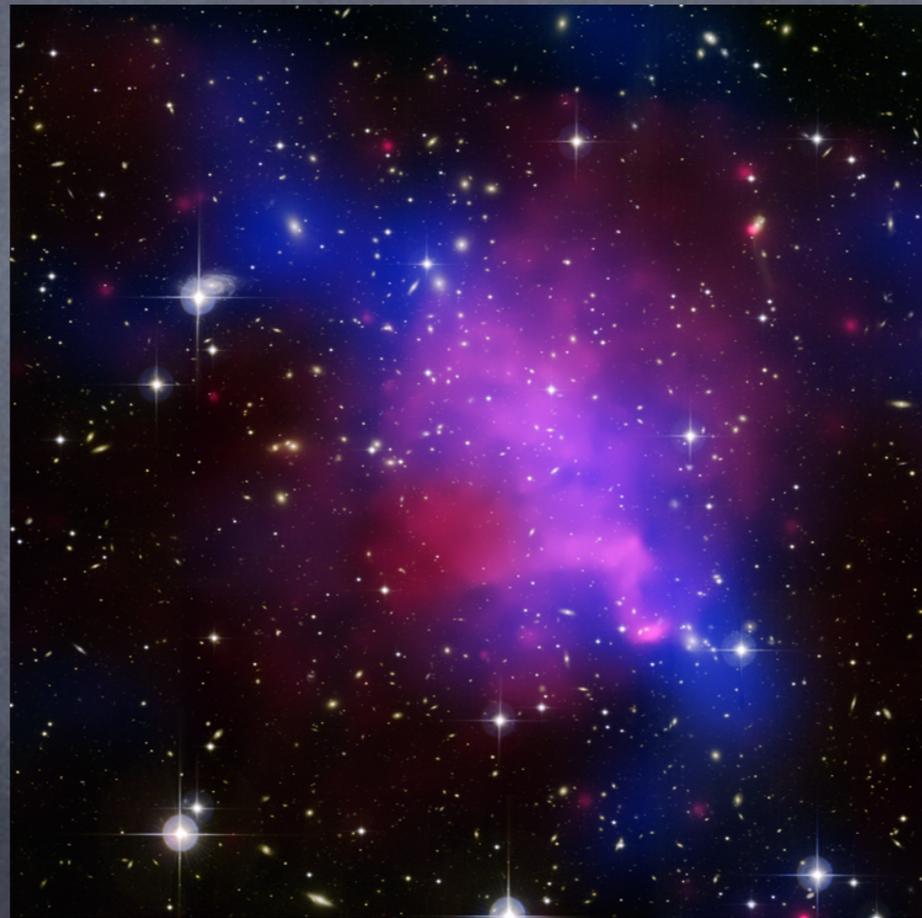


# Weak Lensing

studies of galaxy clusters



Henk Hoekstra  
Leiden Observatory

# Masses are important

**Cluster  
survey**



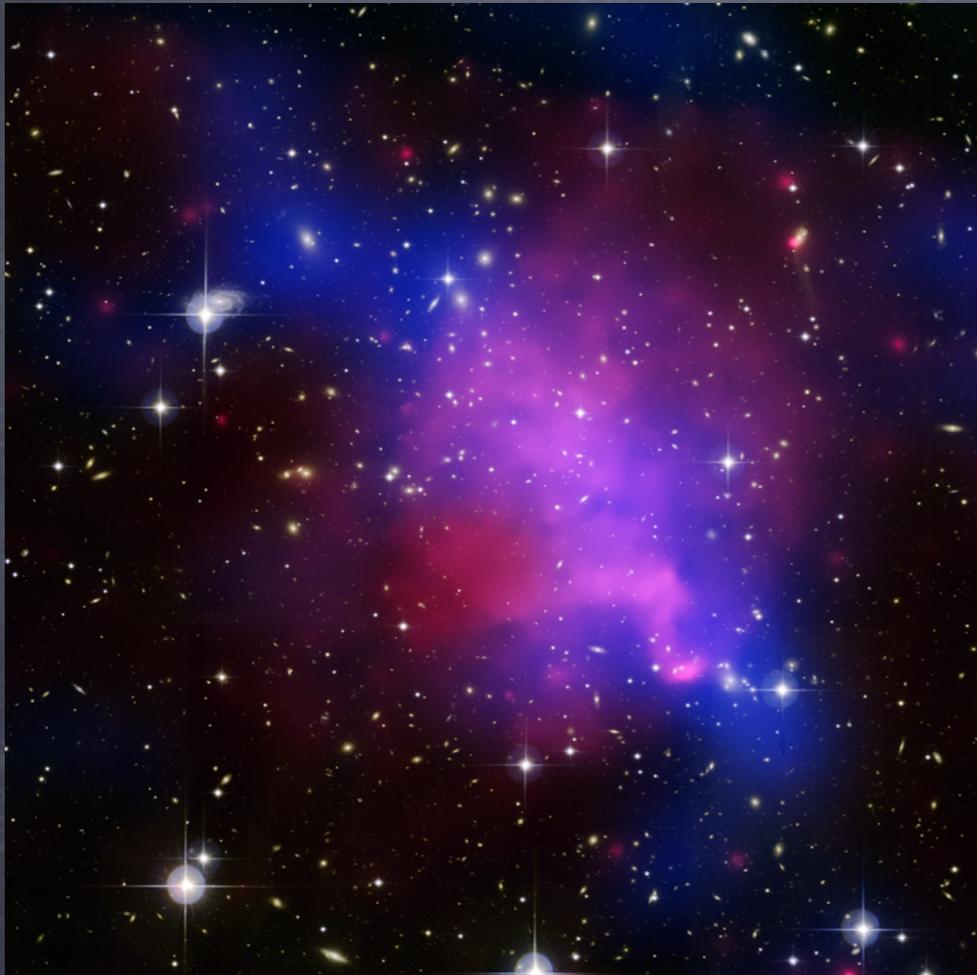
**Mass proxies**



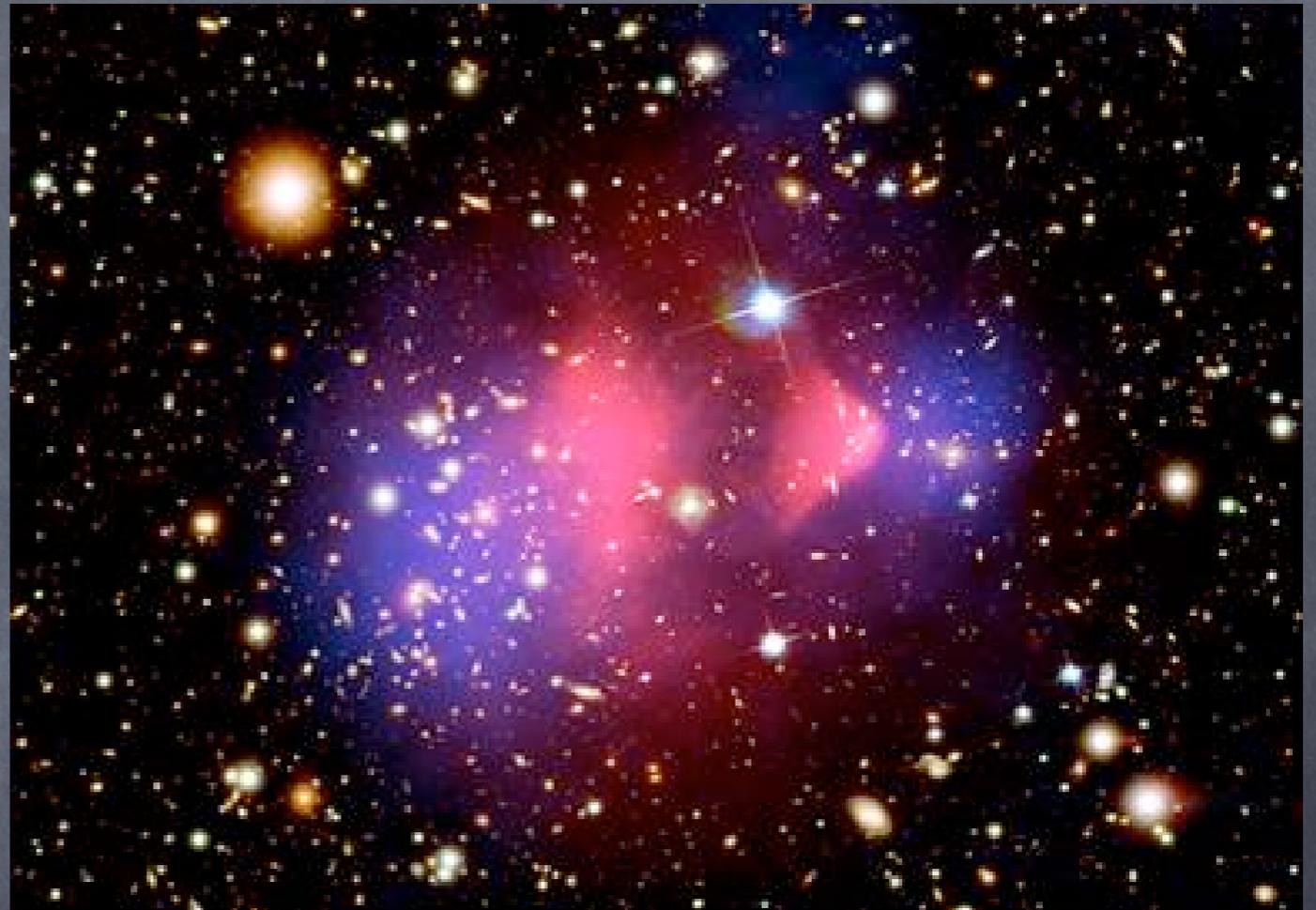
**→ Cosmology?**



# Things can get messy...



Mahdavi et al. (2007)



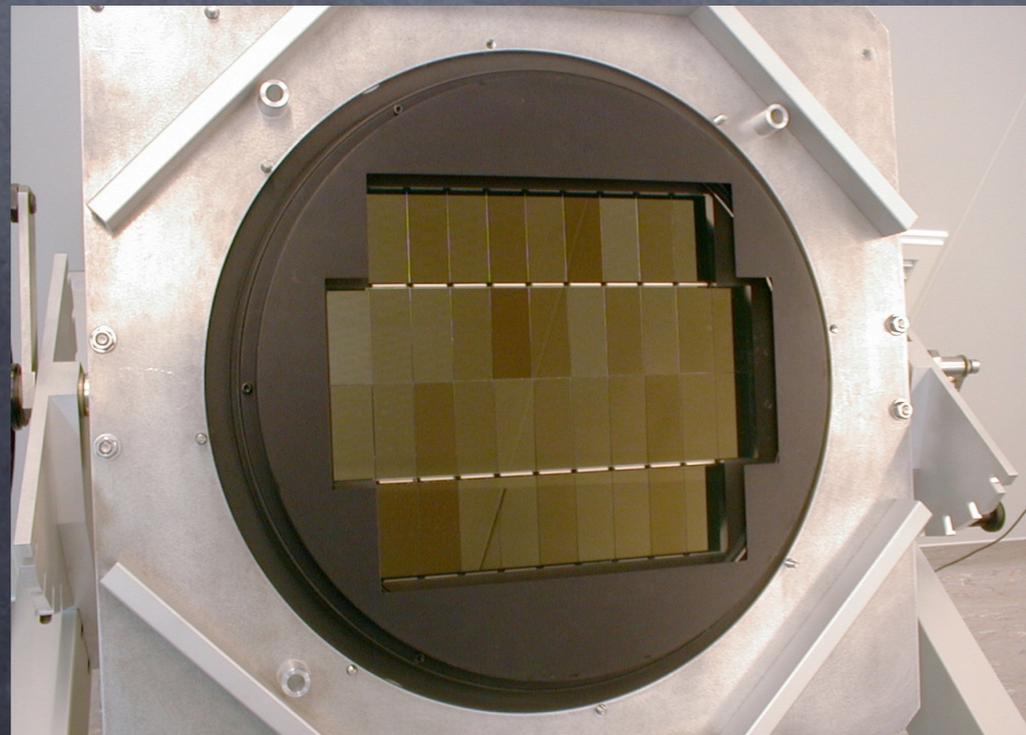
Clowe et al. (2006)

We need to account for these non-relaxed systems

# A revival of cluster lensing?

In 2000 the first cosmic shear detections were published, and cluster weak lensing seemed no longer “fashionable”.

But the measurement techniques and wide field imagers developed for cosmic shear are great for cluster work as well. Now we can reliably measure the lensing signal for large samples of clusters out to large radii!



# We need large( $r$ ) cluster samples

A sample of clusters with accurate weak lensing masses is important for the success of cluster abundance studies.

Requires large range in mass/redshift

Only a relatively small number of clusters have accurate weak lensing masses (but this is changing!)

Cluster mass profiles: comparison with other tracers

Learn about cluster physics

# Modern cluster lensing

Compared to earlier work we now have a better understanding of the source redshift distribution and can correct better for systematic effects.

As the sample sizes increase, the lensing analyses need to become more sophisticated: dealing with contamination by cluster galaxies, centroid errors, contributions from local and distant large scale structure, etc.

# Multi-wavelength comparisons

CCCP: “good for the masses”

The Canadian Cluster Comparison Project is a multi-wavelength study of 50 massive clusters of galaxies.

Henk Hoekstra (PI)

Arif Babul

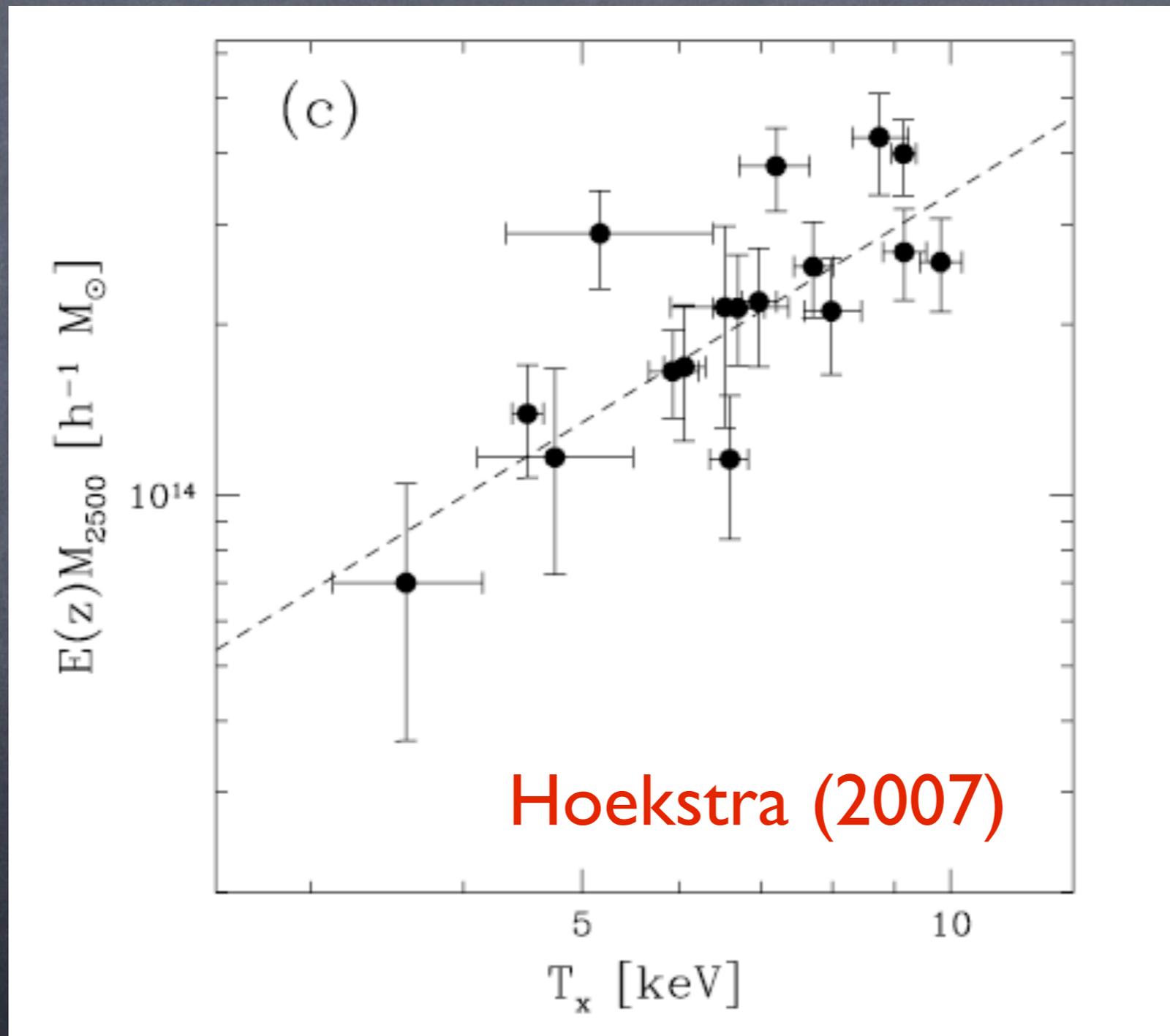
Andi Mahdavi

Chris Bildfell

Jon Sievers



# CCCP: comparison with X-ray

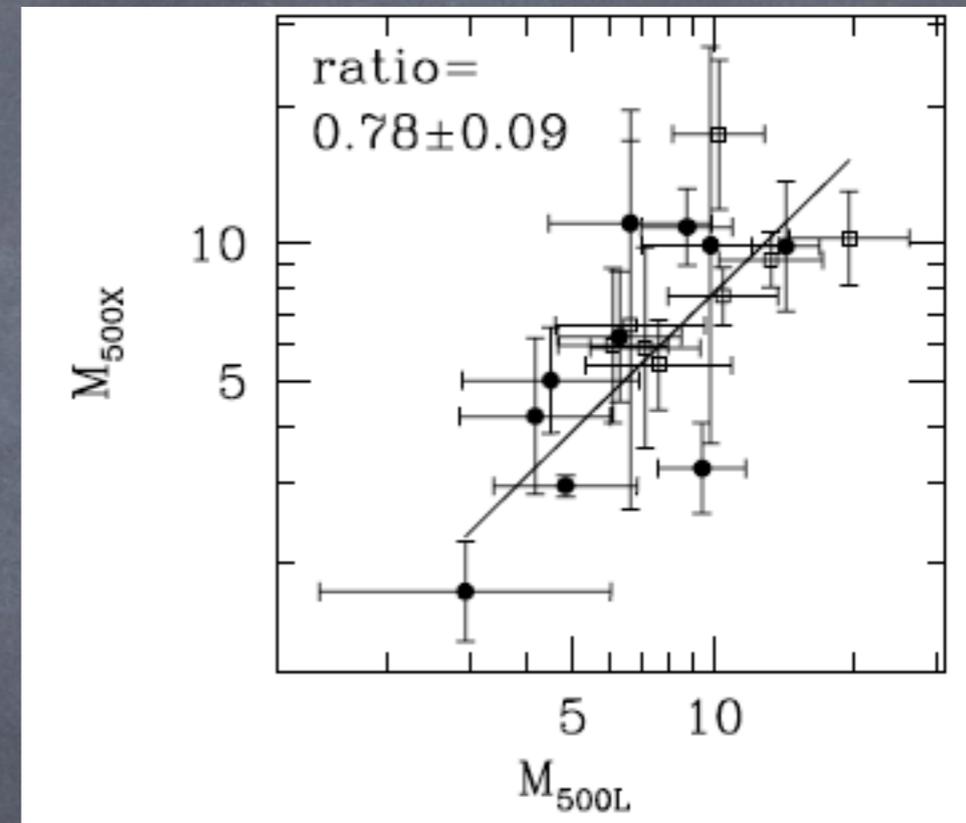
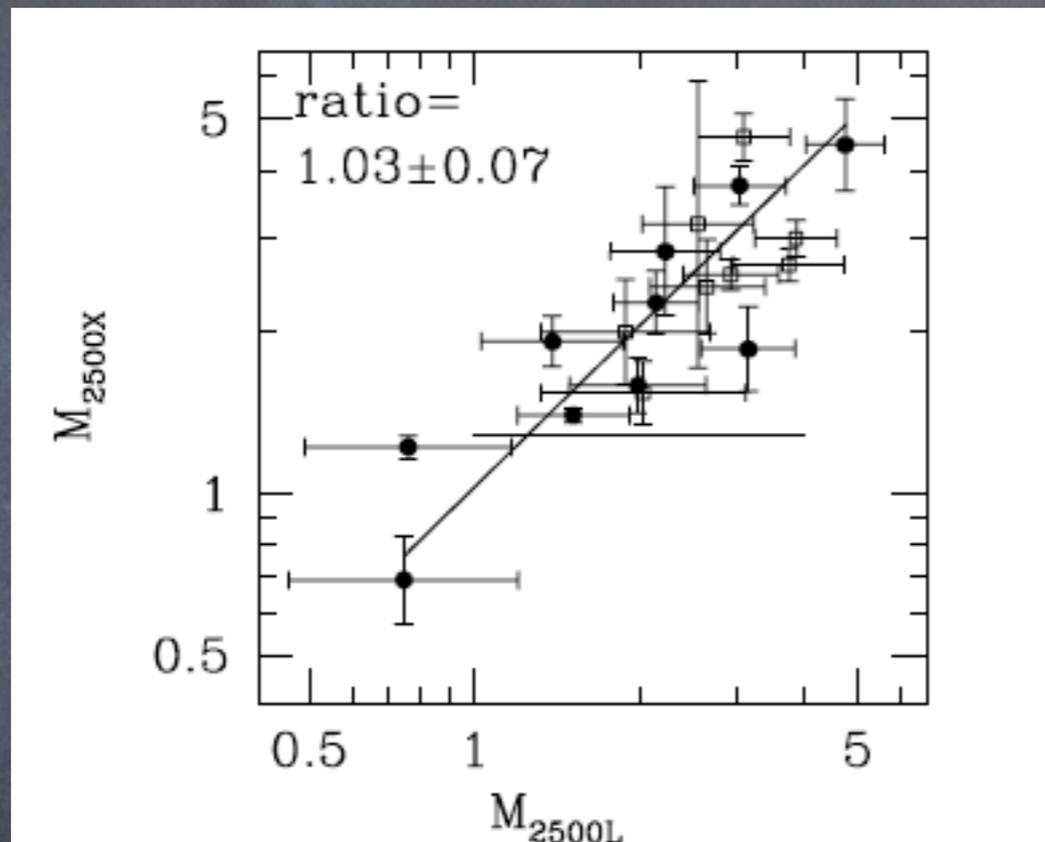


# Lensing vs. X-ray masses

$\Delta \approx 2500$

$\Delta \approx 500$

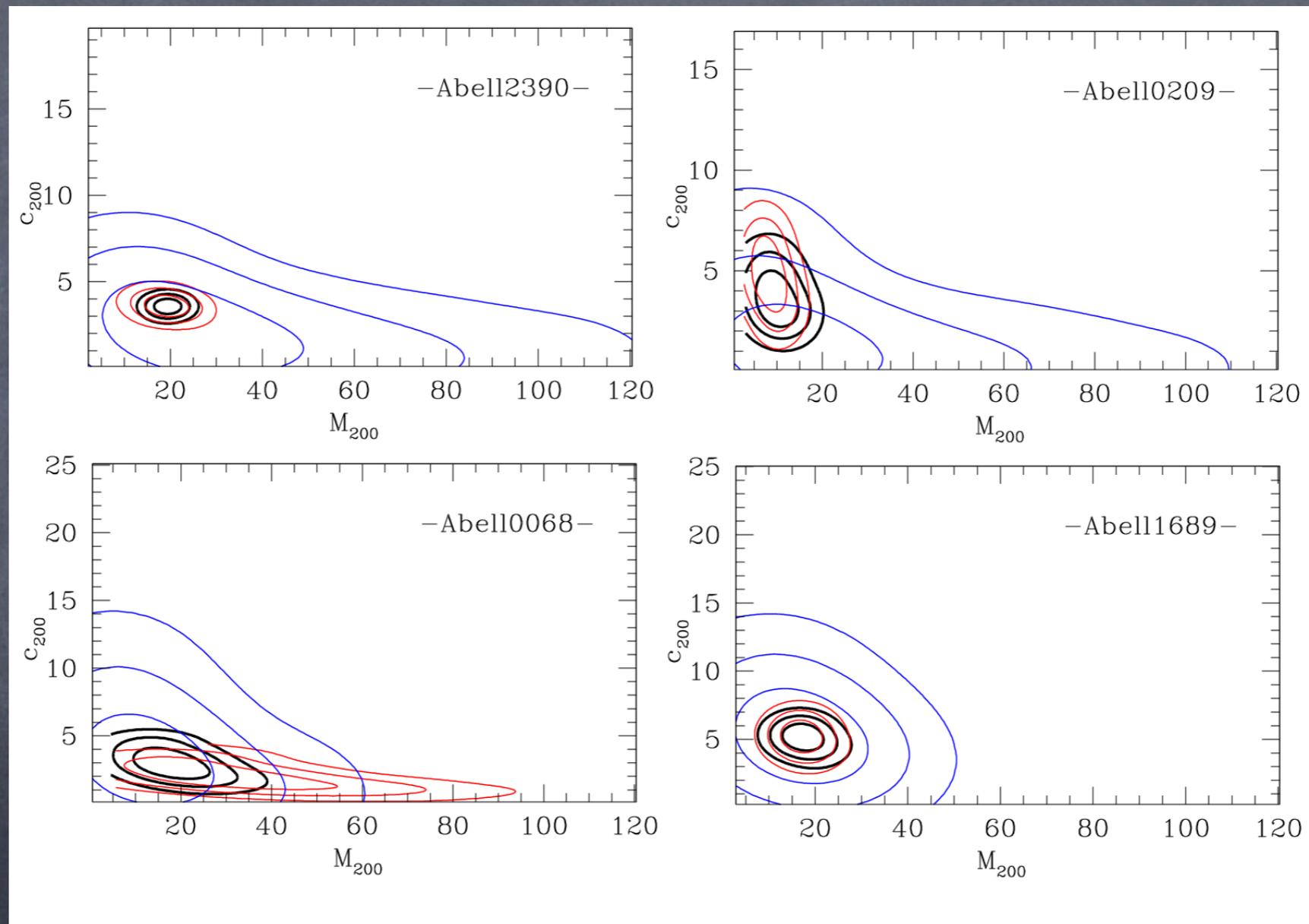
X-ray mass



Lensing mass

Mahdavi et al. (2008): at large radii the gas is not in hydrostatic equilibrium.

# Mass density profiles

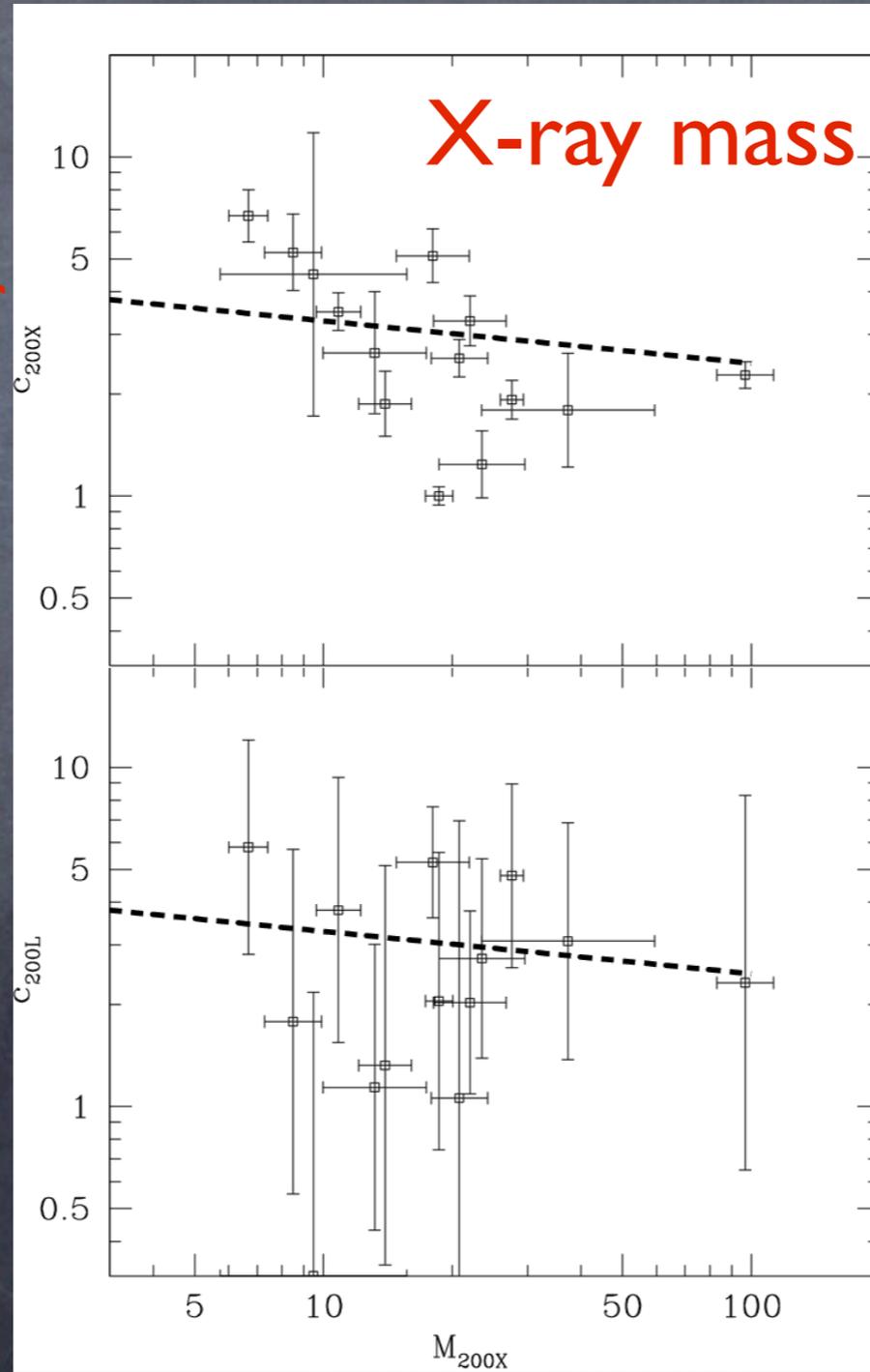


Joint X-ray + lensing model can help constrain profile parameters (Mahdavi et al., in prep)

# Mass density profiles

Correlated  
(X-ray)

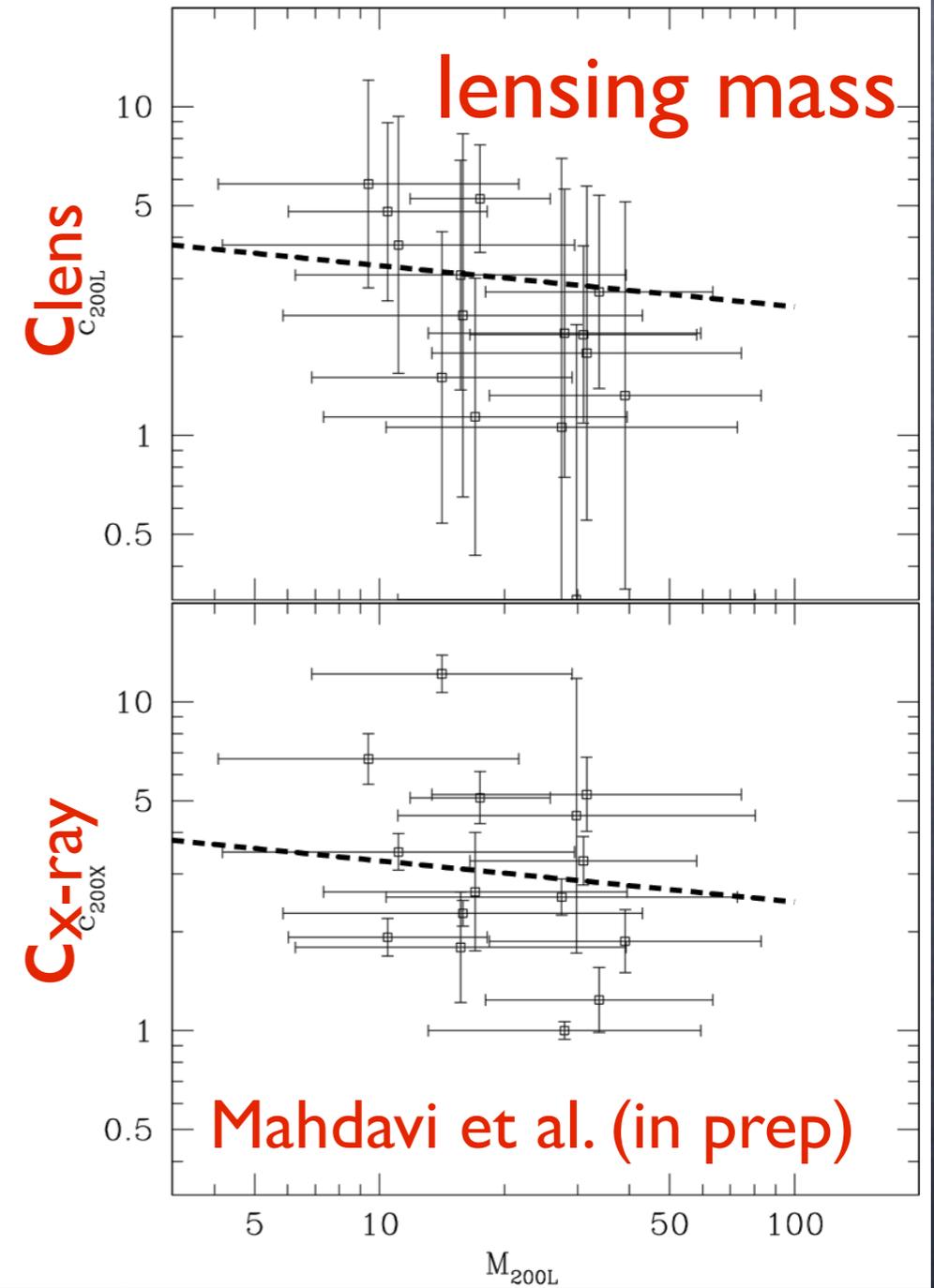
$C_{X\text{-ray}}$



Uncorrelated  
(X-ray + lensing)

$C_{\text{lens}}$

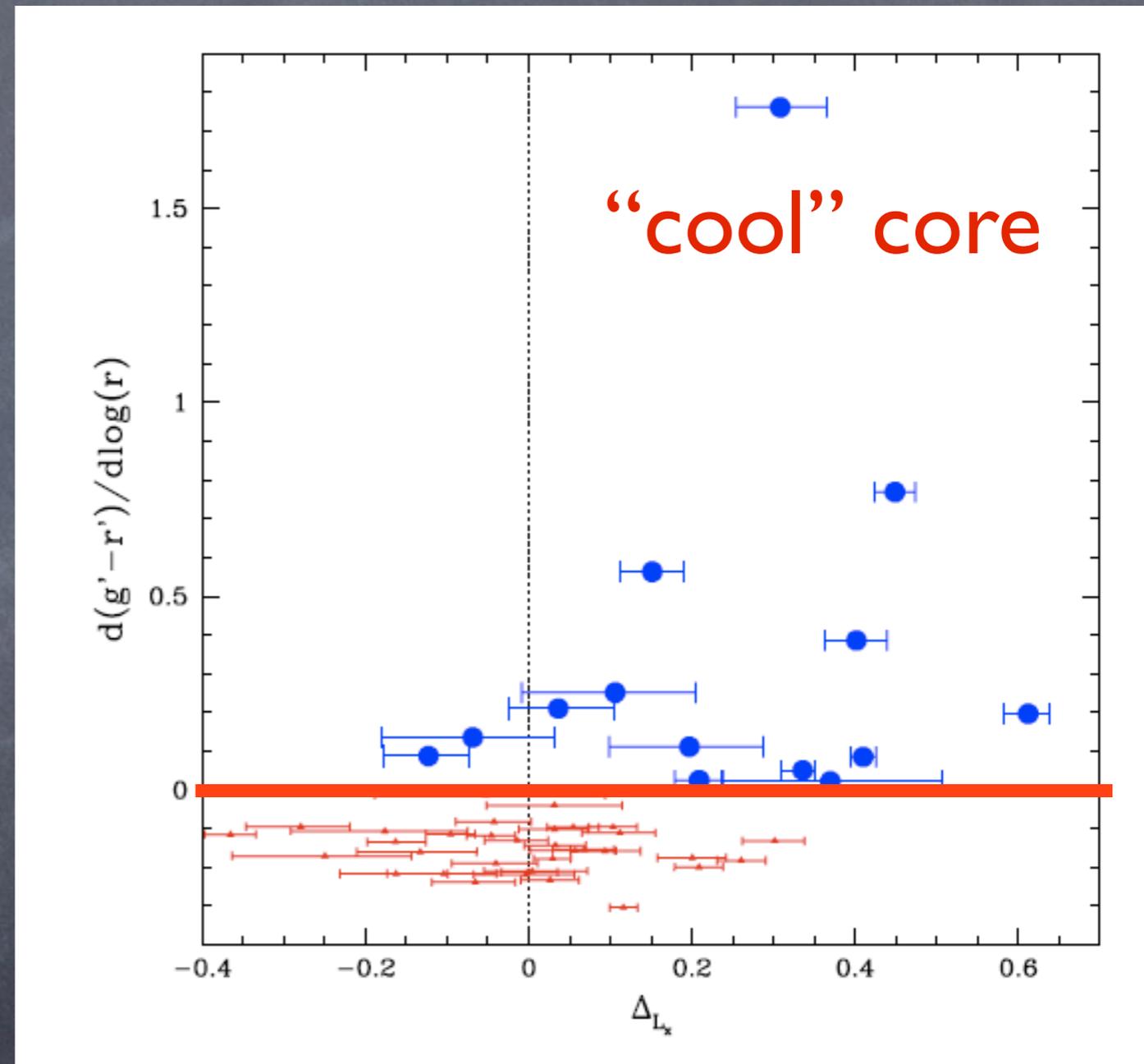
$C_{\text{lens}}$



# BCG properties

Pipino et al. (2009): Blue core systems detected in GALEX data show young stellar populations.

We see no “E+A” BCGs...



Bildfell et al. (2008)

# Limitations of weak lensing

The mass depends on the adopted centre!

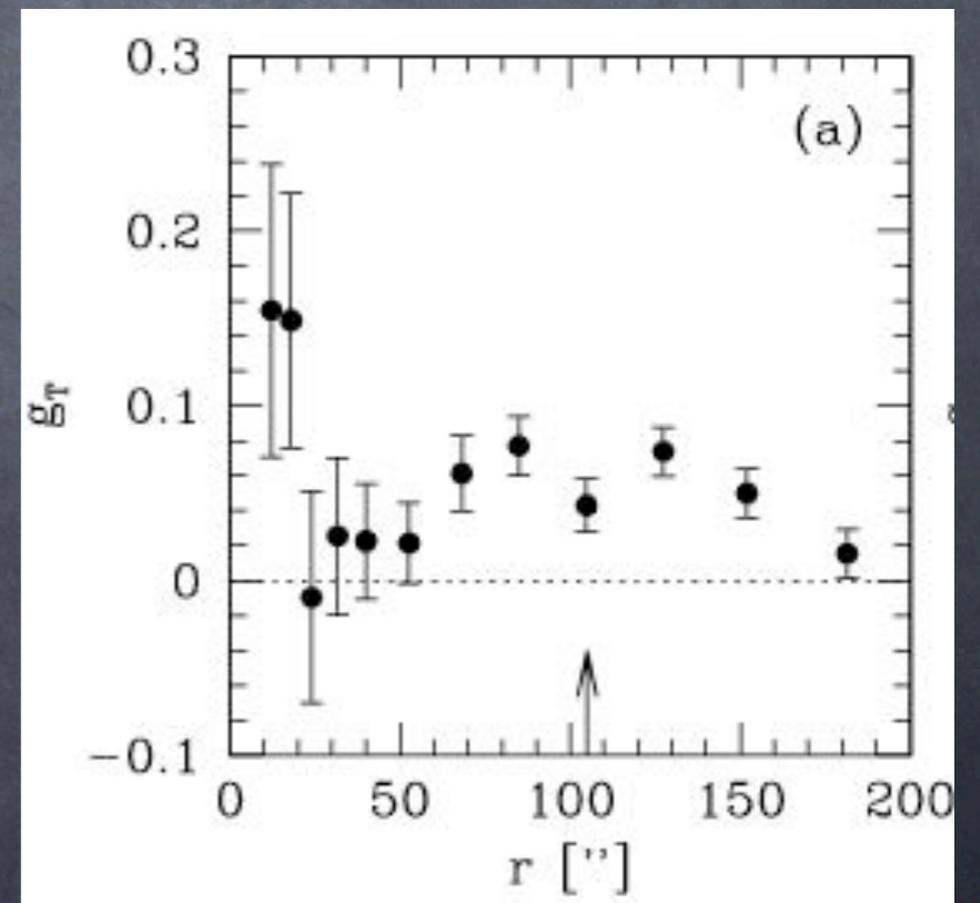
This is particularly problematic if we fit a simple parametric model and is made worse if there is substructure!

Use aperture masses (1-d masses):

- This can minimize the model dependence
- This reduces the sensitivity to the centroid

“mass contrast”

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



# Limitations of weak lensing

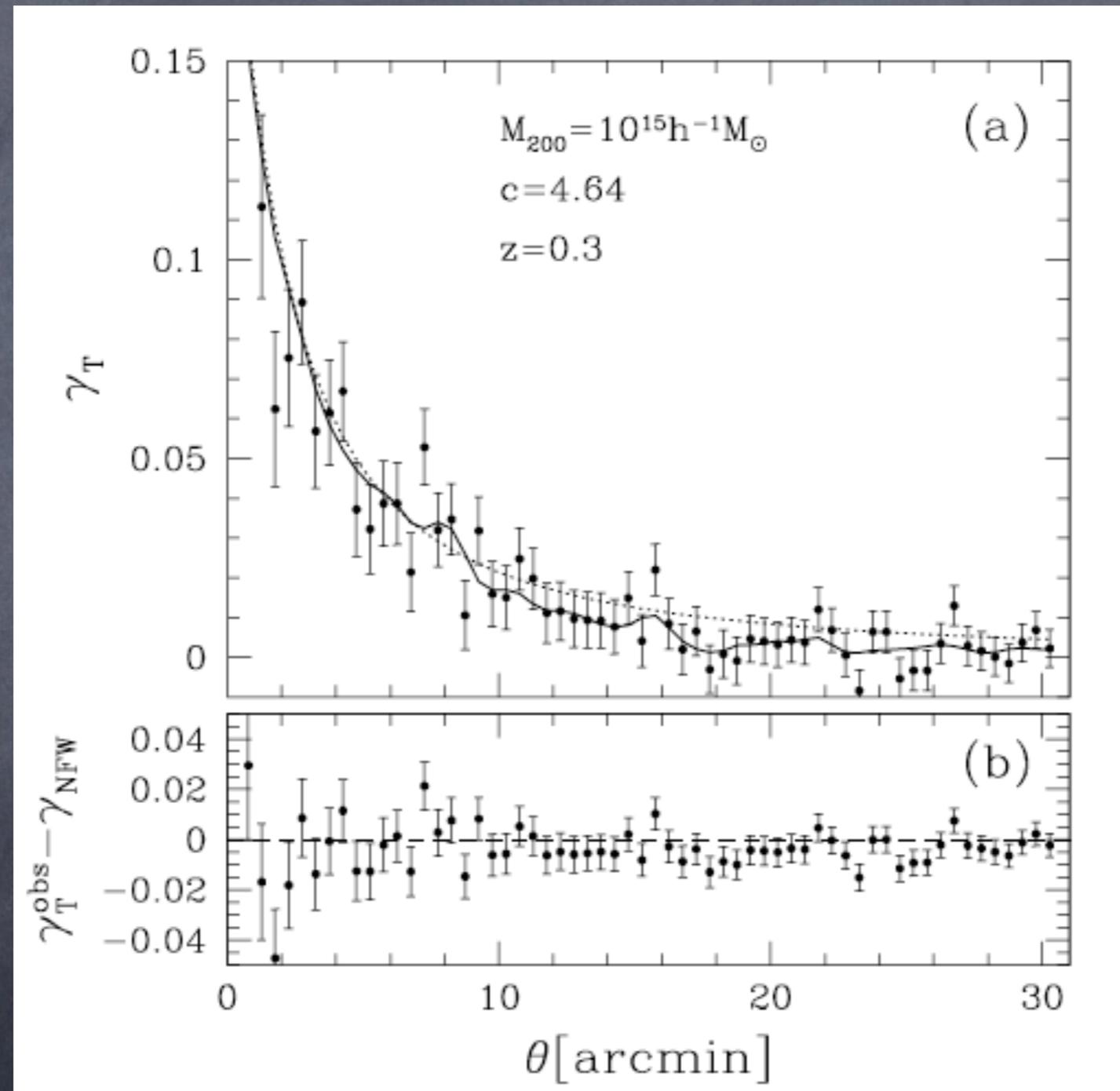
- Weak lensing gives the projected mass distribution
- The weak lensing signal depends on all matter along the line of sight
- The interpretation of the signal requires good knowledge of the source redshifts

Uncorrelated large scale structure is an additional source of noise

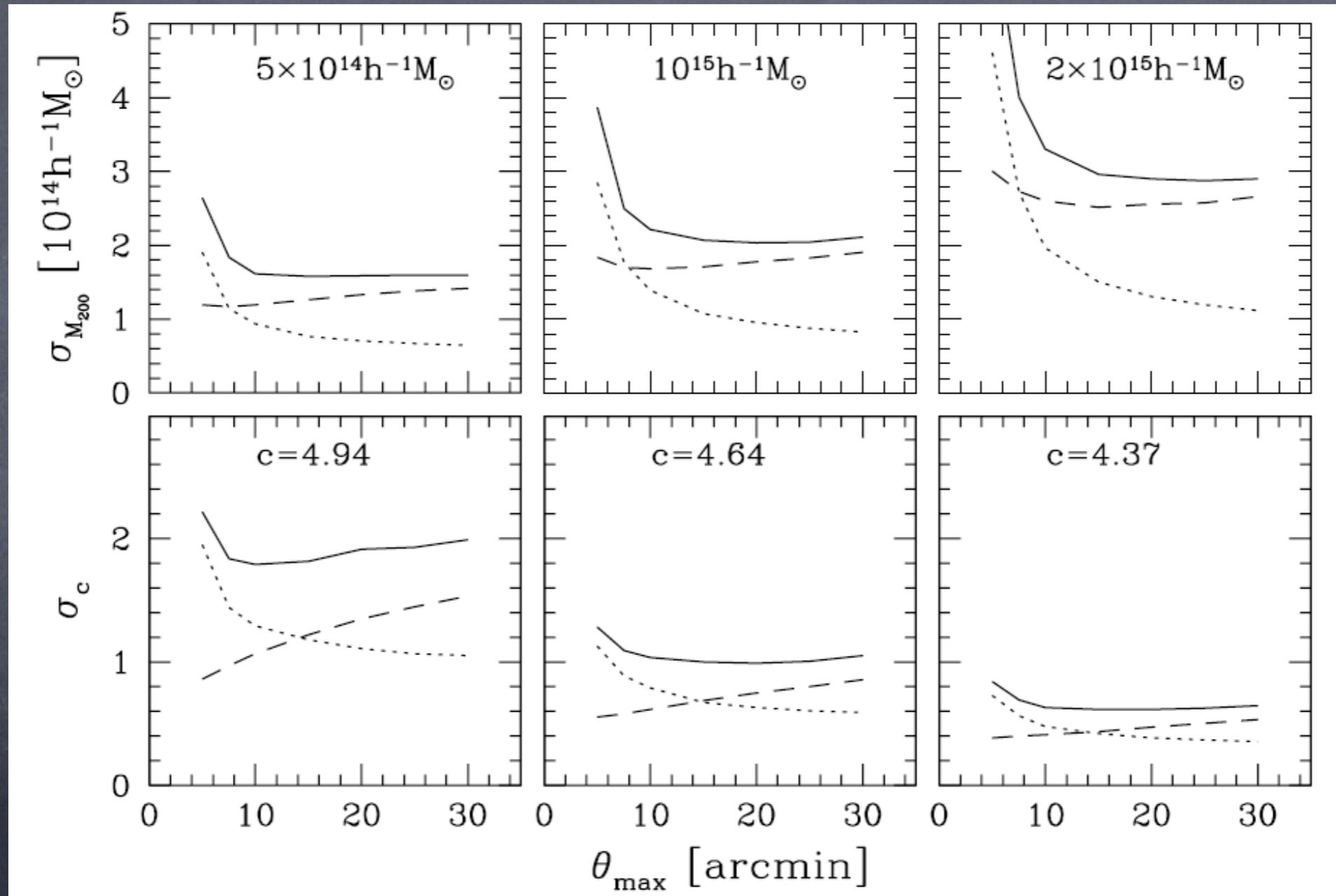


This limits the accuracy with which masses can be determined

# Effects of distant structures



# Effects of distant structures



# Effects of projections



White et al. (2002)

FIG. 5.—Zoom-in of one of our convergence maps showing two clusters that lie almost on top of each other in projection. *Left*: Full  $\kappa$  map. *Middle*: Portion coming from the  $100 h^{-1}$  Mpc slice at low redshift. *Right*: Portion coming from the  $100 h^{-1}$  Mpc slice at higher redshift. The regions shown are  $0''.3$  on a side.

Projections are also important when studying peaks in large scale weak lensing maps and comparing lensing masses to other mass proxies

# Conclusions

- Weak gravitational is the weighing scale of choice, but does have limitations! We need to take those into account.
- Key ingredient in cluster abundance studies.
- Comparison with other probes will provide new insights in cluster physics/formation.

Much progress expected in the coming years