Can Feedback Solve Too Big to Fail Problem?

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Garrison-Kimmel, Oñorbe et al.
dSphs are DM dominated => easy to interpret

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

Fornax, Leo I
$L \sim 10^7 L_{\odot}$
$M_{\text{dyn}}/L \sim 9$

Wolf+10; Tollerud+11

Galaxy Clusters

dEs/
Ellipticals

GCs

“Bright”
dSphs

“Faint”
dSphs

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Fornax: \( M_{\text{dyn}}/M^* \sim 3.5 \)
Leo I: \( M_{\text{dyn}}/M^* \sim 4 \)

Boylan-Kolchin et al. 2012
Boylan-Kolchin et al. 2012

Fornax: \( \frac{M_{\text{dyn}}}{M^*} \approx 3.5 \)

Leo I: \( \frac{M_{\text{dyn}}}{M^*} \approx 4 \)

Why nothing here?

\( V_{\text{max}} \geq \approx 30 \text{ km/s} \)?
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 $1.10^{12} \, M_{\odot} (< \sim 7.10^{11} \, M_{\odot})$

$$N_{\text{extra}} \approx 5 \left( \frac{M_v}{10^{12} \, M_{\odot}} \right)$$

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 \sim 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, $r_{\text{peri}} \sim 70$ kpc (Besla et al., in prep.).

How about field dwarfs?
Similar problem with field dwarfs

**Expected from Abundance Matching**

M_{vir} \sim 10^{10} \, M_{\text{sun}}

**Observed rotation curve**

M_{vir} \sim 10^{9} \, M_{\text{sun}}
Option 3

Feedback: need to remove/redistribute \( \sim 5.0 \times 10^7 M_{\text{Sun}} \) of DM within \( \sim 500 \) pc.

Mass loading is a problem:

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

- Gas mass removed \( \sim 5.0 \times 10^6 M_{\text{Sun}} \)
- Mass-loading factor, typically \( \sim 1-5 \)
- \( \sim 1.0 \times 10^6 M_{\text{Sun}} \)

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

Boylan-Kolchin et al. 2012
Feedback?

Numerical Experiment

Live DM Halo

Fixed potential w/ variable mass dial

$r_{1/2} = 500\text{pc}$

Garrison-Kimmel et al.
Remove baryon fraction of mass from DM only runs: $\Rightarrow \sim 3$ km/s lower

Garrison-Kimmel et al.

MW sats
Run in isolation for 5 Gyr

\[ m_{dm} = 8 \times 10^3 M_{\text{sun}} \]
\[ \epsilon = 10 \text{pc} \]

\[ m_{dm} = 3 \times 10^4 M_{\text{sun}} \]
\[ \epsilon = 70 \text{pc} \]

\[ m_{dm} = 1 \times 10^5 M_{\text{sun}} \]
\[ \epsilon = 120 \text{pc} \]

MW sats

Garrison-Kimmel et al.
Run in isolation for 5 Gyr

\[ m_{dm} = 8 \times 10^3 M_{\odot} \quad \epsilon = 10 \text{pc} \]

\[ m_{dm} = 3 \times 10^4 M_{\odot} \quad \epsilon = 70 \text{pc} \]

\[ m_{dm} = 1 \times 10^5 M_{\odot} \quad \epsilon = 120 \text{pc} \]

\~best current z=0 hydro runs of MW systems

Garrison-Kimmel et al.
Numerics/Set up

Run in isolation for 5 Gyr

$m_{dm} = 8 \times 10^3 M_{\odot}$
$\epsilon = 10 \text{pc}$

$m_{dm} = 3 \times 10^4 M_{\odot}$
$\epsilon = 70 \text{pc}$

$m_{dm} = 1 \times 10^5 M_{\odot}$
$\epsilon = 120 \text{pc}$

~best current z=0 hydro runs of MW systems

Garrison-Kimmel et al.
Galaxy Mass With Time

1 blow-out of $10^8 \, M_{\text{sun}}$

10 blow-outs of $10^7 \, M_{\text{sun}}$
Ten Blowouts of $10^7 M_\odot$ vs One Blowout of $10^8 M_\odot$

10 blow-outs of $10^7 M_{\text{sun}}$

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

Garrison-Kimmel et al.
garrison-kimmel et al.

\[ m_p \sim 7.6 \times 10^2 \, M_\odot, \, \epsilon = 10 \, \text{pc} \]

1 blow-out of $10^8 \, M_\odot$
3 blow-outs of $10^8 \, M_\odot$
10 blow-outs of $10^8 \, M_\odot$
1 blow-out of $10^9 \, M_\odot$

Garrison-Kimmel et al.
Wind Loading Factor \( \left( \frac{M_*}{10^9} \right)^{-1} \)

- **Ursa Minor**
  - \( \frac{M_{\text{wind}}}{M_{\text{gas}}} = 1-10 \)
  - \( L_V = 3.9 \times 10^5 \)

- **Fornax**
  - \( \frac{M_{\text{wind}}}{M_{\text{gas}}} = 1-10 \)
  - \( L_V = 1.7 \times 10^7 \)

- **Sextans**
  - \( L_V = 5.9 \times 10^5 \)
  - \( M_{\text{gal}} = 10^6 \), \( M_{\text{gal}} = 10^7 \), \( M_{\text{gal}} = 10^8 \), \( M_{\text{gal}} = 10^9 \)

Garrison-Kimmel et al.

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Towards more realistic feedback

Use Hopkins, Quartaert, and Murray 2012 scheme / Gadget3

Oñorbe et al.

Dwarf Zoom

- 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

\[
m_{dm} = 1.3 \times 10^3 M_\odot
\]
\[
m_{gas} = 1.7 \times 10^2 M_\odot
\]
\[
\epsilon_{res} = 14\text{pc}
\]

\[
M_* = 2 \times 10^6 M_\odot
\]
\[
M_{gas} = 9 \times 10^6 M_\odot
\]

~2.5% of baryons remain

DM-only run (\(f_b\) subtracted)

Full model hydro

\(n_{sf}=1000\)
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.