Weak Lensing Mass Measurements of Nearby Galaxy Clusters

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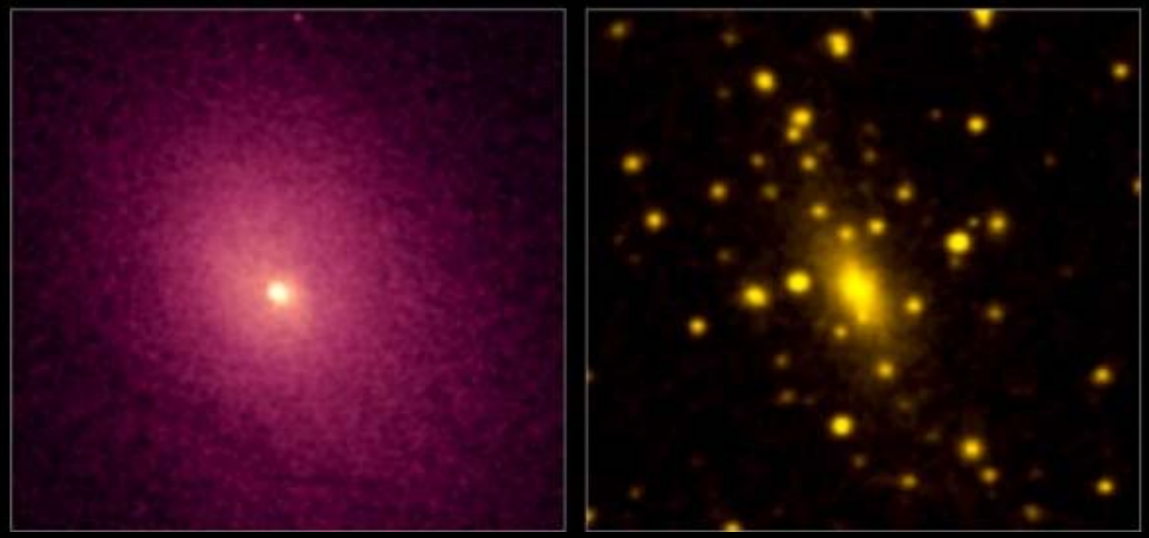
Introduction

- Galaxy clusters: largest grav. bound objects in the universe
- Probes of cosmology & physics of structure formation
- Trace dark matter and the relation to mass
- Map large scale structure of the universe

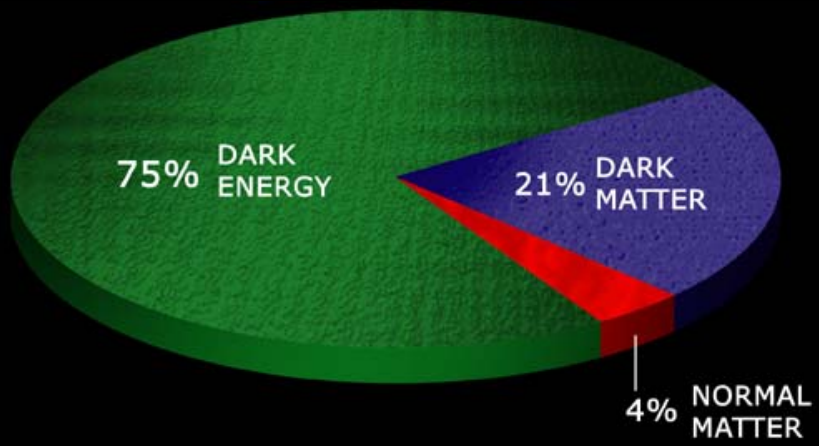
Abell 2218

Introduction

- What methods can we use to probe clusters?
  - X-ray observations
  - Virial analysis
  - Lensing



Abell 2029



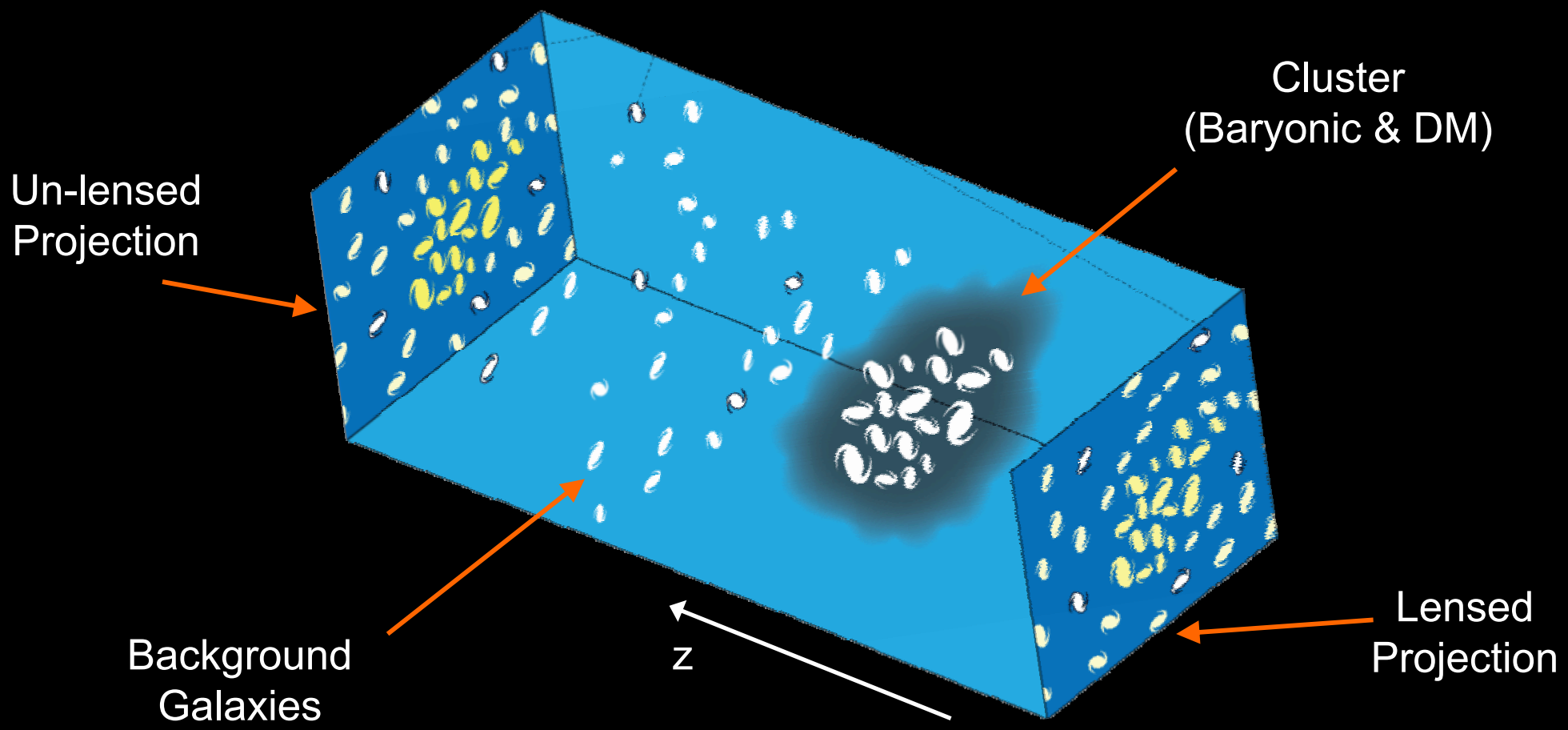
Gravitational Lensing

- weak lensing: small preferential distortions of background galaxy shapes
- strong lensing: clearly visible distortions
- micro lensing: no distortion, only magnification

Double Einstein Ring

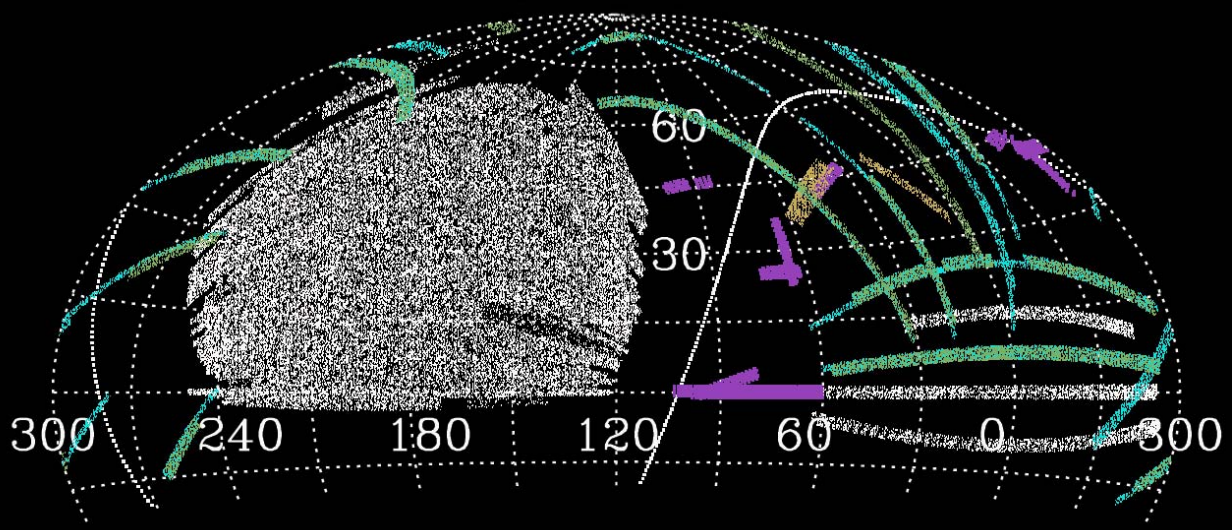
Gravitational Lensing

- weak lensing: small preferential distortions of background galaxy shapes



SDSS

- **S**loan **D**igital **S**ky **S**urvey:
  - 2.5m dedicated telescope in NM
  - 30 2kx2k CCDs, wide FOV
  - Imaging in 5 optical filters (ugriz) to ~22 mag in r

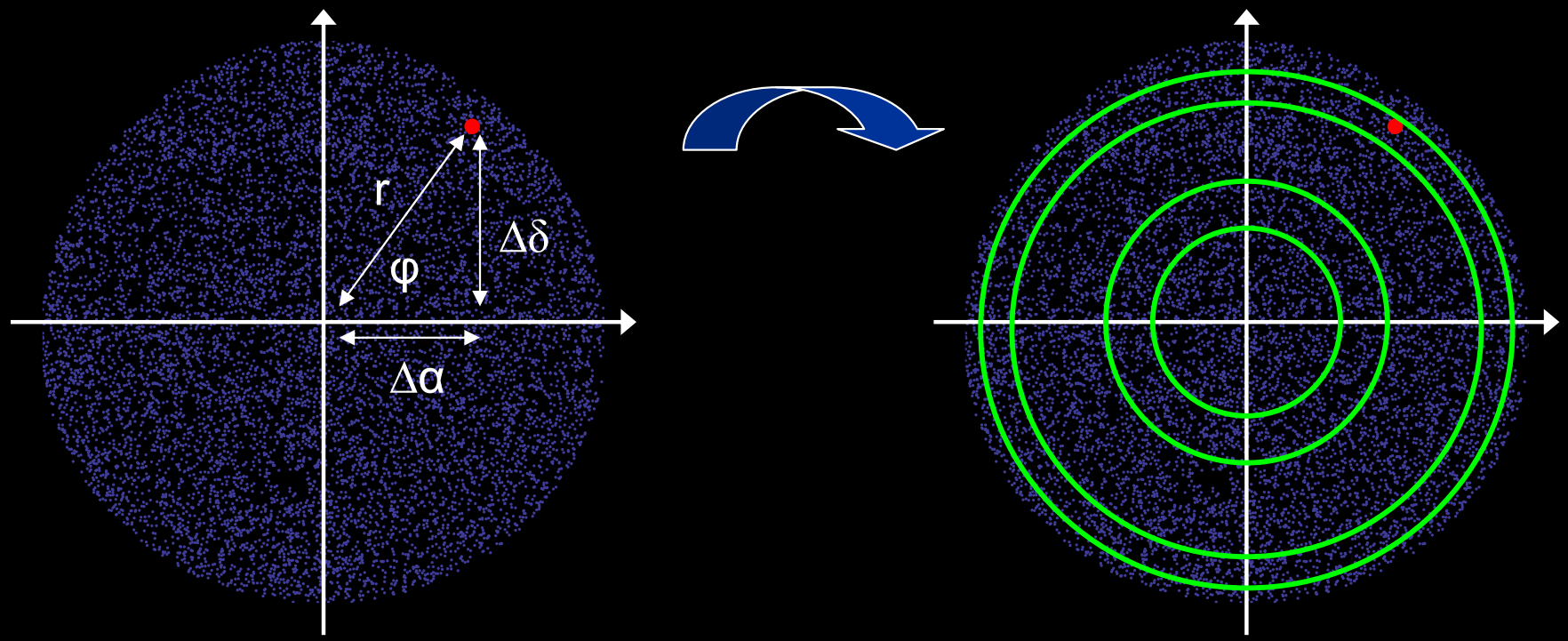


~8000 deg^2 ~12 million galaxies

Master Galaxy Catalog:

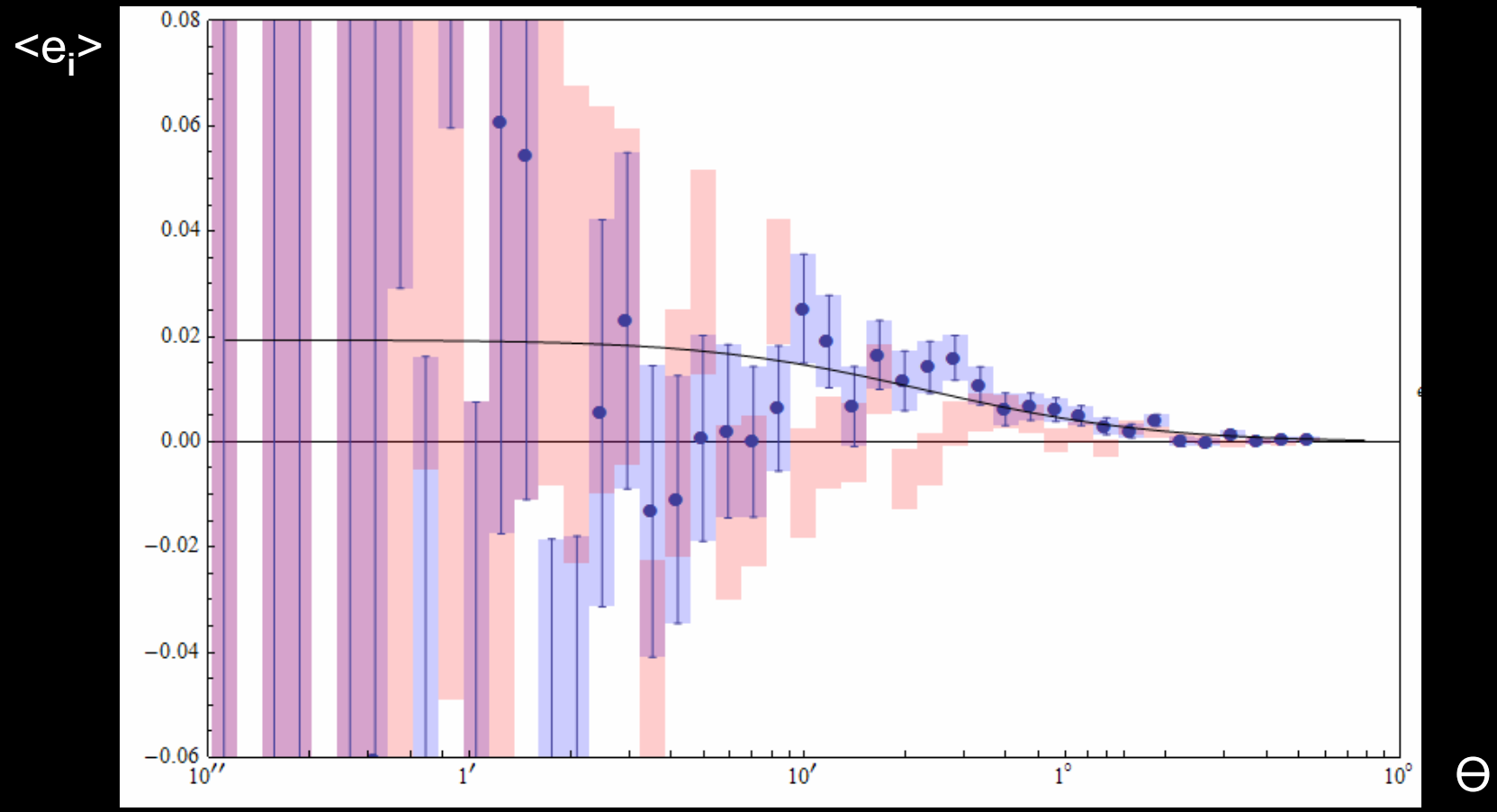
1. sky position (α,δ)
2. shape measurements (e_1,e_2)
3. photoz ~ distance

Making a Measurement



- transform coordinates $(\Delta\alpha, \Delta\delta) \rightarrow (r,\varphi)$
- transform ellipticities $(e_1,e_2) \rightarrow (e_T,e_{OT})$
- in log spaced bins, calculate $\langle e_T \rangle, \langle e_{OT} \rangle, \sigma_e, N$

Shear vs. Radius



$$e_+ = 2\gamma_T \mathcal{R} + e_+^{int}$$

$$\gamma_T(R) \times \Sigma_{crit} = \bar{\Sigma}(< R) - \bar{\Sigma}(R)$$

NFW Model

- **N**avarro **F**rank & **W**hite (1996)
  - "universal profile" for dark matter halos
  - found in N-body simulations to apply over a wide mass range

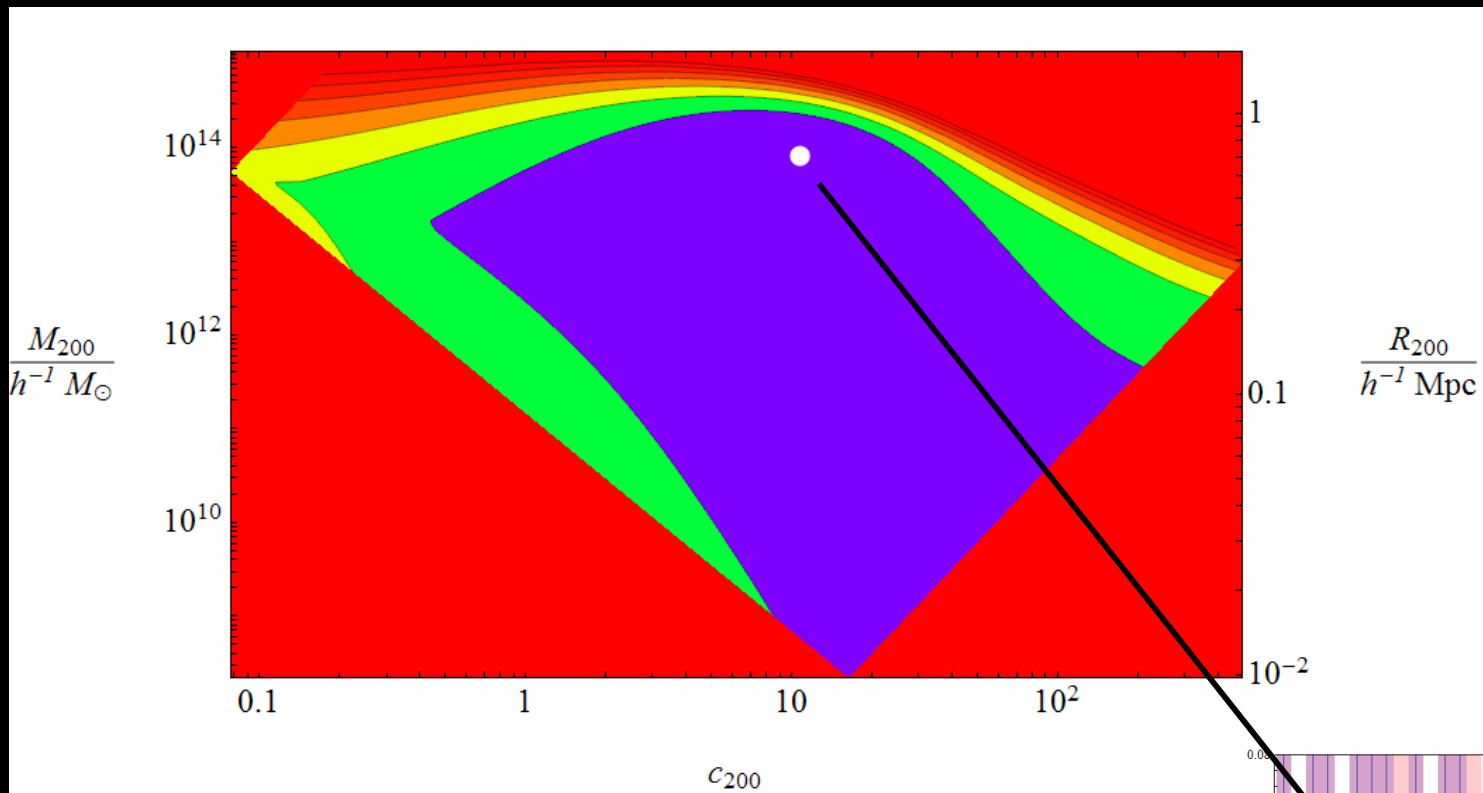
$$\rho(r) = \frac{\delta_c \rho_c}{(r/r_s)(1 + r/r_s)^2}$$

  - two-parameter model (take M_{200},c) which predicts a shear profile

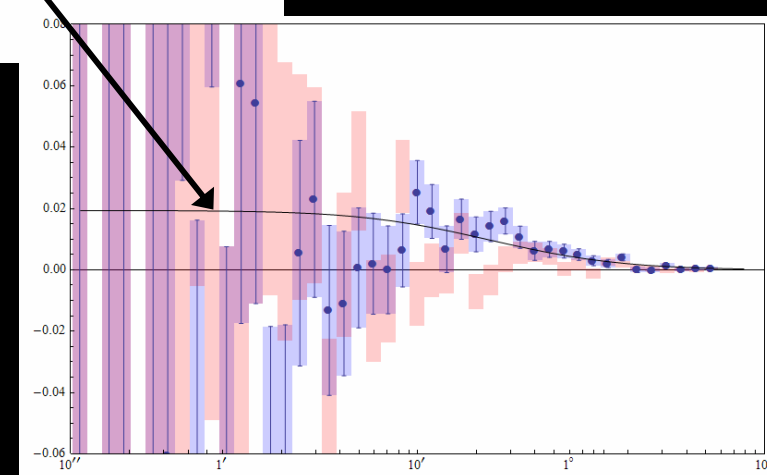
$$\delta_c \sim c$$

$$r_s \sim r_{200} \sim M_{200}$$

Best-Fit NFW Model



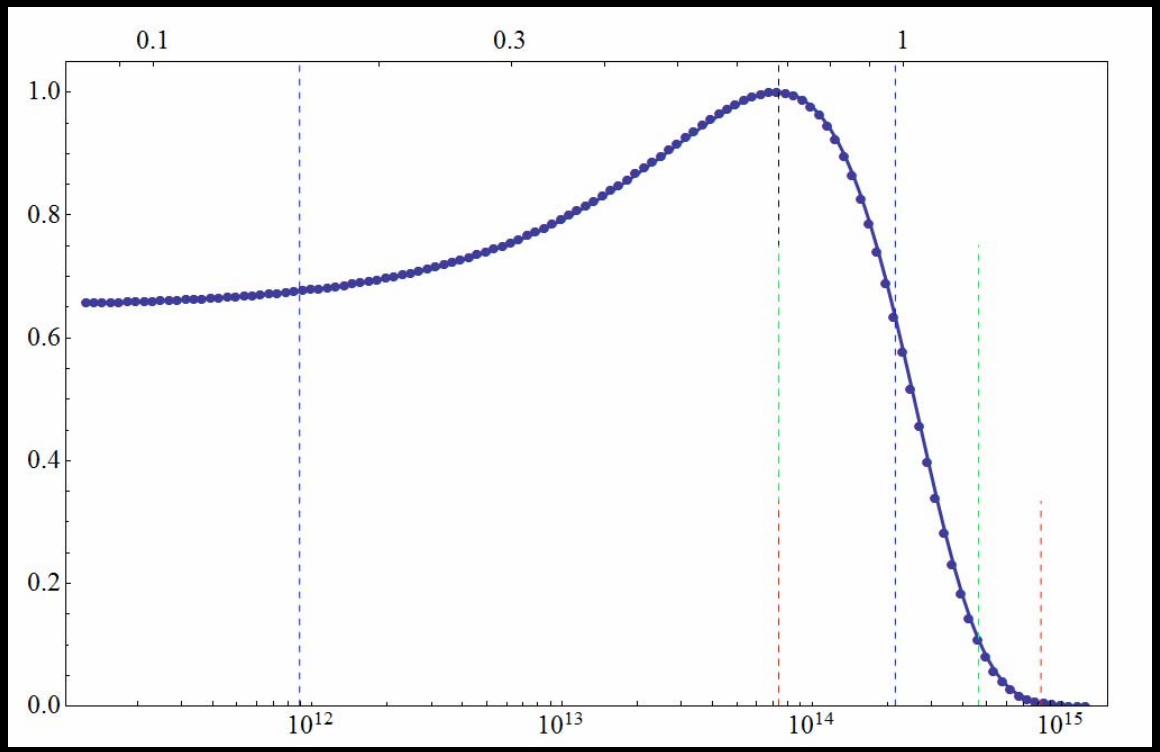
- Explore (M,c) parameter space, find best-fit model by comparing shear profile with $\langle e_T \rangle(\Theta)$ data



- In general, c_{200} is not well-constrained by the data, enforce a prior of $1 < c_{200} < 10$

Mass Determination

- To calculate "best-fit" mass, marginalize (integrate) over c_{200}, i.e. project onto the mass axis



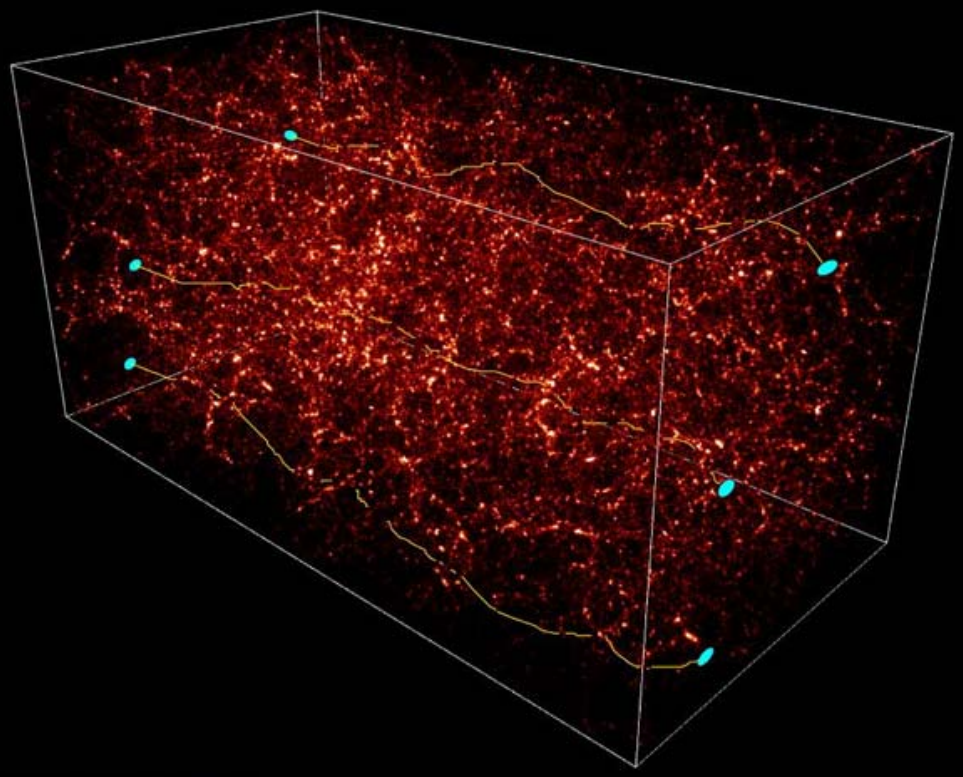
Virgo Cluster

- Nearby (z~0.004 is ~15 Mpc)
- 10 Mpc radius → 40° on sky
- 6 million galaxies used

Log M_{200} = 13.87 (+0.47 -1.92)

Sources of Error

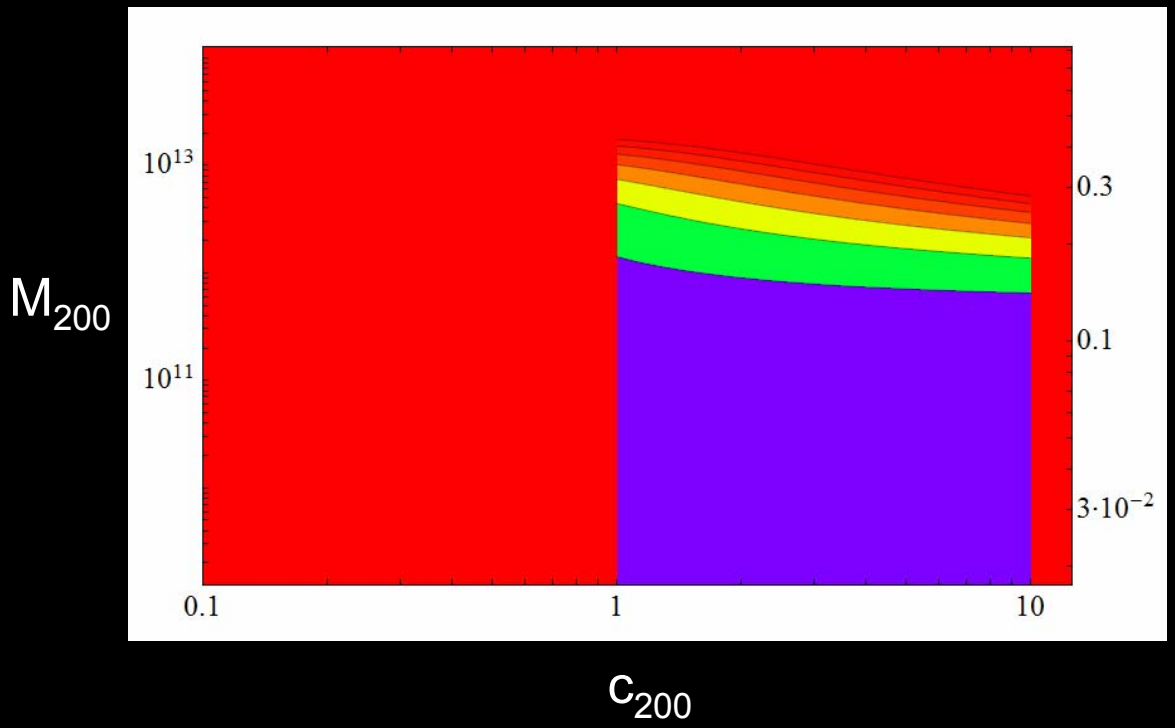
- Best case: intrinsic ellip. distribution with σ_e
  - Our uncertainty ~ $\sigma_e / \sqrt{n}$
- Noise from large-scale structure ("cosmic shear")
  - Expect at ≤ 10% level
- Systematics:
  - mainly in determining shapes of galaxies
  - atmospheric "seeing"
  - PSF corrections



Future: Blank Fields

- Want to identify the null result case:

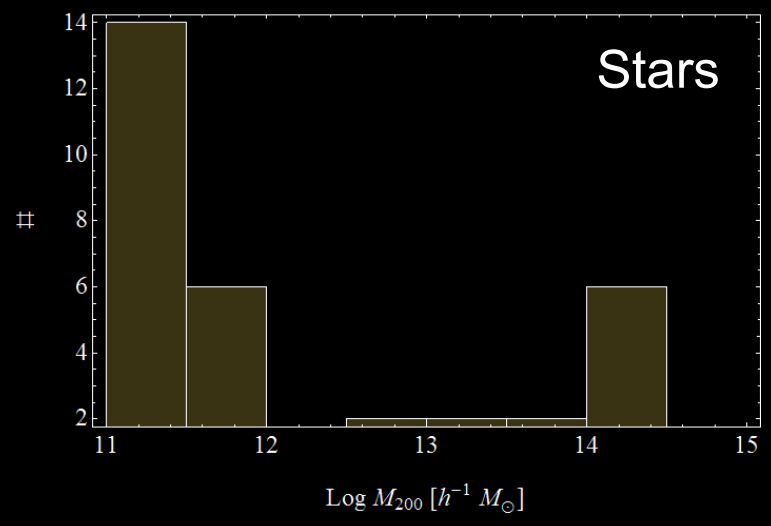
Could a blank region of space produce a WL signal we would interpret as having a cluster-sized mass presence?

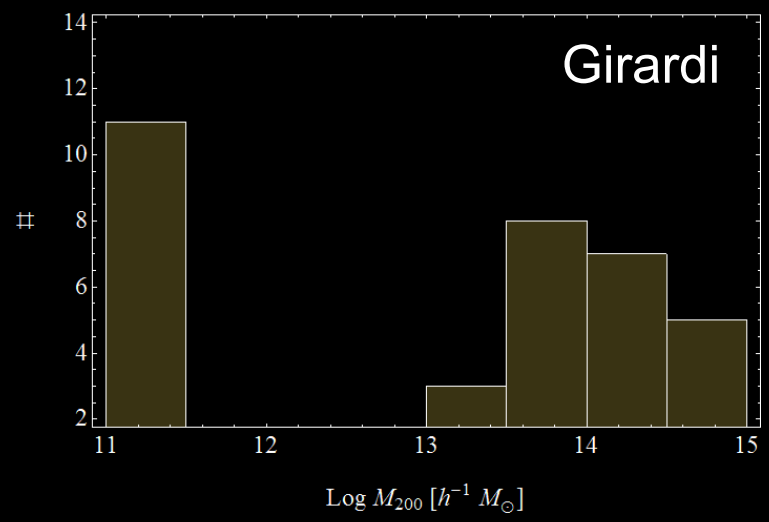


- Choose N (=50) random points on sky
  - Centered on dim stars, avoid edges
  - Replicate redshift distribution of clusters
  - Run through full WL analysis and look for mass

Future: Blank Fields

- Single blank fields:
  - Create PDF of “blank field cluster masses”





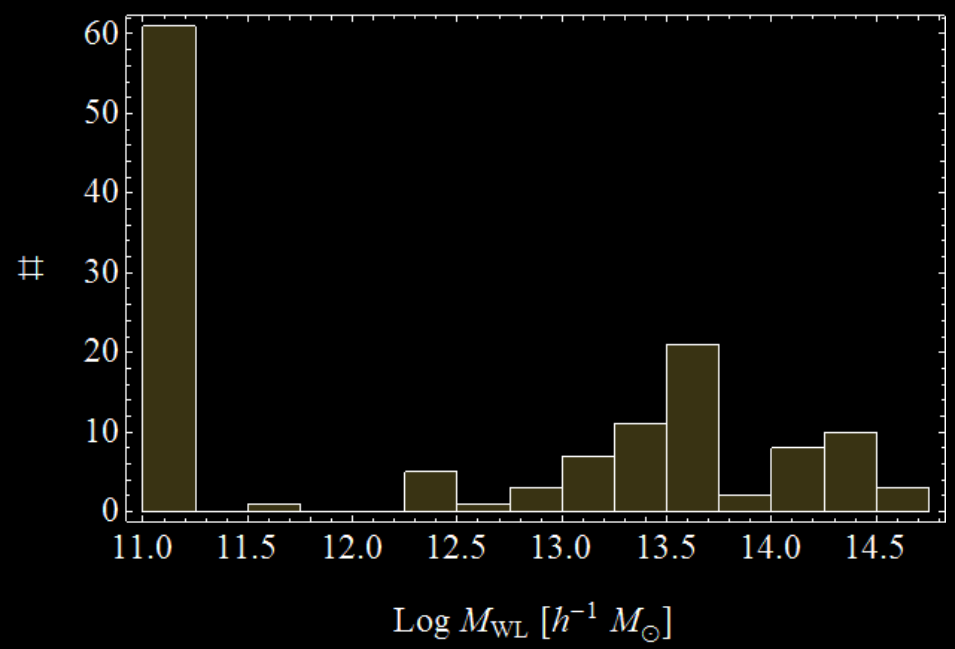
- Stacked blank fields:
  - Check contribution from LSS uncorrelates
  - Check for systematics from combining signals

Future: Abell Catalog

- ~2000 clusters from Abell (1958) inside our master galaxy coverage
- 10x increase in all WL measurements made to date

What can we do with it?

- Combine signals by stacking ensembles of clusters based on an observable



Future: Stacking on Richness

- "Richness" classification: $N(m_3 - 2.0 < m < m_3)$

Log M_{200} ($\pm 1\sigma$)	$z < 0.1$	$z > 0.1$
R-0	$13.65^{(+0.09\ -0.11)}$	$13.95^{(+0.11\ -0.11)}$
R-1	$13.98^{(+0.07\ -0.06)}$	$14.18^{(+0.05\ -0.06)}$
R-2	$14.16^{(+0.10\ -0.10)}$	$14.49^{(+0.07\ -0.09)}$
R-3	$14.67^{(+0.24\ -0.29)}$	$14.38^{(+0.18\ -0.28)}$

Redshift cut since:

1. WL approximations valid for $z < 0.1$
2. In general, want to look for evolution of fundamental relationships (e.g. mass given richness) with z

Calibration

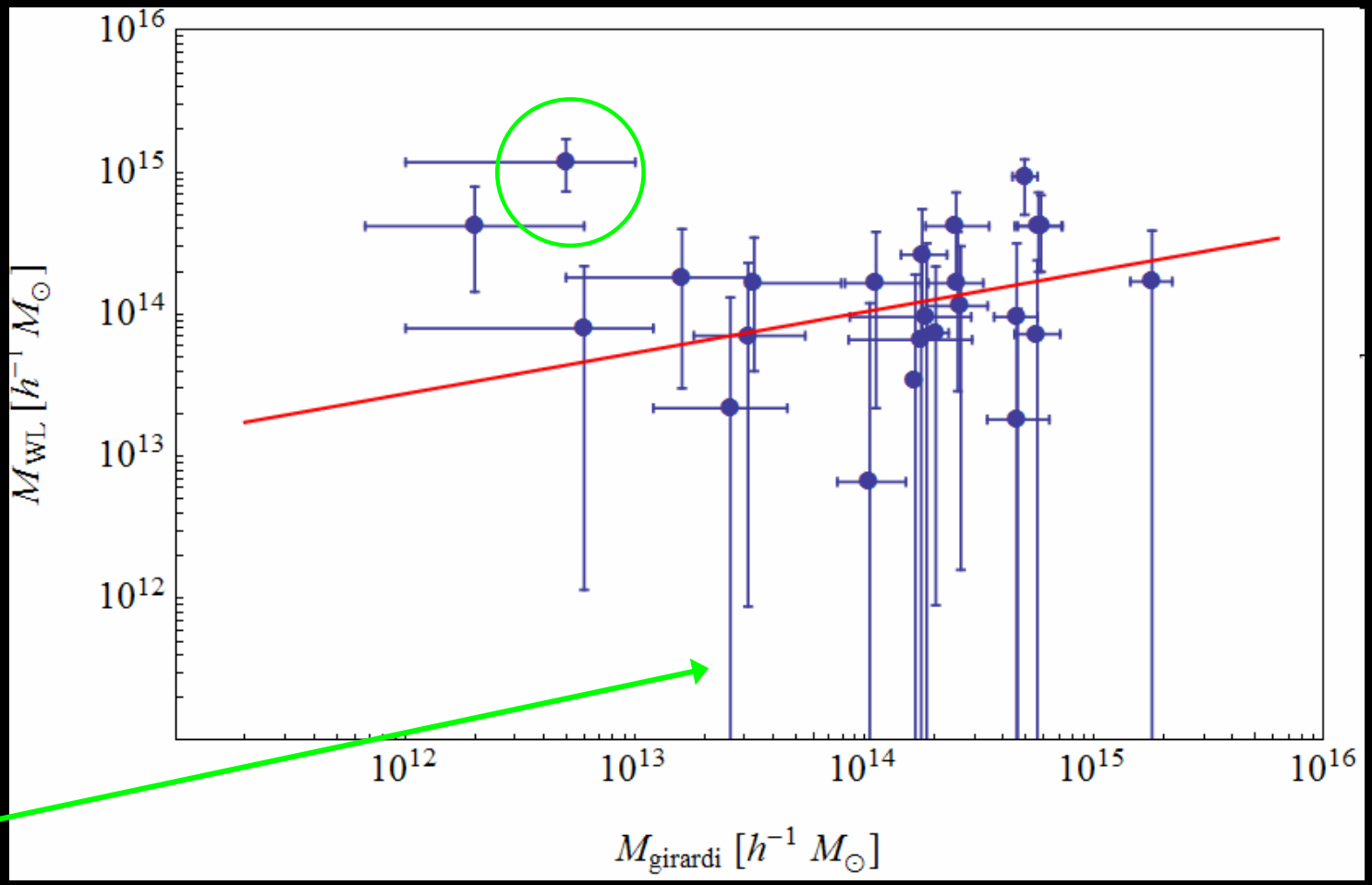
- Want to verify validity of WL technique
  - select subset of clusters (~40) shared with Girardi et al. (1998)
  - Girardi masses calculated via virial analysis
- For each cluster we run through the WL analysis and compute:

$$M_{200}\ (\pm\ 1\sigma)\ (\pm\ 3\sigma)$$

and compare with Girardi

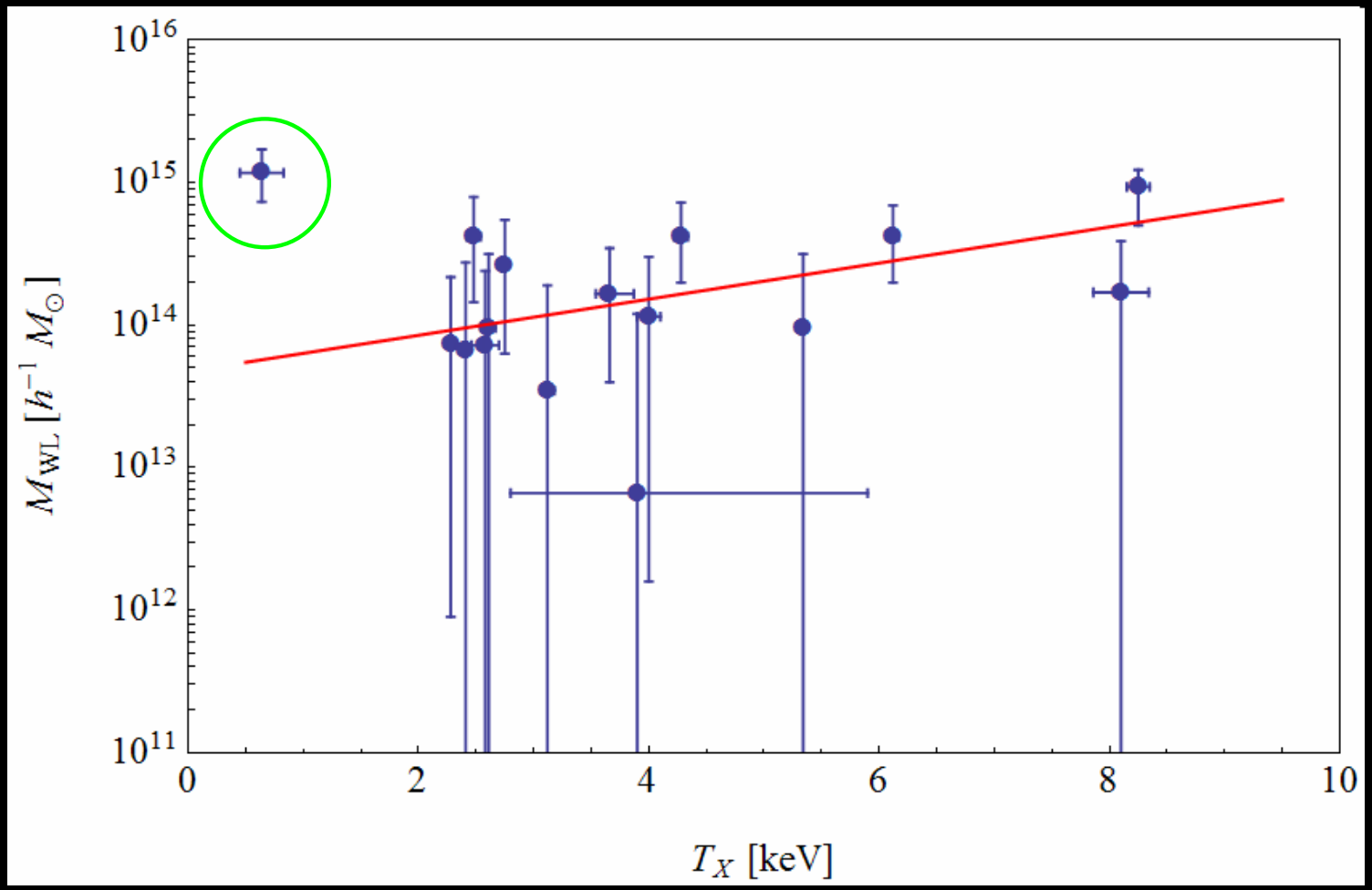
Calibration

Good agreement between WL and dynamical mass measurements (at the < 2σ level)



Upper limit detections consistent

Calibration



- X-ray temperatures for clusters from the literature
- Correlation better than M_{WL}/M_{Gir}, indicative of a better measurement

Future & Summary

What have we done?

1. Demonstrated method for making WL measurements of individual clusters using SDSS North data
2. Verified ability to combine WL signal by stacking on stars & clusters
3. WL masses compare favorably with dynamical estimates (Girardi)

What do we still want to do?

- Mass of every Abell clusters in the SDSS footprint
- Want a measure of N_{gals} that minimizes the scatter with mass
  - Mass-observable relation M-N_{gals} can constrain cosmological parameters
- Trace evolution with redshift (co-add)
- Scaling of mean density profiles w/ e.g. richness