Tracing the Fossils of the First Galaxies to z=0

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Near Field Cosmology

We can detect the **fossil** remnants of the first galaxies in the local universe.

An observed fossil dwarf is defined as:

~ dSph (no gas, diffuse, roughly spherical stellar population)

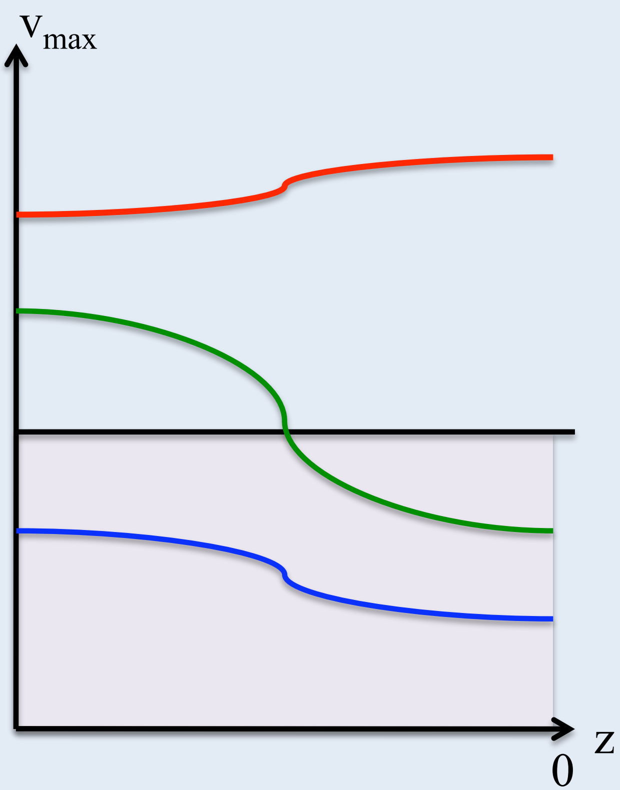
~ SFH dominated by an old, metal poor population

~ $v_{max} < 20$ km s^{-1} : $\sigma_* < \sim 10$-15 km s^{-1}

Fossils' low masses prevent them from accreting gas after the IGM is reheated to 10^4 K during reionization.

Remaining gas goes into stars or is expelled by various feedback mechanisms (ie. SNe) – the result, a dead galaxy which evolves only through its stars from reionization to the present – PERFECT!

What is a Fossil?

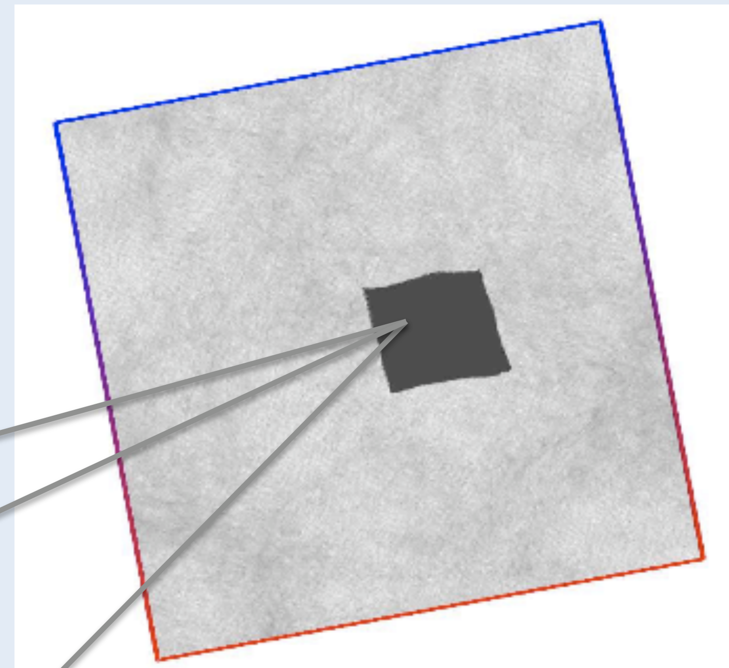


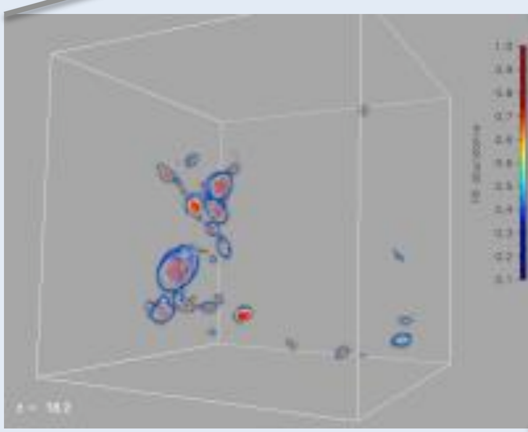
	Theory	**Observation**
non-fossil	$v_{max}(z=0) > v_{filter}$	ie. SMC
polluted fossil	$v_{max}(z=0) < v_{filter}$ **but ..** $max(v_{max}) > v_{filter}$	ie. Pegasus
true fossil	$v_{max}(z=0) < v_{filter}$ **AND** $max(v_{max}) < v_{filter}$	ie. Draco and CVn I

Hybrid Initial Conditions

The final pre-reionization output is transformed in a 1 Mpc^3 box of particles.

We duplicate this box, adding perturbations to account for density variations with l > 1 Mpc.





Ricotti et al (2002a,2002b)

Each HR particle in the resulting N-body simulation represents a ***pre-reionization halo.***

Unique IDs allow us to retrieve the stellar properties at z = 0 of halos > 3 x 10^7 $M_{\odot}$.

1st vs. 2nd Order

1st Order Method:

~ uses the same pre-reionzation output for the entire simulation, $z_{init} = 8.3$

~ does not account for different rates of evolution due to l > 1 Mpc density variations

~ approximates reionization by UV radiation from the first stars (reionization starts in the filaments and expands out into the voids)

2nd Order Method:

~ calculates a z_{eff} for each 1 Mpc^3 subregion using:

$$z_{eff} = z_{init} + (1 + z_{init}) *((1+\delta)^{-0.6} - 1)$$

~uses z_{eff} to construct the high resolution region out of the last four pre-reionization outputs

~ does account for different rates of evolution due to large scale density variations

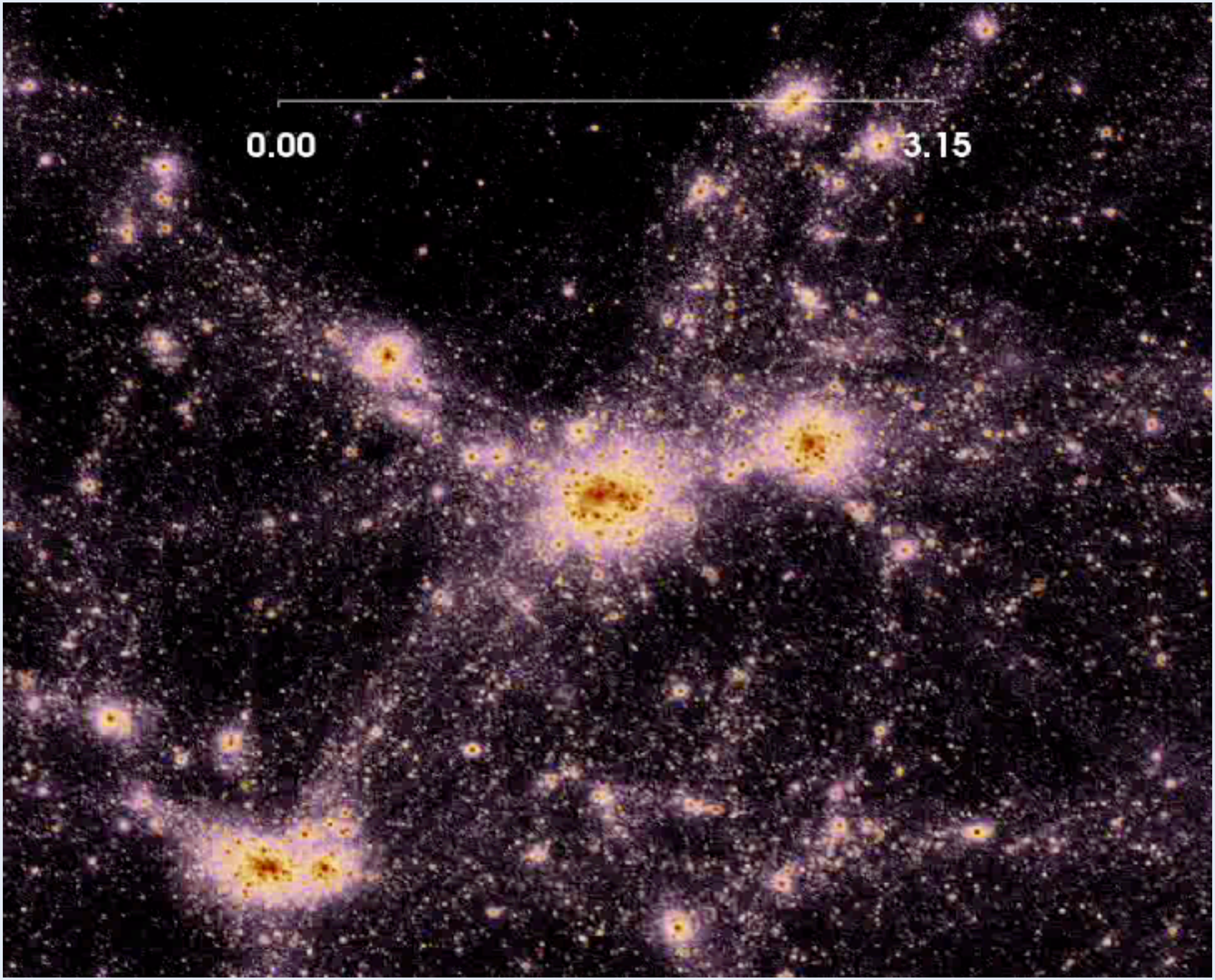
~ approximates reionization by X-rays from BH accretion in the early universe (reionization at approximately the same time everywhere)

Table 1. Table of Simulations

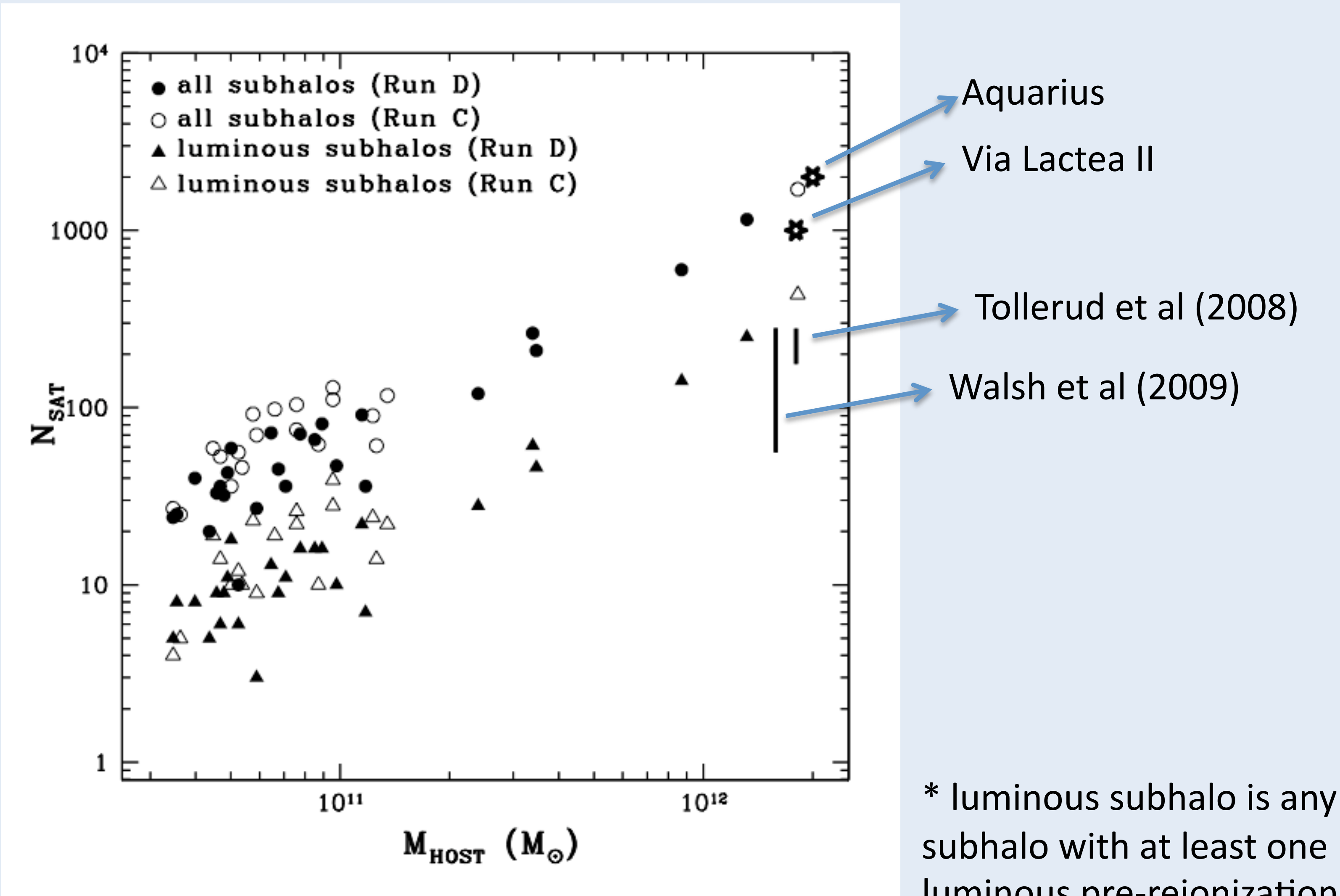
Name	IC Method	Volume (Mpc^3)	HR Volume (Mpc^3)	Mass Res. ($10^6 M_\odot$)	ϵ (kpc)	z_{init}
A	1^{st} order	50^3	$\sim 9^3$	3.16	1	8.3
B	1^{st} order	50^3	$\sim 9^3$	1.0	1	8.3
C	1^{st} order	50^3	$\sim 9^3$	0.316	1	8.3
D	2^{nd} order	50^3	$\sim 9^3$	0.316	1	10.2

Table 2. Table of 'Milky Ways'

Name	Run	Mass ($10^{12} M_\odot$)	R_{vir} (kpc)	v_{max} (km s^{-1})
MW.1	C	1.82	248.1	203.4
MW.2	D	0.87	222.6	196.6
MW.3	D	1.32	194.7	177


0.00
3.15

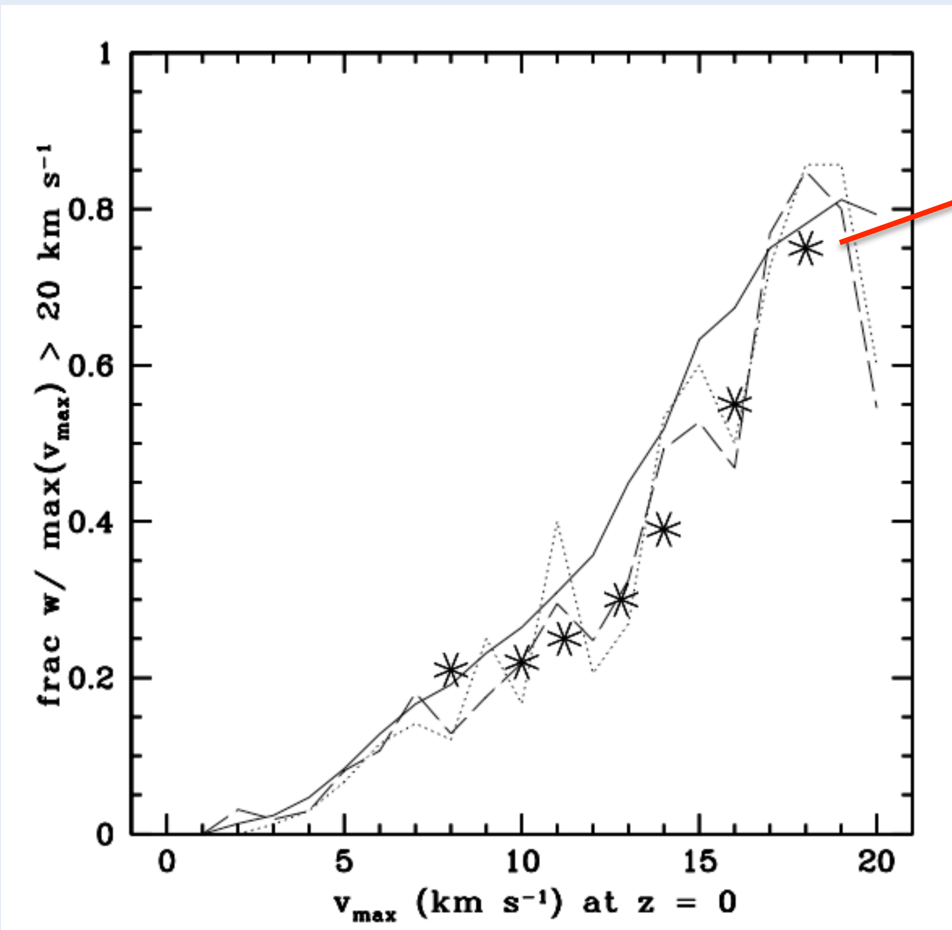
Satellite Numbers



* luminous subhalo is any subhalo with at least one luminous pre-reionization halo

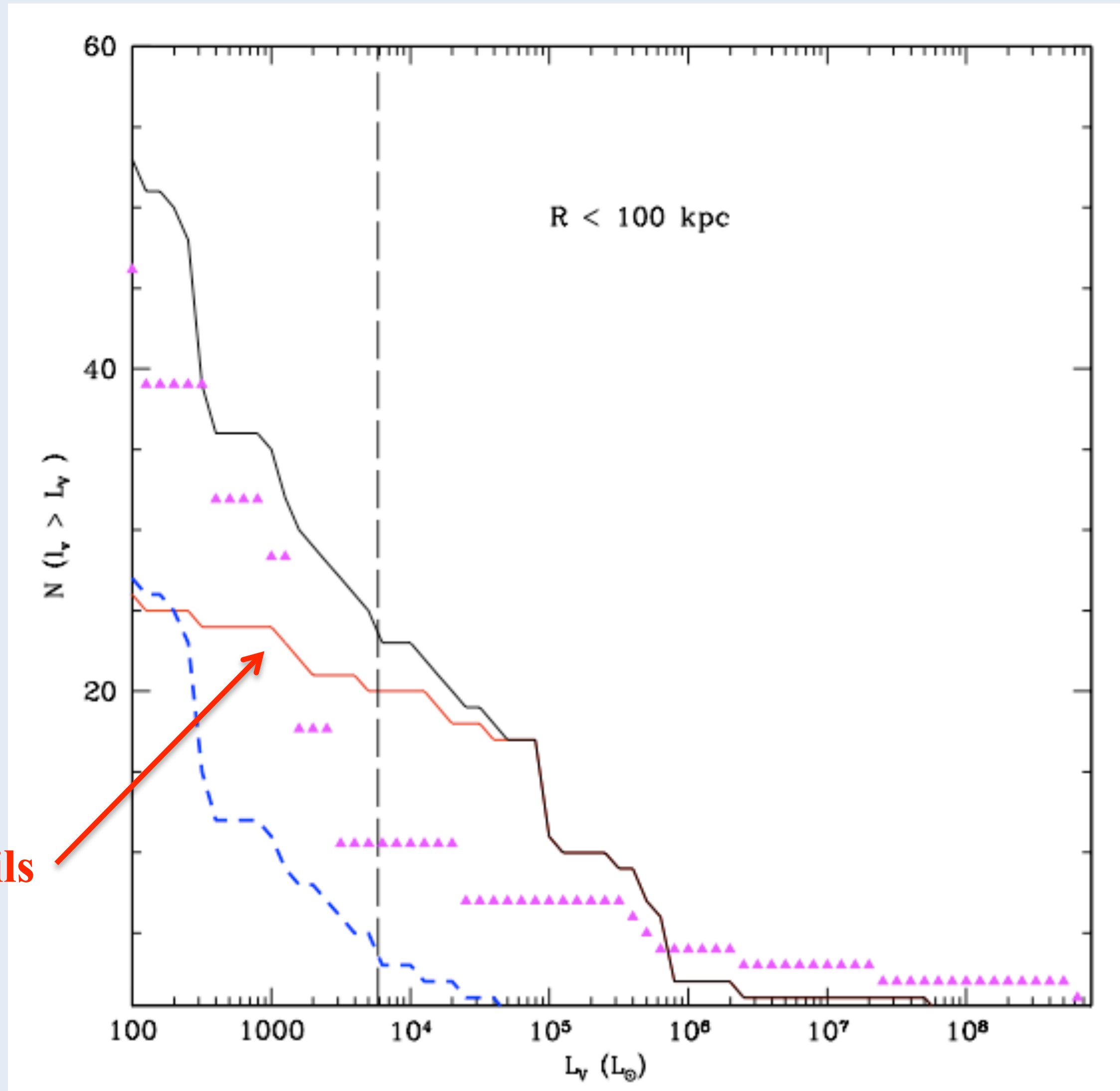
Tidal Stripping

Tidal stripping is limited to the loss of a pre-reionization halo's dark nimbus.



asterisks from Kravtsov et al (2004)

“Primordial” Luminosity Function

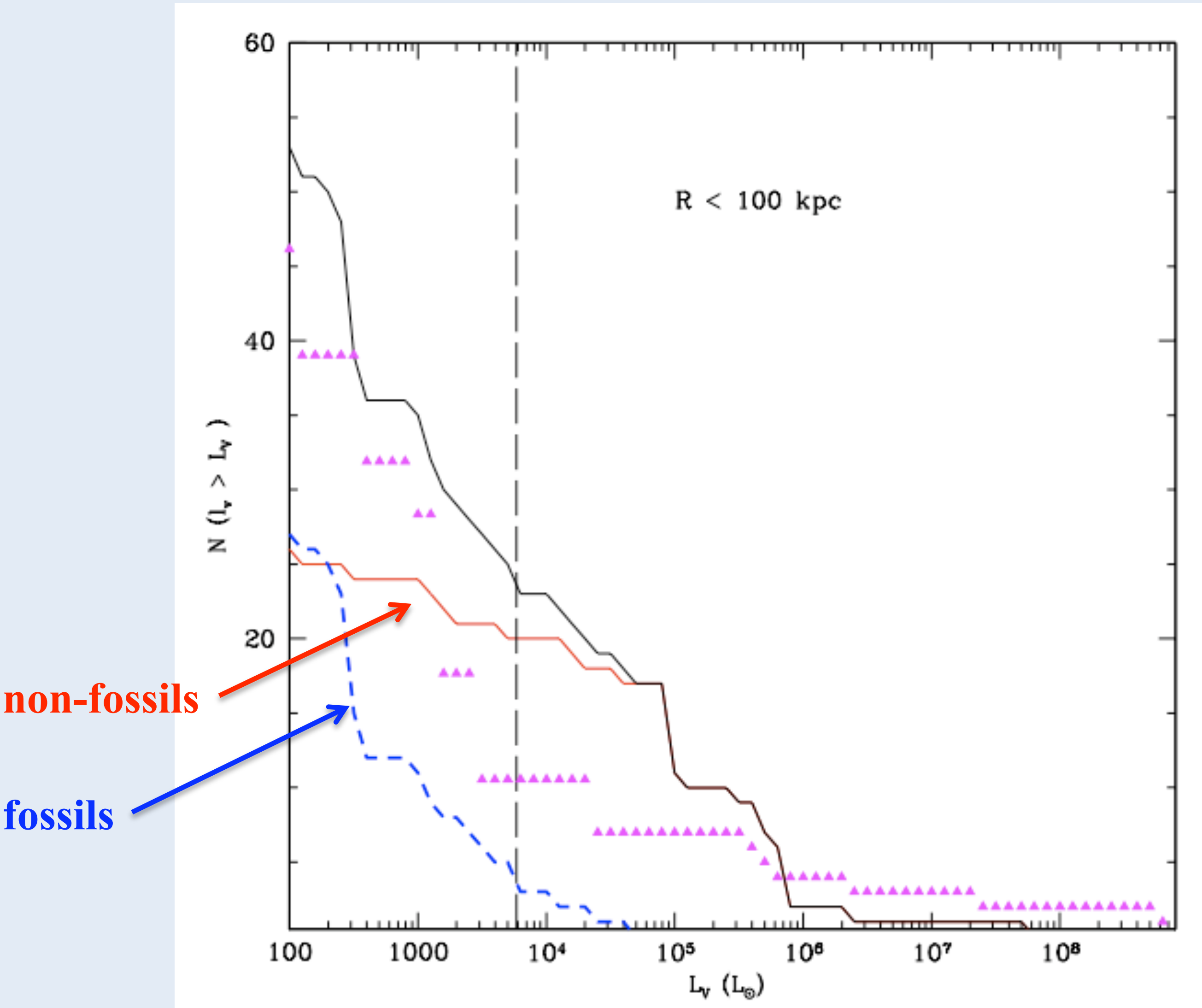


non-fossils

Non-fossils are any subhalo which was able to form stars after reionization.
All of the non-fossils contain a primordial population.

CAUTION: Since these objects may have formed stars after reionization, the z=0 luminosity function will shift to the right with a lower slope relative to the primordial one.

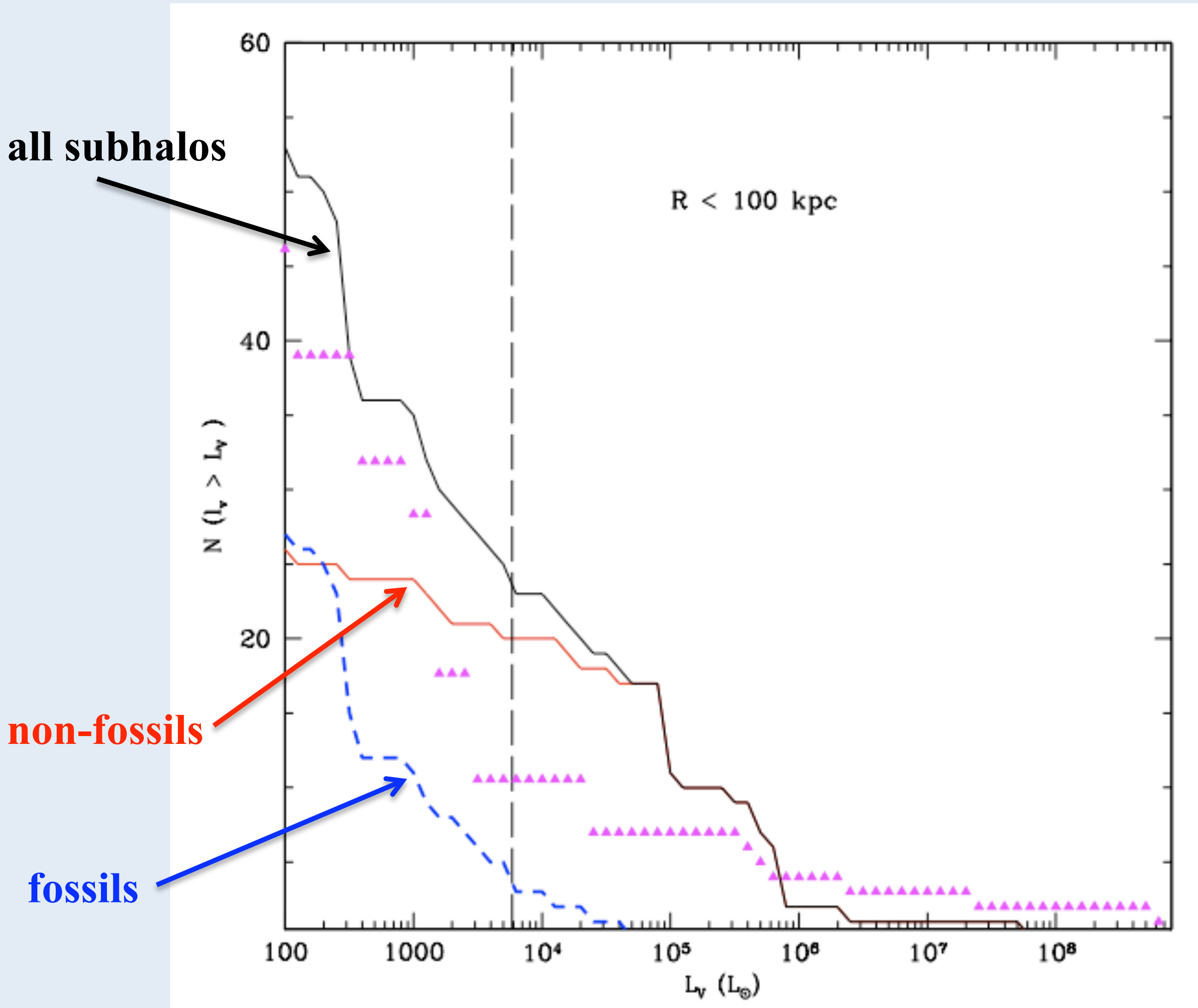
"Primordial" Luminosity Function



Fossils have undergone no significant baryonic evolution after reionization.

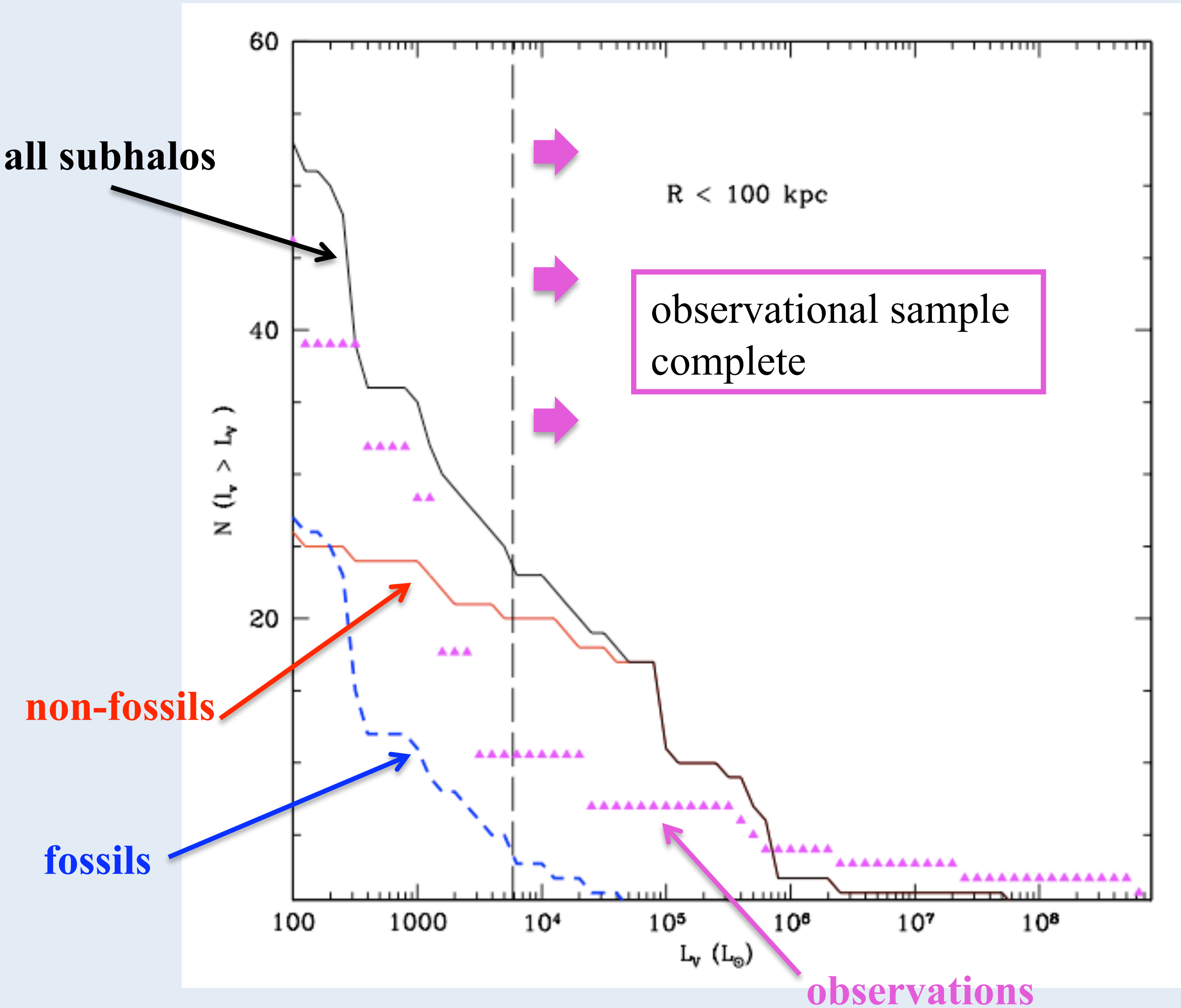
Unlike the non-fossils, their primordial luminosities directly determine the z=0 luminosity function.

"Primordial" Luminosity Function



Dominated by fossils for $\mathbf{L_V < \sim 10^4\ L_\odot}$, and by non-fossil for $\mathbf{L_V > \sim 10^4\ L_\odot}$.

"Primordial" Luminosity Function

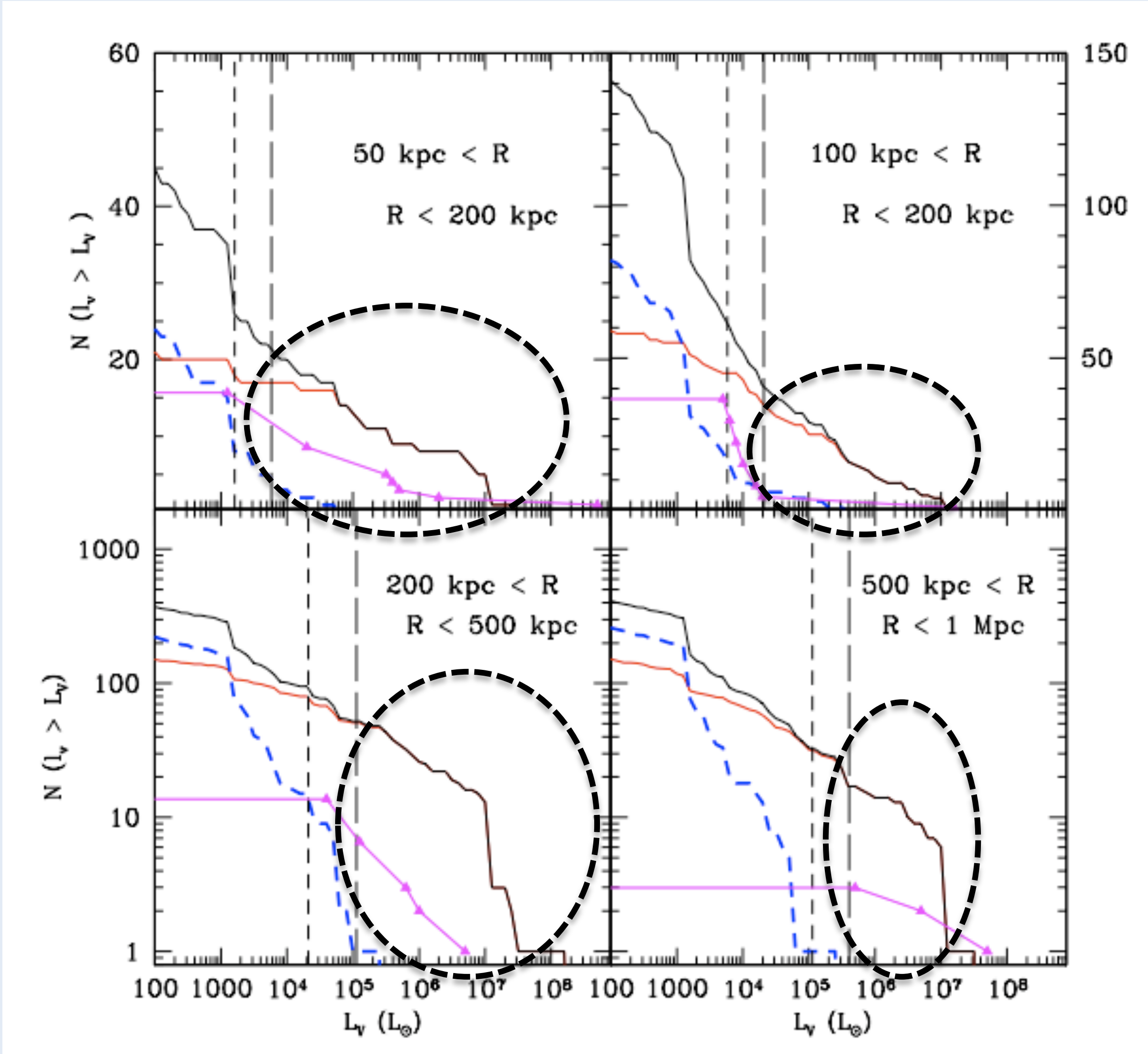


Includes all known dwarfs.

Ultra-faint sample is corrected for SDSS sky coverage and completeness (Walsh et al, 2009)

Sample is complete to the right of the dashed lines.

Where are the bright satellites!?



Take Home Points

- We have developed a novel method for generating initital conditions for N-body simulations which allows us to trace the fossil relics of the first galaxies to the modern epoch.

- Our method is able to reproduce results from published work.

- Fossils dominate the luminosity function for $L_V < 10^4\ L_\odot$ and as a population have $L_V < 10^6\ L_\odot$.

- We overproduce dwarfs with $L_V > 10^4\ L_\odot$.

For all the gory details and to see how we attempt to get rid of the bright dwarfs, check out Bovill & Ricotti (2010a,b) coming soon to an archive near you.


Questions?