Can Feedback Solve Too Big to Fail Problem?

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Collaborators

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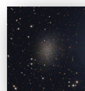
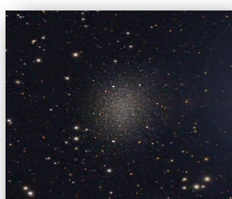
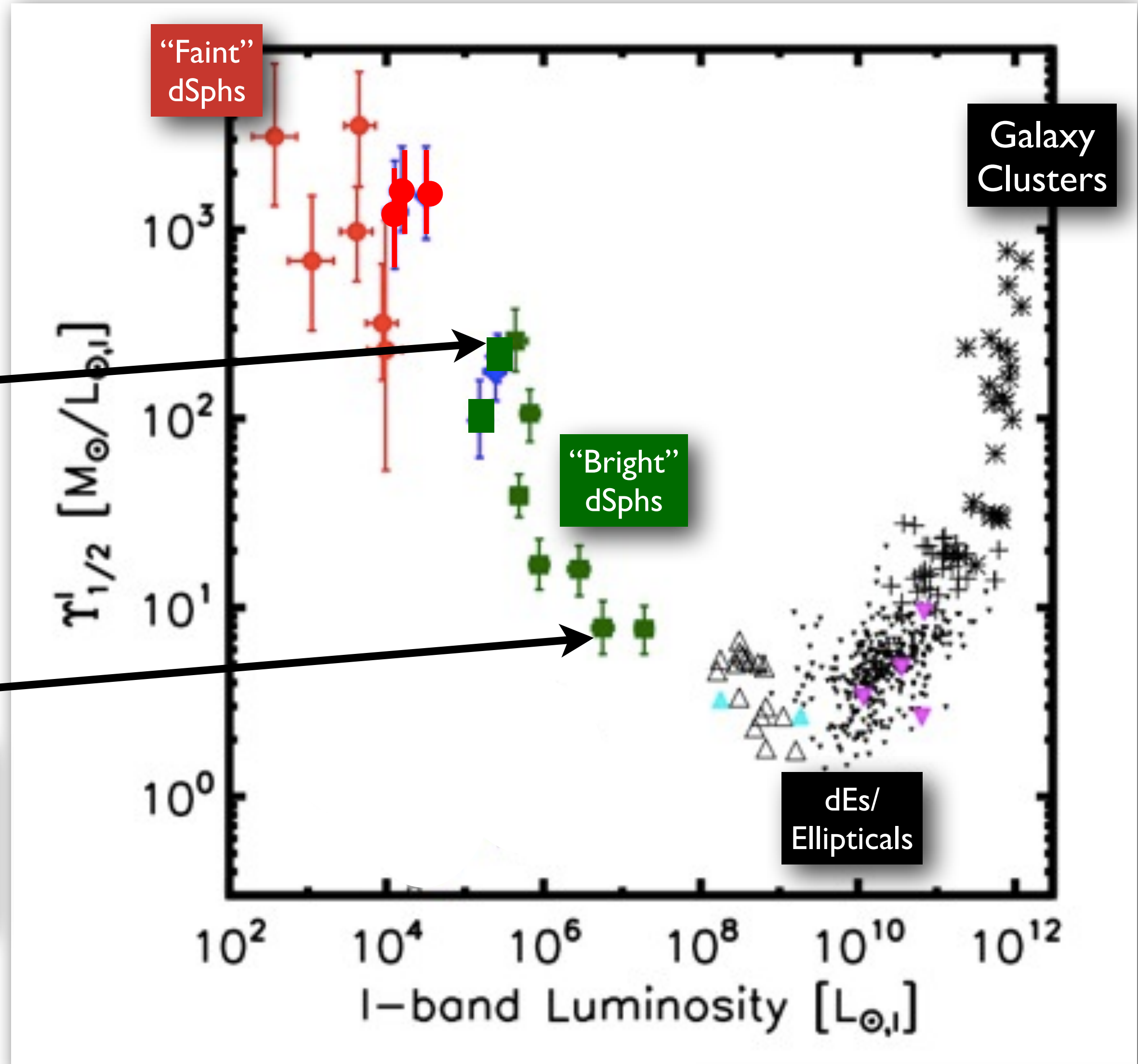
dSphs are DM dominated => easy to interpret

Draco, Ursa Minor
$L \sim 10^5 L_{sun}$
$M_{dyn}/L \sim 200$

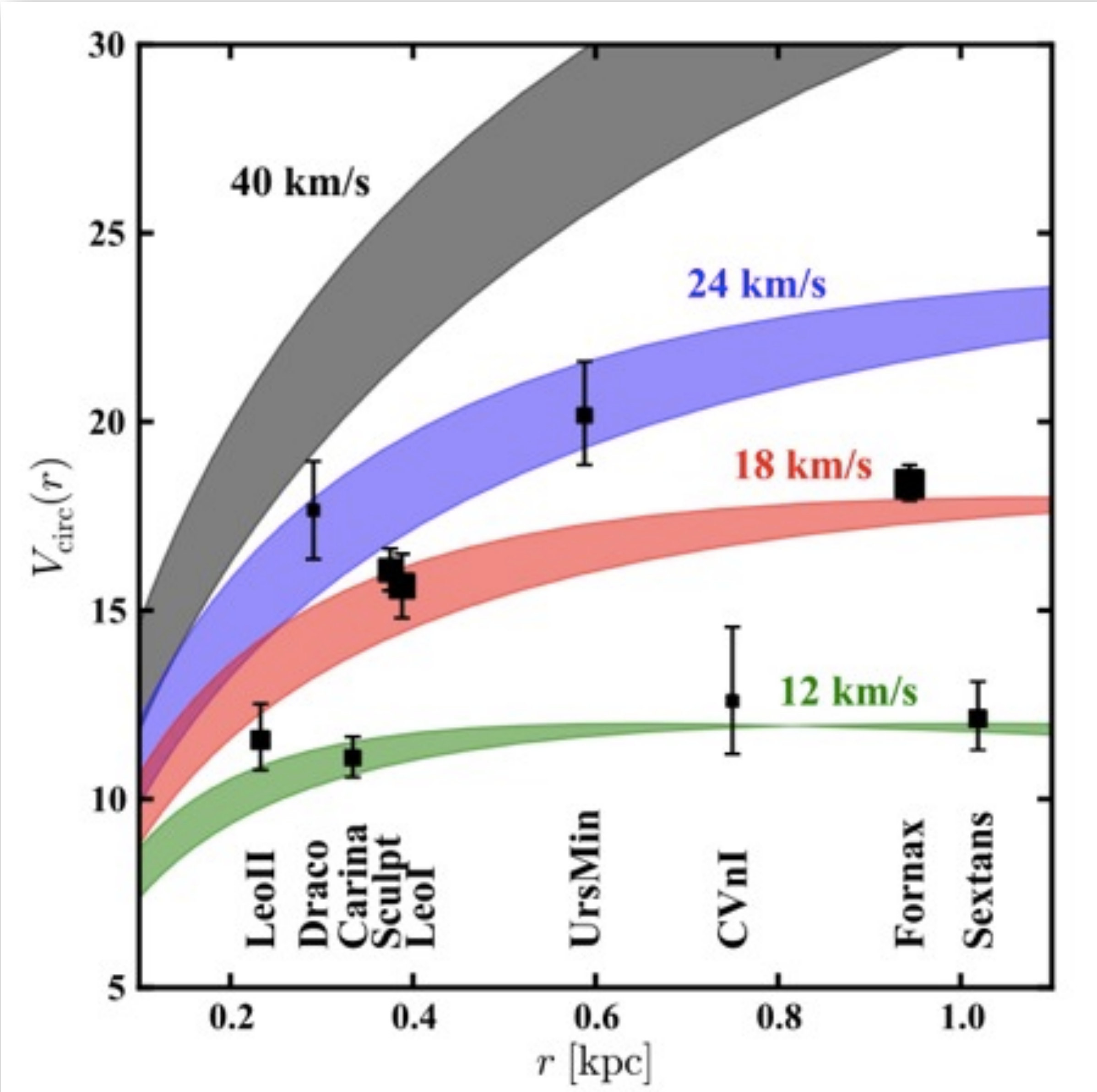


Fornax, Leo I
$L \sim 10^7 L_{sun}$
$M_{dy}n/L \sim 9$

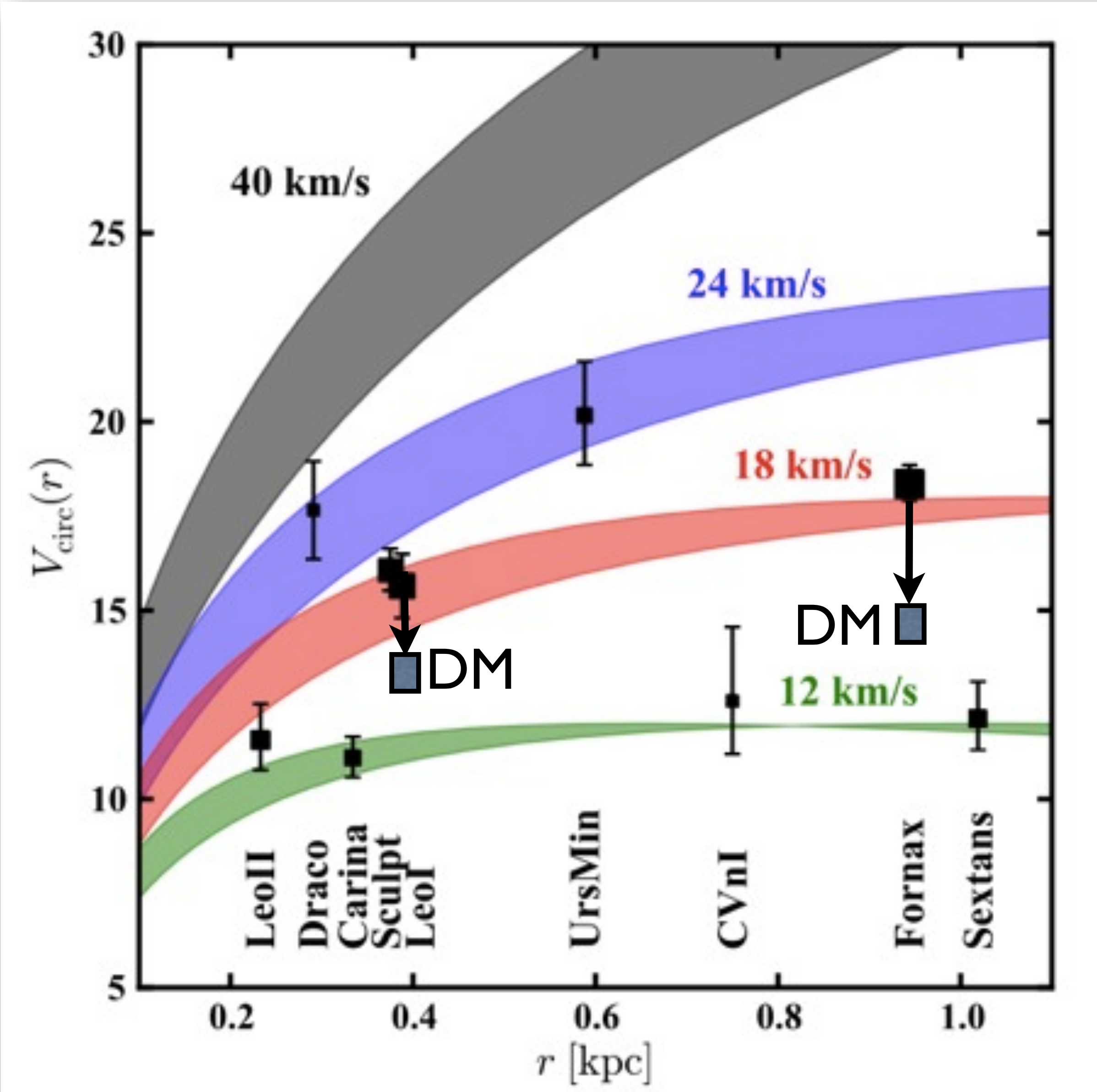




Wolf+10; Tollerud+11



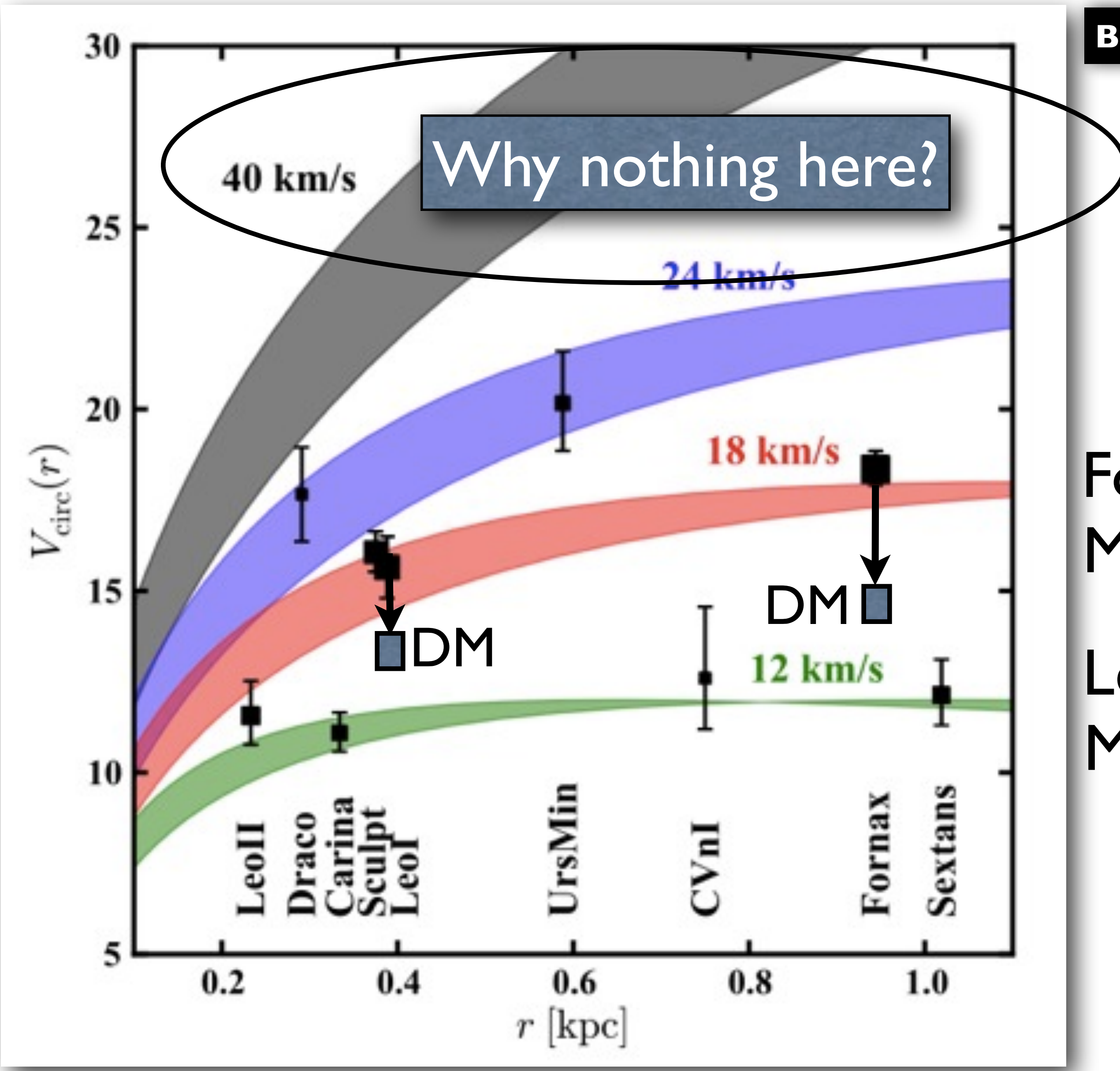
Boylan-Kolchin et al. 2012



Boylan-Kolchin et al. 2012

Fornax:
$M_{dyn}/M^* \sim 3.5$

Leo I:
$M_{dyn}/M^* \sim 4$



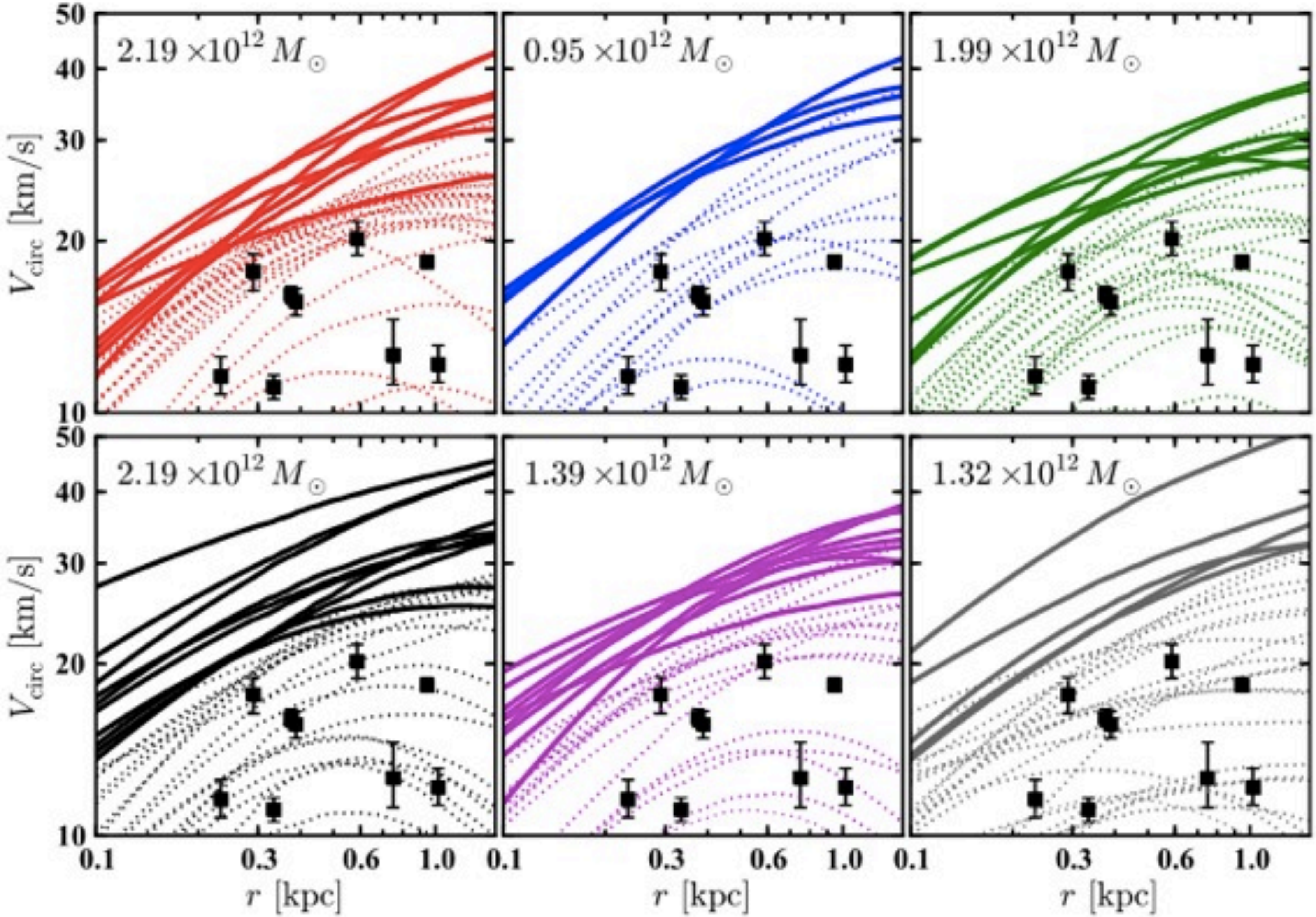
Boylan-Kolchin et al. 2012

V_{max} >~30 km/s?

Fornax: $M_{dyn}/M^* \sim 3.5$

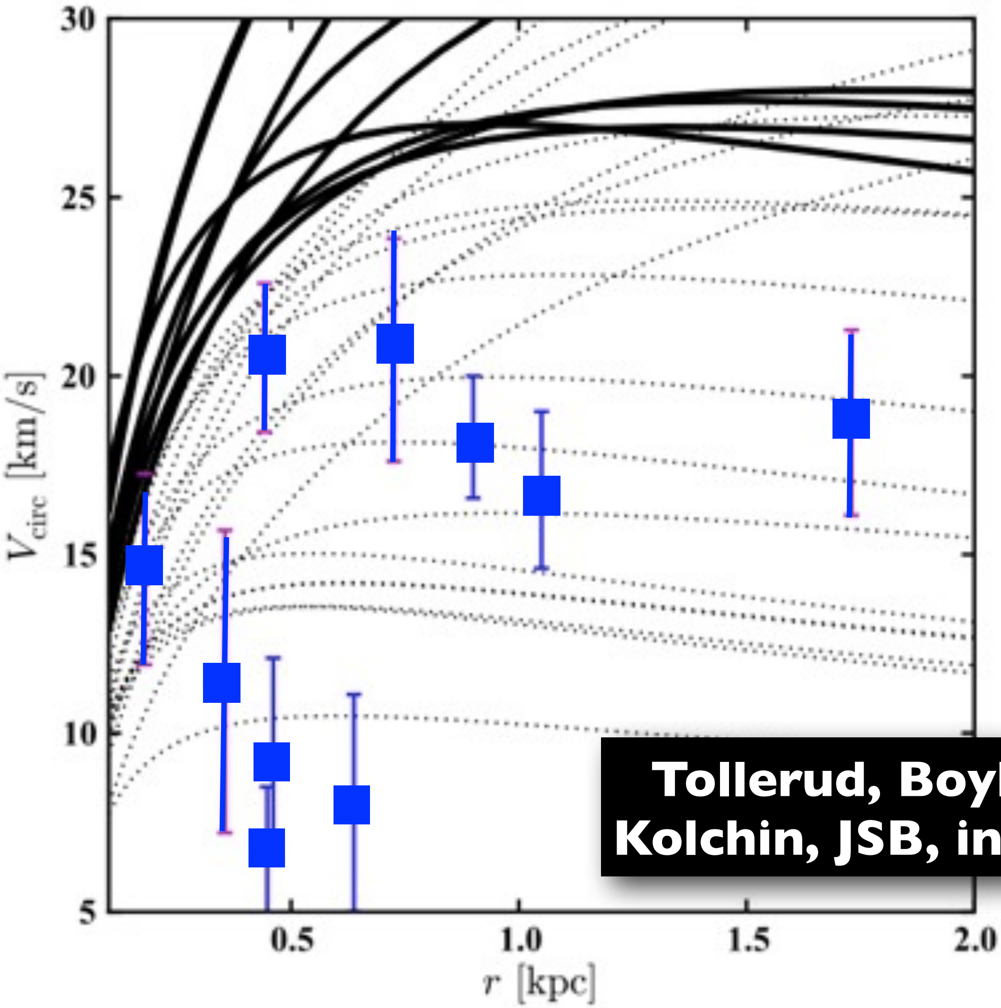
Leo I: $M_{dyn}/M^* \sim 4$

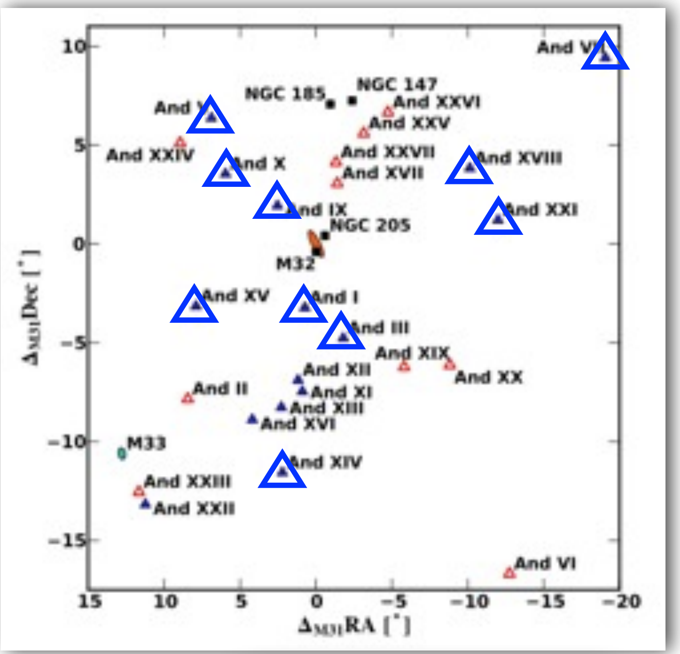
Six Aquarius Halos: ~10-20 massive failures each



Boylan-Kolchin et al. 2011a,b

M31 dSph population looks the same





Tollerud, Boylan-Kolchin, JSB, in prep

Erik **Tollerud**

Reduce Milky Way Halo Mass?

Option 1

Milky Way significantly less massive than 1.10^{12} M_{sun} (<~7.10^{11} M_{sun})

$$N_{\rm extra} \simeq 5 \left(\frac{M_{\rm v}}{10^{12} M_\odot} \right)$$

Would require:

1. LMC and LeoI **both** unbound (vanishingly rare in cosmological simulations)
2. SMC and LMC extreme outliers in subhalo mass function
3. M31 ~3 times more massive than MW (timing argument)
4. Majority of recent dynamical mass estimates of MW halo biased high

Boylan-Kolchin et al. 2012

Tides from disk?

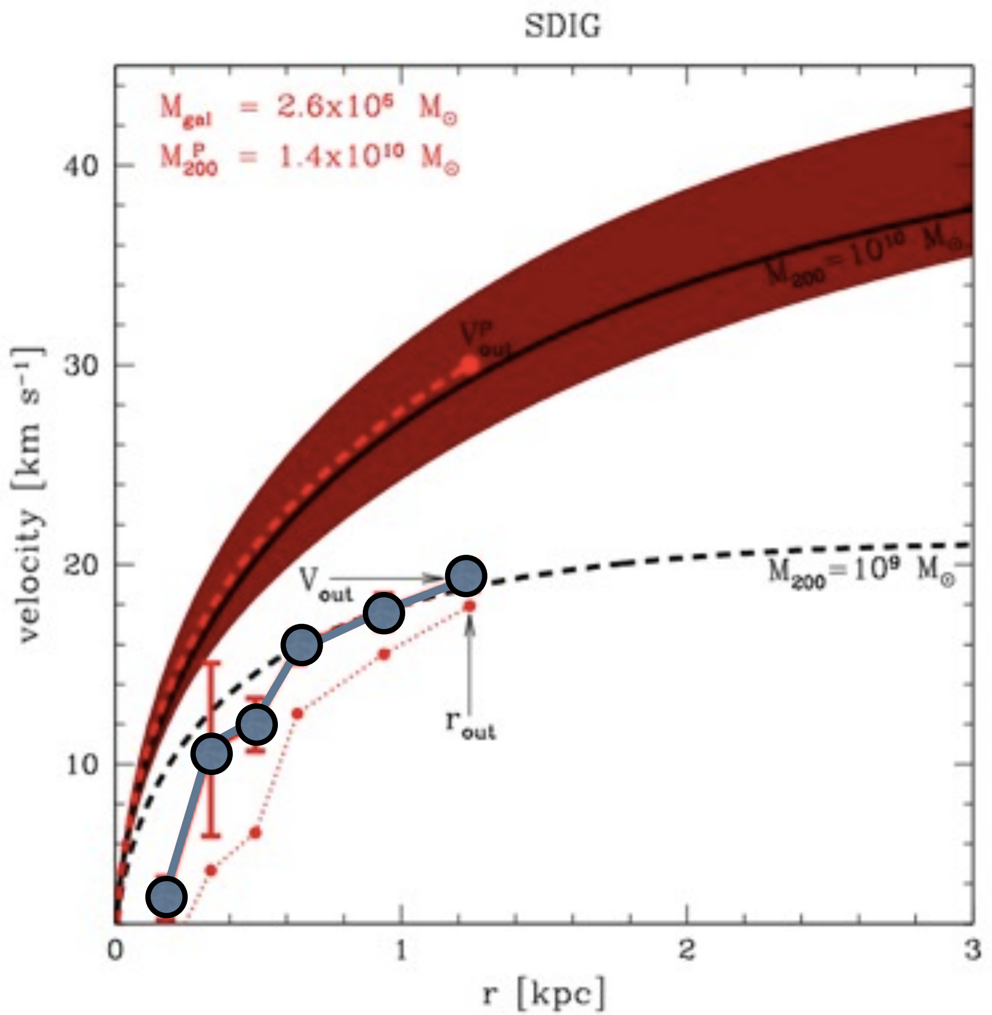
Option 2

Would need to bring massive subhalos preferentially close to disk. Leo I, for example, has likely never been close to the disk, $r_{peri} \sim 70$ kpc (Besla et al., in prep.).

How about field dwarfs?

Ferrero, Abadi, Navarro, Sales & Gurovich 2011

Similar problem with field dwarfs



Expected from Abundance Matching

Mvir ~ 10^{10} Msun

Observed rotation curve

Mvir ~ 10^9 Msun

Feedback?

Option 3

Feedback: need to remove/redistribute ~5.e7M_{sun} of DM within ~500pc.

Mass loading is a problem:

$$M_{\text{blow-out}} = \left[4 N_{100} \epsilon_{\text{SN}} \left(\frac{V_{\text{out}}}{500\,\text{km}\,\text{s}^{-1}} \right)^{-2} \right] M_{\star}$$

Gas mass removed ~5.e6Msun

mass-loading factor, typically ~1-5

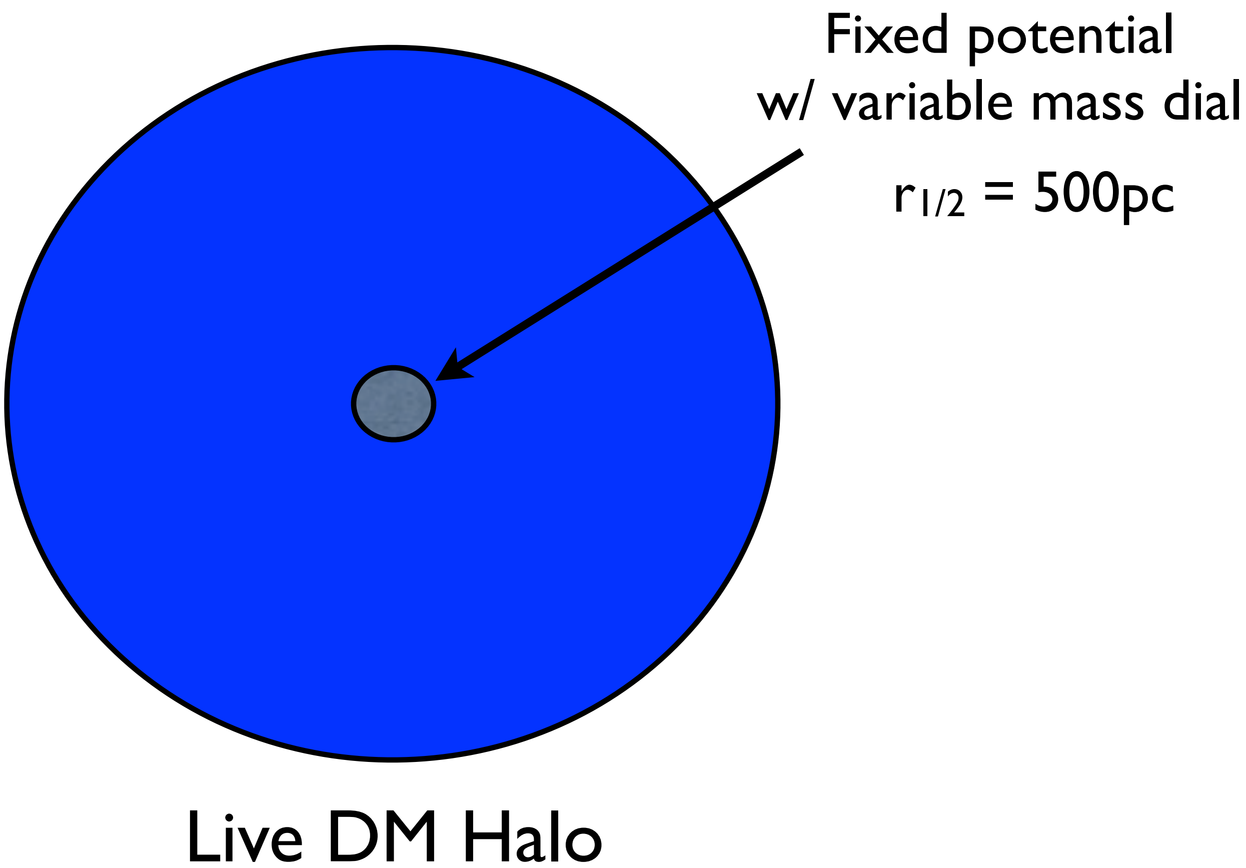
~1.e6 Msun

Maybe if the blow-out is cyclic this helps?   Mashchenko et al.; Pontzen & Governato

Boylan-Kolchin et al. 2012

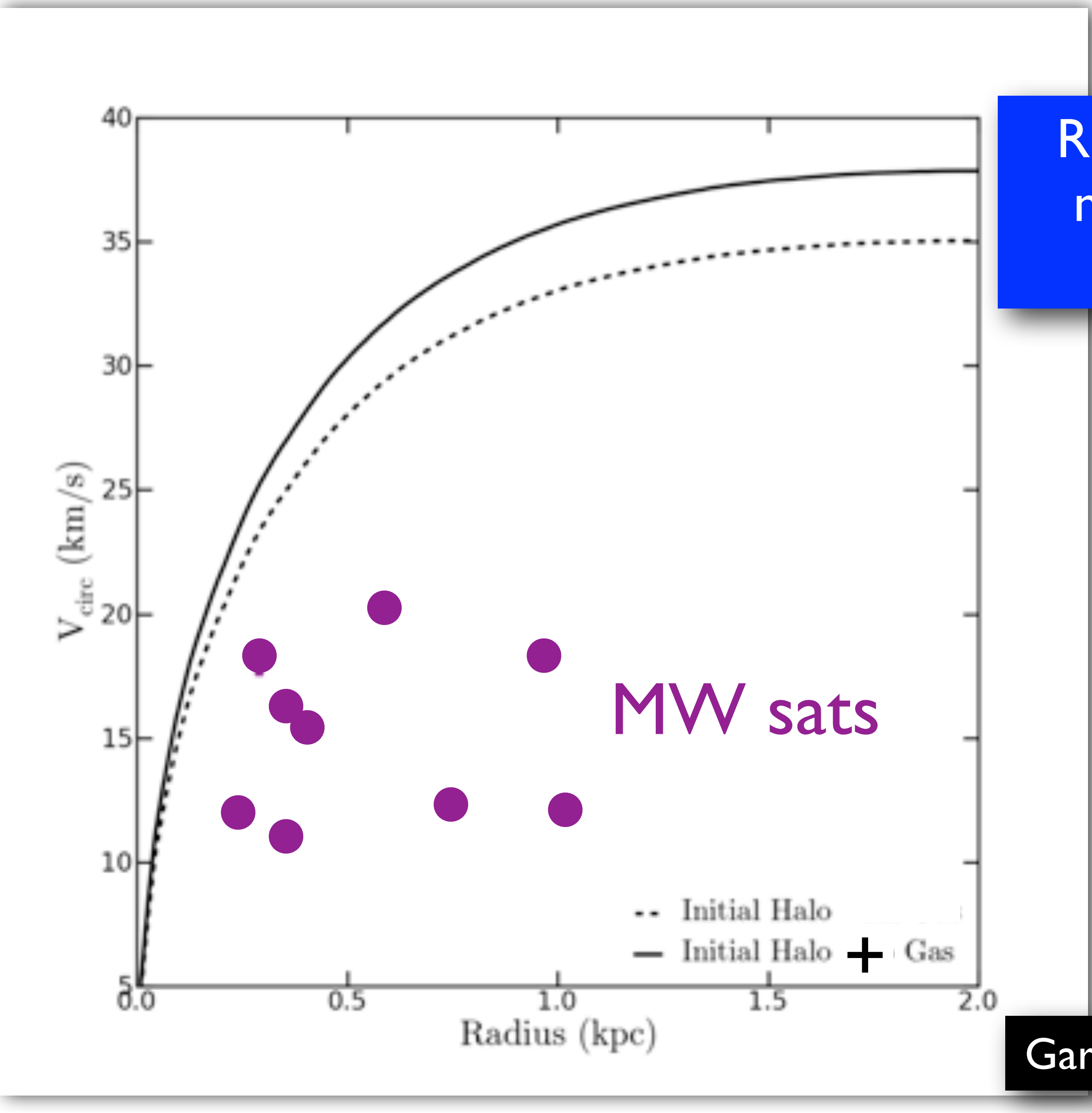
Feedback?

Numerical Experiment



Garrison-Kimmel et al.

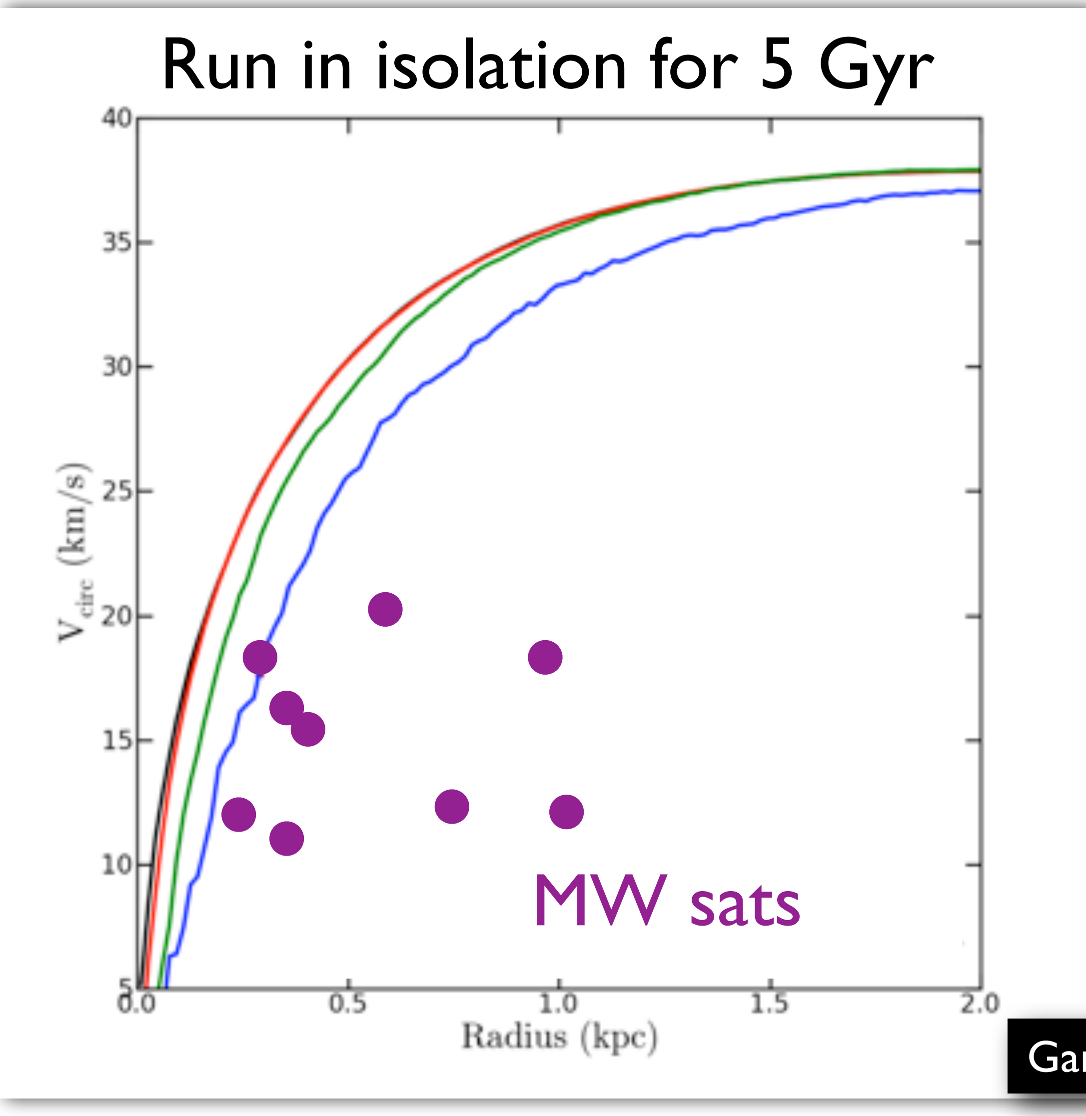
Numerics/Set up



Remove baryon fraction of mass from DM only runs: => ~3 km/s lower

Garrison-Kimmel et al.

Numerics/Set up



$m_{dm} = 8.10^3 M_{sun}$

$\epsilon = 10pc$

$m_{dm} = 3.10^4 M_{sun}$

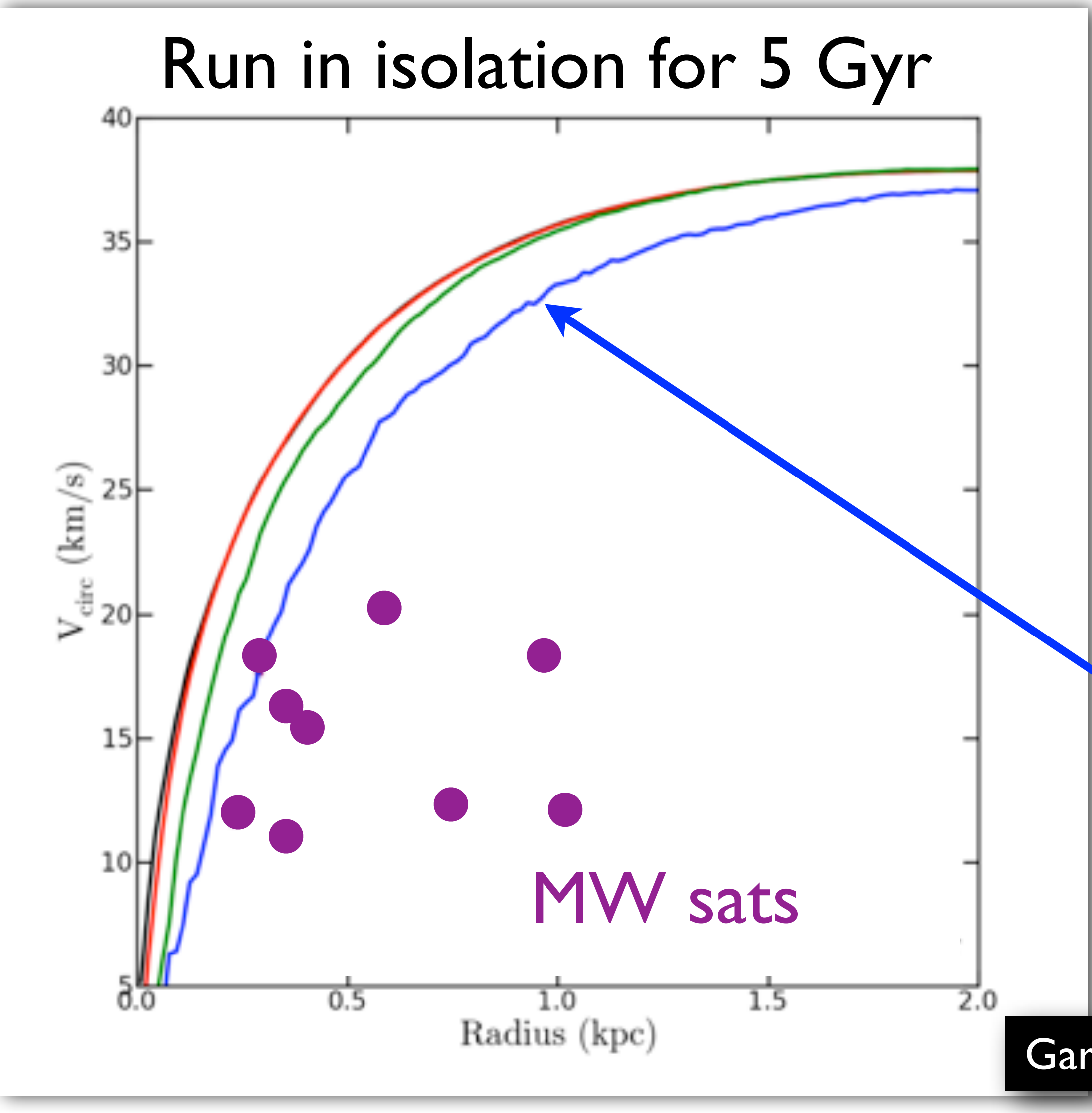
$\epsilon = 70pc$

$m_{dm} = 1.10^5 M_{sun}$

$\epsilon = 120pc$

Garrison-Kimmel et al.

Numerics/Set up



$m_{dm} = 8.10^3 M_{sun}$

ϵ = 10pc

$m_{dm} = 3.10^4 M_{sun}$

ϵ = 70pc

$m_{dm} = 1.10^5 M_{sun}$

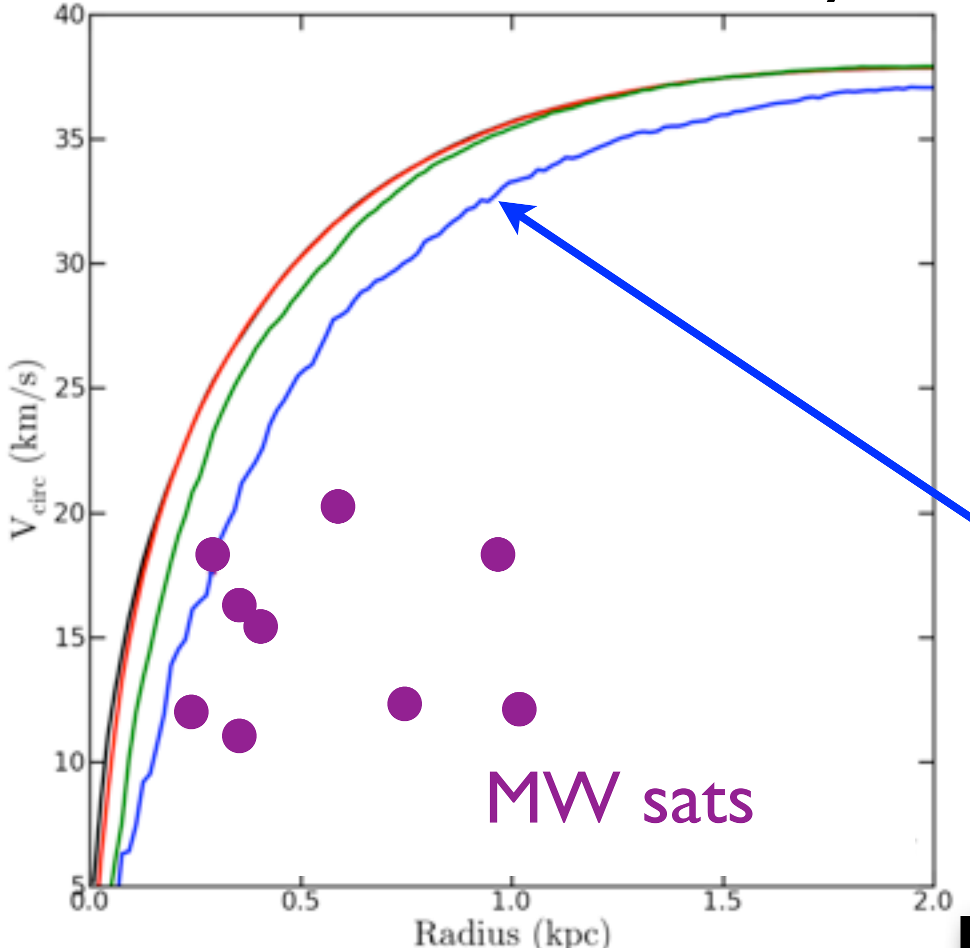
ϵ = 120pc

~best current z=0 hydro runs of MW systems

Garrison-Kimmel et al.

Numerics/Set up

Run in isolation for 5 Gyr



$m_{dm} = 8.10^3 M_{sun}$

$\epsilon = 10pc$

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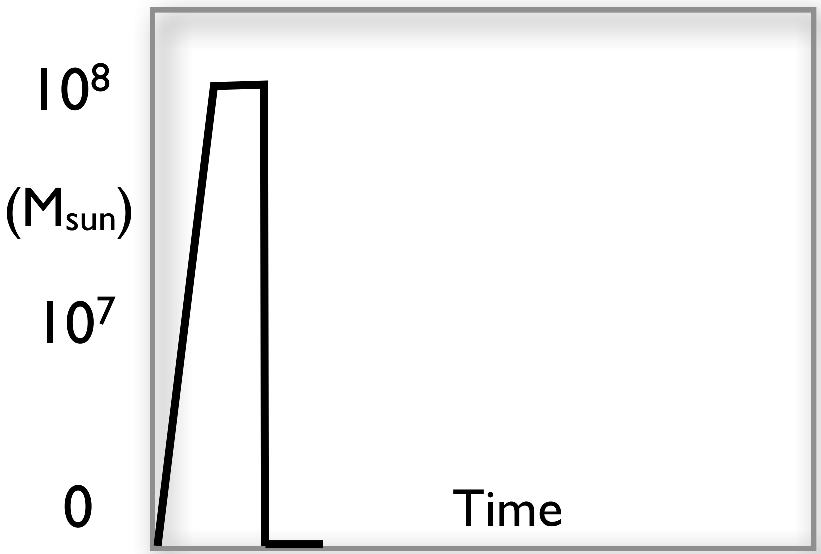
$\epsilon = 120pc$

~best current z=0 hydro runs of MW systems

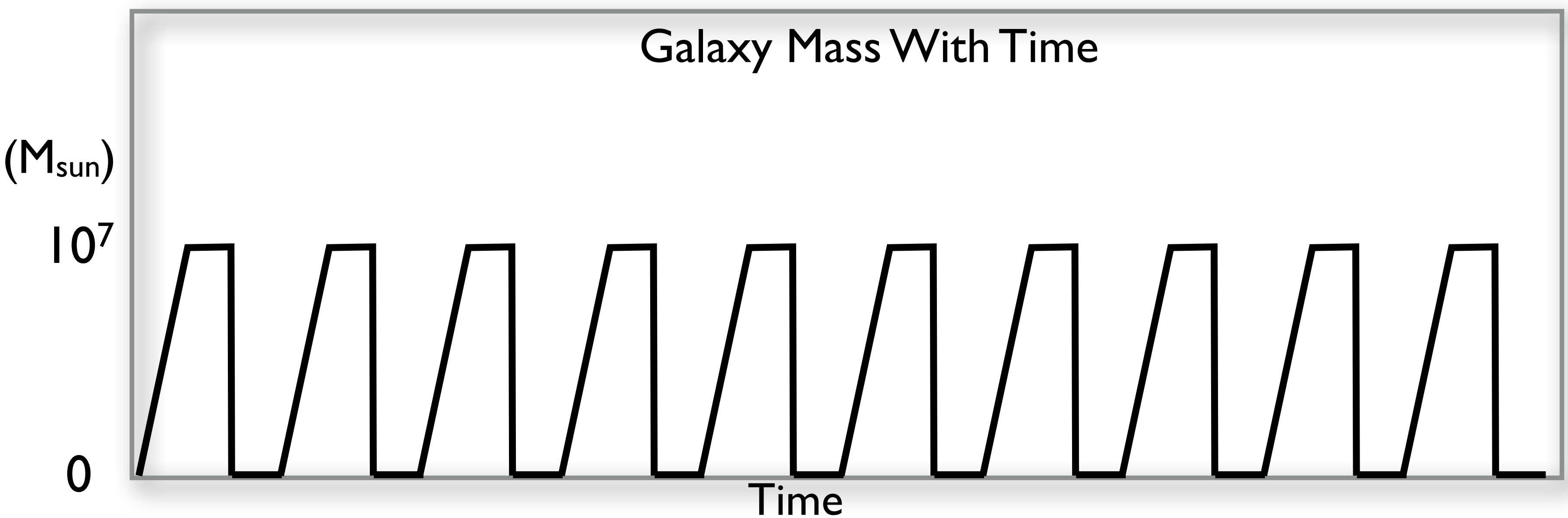
Garrison-Kimmel et al.

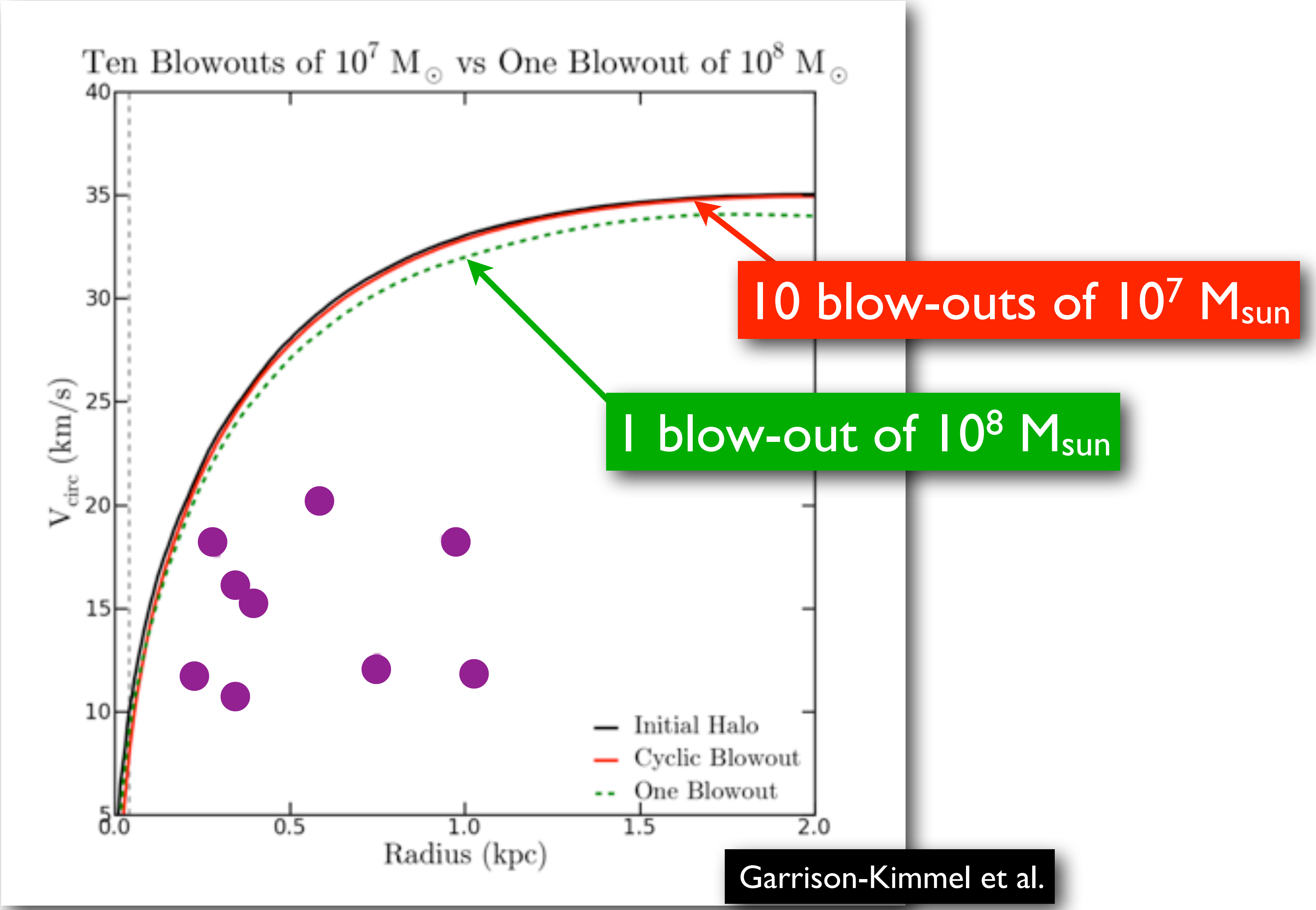
Galaxy Mass With Time



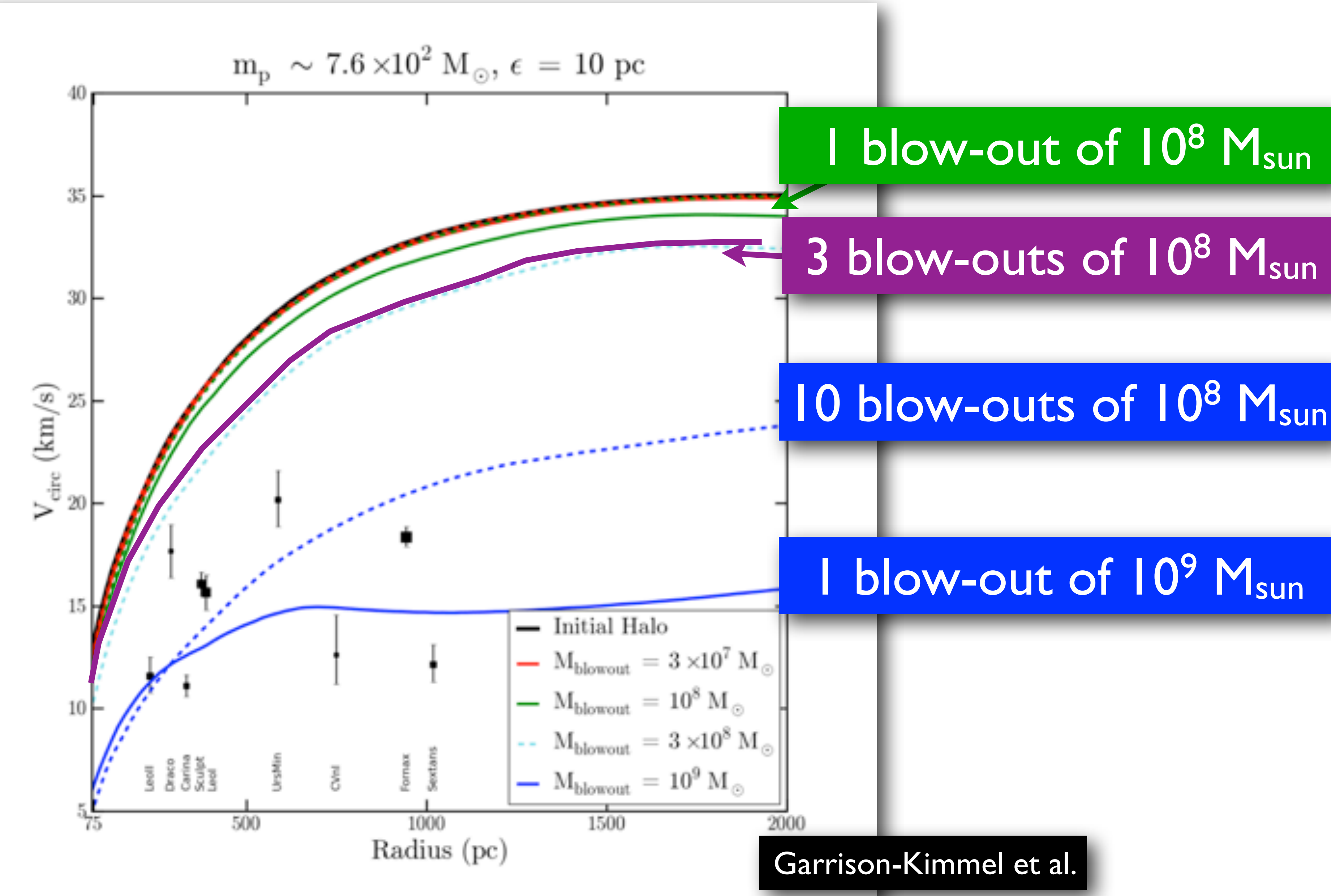
1 blow-out of 10^8 M_{sun}

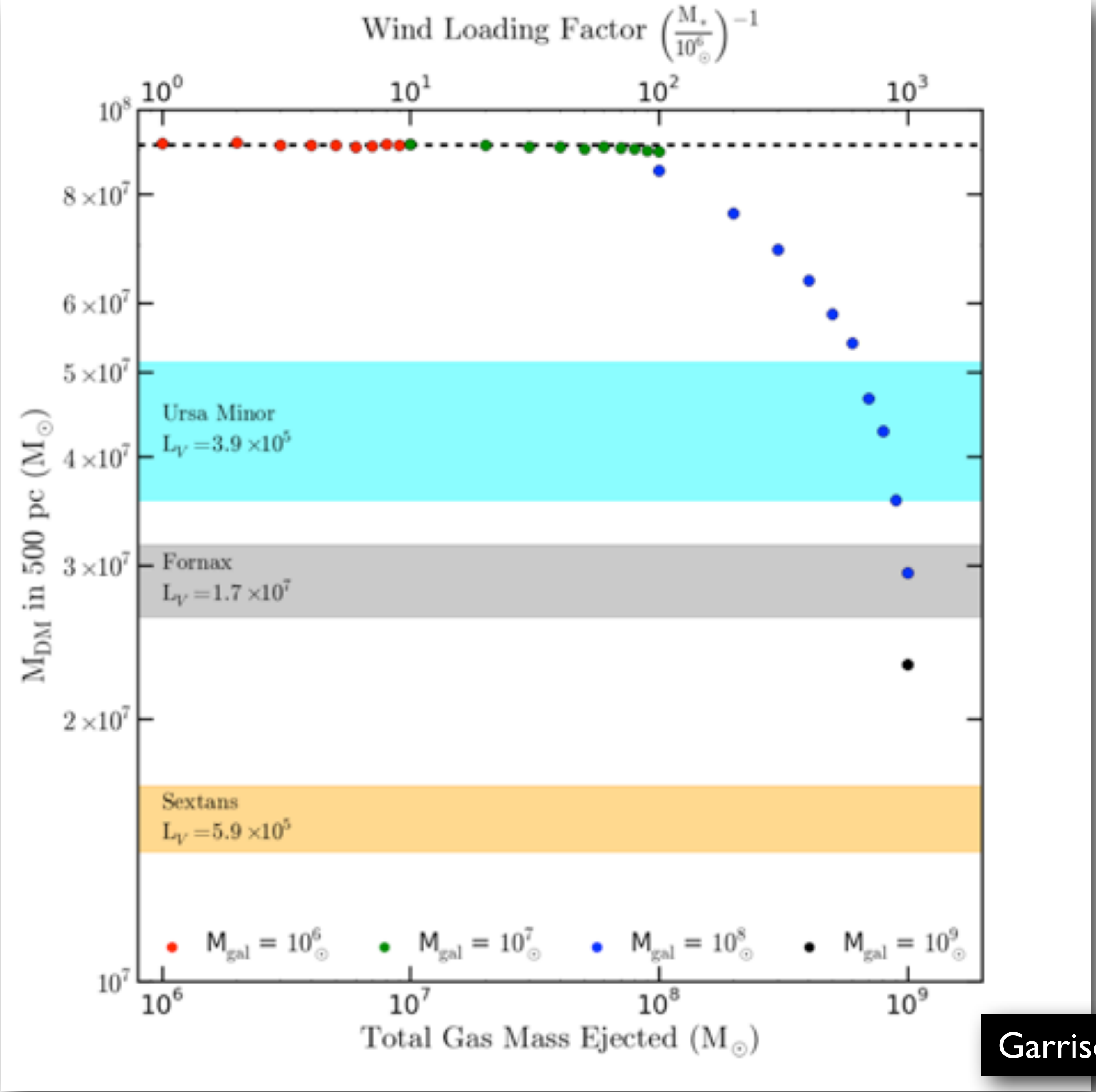
10 blow-outs of 10^7 M_{sun}



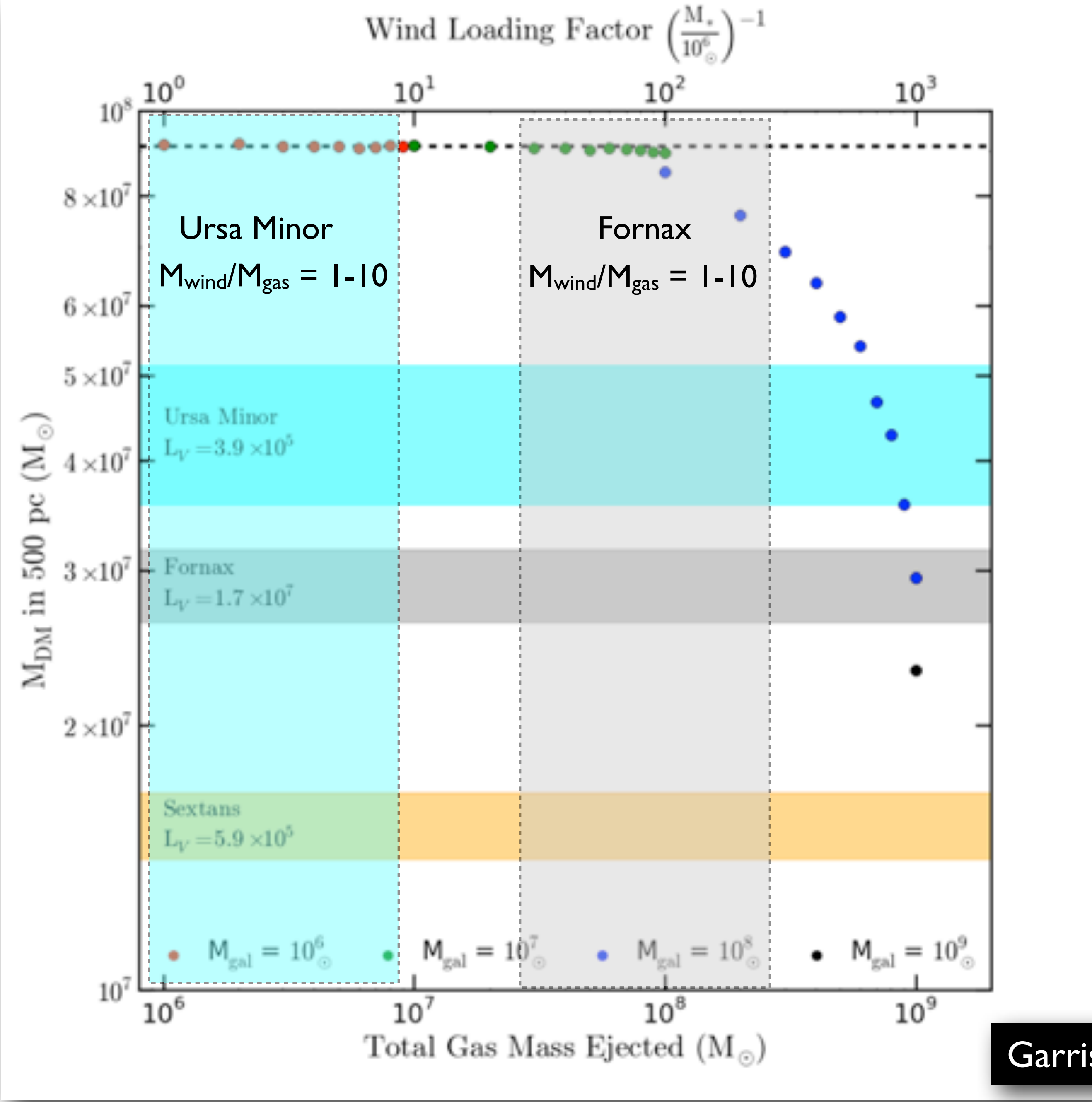


Ten Blowouts of 10^7 $M_\odot$ vs One Blowout of 10^8 $M_\odot$
V_{circ} (km/s)
Radius (kpc)
40
35
30
25
20
15
10
5
0.0
0.5
1.0
1.5
2.0
Initial Halo
Cyclic Blowout
One Blowout
10 blow-outs of 10^7 M_{sun}
1 blow-out of 10^8 M_{sun}
Garrison-Kimmel et al.

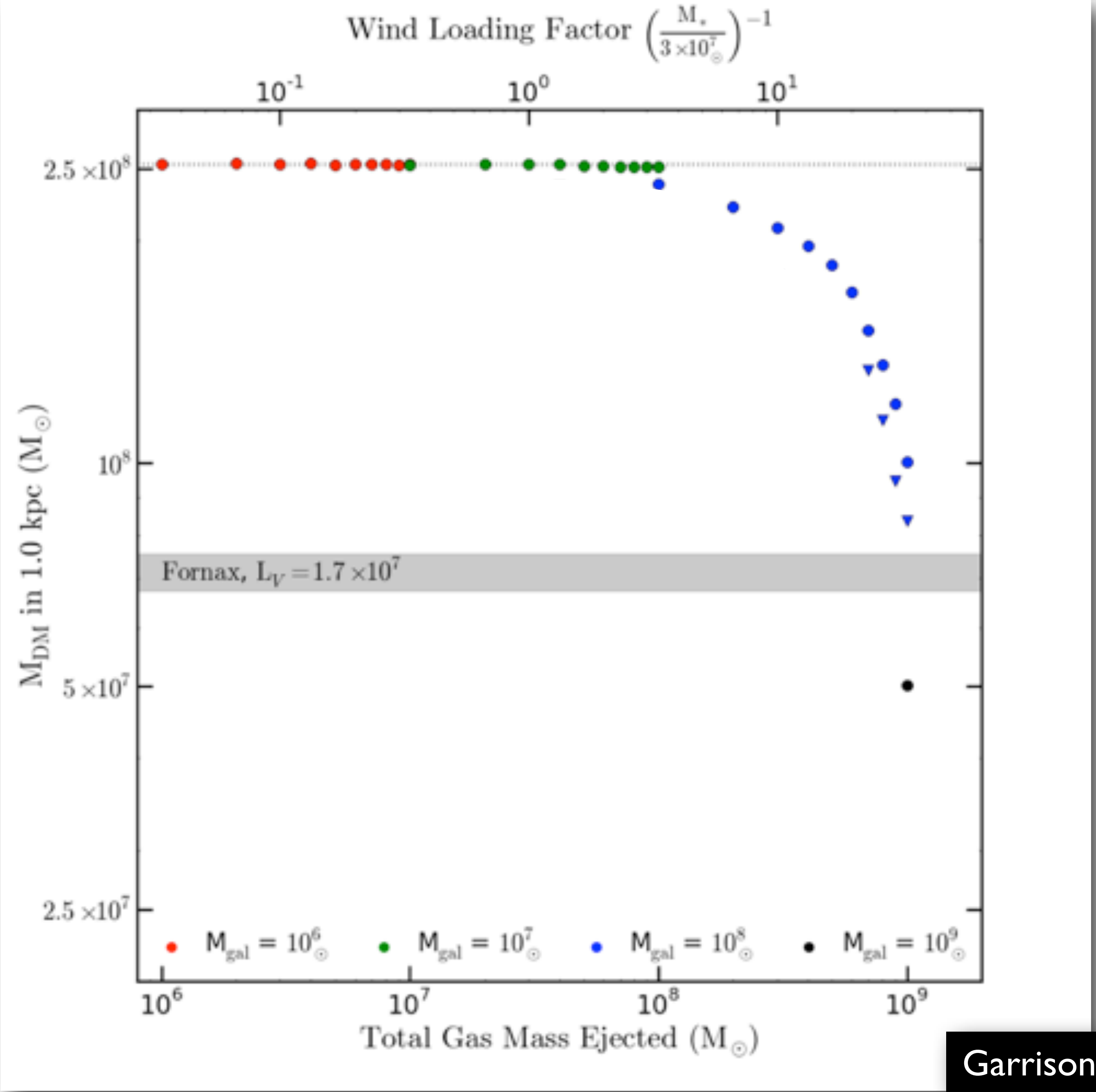

m_p ~ 7.6 ×10^2 M_⊙, ε = 10 pc
V_circ (km/s)
Radius (pc)
Initial Halo
M_blowout = 3 ×10^7 M_⊙
M_blowout = 10^8 M_⊙
M_blowout = 3 ×10^8 M_⊙
M_blowout = 10^9 M_⊙
LeoII
Draco
Carina
Sculpt
LeoI
UrsMin
CVnI
Fornax
Sextans
1 blow-out of 10^8 M_sun
3 blow-outs of 10^8 M_sun
10 blow-outs of 10^8 M_sun
1 blow-out of 10^9 M_sun
Garrison-Kimmel et al.



Garrison-Kimmel et al.



Garrison-Kimmel et al.



Garrison-Kimmel et al.

Towards more realistic feedback

Use Hopkins, Quartaert, and Murray 2012 scheme / Gadget3

Oñorbe et al.

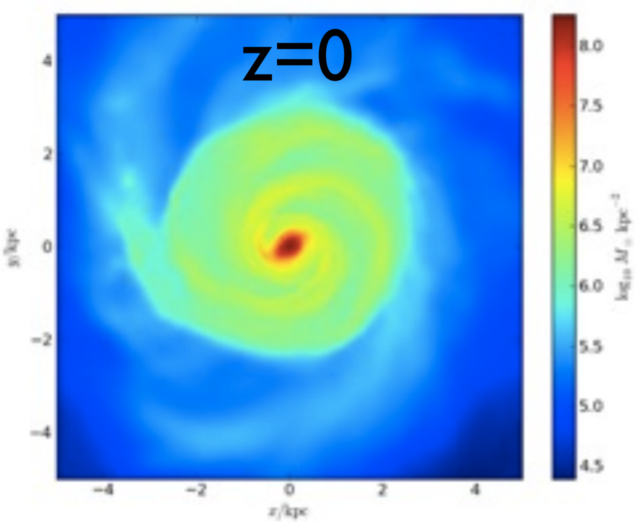
- Self-consistent (resolved) ISM. Hydro never turned off.
- SNe (II & Ia), Radiation pressure from stellar winds, Photoionization (HII Regions)
- Energetics/timing from stellar evolution models, fine-structure cooling to ~100K

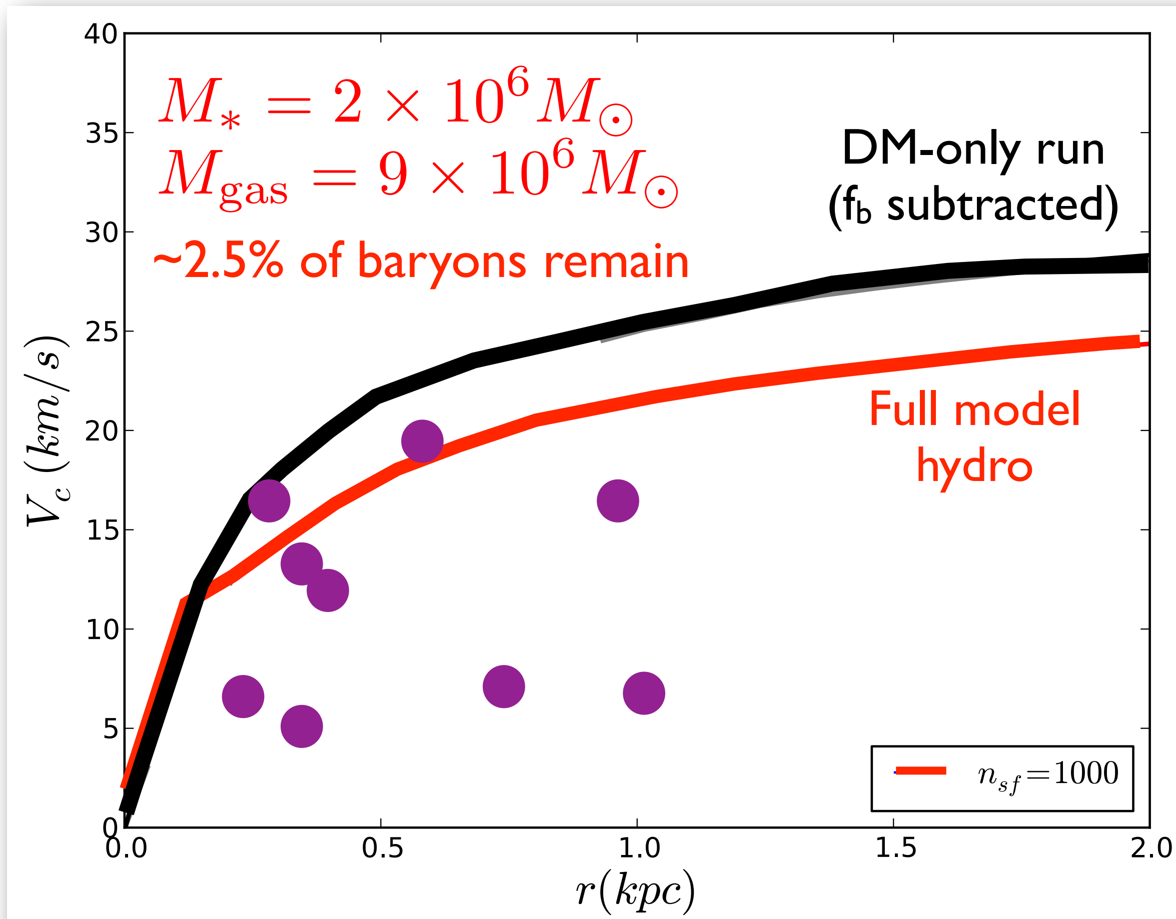
Dwarf Zoom

$$m_{dm} = 1.3 \times 10^3 M_\odot$$

$$m_{gas} = 1.7 \times 10^2 M_\odot$$

$$\epsilon_{\rm res} = 14 {\rm pc}$$





Conclusions

- Feedback not a compelling solution to Too Big to Fail dwarfs problem
- Need very high resolution (~10 pc) to really address the problem
- Cyclic bursts don't seem to help:
  - DM removal per baryon blown out is similar (a little less) than single bursts
- What can we do to fix the problem in context of WIMPy CDM?
  - Smallest possible Milky Way mass **AND**
  - Wind-loading factors >~ 10 **AND**
  - Tides matter a lot more than expected
- See Miguel Rocha's talk on CDM with self-interaction similar to nucleon-nucleon scattering (~ 0.1 cm^2/g) => constant-density cores.