

Impact of Cluster Structure and Dynamical State on Scatter in the SZ Flux-Mass Relation

H.-Y. Karen Yang (UIUC)

Suman Bhattacharya (LANL)

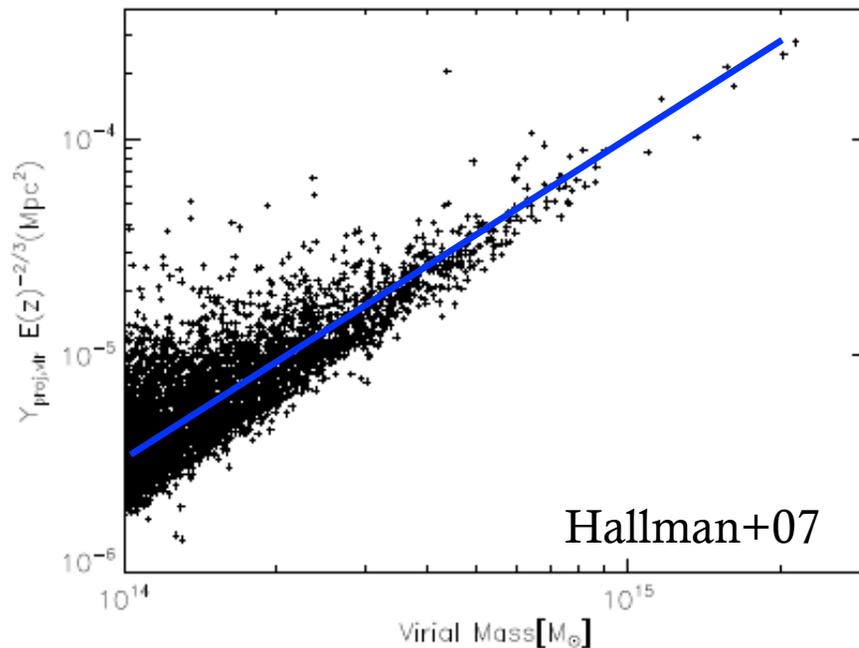
Paul M. Ricker (UIUC, NCSA)

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SZ Flux-Mass (Y_{sz} -M) Relation

Galaxy cluster count is a powerful cosmological probe, but need to infer total mass *via M-Obs. Relations* (*Tx-M, Richness-M, Ysz-M...*)

Y_{sz} - M Relation



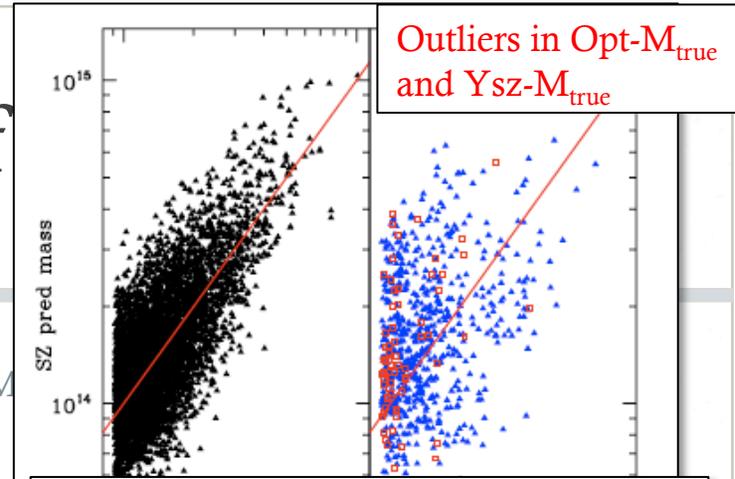
$$Y_{SZ} = \int y d\Omega = \frac{k_B \sigma_T}{m_e c^2} \int n_e(l) T_e(l) dV$$

Need **accurate** and **unbiased** estimates of the form, norm, slope, and **scatter**!

Why study the origin of

(1) Reduce the scatter (e.g. CC exclusion, $Y_x = M$)

$Y_x - M$ Relation (Kravtsov+06)



Outliers in Opt- M_{true} and $Y_{sz} - M_{true}$

Skewness and kurtosis > 0.5 would bias cosmological constraints (Shaw+10)

(Shaw+10)

Boosting effect by merger shocks

Measure a non-Gaussian distribution with higher-order moments:

(3) Because we simply want to know why!

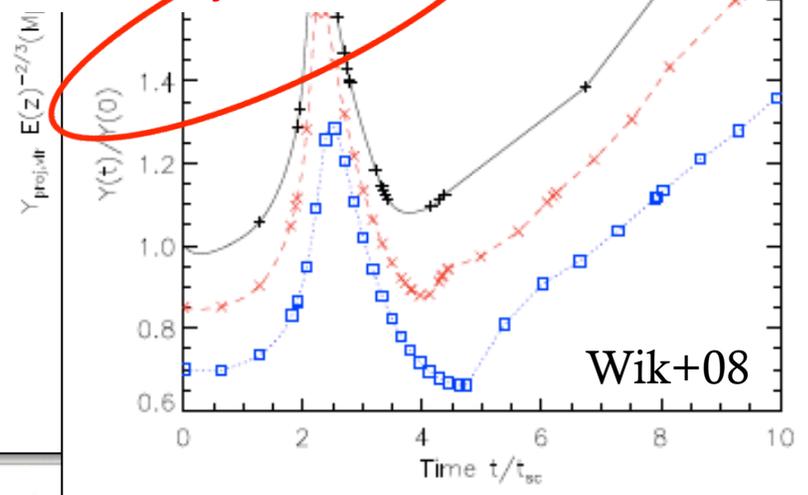
Skewness (1-sided):

$$\gamma = \frac{\langle (Y - \bar{Y})^3 \rangle}{\sigma^3}$$

Kurtosis (peaked and tailed):

$$\kappa = \frac{\langle (Y - \bar{Y})^4 \rangle}{\sigma^4} - 3.$$

Outliers due to projection effect



Wik+08

Method

Cosmological Simulation

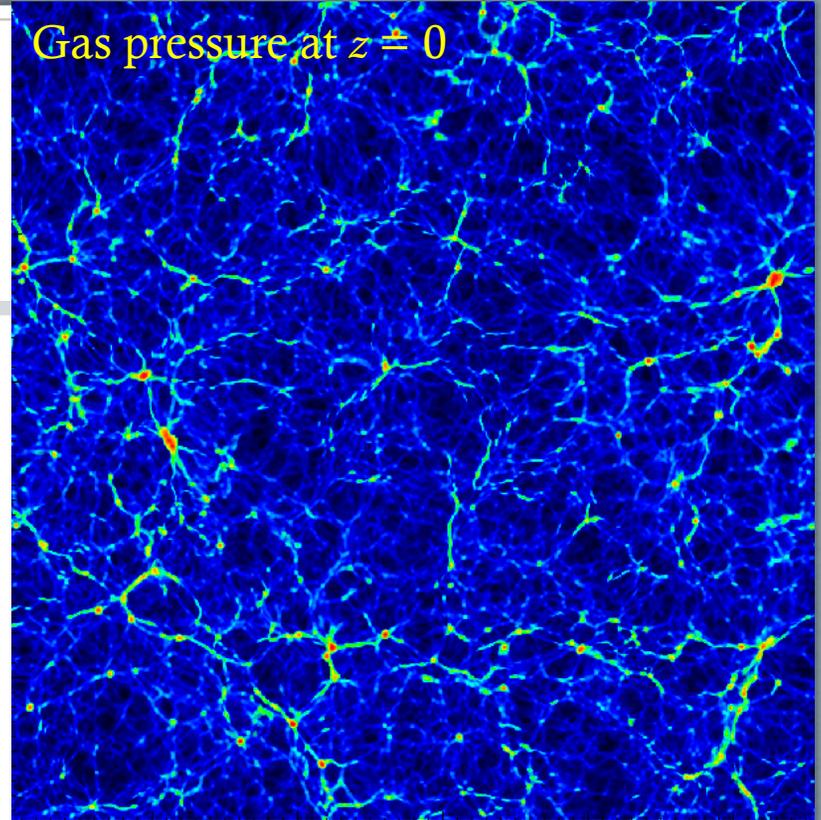
- N-body + adiabatic hydro
- FLASH (Fryxell et al. 2000)
- Box size = 256 Mpc/h,
Resolution = 250 kpc/h
1024³ particles ($m_p = 1.3 \times 10^9 M_{\text{sun}}/h$)
WMAP3 cosmological parameters

Find halos using FOF algorithm

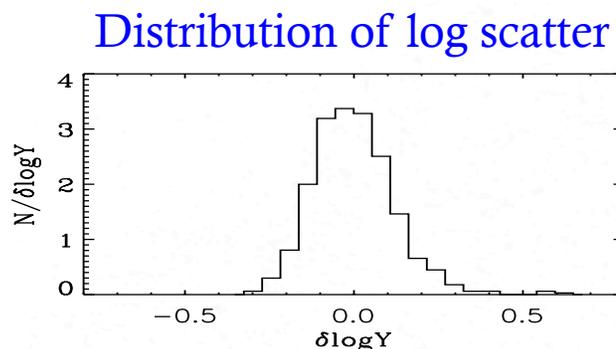
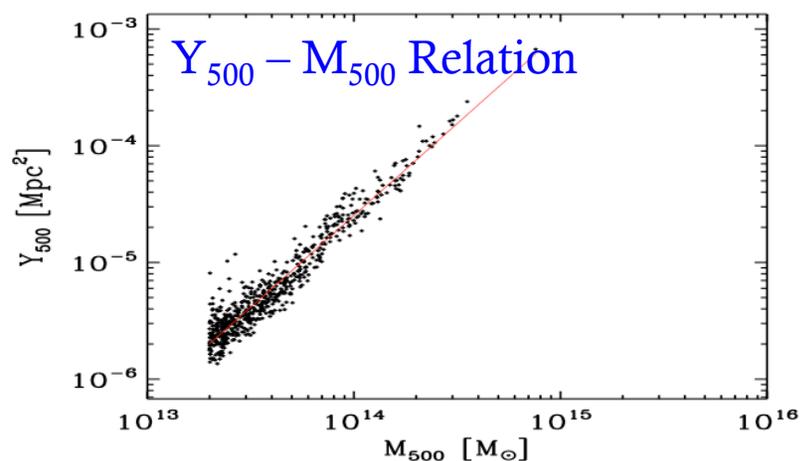
Define mergers

- Merger tree analysis-- Mergers: <10:1 merger within 3 Gyrs
- Substructure measures – Centroid offset and Power ratios

Gas pressure at $z \approx 0$



Simulated Ysz-M Scatter



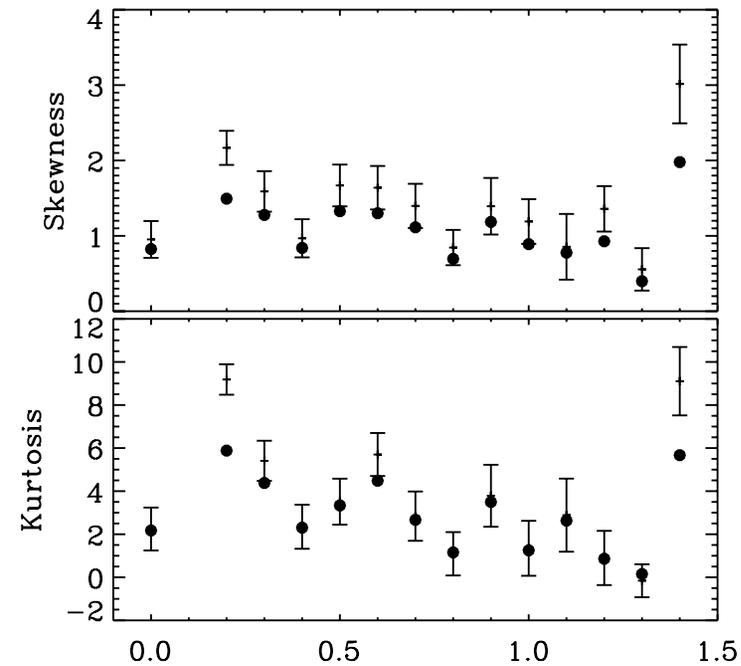
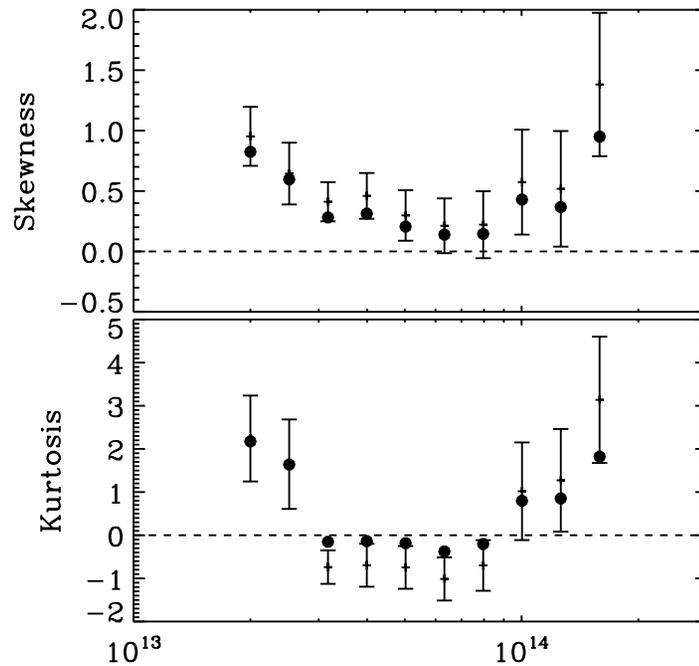
- * *Examine if the scatter is lognormal* by computing skewness and kurtosis

(lognormal: $\gamma = 0, \kappa = 0$)

- * *Correlate with possible sources of scatter* (dynamical state, halo concentration)

(R_{500} is the radius enclosing 500 times the critical density of the universe.)

Is the scatter lognormal?

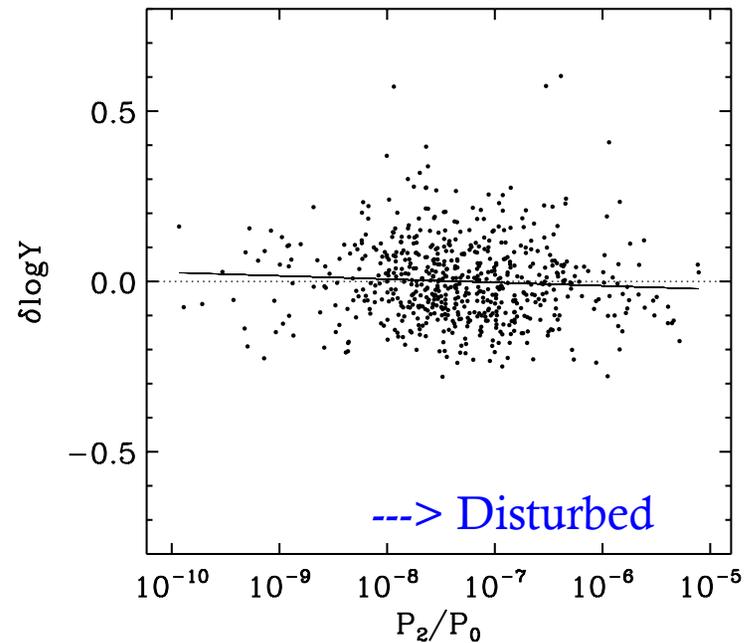
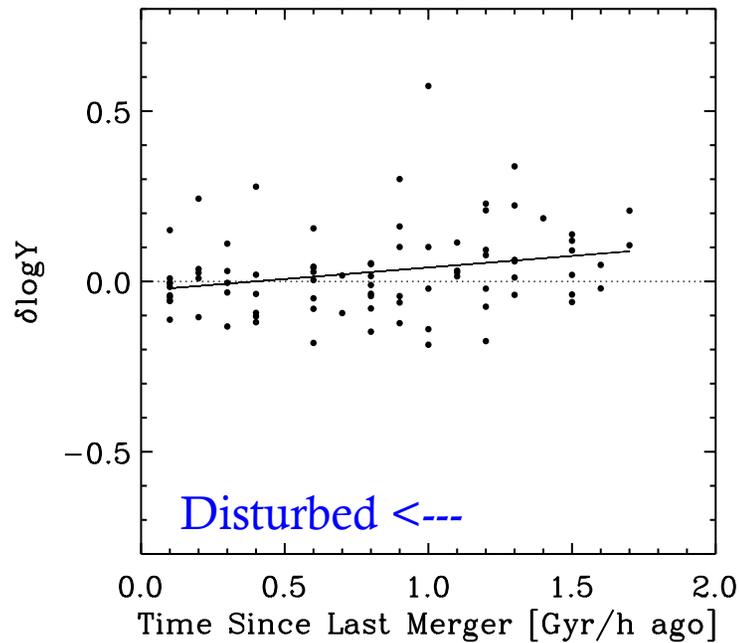


Lower Mass Limit (Msun)

Redshift

- * *Non-negligible positive skewness and kurtosis (>0.5) for a wide range of limiting masses and redshifts, due to shape and projection effect*
- * *Need higher-moment parametrization in the form of Y - M scatter!*

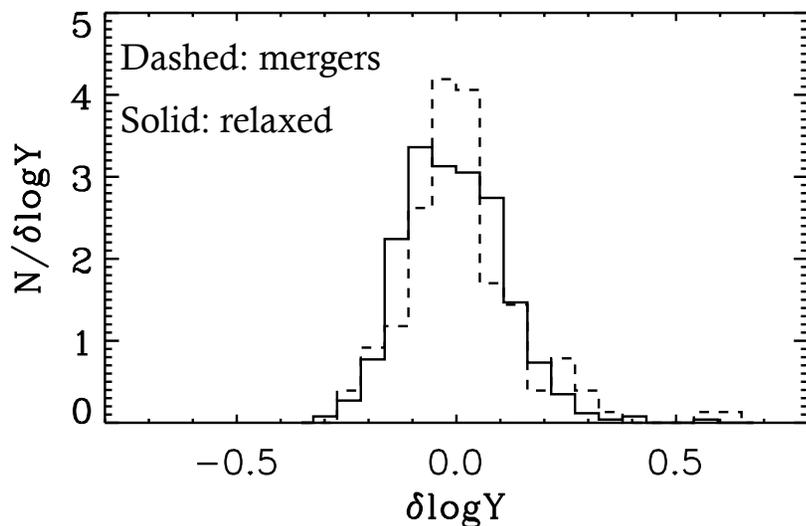
Do mergers bias the Ysz-M relation?



Weak correlation -- recently merged clusters tend to scatter low due to incomplete virialization

Do mergers bias the Ysz-M relation?

Distribution of Scatter

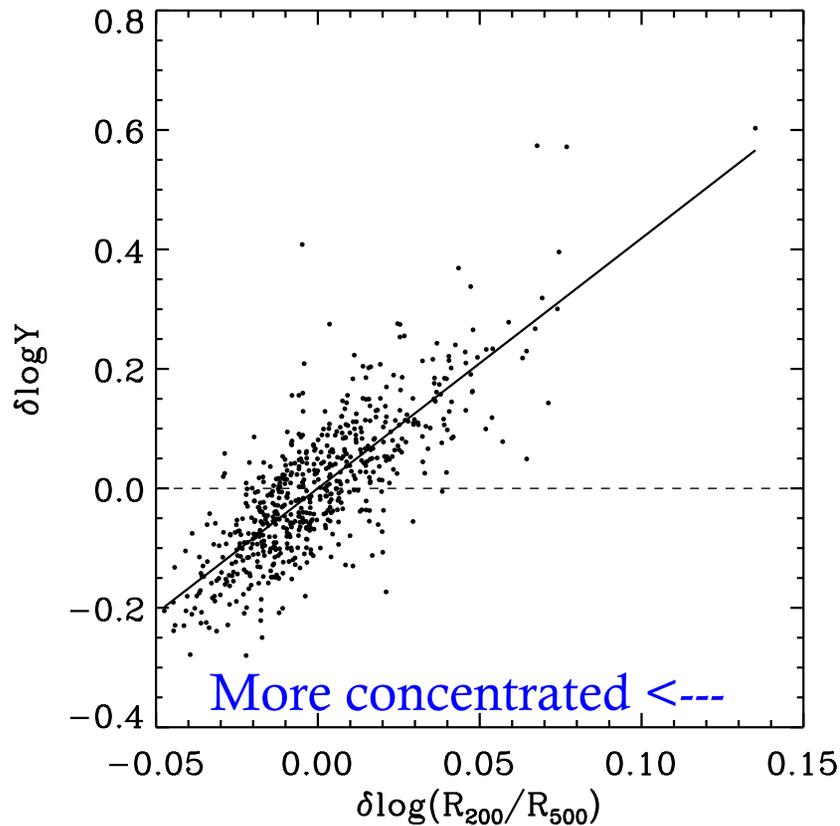


Mergers do NOT bias the relation statistically!

Why?

- (1) Mergers are rare
- (2) Shock heating effect is diluted
 - hard to be captured in R_{500}
 - incomplete thermalization operates in the opposite way
- (3) Mergers move along the scaling relation

Strong correlation with concentration!



(R_{200}/R_{500} is monotonically decreasing with c)

Scatter is largely driven by variations in concentration!

Why?

Virial theorem:

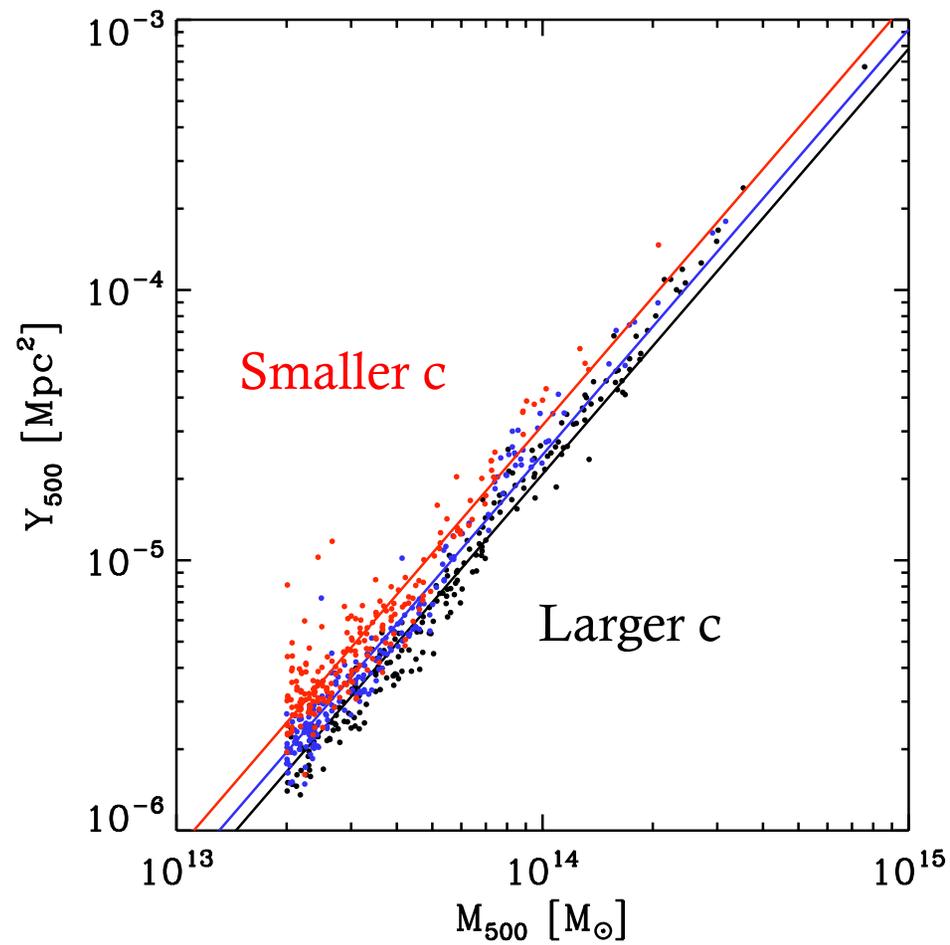
$$O_{vir} \propto M_{vir}^\alpha$$

$$M_\Delta = f_1(c) \times M_{vir}$$

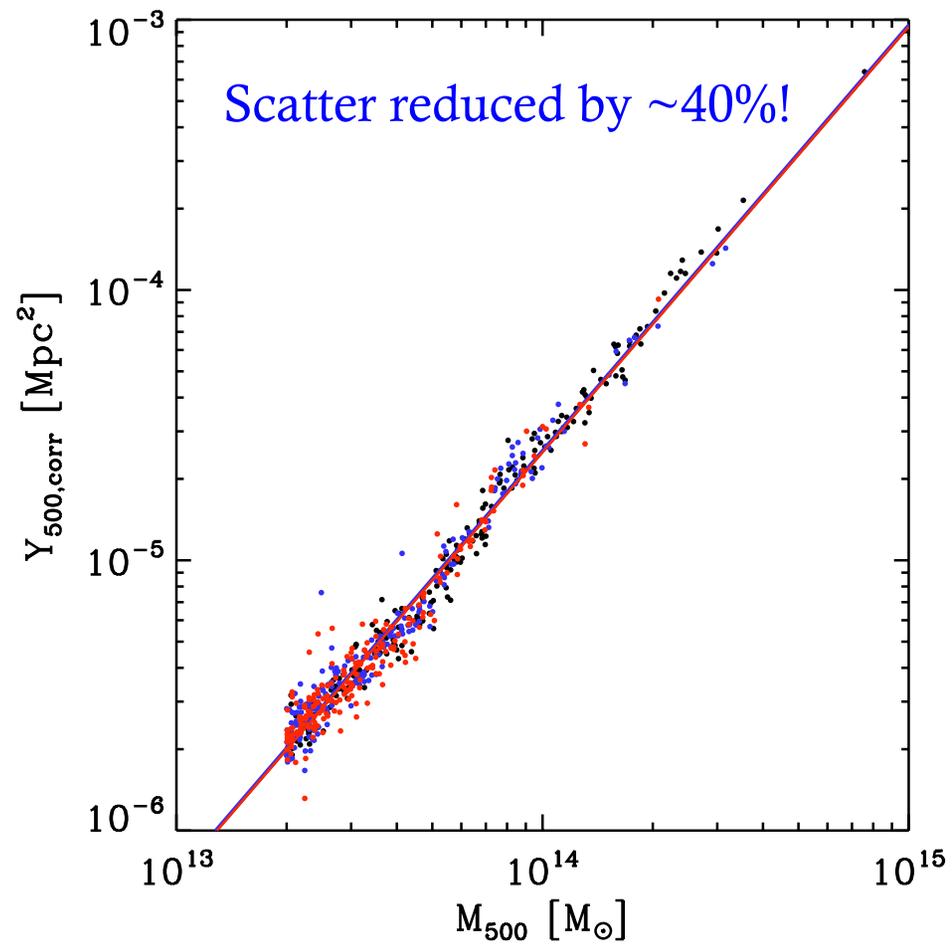
$$O_\Delta = f_2(c, EOS) \times O_{vir}$$

$$\Rightarrow O_\Delta \propto N(c, EOS) M_\Delta^\alpha$$

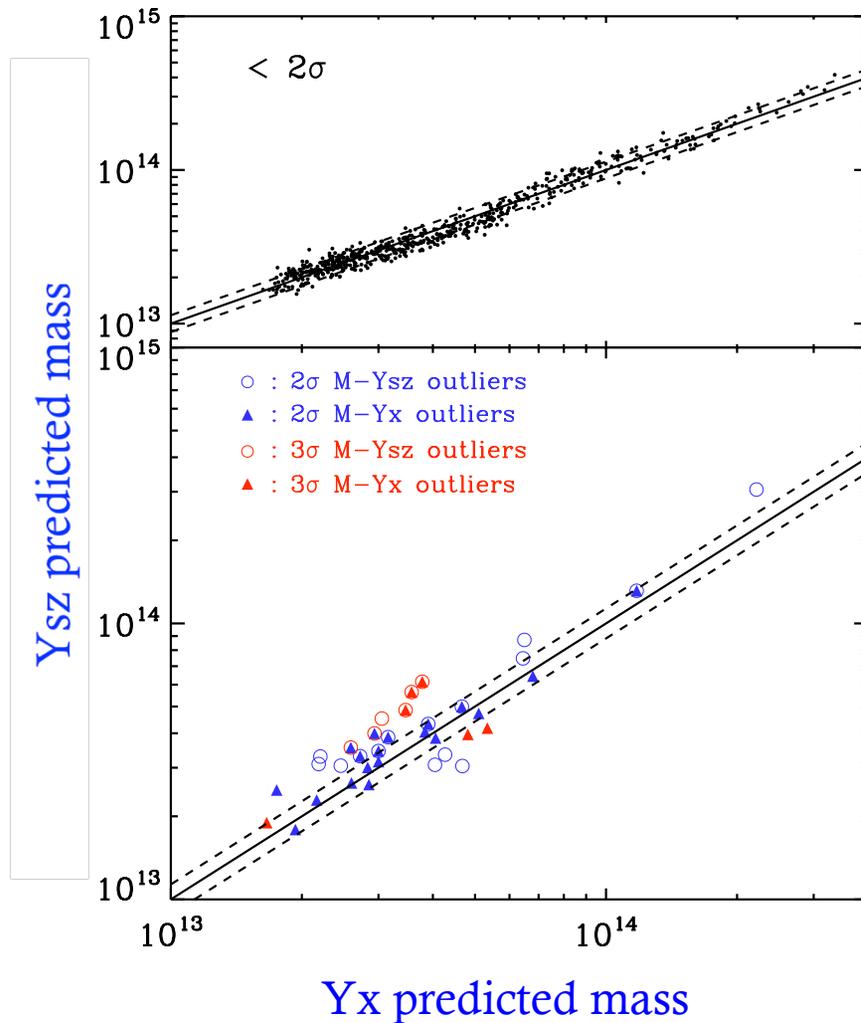
Correct for the effect of concentration



Correct for the effect of concentration



Cross-calibrating mass with X-ray



Low-scatter X-ray mass proxy:

$$Y_X \equiv M_g T_X$$

* *Errors in $M_{Y_{SZ}}$ and M_{Y_X} are NOT correlated:*

Ysz-M outliers – shape & projection

Yx-M outliers – dynamical state

* *Cross-calibration can effectively remove outliers in the true Ysz-M relation*

Summary

- The Y-M scatter is non-lognormal, with non-negligible positive skewness and kurtosis that can bias cosmological constraints.
>> *Higher-order moments need to be included in the form of scatter.*
- The correlation with dynamical state is weak.
>> *Selection bias caused by mergers is negligible.*
- There is a strong correlation with concentration.
>> *Corrections using such correlation can potentially be applied to observed clusters to reduce the scatter*
- Errors for SZ and X-ray predicted masses are not correlated.
>> *Cross-calibrating mass using X-ray data can effectively identify Y_{sz} -M outliers.*