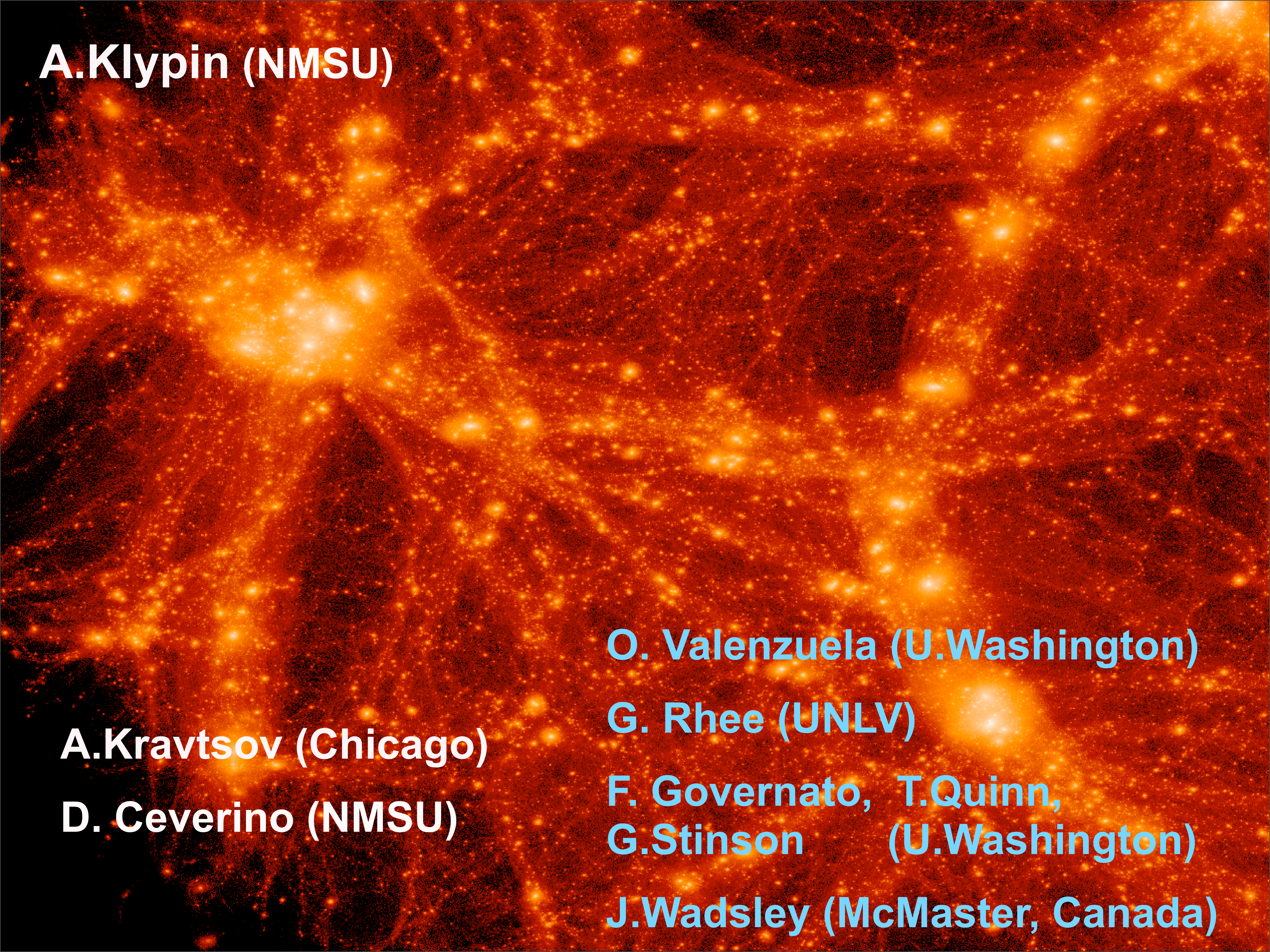

A.Klypin (NMSU)
O. Valenzuela (U.Washington)
G. Rhee (UNLV)
A.Kravtsov (Chicago)
D. Ceverino (NMSU)
F. Governato, T.Quinn,
G.Stinson (U.Washington)
J.Wadsley (McMaster, Canada)

A.Klypin (NMSU)

Dark Matter Halos

A.Kravtsov (Chicago)

D. Ceverino (NMSU)

O. Valenzuela (U.Washington)

G. Rhee (UNLV)

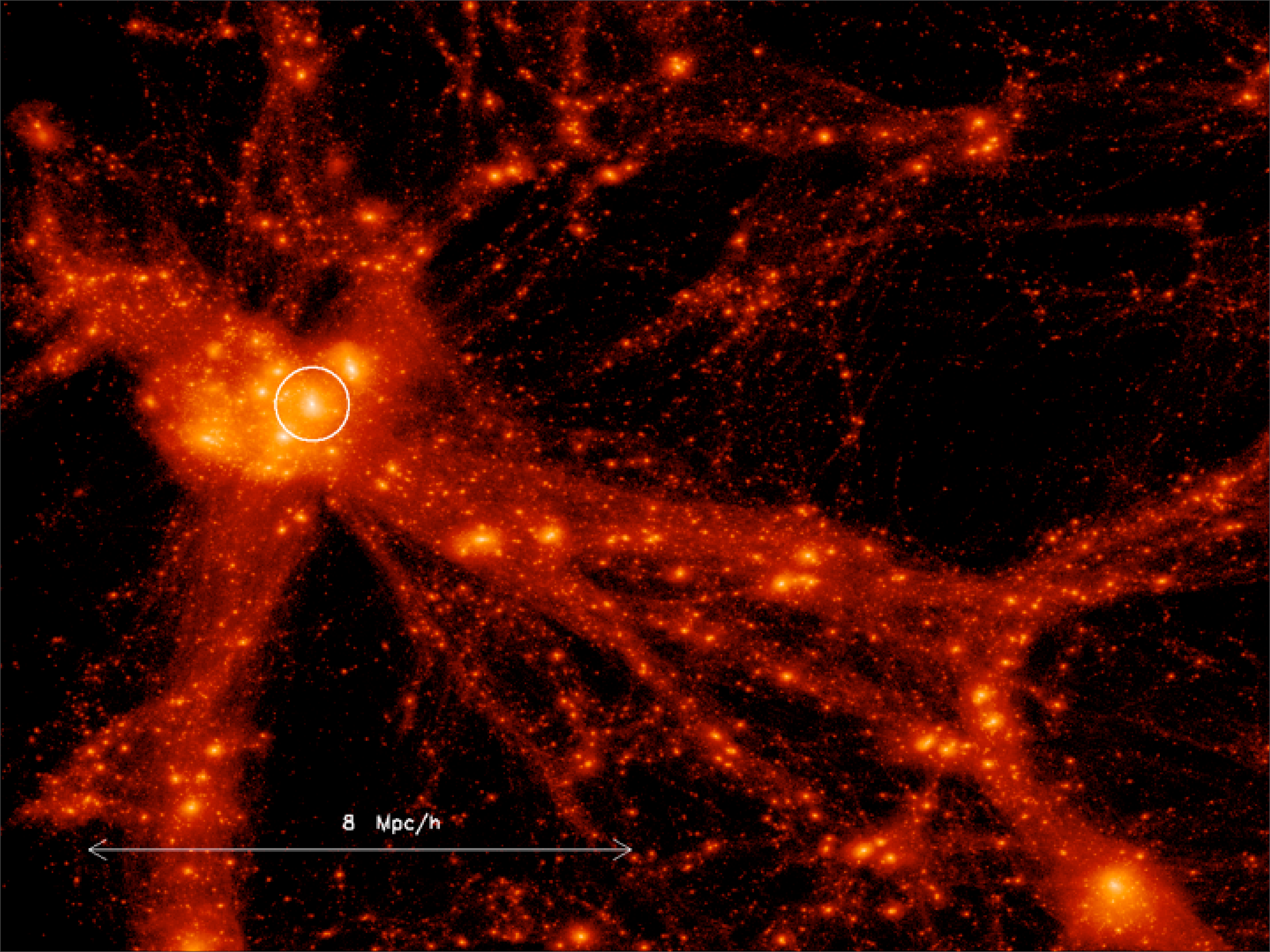
F. Governato, T.Quinn, G.Stinson (U.Washington)

J.Wadsley (McMaster, Canada)

Major codes:

- N-body
- Hydro
- Cooling/Heating/SF
- Metal enrichment
- Radiative transfer
- Multistepping/Multiple masses

GADET	Springel, SDM White
PKDGRAV - GASOLINE	Quinn, Steidel, Wadsley, Governato, Moore
ART	Kravtsov, Klypin, N.Gnedin, Gottlober
ENZO	Bryan, Norman


8 Mpc/h

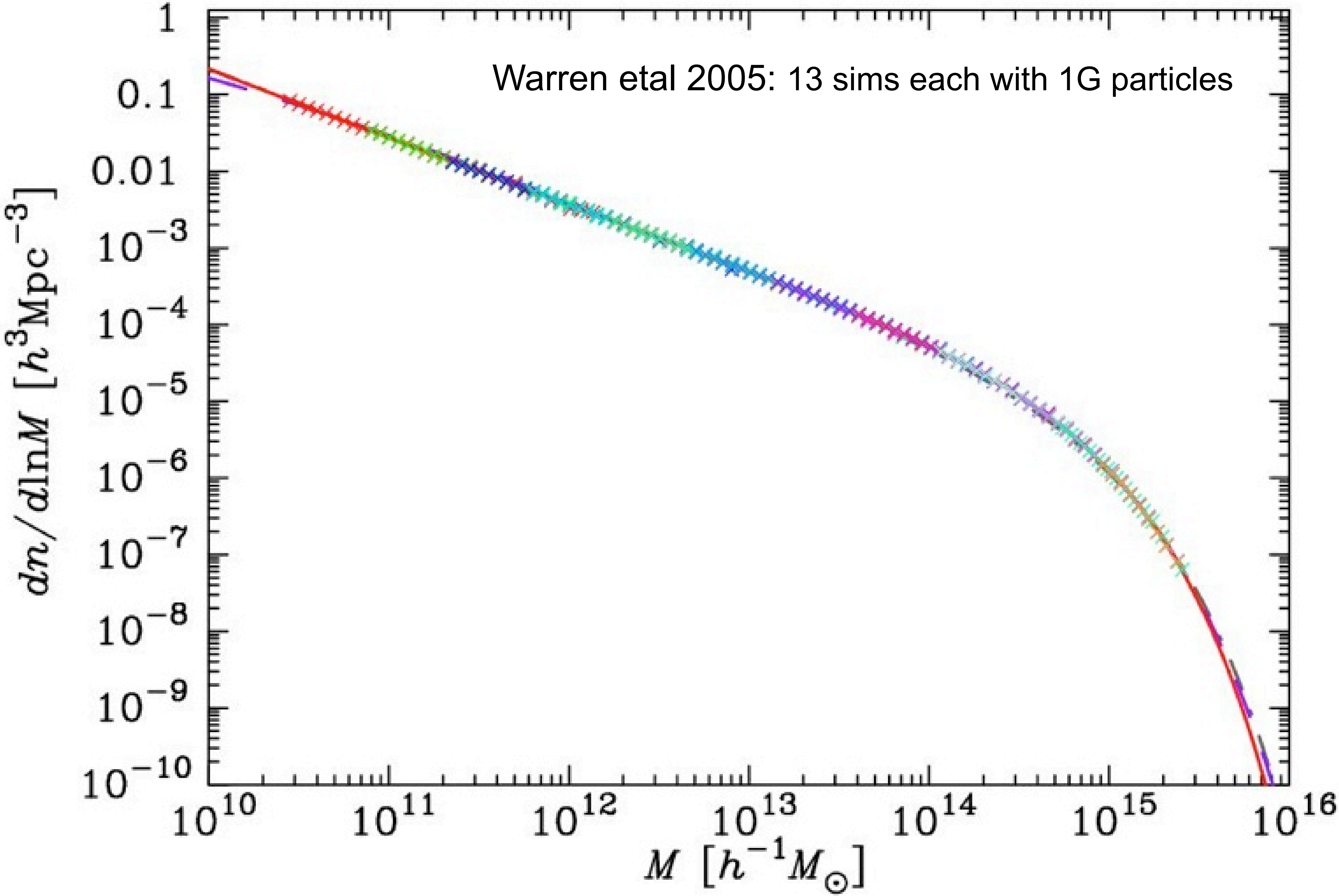

0.8 Mpc/h

Mass function of distinct halos

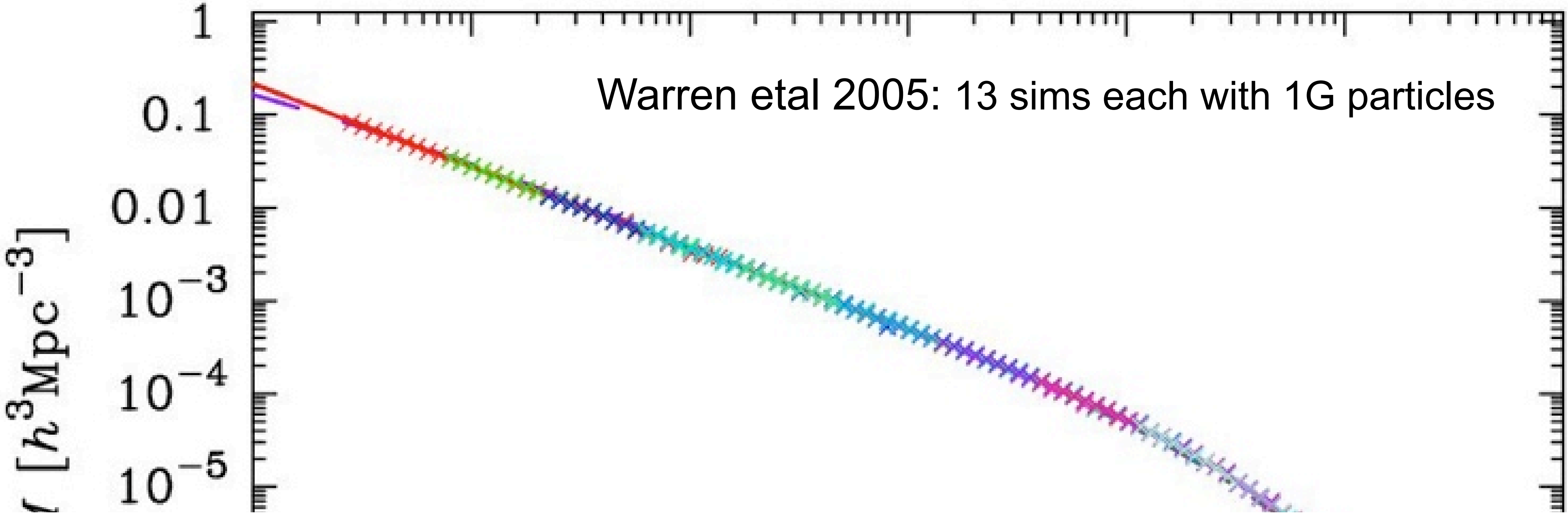
Mass function of distinct halos

- It started long ago: 32 years to be precise
- Now we live through 5th generation of this.

Mass function of distinct halos



Mass function of distinct halos



Mass Function of Dark Matter Halos 3

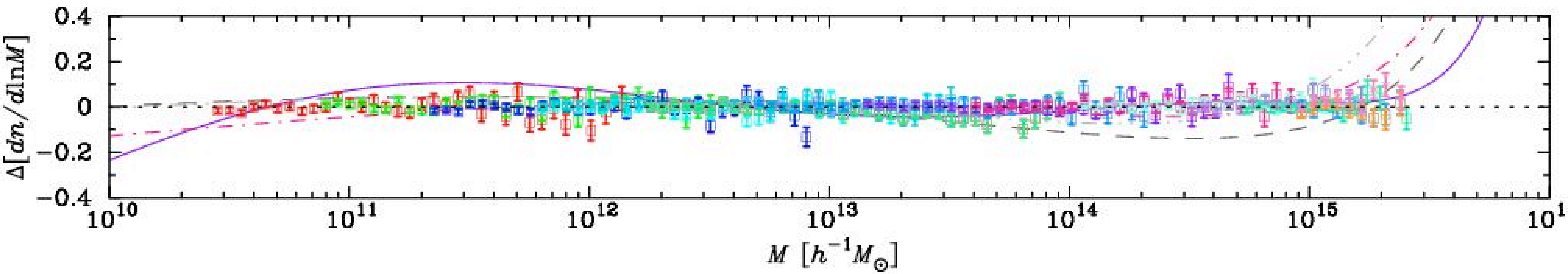
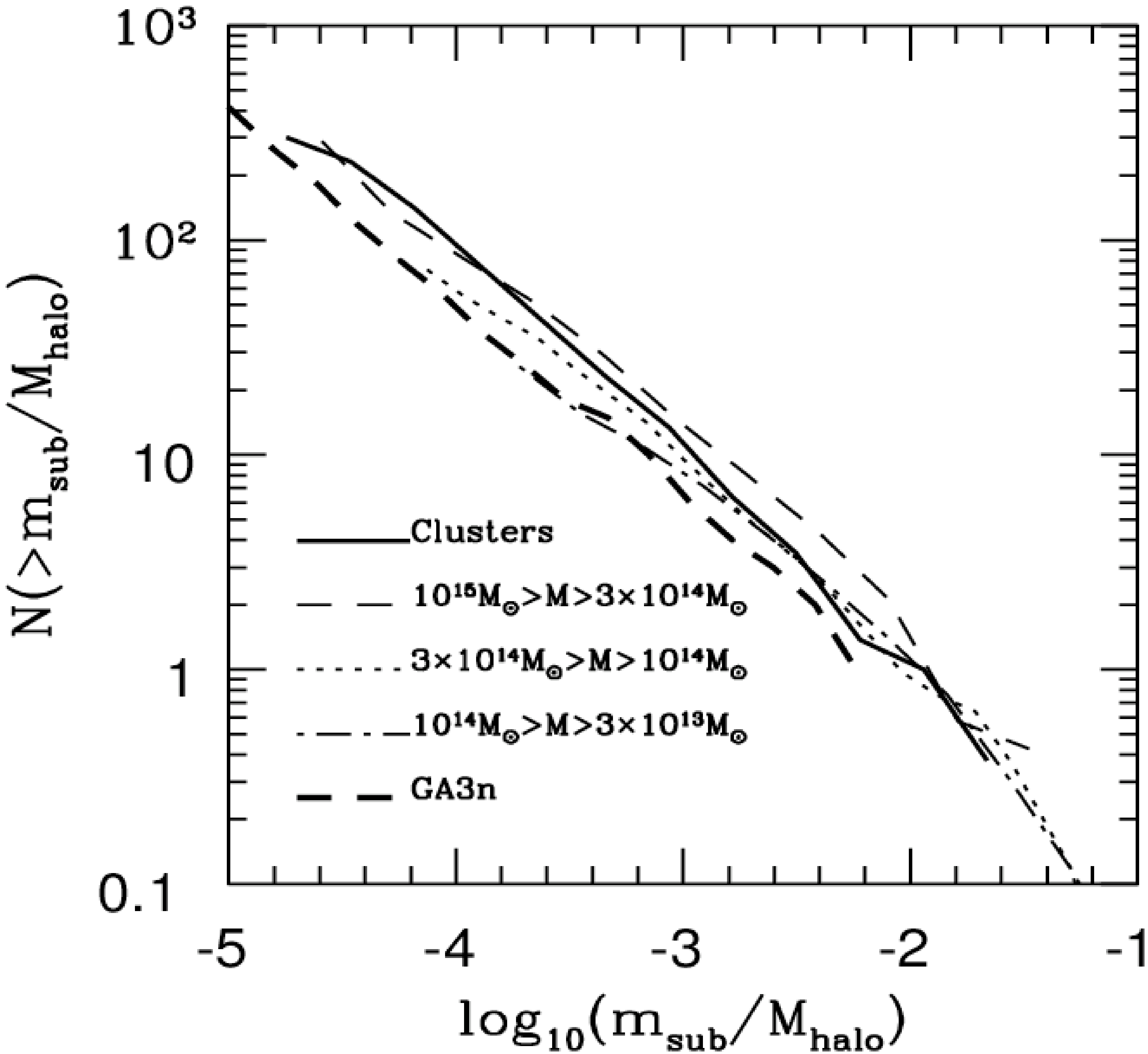


FIG. 2.— Shown are the residuals from the binned simulation data to the fit presented in this work as square data points of different colors per simulation. The Jenkins fit is the solid (purple) line, ST original fit the dashed (dark gray) line, the ST fit with parameters A, a, p free with dot-dashed line (red), and the ST fit with a, p free and amplitude A set to require all dark matter in halos as a triple-dot-dashed line (light gray). The binned mass function from the Virgo Hubble Volume simulation are the asterisk points with errors (pink).

Subhalo mass function

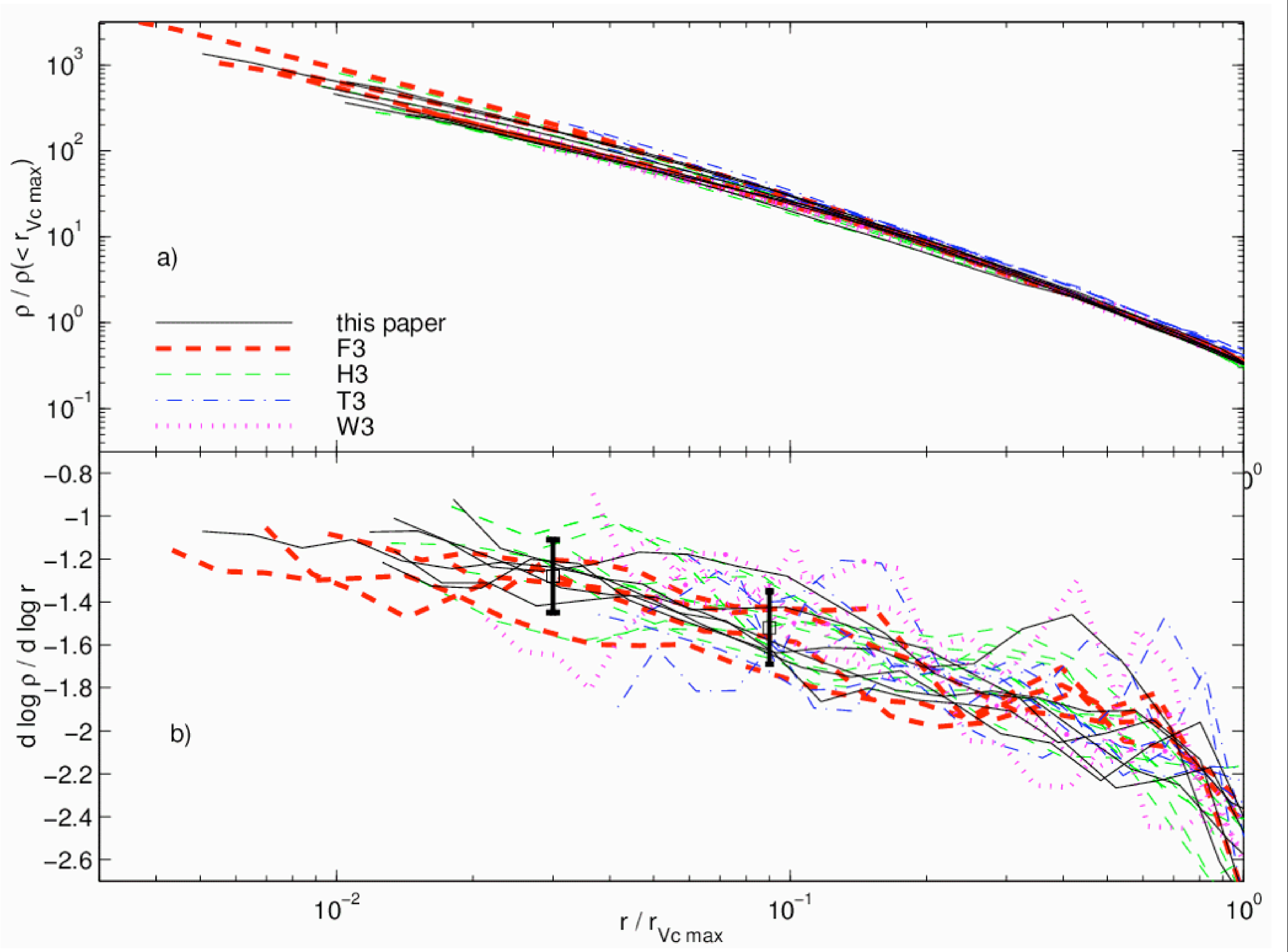
Gao et al 2004

Halos are not self-similar:
Large halos have more substructure.
Yet the effect is very weak.



Cusps: simulations

Diemand etal 2004

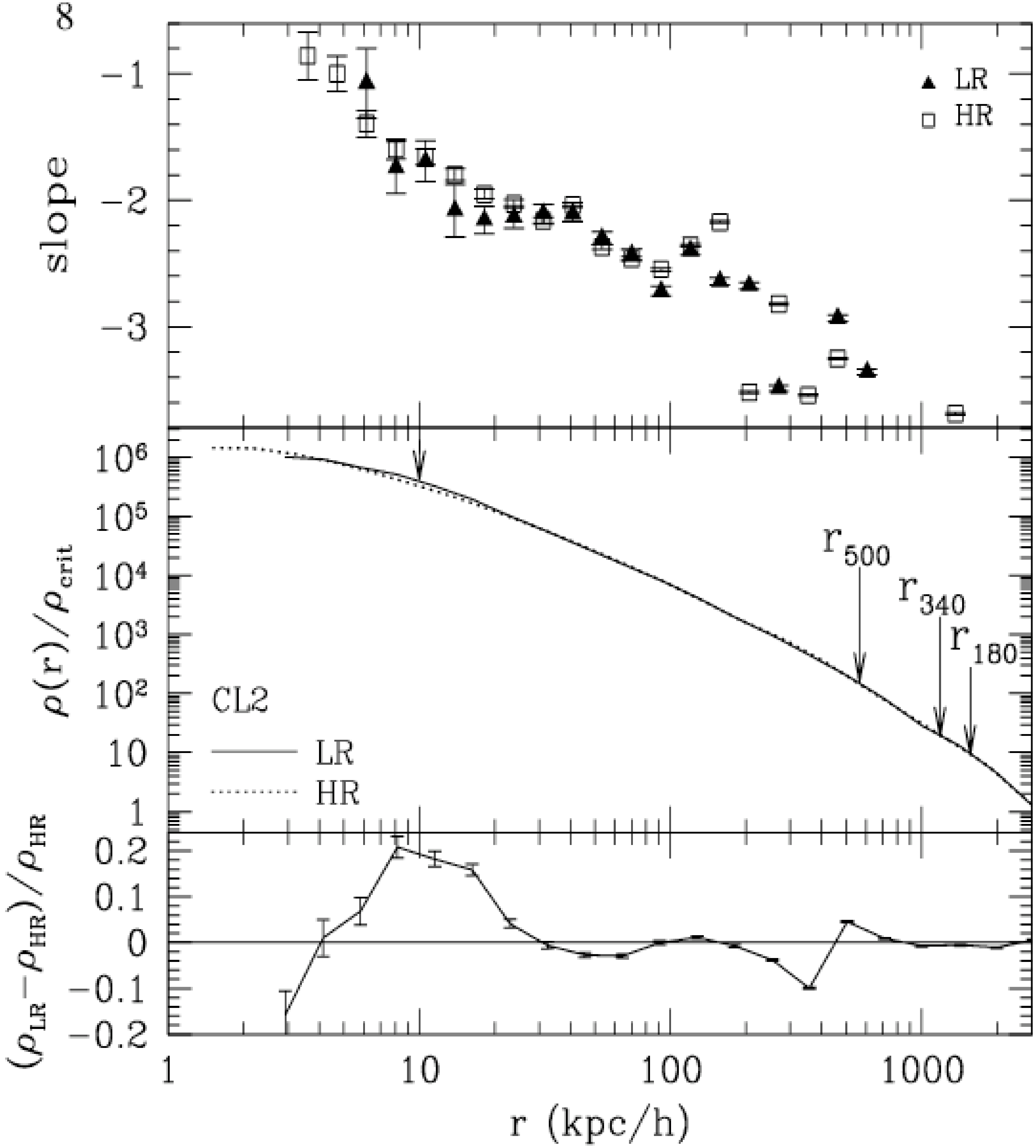


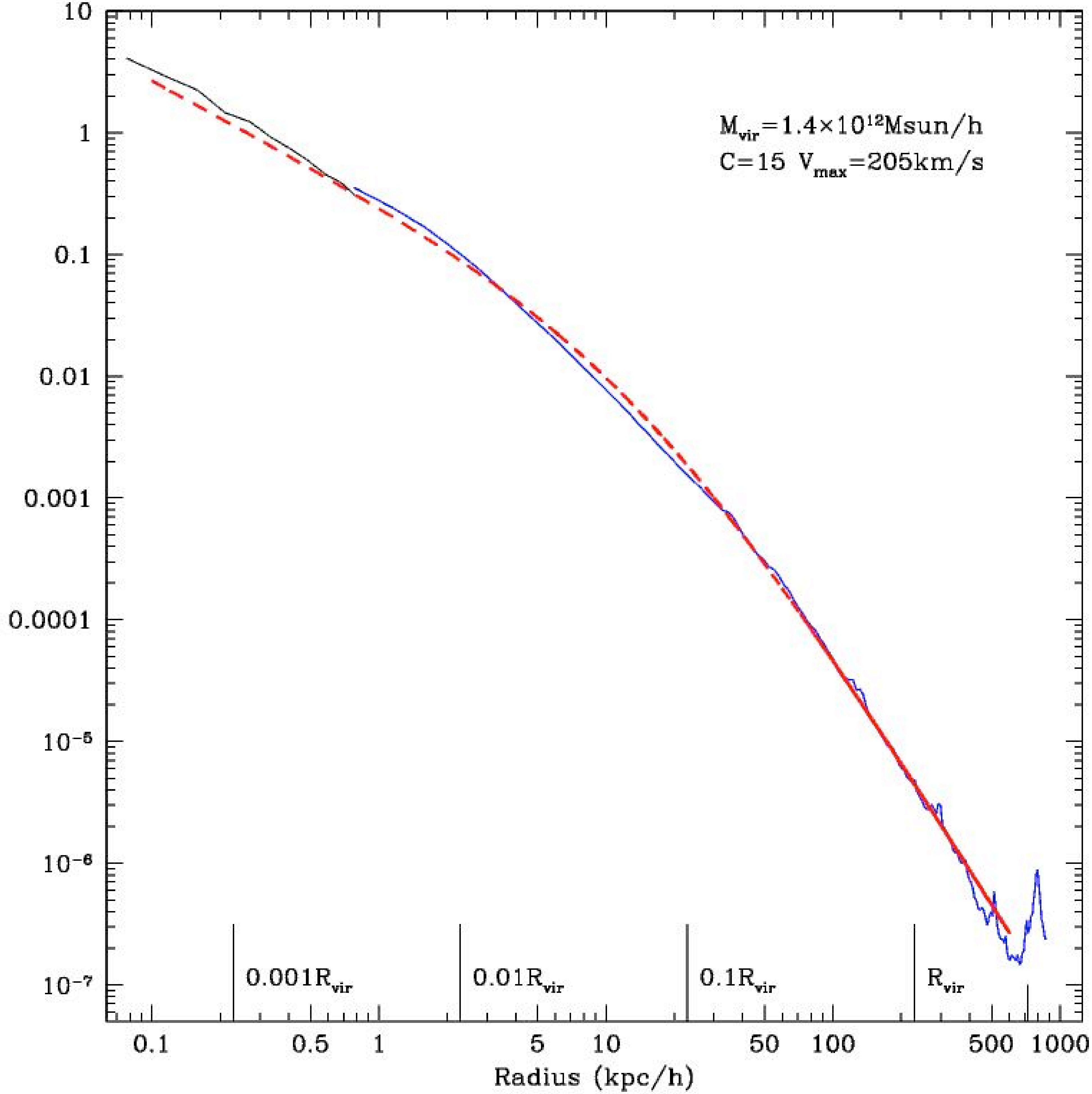
Tasitsiomi etal 2004

Navarro etal 2004

Slope gets shallower with decreasing radius, but it does not go below -1

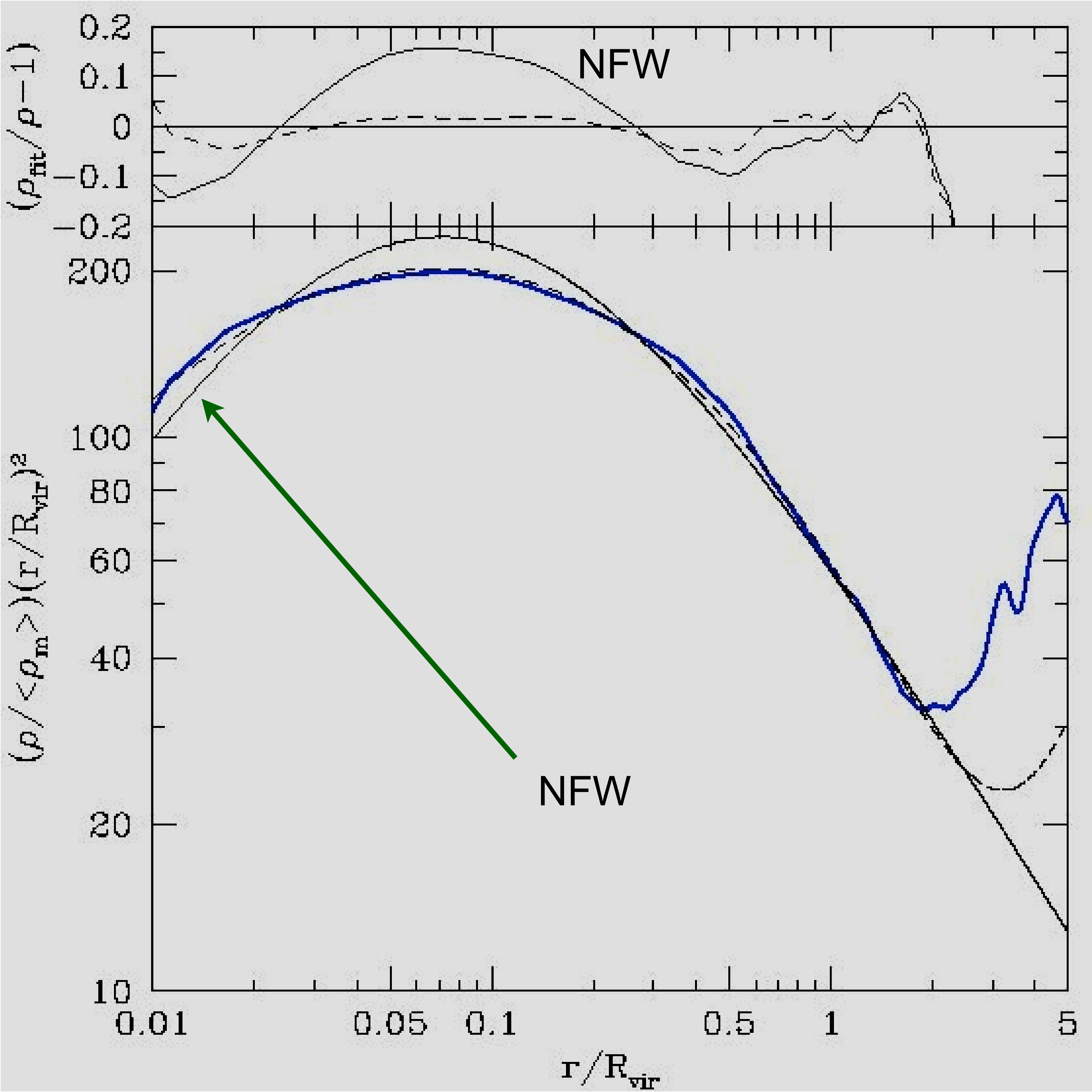
Consistent with what other groups found





$M_{vir}=1.4\times10^{12}$Msun/h
C=15 V_{max}=205km/s
$\rho(M_\odot h^2/pc^3)$
10
1
0.1
0.01
0.001
0.0001
10^{-5}
10^{-6}
10^{-7}
$0.001R_{vir}$
$0.01R_{vir}$
$0.1R_{vir}$
R_{vir}
0.1
0.5
1
5
10
50
100
500
1000
Radius (kpc/h)

Profiles are NOT NFW

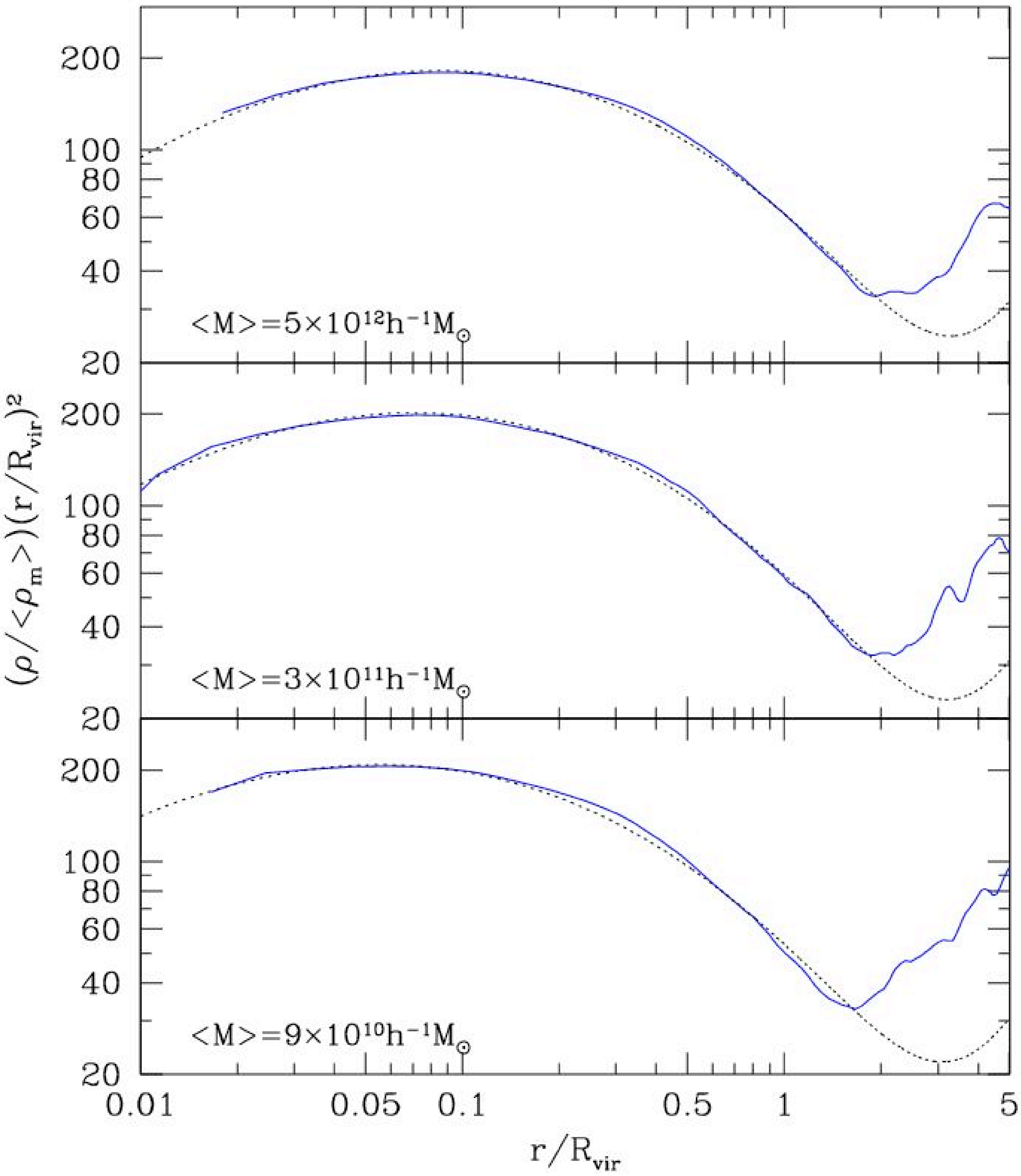


$\rho(r)=\rho_o \exp(-2nr^{1/n})+<\rho>$

n=6-8 3D Sersic

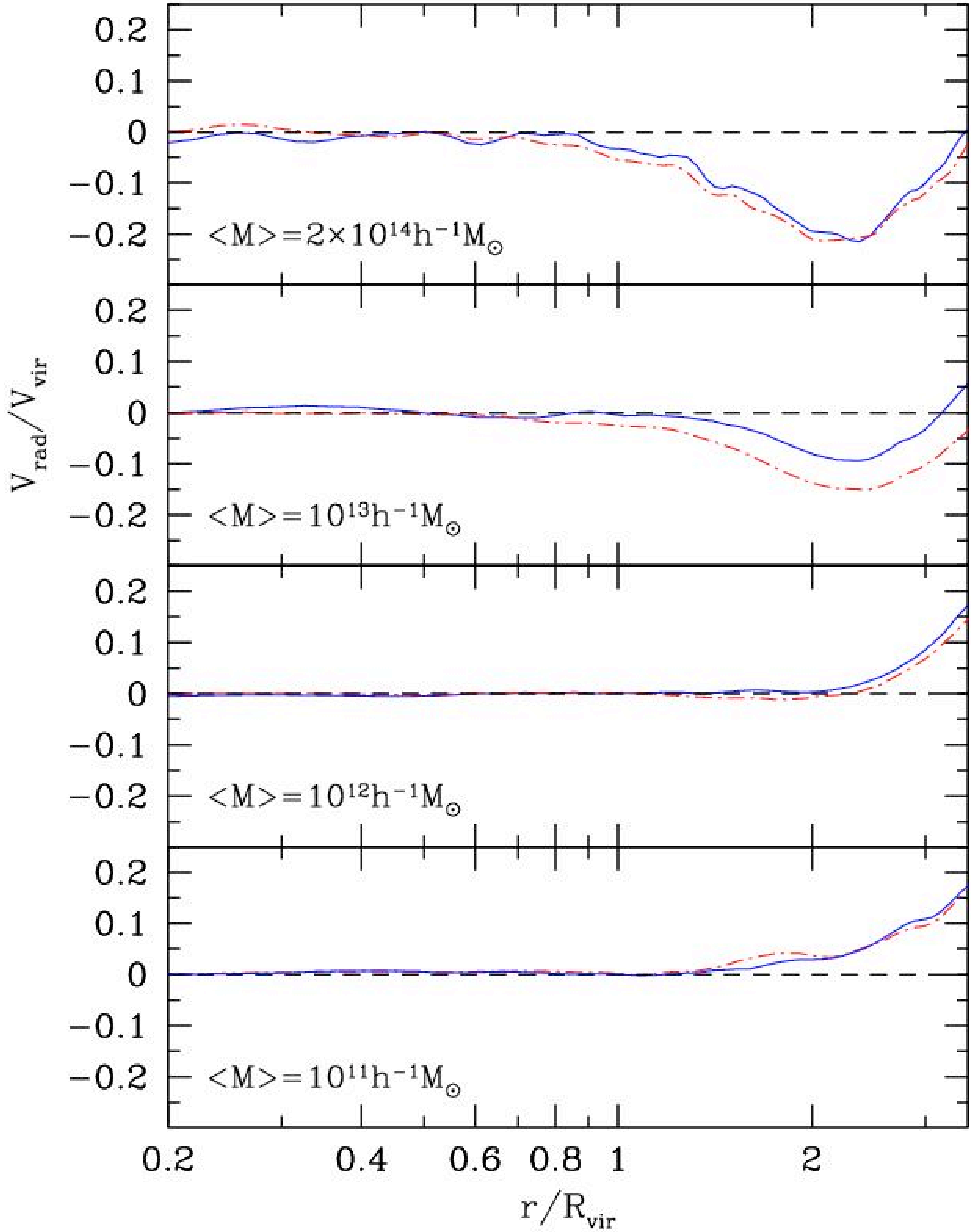
Navarro etal 2004
Merritt, Navarro 2004
Prada etal 2005

Average profiles of Milky Way-size halos



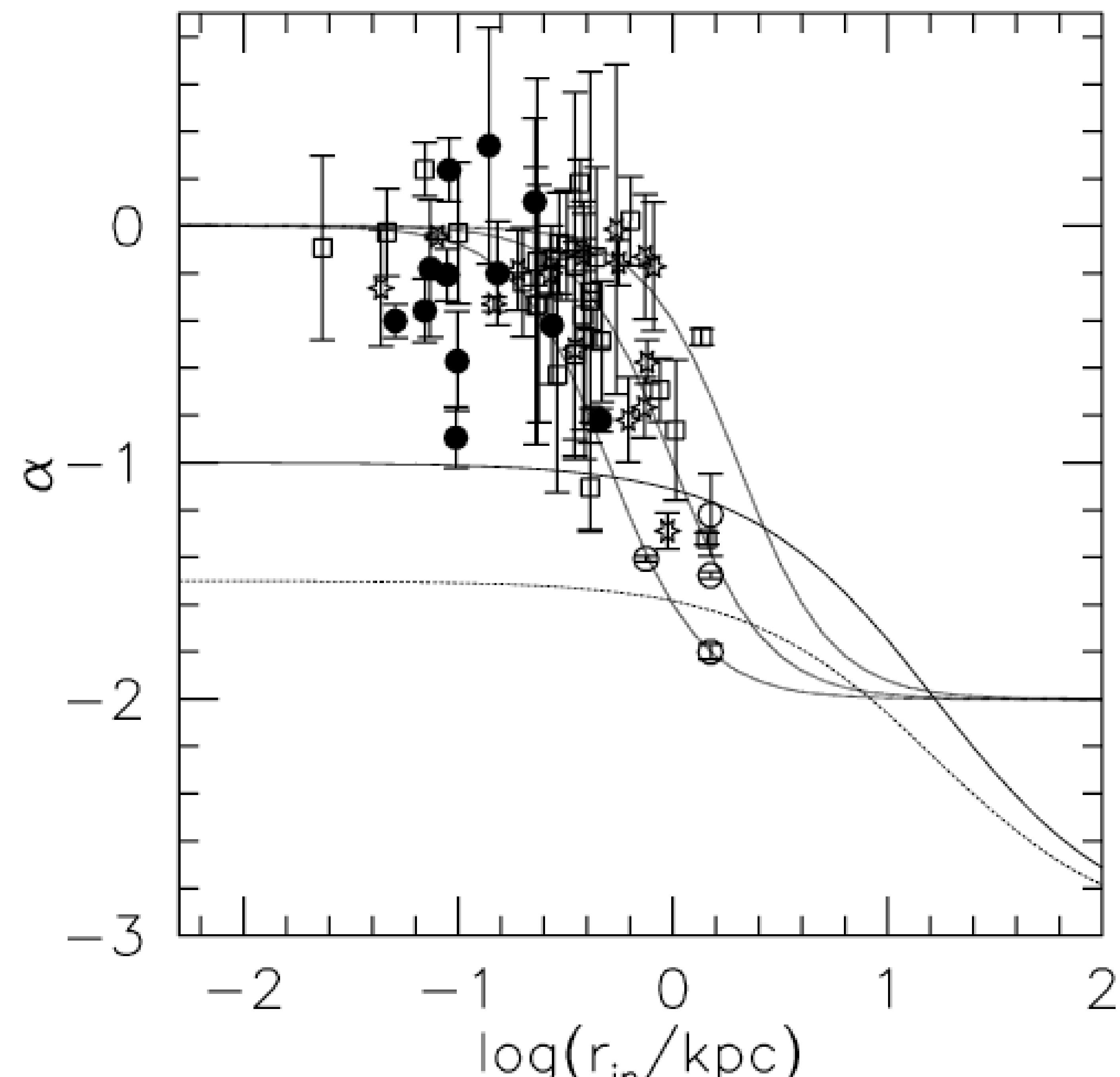
Infall velocities on halos of different mass

Prada et al 2005



Very small scales

Cusps and rotation curves



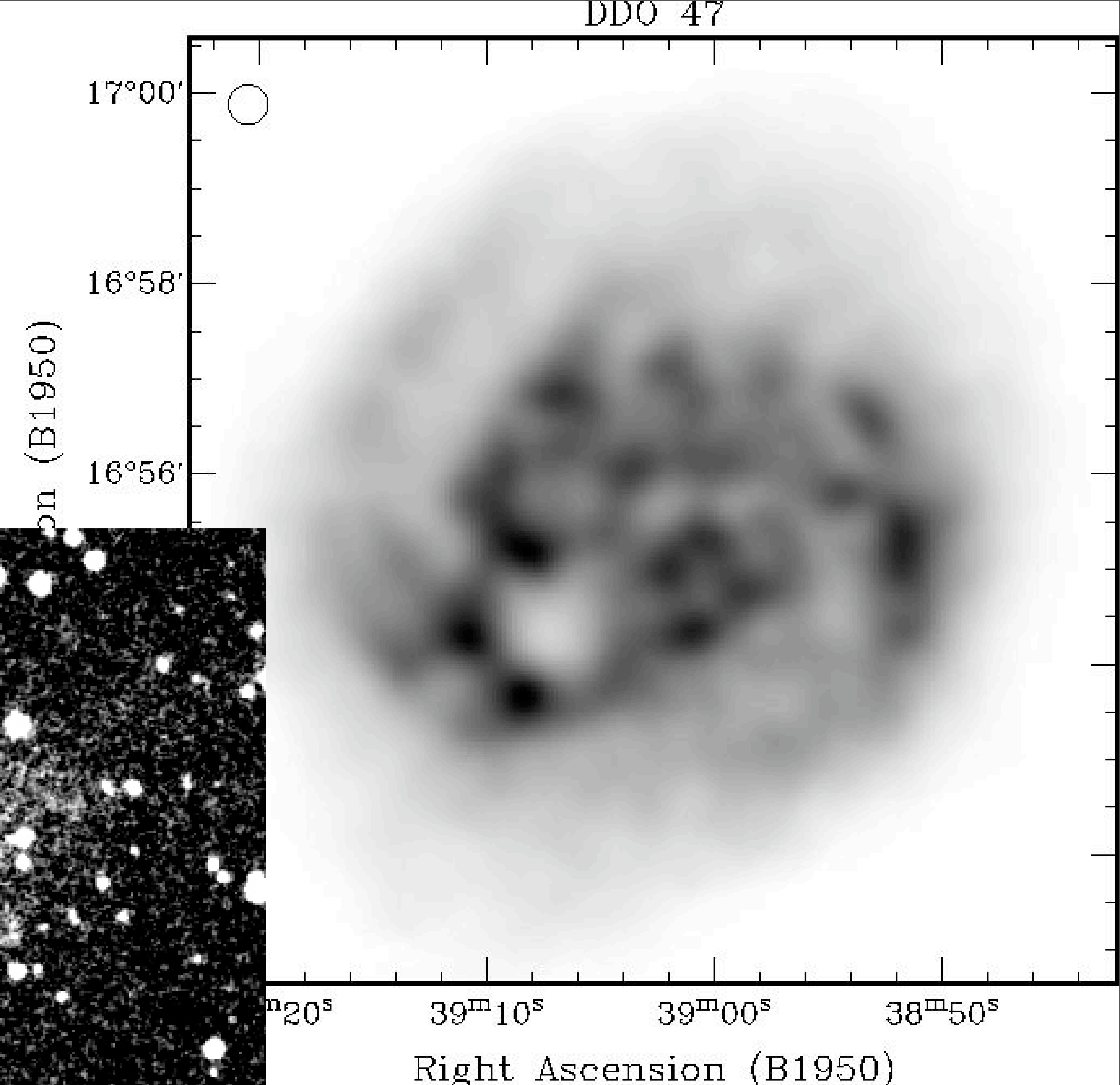
DDO 47:

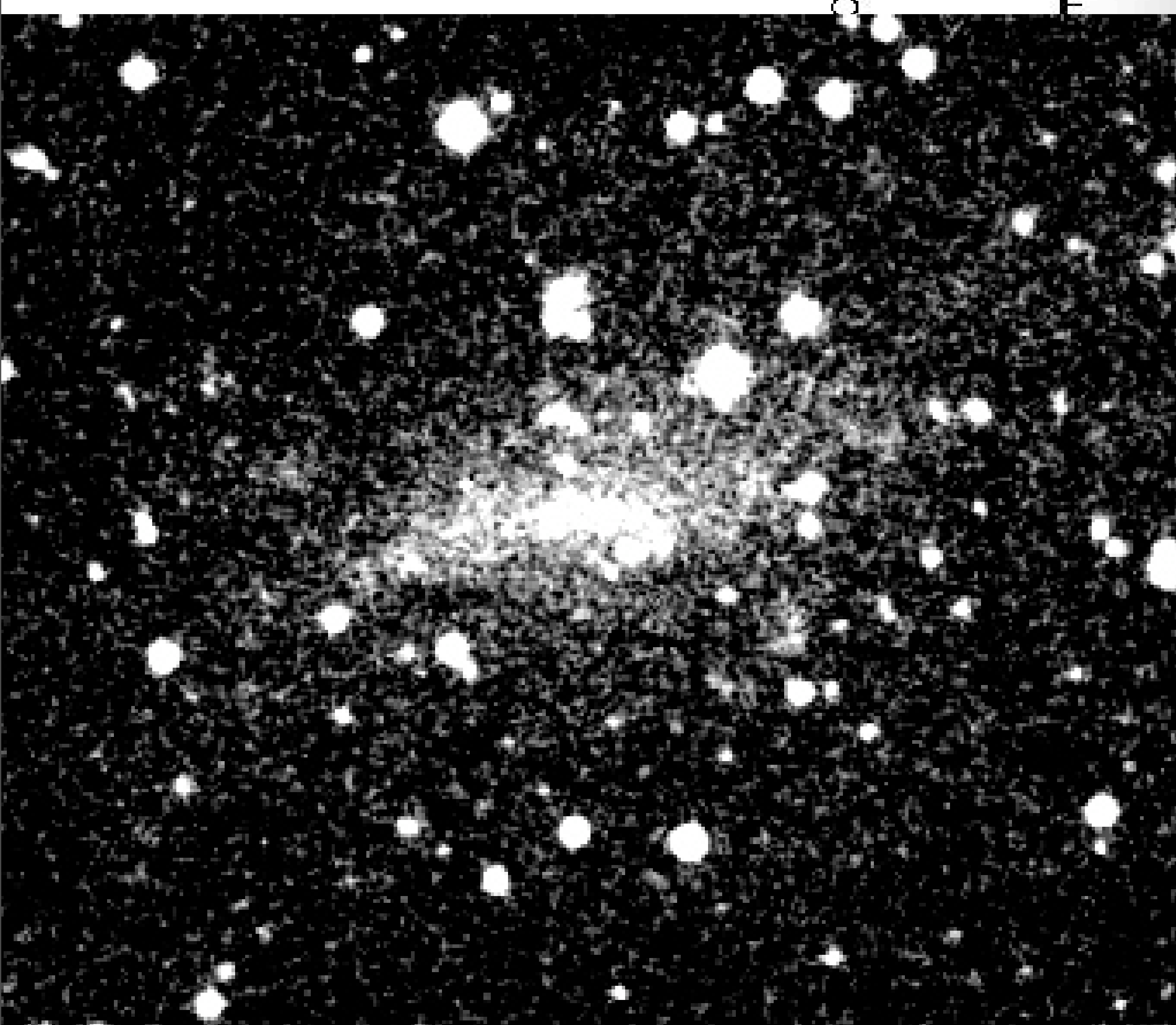
Vmax = 80km/s

Distance = 4Mpc

HI is very lumpy

Stellar light does not align with HI





Observations:

- A large fraction of dwarf Galaxies in the central 1kpc has a maximal disk: stellar populations with observed colors.
- Signs of a weak bar are frequent.
- ISM is very clumpy.

DM in central regions of galaxies:
Can cusps be destroyed?

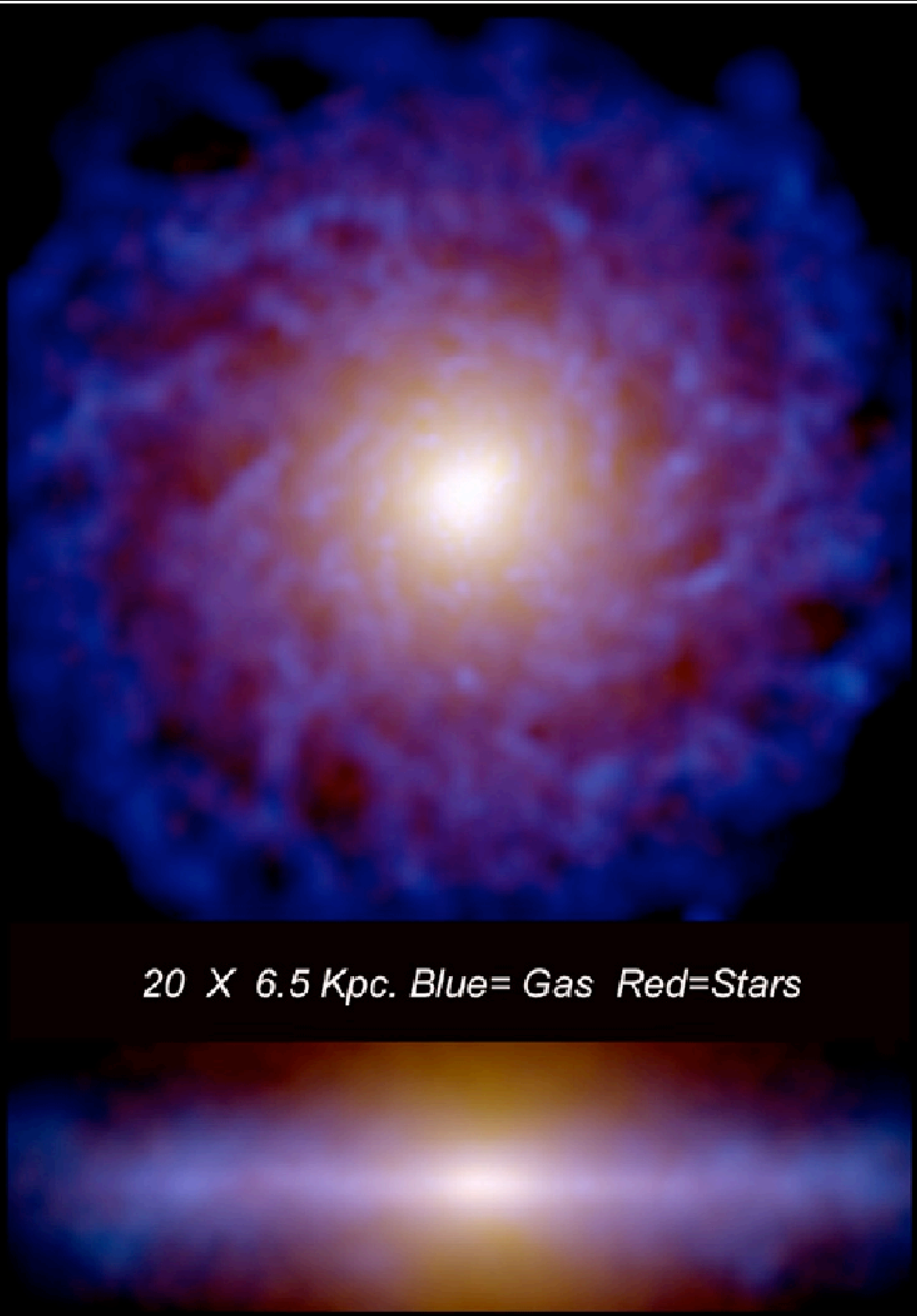
– bars (Weinberg & Katz 2002).
  - Answer **no**: Colin etal 2005: DM density increases as bars form

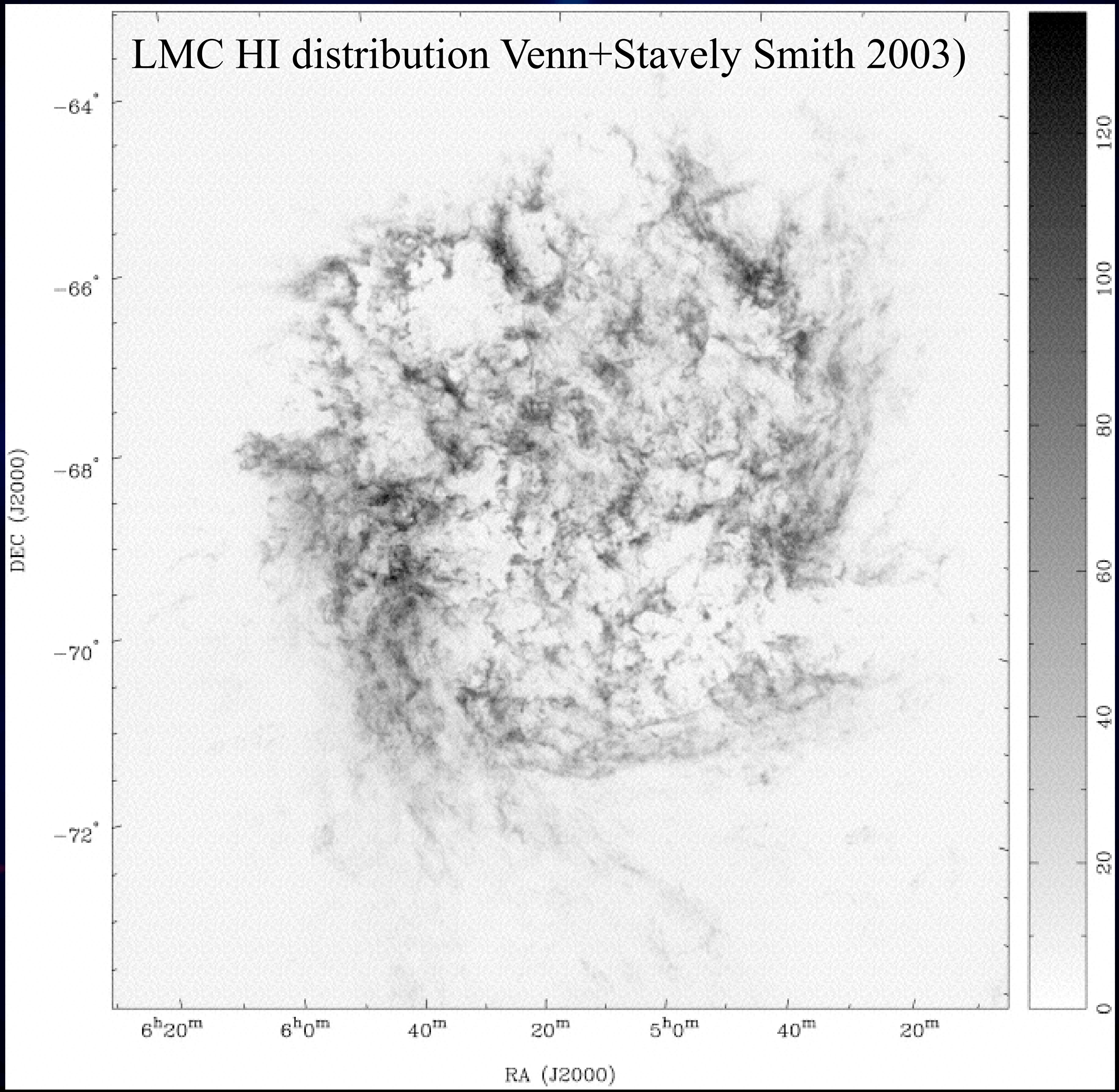
– baryons:

El-Zant, Shlosman, Hoffman (2001)
Gnedin & Zhao (2002)
Mashchenko, Couchman, Wadsley (2006)

  - Very artificial and unrealistic setup
  - Real N-body+Hydro sims (**30pc** resolution) show **increase in DM density**

Cosmological Simulations: feedback, high resolution …



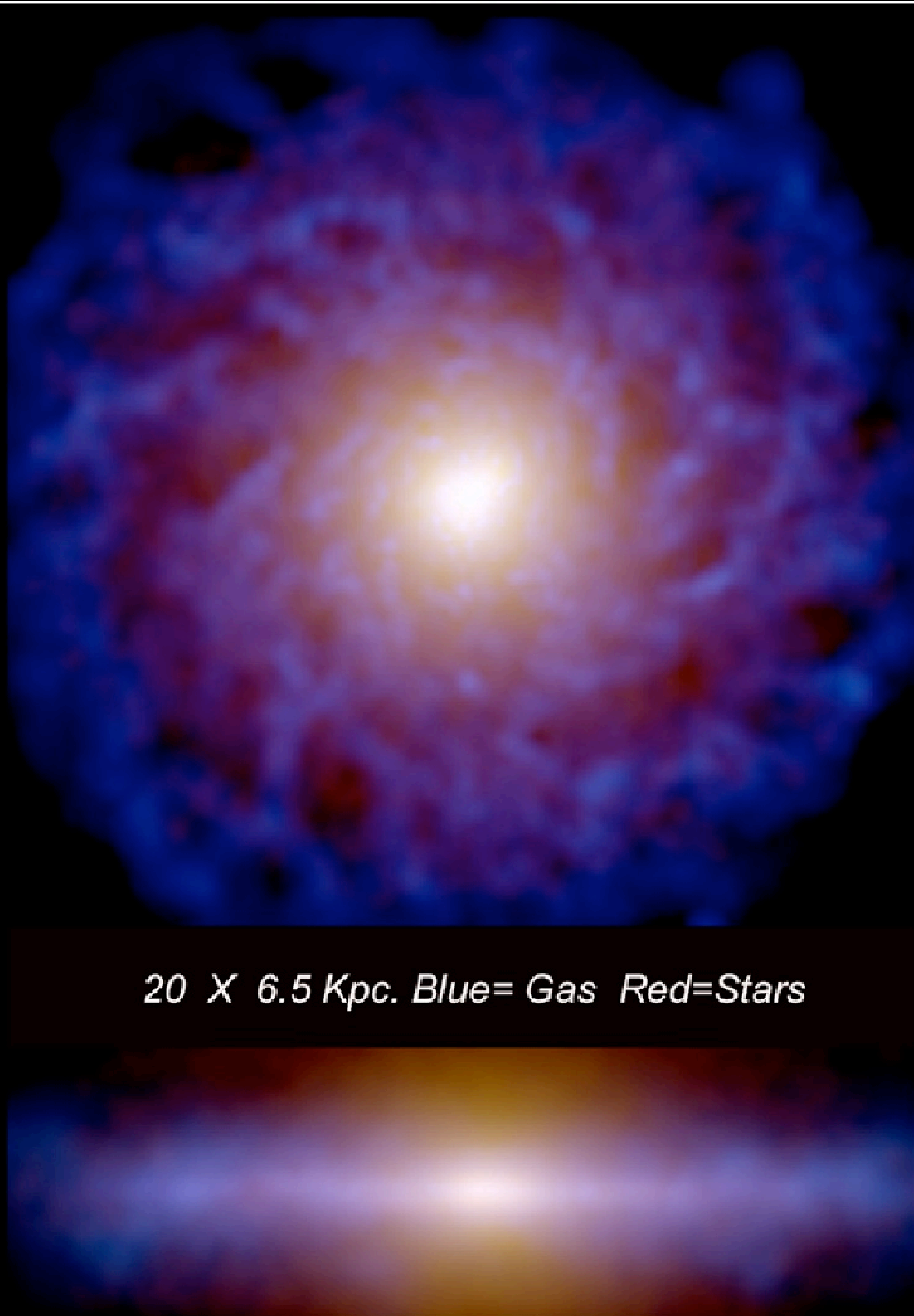


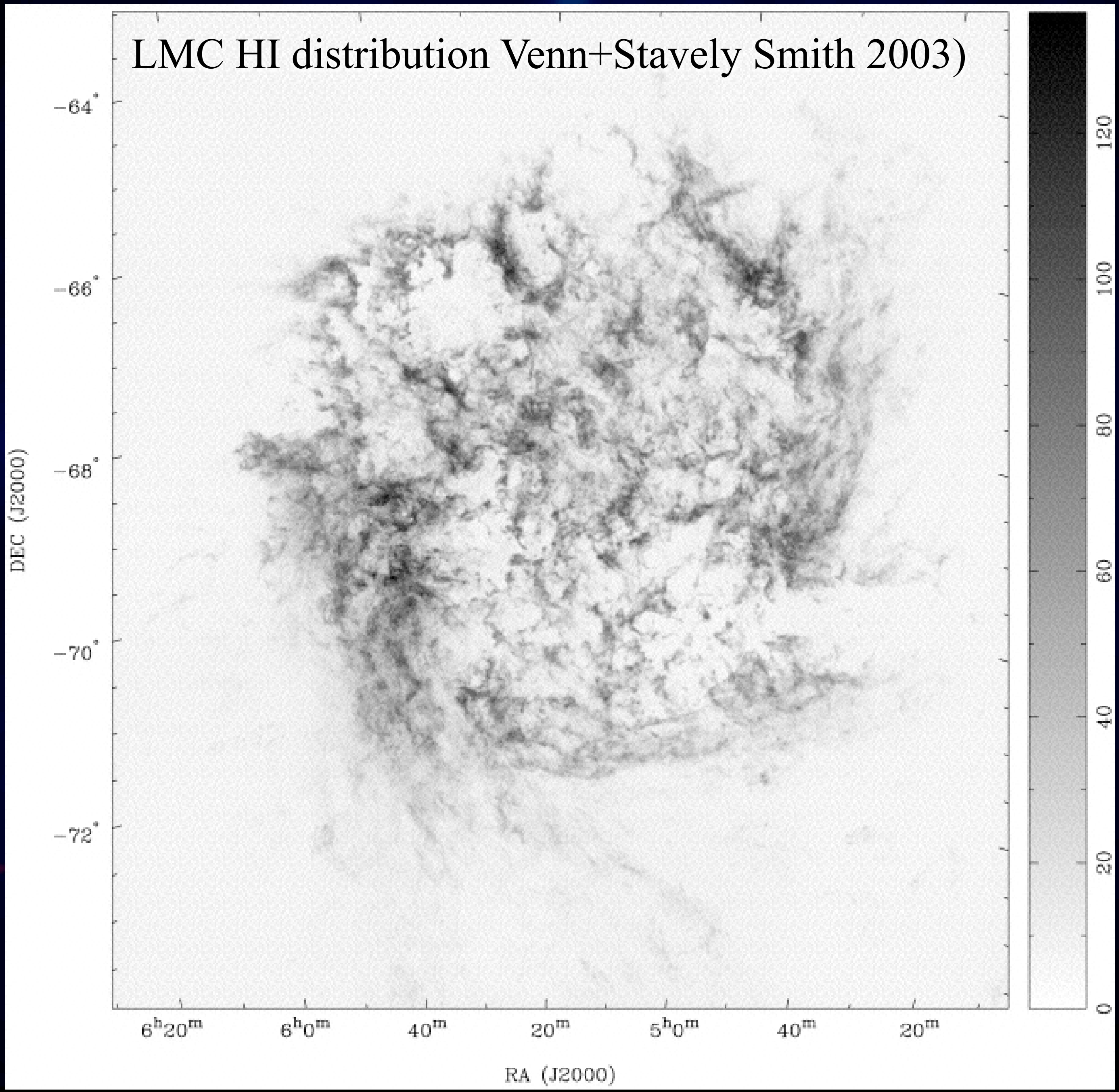
FG2004

Multiphase ISM is nicely reproduced

Governato 2004

Cosmological Simulations: feedback, high resolution …





FG2004

Multiphase ISM is nicely reproduced

Governato 2004

Valenzuela et al 05

Code: GASOLINE

Isolated Galaxy:

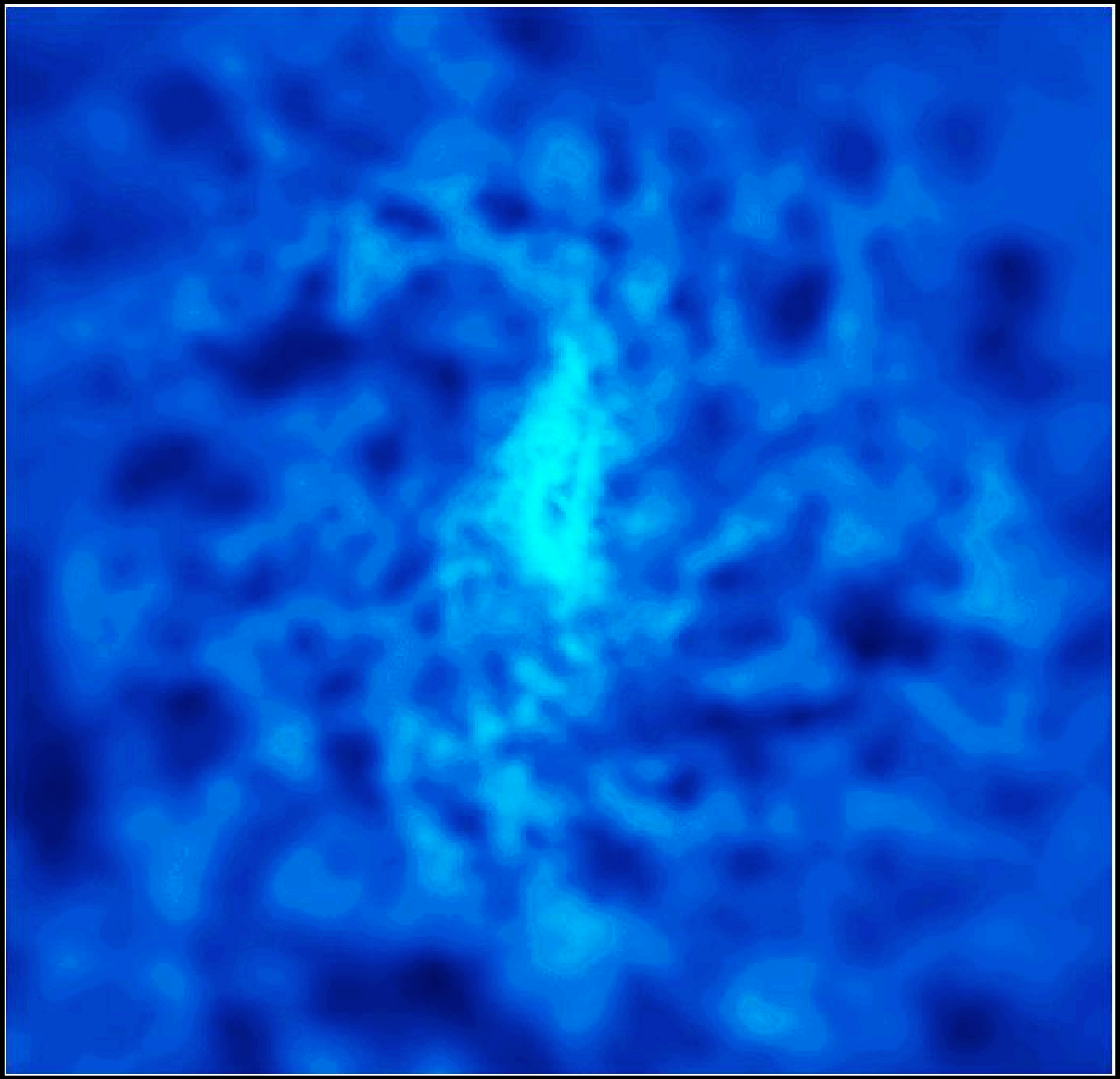
NFW halo	1-2M particles
Exponential disk	200K particles
Gas	100K
Resolution	60 pc

Star formation, feedback ….

simulations:

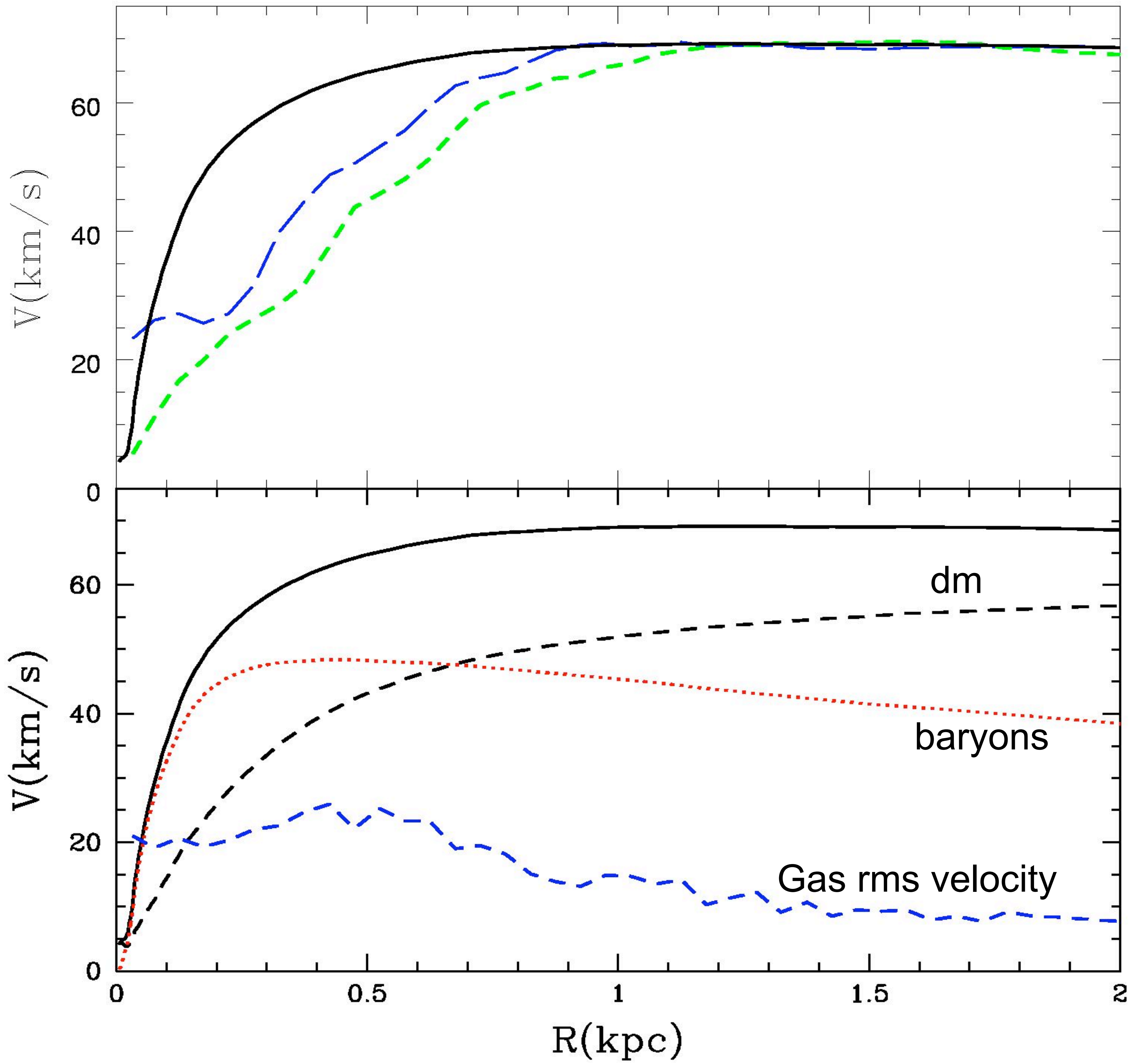
dwarf: 70km/s

Cold gas in central 2kpc region



Simulation: dwarf 5

Resolution: 60pc

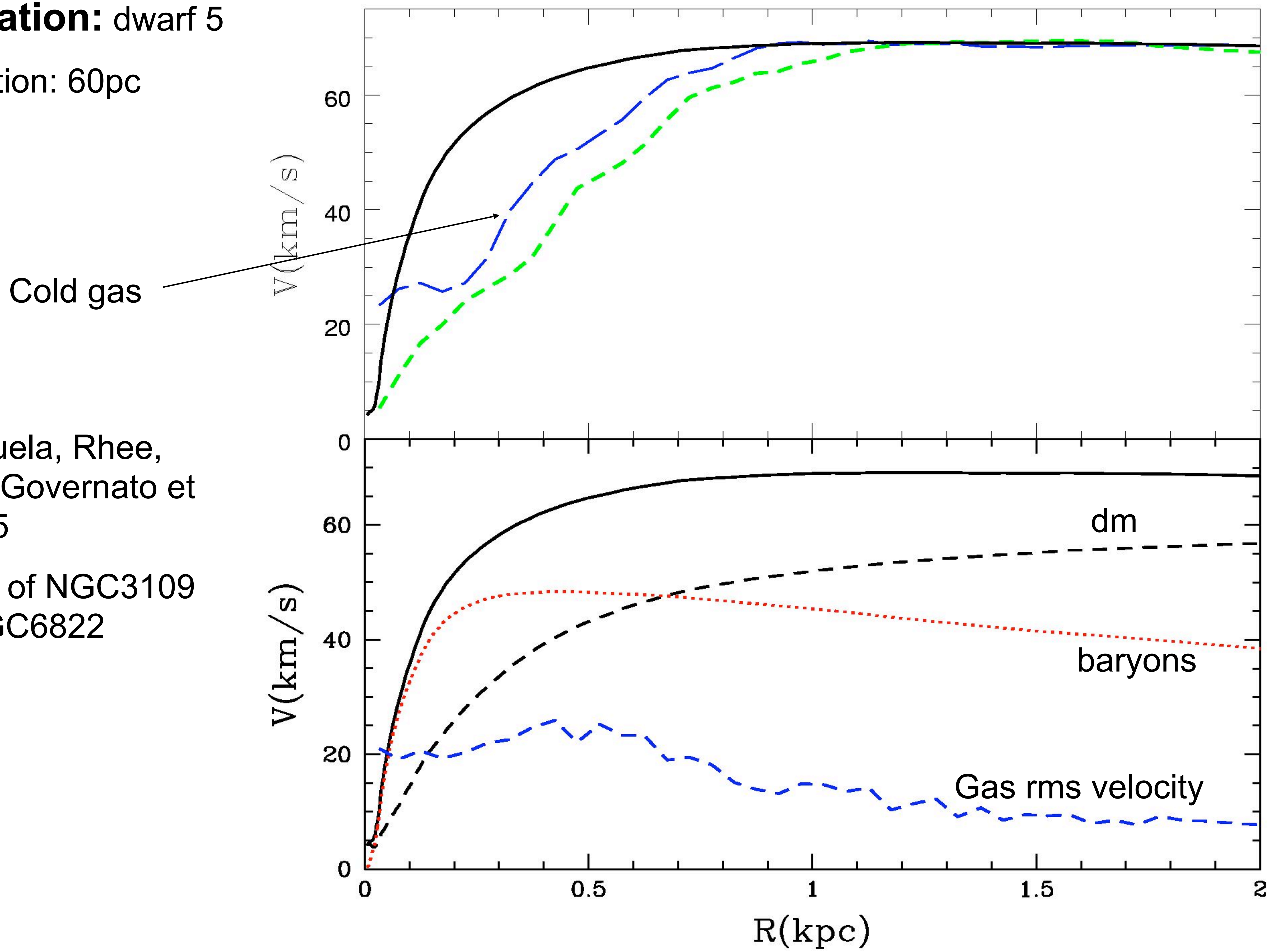


Valenzuela, Rhee, Klypin, Governato et al. 2005

Models of NGC3109 and NGC6822

Simulation: dwarf 5

Resolution: 60pc



Valenzuela, Rhee, Klypin, Governato et al. 2005

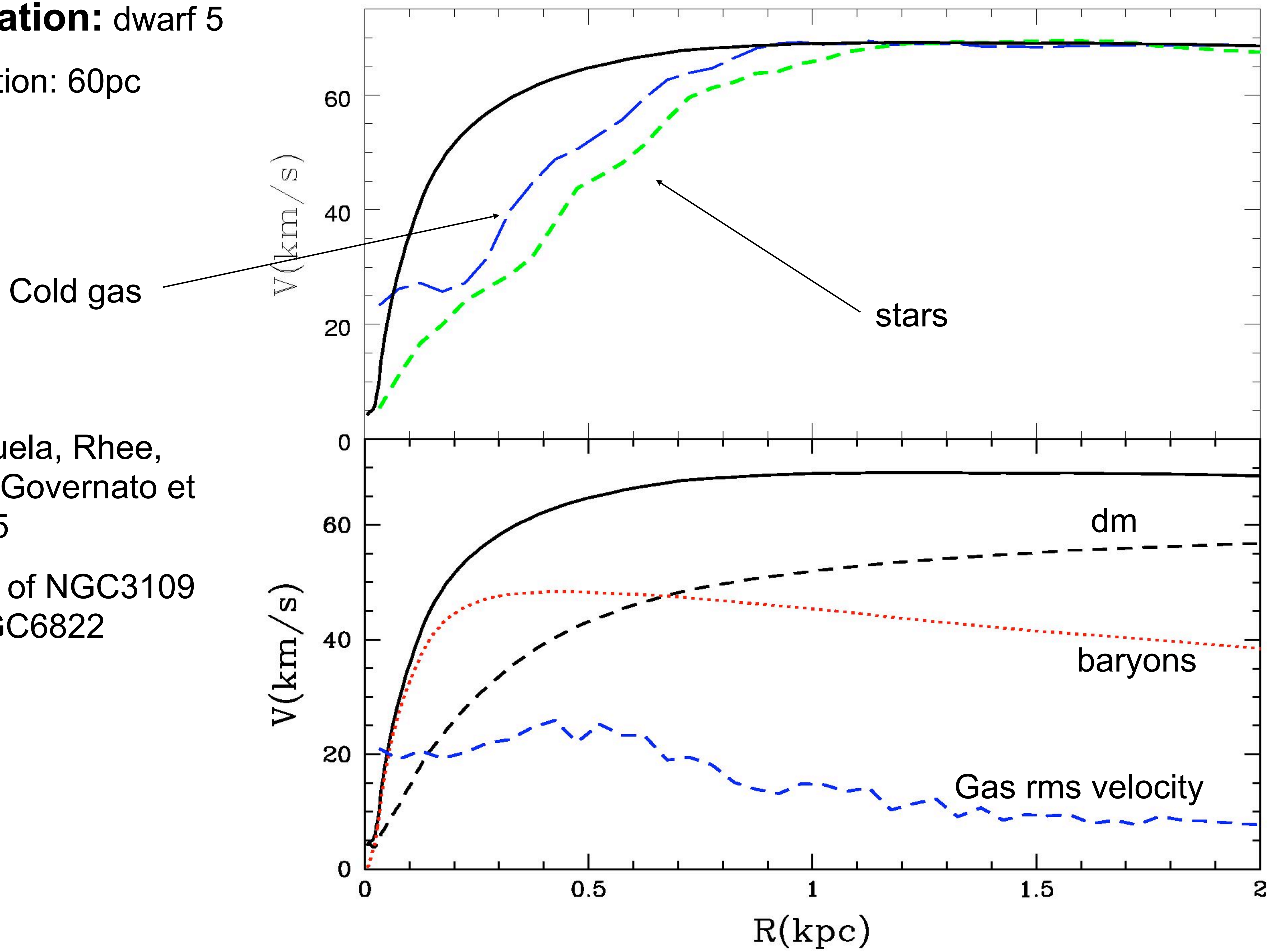
Models of NGC3109 and NGC6822

Simulation: dwarf 5

Resolution: 60pc

Valenzuela, Rhee, Klypin, Governato et al. 2005

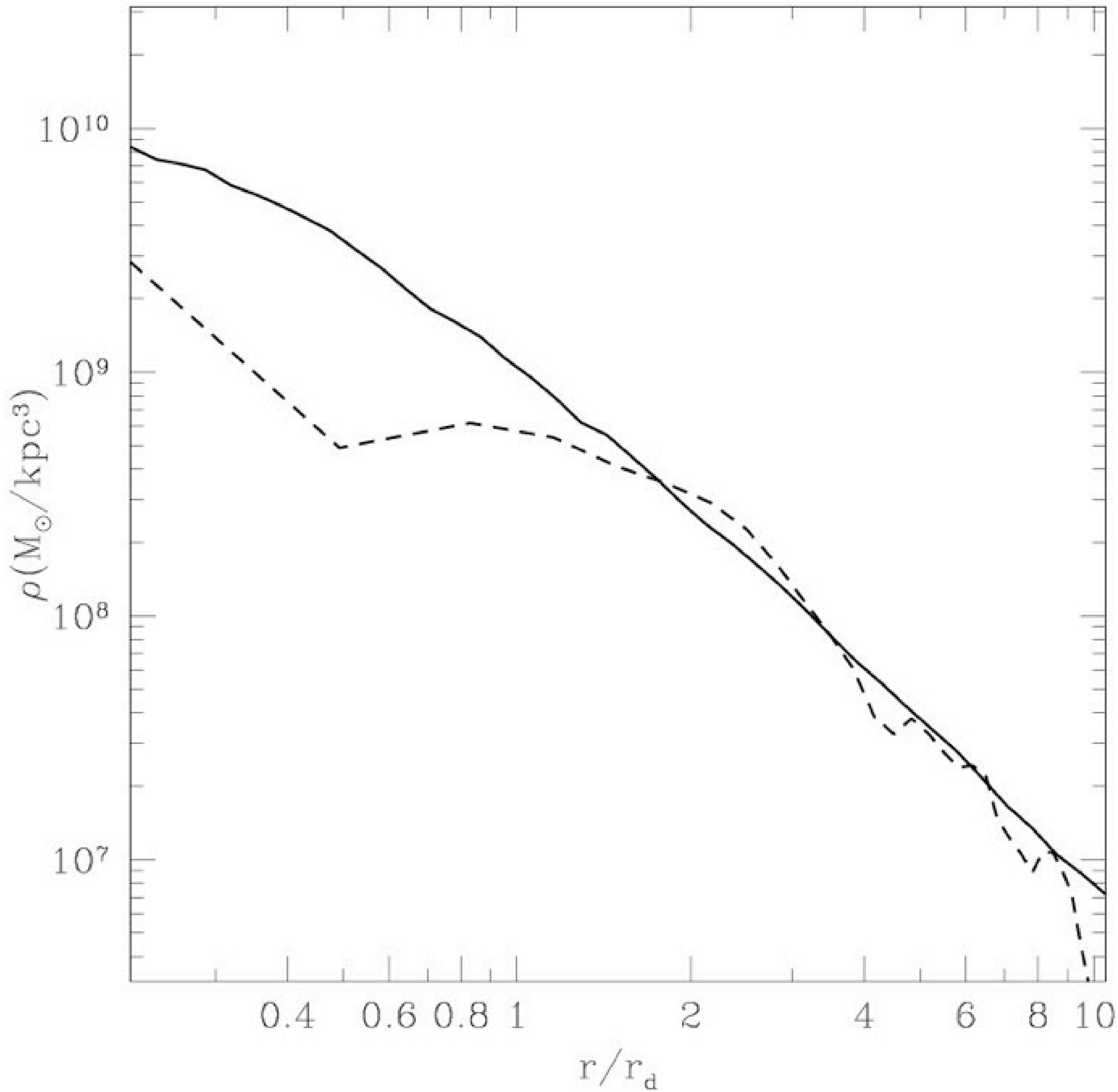
Models of NGC3109 and NGC6822



True and recovered density profiles

Vrot(r) ⇒ ρ(r)

True slope: -1.8
Recovered: -0.5



True and recovered density profiles

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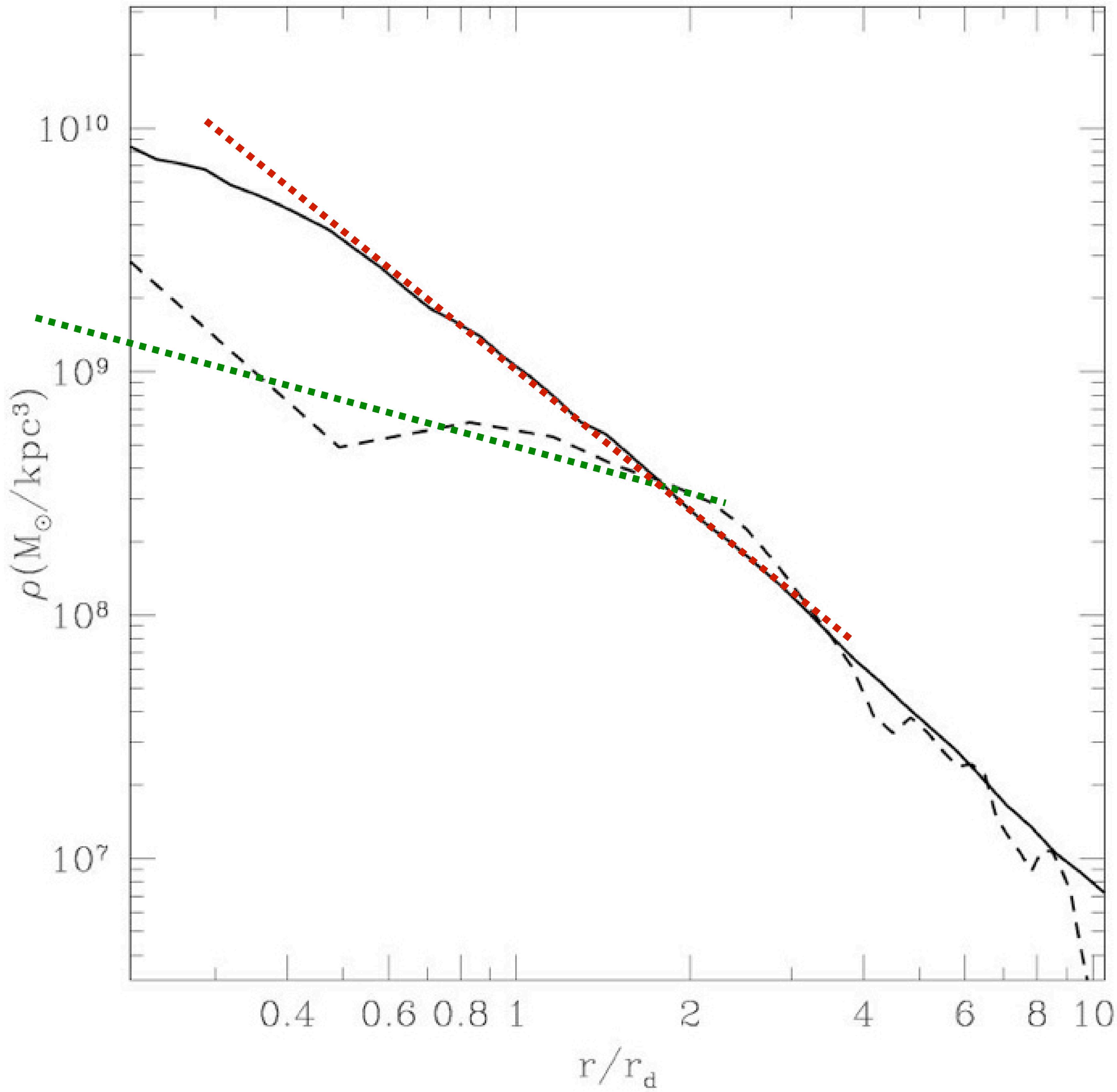
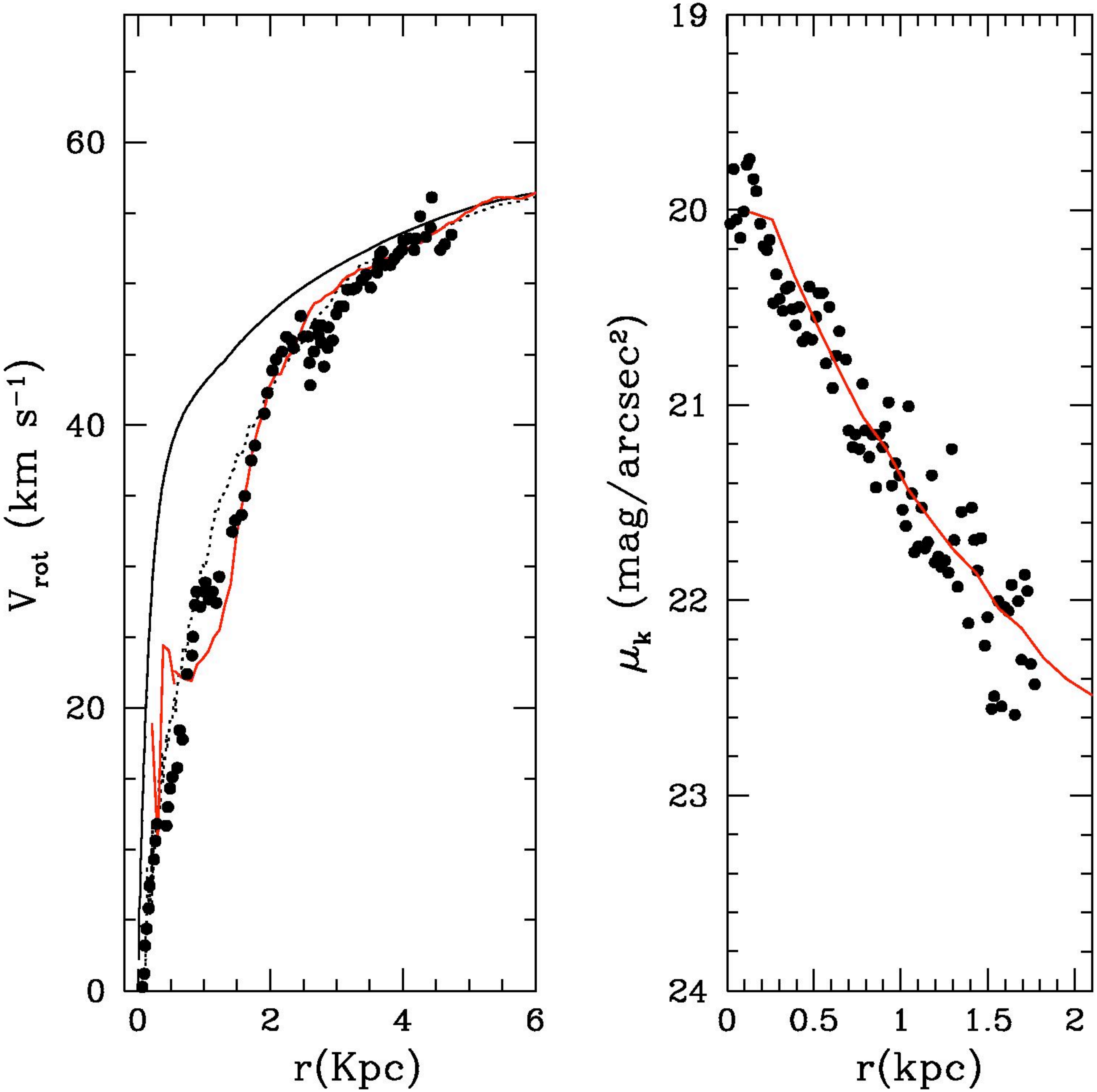


NGC 6822

Magellanic-type dwarf irregular

0.5Mpc from Milky Way



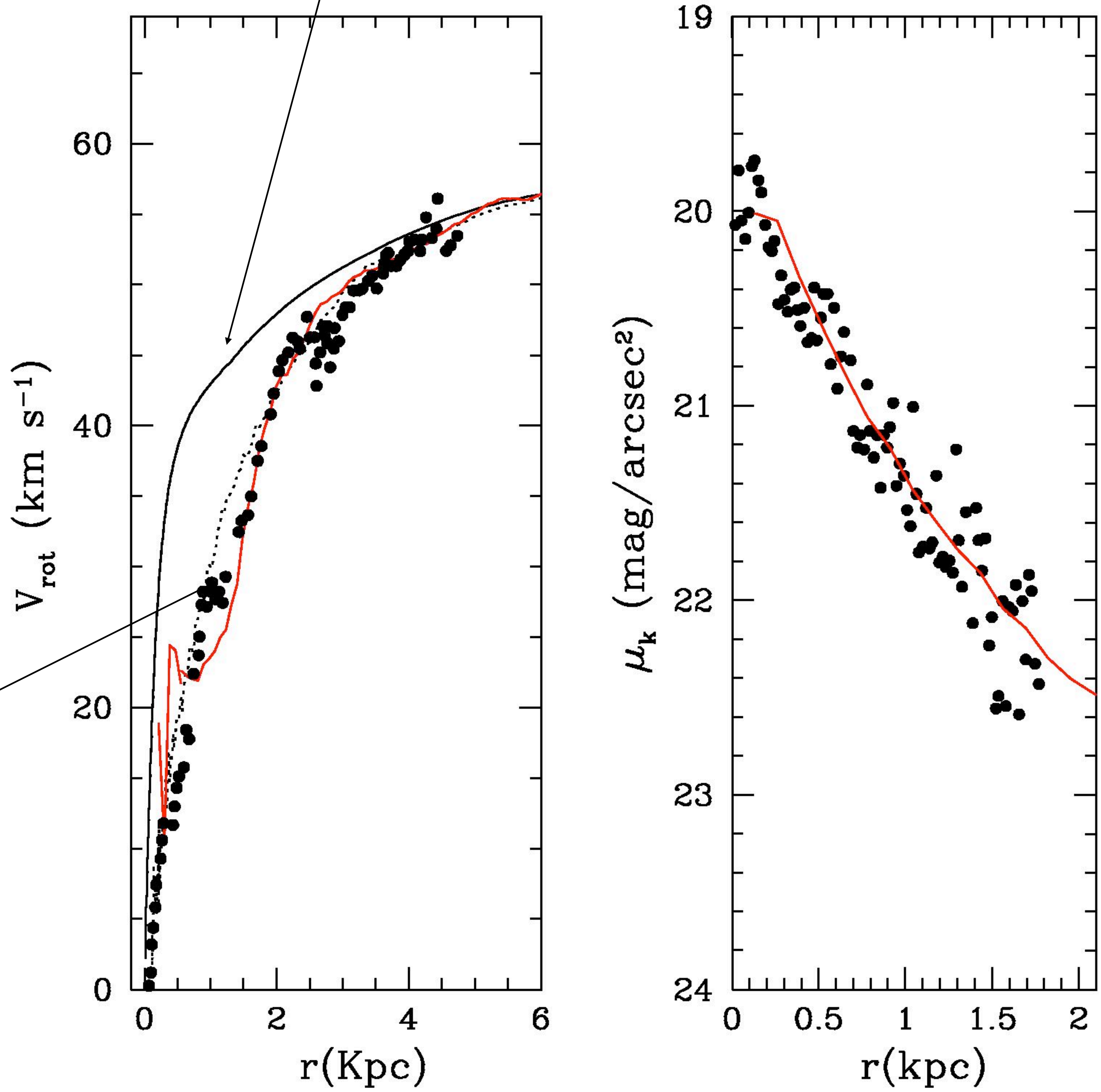
NGC 6822

Magellanic-type dwarf irregular

0.5Mpc from Milky Way

Observations

Vcirc(total)

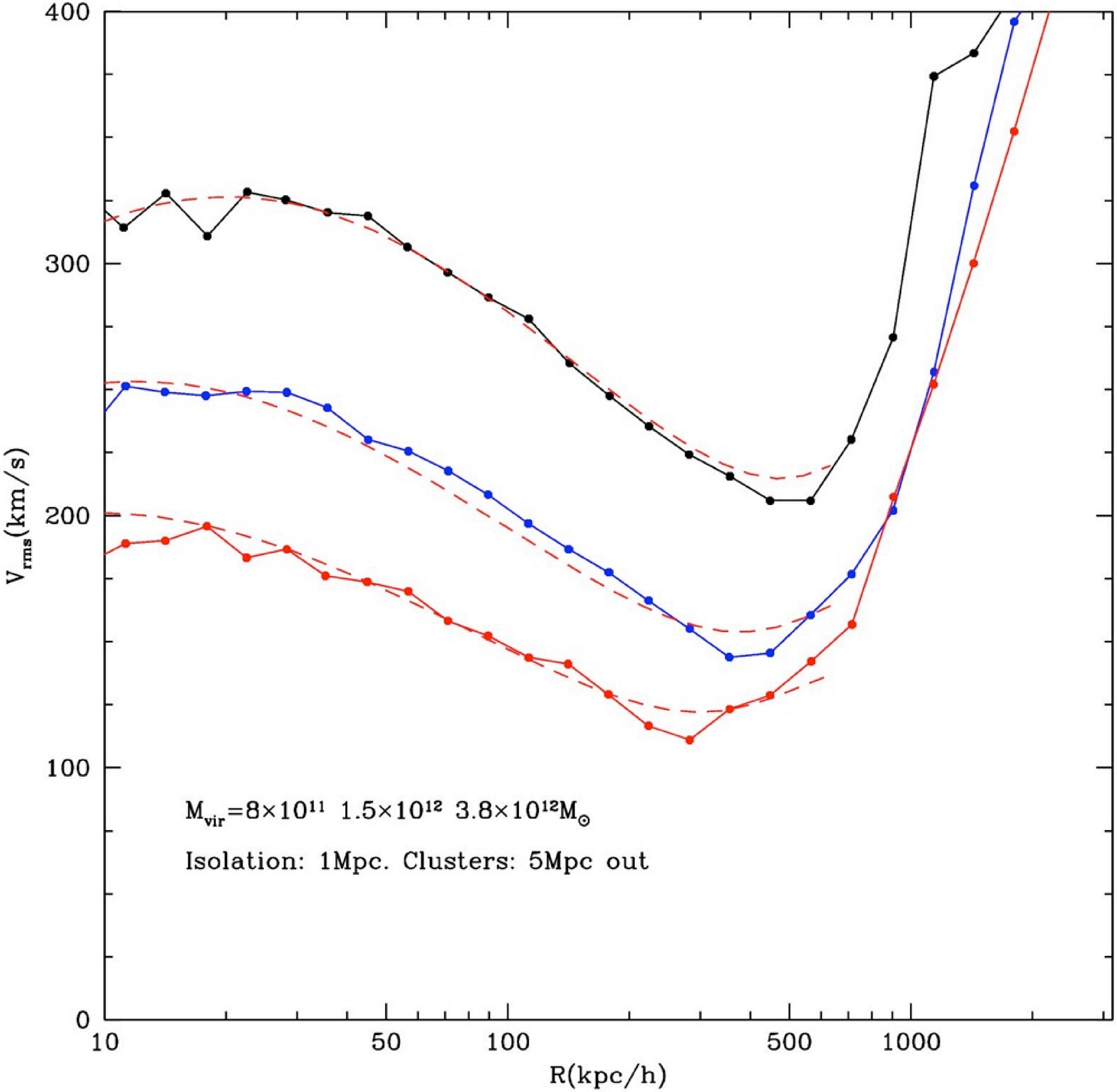


CONCLUSIONS

- ⭐Cusps are not destroyed by baryons
- ⭐Cores are ‘observed’ where there is a real cusp.
- ⭐Observations are compatible with cuspy DM profiles

Adiabatic Compression

- Old prescription (Blumenthal et al) over predicts density of DM by a factor of 2
- Gnedin et al (2004) works much better



400
300
200
100
0
V_{rms}(km/s)
10
50
100
500
1000
R(kpc/h)
M_{vir}=8×10^{11} 1.5×10^{12} 3.8×10^{12}$M_\odot$
Isolation: 1Mpc. Clusters: 5Mpc out

Clustering: all effects combined

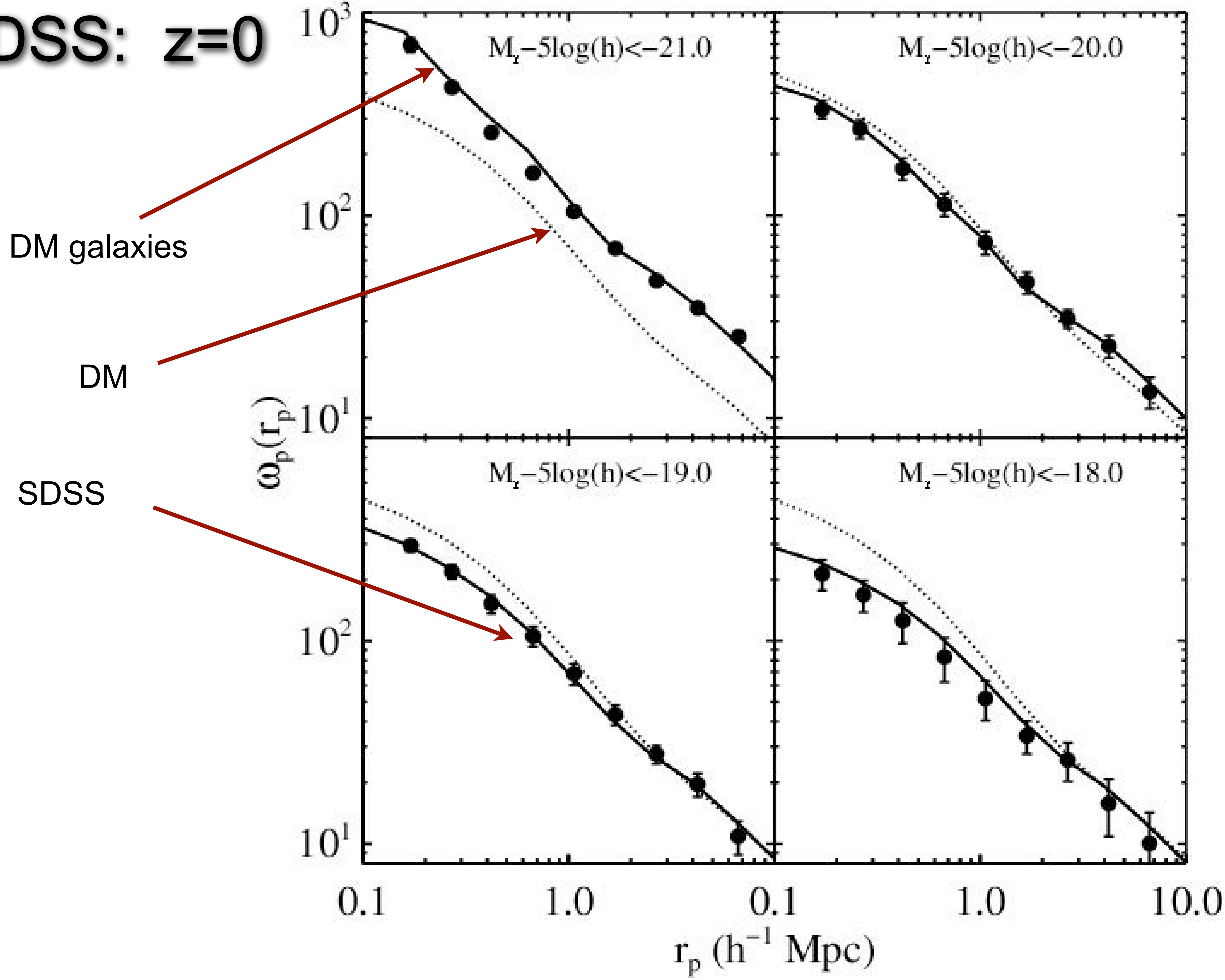
Conroy, Wechsler, Kravtsov (2005): **N-body only**

- Get all halos from high-res simulation
- Use maximum circular velocity (NOT mass)
- For subhalos use V_{max} before they became subhalos
- Every halo (sub or not) is a galaxy
- Every halo has luminosity: **LF is as in SDSS**
- No cooling or major mergers and such. Only DM halos

Young etal, Berrier etal(2005) : Halo occupation distribution

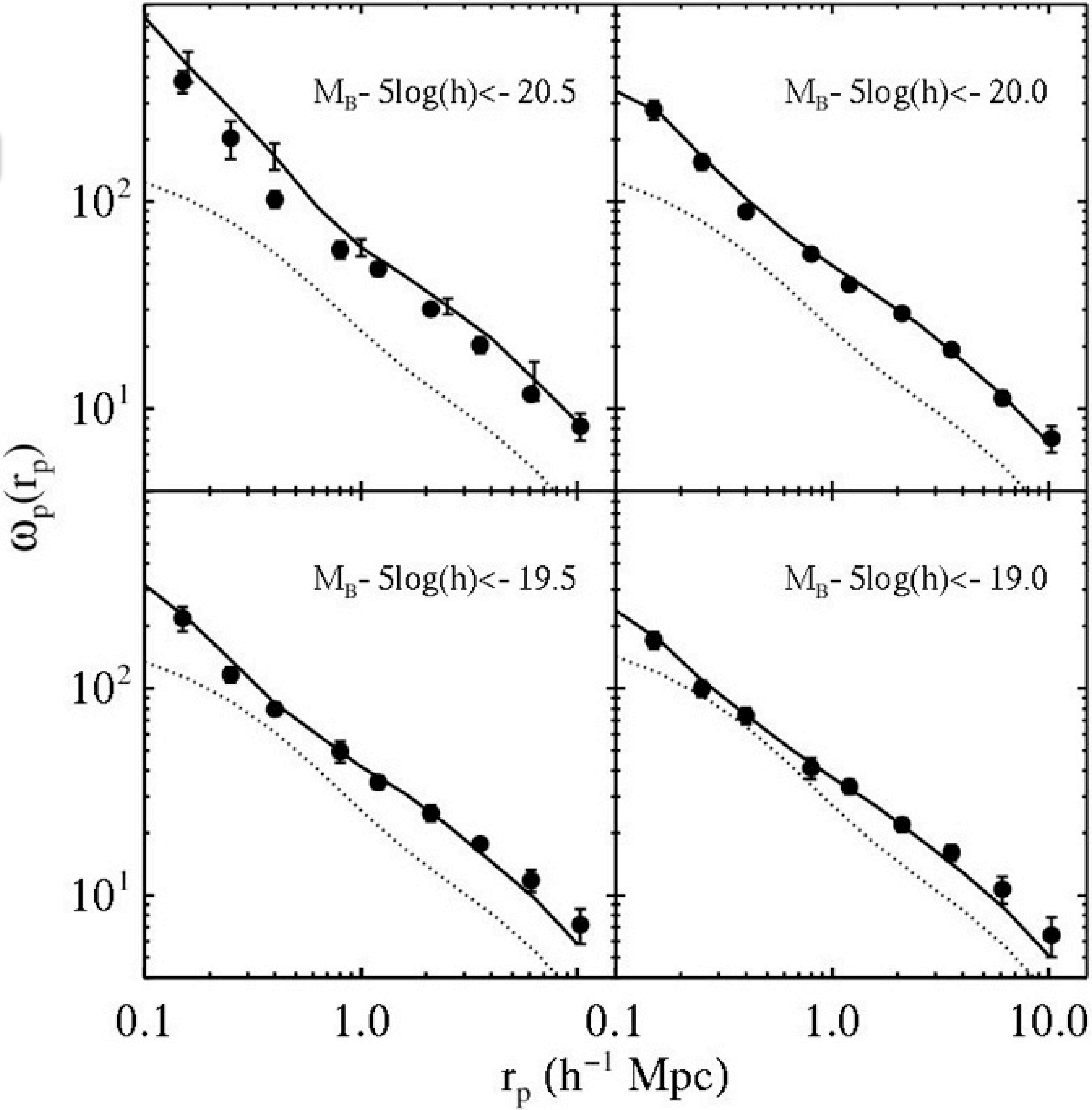
Reproduces most of the observed clustering of galaxies

SDSS: z=0



DM galaxies
DM
SDSS
$M_r - 5\log(h) < -21.0$
$M_r - 5\log(h) < -20.0$
$M_r - 5\log(h) < -19.0$
$M_r - 5\log(h) < -18.0$
$\omega_p(r_p)$
r_p (h^{-1} Mpc)
10^3
10^2
10^1
0.1
1.0
10.0

DEEP: z=1



$M_B - 5\log(h) < -20.5$
$M_B - 5\log(h) < -20.0$
$M_B - 5\log(h) < -19.5$
$M_B - 5\log(h) < -19.0$
$\omega_p(r_p)$
10^2
10^1
0.1
1.0
10.0
r_p (h^{-1} Mpc)

Dark Matter and Galaxies

Dark Matter and Galaxies

- **Central** DM closely correlates with L: Tully-Fisher, Faber-Jackson

Dark Matter and Galaxies

- **Central** DM closely correlates with L: Tully-Fisher, Faber-Jackson

Dark Matter and Galaxies

- **Central** DM closely correlates with L: Tully-Fisher, Faber-Jackson

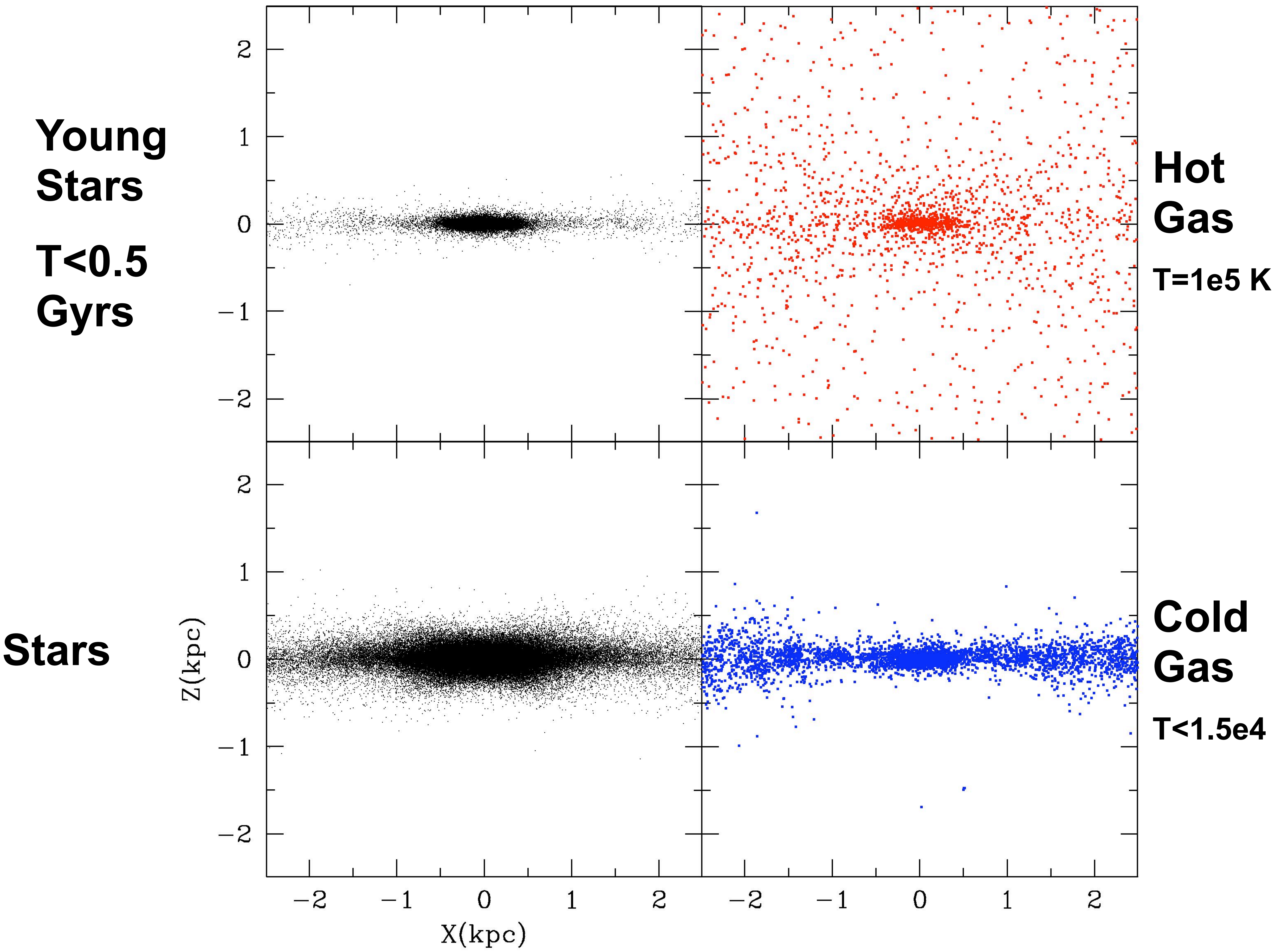
- Morphology-density relation: morphology is mostly defined by halo mass.

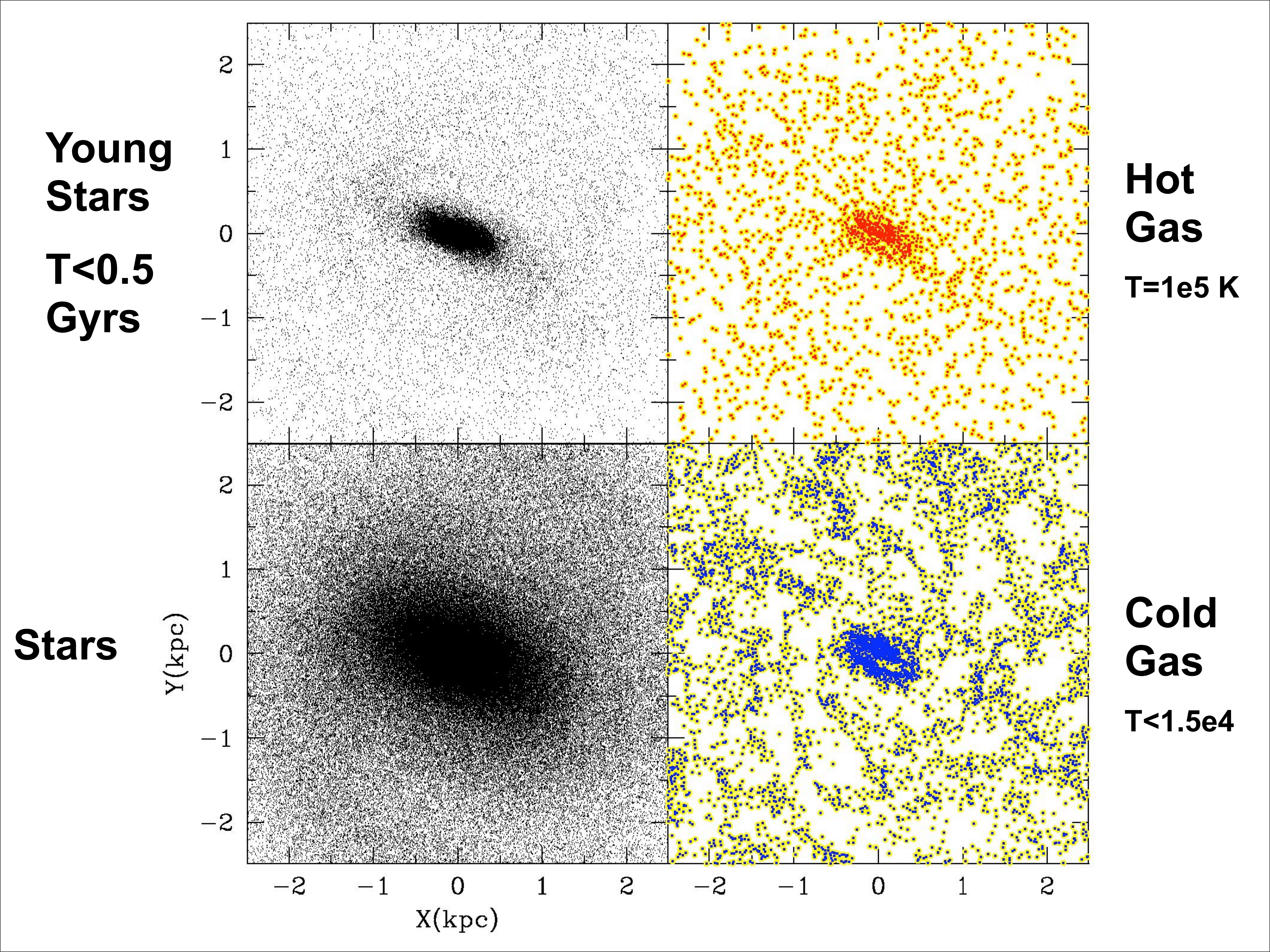
Dark Matter and Galaxies

- **Central** DM closely correlates with L: Tully-Fisher, Faber-Jackson

- Morphology-density relation: morphology is mostly defined by halo mass.

- Environment (how many neighbors) is just an indicator of halo mass


Young Stars
T<0.5 Gyrs
Hot Gas
T=1e5 K
Stars
Cold Gas
T<1.5e4
Z(kpc)
X(kpc)
2
1
0
−1
−2



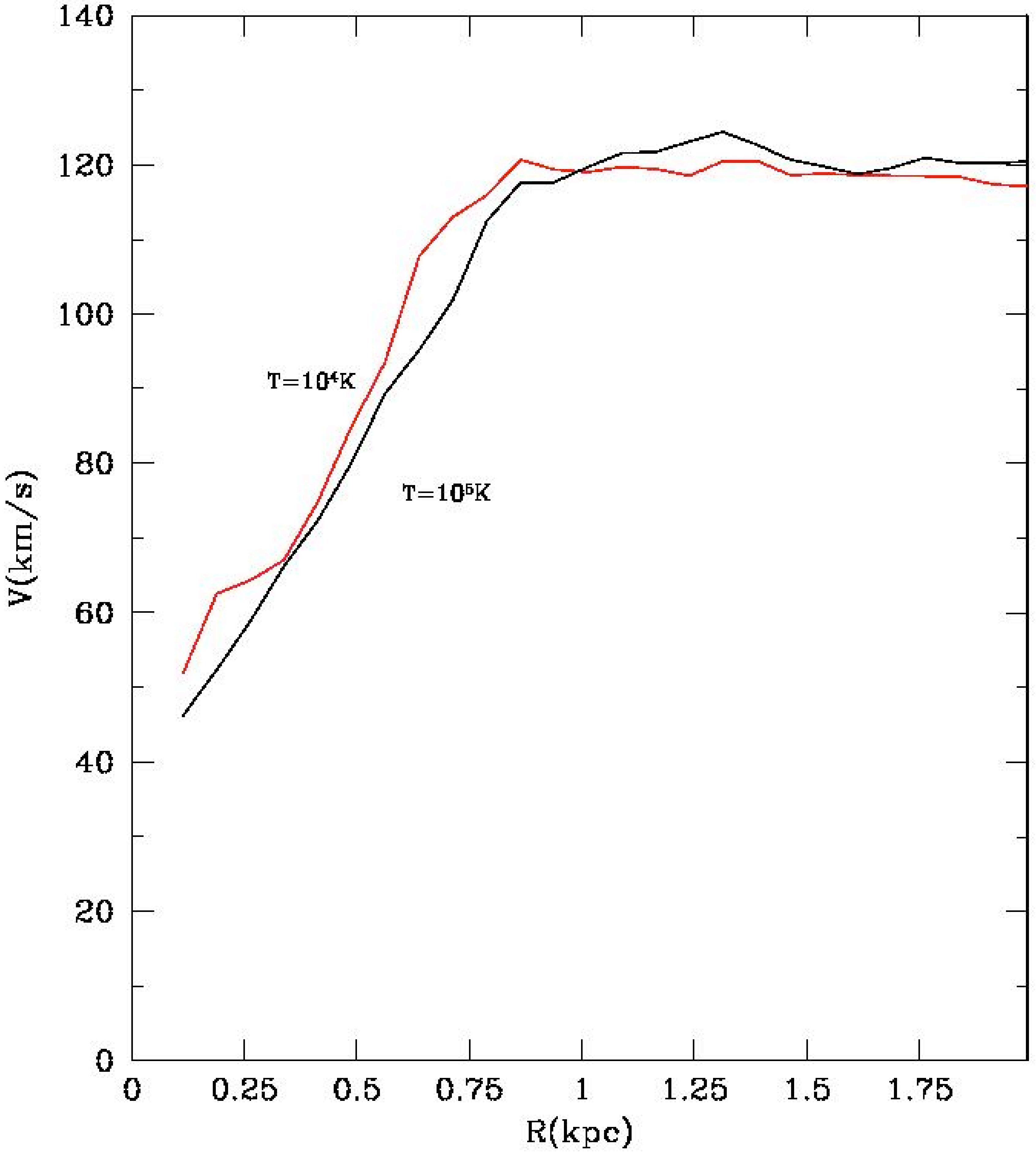
Young Stars
T<0.5 Gyrs
Hot Gas
T=1e5 K
Stars
Cold Gas
T<1.5e4
Y(kpc)
X(kpc)

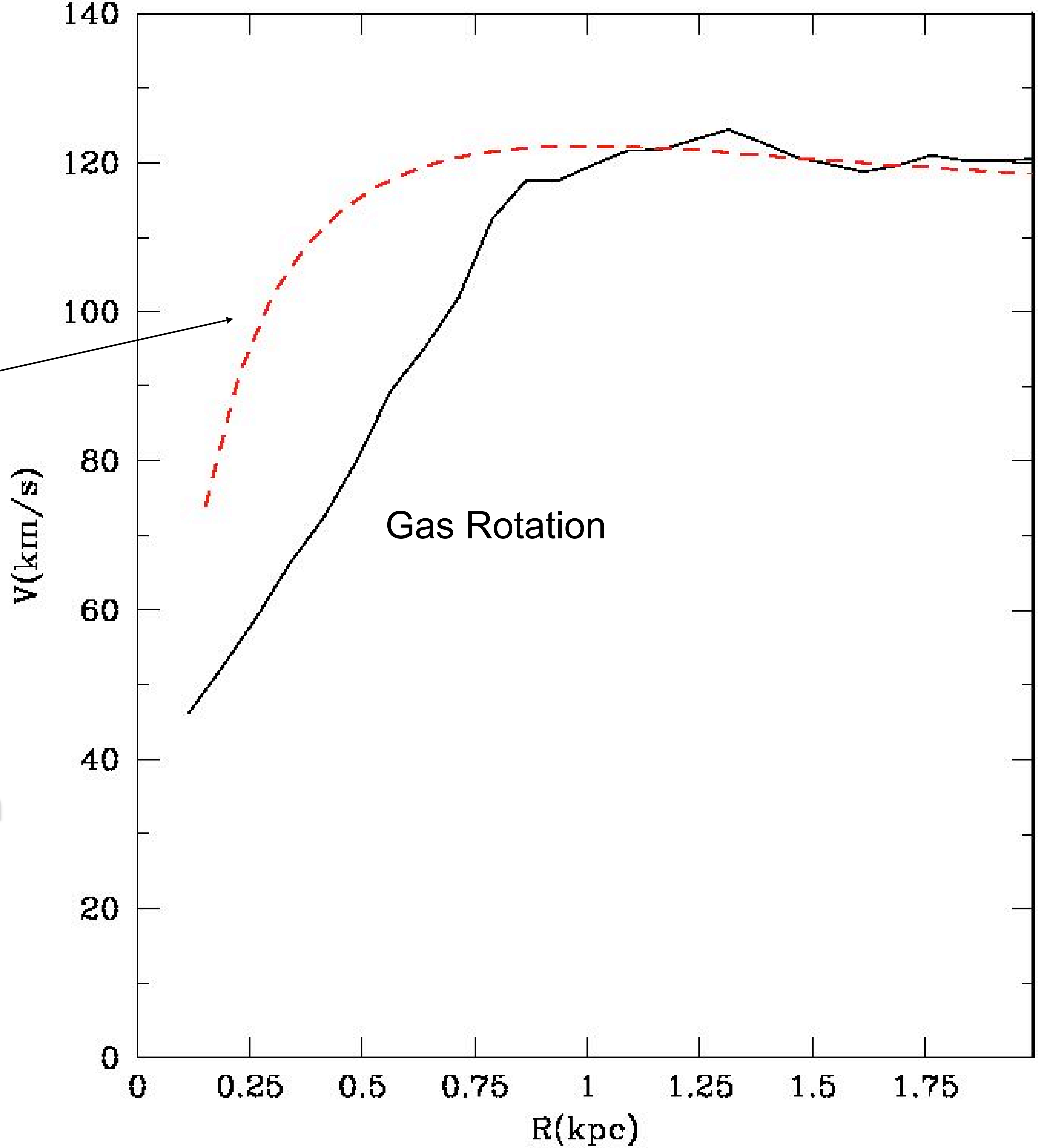
- Cold gas hardly shows any traces of the bar.
- Filaments and lumps of cold gas
- Large bubbles filled by 10^5K gas
- Stellar feedback feeds the multiphase ISM

Rotation Curves:

Cold and Hot gas

Little difference



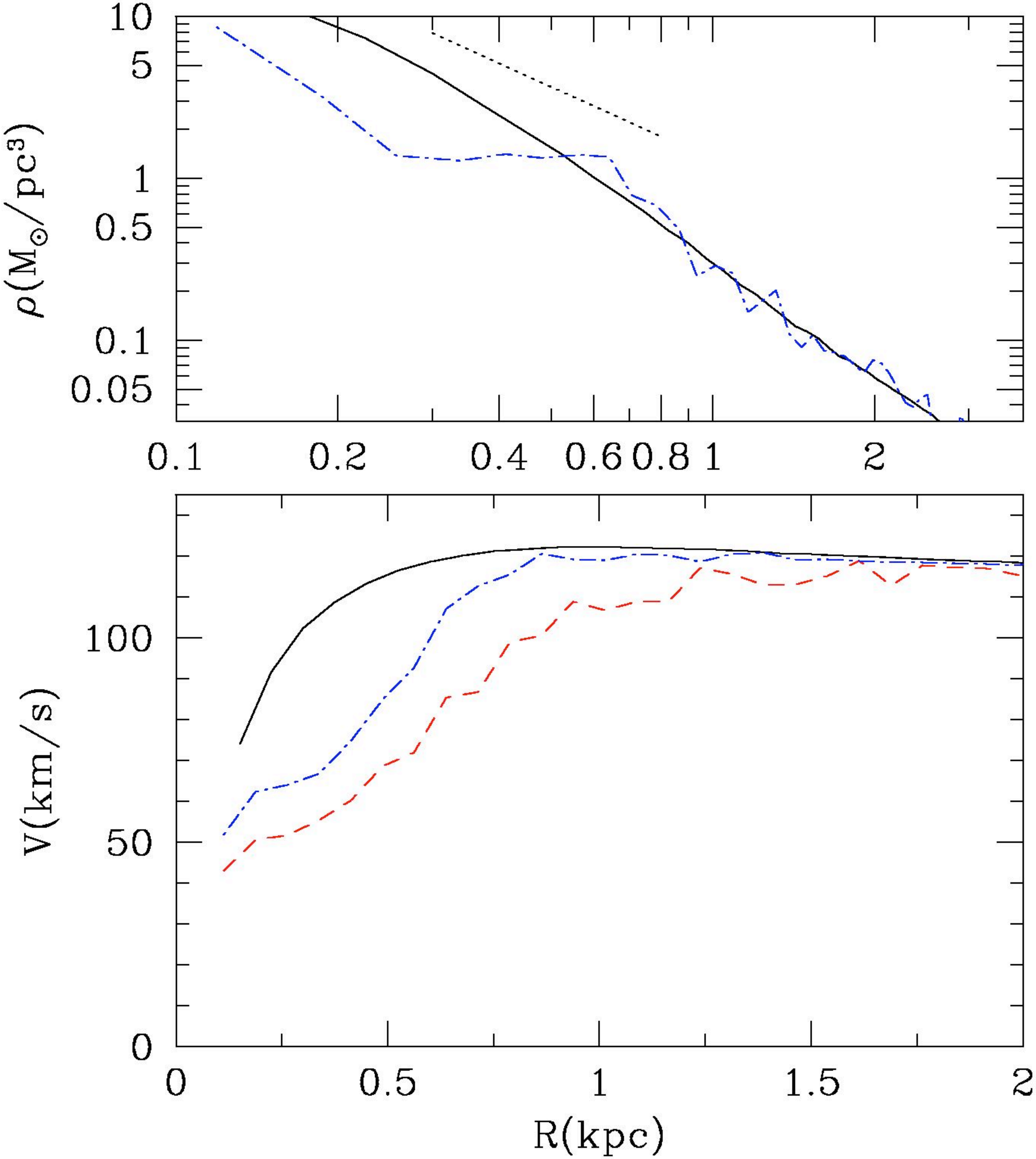


Circular Velocity

Asymmetric drift (aka random motions) cannot help to explain why gas rotates too slow

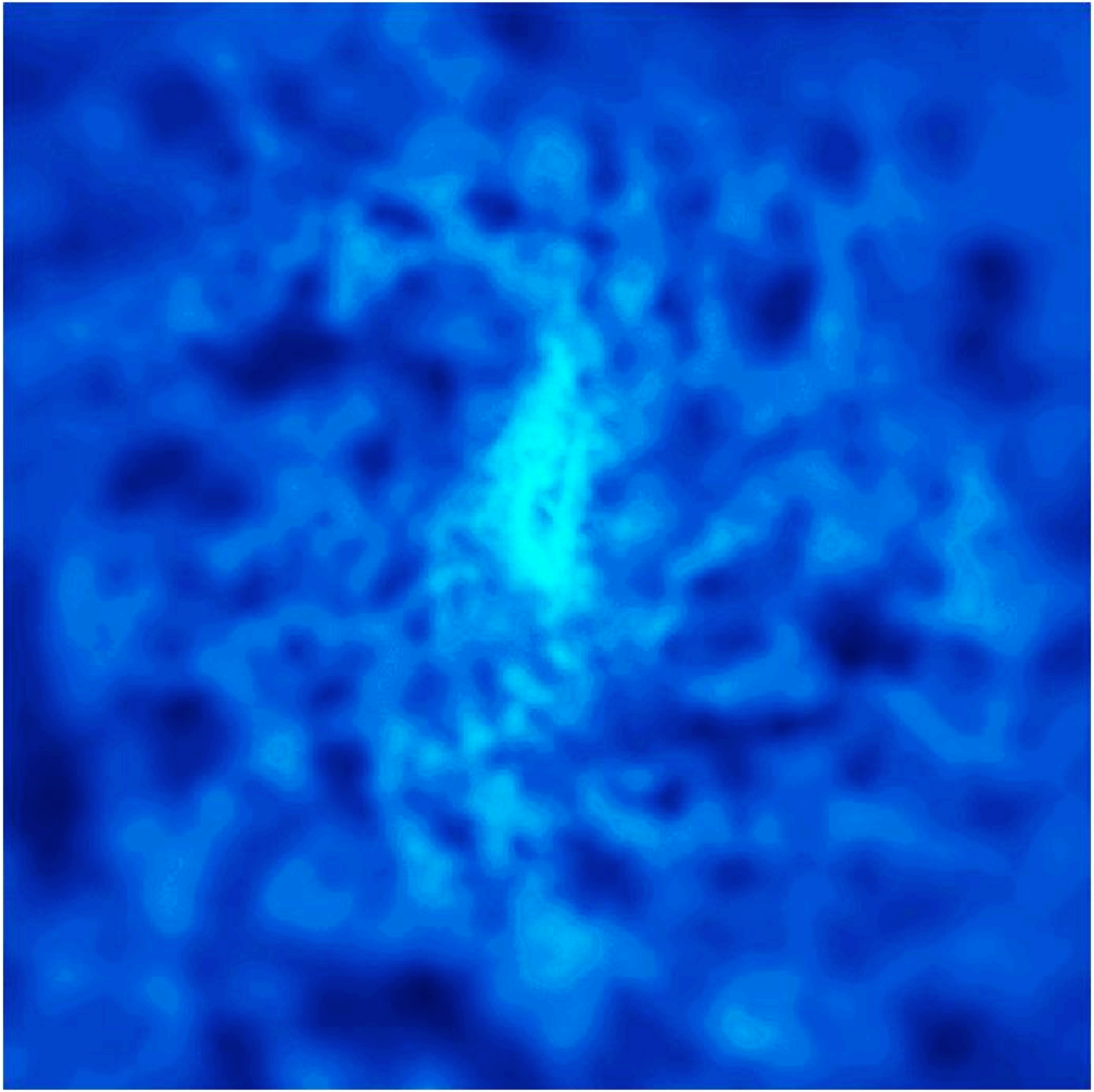
Rms Velocities < 20km/s

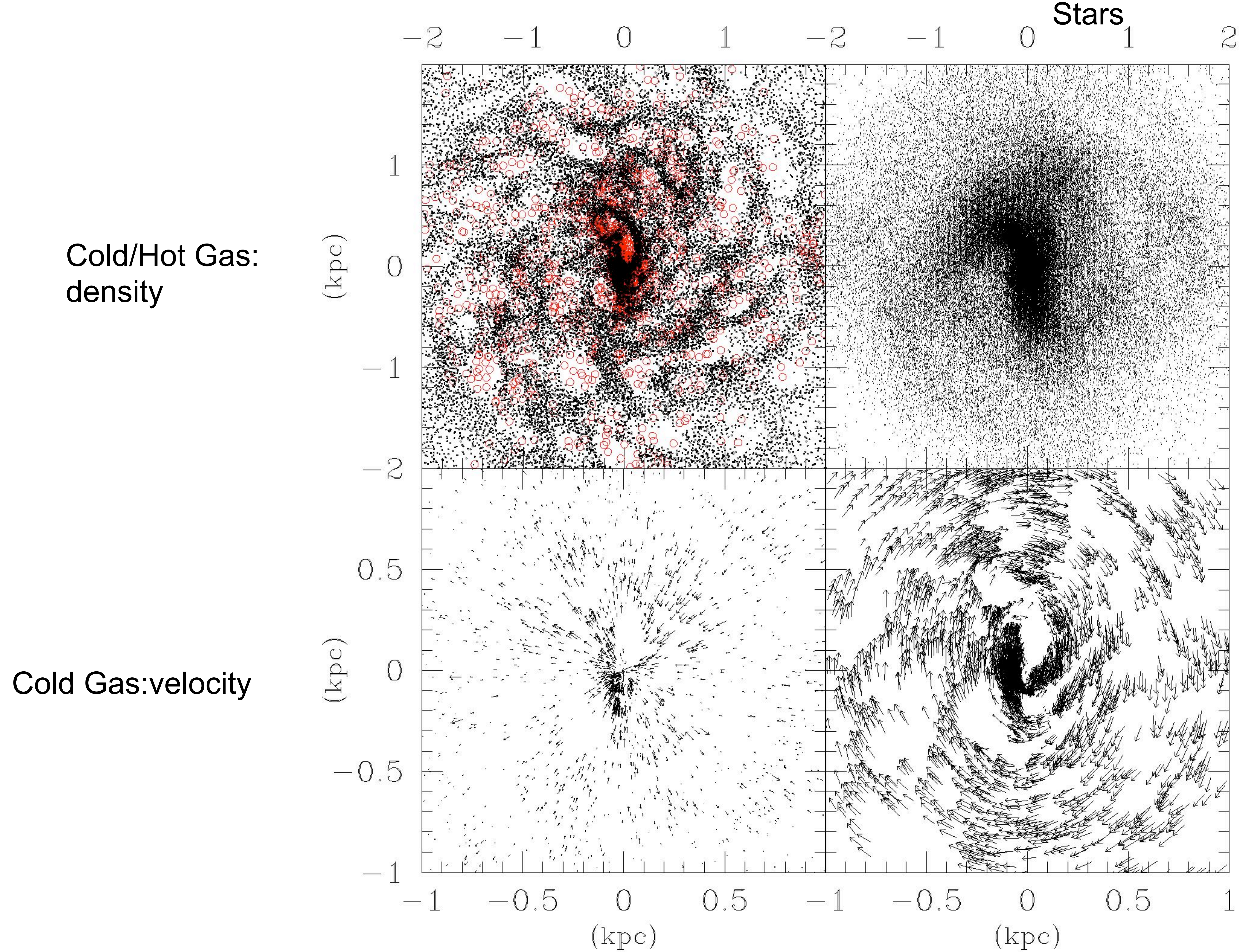
Recovering total density



Cold Gas density in the central 2kpc region:

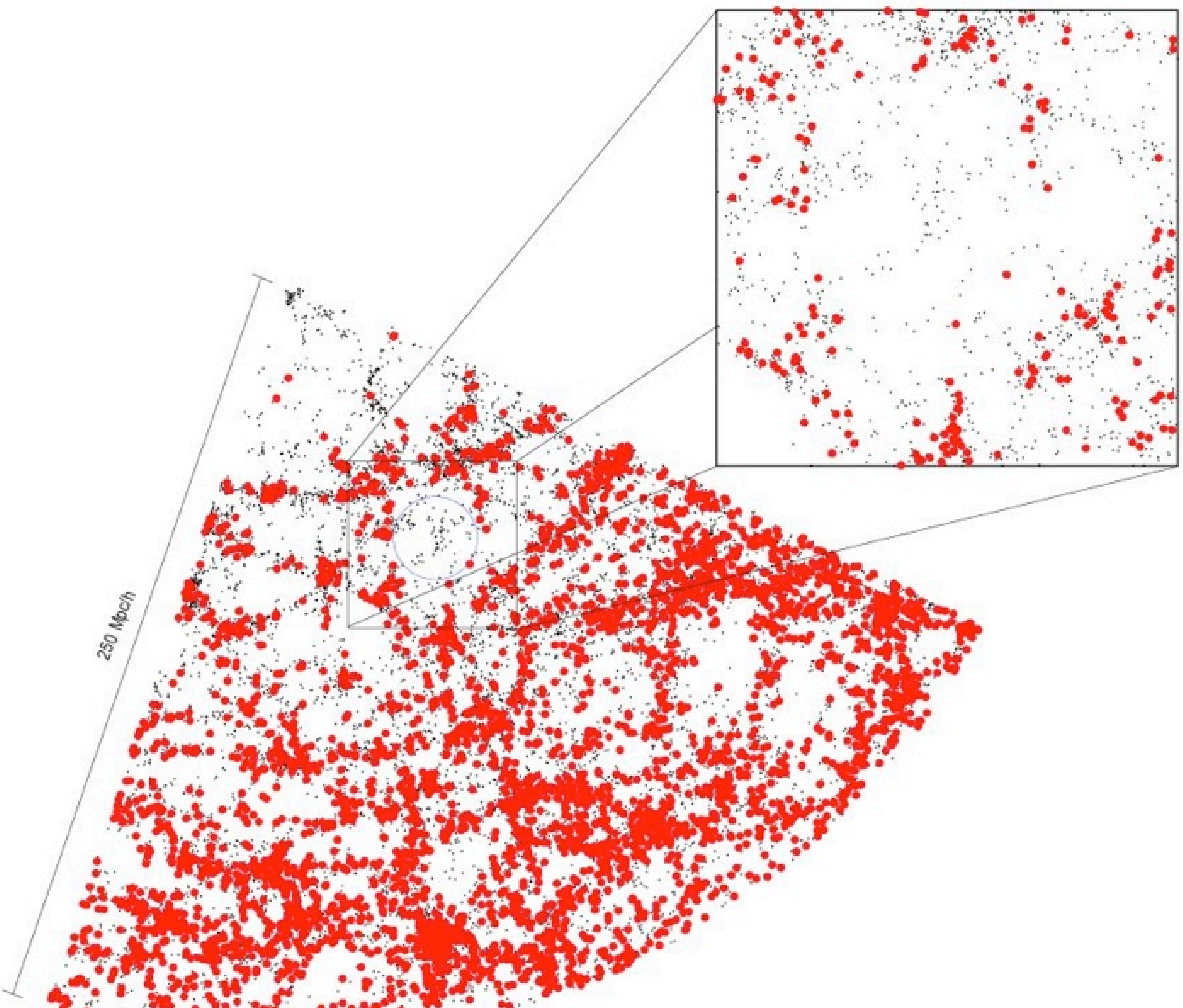
Clear signs of multiphase medium

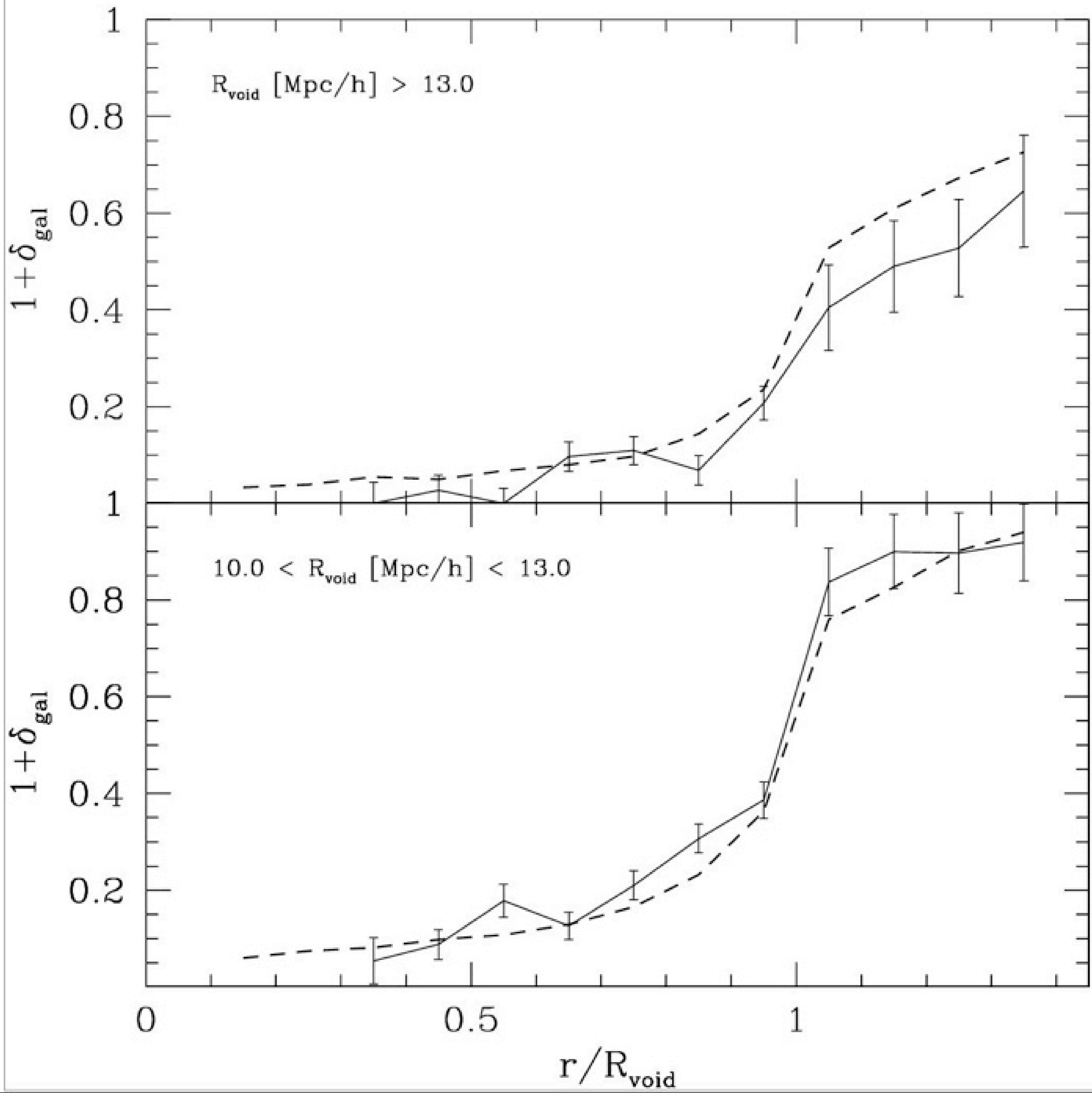



Stars
Cold/Hot Gas:
density
Cold Gas:velocity
(kpc)
−2 −1 0 1 −2 −1 0 1 2
1
0
−1
−2
0.5
0
−0.5
−1
−1 −0.5 0 0.5 −1 −0.5 0 0.5 1

Voids

Patiri et al 2006: SDSS and Millennium Run





R_{void} [Mpc/h] > 13.0
10.0 < R_{void} [Mpc/h] < 13.0
$1+\delta_{gal}$
r/R_{void}
0
0.5
1
0.2
0.4
0.6
0.8