Applications of Cosmological N-body/ SPH simulations

Baryonic Effects on matter clustering and the Properties of Dark Matter Halos

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Facts of Baryons

- Universal baryon fraction of mass: ~16% (WMAP's result)
- DM dominates on large scale, while on small scale, baryon are dominated and important.
- Baryon physics, very complicated,

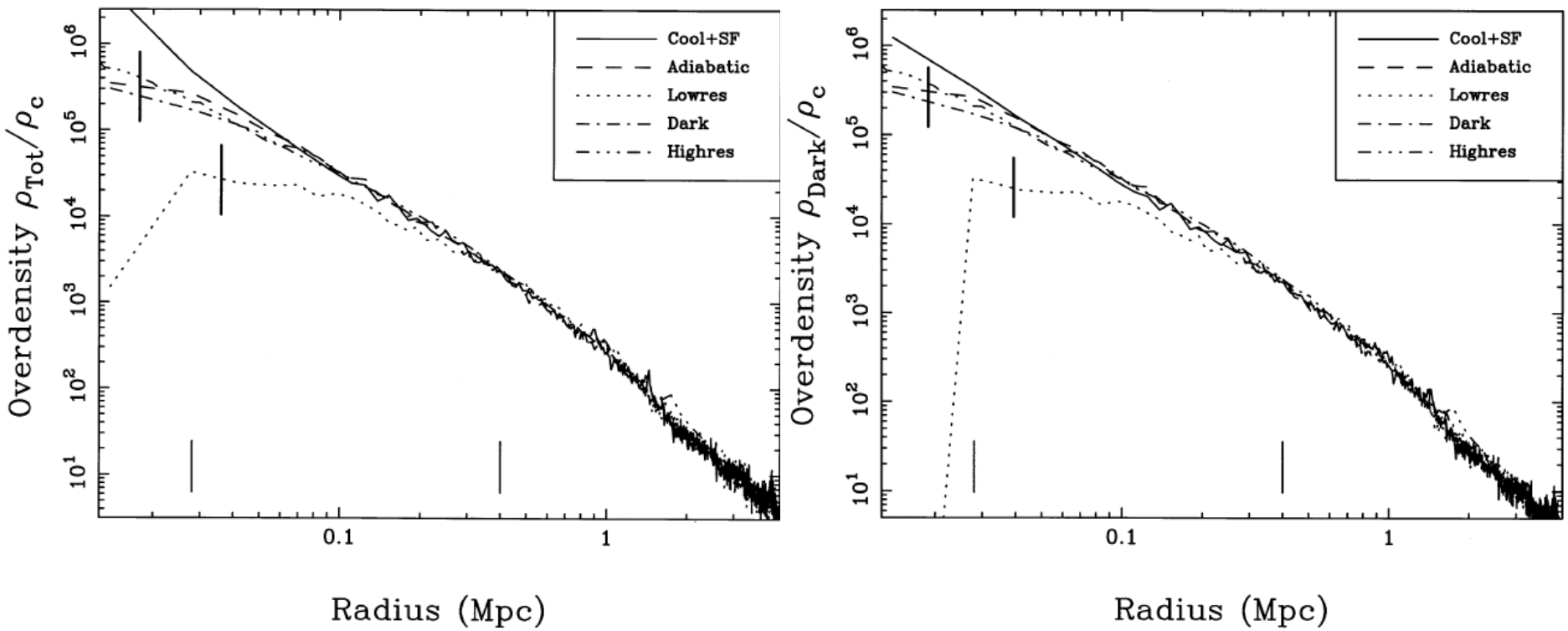
  1st order: gas shock-heating, cooling, star formation, SN/AGN feedback, metal enrichment;

  2nd order: heating by UV background & cosmic ray, evaporation, ram pressure stripping, gravitational heating, magnetic field, heat conduction, turbulence, convection, etc.
- Dynamics: AC effect, dynamical friction of sinking satellites, interaction between rotation disk/bars and halo matter, etc.

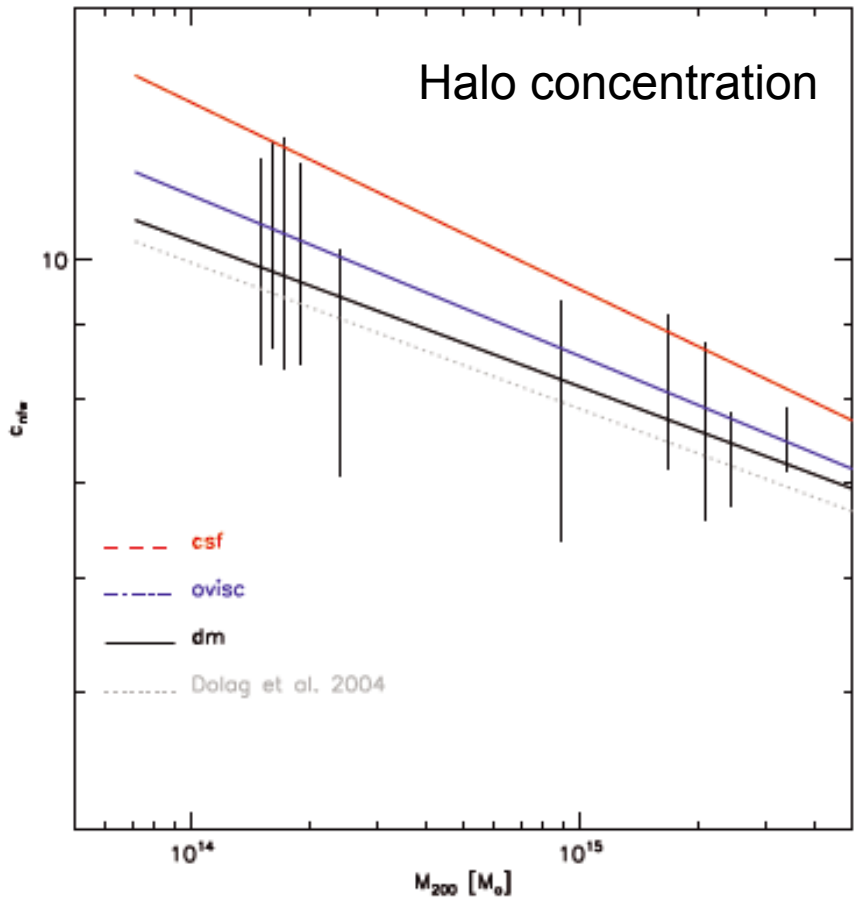
What halo properties could be influenced by baryon physics?

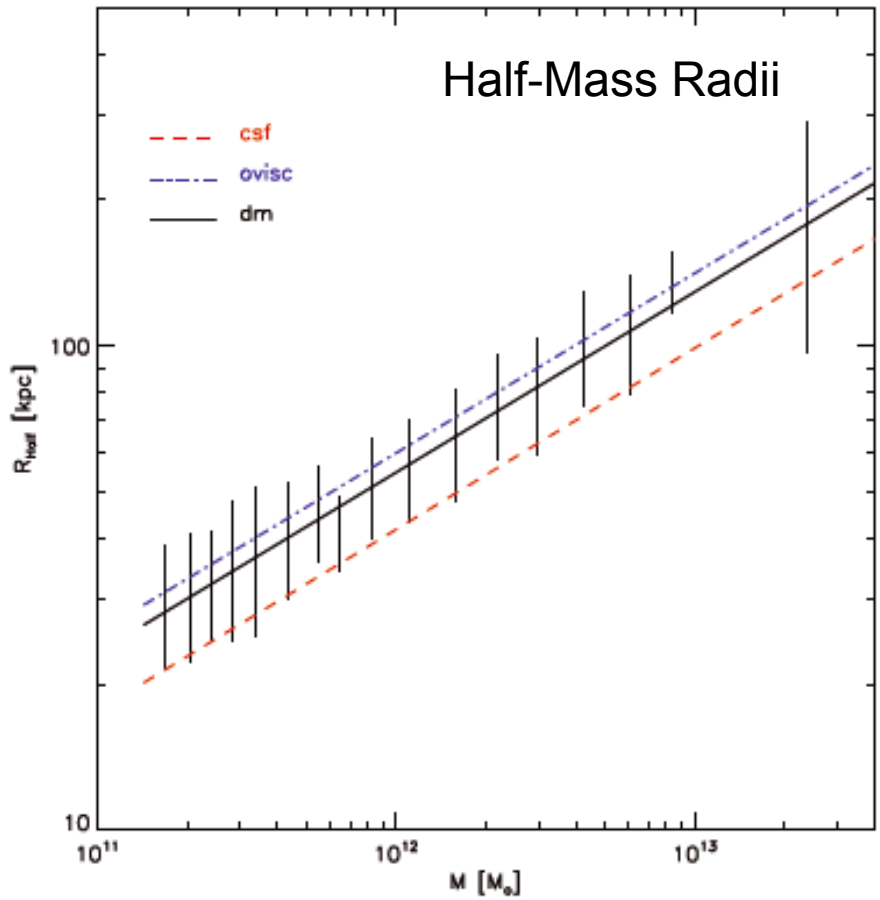
- Matter distribution (DM, stellar components, cold/hot gas) within halo, especially at inner halo
- Clustering of matter
- Baryon/stellar fraction, temperature/entropy profiles
- Halo shape (tri-axial): density or potential well, x-ray
- Properties of halo sub-structures
- Angular momentum distribution and alignment (of gas, stars and DM)
- Alignment of sub-structures, satellite halos, "galaxies", etc.
- Gravitational lensing: giant-arc, shear field, weak lensing, …

The effects are important for precise cosmology at several percentage level!

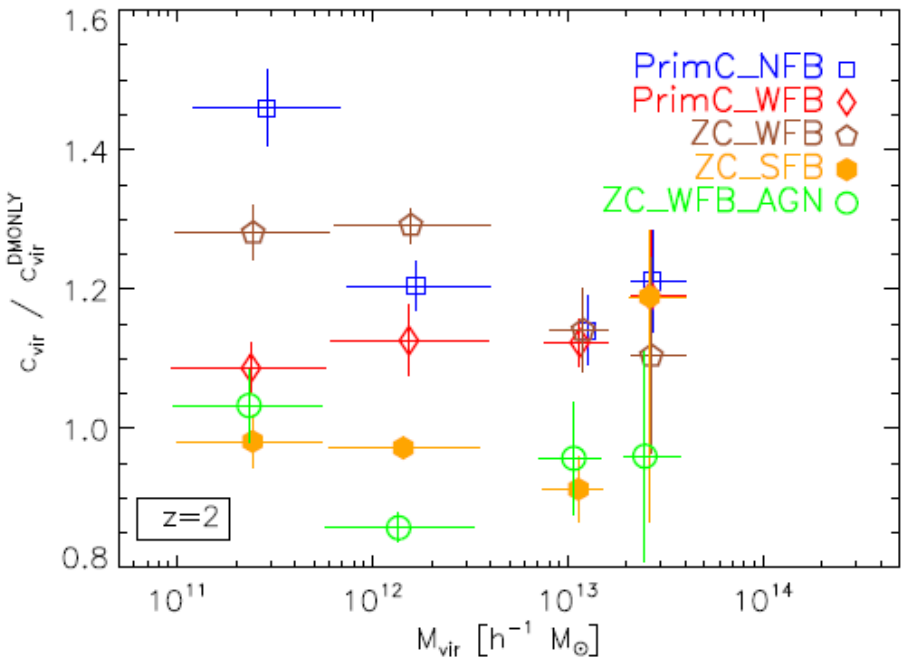


Simulations for two cluster halos:
Lewis, et al., 2000, ApJ, 536, 623-644

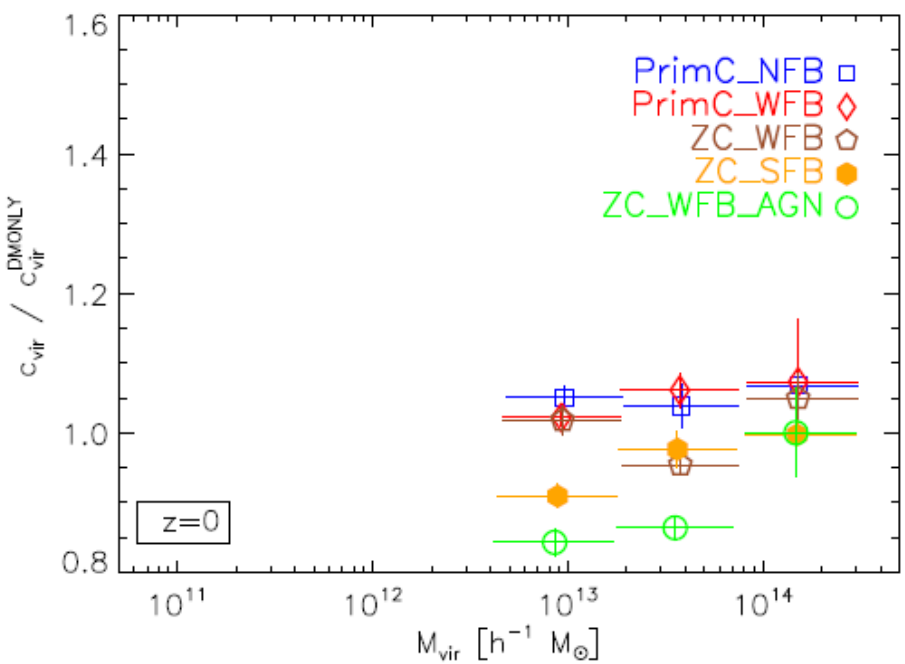




Dolag, et al., 2009, MNRAS, 399, 497-514

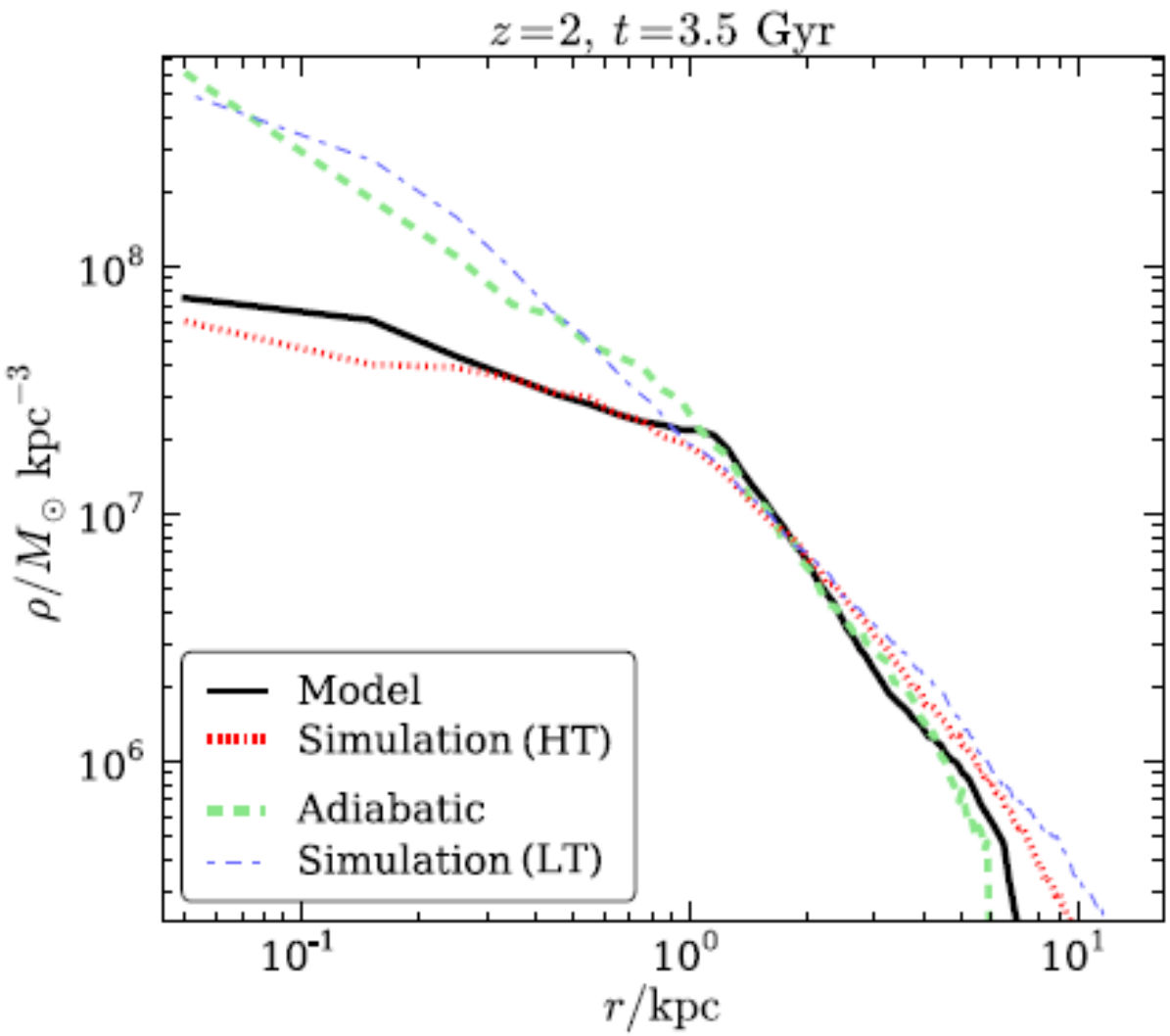


Very strong SN Feedback &
AGN feedback
Can reduce halo concentration



Duffy+ 2011, MNRAS, 405,2161

How supernova feedback turns dark matter cusps into cores

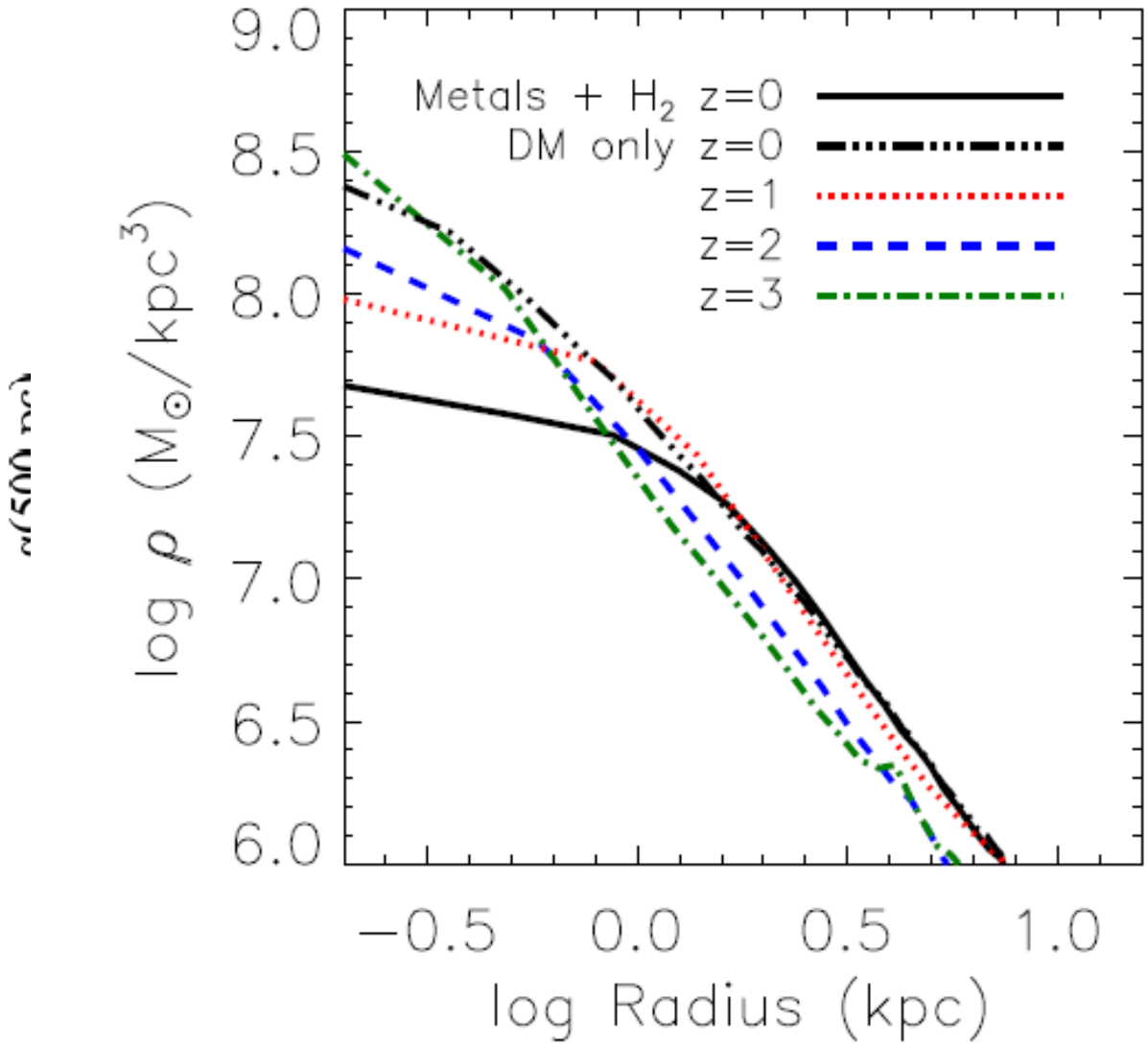


High-Threshold:
H-density> 100 cm $^{-3}$

LT:
H-density>0.1 cm^{-3}

Pontzen & Governato, 2012, MNRAS, 421, 3464

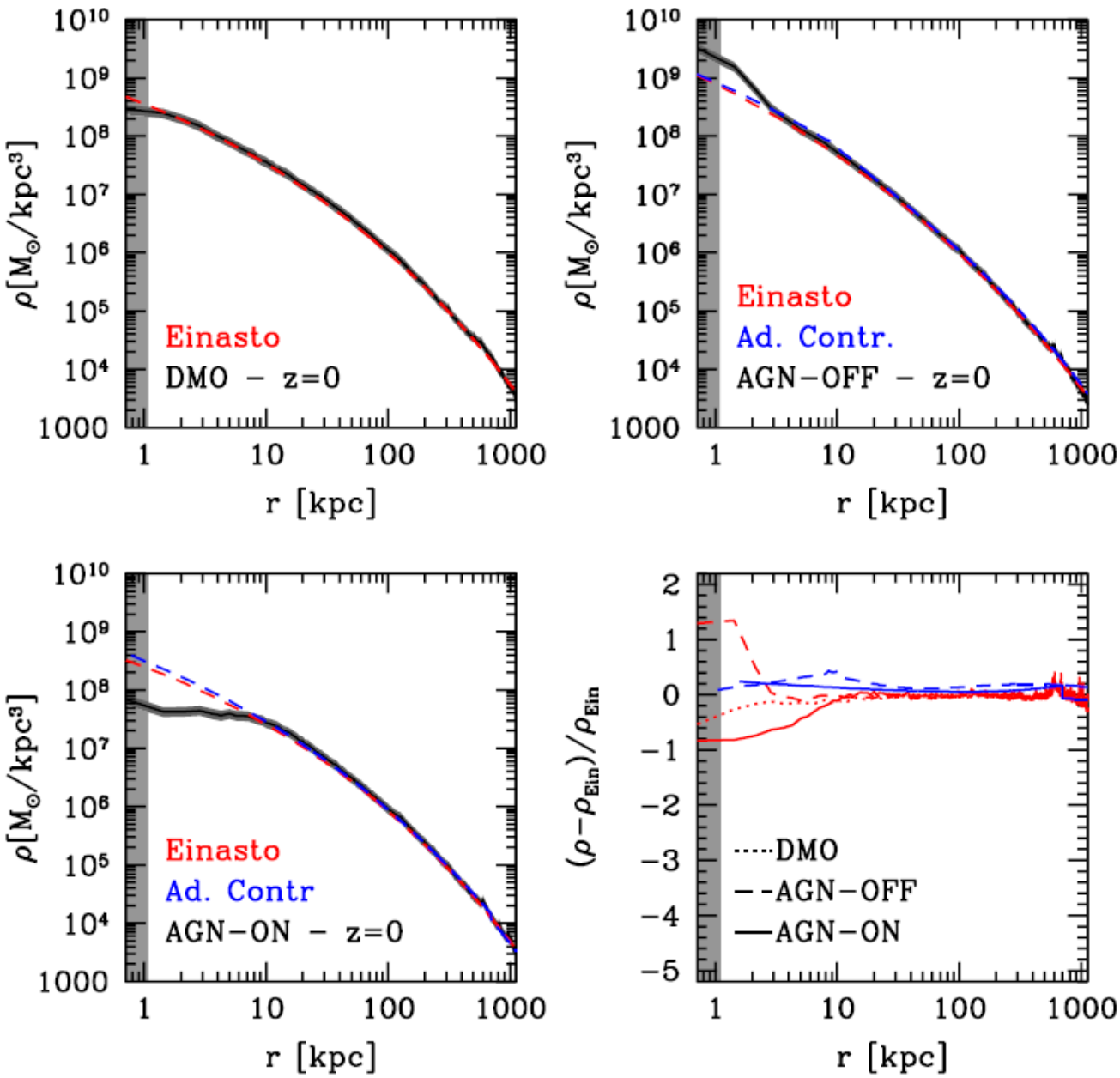
Cuspy No More: How Outflows Affect the Central Dark Matter and Baryon Distribution in CDM Galaxies



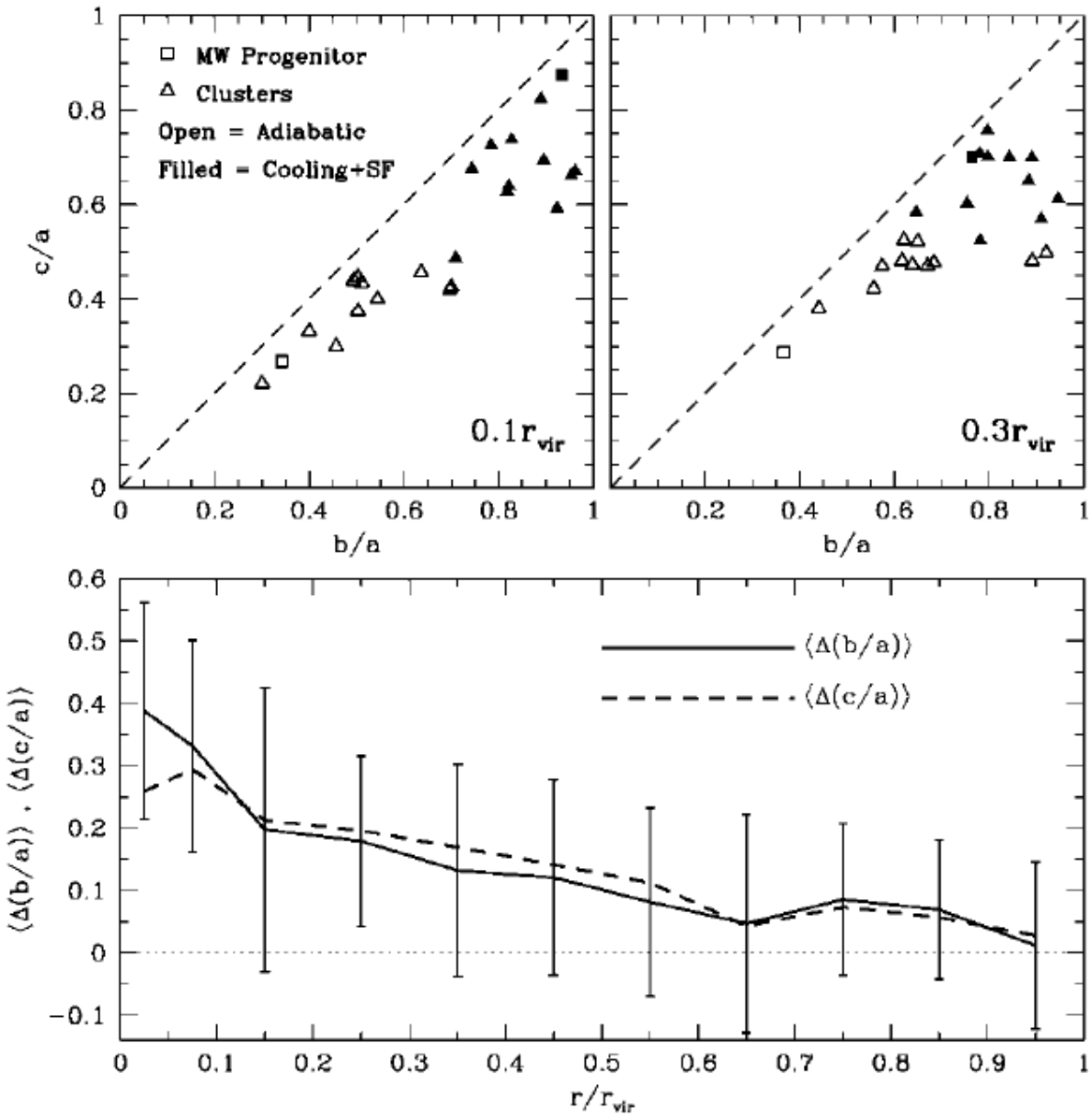
Supernovae driven gas outflows

Code: Gasoline
Metal-line cooling
H2 cooling

F.Governato + 2012, MNRAS, 422, 1231(arxiv:1202.0554)



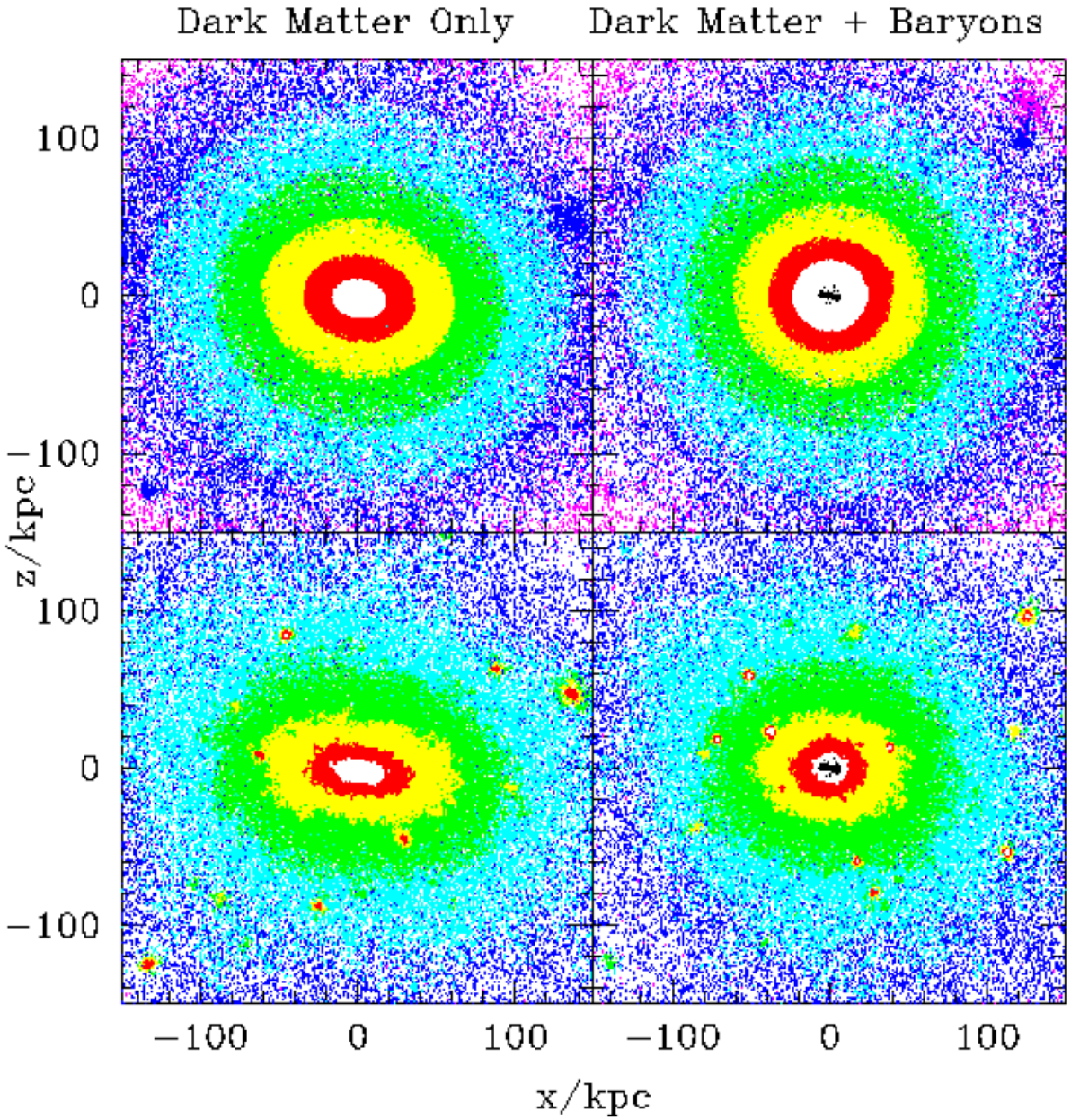
Martizzi+ 2012,
arxiv: 1112.2752



But, they used inertia tensor as shape indicator, easily affected by sub-structures

Kazantzidis, et al., 2004, ApJ Letter, 611, L73-L76

Baryonic Effect on Halo Potential Well
(Abadi, Navarro et al., 2010, MNRAS, 407, 435)



What we have done so far?

We have done a set of N-body/SPH simulations and studied following baryonic effects:

1. Clustering and weak lensing : Jing, et al. 2006, ApJ
2. Galaxy HOD: Zhu, et al. 2006
3. Galaxy merging time-scale: Jiang et al. 2008 ApJ; A&A 2010
4. Mass distribution and entropy profile: Lin et al. 2006, ApJ
5. SZ Effect tomography (thermal and kinetic): Shao, et al. 2011a,b
6. Substructure properties, Elahi P.J. and Lin W.P., submitted
7. Mass distribution, halo shape and alignment: Lin et al. , in preparations

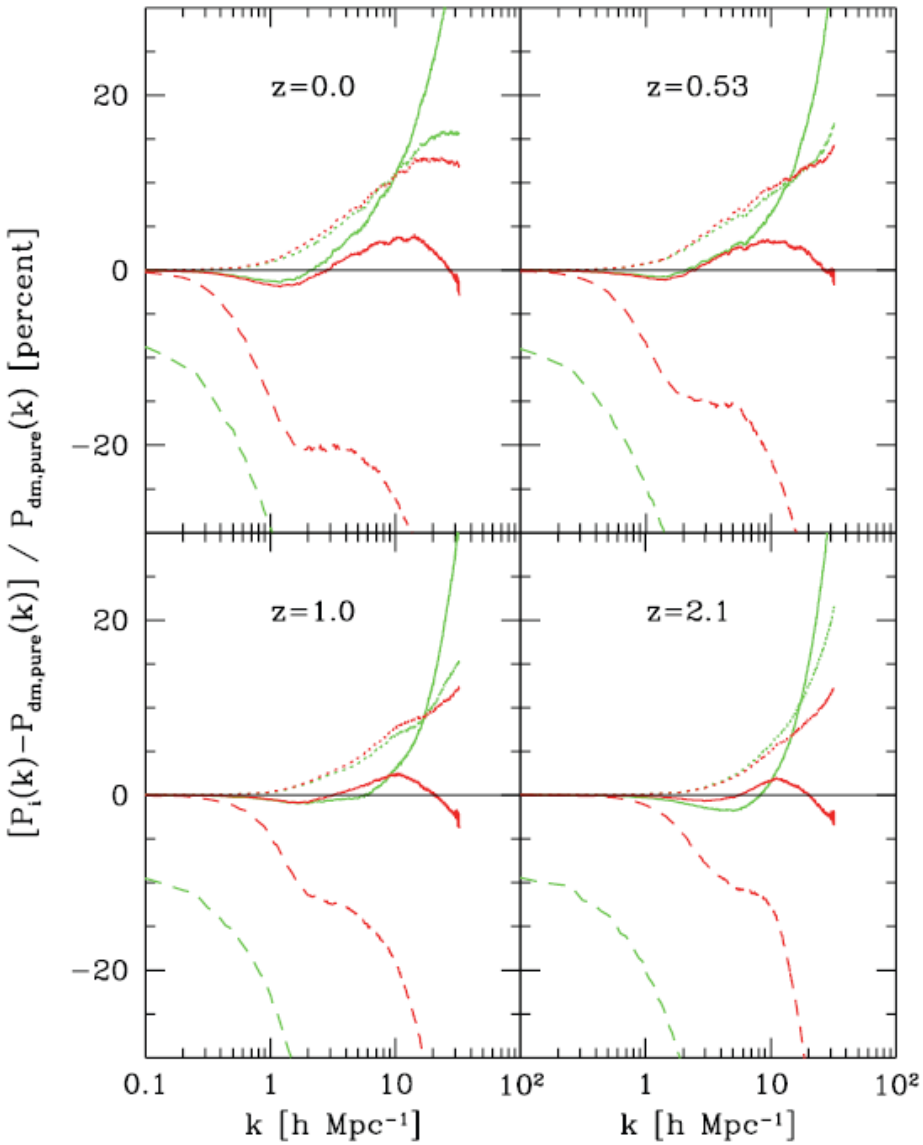
Brief of simulations

- LCDM (WMAP parameters), Box： 100 Mpc/h
- Gadget-v2 (Springel 2005)
- A set of simulations using the same IC and all started from z=120, softening 4.5kpc (if not indicated)

1. Pure DM simulation 512^3 (PDM, as reference)
2. Non-radiative (A4 or Gas512) 512^3 DM + 512^3 Gas
3. SF1: 512^3 DM + 512^3 Gas with cooling, SF, SNFB(9kpc/h)
4. SF2: 512^3 DM + 512^3 Gas with cooling, SF, SNFB(4.5kpc/h)
5. SF3: 512^3 DM + 512^3 Gas with cooling, SF, SNFB(4.5kpc/h), baryon fraction is reduced by half.

The simulations were done at Shanghai supercomputer center.

The influence of baryon on the clustering of each matter components

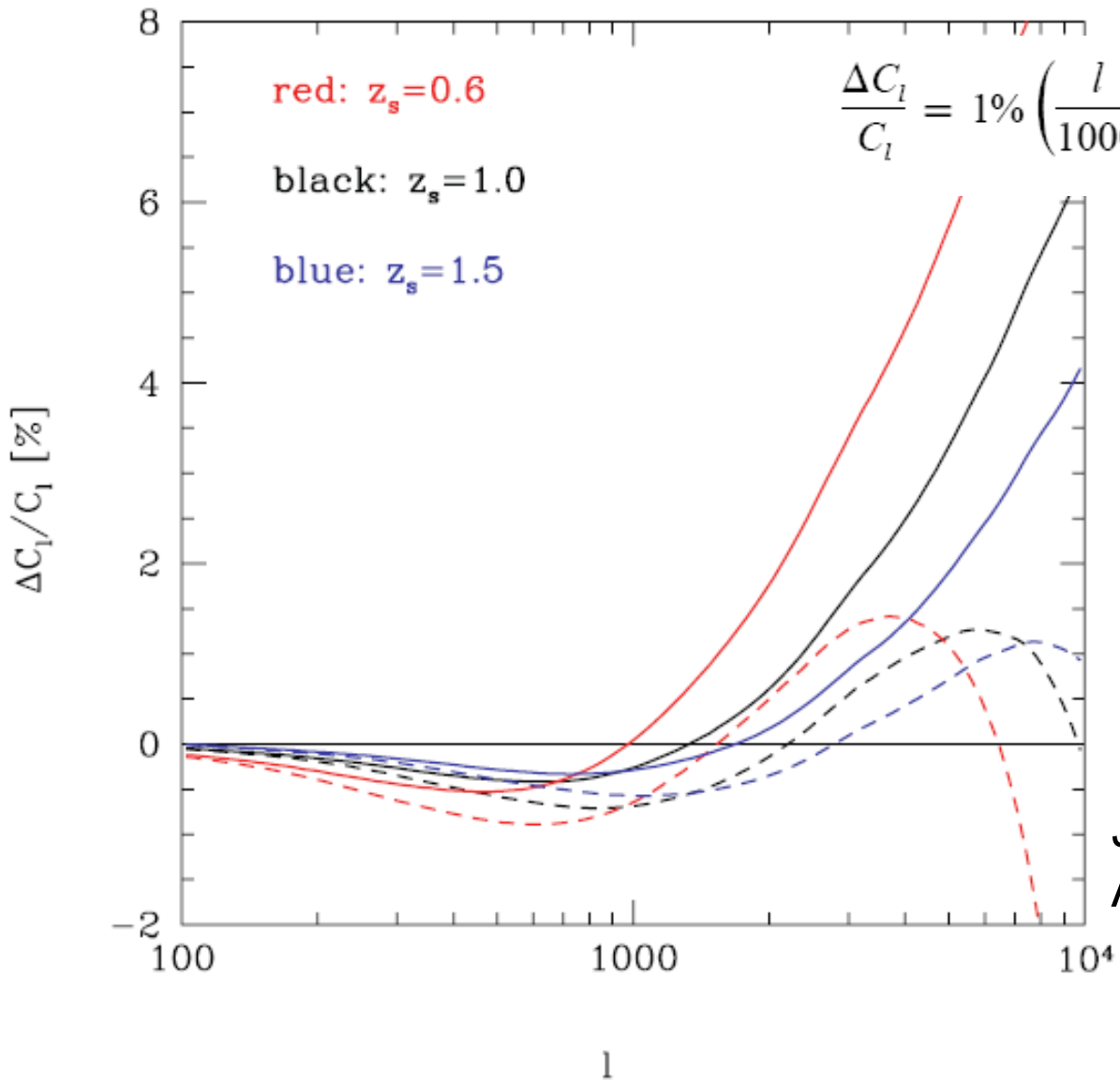


Red: Non-radiative
Green: SF

Dotted lines: DM
Dashed lines: Gas
Solid lines：Total

Jing Y.P., et al. 2006, ApJL, 640, L119

Effect of baryon on the shear power spectrum



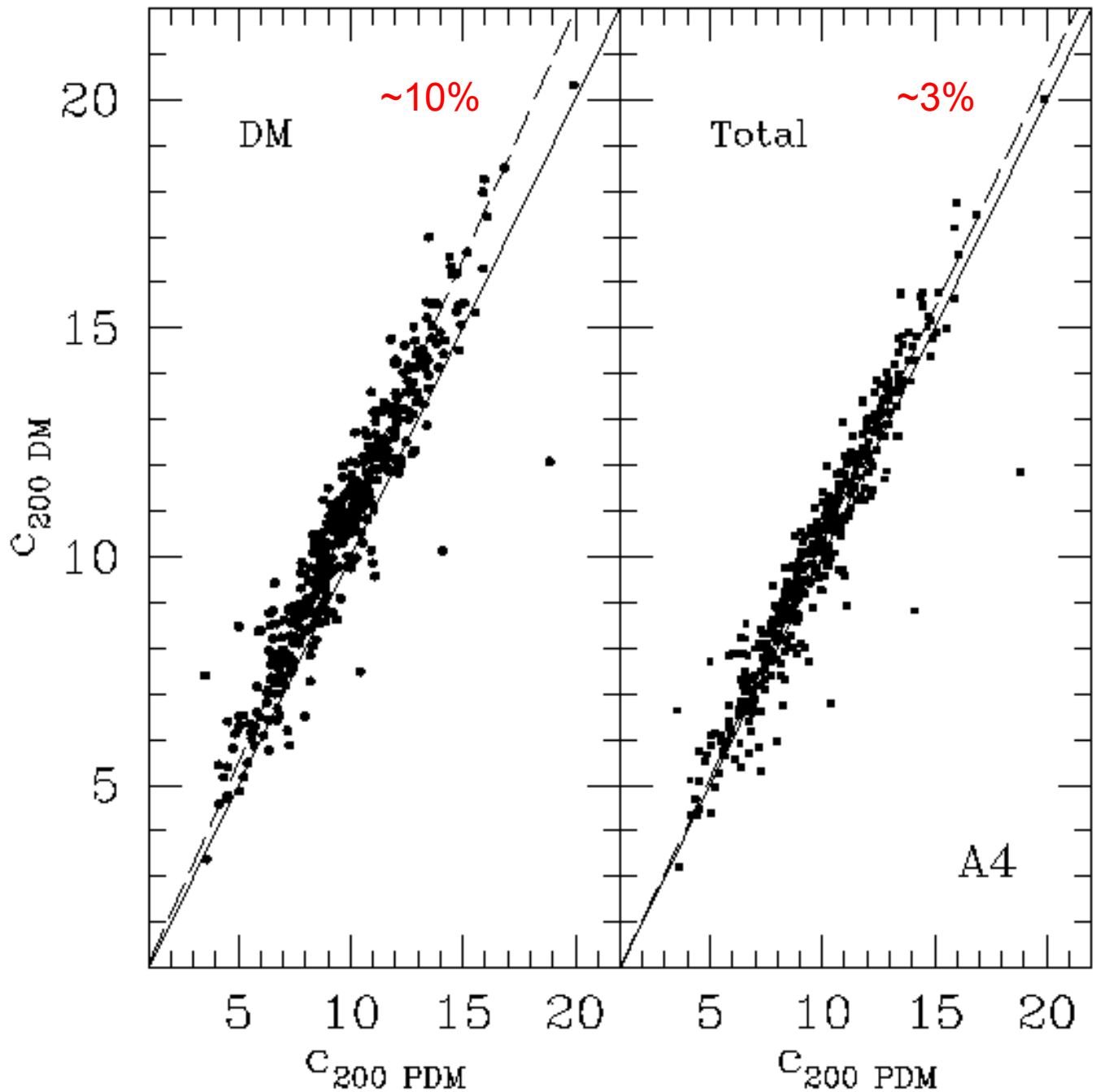
Solid: SF

Dashed: Non-radiative

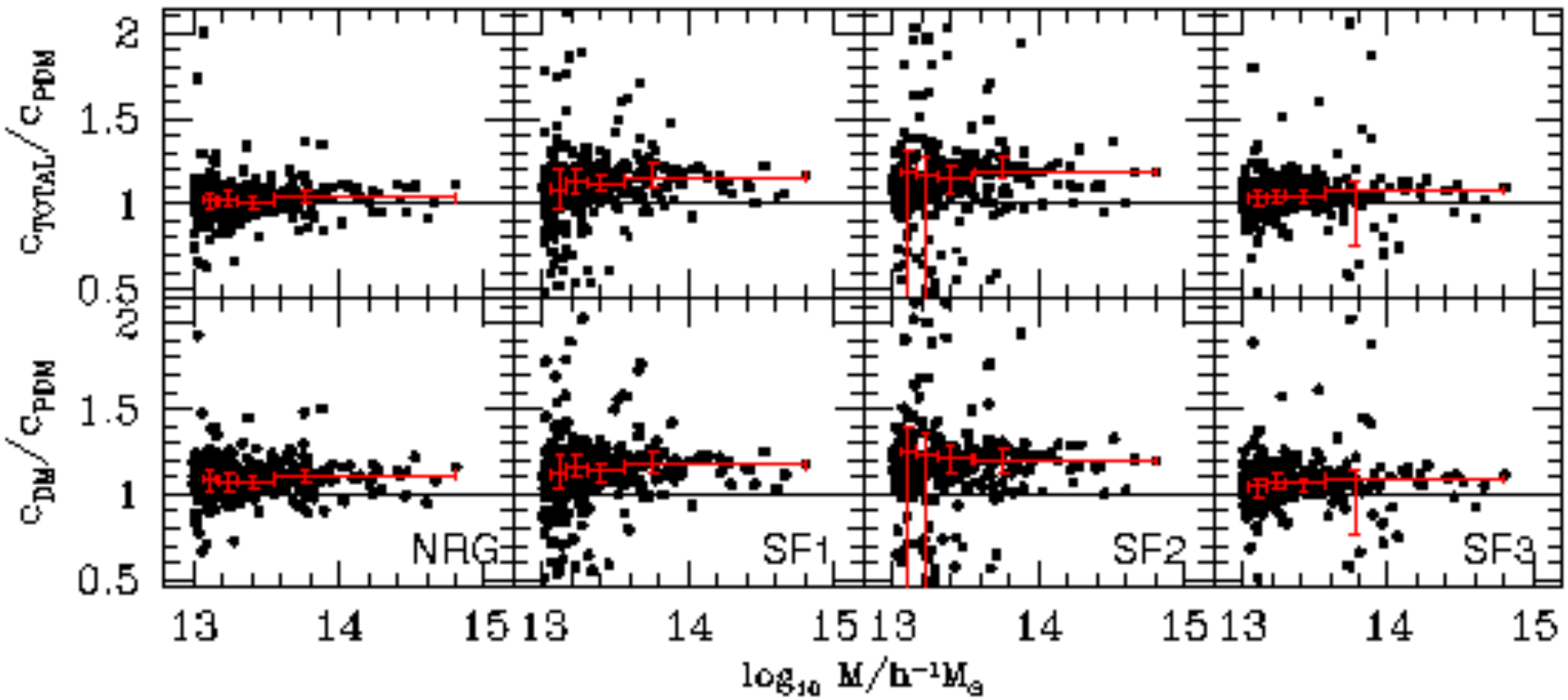
Jing Y.P., et al. 2006, ApJL, 640, L119

Lin, et al., 2006， ApJ

Adiabatic
A4(512^3)
Gadget-v2

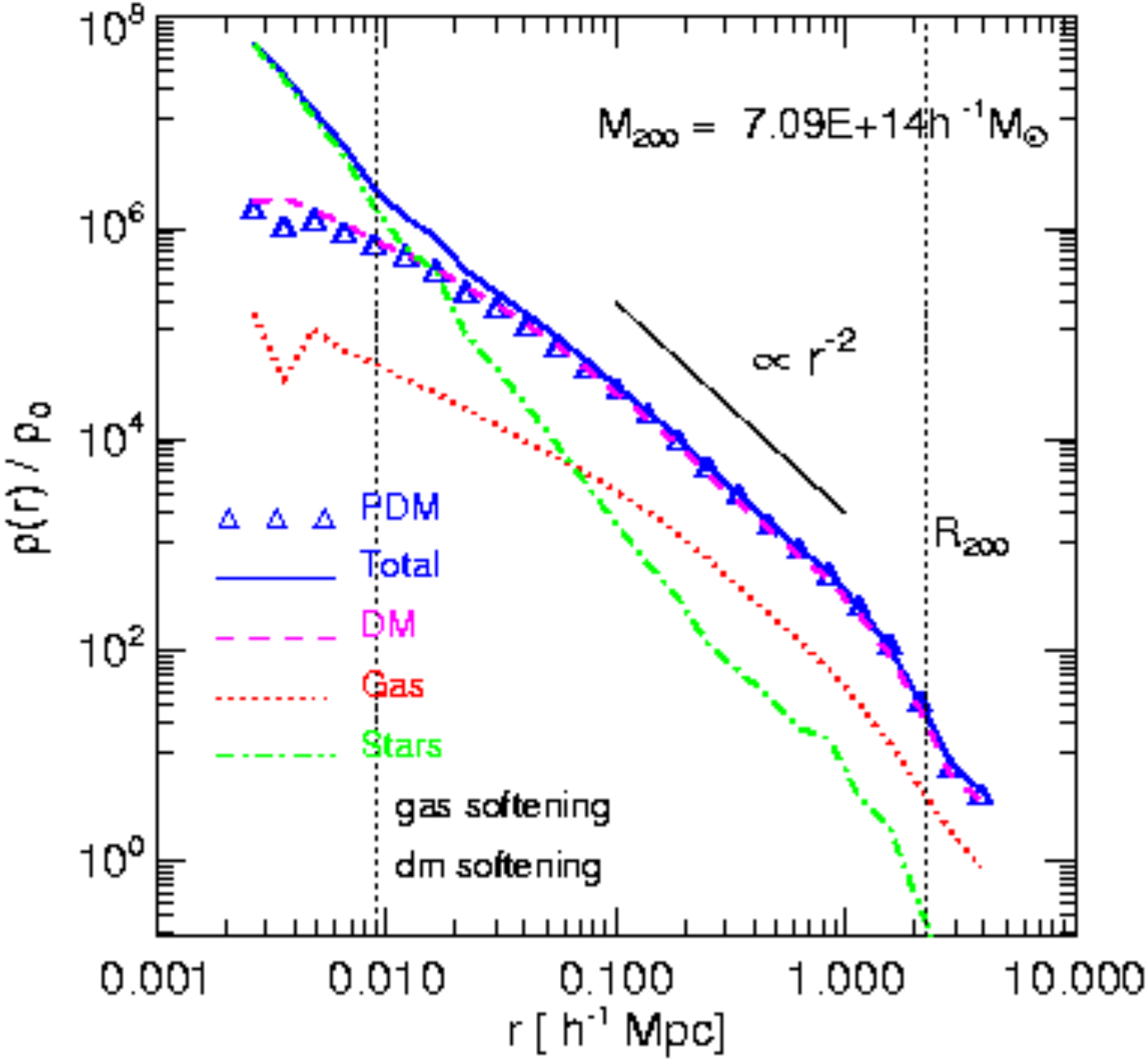


The case with Cooling,SF,SNFB

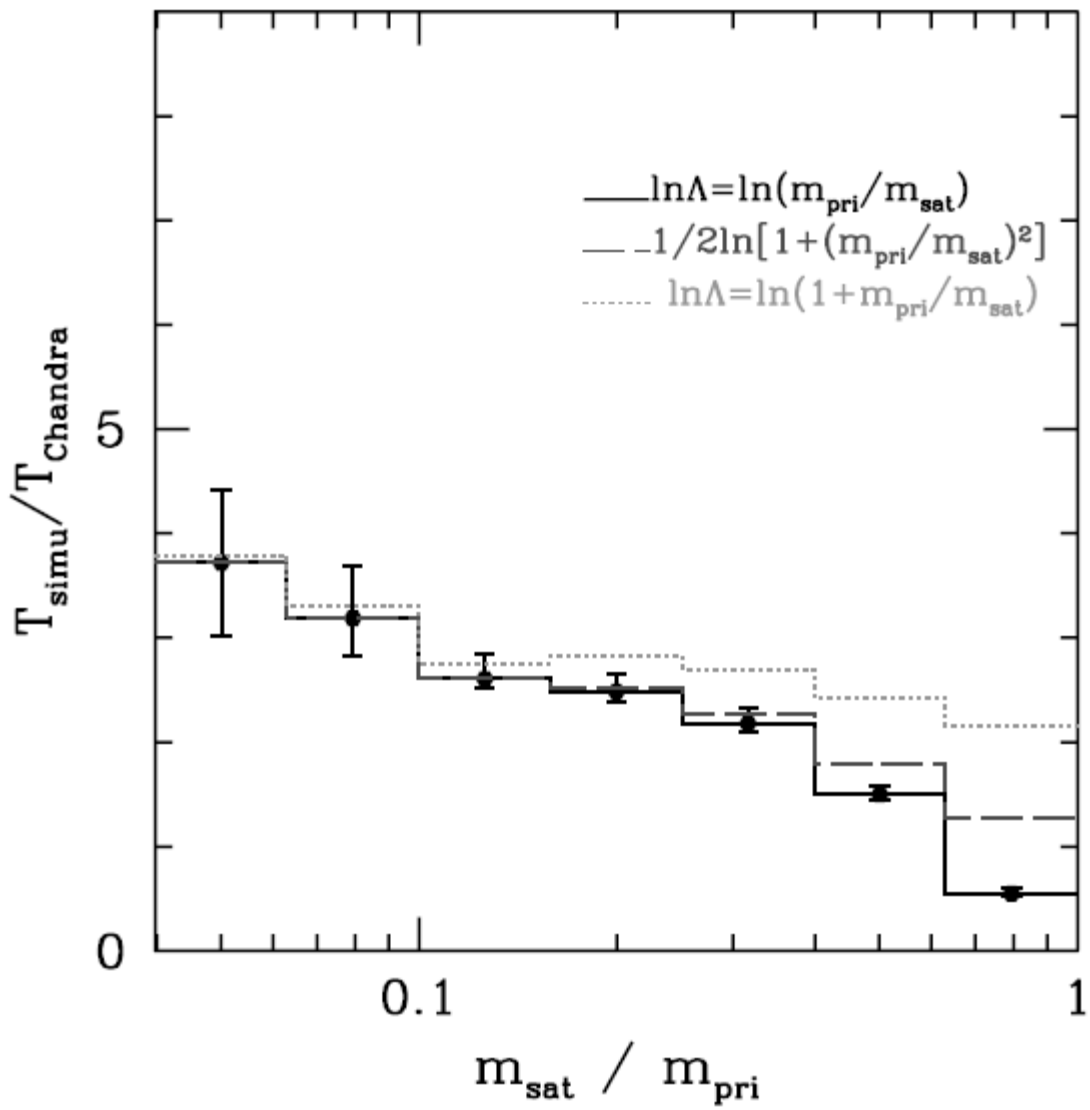


Mass concentration increases by 10-20%

Consistent with Duffy et al. 2010 in the case of no AGN feedback


M_{200} = 7.09E+14 $h^{-1} M_\odot$
$\propto r^{-2}$
R_{200}
PDM
Total
DM
Gas
Stars
gas softening
dm softening
$\rho(r) / \rho_0$
r [h^{-1} Mpc]
10^8
10^6
10^4
10^2
10^0
0.001
0.010
0.100
1.000
10.000

Galaxy merging timescale

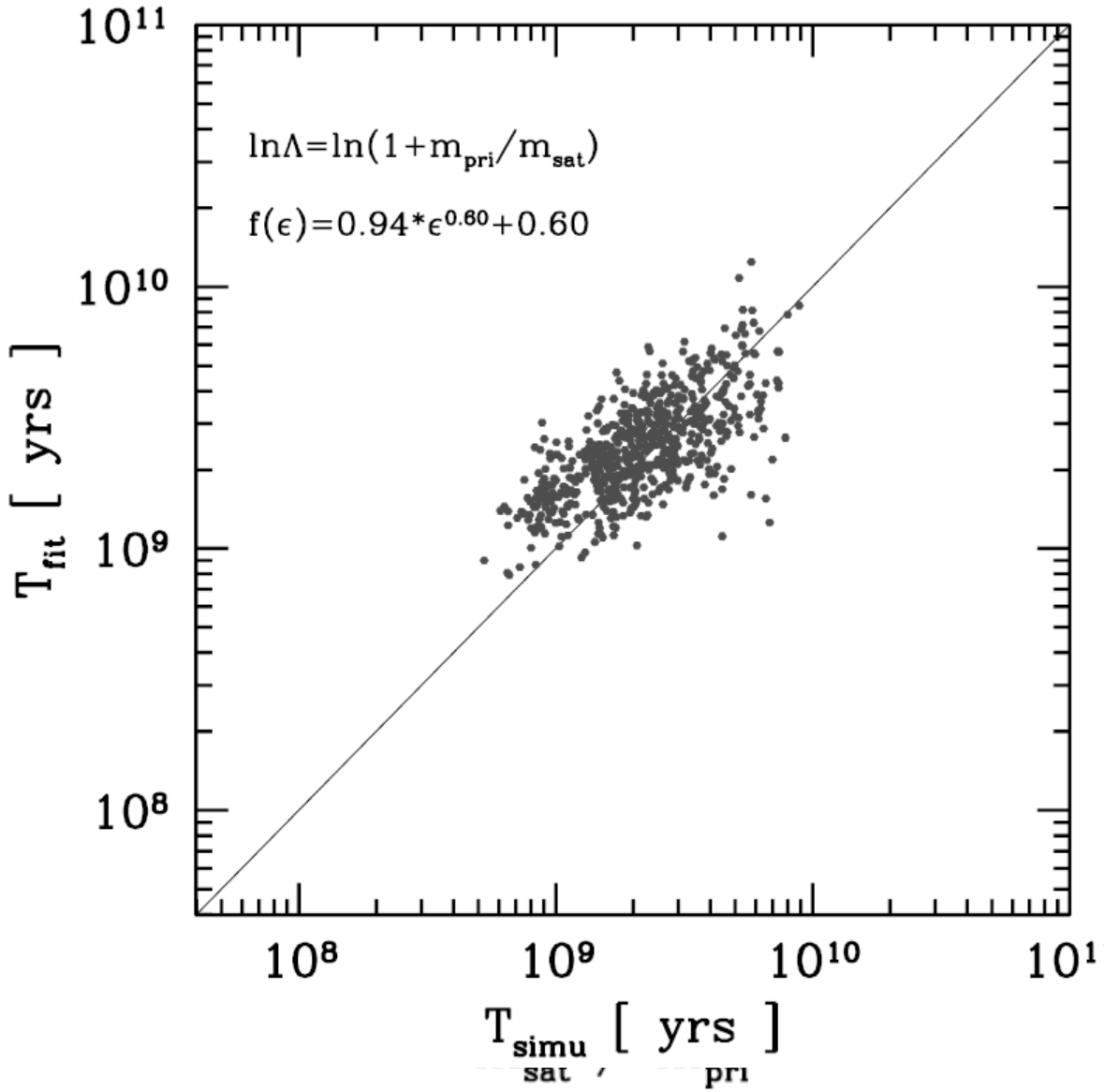


$$T_{\rm Chandra} = \frac{1}{2}\frac{f(\epsilon)V_c r_c^2}{CGm_{\rm sat}\ln\Lambda};$$

ε：Circularity parameter
$\ln\Lambda$: Coulomb logarithm

Jiang et al., 2008, ApJ

Galaxy merging timescale

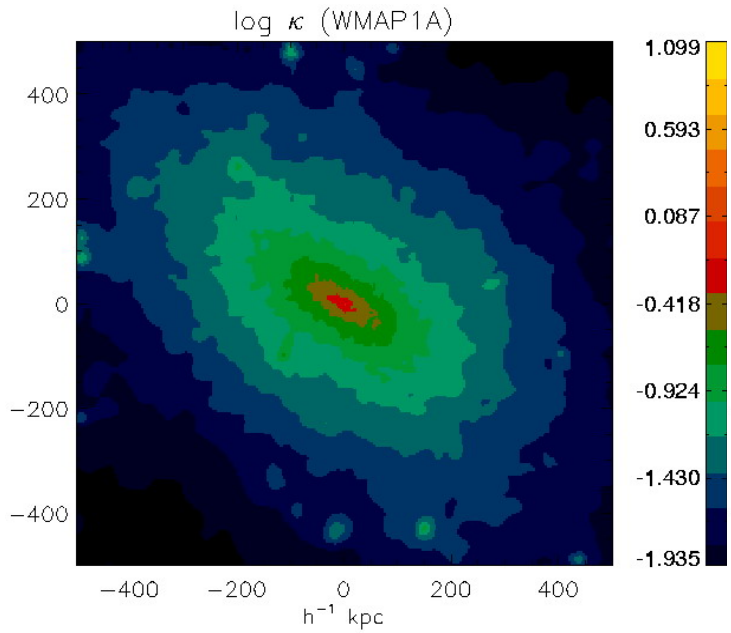


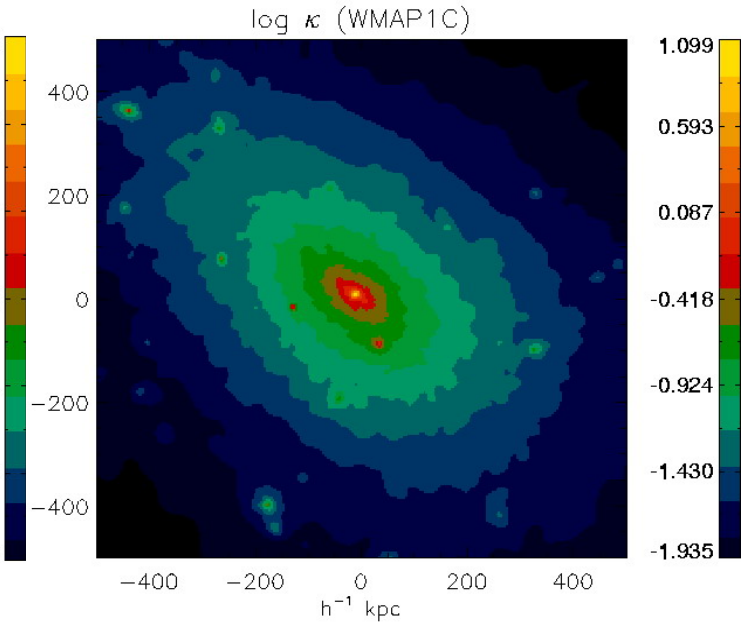
$$\frac{1}{1 + (m_{\rm pri}/m_{\rm sat})]} \frac{r_{\rm vir}}{V_c}$$

Jiang et al., 2008, ApJ

Evidence: 2-D halo shape

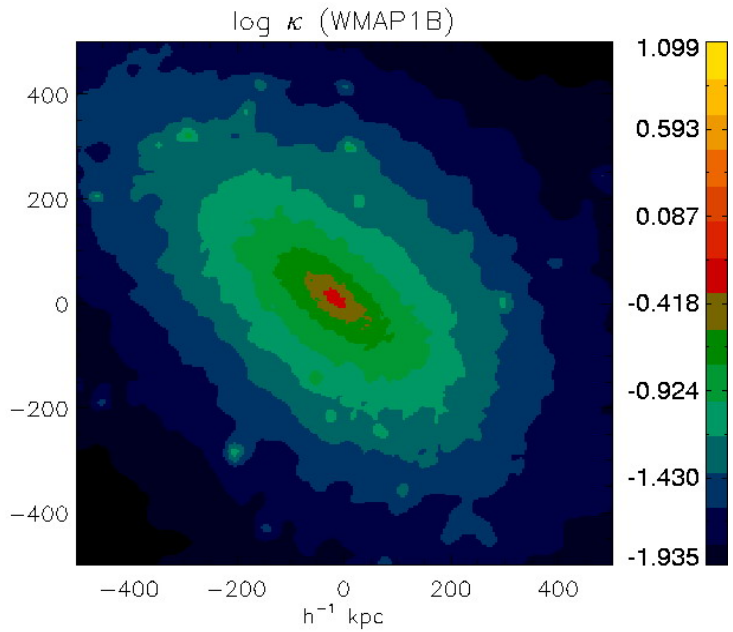
A





C

B



A: Pure Dark Matter

B: Non-Radiative（A4）

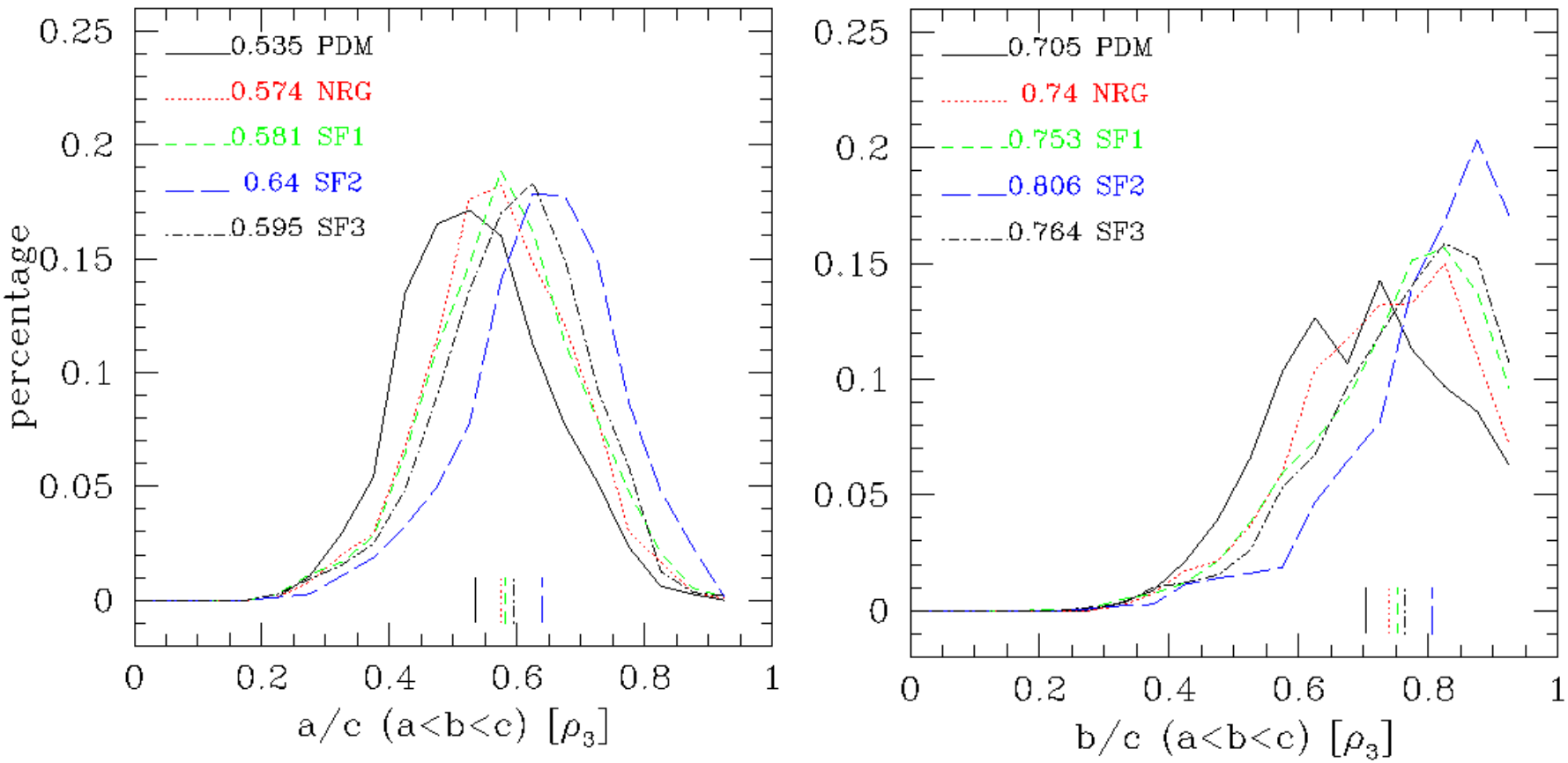
C: Star Formation（SF1）

Methods for tri-axial shape

- Using SPH method to calculate space density of matter (Star-only or including DM & Gas)
- Selection particles with the same density (bin)
- Using FoF methods again with short-linking length to find out the largest group, such that the impact by substructures is minimized
- Calculating the inertia tensor of the ellipsoids

  →axis ratios
- Comparing results of different sets of simulations

Influence of baryon on tri-axial halo shape (of iso-density surface)

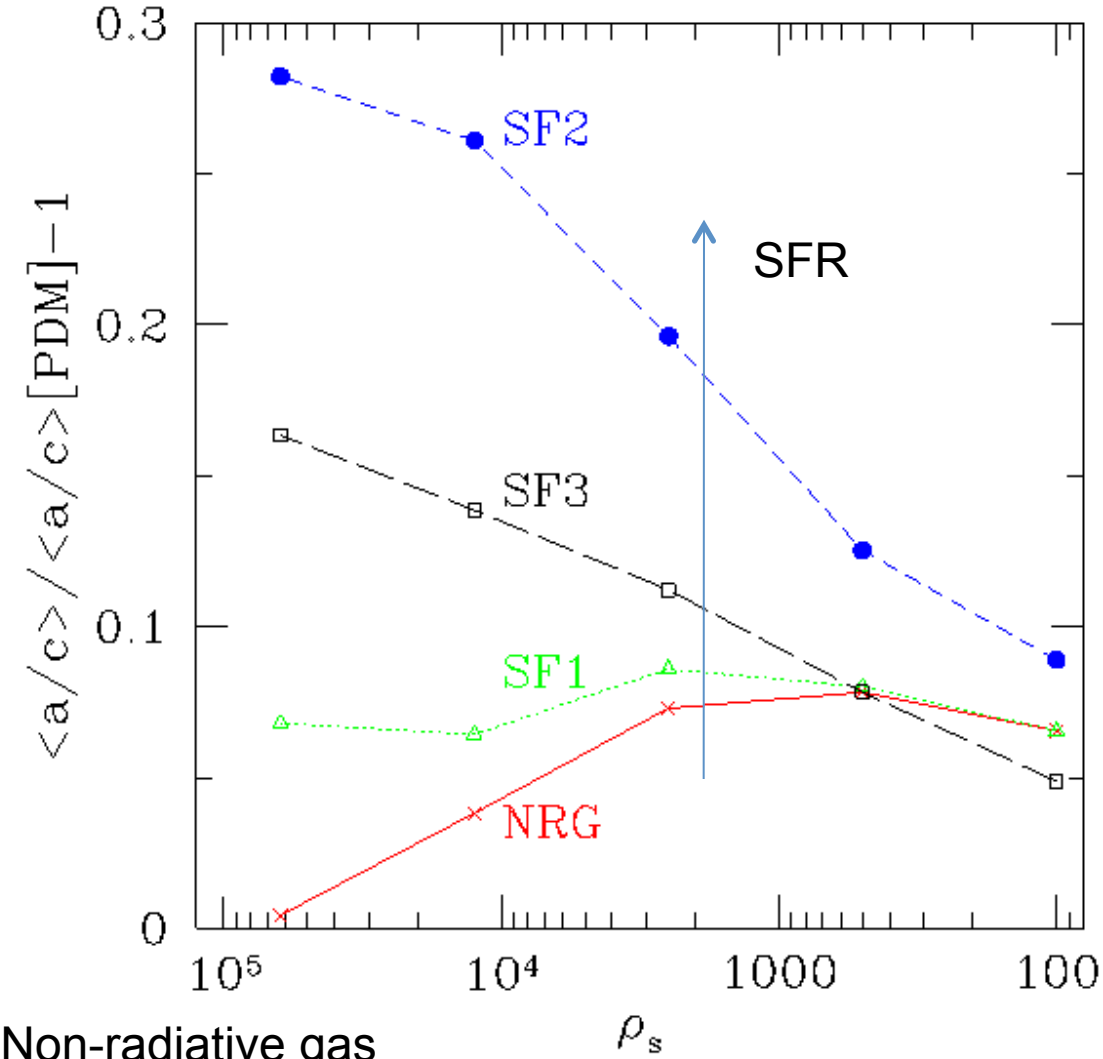


PDM: DM-only, NRG: Non-Radiative, SF: with gas cooling, star formation and SN feedback

Force softening length: 4.5 kpc, except for SF1 (9.8 kpc)

SF3: baryon fraction is reduced to 8%

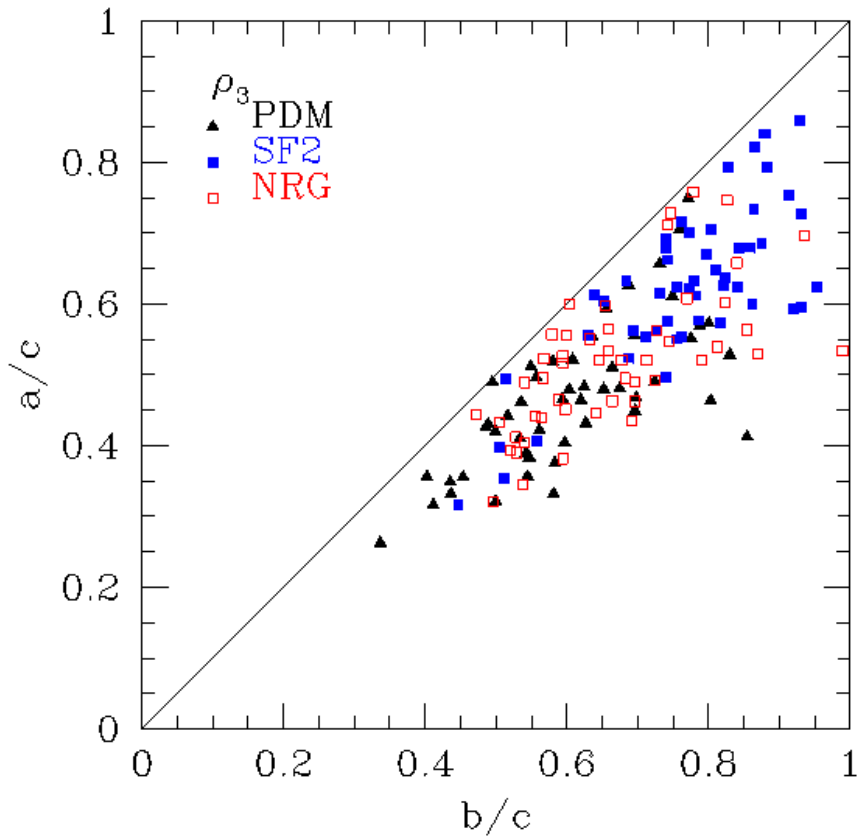
Lin et al., in preparation

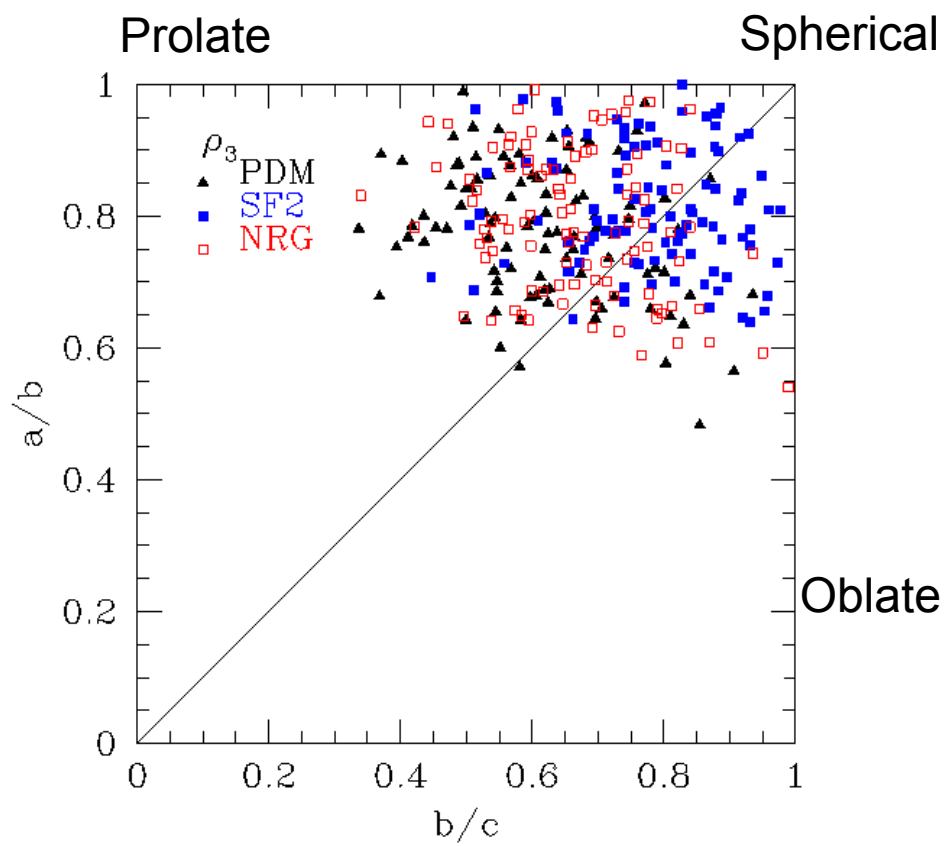


NRG: Non-radiative gas
SF1: softening length 9.8 kpc
SF2: softening length 4.5 kpc
SF3: softening length 4.5 kpc, but baryon fraction is 8%

Lin et al., in preparation

Shape changed





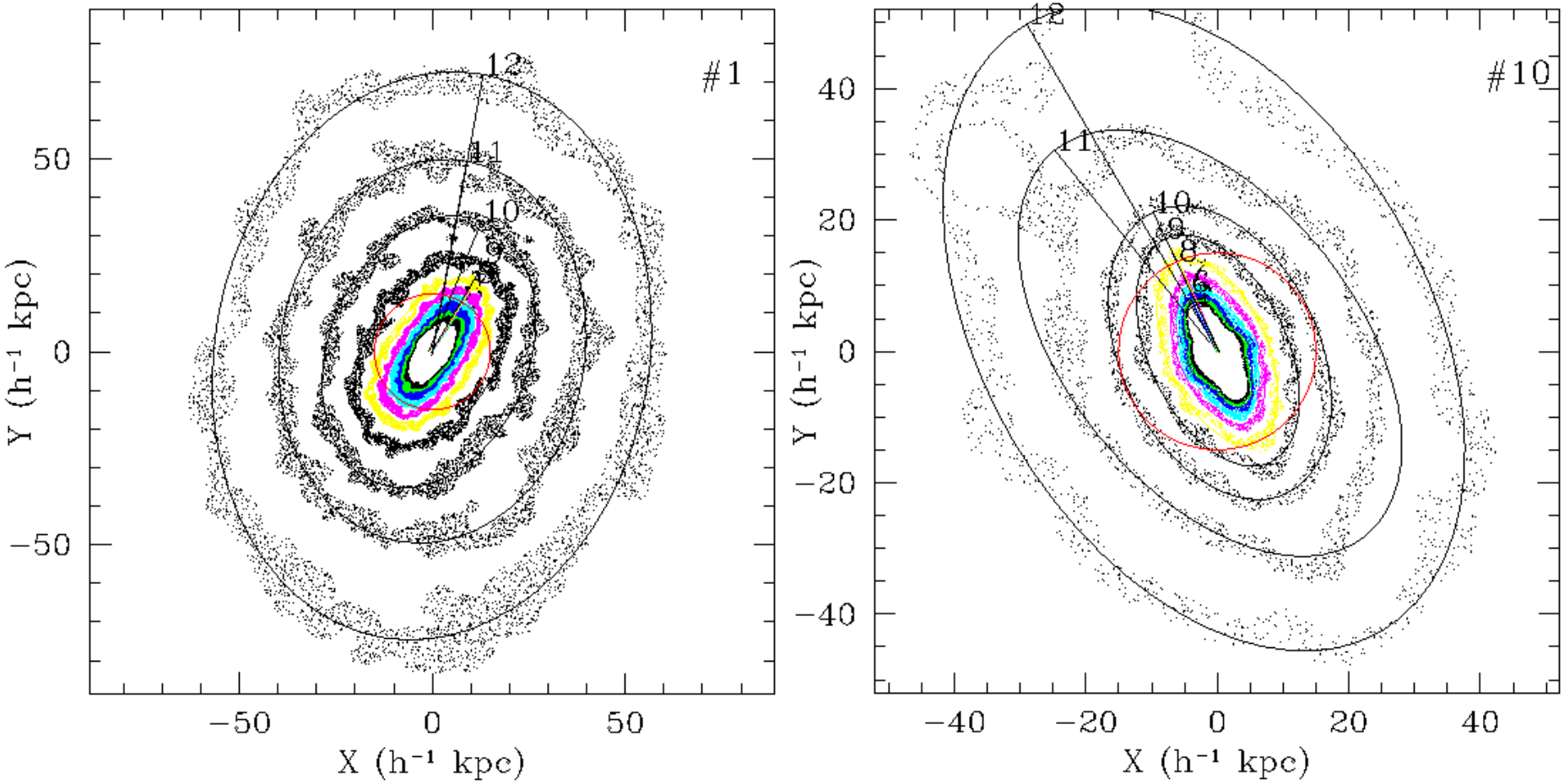
Prolate →
Spherical

Two types of alignment

- “central alignment”: The central alignment between the major axis of stellar components and that of total mass

  i.e. at radius of 15 kpc/h, or 5% Virial Radii
- “overall alignment”: The alignment between the major axis of simulated brightest cluster galaxy (“BCG”) and that of the whole halo

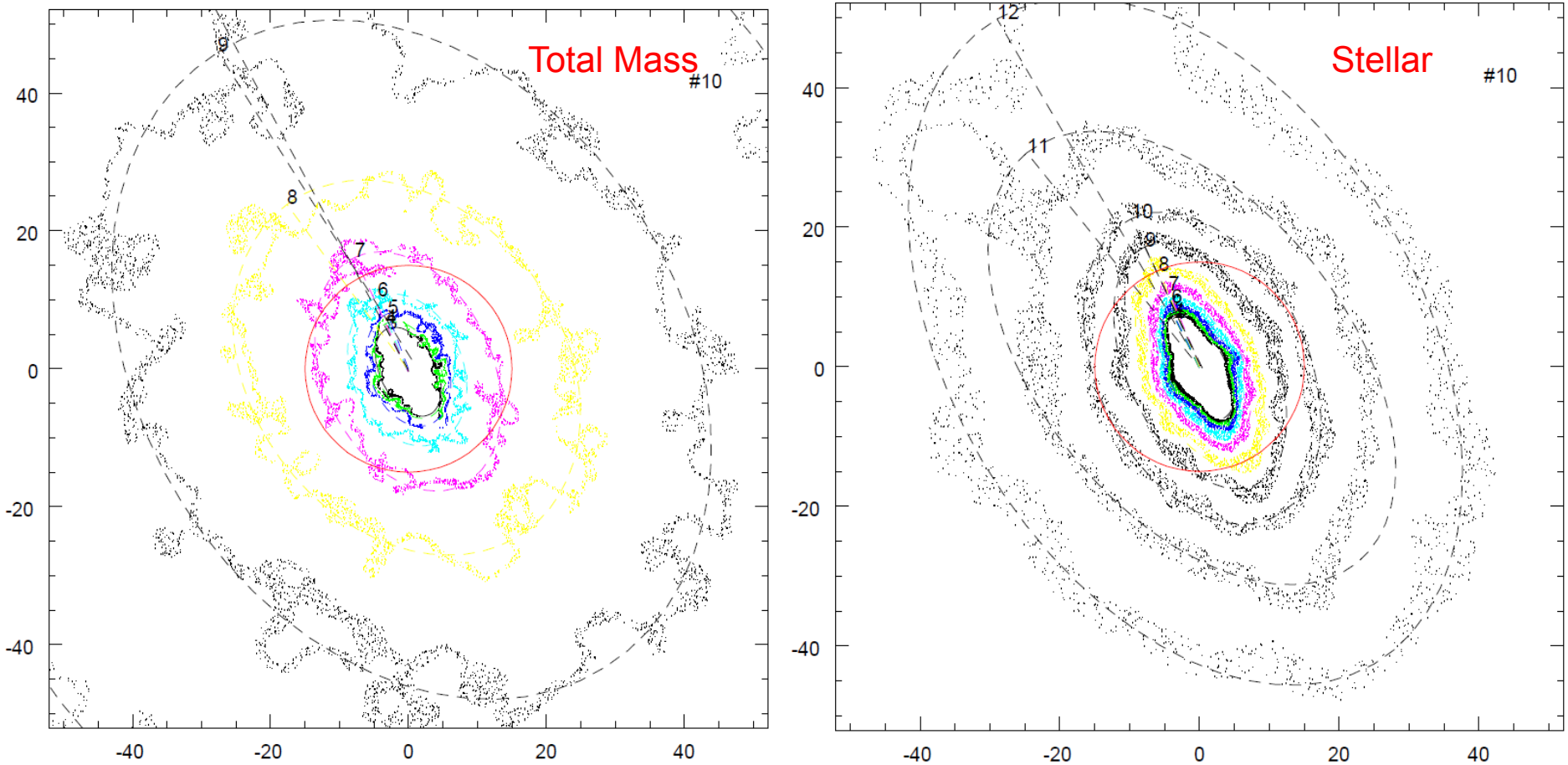
Projected stellar density contours



Red circle with radius of 15 kpc/h
Notice: The iso-photo twist

Lin et al., in preparation

2D Density Map

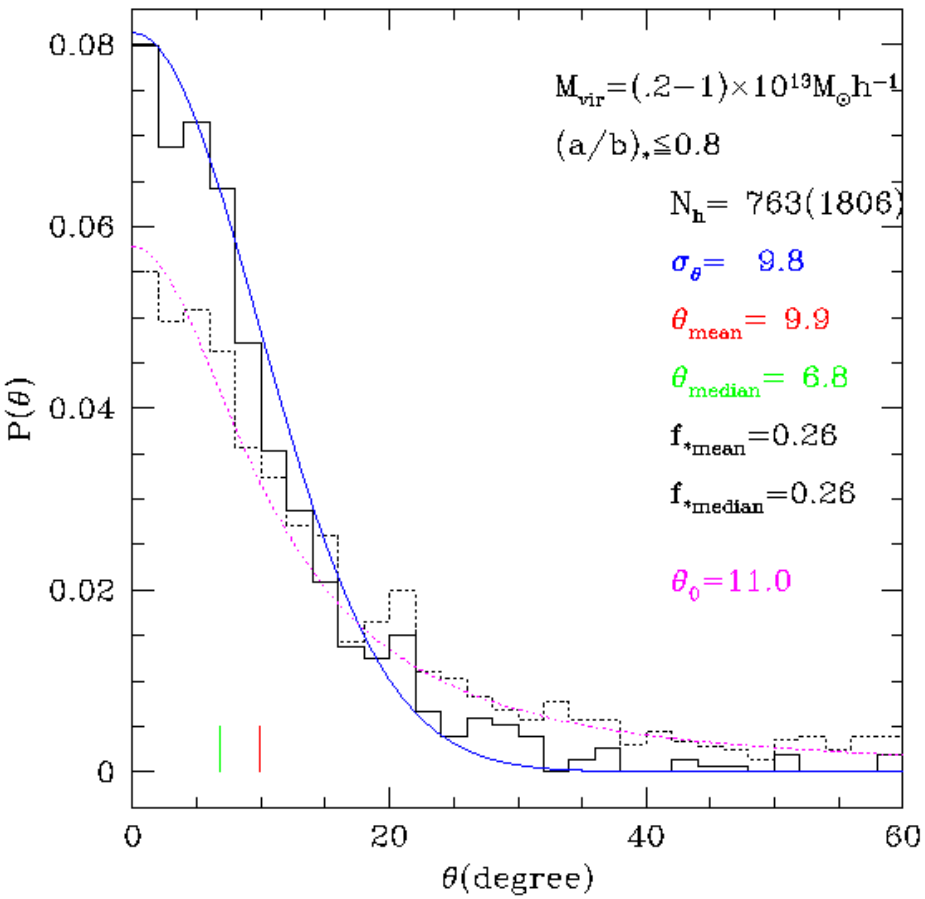


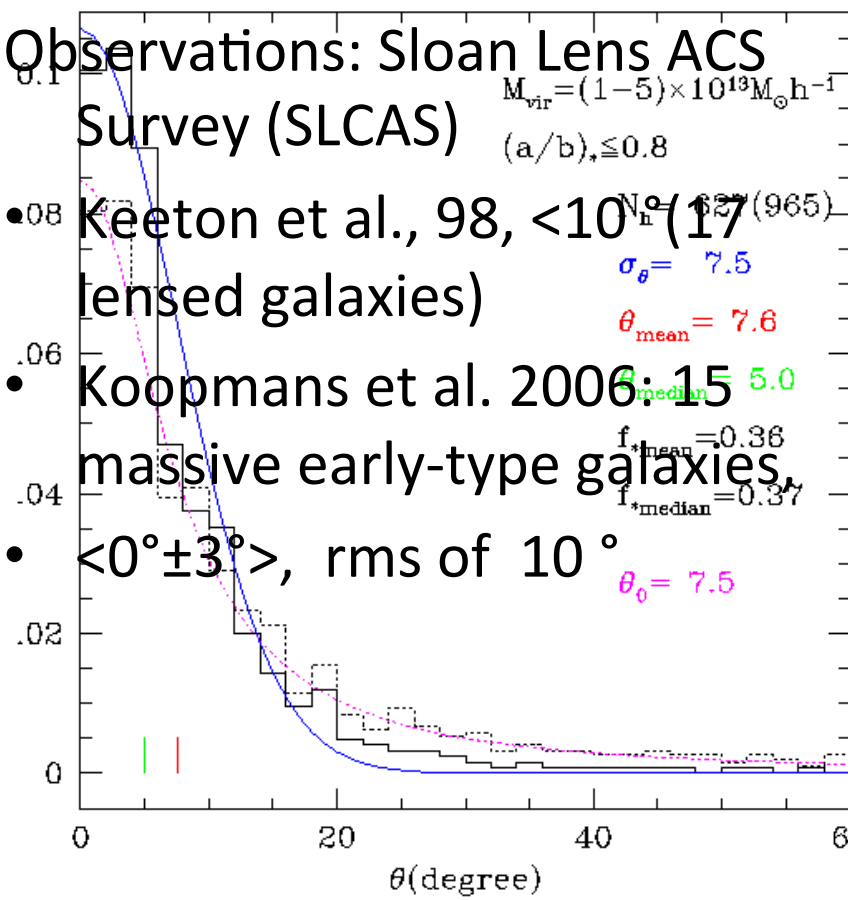
Difference of Position Angle at r_e~15.0kpc: 0.22 Degree!

Well-aligned

Lin et al., in preparation

Probability of Mis-alignment angle: central alignment (at 15 kpc/h)



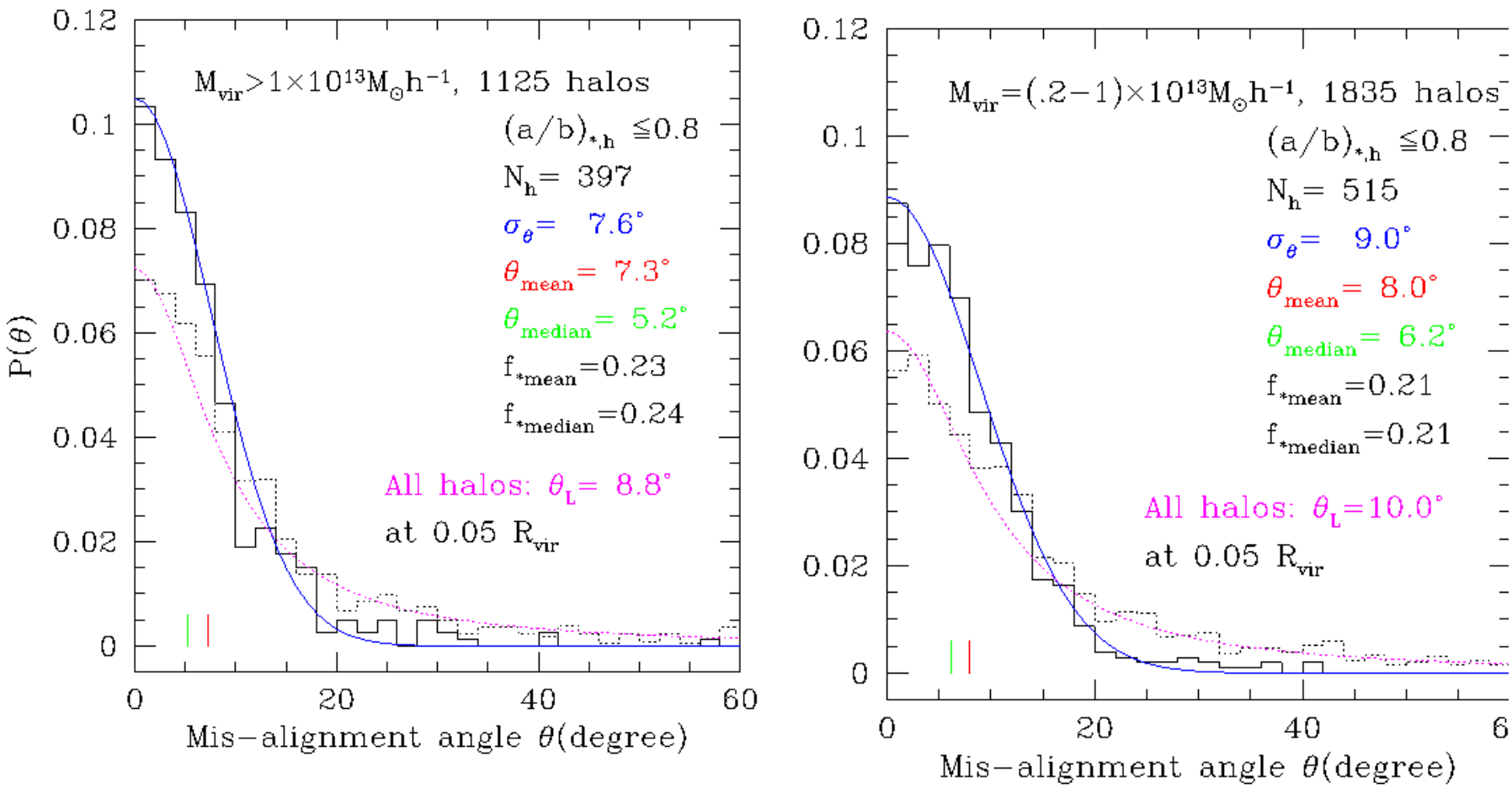


Observations: Sloan Lens ACS Survey (SLCAS)

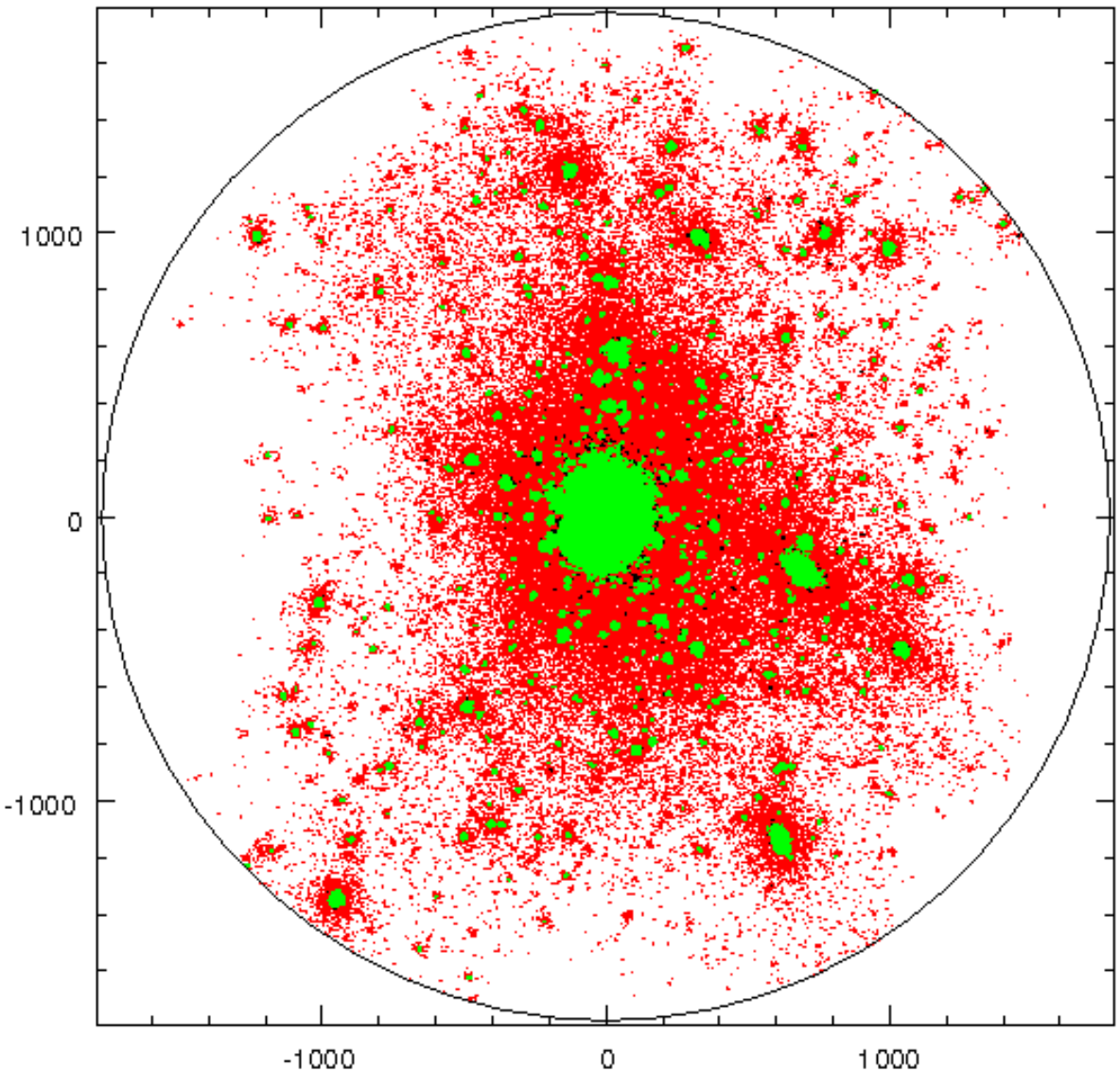
- Keeton et al., 98, <10° (17 lensed galaxies)
- Koopmans et al. 2006: 15 massive early-type galaxies, <0°±3°>, rms of 10 °

Lin et al., in preparation

The alignment at 5% Virial Radii

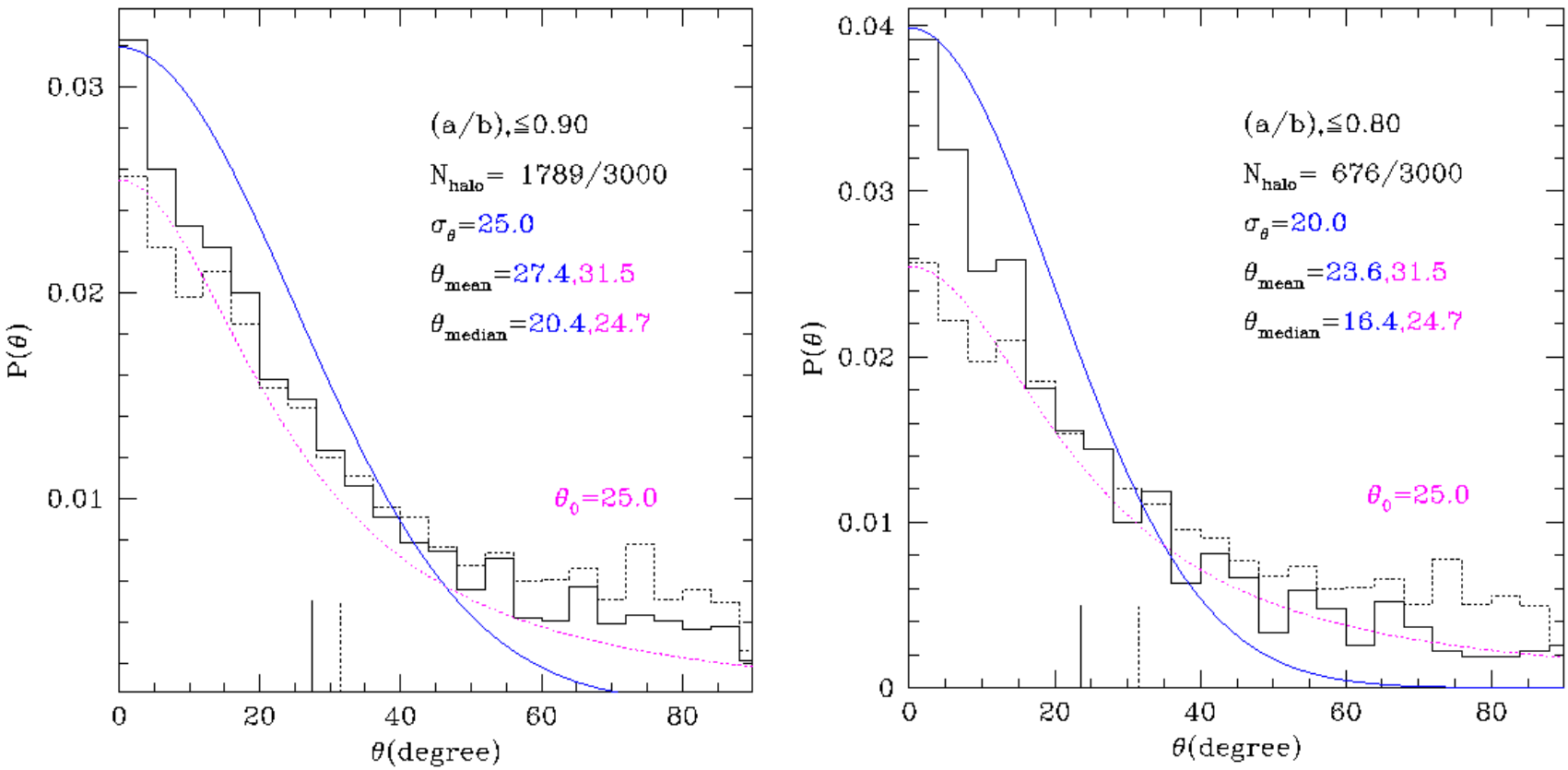


Lin et al., in preparation

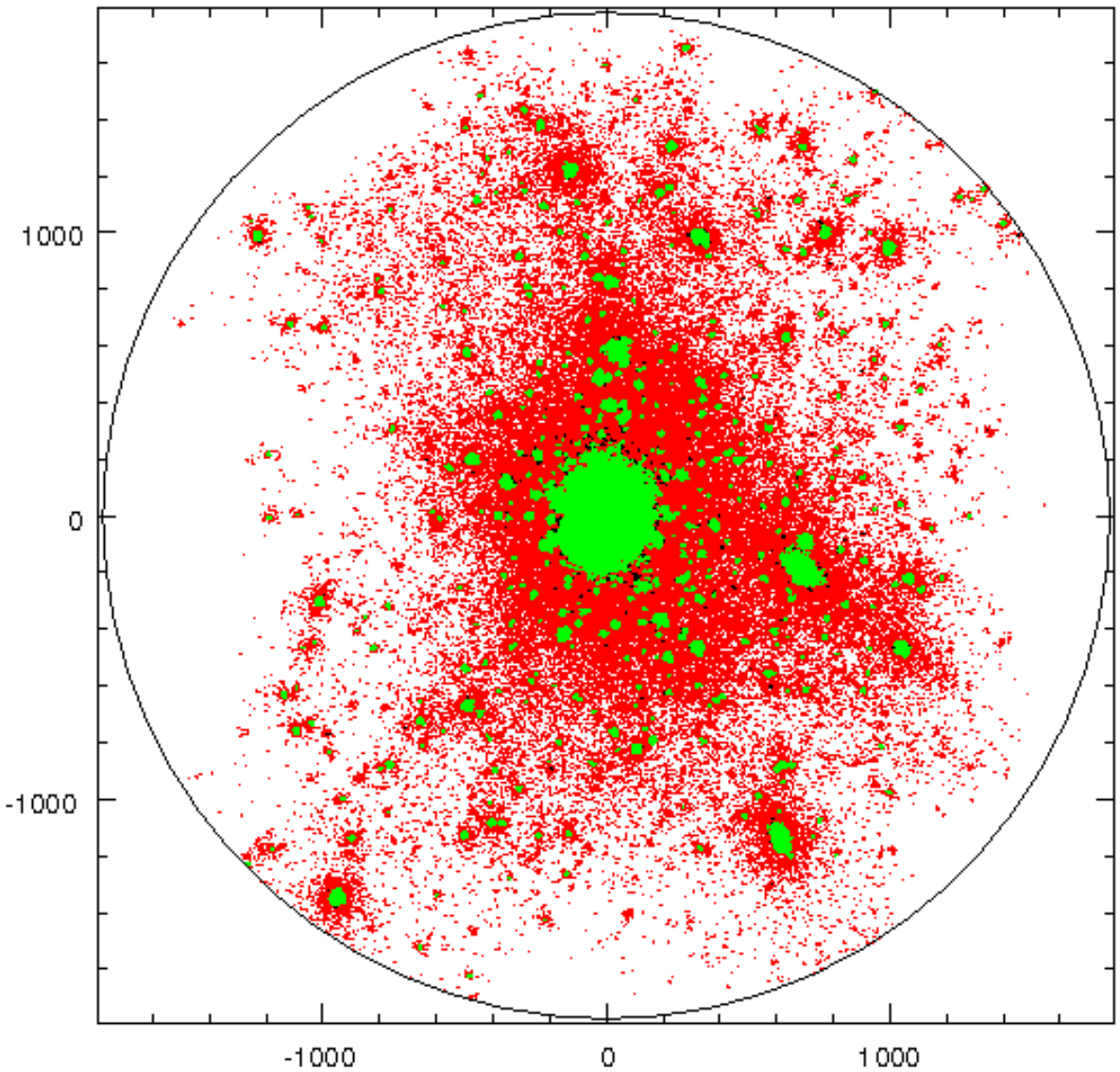


Rvir =1.78 Mpc
Mvir =6.3E14 $M_\odot$
K-band surface brightness:
μ_k =20 m/acrsec^2
~100 $M_\odot$/pc^2
Definition of “galaxies”

Probability of Mis-alignment angle overall alignment: total mass vs "BCG"



Results implied by weak lensing: about 30 degree, Okumura & Jing, 2009; Okumura, Jing & Li, 2009



Open issues

1. Definition of “galaxies”
2. Population of Satellites
3. Alignment of Satellites
4. Clustering of “galaxies”
5. “Color” of “galaxies”
6. Intra-cluster “Stars”
7. Angular momentum
8. Dynamic of Sinking Satellites
9. Numerical effects
10. Over-Cooling
11. Over-Merging/ Stripping

summary

- Gas segregation toward halo center will make halo more concentrated , however very strong feedback (SN or AGN) will make the halo less cuspy and even build-up core;
- Baryon physics can alter matter clustering and have significant impact on weak lensing measurement which should be considered for precise cosmological experiment;
- We provided a fitting formula for galaxy merging timescale;
- The distribution of baryon can transform particle orbits and make halo significantly more spherical.
- The mis-alignment angle between “BCG” and halo orientation is about 30°, consistent with results implied from weak lensing observations.
- Many problems remained for comparison of simulation and observational results.

Many thanks

Questions and comments?