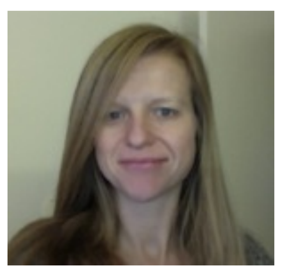

Hunting for the Smallest Substructures: Ultrafaint Galaxies as Satellites of Known Local Group Dwarfs

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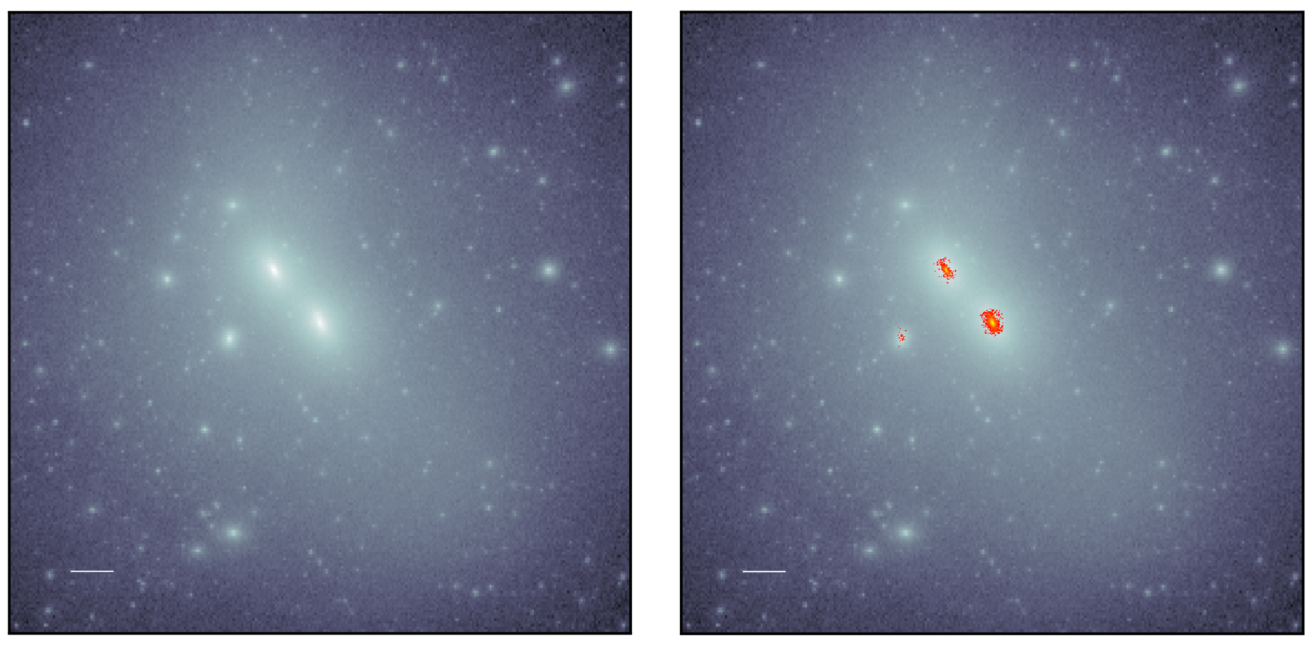
Introduction

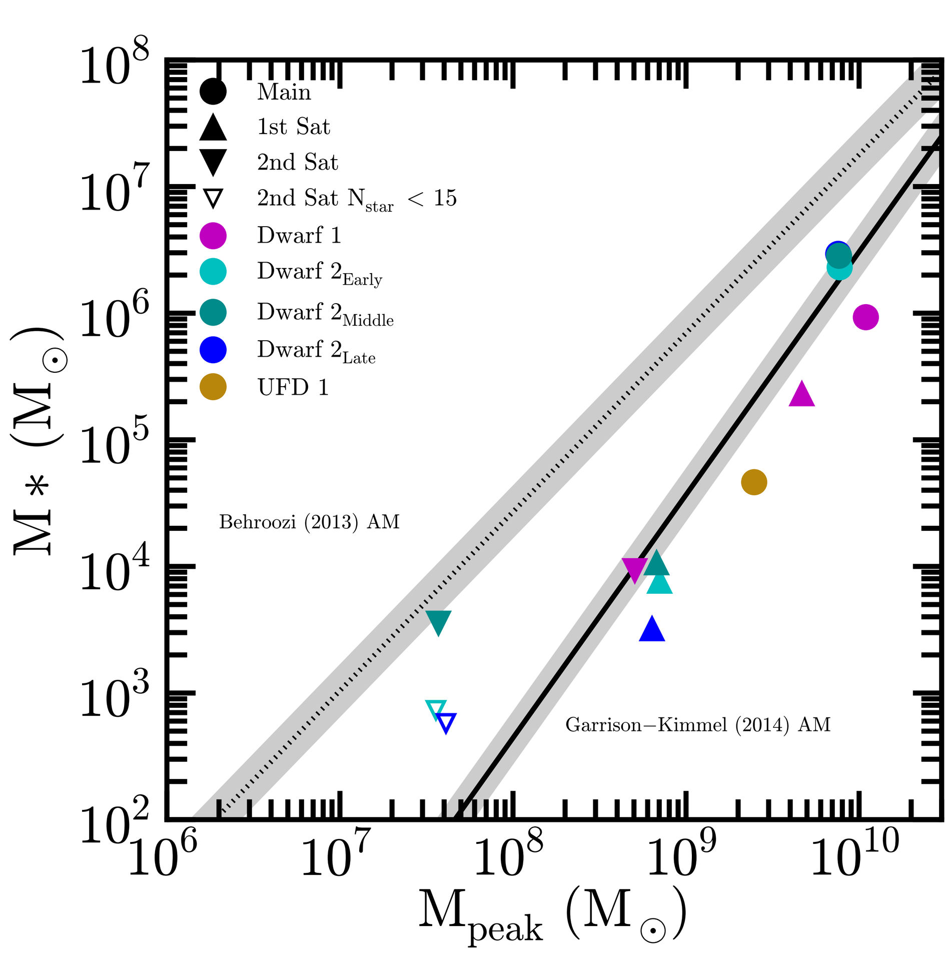
If ΛCDM is correct, then all dark matter halos hosting galaxies, from those hosting dwarfs to those hosting giants, are filled with abundant substructure down to very low mass scales (<< 10^9 $M_\odot$). Specifically, even the dark matter halos of Local Group field dwarfs should be filled with subhalos, many of which should be fairly massive (~ 10^8 $M_\odot$), and thus are potential targets for hosting small (ultra-faint) galaxies. If these tiny satellites are detected, it would provide evidence that low-mass dark matter halos contain substructure, as predicted in the standard paradigm.

Massive subhalos form stars



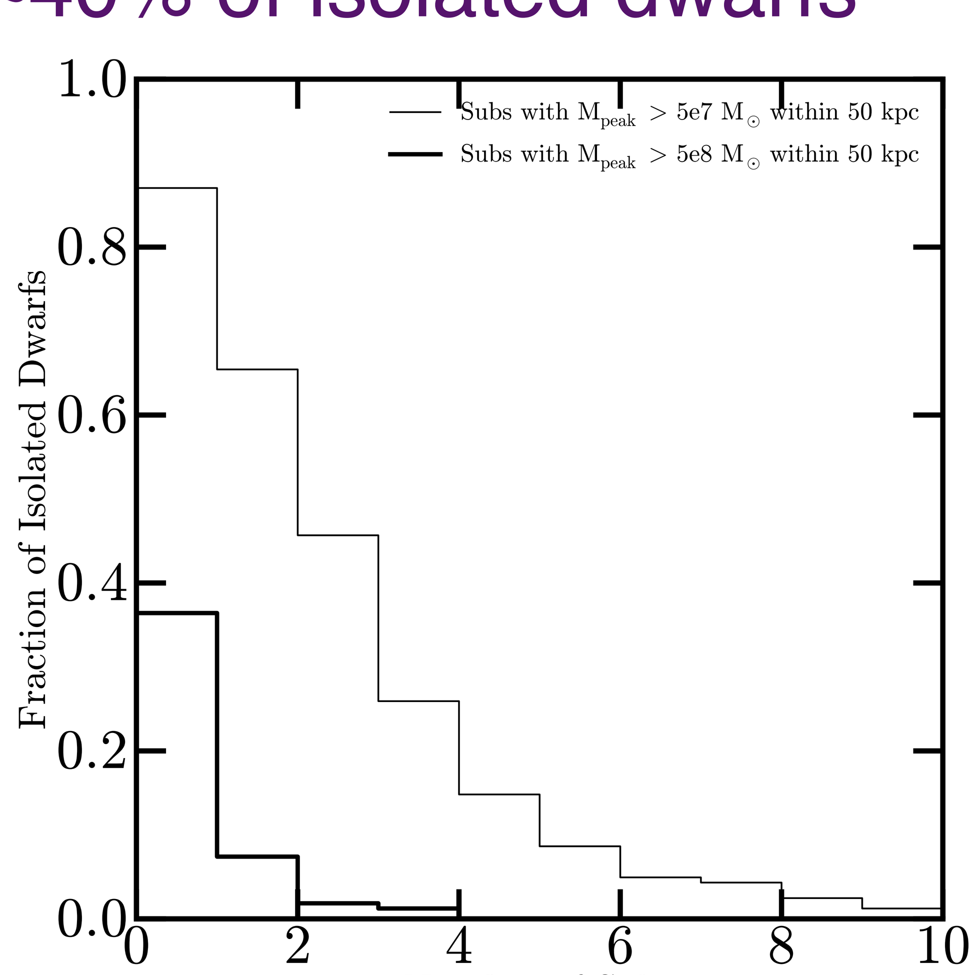
Left: Dark matter only visualization of one of the simulated Dwarfs (Dwarf 1, M_{vir} ~ 10^{10} $M_\odot$) and its subhalos. The largest subhalo (up and to the left of its host) has a dark matter mass that peaked at almost half of the host's virial mass (M_{peak} ~ 5×10^9 $M_\odot$). Right: Stellar mass density for all massive star-forming satellites overlaid on top of the dark matter. The two most massive satellites form approximately 2×10^5 $M_\odot$ and 5×10^3 $M_\odot$ in stars respectively. A distance of 5 kpc is marked in the lower left corner.

They sit on the M*-M_{halo} relation



Stellar mass - halo mass relationship for all 5 hosts (circles) and the satellites (up and down triangles) that form at least 15 star particles ('massive satellites', solid symbols). The 2nd most massive satellites in runs Dwarf 2_{Early} and Dwarf 2_{Late} form fewer than 5 star particles (open symbols), highlighting the stochasticity of star formation at these low masses. Two different abundance matching extrapolations are shown as black lines with 0.2 dex in scatter. With surprisingly little scatter, most of our satellites lie on the Garrison-Kimmel[c] abundance matching relationship (that has been shown to match the MW and LG stellar mass functions).

Massive subhalos exist in ~40% of isolated dwarfs



All subhalos in our simulations with peak masses greater than 5×10^8 $M_\odot$ host galaxies with stellar masses of at least 3000 $M_\odot$. An analysis of the much larger isolated dwarf sample in the collisionless ELVIS Local Group simulations[c] shows that these subhalos exist within ~40% of isolated massive (M_{vir} ~ 10^{10} $M_\odot$) dwarfs.

METHODS

We run ultra-high resolution simulations (m_{gas} ~ 250 $M_\odot$, force res ~ 1pc) of isolated dwarf galaxies (10^9 $M_\odot$ < M_{vir} < 10^{10} $M_\odot$) with GIZMO[a], a state-of-the-art code that utilizes the highly sophisticated FIRE (Feedback in Realistic Environments) recipes[b] for converting gas into stars and capturing the energy fed back from those stars into the surrounding medium. Included are stellar winds from O-type and AGB stars, supernovae explosions, radiation pressure in optically thick gas, long-range radiation flux escaping star-forming regions, and photoionization heating from young stars. We run five simulations of three dwarf halos. Two halos have M_{vir} ~ 10^{10} $M_\odot$ (Dwarf 1 and Dwarf 2). For Dwarf 2 we present three runs (Early, Middle and Late) with slight variations in the sub-grid physics. We also run one isolated ultra-faint (UFD, M_{vir} ~ 10^9 $M_\odot$). Dwarf 1, Dwarf 2_{Early}, and the UFD were all run with the same sub-grid recipes. Using these simulations, we predict that isolated dwarf galaxies (M*~10^6 $M_\odot$) in the Local Group should host ultra-faint galaxies (M* ~ 3000 $M_\odot$) as satellites.

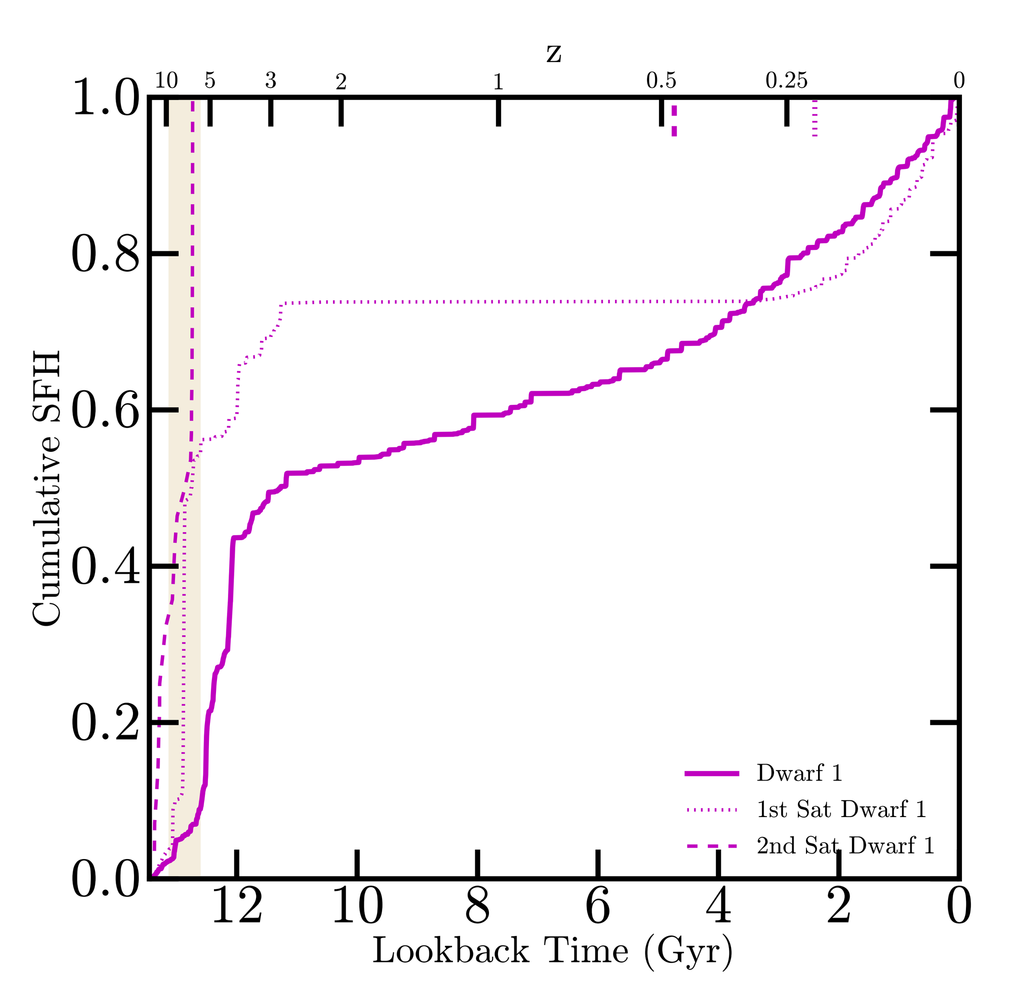
References

a Hopkins P. F., 2014, ArXiv e-prints, arXiv:1409.7395

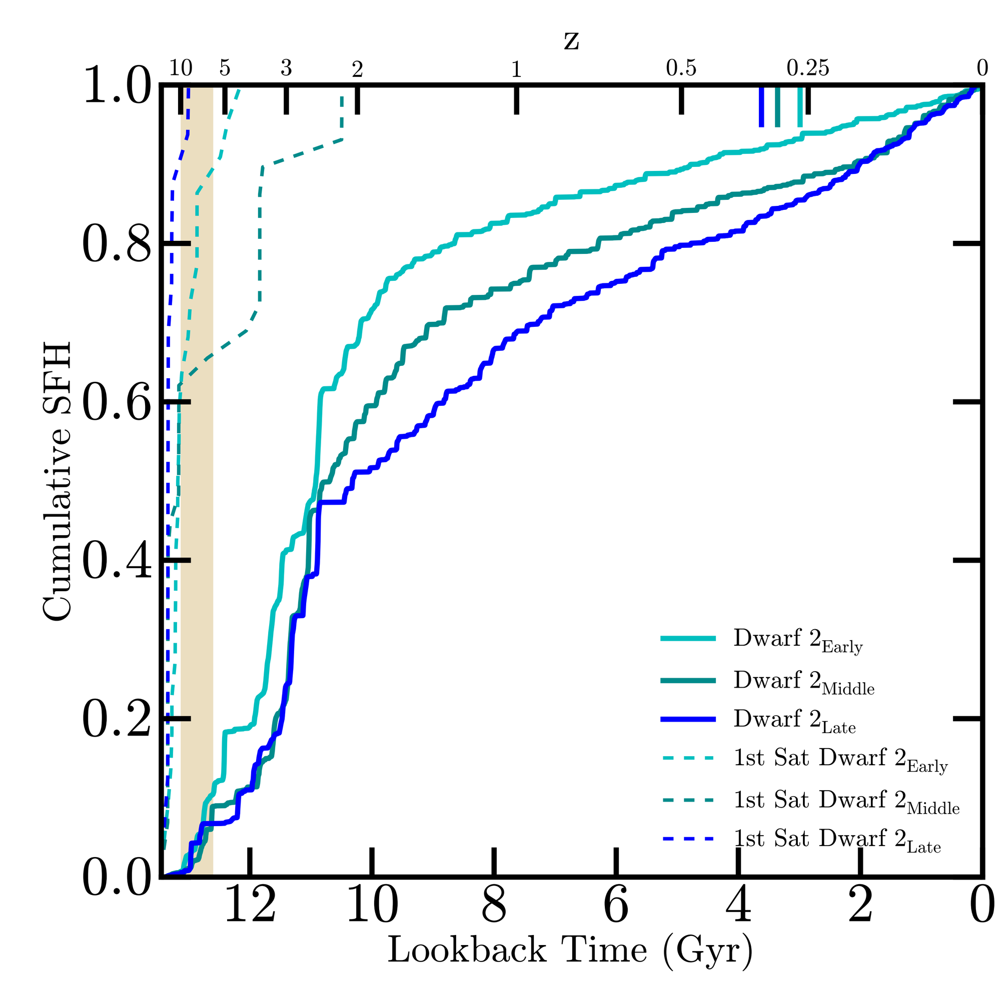
b Hopkins P. F., Keres D., Onorbe J., Faucher-Giguere C.-A., Quataert E., Murray N., Bullock, J. S., 2014, MNRAS, 445, 581

c Garrison-Kimmel S., Boylan-Kolchin M., Bullock J. S., Lee K., 2014, MNRAS, 438, 2578

Ultra-faint satellites form all or most of their stars before reionization



Cumulative star formation history for Dwarf 1 (solid line) and its two massive satellites. The ultra-faint satellite (dashed line) forms all of its stars before the end of reionization (shown as a gold vertical band). The most massive satellite (dotted line) has its star formation quenched for ~ 8 Gyr, forming stars again only at infall (lines in upper-right corner).

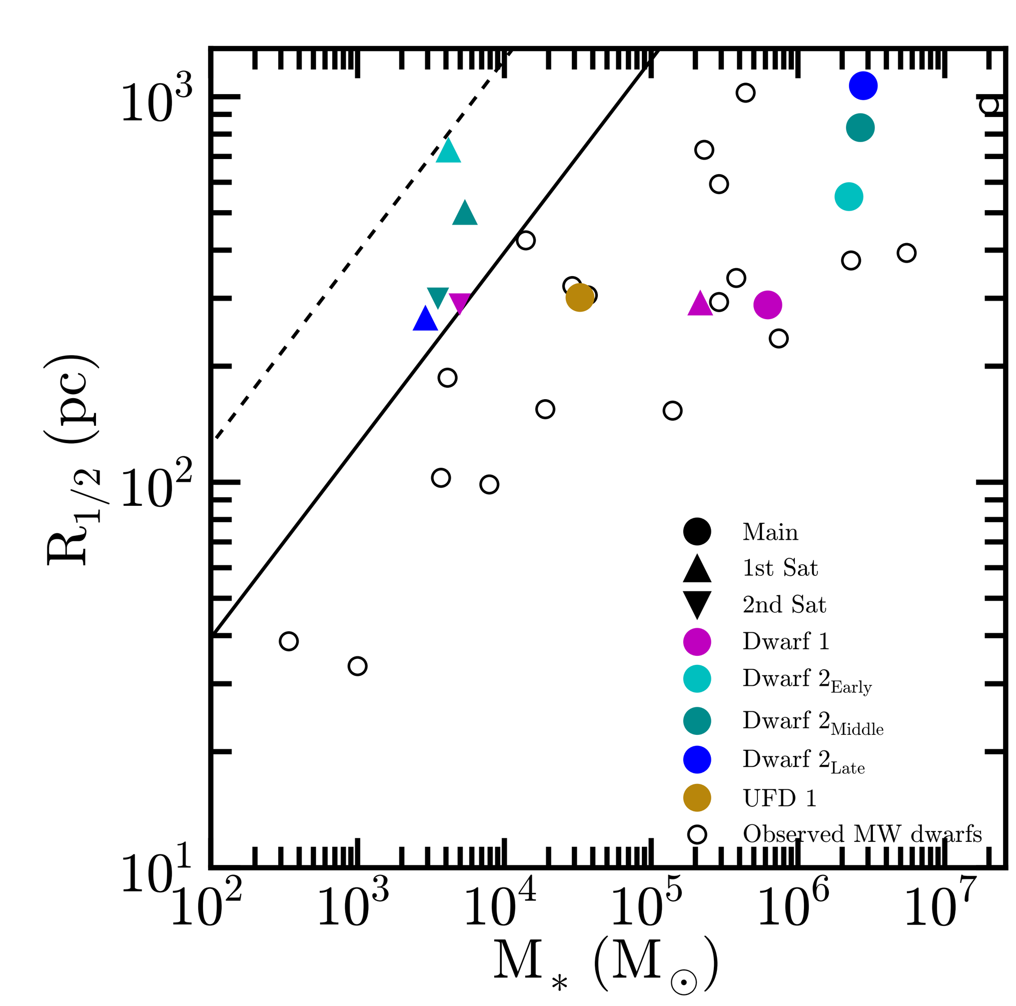


Cumulative star formation history for the three runs of Dwarf 2 (solid lines) and their satellites. All Dwarf 2 runs start with the same initial conditions, but have different sub-grid physics prescriptions, leading to varying SFHs. In all 3 runs, the ultra-faint satellites (dashed lines) form most of their stars before reionization (gold vertical band).

SUMMARY

- In the ΛCDM paradigm, dark matter halos of Local Group field dwarfs should be filled with subhalos. We predict that some of them should form stars.
- Isolated dwarf galaxies (M*~10^6 $M_\odot$) in the Local Group should host ultra-faint galaxies (M* ~ 3000 $M_\odot$) as satellites.
- These satellites form most of their stars in the first billion years after the Big Bang and are subsequently deprived of gas because of the ionizing background.
- The extended ~50 kpc regions around Local Group "field" dwarfs may provide efficient search locations for discovering new ultra-faint dwarf galaxies.
- If these tiny satellites are observed, it would provide evidence that dark matter substructure persists to very small scales, as predicted in the standard paradigm.

Some satellites observable now, others in the near future



Half-light radius vs stellar mass for all main galaxies and their massive satellites. The current detection limit (30 mag/arcsec²) is shown as a solid black line. For reference, the dashed line represents 32.5 mag/arcsec² and is likely what will be achievable in the near future with LSST. Observed Milky Way dwarfs are shown as open circles.