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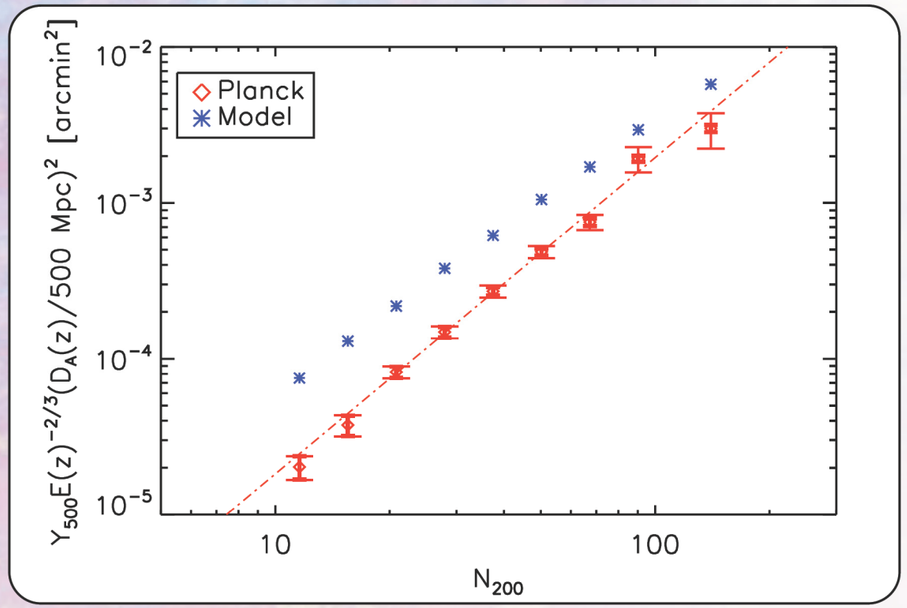
The SZ-Optical Scaling Relation

James G. Bartlett (APC - Université Paris Diderot/JPL - California Institute of Technology)
For the Planck Collaboration

Planck Collaboration arXiv 1101.2027

SZX Huntsville, September 2011



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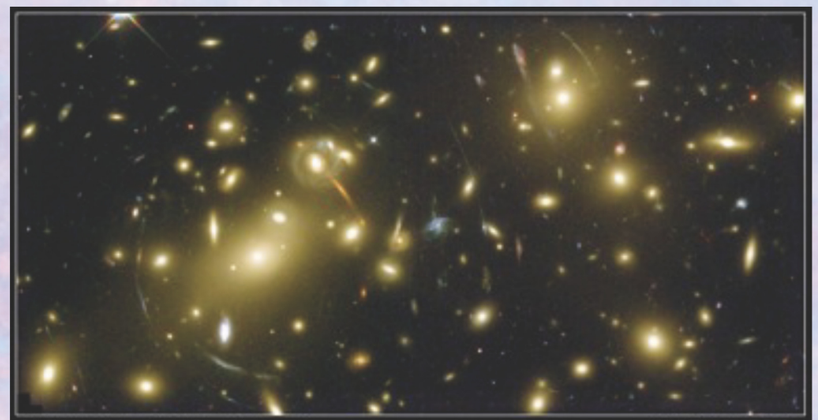
THREE FACES OF GALAXY CLUSTERS

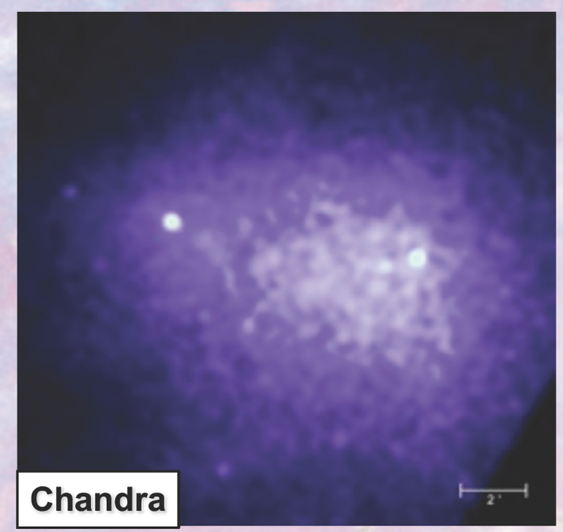
Dark Matter
Lensing
Dynamics

M_{500}



Galaxies:
Optical
IR

N_{200}



Hot gas:
X-rays

L_{500}, T

SZ Effect

Y_{500}

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PLANCK SZ-OPTICAL RELATIONS

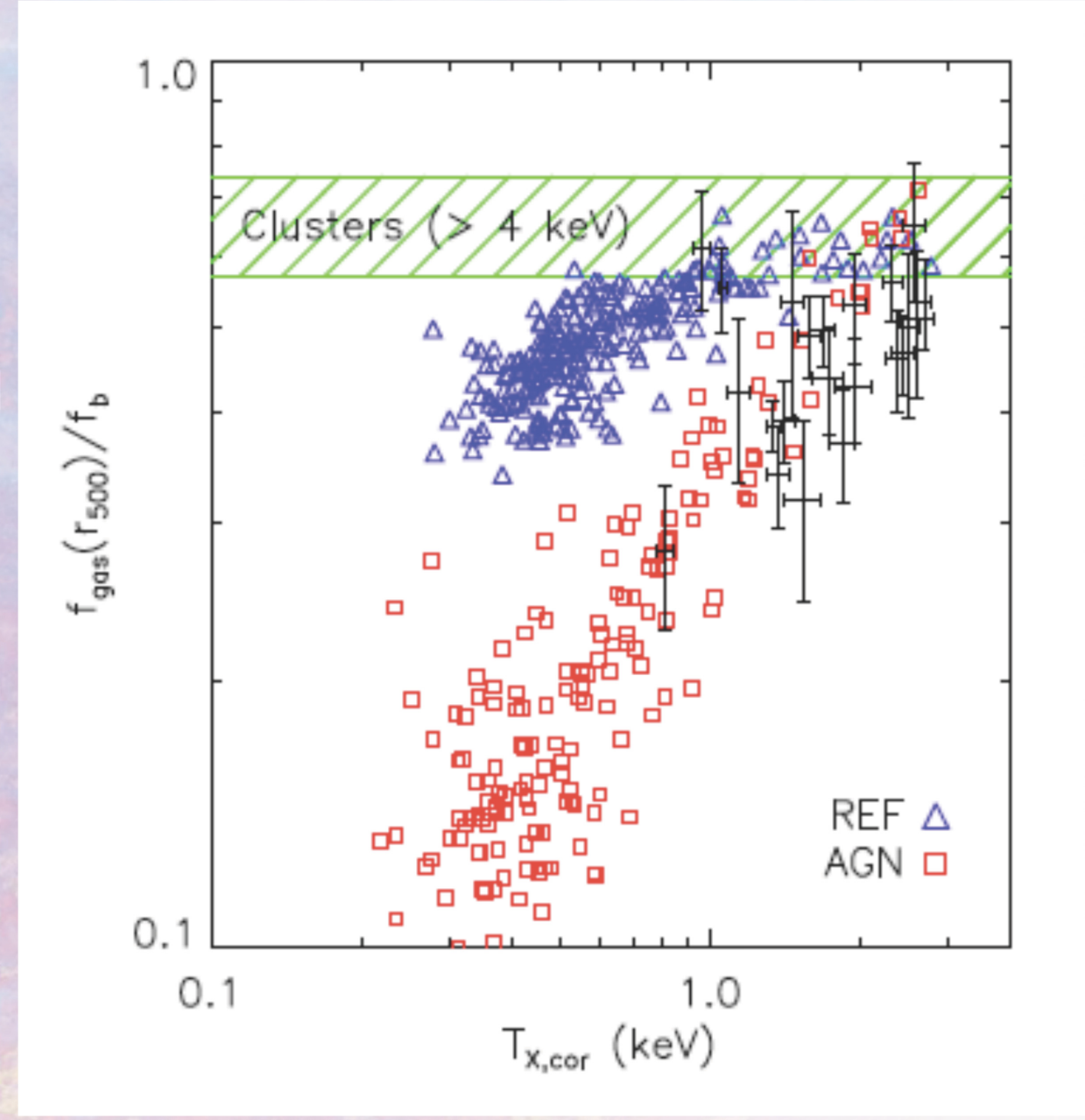
- **NEW with Planck:** SZ-optical scaling relation
- SZ-Richness-Mass (Y_{500}, N_{200}, M_{500})
  - Optically selected cluster population: different population & smaller systems
  - **Motivation: a new scaling law**
    - Understanding the cluster population
    - Galaxy formation (gas-galaxy connection)
    - Reaching low-mass systems (feedback effects)
      - *Transition systems; SZ power spectrum*
- Possible thanks to Planck's all-sky coverage

IMPORTANCE OF LOW-MASS SYSTEMS

McCarthy et al.(2010)

Simulations: red, blue
Data: Sun et al. (2009)

- Feedback processes should preferentially affect low mass objects
- Low-mass systems important to SZ power spectrum (e.g., SPT, ACT results)
- Where most of the mass is!



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THE PLANCK STUDY

Planck SZ observations of the MaxBCG catalog

- The MaxBCG optical cluster catalog: N_{200}, M_{500}
  - Red-sequence galaxy groupings around BCGs in SDSS galaxy photometric catalog (*Koester et al. 2007*)
  - 13,823 clusters/groups over 7,500 sq. degs.
  - Richness N_{200} (>0.4L* E/S0 ridgeline galaxies): 10-190
  - $0.1<z<0.3$ with $\Delta z \sim 0.01$ (from spectroscopic subsample)
  - Two weak-lensing calibrated M_{500}-N_{200} relations
    - *Johnston et al. (2007)*
    - *Rozo et al. (2009):* restricted to public MaxBCG catalog ($N_{200}>10$) & better treatment of photo-zs

PLANCK SZ MEASUREMENTS

6-band (100-857 GHz) matched SZ filter (*Melin et al. 2006*)

- Filter
  - Optimized for thermal SZ spectrum
  - Spatial template: universal pressure profile (Arnaud et al. 2010)

- For each MaxBCG cluster: Y_{500} *13,104 clusters*
  - N_{200} => M_{500} (weak-lensing calibration)
  - M_{500} => R_{500}: adapt filter scale
  - Determine $\tilde{Y}_{500} = Y_{500} E^{-2/3}(z)(D_{\rm A}/500{\rm Mpc})^2$

    Scaled (intrinsic) SZ signal strength (arcmin^2)

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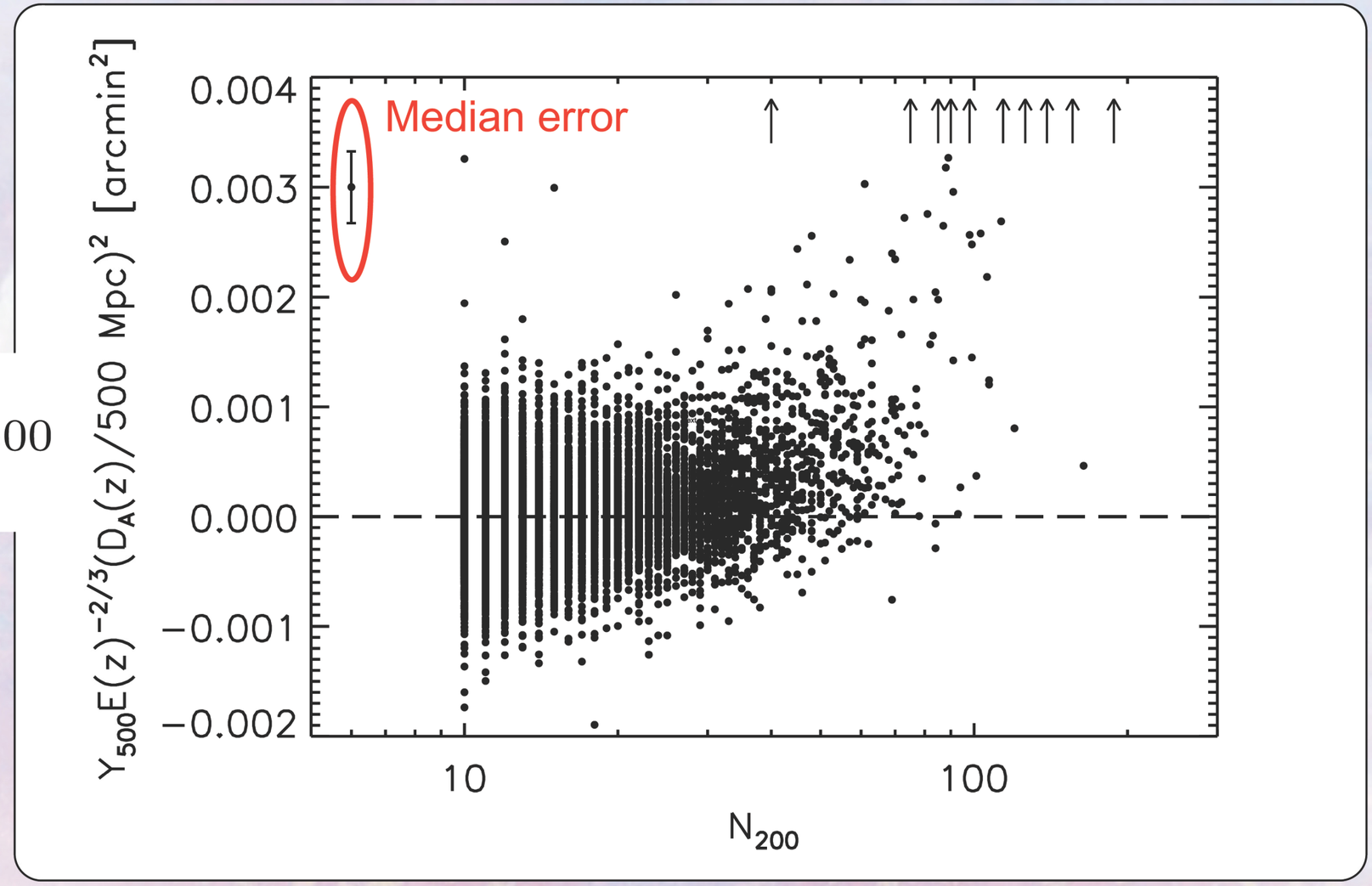
INDIVIDUAL SZ MEASUREMENTS

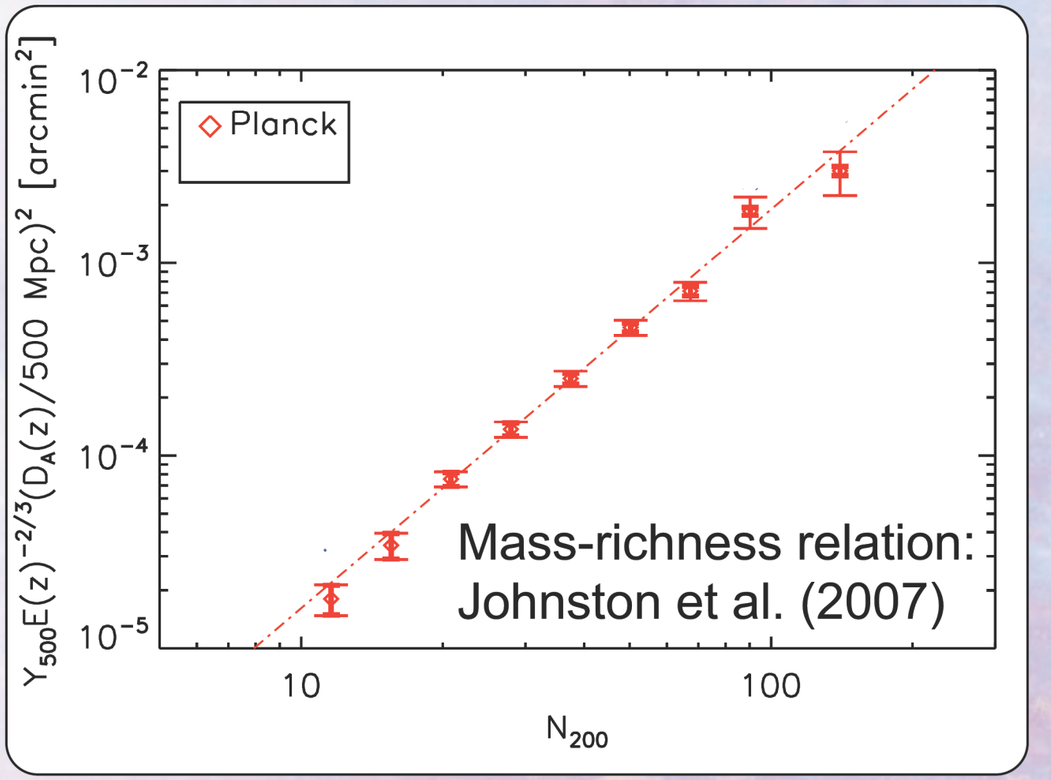


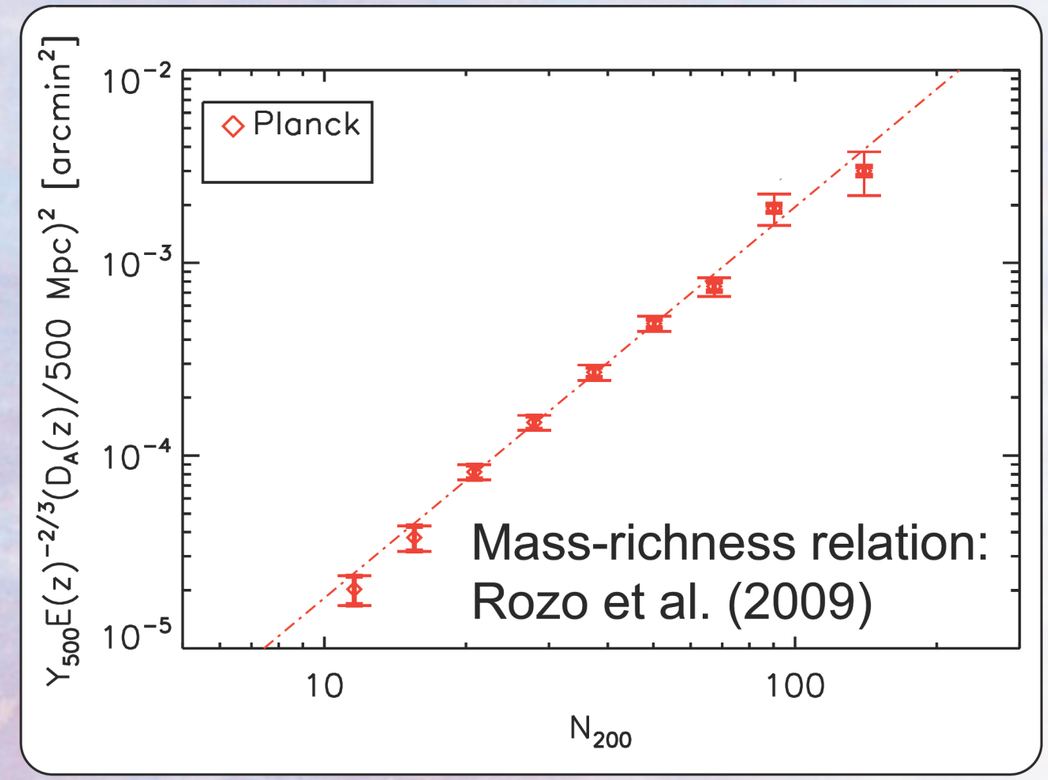
$\tilde{Y}_{500}$

S/N of each measurement is low => bin-up

THE SZ-RICHNESS SCALING LAW

Scaled, bin average SZ signal





- The measurements are insensitive to mass calibration
- Solid error bars: measurement uncertainty
- Thin error bars: bootstrap over 10,000 samples
- Well described by power law

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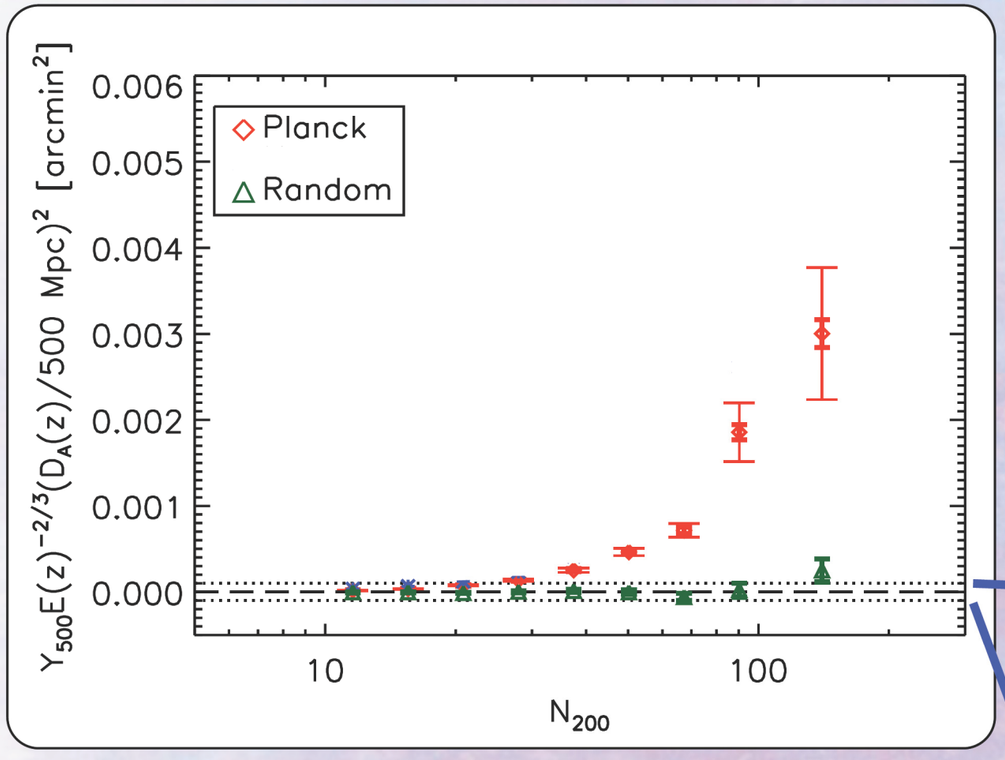
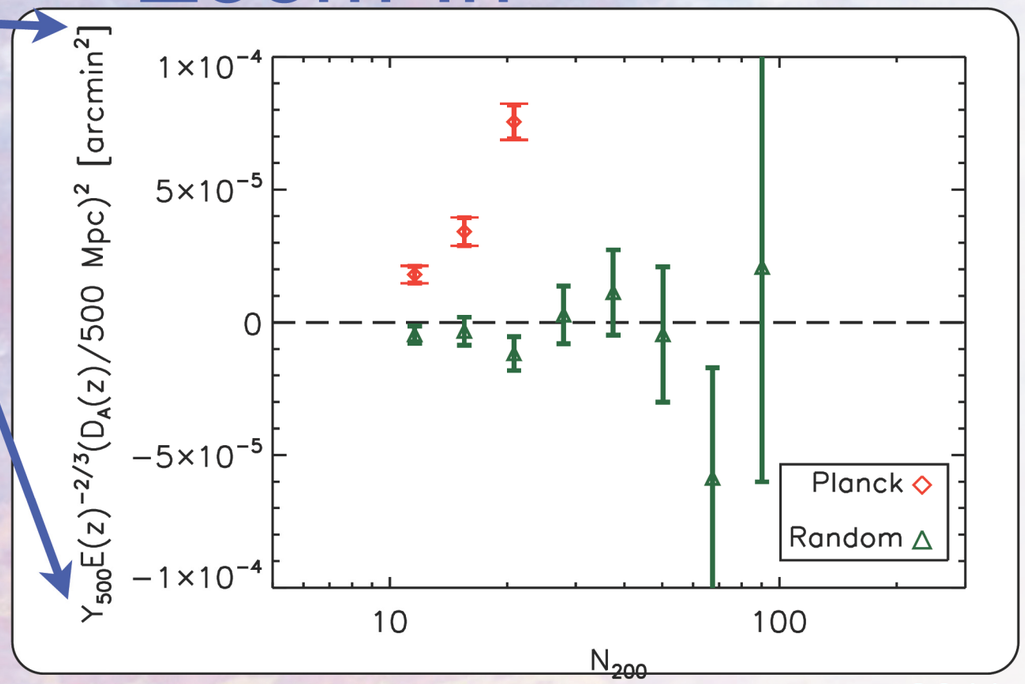
HIGHLY SIGNIFICANT SZ DETECTION



Null Test: Randomly placed filter positions

Zoom-In



Highly significant detection for all richness bins

THEORETICAL PREDICTIONS

Weak lensing + X-ray based model

- Mass-richness relations calibrated from weak-lensing (Johnston et al. 2007, Rozo et al. 2009)

$$M_{500} - N_{200}$$

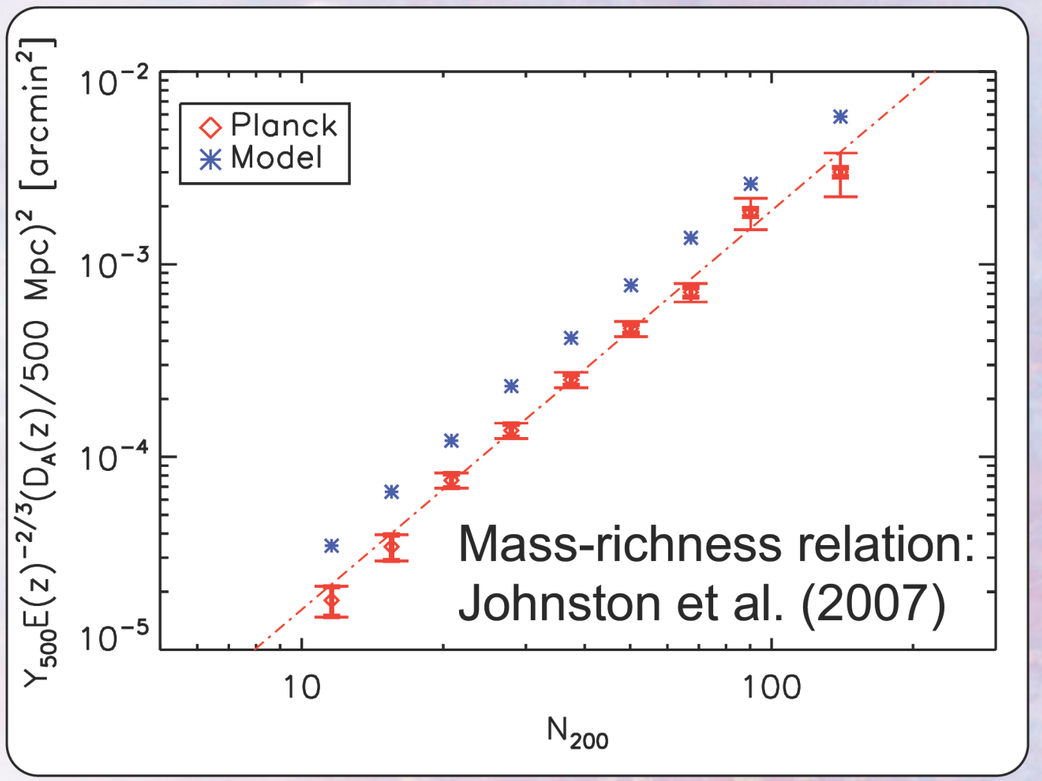
- REXCESS X-ray model (STD case, Arnaud et al. 2010)

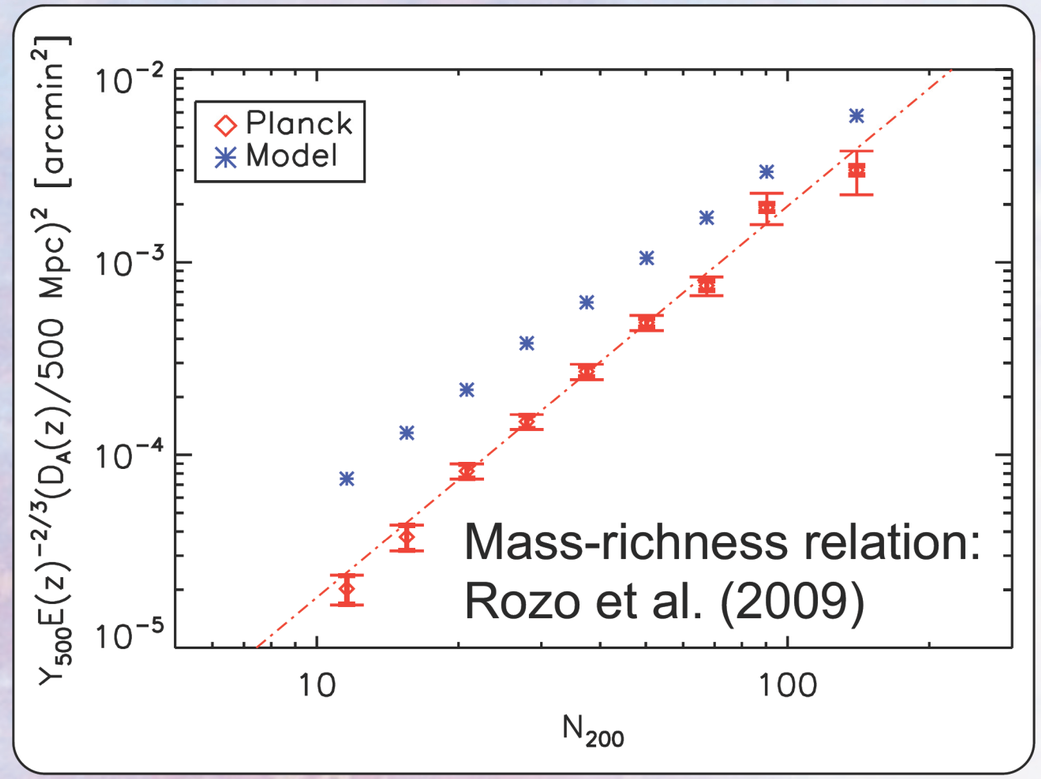
$$Y_{500} - M_{500}$$

- Each cluster weighted with the same (inverse noise) weight as in the real data

COMPARISON TO THEORY

- Higher mass calibration in Rozo et al.: model points move up
- Data points insensitive to mass calibration: data points ~same





Disagreement between theory and observations

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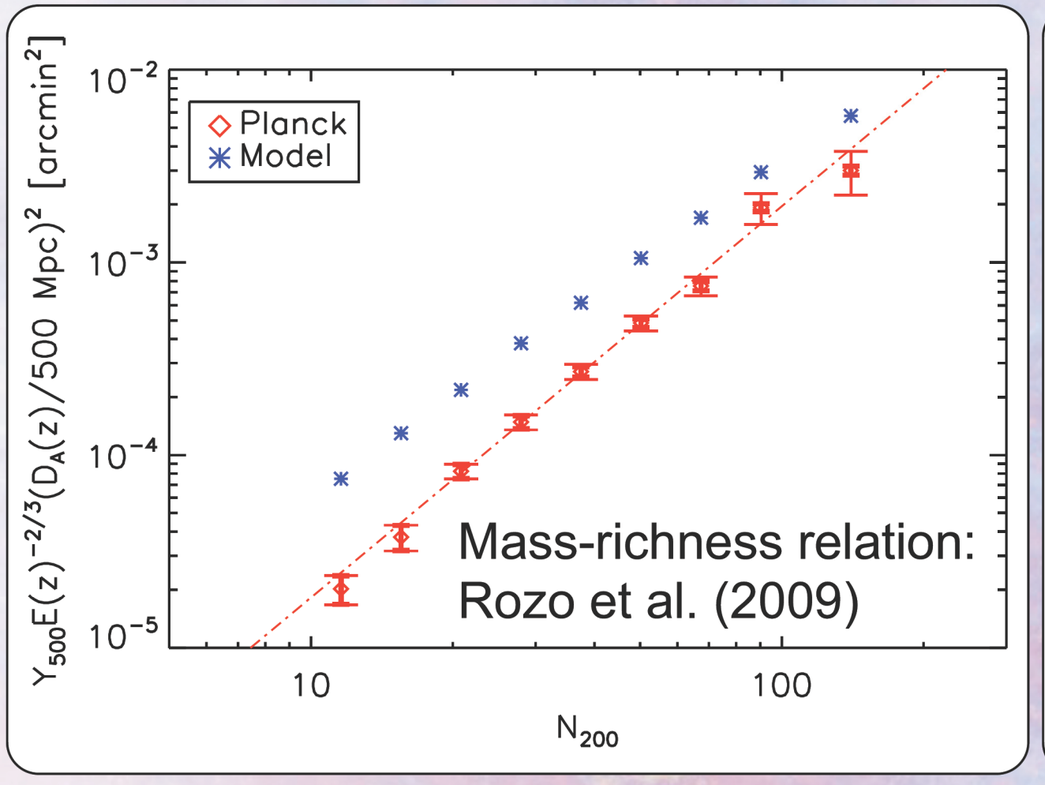
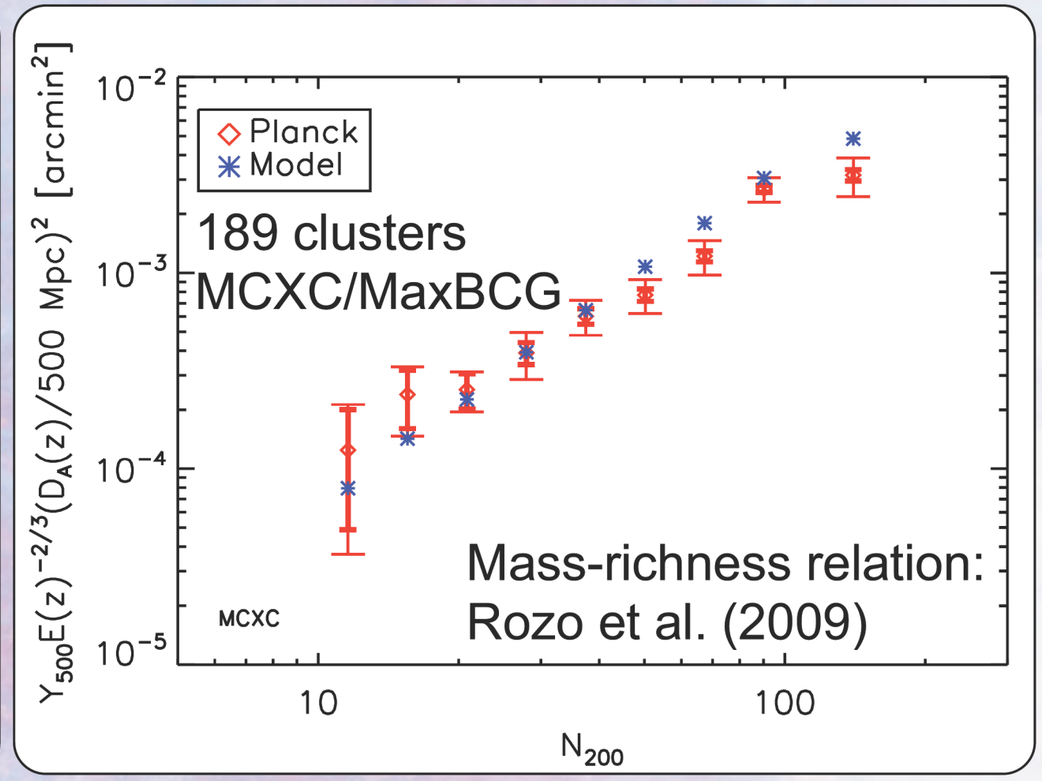
AN X-RAY SUBSAMPLE OF MAXBCG

X-ray clusters from MCXC (Piffaretti et al. 2010)

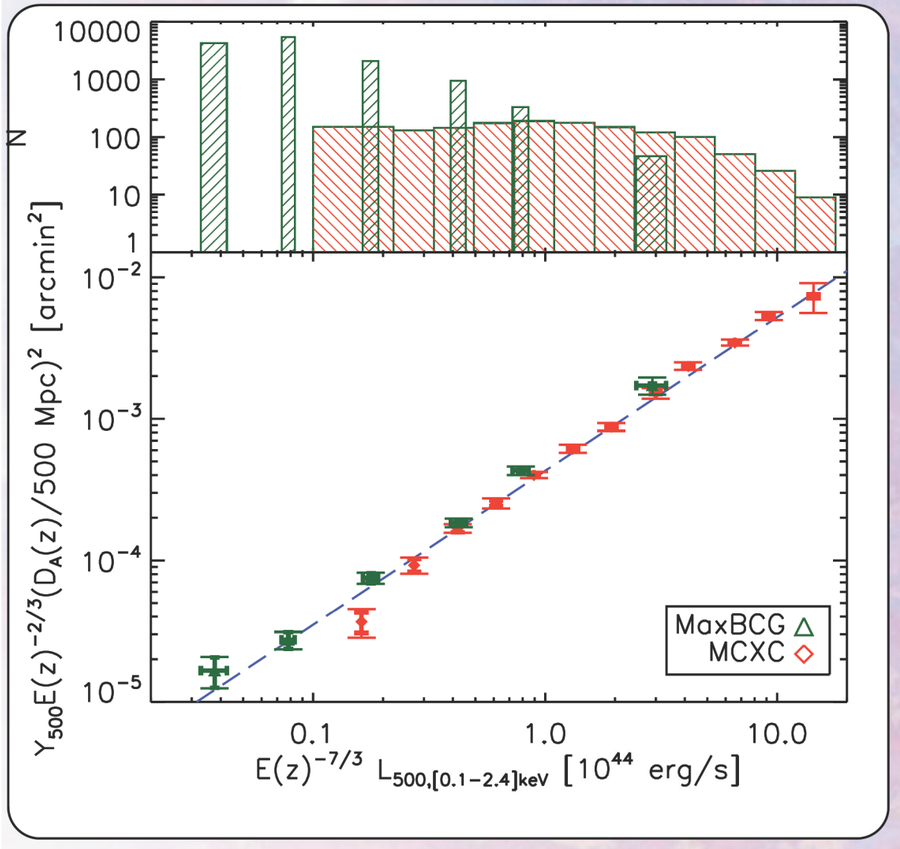


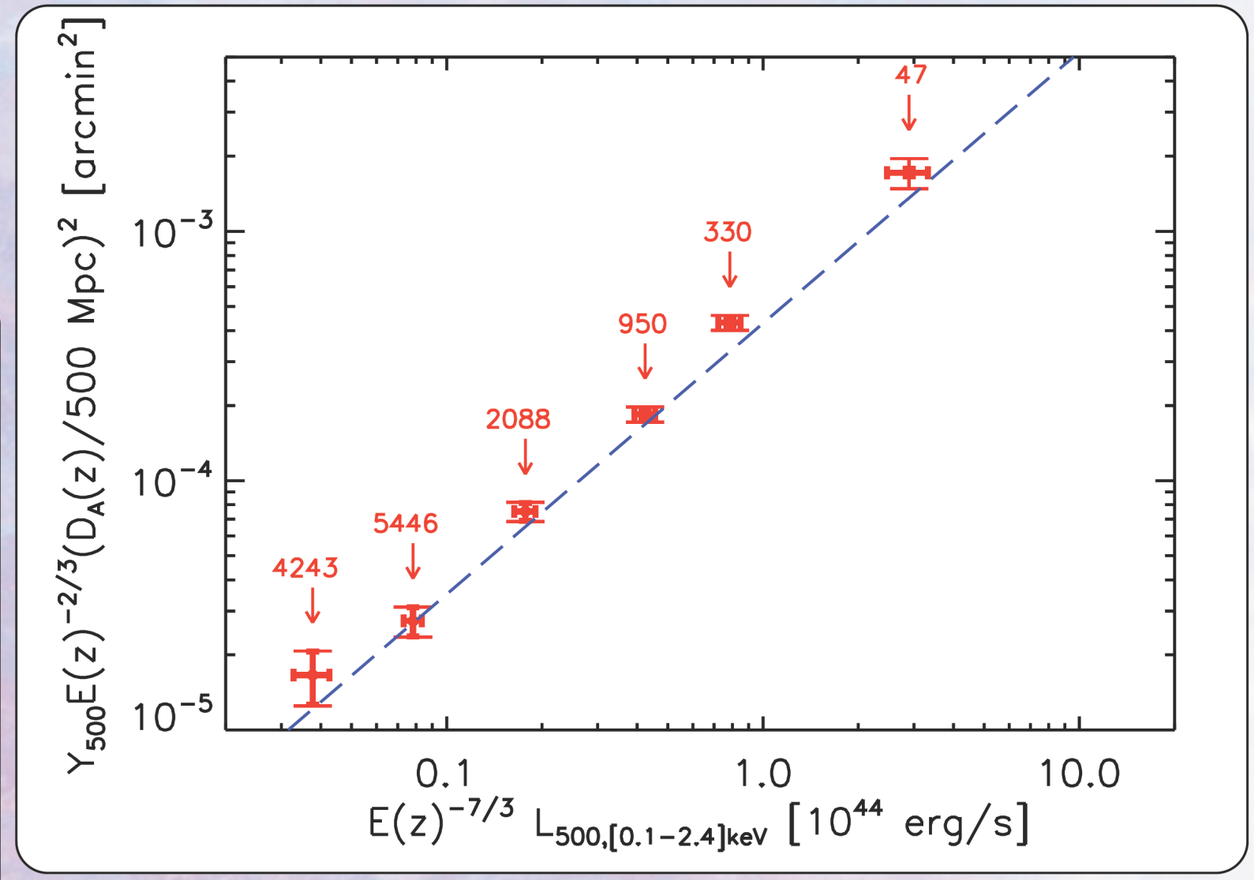


The X-ray subsample of MaxBCG agrees better with theory

SZ-L_X COMPARISON

SZ-Lx matches theory!





Mean X-ray luminosity (stacked in richness bins); *Rykoff et al. (2008)*

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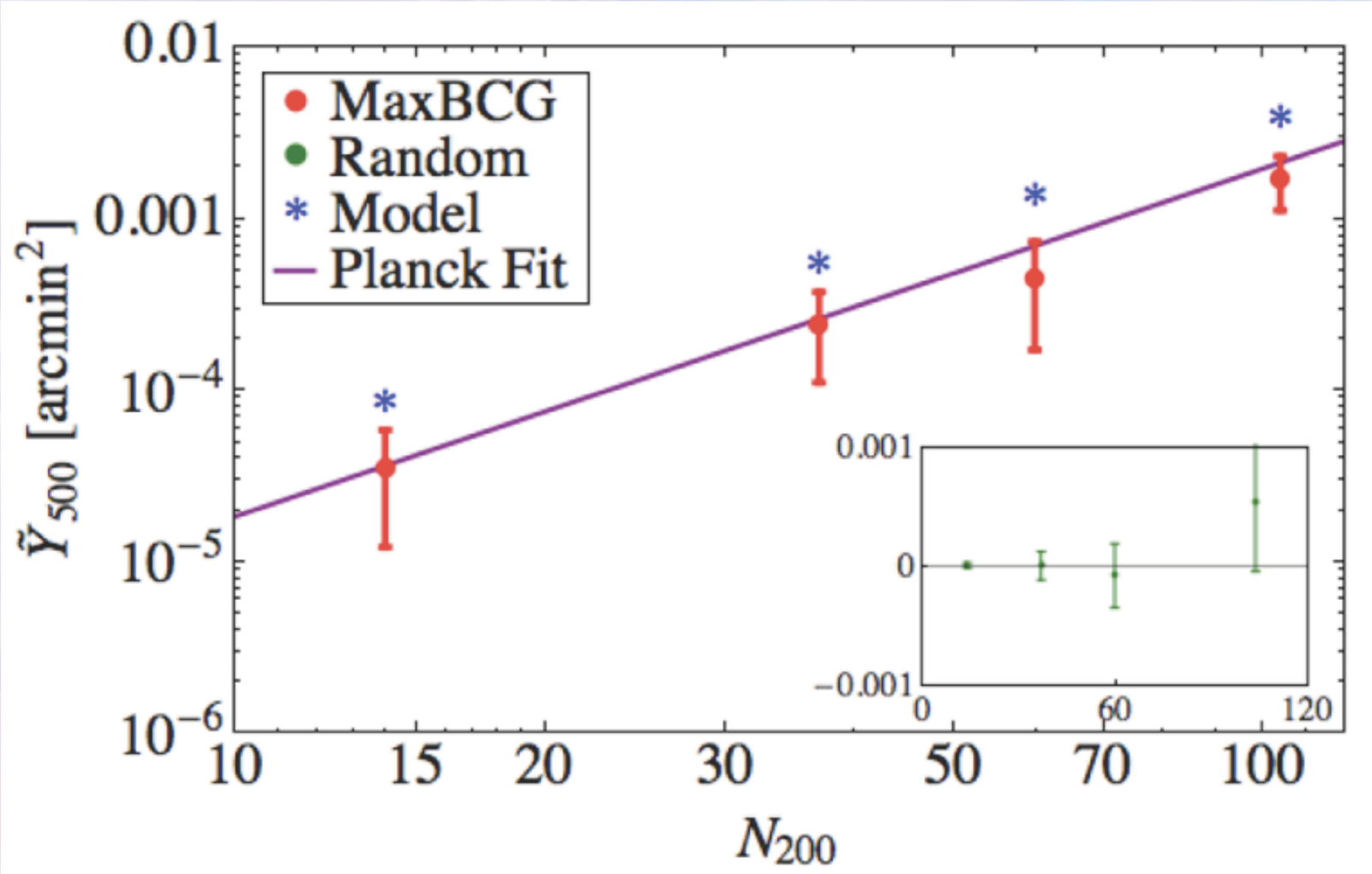
WMAP Look



Draper et al. arXiv1106.2185

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WHAT'S GOING ON?

Looking for a factor of ~2 at N_{200}=40

- Catalog contamination
  - Must be very large: c~50%...
- *"Scatter"*: large, e.g., M-N_{200} has ~45% scatter (*Rozo et al. 2009*)
  - Must be very asymmetric to cause the observed shift of ~factor 2 in mean
  - MC's don't show this effect
  - Estimated intrinsic scatter

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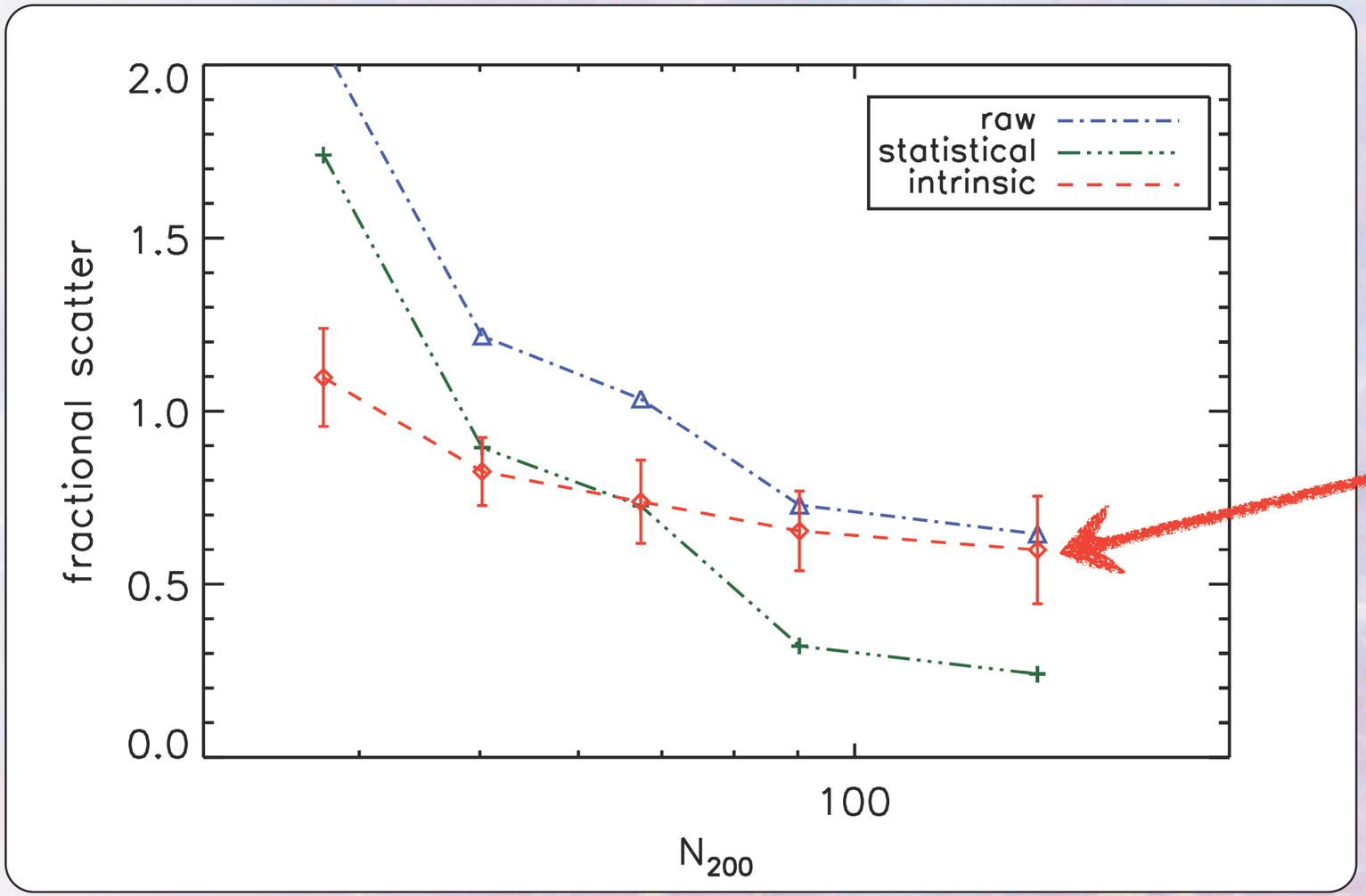
MEASURED INTRINSIC SCATTER



Consistent with 45% M-N_{200} scatter

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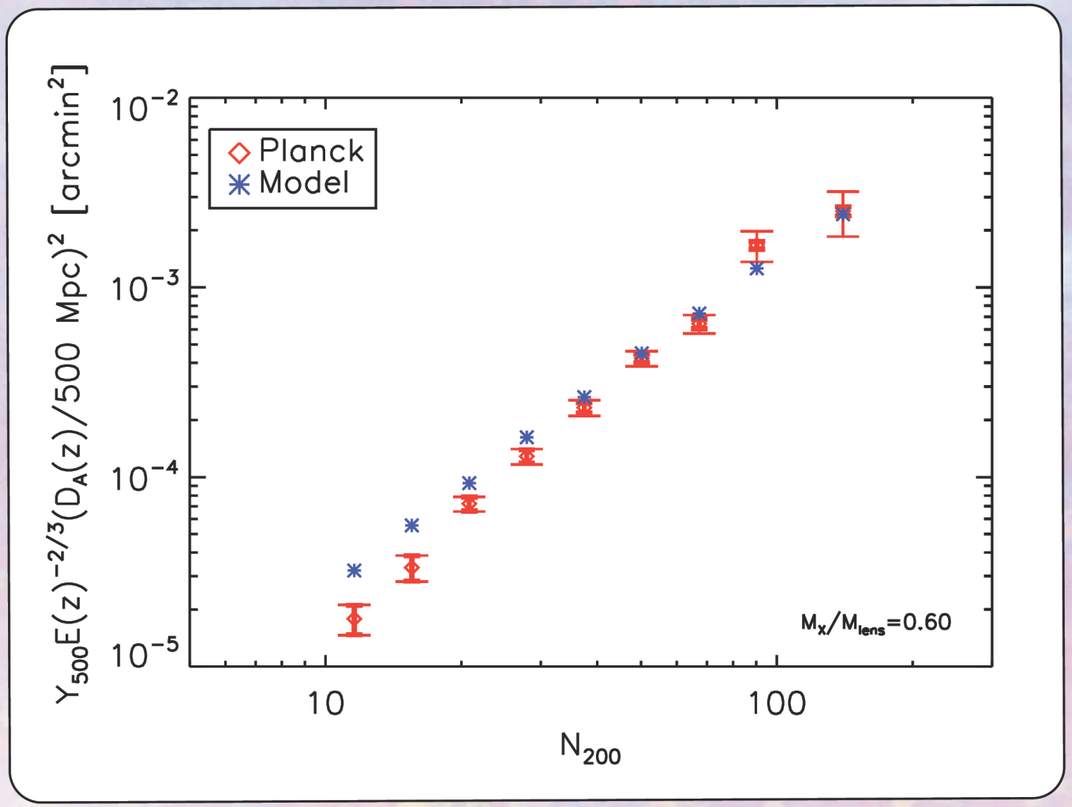
As a Pure Mass Offset

- Hydrostatic mass bias: Mx/Mlens<1
  - Model: Y(Mx=Mlens) from Arnaud et al. (2010)
  - Goes in right direction
  - However, need Mx/Mlens~0.6 to explain result...



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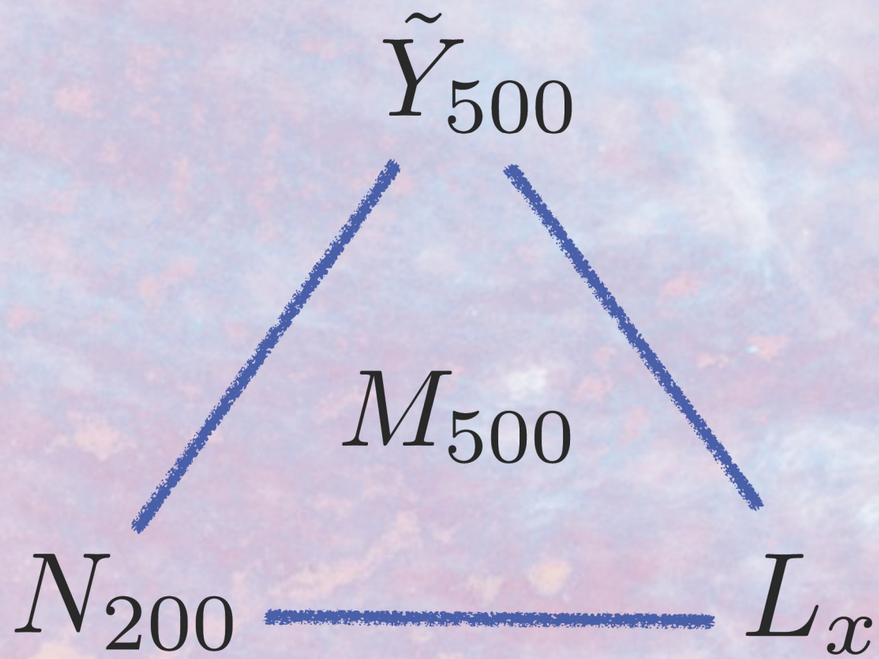
THE OBSERVATIONAL TRIANGLE



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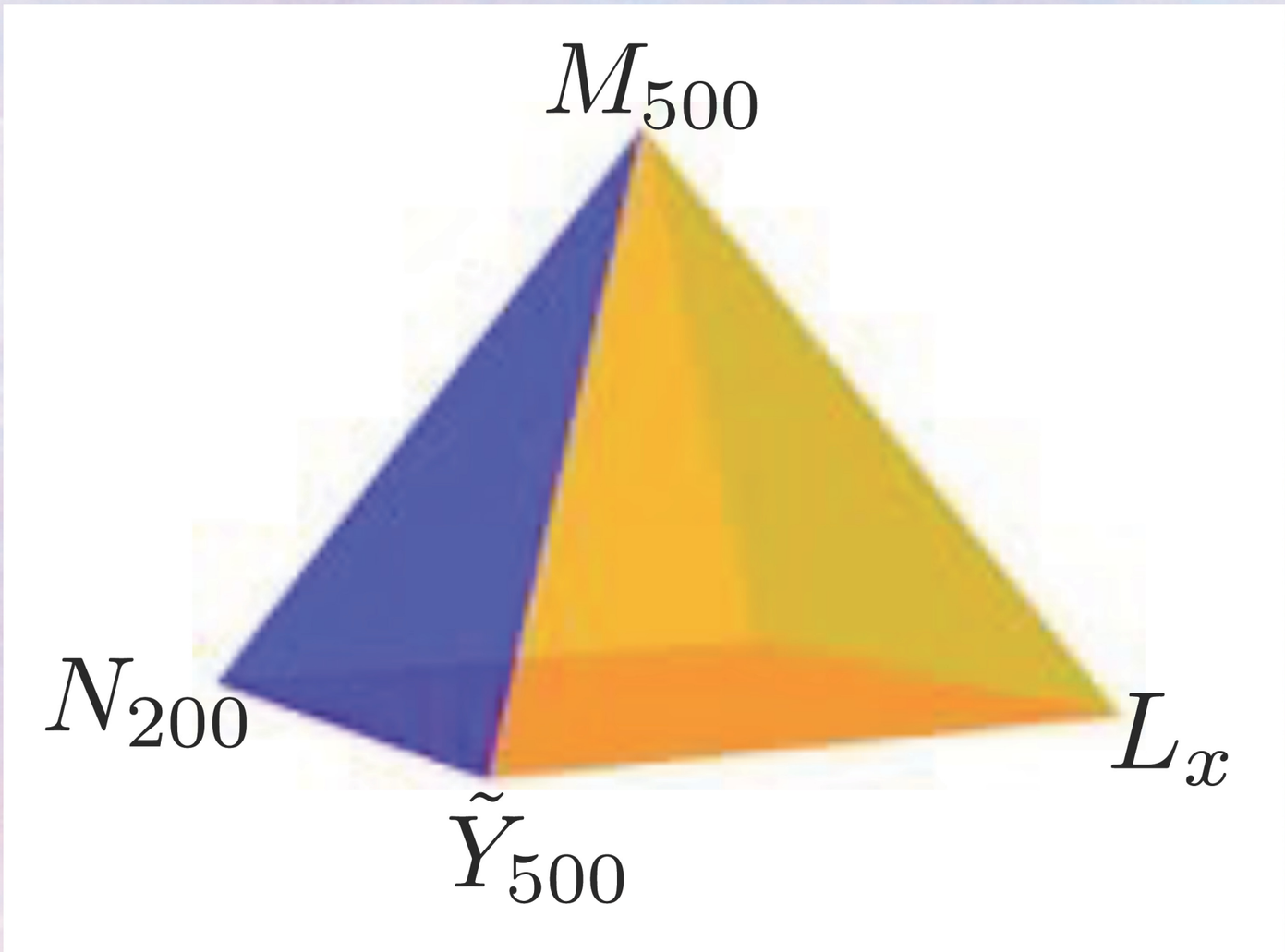
THE OBSERVATIONAL PYRAMID



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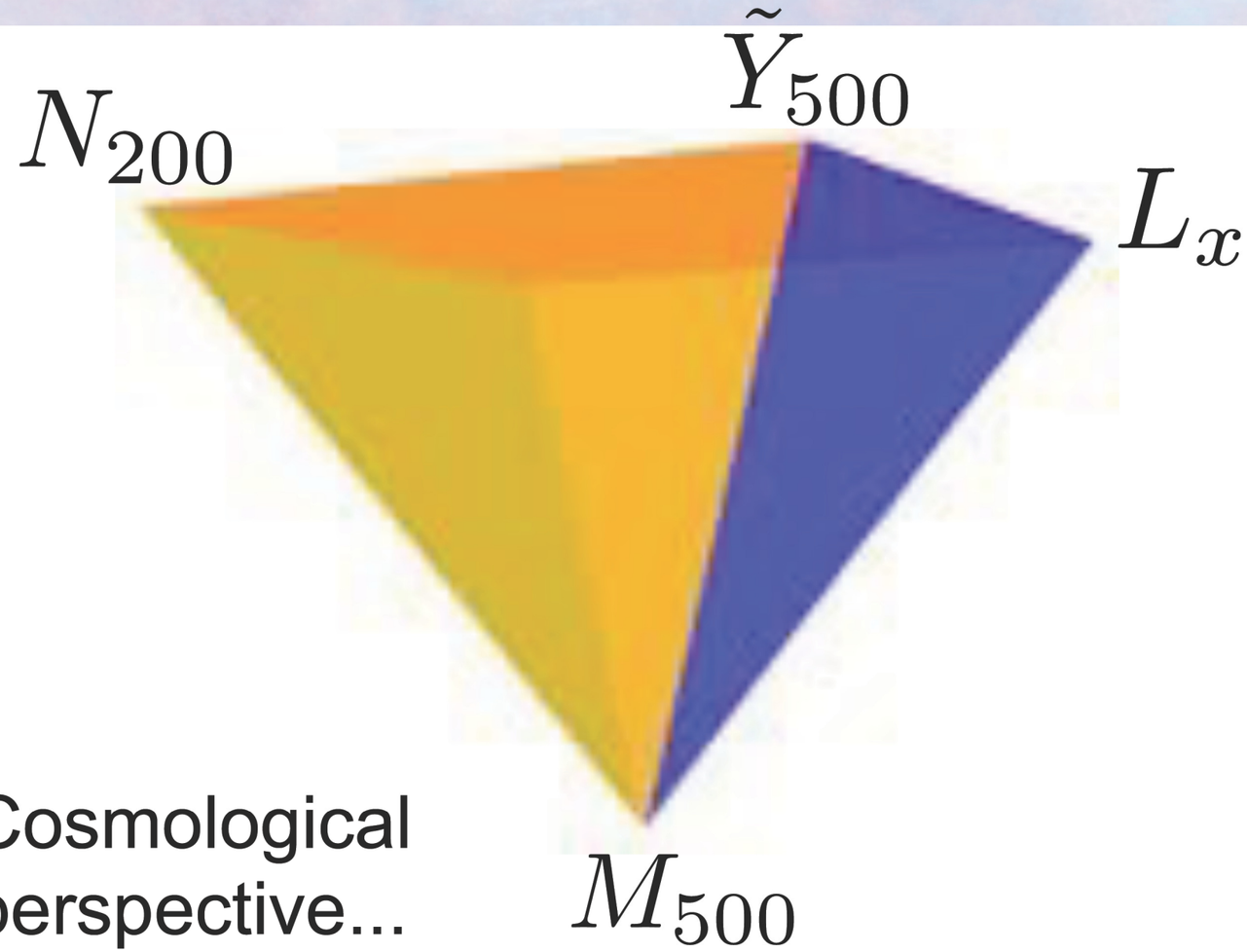
THE OBSERVATIONAL PYRAMID



Cosmological perspective...

CONCLUSIONS (1/2)

The Measurement

- First SZ-richness scaling relation: Y_{500}-N_{200}
  - *13,104 SZ-optical measurements*
  - *Possible thanks to Planck's all-sky coverage*
- Significant detection of SZ signal down to lowest richness/mass systems
- Well-described by a power law over the full range
  - No indication of any change at low mass (see also Sun et al. 2011)

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CONCLUSIONS (2/2)

An Intriguing Discrepancy

- Y_{500}-N_{200} has lower normalization than predicted
  - *Factor of 2 at N_{200}=40*
  - Y_{500}-L_x mean relation matches theory
  - X-ray subsample of MaxBCG matches theory better
  - WMAP recently found same result (Draper et al. 2011)
- On-going discussion
  - *Hint for sub-populations of clusters?*
  - *Optical selection effects?*
  - *Difference between M_x and M_{lens}?*
  - *Combination of several things...*

Ongoing Work to Understand the Origin

See Talk by E. Rozo

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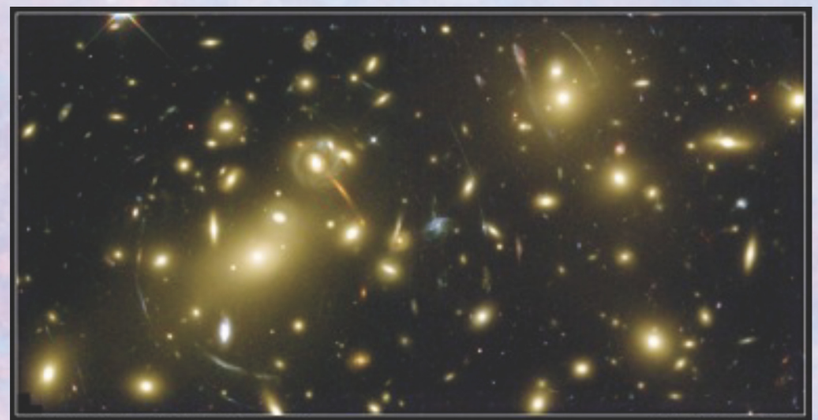
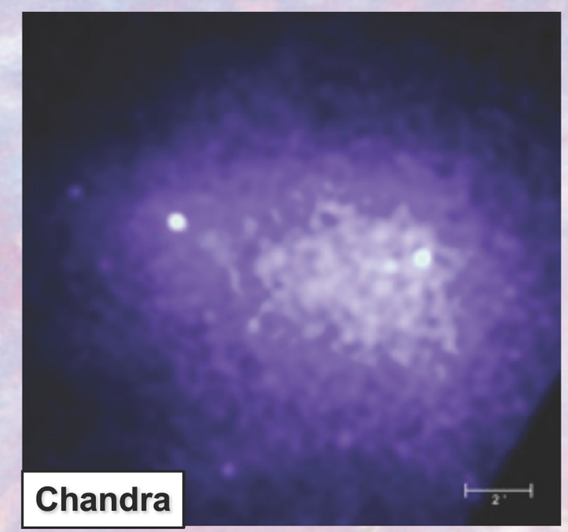
Dark Matter
Lensing
Dynamics

M_{500}



Galaxies:
Optical
IR

N_{200}



Hot gas:
X-rays

L_{500}, T

SZ Effect

Y_{500}