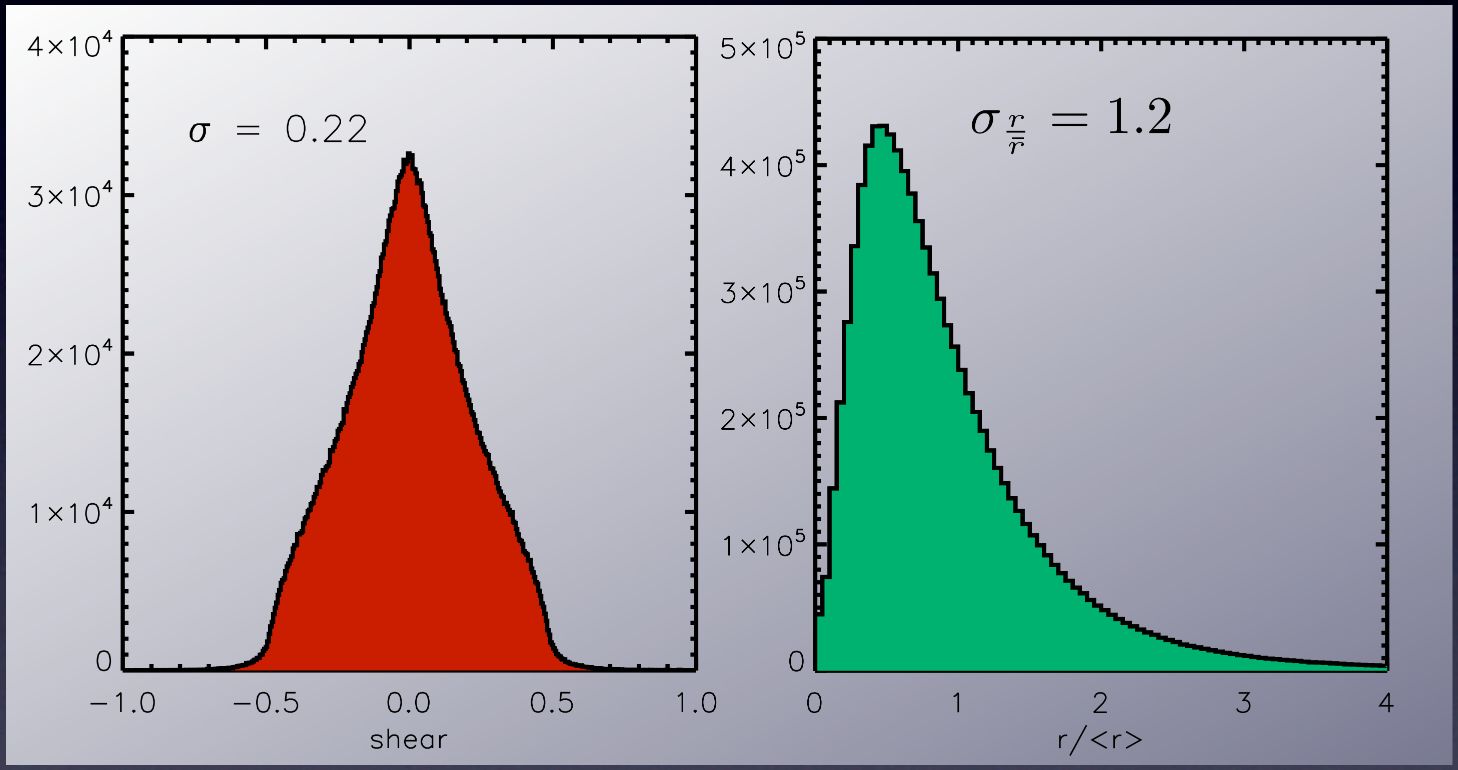
The effect of Magnification on Luminosities



Scranton et al 2005

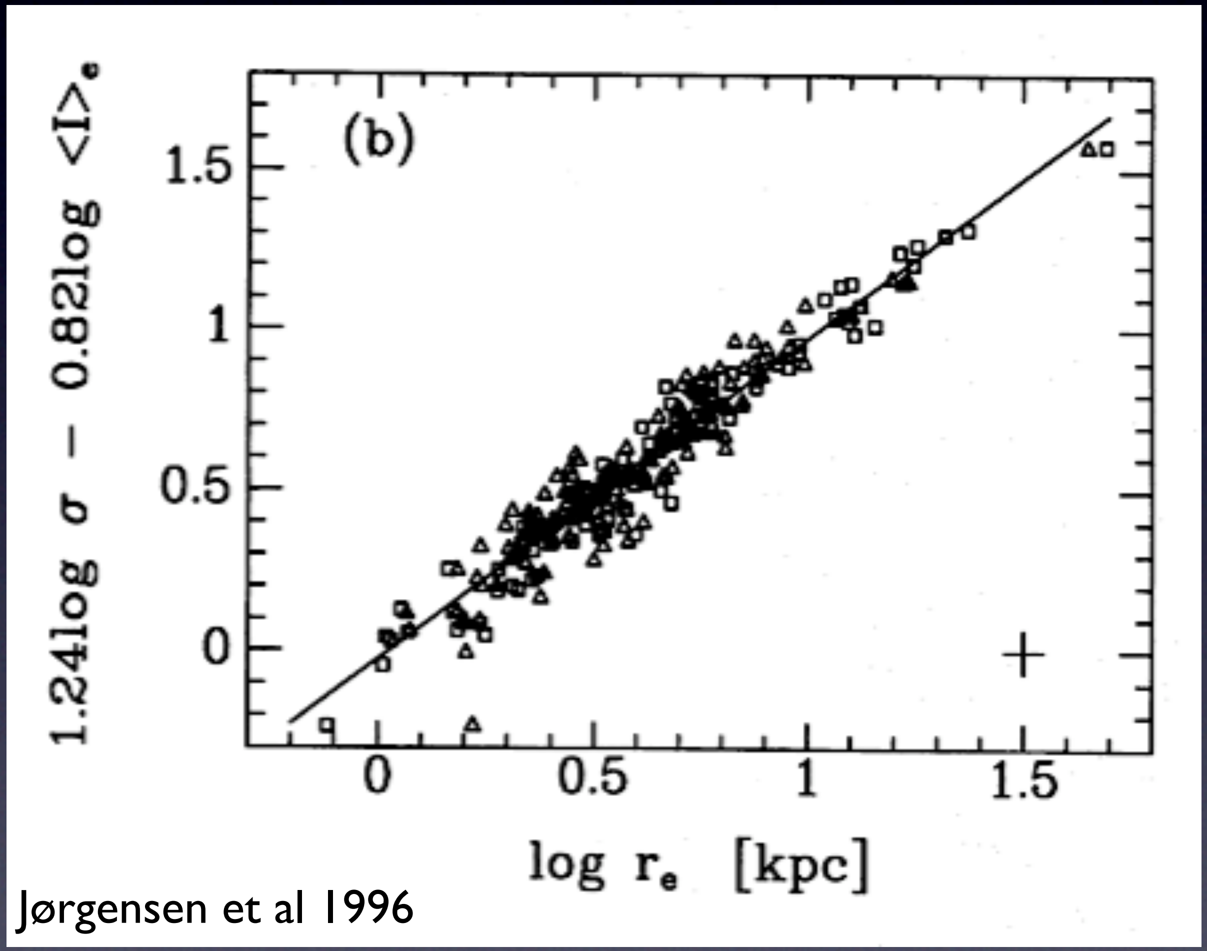
A heroic effort:
13.5 million galaxy lenses
225,000 quasar sources

Why shear is still much better than the alternatives:



We want a way to reduce the intrinsic scatter.

The Fundamental Plane of Early Type Galaxies

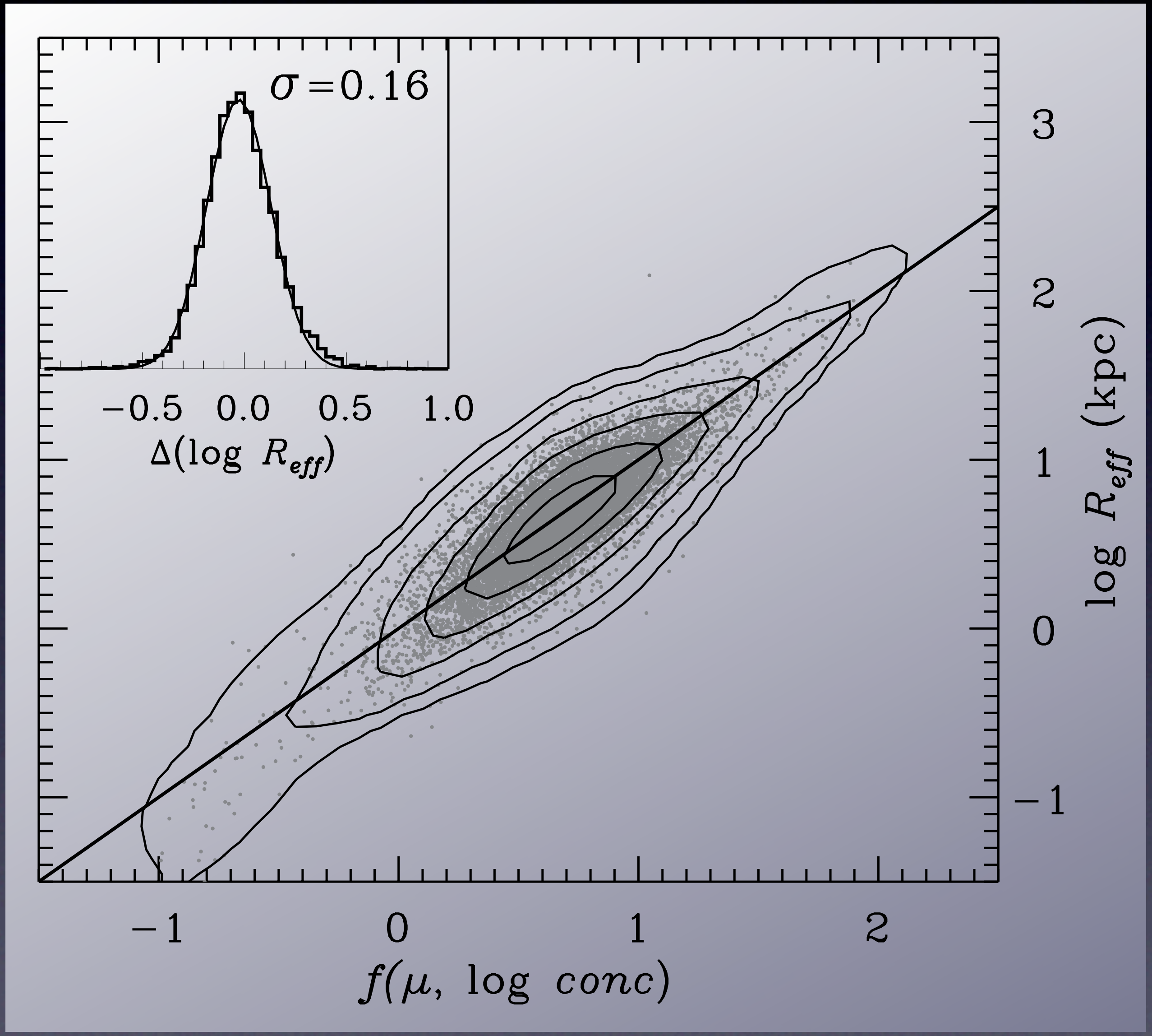


~15% intrinsic scatter

no detected variation with environment

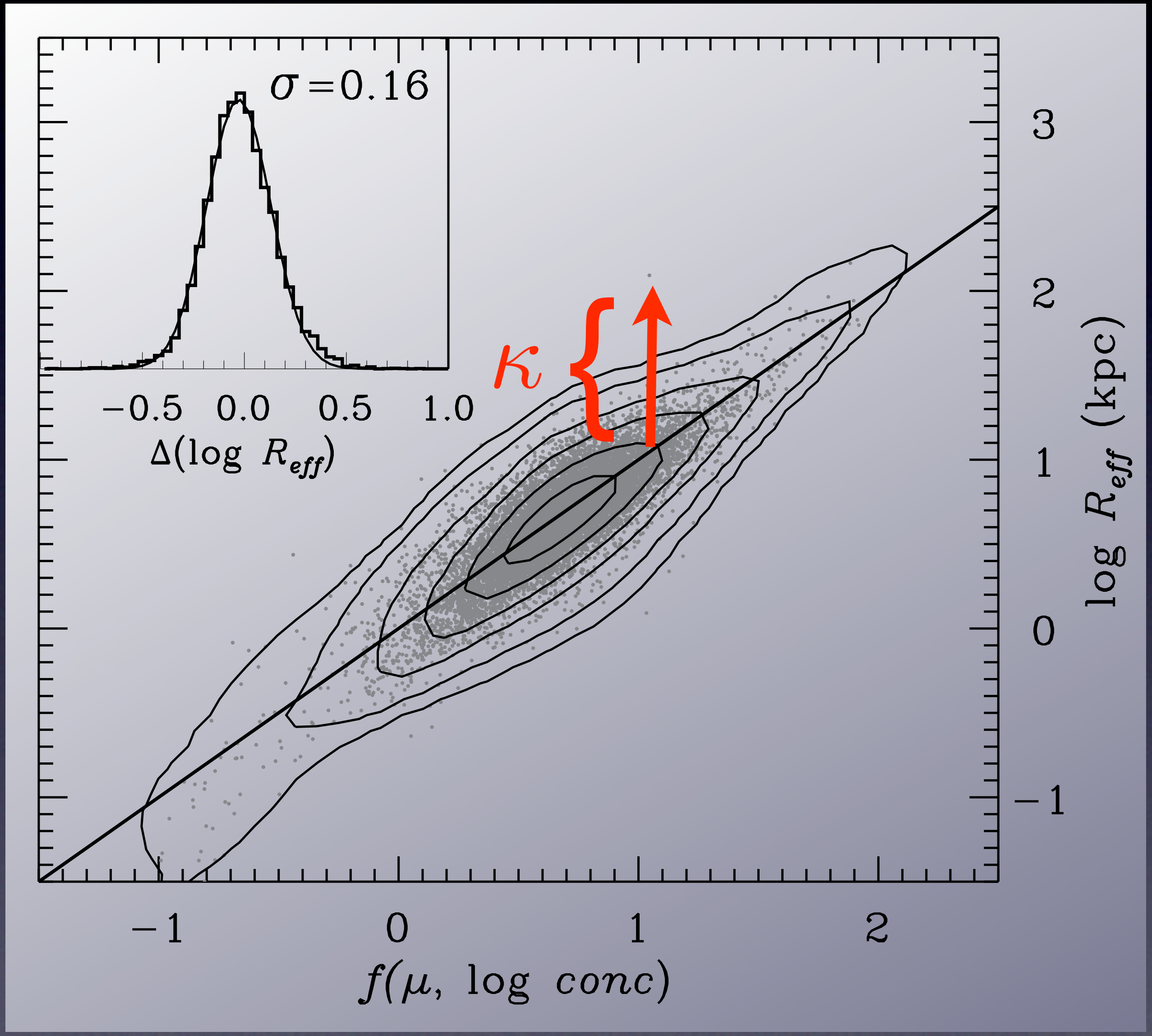
a photometric analogue exists

The Effect of Magnification on the Photometric Plane



at fixed mass, concentration and effective radius are inversely correlated

The Effect of Magnification on the Photometric Plane



$$\kappa = \log\left(R_{eff}\right) - f\left(\mu, \log conc\right)$$

Constructing a Sample using SDSS

60,000 Lenses:

log (stellar mass) > 11.0

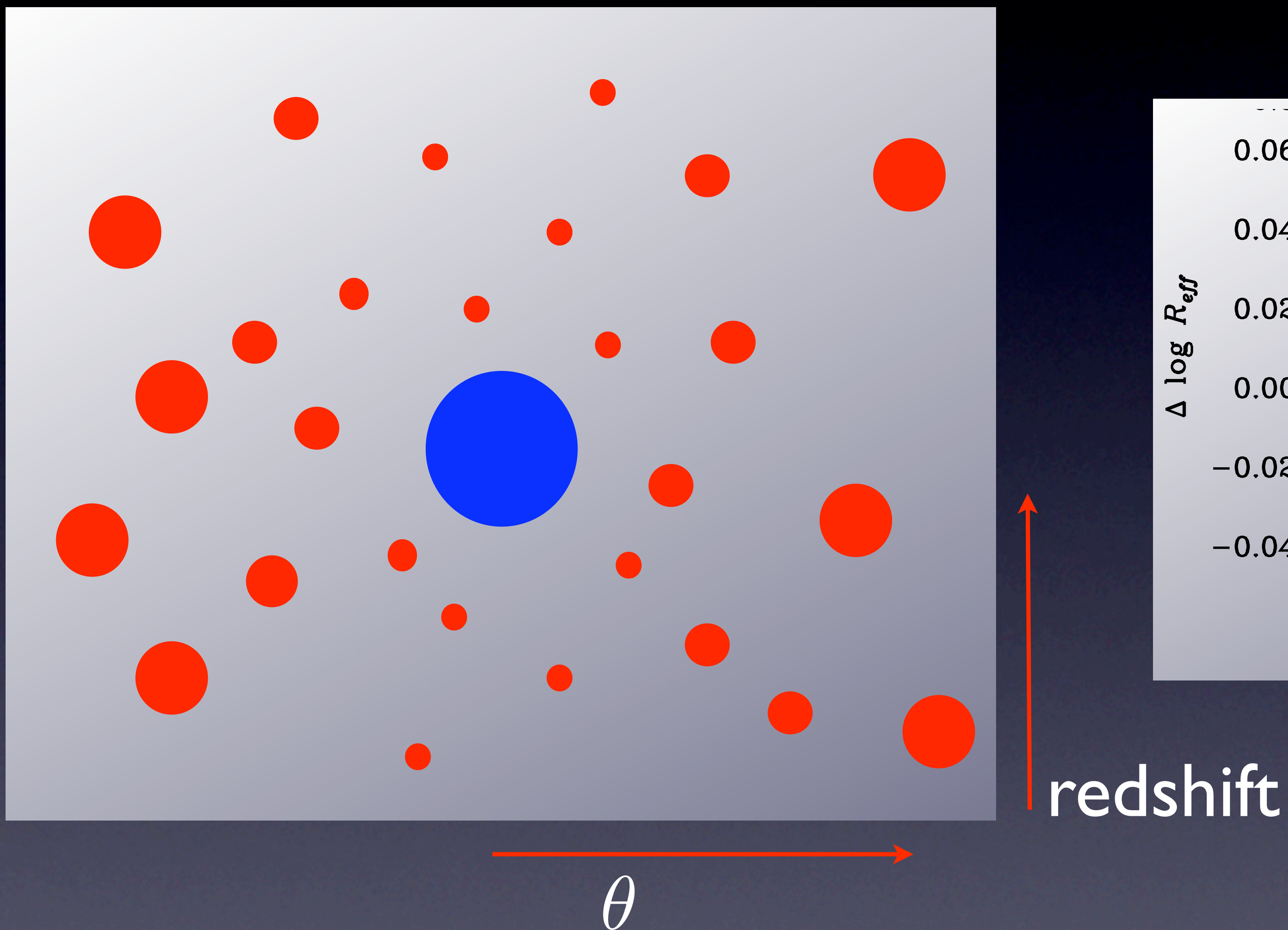
0.2 < z < 0.4

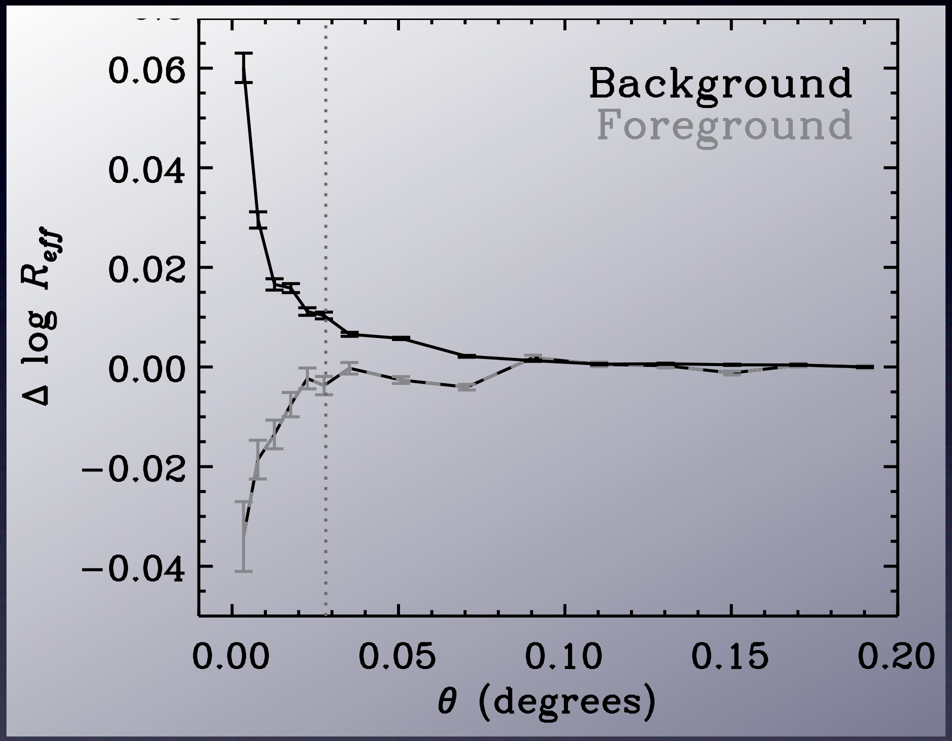
10 million Sources:

resolved galaxies

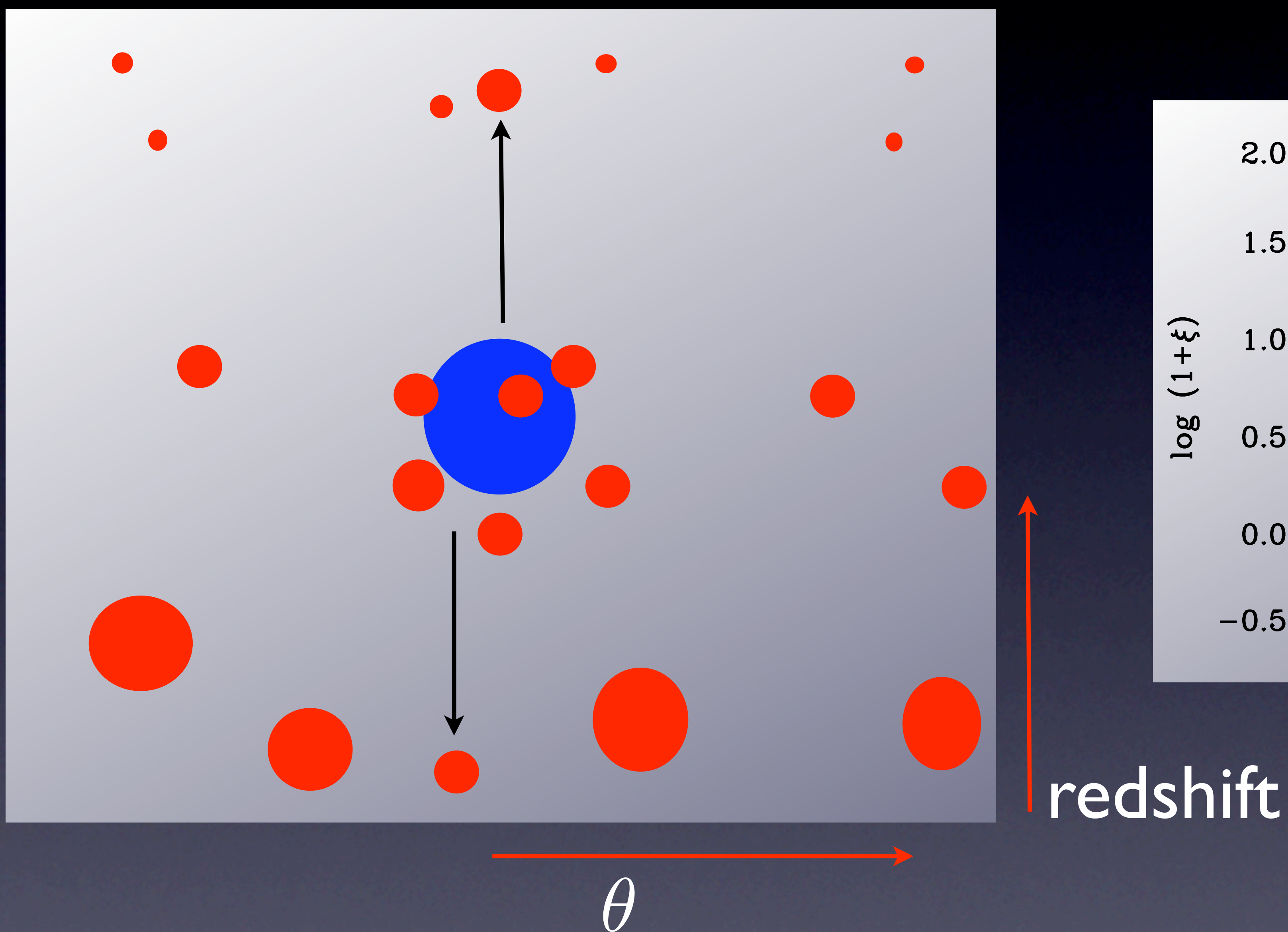
early-type SEDs (35%)

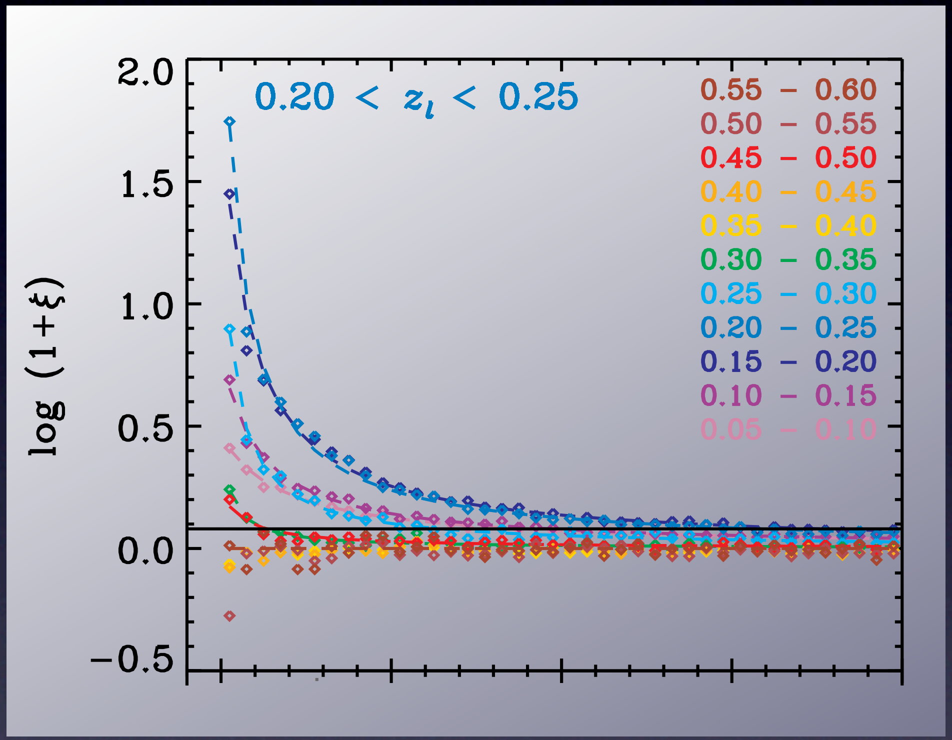
Systematics: Sky Subtraction



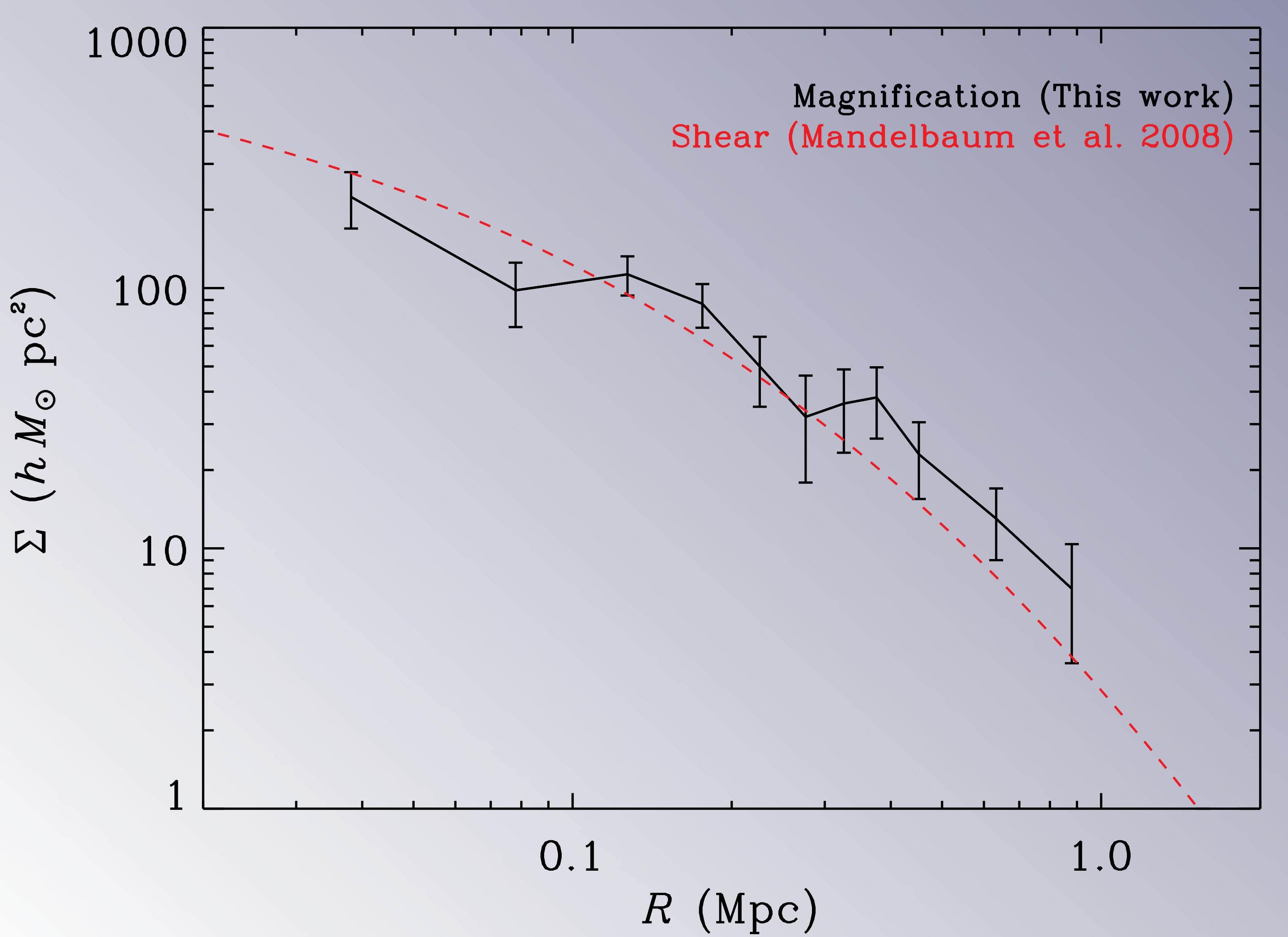


Systematics:
Source Clustering with Photo-z's





Lensing Detection:
Comparing to Existing Measurements



- Currently: we can control systematics in ground-based cosmic shear
- Galaxy scaling relations can yield much more weak lensing signal