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

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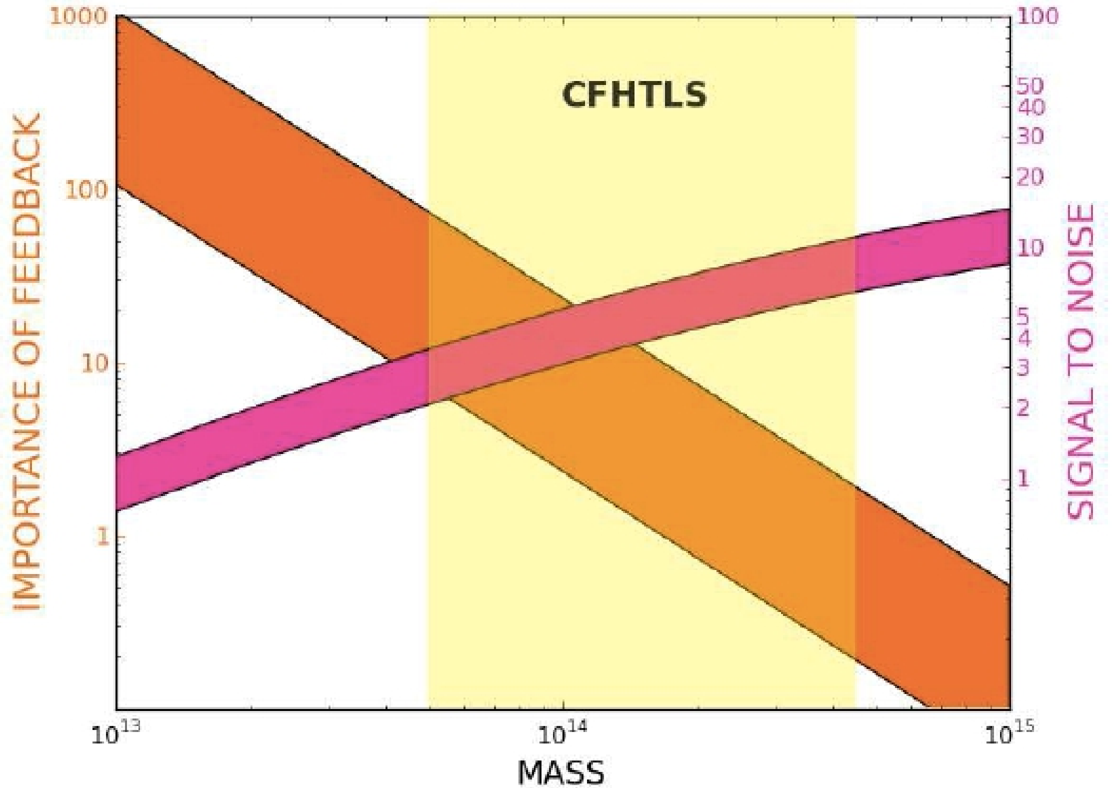
COSMOS, CFHTLenS and XMM-CFHTLS collaborations

Scaling in low mass systems

Ratio of radio galaxy AGN feedback to gravitational potential for groups in COSMOS (Giodini+10)



Lensing signal

- Gas component more dominant for low mass systems
- Scaling at low masses more strongly affected by feedback from AGN and star formation
  - Simulations including cooling and feedback indicate that low mass systems follow a different scaling than high mass systems (e.g. Le Brun+14, Planelles+14, Pike+14)

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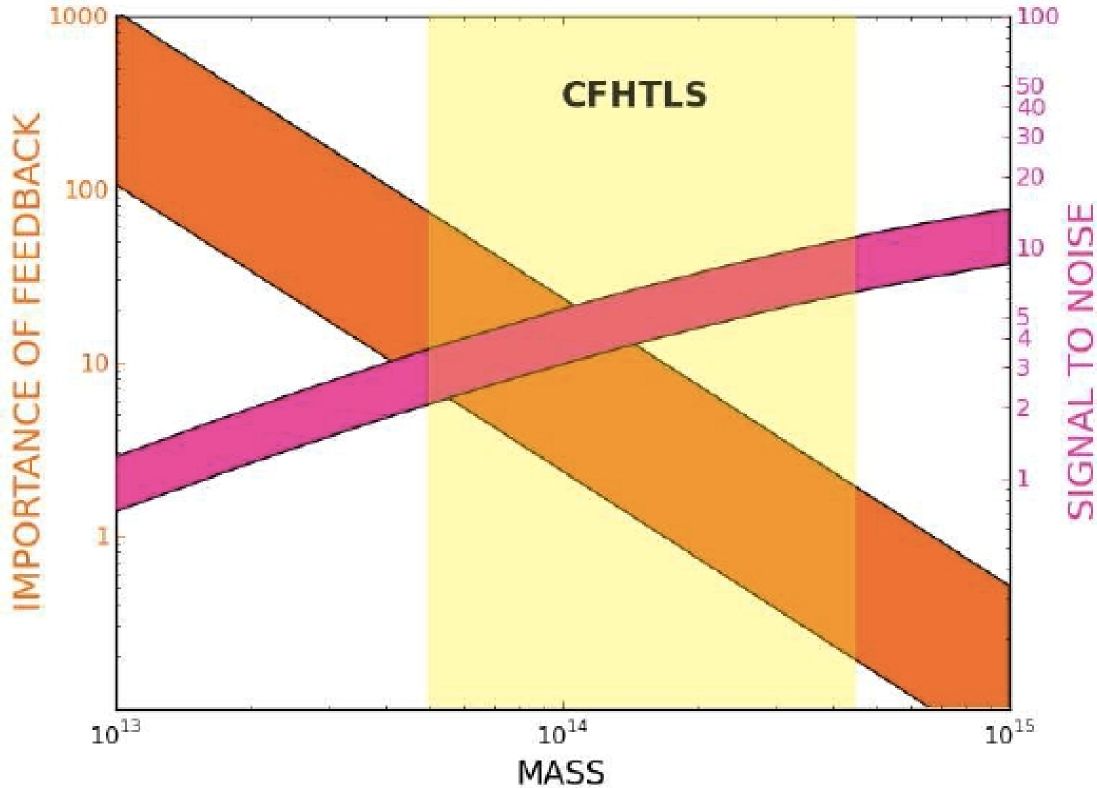


Lensing signal

- Lensing measurements of low mass systems observationally demanding → previous work mainly relying on X-ray masses assuming hydrostatic equilibrium (HSE) (e.g. Sun+09, Eckmiller+14, Lovisari+14)
    - Direct measurement of a break hard
    - Indicates stronger deviations from self-similarity and larger scatter for relations including low mass systems

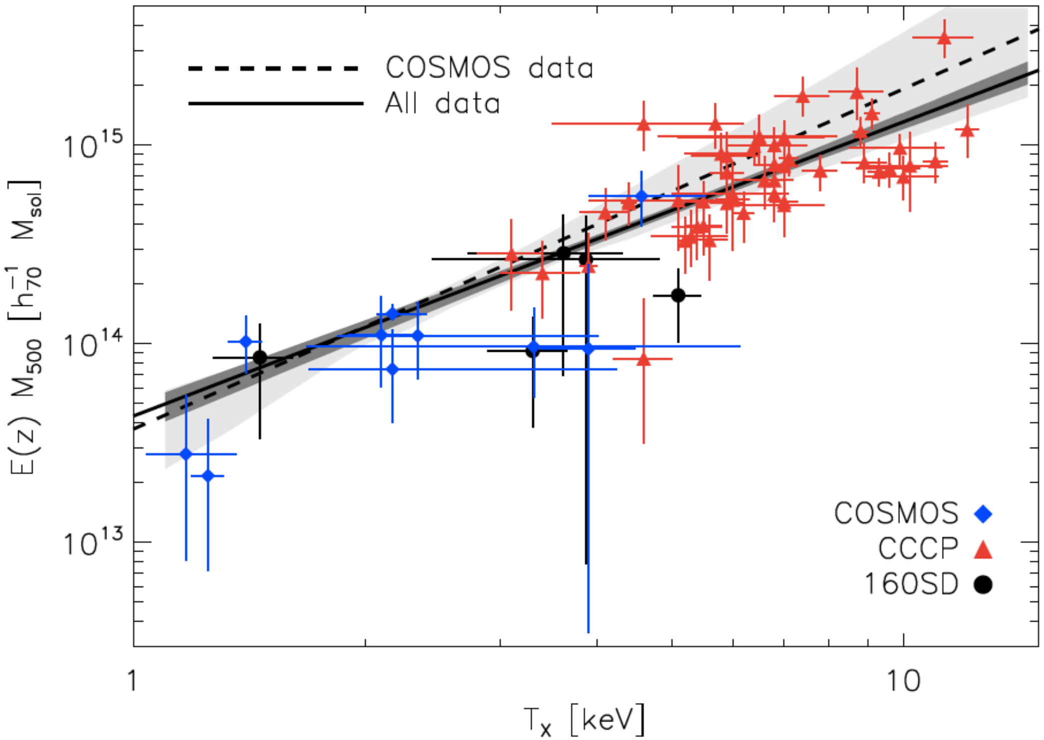
COSMOS M – Tx relation

Kettula et al. 2013 / ArXiv:1309.3891

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:
10 COSMOS groups
50 CCCP systems
Hoekstra+12, Mahdavi+13
5 systems from 160SD
Vikhlinin+98, Mullis+03

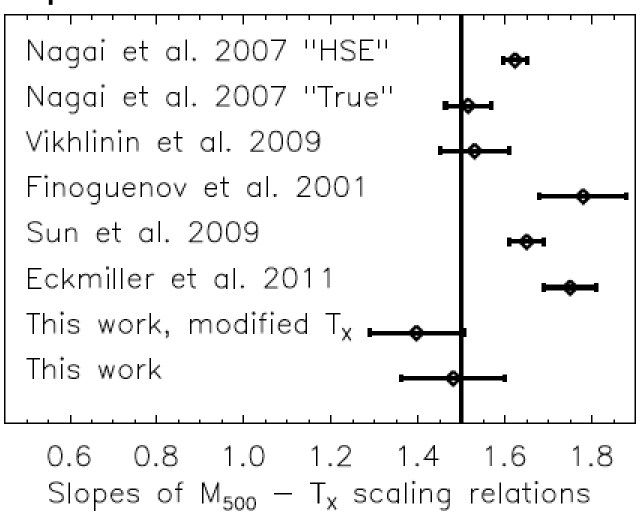


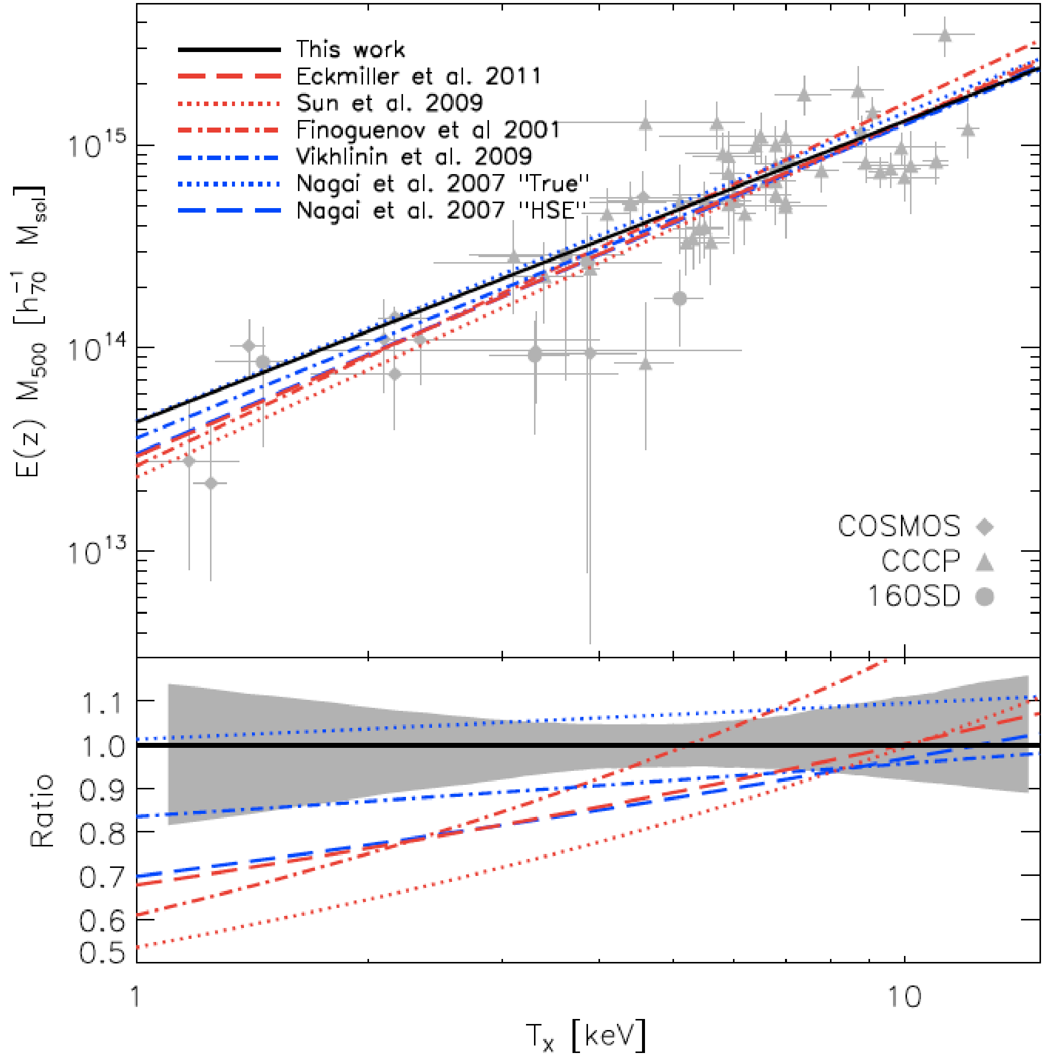
Sample	Slope α	Normalisation $\log_{10} N$	Intrinsic scatter %	χ^2	degrees of freedom
COSMOS	$1.71^{+0.57}_{-0.40}$	$0.39^{+0.04}_{-0.10}$	28 ± 13	5.07	8
COSMOS+CCCP+160SD	$1.48^{+0.13}_{-0.09}$	$0.34^{+0.02}_{-0.04}$	28 ± 7	112.57	63

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

COSMOS M – Tx relation

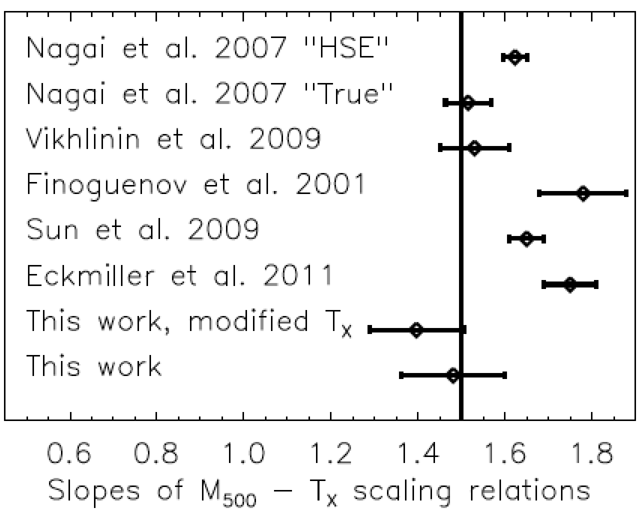
- WL and simulations indicate that groups and clusters follow the same M-Tx scaling
- Group level relations assuming HSE are steeper
- First observational support for HSE mass bias at group scales, up to 30-50 % at 1 keV

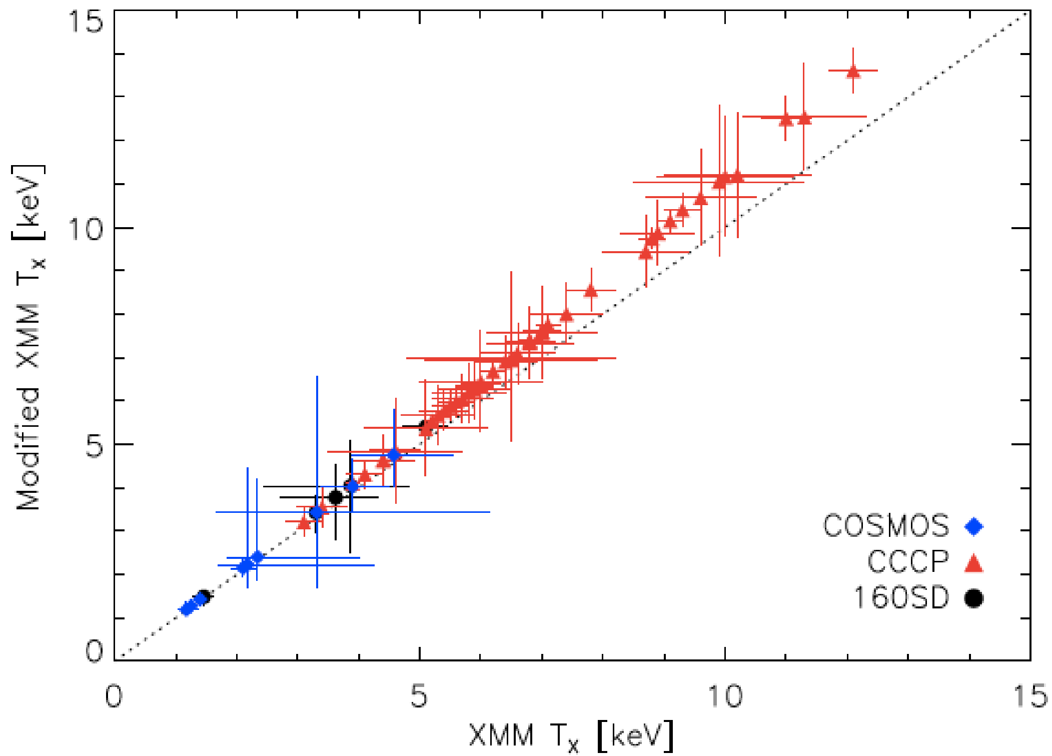




Chandra vs XMM calibration

- Chandra gives systematically higher Tx than XMM-Newton
- Modify our XMM based temperatures to match Chandra calibration and refit M-Tx
  → **Conclusions unaffected!**



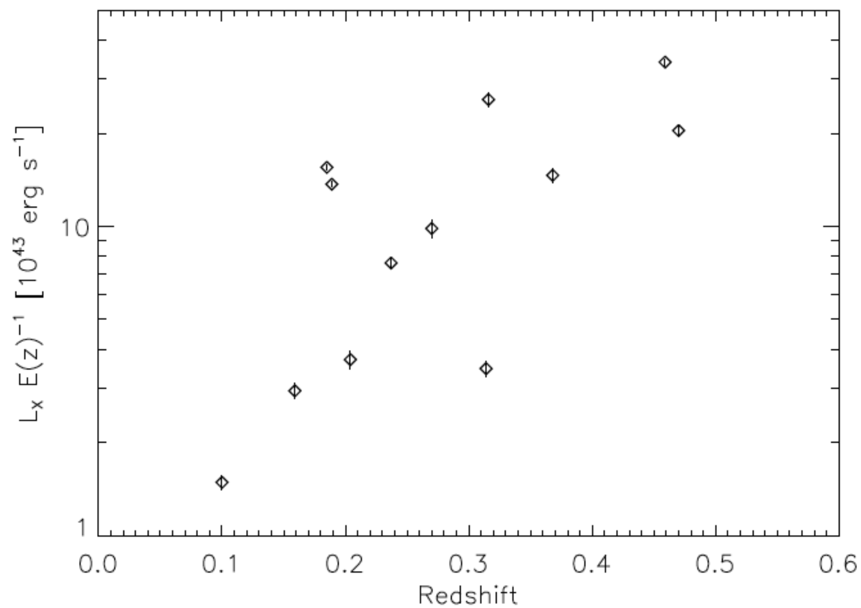


$$T_X^{\mathrm{modified}} = T_X^{\mathrm{XMM}} \times \left(1 + \frac{0.15\, T_X^{\mathrm{XMM}}}{10\mathrm{keV}} \frac{1}{1+z}\right)$$

Low mass clusters in CFHTLS

Kettula et al., MNRAS submitted / ArXiv:1410.8769

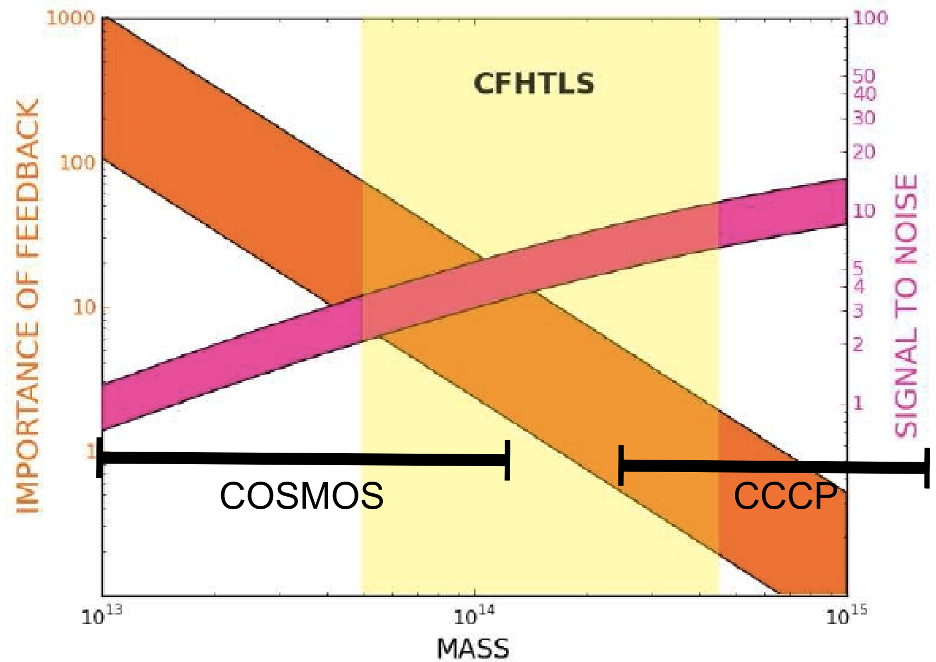
- 154 sq. deg. fields of CFHTLS-Wide
- XMM-CFHTLS (Mirkazemi et al., ApJ submitted)
  - Extended ROSAT All Sky Survey (RASS) emission and CFHTLS multiband and HECTOSPEC/MMT spectroscopic follow-up
  - 12 systems with > 400 counts
  - Measure core-excised X-ray luminosity Lx using a 0.5-2.0 keV band and temperature Tx
- CFHTLenS
  - CFHT 5 band lensing data
  - Fit NFW profile to shear profile assuming Duffy+08 mass-concentration



Low mass clusters in CFHTLS

Kettula et al., MNRAS submitted / ArXiv:1410.8769

- 70 systems in total
- M ~ 1E13-1E15 Msol
- Tx ~ 1-10 keV
- Lx ~1E43-1E45 erg / s
  1) Use offset between BCG and X-ray peak to divide into subsamples of 15 merging (> 3 % of R200) and 55 relaxed systems (< 3 % of R200)
  2) Use the three surveys as approximate mass bins
  3) Study the effects of X-ray cross-calibration by converting our XMM measurements to match Chandra calibration

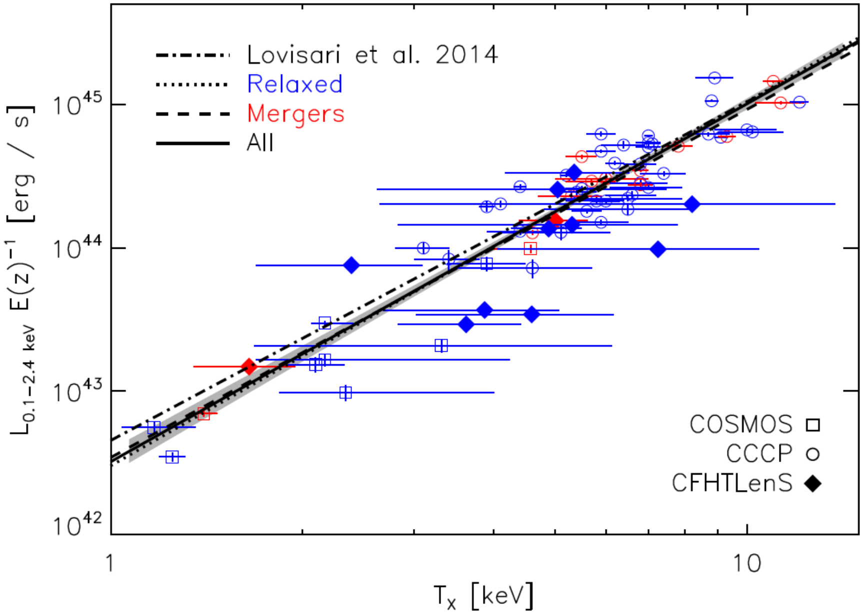


10 low mass systems from COSMOS (Kettula et al. 2013)
48 high mass systems from CCCP with updated lensing analysis (Hoekstra et al., submitted)

Lx – Tx relation

	α	$\log_{10} N$	$\sigma_{\log(A\|B)}$
L_X-T_X			
All data	$2.49^{+0.11}_{-0.11}$	$0.25^{+0.03}_{-0.03}$	$0.16^{+0.02}_{-0.02}$
Mergers	$2.43^{+0.16}_{-0.17}$	$0.23^{+0.04}_{-0.04}$	$0.13^{+0.04}_{-0.03}$
Relaxed	$2.54^{+0.14}_{-0.15}$	$0.25^{+0.03}_{-0.03}$	$0.18^{+0.03}_{-0.02}$
CFHTLS	$2.30^{+0.87}_{-0.87}$	$0.13^{+0.15}_{-0.13}$	$0.28^{+0.16}_{-0.13}$
COSMOS	$2.46^{+0.44}_{-0.47}$	$0.17^{+0.20}_{-0.21}$	$0.16^{+0.10}_{-0.07}$
CCCP	$2.04^{+0.20}_{-0.19}$	$0.32^{+0.03}_{-0.03}$	$0.15^{+0.02}_{-0.02}$

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

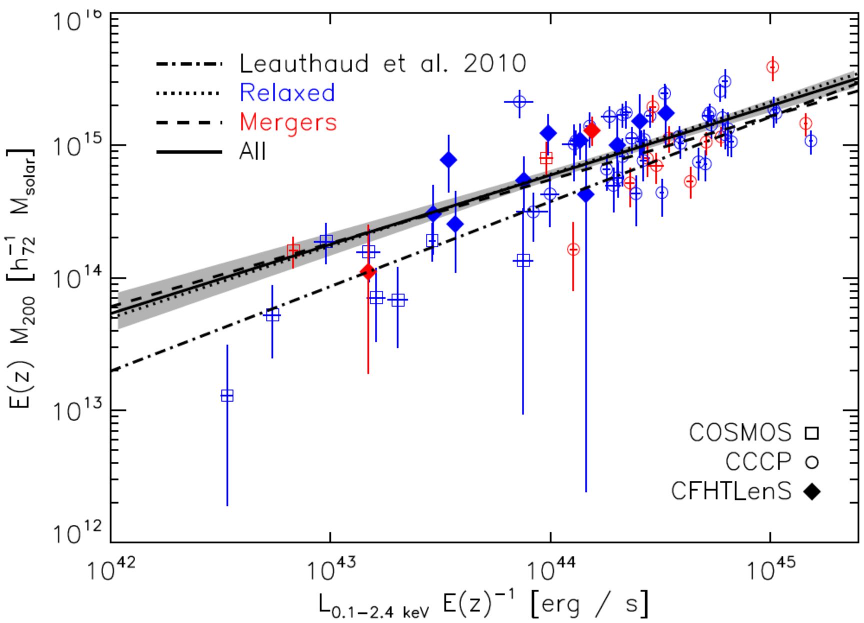


- Slope steeper than self-similar prediction of 2.0
- For the full sample Chandra calibration results in Δslope = - 0.29 +- 0.11

M – Lx relation

	α	$\log_{10} N$	$\sigma_{\log(A\|B)}$
		M_{200}-L_X	
All data	$0.52^{+0.06}_{-0.06}$	$0.30^{+0.04}_{-0.04}$	$0.20^{+0.03}_{-0.02}$
Mergers	$0.48^{+0.13}_{-0.13}$	$0.26^{+0.09}_{-0.10}$	$0.24^{+0.08}_{-0.06}$
Relaxed	$0.54^{+0.07}_{-0.06}$	$0.31^{+0.04}_{-0.04}$	$0.20^{+0.03}_{-0.03}$
CFHTLS	$0.66^{+0.24}_{-0.22}$	$0.46^{+0.07}_{-0.08}$	$0.12^{+0.10}_{-0.07}$
COSMOS	$0.70^{+0.30}_{-0.30}$	$0.26^{+0.25}_{-0.28}$	$0.29^{+0.18}_{-0.12}$
CCCP	$0.32^{+0.11}_{-0.11}$	$0.41^{+0.07}_{-0.07}$	$0.20^{+0.03}_{-0.03}$

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

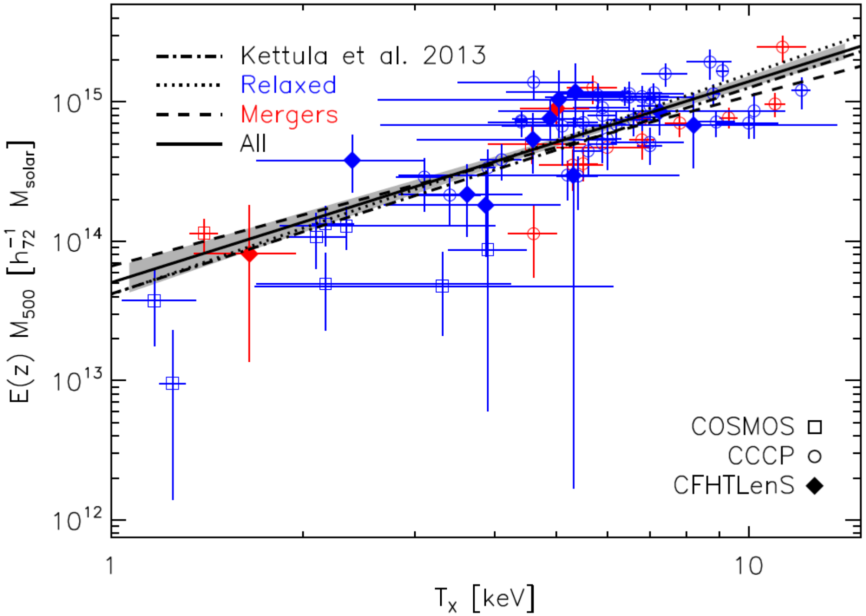


- Slope flatter than self-similar prediction of 0.75
- Unaffected by X-ray cross-calibration
- CCCP results in flatter relation

M – Tx relation

	α	$\log_{10} N$	$\sigma_{\log(A\|B)}$
	M_{500}-T_X		
All data	$1.44^{+0.14}_{-0.13}$	$0.01^{+0.03}_{-0.03}$	$0.14^{+0.03}_{-0.02}$
Mergers	$1.22^{+0.29}_{-0.30}$	$-0.02^{+0.07}_{-0.07}$	$0.20^{+0.08}_{-0.06}$
Relaxed	$1.58^{+0.17}_{-0.16}$	$0.02^{+0.03}_{-0.03}$	$0.13^{+0.03}_{-0.03}$
CFHTLS	$1.46^{+1.05}_{-0.89}$	$0.17^{+0.12}_{-0.12}$	$0.17^{+0.13}_{-0.09}$
COSMOS	$1.47^{+0.72}_{-0.70}$	$-0.09^{+0.31}_{-0.34}$	$0.27^{+0.20}_{-0.13}$
CCCP	$1.21^{+0.25}_{-0.23}$	$0.04^{+0.04}_{-0.04}$	$0.15^{+0.03}_{-0.02}$

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

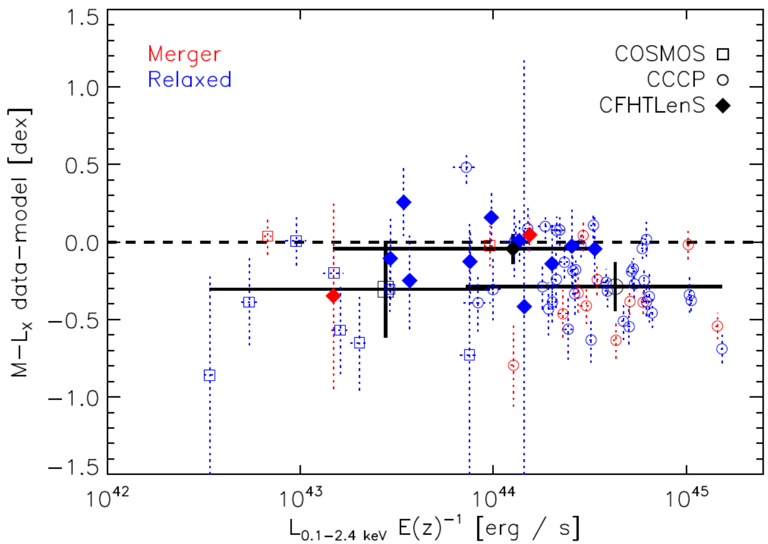


- Slope consistent with self-similar prediction of 1.50
- For the full sample Chandra calibration results in Δslope = - 0.16 +- 0.13

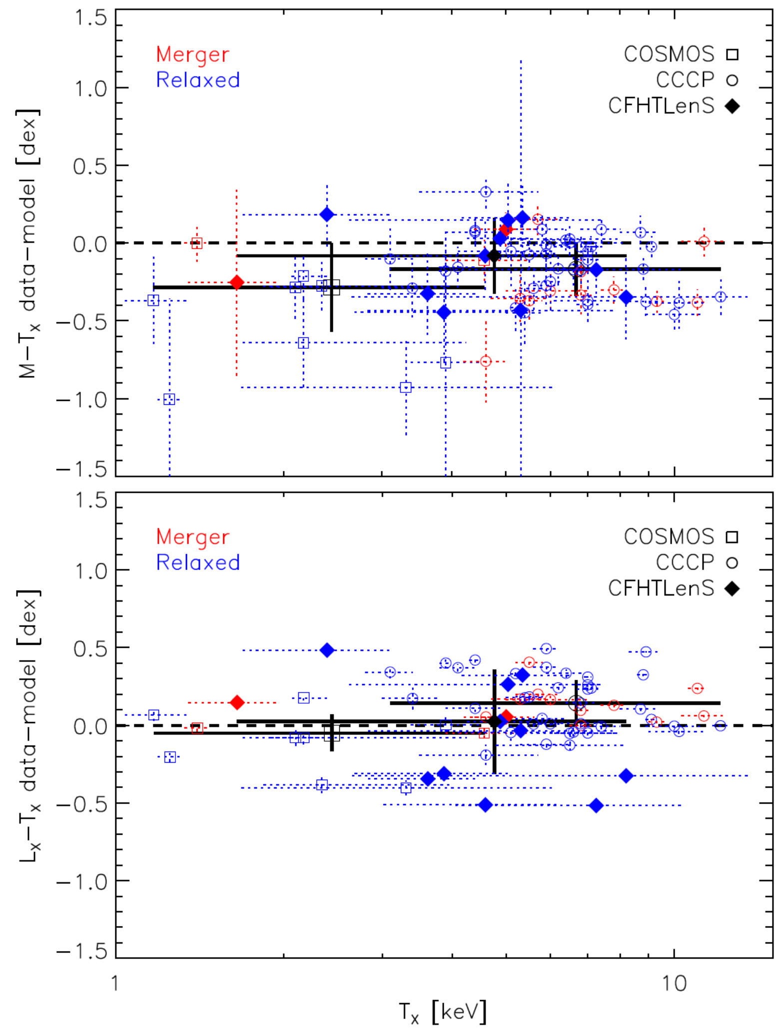
Mergers vs relaxed

- Simulations show that weak lensing masses obtained by fitting an NFW profile have a scatter of ~ 20-25 % and may be biased low by a few % due to triaxiality and substructure (e.g. Meneghetti+10, Becker & Kravtsov '11)
  - Merging clusters expected to have stronger triaxiality and substructure than relaxed
  - A marginal trend for flatter slope, lower normalization and larger scatter in mass in merging clusters
  - Need larger sample of merging systems for better statistics
  - Aperture mass might provide better mass calibration for mergers

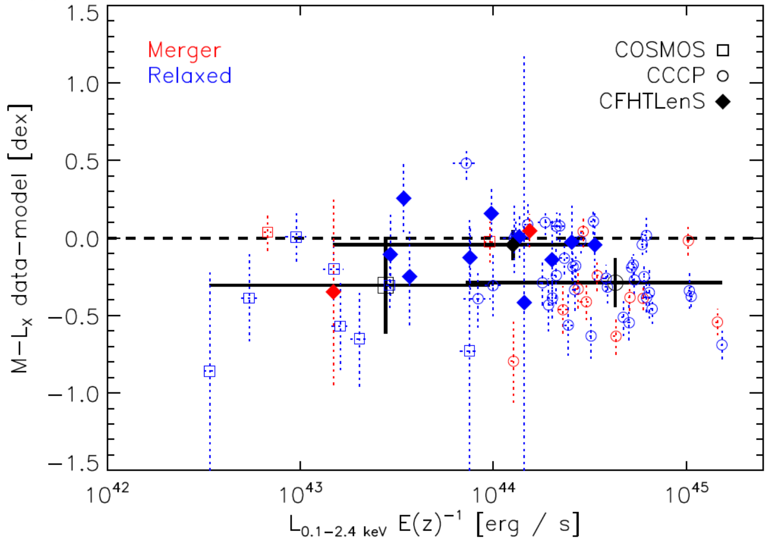
Mass dependence

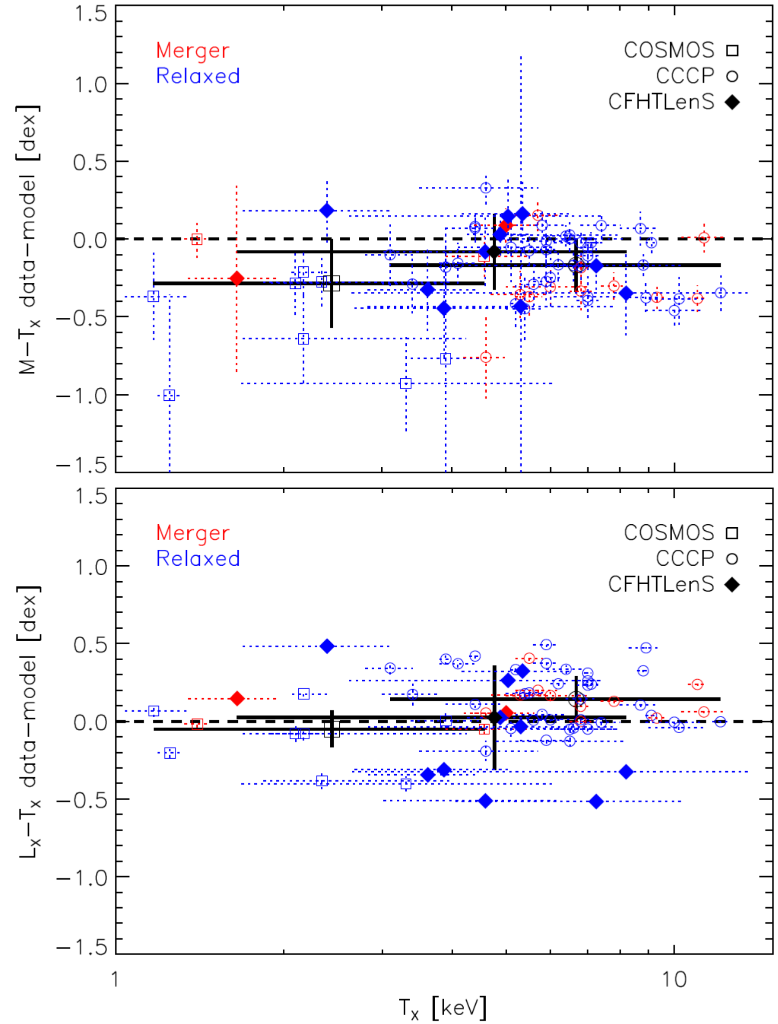


- CFHTLS only and COSMOS only relations consistent with the full sample, but large uncertainties
- Tendency for enhanced scatter in mass for COSMOS
- CCCP only results in flatter M-Lx than CFHTLS and COSMOS
- Stacked residuals wrt CFHTLS only relation
  - No significant deviations in Lx-Tx and M-Tx



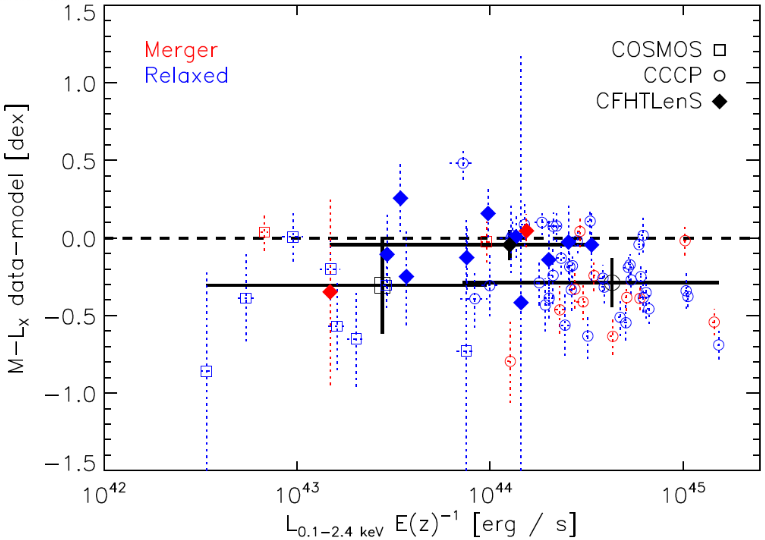
Mass dependence

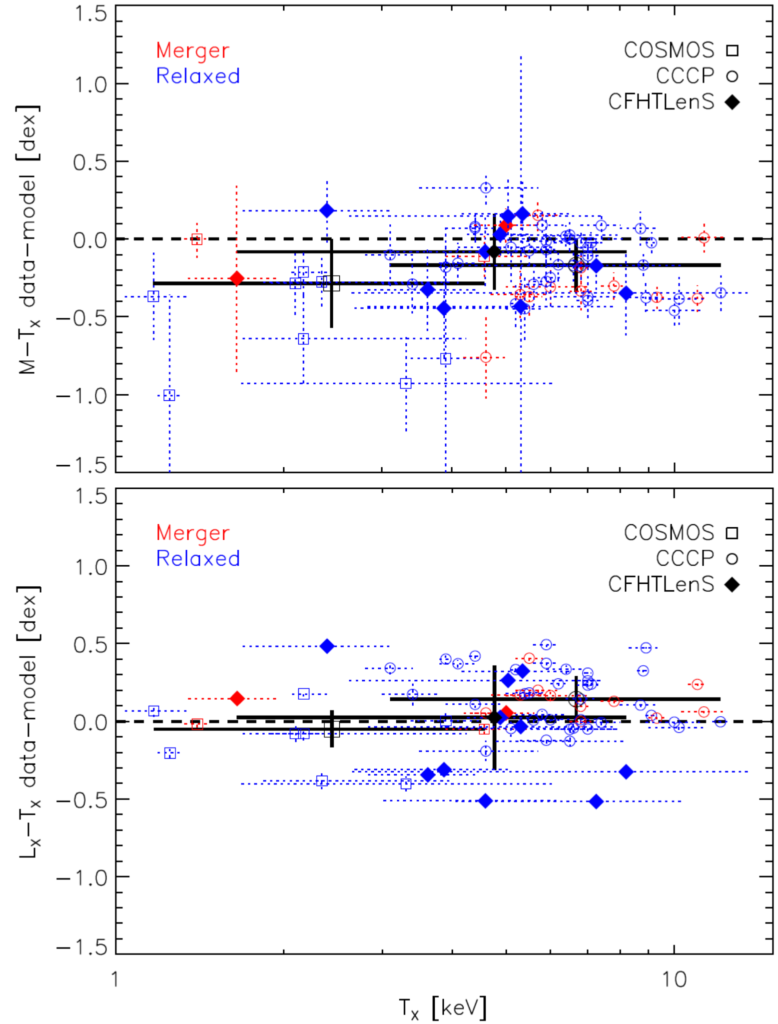




- CFHTLS systems have higher mass for their luminosity
  1) X-ray emission lines contribute significantly over the bremsstrahlung continuum to groups in COSMOS
  2) Interplay between the steep decline of the mass function and scatter in Lx → massive clusters in CCCP scatter to higher Lx

Mass dependence

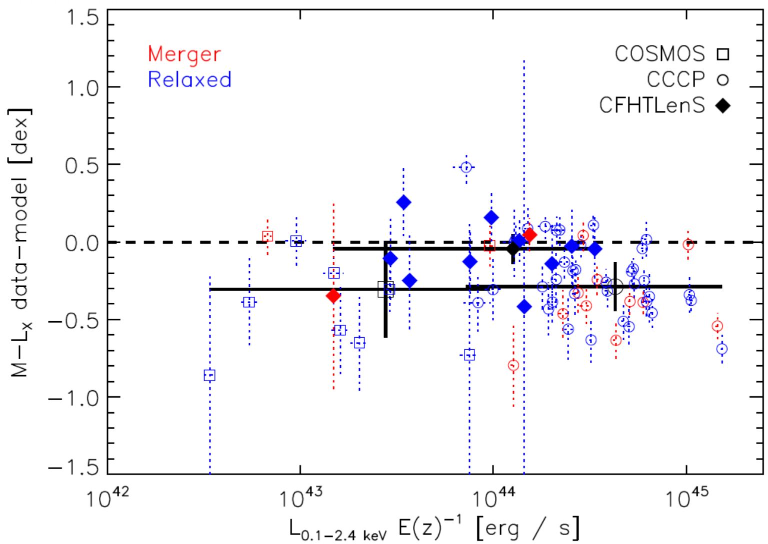


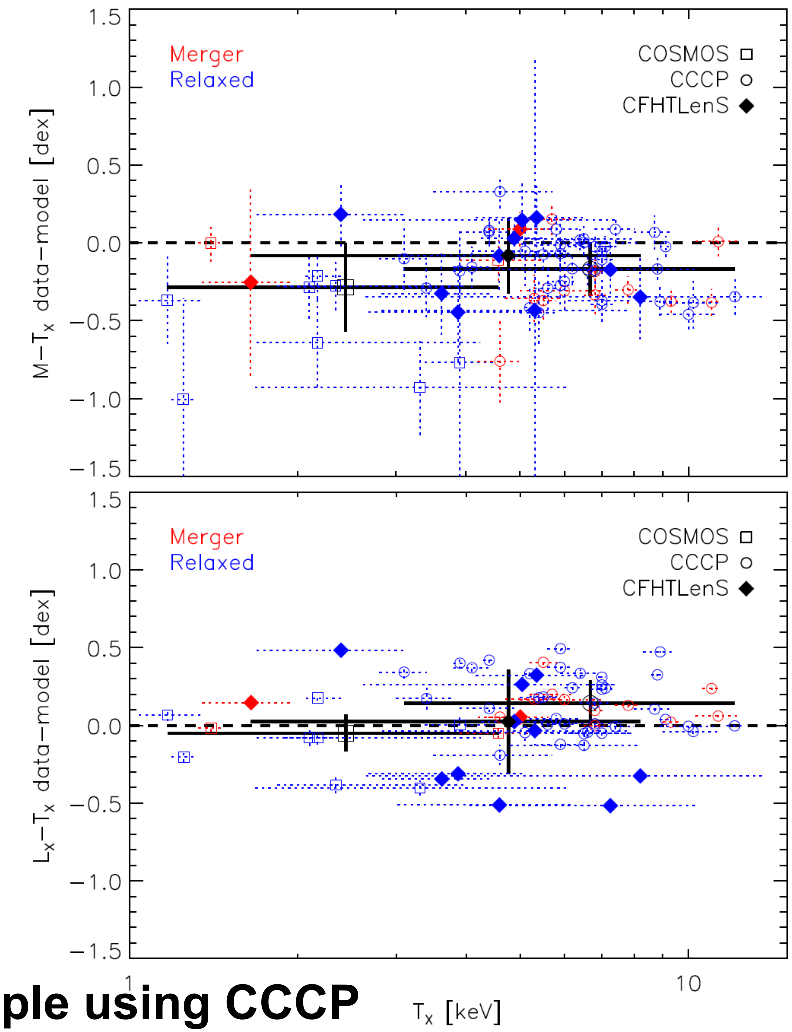


- Test if CCCP drives the M-Lx relation fitted to the full sample by using a different high mass sample
  - Match lensing masses of WtG clusters in the Sereno+14 catalog to Lx in the BAX cluster database → 30 clusters

	α	$\log_{10} N$	$\sigma_{\log(A\|B)}$
WtG	$0.66^{+0.18}_{-0.17}$	$0.18^{+0.17}_{-0.18}$	$0.13^{+0.04}_{-0.03}$
COSMOS + CFHTLS + WtG	$0.57^{+0.04}_{-0.04}$	$0.29^{+0.04}_{-0.04}$	$0.12^{+0.03}_{-0.03}$

Mass dependence





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COSMOS + CFHTLS + WtG	$0.57^{+0.04}_{-0.04}$	$0.29^{+0.04}_{-0.04}$	$0.12^{+0.03}_{-0.03}$

Consistent slope with the full sample using CCCP
→ relations using the full mass range are robust!

Conclusions

- Provides the current limitations for using Lx and Tx as cluster mass proxies
- Mergers contribute little to X-ray selected samples
  - A marginal trend for flatter slope, lower normalization and larger scatter in mass in merging clusters
- Temperature is a good low scatter mass proxy for X-ray selected samples
- Not able to directly measure breaks in the relations
  - Intermediate mass systems have higher mass for their luminosity
- Demonstrates the importance of having:
  1) more measurements of low mass systems
  2) well understood samples on all mass scales