THE DARK ENERGY SURVEY

First Results in Galaxy Cluster Weak Lensing

Rutuparna Das
University of Michigan

with the Dark Energy Survey Collaboration

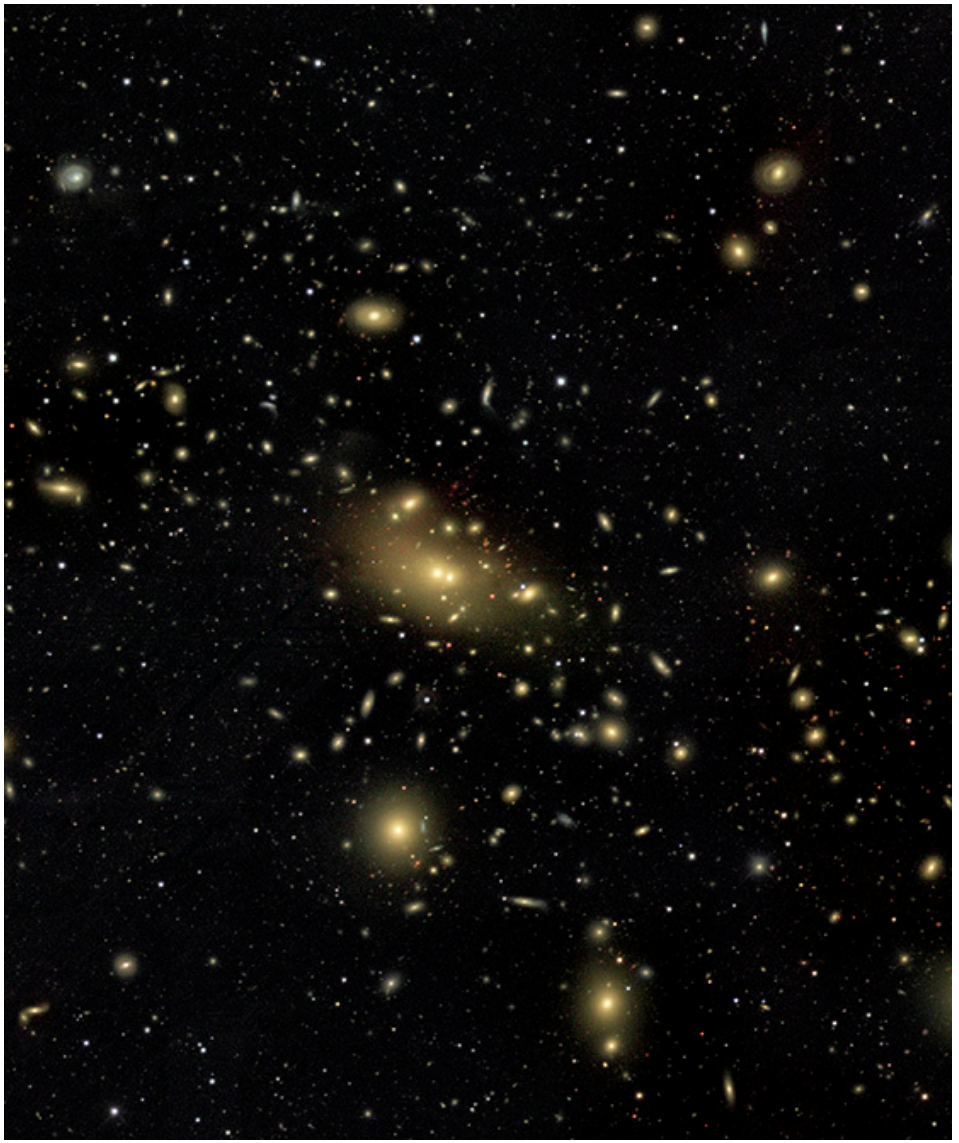
Aug 4, 2015 – DPF Meeting – Ann Arbor

Overview

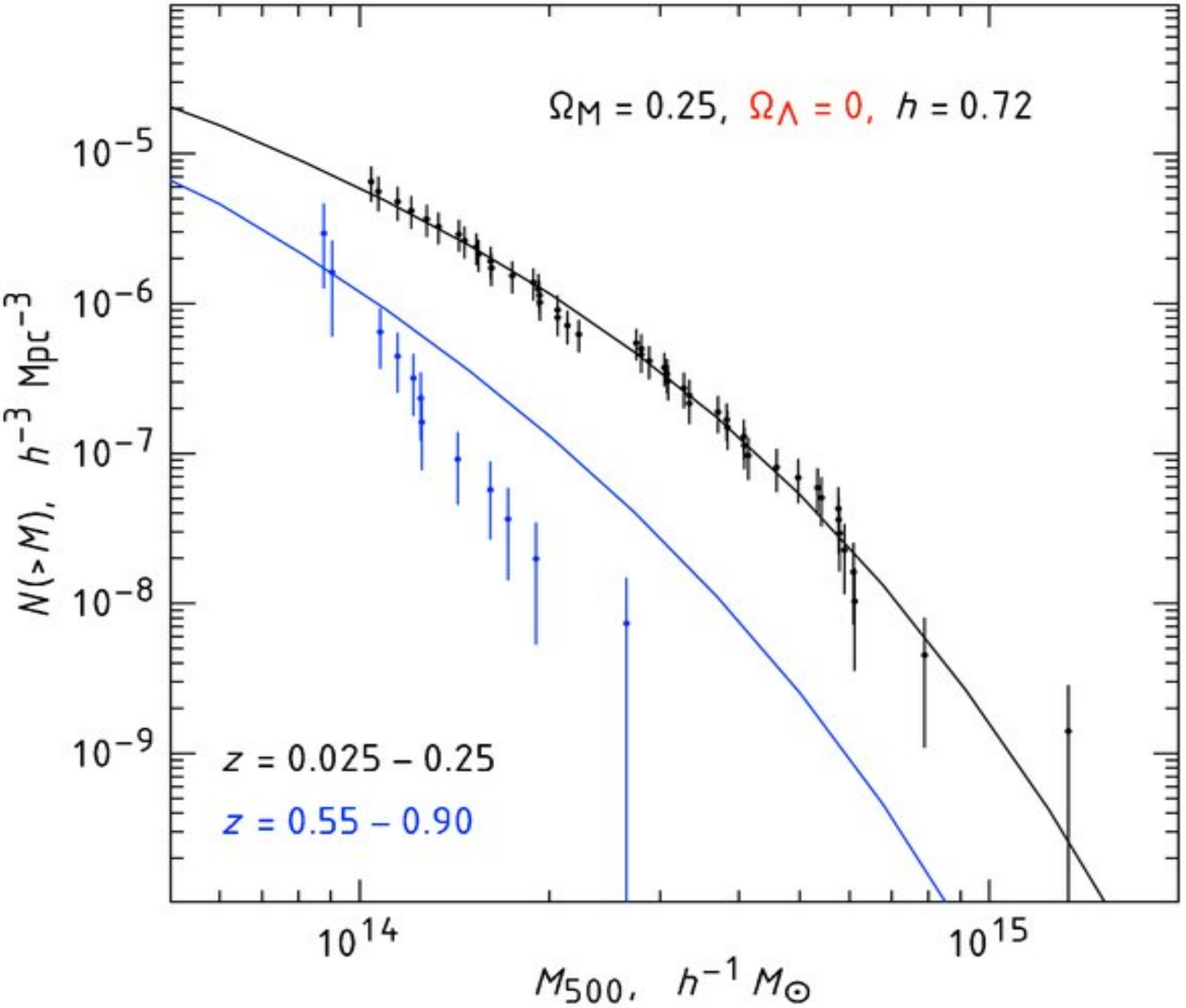
- Galaxy clusters and Dark Energy
- How to measure cluster mass
- Scaling relations between cluster mass and other observables
- DES projects
  - Four massive clusters
  - Mass calibration of optically-selected clusters
  - Mass calibration of SZ-selected clusters
  - Mass calibration of X-ray selected clusters

Galaxy Clusters and Dark Energy

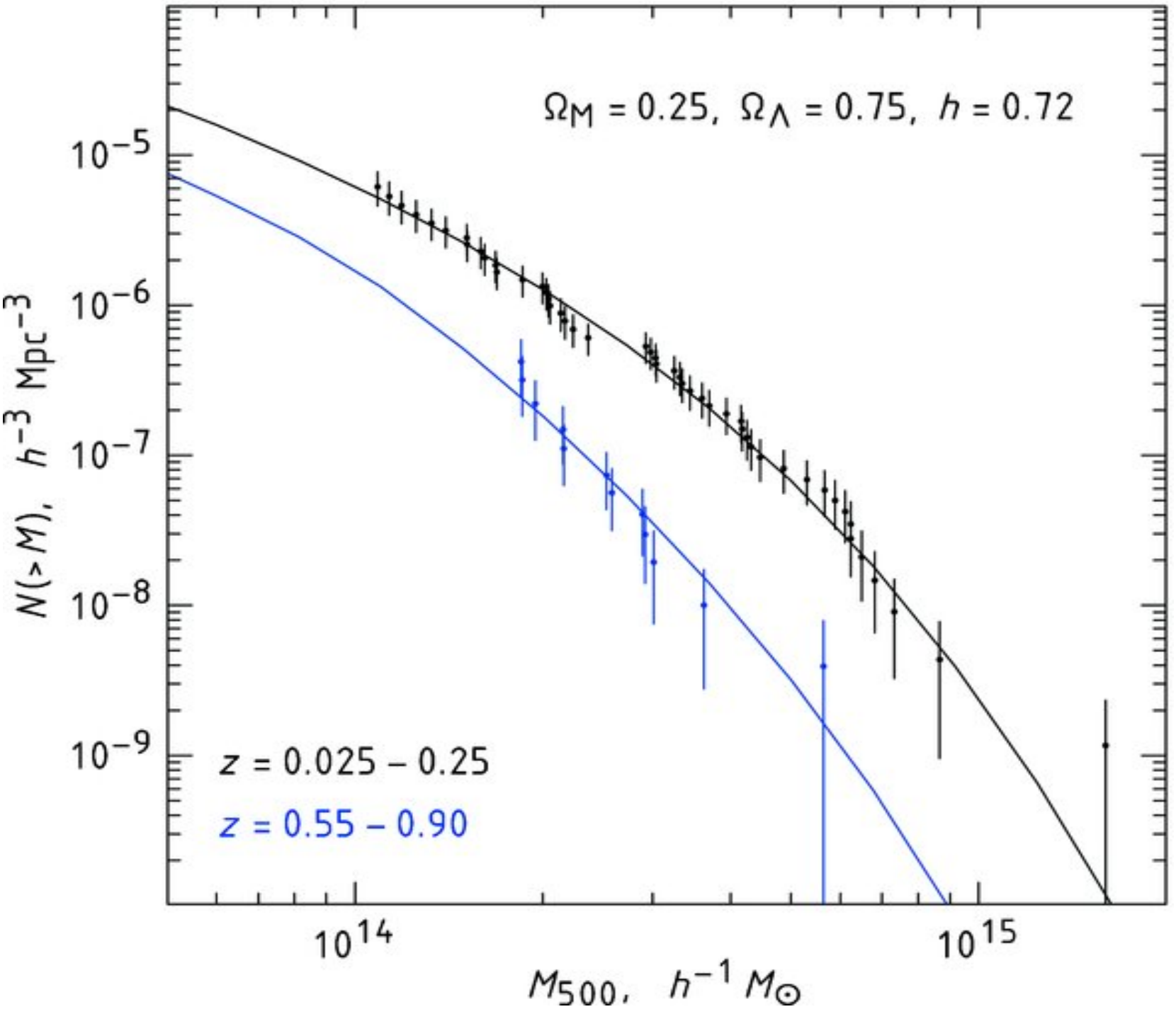
- Number of high-mass clusters grows over time
- Negative pressure of dark energy hinders rate of cluster growth
- Evolution of cluster mass function over time → constraints on evolution of dark energy



Mass Function – Vikhlinin et al, 2009



Mass Function – Vikhlinin et al, 2009



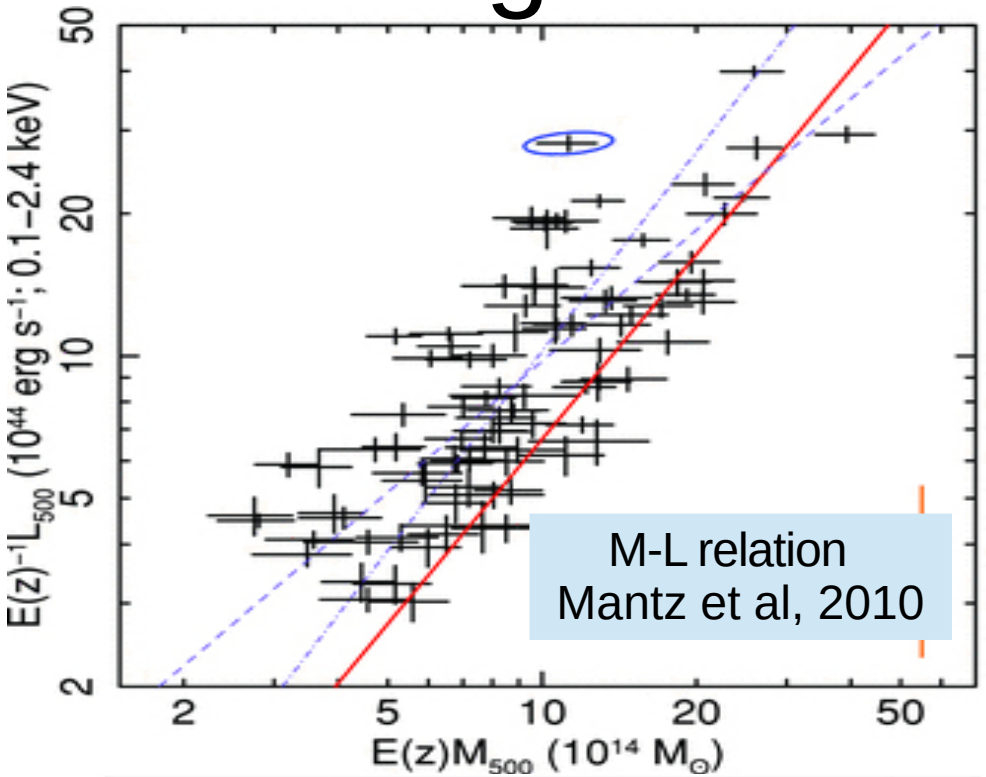
Measuring Cluster Mass

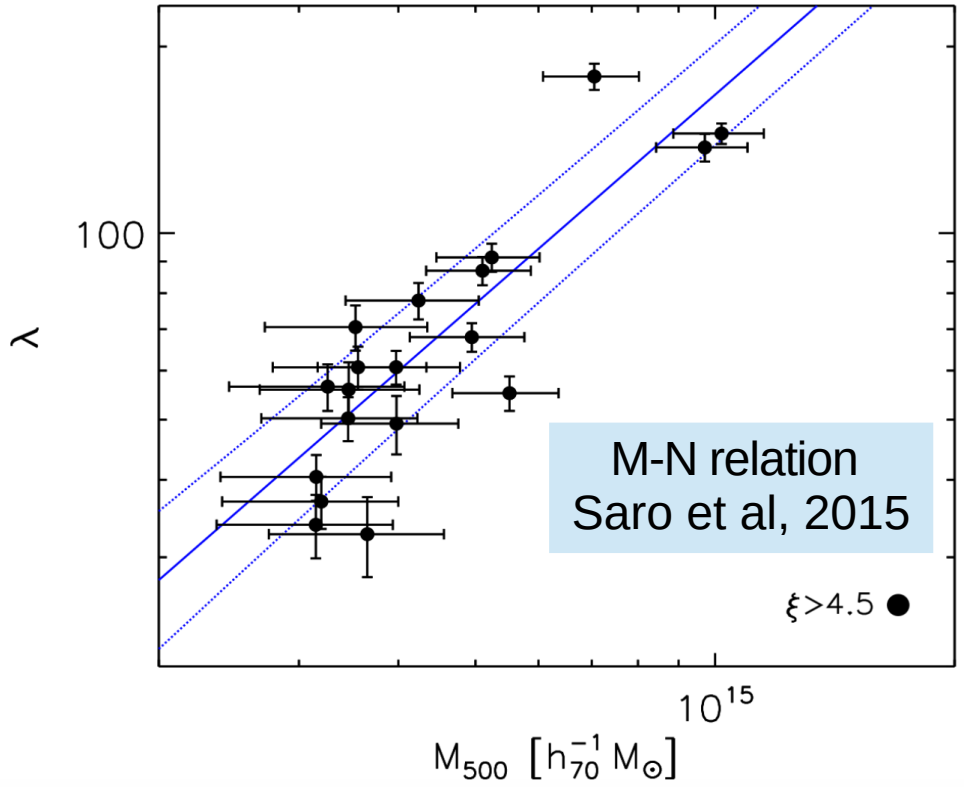
- Direct measures of cluster mass: weak lensing, dynamical mass, X-Ray hydrostatic mass
  - susceptible to systematic bias → hard to measure both data and errors
- Proxies for cluster mass – easier to measure
- Possible proxies: richness, SZ, X-ray temperature, etc.
- Need to understand:
  - Proxy → mass relation
  - Relationship between masses measured by different methods

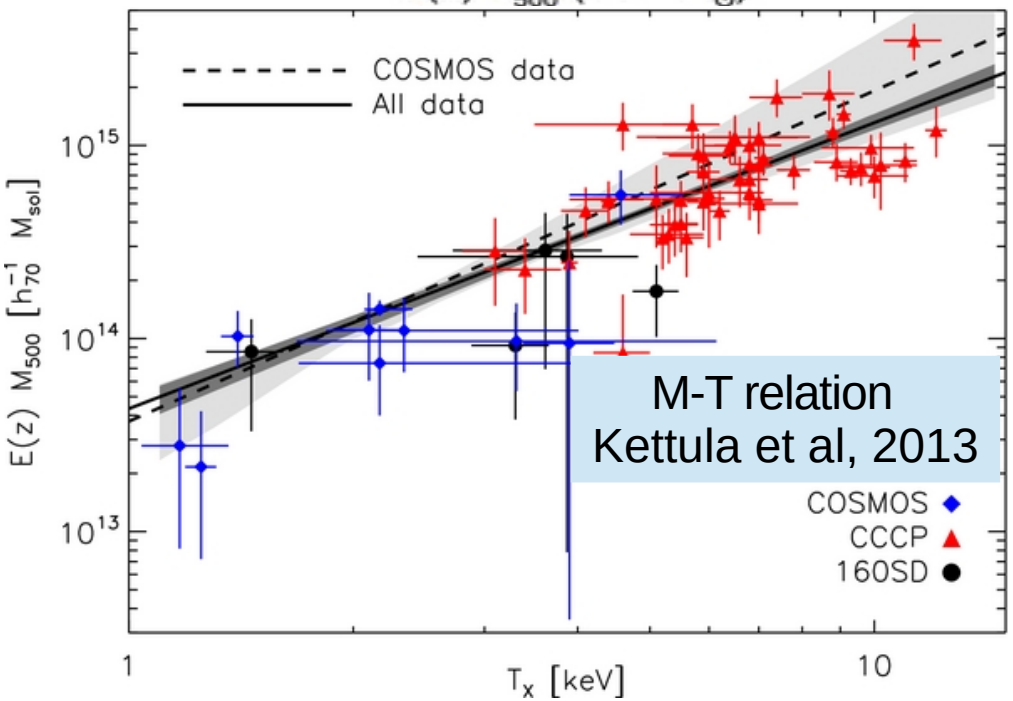
Measuring Cluster Mass

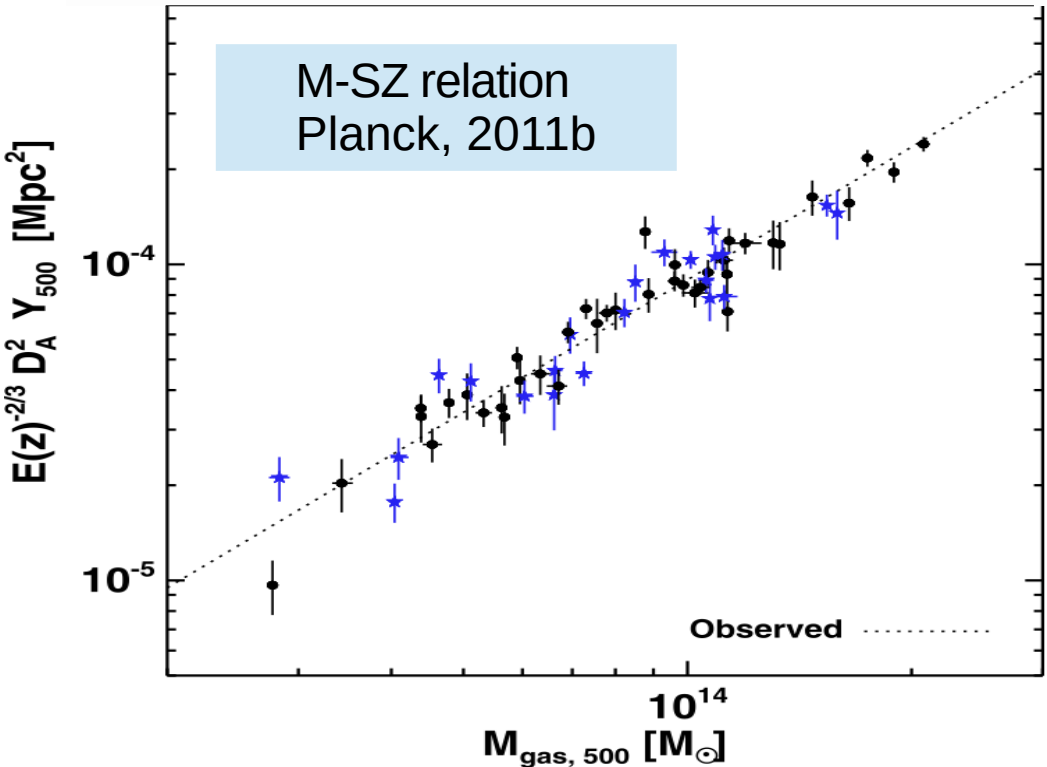
- Direct measures of cluster mass: weak lensing, dynamical mass, X-Ray hydrostatic mass
  - susceptible to systematic bias → hard to measure both data and errors
- Proxies for cluster mass – easier to measure
- Possible proxies: richness, SZ, X-ray temperature, etc.
- Need to understand:
  - Proxy → mass relation
  - Relationship between masses measured by different methods
- **Scaling Relations**

Scaling Relations



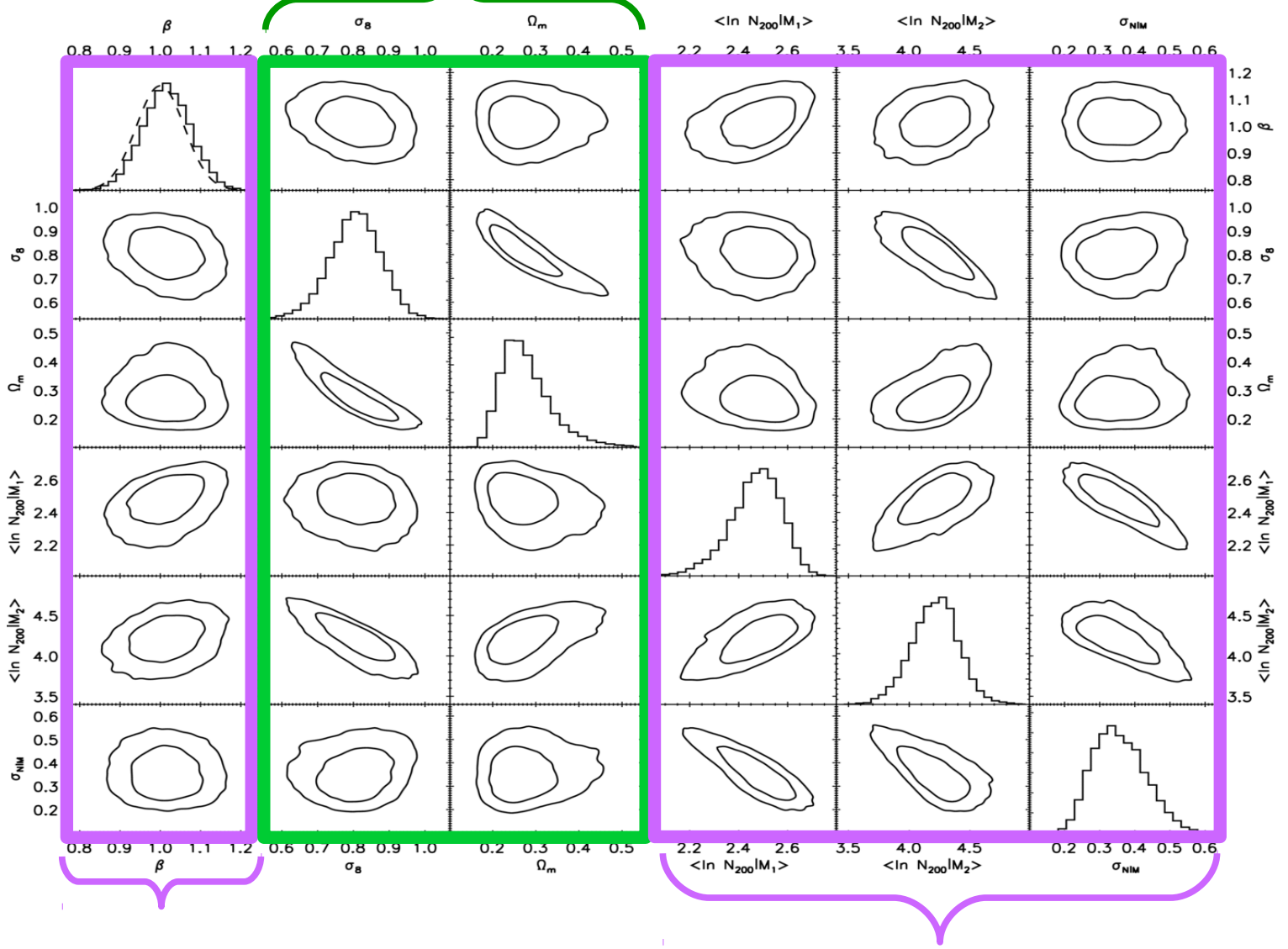






Simultaneous Measurement of Scaling Relations and Cosmological Parameters – Rozo et al., 2010

cosmological parameters



scaling relation parameters

Measuring Cluster Mass

- Direct measure of mass – weak gravitational lensing
- Light from background galaxies distorted when passing by cluster
- High cluster mass → high distortion of background galaxies

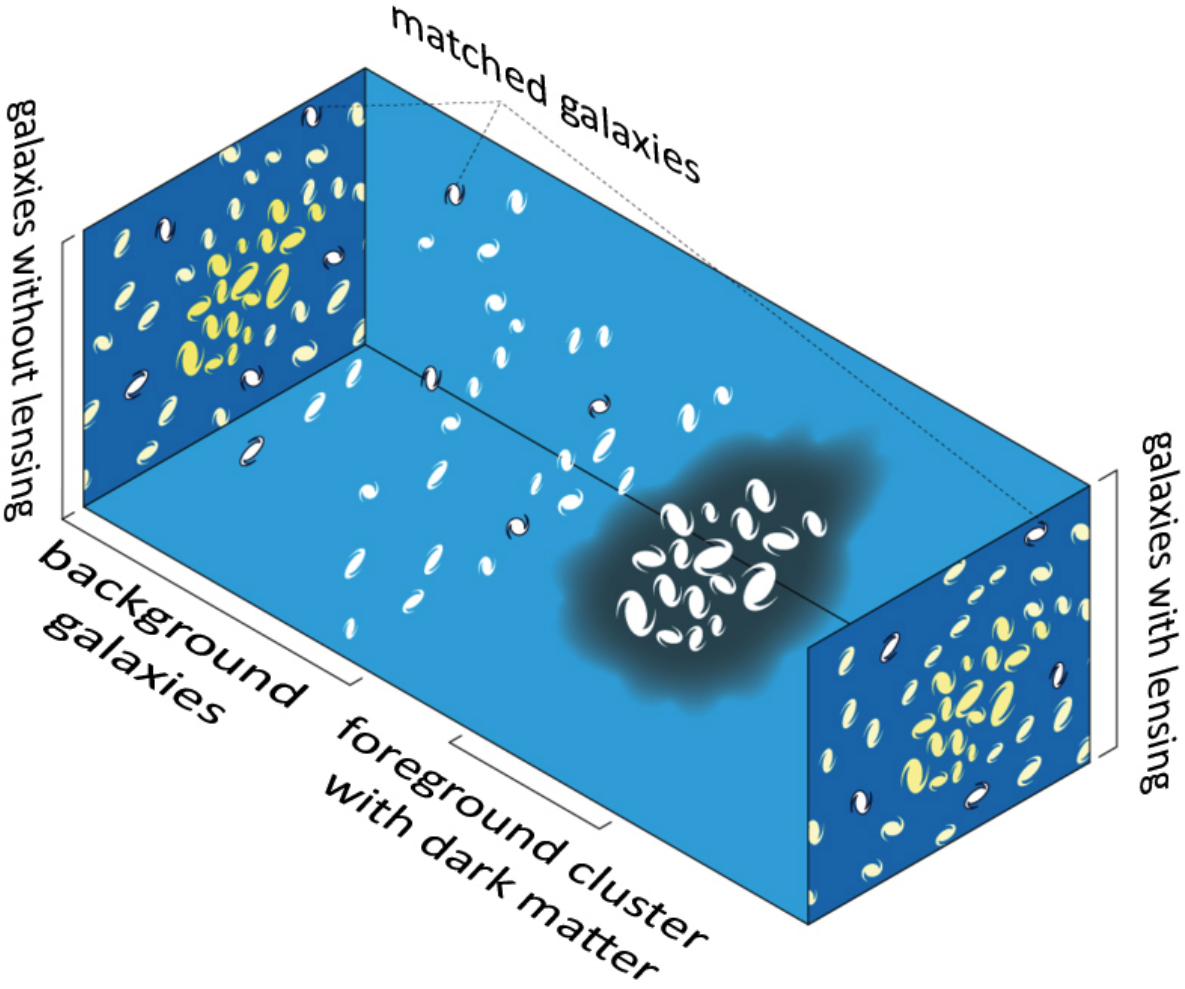


figure credit: Michael Sachs (University of California, Davis), via Wikipedia

Weak Gravitational Lensing

Unlensed

Lensed

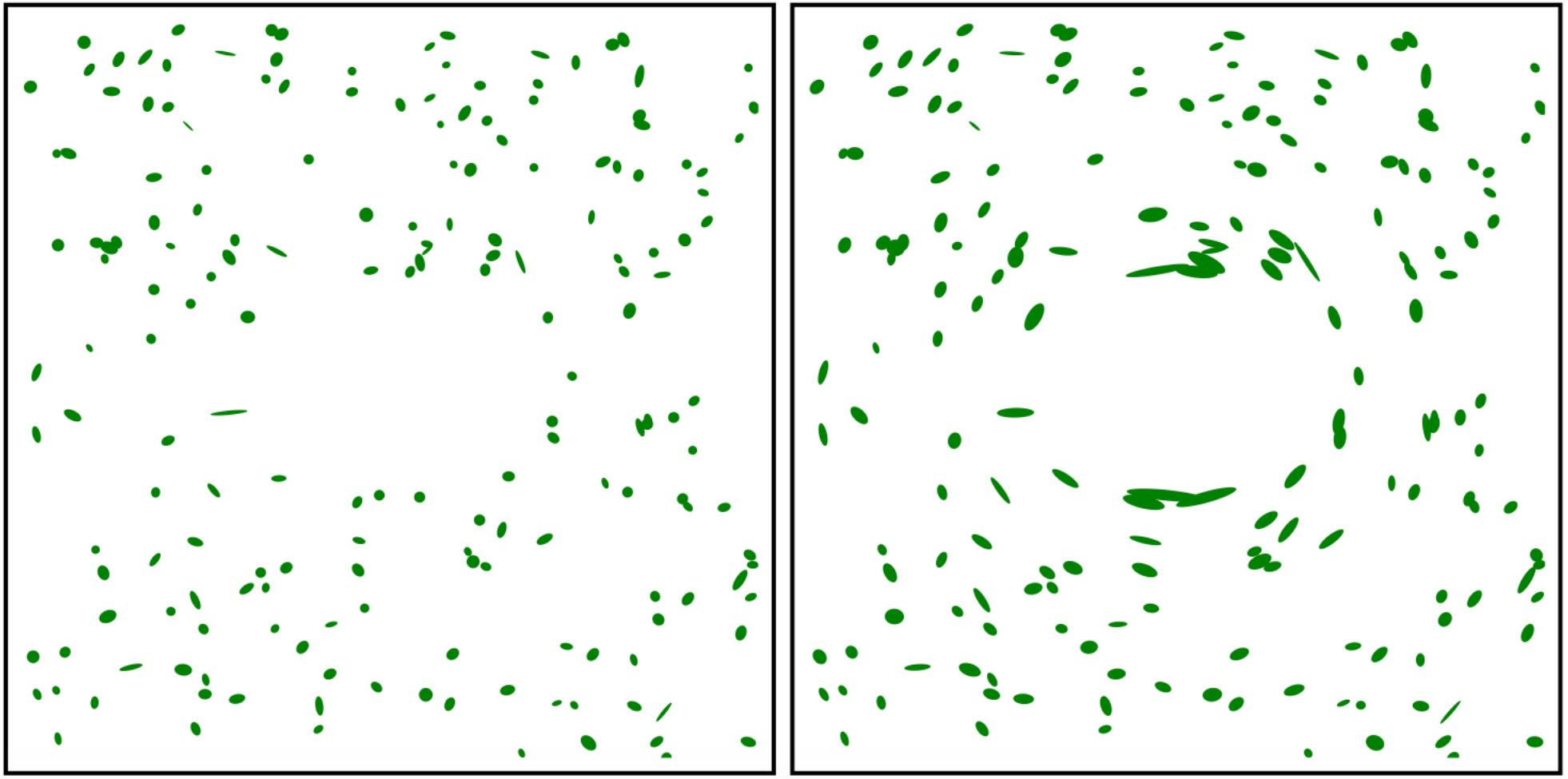
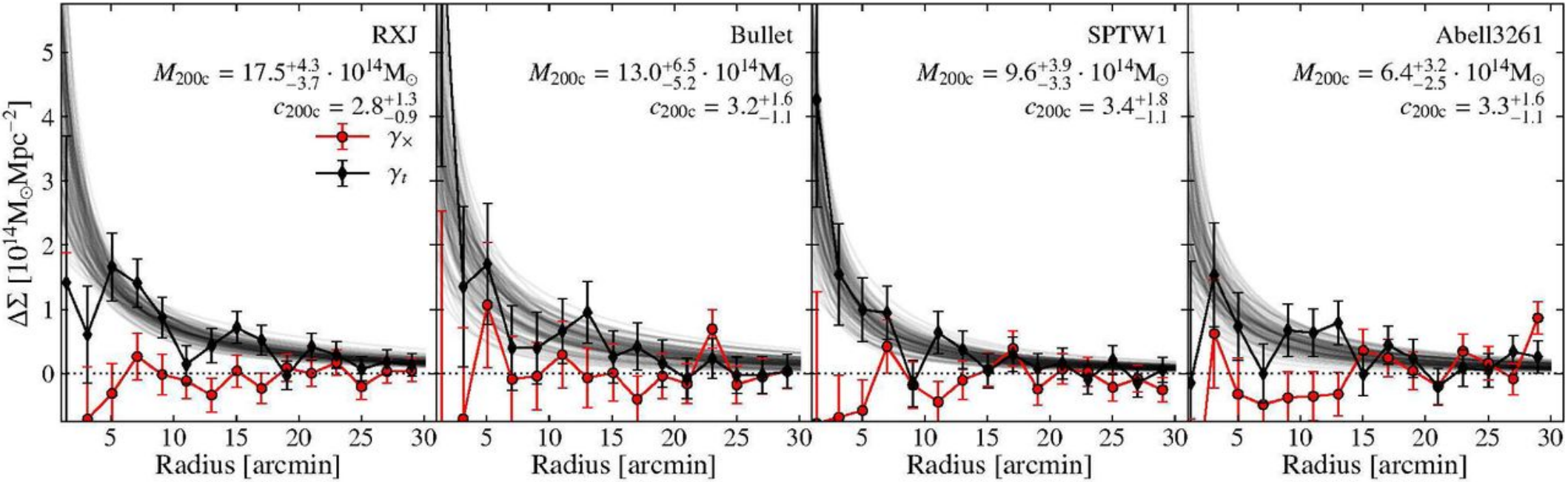


figure credit: Wikipedia

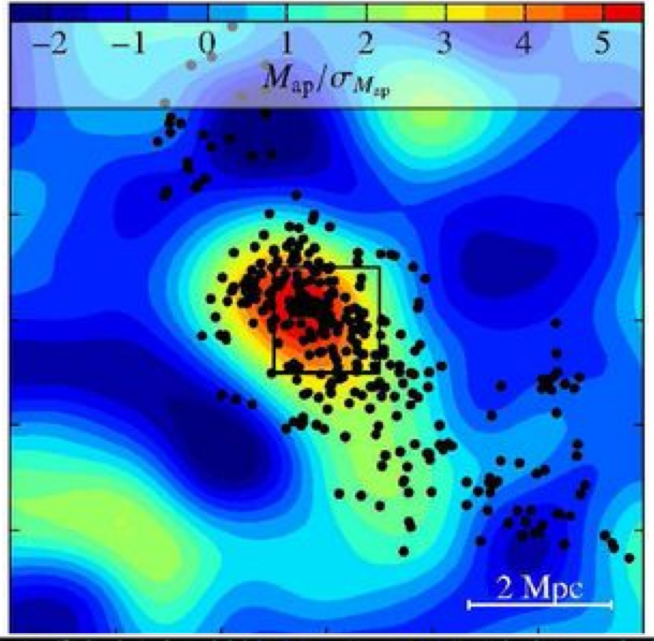
DES Cluster Weak Lensing Projects



Melchior et al., 2015

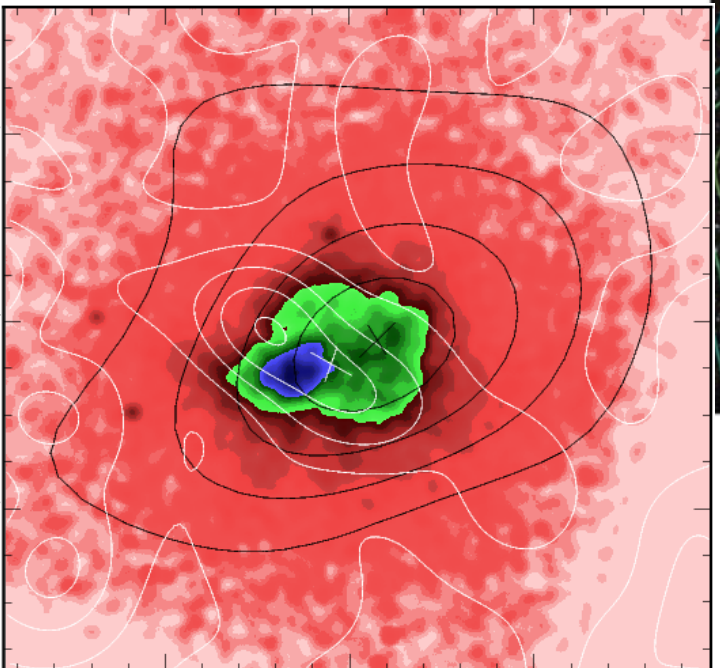
Richness

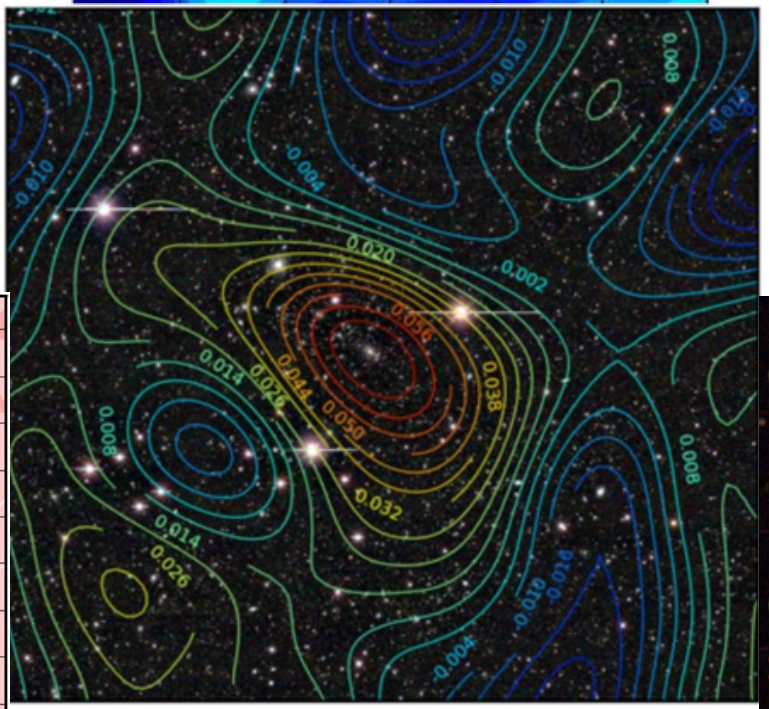
Image: Melchior et al. 2015



SZ Effect

Image: Hurley-Walker, 2012



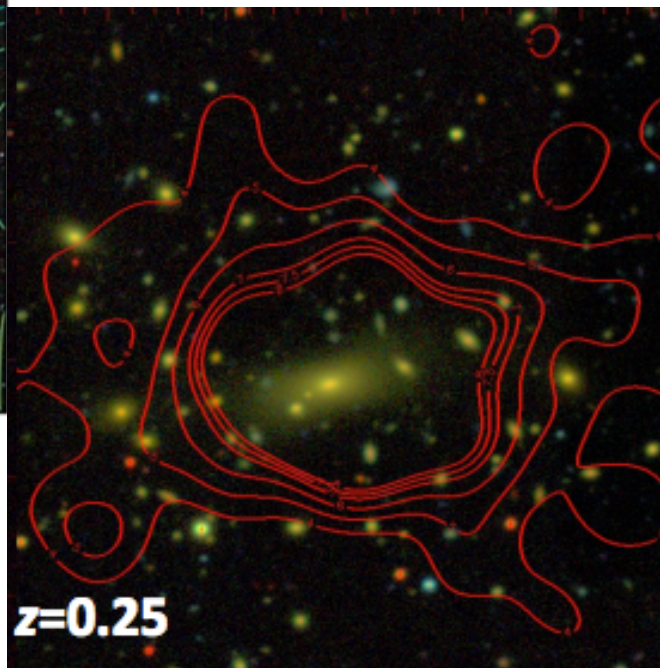


WL Mass Map

Cluster RXJ2238, z=0.35

X-Ray

Image: Philip Rooney and Chris Miller



Optically Selected Clusters

- RedMaPPer cluster-finding algorithm
- thousands of clusters found
- Expecting to find tens of thousands by end of survey
- Binned over richness to get mass-richness scaling relation

Optically Selected Clusters

Preliminary Measurements

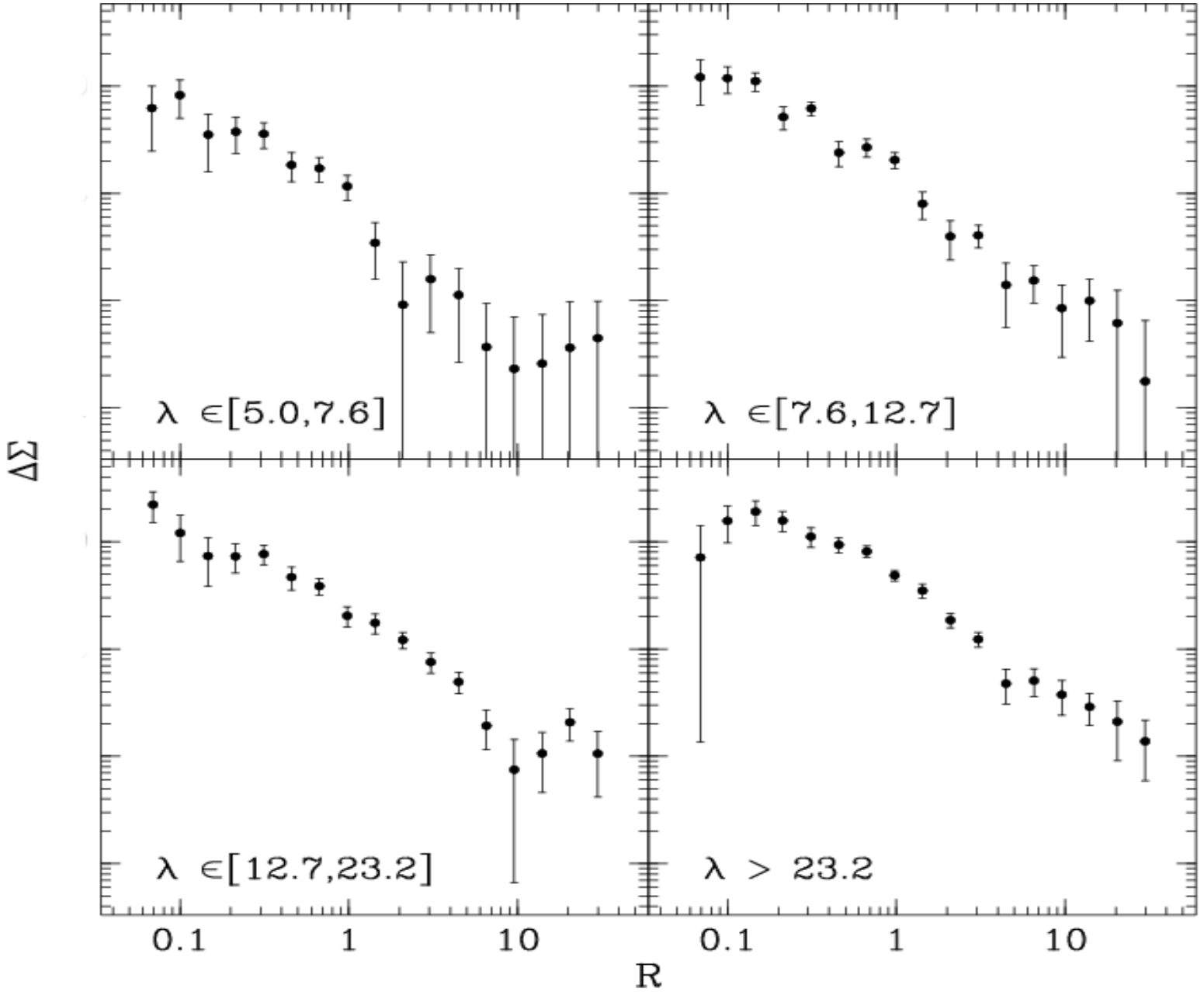
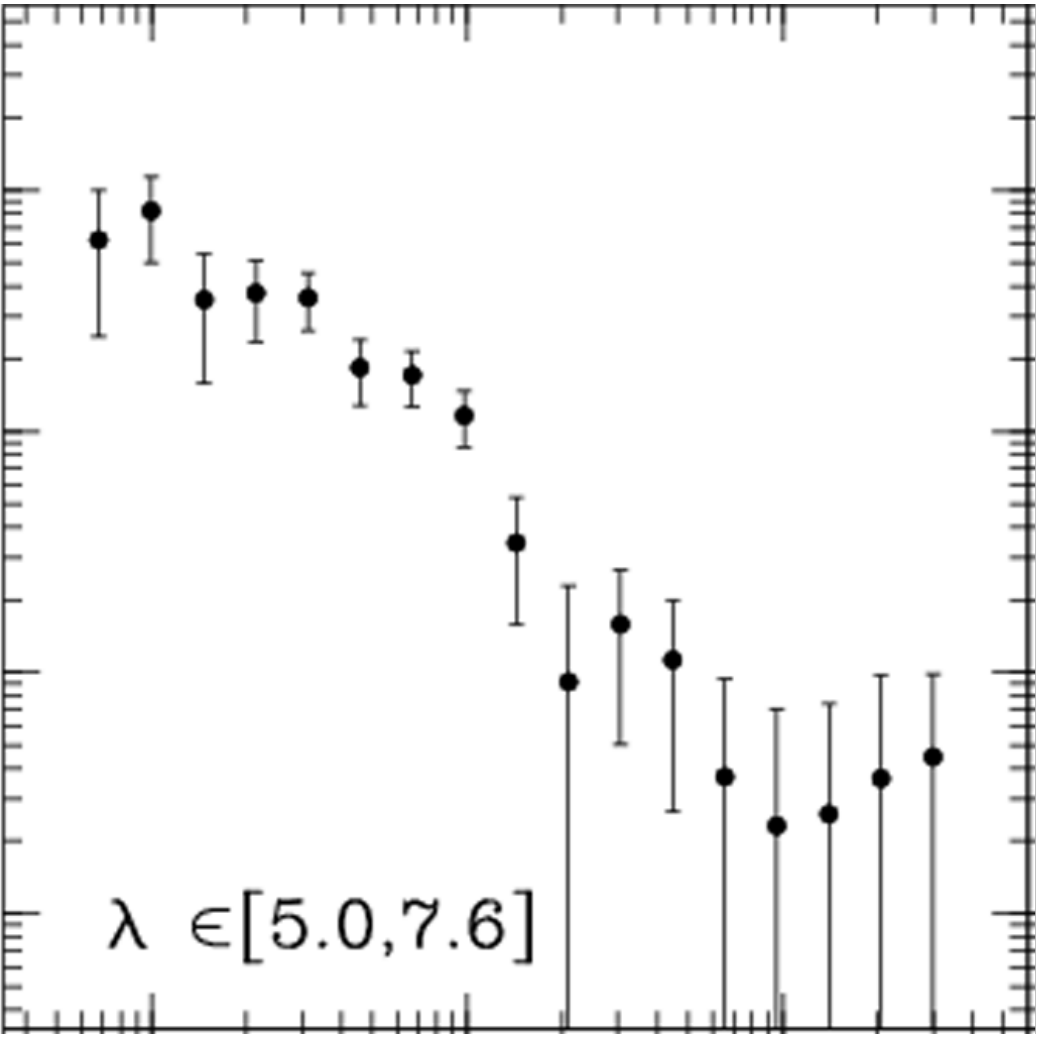


figure credit: DES RedMaPPer Mass Calibration group

Optically Selected Clusters

Preliminary Measurements



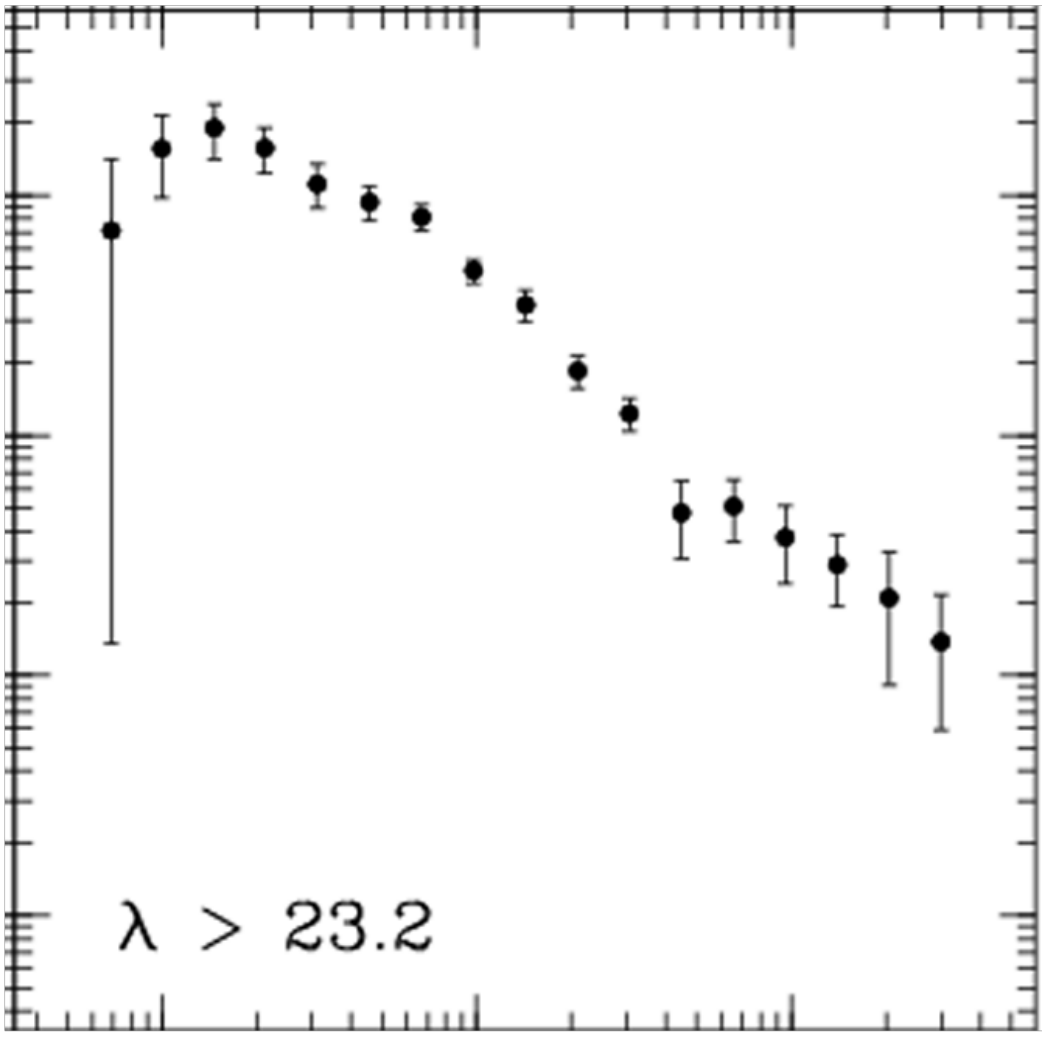
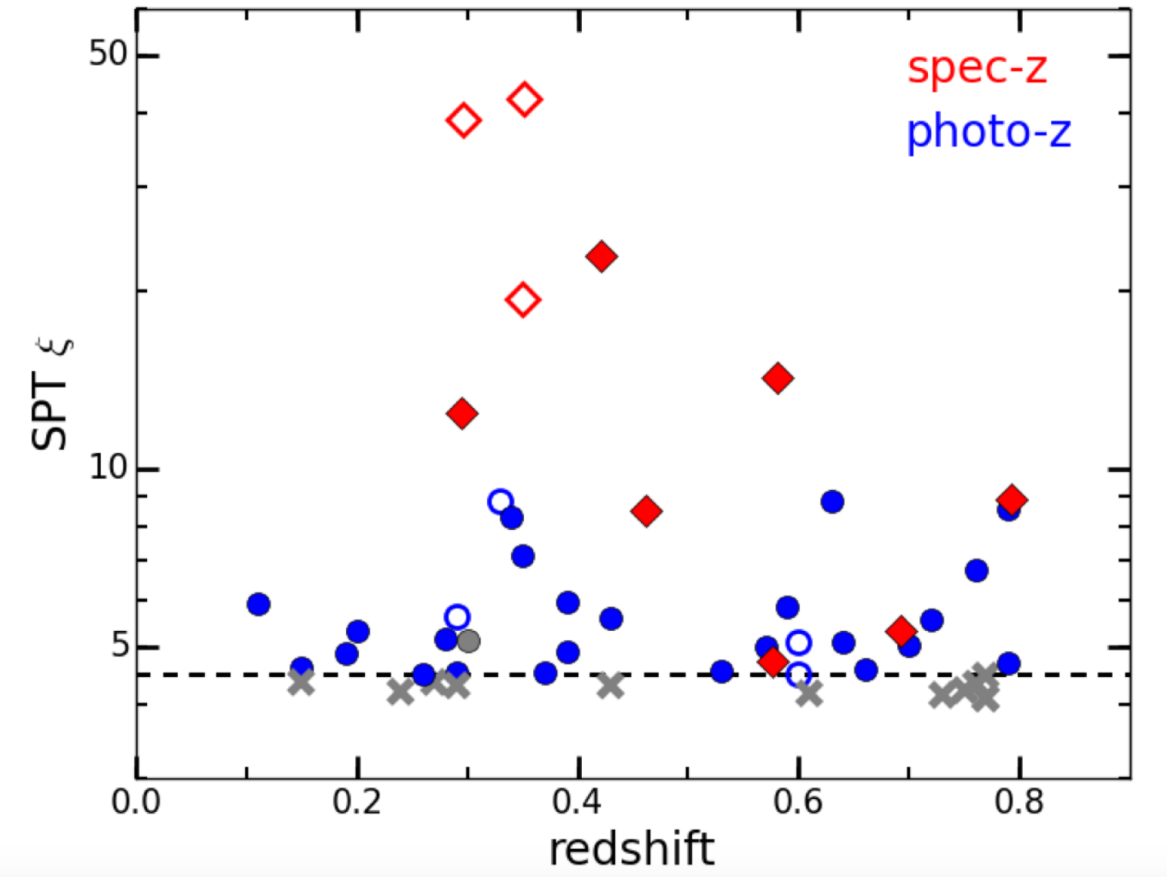


figure credit: DES RedMaPPer Mass Calibration group

SZ-Selected Clusters

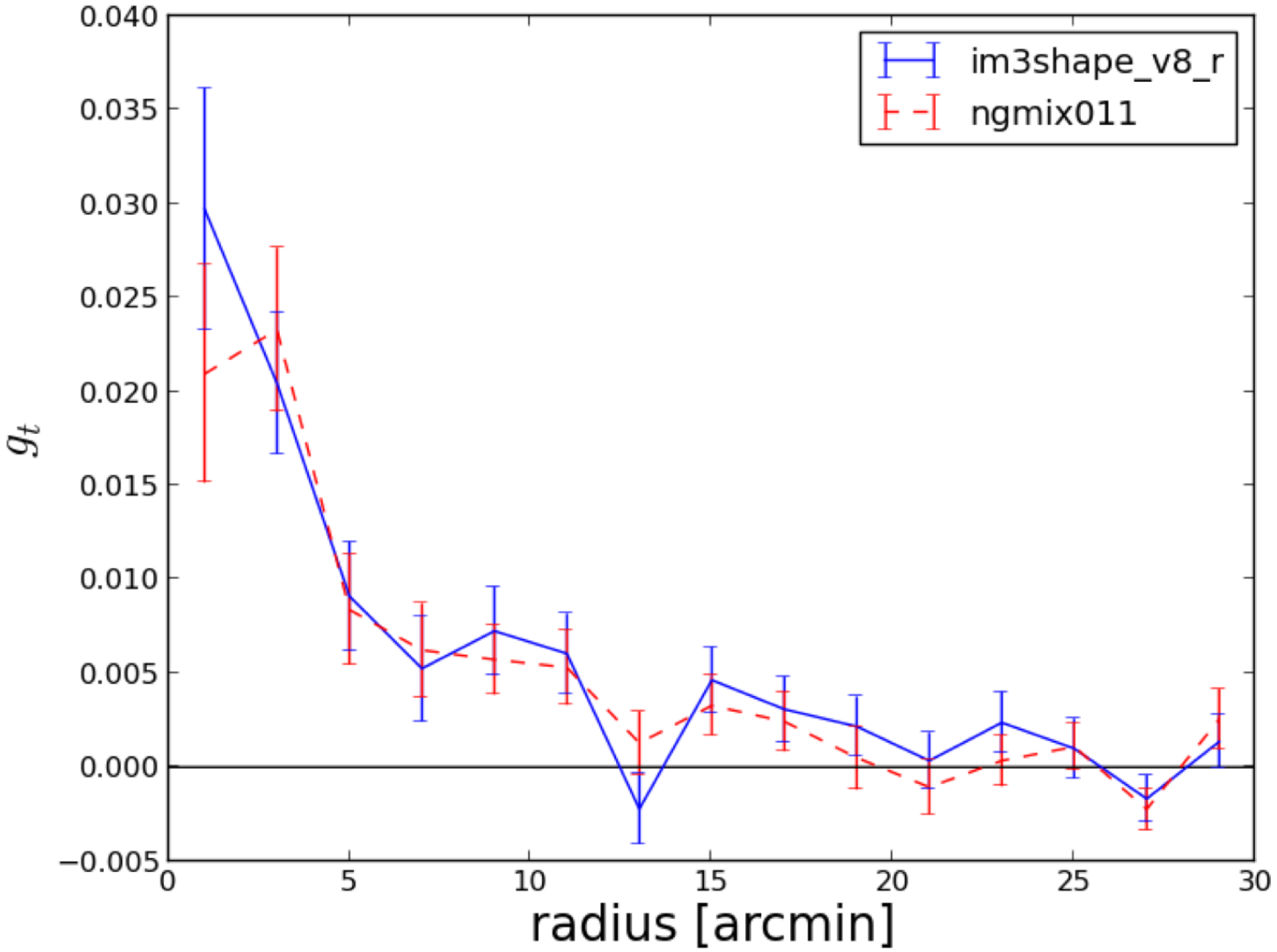
- Found by SPT
- 96 clusters in the SPT sample
- 39 clusters used
- Binned over SZ detection significance to get mass-SZ scaling relation



Gangkofner et al.; in prep

SZ Selected Clusters

Preliminary Measurements



Gangkofner et al.; in prep

X-Ray Selected Clusters

- Found by XCS
- ~175 clusters in the XCS sample
- ~120 clusters used
- Binned over X-ray temperature to get mass-temperature scaling relation

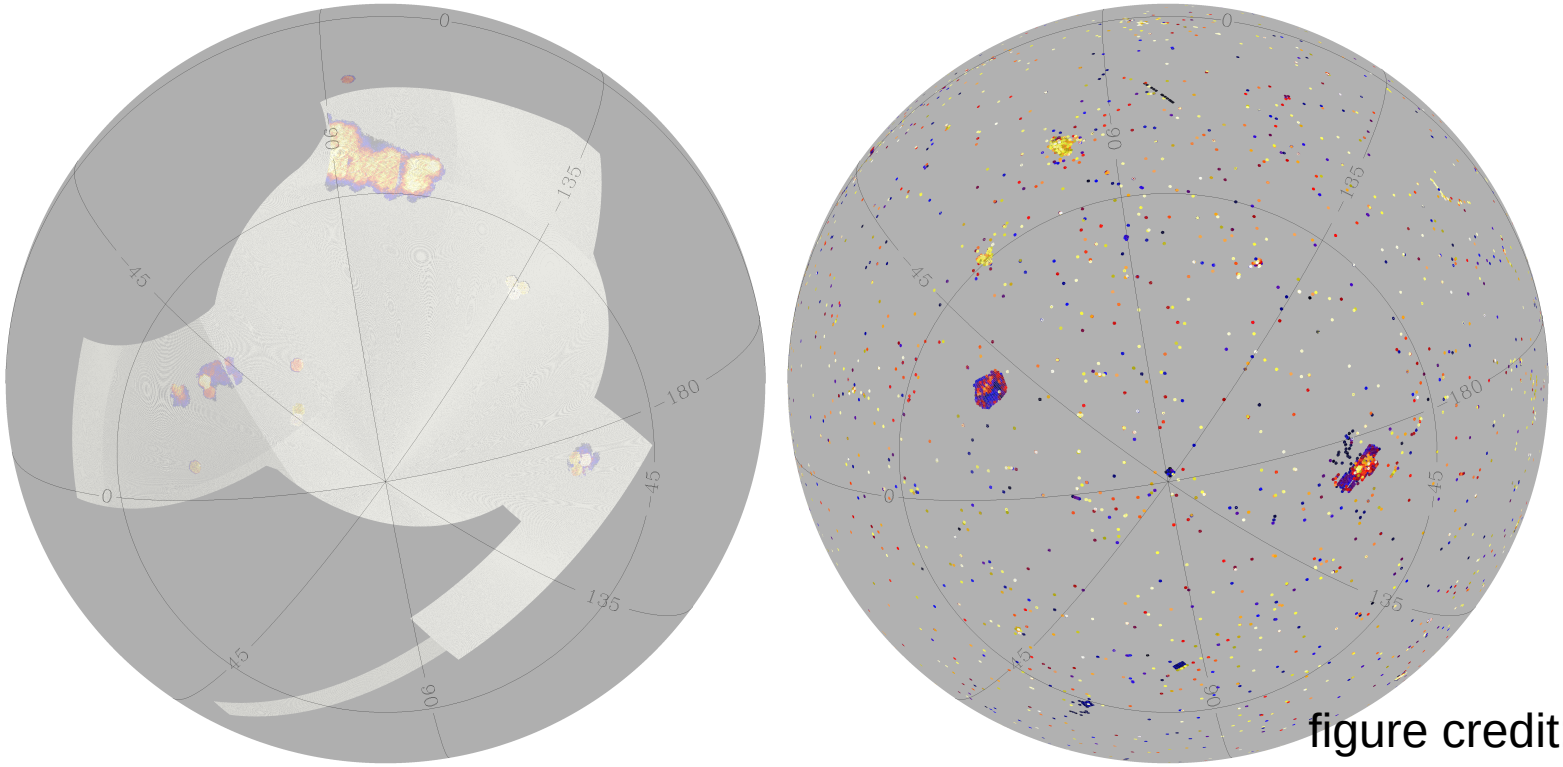
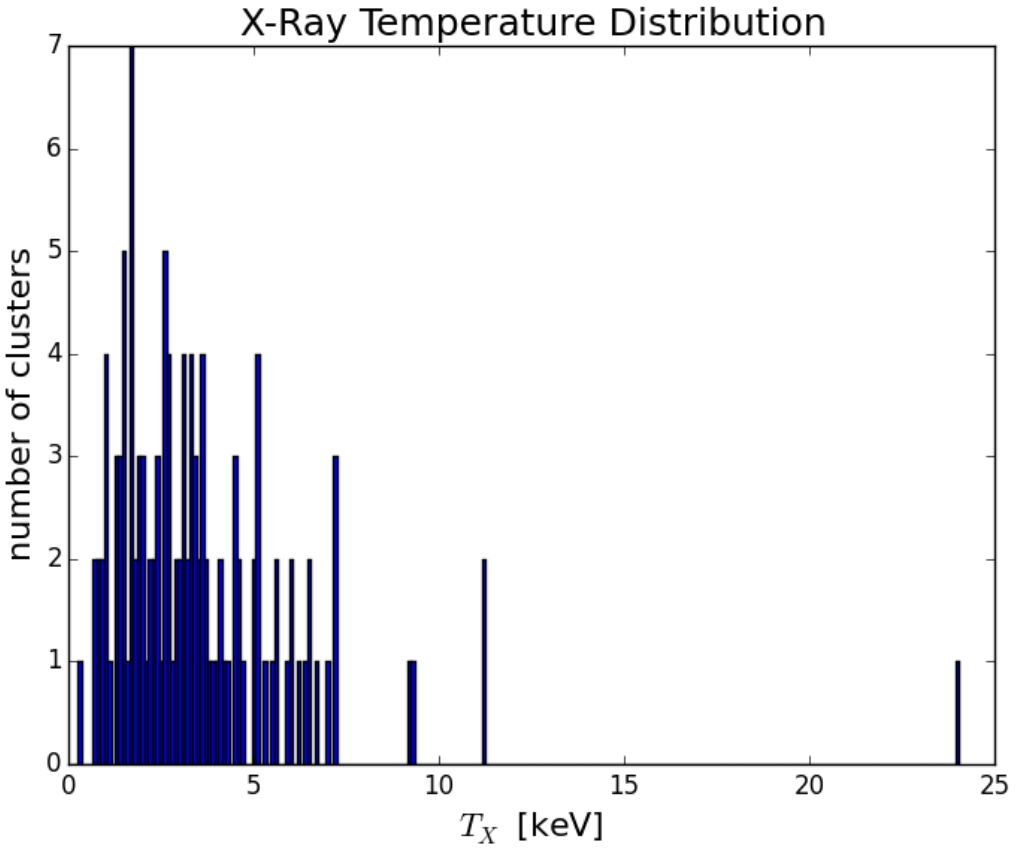
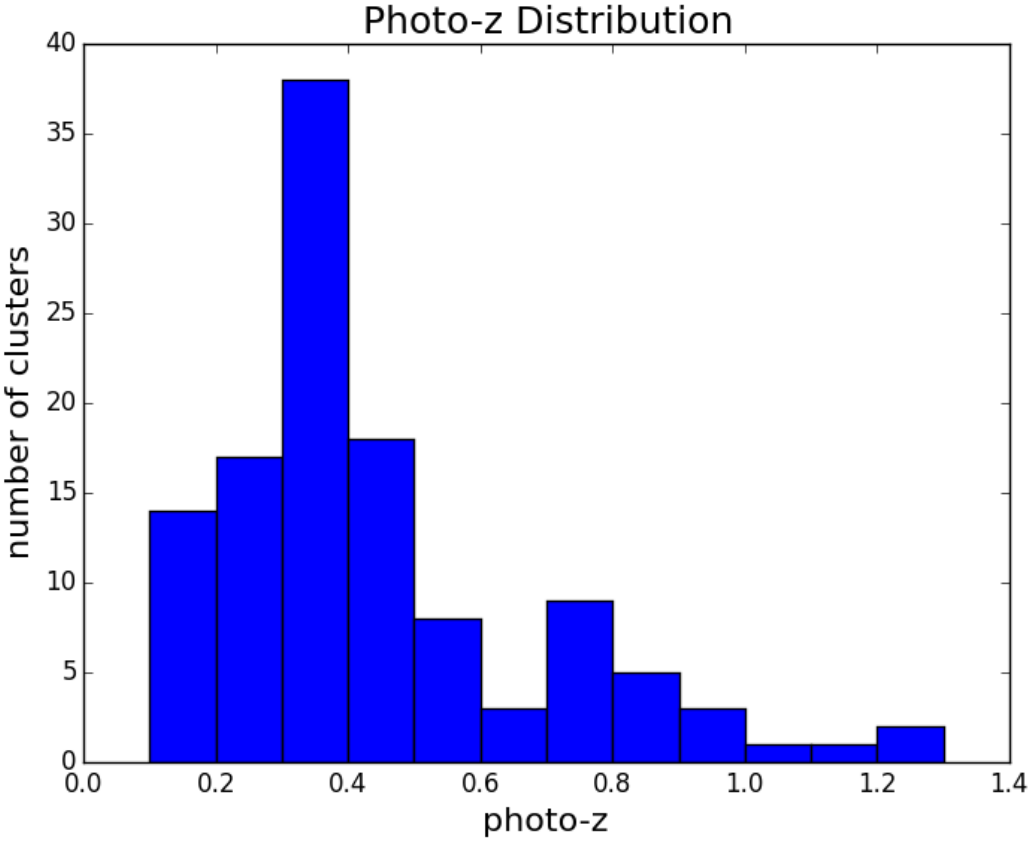


figure credit: Chris Miller

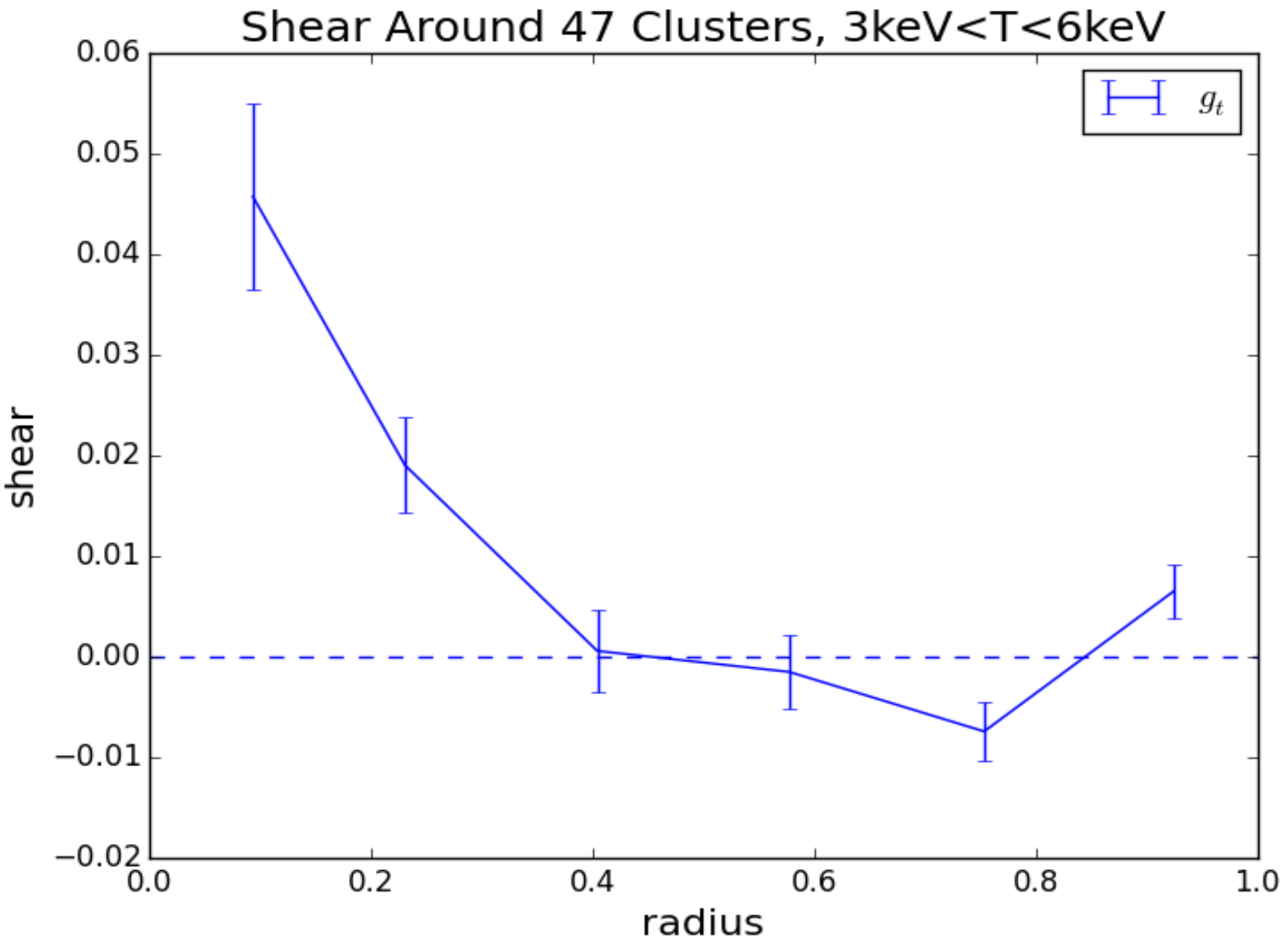
X-Ray Selected Clusters





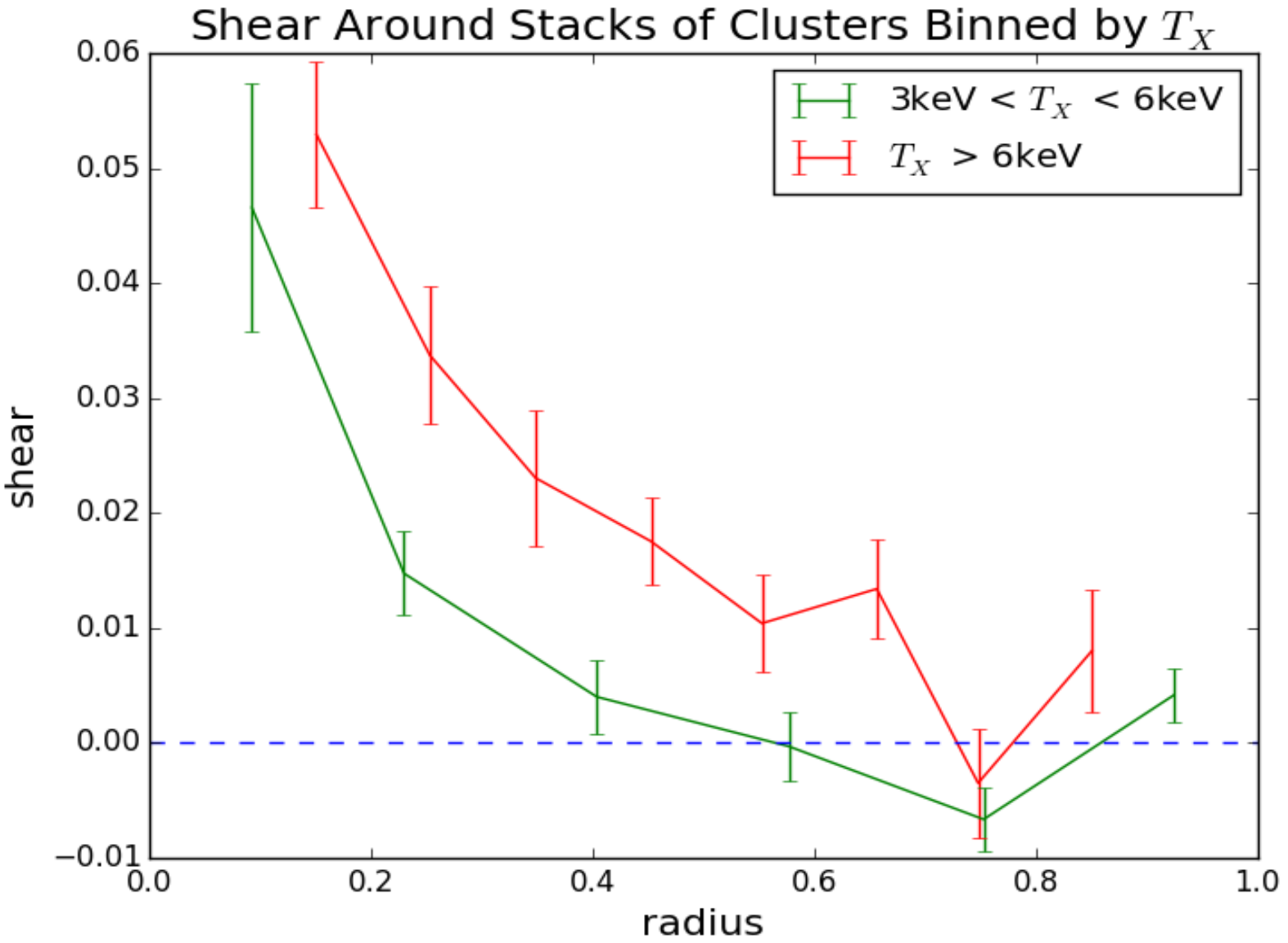
X-Ray Selected Clusters

Preliminary Measurements



X-Ray Selected Clusters

Preliminary Measurements



X-Ray Selected Clusters – Next Steps

- Measure mass-temperature scaling relation within Planck cosmology

Scaling relation parameters (variables)

$$P(\mu_{s,WL}|\mathbf{S}_{o,i},\theta,\psi) = \int \mathrm{d}\mu_s \; P(\mu_{s,WL}|\mu_s)P(\mu_s|\mathbf{S}_{o,i},\theta)P(\mu_s|\psi)$$

Probability of measuring a certain stacked WL mass, given observables (temperature), scaling relation variables, and cosmology

observables

cosmology

In Conclusion...

- Characterizing cluster mass function → constraints on cosmological parameters
- Measuring mass proxies is easier than directly measuring cluster mass → scaling laws
- DES is characterizing scaling relations between cluster mass and richness, SZ, and X-ray observables
- Preliminary results look promising
- Lots of wonderful science coming up!

References

- A. Vikhlinin et al. 2009 ApJ 692 1060
- Eduardo Rozo et al. 2010 ApJ 708 645.
- Gangkofner et al. In prep.
- Hurley-Walker N., et al; AMI Consortium. MNRAS 2012;419:2921.
- K. Kettula et al. 2013 ApJ 778 74.
- Melchior, P. et al. MNRAS 2015;449:2219.
- Planck Collaboration. A&A. Vol. 536. 2011b. p. A11.
- Saro, A. et al. Submitted to MNRAS.

Thank you!