Are The Ultra-Faint Galactic Satellites The Fossils Of The First Galaxies?

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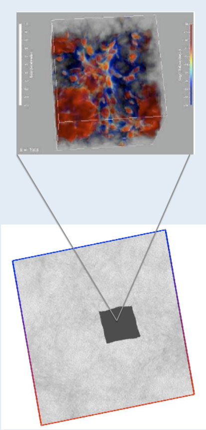
Introduction

The discovery over the last five years of more than 20 ultra-faint Local Group dwarfs[1] provides an opportunity to investigate the formation of the first galaxies. As a result of their shallow potentials (v_{max} < 20 km/s), a fraction of the first galaxies, which formed stars before reionization, will not accrete additional gas from the IGM afterwards (Ricotti & Gnedin, 2005). The stellar properties of such galaxies change only via the evolution of their stars from reionization to the present. We expand upon Bovill & Ricotti (2009) (BR09), which compared the properties of the first galaxies at formation to observations of the ultra-faints. Our new simulations directly track remnants of the first galaxies to z=0, giving us a direct, z=0 comparison of their distribution and properties to those observed for the ultra-faints.

Simulations

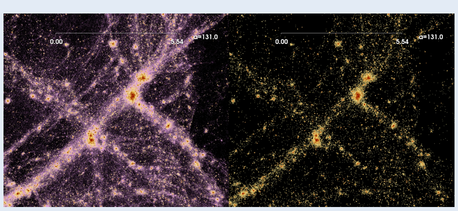
We generate hybrid initial conditions, which allows us to evolve our pre-reionization simulations[2] to z=0.



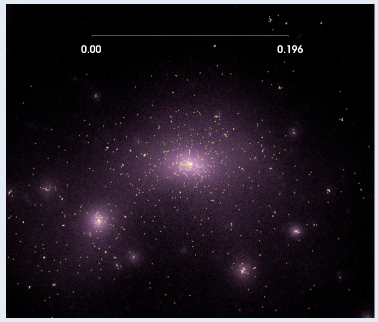
1 – We build a high resolution region at z_{init} within a 50^3 Mpc^3 N-body simulation. This region is built from the final outputs of the pre-reionization simulations. Each high resolution particle in our N-body simulation is a proxy for a halo in our pre-reionization simulations.

2 – Our N-body simulation is run from z_{init} to z=0 with Gadget2 (Springel, 2005) on the HPCC at U. Maryland.

3 – Simulations are analyzed at z=0 using AHF (Knollmann & Knebe, 2009). Here we present the results from a high resolution simulation run from z_{init} = 10.2 to z = 0 with ~450^3 particles.



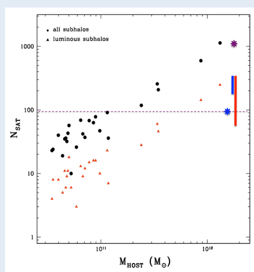
Distribution of dark (purple) and luminous (yellow/orange) pre-reionization halos (left) and only luminous pre-reionization halos (right). Bar shows scale in Mpc.



One of two Milky Way mass halos in our simulation with pre-reionization halos with $L_V > L_{DRACO}$ (yellow) and $L_V < L_{DRACO}$ (purple). The bar across the top shows the scale in Mpc.

Fossils in the Local Group

When corrected for SDSS sky coverage, there are more Milky Way satellites than subhalos for which $v_{max}(t)$ > 20 km/s, the threshold for IGM accretion after reionization and the definition of a fossil dwarf.



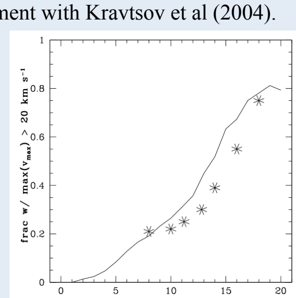
The number of subhalos as a function of the mass of the host halo. We plot the total number of subhalos (black circles) and the number of luminous subhalos (red triangles). A luminous subhalos is a halo at z=0 which contains a remnant of a first galaxy. For comparison, we also show the results from Aquarius, corrected for our lower resolution (purple star), the number of luminous satellites estimates by Tollerud et al (2007) and Walsh et al (2009) (blue and red lines), and the number of currently known Milky Way satellites corrected for SDSS sky coverage (blue star). The purple dased line shows the number of subhalos with $v_{max}(t)$ < 20 km/s for Aquarius (see table and BR09).

So about 70% of Milky Way lum.subhalos are fossils!

Distance from center	# of Lum. Dwarfs (Tollerud et al , 2007)	Dark halos with $v_{max}(t)$ >20 km/s			
		Via Lactea I		Aquarius	
		today	any time	today	any time
< 200 kpc	176 to 330	14	36 +/- 8	34	91 +/- 20
< 417 kpc	304 to 576	28	72 +/- 16	69	182 +/- 40

When we apply the $v_{max}(t)$ > 20 km/s fossil definition to our simulated halos we find the fraction of halos with vmax < 20 km/s at z=0 which fit the fossil definition is in agreement with Kravtsov et al (2004).

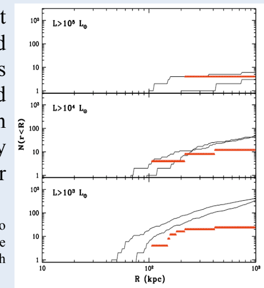
We show the fraction of halos for which max(v_{max}) > 20 km/s as a function of v_{max} at z=0 for our simulations (black line) and the same dependence from Kravtsov et al (2004) (asterisks).



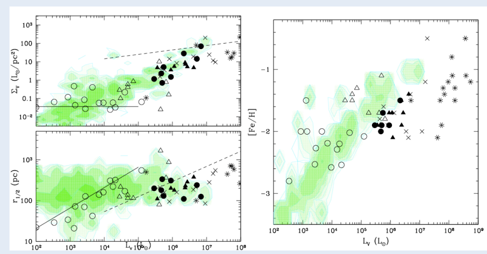
Radial Distribution

We find good agreement between the observed distribution of ultra-faints around out Milky Way and the radial distribution around two Milky Way mass halos in our simulation.

Radial distribution of fossils around two Milky Way mass halos (black) and the observed distribution of ultra-faints which show no signs of tidal disruption (red).



Stellar Properties



Distributions half light radii (bottom) and average surface brightness (top) as a function dwarf luminosity (left) and of Fe abundance as a function of luminosity (right). The properties of the classical dIrrs (astericks), dEs (crosses), Milky Way dSphs (closed circles), M31 dSphs (closed triangles) and ultra-faint Milky Way dwarfs (open circles), and ultra-faint M31 dwarfs (open triangles) are plotted over those of our simulated dwarfs (green contours). The lines on the left plot show the detection limit of SDSS (solid) and the expected trend when only the classical dwarfs are considered (dashed).

When the pre-reionization fossils from BR09 are evolved to z=0, we find excellent agreement between the properties of our simulated dwarfs and those of the ultra-faints. We also confirm the BR09 result of the existence of a population of even lower surface brightness dwarfs below the detection limit of SDSS. For addition comparisons of metallicity spread, velocity dispersion and mass to light ratios please see BR09 and Bovill & Ricotti (2010, coming soon to astro-ph).

Conclusions

(1) About 70% of Milky Way satellites are fossils.
(1) The stellar properties of the ultra-faints agree with predictions for pre-reionization fossils.
(2) We confirm the BR09 prediction of a fossil population with surface brightnesses below SDSS detection limits.

References

1 – Belokurov et al 2006, 2007, 2009 : Irwin et al 2007 : : Geha et al 2009 : Grillmair, 2009 : Ibata et al2007 : Majewski et al 2007 : Martin et al 2006 : Walsh et al 2007 : Willman et al 2005b, 2005a : Zucker et al 2006b, 2006a
2 – Ricotti, M. et al 2002a,b,2008

Bovill M. S. Ricotti M. 2009 : Knollmann Knebe 2009 : Kravtsov et al (2004) : Ricotti, M., Gnedin, N. Y. 2005 : Springel, V. 2(005) : Tollerud et al (2007) : Walsh et al (2009)