The Low Mass Galaxy-Halo Relation

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Abstract

We use hydrodynamic cosmological simulations of the Local Group to study the relation between low mass galaxies and halos. We show that the widely used method of abundance matching based on dark matter only (DMO) simulations fails at the low mass end because two of its underlying assumptions are broken: few halos of mass $< 10^{9.5}\mathrm{M}_\odot$ host a visible galaxy, and baryon effects lower halo growth rates. Correcting for these effects resolves the reported discrepancy between observations of individual dwarf galaxies and the values predicted by abundance matching in ΛCDM.

We also study the discriminating factors for galaxy formation in the early universe imposed by reionization, and connect them to properties of today's galaxies and halos. The sparse sampling of low mass halos by galaxies and the subsequent evolution introduce strong biases: *luminous* halos are more concentrated and formed earlier than *dark* ones. In addition, luminous satellites of total mass $10^8 - 10^9\mathrm{M}_\odot$ or v_{max} of $12 - 20\mathrm{kms}^{-1}$, similar to the Local Group dwarf spheroidals, are on more radial orbits with higher infall velocities and earlier infall times, resulting in stronger stripping.

Abundance Matching

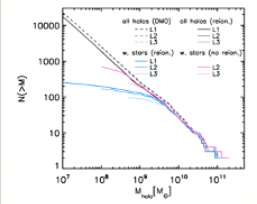
Abundance matching is a simple but powerful method to statistically link observed galaxies and dark matter halos. Assuming a monotonic relationship between stellar mass and halo mass and equating the cumulative abundances,

$$\int_{\mathrm{M_{h,max}}}^{\mathrm{M_{h,min}}} N_h(m)dm = \int_{\mathrm{M_{*,max}}}^{\mathrm{M_{*,min}}} N_*(m)dm,$$

where $N_h(m)$ and $N_*(m)$ are the halo and stellar mass functions, allows a determination of the average stellar – total mass relation. However, for individual dwarf galaxies, observations combined with stellar kinematics imply much higher stellar – total mass ratios. A failure of ΛCDM?

One key assumption is that each halo hosts one galaxy, and that halo masses can be derived from Dark Matter Only (DMO) simulations.

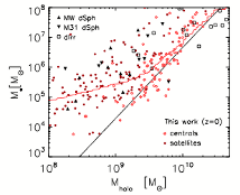
The Halo Mass Function



Halo mass function in DMO (dashed) and hydrodynamic (solid) simulations at z=0. Grey lines include all halos, coloured lines count only those that contain stars: blue with reionization and purple without.. L1 are our highest resolution simulations, L2 and L3 are lower by factors of 12 and 144. Simulations with reionization are converged.

The number of halos that host galaxies after reionization (blue) is significantly below the DMO result (dashed) assumed in abundance matching.

The M_*-M_{halo} Relation



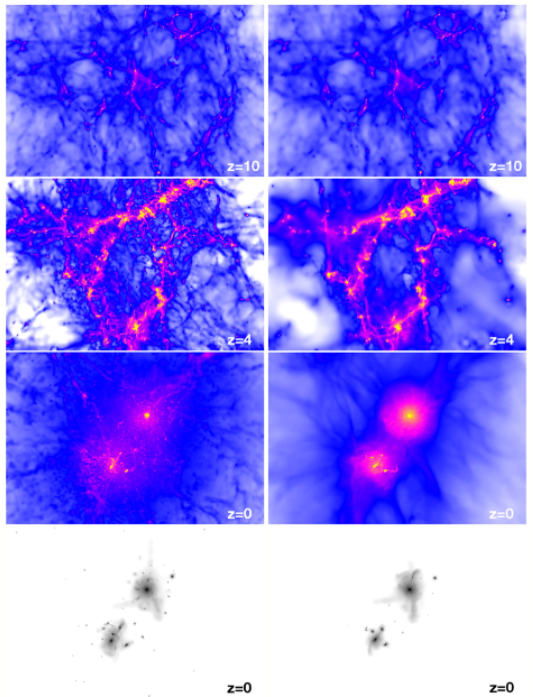
M_*-M_{halo} relation for Local Group galaxies at z=0. Black symbols show observational estimates (Misgeld & Hilker, 2011; Woo et al., 2008; Peñarrubia et al., 2008; Tollerud et al., 2012; Ferrero et al., 2012; McGaugh, 2005; Oh et al., 2011; Stark et al., 2009; Côté et al., 2000), red symbols show results measured directly in our simulation.

Abundance matching using DMO halo mass functions of ΛCDM underpredicts the M_*-M_{halo} relation for dwarf galaxies (Moster et al., 2013, black line). Correcting the halo mass function for the effects of baryons and dark halos (red line) brings ΛCDM into agreement with observations.

The Local Group Simulations

Dark matter density in a Local Group zoom simulations at z=0. We simulated 12 LG volumes with the EAGLE code, with mass resolution up to $1.0 \times 10^4\mathrm{M}_\odot$ (gas) and $5.0 \times 10^4\mathrm{M}_\odot$ (DM), fully hydrodynamic and as Dark Matter Only (DMO). **Scan the QR code to reveal the stars and see which halos host galaxies!**

The Impact of Reionization

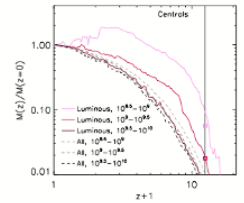


Gas density distribution (top three rows) and stellar density distribution (bottom row, only halos with $m_* > 4 \times 10^6\mathrm{M}_\odot$) in a Local Group simulation without reionization (left) or with reionization (right). Following reionization at z=11.5, gas is removed from low mass halos, and reduced cooling results in a less fragmented IGM. The difference increases over time to z=0. **The number of collapsed and star-forming halos is much lower with reionization included, and compatible with observations.**

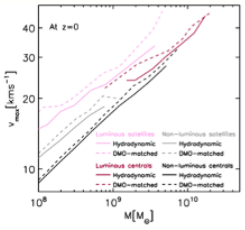
Let Me Explain!

Scan the QR code to reveal this poster's *dark* side, read the papers, or watch me explain its key concepts in three minutes! Of course, you can always talk to me in person.

Galaxies in Which Halos?

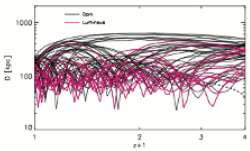


Assembly history for present-day centrals grouped according to mass at z=0. The vertical line indicates hydrogen reionization at z=11.5, and the squares indicate mass ratios that corresponds to the same halo mass ($10^{7.5}\mathrm{M}_\odot$) at this time. **Halos of lower final mass generally formed earlier, but this trend is greatly amplified for luminous halos: at low mass, luminous halos become increasingly biased towards earlier formation times.** Also, note that luminous centrals in halos below $10^9\mathrm{M}_\odot$ today are likely to have been tidally stripped in the past.



Relation of halo mass and v_{max} in our simulations. **Because stars form preferentially in halos of higher concentration, luminous halos are more concentrated.** The effect of galaxy formation itself is manifest in the difference between the relations measured in the matched DMO simulation and directly in the hydrodynamic simulation, where outflows leave halos slightly less concentrated.

No Ordinary Satellites



Evolution of galactocentric distance for dark and luminous satellites of the simulated "Milky Way" with v_{max} between $12 - 25$ kms^{-1}. The grey dashed line shows the evolution of the host halo's virial radius. **Luminous halos in this v_{max} range fell in earlier and on more radial orbits, leading to greater than average stripping and mass loss.**

References & Contact

"Bent by baryons", T.S. et al. (2014)
arXiv:1404.3724
"The chosen few", T.S.et al. (2014)
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The Low Mass Galaxy-Halo Relation

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