Constraining Cosmology with Weak Lensing Of Galaxy Clusters

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collaborators

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Talk Overview

- Over view of methods of cross-correlation weak lensing

- New results from the SDSS MaxBCG Cluster catalog

  1. Stacked weak lensing mass profiles

  2. Modeling of weak lensing profiles

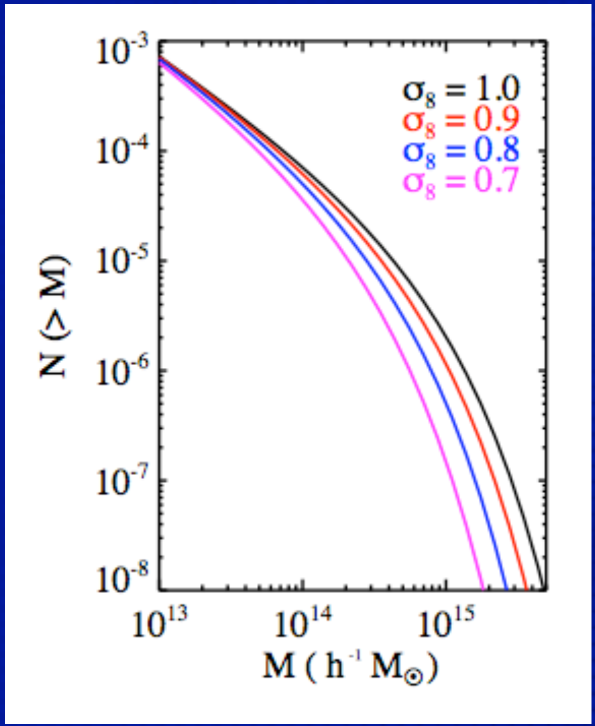
     Papers out next week

- Cosmological constraints using these methods for this Data-set as well as future data sets

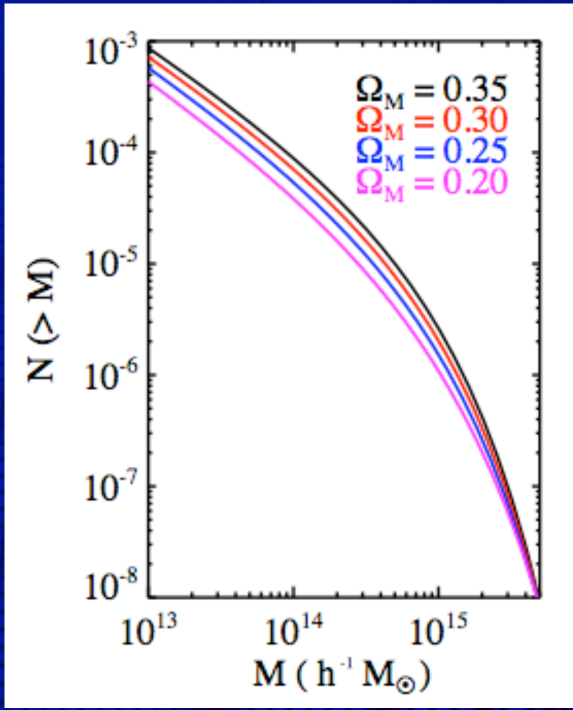
Cosmology from Clusters

Cluster number counts are a strong function of sigma_8 and Omega_M

Variation with Sigma_8



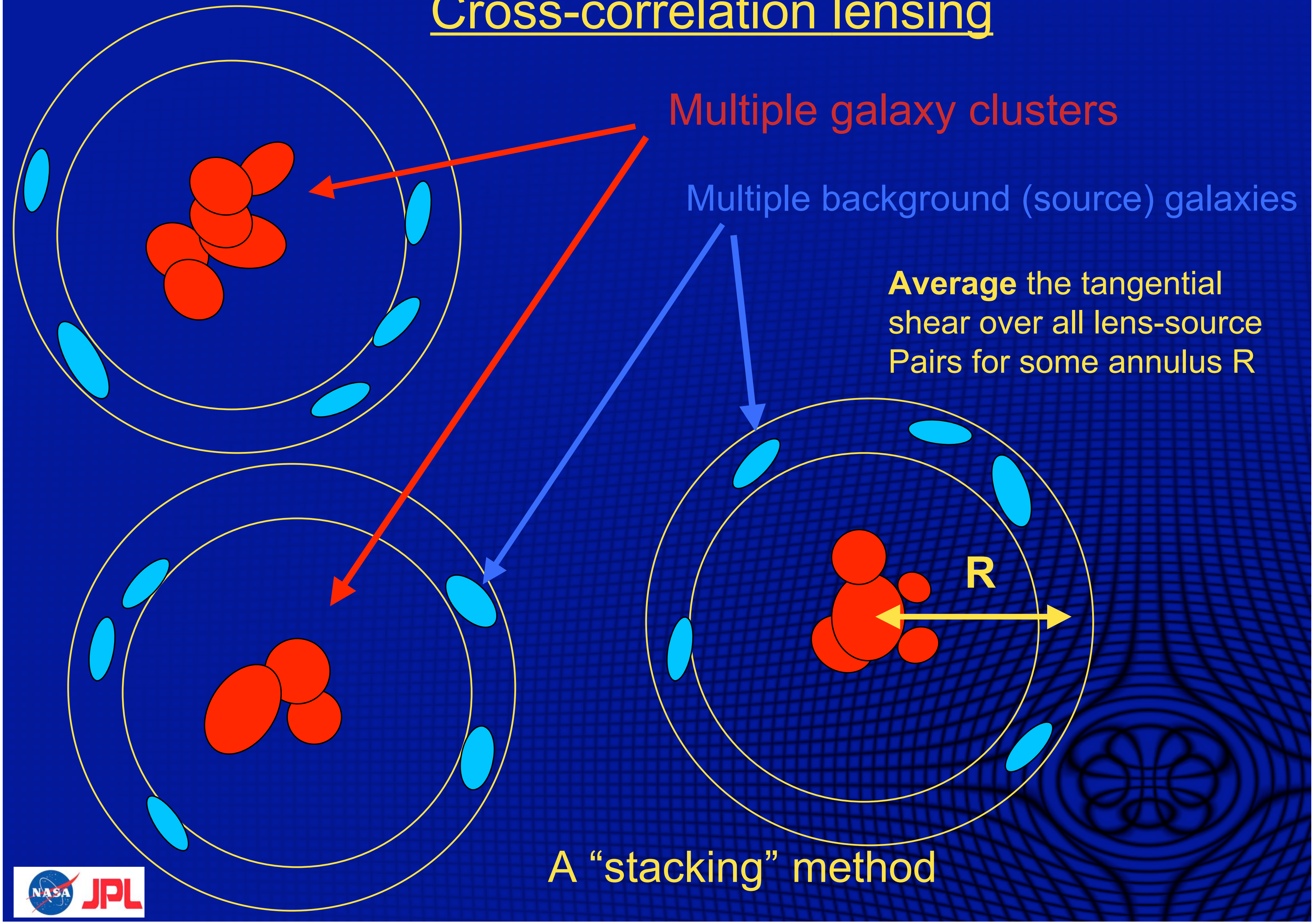
Variation with Omega_M



This requires that you can:

- **Find Clusters with an understandable selection function**
- **Calibrate the masses of the clusters -> weak lensing**

Cross-correlation lensing



What is measured with weak lensing around clusters?

Centered on galaxy clusters

$$\rho(r) = \bar{\rho}(1 + \xi_{cm}(r)) = \bar{\rho} + \Delta\rho(r)$$ 3D density

$$\bar{\rho} = \Omega_m \rho_{crit}$$ Average mass density of Universe

Lensing is only sensitive to the projection of mass

2D density $$\Sigma(R) \equiv \int dz \; \rho(r)$$ $$r^2 = R^2 + z^2$$

$$\Delta\Sigma(R) \equiv \bar{\Sigma}(< R) - \Sigma(R)$$ a non-local equation

And the observable tangential shear

Only Physics Here!

$$\Sigma_{crit}\gamma_T(R) = \Delta\Sigma(R)$$

Inversion methods

(Johnston et al. 2007)

differentiate this $\Delta\Sigma(R) \equiv \bar{\Sigma}(< R) - \Sigma(R)$

$$-\Sigma'(R) = \frac{2\Delta\Sigma(R)}{R} + \frac{d\Delta\Sigma(R)}{dR}$$

and this local equation is useful only because

Von Zeipel's formula (1908, from globular cluster work)

$$\Delta\rho(r) = \frac{1}{\pi}\int_r^\infty \frac{-\Sigma'(R)\ dR}{\sqrt{R^2 - r^2}}$$

An Abel type deprojection

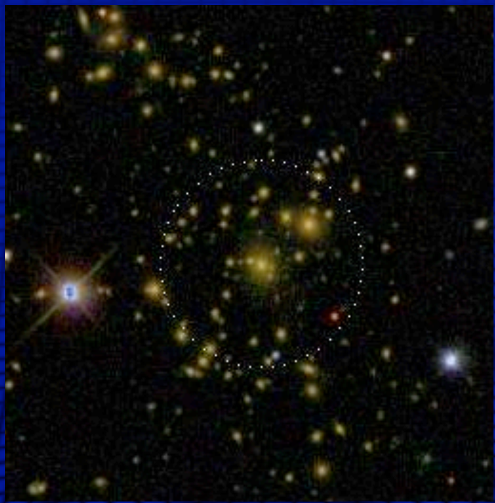
This assumes spherical symmetry which should be the case for a stacked sampled of clusters

There exists a similar formula for the mass profile M (r)

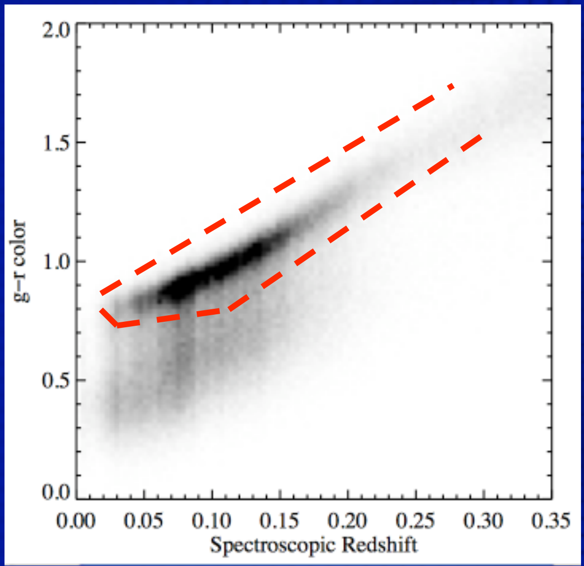
SDSS galaxy clusters - The MaxBCG catalog

A new red sequence optically selected clusters catalog from the SDSS data (Koester et al 2007). Colors give a good photoz (redshift estimate)

Largest galaxy clusters catalog to date by about a factor of 10
~500,000 group/clusters detected to lowest richness
~20,000 over 10^{13} solar masses



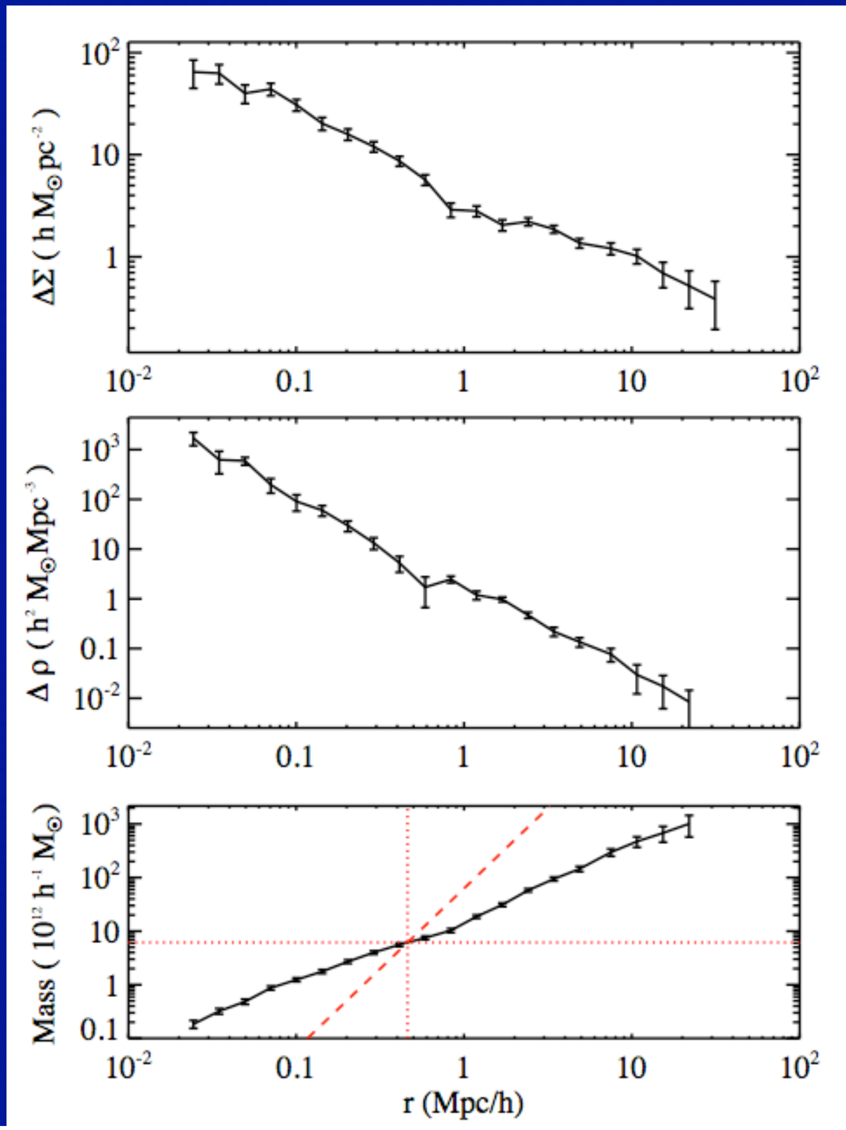
Redshift range z = 0.05 to 0.3 so probes the low z universe



All clusters has a Photometric redshift, z, and two Measures of richness:

- $\mathbf{N}_{200}$ - Number of galaxies
- L_{200} - Total luminosity

Lensing and Inversions Results for one richness bin



The measured shear

$$\Delta\Sigma(R)$$

The inverted quantities

$$\Delta\rho(r)$$

$$M(r)$$

Can obtain virial masses

NFW Halos and virial masses

Universal halo profiles are a generic prediction of CDM simulations (Navarro, Frenk & White 1997)

$$\rho(r) = \frac{\rho_s}{r/r_s(1 + r/r_s)^2}$$

A two parameter model, usually re-parametrized by M_{200} or

$$M = M_{200} = M(r_{200})$$

r_{200} is radius at which $M(r_{200}) = 200\rho_{crit}\frac{4\pi}{3}r_{200}^3$

And concentration parameter $c = r_{200}/r_s$

Halo model decomposition

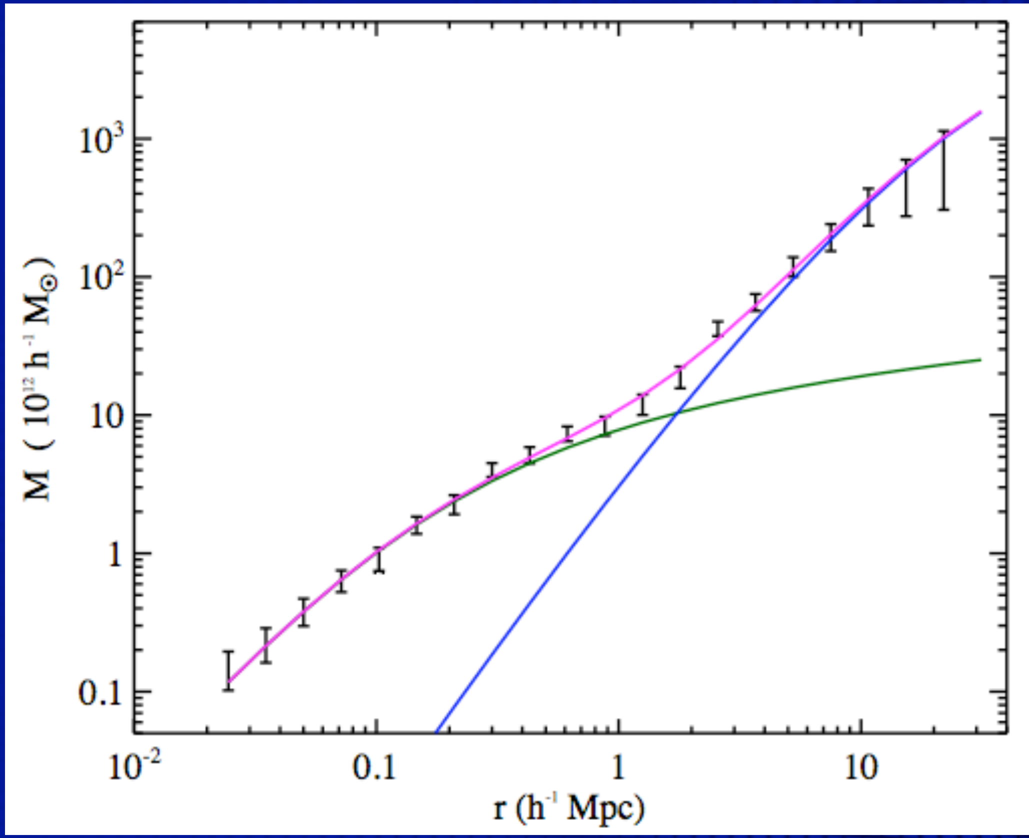
Three parameter fit

One halo term

Two-halo term

$$\Delta\rho(r, M, c, b) = \rho_{halo}(r, M, c) + b\ \rho_{crit}\Omega_m\ \xi(r)$$

$$M(r, M, c, b) = M_{halo}(r, M, c) + b\ \rho_{crit}\Omega_m\ J_3(r)$$



$$J_3(r) = 4\pi \int_0^r dr\ r^2 \xi(r)$$

The data seems to Be well fit by the Halo model

$$\rho_{halo}(r, M, c)$$

Is predicted from Simulations to be a Universal 2-parameter Function - The NFW profile

A more complicated model for the profile

$$\Delta\Sigma(R) = \frac{M_0}{\pi R^2}$$

1) A point-mass term to model stars

$$+ \, p \, \Delta\Sigma_{NFW}(R \,|\, R_{200}, c)$$

2) The NFW profile for correctly centered clusters

$$+ \, (1-p) \, \Delta\Sigma_{NFW}^{NC}(R \,|\, R_{200}, c, \sigma_G)$$

3) The NFW convolved with a Gaussian to model the clusters with "Non-central" or miscentered clusters

$$+ \, B \, \Delta\Sigma_L(R)$$

4) The two-halo term for the contribution of neighboring clusters (halos)

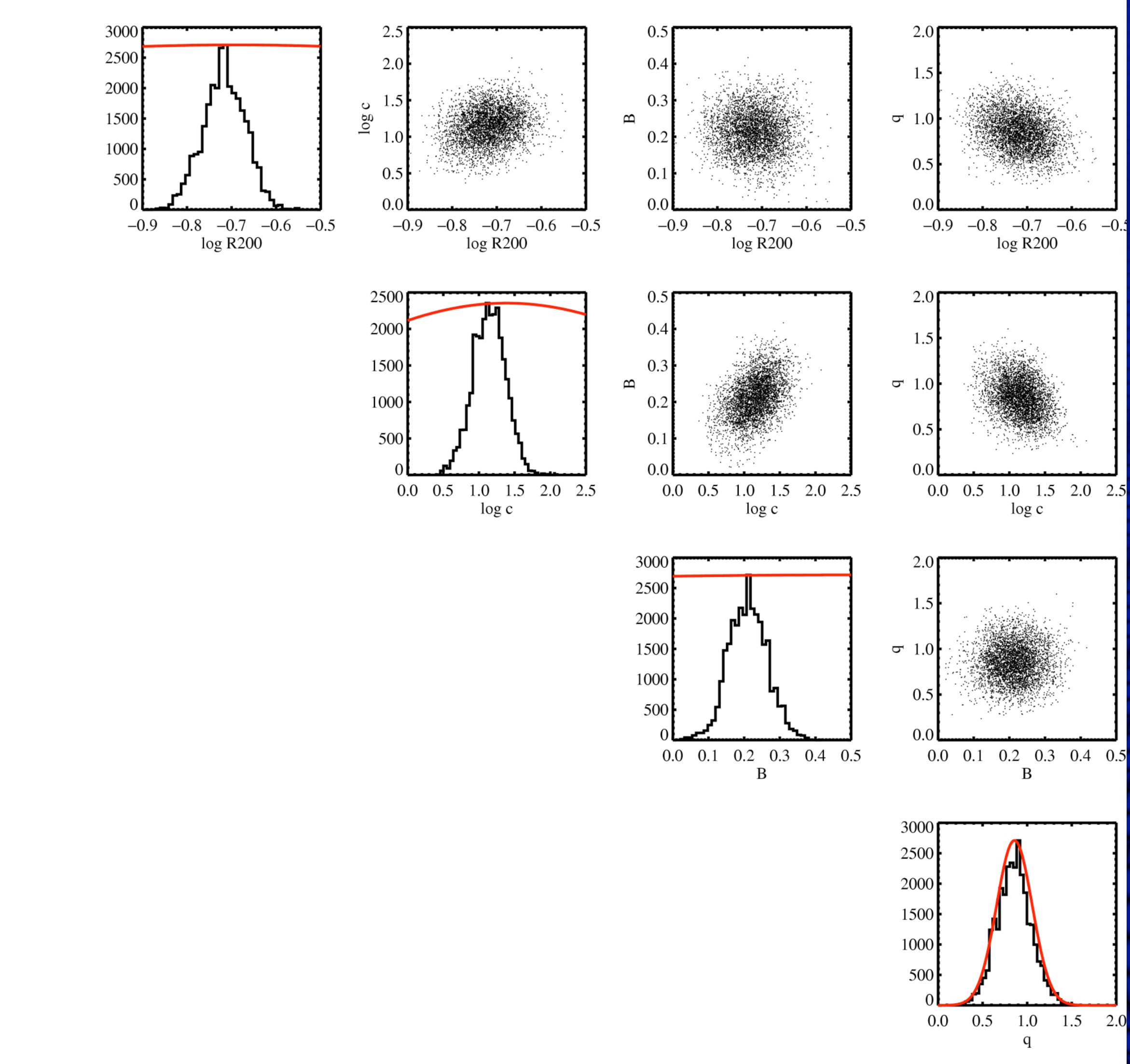
This is a 6 parameter model!

$$B \equiv \Omega_m \, \sigma_8 \, b(M)$$

There are also various other corrections needed

Profiles are fit with an MCMC fitting routine

MCMC chains

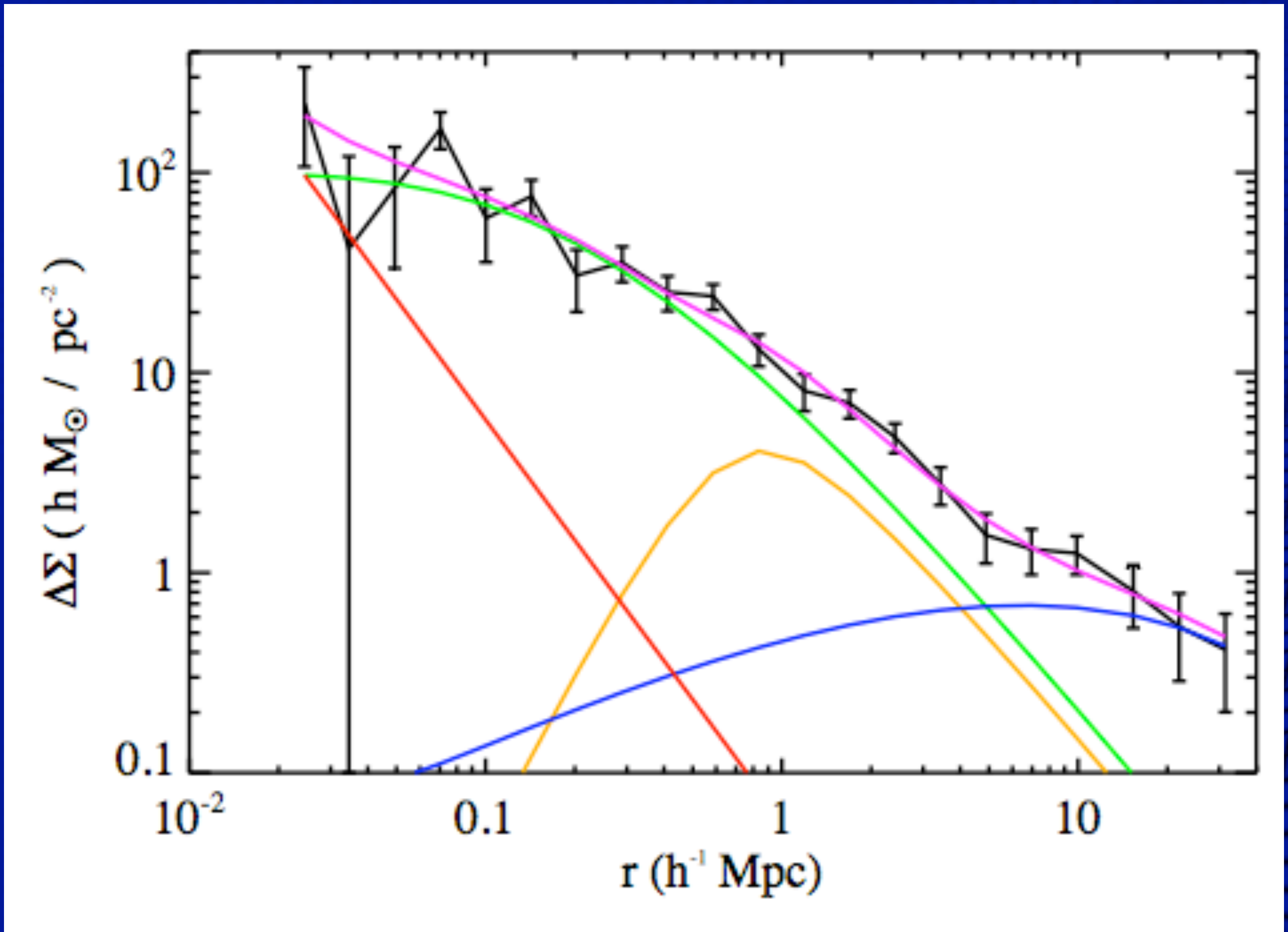


Red is prior

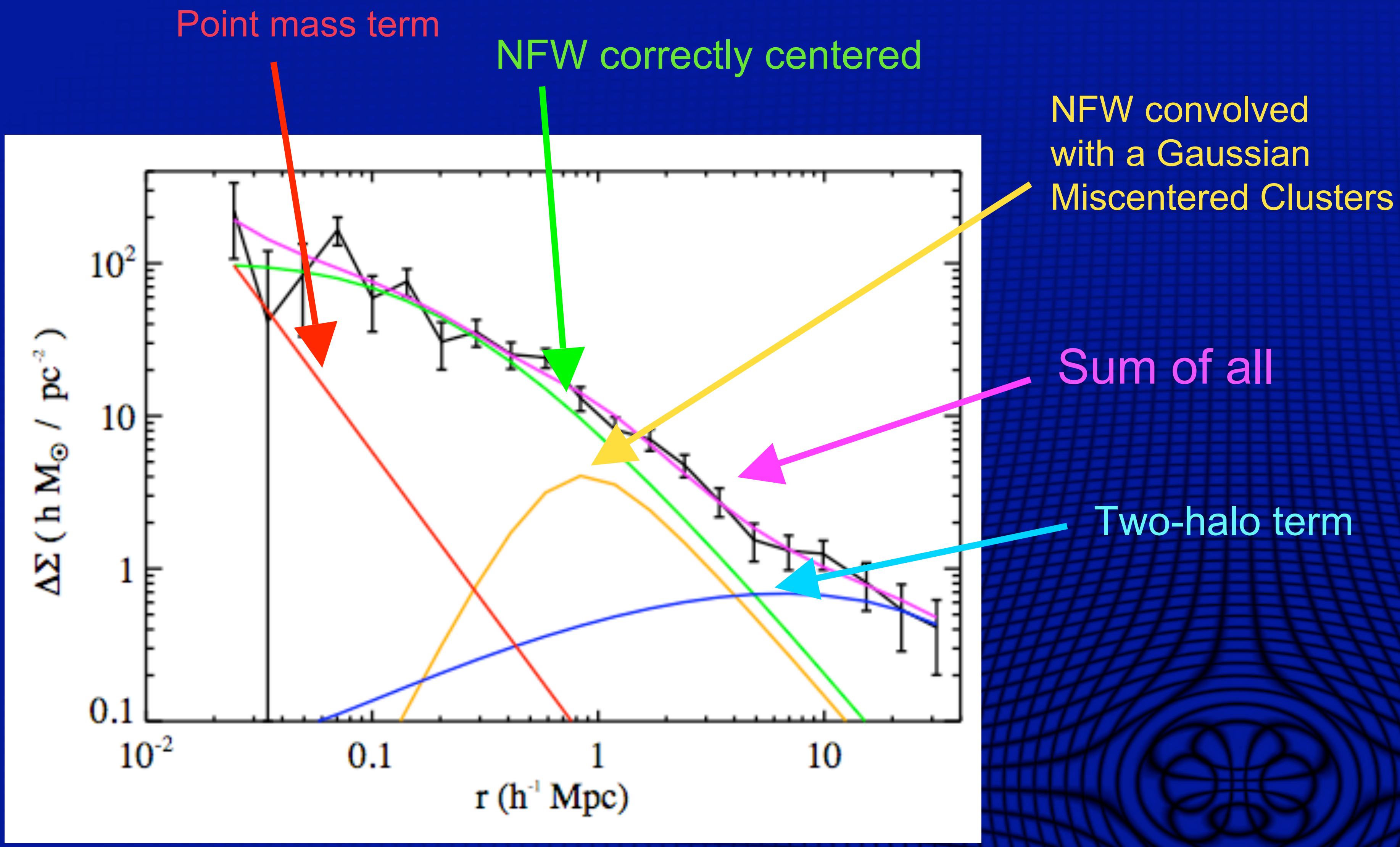
Correlation is minimal

No major degeneracies

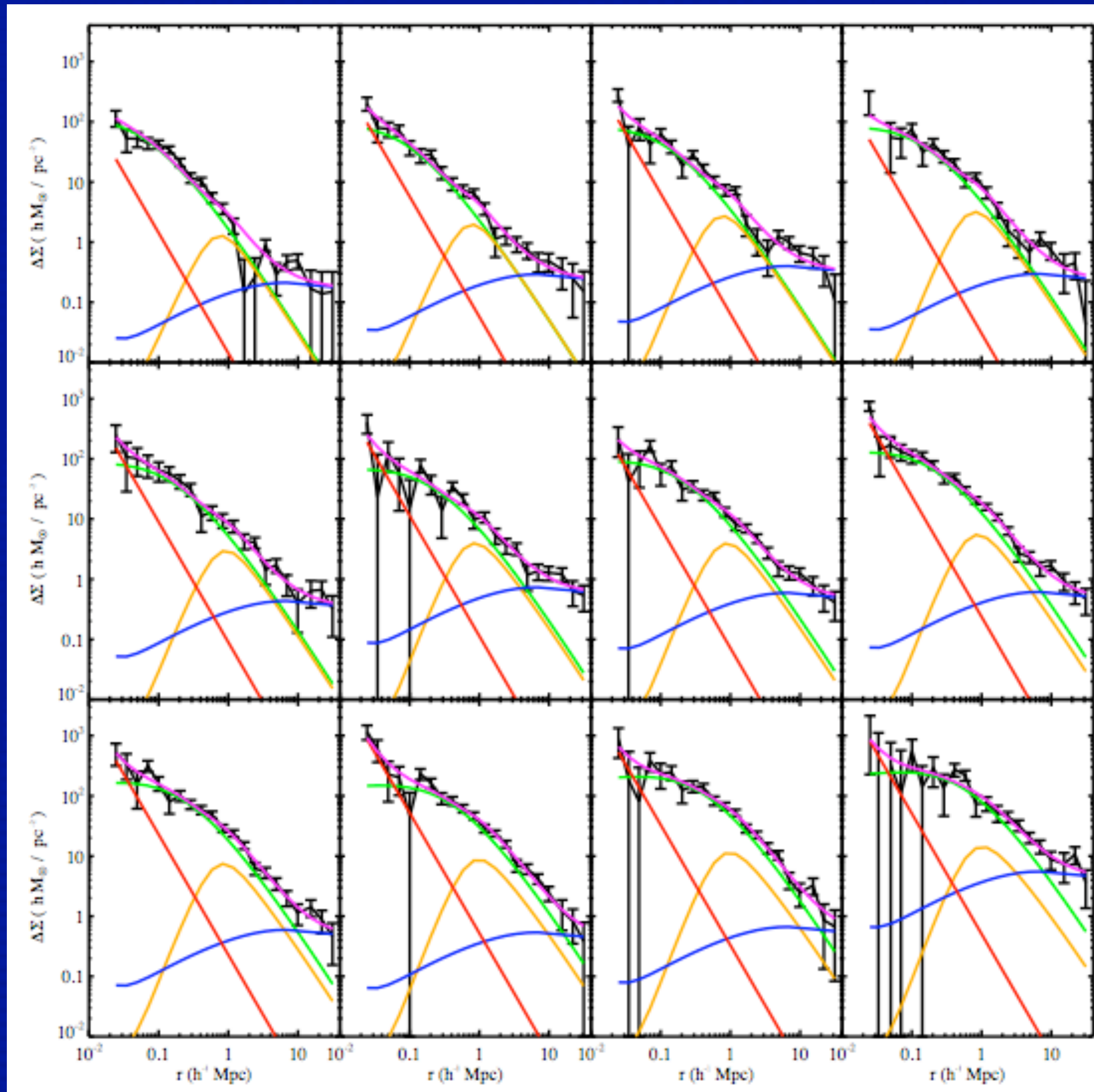
6-parameter fit for one richness bin



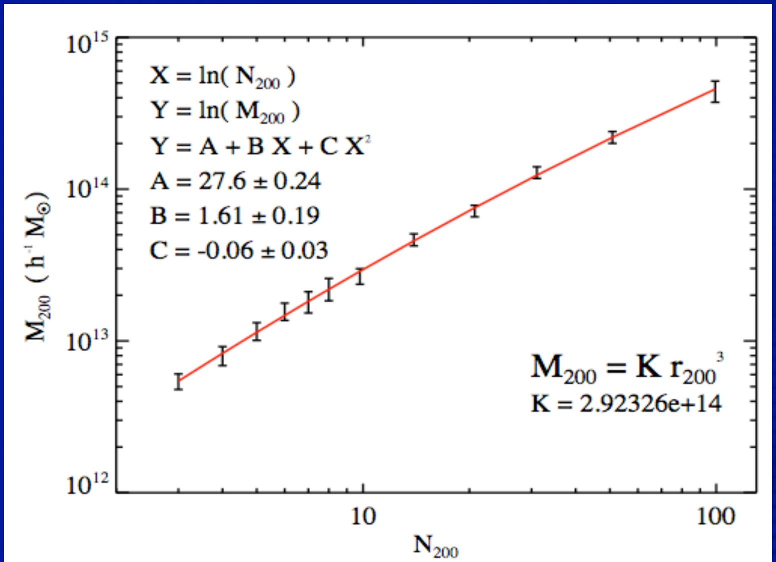
6-parameter fit for one richness bin



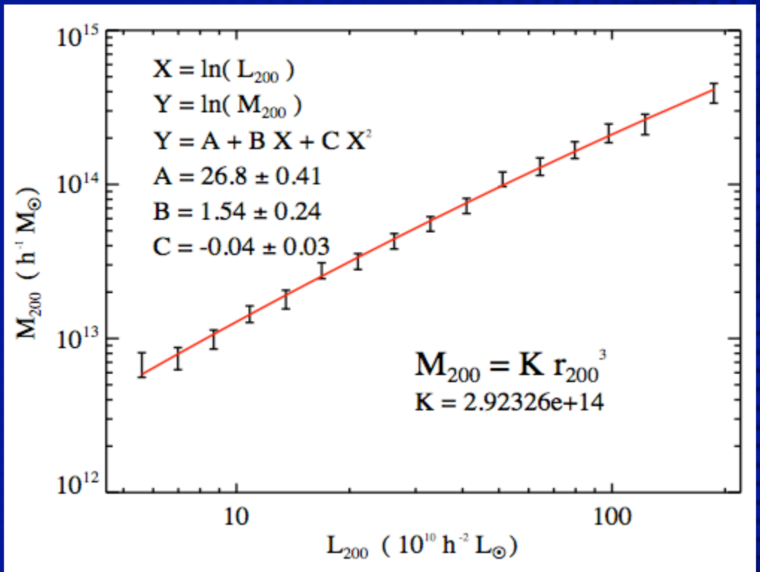
Halo fits for the 12 N200 richness bins



Mass-richness relations



N_{200} binning



L_{200} binning

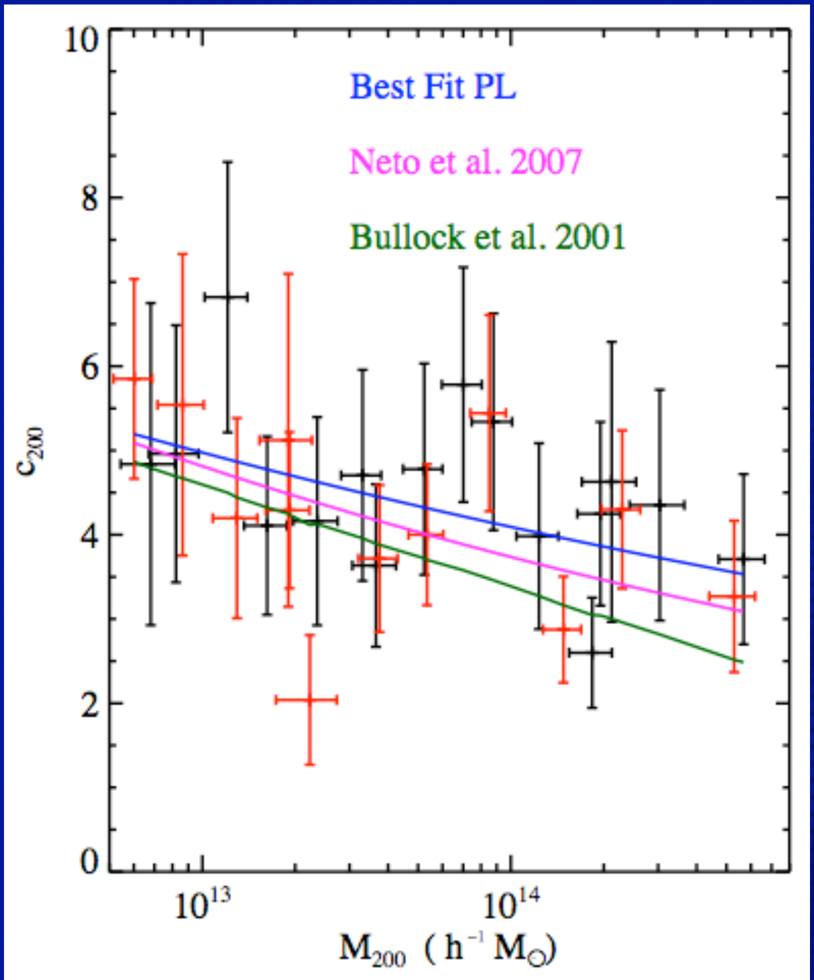
These mass-richness relations allow a mass calibration of the entire sample

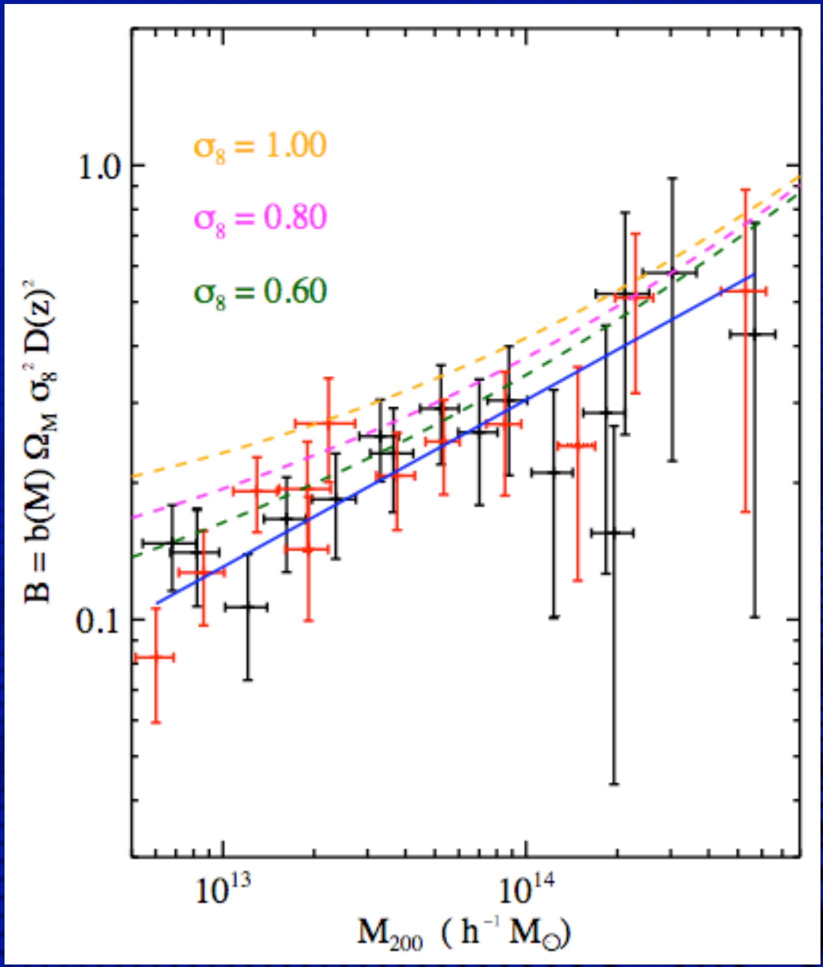
NFW parameter scaling relations

Halo Concentration

Black is L_{200} bins
Red is N_{200} bins

Bias or Amplitude
of two-halo term





The drop off with mass is a generic prediction of CDM structure formation

Increase with mass also A generic prediction of CDM structure formation

Dynamical measures of mass

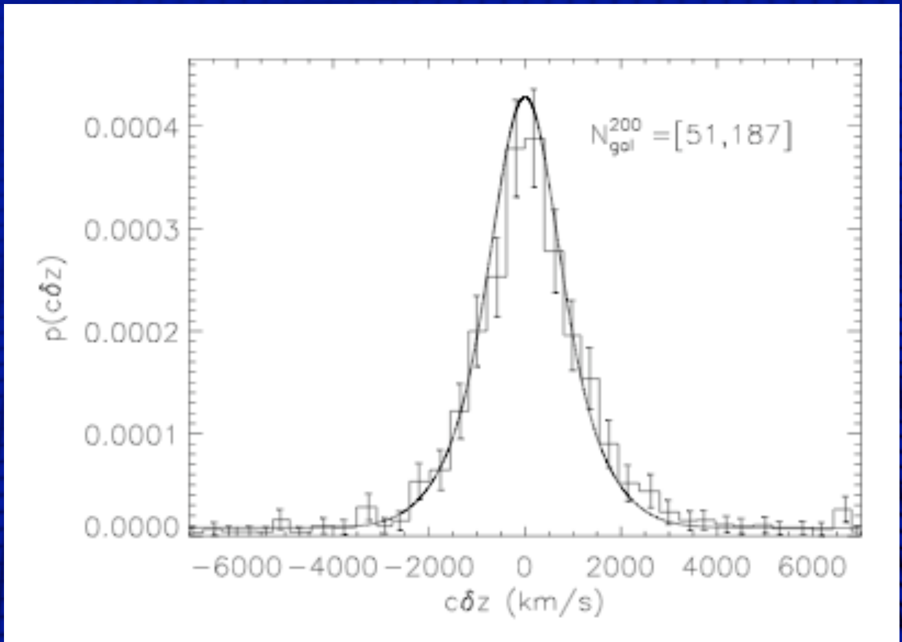
Our main alternative way of measuring mass

Stack the velocity differences of satellite galaxies around
The BCG

Project lead by Tim McKay and
student Matt Becker (Michigan)

Simplest Method: fit a Gaussian
plus a constant

$$P(v) = C + A\exp(-0.5\ (v/\sigma)^2)$$



However there is likely to be a spread of mass and so a spread in sigma

Lensing versus dynamical mass measurements

Velocity dispersion converted to mass with Evrard et al. 2007 formula

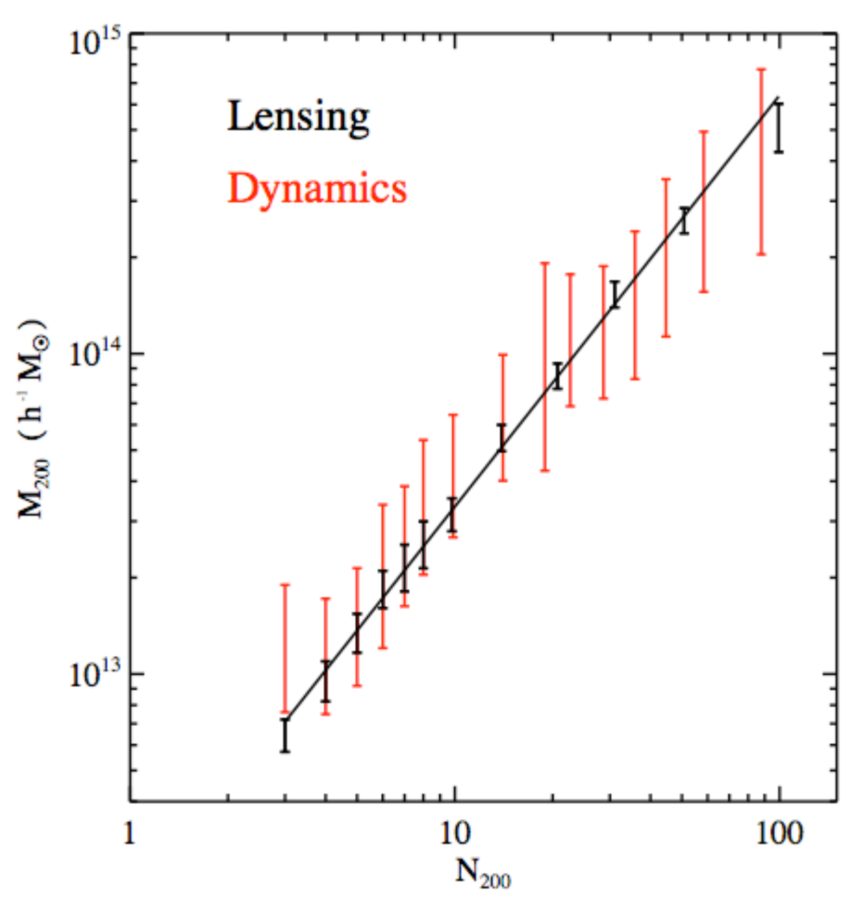
$$M_{200} = \frac{10^{15} M_{\odot}}{h(z)} \left[\frac{\sigma}{1084\ km/s} \right]^{2.977}$$

"Universal" relation from DM sims

Weak lensing masses and dynamical masses in agreement to within 20-30%

Any differences can be attributed to any of :

- velocity bias
- velocity-to-mass error
- photoz error
- shear calibration error
- mass modeling error
- ????



Ways of constraining cosmology with clusters

- The cluster mass function

  the most common method

Small scale lensing signal

Large scale lensing signal

- Using the lensing data to remove the bias

And directly probe the growth of the linear correlation function

Measuring both the cluster-mass correlation
Function and the cluster-cluster correlation function
Allows for a direct measurements of

$$\Omega_m \sigma_8 \; D(z)$$

The linear growth factor

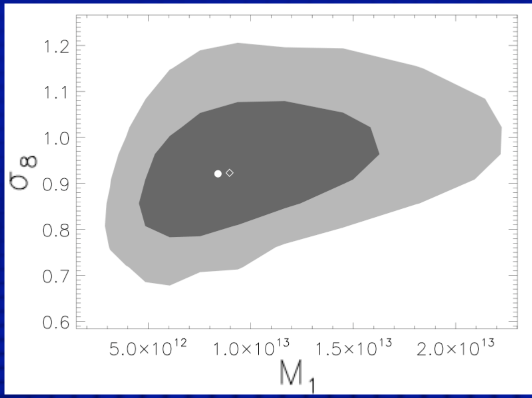
- Measuring baryon wiggles in the cluster shear signal

Measuring the mass function

Harder than you think

Requires understanding:

- Mass richness calibration
- Scatter in mass richness relation
- Purity and completeness of sample
- The relationship between "halos" and "clusters"



Eduardo Rozo et al. 2007 astroph-0703571 analysis of SDSS clusters
Uses HOD formalism and mock catalogs to marginalize
Over many nuisance parameters regarding the selection function

Main result is $\sigma_8 = 0.92 \pm 0.1$ With flat+CMB+SN priors

The first result does not include mass-richness relation from lensing
Lensing addition is forthcoming, expect error 0.03 on σ_8

Large scale cosmological constraints

Weak lensing of clusters gives you a measure of

$$\Omega_m \; \xi_{cm}(r, M, z) = \Omega_m \; b(M) \; \xi(r) \; D^2(z)$$

Cluster auto-correlations gives you a measure of

$$\xi_{cc}(r, M, z) = b^2(M) \; \xi(r) \; D^2(z)$$

Can rearrange these two equations to separate scale dependence from Mass dependence

$$\frac{(\Omega_m \; \xi_{cm}(r, M, z))^2}{\xi_{cc}(r, M, z)} = \Omega_m^2 \; \xi(r) \; D^2(z)$$

Should be mass independent and measures the linear growth factor D(z)

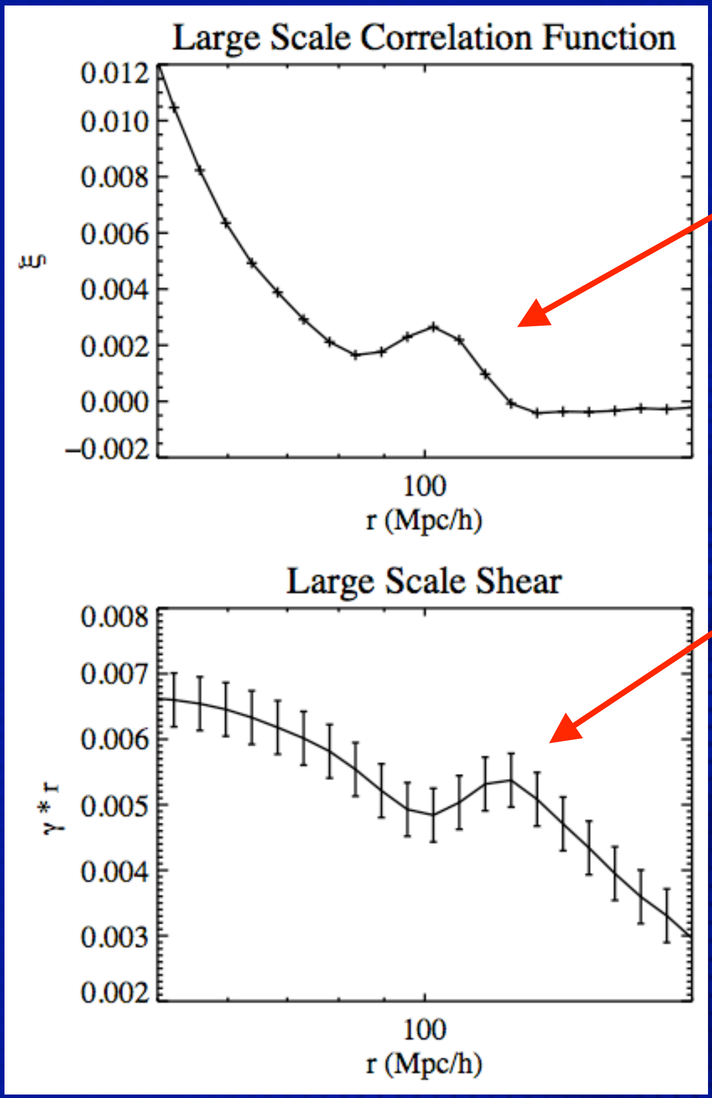
$$\frac{\xi_{cc}(r, M, z)}{\Omega_m \; \xi_{cm}(r, M, z)} = \frac{b(M)}{\Omega_m}$$

Should be scale independent

Both of these constrain cosmology

Main weakness is that it
Will have large sample variance

Detecting Baryonic features with Weak Lensing



The baryon bump

The shear profile by itself a less prominant BAO Bump and More difficult to measure

SDSS has good Measurements to 30 Mpc/h

Large area surveys like LSST DUNE, SNAP will be able to Measure this scale length

Edgar Shaghoulian working out MCMC predictions

Conclusions

• New weak lensing techniques solving an old problem of how to calibrate the masses of clusters

• Exciting SDSS cluster science results are forthcoming which will provide a strong consistency test on current LCDM cosmological models

• Near term and future missions will have the ability to exploit these methods much further and should provide a new way to probe dark energy

- SNAP
- DUNE
- LSST

The End