The Galaxy Cluster X-ray Concentration-Mass relation: theory and observations

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Star Formation and Gas Reservoirs in Nearby Groups and Clusters

NFW
Navarro, Frenk, White

1996 "The Structure of Cold Dark Matter Halos"

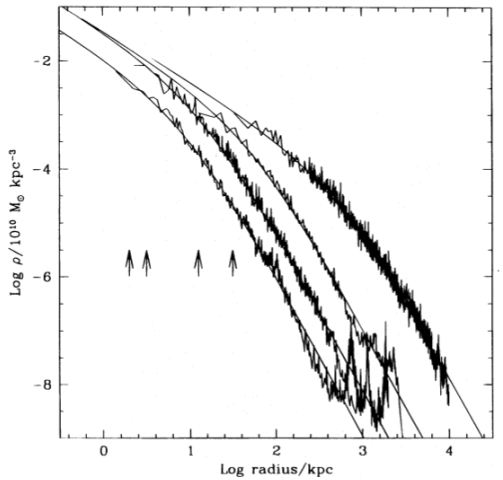


FIG. 3.—Density profiles of four halos spanning 4 orders of magnitude in mass. The arrows indicate the gravitational softening, h_g, of each simulation. Also shown are fits from eq. (3). The fits are good over two decades in radius, approximately from h_g out to the virial radius of each system.

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

$$\rho_s = \frac{\rho_{cr}\Delta}{3}\frac{c}{\ln(1+c) - c/(1+c)}$$

$$c_\Delta = r_\Delta / r_s$$

$$M(<x) = 4\pi\rho_s r_s^3[\log(1+x) - x/(1+x)]$$

$$M_* = 3.3e13 M_{sun}$$

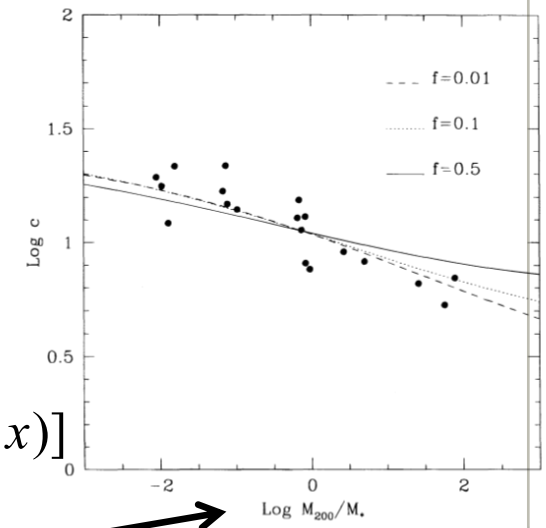


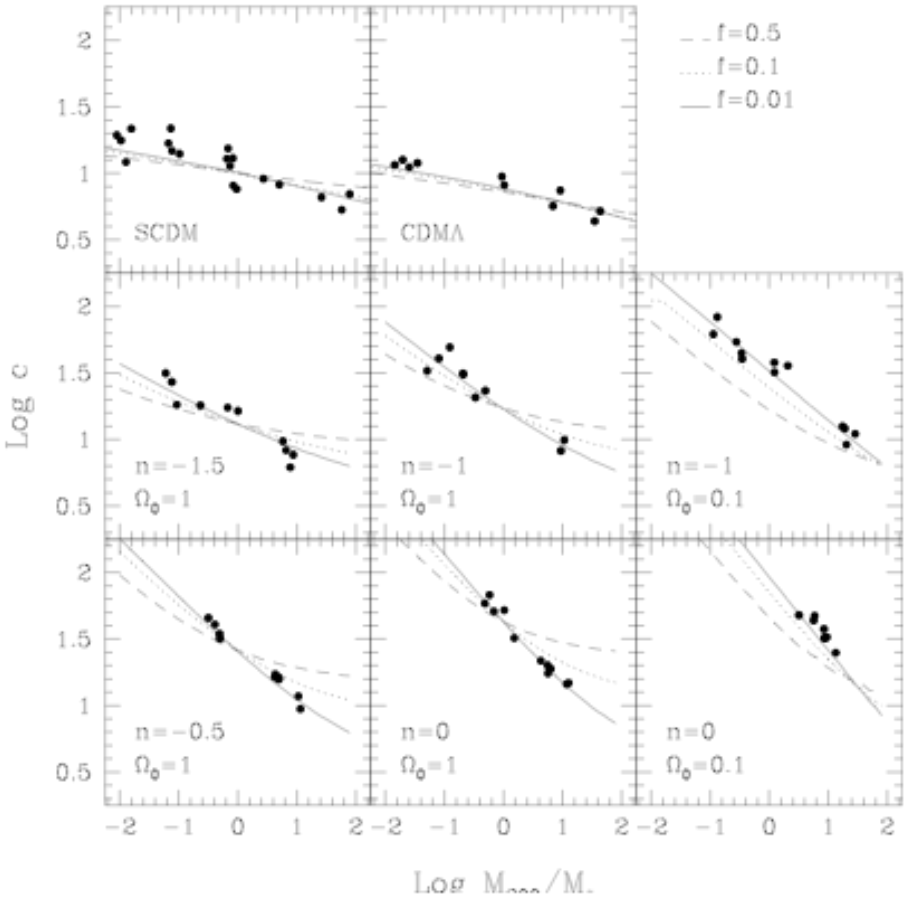
FIG. 8.—Concentration c as a function of the mass of the halo. The curves show the mass-concentration relation predicted from the formation times of halos. All curves are as in Fig. 7 and have been normalized so that they cross at $M_{200} = M_*$.

$$C_{200} = R_{200}/r_s$$

NFW
Navarro, Frenk, White

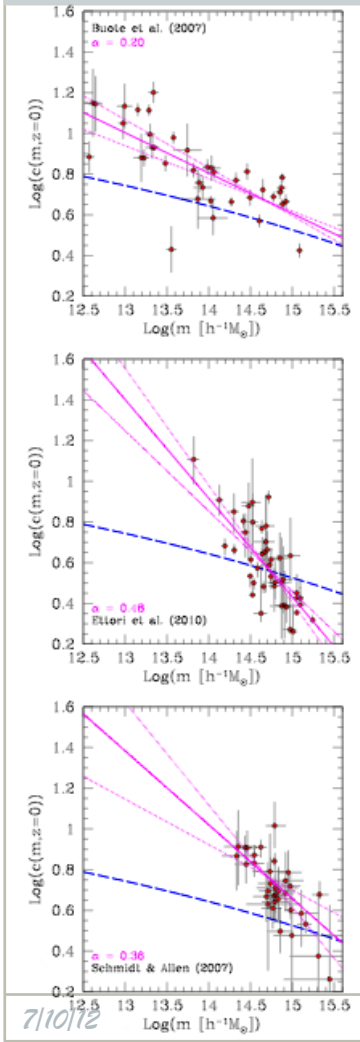
1997 "Universal density profile from hierarchical clustering"

- Groups formed when the universe was denser -> higher concentration



X-ray C-M relation

$$c = c_0 \left[\frac{M}{M_0} \right]^{\alpha}$$



- *Pointecouteau et al. 05, Vikhlinin et al. 06* agree with simulations.
- *Buote et al. 2007, Schmidt & Allen 2007, Ettori et al. 2010* claimed agreement within the errors but…

Fedeli 2012

Problem

The relation is stepper in observation than in theory.

B07: α=-0.20
E10: α=-0.48
SA07: α=-0.36

Gao et al. 08 α=-0.10

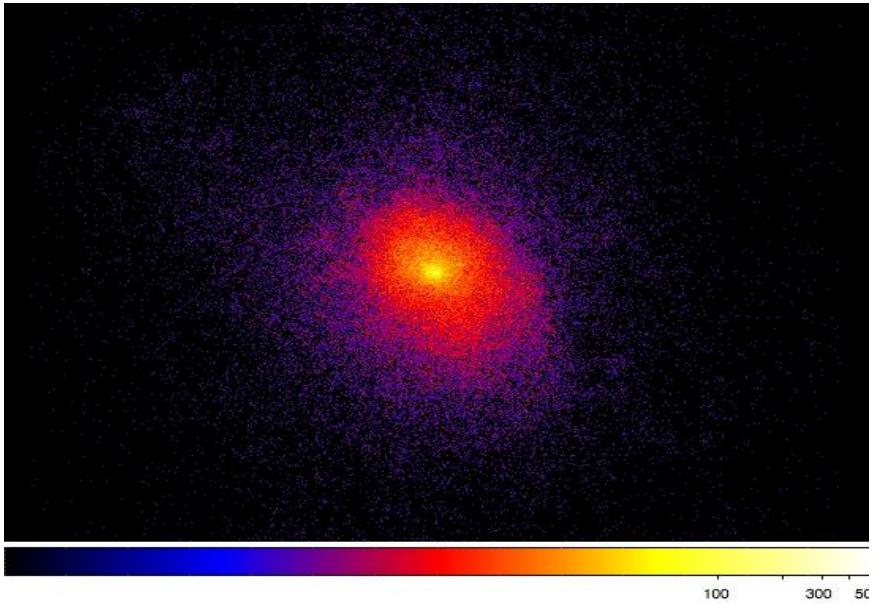
c-M relation: different approaches

SIMULATIONS	*OBSERVATIONS*
• NFW fit to 3D profile	• Information is projected
• Fit done from the re[RADIAL RANGE] central regions to th[RADIAL RANGE] virial radius or beyond	• [RADIAL RANGE]dial range is [RADIAL RANGE]rmined by the S/N [RADIAL RANGE]or field of view
• Most work based o[BARYONS] DM-only simulati[BARYONS]	• [BARYONS]e real Universe has [BARYONS]yons!
• In cosmological b[SELECTION FUNCTION]xes [SELECTION FUNCTION]selection based o[SELECTION FUNCTION]	• [SELECTION FUNCTION]Observational selection [SELECTION FUNCTION]tion: cut in L_X (in [SELECTION FUNCTION]th[SELECTION FUNCTION] best scenario)

SAMPLE

52 simulated clusters with 4 different physics *(Fabjan, Borgani, ER, et al. 2011, ER et al. 2012)*:

- DM-only
- NR (no-radiative)
- CSF (cooling-star formation-feedback)
- AGN



Synthetic X-ray catalogue *(ER et al. 2012)*:
20 CSF clusters processed through X-MAS *(Gardini, ER et al. 2004, ER et al. 2008)* to create Chandra-like observations

FIT PROCEDURE

Typical SIM radial range: from [0.07-1.4] of R_{200} (=[0.05-1] R_{vir})

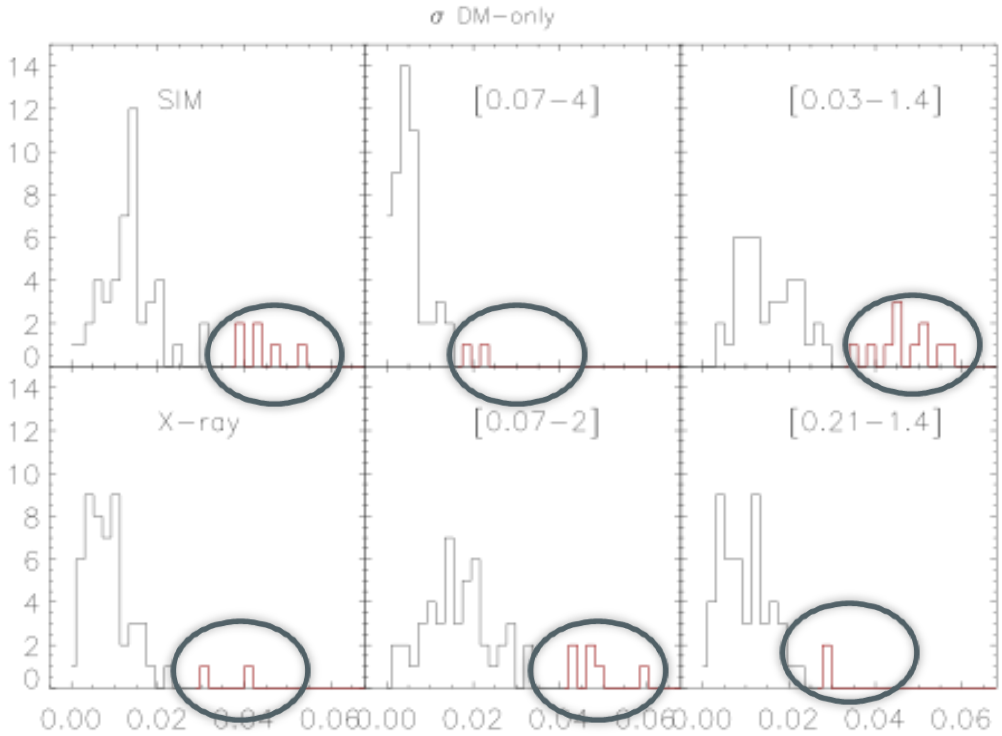
Halos presenting large residuals have been eliminated

$$c = c_0 \left[\frac{M}{M_0} \right]^{\alpha}$$

$M_0 = 5 \times 10^{14}\ M_{sun}/h$

Residuals

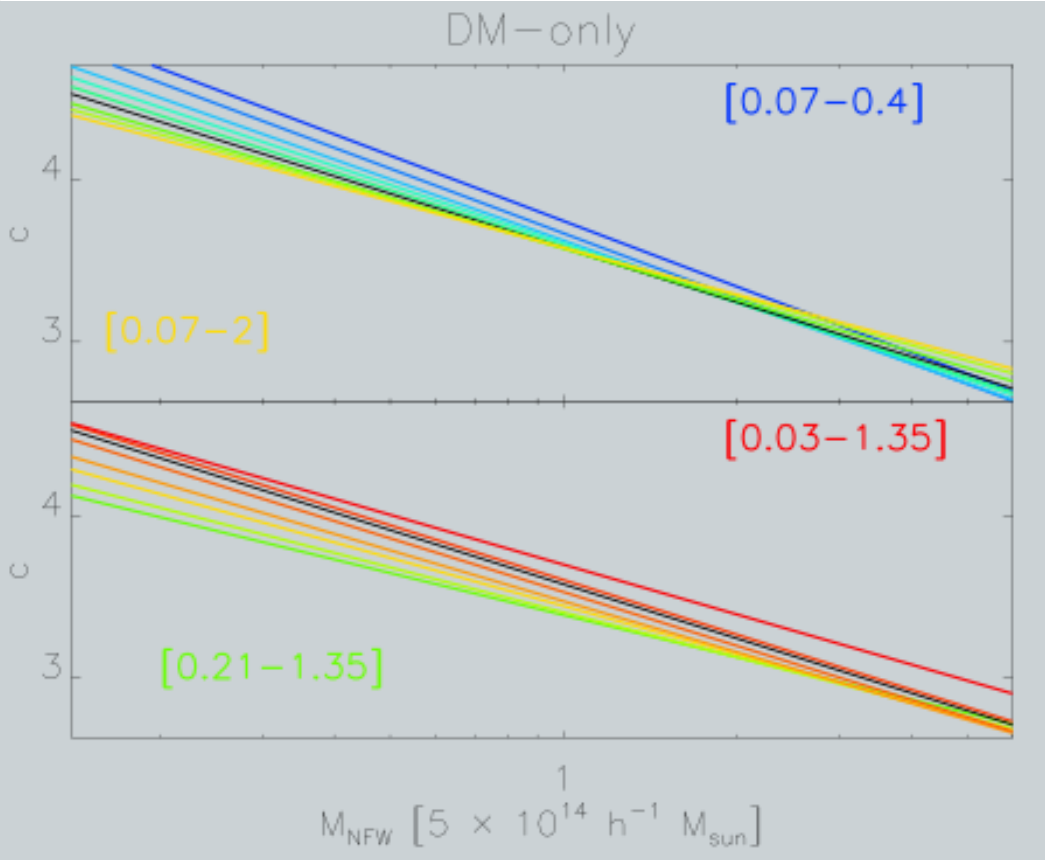
$$\sigma^2 = \frac{\sum_1^{N_{bin}} [\log(\rho_i) - \log(\rho_{NFW})]^2}{N_{bin}}$$



Max slope= -0.2
+20%
Min slope =-0.12
-15%

RADIAL RANGE

$$c = c_0 \left(\frac{M}{M_0}\right)^{\alpha}$$



~ Black line = SIM radial range [0.07-1.4] R_{200}

EXTERNAL RADIUS:

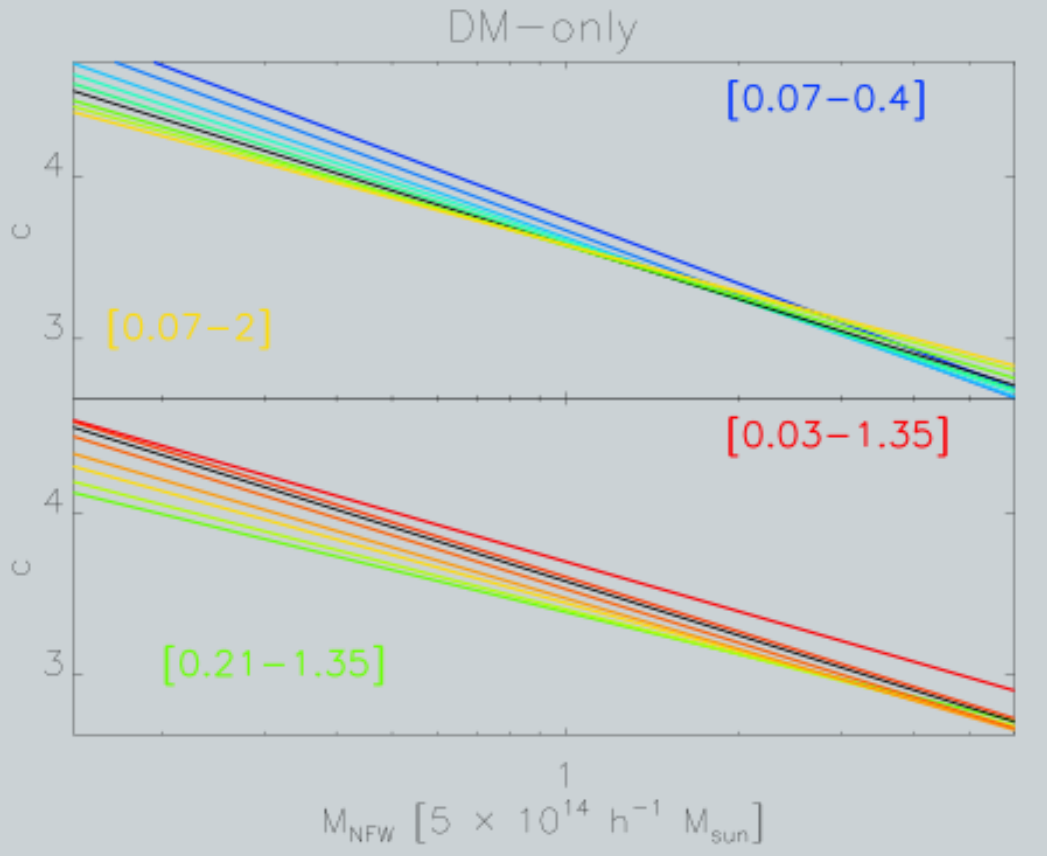
~X-ray has a steeper slope

~the difference is caused by the 17 least massive systems

Max slope= -0.2
+20%
Min slope =-0.12
-15%

RADIAL RANGE

$$c = c_0 \left(\frac{M}{M_0}\right)^{\alpha}$$



~ Black line = SIM radial range [0.07-1.4] R_{200}

INTERNAL RADIUS:

~ modifying the inner radius changes the normalization

~ X-ray (to 50 kpc) and strong-lensing results might have an higher normalization

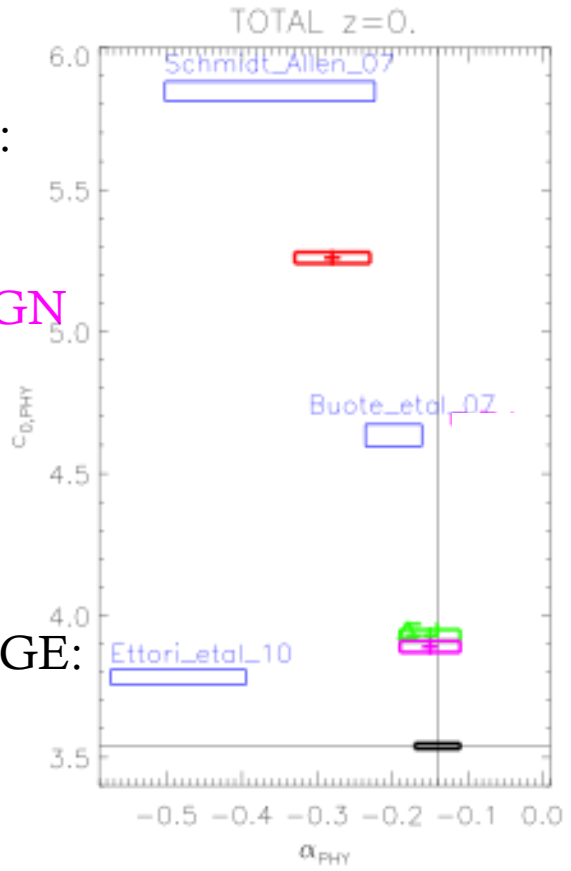
$$c = c_0 \left(\frac{M}{M_0}\right)^{\alpha}$$

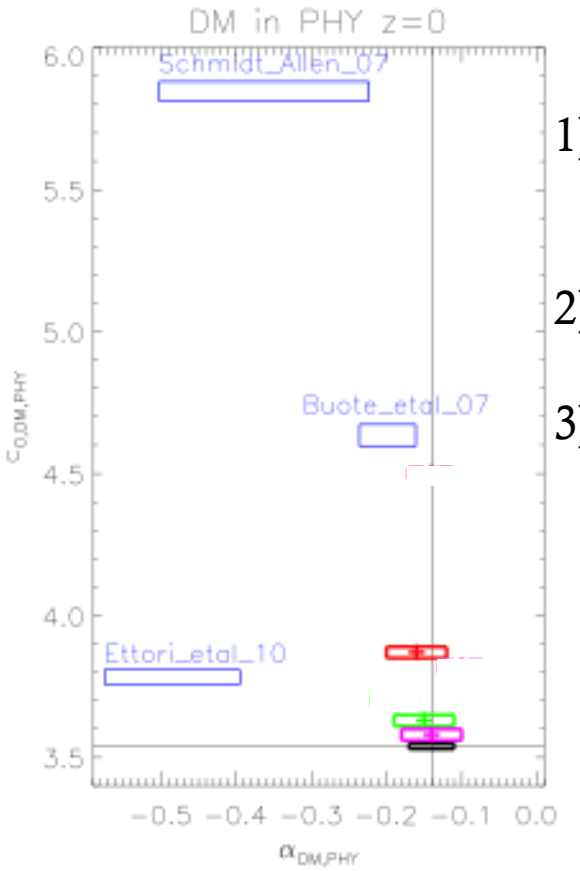
BARYONS

RESULTS considering only clusters with a good NFW fit

ICM PHYSICS:
RED: CSF
GREEN: NR
MAGENTA:AGN

RADIAL RANGE:
___ SIM
[0.07-1.4] R_{200}

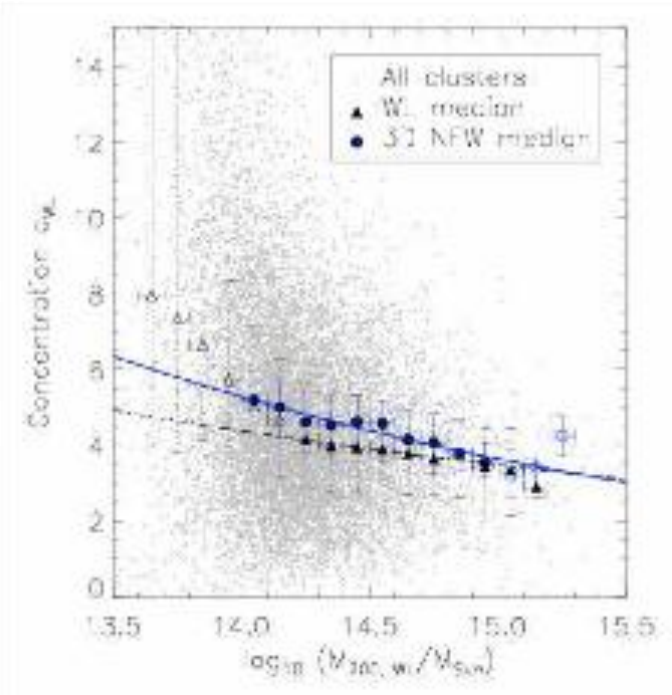




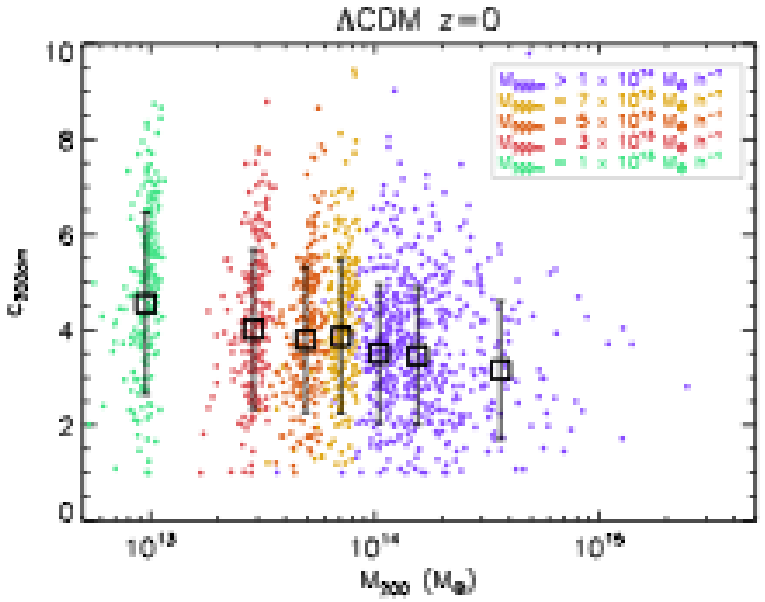
1) Normalization is higher with baryons
2) Slope is higher for total CSF
3) Slopes and normalizations of the only DM component agree better within each other.

X-ray SELECTION FUNCTION

Selection Function influences scaling-relation *results (Nord et al. 08, Pratt et al. 2009, Allen et al. 2012)*, what about the c-M relation?

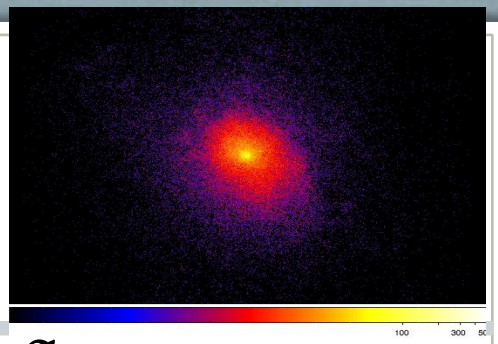


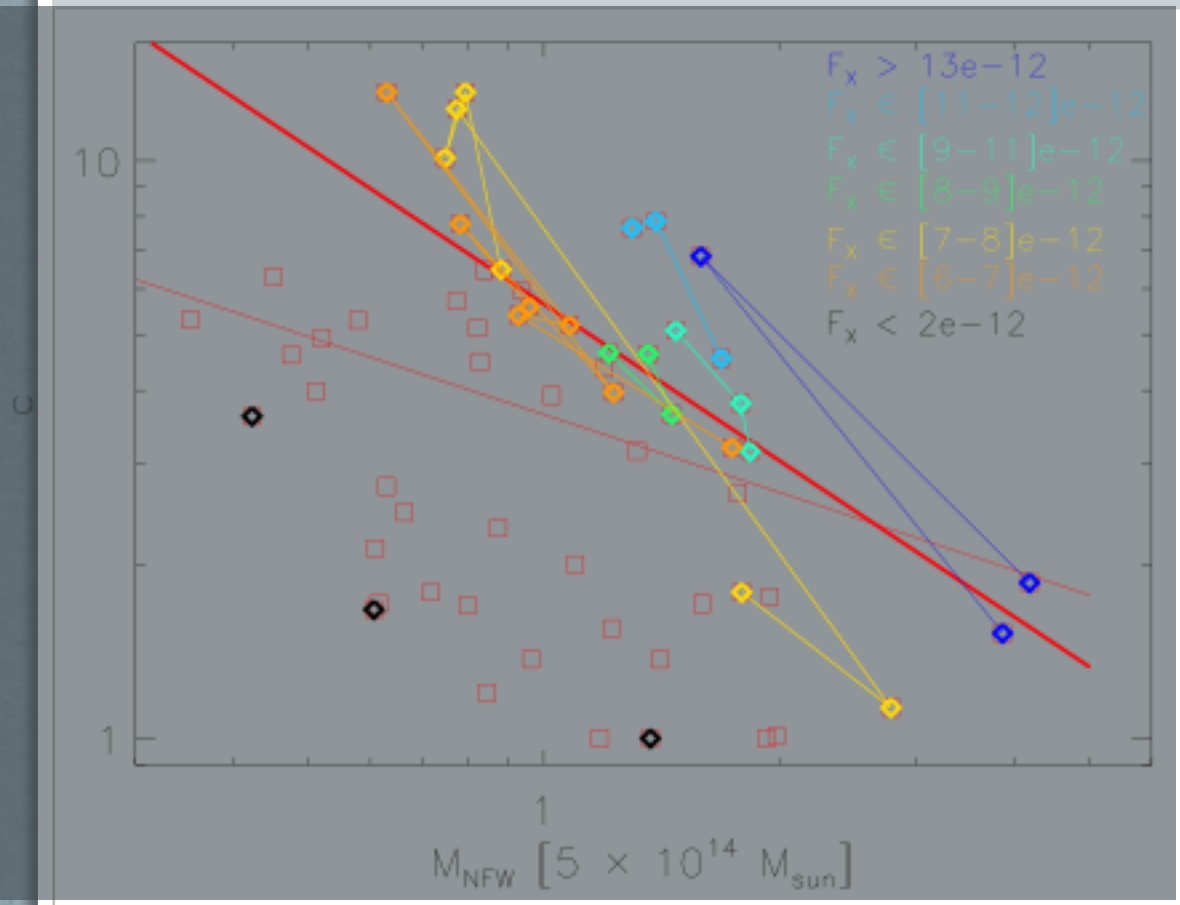
Bahe et al. 2012



De Boni et al. 2012

X-ray SELECTION FUNCTION





If the flux-cuts were parallel => change in c0

If the flux cut were orthogonal => no change

The location of the flux-cuts implies a change of slope.

CONCLUSION

- The comparison between simulations and observations needs to be conducted in a fair way!
- The approaches are INTRINSICALLY different and this might bias the comparison. This is the case for the c-M relation.
- Lowering the external fitting radius => slope reduced
- Decreasing the central excision => normalization increased
- Baryons => all physics: normalization increased
- Selection function=> slope: increased