MASS PROFILES AND GALAXY ORBITS IN GROUPS AND CLUSTERS

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Collaborators & papers:

on the observational side:

A.B. & M. Girardi 2003,
P. Katgert, A.B. & A. Mazure 2004,
A.B. & P. Katgert 2004,
A.B. & P. Salucci 2006
A.B., G. Mamon,T. Ponman in prep.

on the numerical side:

A.B., G. Murante, S. Borgani, A. Diaferio, K. Dolag,
& M. Girardi 2006 & in prep.

MASS PROFILES

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Why using the cluster galaxies to determine the total mass profile?

- less direct than lensing and X-ray ↓

- sample mass profile to larger radii ↑
- IC gas not fully thermalized (?) ↑

(Rasia et al. 2004, Faltenbacher et al. 2005)

- lensing inefficient for nearby clusters ↑

(Natarajan & Kneib 1997)

…and in any case, 3 is better than 1!

Tracers of the grav. potential: ***galaxies***

Observables:

R, radial distance from the cluster centre
v, rest-frame l.o.s. velocity wrt the cluster <v>

Combine many clusters: scale R with the cl. virial radii, r_{200}, and $v-<v_{cluster}>$, with the cl. vel. disp., σ_p (or V_{200})

Methods:

Jeans analysis (e.g. Binney & Tremaine 1987)

Caustic method (Diaferio & Geller 1997)

M(<r) from the Jeans analysis

Assumes dynamical equilibrium of the system

- I(R) and σ_p(R) $\leftrightarrow$ ν(r), σ_r(r), M(<r), through β(r)
  - or, more generally: f_p(R,v) $\leftrightarrow$ Φ(r) + f(E,L^2)
  -

- Mass – orbits degeneracy:
- given R,v the M(<r) solution depends on β(r)
- ($\beta(r) \equiv 1 - \sigma_t^2/\sigma_r^2$, velocity anisotropy profile)

Possible solutions to this problem include:

- analysis of the shape of the velocity distribution
- use of several tracers of the cluster potential

The Jeans equation

$$M(r) = -\frac{r < v_r^2 >}{G}\left(\frac{d\ln\nu}{d\ln r} + \frac{d\ln < v_r^2 >}{d\ln r} + 2\beta\right)$$

r, clustercentric radial distance

$<v_r^2>$, or σ_r, radial component of velocity dispersion

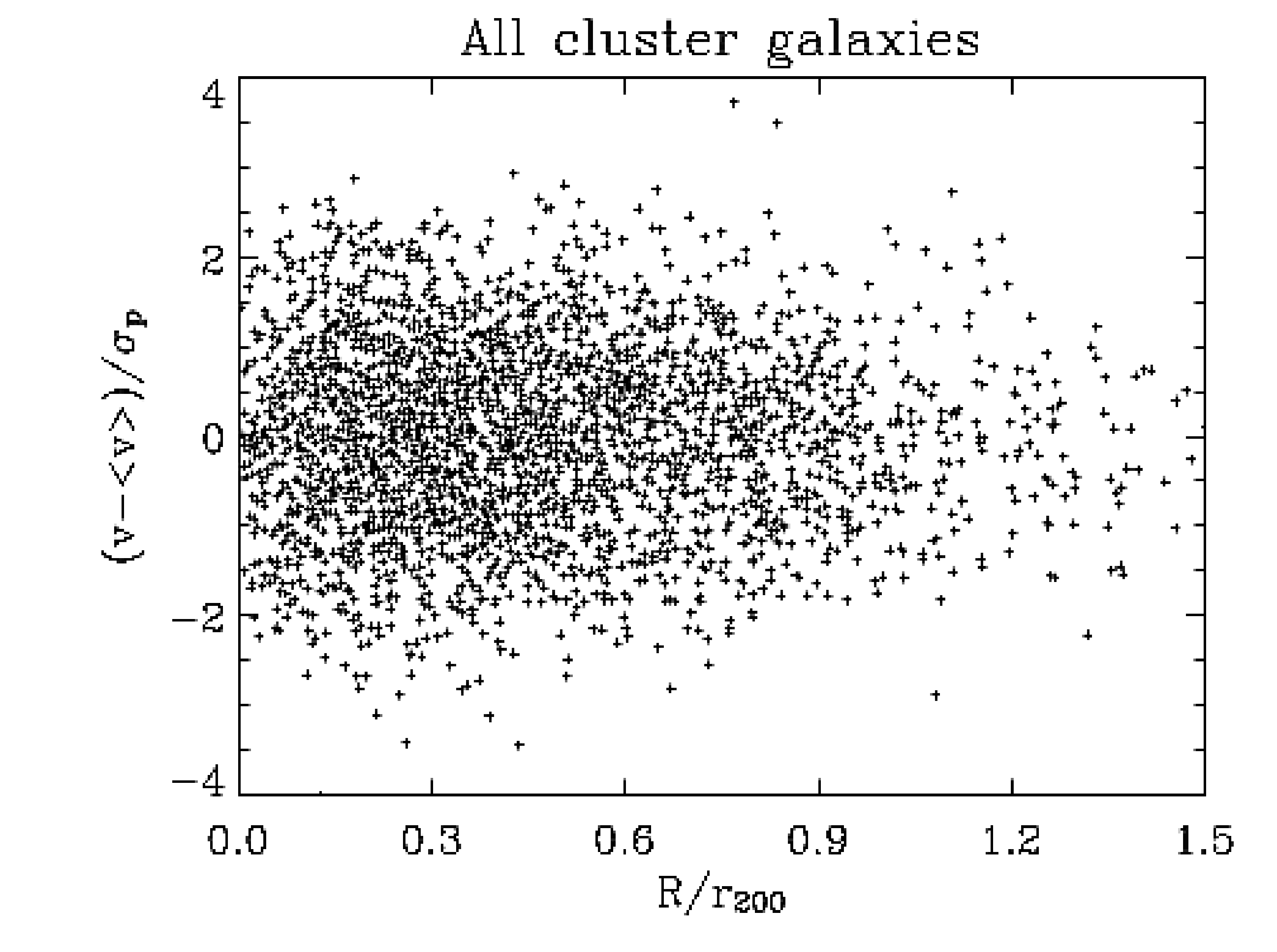
ν, number density of cluster galaxies

β, velocity anisotropy:

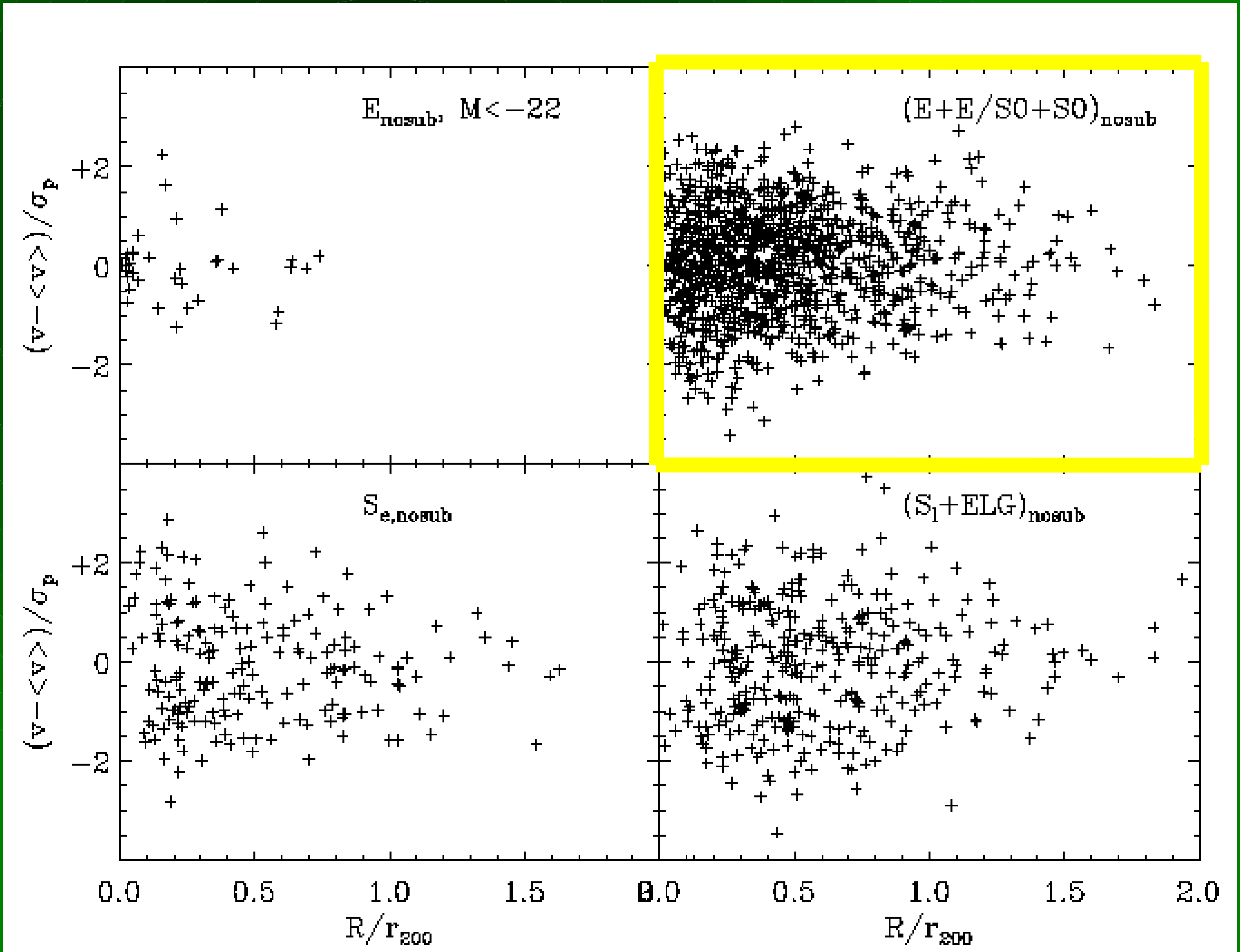
$$\beta(r) \equiv 1 - \frac{< v_t^2 >}{< v_r^2 >}$$

“Ensemble” cluster in projected phase-space:

ENACS, ≃3000 galaxies



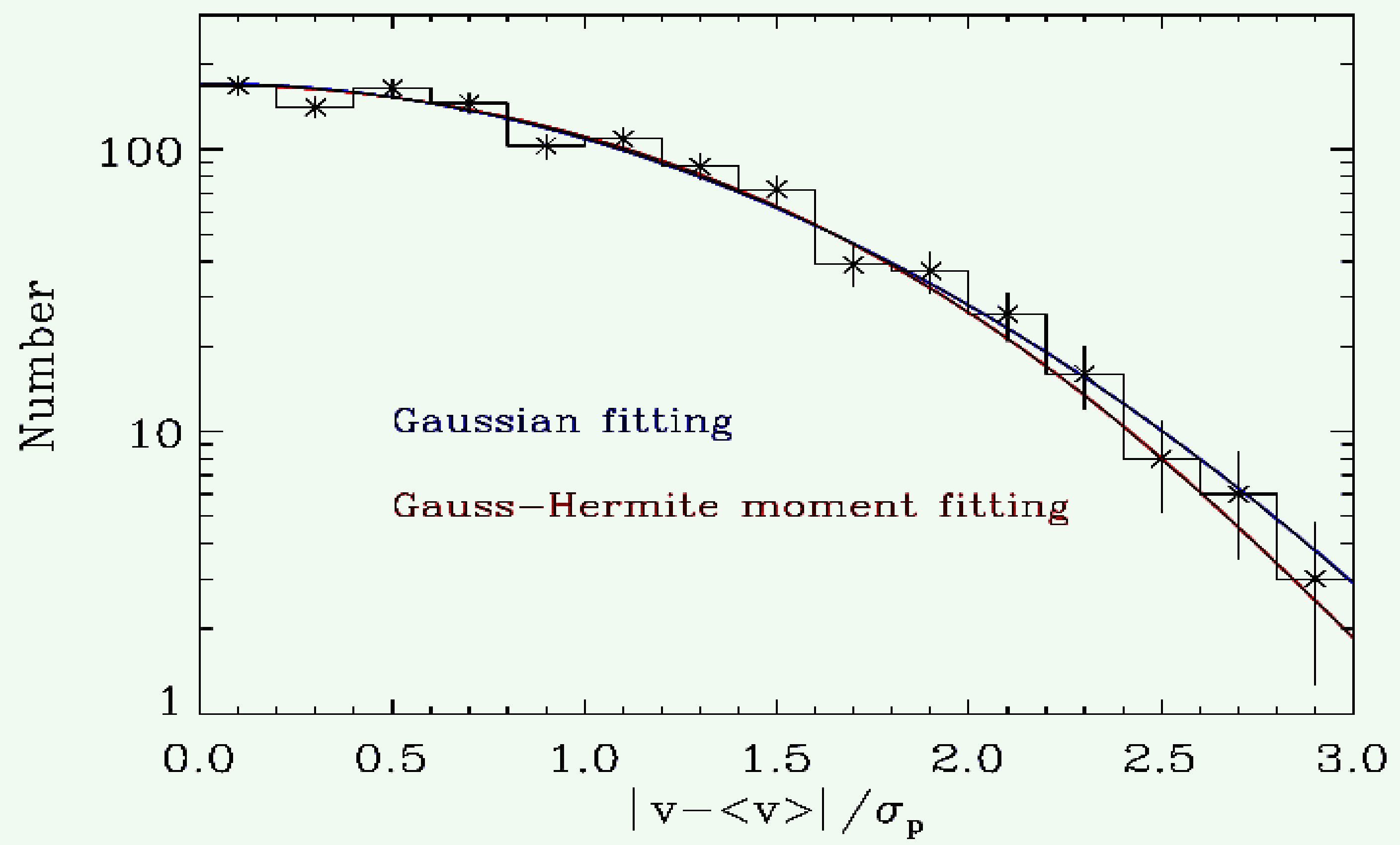
Select early-type galaxies as tracers of the cl. potential:



≃1000 galaxies

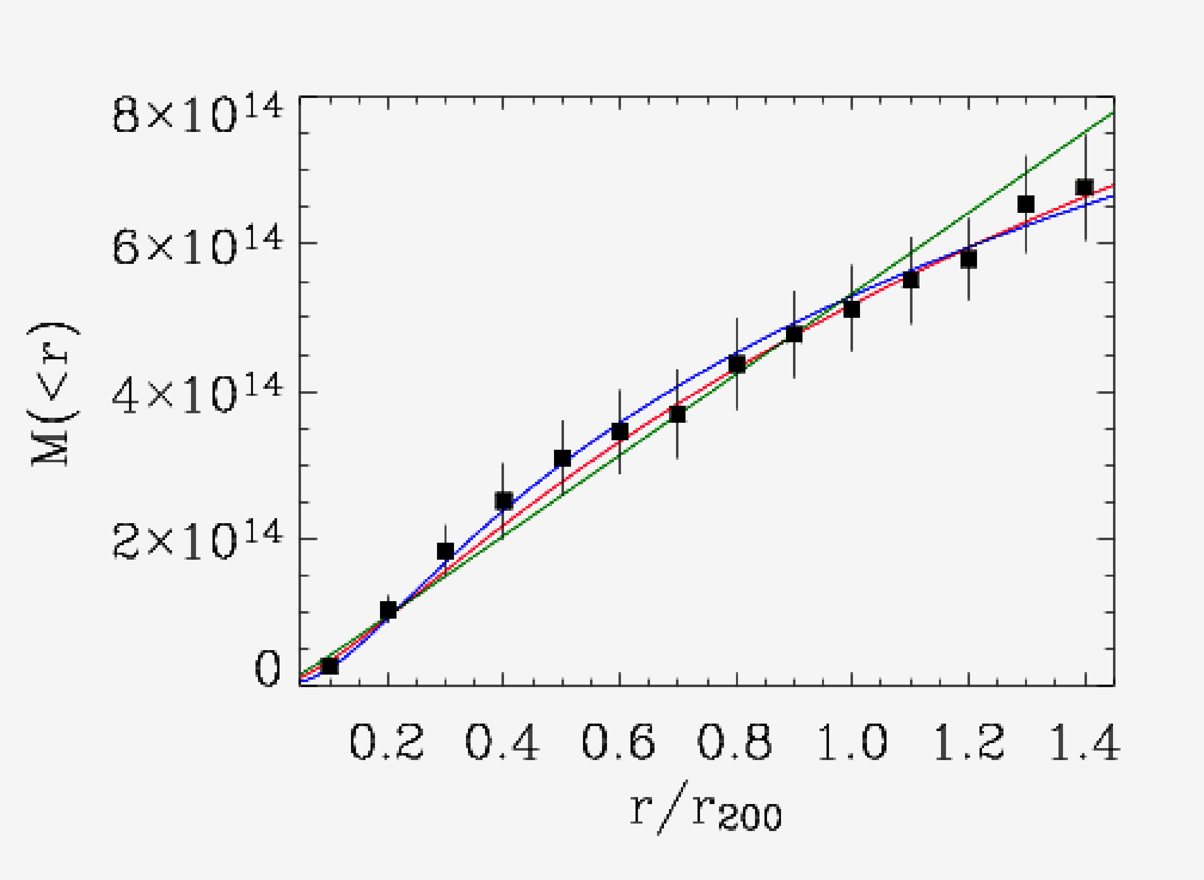
The shape of the tracer velocity distribution → constrains the tracer velocity anisotropy β

(Katgert, B. & Mazure 04)



$$\left(\langle v_r^2\rangle / \langle v_t^2\rangle\right)^{1/2} \simeq 1.0^{+0.05}_{-0.2}$$

Assuming isotropic orbits for the tracers



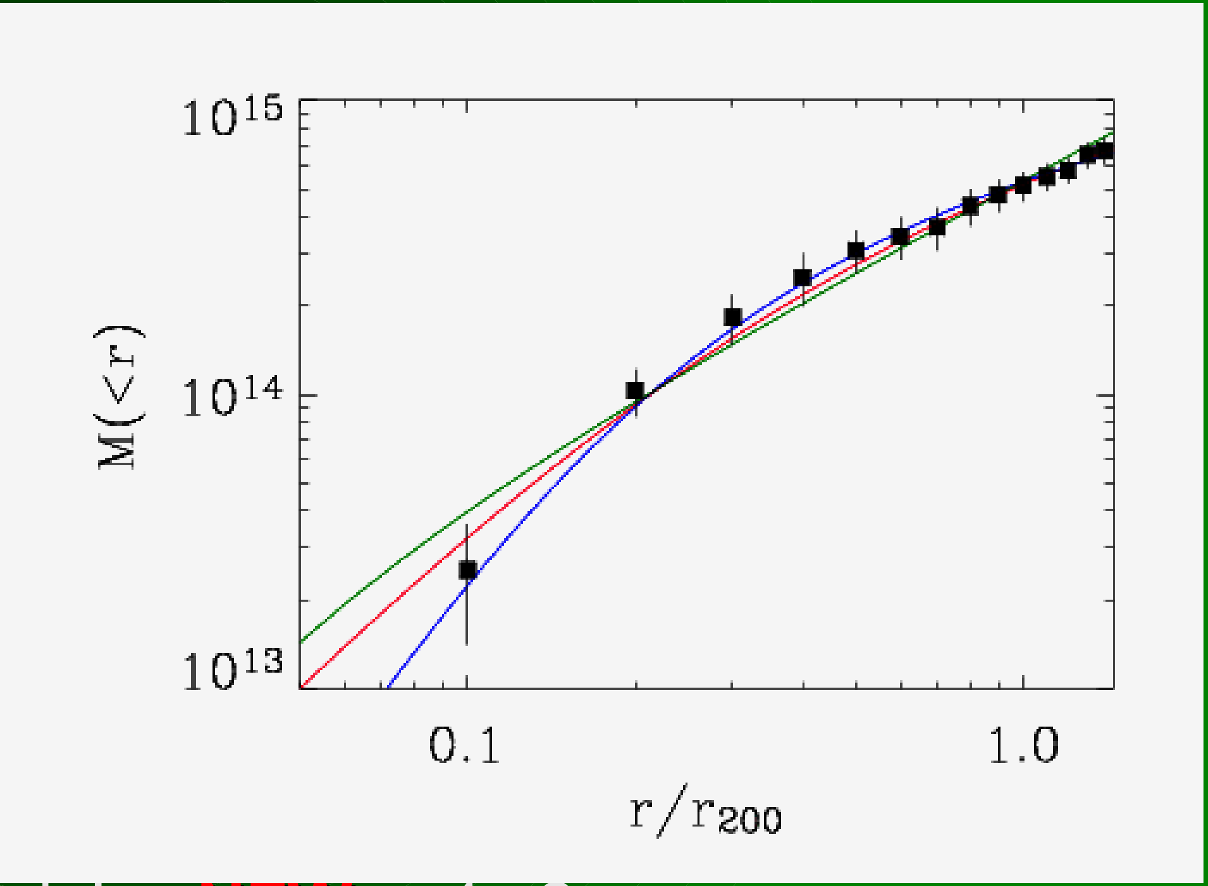
$\rho(r) \propto r^{-2.4\pm0.4}$ at $r=r_{200}$

Fitting models: **NFW** $c=4\pm2$,

Burkert 95 $r_{core}=0.15\ r_{200}$

Isothermal gives poor fit

Assuming isotropic orbits for the tracers



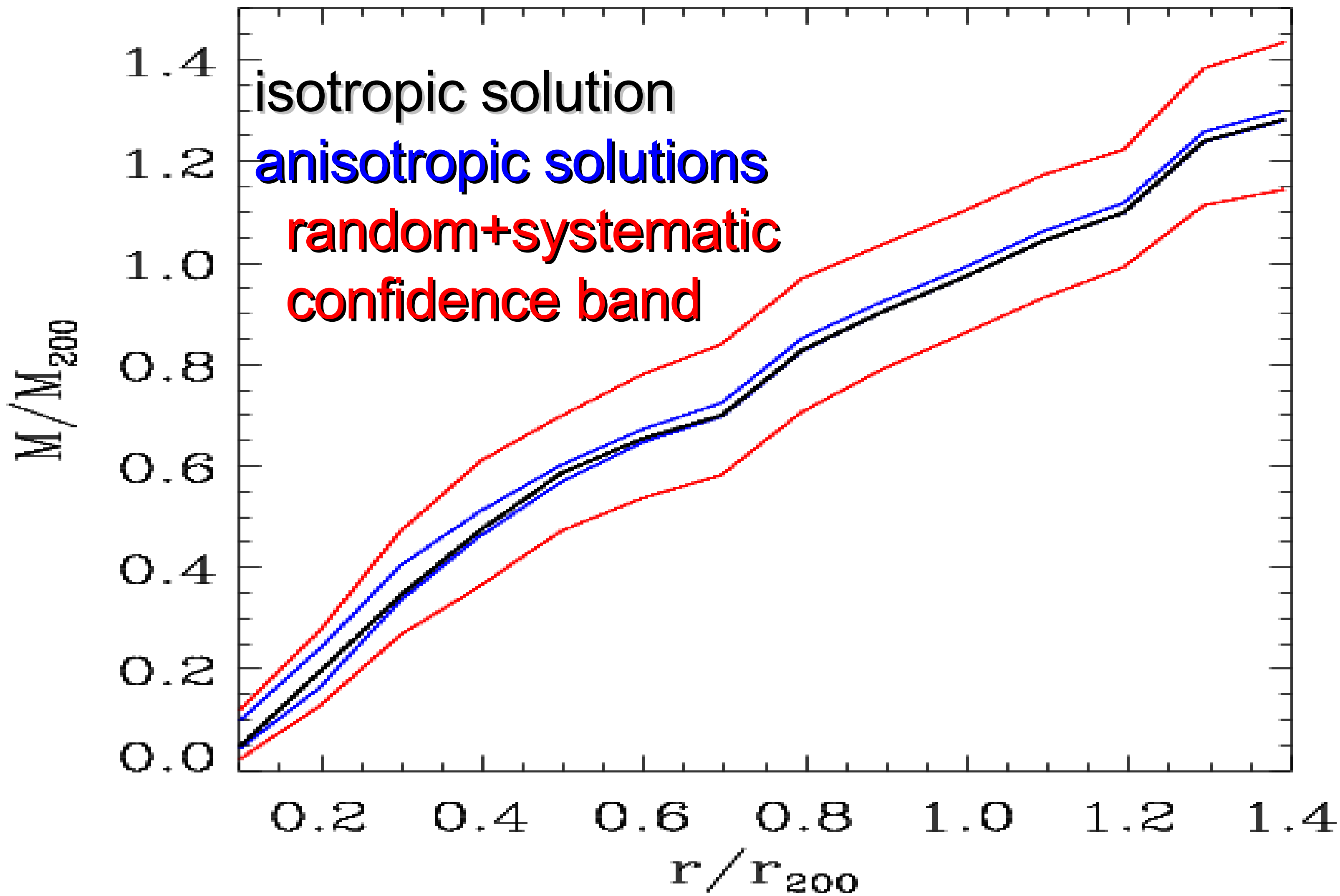
$\rho(r) \propto r^{-2.}$

Fitting models: **NFW** c=4±2,

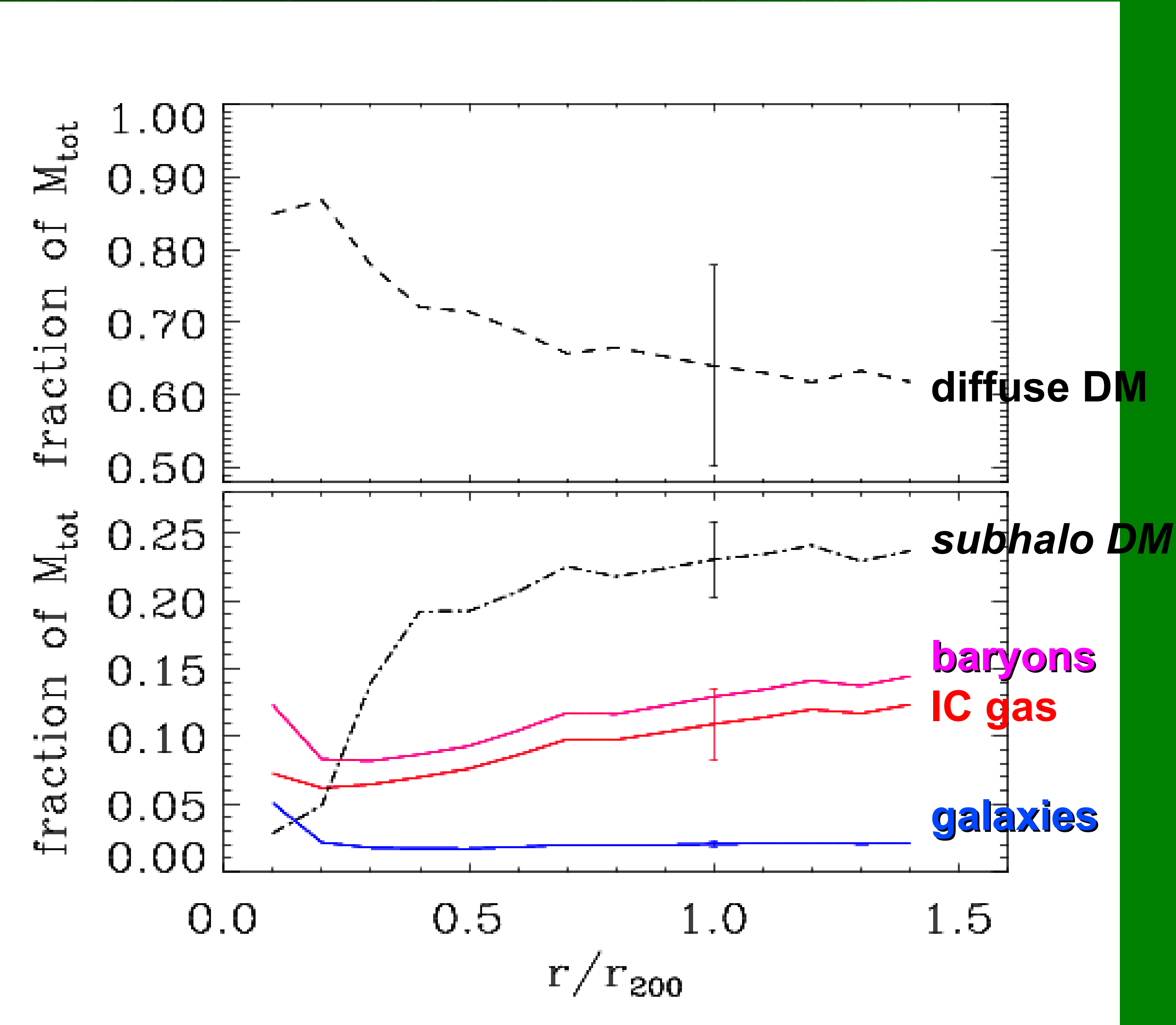
Burkert 95 r_{core}=0.15 r_{200}

Isothermal gives poor fit

Resulting M(<r): *(Katgert, B. & Mazure 04; B. & Salucci 06; see Mamon & Boué 07)*

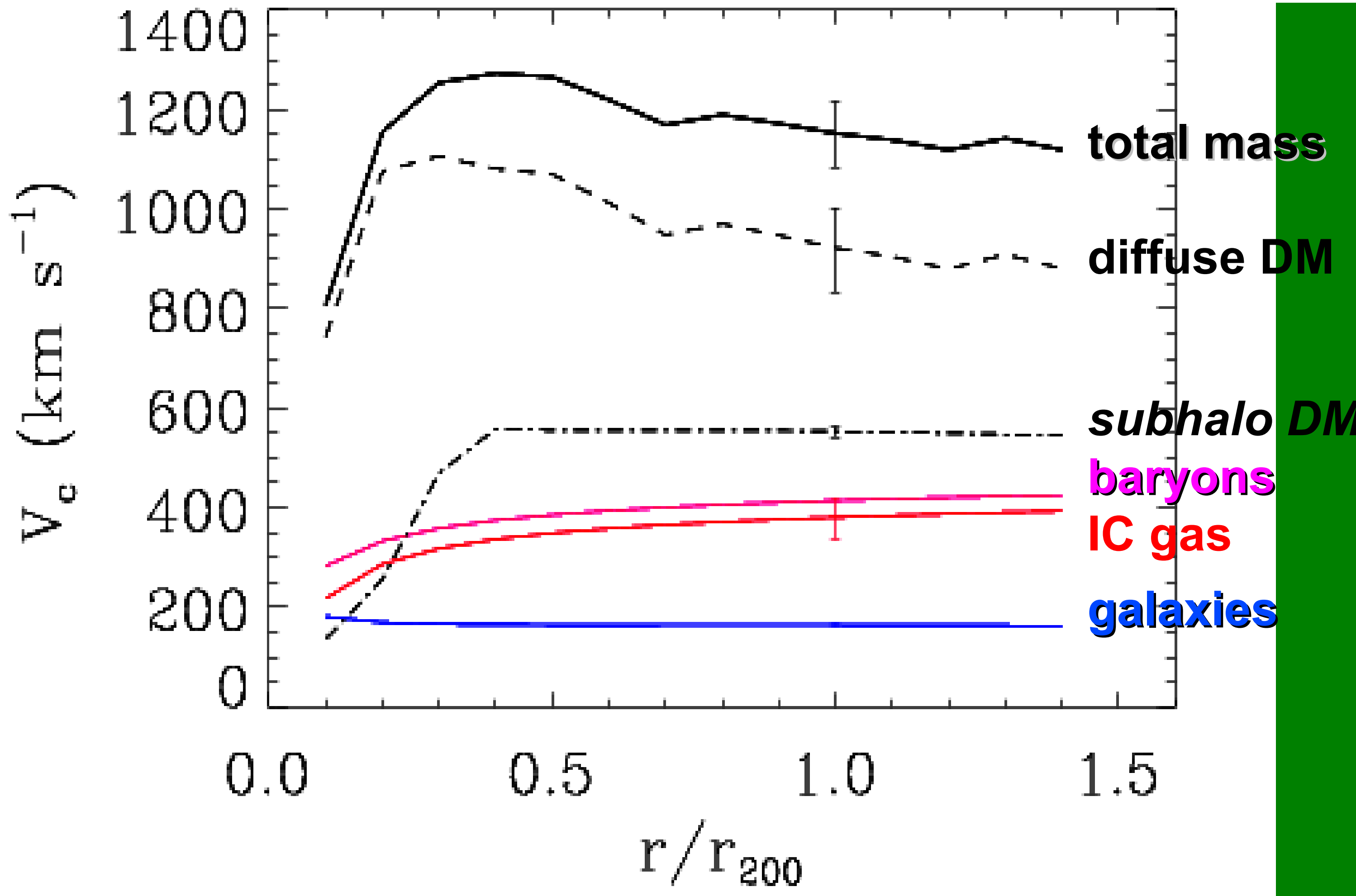


Split M(<r) into its components *(B. & Salucci 06):*



Split M(<r) into its components

$$V_c(r) \equiv \sqrt{\frac{G\,M(r)}{r}}$$



Fit models to the $V_c(r)$ profiles

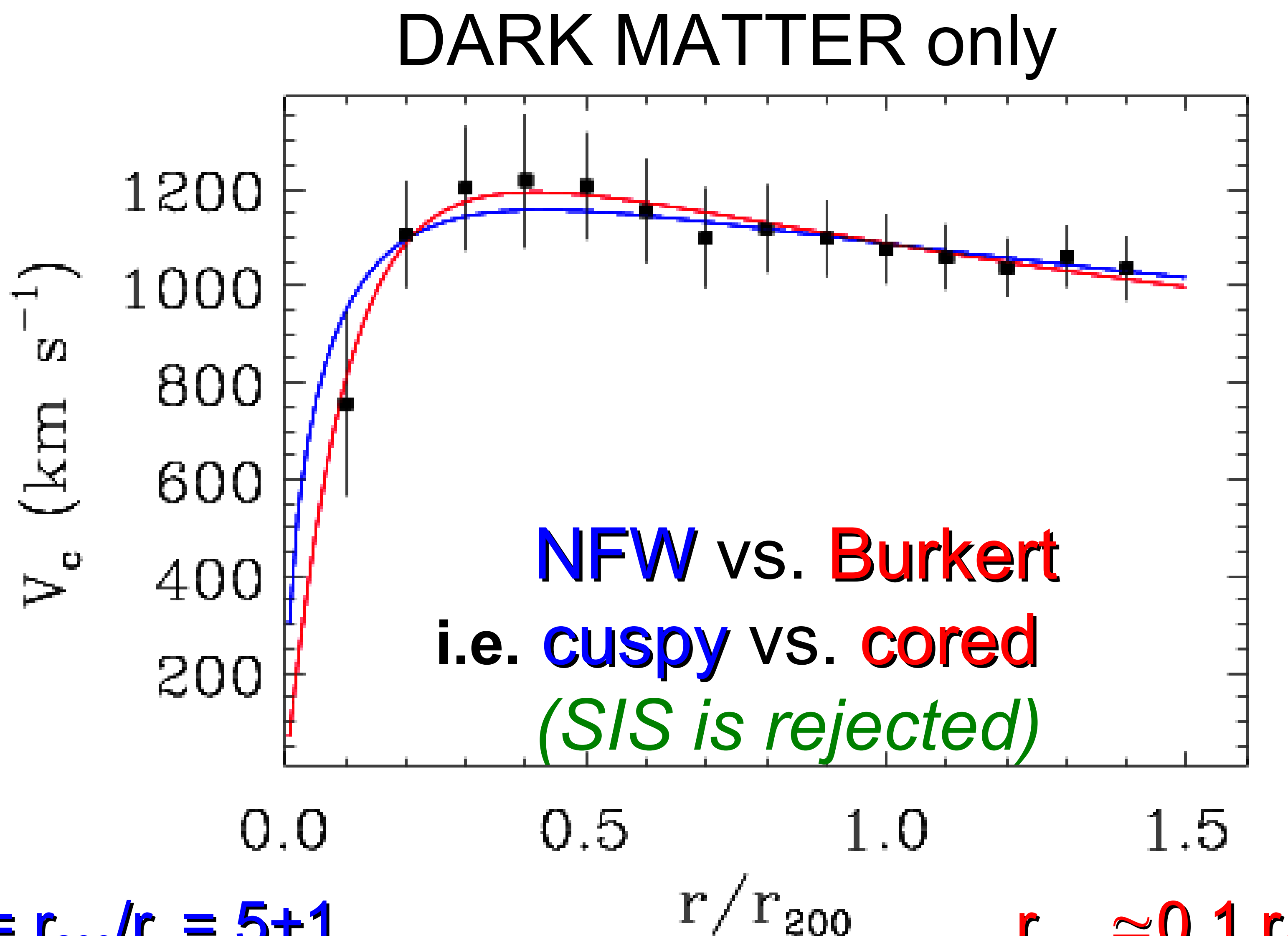
The cuspy model of NFW, motivated by cosmological num. simulations with CDM:

$$\rho_{NFW}(r) = \frac{\rho_0}{(r/r_s)(1+r/r_s)^2}$$

…vs. the cored model of Burkert (1995), motivated by the problems of NFW on galactic scales (e.g., de Blok et al. 2003, Gentile et al. 2004):

$$\rho_{Burkert}(r) = \frac{\rho_0}{(1+r/r_0)[1+(r/r_0)^2]}$$

Fitting models to the $V_c(r)$ profiles



$c = r_{200}/r_s = 5 \pm 1$

$r_{core} \simeq 0.1\ r_{200}$

SHOULD WE TRUST THESE MASS PROFILES?

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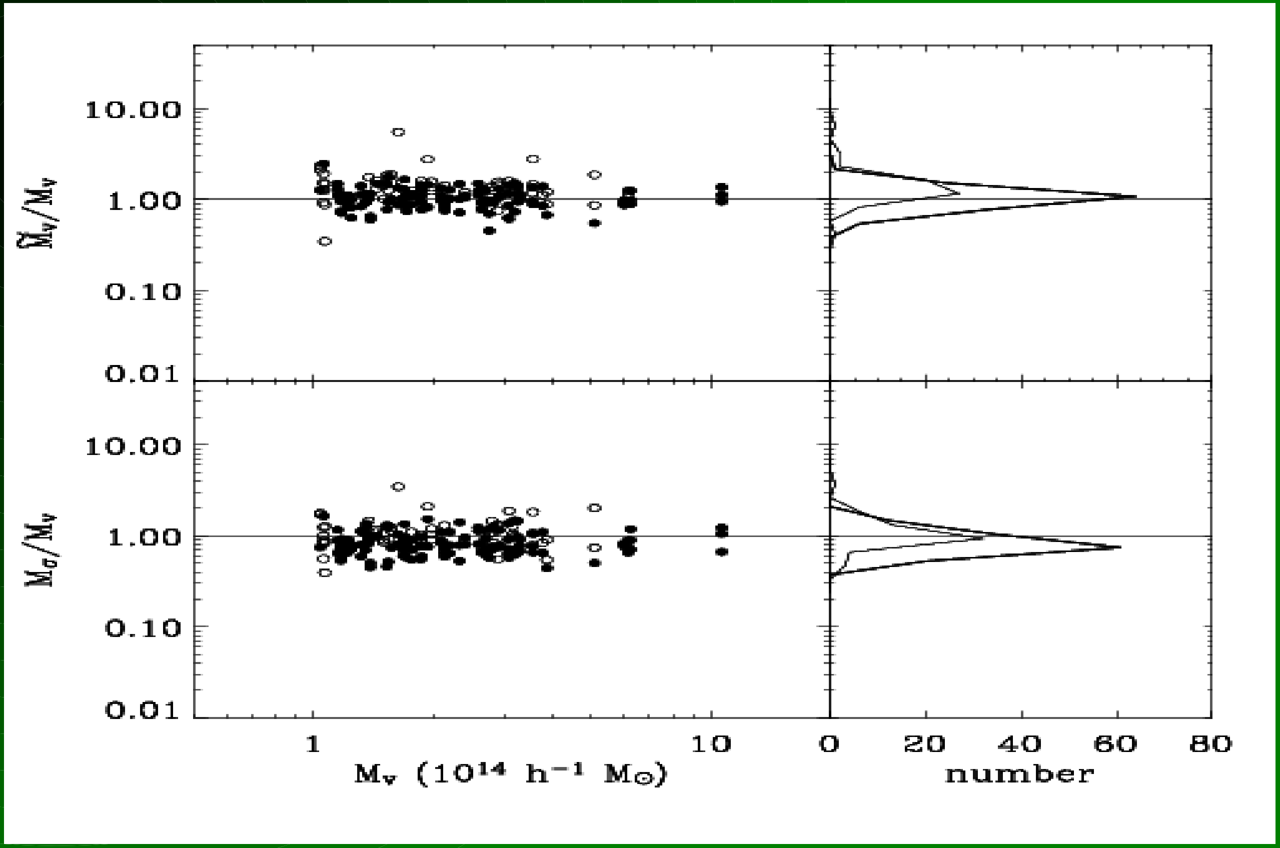
⇒ compare to clusters extracted from cosmological simulations *(B. et al. 06; see Borgani et al. 04)*

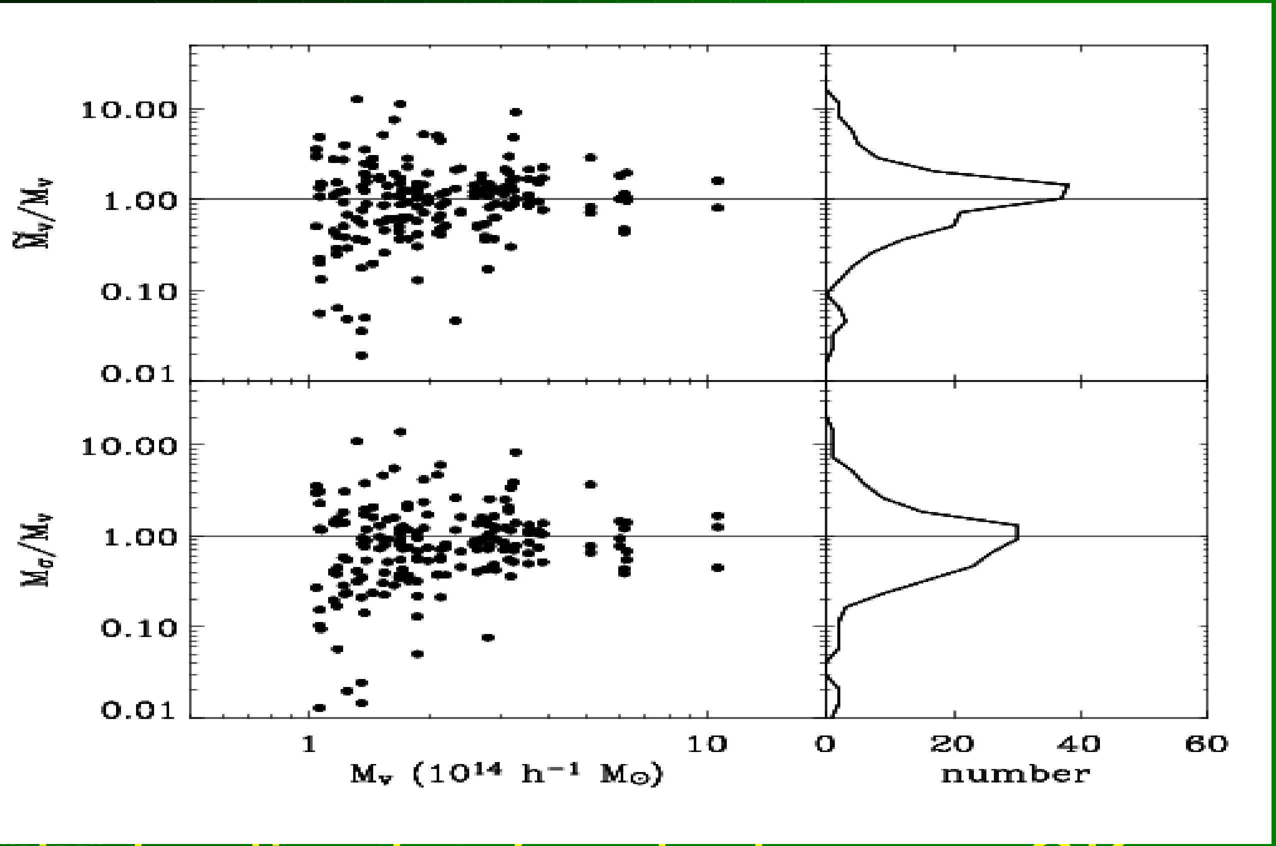
Virial mass estimates ≈unbiased for $N_{part} \geq 60$



⇒ compare to clusters extracted from cosmological simulations

Virial mass estimates ≈unbiased for $N_{part} \geq 60$

For smaller N_{gal} select 'old' (red) galaxies

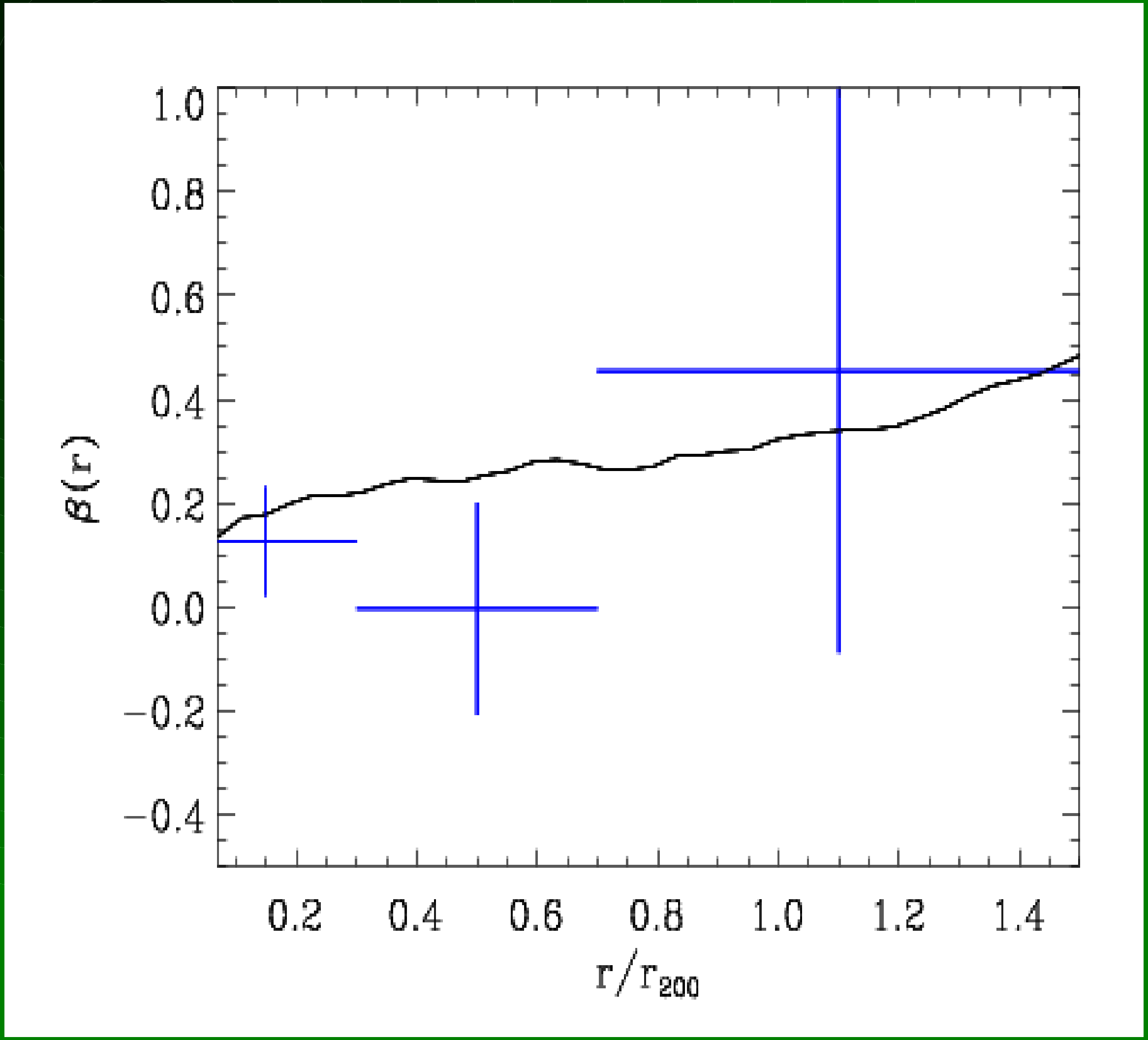


⇒ Global dynamical estimates for clusters are OK: V_{200}, r_{200} can be used for scaling vel.s and radii

(unless N_{gal} very small: groups)

We can trust total masses, can we trust the mass profile?

Use the shape of velocity distribution to constrain β(r)



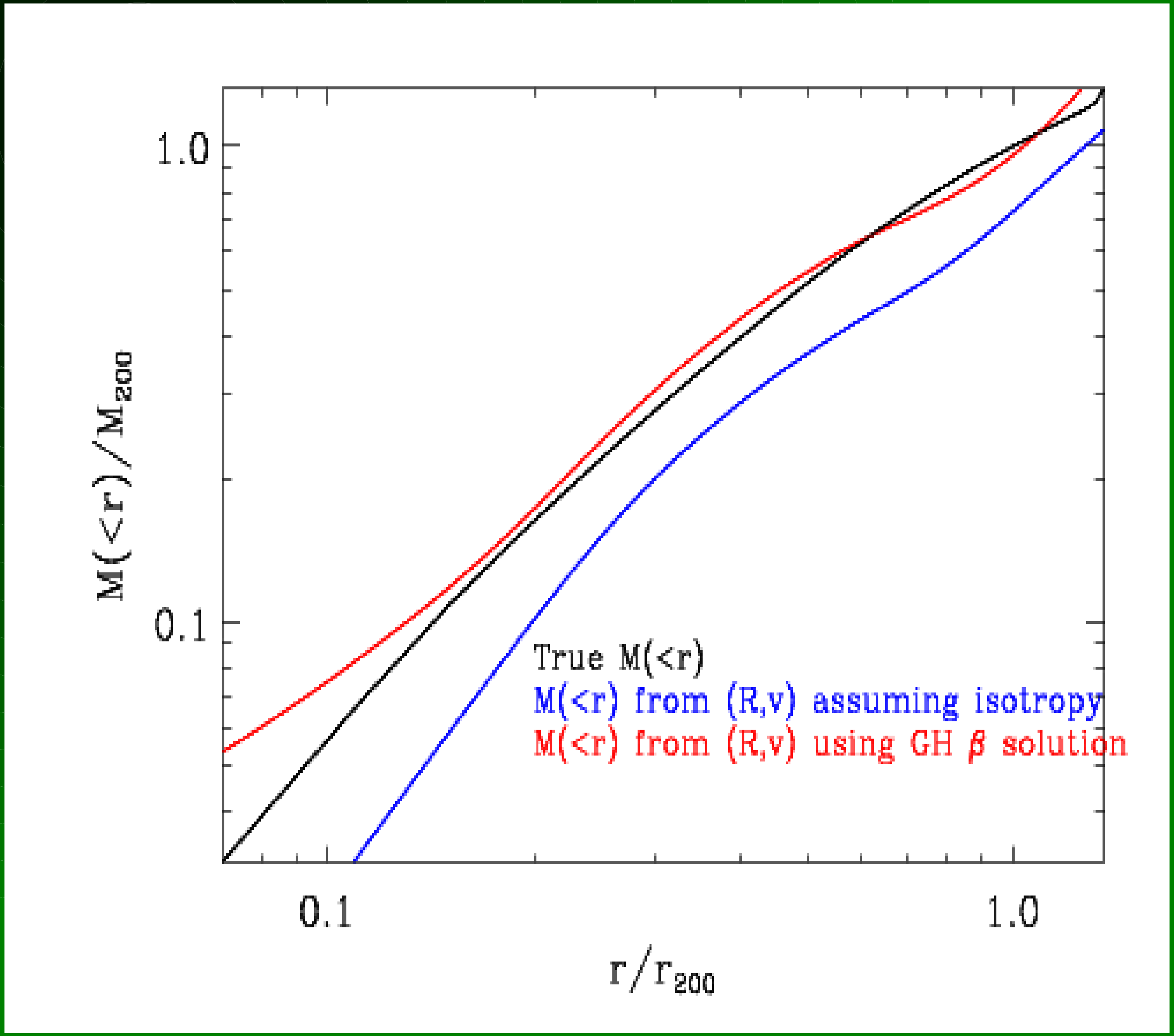
Stacked cluster from simulations, ≈4000 objs

(B. et al. in prep.)

Model the inferred anisotropy with a suitable function and use the projected profiles to determine M(r):

Good agreement!

the isotropic solution can be rejected because it gives the wrong normalisation



Stacked cluster from simulations, ≈4000 objs

(B. et al. in prep.)

MORE MASS PROFILES

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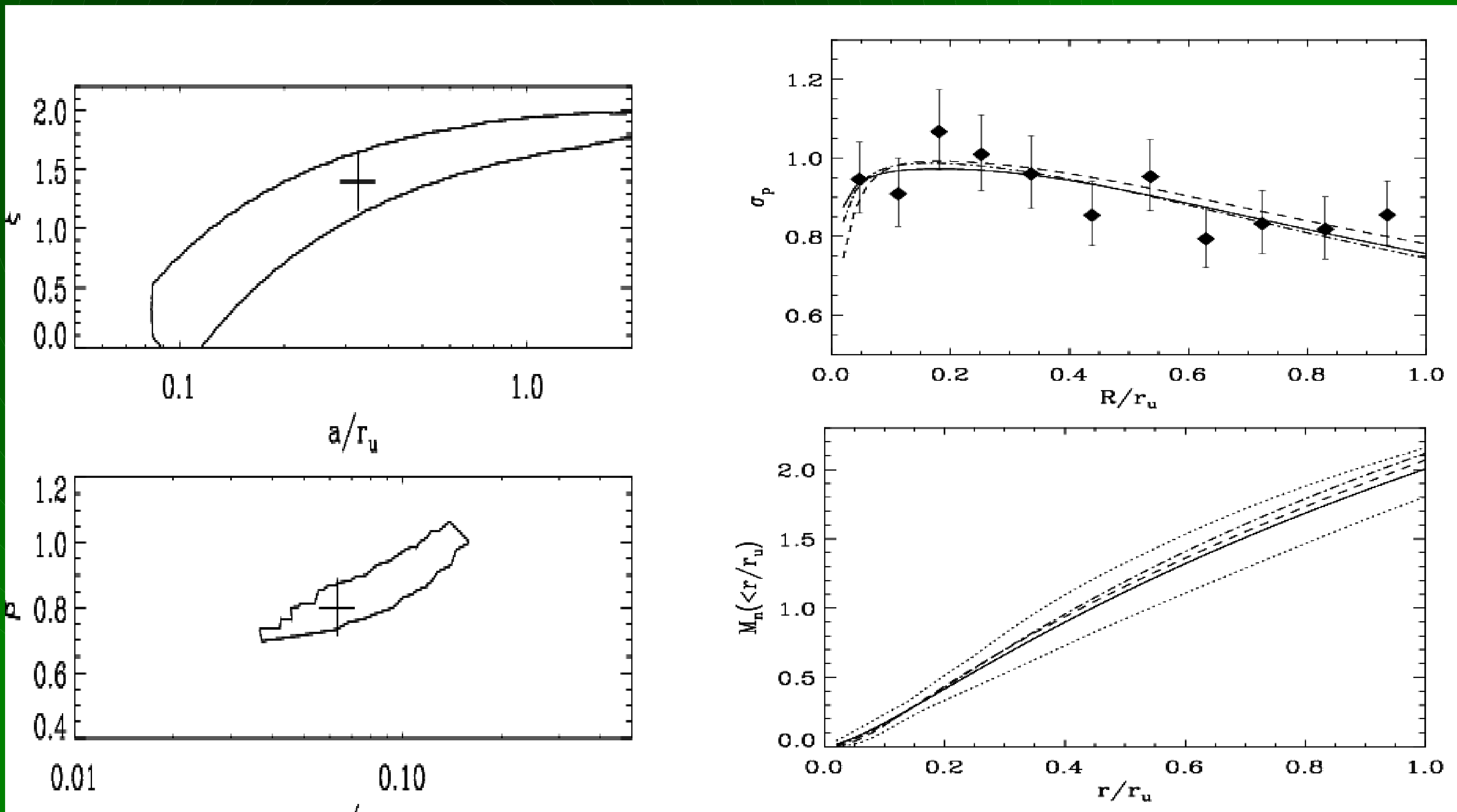
Extending M(<r) results to lower-mass systems: 1) poor clusters from 2dFGRS *(B. & Girardi 03)*

≃ 600 galaxies

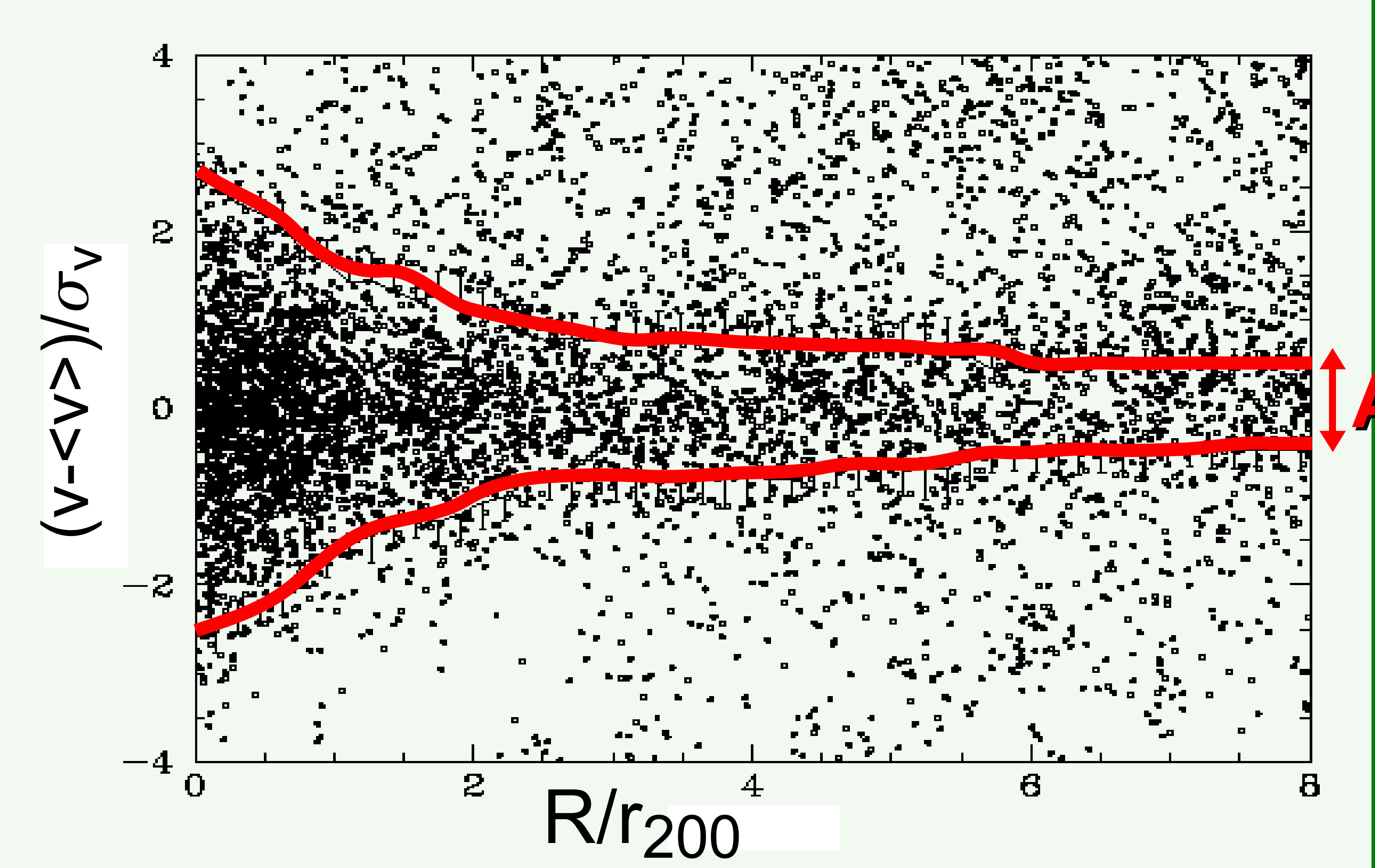


Similar conclusions as for ENACS, higher c

M(<r) from the caustic method:

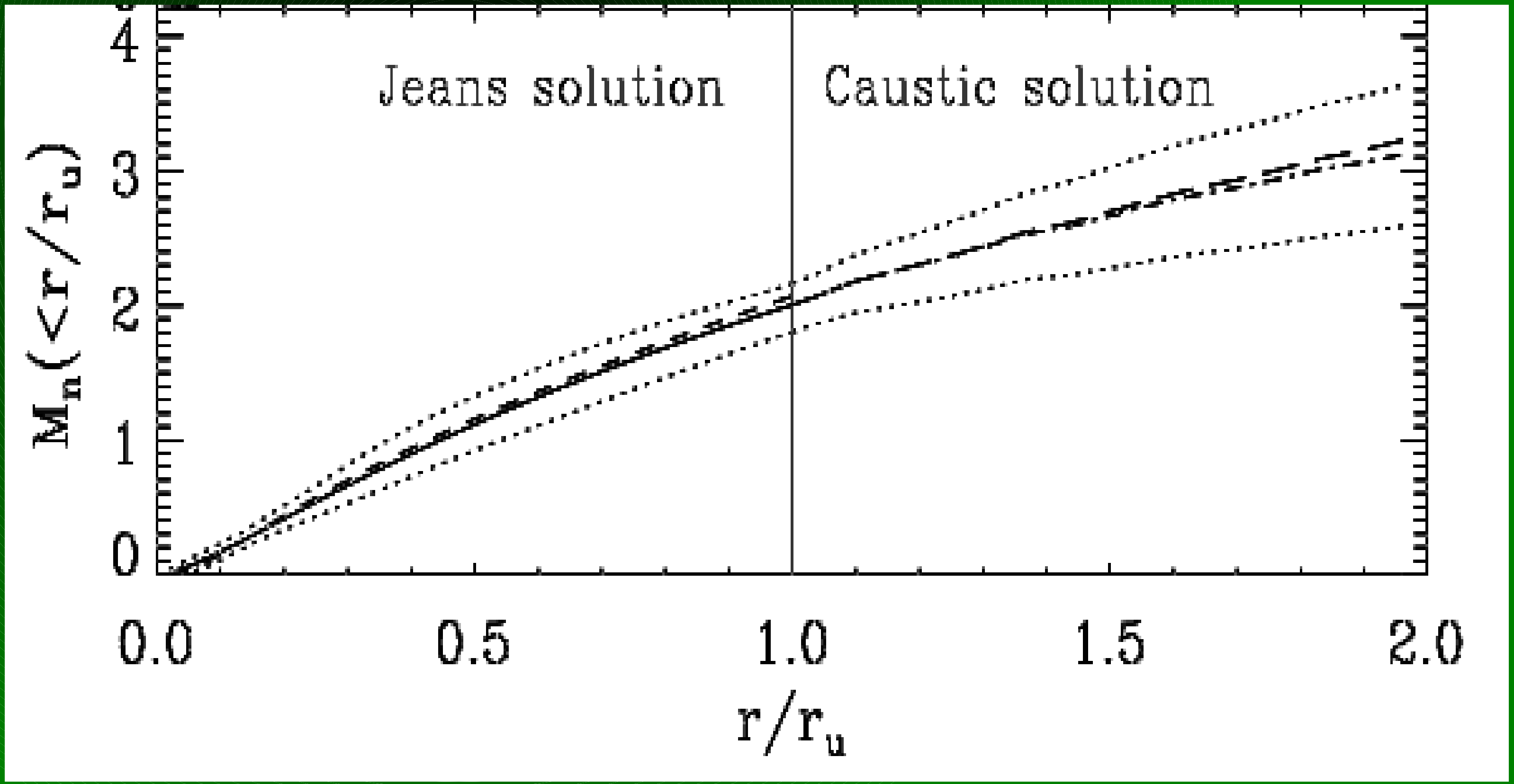
Based on num.sims.: from caustic amplitude A(r) → Φ(r) through F(Φ,β,r)≈const ...*outside the center, indipendent of dynamical status of the cluster*

(from Rines et al. 2003)



Caustic method: extend M(<r) at r > r_{200}
(no need to assume β)

2dFGRS, ≃1300 cluster galaxies

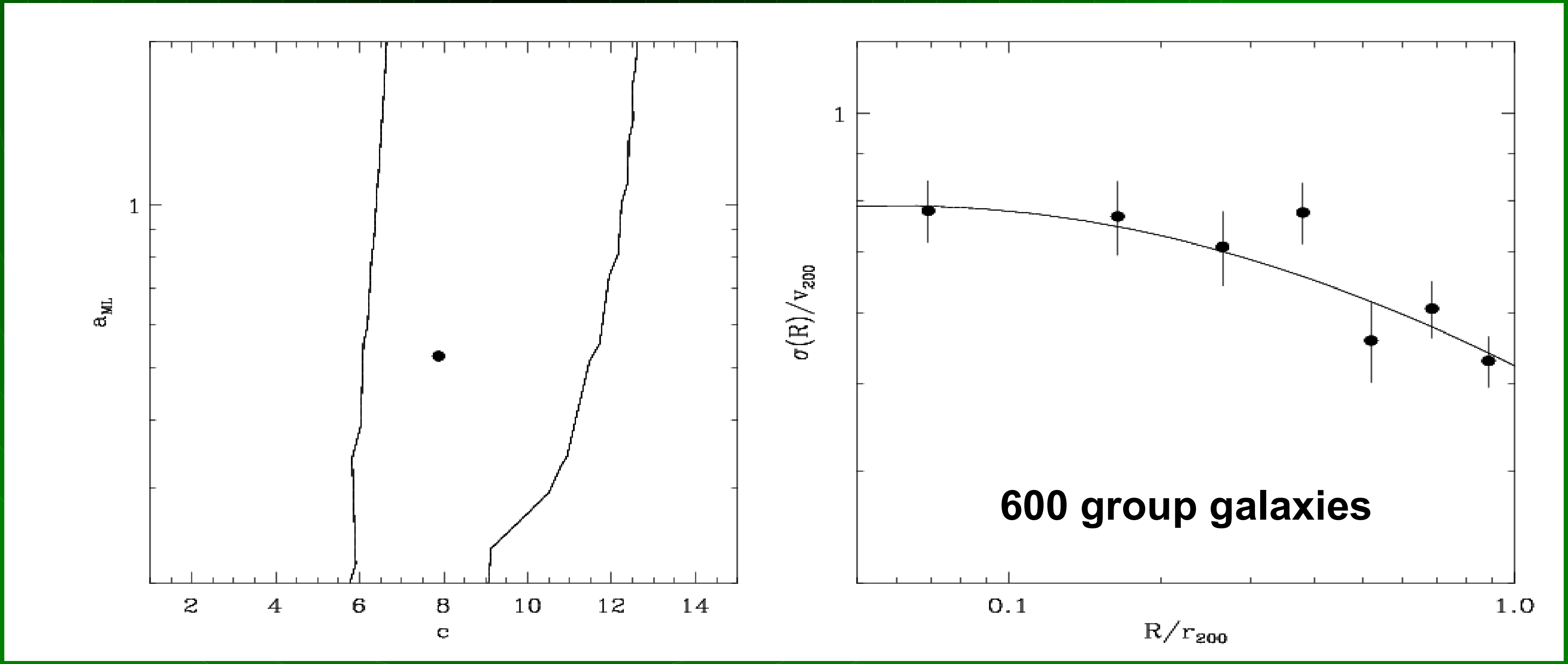


The caustic M(r) nicely continue the M(r) found with the Jeans solution i.e. $\rho(r) \sim r^{-3}$ at large r

Extending M(<r) results to lower-mass systems

2) groups from GEMS *(B., Mamon & Ponman in prep.)*

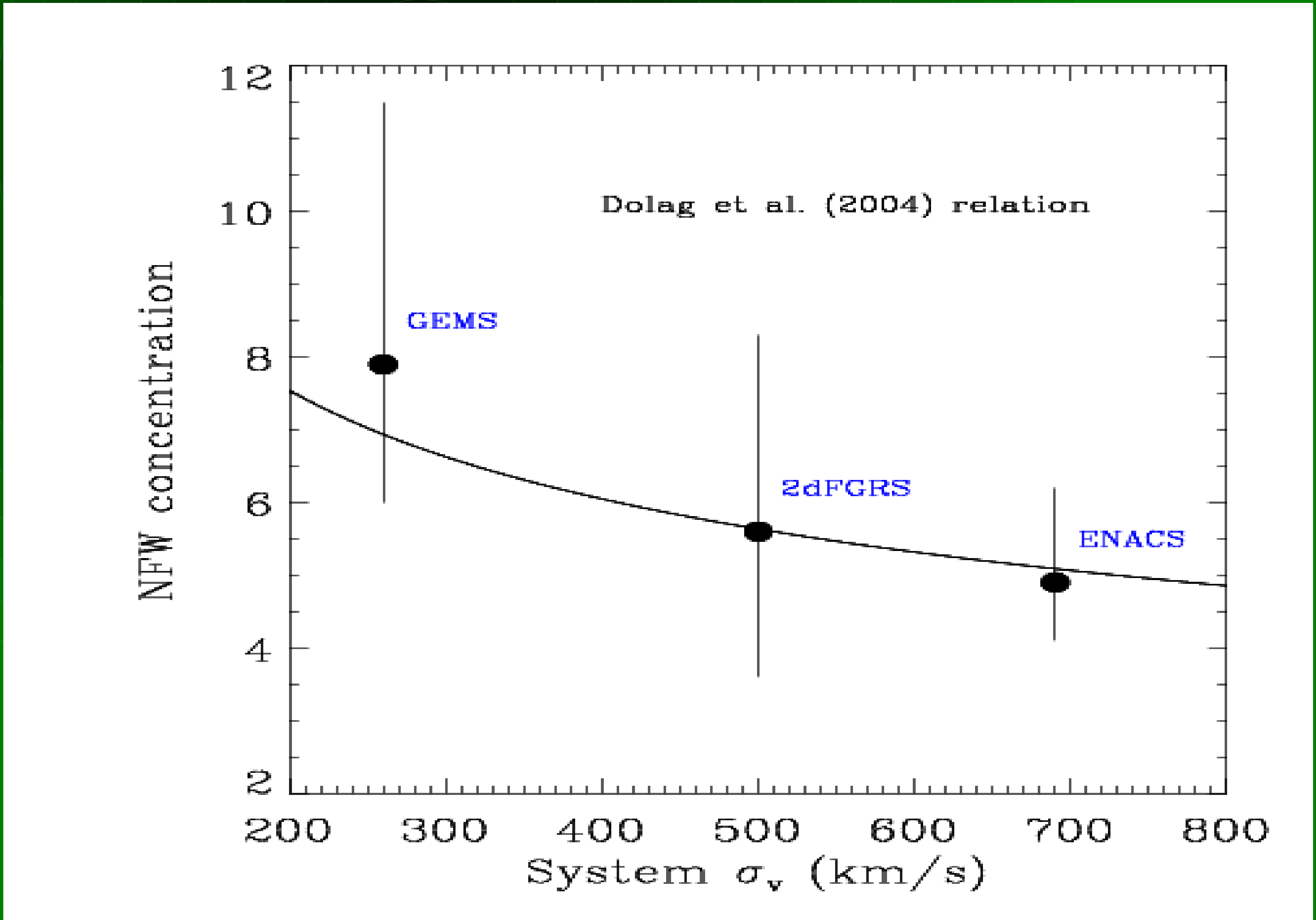
Use X-ray Temperatures for scaling through M=M(Tx) !



Joint best-fit for M(r) and β(r):

NFW acceptable fit with higher c than for clusters, no real constraint on β, but result for c is robust

Combining results: NFW c=c(M) in agreement with theoretical predictions



ORBITS OF GALAXIES IN CLUSTERS

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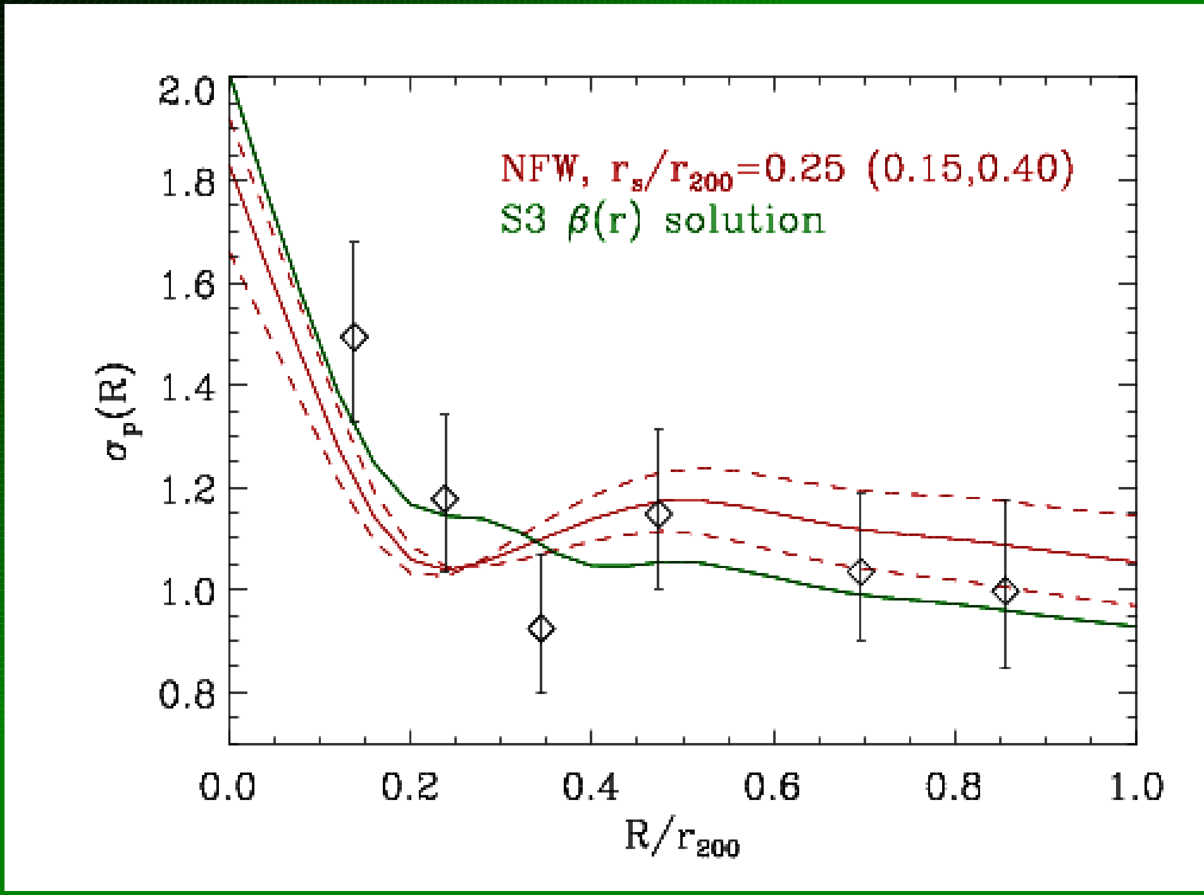
Given M(r), invert Jeans eq. ⇒ $\beta(r)$

(B. & Katgert 04; see Binney & Mamon 82, Solanes & Salvador-Solé 90)

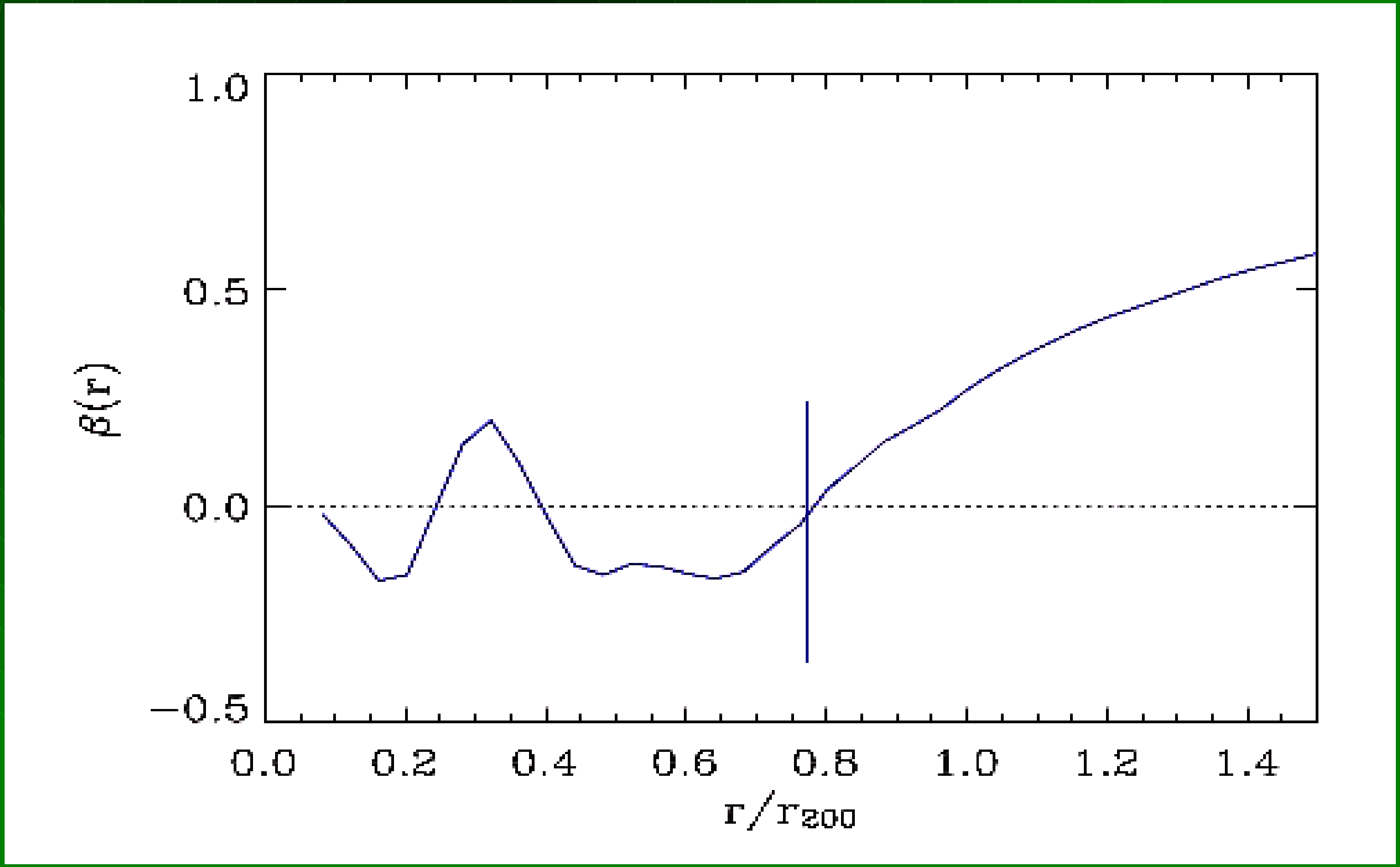
Velocity distribution shape ⇒E+S0 on nearly isotropic orbits

What about other morphological classes?

Early spirals (Sa, Sab) are in equilibrium within the same grav. potential traced by E+S0, and move on nearly isotropic orbits



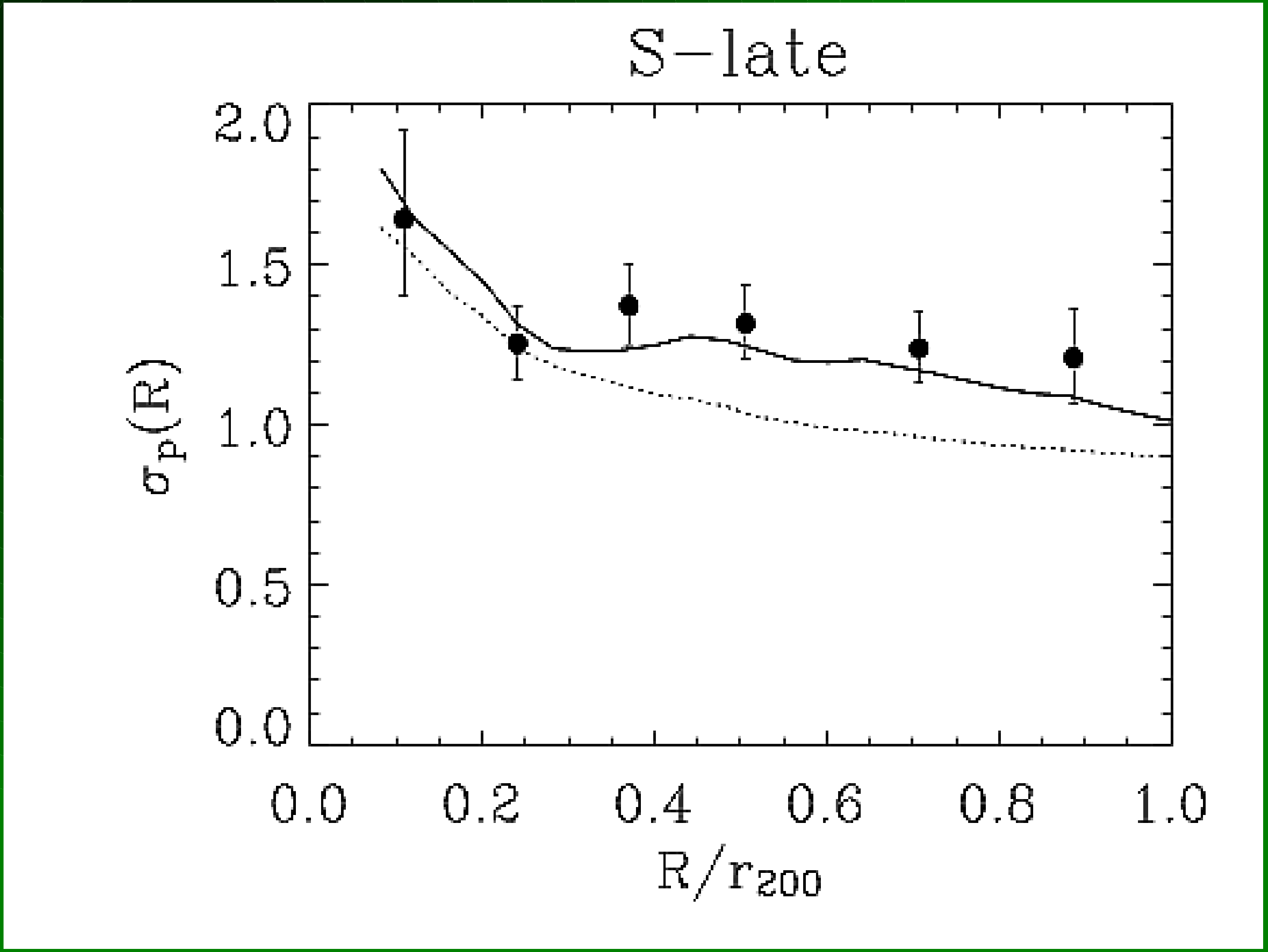
Also *Late* Spirals in equilibrium *but move on increasingly radial orbits with increasing radius*



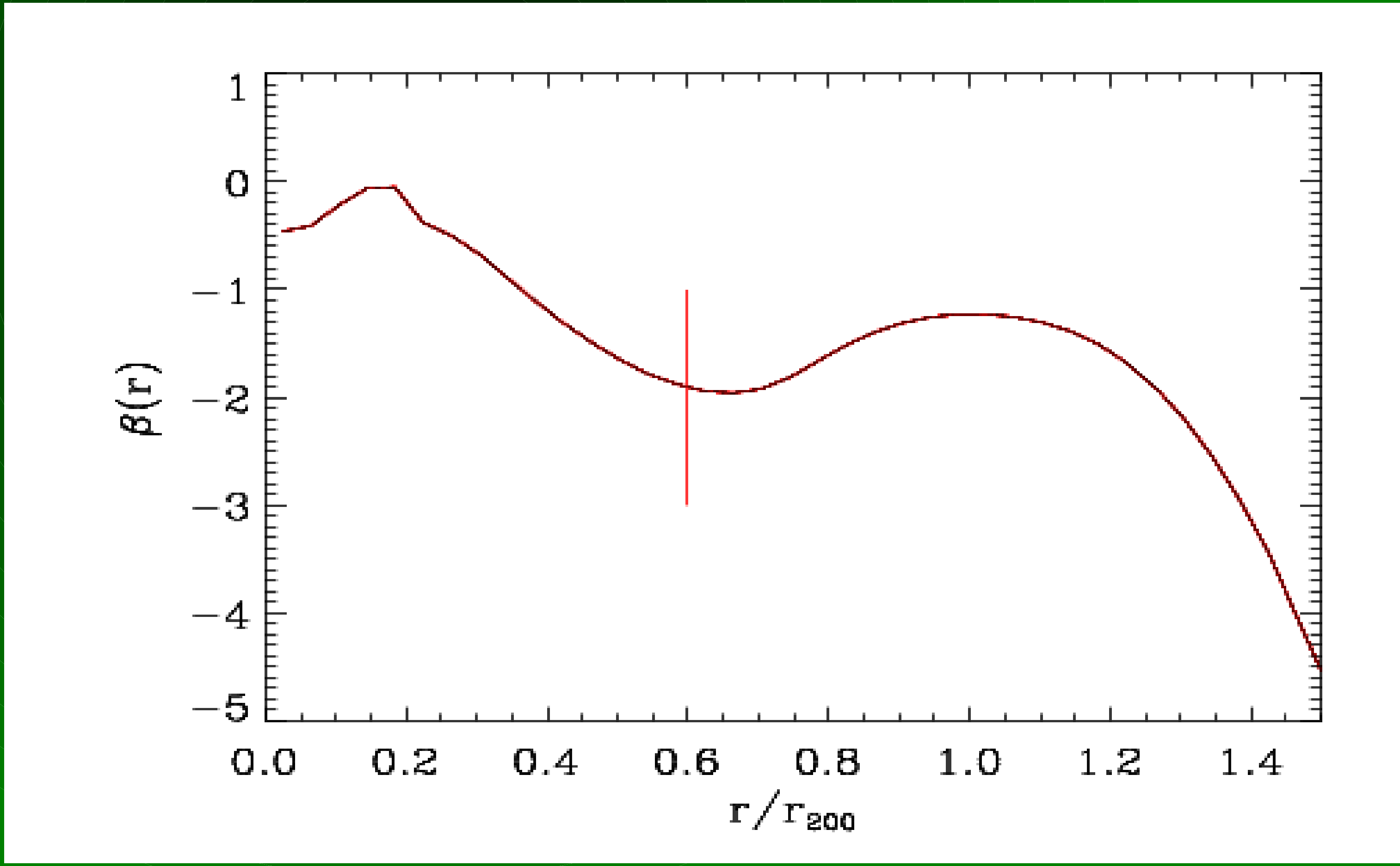
Newcomers into cl potential, memory of infall

Also *Late* Spirals in equilibrium *but move on increasingly radial orbits with increasing radius*

Anisotropic (solid line) vs. isotropic (dotted line) solution: the isotropic solution does *not* fit the data in this case!



Galaxies in substructures
move on tangential orbits



Selection process?

Substructures with small pericenter tidally disrupted

SHOULD WE TRUST THESE ANISOTROPY PROFILES?

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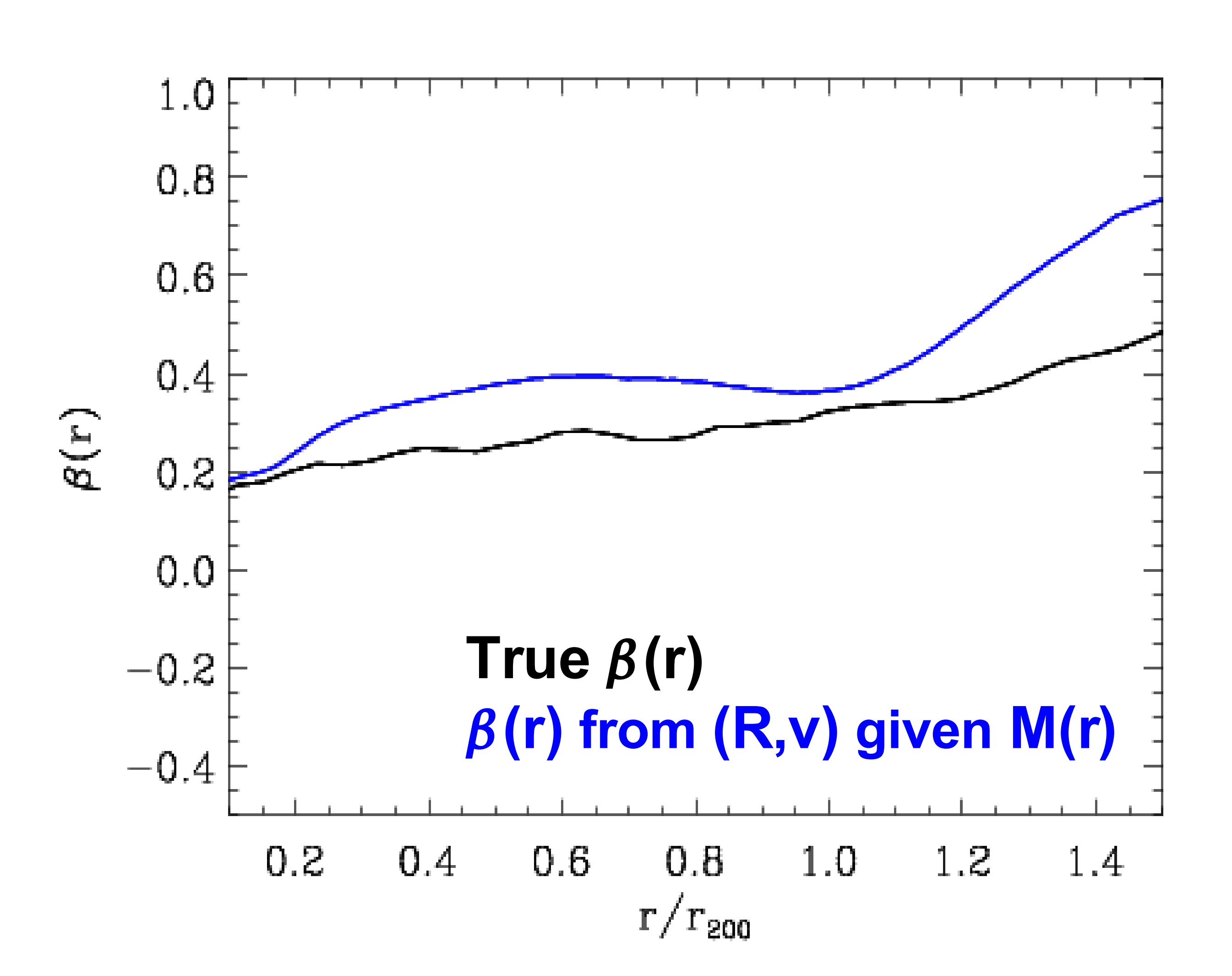
⇒ compare to clusters extracted from cosmological simulations *(B. et al. in prep.; see Borgani et al. 04)*

Overestimate probably due to unidentified interlopers in (R,v) space



ORBITS OF GALAXIES IN CLUSTERS: EVOLUTION

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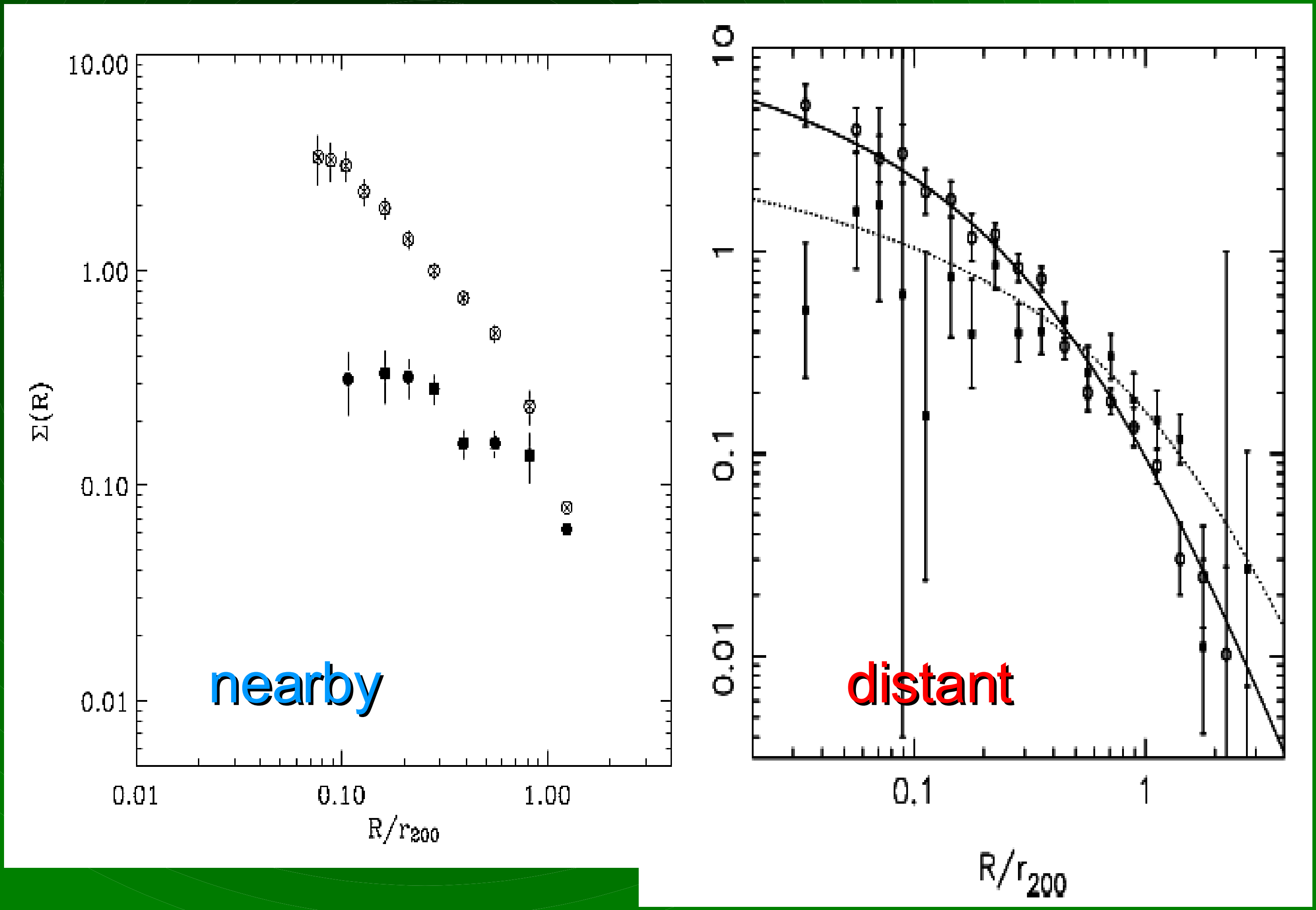
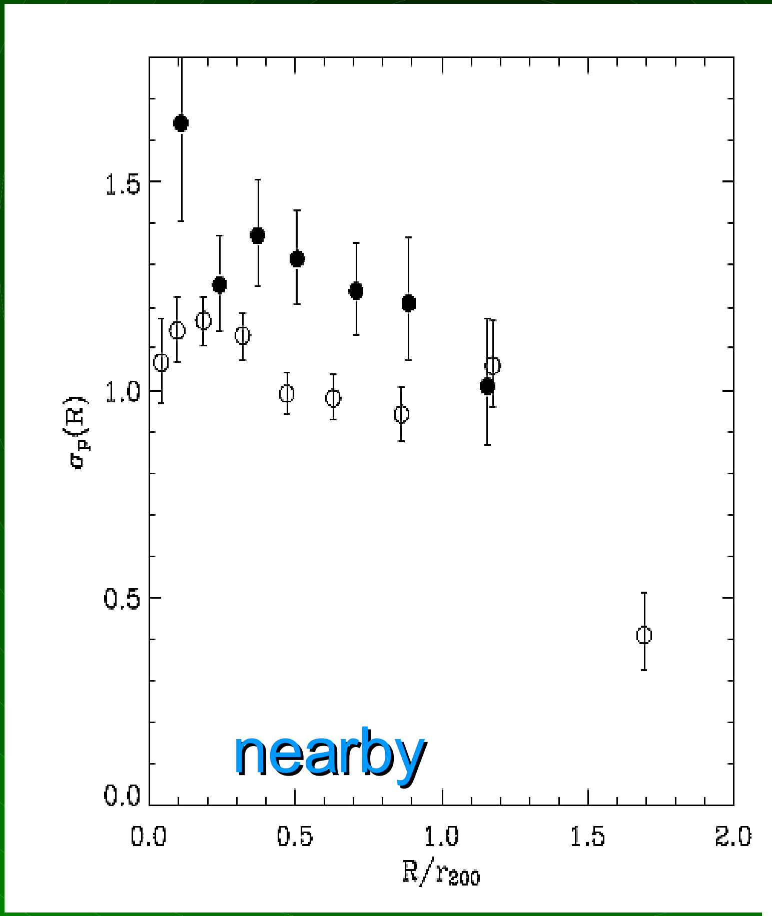
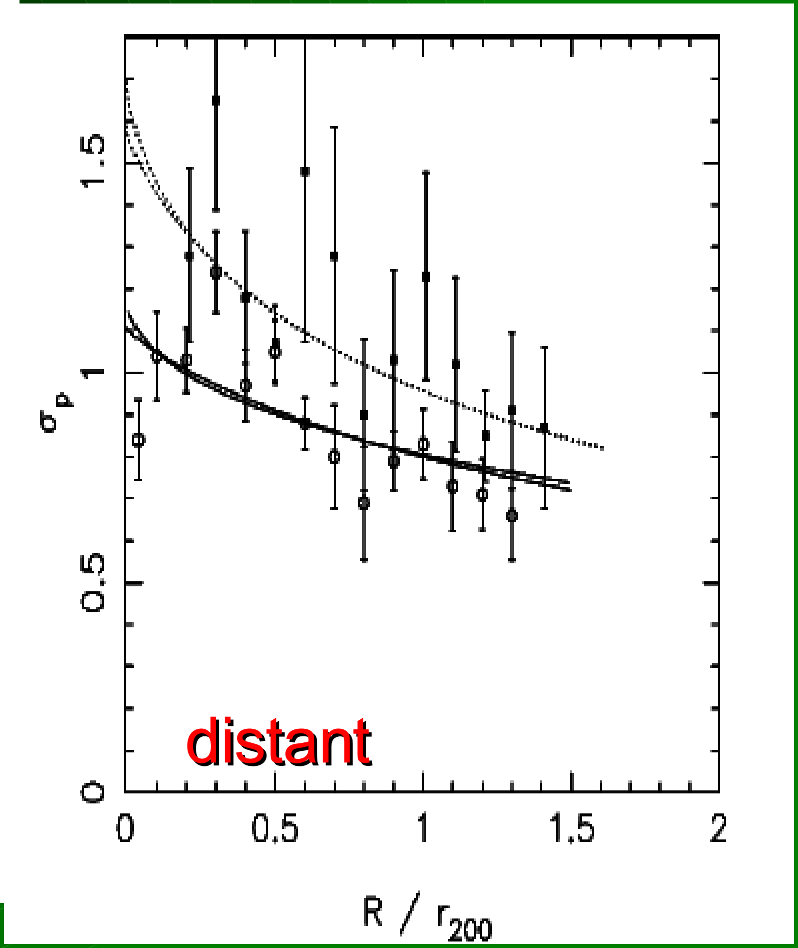
Compare ENACS vs. CNOC



Number density profiles for early- (empty symbols) and late- (filled symbols) cluster galaxies

Compare ENACS vs. CNOC





$\sigma_p(R)$ profiles for early- (empty symbols) and late- (filled symbols) cluster galaxies

Early-type galaxies at z≈0 & z≈0.3: isotropic orbits
(Katgert, B. & Mazure 04; van der Marel et al. 00)
Late-type galaxies at z≈0: radial orbits *(B. & Katgert 04)*

No evolution of (R,v) distributions
of early- and late-type galaxies from z≈0 to z≈0.3
(Carlberg et al. 97 vs. B. & Katgert 04)

⇒ late-type galaxies at z≈0.3 must also be on radial orbits like late-type galaxies at z≈0

The late-type -galaxy fraction increases with z,
hence more cl. galaxies are on radial orbits at higher z
⇒ the infall rate increases with z
(in agreement with Ellingson et al. 2001)

CONCLUSIONS

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Dark Matter density profile in clusters and groups as predicted by CDM models; cannot exclude cored profiles, but core $\simeq 0.1\ r_{200}$ ~ size of central cD

(implications on DM cross-section)

DM more concentrated than baryons

(implications on how effective are the dynamical friction & adiabatic contraction processes)

E, S0, Sa, Sab move on isotropic orbits,
Sbc...Irr move on slightly radial orbits *(? TBC w. sims)*
Higher fraction of radial orbits galaxies at higher z

(implications on clusters accretion history)

- The best fitting Burkert core-radius is small,
  $0.1\ r_{200}$ ~ size of central cD
  → DM scattering cross section $<2\ cm^2\ g^{-1}$
(By comparison with simulation res. of Meneghetti et al. 2001)

Much smaller than the 5 $cm^2 g^{-1}$ needed to fit dwarf galaxy mass density prof., Davé et al. (2000)

- DM is *more* concentrated than the total matter

Dynamical friction mechanism ineffective in transferring galaxy energy to DM in clusters or counteracted by adiabatic contraction (e.g. Zappacosta et al. 2006)

Work in progress and future work

Num.simulations: optimize algorithm for M(r) and β(r) & investigate physics of evolution of orbits of galaxies in cls

GEMS: *CDM M(r) OK on cluster scales, not on galactic scales*
⇒ investigate intermediate scales: galaxy groups

CIRS & WINGS: Improve current constraints on cluster M(r) and β(r) using larger data-bases *(ongoing collaborations with Diaferio & Rines, and Bettoni, Cava, Fasano, Poggianti et al.)*

ICBS: Extend the analysis to higher-z clusters *(possible collaboration with Dressler, Poggianti et al.)*

That's all folks!

FIRST RESULT OF THE r-EXCESS PROJECT:
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