The c-M relation: observations & simulations

Elena Rasia, University of Michigan

Reconciling extremely different concentration-mass relations

Meneghetti & Rasia (to be sub.)

X-ray c-M relation: understanding the bias

Rasia, Mazzotta, Ettori, Borgani, Meneghetti (to be sub.)

Apple to Apple is not enough!

Comparing apple to apple is not enough…

We need to pay also attention at the analysis procedure!

Same apple BUT the cooked one has more concentration of sugar

NFW
Navarro, Frenk, White

1996 "The Structure of Cold Dark Matter Halos"

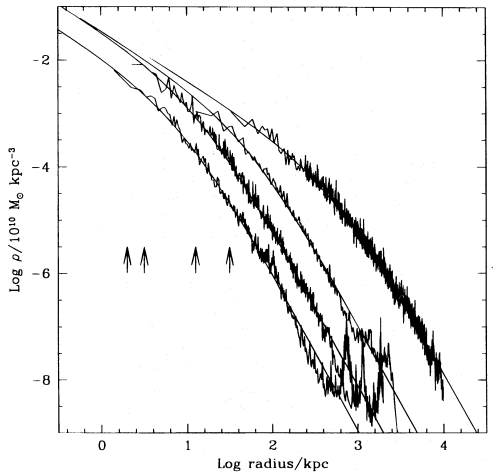


FIG. 3.—Density profiles of four halos spanning 4 orders of magnitude in mass. The arrows indicate the gravitational softening, h_g, of each simulation. Also shown are fits from eq. (3). The fits are good over two decades in radius, approximately from h_g out to the virial radius of each system.

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

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

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

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

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

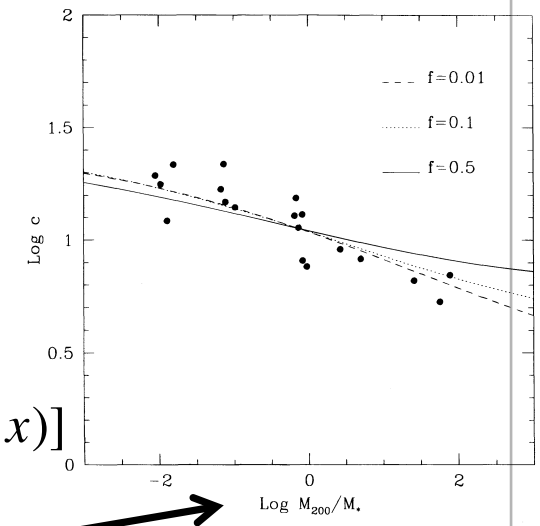


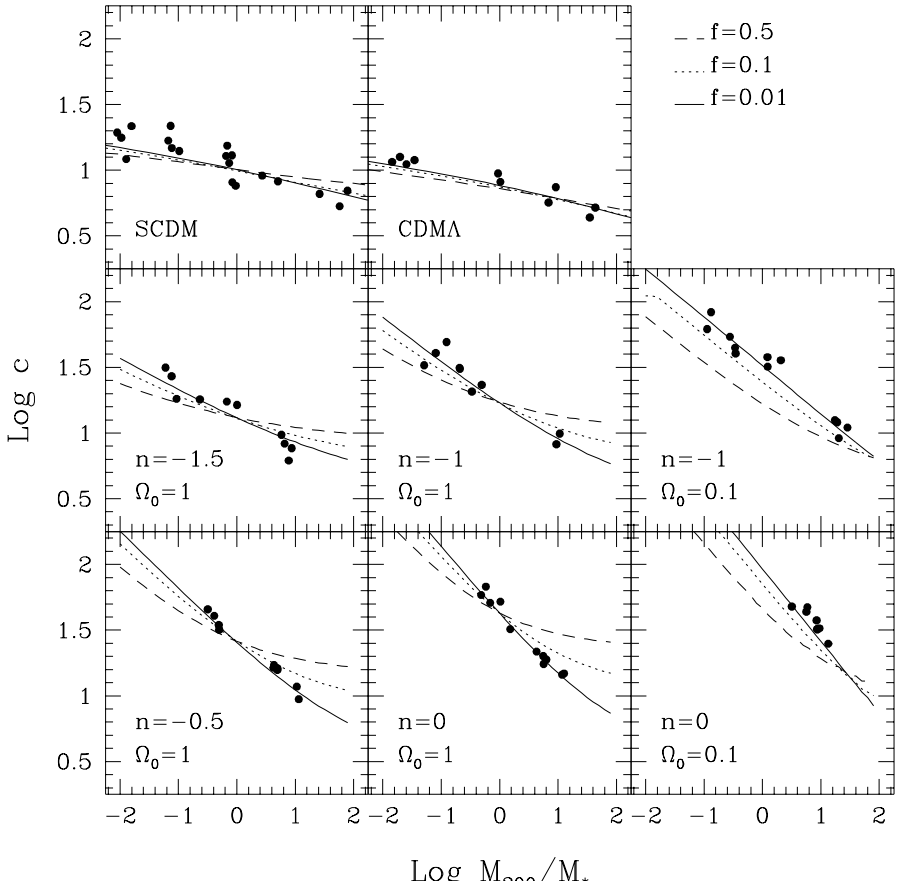
FIG. 8.—Concentration c as a function of the mass of the halo. The curves show the mass-concentration relation predicted from the formation times of halos. All curves are as in Fig. 7 and have been normalized so that they cross at $M_{200} = M_*$.

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

NFW
Navarro, Frenk, White

1997 "Universal density profile from hierarchical clustering"

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



1st Comparison: between two theoretical papers

PROBLEM

- Duffy et al.08 (**D08**), Prada et al.12 (**P12**)
- Both use DM-only simulations
- Have a very similar cosmological model

BUT

- C-M relation differ in NORMALIZATION (Prada et al. 12 is higher)
- And in shape (Prada et al. 12 presents an upturn at high masses)

D08 vs P12
Methods and binning

- D08: Method STANDARD: density profiles fitting by NFW between [0.05-1] R_{vir}

- P12 Method through circular velocity

$V_{max}=\max[(GM/R)^{1/2}]$

$V_{200}=(GM_{200}/R_{200})^{1/2}$

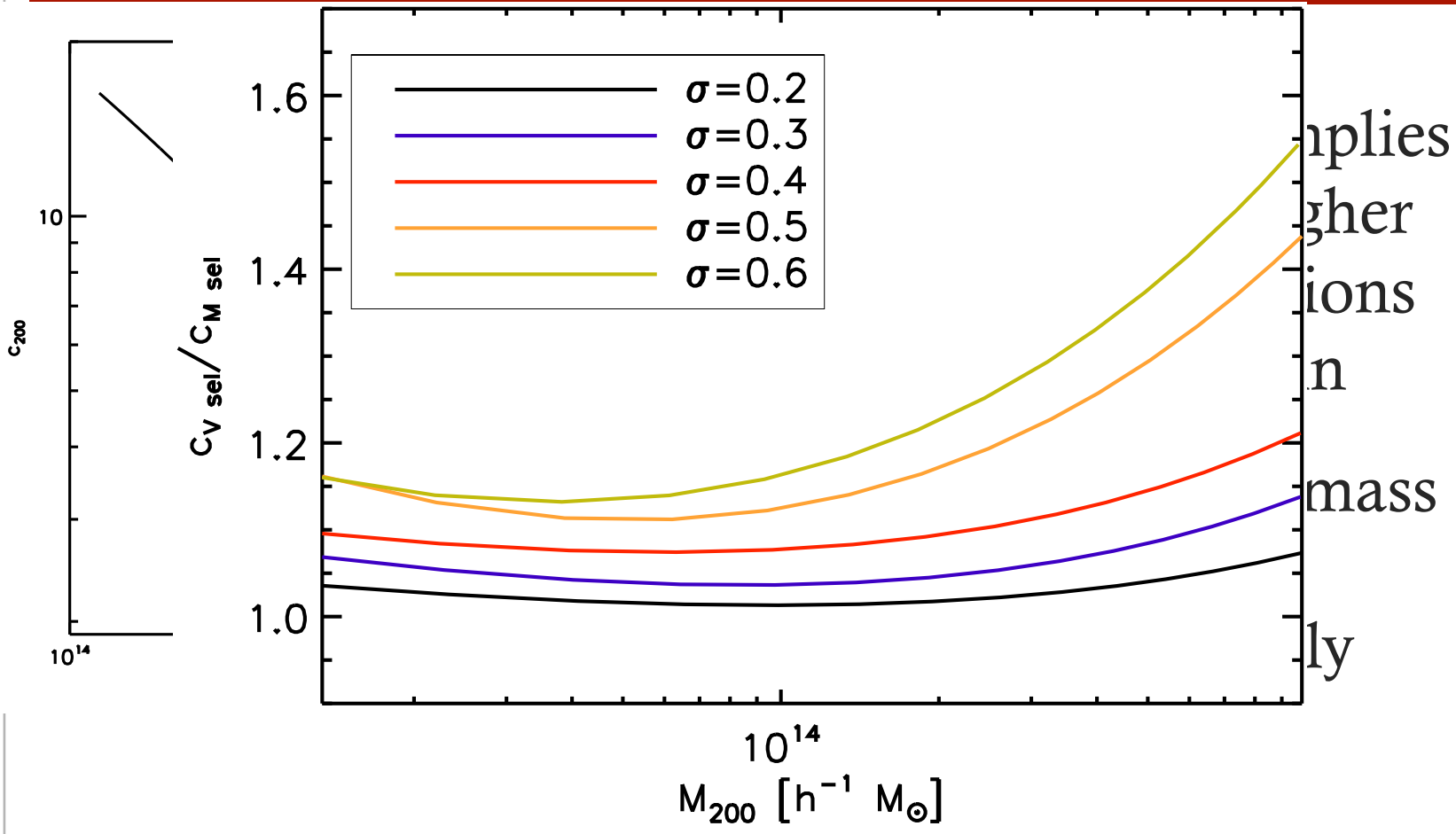
$$\frac{V_{\max}}{V_{200}} = \sqrt{\frac{0.216c}{f(c)}} = F(c)$$

$$f(c) = \ln(1+c) - c/(1+c)$$

- D08: Bin in Mass

- P12: Bin in Velocity

BINNING



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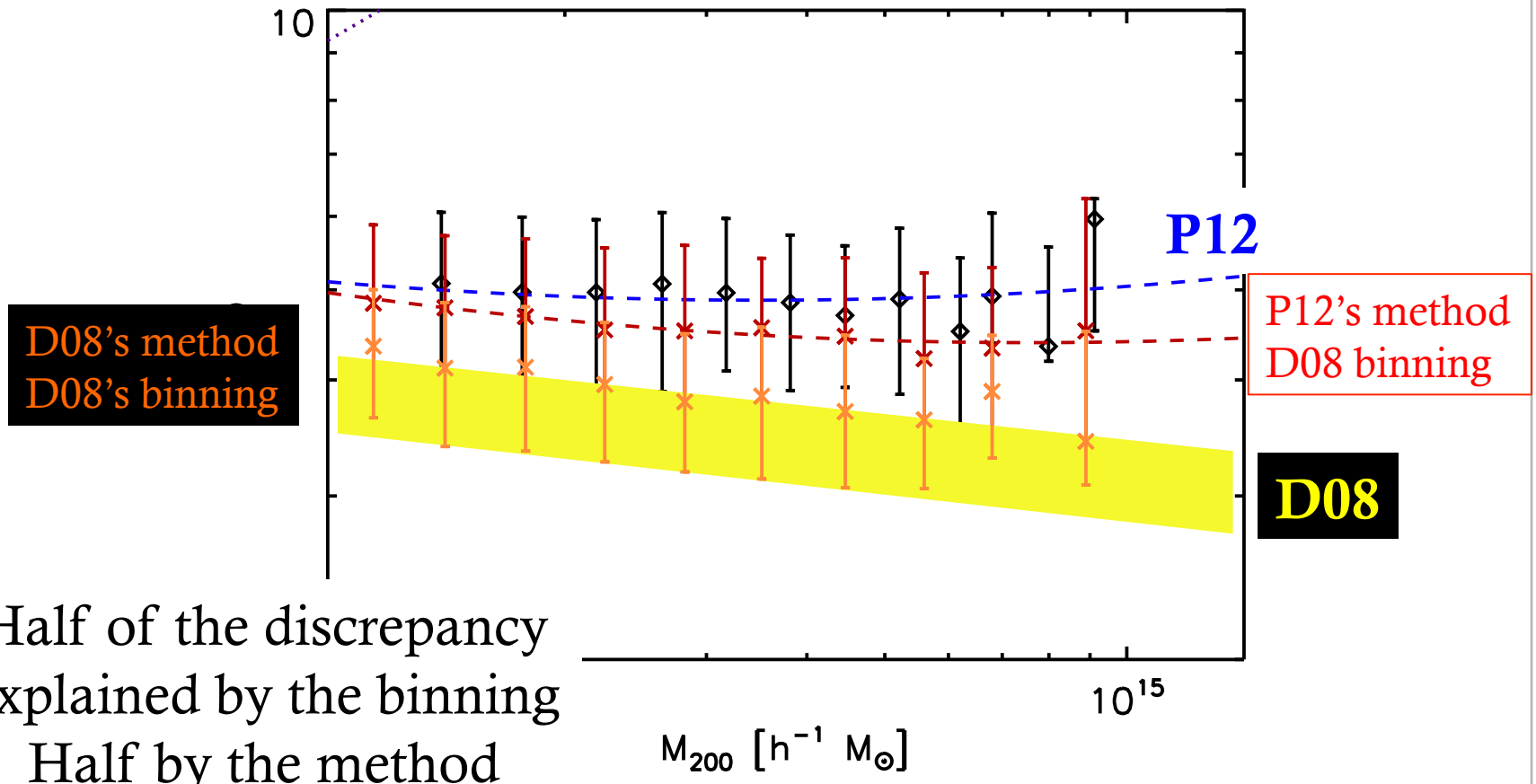
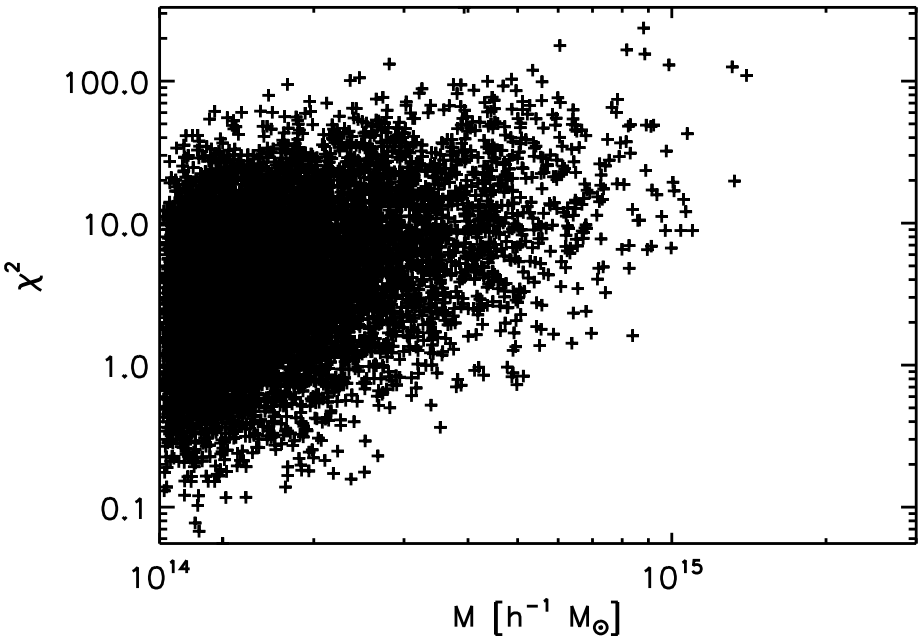
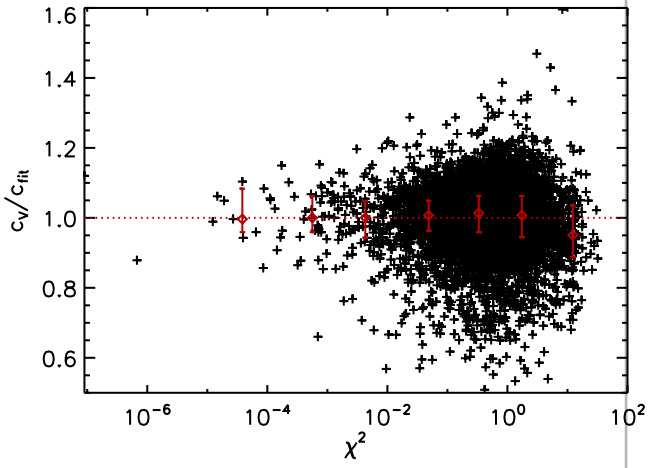
METHOD: MultiDark simulations

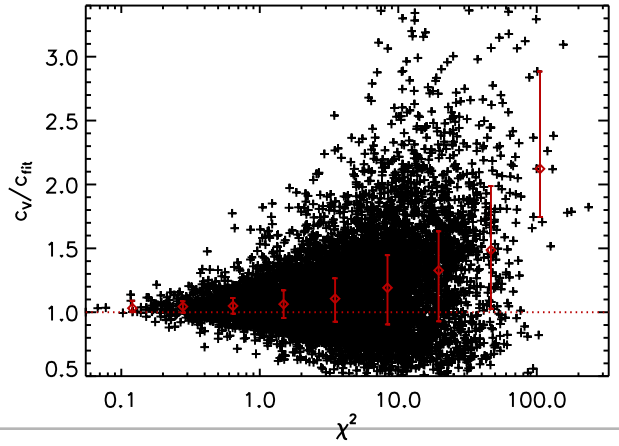


Half of the discrepancy explained by the binning
Half by the method

WHY?

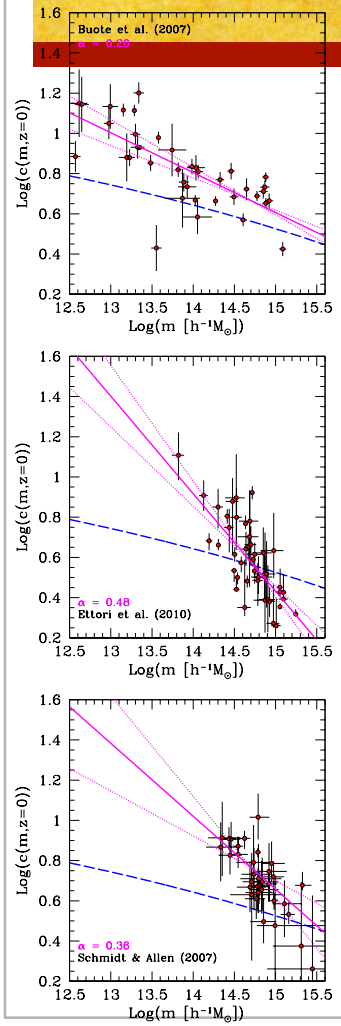

100.0
10.0
1.0
0.1
χ^2
10^{14}
10^{15}
M [h^{-1} $M_\odot$]


1.6
1.4
1.2
1.0
0.8
0.6
c_v/c_{fit}
10^{-6}
10^{-4}
10^{-2}
10^{0}
10^{2}
χ^2


3.0
2.5
2.0
1.5
1.0
0.5
c_v/c_{fit}
0.1
1.0
10.0
100.0
χ^2

2nd Comparison: X-ray and simulation

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



- *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

- NFW fit to 3D profile
- Fit done from the really central regions to the virial radius or beyond
- Most work based on DM-only simulations
- In cosmological boxes, selection based on M

OBSERVATIONS

- Information is projected
- Radial range is determined by the S/N or field of view
- The real Universe has baryons!
- Observational selection function: cut in L_X (in the best scenario)

RADIAL RANGE

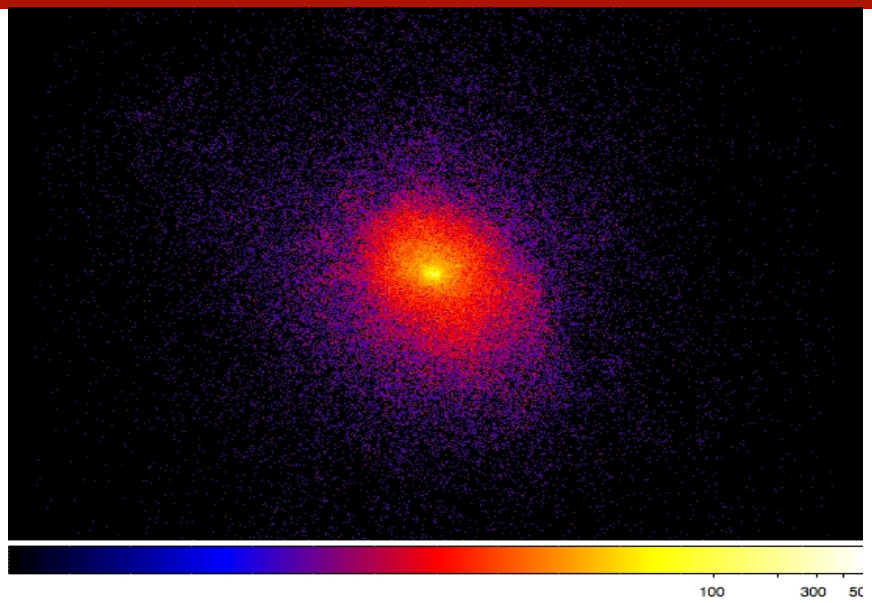
BARYONS

SELECTION FUNCTION

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, NJP, 14 , 501*)*:
20 CSF clusters processed through X-MAS *(Gardini, ER et al. 2004, ER et al. 2008)* to create Chandra-like observations

*(Video Abstract: iopscience.iop.org/1367-2630/14/5/055018)

STANDARD FITTING PROCEDURE

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

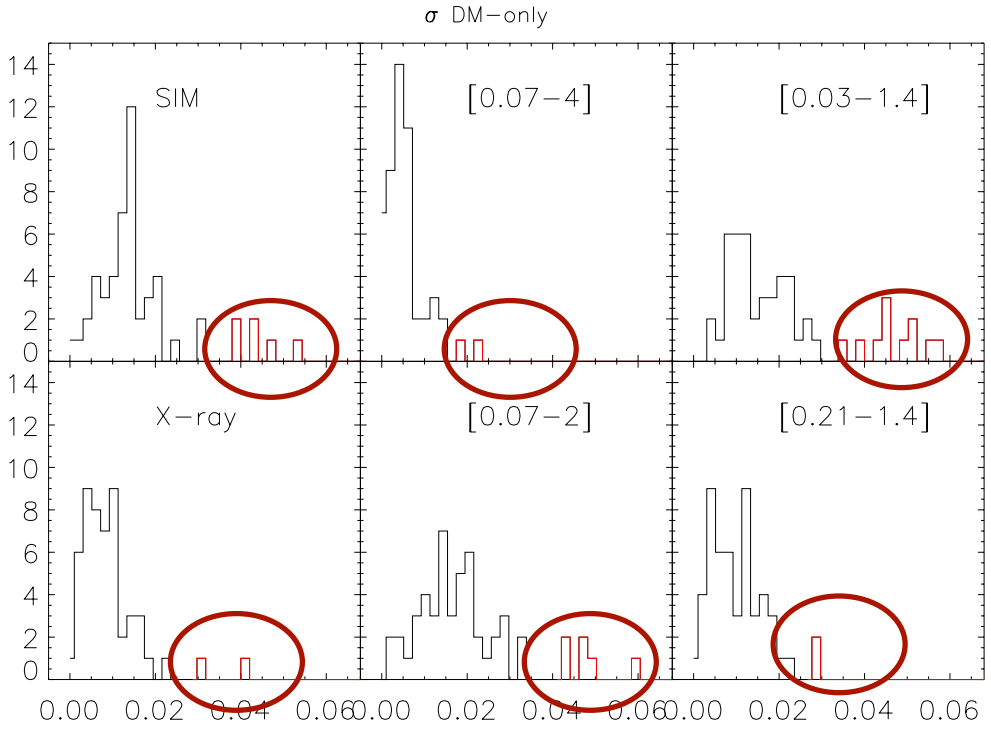
Halos presenting large residuals have been eliminated

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

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

Residuals

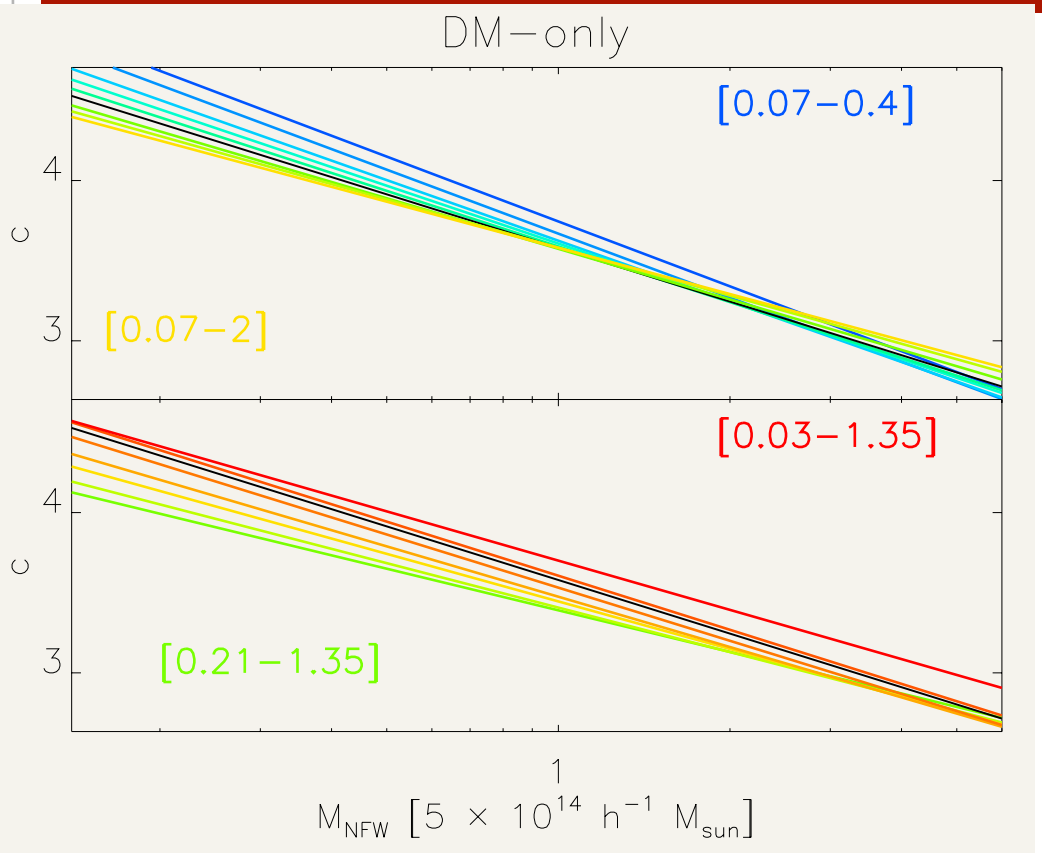
$$\sigma^2 = \frac{\sum_1^{N_{bin}} [\log(\rho_i) - \log(\rho_{NFW})]^2}{N_{bin}}$$



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

RADIAL RANGE (DM ONLY)

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



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

EXTERNAL RADIUS:

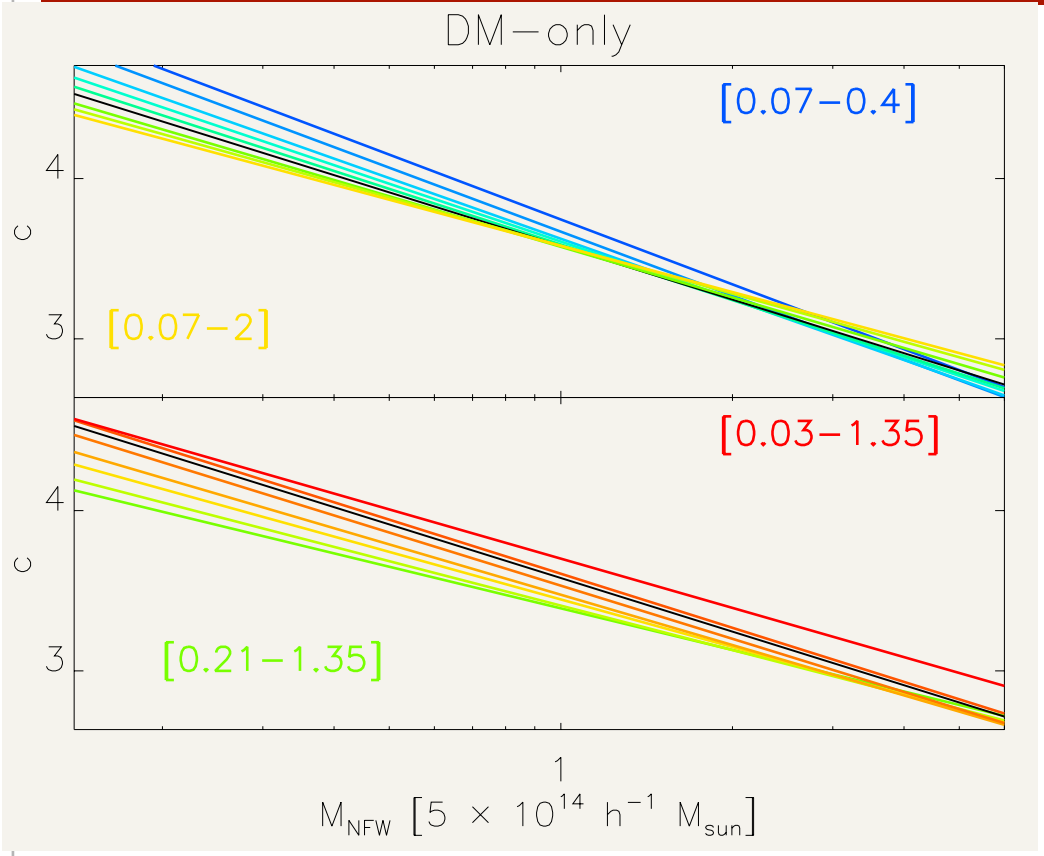
~X-ray has a steeper slope

~the difference is caused by the 17 least massive systems

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

RADIAL RANGE (DM ONLY)

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



~ 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

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

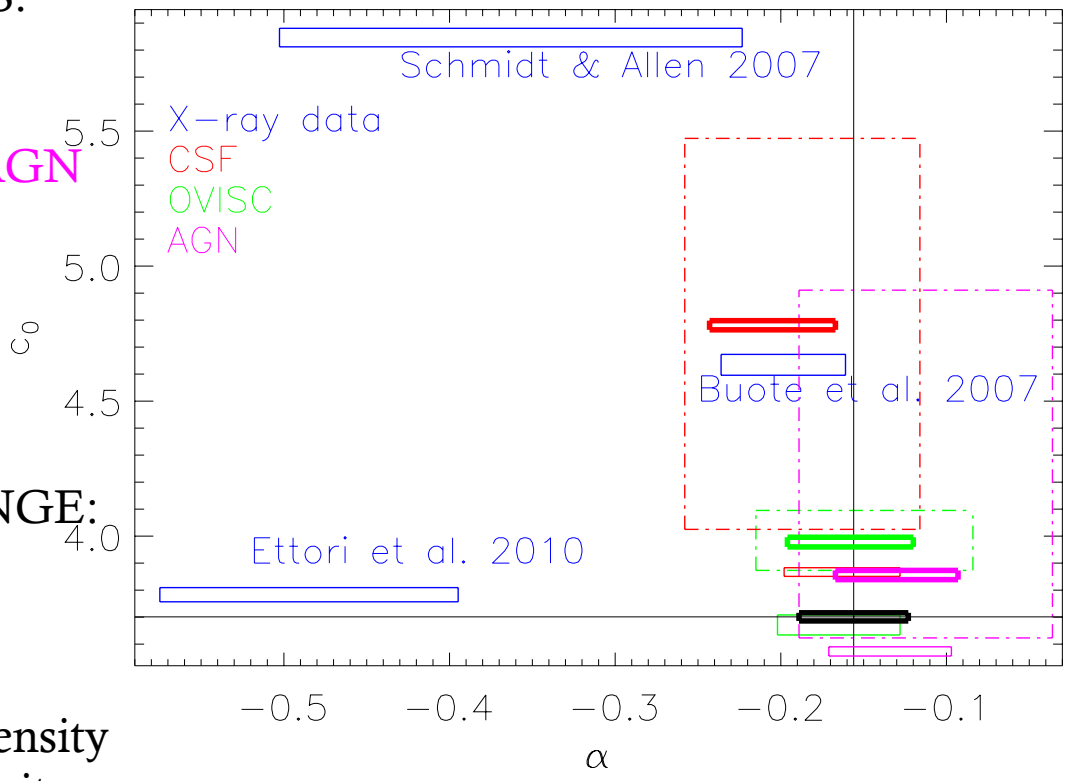
BARYONS

RESULTS considering only clusters with a good NFW fit

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

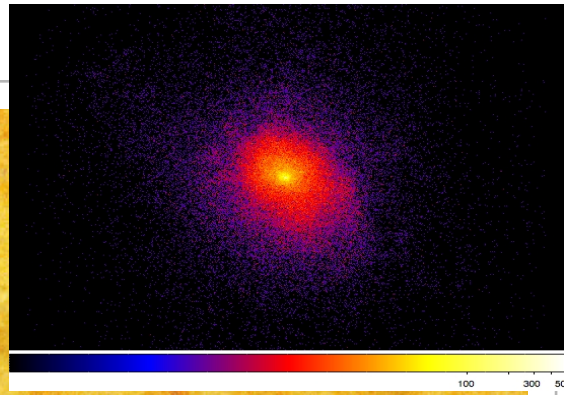
RADIAL RANGE:
___ SIM
[0.07-1.4] R_{200}

BOLD: total density
THIN: dm density

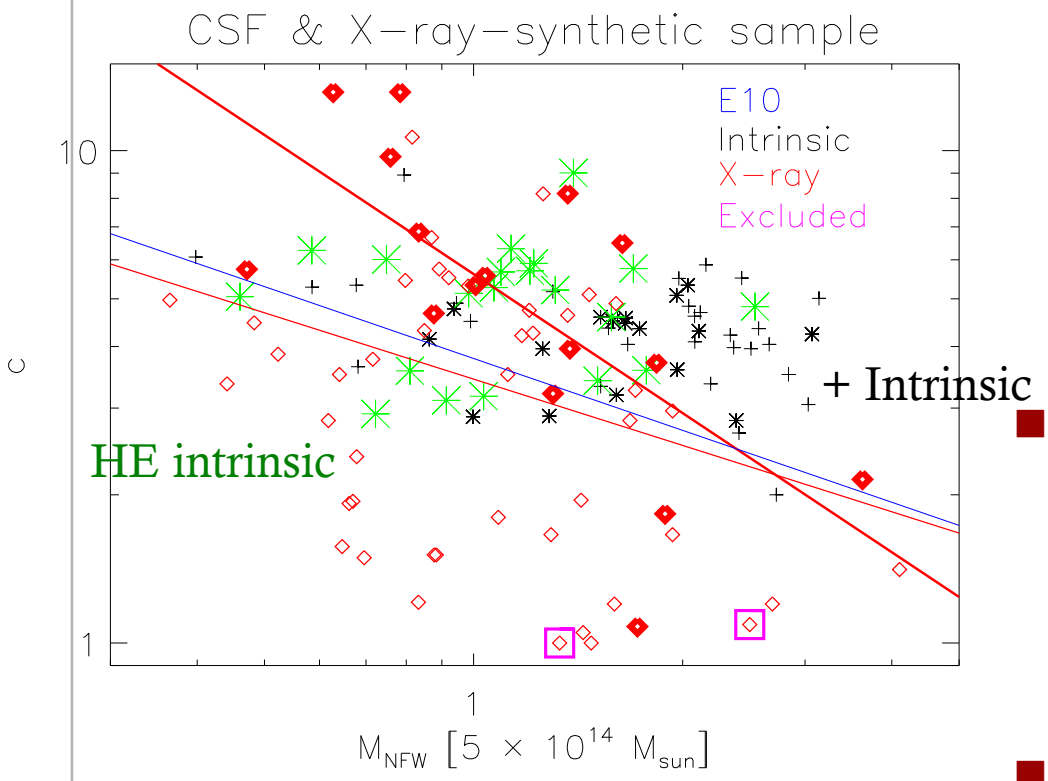


1) Normalization is higher with baryons
2) Slope is higher for total CSF
3) Slopes and normalizations of the only DM component agree better within each other.

X-RAY



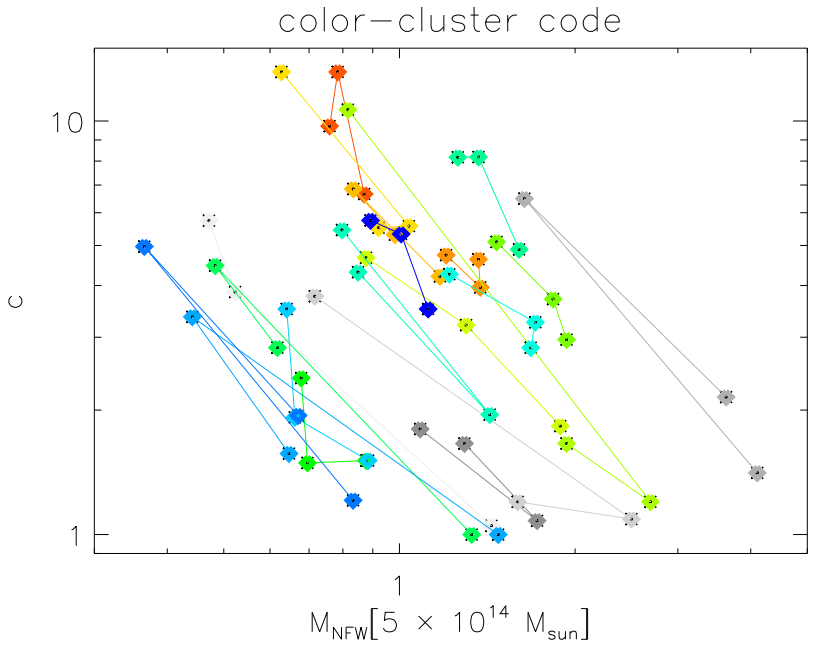
Xray+HydrostaticEquilibrium



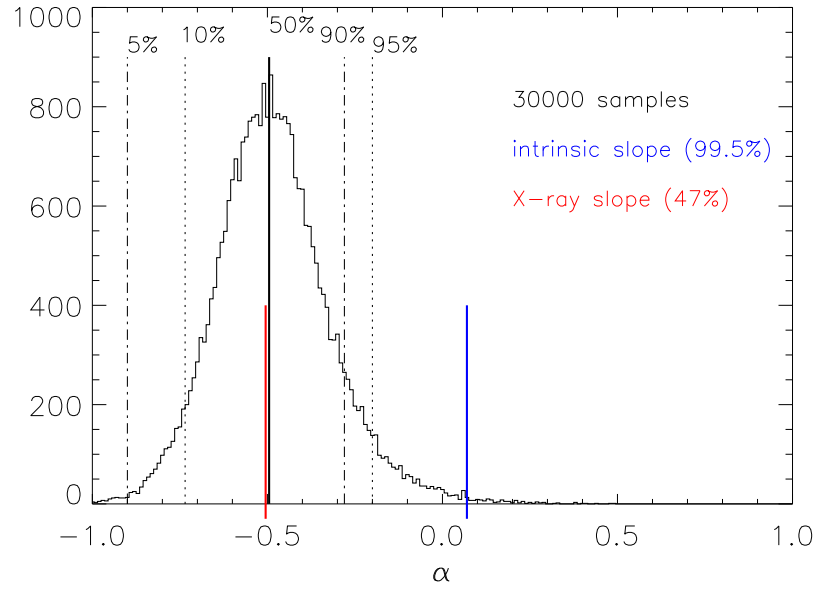
- From the R12 synthetic catalogue (60 X-ray images), we perform the X-ray analysis and computed the mass profiles the we fit with the NFW model
- The HE alone (intrinsic) does not explain the large increase of the scatter and the steepening of the slope
- It is the complete X-ray analysis that steepen the c-M

TESTING our sample

The 60 X-ray images for the 20 clusters

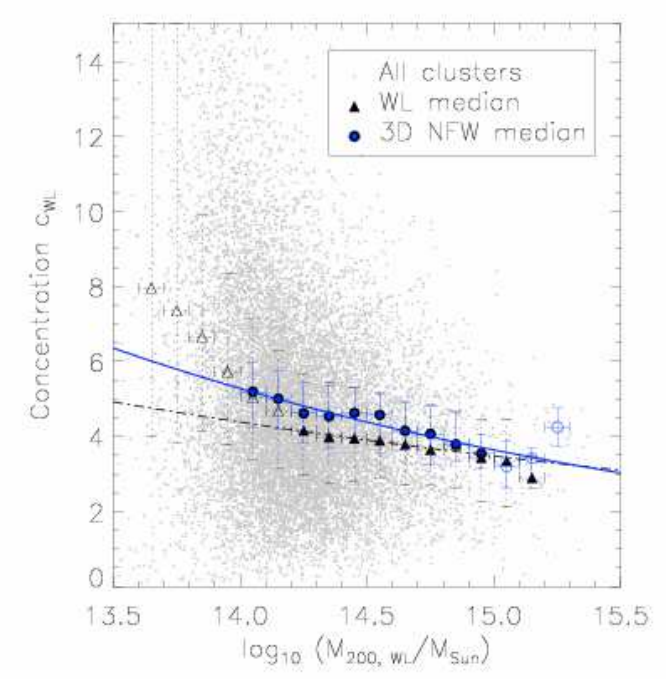


30000 realizations (combinations of the 20 clusters observed from random directions)

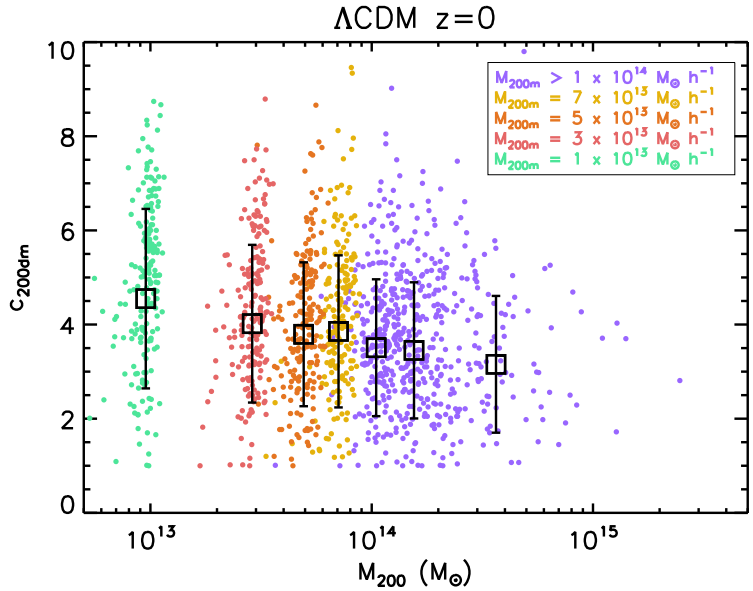


X-ray SELECTION FUNCTION

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

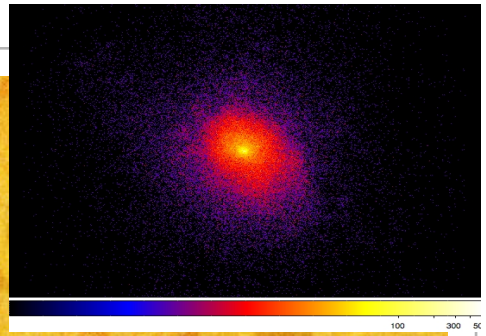


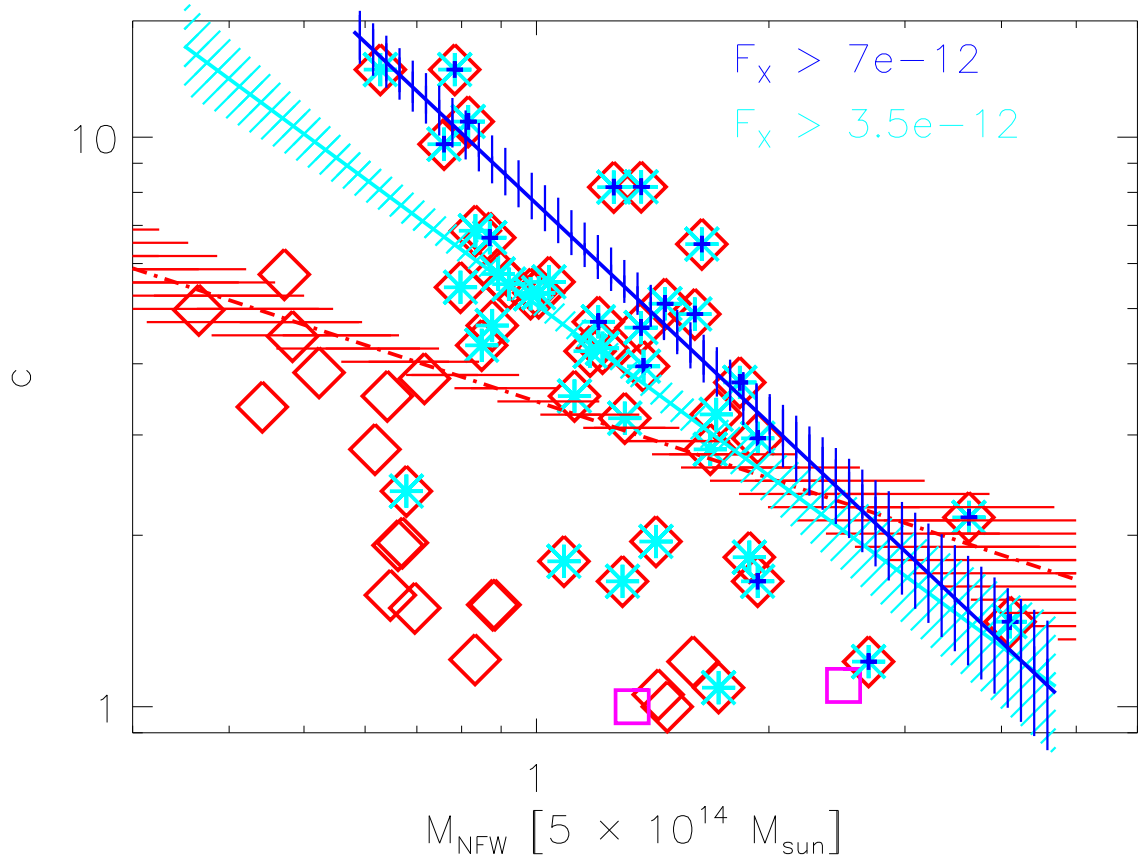
Bahe et al. 2012



De Boni et al. 2012

X-ray SELECTION FUNCTION



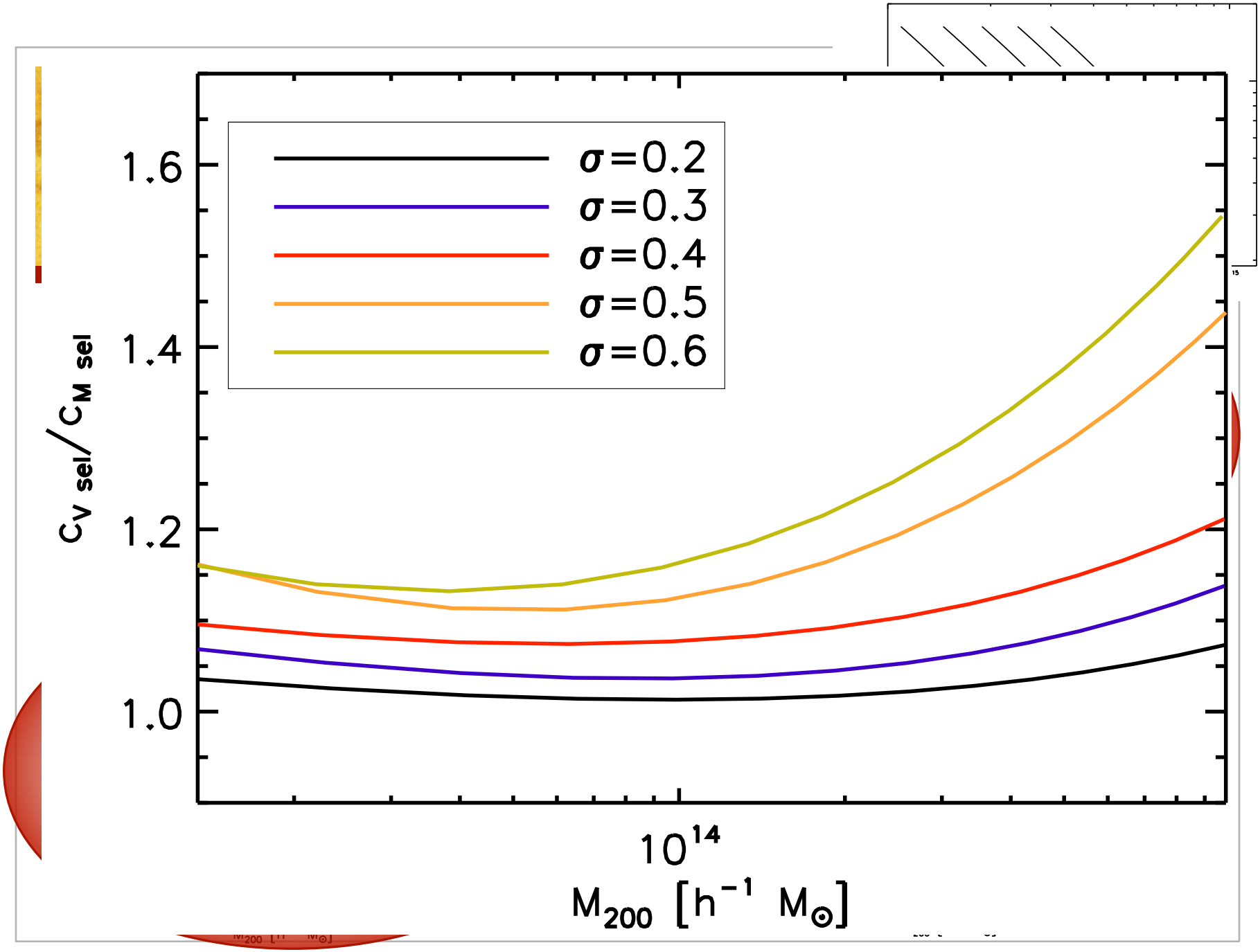


L_X>1.4 10^{45} erg/s
L_X> 7 10^{44} erg/s

If we select our sample on the basis of the X-ray emission we tend to have more concentrated halo at fixed mass

CONCLUSIONS

- Comparisons NEEDS to be fair!
- If approaches are INTRINSICALLY different a bias in the comparison is very likely. This is the case for the c-M relation.
- D08 and P12 differences in normalization and shape are fully explained by understanding their procedure
- As for the X-ray simulations comparison: small part of the gap is explained by ICM physics and radial range but the majority has to be ascribed to the different methodology and selection functions.
- Radial range: lowering the external fitting radius => slope reduced
- Radial range: decreasing the central excision => normalization increased
- Baryons => all physics: normalization increased
- X-ray approach and Selection function=> slope increased


σ=0.2
σ=0.3
σ=0.4
σ=0.5
σ=0.6
1.6
1.4
1.2
1.0
$c_{V\ sel}/c_{M\ sel}$
10^{14}
M_{200} [h^{-1} $M_\odot$]