Weak Lensing

studies of high redshift clusters

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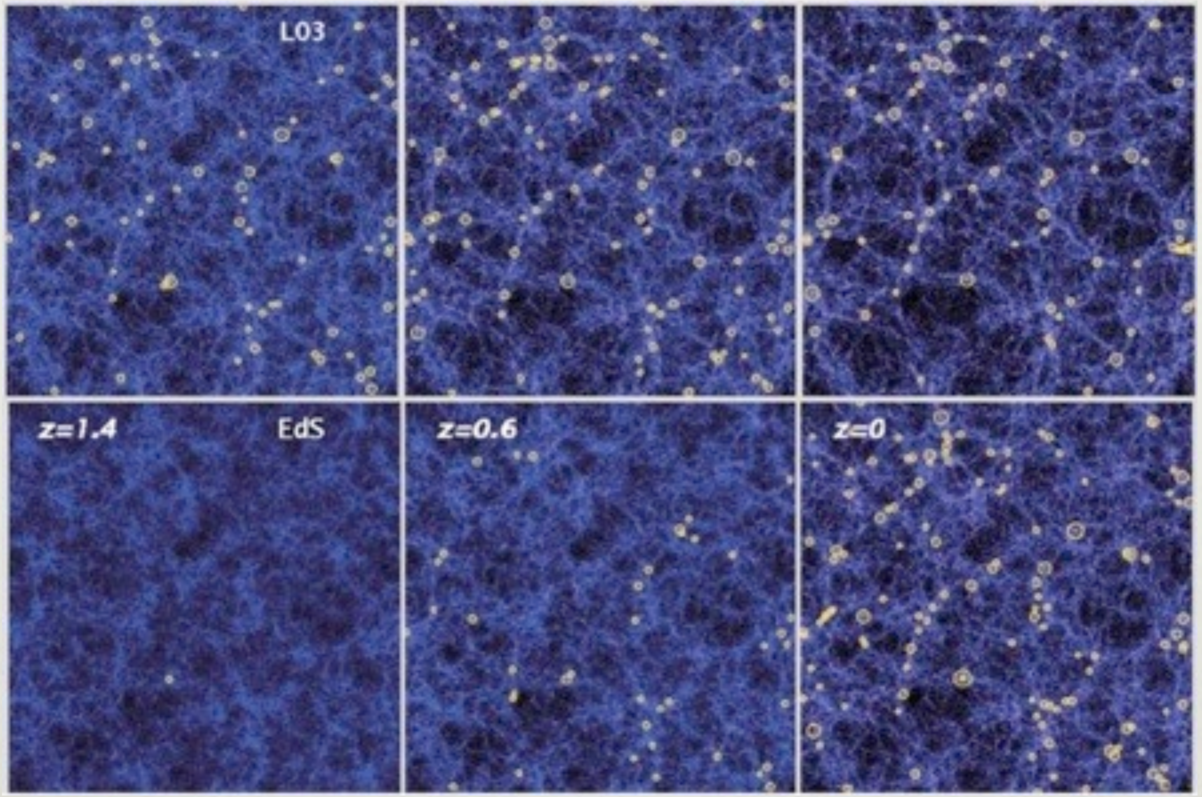
PROBES OF STRUCTURE FORMATION

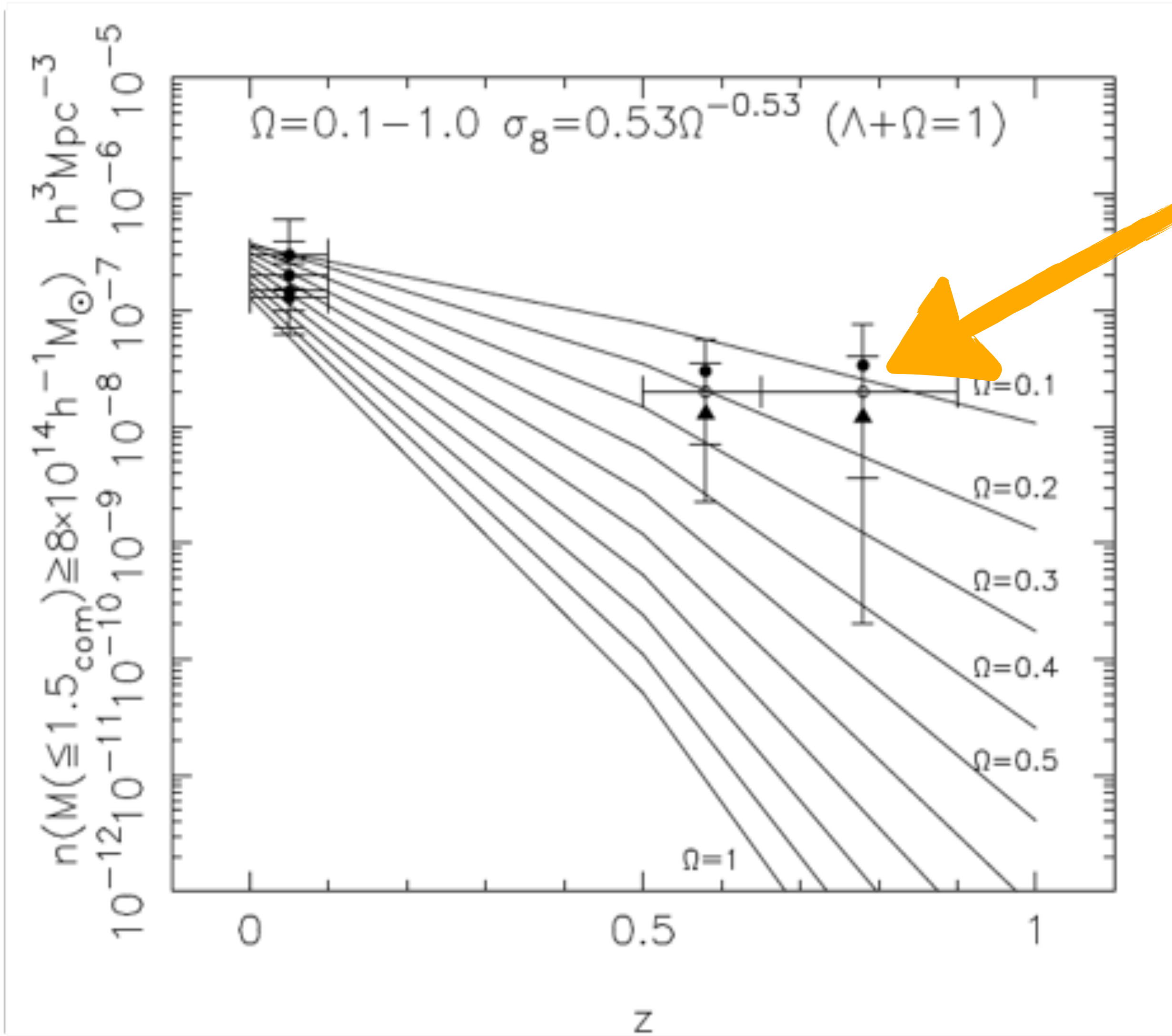
Borgani et al.



The growth of structure can be quantified by:

- counting peaks (cluster abundance studies)
- measuring two-point statistics (power spectrum analysis)

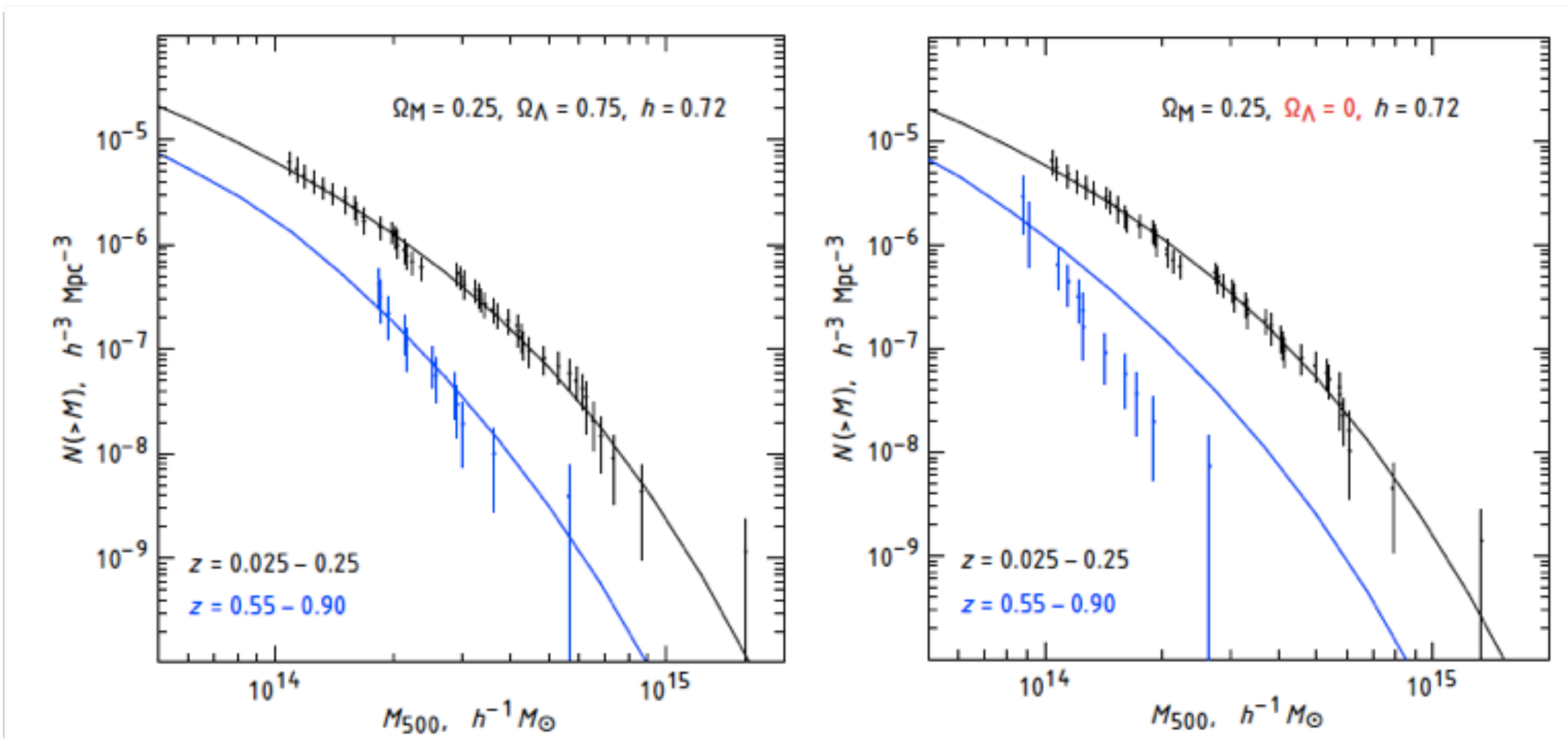
High redshifts are important



MS1054-03

Bahcall & Fan (1998)

High redshifts are important

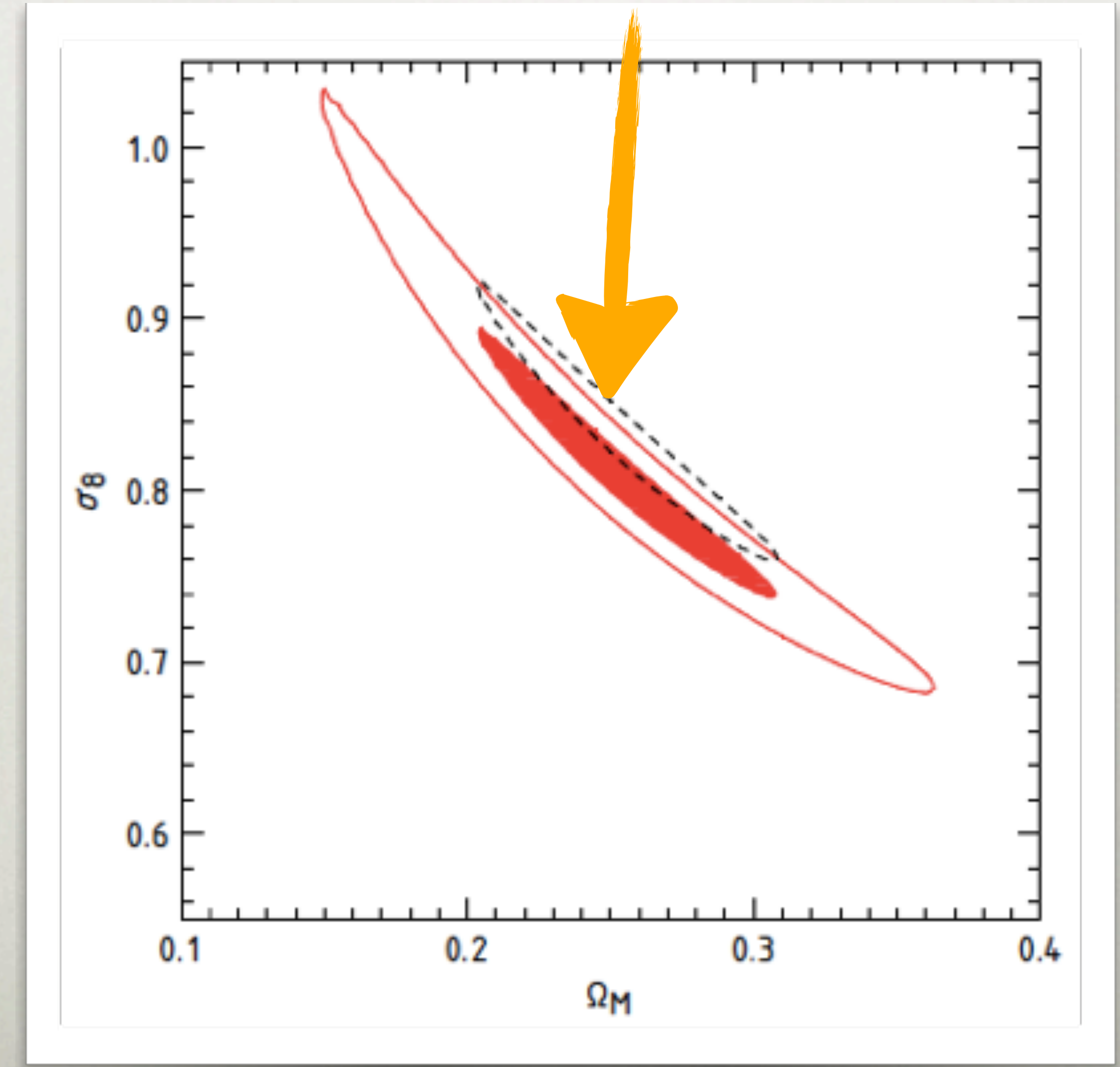


Vikhlinin et al. (2009)

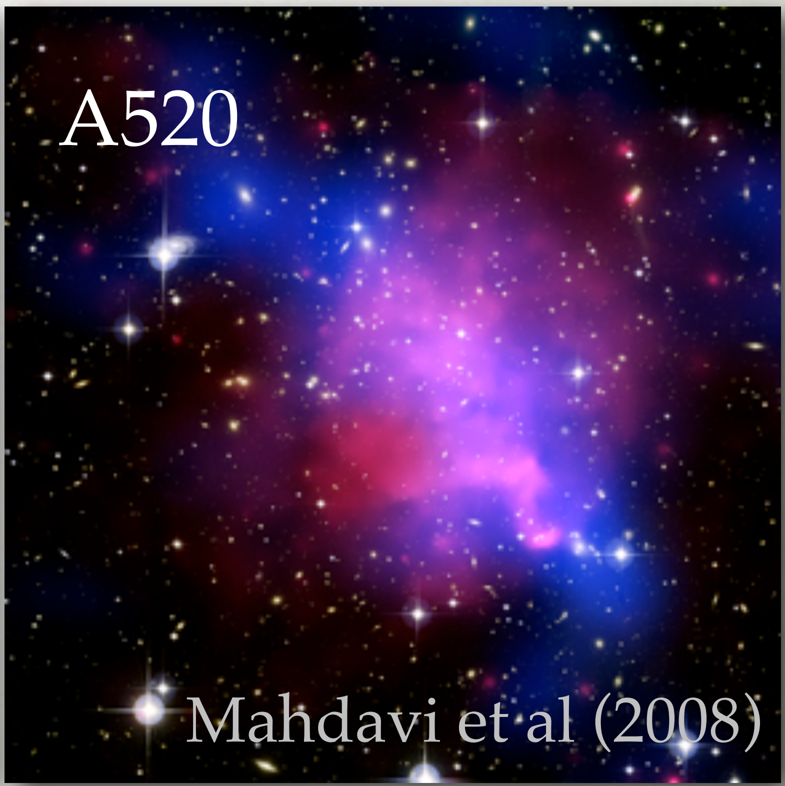
Masses are important

9% change in mass normalization

Vikhlinin et al. (2009)

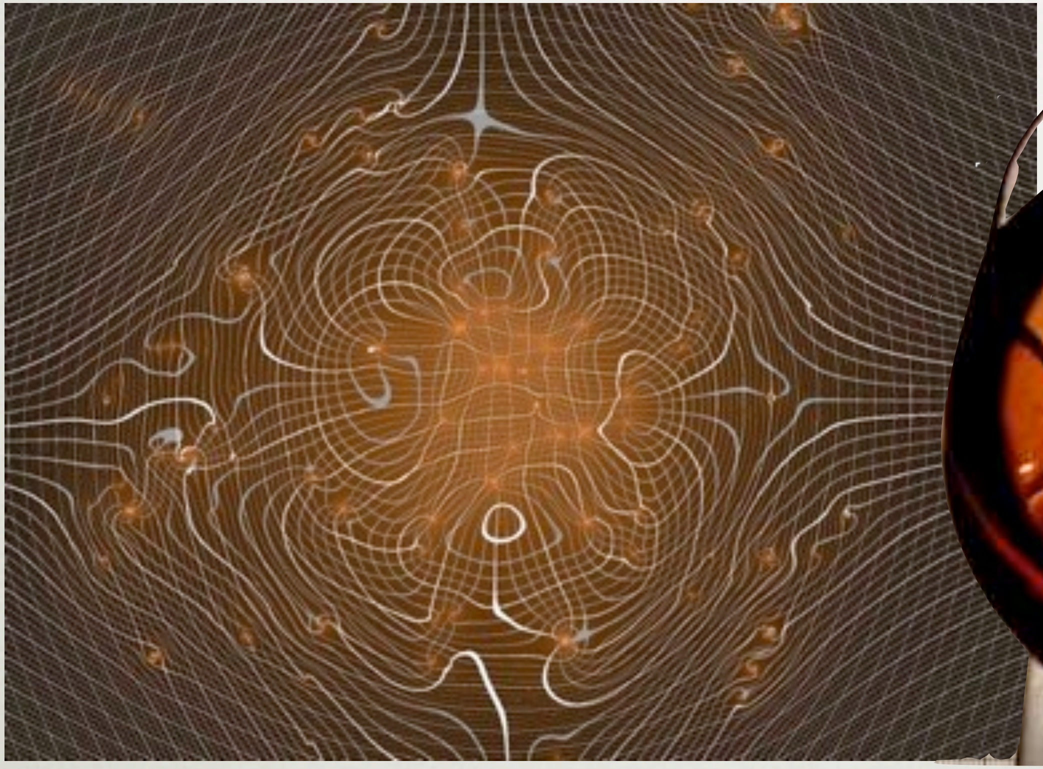


How to measure the mass of ...



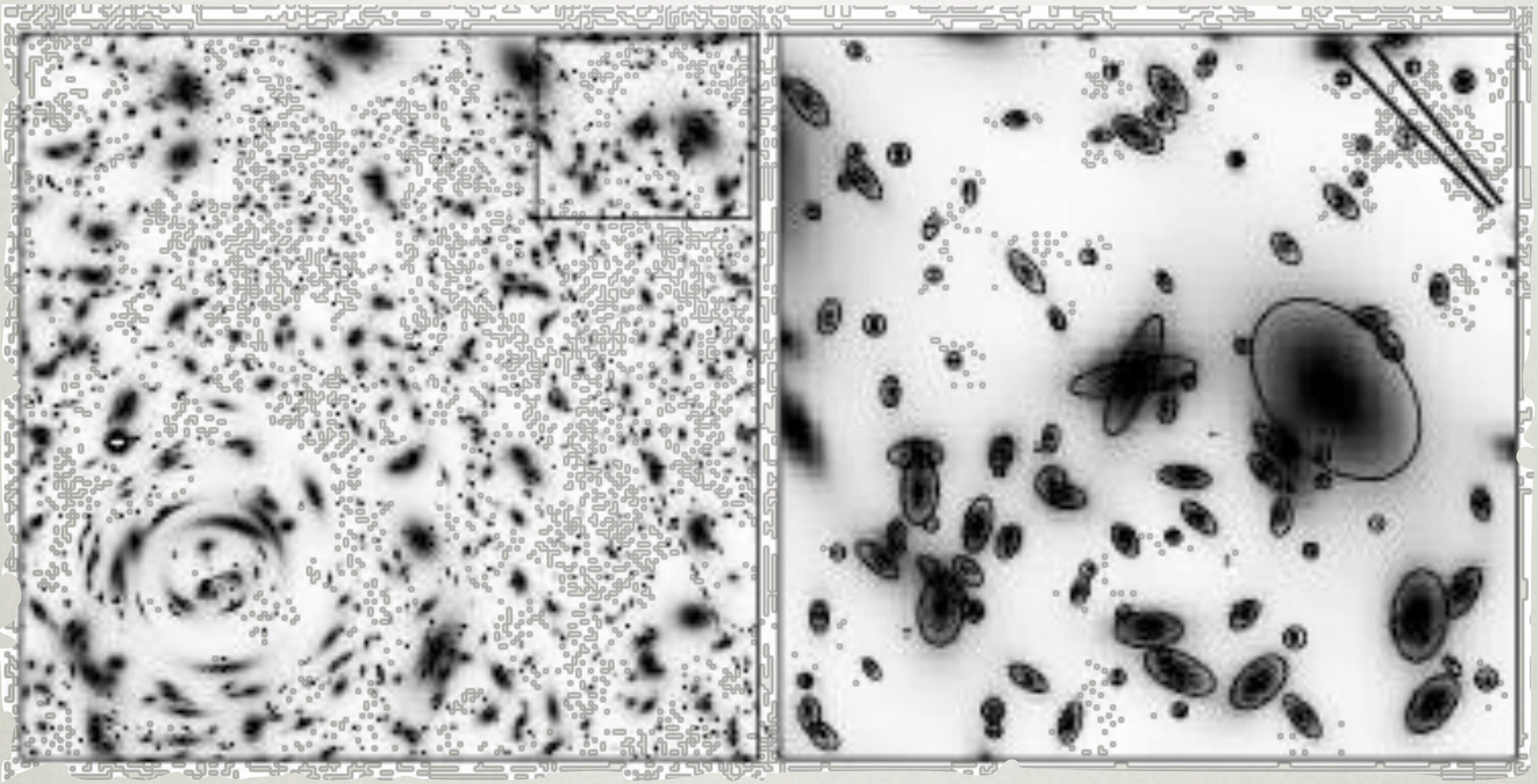
Clusters have a complicated history of multiple mergers resulting in complicated geometries with a lot of substructure. This is particularly important at high redshifts.

Gravitational lensing



The cluster mass distribution causes a remapping of the background sky resulting in coherent distortions in the shapes of background galaxies.

Weak gravitational lensing

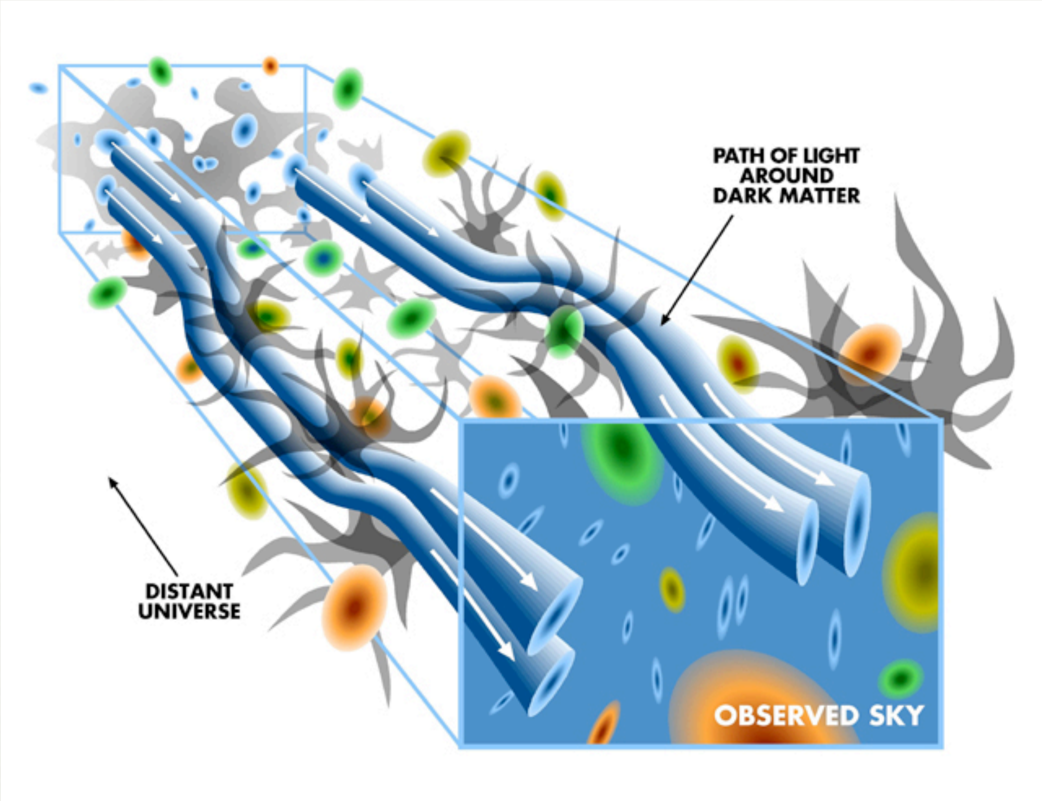


A measurement of the ellipticity of a galaxy provides an unbiased but noisy measurement of the gravitational lensing shear

We can 'see' dark matter

Weak gravitational lensing provides an important link between the observable universe and numerical simulations.

Weak lensing by LSS

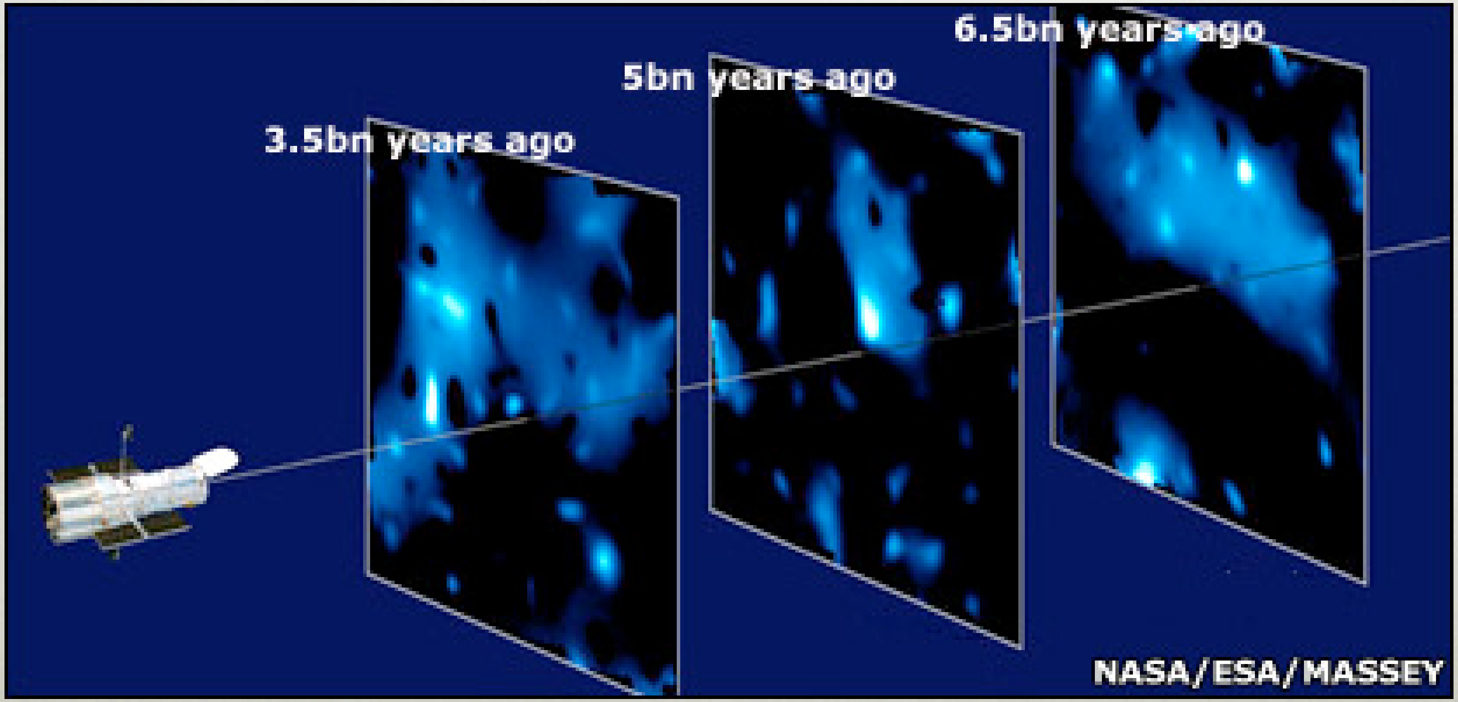


The statistics of shape correlations as a function of angular scale, or cosmic shear, can be used to *directly* infer the statistics of the density fluctuations.

Slicing the Universe

If we have redshift information for the sources we can measure the mass distribution as a function of redshift: tomography allows us to accurate cosmology.

This application has driven much of the progress in the subject.



Modern cluster lensing

Improvements since the early days:

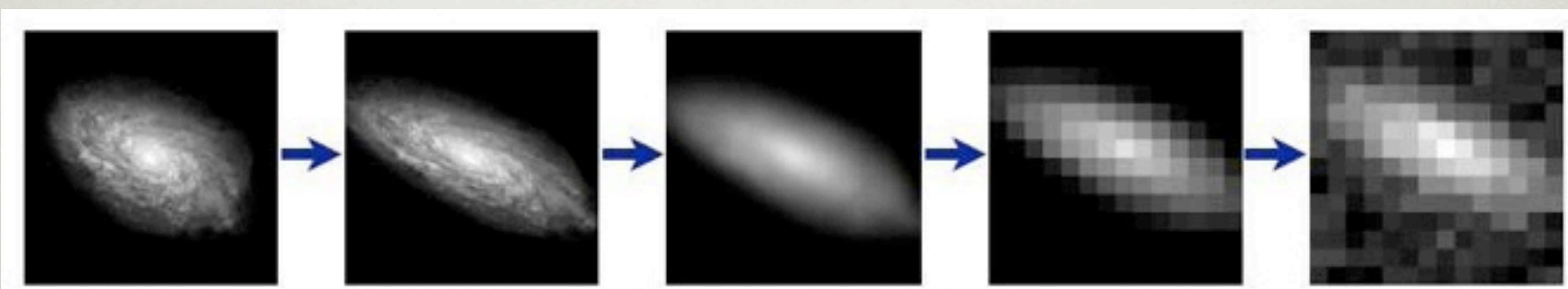
- measure signal out to larger radii
- better knowledge of the source redshift distribution - better corrections for systematic effects

As the sample sizes increase, the lensing analysis needs to become more advanced: deal with contamination by cluster galaxies, centroid errors, contributions from local and distant large scale structure, etc.

PSF correction

It is relatively easy to create simulated data to test the measurement techniques.

Several (blind) challenges have been carried out to benchmark the various methods, such as STEP and GREAT'08/'10

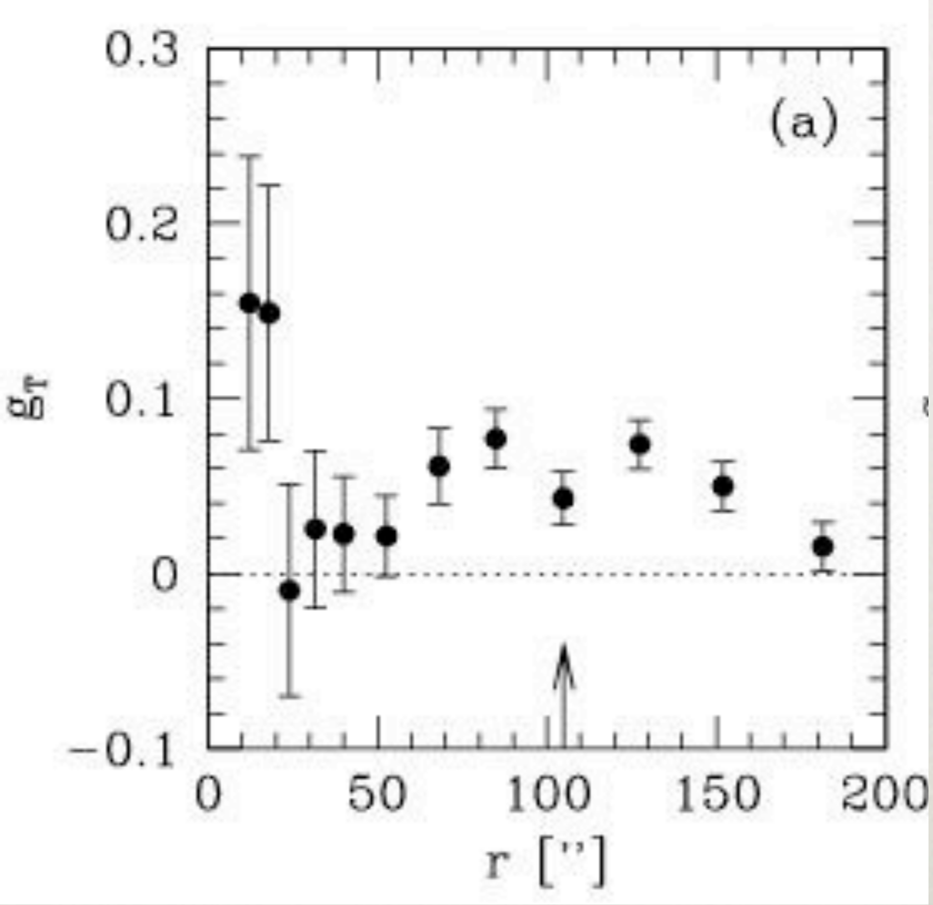


?

We can currently reach an accuracy of 1-2% in the shear measurement.

Limitations of weak lensing

"mass contrast" $g_T(r) \propto \langle \Sigma(< r) \rangle - \langle \Sigma(r) \rangle$



Weak lensing is sensitive to the *projected* mass *contrast*.

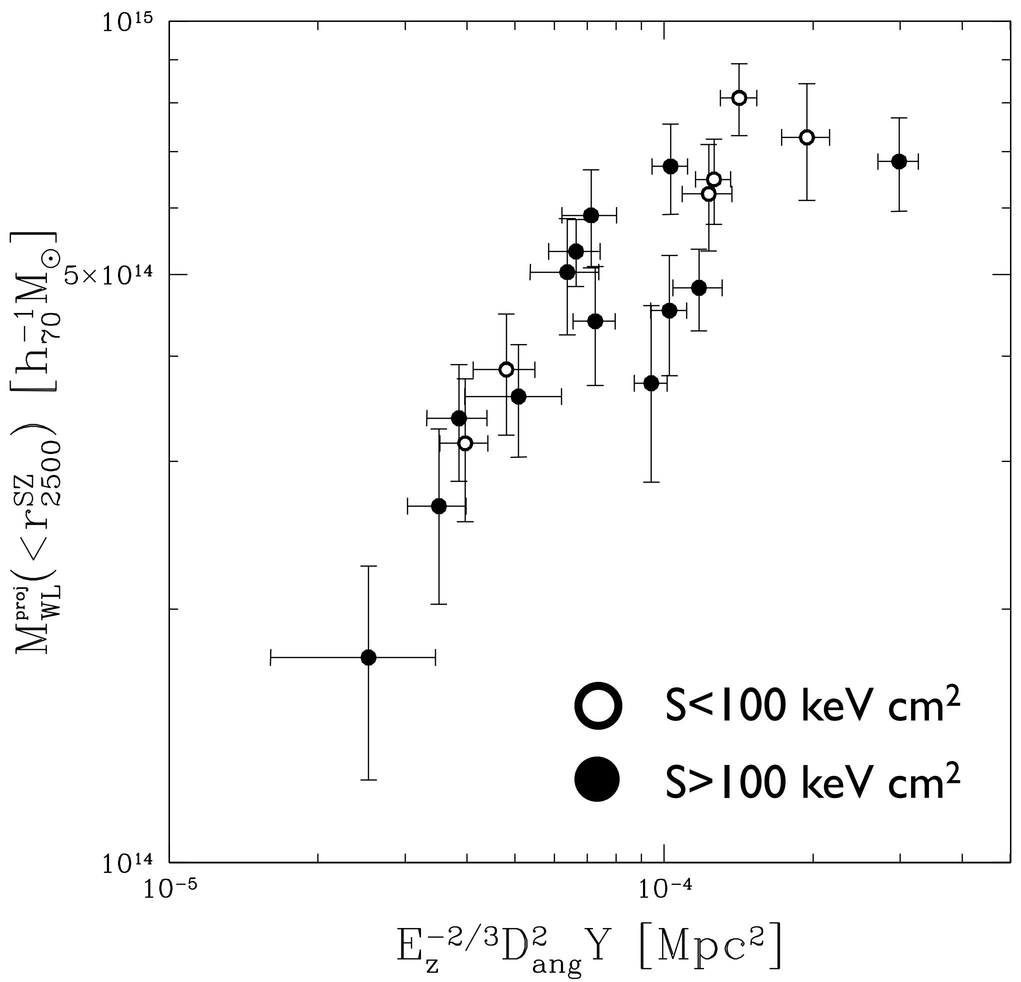
Limitations of weak lensing

Accurate shape measurements do not imply accurate masses!

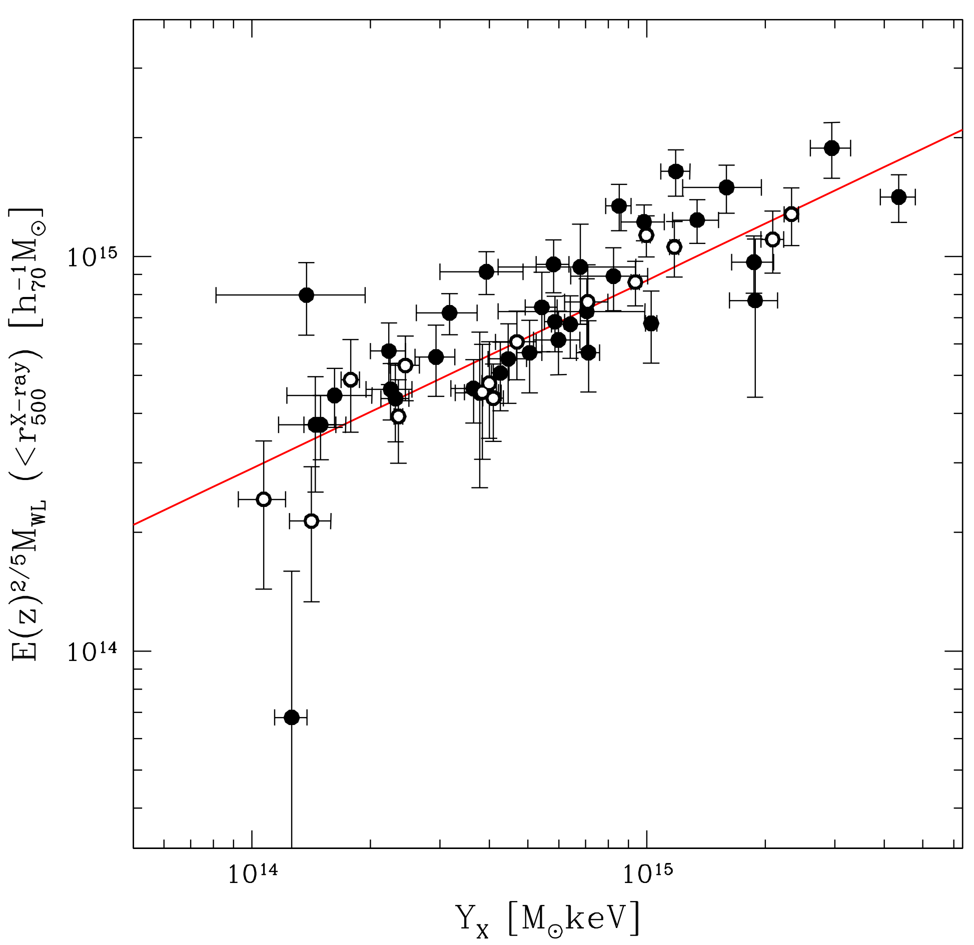
- Weak lensing is sensitive to the *projected* mass distribution.
- The signal depends on *all matter along the line of sight*.
- We require *good* knowledge of the source redshifts.
- Need to account for *contamination* by cluster members.
- What to pick as the *cluster centre*?

RESULTS AT z~0.2-0.4

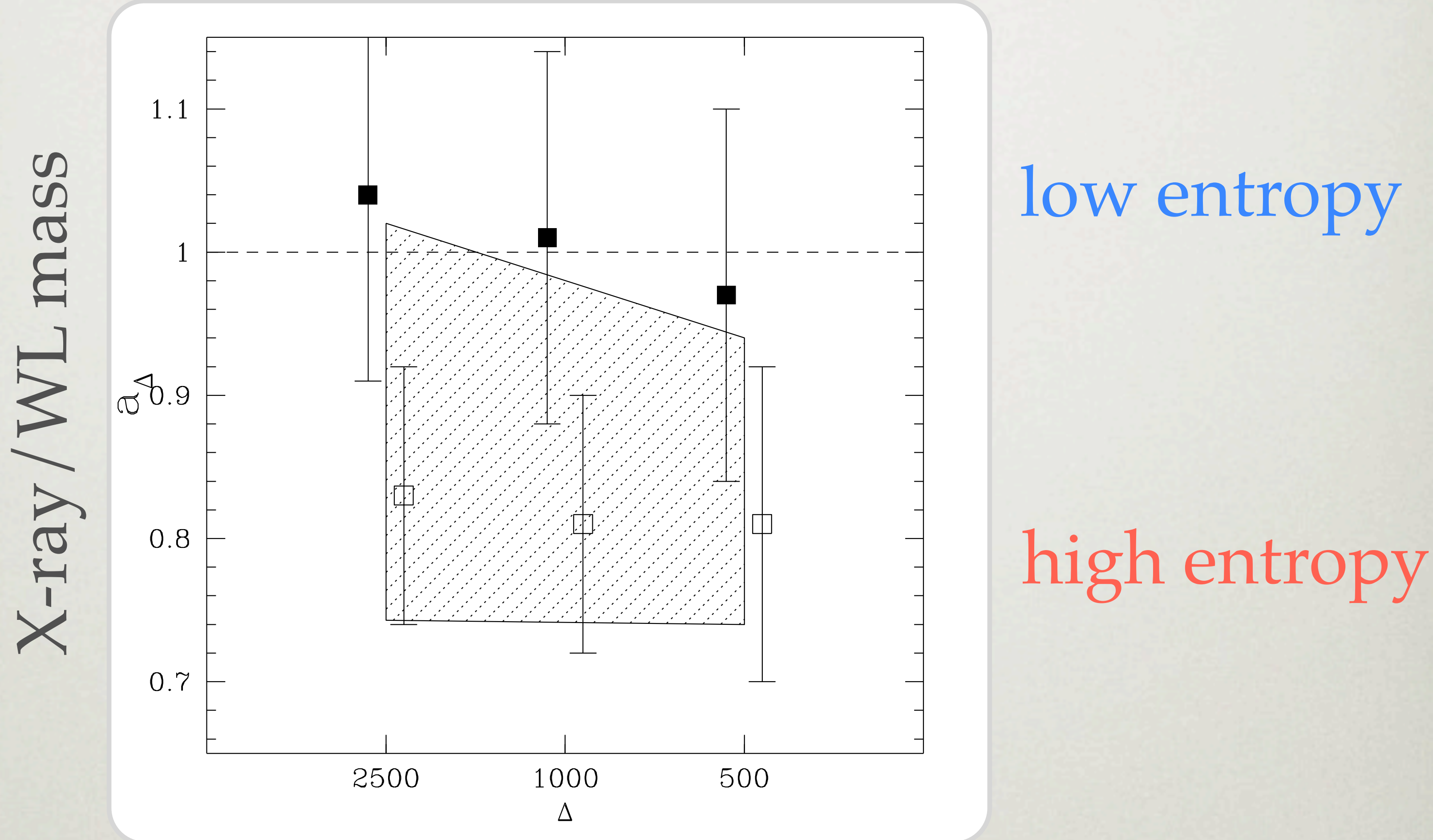
"real" SZ (Hoekstra et al. 2012)



"X-ray" SZ (Mahdavi et al.)



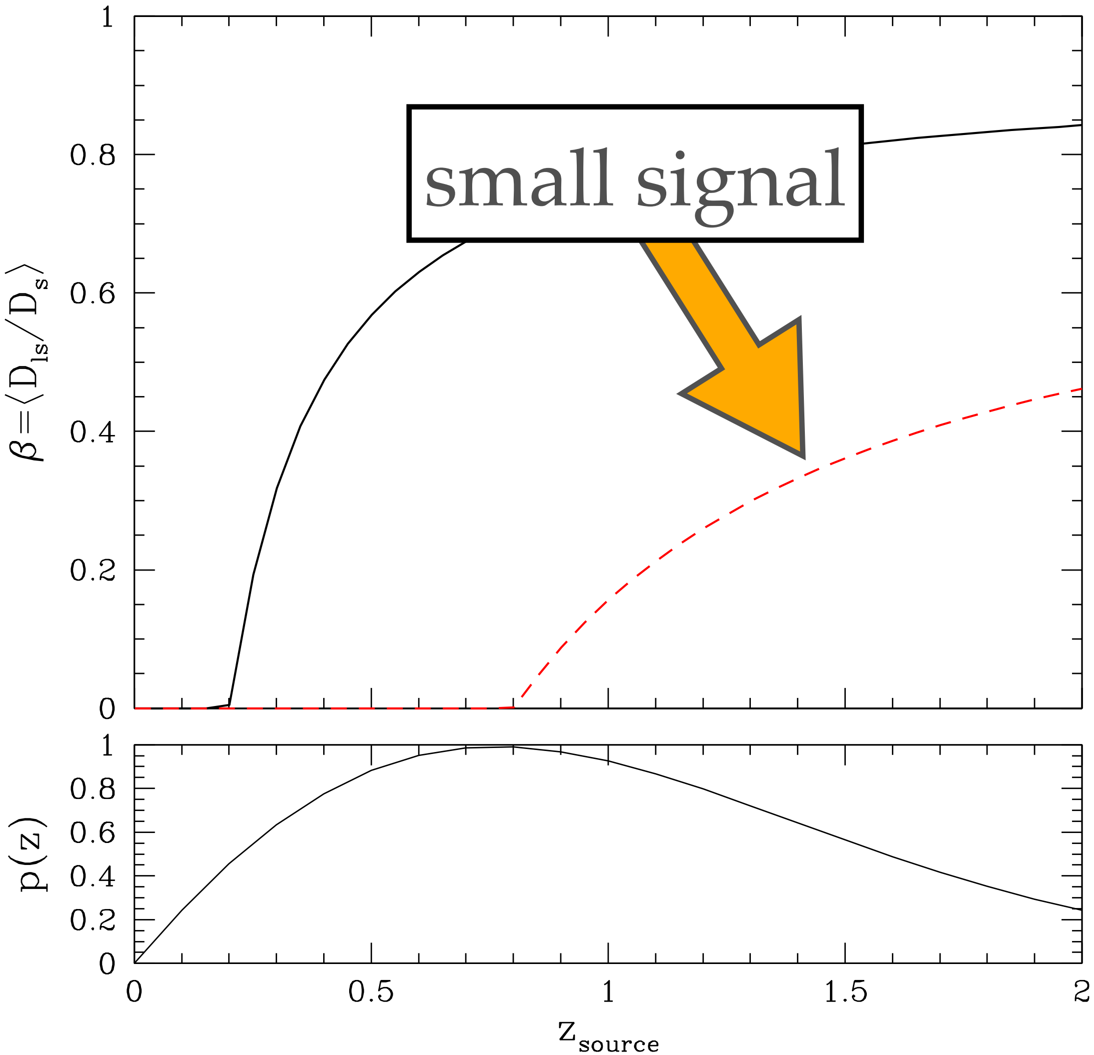
Results at z~0.2-0.4



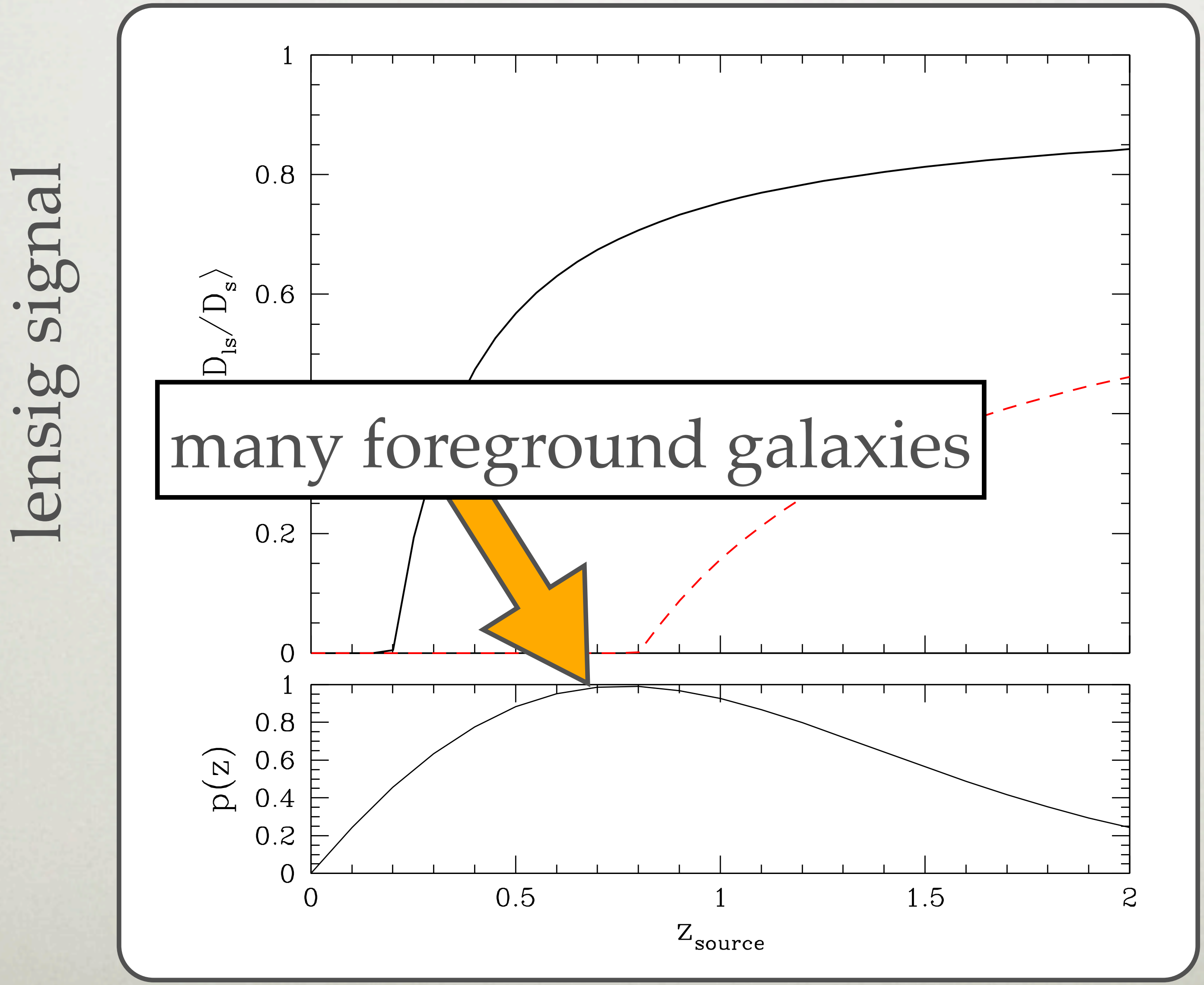
Mahdavi et al. (in prep):
gas is not (always) in hydrostatic equilibrium.

At high redshift?

lensig signal

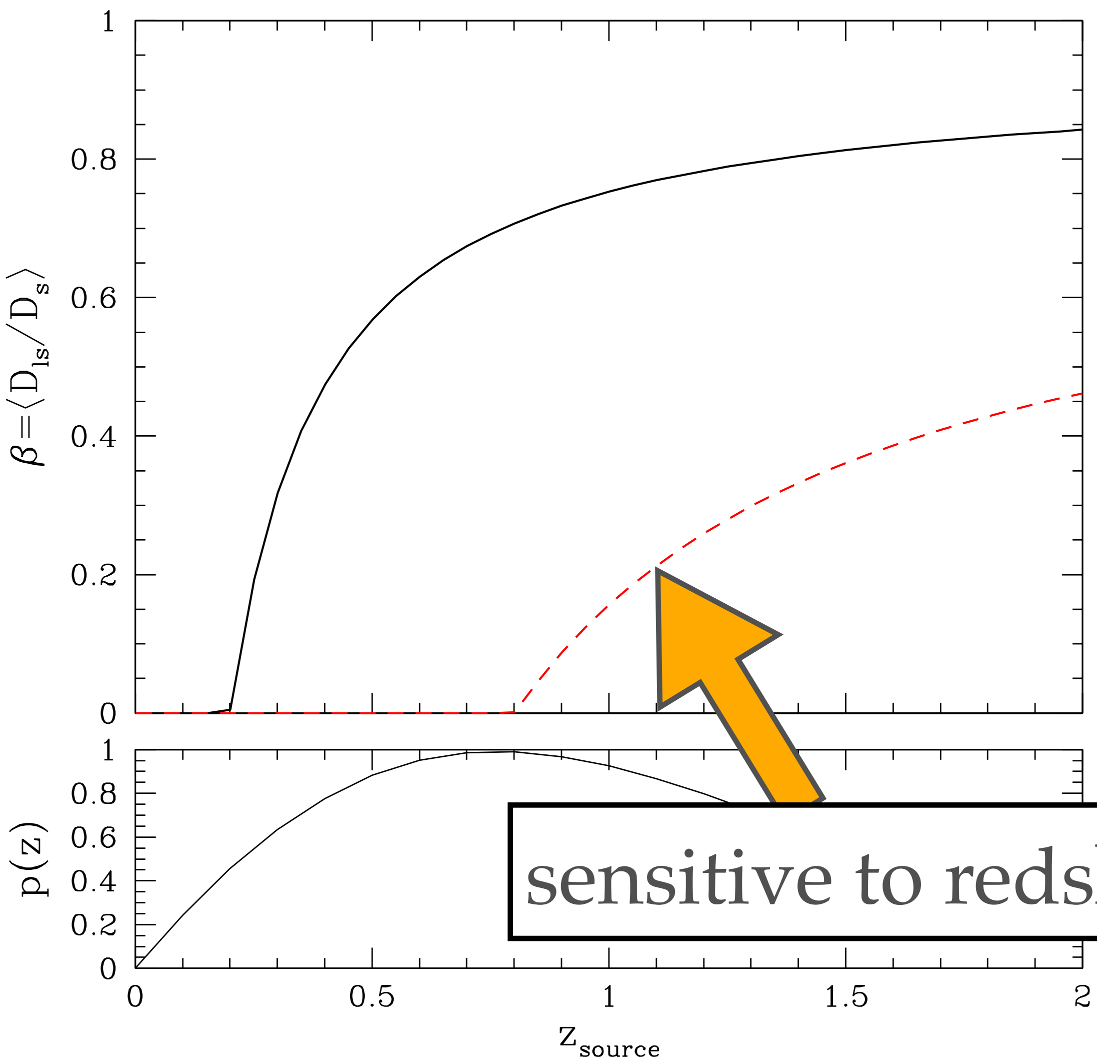


At high redshift?



At high redshift?

lensig signal



sensitive to redshift errors

At high redshift?

- signal is low

    try to get higher redshift sources

- fewer background galaxies

    try to observe fainter galaxies

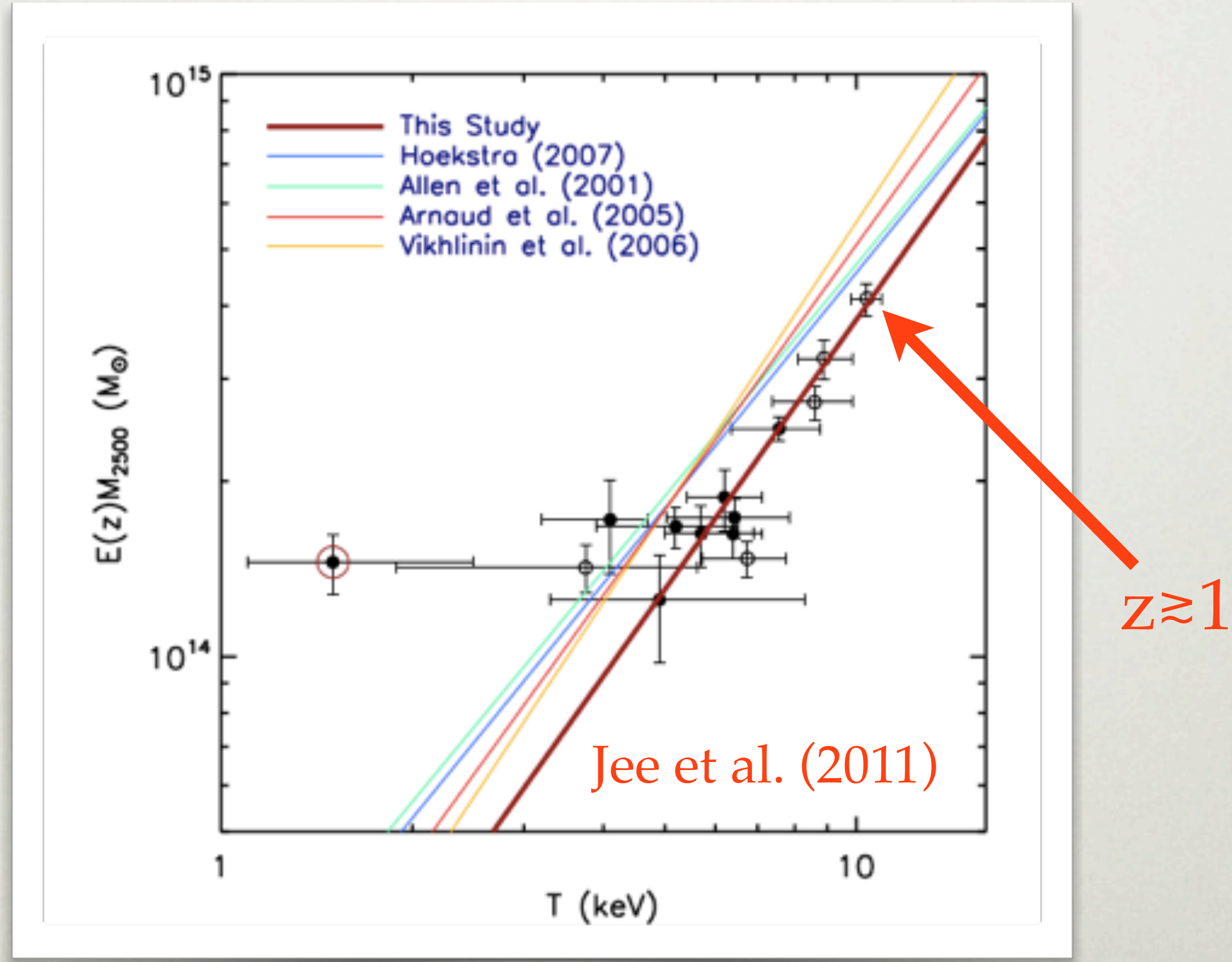
- more sensitive to redshift uncertainties

    get photometric redshifts for the sources

- sources are small

    get space-based observations

"LARGE" SAMPLE WITH HST

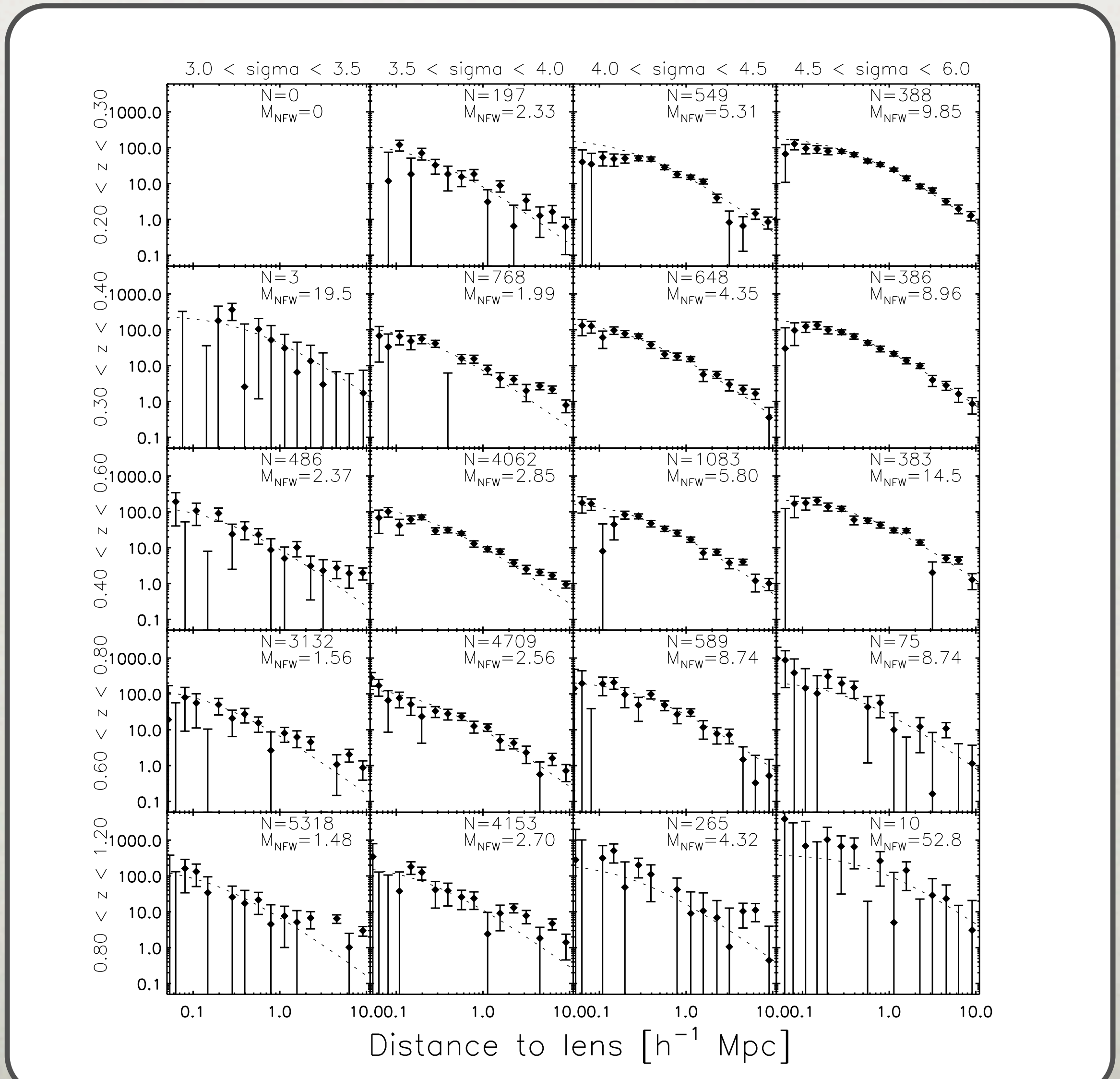


Normalization 20-30% lower at z~1?

RCS2 - 28,000 clusters

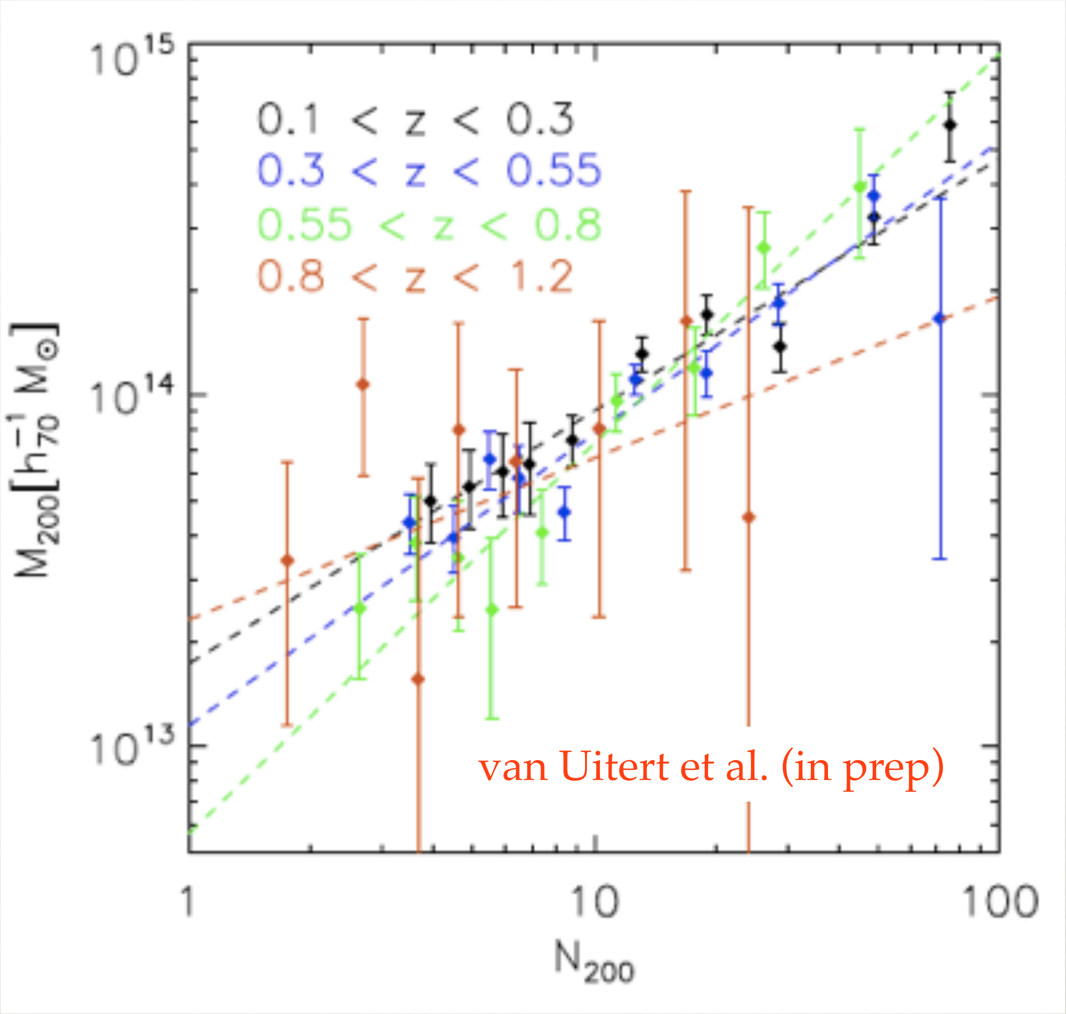
van Uitert et al. (in prep)

lensing signal



z~0.9

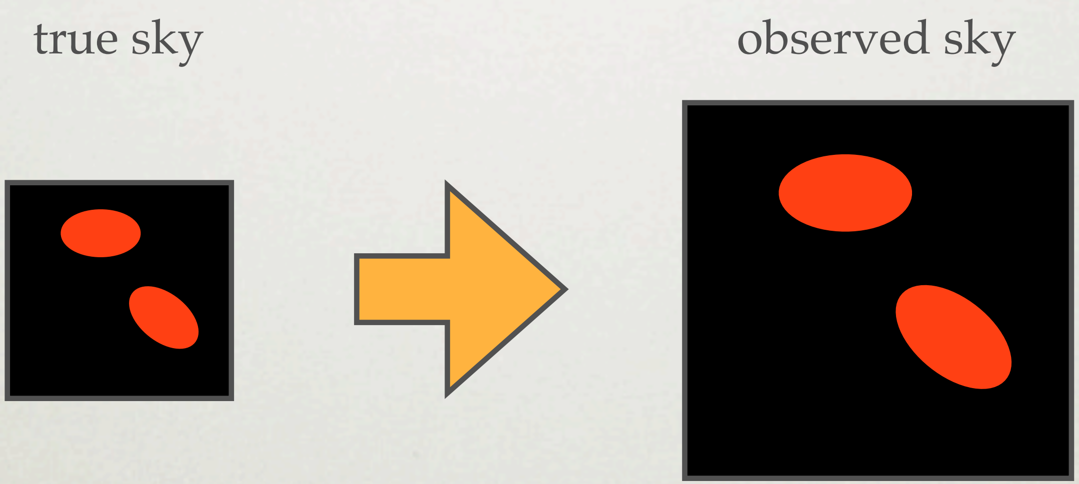
RCS2 - 28,000 clusters



We can start to study the evolution of the mass-richness relation

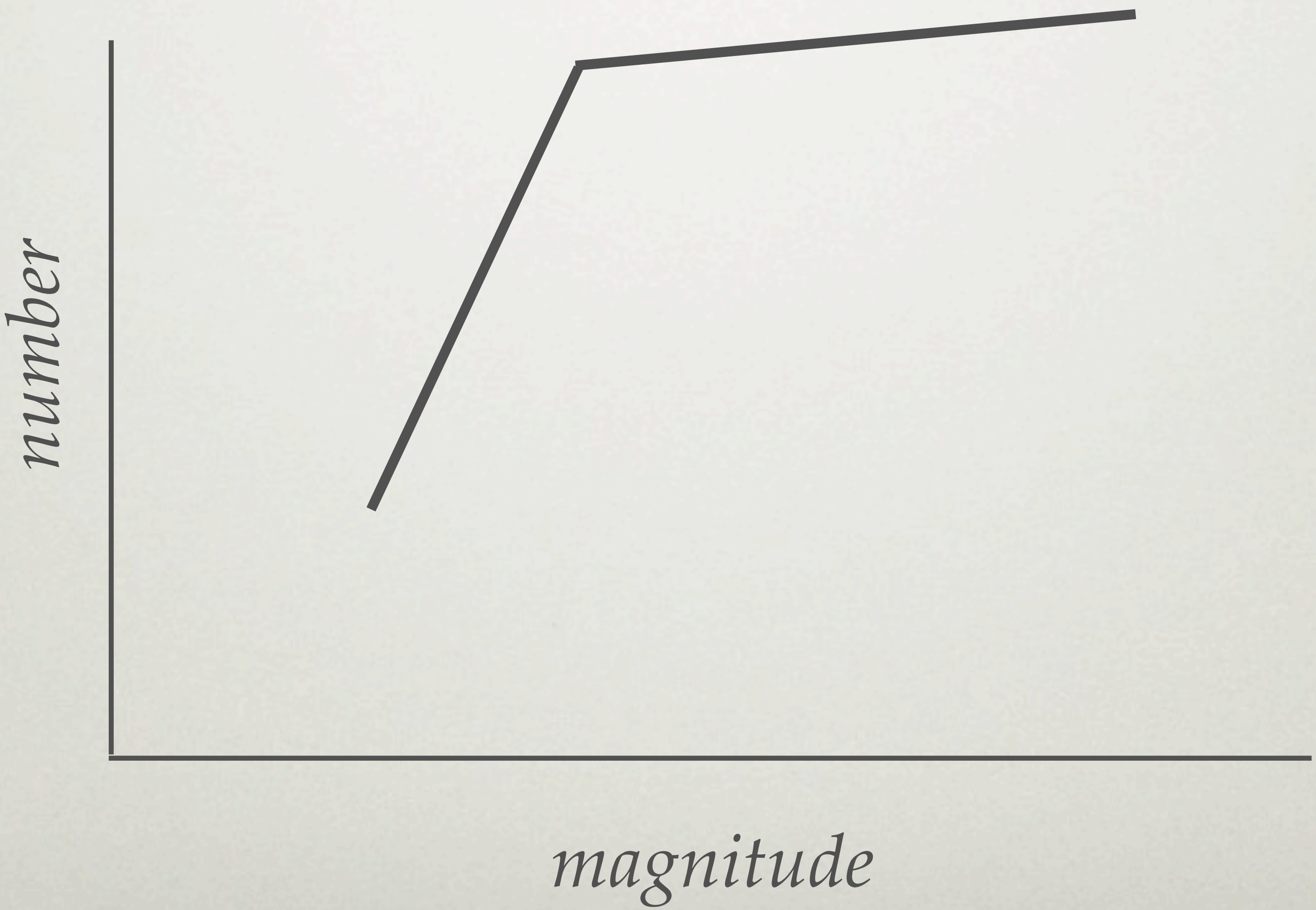
There is another way...

Gravitational lensing not only distorts the background, but also changes the angular size of a patch of sky.

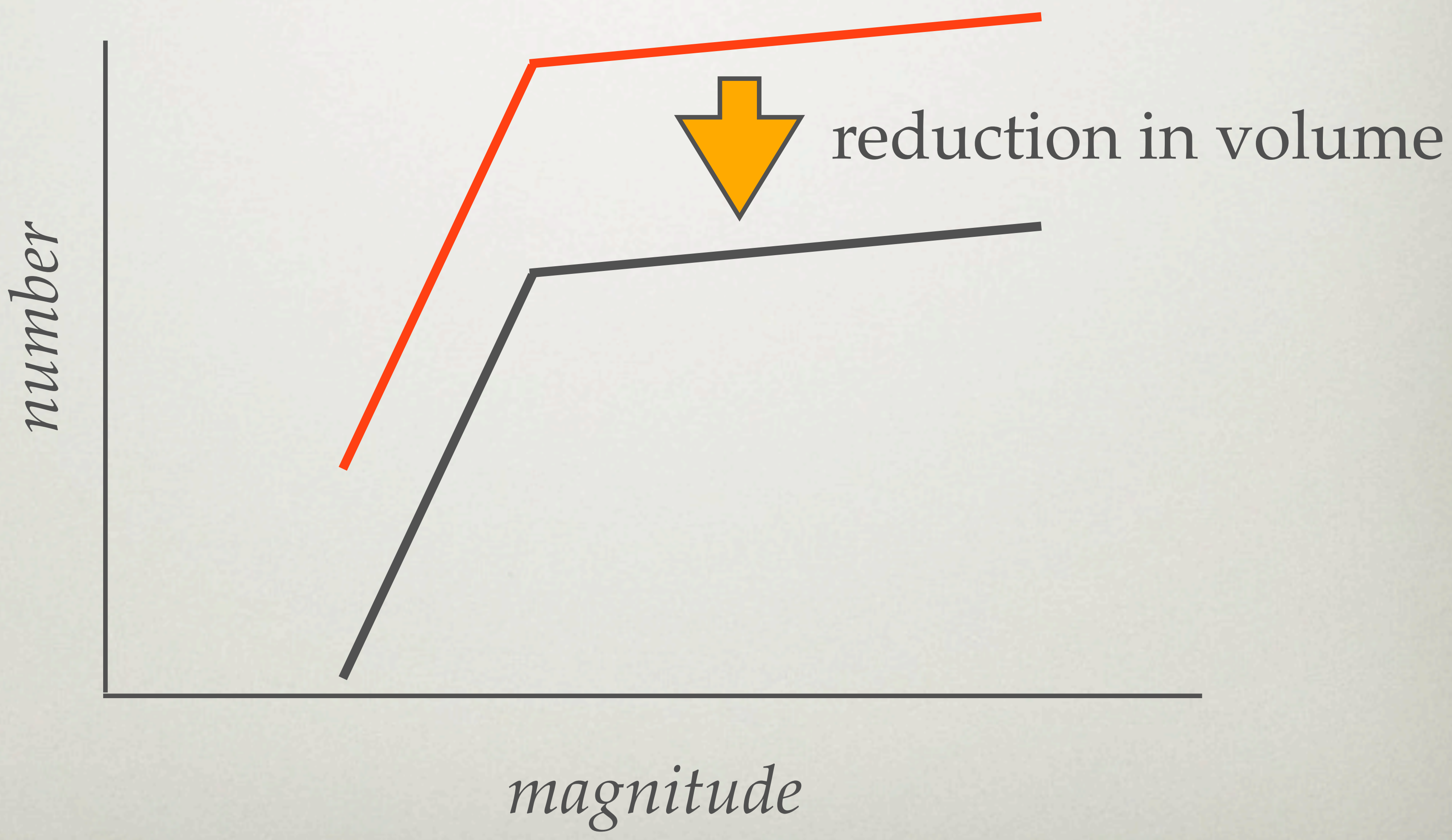


- true survey area is $1/\mu$ times larger
- objects are μ times larger (=brighter)

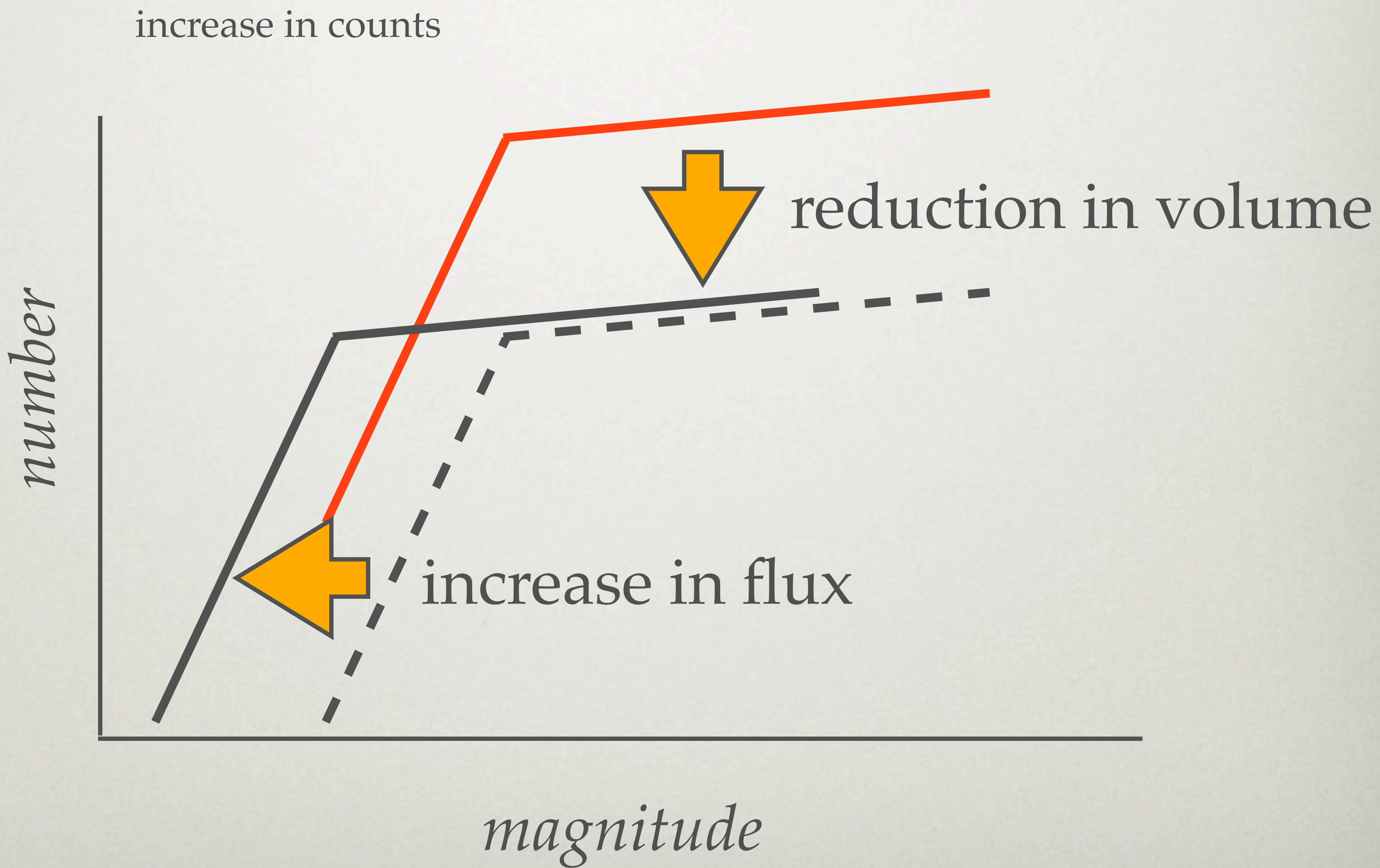
Magnification



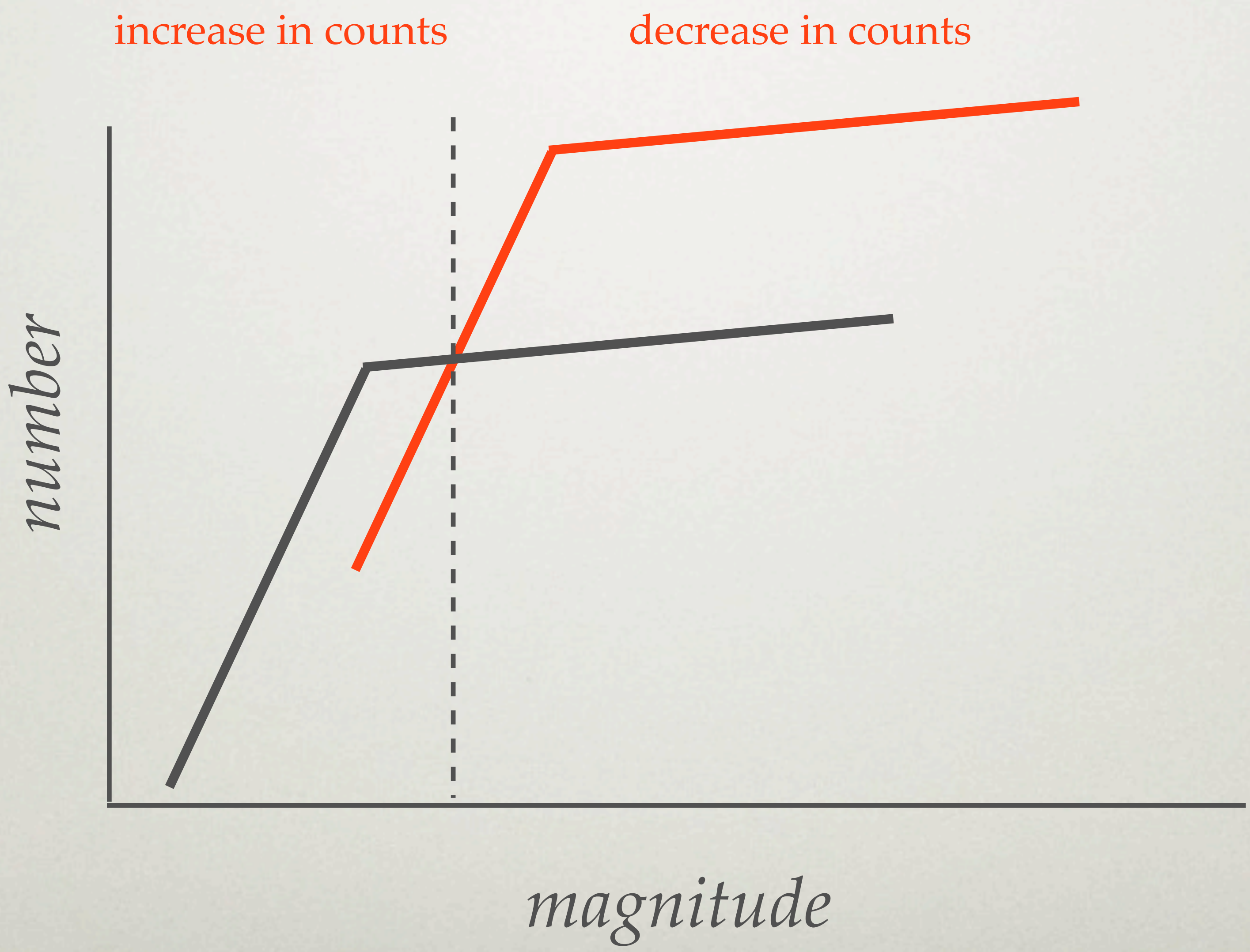
Magnification



Magnification

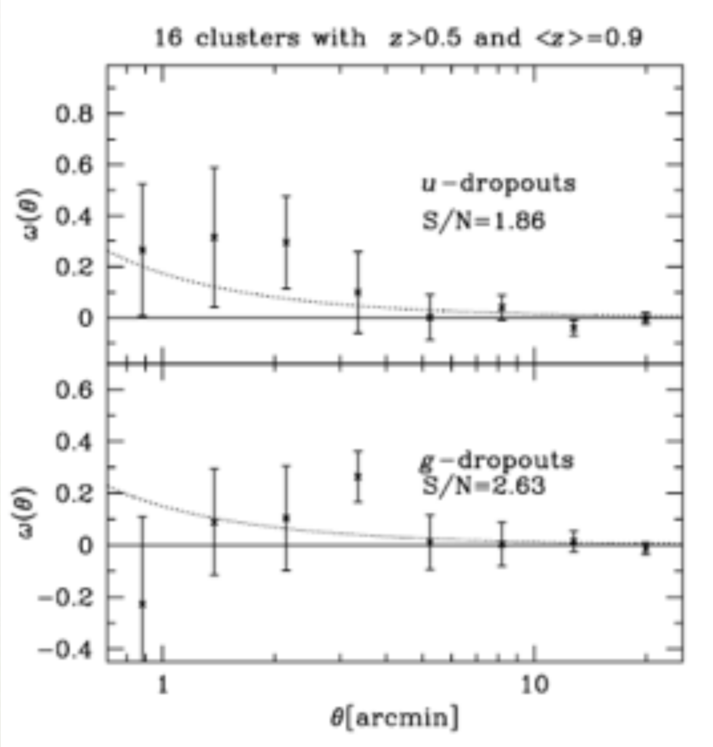


Magnification



There is another way!

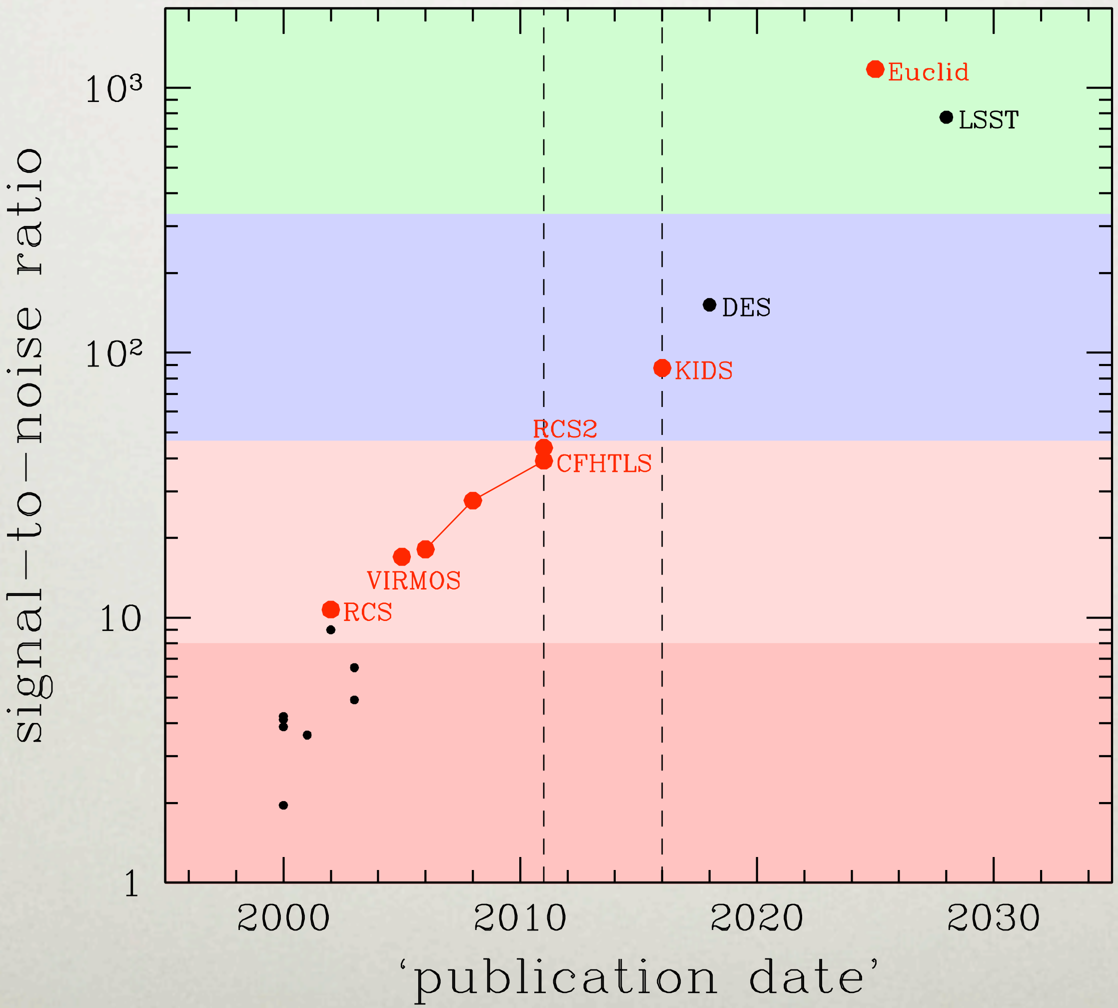
Hildebrandt et al. (2011) used the magnification of LBGs to detect the lensing signal of clusters discovered by SpARCS.



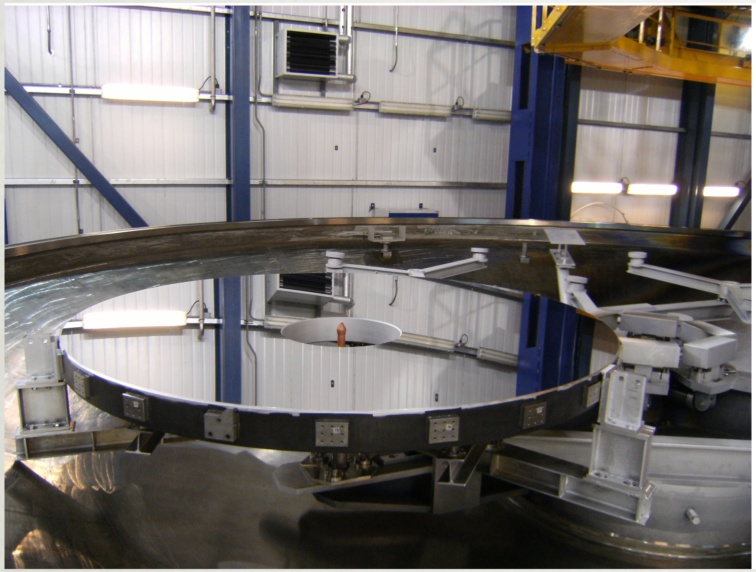
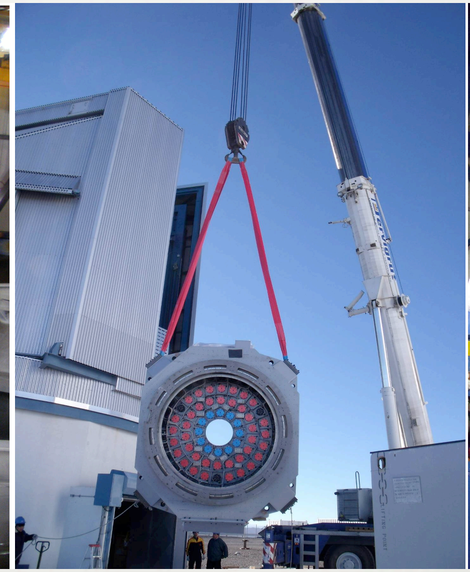
In combination with wide area surveys this approach will provide a new way to study masses at high redshifts.

Lots of data coming!

cosmic shear only



Lots of data coming!


KiDS + VIKING: (1500 deg^2,ugriZYJHK)

- has started fall 2011
- goal is completion in ~3 years

The future

Understand the origin of the accelerated expansion of the Universe

- probe its very nature: is dark energy the cause or modified gravity?
- distinguish these effects decisively

- **Cosmic expansion history**

  dark energy equation-of-state *w(t)*

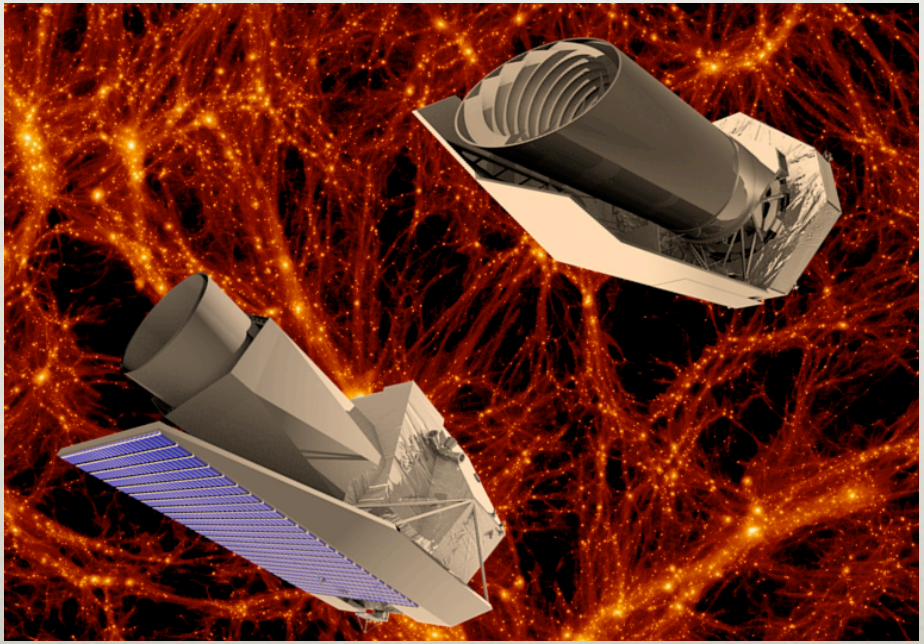
- **Cosmic history of structure formation**

  growth rate of structure *f(z)*

Euclid: how can we do this?

Euclid is a 1.2m telescope with a scheduled launch in ~8 years.
Its primary cosmology probes, which drive the design, are:

- **Weak lensing by large scale structure**
- **Clustering of galaxies**



Euclid: how can we do this?

Euclid will survey the

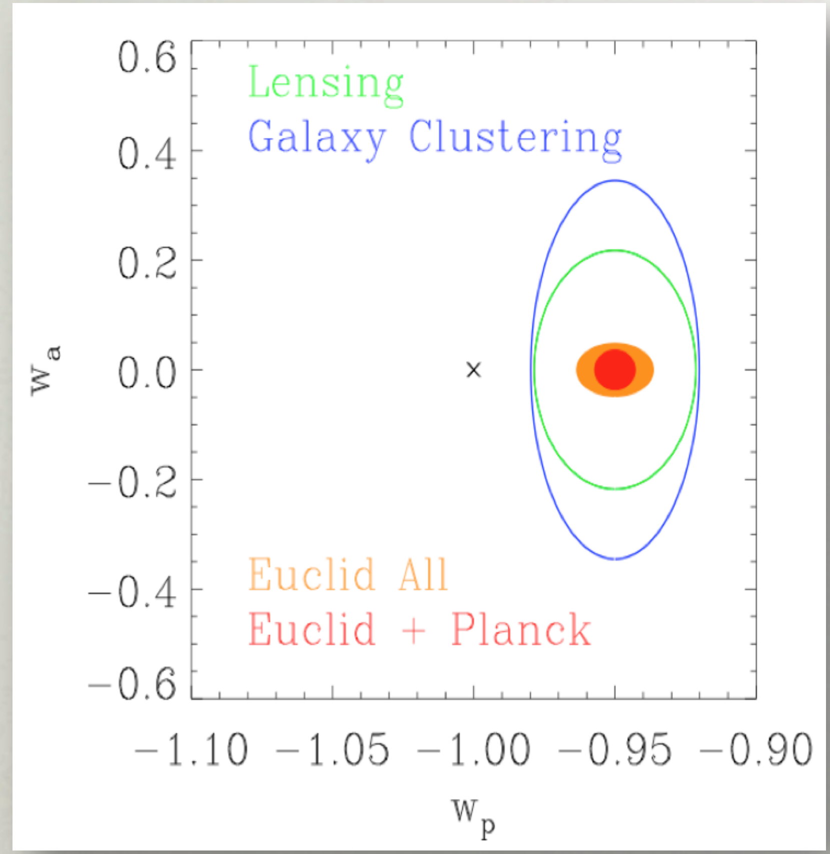
- best 1/3 of the sky (15000 deg^2)
- similar resolution at HST in optical
- NIR imaging in 3 filters (YJH)
- images for $2x10^9$ galaxies

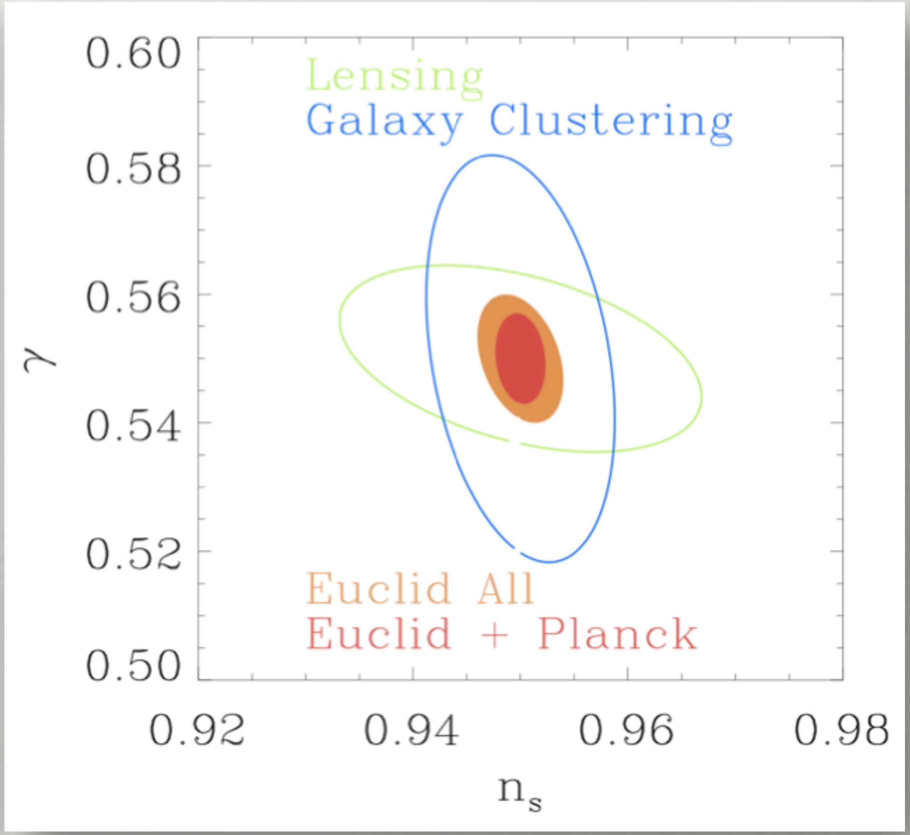
and carry out an unprecedented redshift survey with

NIR spectra for $5x10^7$ galaxies ($0.7<z<2$)

For more information see Laureijs et al. (2011)

Euclid: performance



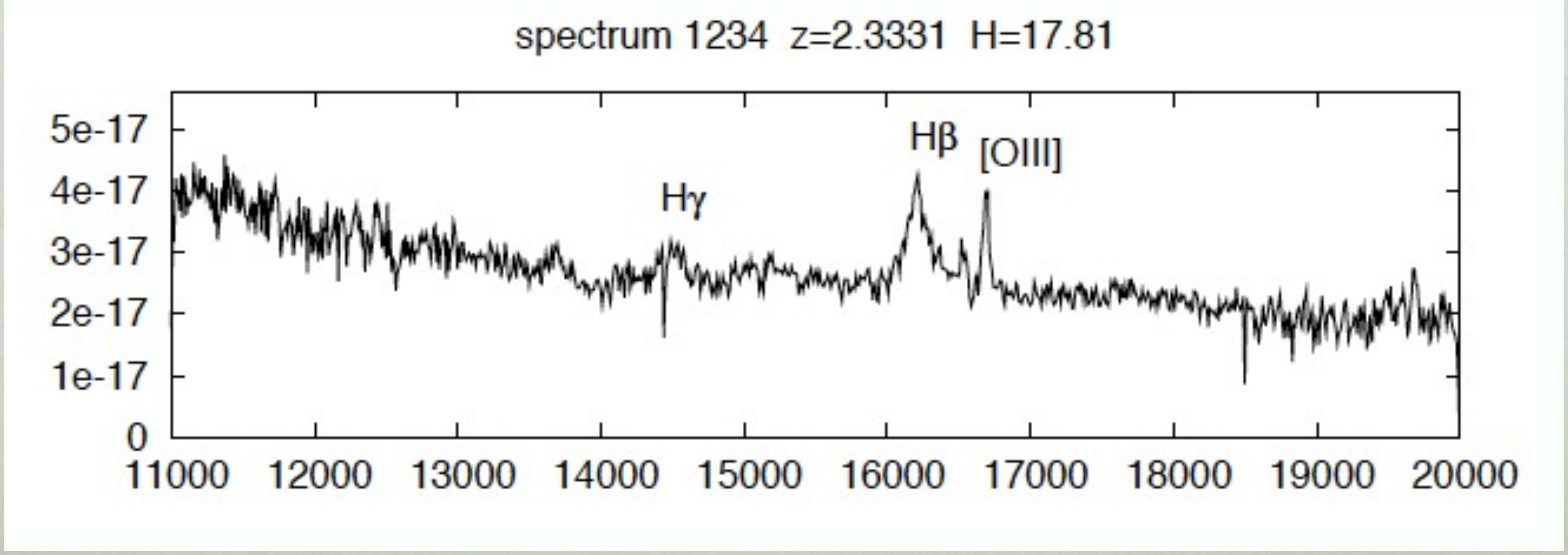


Euclid will test all aspects of the the current cosmological paradigm.

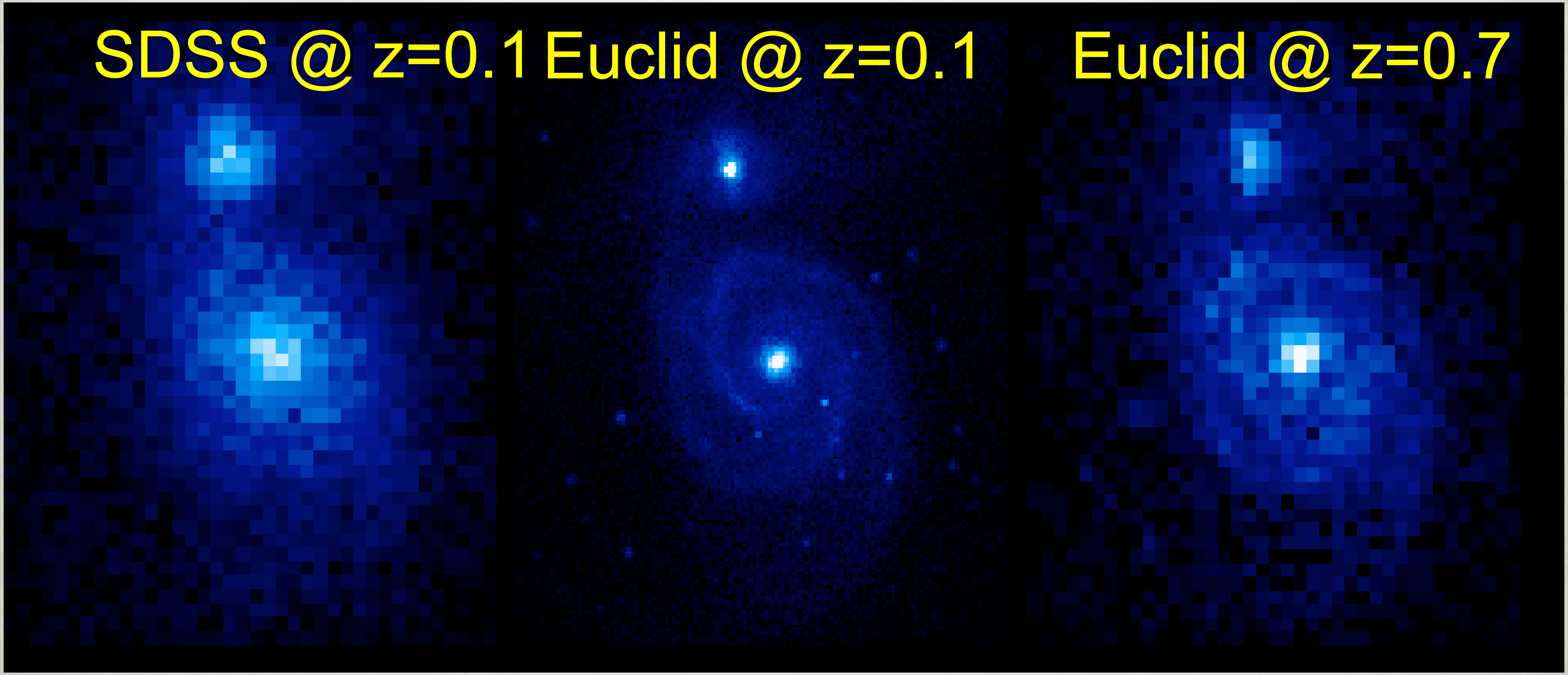
Euclid: lots of spectra

- R=250 spectroscopy, observed with two roll-angles
- wavelength range: $1.1\mu m<\lambda<2\mu m$
- $F>3\times10^{-16}$ erg/s/cm^2
- ~10^7 Hα emitters; for 10^5 galaxies also Hβ and [OIII]

Simulated spectrum



Euclid is SDSS at z~1



Euclid images of z~1 galaxies will have the *same* resolution as SDSS images at z~0.05 and will be at least 3 magnitudes *deeper*.

Euclid: there is much more!

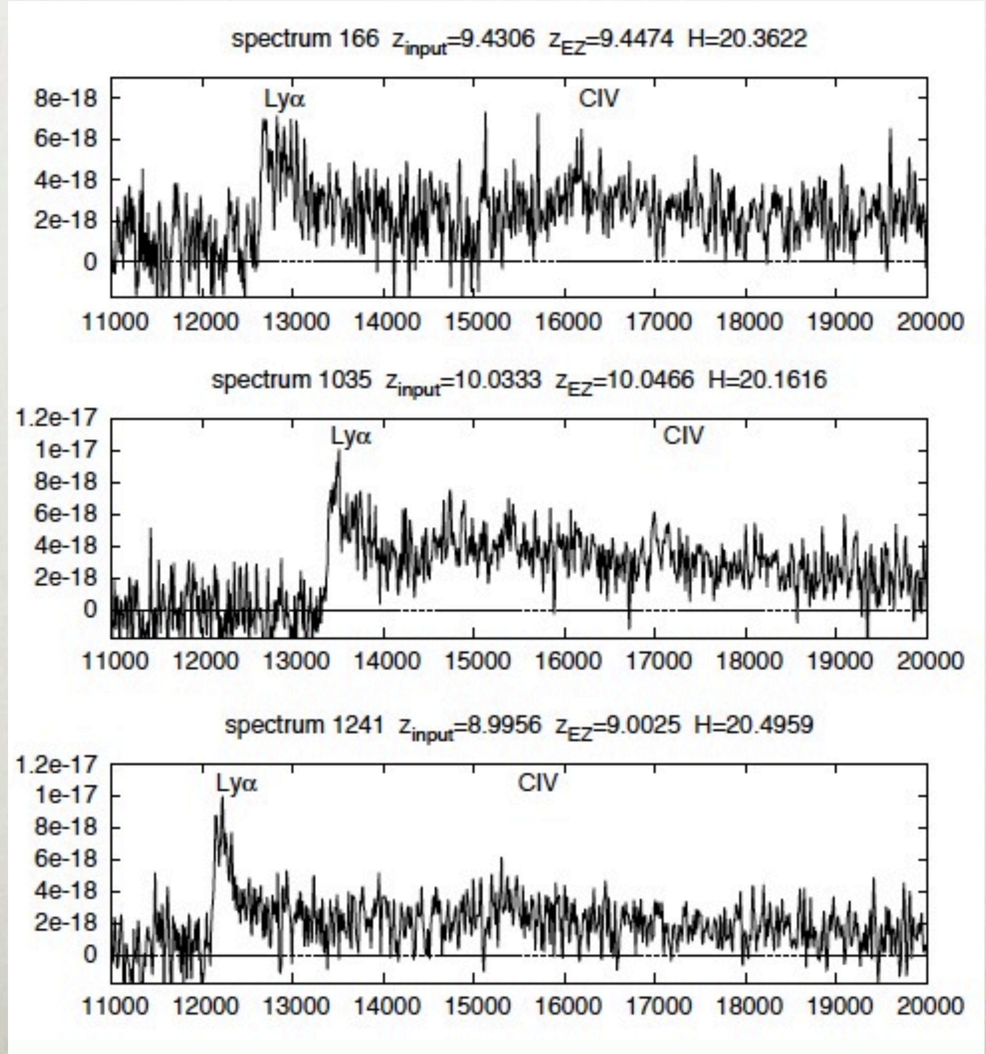
The primary cosmology probes drive the design of the survey, but the resulting data set enables an enormous amount of legacy science, which cannot be done otherwise:

Euclid will image 15000 deg^2 in YJH_{AB}=24, which would take 680 years to complete with VISTA or 66 years with SASIR (planned for 2017). The deep survey of 40 deg^2 down to YJH_{AB}=26 would take 72 years with VISTA.

The Euclid NIR imaging is a 100 times more ambitious than anything currently underway (and >10 times any conceived project). The same is true for the spectroscopy. Euclid probes a much larger volume than the SDSS: 20 Gpc^3 at z~2±0.05 compared to ~0.3 Gpc^3 probed by SDSS at z~0.2

Euclid: high-z enough?

We expect to discover ~30 QSO with z>8. Currently none have been found.



Roche et al. (2011)

Euclid: cluster studies

Euclid will also be great for cluster studies:

- *find high redshift clusters*
- *improve mass calibration*

Euclid will improve S/N per cluster by a factor ~2-3.

Compared to RCS2 results: factor 10 increase in precision.

Thanks to design/cosmic shear work also *high accuracy*!

More details in talk by Andrea Biviano.

Conclusions

Weak lensing studies of individual high redshift clusters are expensive and are limited by the shape noise.

Ensemble averaged masses for z~1 clusters are feasible using ground based data, with more results from magnification measurements expected soon.

The precision will improve dramatically once we have *Euclid* data.