Effects of baryons on the circular velocities of dwarf satellites

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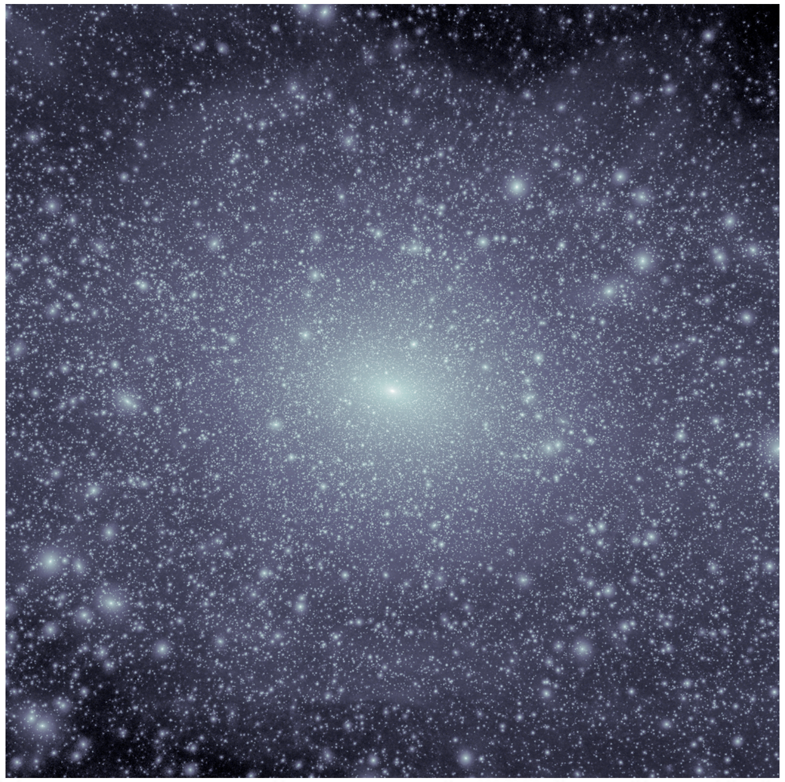
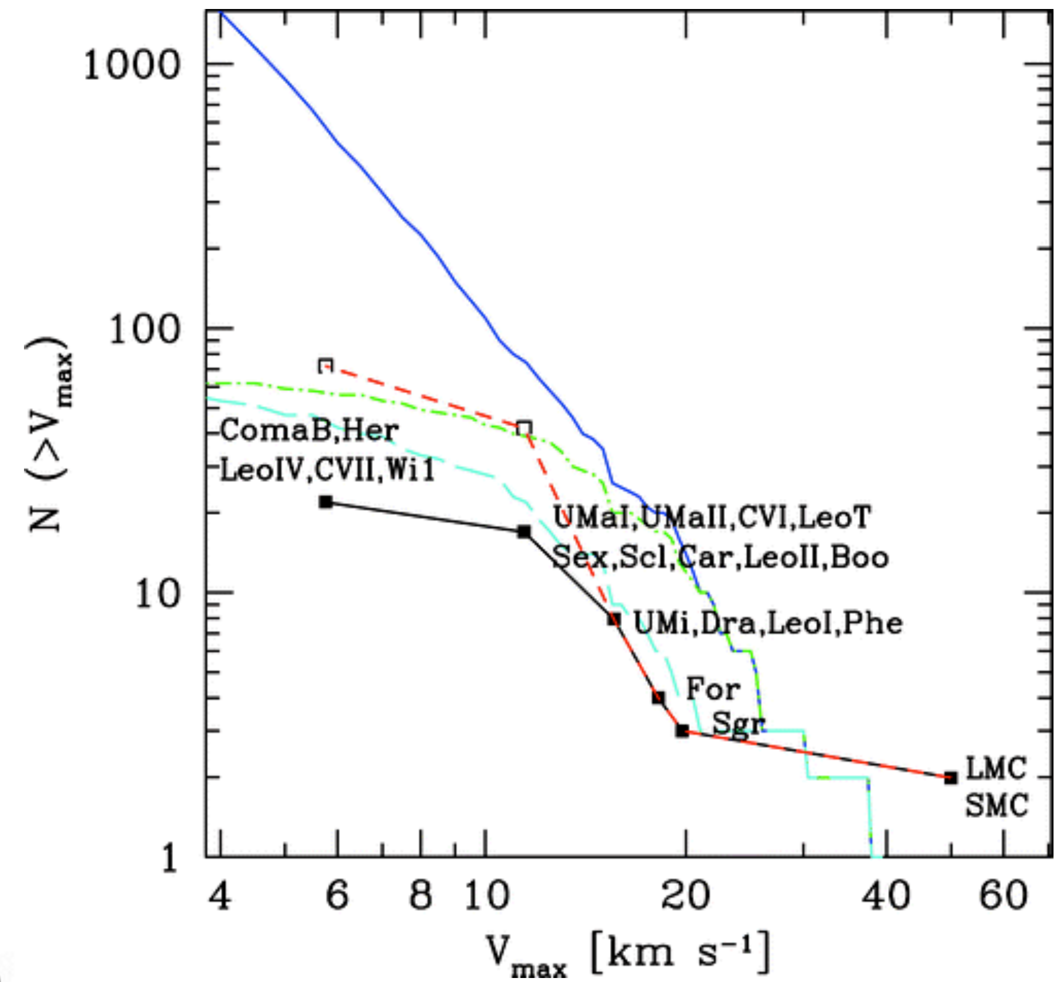
LCDM and dwarfs: love to hate

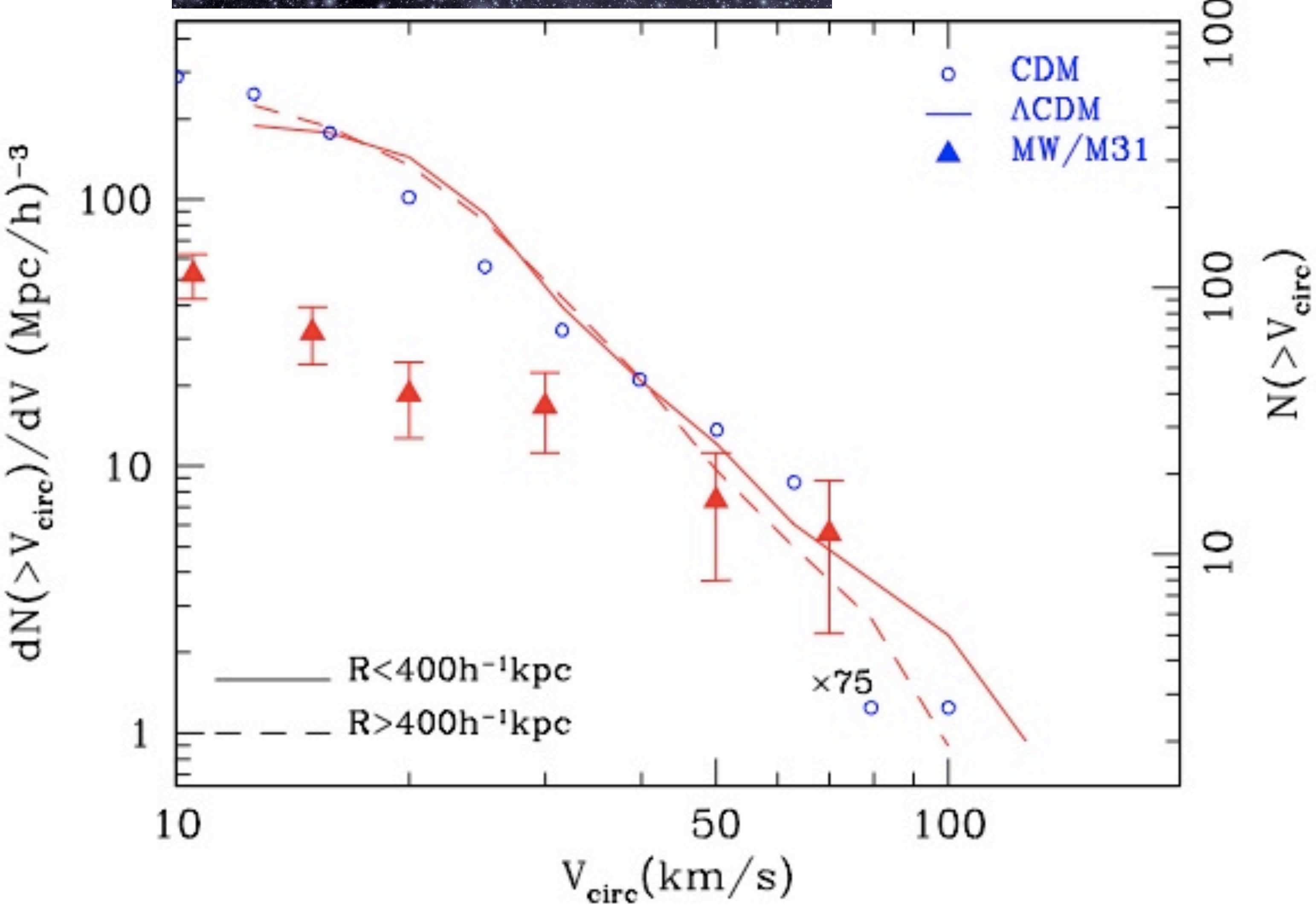
- Missing satellites
- Core/cusp
- Too big to fail
- Velocity function of (dwarf) galaxies

Missing Satellites Klypin et al./Moore etal. 1999



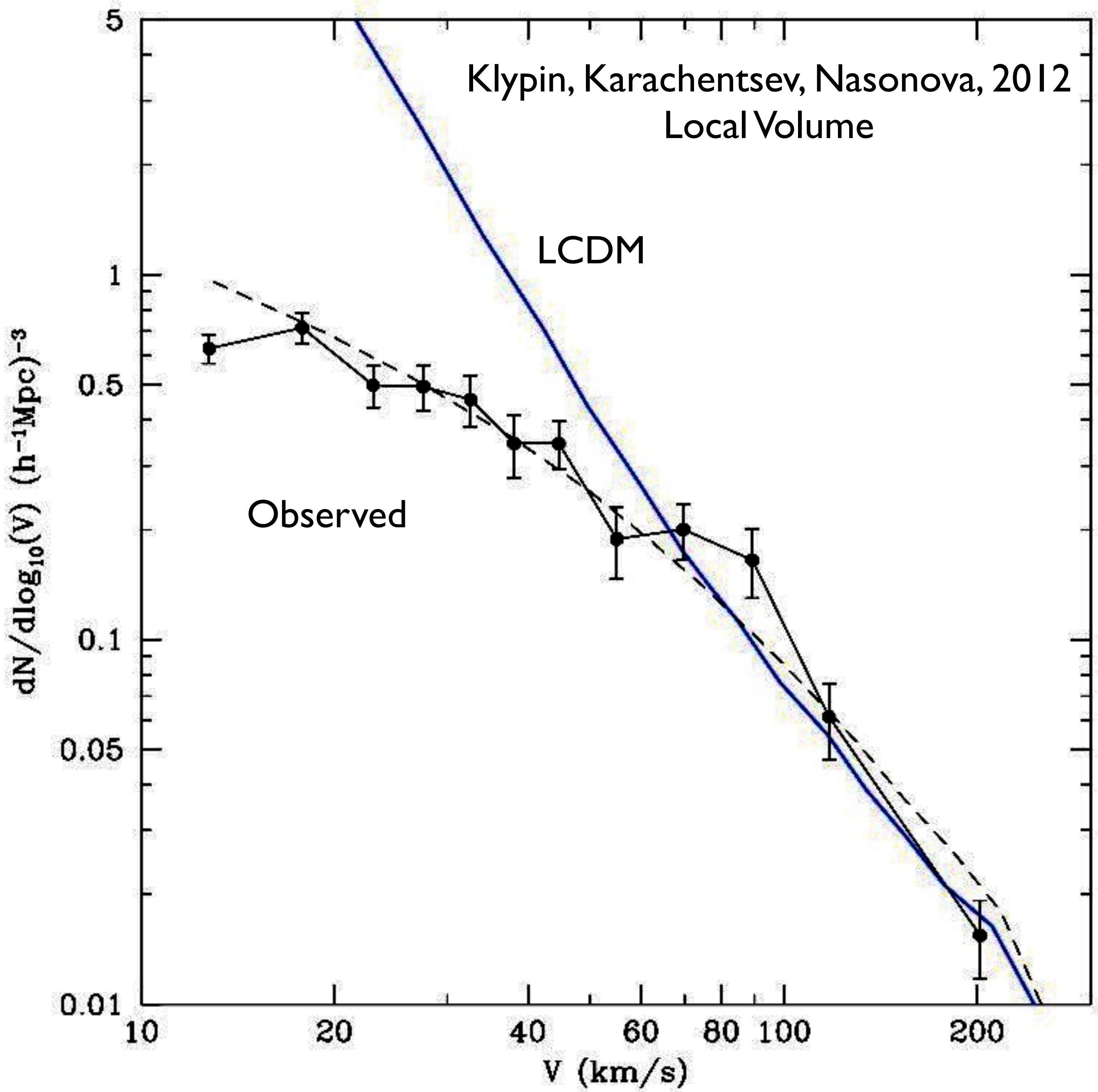
Diemand et al. 2008

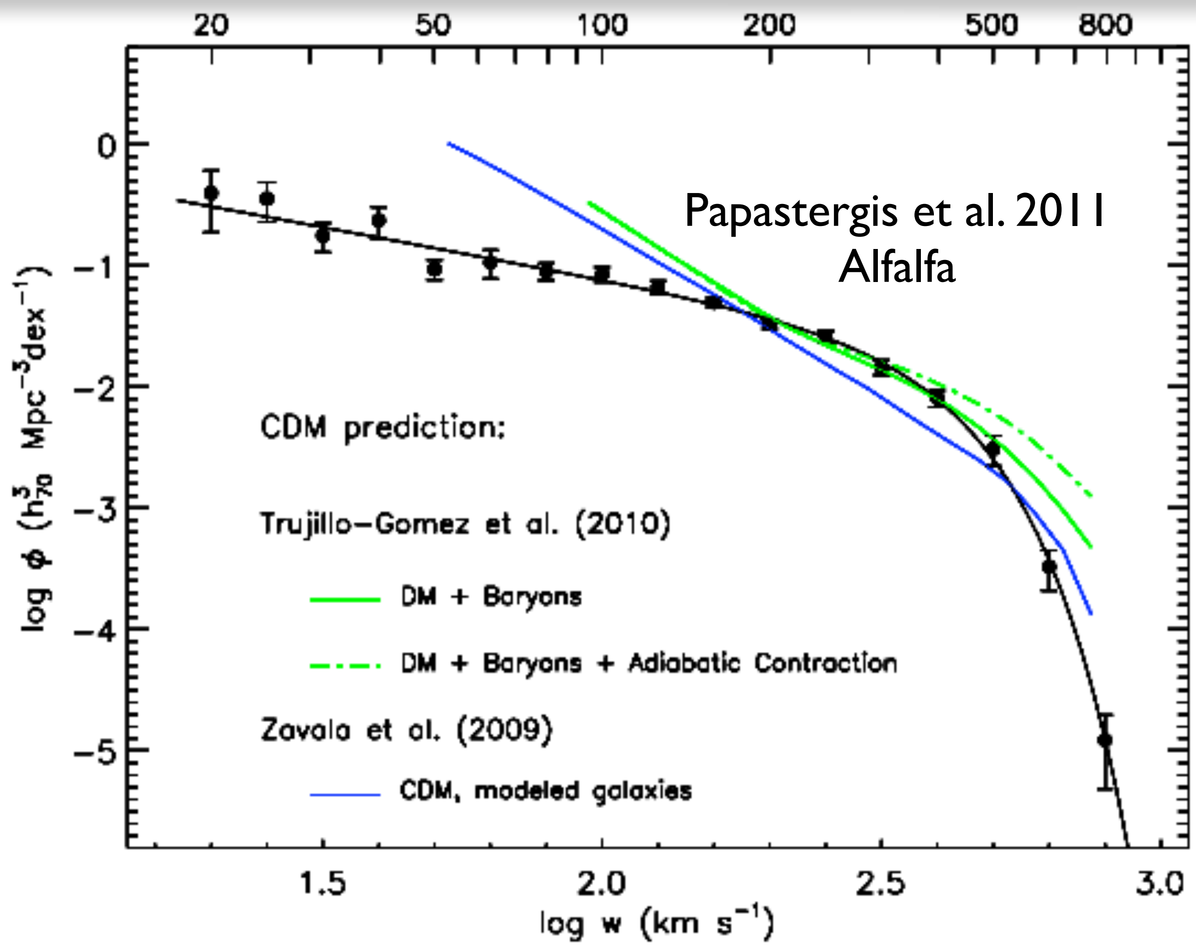




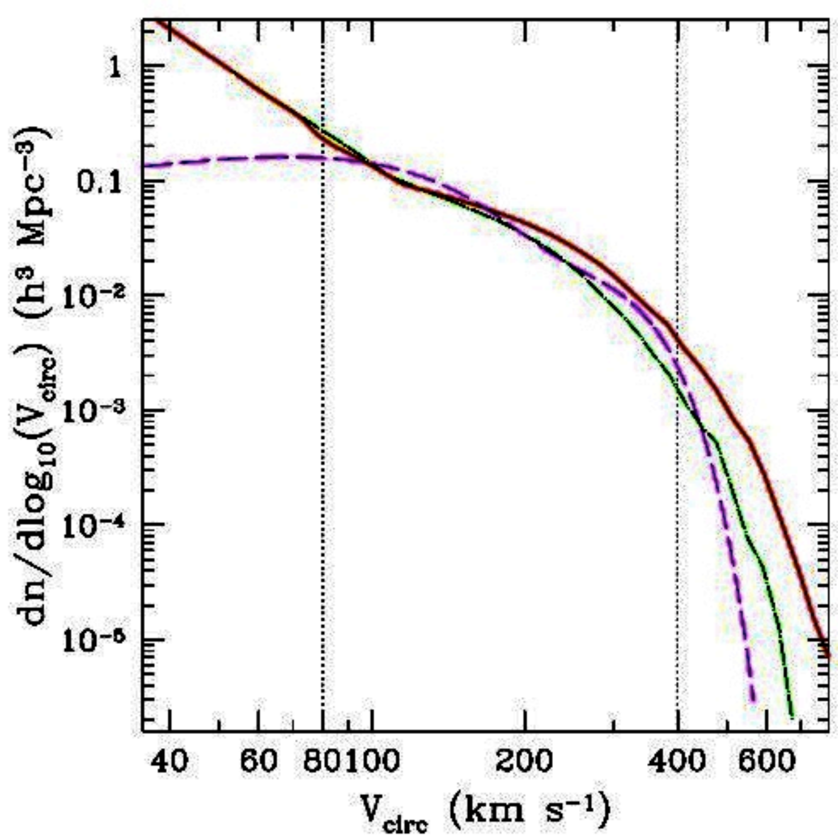
Klypin et al. 1999

Velocity function of galaxies

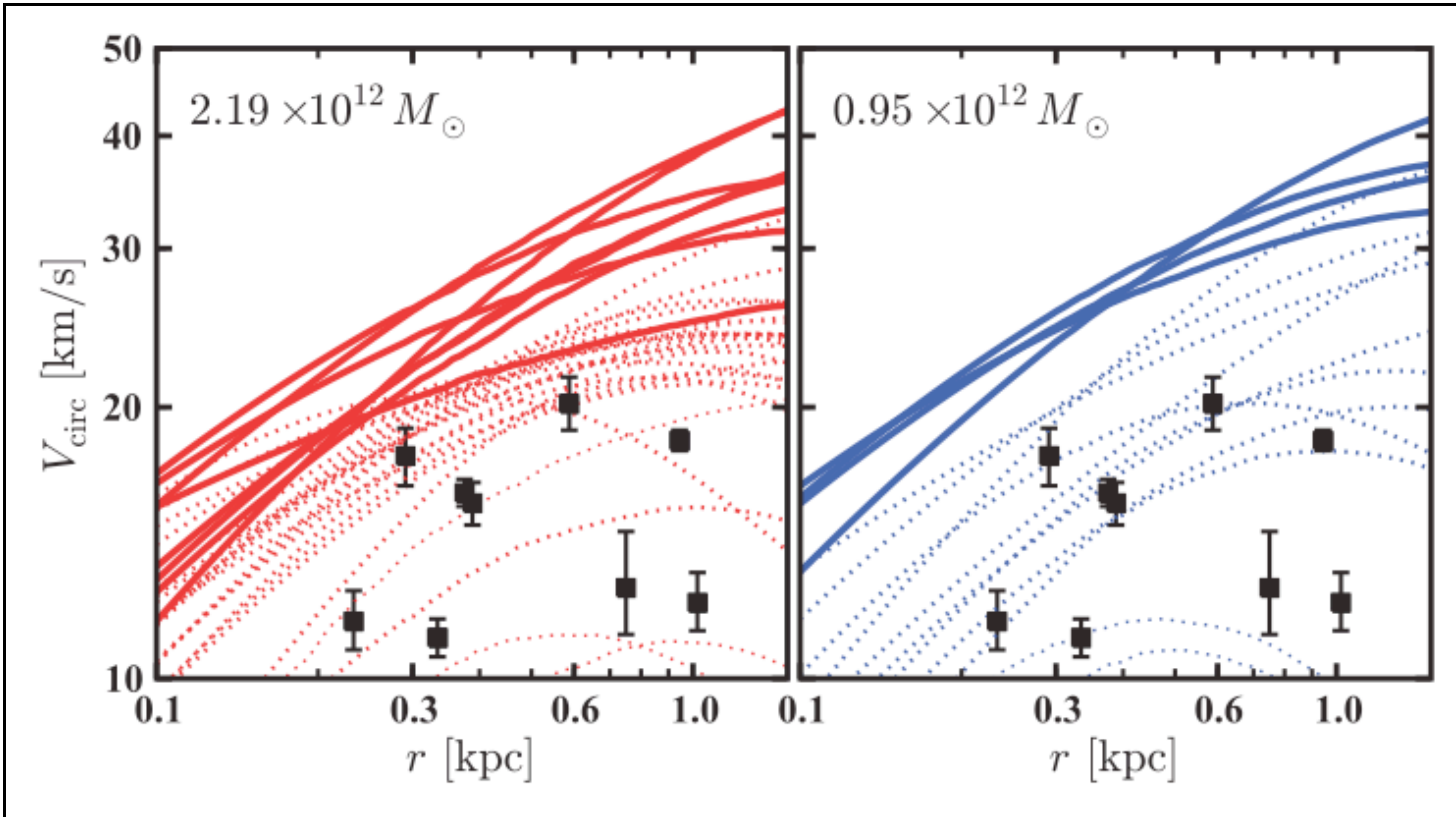




Trujillo-Gomez et al. 2011



"Massive Failures" - Boylan-Kolchin 2011 & 2012



"Massive Failures" MW observations:

- 9 dSphs have 12 km/s < V_max < 30 km/s
- 3 dIrr can have V_max >30 km/s

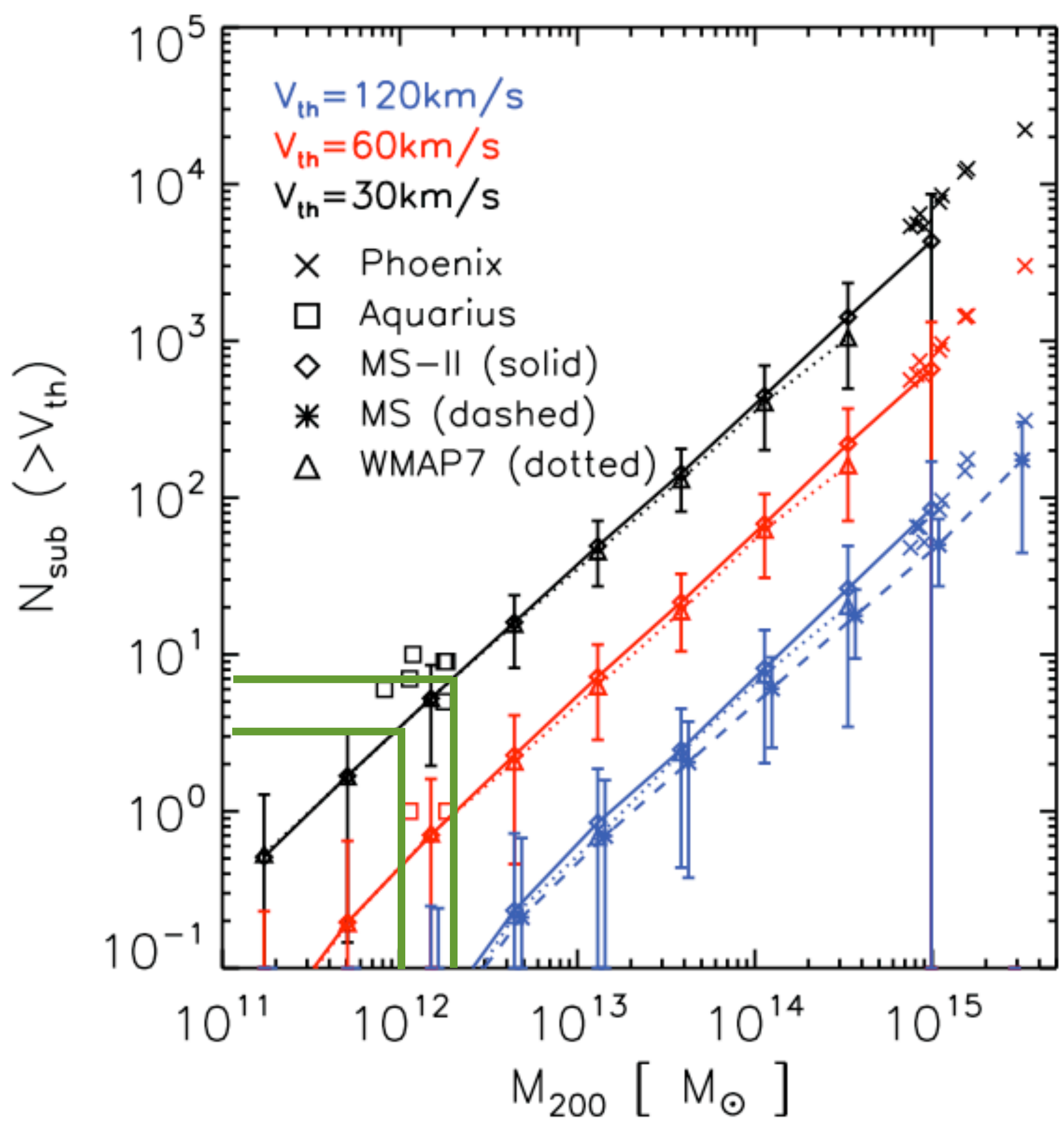
Aquarius simulations:

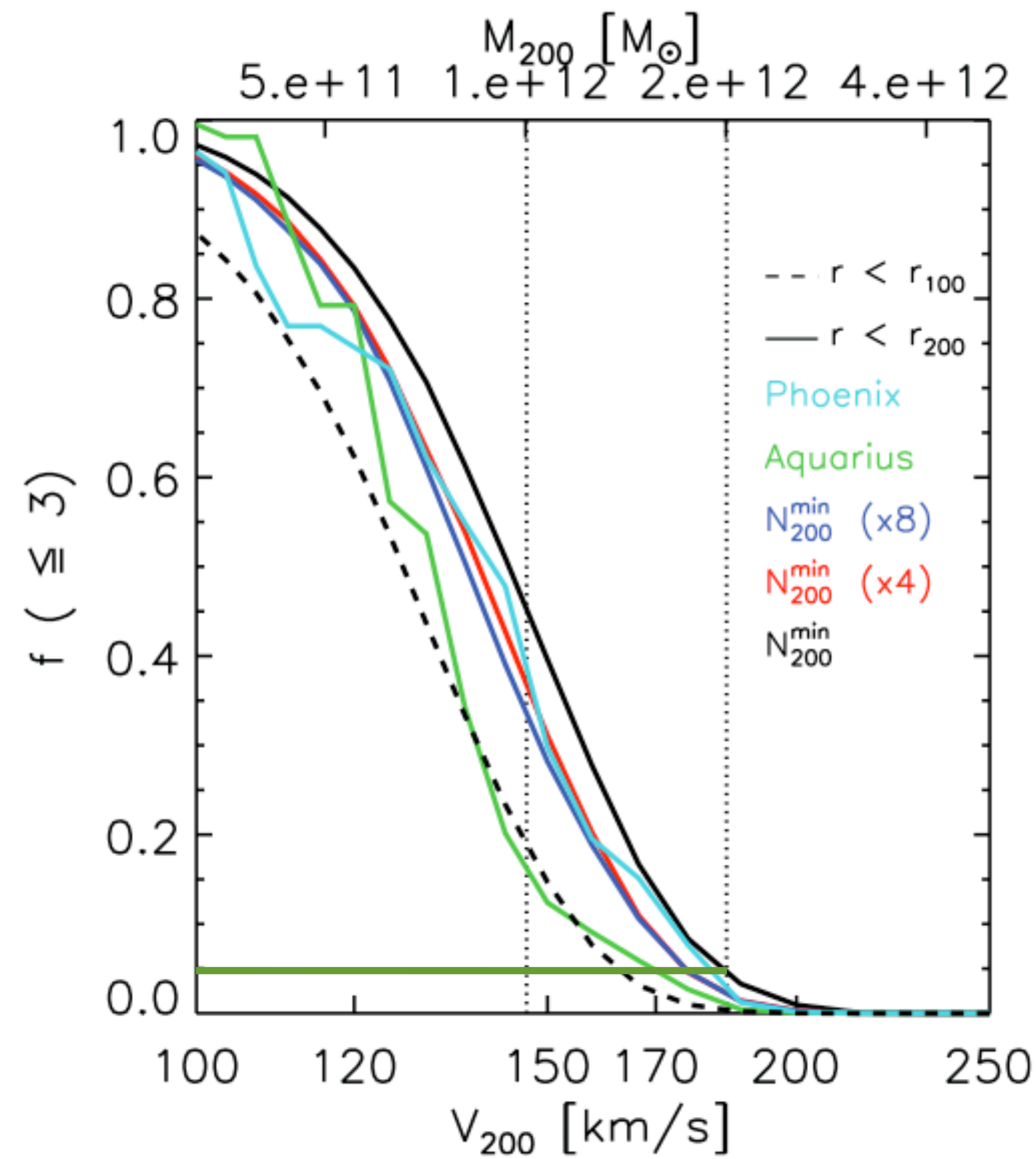
- 8 subhalos with V_max > 30 km/s

However: *Aquarius uses outdated cosmology with with 25% higher amplitude of fluctuations on the scale of dwarf => more satellites each having higher concentration than for WMAP7*

Massive Failures: “Solutions”

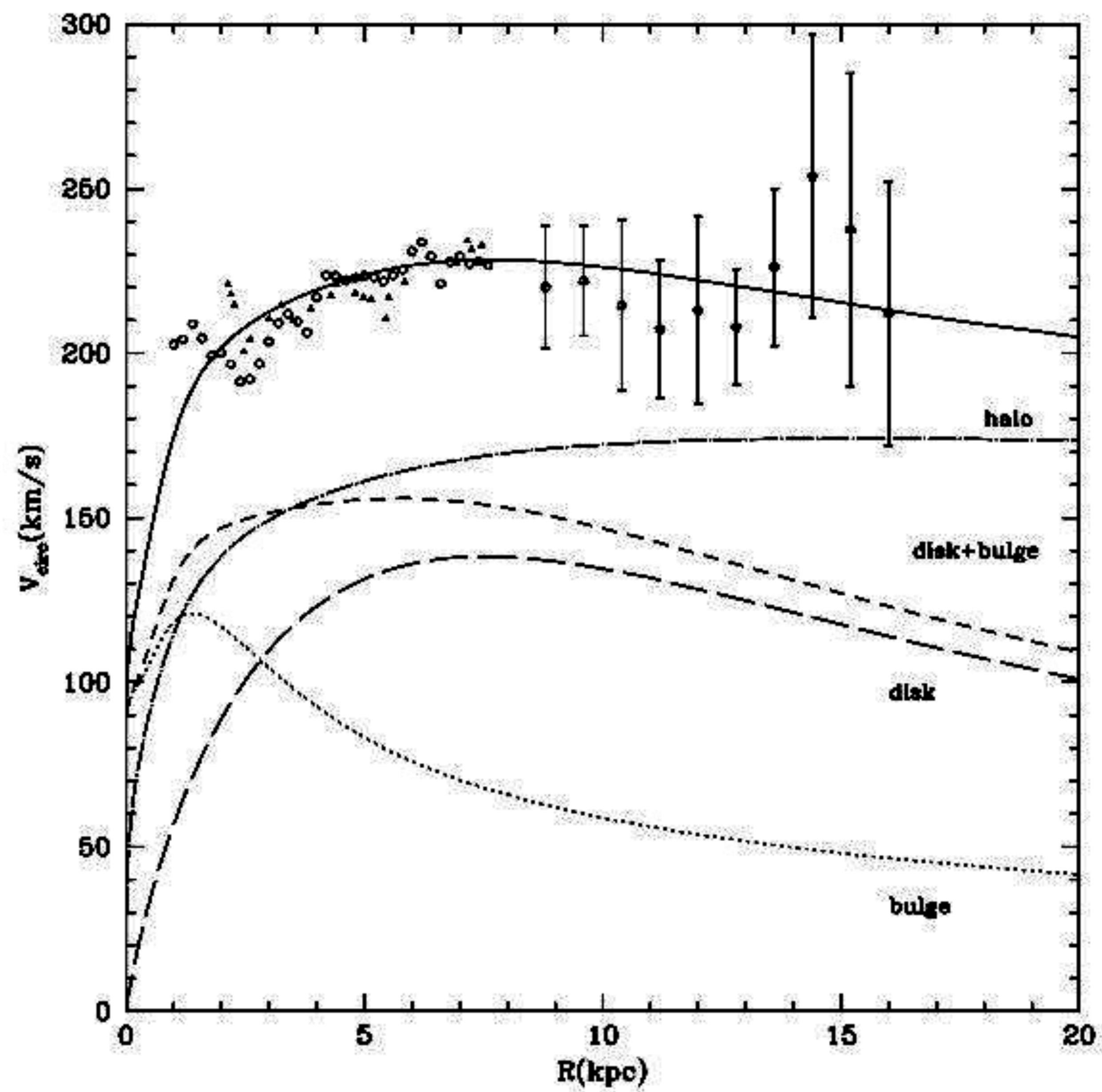
Reduce Mass of MW to 10^{12}Msun: Vera-Ciro et al. 2012; Wang et al. 2012

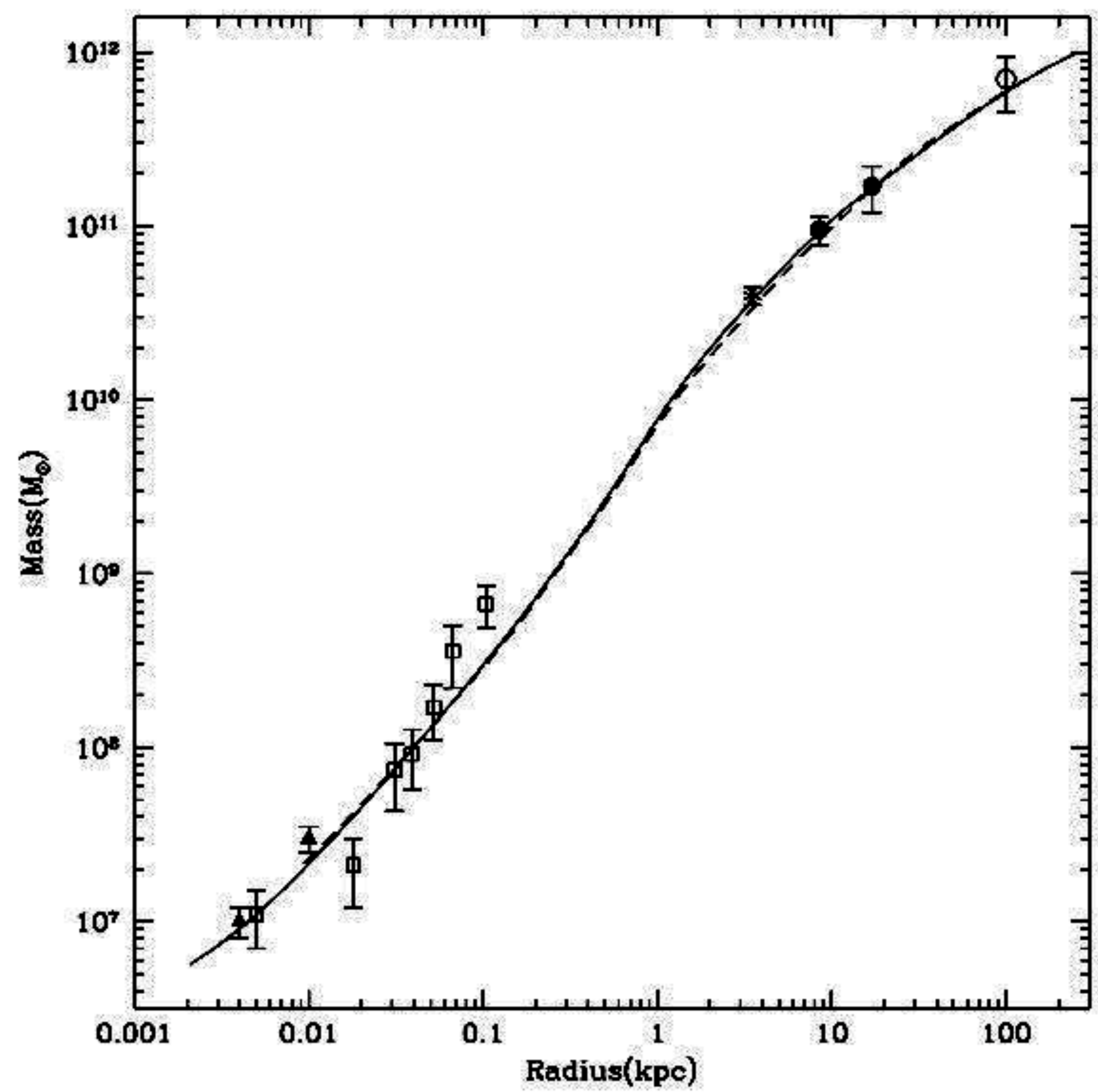




Wang et al. 2012

MW models with 1012Msun are compatible with observations

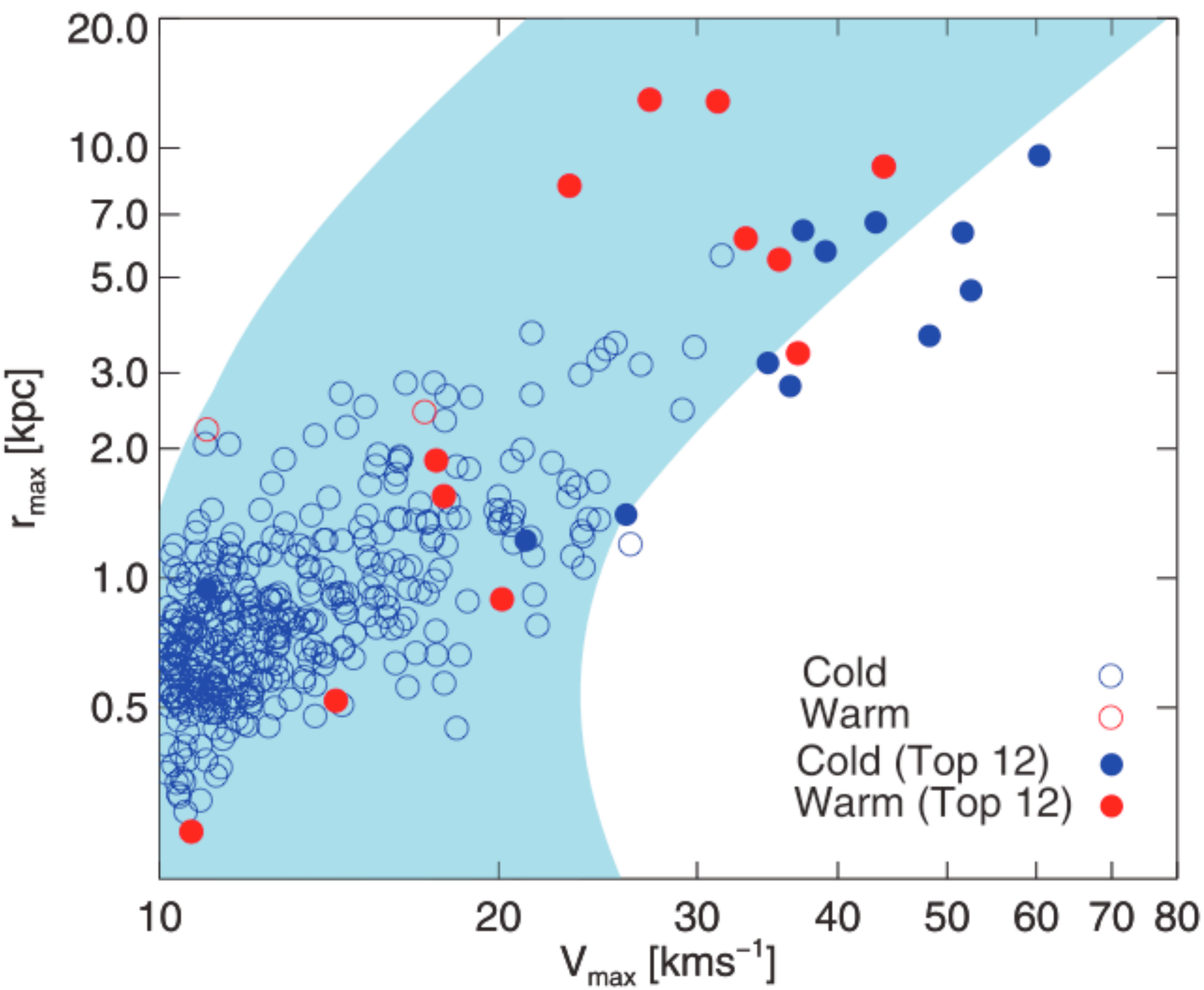




Klypin et al. 2002

"Massive Failures" Solutions - **Change CDM**

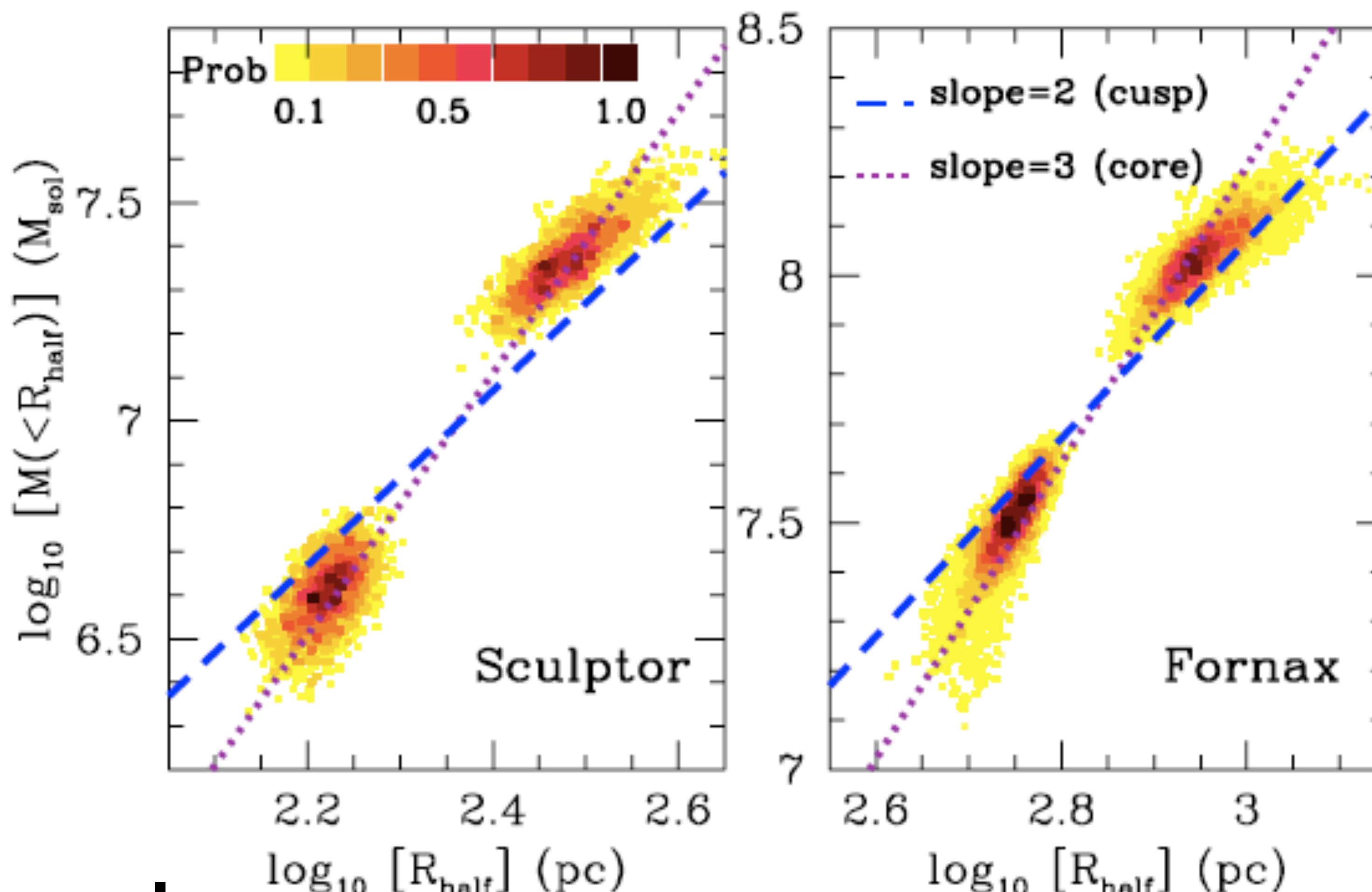
Lovell et al. 2012, Vogelsberger et al. 2012



Lovell et al. 2012

Walker & Pennarubia 2011

Derived Quantities		Fornax	Sculptor
$\log_{10}[M(r_{\mathrm{h},1})/M_\odot]$	...	$7.67^{+0.07(+0.12)}_{-0.08(-0.20)}$	$6.77^{+0.07(+0.13)}_{-0.07(-0.15)}$
$\log_{10}[M(r_{\mathrm{h},2})/M_\odot]$	$6.97^{+0.04(+0.07)}_{-0.04(-0.07)}$	$8.20^{+0.06(+0.13)}_{-0.06(-0.12)}$	$7.53^{+0.08(+0.17)}_{-0.07(-0.13)}$
$\Gamma \equiv \Delta \log M / \Delta \log r$	...	$2.61^{+0.43(+1.07)}_{-0.37(-0.68)}$	$2.95^{+0.51(+1.22)}_{-0.39(-0.70)}$
$3 - \Gamma^{b}$	...	$0.39^{+0.37(+0.68)}_{-0.43(-1.07)}$	$0.05^{+0.39(+0.70)}_{-0.51(-1.22)}$

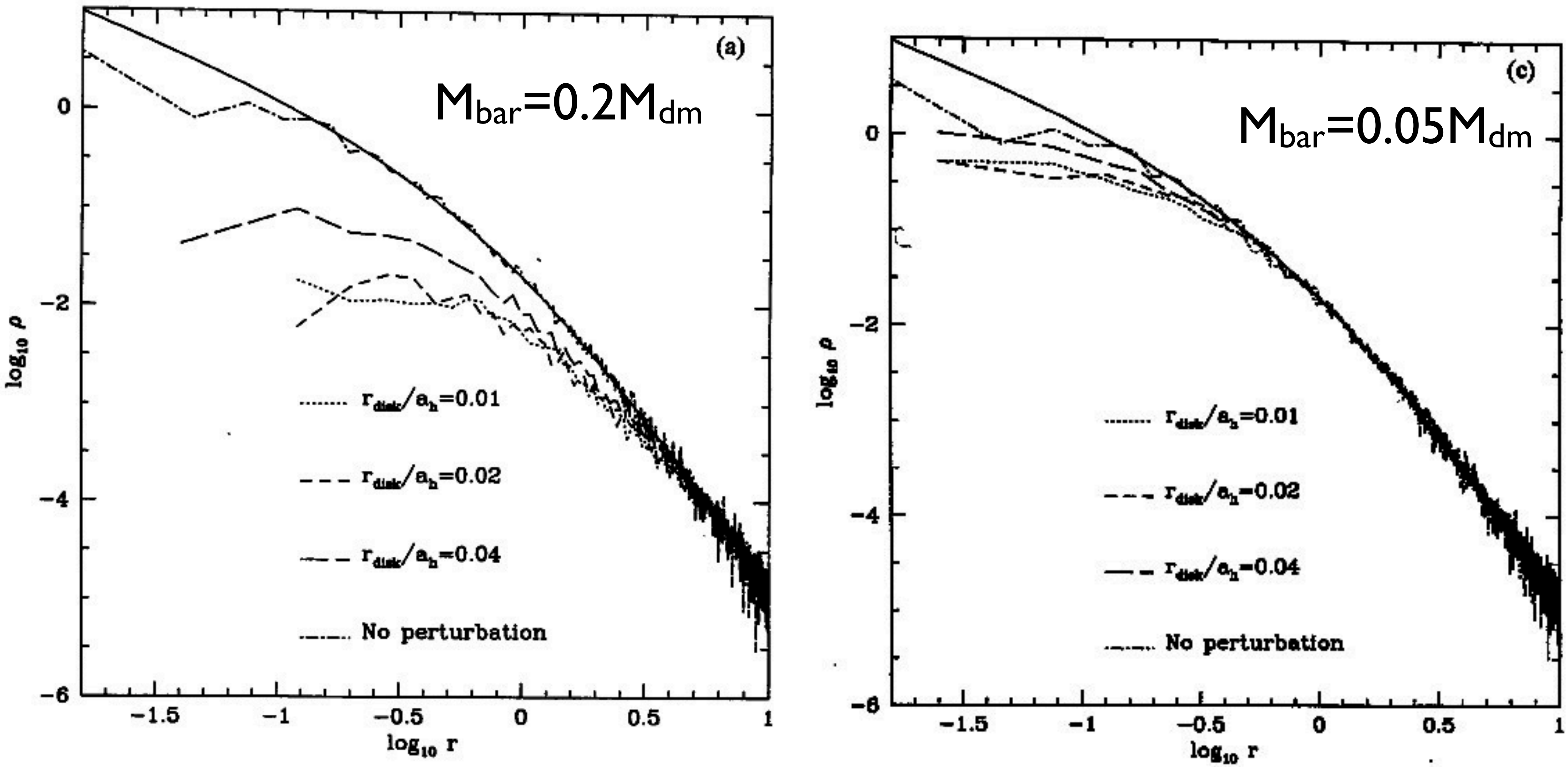


Gamma =2 => slope= -1

Cusps and cores: if baryons are removed, will cusp flatten?

Navarro, Eke, Frenk 96.

One episode of instantaneous baryon removal flattens DM cusp



Numerics: 10k particles, force softening 0.03 => **central region is not resolved. Unrealistic size of baryons: too small, too dense**

Massive Failures: “Solutions” - **Baryons**

di Cintio et al. 2011 & 2012,

Vera-Ciro et al. 2012,

Zolotov et al 2012, Brooks &Zolotov 2012

- adiabatic contraction/expansion
- feedback +UV
- tidal stripping

Baryons: What effects we ***naively*** expect

N-body simulations already include baryons: they follow DM

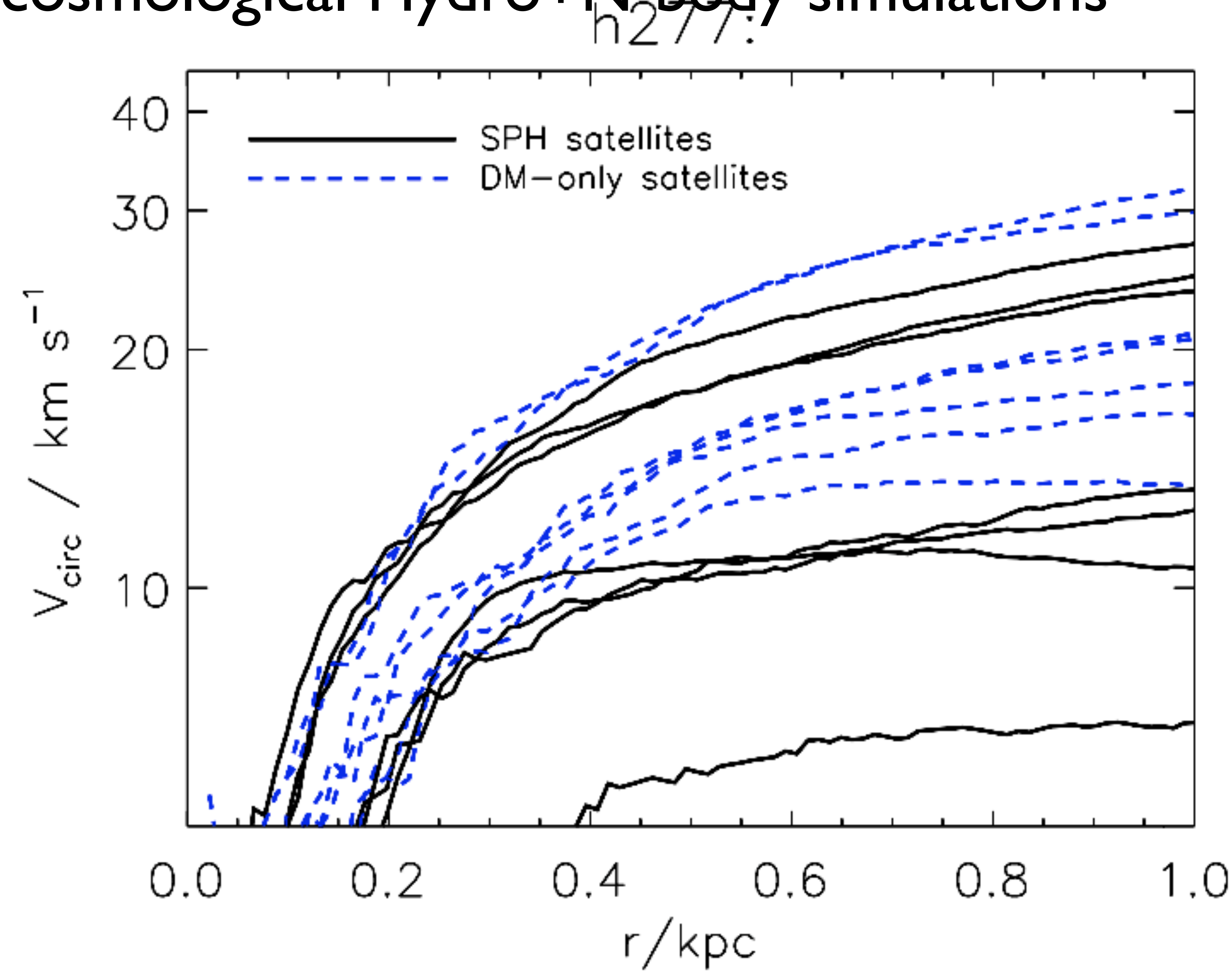
feedback+UV:

- Stellar mass in real dwarfs is very small. Fornax has 10^7Msun, Draco has 2.10^5Msun.
- *removes most of baryons: expected effect on velocities is $\sqrt{}$(Bar_fraction) =>10% in Vcirc:* ***too little to worry about***

tidal stripping:

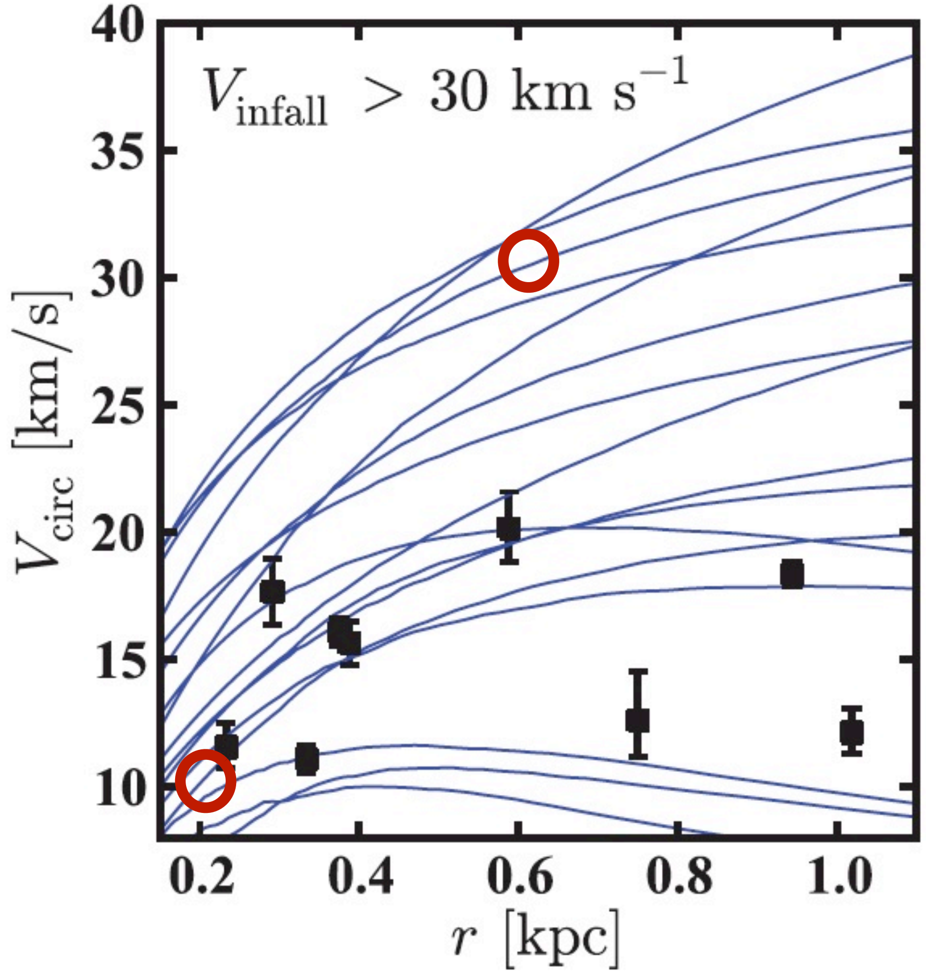
- *already included in N-body*

Zolotov et al 2012:
Effects of baryons in cosmological Hydro+N-body simulations

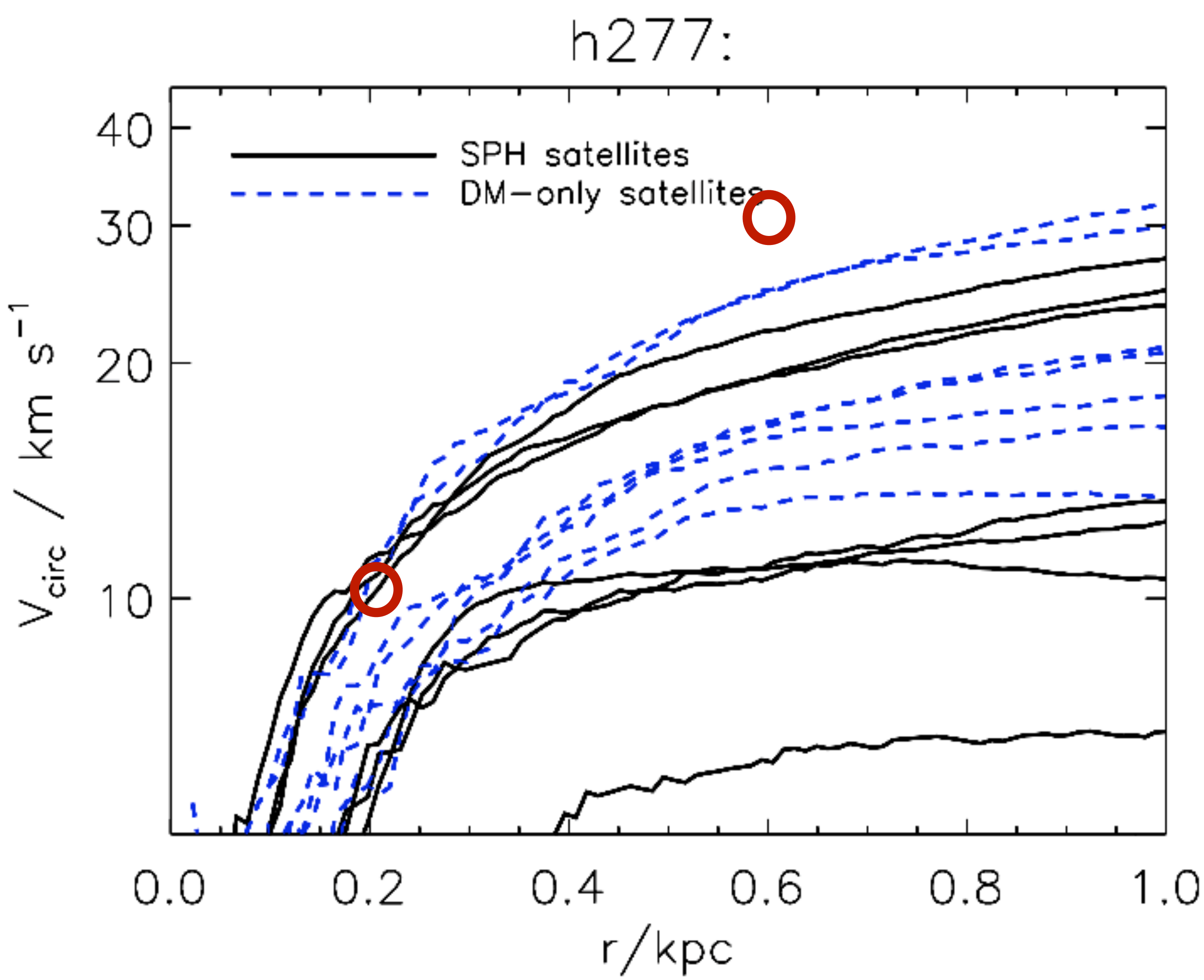


below. The spline force softening of the high resolution regions of both h277 and h258 is 174 pc. High resolution dark matter particles have masses of $1.3\times10^5\ M_\odot$, while gas particles start with $2.7\times10^4\ M_\odot$. Star parti-

Boylan-Kolchin et al



Zolotov et al



Resolution is a very serious problem even with the best current simulations

Satellite	M_V	$L_V [L_\odot]$	d_{sun} [kpc]	R_{half} [pc] [a]
SDSS-discovered Satellites				
*Boötes I	-6.3	1.49×10^3	60	242
*Boötes II	-2.7	7.80×10^2	43	72
*Canes Venatici I	-8.6	1.24×10^5	224	565
*Canes Venatici II	-4.9	7.11×10^3	151	74
*Coma	-4.1	2.58×10^3	44	77
*Hercules	-6.6	2.15×10^4	138	330
*Leo IV	-5.0	9.38×10^3	158	116
*Leo T	-7.1	5.92×10^4	417	170
†Segue 1	-1.5	9.37×10^2	23	29
*Ursa Major I	-5.5	1.49×10^4	106	318
*Ursa Major II	-4.2	2.83×10^3	32	140
*Willman 1	-2.7	1.36×10^3	38	25
Classical (Pre-SDSS) Satellites				
Carina	-9.4	4.92×10^5	94	210
*Draco	-9.4	4.92×10^5	79	180
Fornax	-13.1	1.49×10^7	138	460
LMC	-18.5	2.15×10^9	49	2591
Leo I	-11.9	4.92×10^6	270	215
* Leo II	-10.1	9.38×10^5	205	160
Ursa Minor	-8.1	1.49×10^5	69	200
SMC	-17.1	5.92×10^8	63	1088
Sculptor	-9.8	7.11×10^5	88	110
Sextans	-9.5	5.40×10^5	86	335
Sagittarius	-15	8.55×10^7	28	125

[a] Satellite projected half light radius.

In order to resolve stellar feedback in dwarfs, the resolution should be (optimistically) 10-20 pc

It cannot be done with 200 pc resolution

Tollerud et al

Very high resolution N-body simulations:
20 pc $m_1 = 2x10^4\ M_{sun}$ $Neff = 1.3x10^6$

Testing numerous effects:

- baryon removal: slow vis. instantaneous
- More realistic Milky Way models
- Tidal stripping for various orbits
- Time-dependance

Cosmological N-body sims	Corrected N-body sims
Baryons are locked up in DM particles	Baryons removed: reduces Vcirc of satellite
Milky Way does not have baryon excess mass in the central 10 kpc	Add disk mass: increases tidal force

Satellites:

r_s=4 kpc v_{max}=63 km/s m_{vir}=3.2x10^{10} M_{sun}

MW halo:

r_s=25 kpc v_{max}=180 km/s m_{vir}=1.4x10^{12} M_{sun}

MW disk:

r_0=3 kpc m_{vir}=6x10^{10} M_{sun}

Orbits:

50 kpc 100 kpc 150 kpc

Isolated dwarf:

effects of removal
of 20% of mass

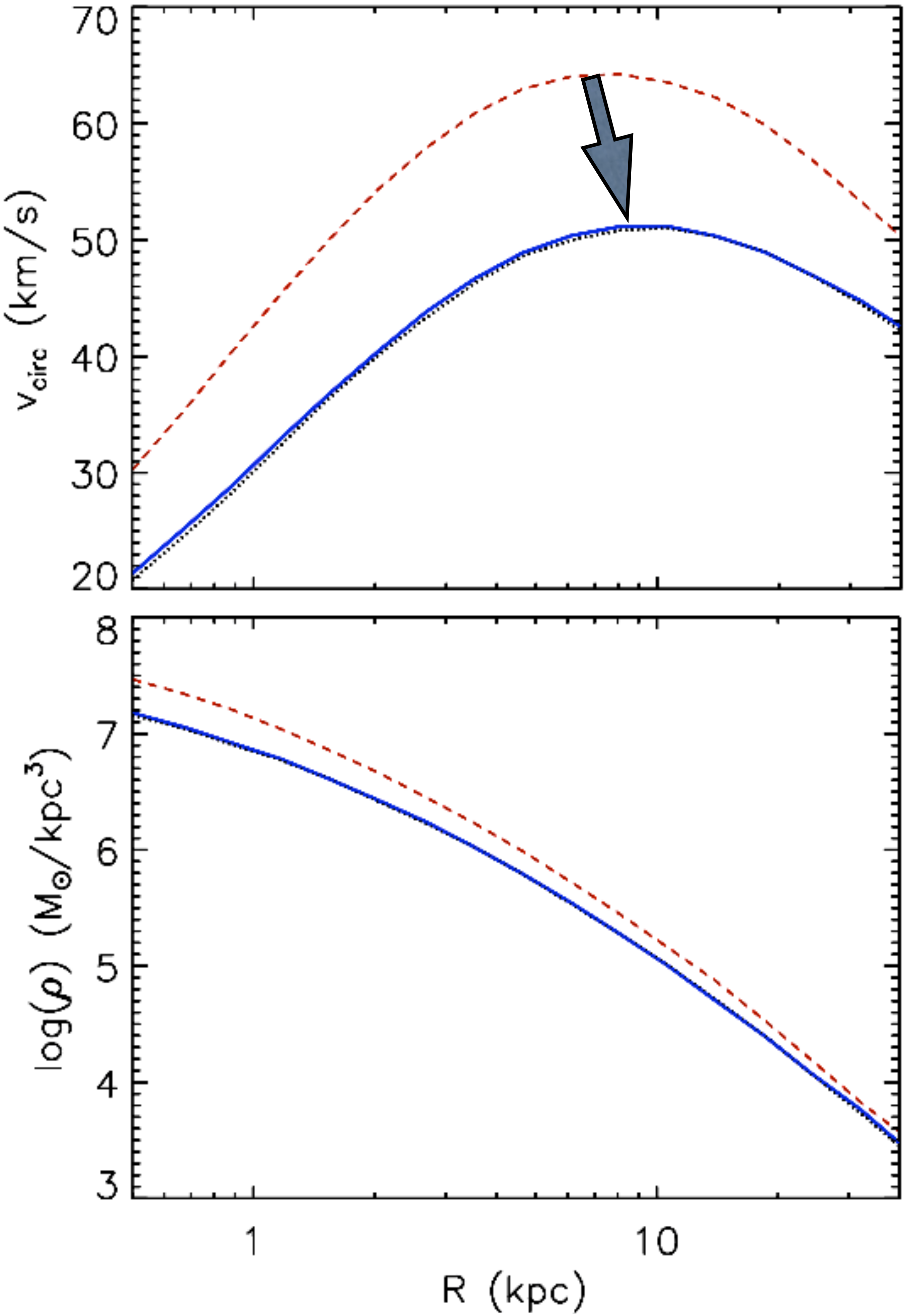
Instantaneous or slow removal of baryons produce the same effect

Adiabatic expansion is a good approximation:

Vcirc declines by 20% and Rmax increases by 20%

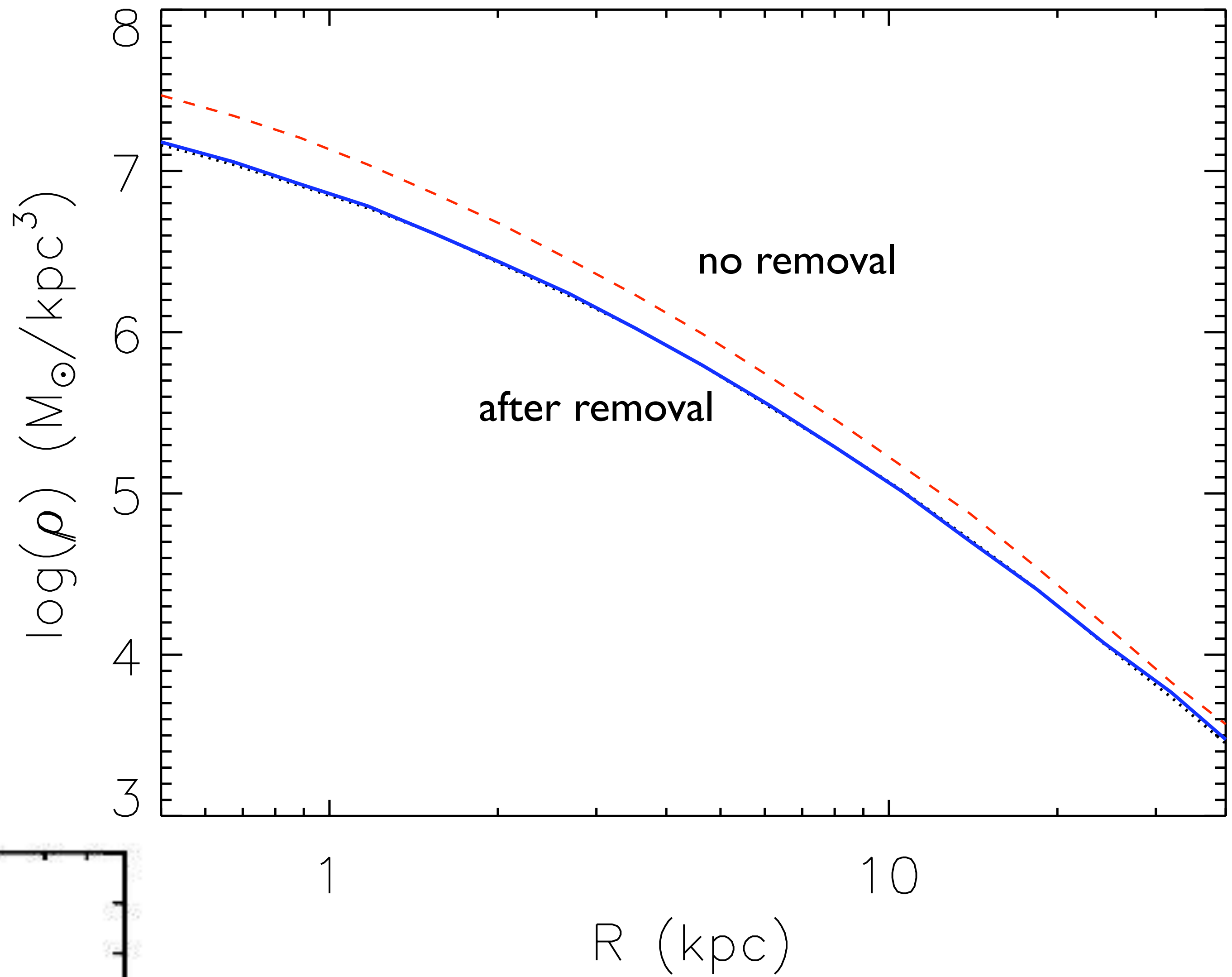
Effect is much stronger at R<Rs:

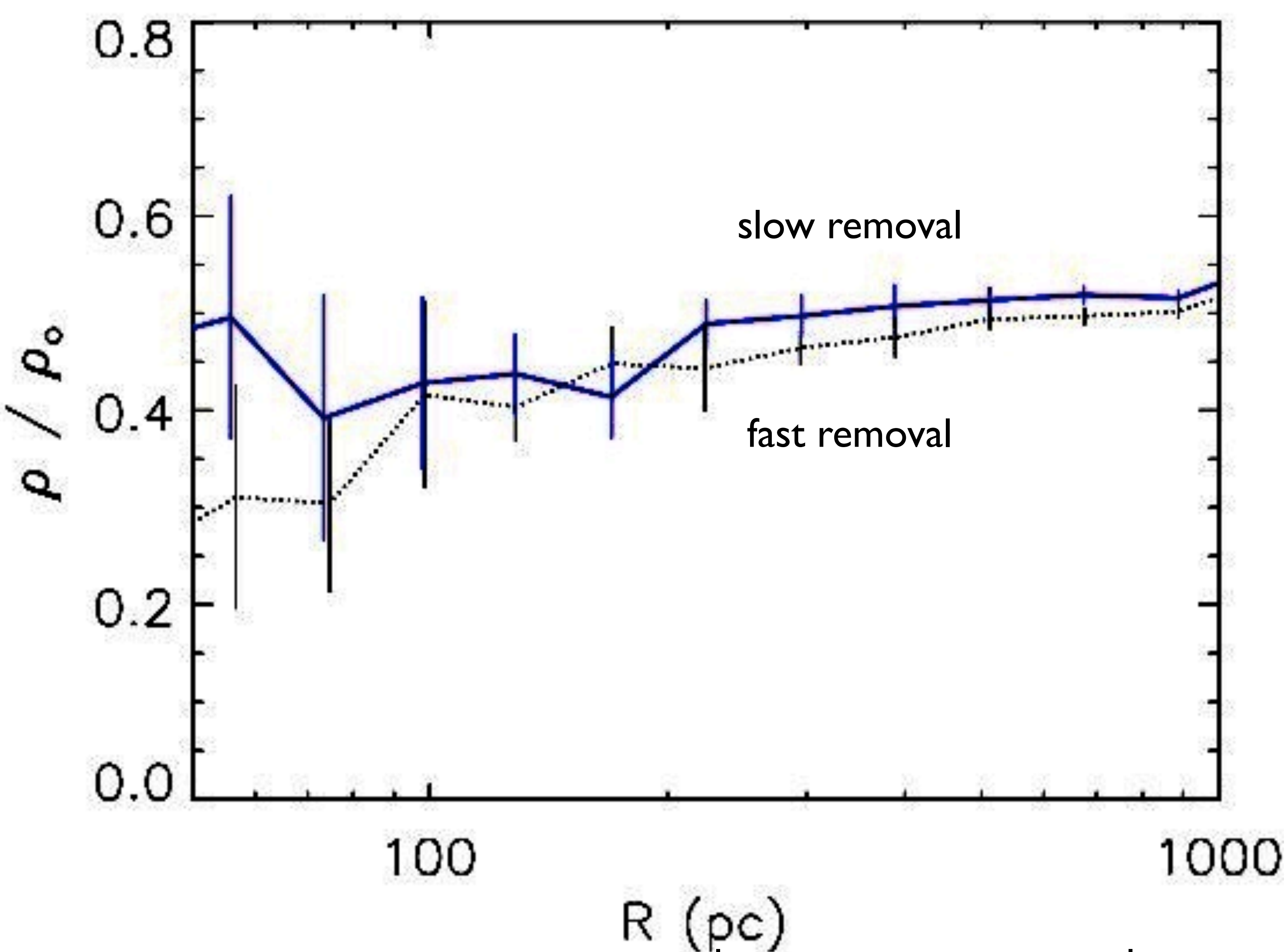
at 1kpc V_{circ} declines by factor 1.4



Does the baryon removal create a core?

No





after removal / no removal

Tidal stripping of a distressed dwarf:

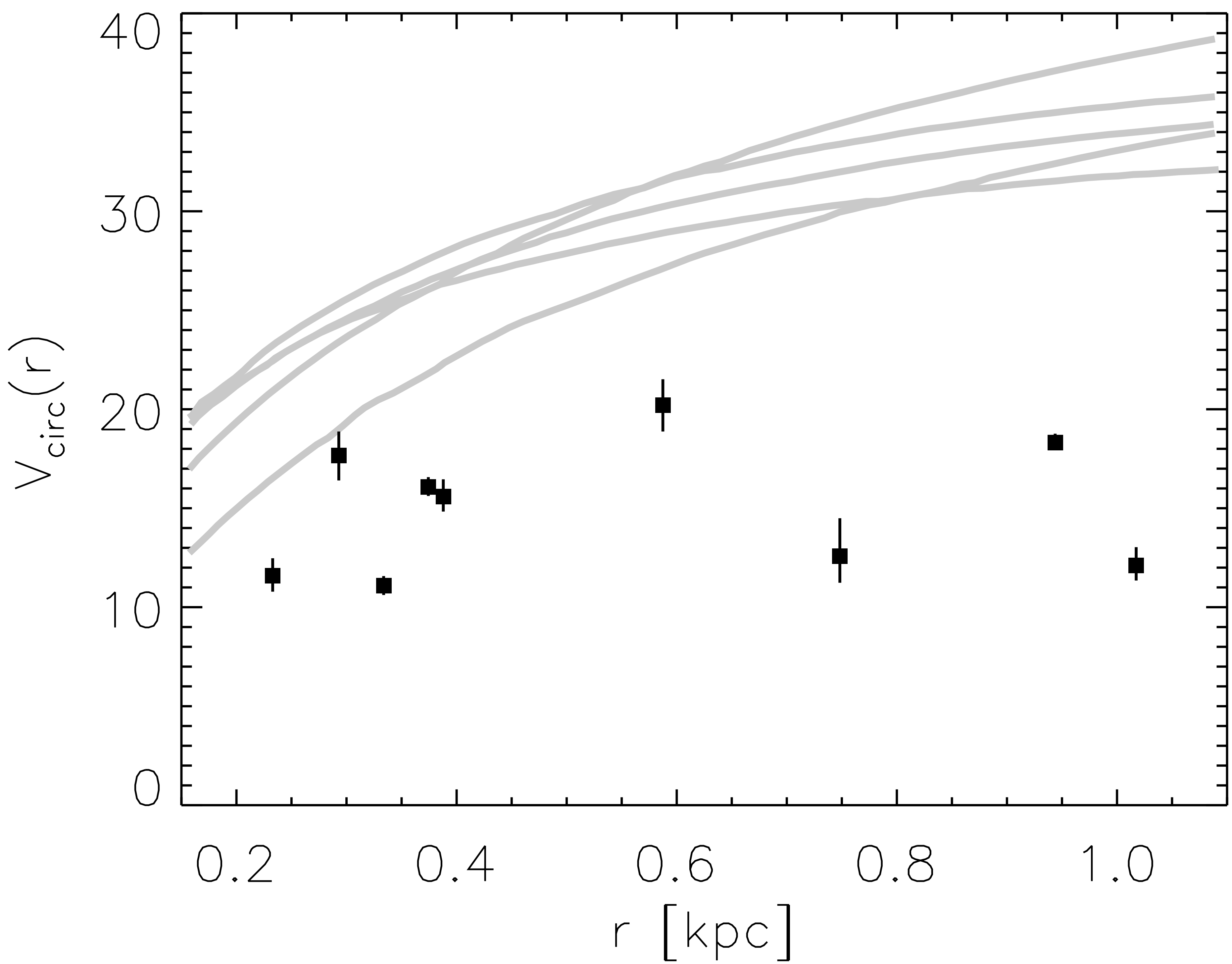
Cumulative effect:

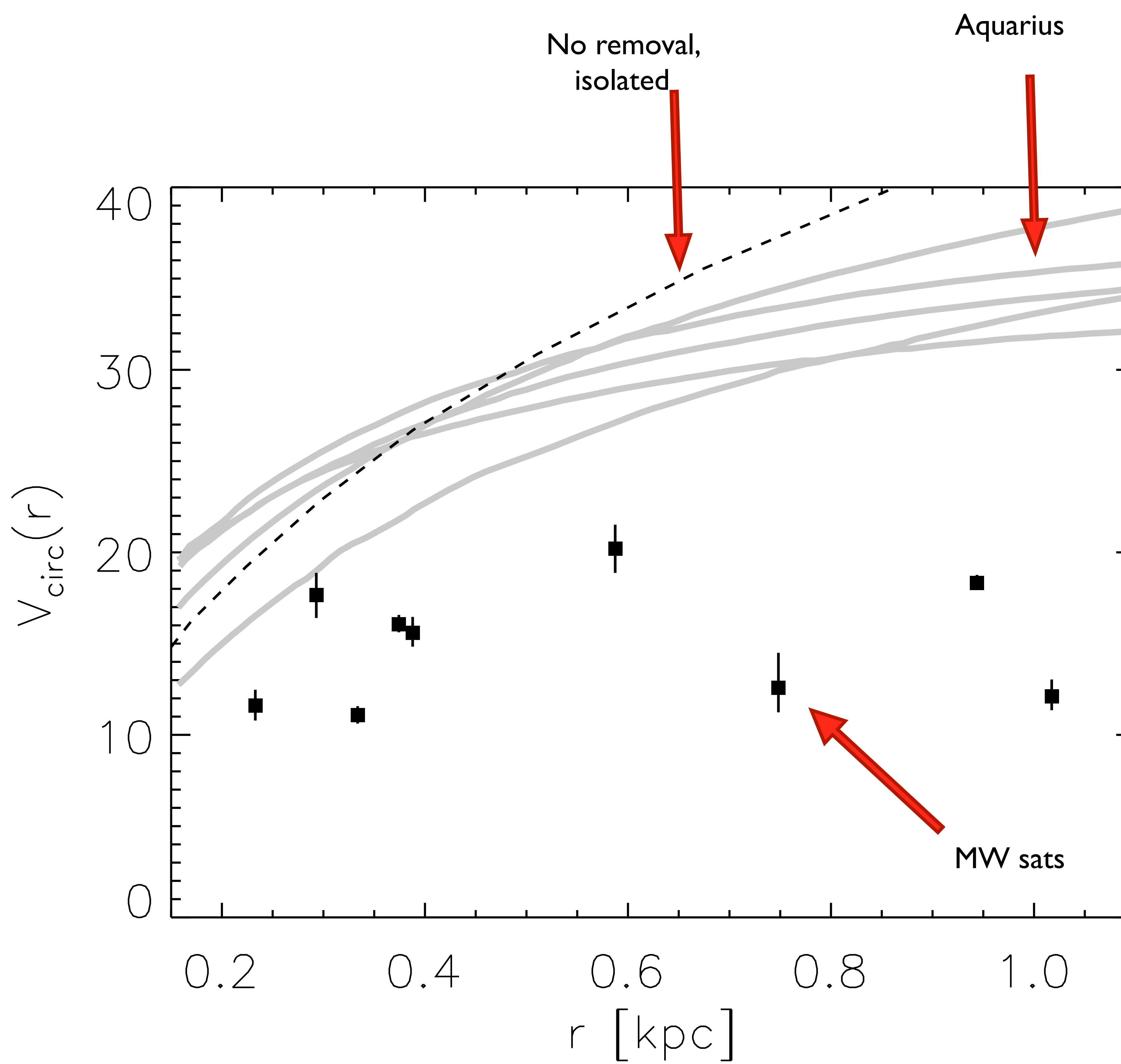
- reduce mass by removing baryons

  and

- tidal forces with baryons added to mimic stellar disk of MW

Boylan-Kolchin et al

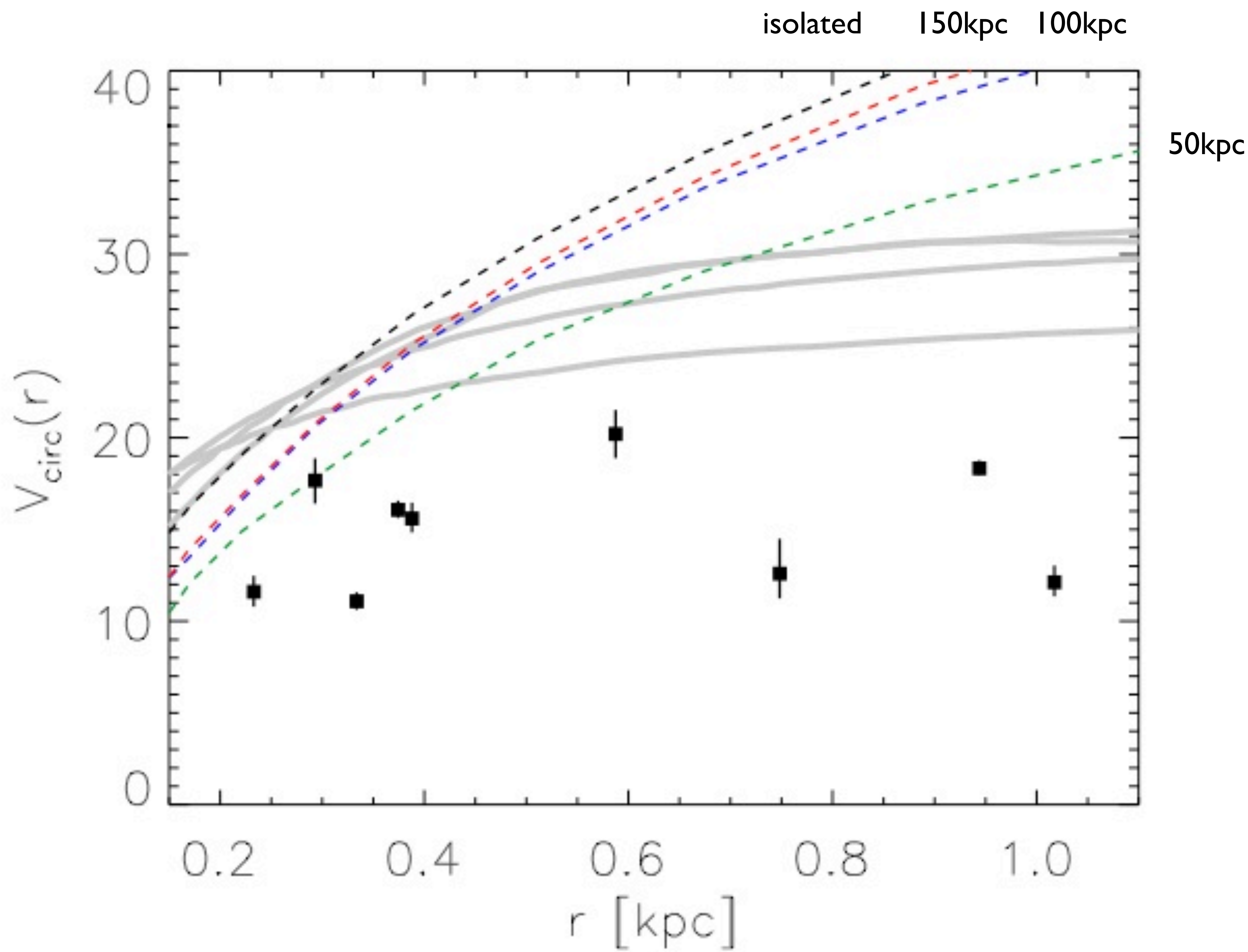




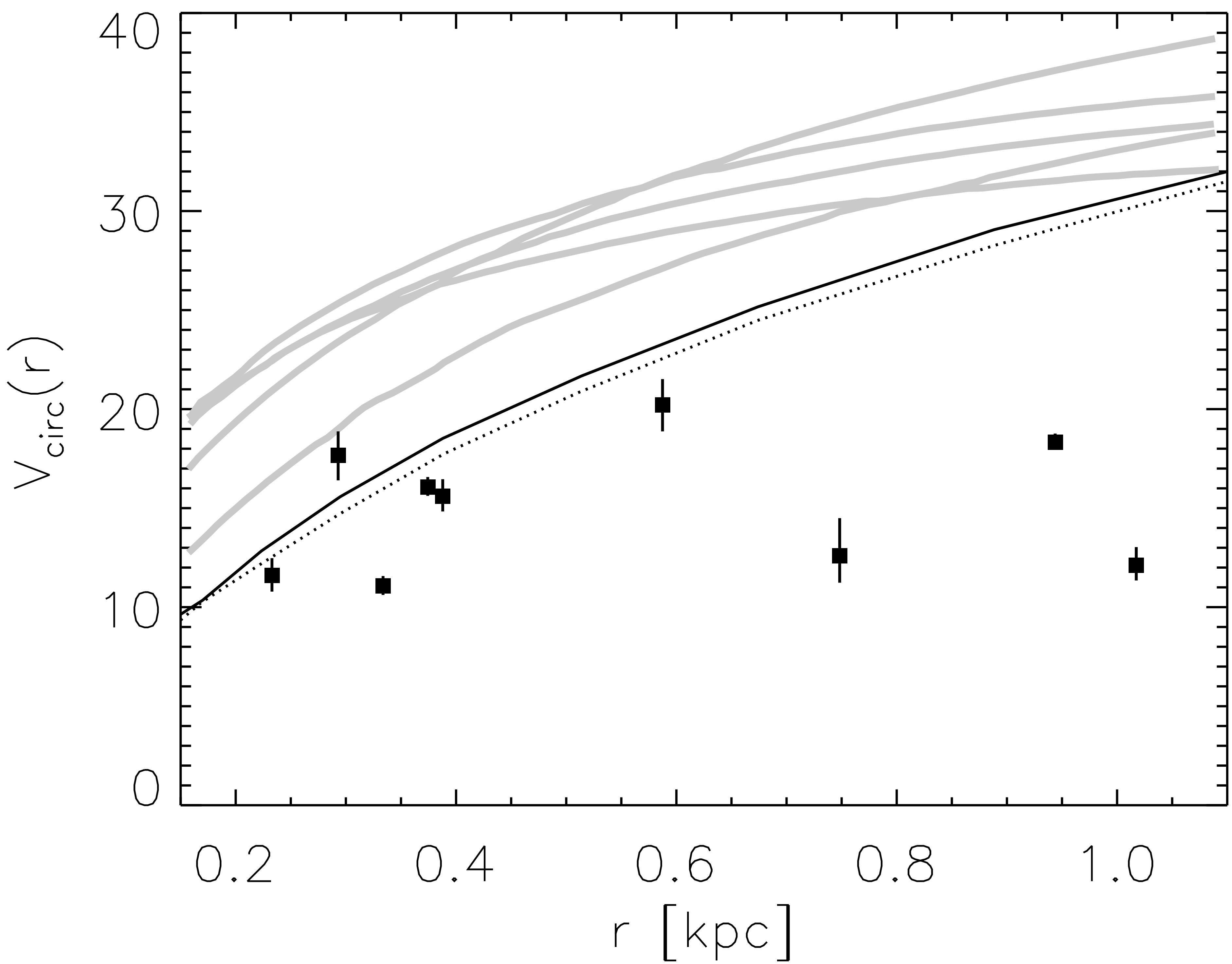
No removal,
isolated
Aquarius
MW sats
$V_{circ}(r)$
r [kpc]
0
10
20
30
40
0.2
0.4
0.6
0.8
1.0

Just stripping

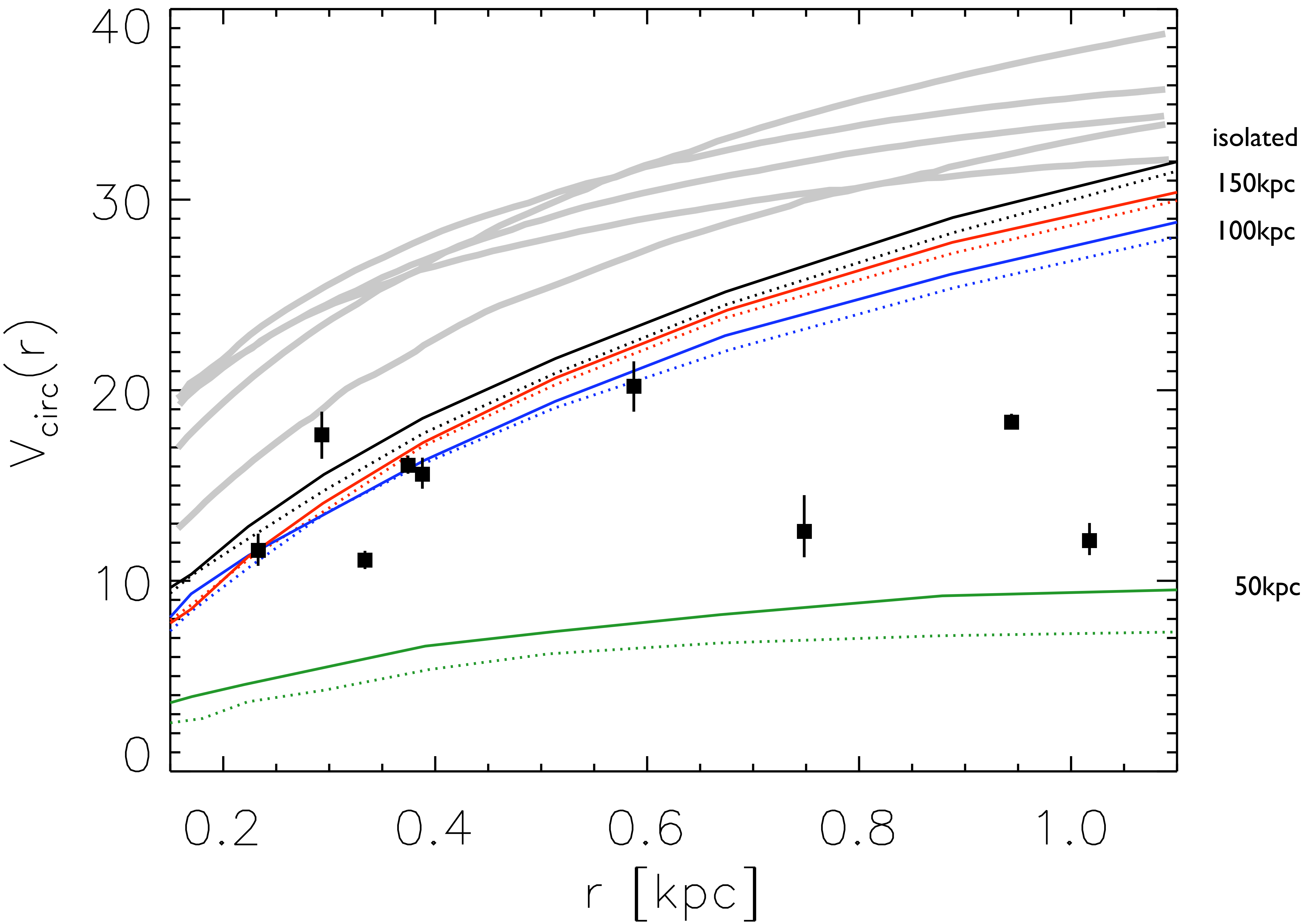
stripping by MW halo, no stellar disk

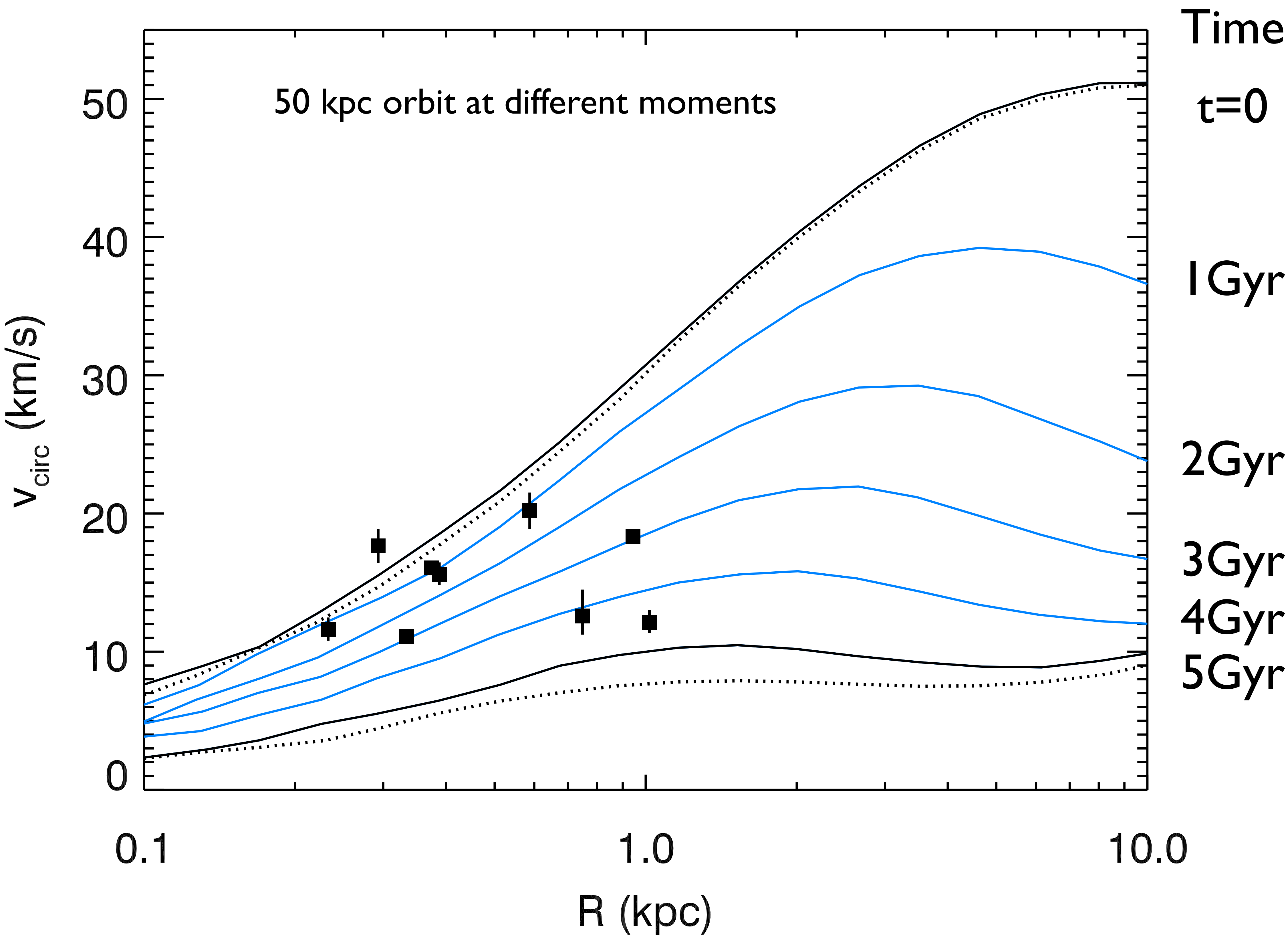


No stripping. Only baryon removal



All included: stripping + MW with stellar disk + baryon removal




Time
t=0
1Gyr
2Gyr
3Gyr
4Gyr
5Gyr
50 kpc orbit at different moments
v_{circ} (km/s)
R (kpc)
0
10
20
30
40
50
0.1
1.0
10.0

Conclusions

- Effects of baryons on dSph are strong
- Removal of a large fraction of baryons from the central region results in adiabatic expansion of the dwarf
- Fast or slow expansion produce the same results
- Unless we go through many cycles of infall-expansion-infall-expansion... the cusp is not flattened. It seems that there are not enough stars in dSph to get to Mashchenko-Governato-Pontzen scenario.
- Numerically very difficult problem for hydro. Easy to get through N-body
- Estimates of annihilation signal may be compromised if they use a large boost factor from substructure.