Weak lensing calibrated scaling relations for galaxy groups and clusters in the COSMOS and CFHTLS fields

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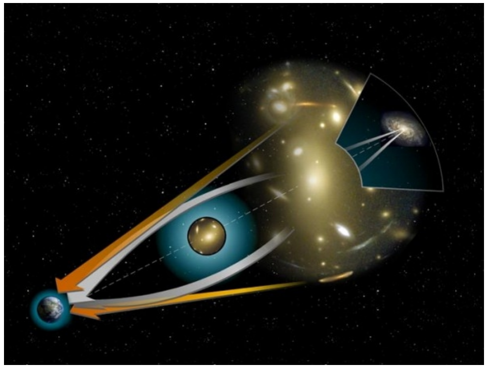
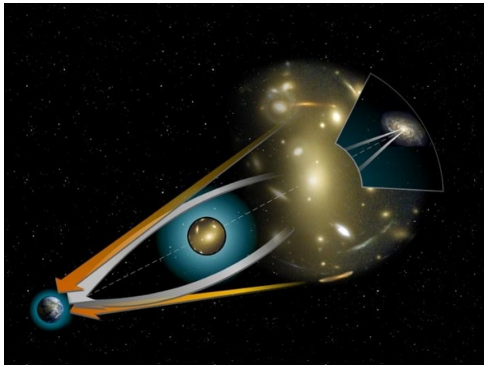
COSMOS, CFHTLenS and XMM-CFHTLS collaborations

Introduction

- Mass calibration of observables currently the biggest challenge in cluster count cosmology
- Calibrate weak lensing masses to X-ray observables for low and intermediate mass systems
    - X-ray masses assuming hydrostatic equilibrium (HSE) biased low
- Simulations indicate that baryonic feedback gets stronger with decreasing mass
    - Scaling relations involving low mass systems can have slopes differing from relations including only high mass systems



Introduction



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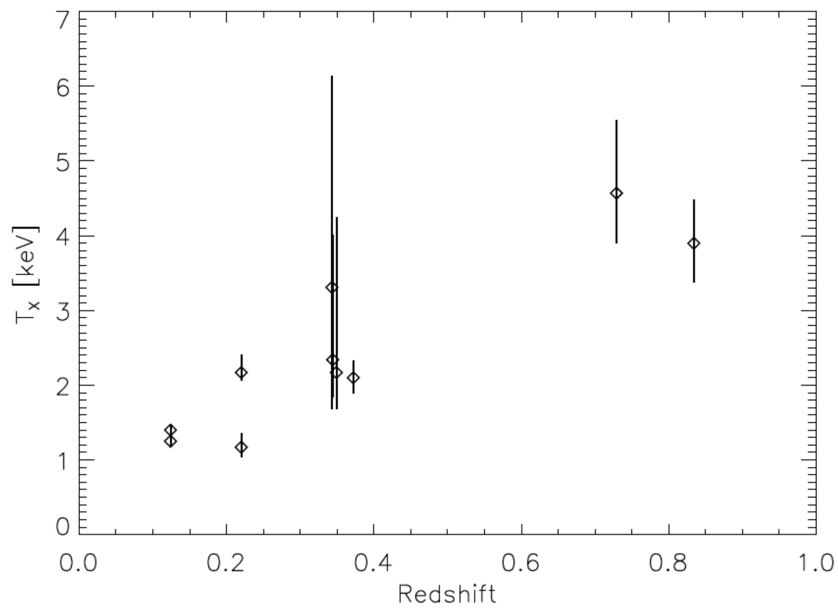
- Contents:
  1) COSMOS M-Tx
  2) CFHTLS

COSMOS M – Tx relation

Kettula et al. 2013 / ArXiv:1309.3891

- M – Lx relation using stacking analysis by Leauthaud+'10
- COSMOS X-ray galaxy group catalog (George+'11)
- S/N > 10 sigma → 10 individual systems with z = 0.124 – 0.834
- pn spectra from 0.1 – 0.5 R500
- Absorbed APEC model in 0.5 – 7.0 keV band
- Include scatter from central 0.1R500 to extraction region
- Local background estimates

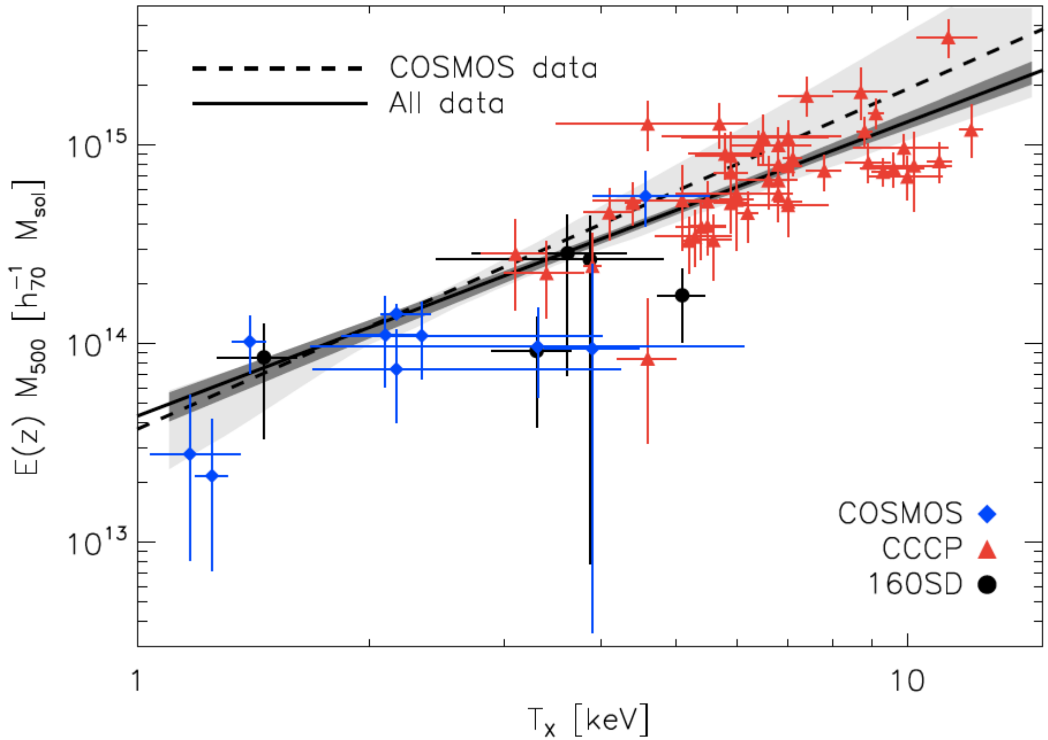


- COSMOS lensing catalog (Leauthaud+ '07,'10,'12)
- Weak lensing mass by fitting NFW profile to shear profile
- Exceptional COSMOS data allows us to perform unique lensing measurements of low mass systems
- M500 ~ 1E13 – 1E14 Msol

COSMOS M – Tx relation

Assume power-law relation as in Kaiser (1986):

$$\log_{10} \frac{M_{500}E(z)}{10^{14}h_{70}^{-1}} = \log_{10} N + \alpha \times \log_{10} \frac{T_X}{3keV}$$



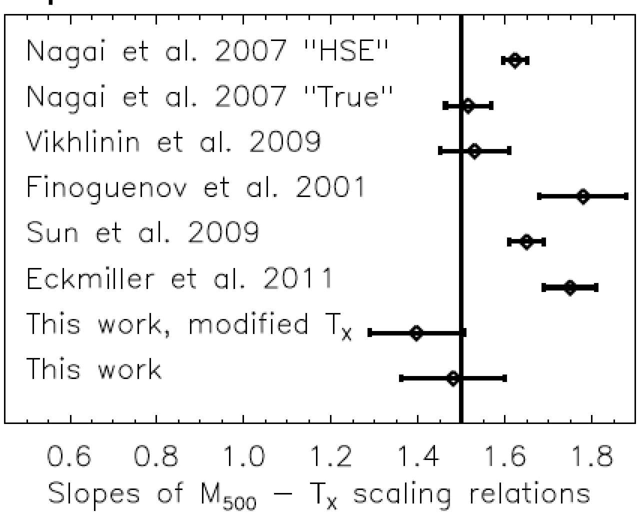
Include:
50 CCCP systems
Hoekstra+'12, Mahdavi+'13
5 systems from 160SD
Vikhlinin+'98, Mullis+'03

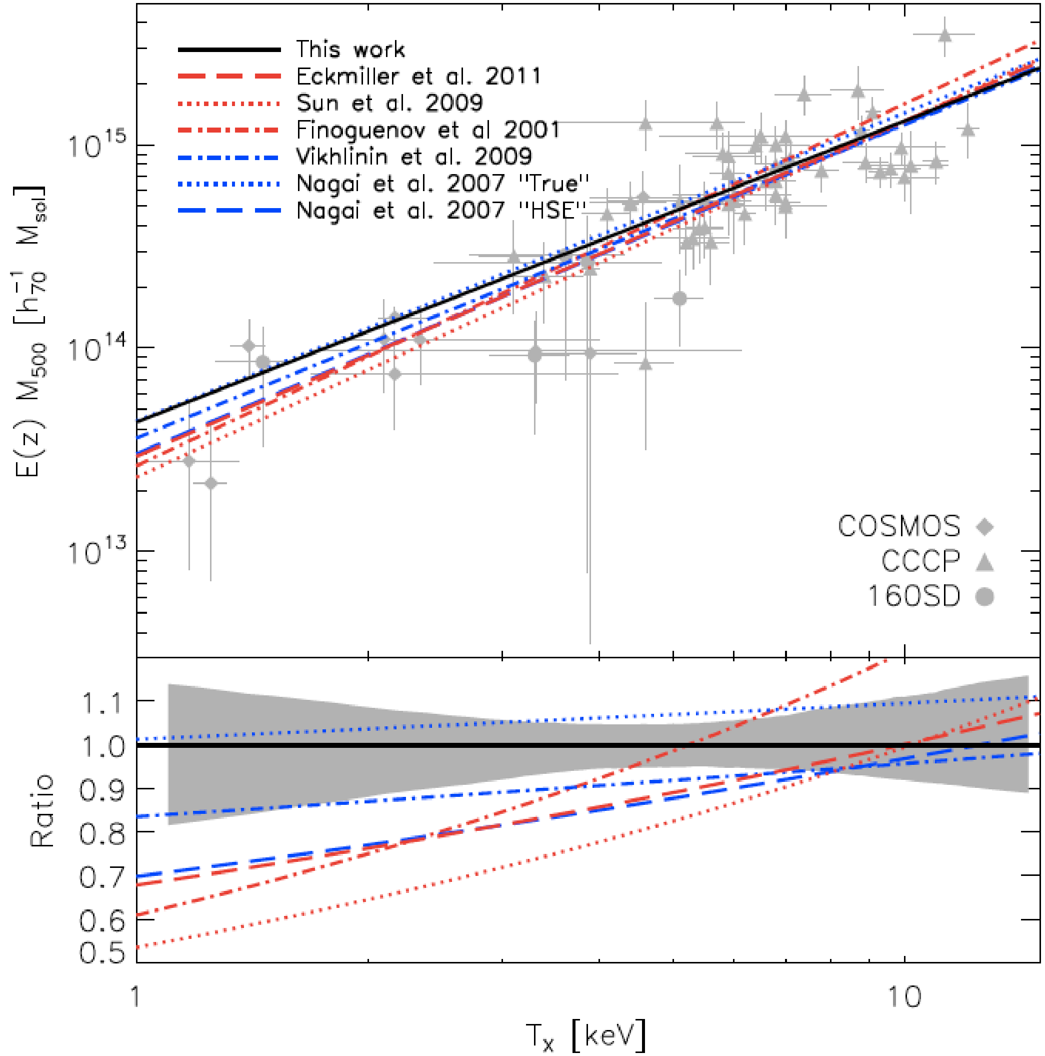
Sample	Slope α	Normalisation $\log_{10} N$	Intrinsic scatter %	χ^2	degrees of freedom
COSMOS	$1.71^{+0.57}_{-0.40}$	$0.39^{+0.04}_{-0.10}$	28 ± 13	5.07	8
COSMOS+CCCP+160SD	$1.48^{+0.13}_{-0.09}$	$0.34^{+0.02}_{-0.04}$	28 ± 7	112.57	63

Slope consistent with self-similar prediction of 1.5, scatter ~28%

COSMOS M – Tx relation

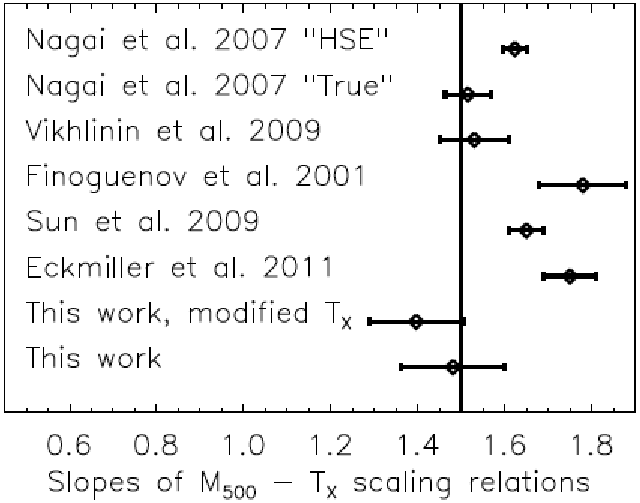
- Simulations and WL indicates that groups and clusters follow the same M-Tx scaling
- Group level relations assuming HSE are steeper
- First observational support for HSE mass bias at group scales, up to 30-50 % at 1 keV

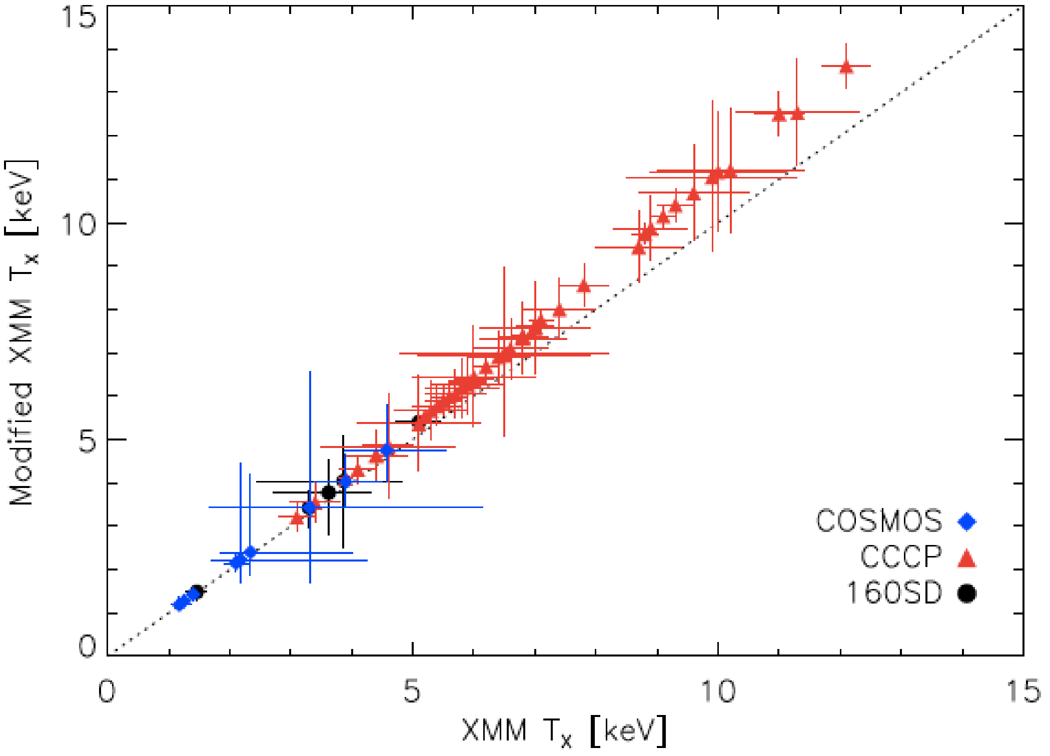




Chandra vs XMM calibration

- Chandra gives systematically higher Tx than XMM-Newton
- Modify our XMM based temperatures to match Chandra calibration and refit M-Tx





$$T_X^{\rm modified} = T_X^{\rm XMM} \times \left(1 + \frac{0.15\ T_X^{\rm XMM}}{10{\rm keV}} \frac{1}{1+z}\right)$$

Chandra vs XMM calibration

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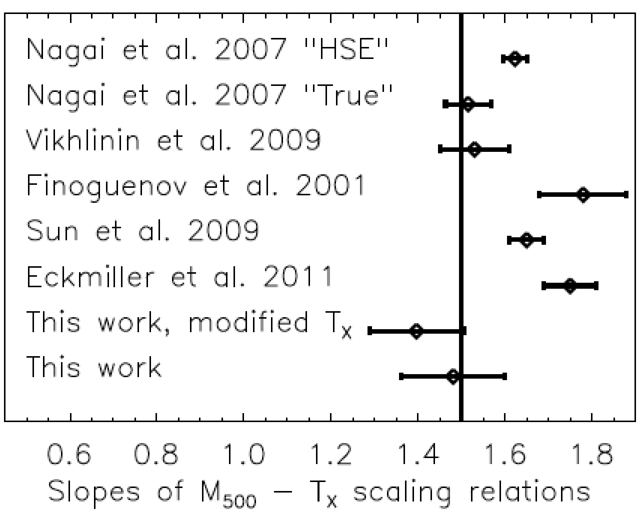
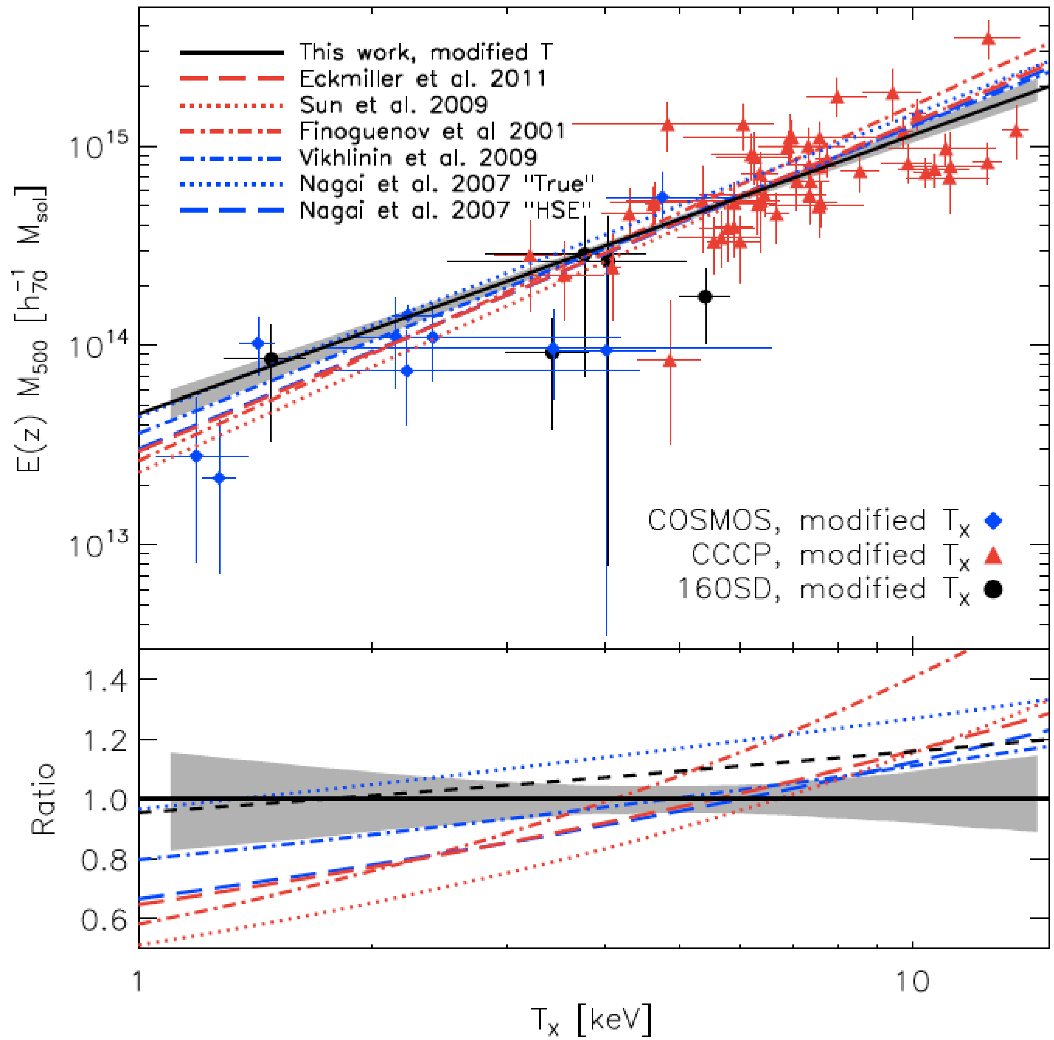
  → **Conclusions unaffected!**

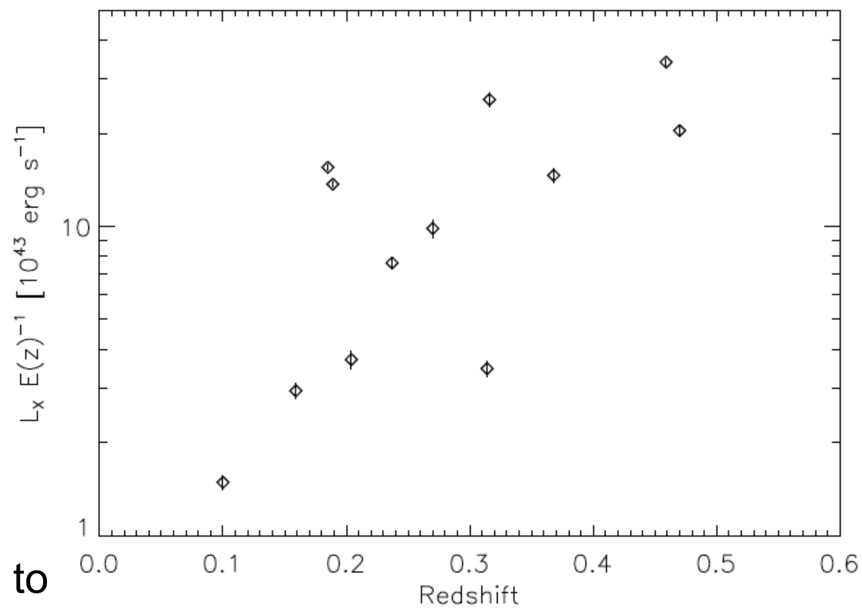




Low mass clusters in CFHTLS

Kettula et al., submitted

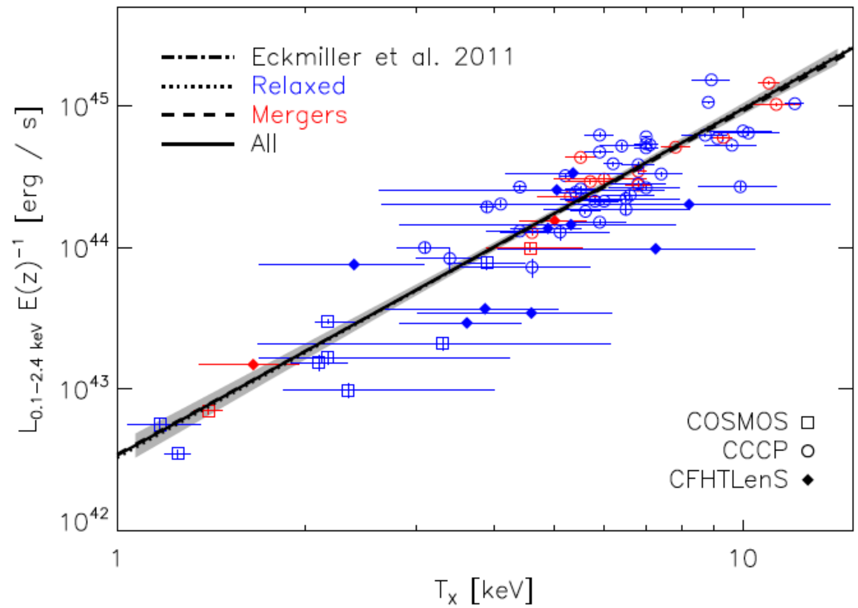
- 12 systems with > 400 counts in XMM-CFHTLS (Mirkazemi et al., submitted)
    - Measure core-excised luminosity Lx and temperature Tx
- Lensing: CFHT 5 band data from CFHTLenS
    - Fit NFW profile to shear profile
- Combine with 10 low mass systems from COSMOS and 50 high mass systems from CCCP
    - Sample of 72 systems with high quality lensing and X-ray data
    - M ~ 1E13-1E15 Msol
    - Use offset between BCG and X-ray peak to divide into subsamples of 15 merging (> 3 % of R200) and 52 relaxed systems (< 3 % of R200)



Scaling

	α	$\log_{10} N$	$\sigma_{A\|B}$
	L_X-T_X		
All data	$2.46^{+0.12}_{-0.11}$	$0.24^{+0.03}_{-0.03}$	$0.17^{+0.02}_{-0.02}$ dex
Mergers	$2.43^{+0.17}_{-0.17}$	$0.23^{+0.04}_{-0.04}$	$0.13^{+0.04}_{-0.03}$ dex
Relaxed	$2.47^{+0.15}_{-0.14}$	$0.24^{+0.03}_{-0.03}$	$0.19^{+0.03}_{-0.02}$ dex
	M_{200}-L_X		
All data	$0.53^{+0.06}_{-0.05}$	$0.29^{+0.04}_{-0.04}$	$0.19^{+0.03}_{-0.02}$ dex
Mergers	$0.51^{+0.14}_{-0.14}$	$0.28^{+0.10}_{-0.10}$	$0.27^{+0.09}_{-0.06}$ dex
Relaxed	$0.55^{+0.07}_{-0.06}$	$0.29^{+0.04}_{-0.04}$	$0.18^{+0.03}_{-0.03}$ dex
	M_{500}-T_X		
All data	$1.46^{+0.13}_{-0.13}$	$-0.00^{+0.03}_{-0.03}$	$0.13^{+0.02}_{-0.02}$ dex
Mergers	$1.29^{+0.31}_{-0.32}$	$-0.01^{+0.07}_{-0.08}$	$0.23^{+0.09}_{-0.06}$ dex
Relaxed	$1.57^{+0.16}_{-0.16}$	$-0.00^{+0.03}_{-0.03}$	$0.09^{+0.03}_{-0.03}$ dex

α is the slope of the relation, $\log_{10} N$ the normalisation and $\sigma_{A|B}$ the intrinsic scatter in the independent variable.



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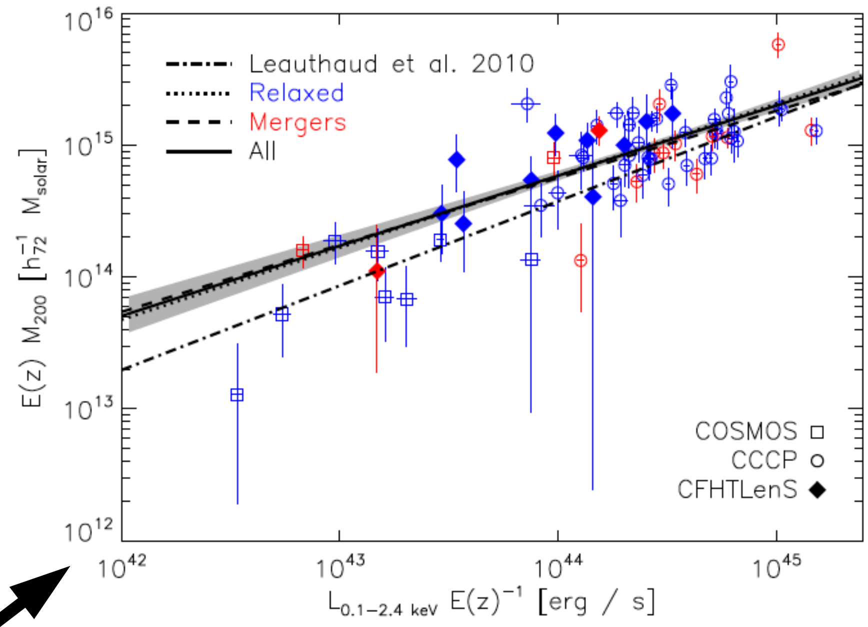

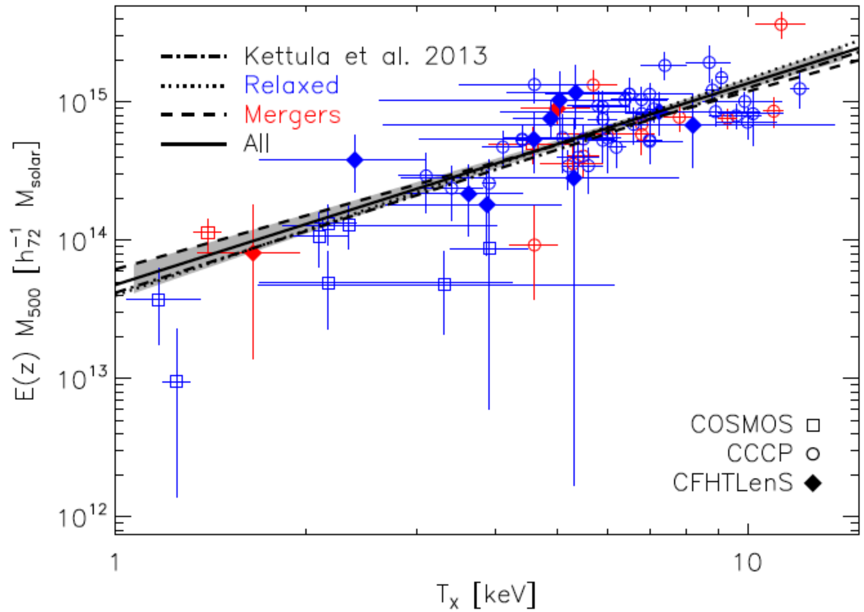

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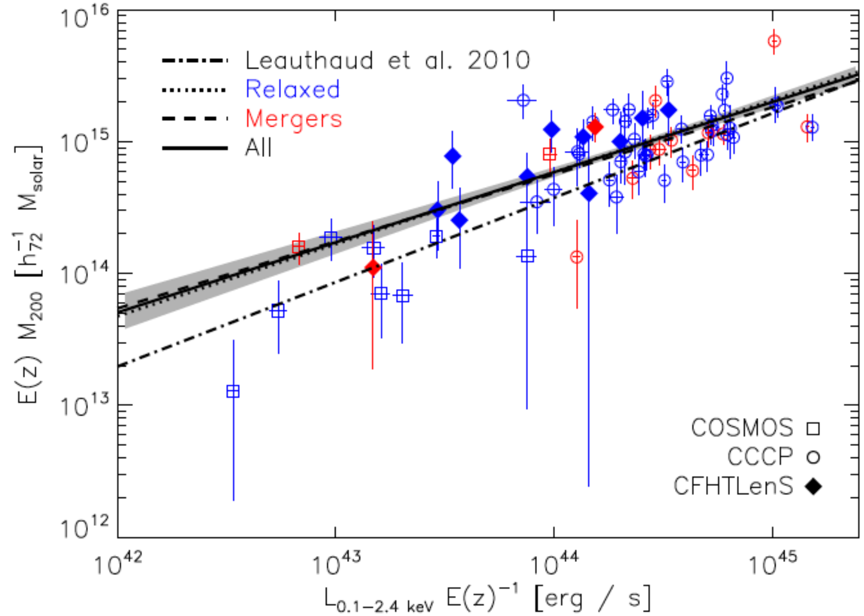

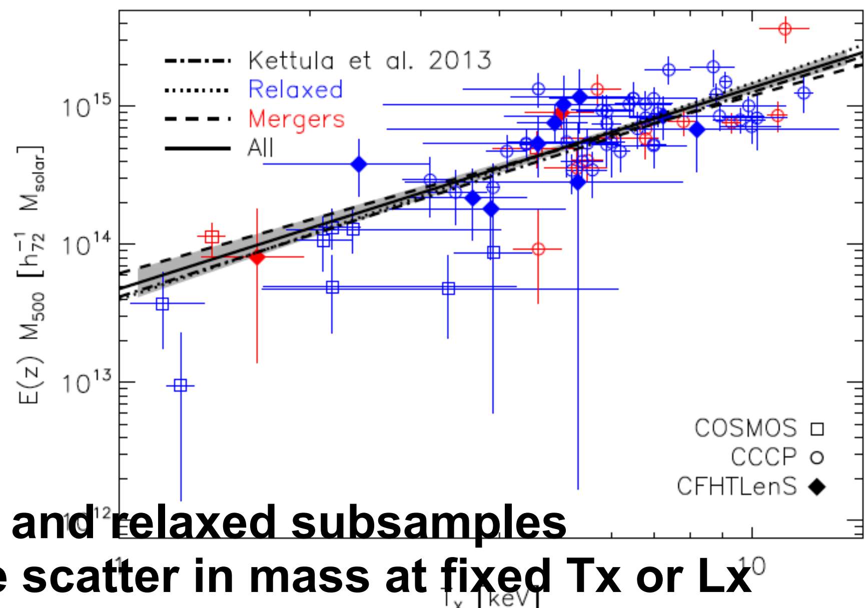

- **Slopes consistent for merging and relaxed subsamples**
- **Merging systems display more scatter in mass at fixed Tx or Lx**
- **Steepening of slopes at low mass?**

Intrinsic mass scatter in mergers

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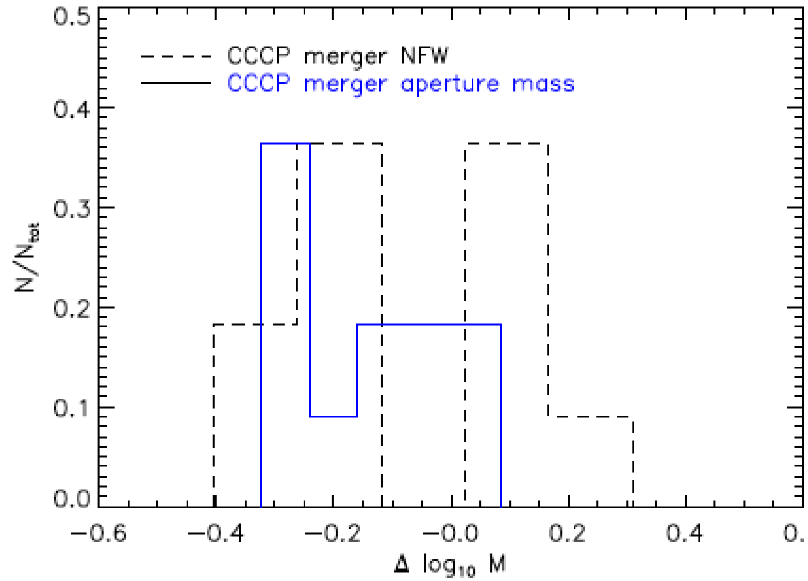
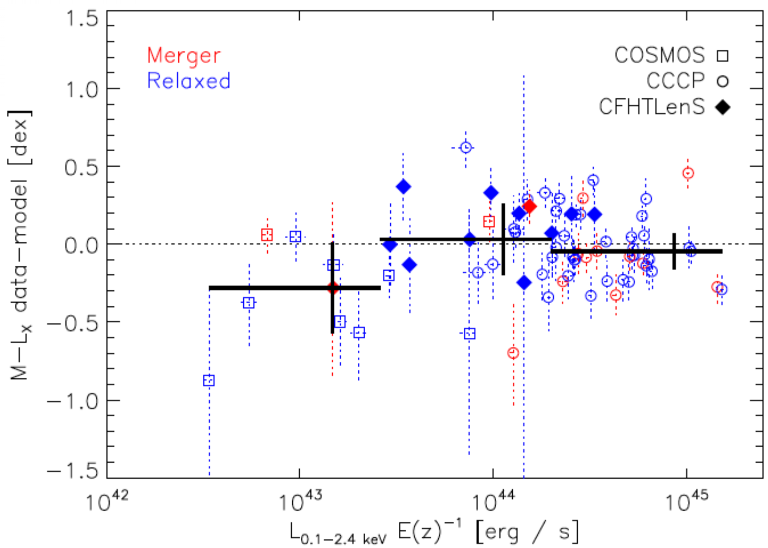
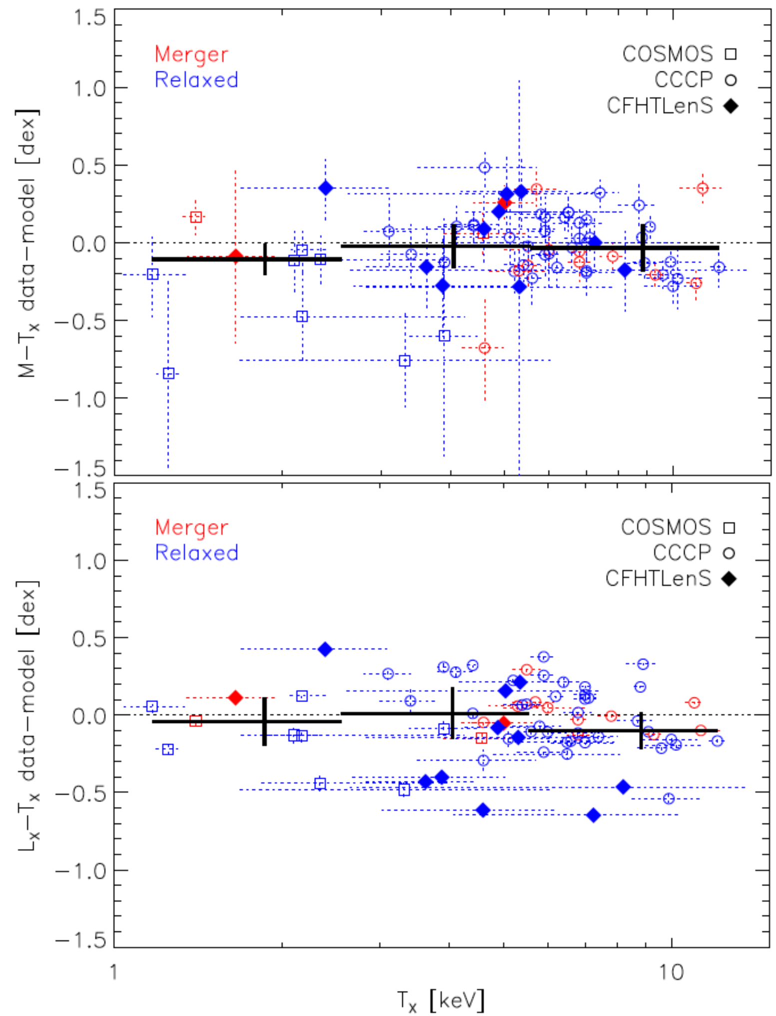


- Assumption of NFW profile breaks down for merging clusters?
- Aperture densitometry mass measurements available for CCCP (Hoekstra+'12)
- Compare M-Tx residuals using NFW and aperture mass for 11 merging clusters in CCCP
  - Slightly different scaling with ~ 50% smaller scatter for aperture mass

Low mass steepening





- Stacked residuals in three logarithmic bins
  - M-Lx and M-Tx overestimate mass in lowest Lx and Tx bin by ~ 1 sigma

→ More observations of low mass systems needed to characterise low mass behaviour

Conclusions

- Lensing calibrated scaling relations for low and intermediate mass systems and divide into merging and relaxed subsamples on BCG to X-ray peak offset
- In contrast to previous relations assuming HSE both groups and clusters follow the same M-Tx scaling
  - Mass dependent HSE mass bias reaching 30-50 % at 1 keV
- Merging and relaxed clusters follow the same Lx-Tx, M-Lx and M-Tx scaling
  - Mergers scatter more at fixed M → mergers require different mass modeling than NFW
  - Mergers contribute little to the global scatter of X-ray selected samples, but can affect samples dominated by merging clusters
  - Tx a low scatter mass proxy for X-ray selected samples
- Residuals show a possible steepening for M-Lx and M-Tx relations at low masses
  - More measurements of low mass systems needed