The relation between galaxy cluster mass and SZ signal

Planck Collaboration

presented by

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Argument

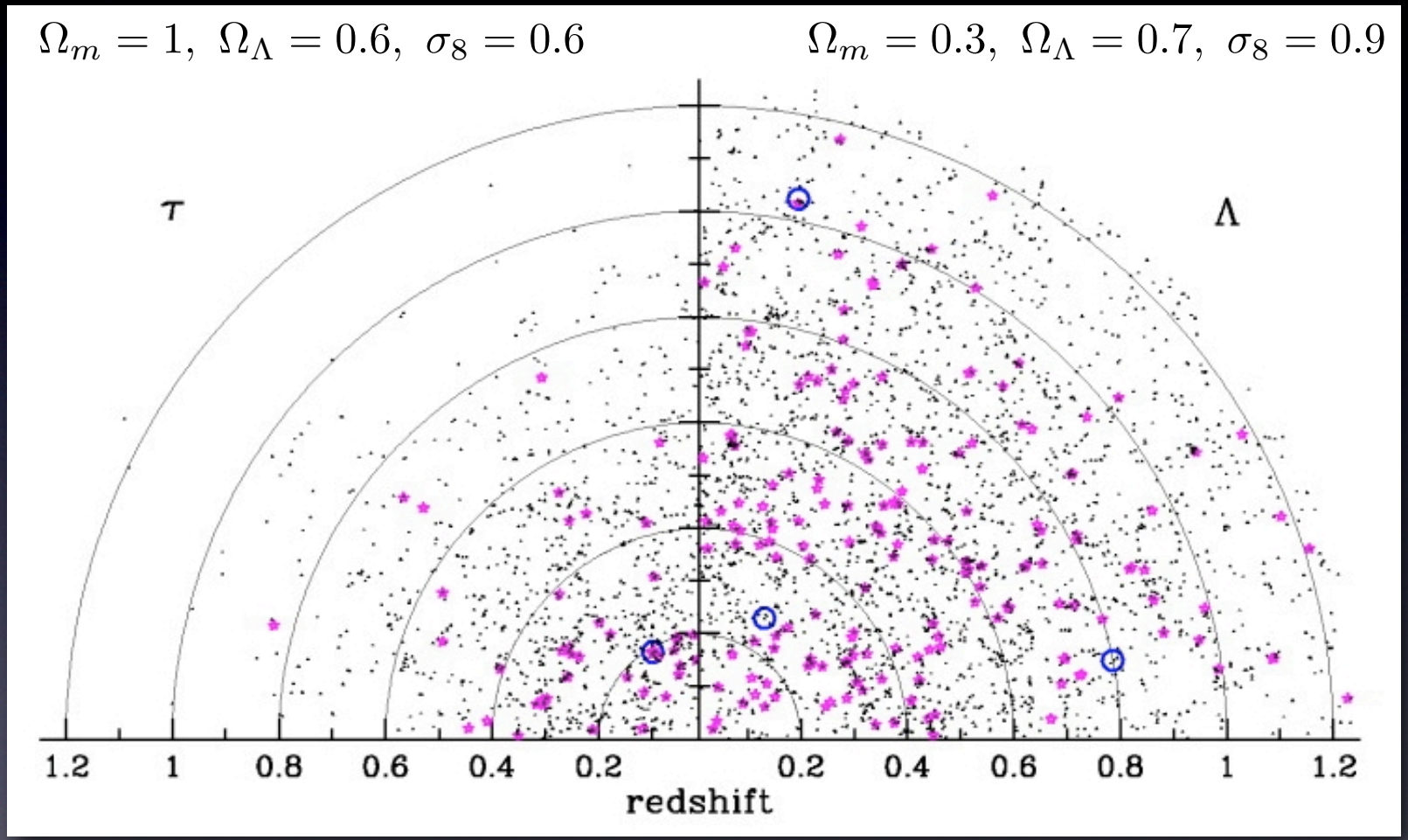
The relation between SZ effect signal and mass (Y-M) is a topic of intense interest in the cluster community

- *Cosmology:*
  - Relationship between SZ signal and mass is (Y-M) needed for *any* precision cosmological test using the *Planck* cluster sample alone
  - Needed to test virtually any model outside of ΛCDM with clusters

- *Astrophysics:*
  - Relationship between SZ signal and mass (Y-M) is a test of structure formation
  - Relationship between weak lensing and X-ray mass (M_X-M_{WL}) is a test of non-thermal pressure support (expect ~10% HE mass bias)

Cosmology with the cluster mass function

$N(M, z)$ depends on $\Omega_m,\ \sigma_8\ [\Omega_b, n, h, \Omega_\Lambda]$



Evrard et al. 2002

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Cluster mass measurements

X-rays:

- Hydrostatic 3D mass is proportional to the logarithmic gradient of ICM density and temperature profiles with radius
- Assumes spherical symmetry, zero non-thermal pressure support

$$M(r) = -\frac{kT}{\mu m_p}\frac{r}{G}\left[\frac{d\ln\rho}{d\ln r} + \frac{d\ln T}{d\ln r}\right]$$

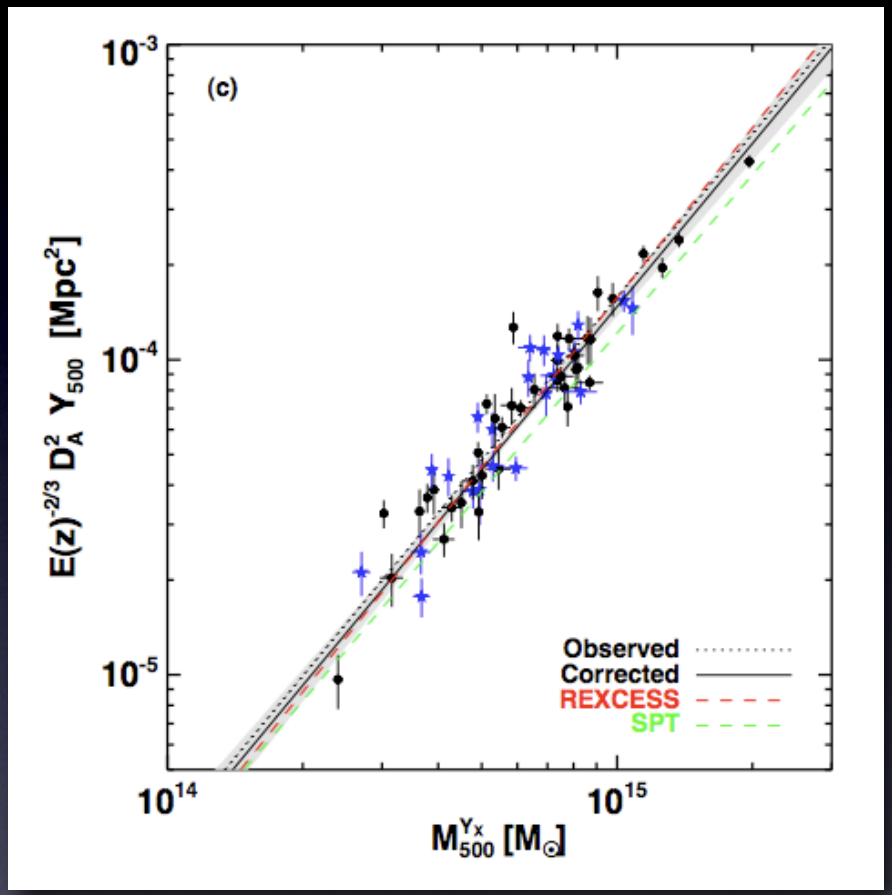
Lensing:

- 2D projected mass measured from weak lensing shear
- 3D mass from fitting spherical NFW model to reduced shear profile g
- May be sensitive to projection along LoS, LSS ...

$$g = \gamma/(1-\kappa)$$

- **These masses are independent**

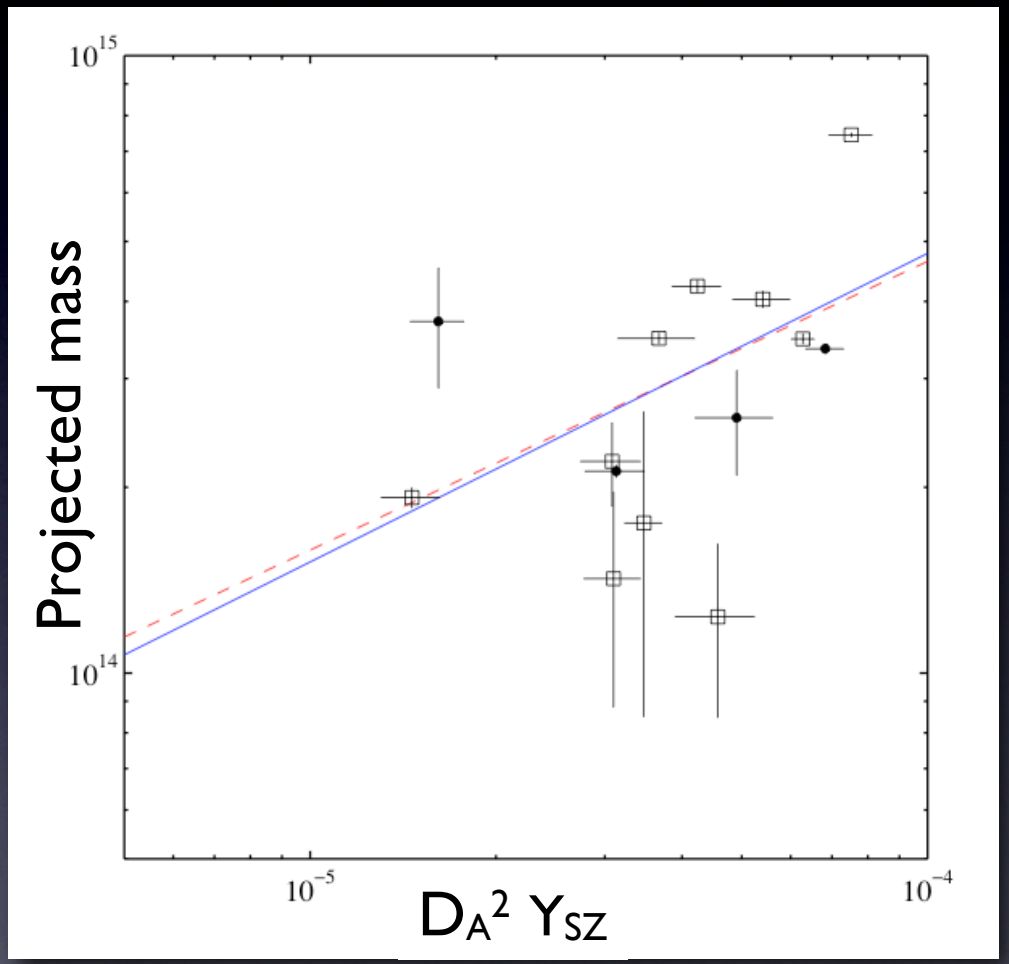
Planck Early Results XI



- Planck early paper result based on mass proxy derived from X-ray hydrostatic mass estimates ($Y_X = M_{gas,500} \cdot T_X$)
- Covariance, normalisation due to HE assumption, reduced scatter?

State of the art - I

Y_{SZ}-M_{WL} relation (2D quantities)

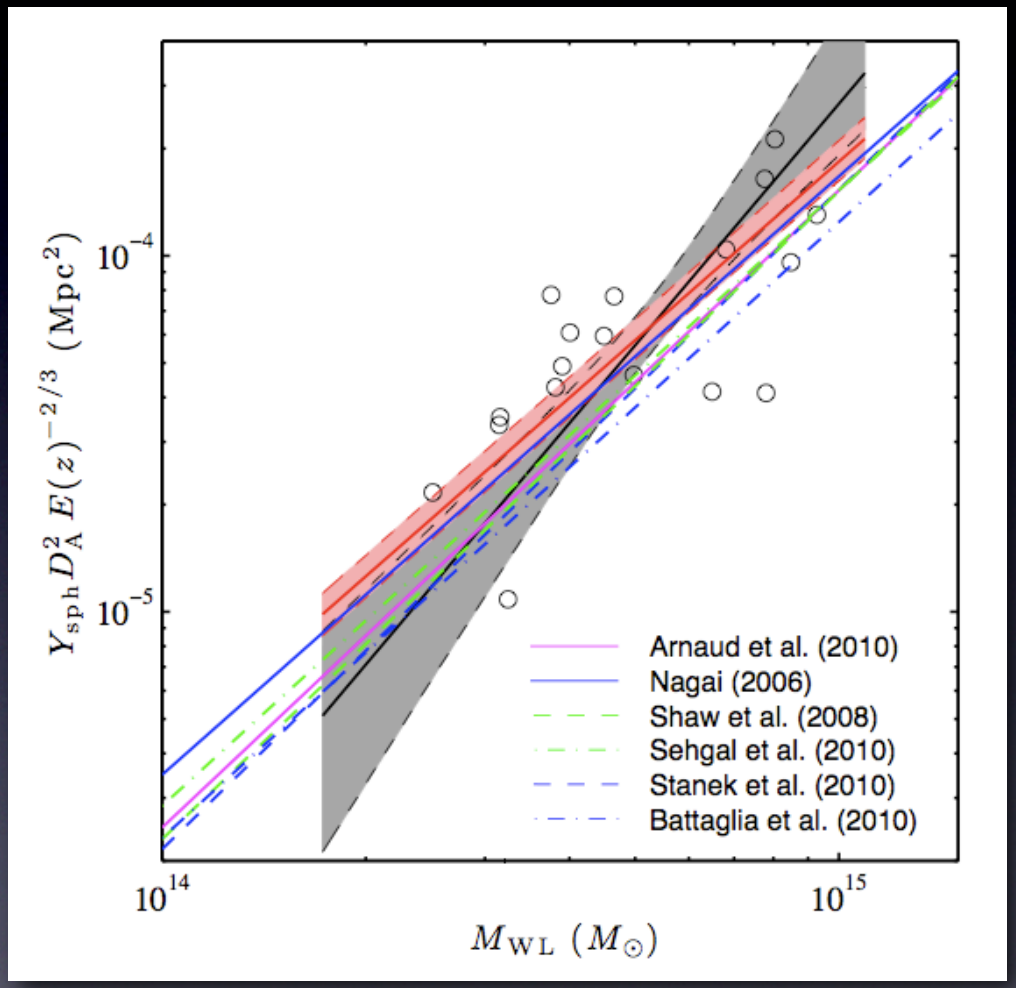


Marrone et al. 2009

- 14 clusters from LoCuSS
- Y_{SZ} from SZA
- M_{WL} from Subaru
- NO X-RAY DATA

State of the art - II

Y_{SZ}-M_{WL} relation (3D quantities)

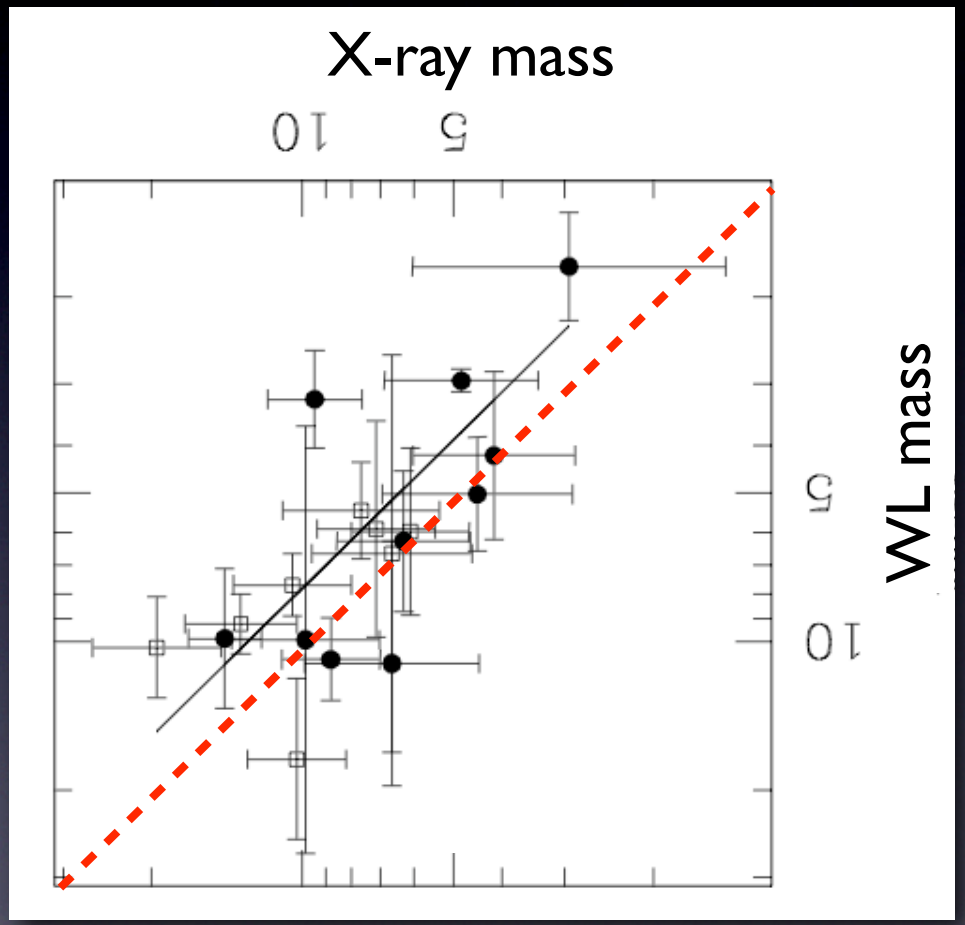


Marrone et al. 2011

- 18 clusters from LoCuSS
- Y_{SZ} from SZA
- M_{WL} from Subaru
- NO X-RAY DATA

State of the art - III

M_X-M_{WL} relation

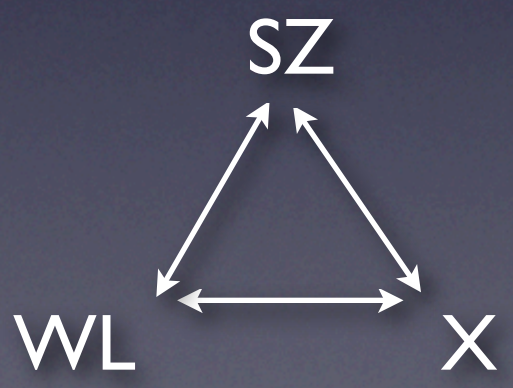


Mahdavi et al. 2008

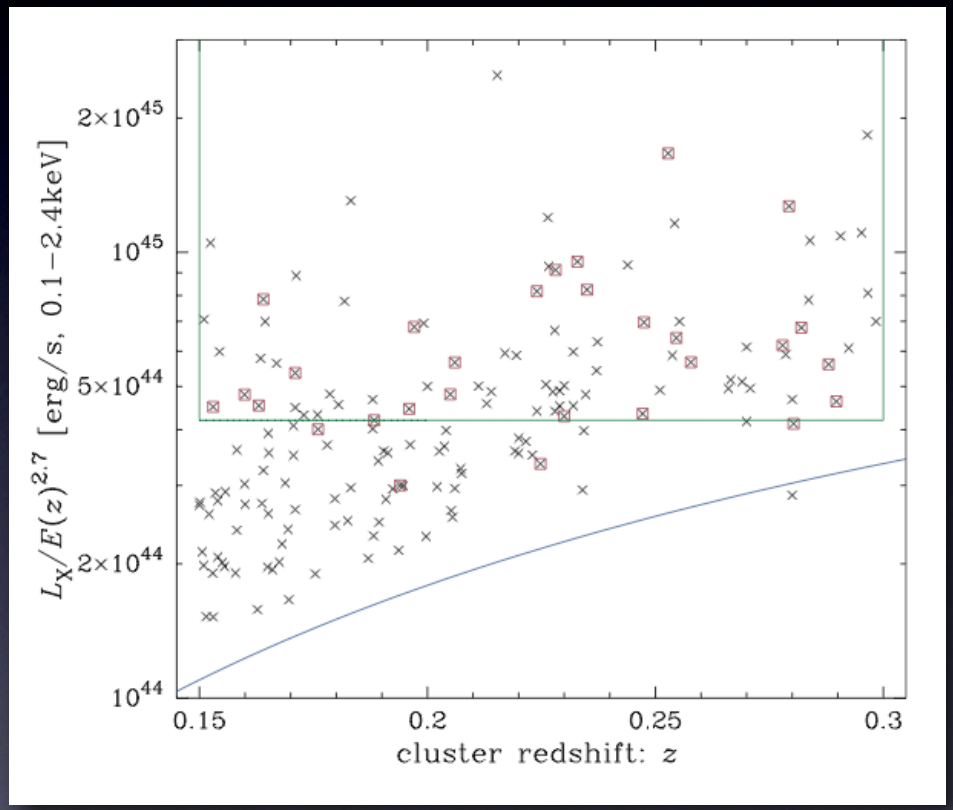
- 18 massive clusters
- M_X from Chandra
- M_{WL} from CFHT
- NO SZ DATA
- EXTRAPOLATION to R_{500} needed for 14/18 clusters

Scientific objectives

- Determine Y_{SZ}-M_{HE} and Y_{SZ}-M_{WL} relationships
- Investigate scatter and dependence on mass measurement method
- Investigate trends with radius/overdensity and dynamical state
- Try to give a 'holistic' view of clusters through X-ray, SZ and lensing



Non-Planck data used



Okabe et al. 2010

Subaru weak lensing mass data for LoCuSS clusters

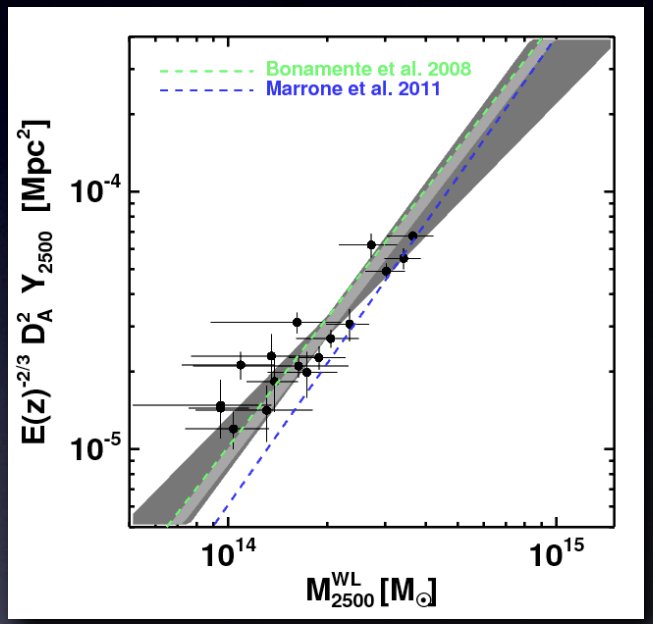
- High-quality data with *homogeneous* analysis approach
- NFW mass profile fits published in Okabe et al. (2008, 2010)

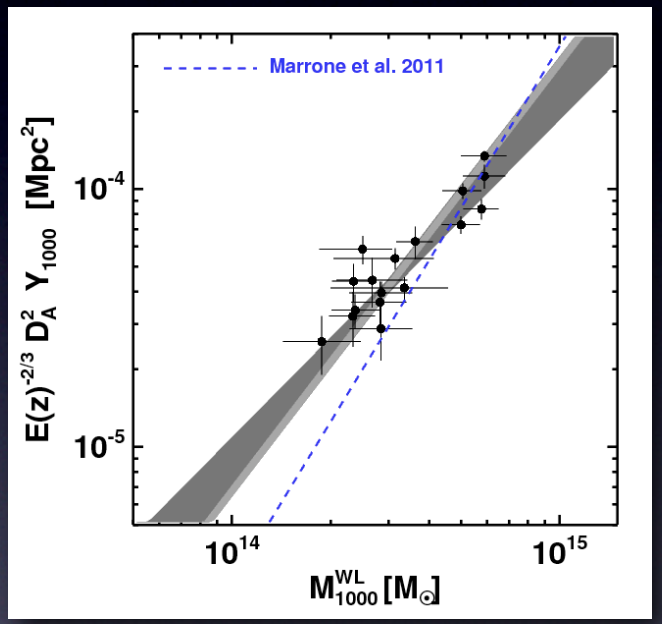
Deep archive X-ray observations with *XMM-Newton*

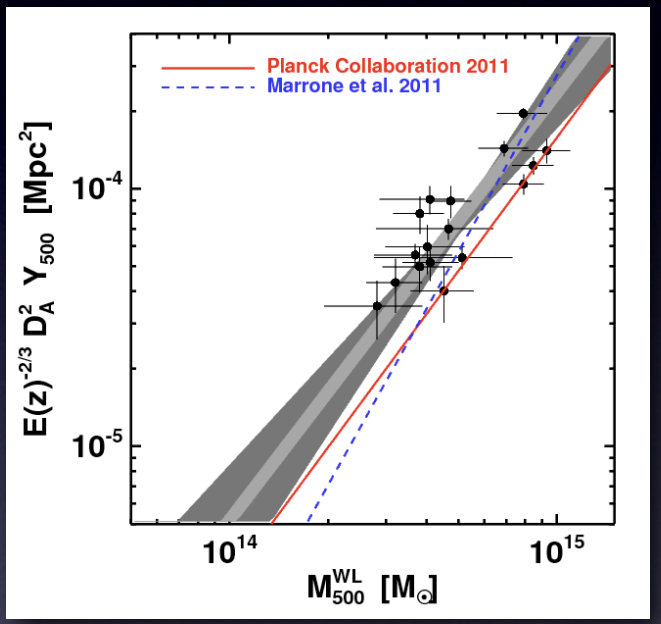
- High-quality data
- *Homogeneous* analysis approach
- X-ray profile measurements available out to R_{500}


A1835
ZwCl1454.8+2233
A383
A291
RXJ2129.6+0005
RXJ1720.1+2638
A2390
A963
A2261
A1914
A68
A2219
A2631
A209
ZwCl1459.4+4240
A267
A2034
A520
A521

Planck Y-M_{WL} relation



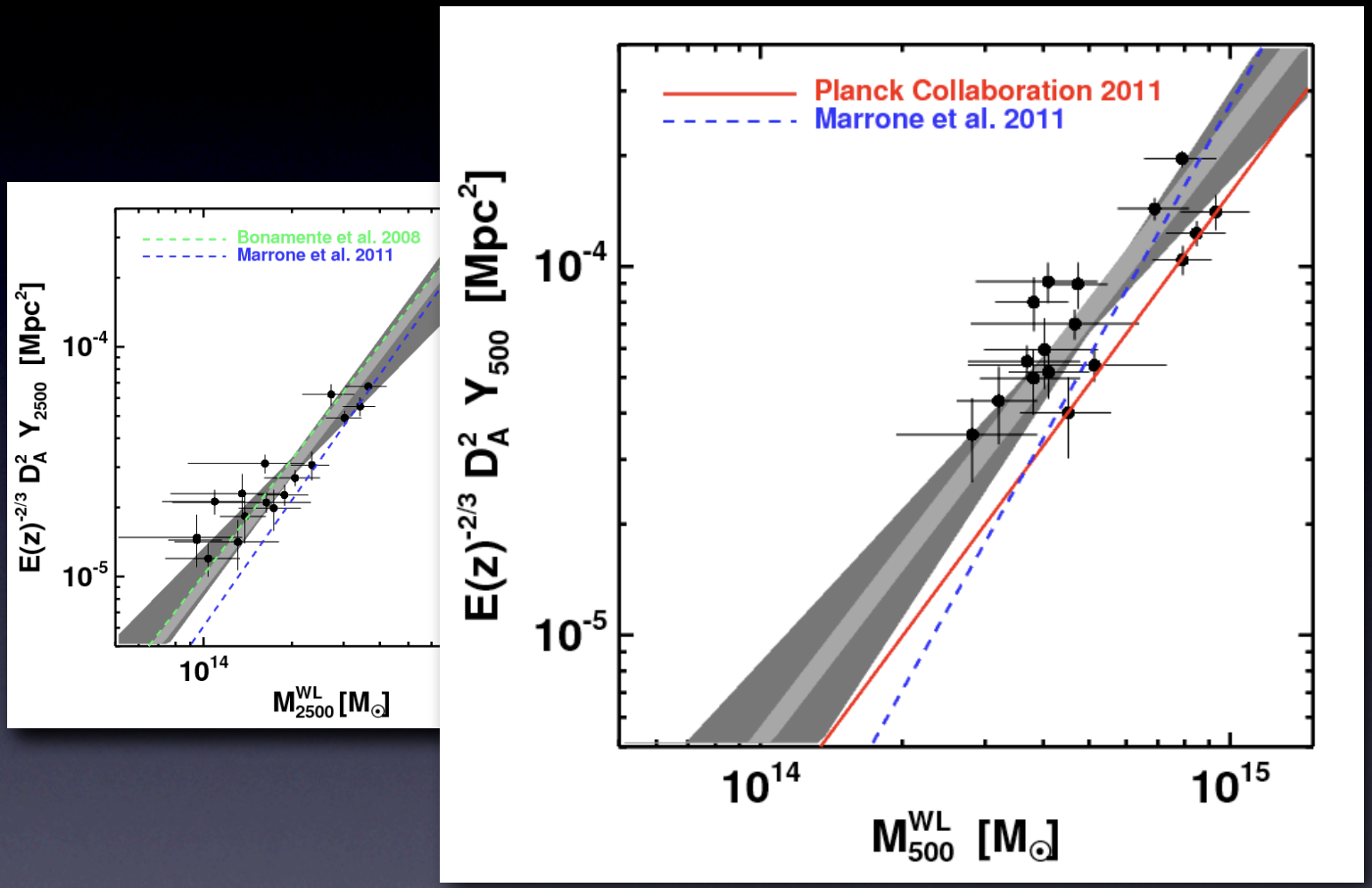




- Other SZ refs:

Bonamente et al. (2008, OVRO/BIMA); Marrone et al. (2011, SZA)

Planck Y-M_{WL} relation



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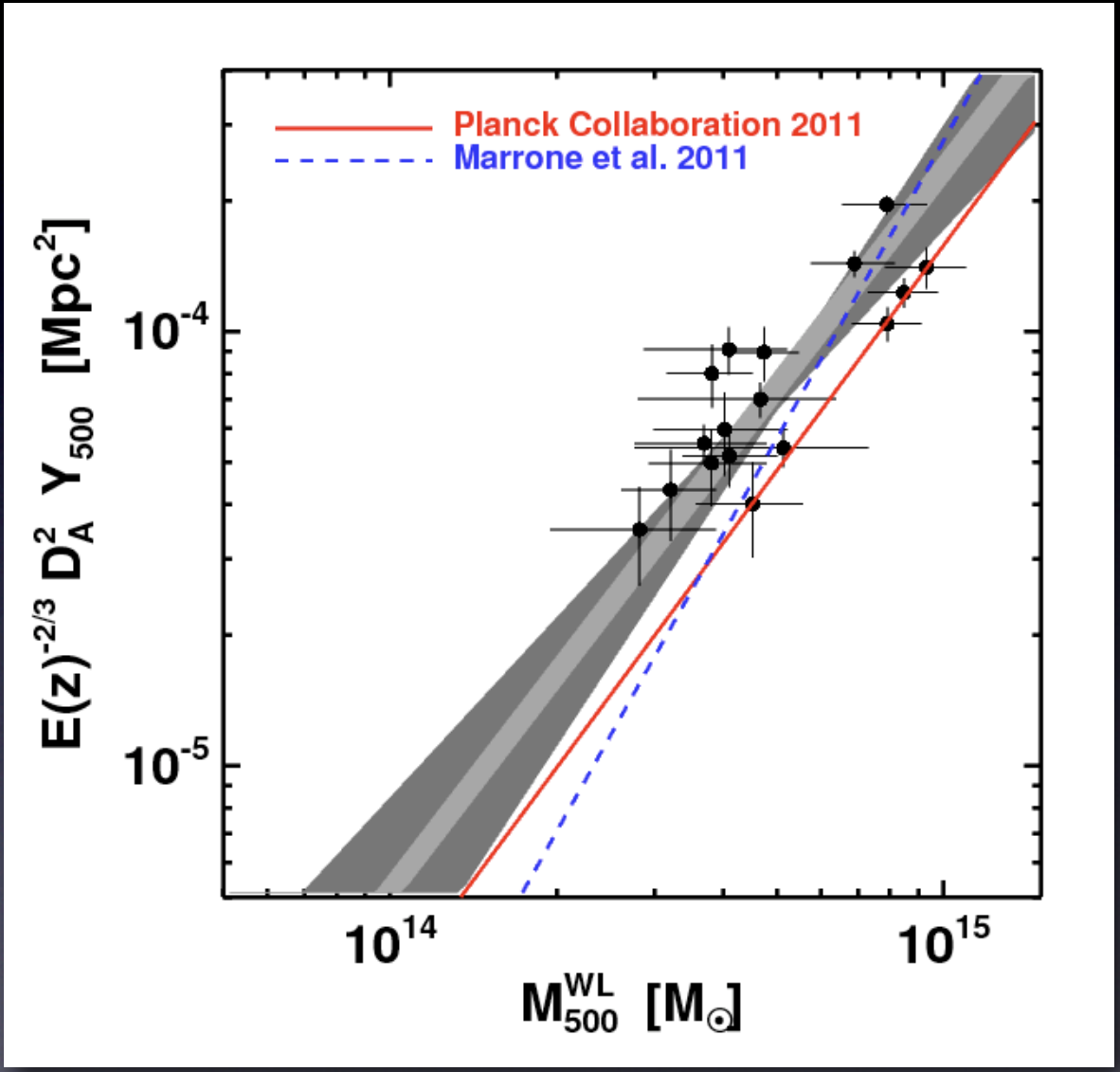
Y_{500}-$M_{WL,500}$ relation



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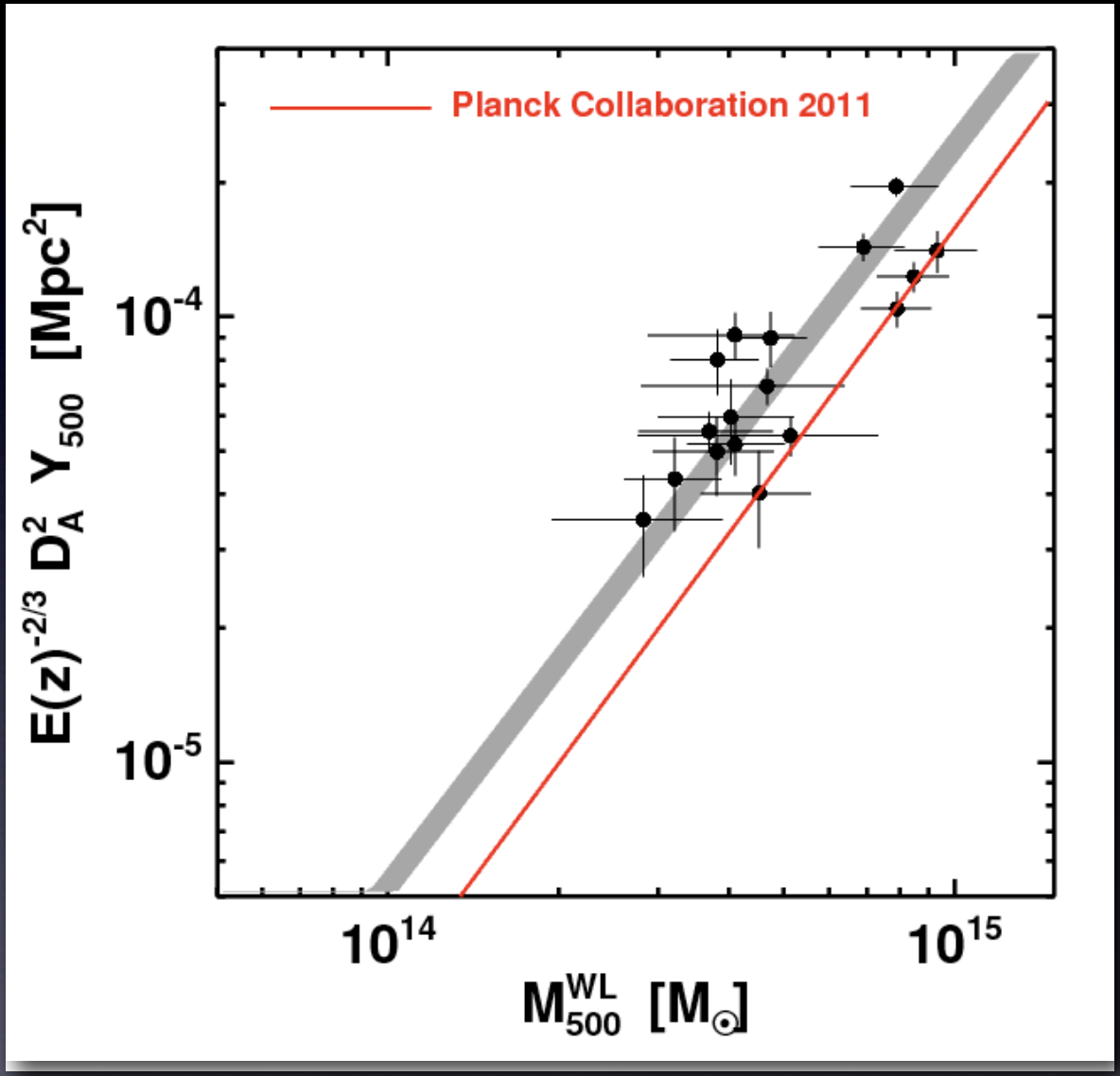
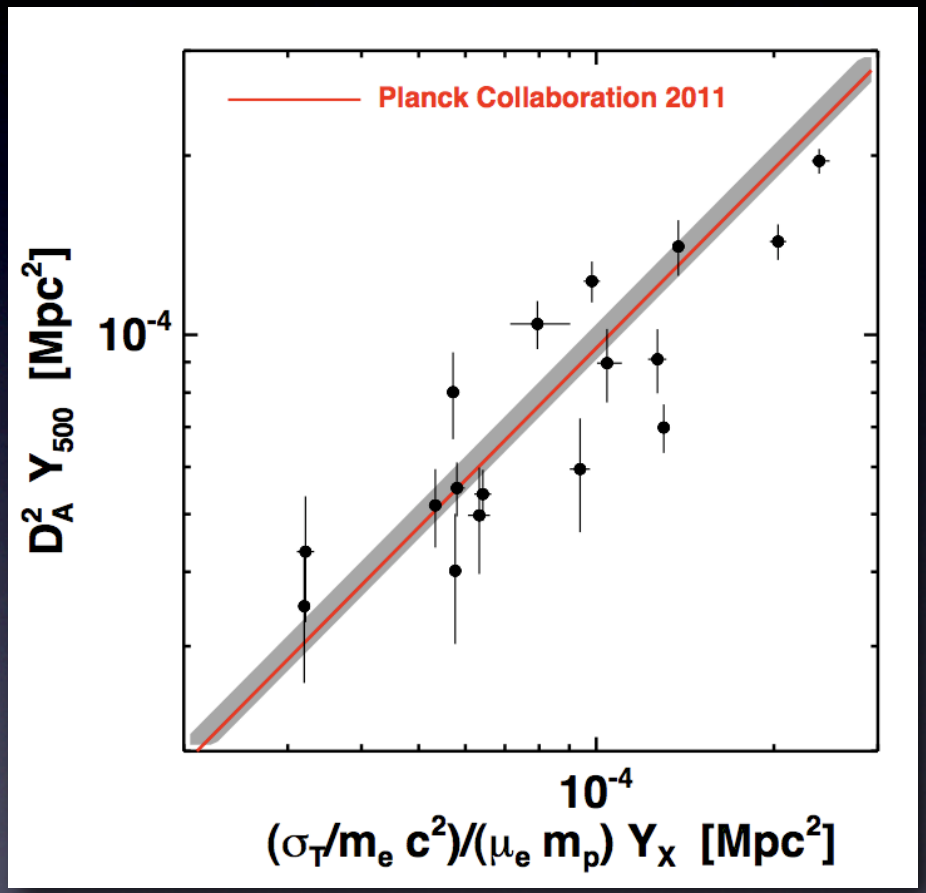
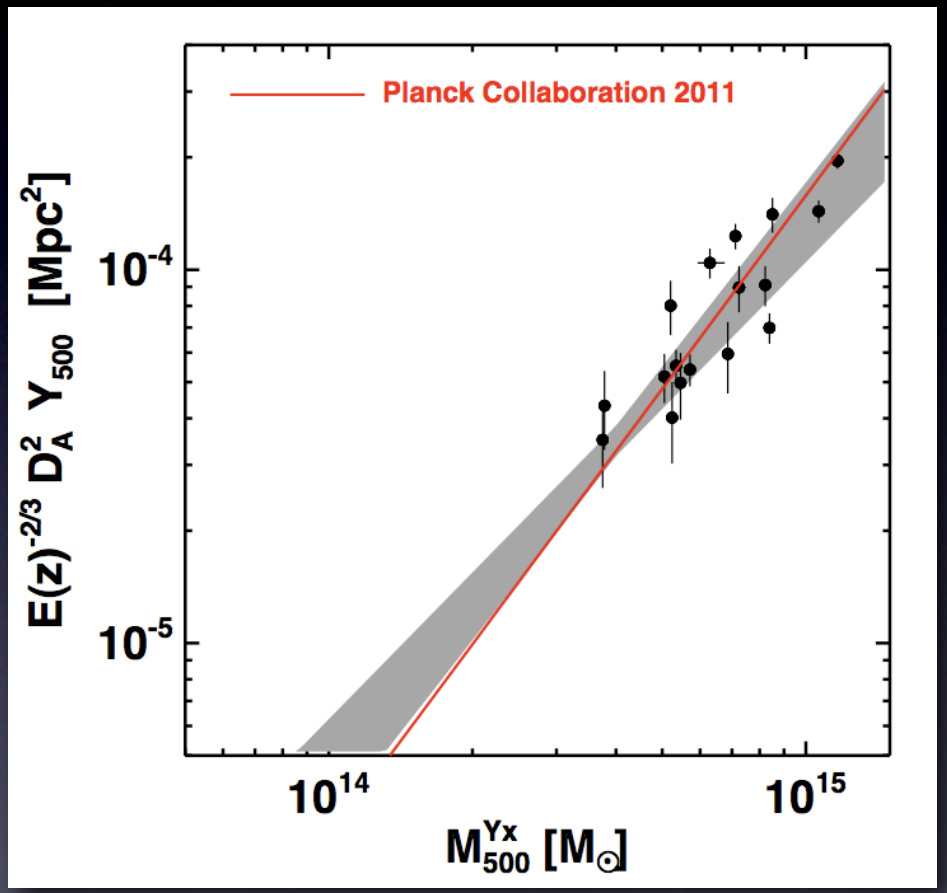


SZ signal

Comparison to Planck Early results

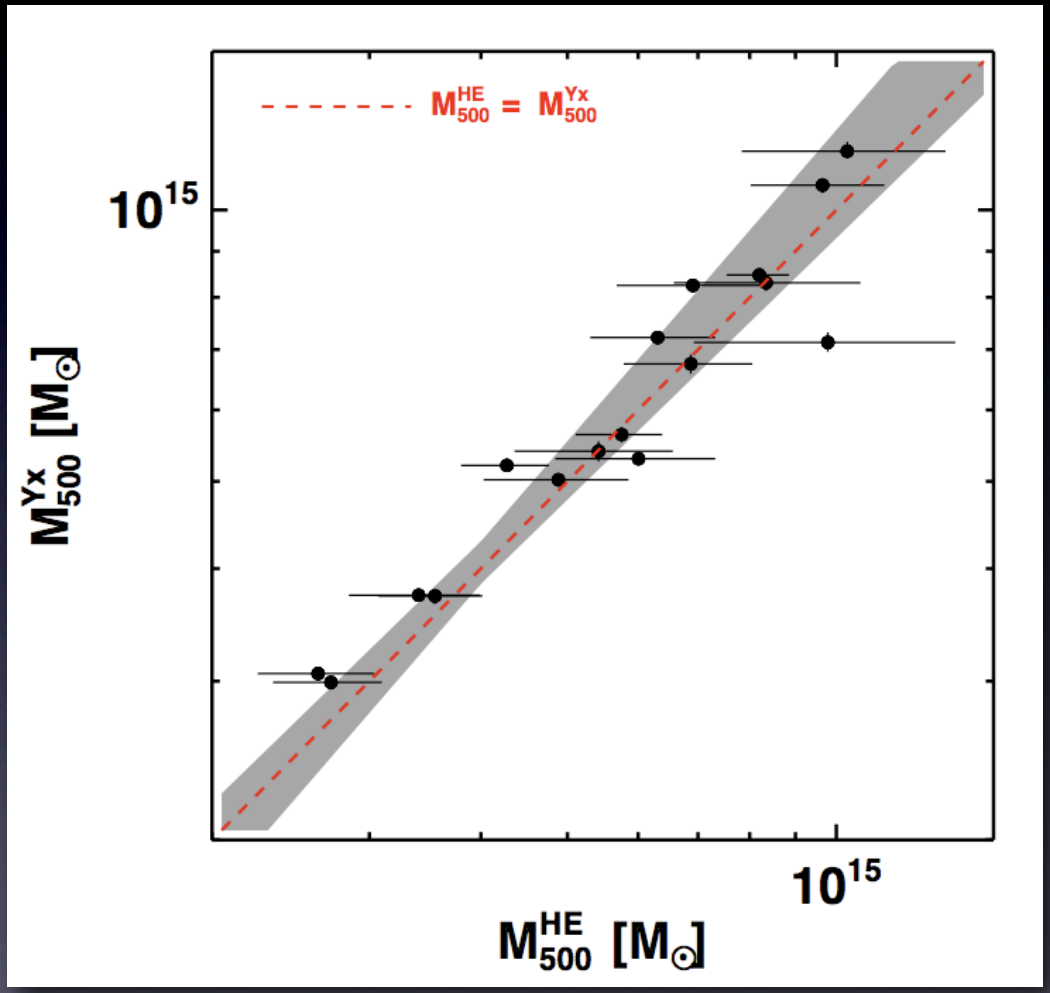




$$Y_{\mathrm{X}} = M_{\mathrm{gas},500} \cdot T_{\mathrm{X}}$$

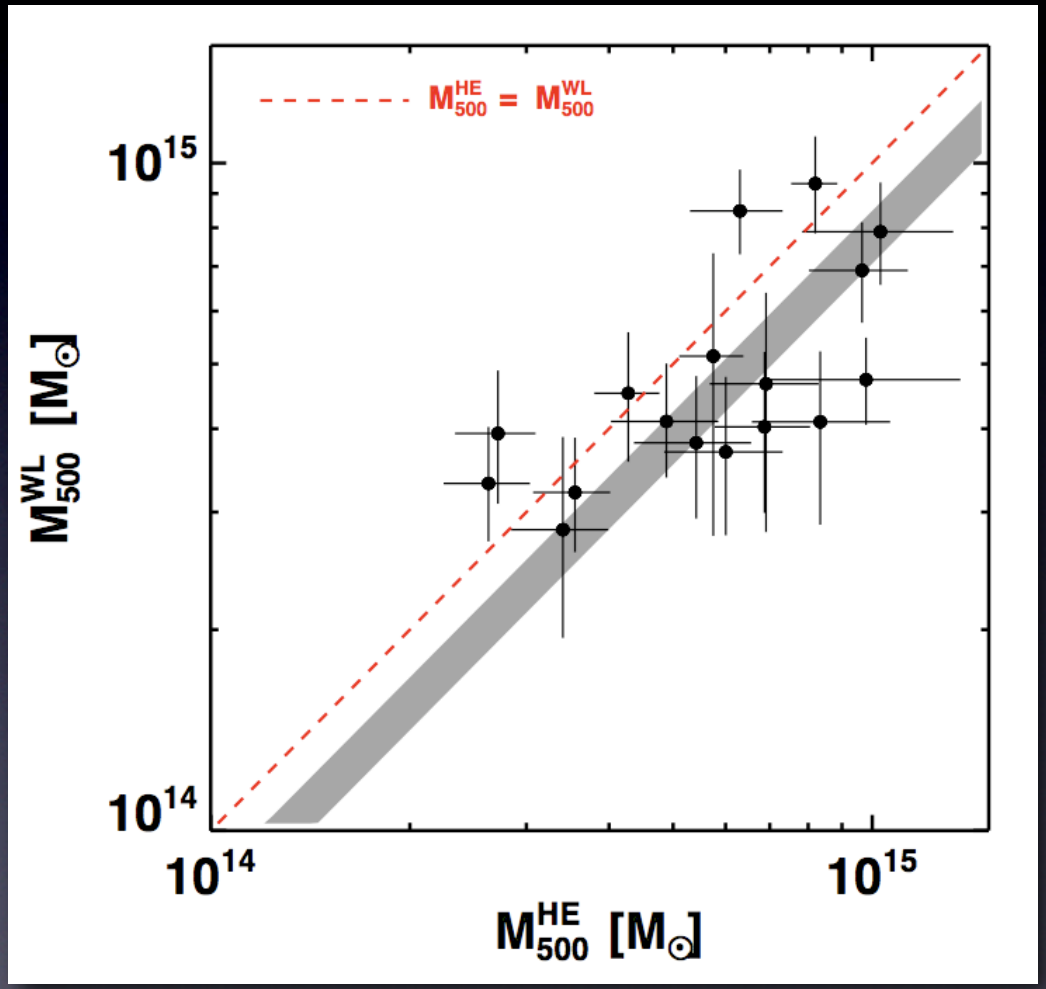
Mass comparison

$M_{500,\,HE}$ vs $M_{500,Yx}$



Mass comparison

$M_{500,\,HE}$ vs $M_{500,\,WL}$



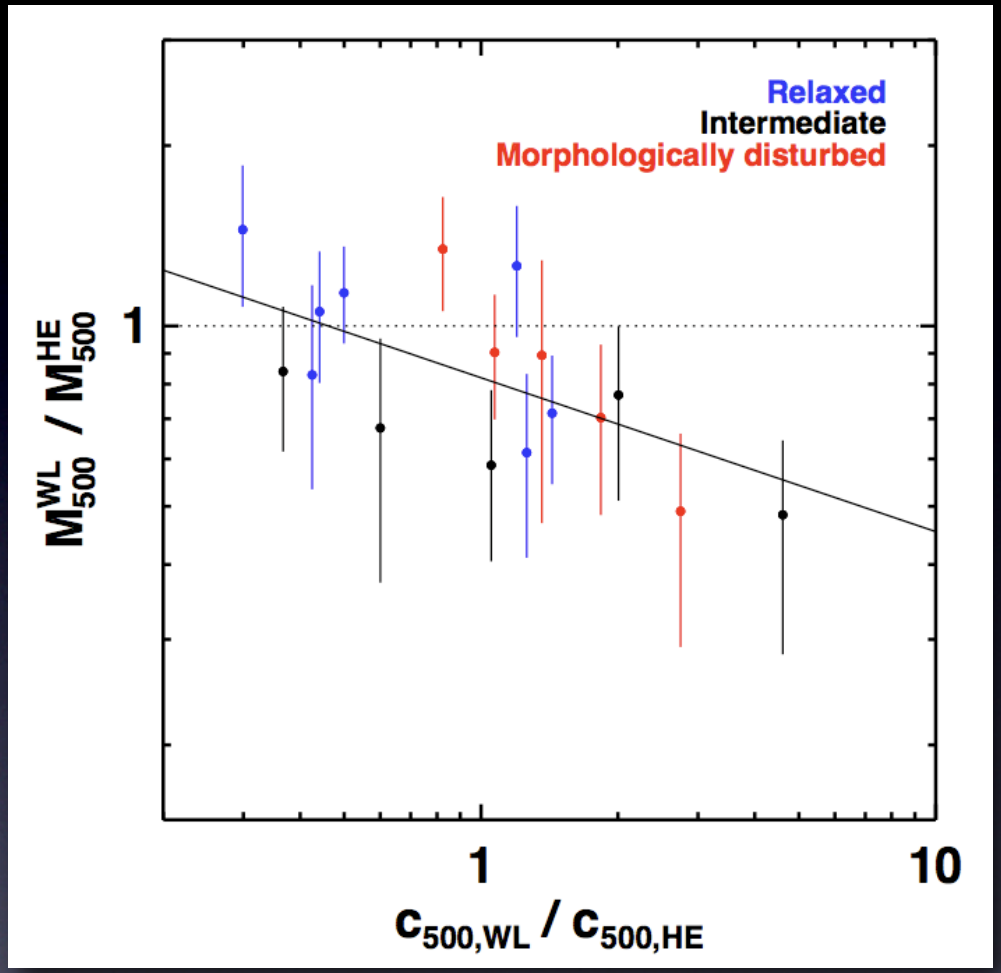
$$M_{500}^{\mathrm{WL}} = (0.78 \pm 0.08)\, M_{500}^{\mathrm{HE}}$$

Masses

- X-ray HE masses are on average 22 ± 8 % *larger* than LoCuSS WL masses (2.6σ significance)
  - Relaxed systems: 6 ± 10 %
  - Intermediate and disturbed systems: 28 ± 12 %

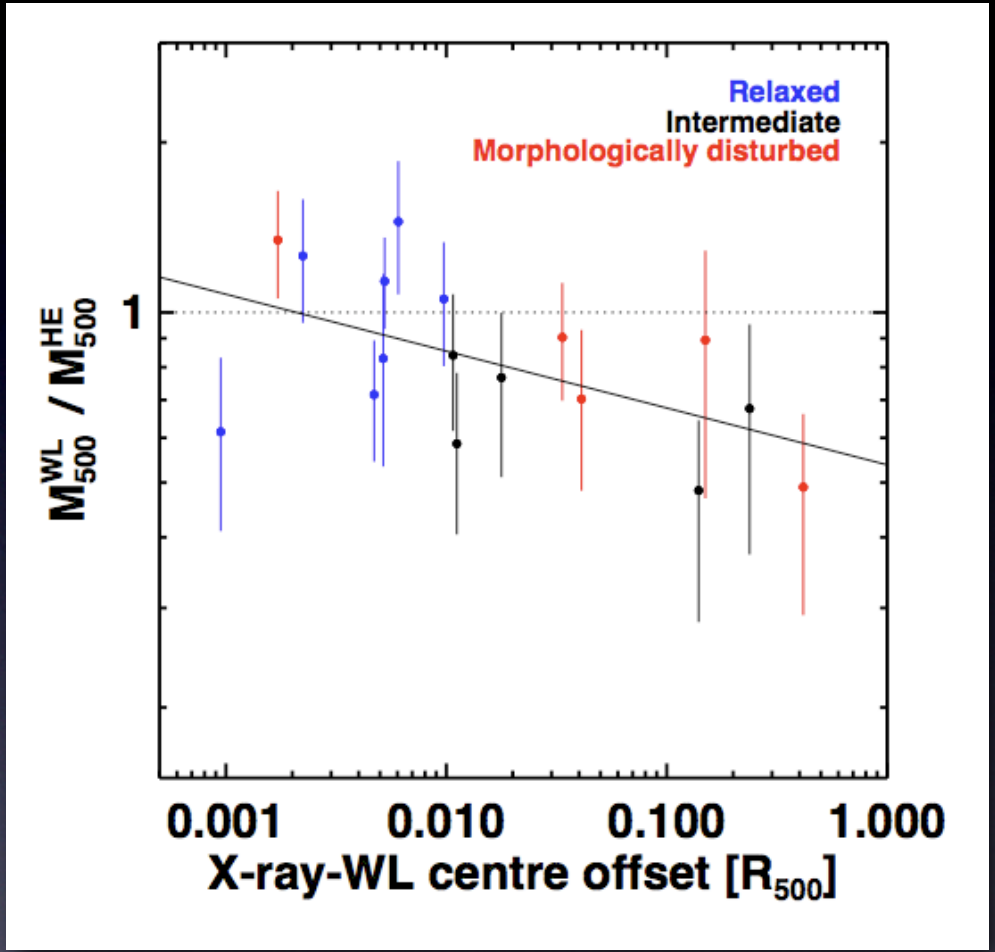
- This is exactly the opposite of expectations for a typical 'hydrostatic mass bias'

NFW concentration



- A dependence of HE bias with radius means X-ray profiles are already over-concentrated
- 'Correcting' for this would make the X-ray profiles even less concentrated, exacerbating the problem

Centre offset



- Once can imagine that mis-centring will affect concentration, both in the WL and X-ray cases

Summary

- Good constraint on Y-M relation using WL masses
  - Normalisation offset wrt Early Paper calibration from HE X-rays
  - Larger scatter, in line with expectations from simulations
- SZ fluxes and HE X-ray masses agree with Early Paper values
- HE X-ray masses *larger* than WL masses by 22 ± 8 % on average
  - WL concentration tends to be larger than X-ray concentration, cannot resolve problem by appealing to HE bias
  - Mis-centring introduces secondary mass normalisation effect
  - Other effects from WL modelling, dilution...?

Perspectives

- In general
  - neither method is 'better' - each has its own associated biases
  - each method probes different aspects of the mass distribution (2D vs 3D, larger and smaller radii, etc)
  - what is the 'correct centre' of a cluster?
  - a fully co-ordinated approach is needed
- Relaxed systems
  - stronger constraints on agreement between HE X-ray and WL masses
  - constrain irreducible scatter
- Intermediate and unrelaxed systems
  - co-ordinated approach needed
  - use simulations to inform analysis on WL and X-ray sides
- Large, representative samples with *data quality control* needed

The scientific results that we present today are the product of the Planck Collaboration, including individuals from more than 50 scientific institutes in Europe, the USA and Canada

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA) and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.

State of the art - III

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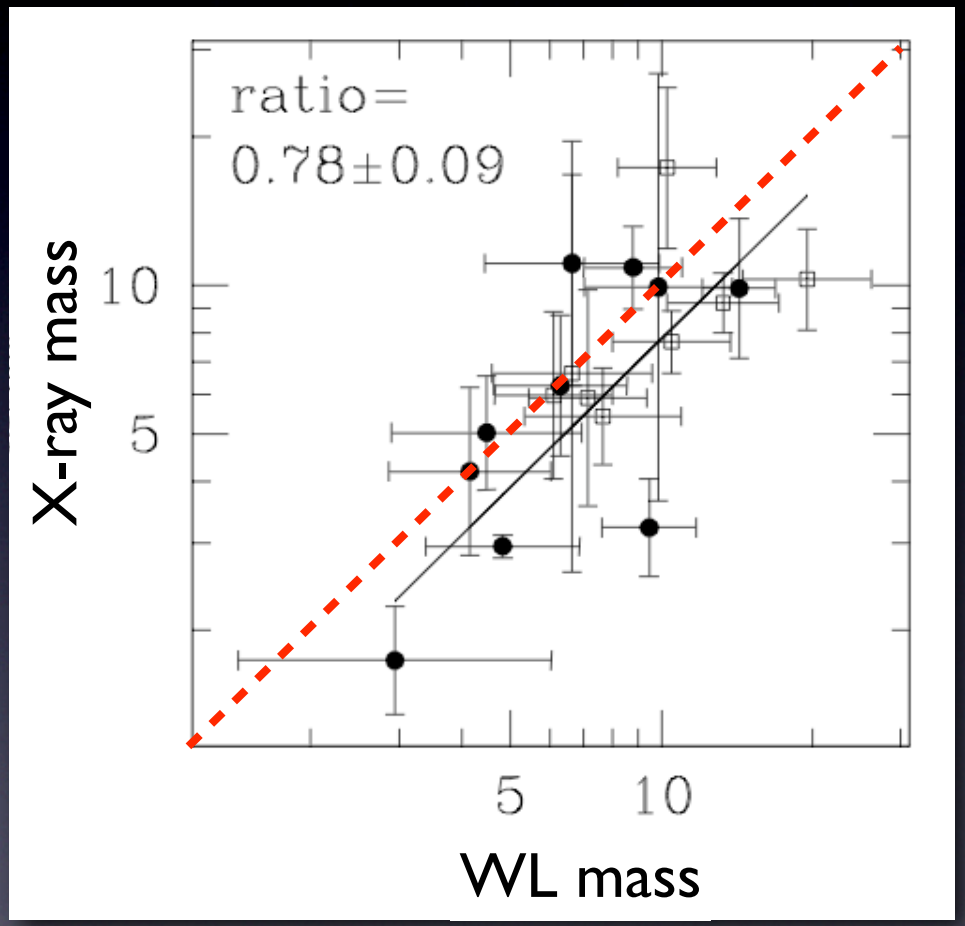

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