

The Scatter in Cluster Scaling Relations with a Complete Cluster Sample

Matthew Kirby¹, Eduardo Rozo¹, Steve Allen², Adam Mantz², Glenn Morris², Anja von der Linden³

¹Department of Physics, University of Arizona, Tucson, AZ (contact: matthewkirby@email.arizona.edu)

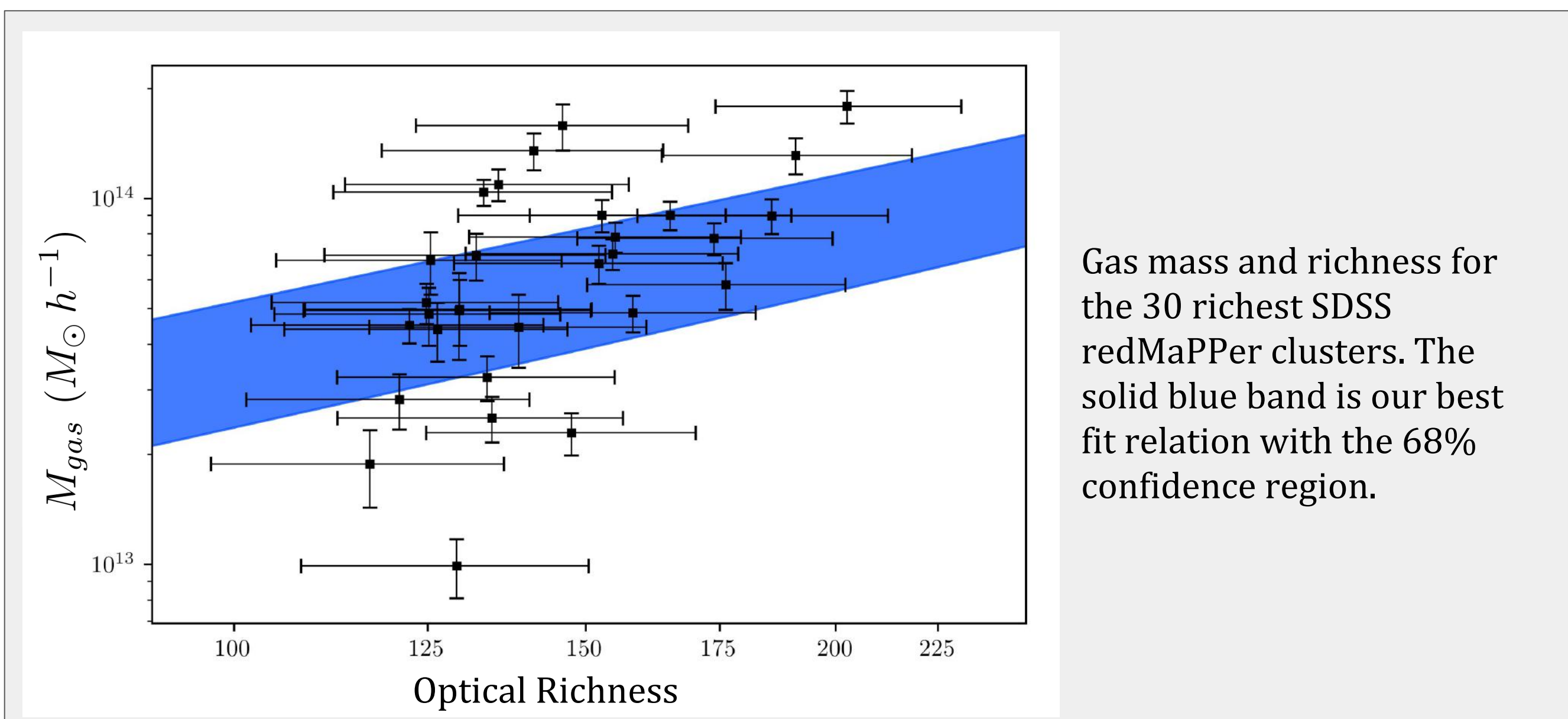
²Kavli Institute for Particle Physics and Cosmology, Stanford University, Stanford, CA,

³Department of Physics and Astronomy, Stony Brook University, Stony Brook, NY

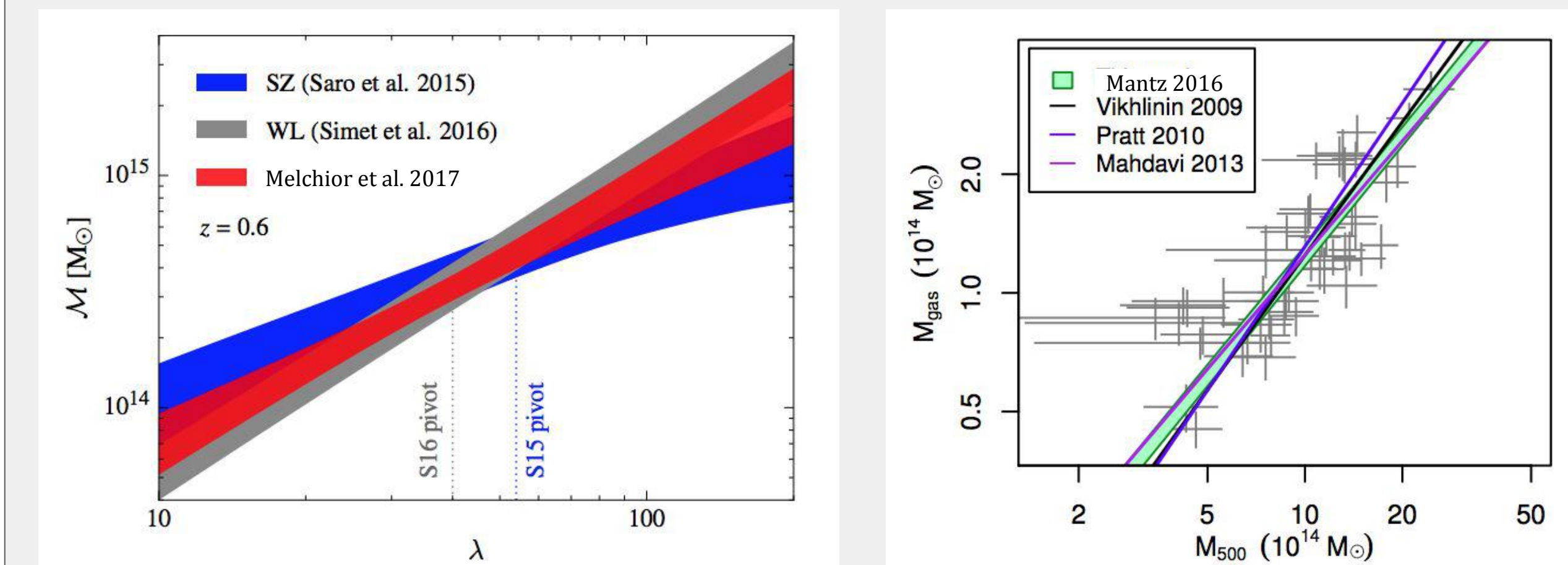
30 Second Summary

- ◆ We measured gas masses for the 30 richest SDSS redMaPPer clusters using newly acquired Chandra x-ray data.
- ◆ We developed a likelihood framework that accounts for our cluster selection function to measure the richness–mass and gas mass–mass scaling relations and their scatter.
- ◆ We find that the weak lensing mass calibration of SDSS clusters in Simet et al. 2016^b is fully consistent with the weak lensing mass calibrations of x-ray clusters in the Weighing the Giants sample (Mantz et al. 2016^a).
- ◆ Combining the SDSS redMaPPer weak lensing calibration, the Weighing the Giants calibration of the gas mass–mass scaling relation, and our Chandra data, we are able to place a 95% upper limit on the scatter in the richness–mass relation of $\sigma_{\ln \lambda} < 0.459$ at a pivot mass of $M_p = 5.67 \times 10^{14} M_{\odot} h^{-1}$.

I. Data



- ◆ We place informative priors on the mean of the mass–richness relation and the gas mass–mass scaling relation.
- ◆ Mass–richness priors are taken from the weak lensing mass calibration of the SDSS redMaPPer clusters in Simet et al. 2016^b shown on left below (Melchior et al. 2017^c).
- ◆ Gas mass–mass priors are taken from the weak lensing mass calibration of x-ray clusters in the Weighing the Giants sample in Mantz et al. 2016^a shown on right below.



II. Likelihood Model and Validation

- ◆ Cosmological constraints from optical survey data require a detailed understanding of the richness–mass relation of galaxy clusters.
- ◆ We measure the gas mass of the 30 richest clusters in SDSS redMaPPer using newly acquired Chandra data.
- ◆ This sample of richness selected clusters represents the first complete sample of redMaPPer clusters with high quality x-ray data, allowing us to place constraints on the scatter of the richness–mass relation for the first time.

Likelihood

Use weak lensing priors to anchor cluster masses

The probability that each cluster has their observed richness and gas mass given our scaling relations

$$\mathcal{L} = P(\theta) P(\lambda_1 > \lambda_2 > \dots > \lambda_N | \theta) \prod_{i=1}^N P(\lambda_i, M_{gas,i} | \theta)$$

Our selection function: The probability that the richest cluster has observed richness λ_1 , the second richest cluster has richness λ_2 , etc

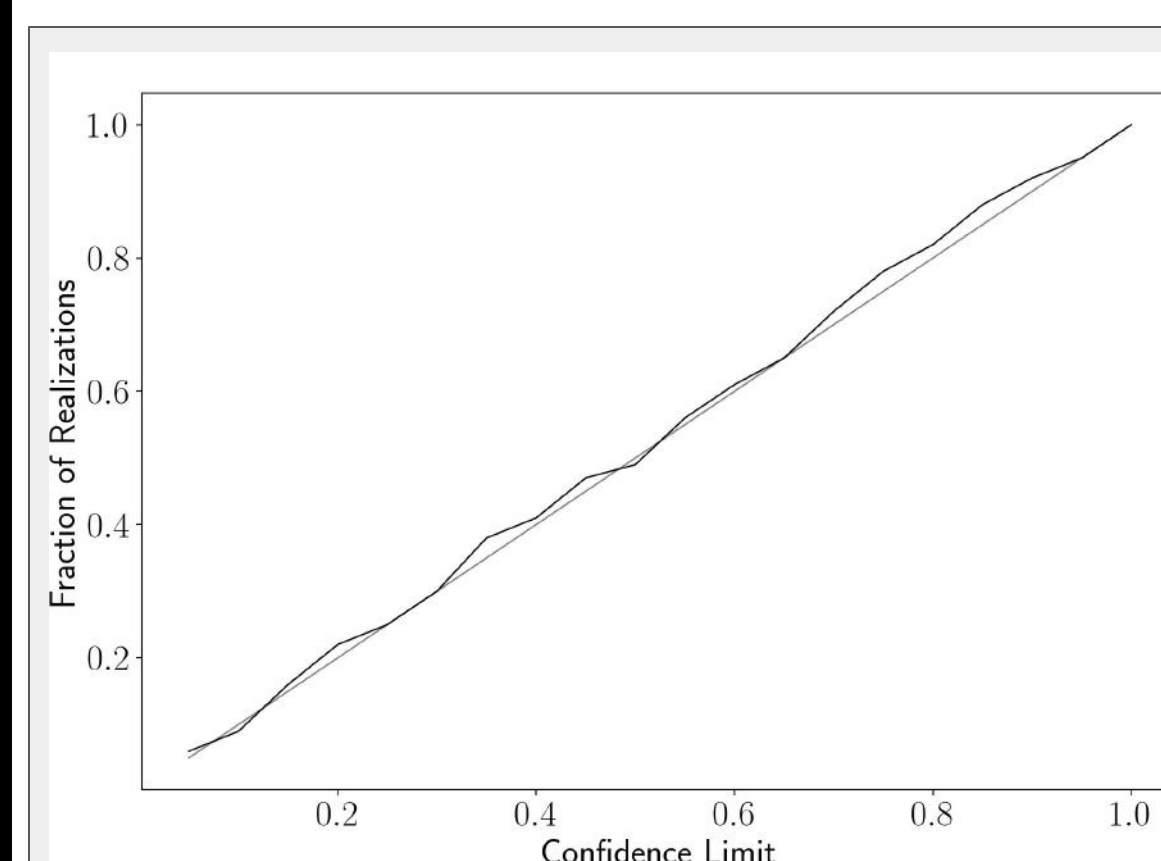
- ◆ We model our selection function with a Poisson distribution and the distribution $P(\lambda_i, M_{gas,i} | M)$ as a bivariate Gaussian distribution

Scaling Relations - Power Laws in Mass

$$\langle \lambda | M_{200m} \rangle = \lambda_0 \left(\frac{M_{200m}}{M_{pivot,\lambda}} \right)^{\alpha_\lambda} \quad \sigma_\lambda^2 = \langle \lambda | M \rangle + \langle \lambda | M \rangle^2 \sigma_{\ln \lambda}^2$$

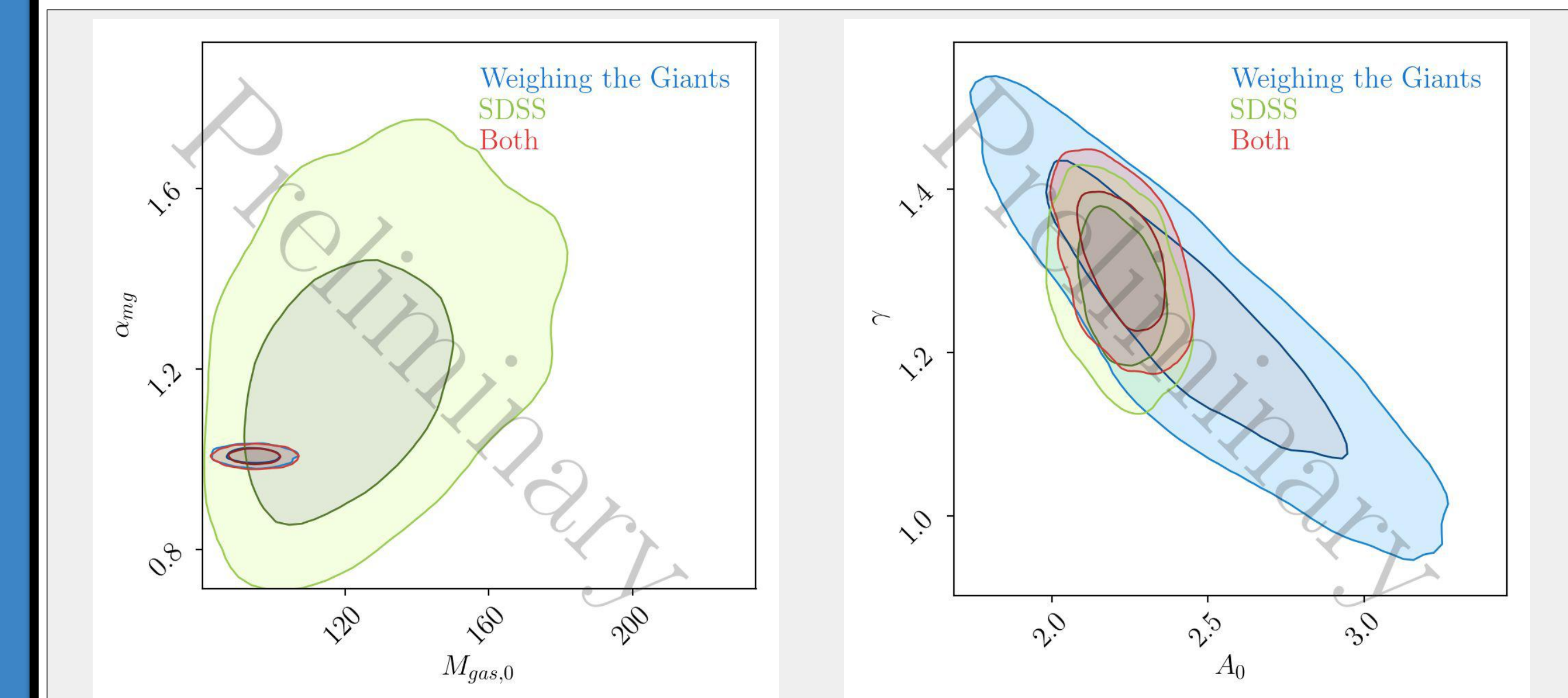
$$\langle M_{gas} | M_{500c} \rangle = M_{gas,0} \left(\frac{M_{500c}}{M_{pivot,mg}} \right)^{\alpha_{mg}} \quad \sigma_{mg}^2 = \langle M_{gas} | M \rangle^2 \sigma_{\ln M_g}^2$$

Validation



We validate our likelihood analysis using 100 synthetic data sets. We check that the probability that our input parameters fall within the 68% confidence contour is 68%. The figure on the left, repeats this check for many confidence intervals between 2% and 98%.

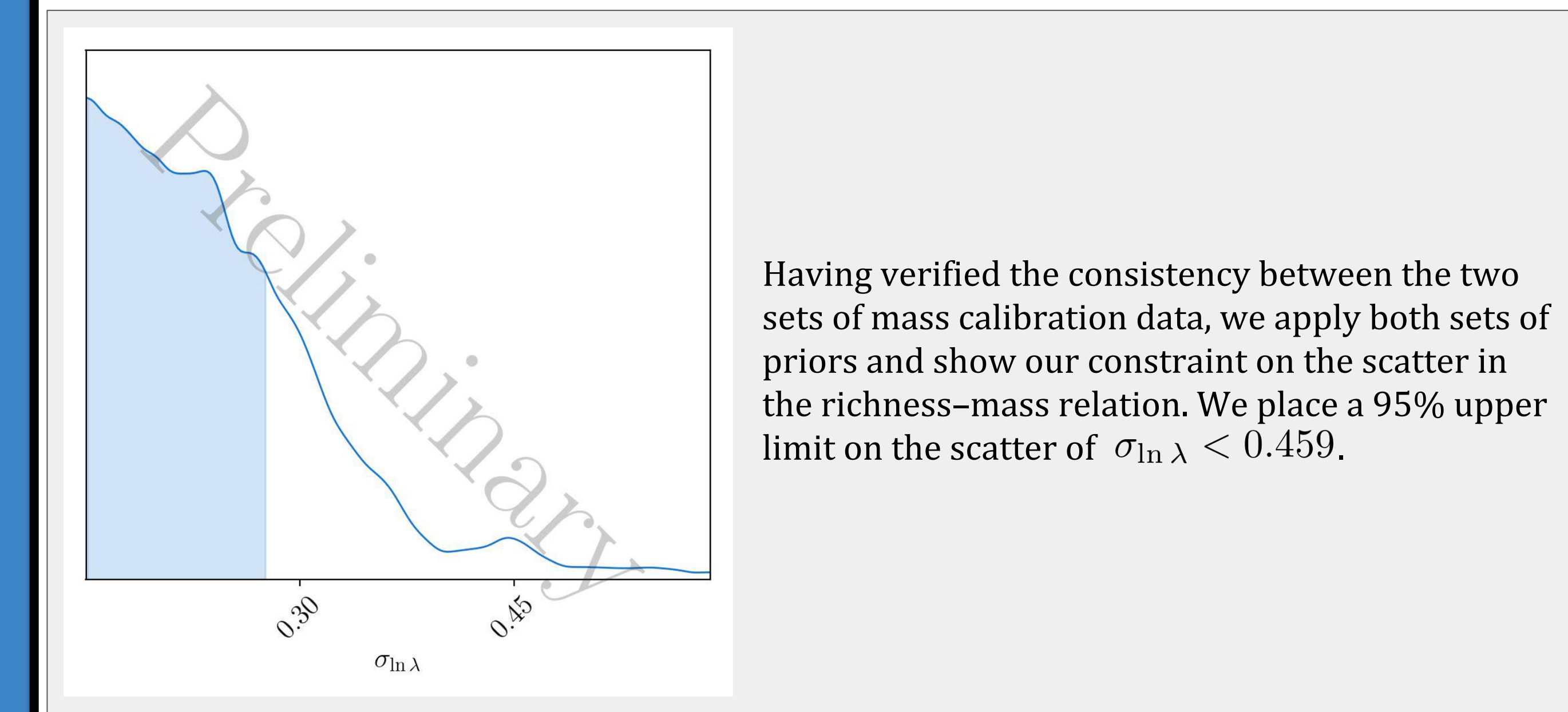
III. Results



Left: Posteriors on the slope and amplitude of the gas mass–mass relation.

Right: Posteriors on the slope and amplitude of the mass–richness relation.

- ◆ The SDSS redMaPPer and Weighing the Giants scaling relations are fully consistent with each other.
- ◆ Neither scaling relation is able to improve upon the other when combined with our data set. The posteriors are identical to their priors.



IV. Conclusions

- ◆ We have shown that the mass calibrations from SDSS redMaPPer weak lensing and Weighing the Giants x-ray samples are consistent within reported uncertainties.
- ◆ We have placed a 95% upper limit on the scatter in the richness–mass relation of $\sigma_{\ln \lambda} < 0.459$.