Evolution of the dark matter distribution on galaxy cluster scales

Gabriel W. Pratt

MPE

“How did the Universe originate
and *what is it made of?*”

ESA Cosmic Vision document

Clusters of galaxies are dark matter dominated

5% Galaxies

10-15% Intracluster medium (ICM)

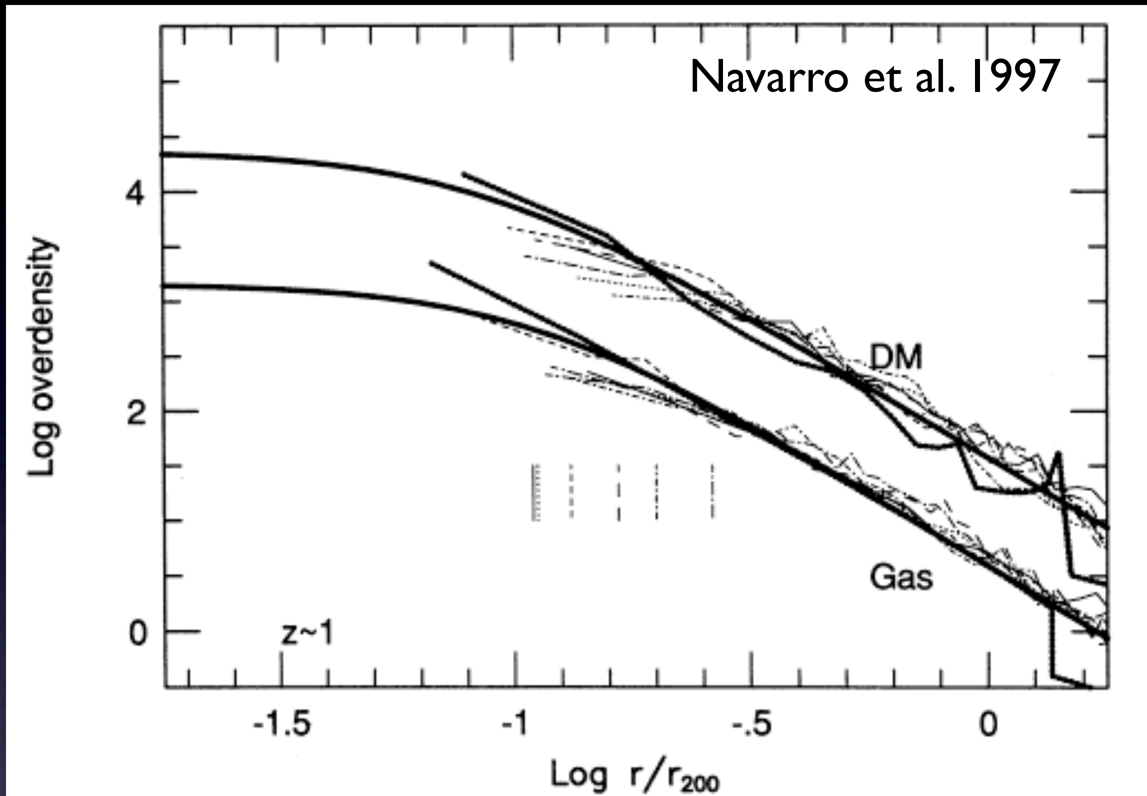
$$\begin{aligned} T &\sim 10^6 - 10^8 \mathrm{K}\ (1 - 15\ \mathrm{keV}) \\ n_e &\sim 10^{-4} - 10^{-2}\ \mathrm{cm}^{-3} \\ Z &\sim 0.3 Z_\odot \end{aligned}$$

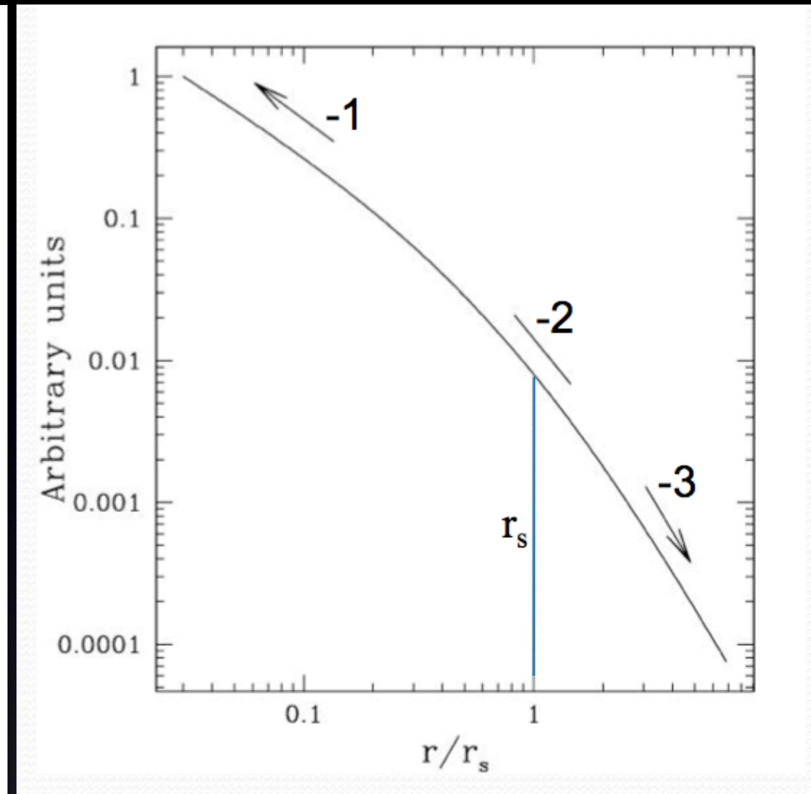
80-85% Dark matter*

*First postulated by Zwicky (1933)

Coma cluster X-ray/optical overlay

Universal density profile of cold dark matter haloes



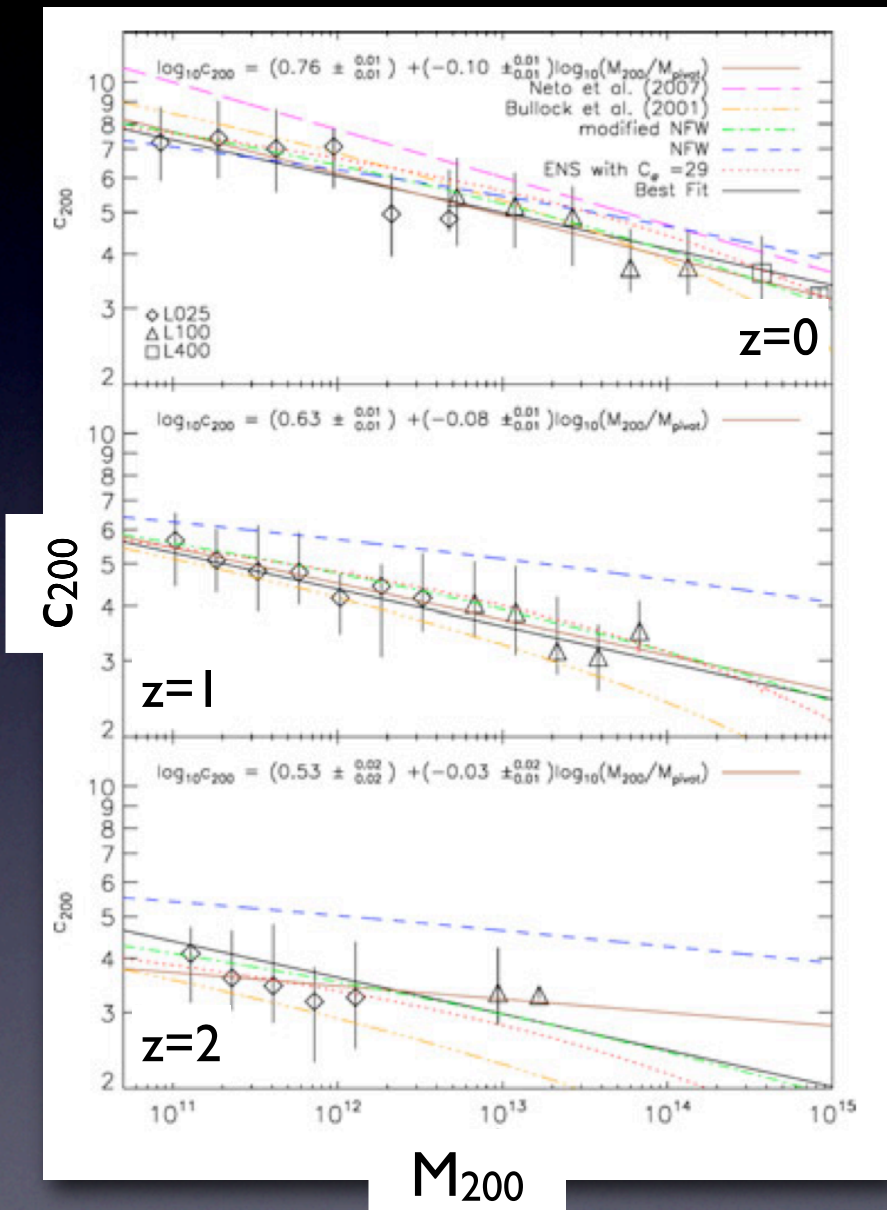


$$\rho_r = \frac{\rho_c(z)\delta_c}{(r/r_s)(1+r/r_s)^2}$$

$$r_\delta = c_\delta r_s$$

$$\delta_c = \frac{200}{3}\frac{c^3}{[\ln(1+c) - c/(1+c)]}$$

Dark matter halo concentration



Duffy et al. 2008

Reflects background density of Universe at epoch of halo formation

- Decreases with *M*

- Decreases with z

$$c(M,z) = A\left(\frac{M}{M_0}\right)^{\beta}(1+z)^{\alpha}$$

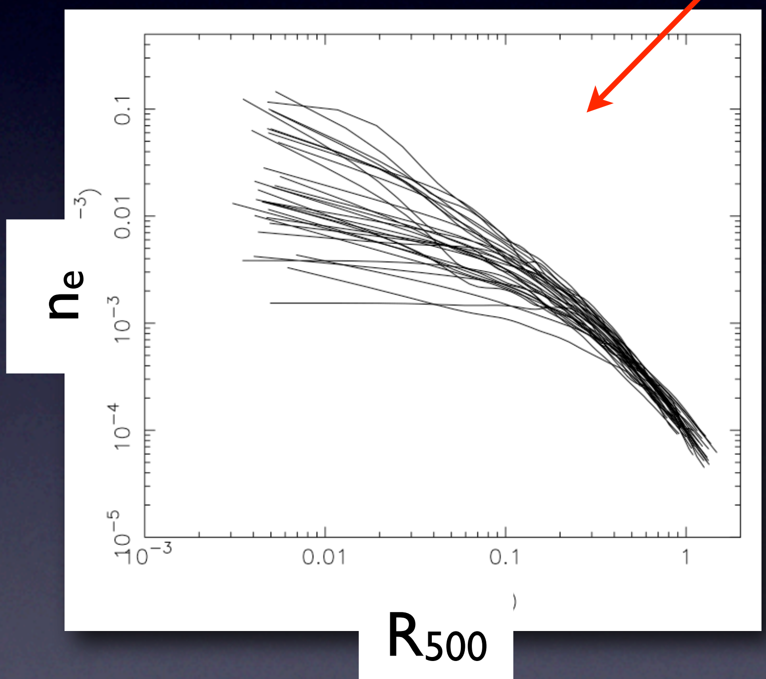
- 20% dispersion in c at given M

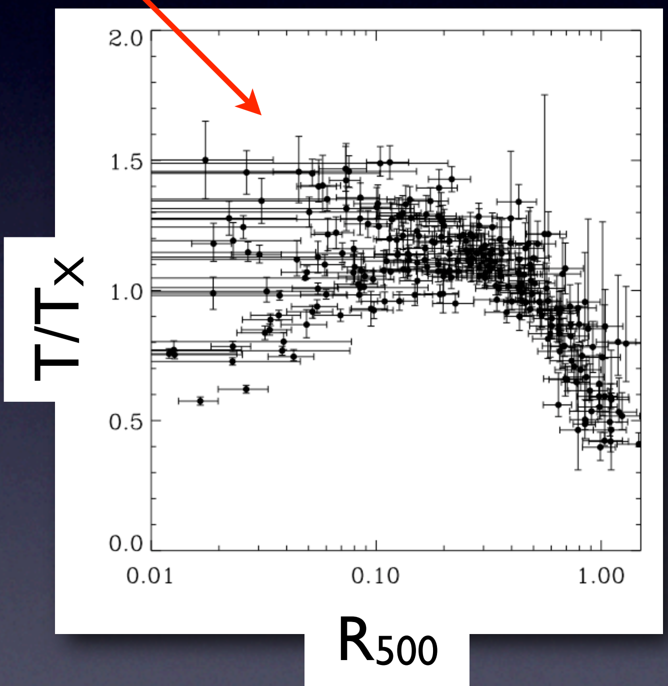
- Depends on cosmology

X-ray mass measurement

Assume spherical symmetry, hydrostatic equilibrium

$$M(r) = -\frac{kT}{\mu m_p}\frac{r}{G}\left[\frac{d\ln\rho}{d\ln r} + \frac{d\ln T}{d\ln r}\right]$$





Integrate NFW: $M(r) = 4\pi\rho_c(z)\delta_c r_s^3 m(r/r_s)$

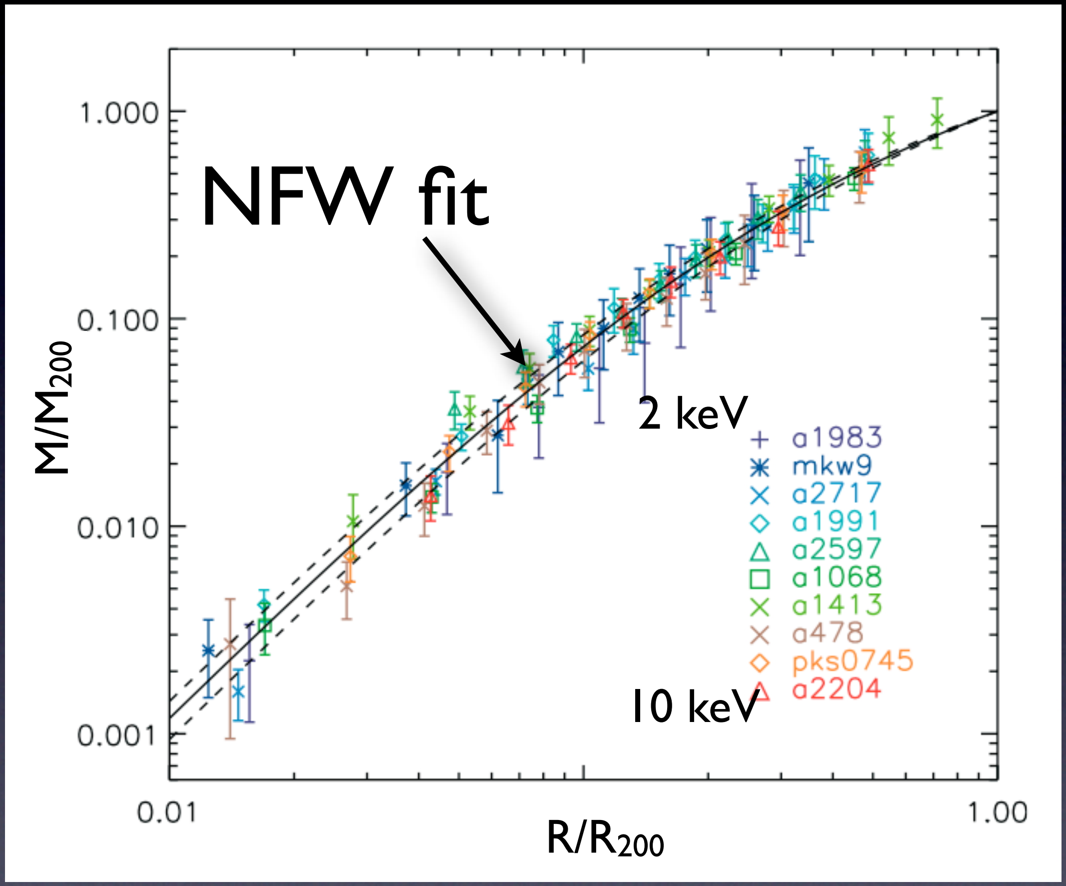
Suto et al. 1998

$$m(x) = \ln(1+x) - x/(1+x)$$

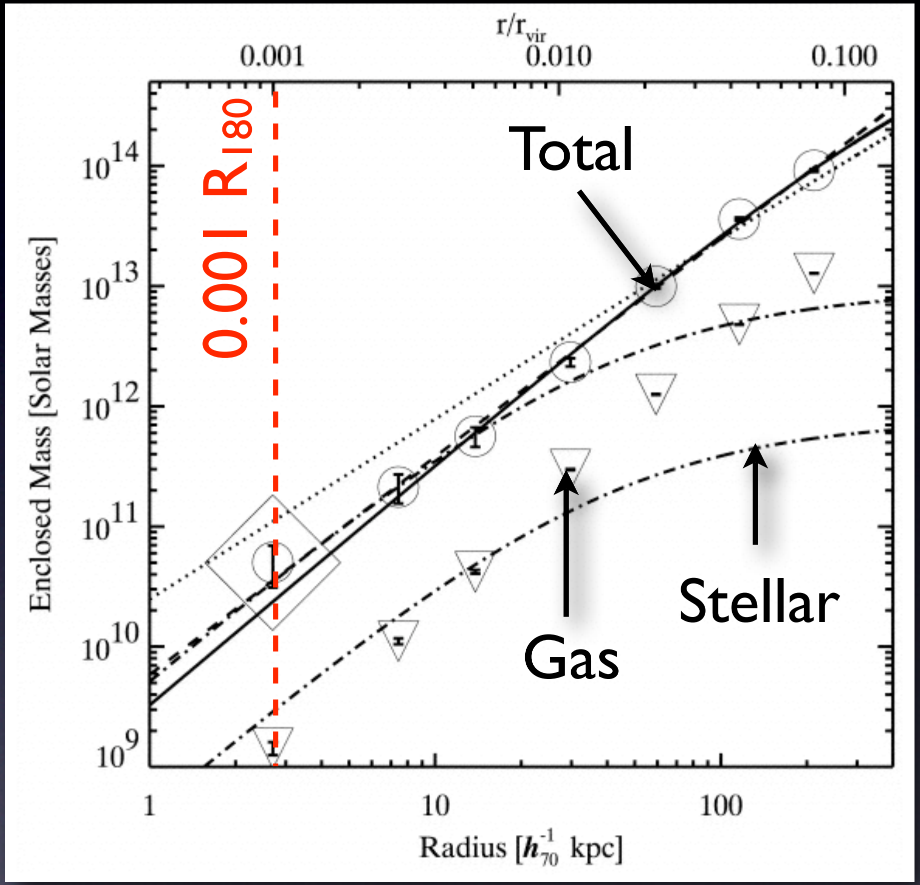
Current constraints

Scaled total mass/density profiles

Regular systems (z < 0.2), assume spherical symmetry, HE



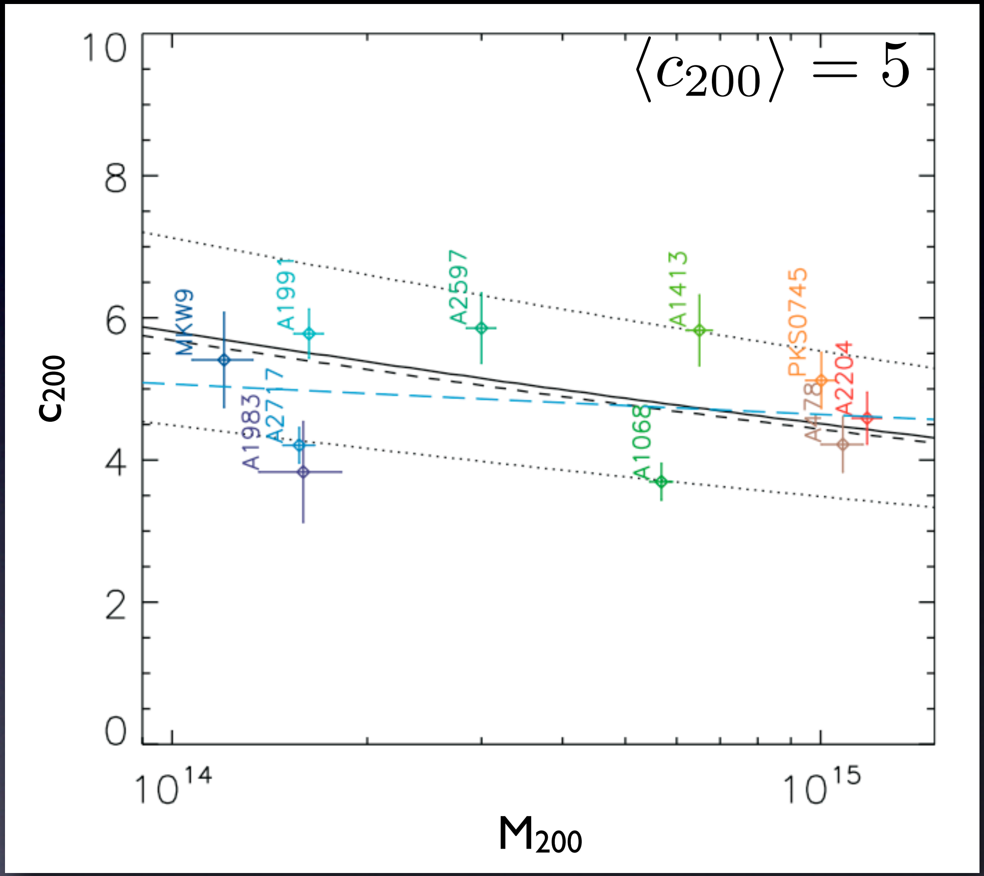
Pointecouteau, Arnaud & Pratt 2005
(also Pratt & Arnaud 2005; XMM, regular)



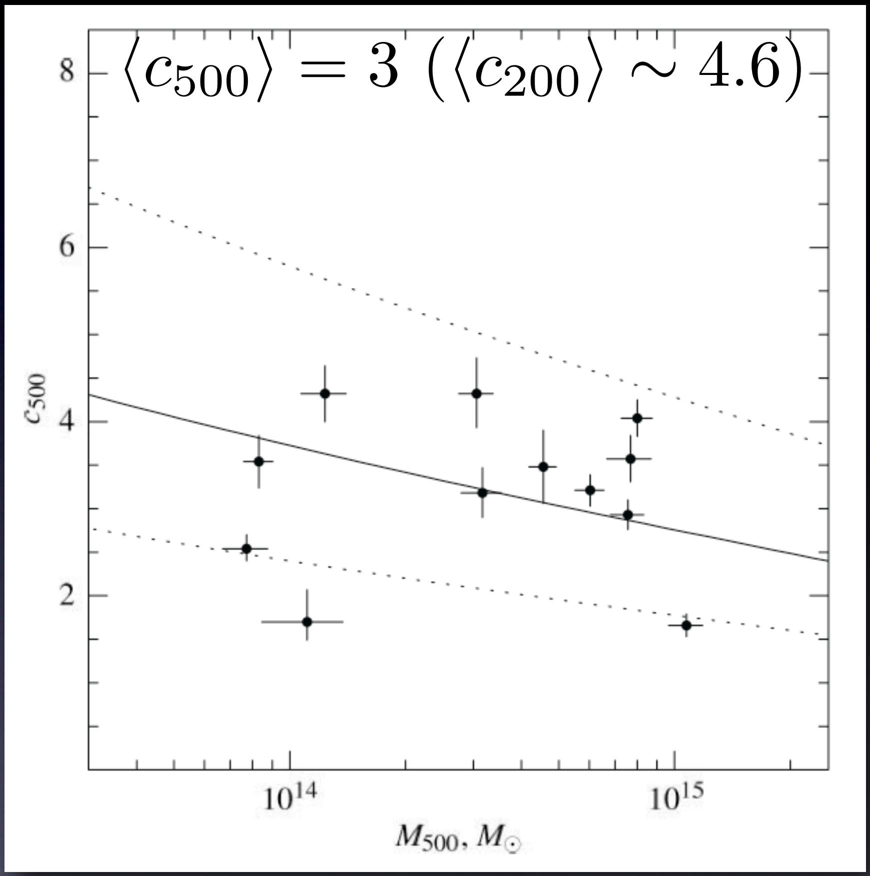
Lewis & Buote 2003 (Abell 2029)

Dark matter constraints: *c* - *M* relation

Quantitative test of CDM scenario



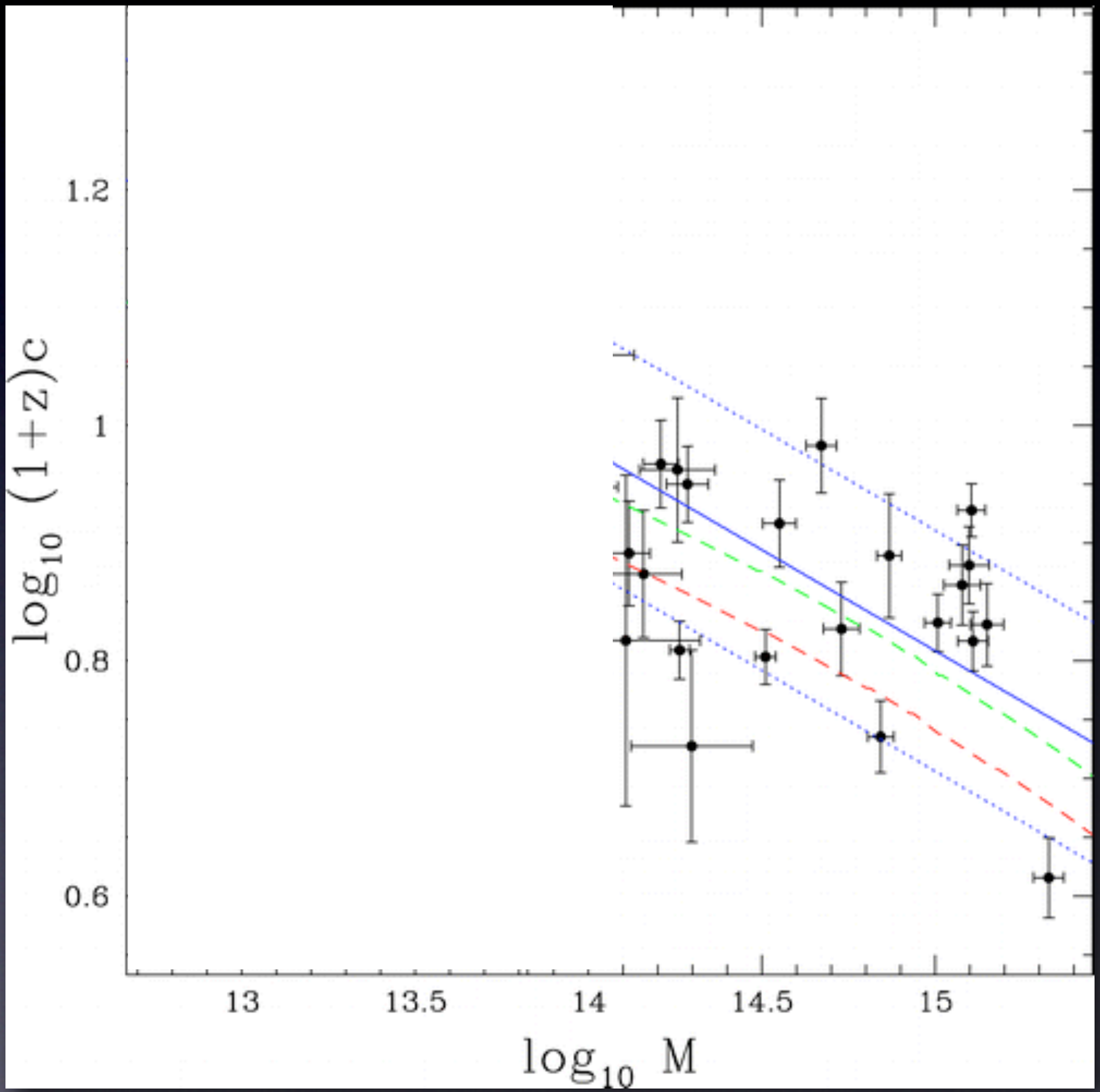
Pratt & Arnaud 2005;
Pointecouteau, Arnaud & Pratt 2005
(XMM, relaxed)



Vikhlinin et al 2006 (Chandra, relaxed)
see also: Gastaldello et al. 2007, Buote et al. 2007, Humphrey et al. 2006, Schmidt & Allen 2007

Dark matter constraints: *c* - *M* relation

Extension to lower masses



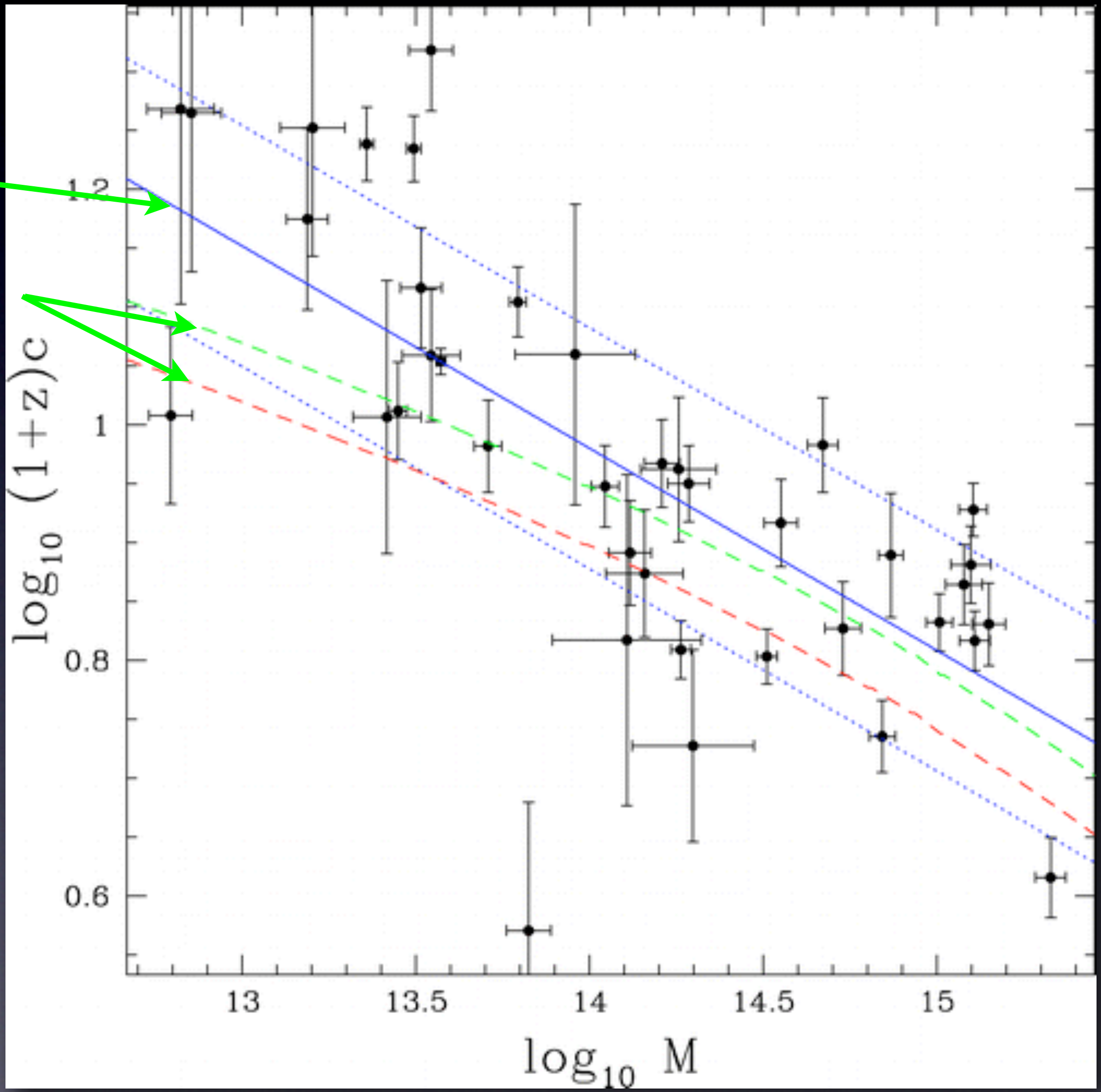
Buote et al. 2007

Dark matter constraints: *c* - *M* relation

Extension to lower masses

Best fit

Theoretical predictions
Ω_M=0.3, Ω_Λ=0.7, σ_8=0.9

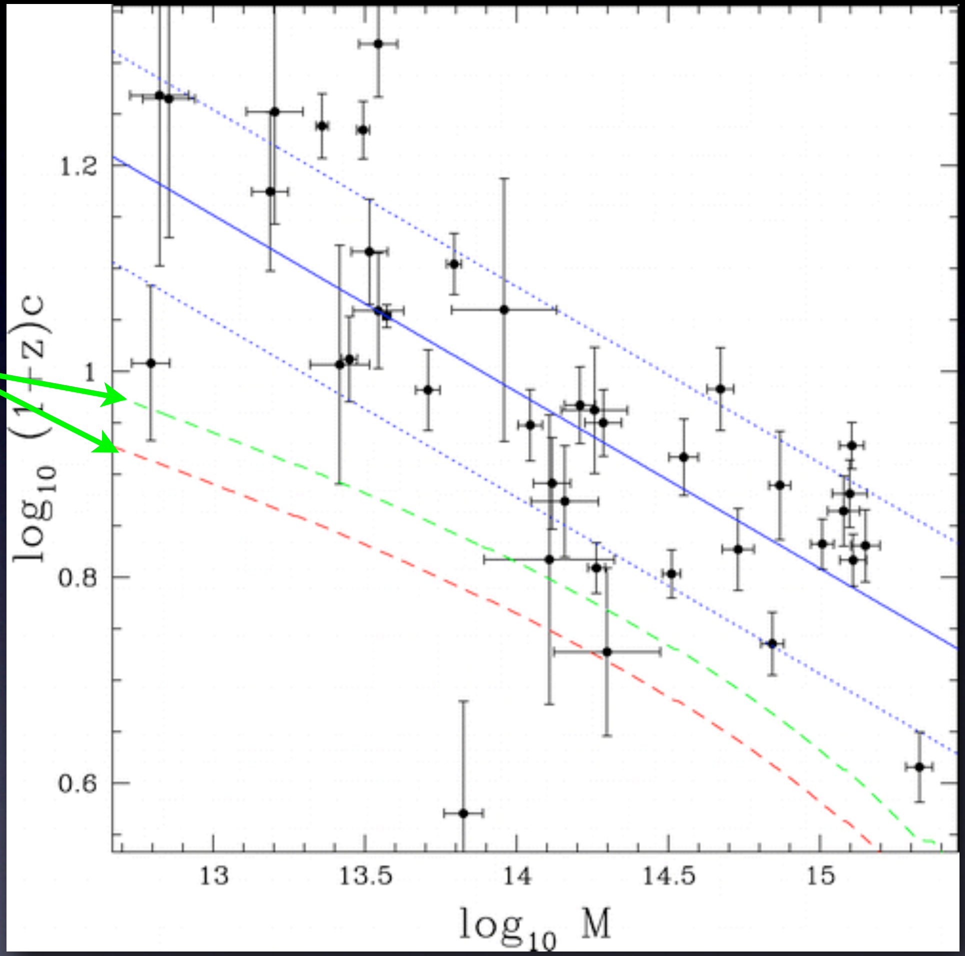


Buote et al. 2007

Cosmological constraints

$z < 0.2$
$0.7 < kT < 12$ keV

Theoretical predictions
WMAP3 cosmology
$\Omega_M=0.24$, $\Omega_\Lambda=0.76$, $\sigma_8=0.76$

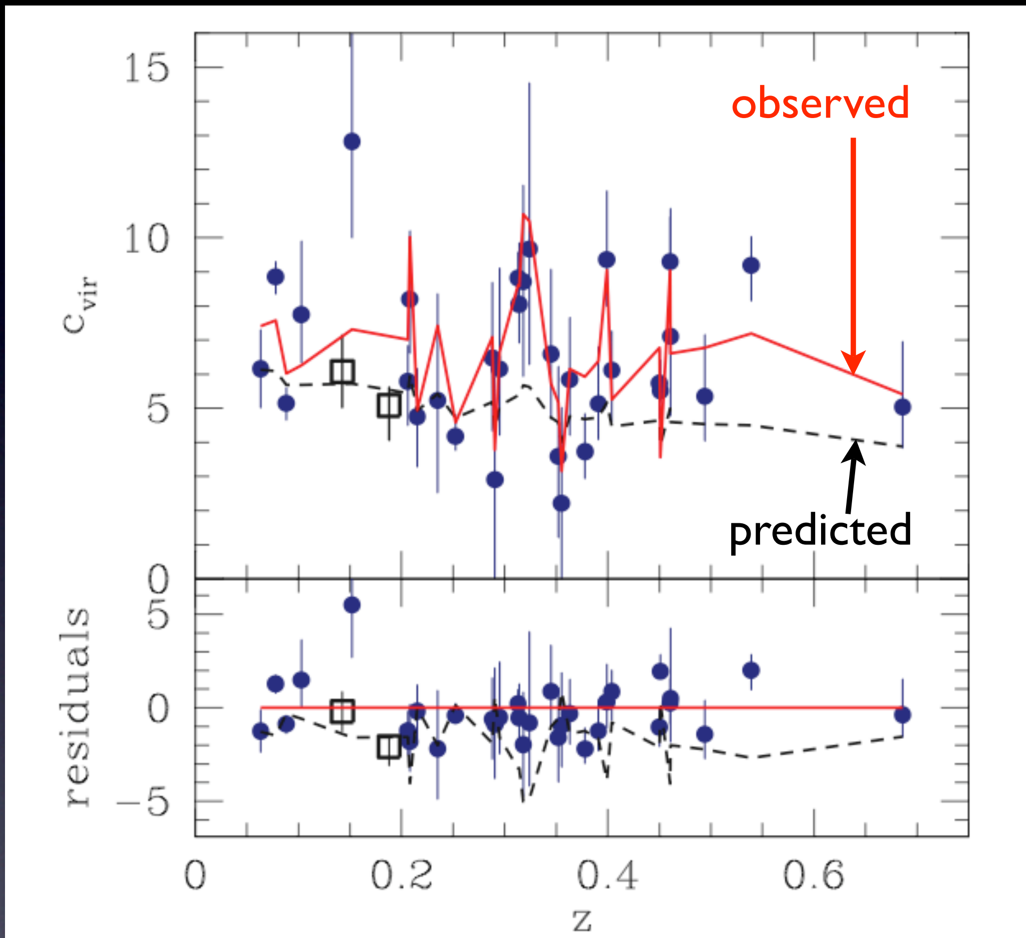


Buote et al. 2007;
Chandra/XMM

Incompatible with WMAP3

$\sigma_8 > 0.8$ at 99%

Evolution of *c* - *M* relation



Schmidt & Allen 2007;
Chandra

kT > 5 keV
0.1 < z < 0.7

- No evolution

- *c*-*M* relation steeper than expected?

Future progress

Sample requirements

- Morphologically relaxed
  - Essential for HE assumption (calibrate non-HE from velocity broadening)
  - *eROSITA* survey
  - (Ideal sample for calibration of mass-observable relations)

- Wide mass/temperature range
  - leverage on *c(M)*
  - (0.3 - 15 keV / $10^{12.5} - 10^{15}\ M_\odot$, i.e., galaxies → rich clusters)

- Wide z range (z > 1)
  - essential for evolution of *c-M*

- Many objects (100s)
  - essential to constrain σ(c(M,z))

- Optical coverage for stellar mass estimation and lensing
  - Synergy with *PanSTARRS*, *DES*, etc

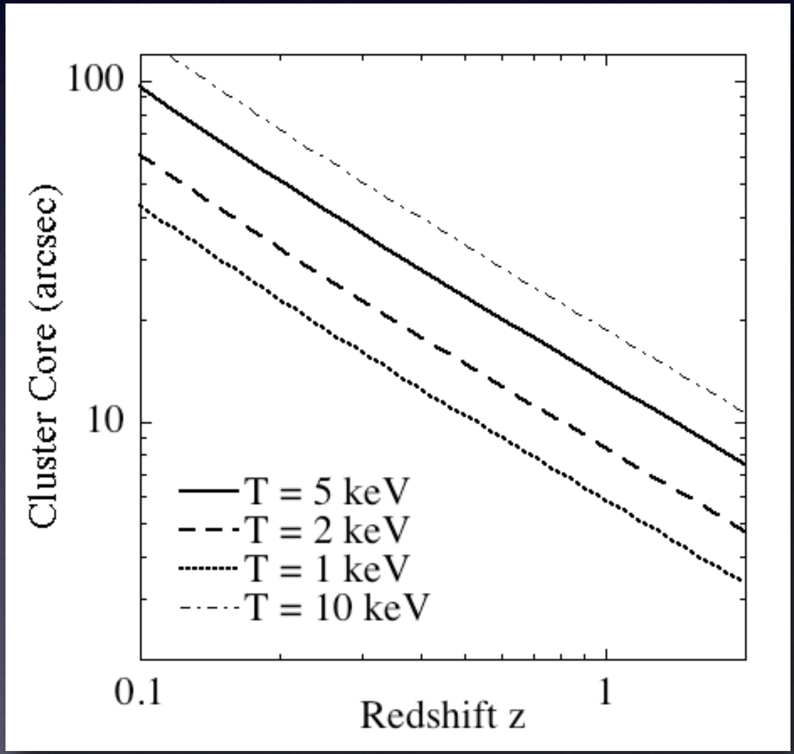
Technical requirements

- High throughput
  - 1 keV group flux ~10^{-16} erg cm^{-2} s^{-1} at z~1

- Low background
  - group and cluster outskirts are background limited ($S_X \propto R^{-2} \rightarrow R^{-3}$)

- High spatial resolution (< 5”)
  - central regions of distant systems (resolution and AGN effects)

- Large FoV
  - for mapping extended emission in nearby systems (R_{500} > 15’)



Courtesy M. Arnaud

Conclusions

- Dark matter distribution and its evolution critical test of:
    - current structure formation paradigm
    - nature of dark matter

- X-ray observations give us the best means to measure this accurately on cluster scales

- Current constraints weak

- IXO will usher in a new era