Calibrating the galaxy cluster mass scale for cosmology

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Outline

- Calibrating the Planck SZ mass proxy using the ***velocity dispersion - mass*** relation

S. Amodeo, S. Mei, A. Stanford, J.G. Bartlett, J.-B. Melin, C. Lawrence, R. R. Chary & Planck collaborators

- The relation between **mass** and **concentration** in X-ray galaxy clusters at high redshift

S. Amodeo, S. Ettori, R. Capasso, M. Sereno

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Cosmological constraints from **cluster counts**

$$\frac{dN}{dz} = \int d\Omega \int dM_{500}\, \chi(z, M_{500}, l, b) \frac{dN}{dz\, dM_{500}\, d\Omega}$$

Survey selection function
Scaling relation observable - Mass

Mass function

- Planck XXIV 2015: cosmology from 439 SZ detected clusters

- SZ Y - Mass relation
  based on XMM hydrostatic masses (Planck XX 2013)

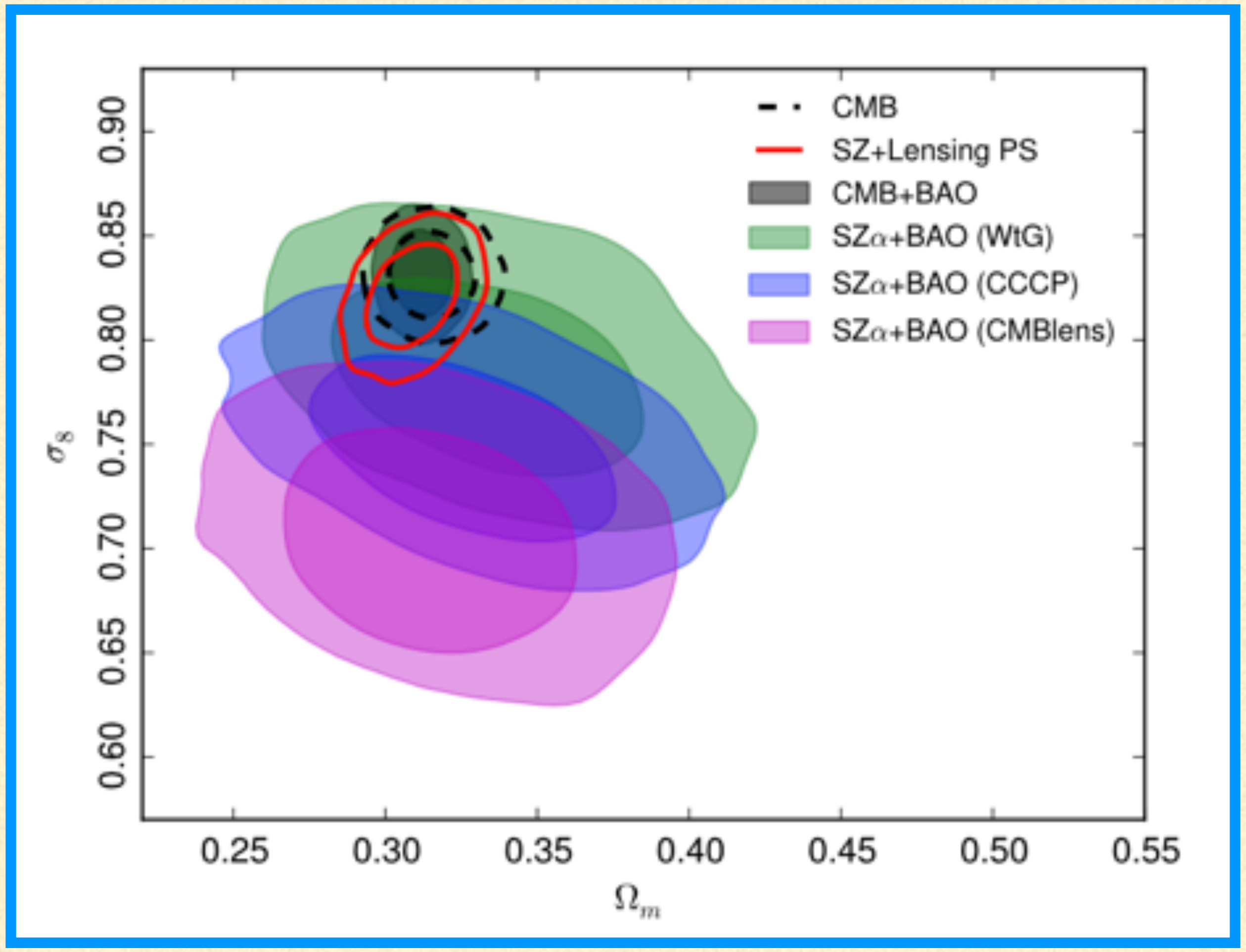
$$E^{-\beta}(z)\left[\frac{D_A^2(z)\bar{Y}_{500}}{10^{-4}\mathrm{Mpc}^2}\right] = Y_\star\left[\frac{h}{0.7}\right]^{-2+\alpha}\left[\frac{(1-b)M_{500}}{6\times10^{14}M_\odot}\right]^{\alpha}$$

- <u>**Mass bias parameter**</u>: accounts for any difference between the Planck SZ mass proxy and the true mass

$$\boxed{M_{500,SZ} = (1-b)M_{500}}$$

Planck 2015, XXIV

Tension between cluster and primary CMB constraints



Mass bias priors from

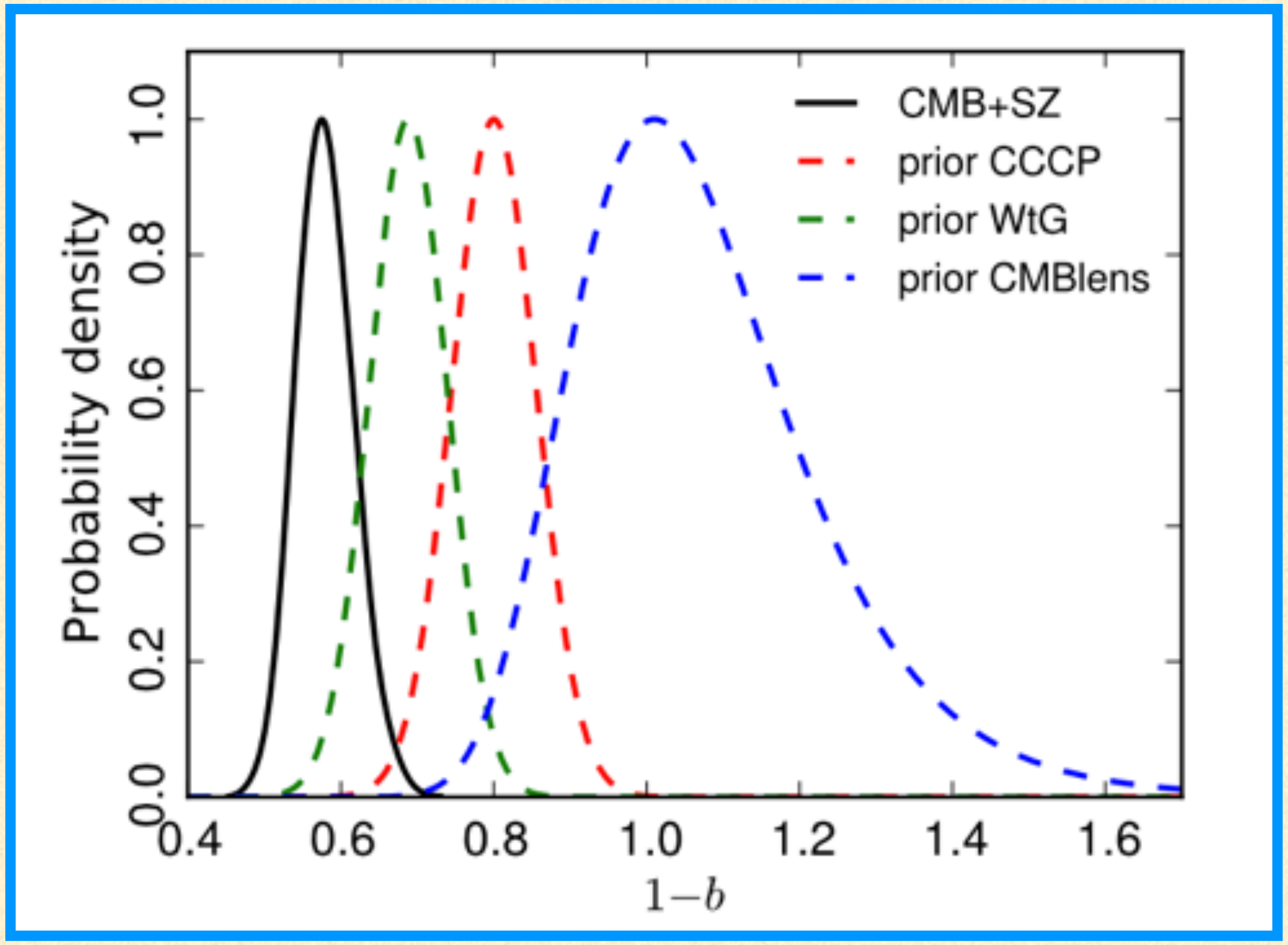
- gravitational shear:
  WtG, *von der Linden et al. 2014a*
  CCCP, *Hoekstra et al. 2015*
- CMB halo lensing:
  Melin & Bartlett 2014

Planck 2015, XXIV

Tension between cluster and primary CMB constraints

Agreement with

$$1 - b = 0.58 \pm 0.04$$



Are clusters more massive than predicted from SZ-M ?

… or …

Do we need extensions to the standard ΛCDM ?

- Mass bias: main uncertainty in cluster counts cosmology

- Use independent techniques to estimate Mass

Galaxy dynamics

- assume virialization
- independent of ICM properties
- **σ - *M*** well calibrated with cosmological N-body and hydrodynamical simulations
(e.g. Evrard et al. 2008, Munari et al. 2013)

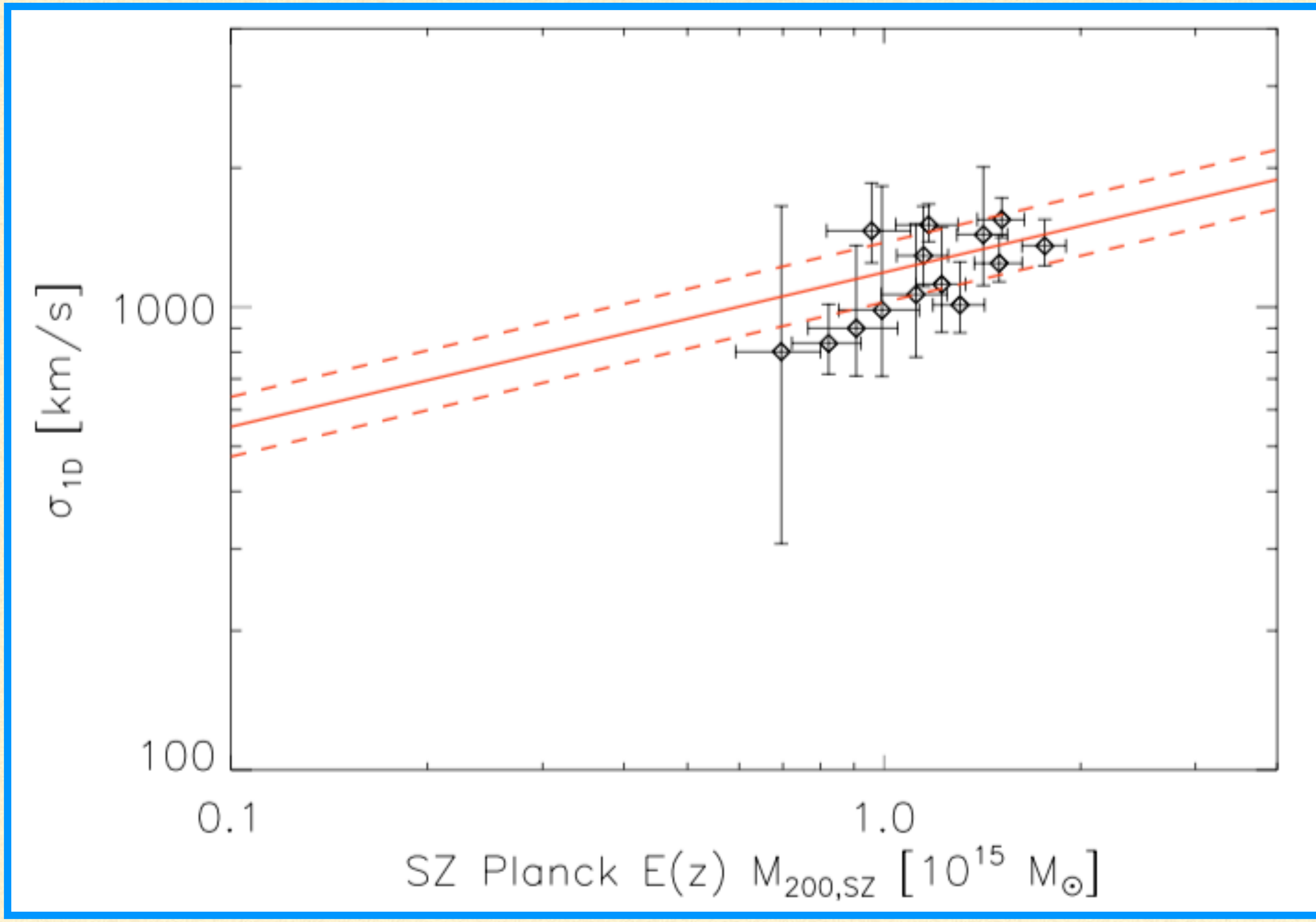
$$\boxed{\sigma_{1D} = A_s \left[\frac{E(z)\, M_{200}}{10^{15} M_\odot} \right]^{1/3}}$$

Gemini follow-up of a sample of Planck SZ clusters (P.I. J.G. Bartlett)

- 14 clusters $0.25 < z < 0.45$, $10 < N_{gal} < 40$
- significant range in mass (Planck 2015, XXVII)

$$2 \times 10^{14} M_\odot \lesssim M_{500,SZ} \lesssim 10^{15} M_\odot$$

- Gemini - GMOS optical spectroscopy
- Velocity dispersions and dynamical masses
- SZ Planck $M_{200,SZ}$ from c_{200} - M_{200} by *Dutton & Macciò 2014*



$$\sigma_{1D} = A \times \left(\frac{E(z) M_{200,SZ}}{10^{15} M_{\odot}} \right)^{1/3}$$

$$A = 1185 \pm 65\,\mathrm{km/s}$$

$$\sigma_{tot} = 0.07 \pm 0.01\,\mathrm{dex}$$

$$\boxed{M_{500,SZ} = (1-b) M_{500}}$$

- assume *1-b* independent of overdensity

- assume $M_{200,\sigma_{1D}} = M_{200}$

- compare to Munari et al. 2013:
  hydrodynamical simulations of galaxies + SF + gas cooling driven by SN + AGN feedback

  $A_s = 1177 \pm 4.2\,\mathrm{km/s}$

$$\boxed{(1-b) = \left(\frac{A_s}{A}\right)^3 = 0.98 \pm 0.16}$$

Conclusions I

1. We obtain an interesting constraint on (1-b) with only 14 clusters

$$\boxed{(1-b) = 0.98 \pm 0.16}$$

2. The result maintains the tension between Planck cluster counts and primary CMB at >2σ

3. More clusters and at lower mass would notably improve the constraints

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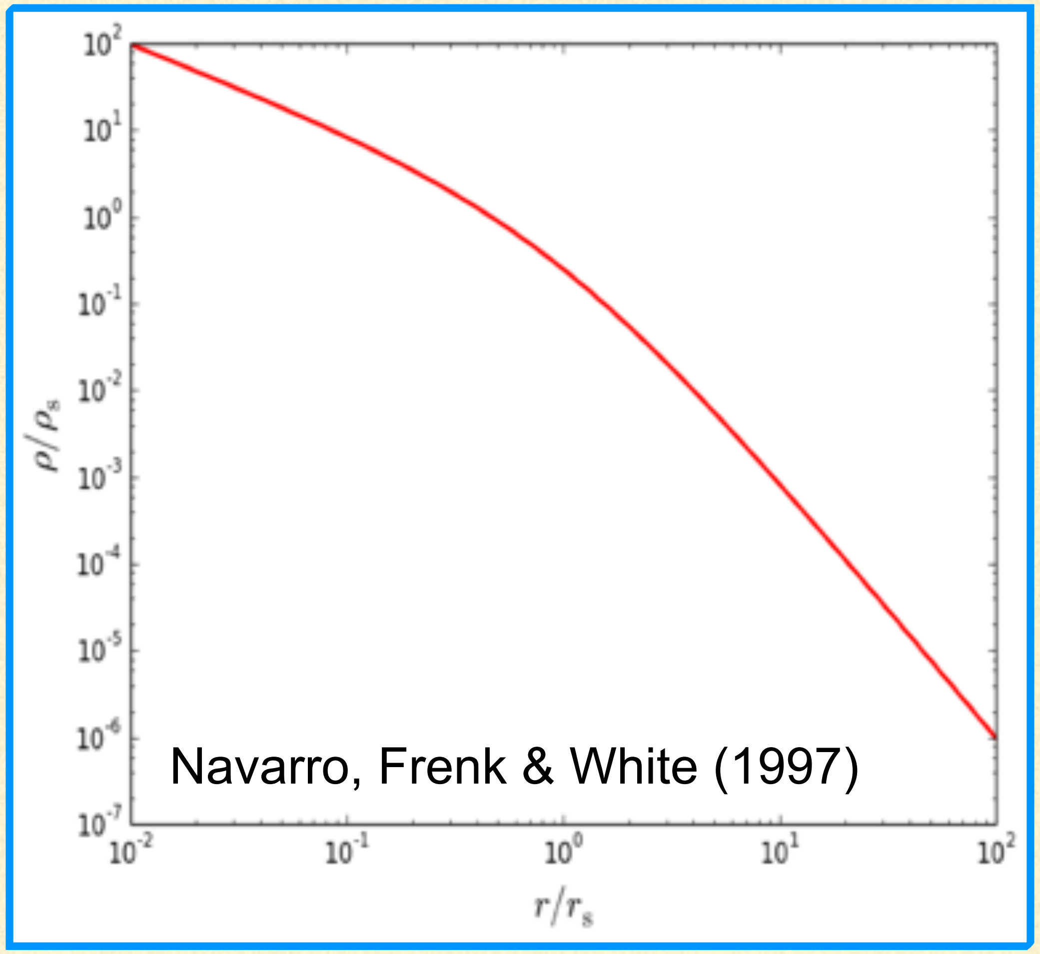
Distribution of matter & Mass Assembly History

- Galaxy clusters described by the *universal* NFW profile
  2 parameters: **(r_s, c)** or **(M, c)**

$$\rho(r) = \frac{\rho_s}{(r/r_s)(1 + r/r_s)^2}$$

$$c_\Delta \equiv \frac{r_\Delta}{r_s}$$



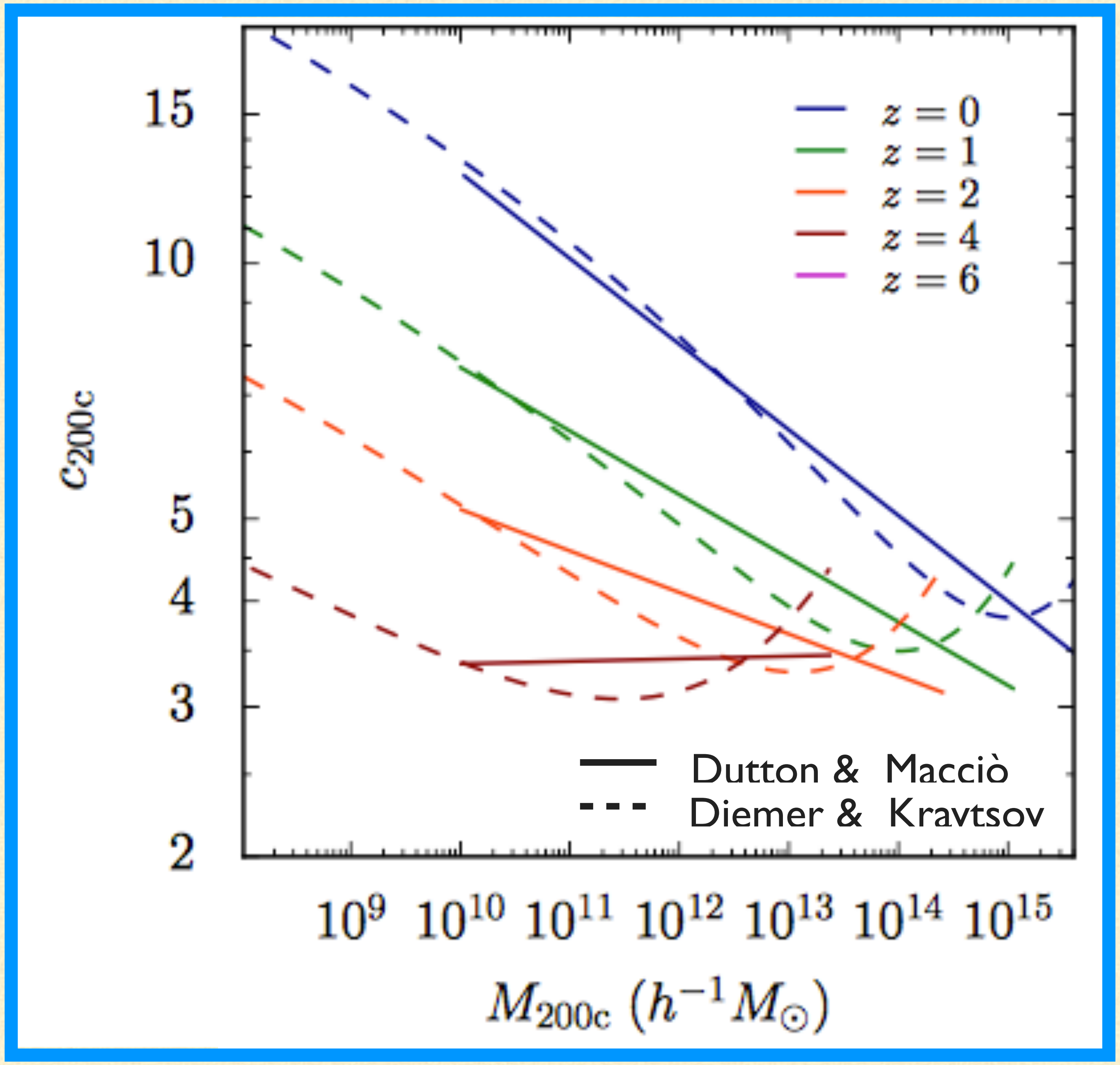
Distribution of matter & Mass Assembly History

- Galaxy clusters described by the *universal* NFW profile
  2 parameters: **(r_s, c)** or **(M, c)**

- **c(M)** linked to the halo's assembly history and time of formation

- CDM predicts anti-correlation

- what is observed at high z? (z~1)

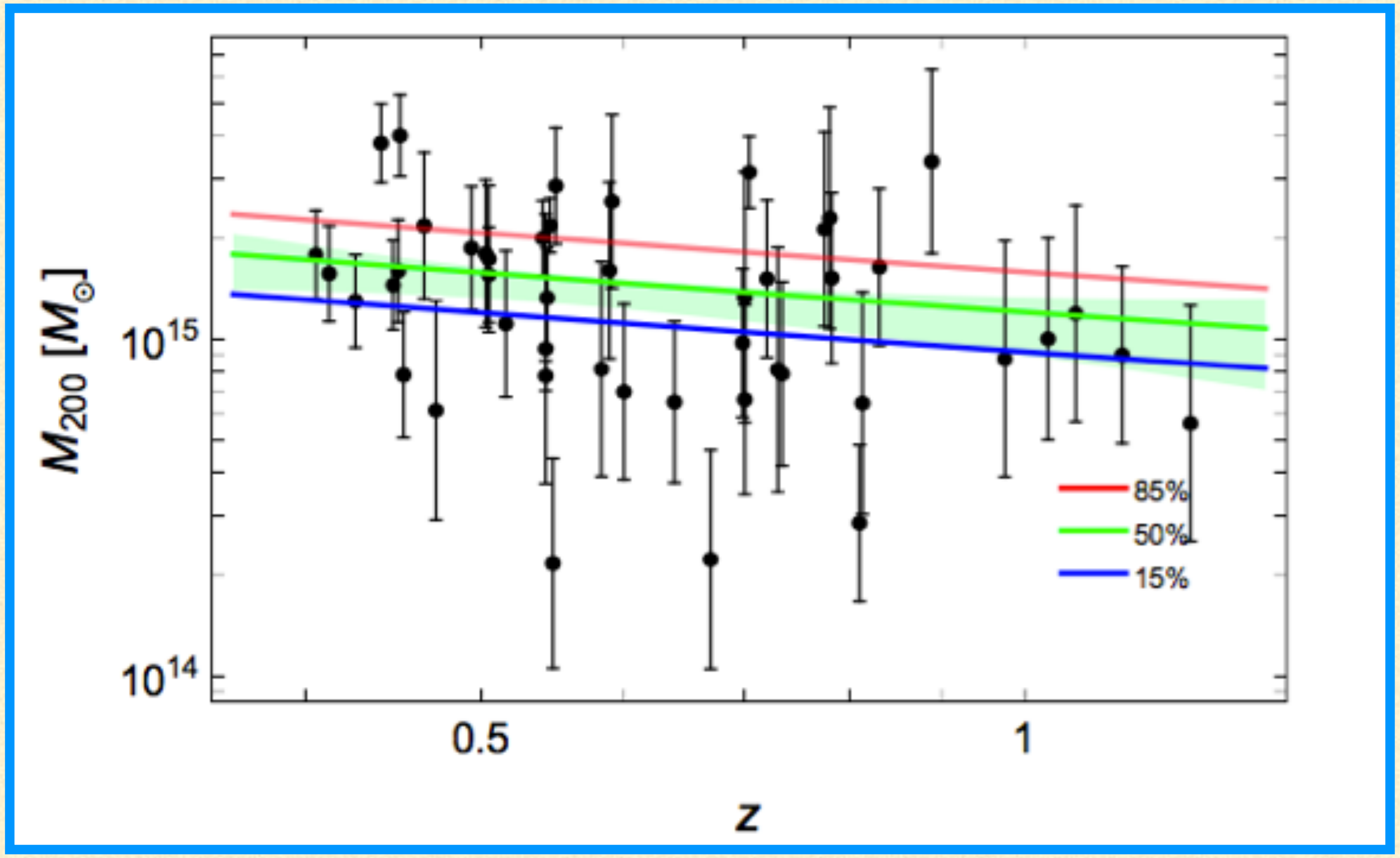


Credit: Diemer & Kravtsov

The relation between mass and concentration in X-ray galaxy clusters at high redshift

S. Amodeo, S. Ettori, R. Capasso and M. Sereno, 2016, A&A, 590, A126

- 47 galaxy clusters by the Chandra X-ray Observatory
- 0.4 < z < 1.2
- regular X-ray morphology
- very luminous at each z



Total mass profile from X-ray analysis

Ettori et al. 2010

1. spherical symmetry

2. hydrostatic equilibrium

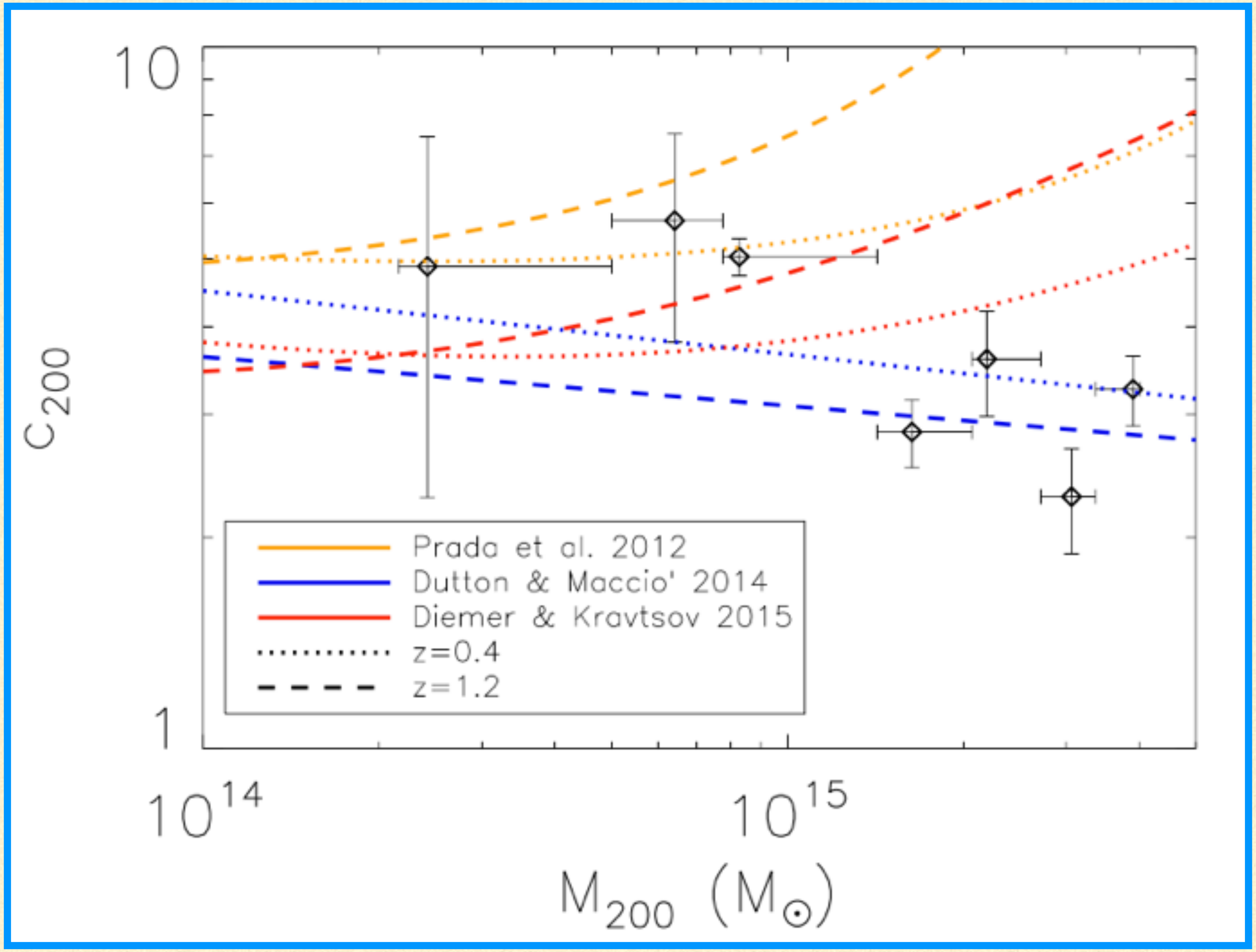
$$M_{tot}(<r) = -\frac{kT_{gas}(r)\,r}{\mu m_p G}\left(\frac{d\ln n_{gas}}{d\ln r} + \frac{d\ln T_{gas}}{d\ln r}\right)$$

3. *NFW* mass model: 2 free parameters **(r_s, c)**

4. constraints on **(r_s, c)** by minimising:

$$\chi_T^2 = \sum_i \frac{(T_{data,i} - T_{model,i})^2}{\epsilon_{T,i}^2}$$

The concentration - mass relation

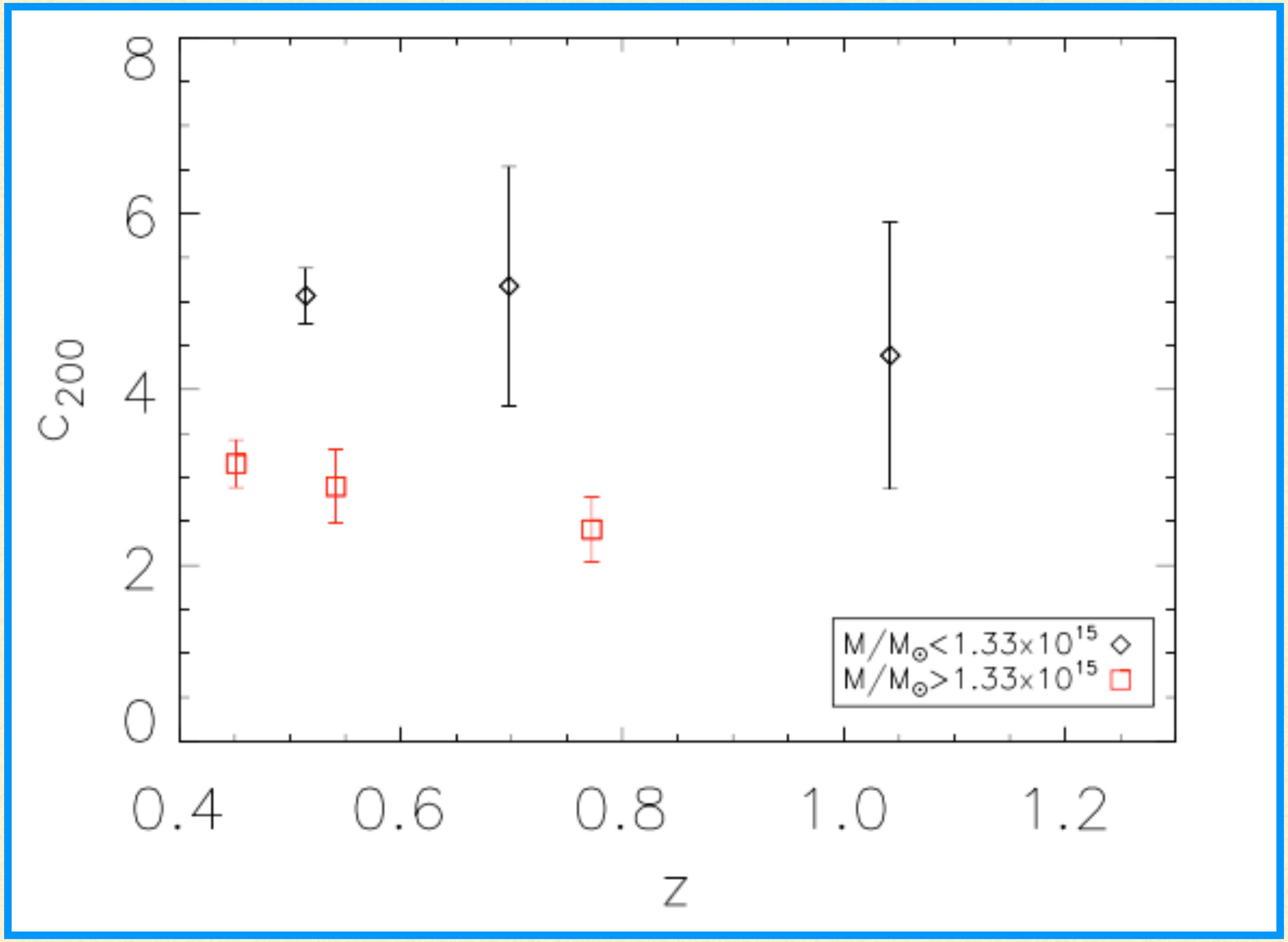


Amodeo et al. 2016

First constraints @ z > 0.7 from X-ray data

No evidence of plateau/upturn

The concentration - redshift relation



At a fixed mass range, systems with lower concentration are found at higher redshifts

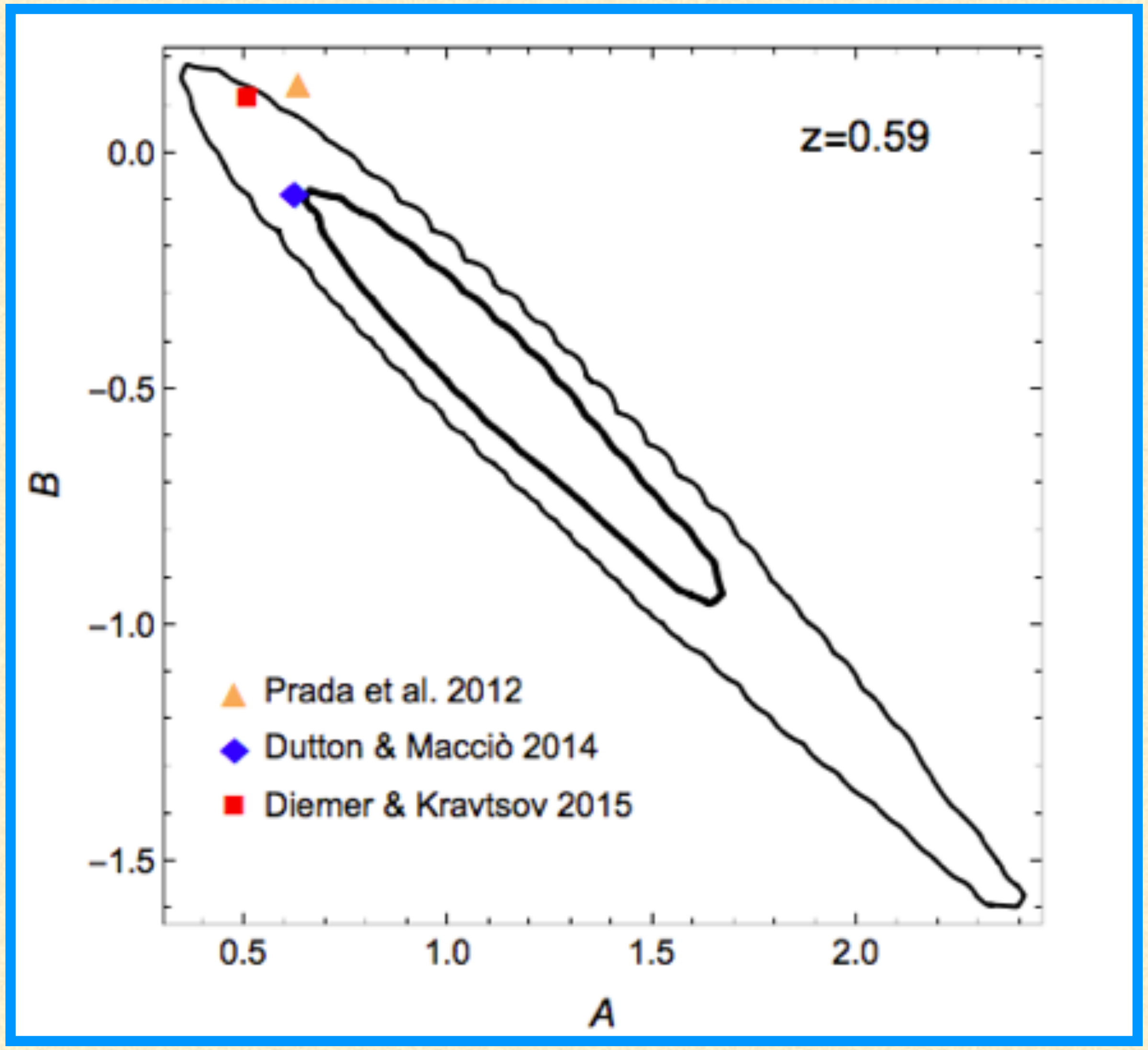
Amodeo et al. 2016

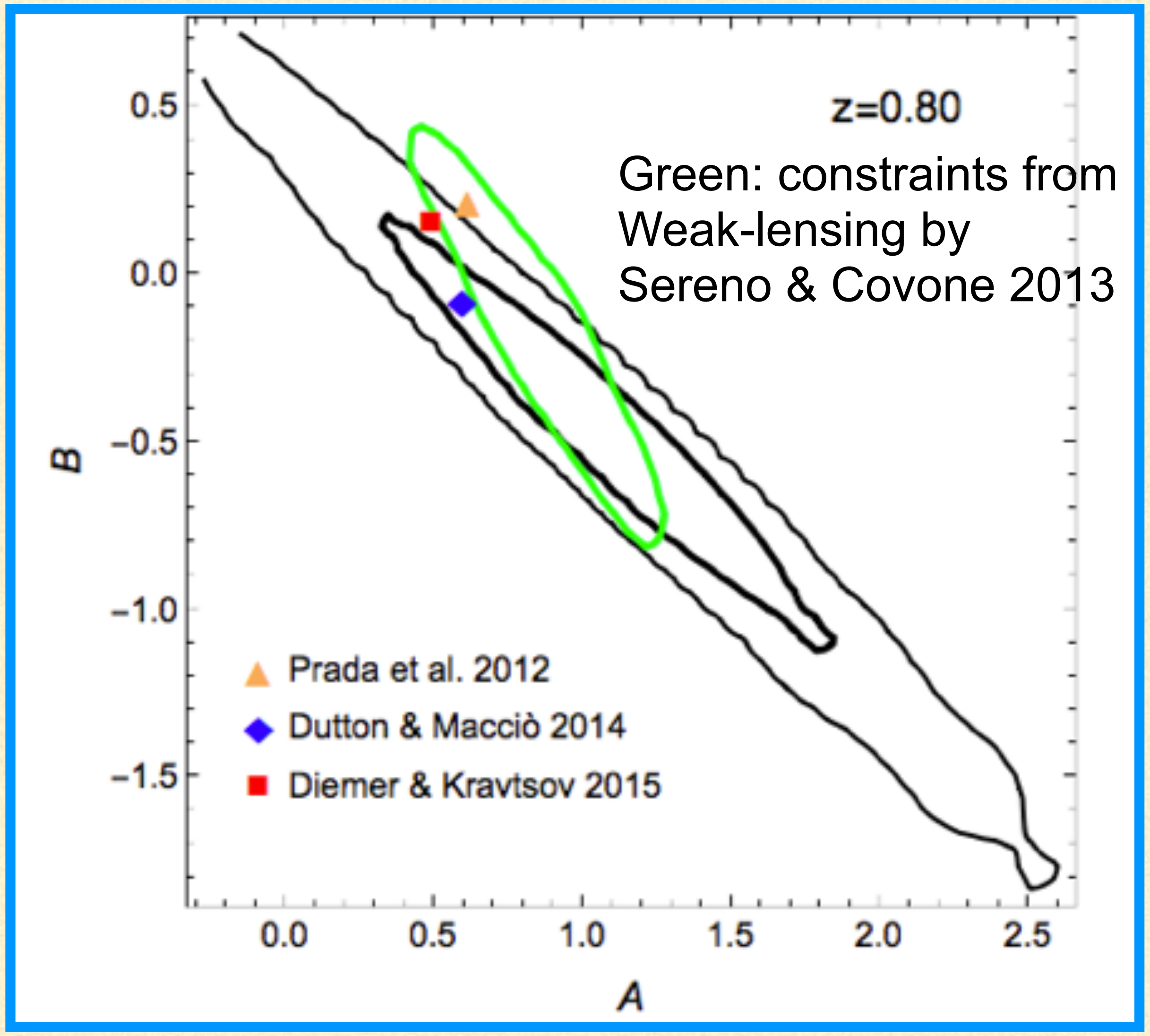
Fitting the observed c(M,z)

$$\log c_{200} = A + B \log\left(\frac{M_{200}}{10^{14} M_\odot}\right) + C \log(1+z) \pm \sigma_{\log c_{200}}$$

LIRA (Sereno 2016)
Bayesian linear regression

A	B	C	$\sigma_{\log_{10} c_{200}}$
1.15 ± 0.29	-0.50 ± 0.20	0.12 ± 0.61	0.06 ± 0.04





Conclusions II

1. We characterise the high-mass end of the distribution of galaxy clusters at $0.4 < z < 0.7$

2. We obtain the first constraints on the c-M at $z > 0.7$ from X-ray data

3. We confirm the expected trend of lower concentrations for higher mass systems and, at a fixed mass range, lower concentrations for higher redshift systems

4. A homogeneous sample, extended to lower redshifts, would improve the constraints on the c-M-z relation