Statistics of the Largest Structures

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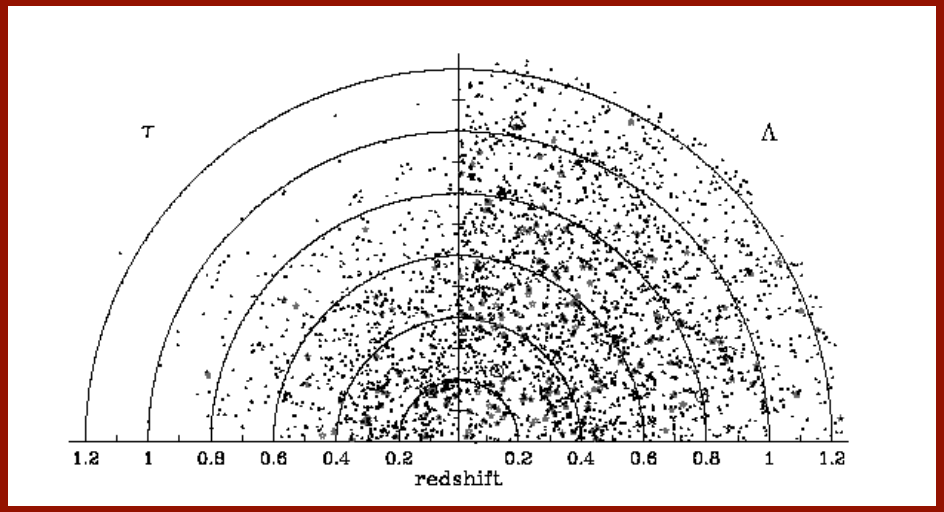
Outline

- Clusters: Signposts of Large Scale Structure
  - Senistive to cosmology
  - Galaxy formation, evolution
- MaxBCG-SDSS
- Cosmology and Mass Calibration
- Information from Galaxy Populations

Clusters and Cosmology



$$n(M,z) = \frac{d\ln\sigma^{-1}(M,z)}{d\ln M} f(M,z)$$

Jenkins et al., 2001

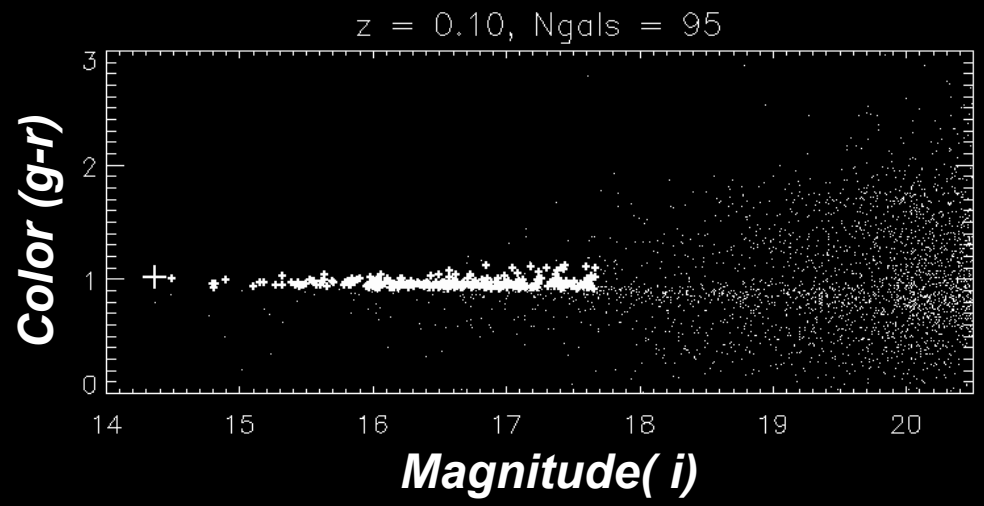
Evrard et al., 2002

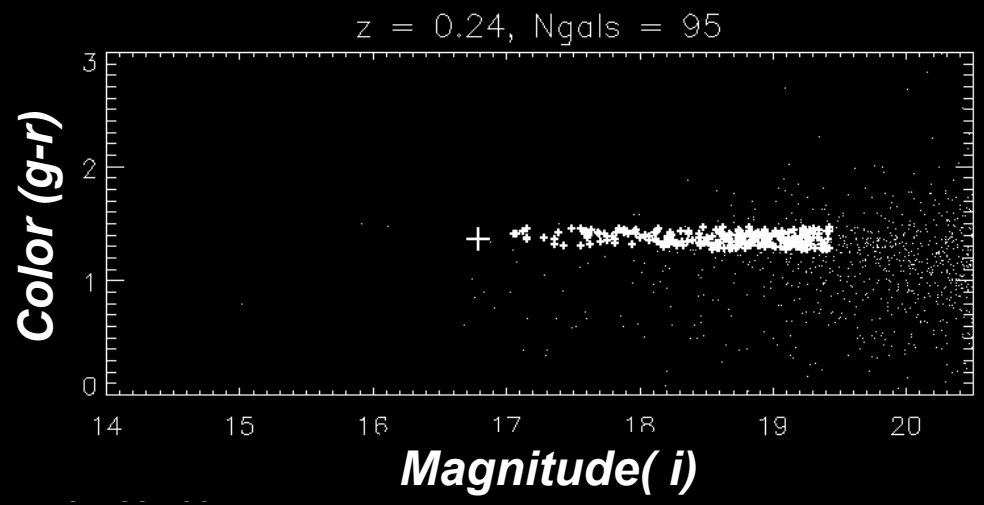
- High S/N peaks in LSS map
- Exponentially sensitive to cosmology
  - Number density above some mass
  - Growth rate of structure
  - Mass functions
- Requires *clusters* with *redshifts* and *mass proxies*

MaxBCG-SDSS

MaxBCG-SDSS

Fields of 2 rich maxBCG clusters (r<1.5 Mpc)

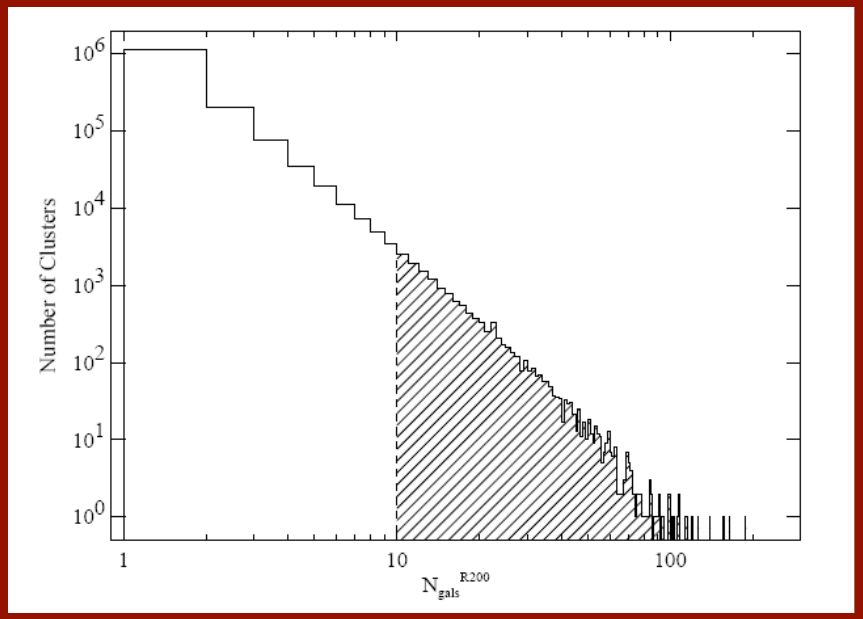


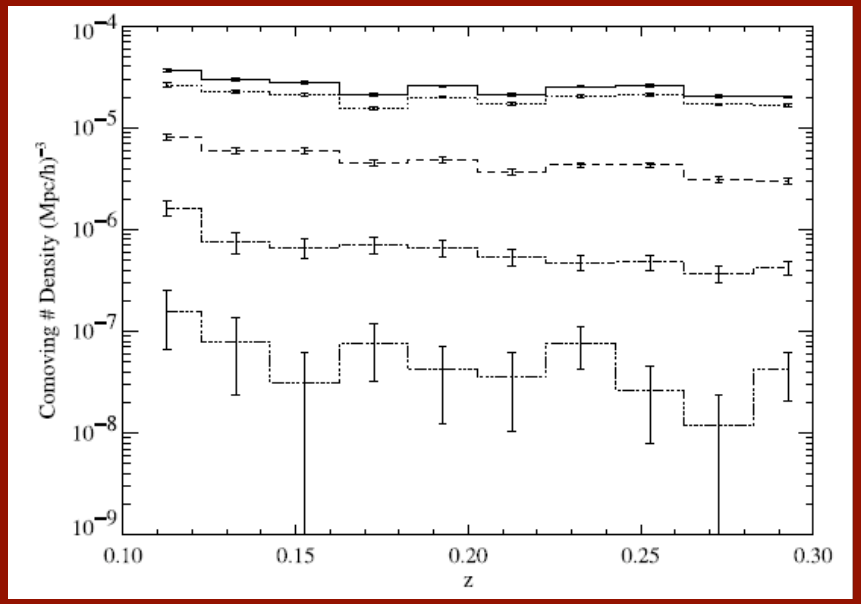


MaxBCG-SDSS

(*Koester et al., ApJ: 660,1, 221 & 239*)

- Run on 8000 sq. SDSS data
- Distill ~23 x 10^6 galaxies down to ~150,000 clusters
  - Redshift error < 0.02
  - Richness, N_{200}, number of red galaxies > 0.4L* (public: N200 > 9)
  - >90% pure and complete (Koester et al., 2007; Rozo et al., 2007)





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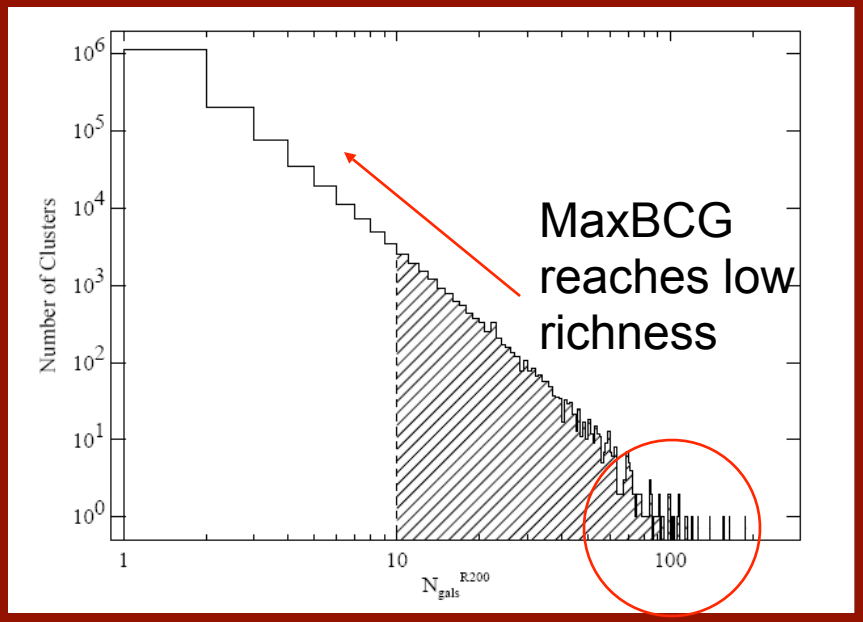
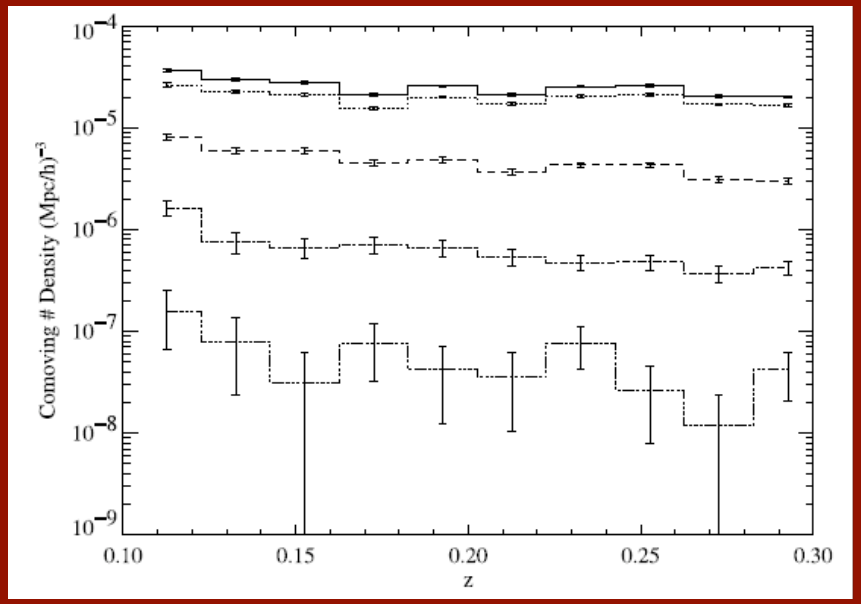




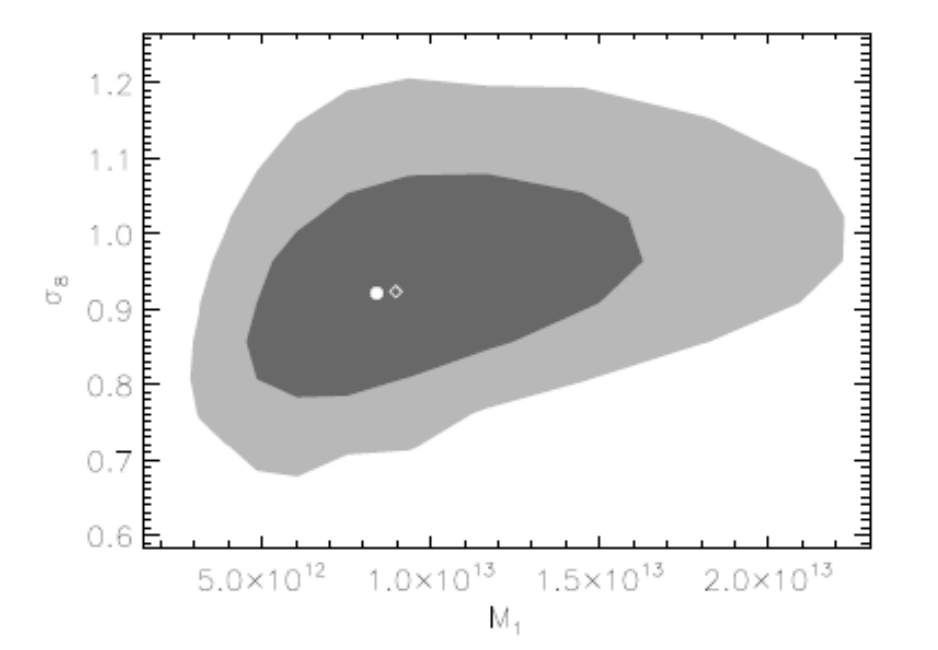
Cosmology Proof of Concept

(*Rozo et al., astro-ph/0703574, 0703571*)

- Constrain cosmology with abundances
- Calibrate MaxBCG on mock catalogs
  - Calibrate ~ mass dependent purity and completeness

1) Can recover σ_8 from sims
2) Data gives σ_8 =0.92+/- 0.1

Redshifts are as good as they'll get, but we've done very little about the masses.



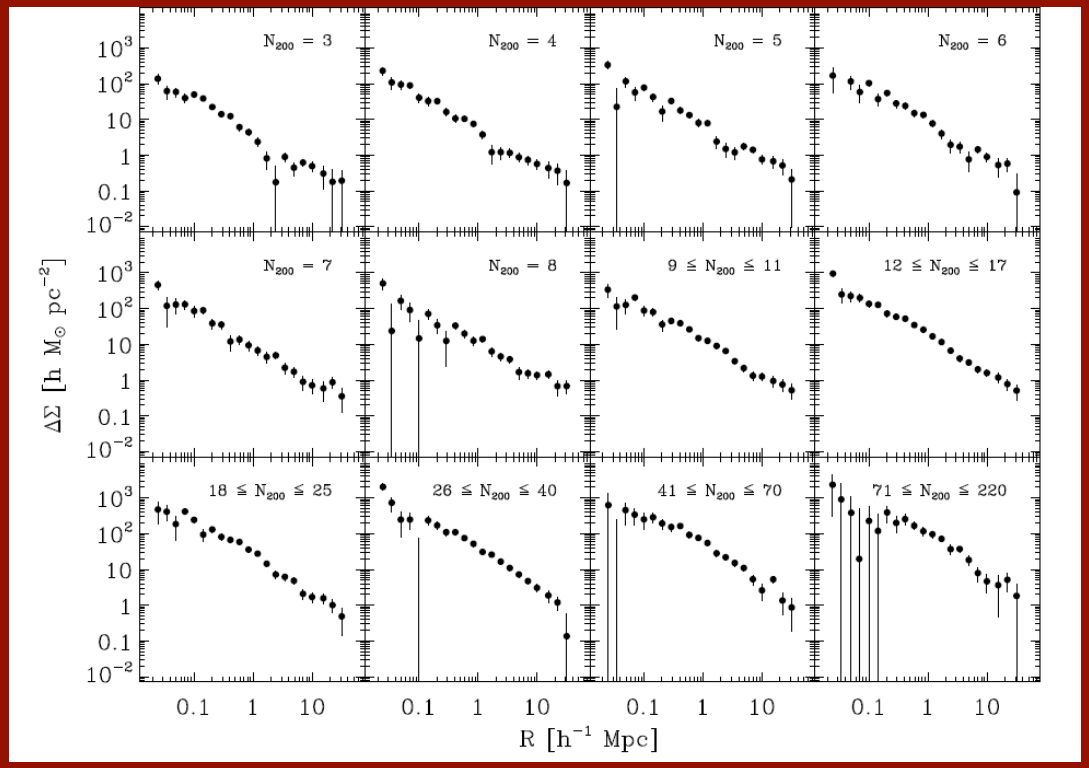
Mass Calibration

- Cosmology:
  - Redshifts: $\sigma_z < 0.02$
  - Masses: need work to move beyond abundances
- Use other methods to inform cluster mass
  - Weak lensing (SDSS imaging)
  - Dynamics (SDSS Spectroscopy)
  - X-ray luminosities (RASS)

Weak Lensing

(*Sheldon et al., arXiv:0709.1153*)

- Mass induces coherent distortions in shapes of background galaxies (G. Bernstein on Monday, and A. Zentner this morning)
- Stacking clusters enhances low signal => high S/N



Systematics:

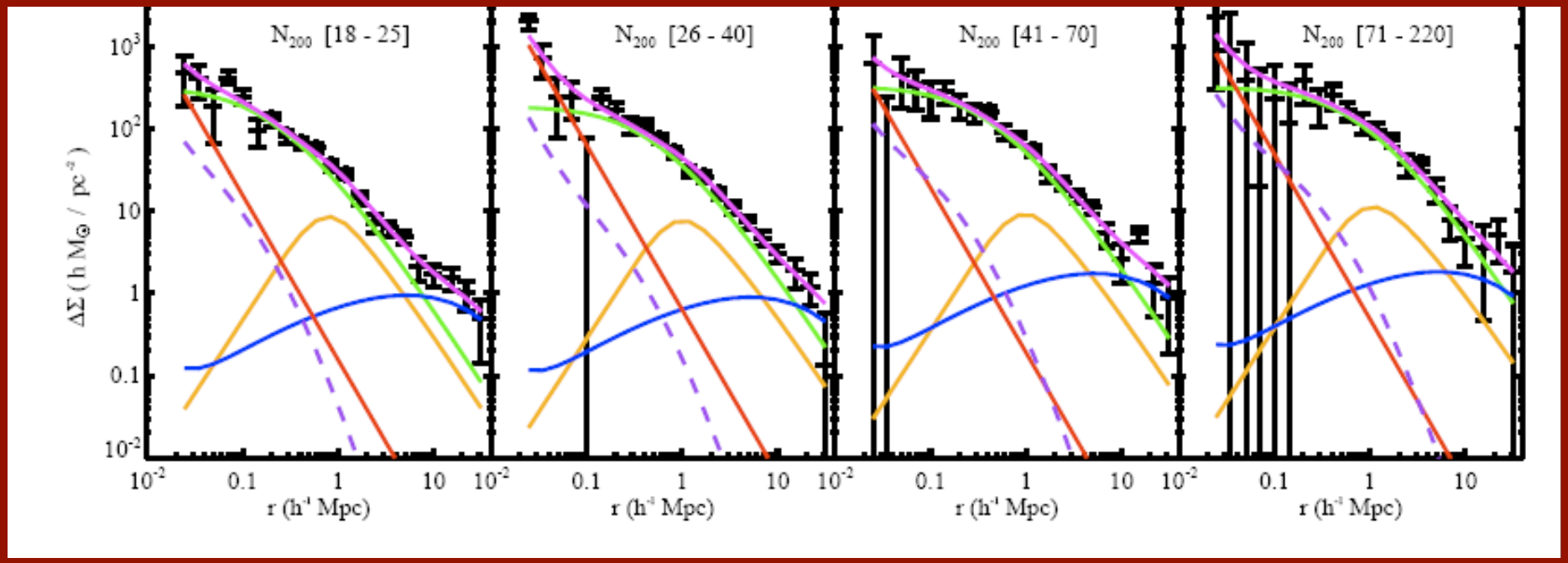
1) Photoz measurements
2) Shear calibration: actual distortion vs. measured distortion

Exquisite control of these required to turn signal into meaningful statement about mass

Weak Lensing

(*Johnston et al., arXiv:0709.1159*)

- Now invert 2D mass map into 3D average halo profile
  - Lensing signal: NFW + 2-halo + BCG point mass + *miscentering*



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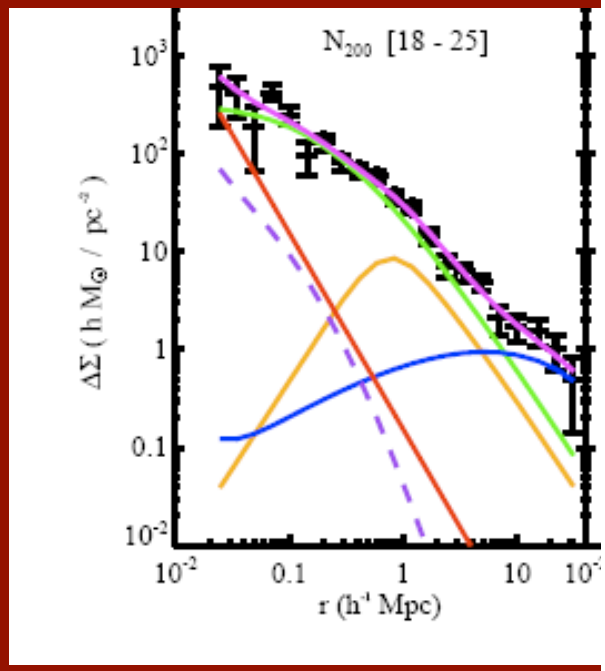
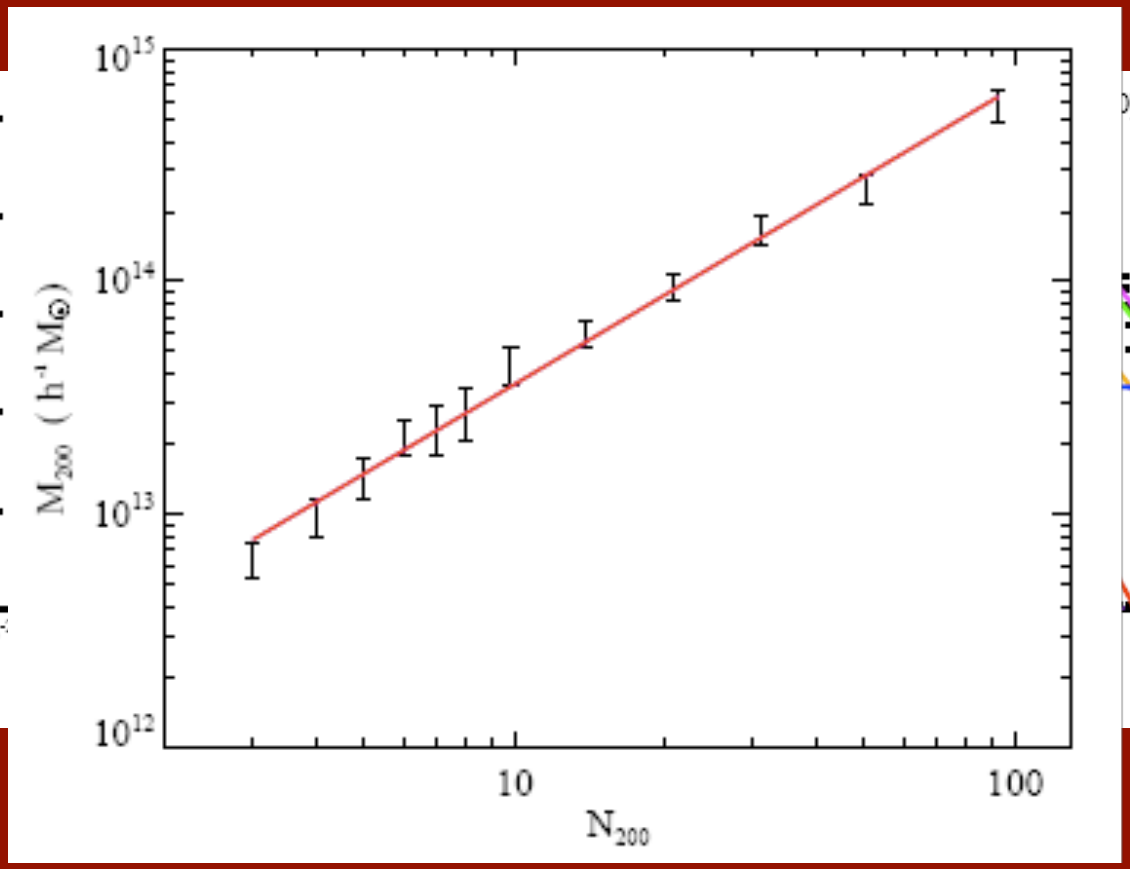
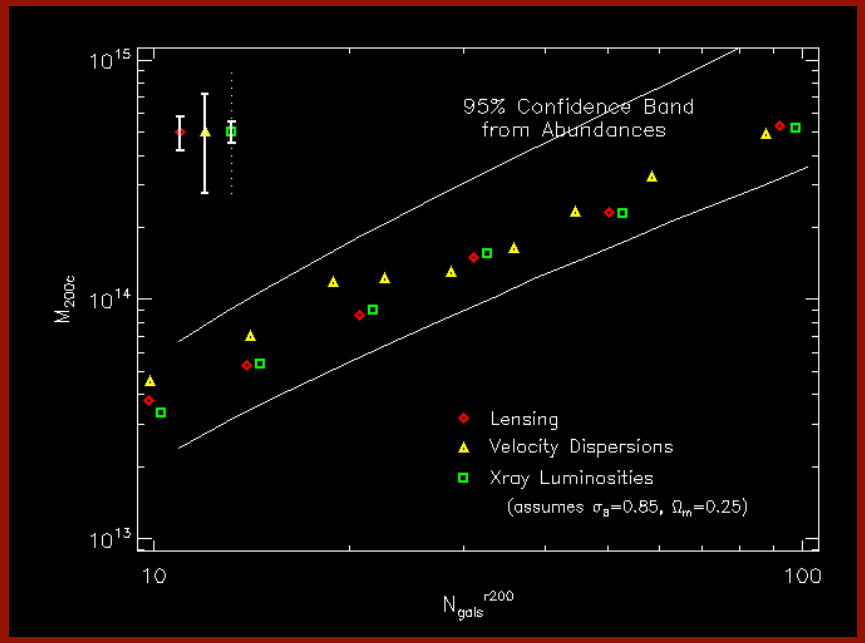




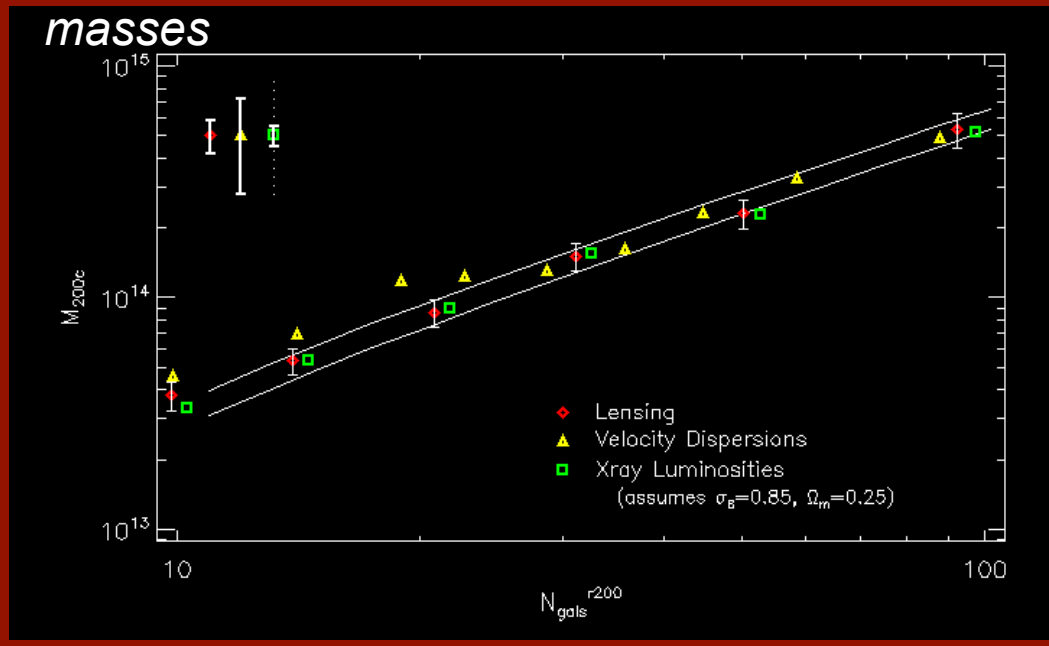
Cosmology with Mass Calibration

Masses from lensing, combined with dynamical masses (Becker et al., *ApJ 669,2, 905*) and x-ray masses (Rykoff et al.,arXiv:0709.1158, *ApJ* accepted)

Rozo et al., 2007



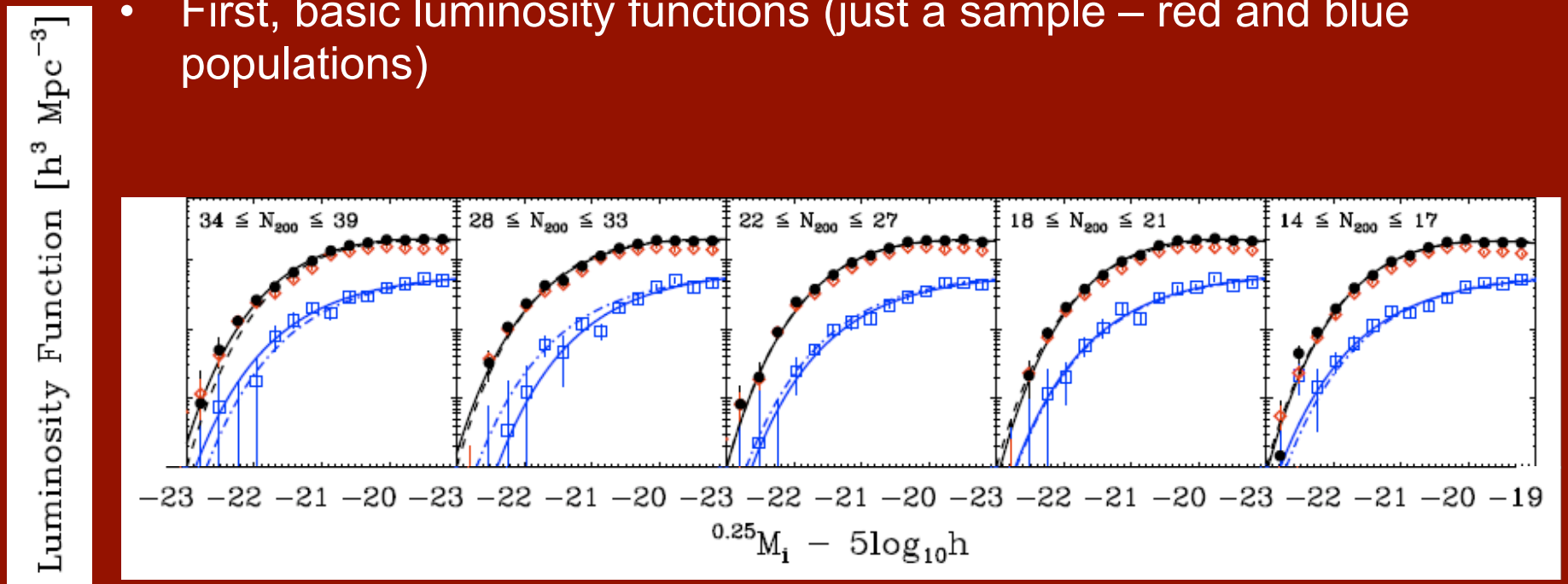
Rozo et al., 2007+Sheldon/Johnston masses



…updated cosmological constraints in progress…

Optical Properties

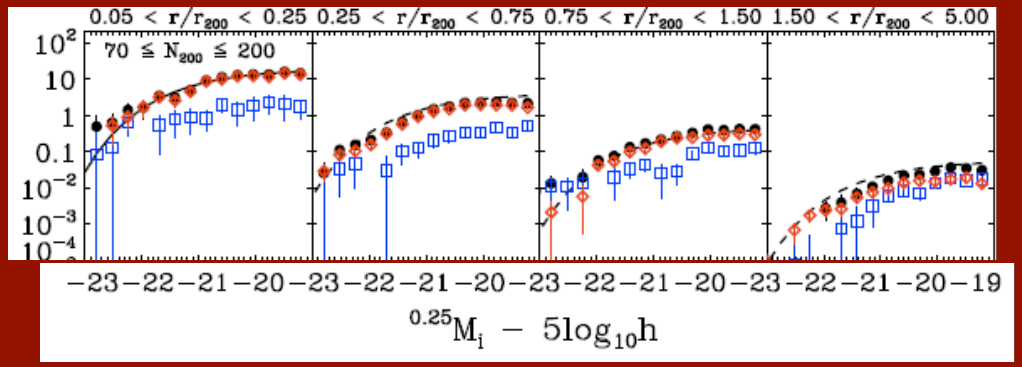
- Measuring serves a few purposes
  - Understand cluster evolution and galaxy formation
  - Improved richnesses (mass proxy), cluster finding
- Hansen et al. (2007, *arXiv:0710.3780*): cluster galaxies at z=0.25
  - K-correction to z=0.25, global background subtraction
- First, basic luminosity functions (just a sample – red and blue populations)

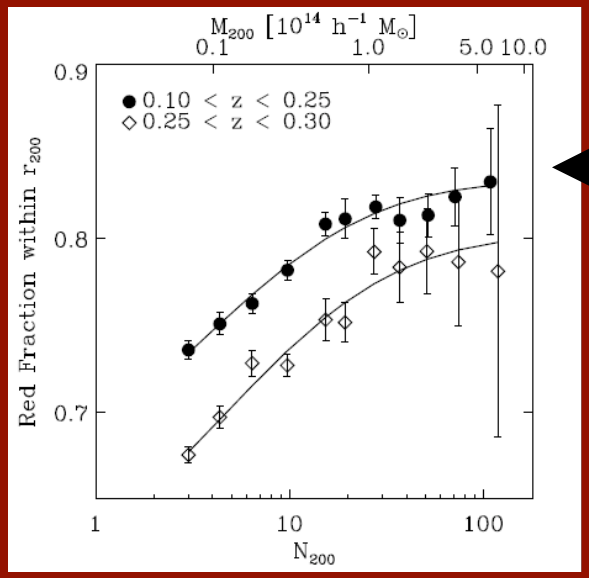


Optical Properties

- Great statistics allow various sub-bins

Radial dependent luminosity functions

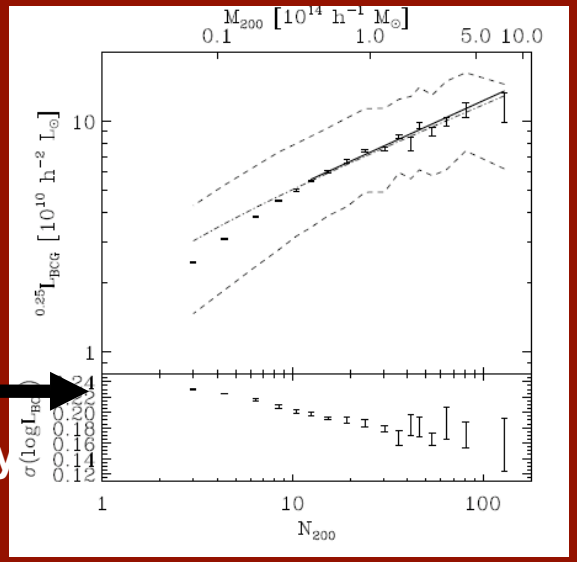




Red fraction

and

BCG luminosity fraction

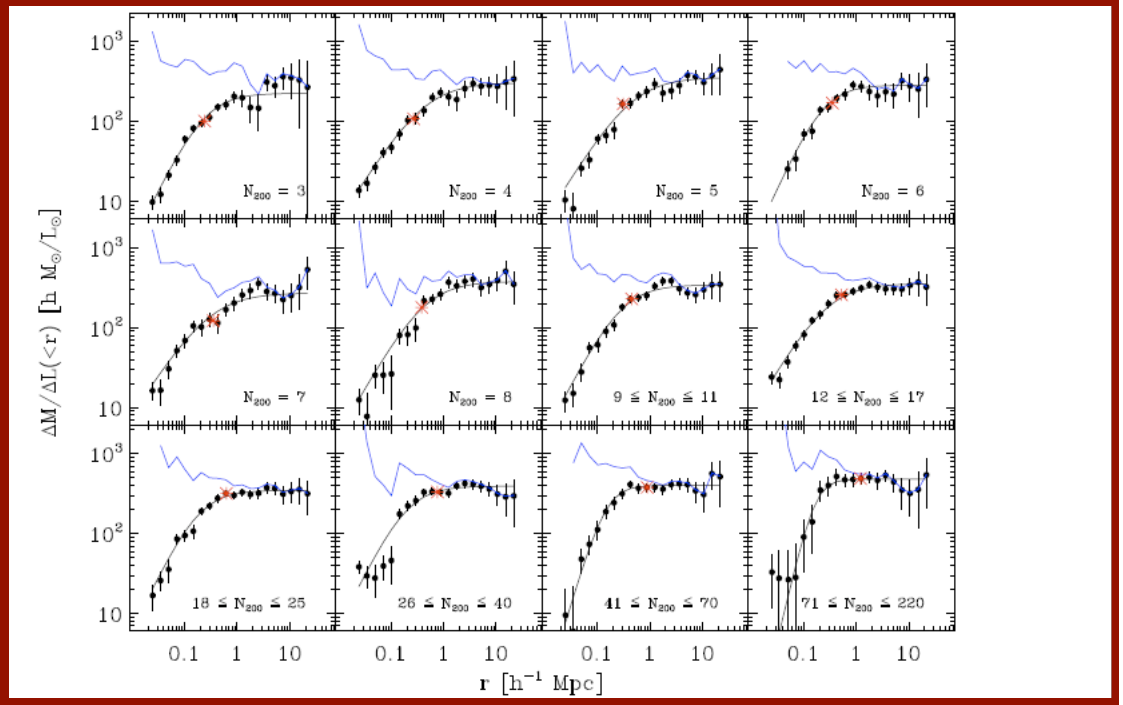


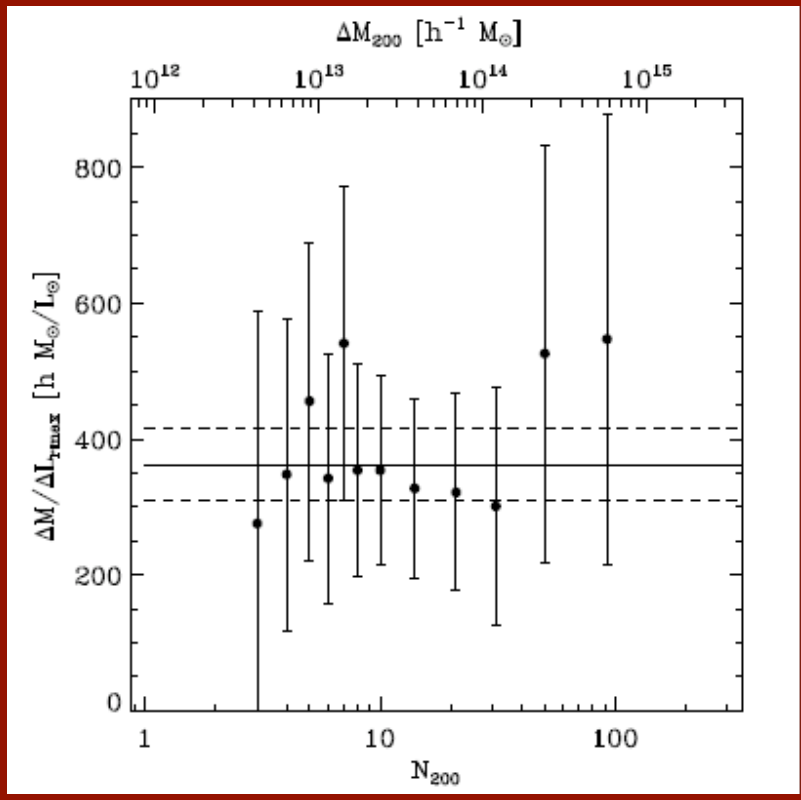
Among many conclusions:

1) Various scaling relations
2) Increasing red fraction with z
3) BCG luminosity increases with mass

Mass-to-Light

- MaxBCG-SDSS applied to M/L
- Sheldon et al., 2007: Combine WL+Hansen et al. luminosity measurements





$$\langle M/L \rangle \, b_{M/L}^{-2} = \begin{cases} 362 \pm 54h & \text{within } 22h^{-1}\text{Mpc} \\ 357 \pm 9h & \text{asymptotic fit} \end{cases} \quad (20)$$

$$\Omega_m b_{M/L}^{-2} = \begin{cases} 0.20 \pm 0.03 & \text{within } 22h^{-1}\text{Mpc} \\ 0.194 \pm 0.008 & \text{asymptotic fit} \end{cases} \quad (21)$$

Where We Stand

- Cosmology:
  - Laying groundwork for future optical surveys, or for cross-calibration of non-optical (SPT+DES)
  - Lensing greatly improves mass calibration & cosmology
    - Scatter in mass at fixed observable and covariance of mass proxies non-trivial
  - Galaxy population work is improving richness measurements, understanding of cluster selection
  - Working on “centering”, maxBCG calibration
  - What else can we pull in?
    - WMAP → stacked SZ masses?
- Cluster astrophysics
  - What do optical clusters look like in X-ray, IR, radio, etc.