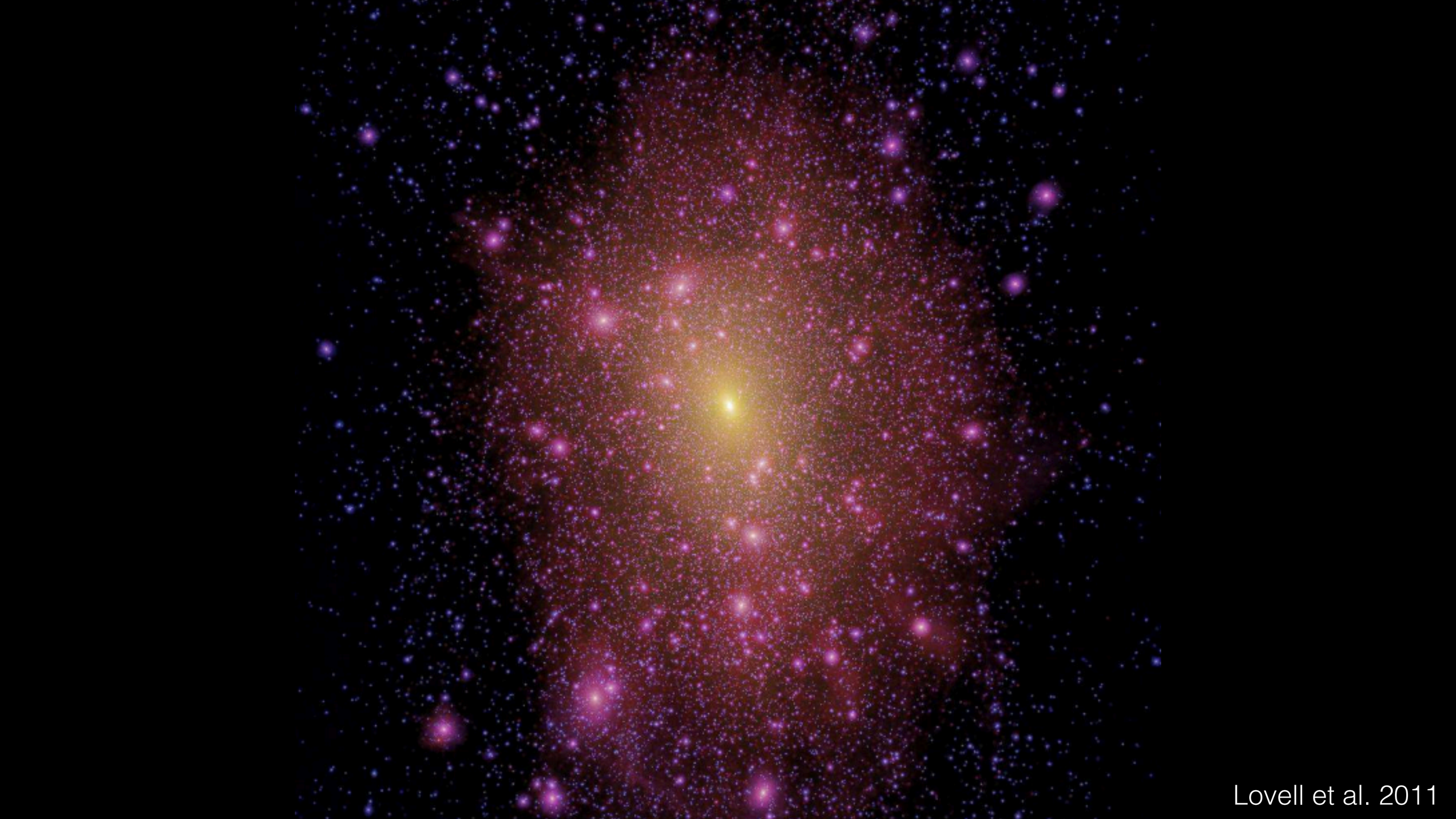
Modeling Subhalos and Satellites in Milky Way-like Systems

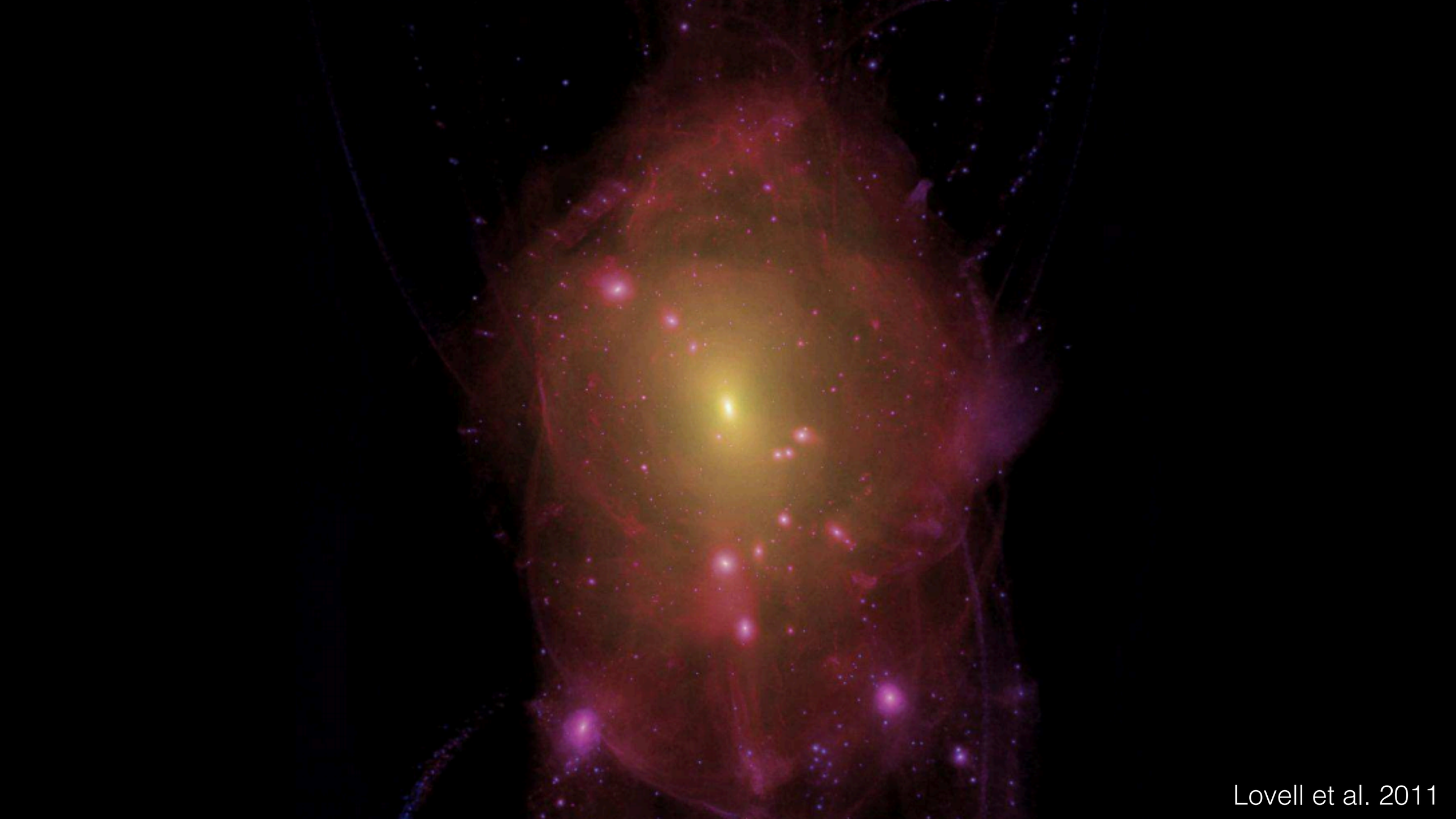
Ethan Nadler (Stanford/KIPAC)

KIPAC

5/21/18



Lovell et al. 2011



Lovell et al. 2011

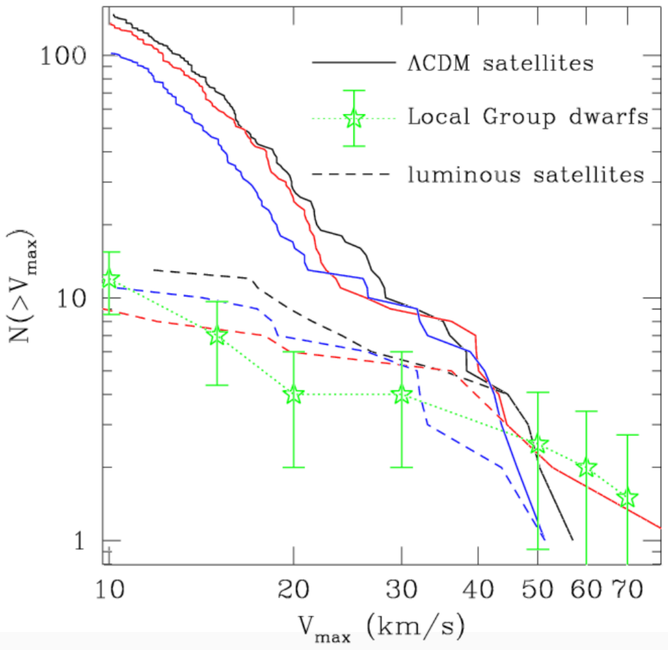
Small-Scale Challenges to ΛCDM?

1. Missing Satellites: reionization, stellar feedback suppress galaxy formation

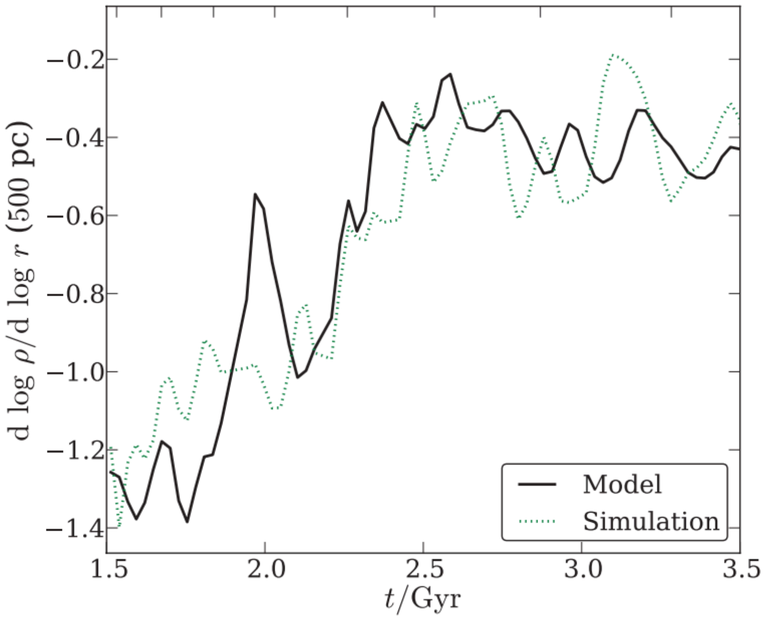
2. Cusp/core: stellar feedback —> rapid gas outflows, softened density cusps

3. Too Big to Fail: solved by stellar feedback + subhalo disruption?

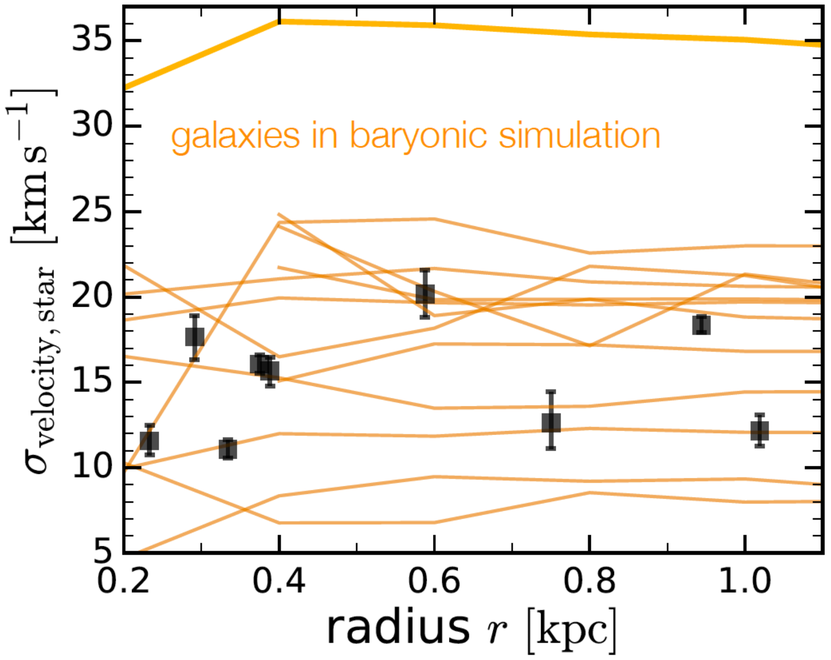
Kravstov et al. 2004

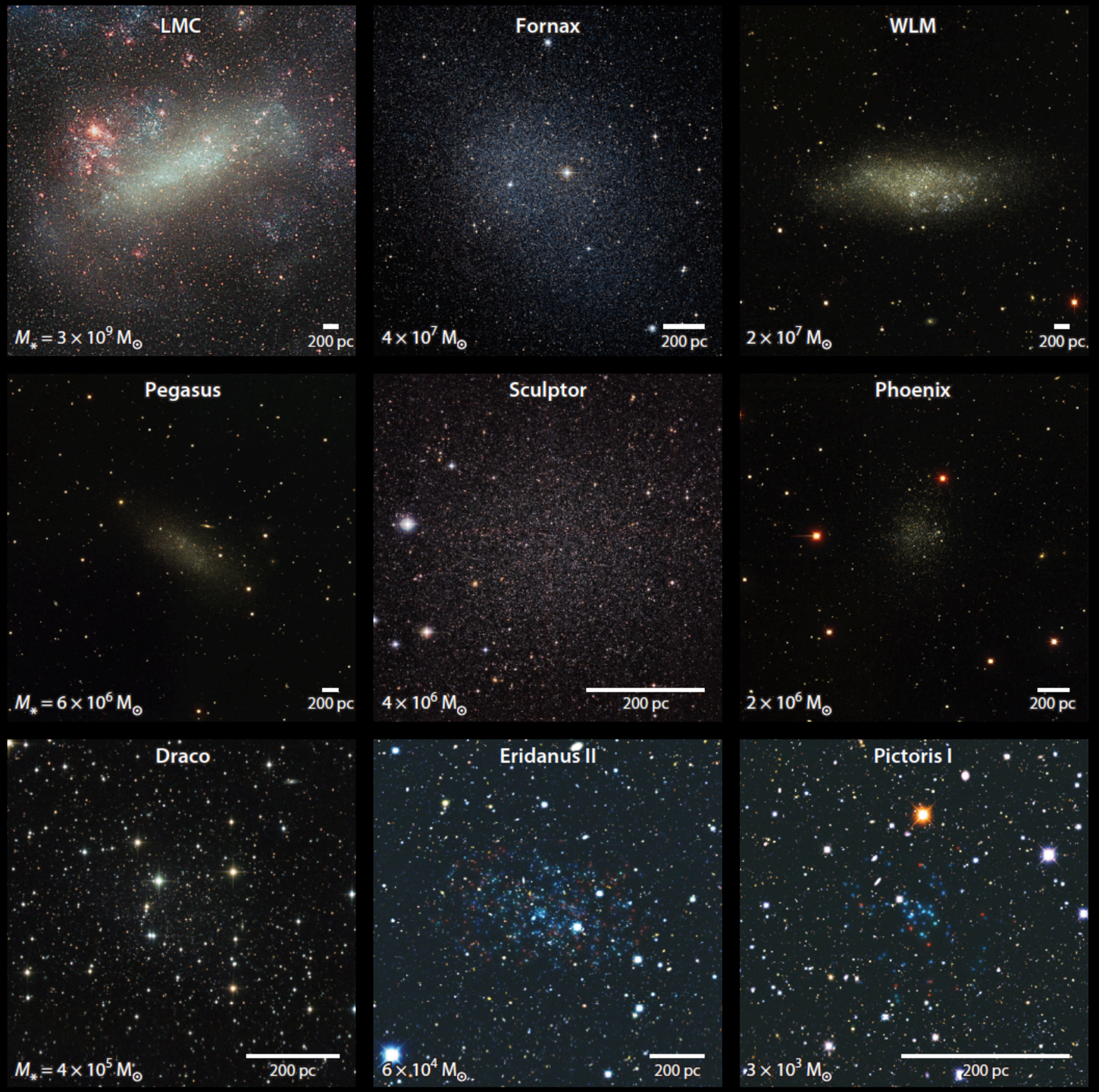


Pontzen & Governato 2012



Wetzel et al. 2016





Bullock &
Boylan-Kolchin 2017

Outline

1. Insights from Hydro Simulations

2. Constructing Subhalo Populations

3. Modeling Milky Way Satellites

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1. Insights from Hydro Simulations

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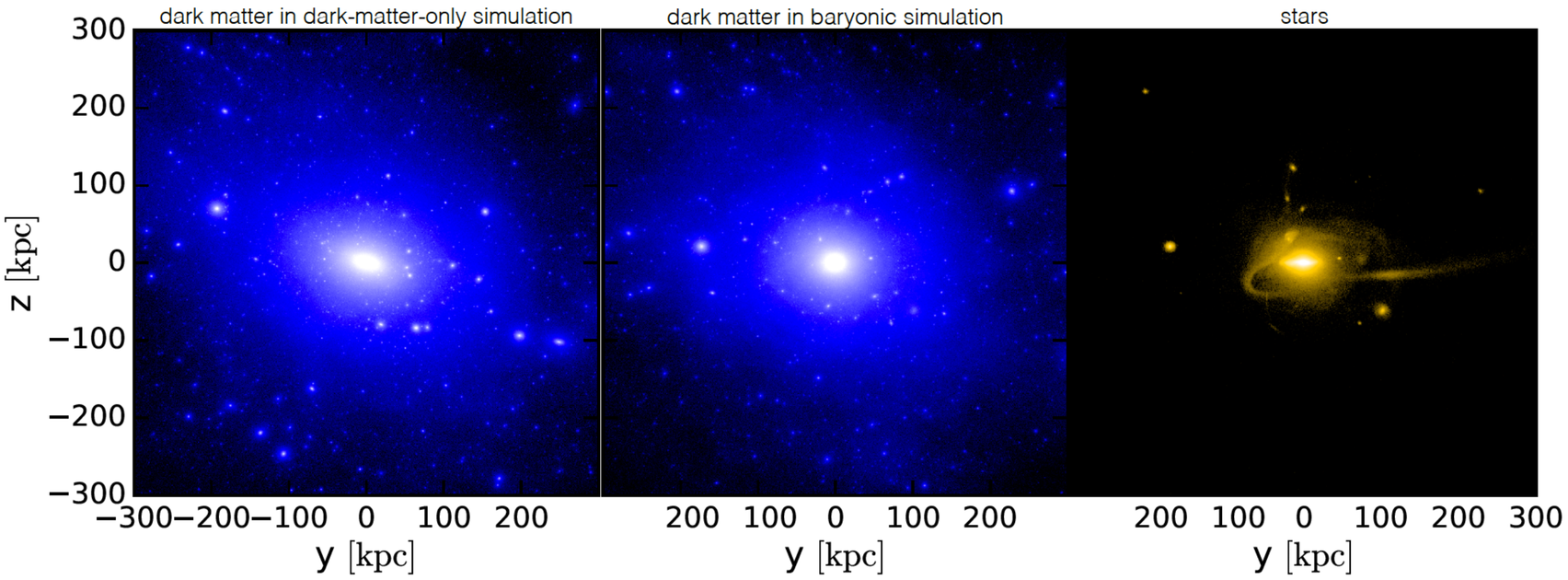
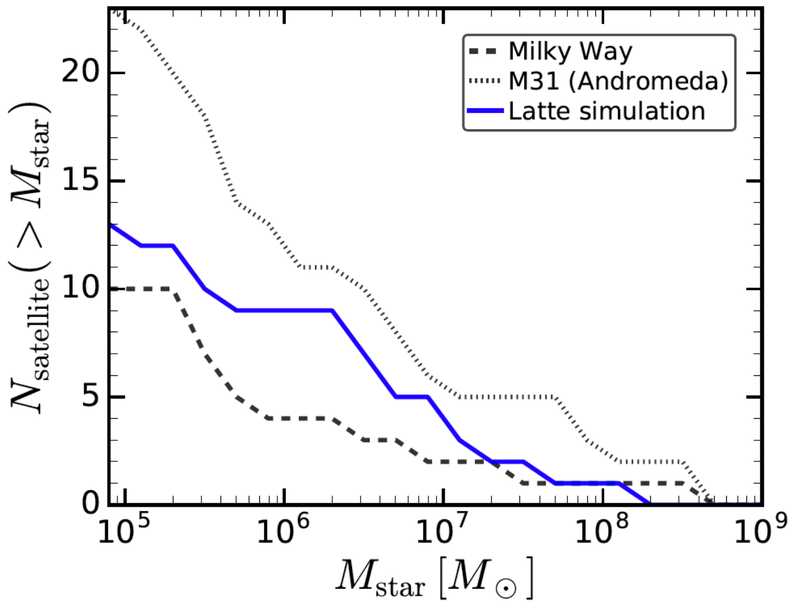
Simulating Milky Way Analogs

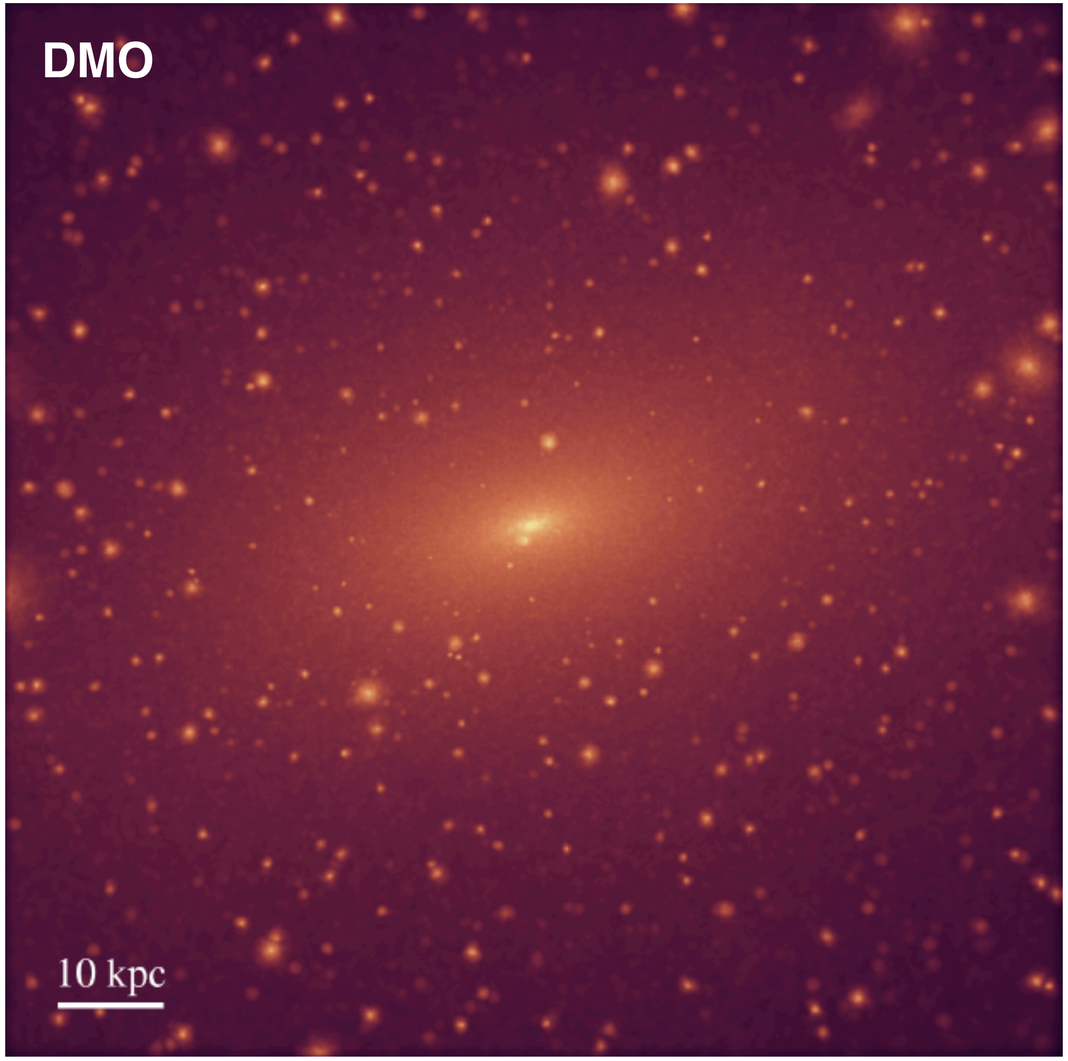
- High-resolution hydrodynamic zoom-in simulations produce “realistic” Milky Ways
- Star formation, stellar feedback, photo-ionization models …
- Classical satellite luminosity functions consistent with MW/M31

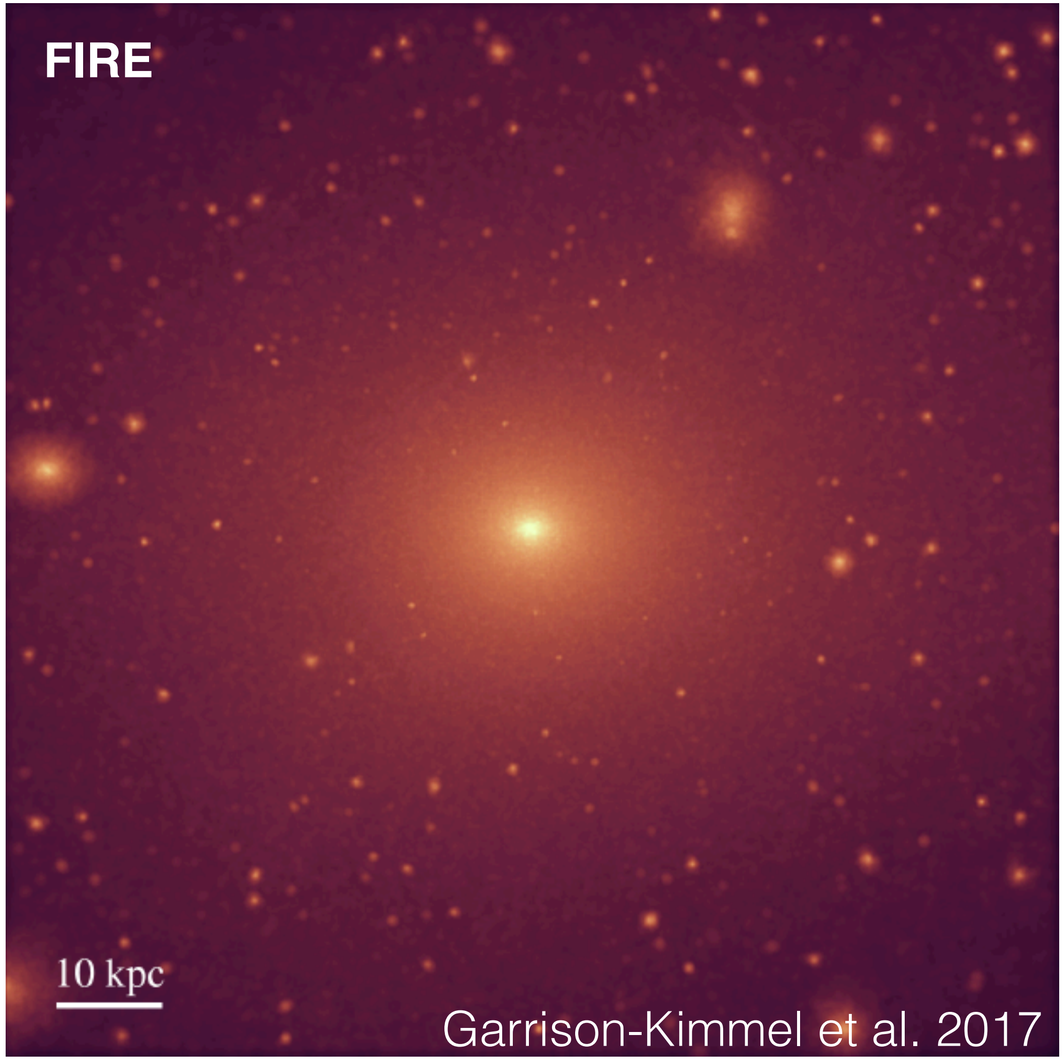


Wetzel et al. 2016



Subhalo Disruption

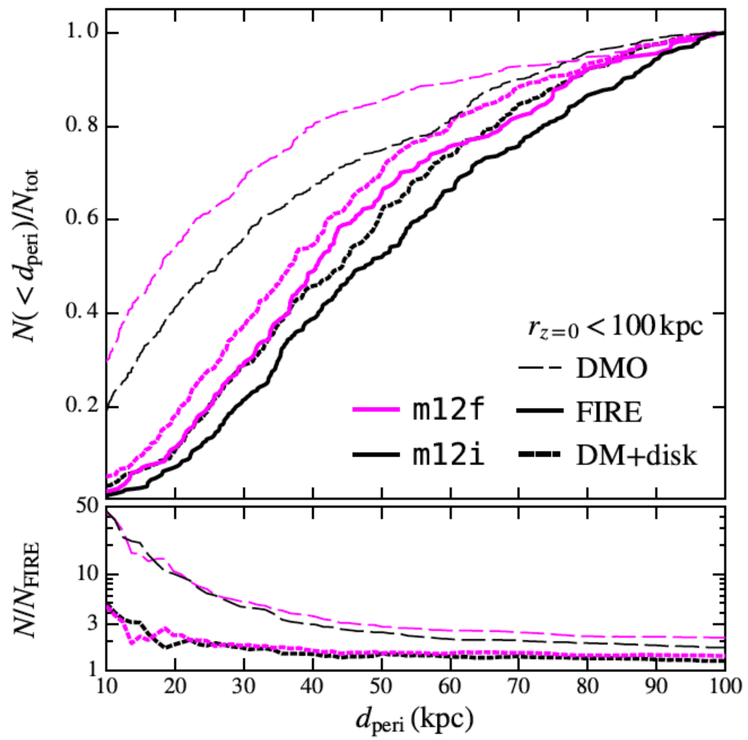


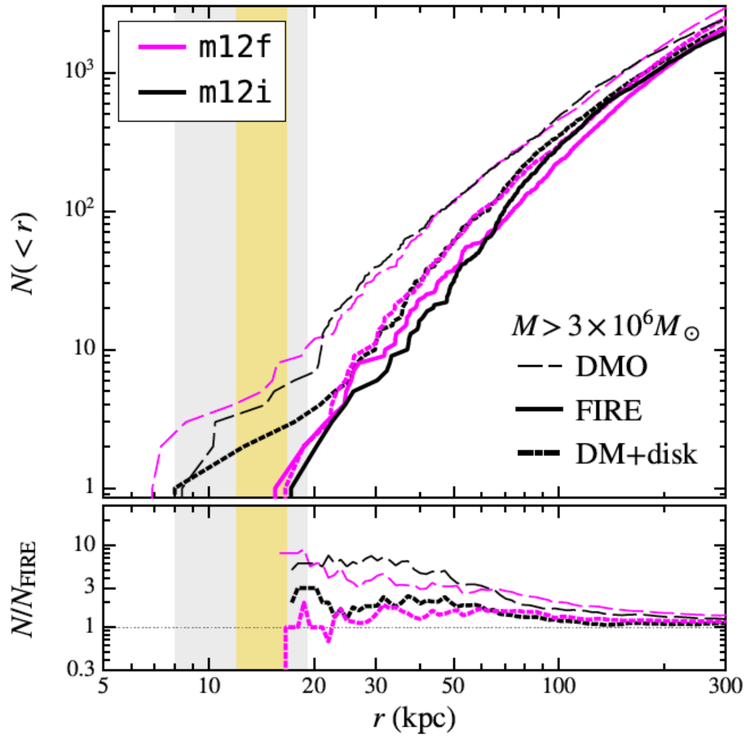


Garrison-Kimmel et al. 2017

Subhalo Disruption: Implications

- Significant reduction in number of surviving subhalos within 50 kpc of galactic disk
- Implications: stellar streams, lensing anomalies, satellite completeness corrections





Garrison-Kimmel et al. 2017

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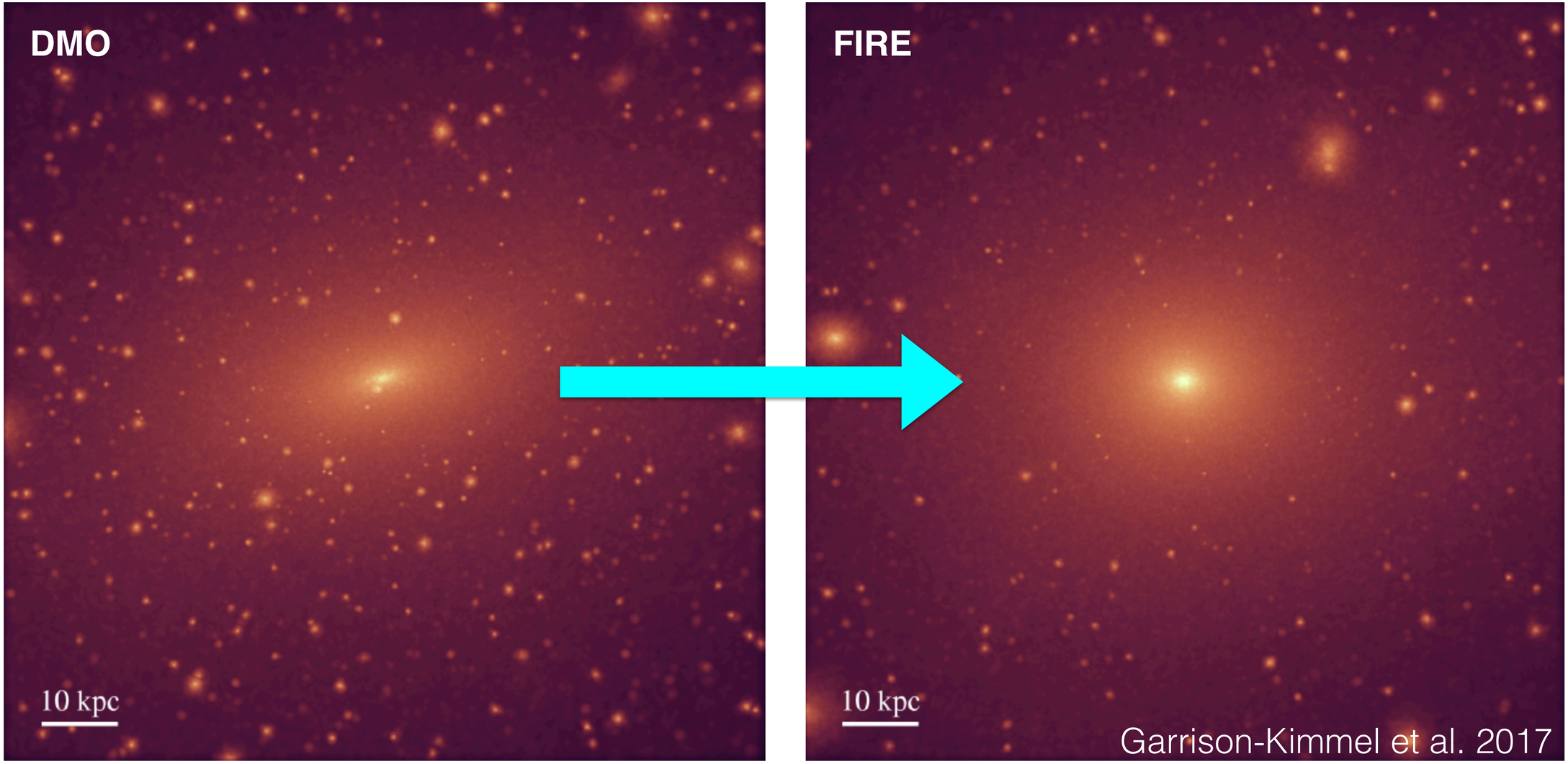
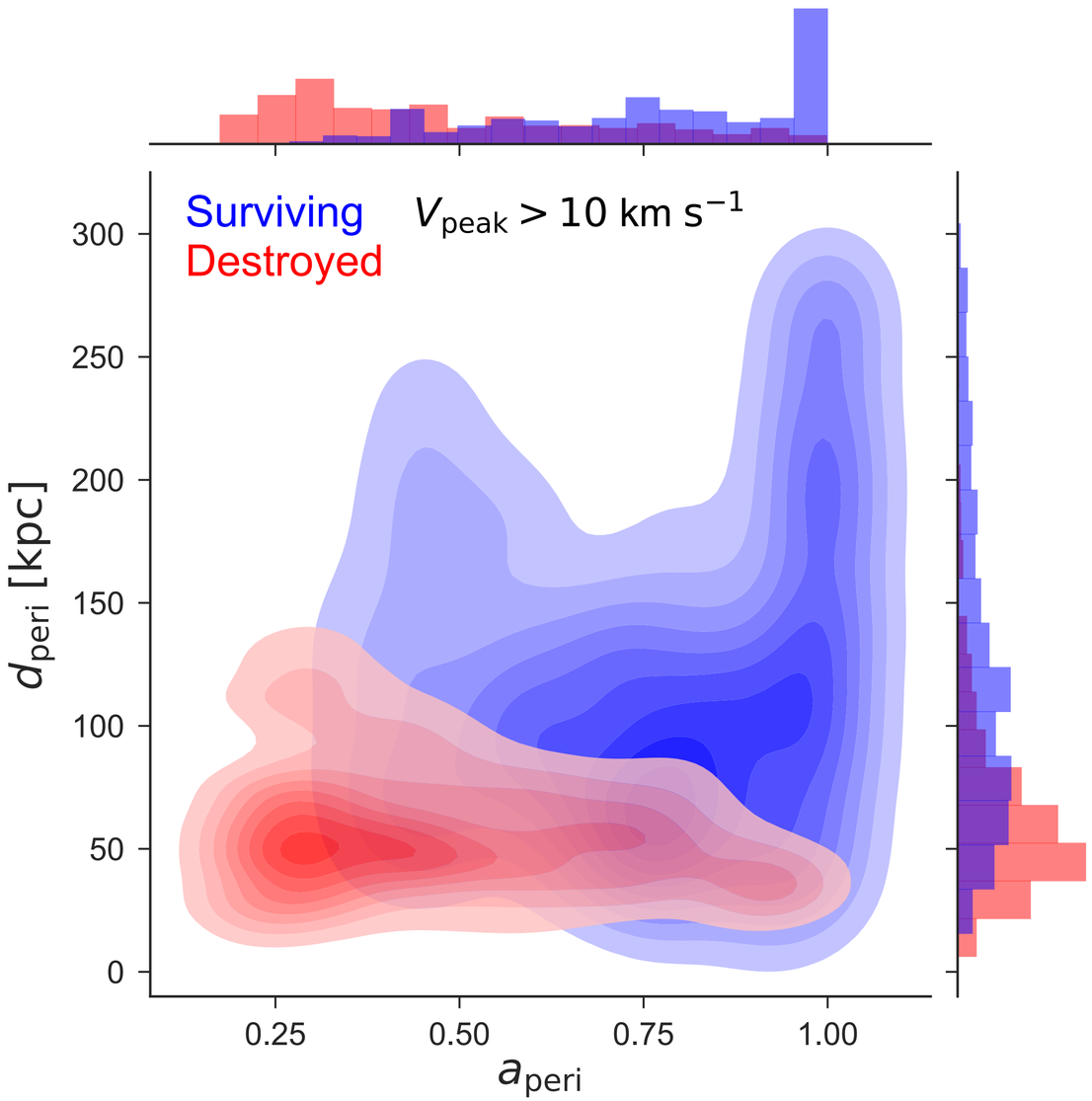
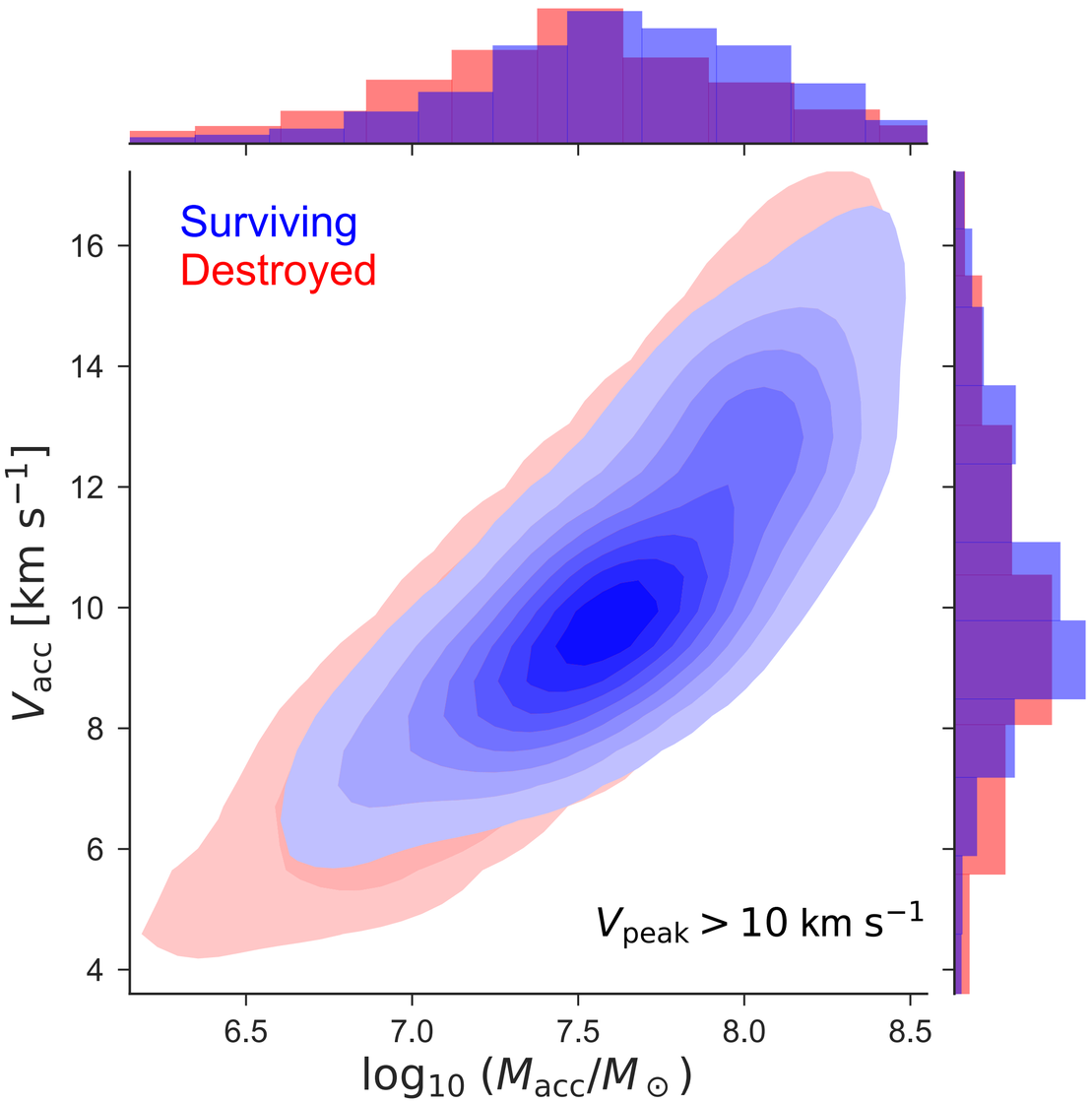
Constructing Subhalo Populations



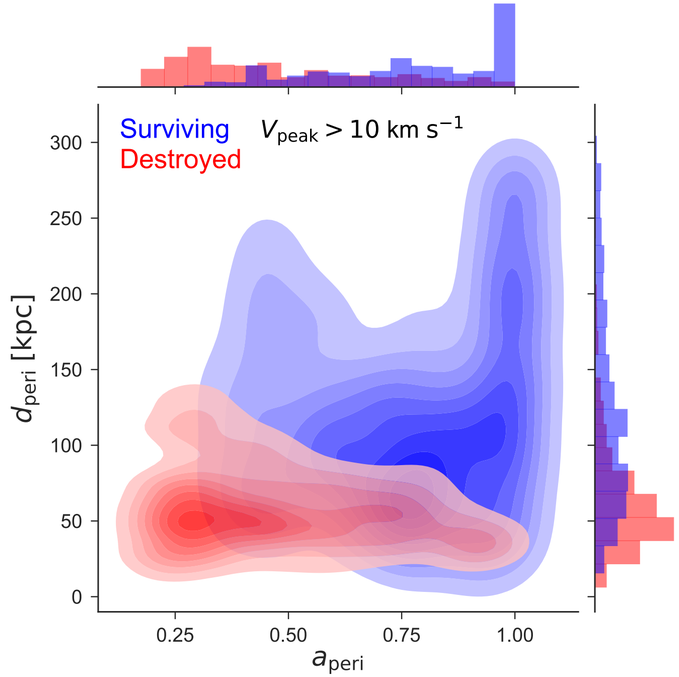


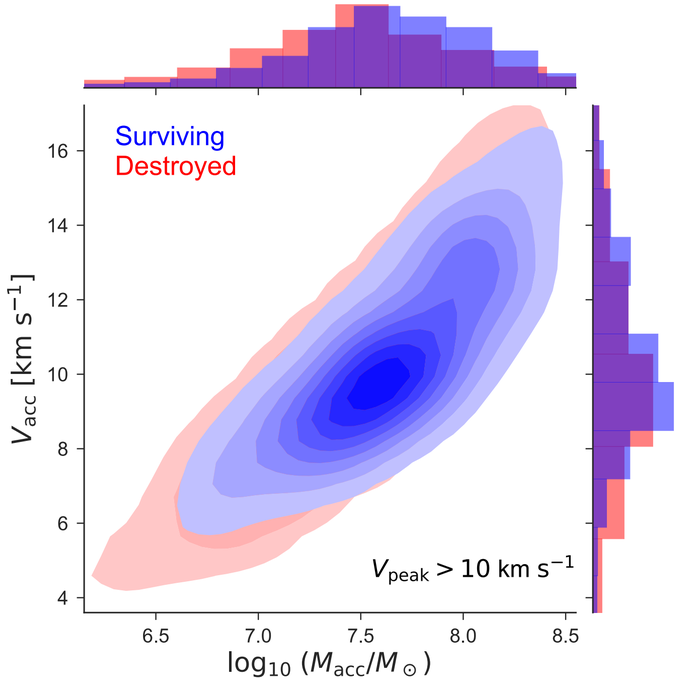


Nadler et al. 2017

Random Forest Classification

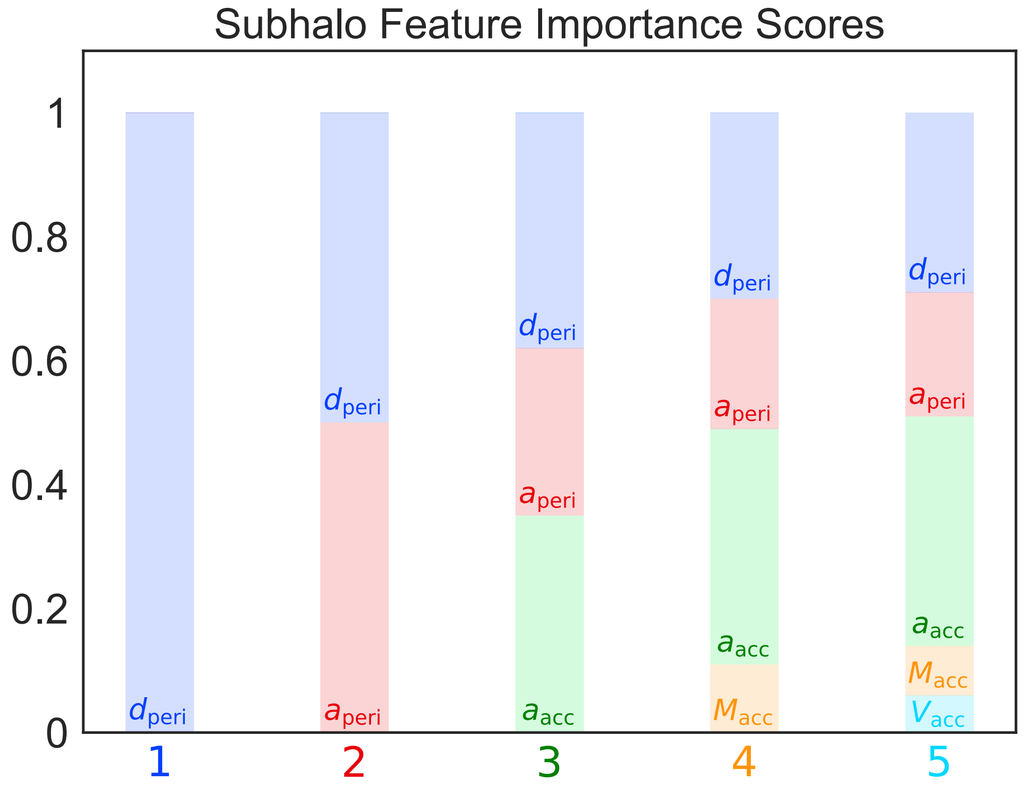
Decision trees classify disrupted/surviving subhalos

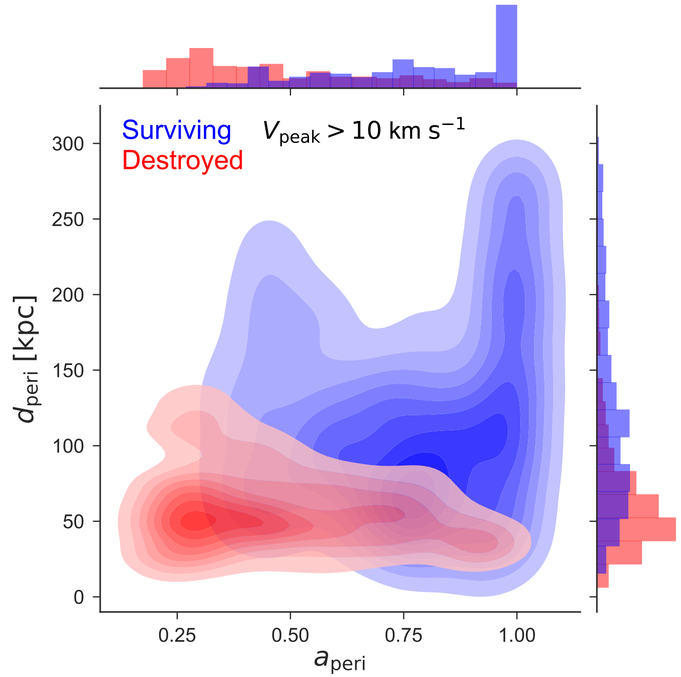


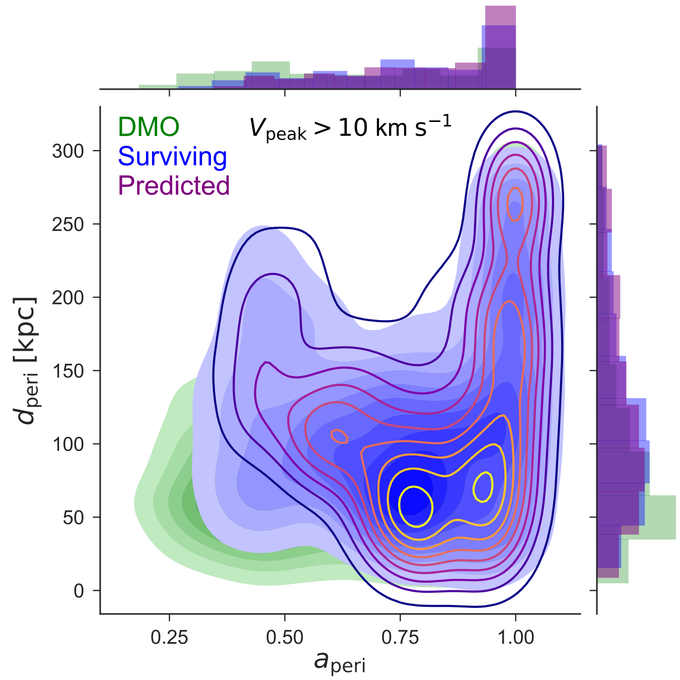


Random Forest Classification

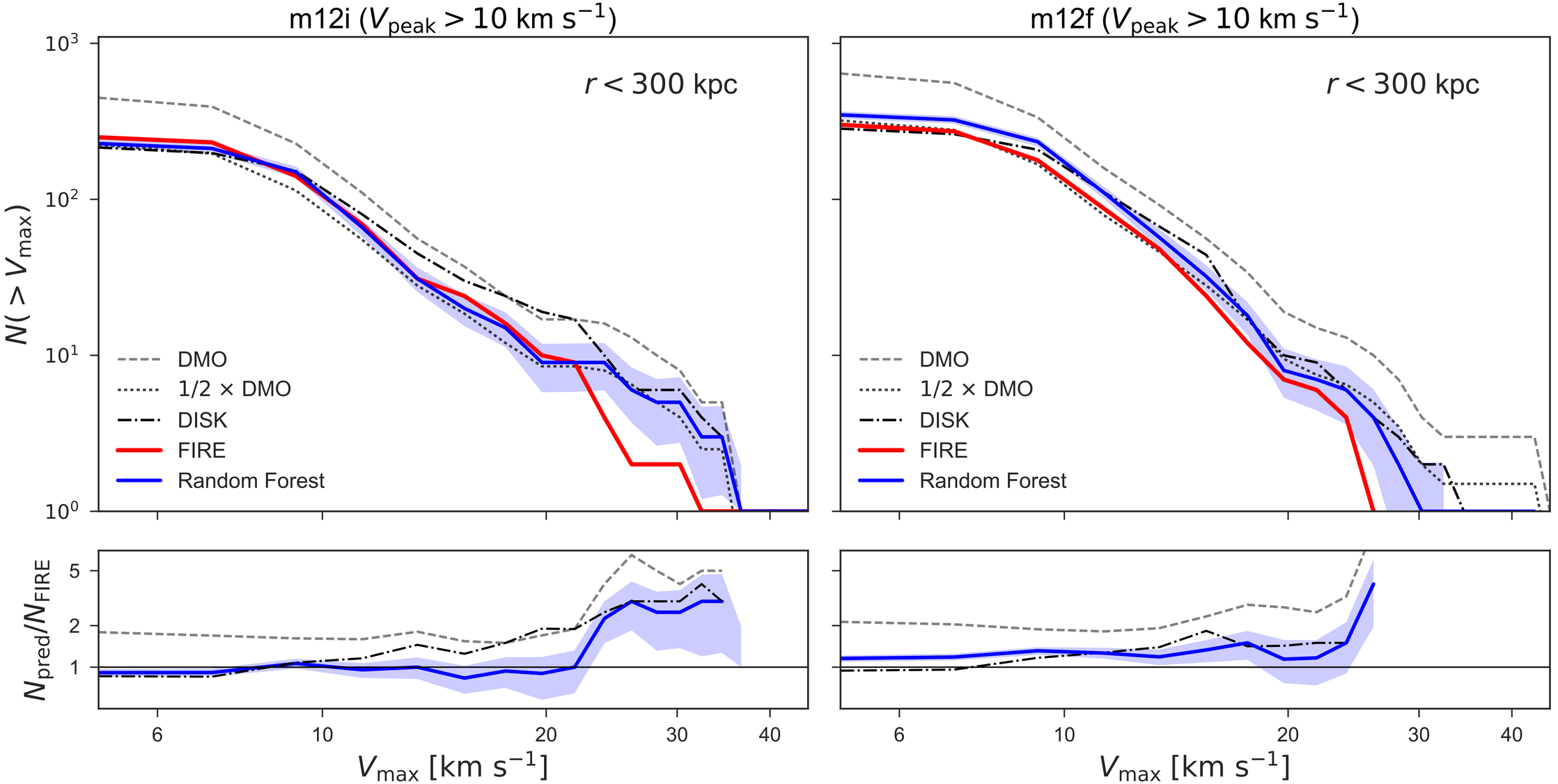
- Five subhalo features encode ~90% of disruption
- Predicted subhalo properties consistent with FIRE



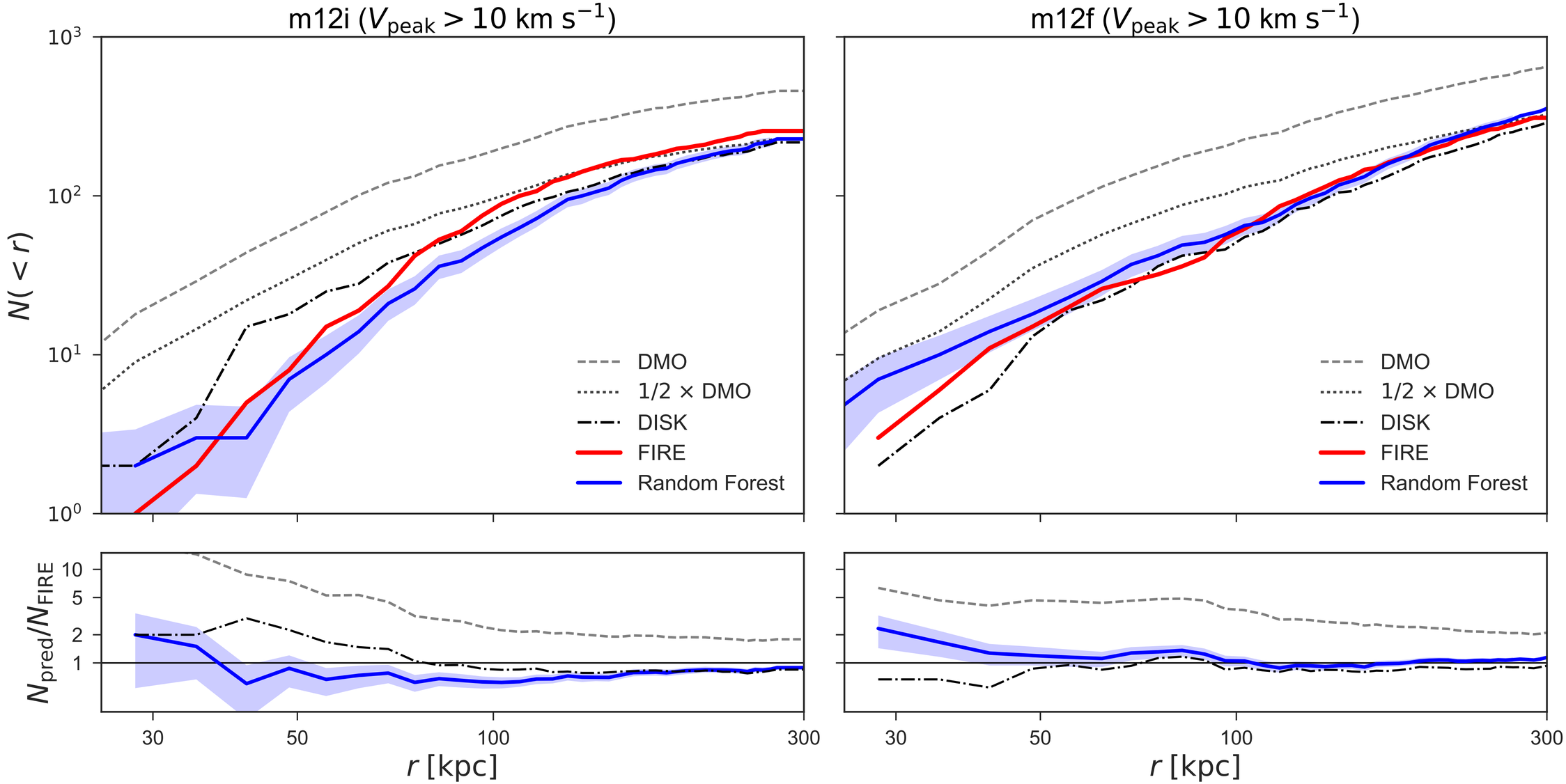




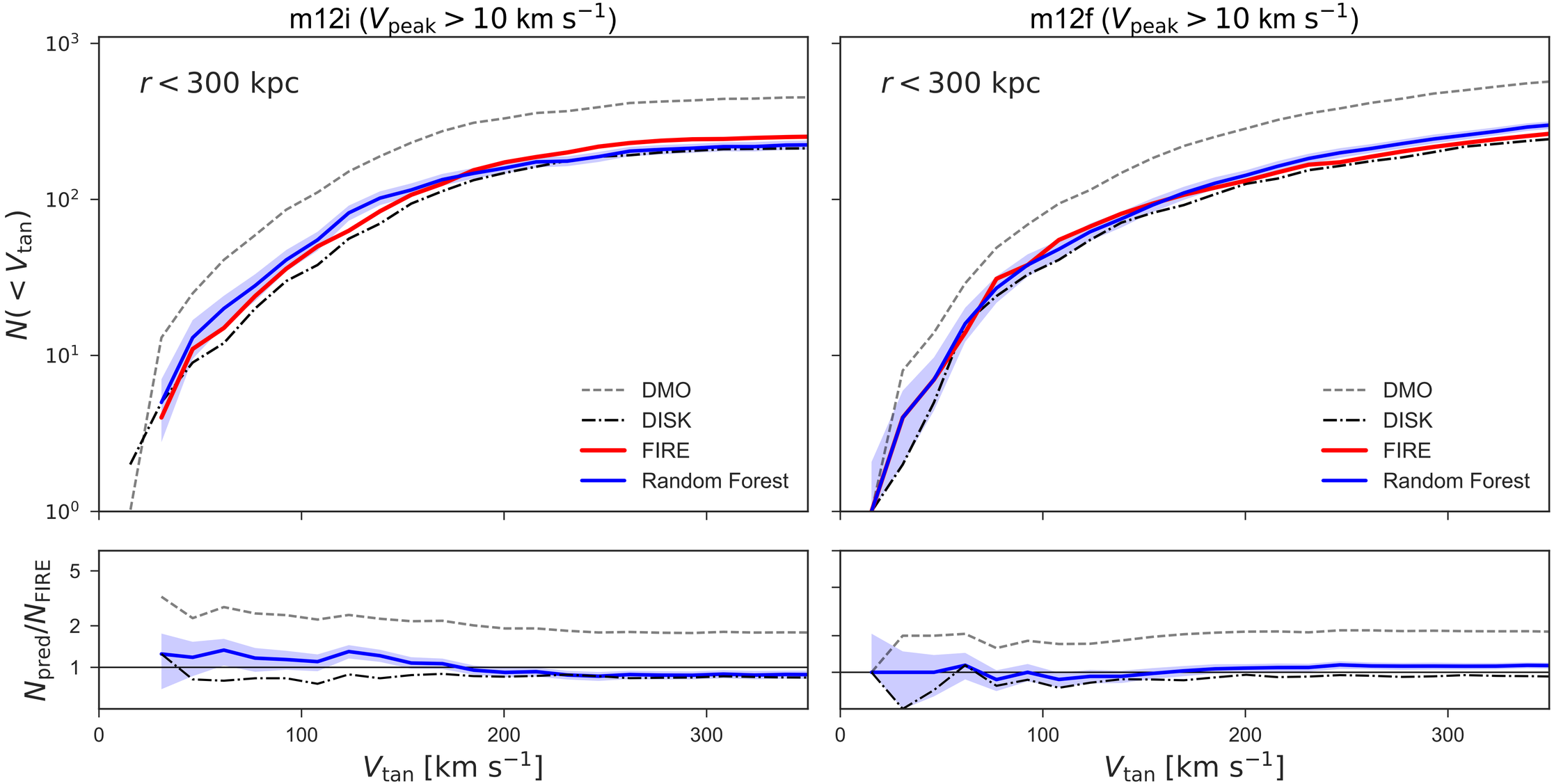
Velocity Functions



Radial Distributions

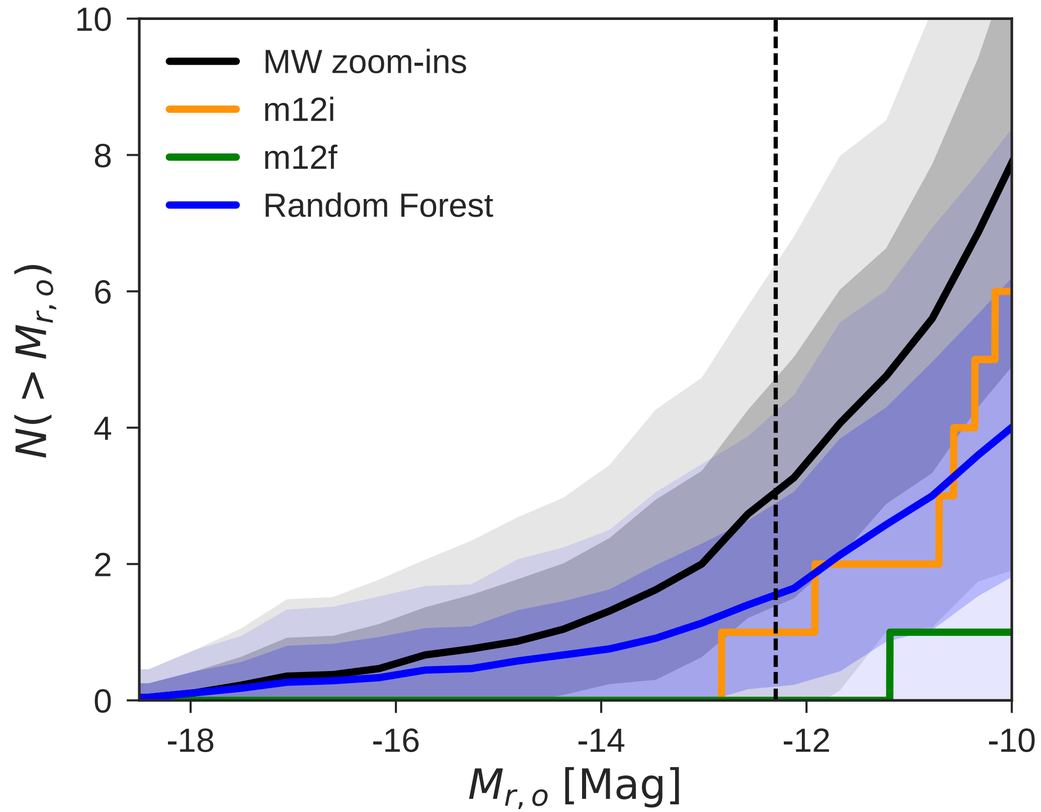


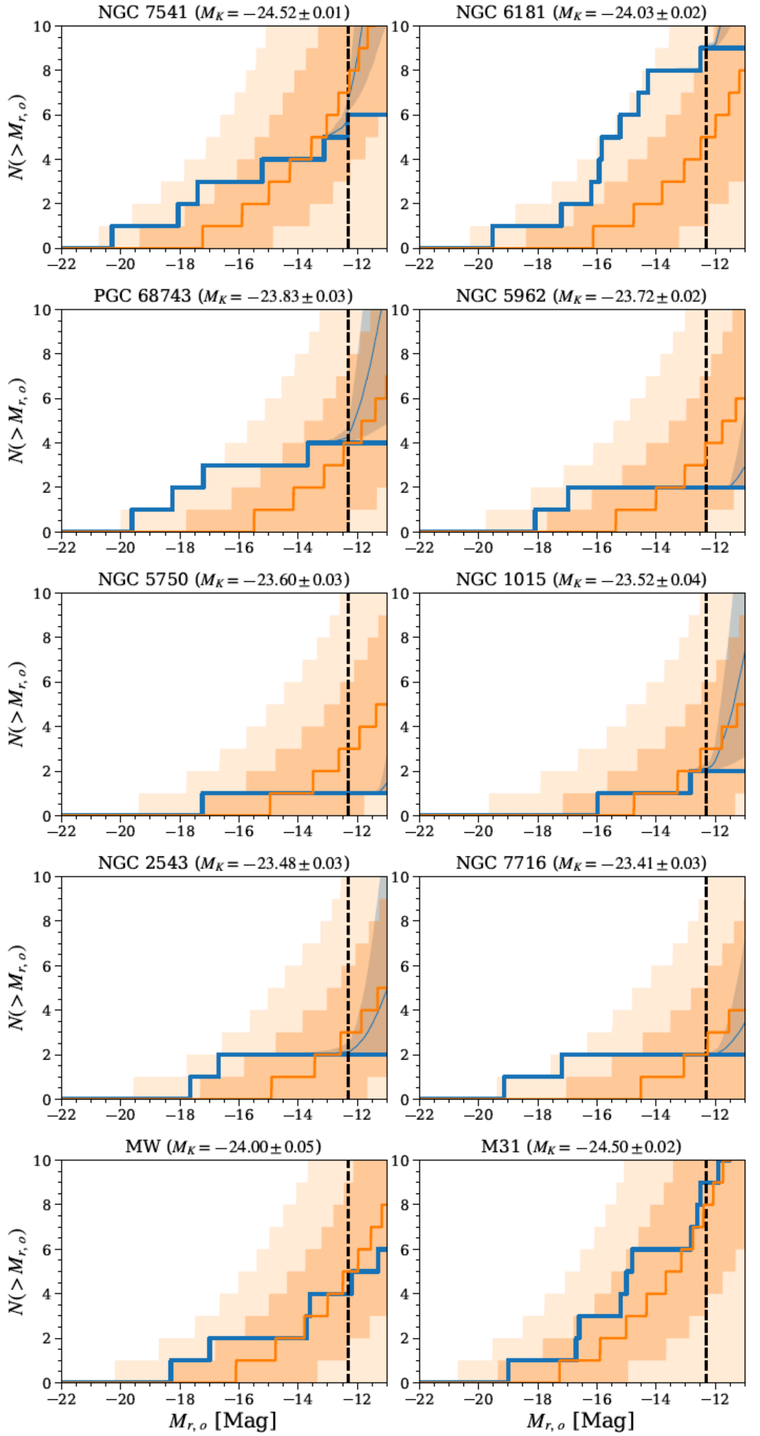
Orbital Velocity Distributions



Modeling Milky Way Analogs

- Generalize for different host halo masses
- Use to model SAGA systems (Geha et al. 2017)





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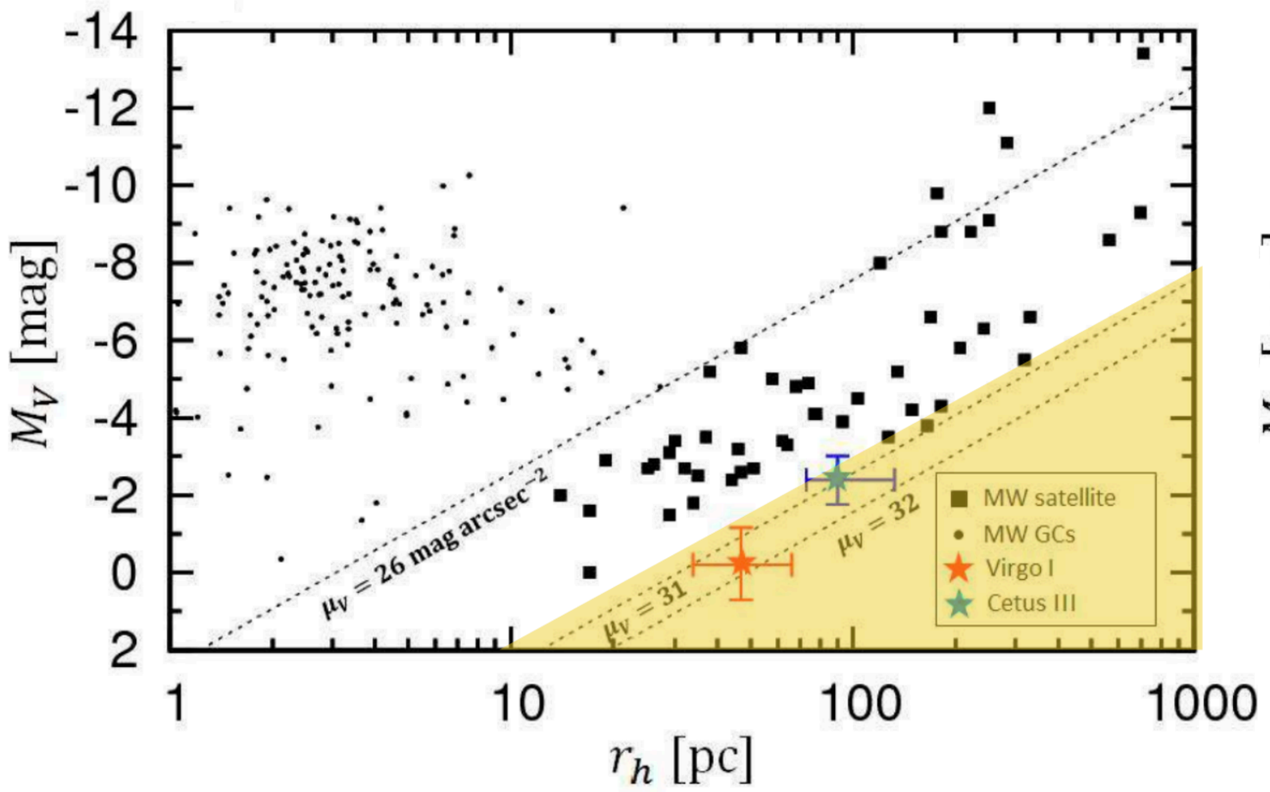
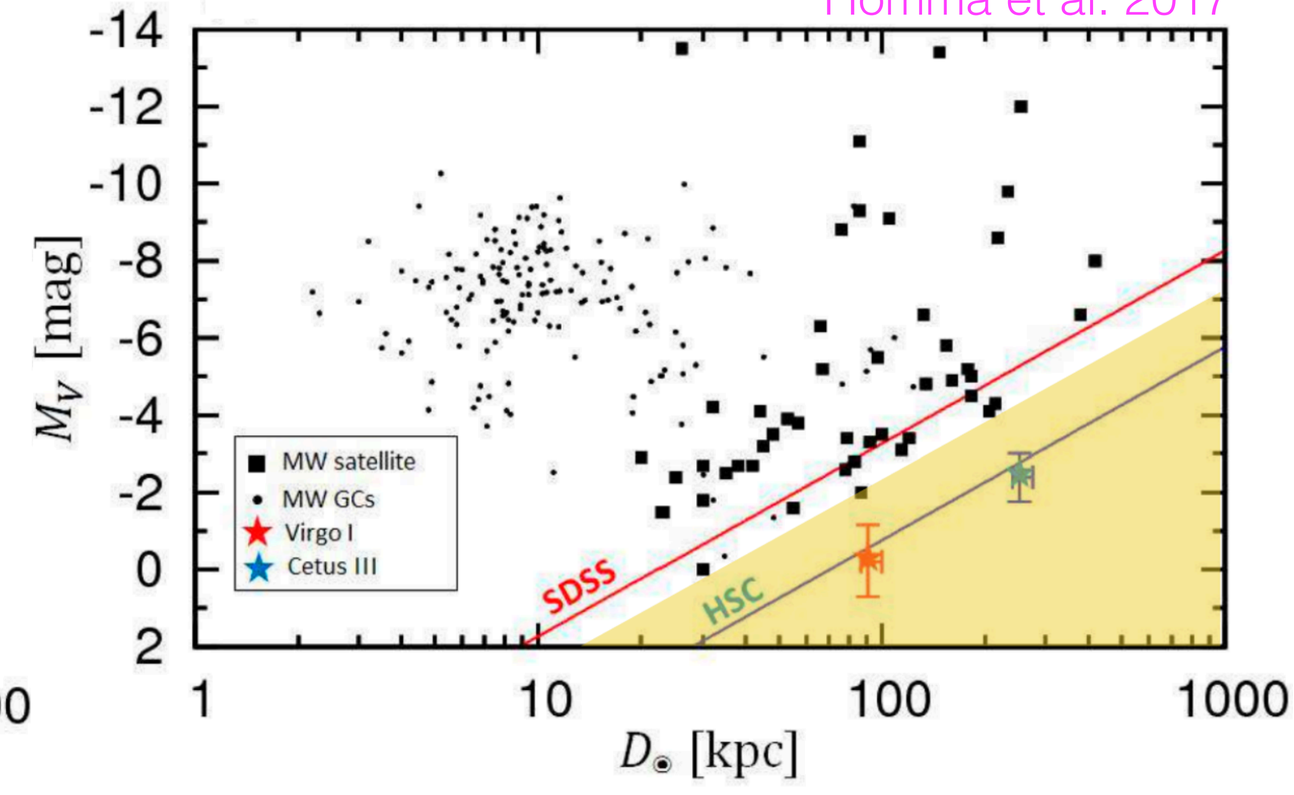
Modeling Milky Way Satellites

Homma et al. 2017





How do the MW satellite luminosity function, radial distribution, and **size** distribution constrain the low-mass galaxy-halo connection?

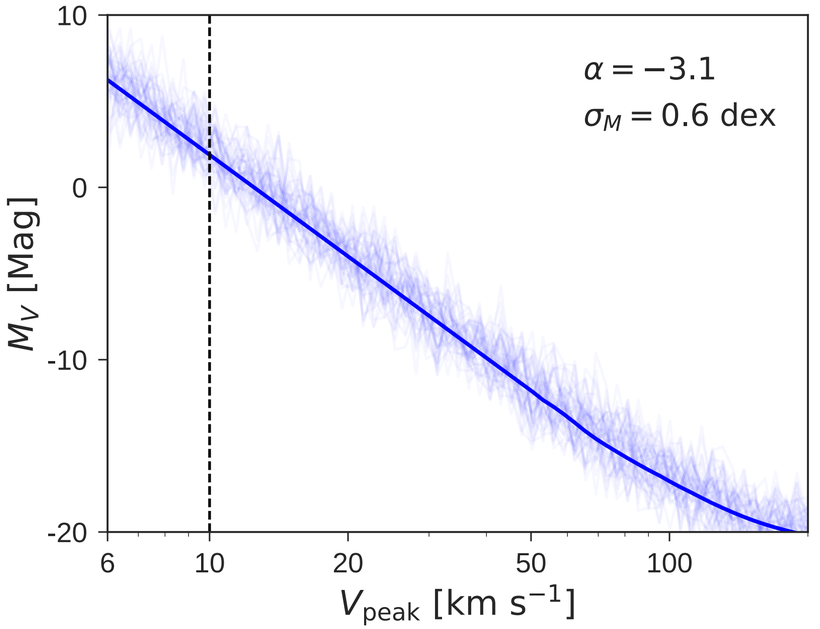
Model Building: Luminosities

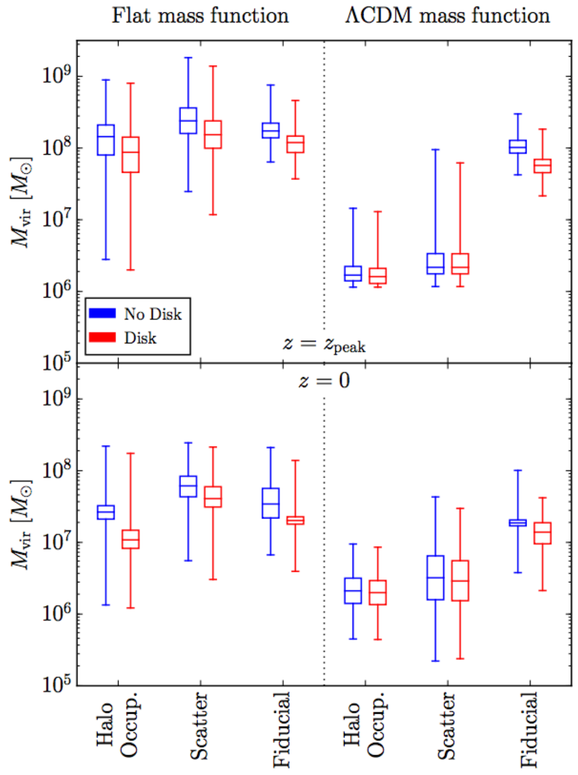
- Abundance match to GAMA luminosity function (measured down to $M_r \sim -12$)
- Parameters: abundance matching slope, scatter, galaxy formation threshold

α : abundance matching slope

σ_M : abundance matching scatter

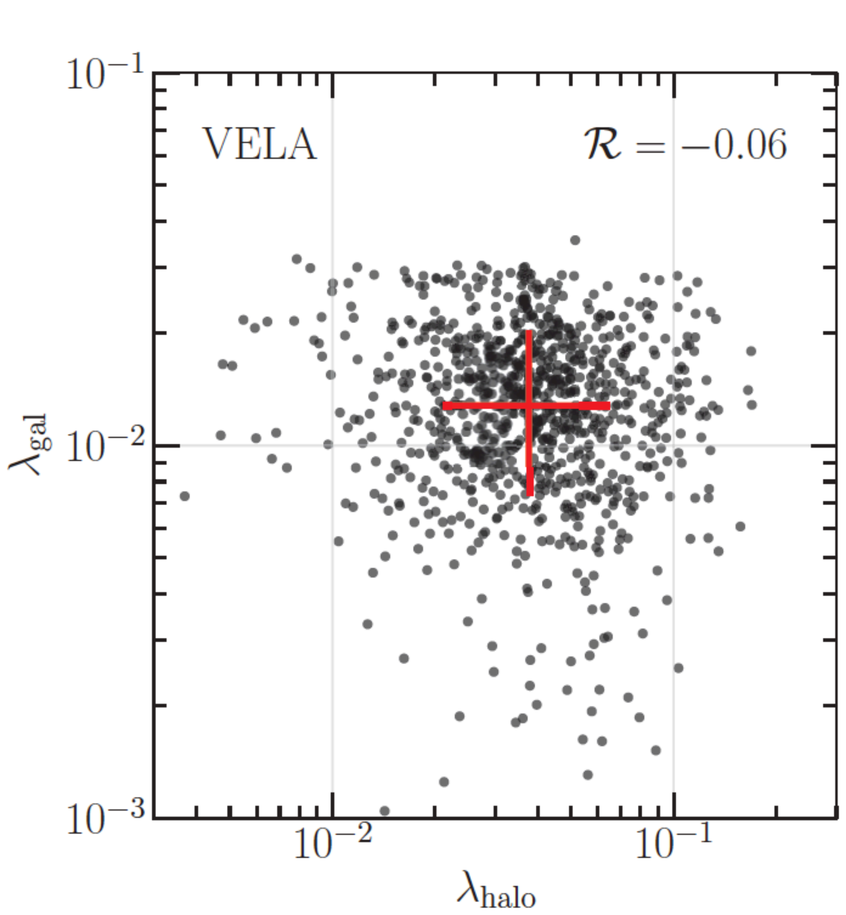
$\mathcal{M}_{\rm min}$: peak subhalo mass threshold

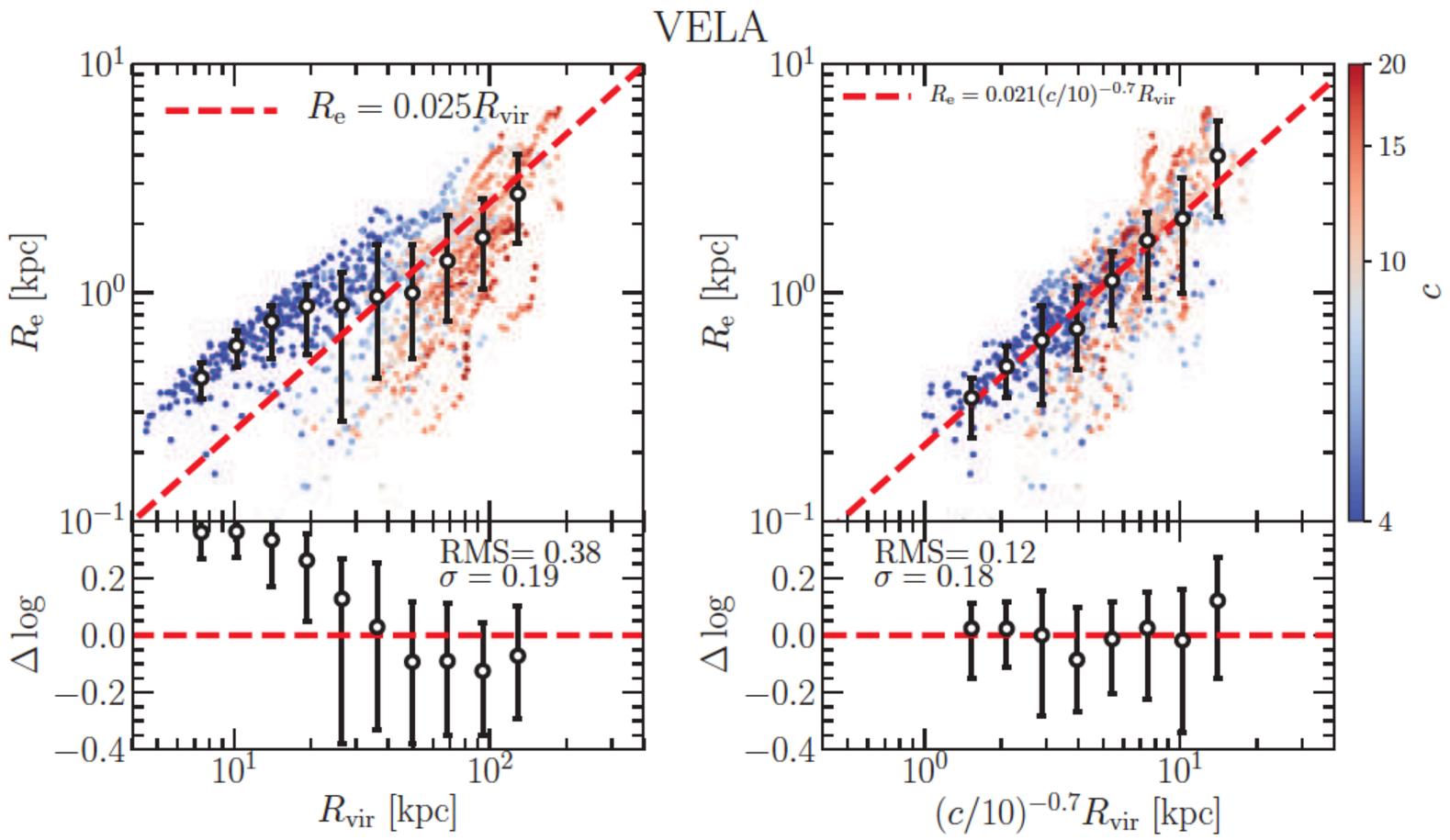




Jethwa et al. 2018

Model Building: Sizes





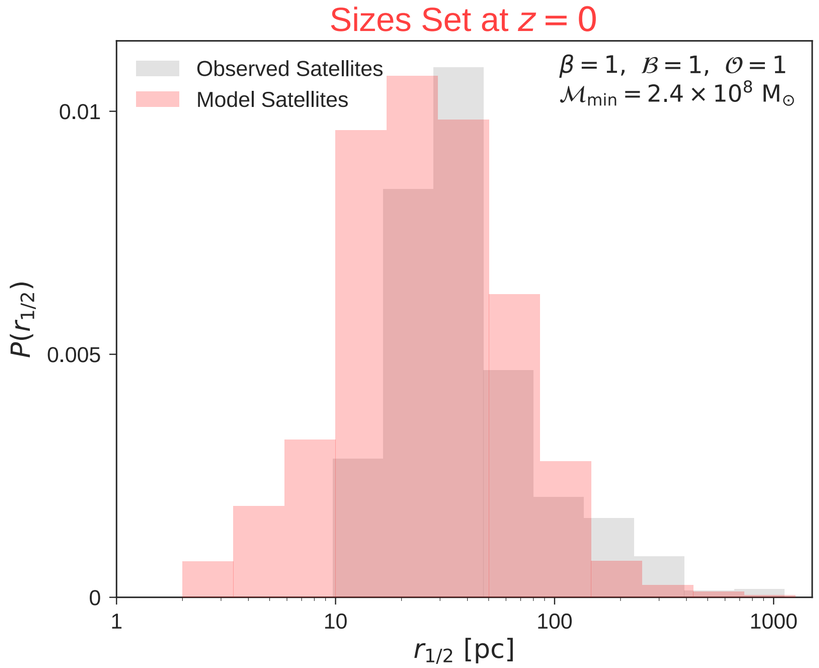
Jiang et al. 2018

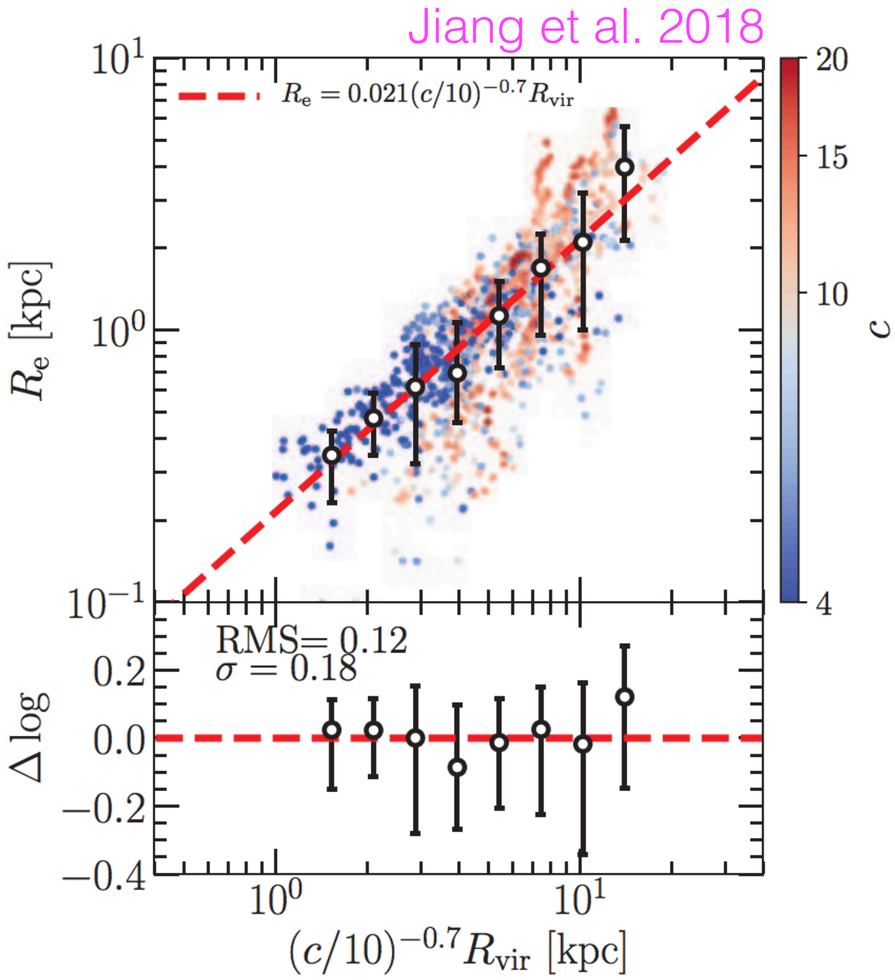
Model Building: Sizes

- Does the tight relationship between galaxy size and halo size hold for ultra-faint dwarf satellites?
- Parameters: accretion vs. present-day size, scatter

$$\beta : R_{\rm vir,acc}\left(\frac{R_{\rm vir,0}}{R_{\rm vir,acc}}\right)^{\beta}$$

σ_R : size scatter



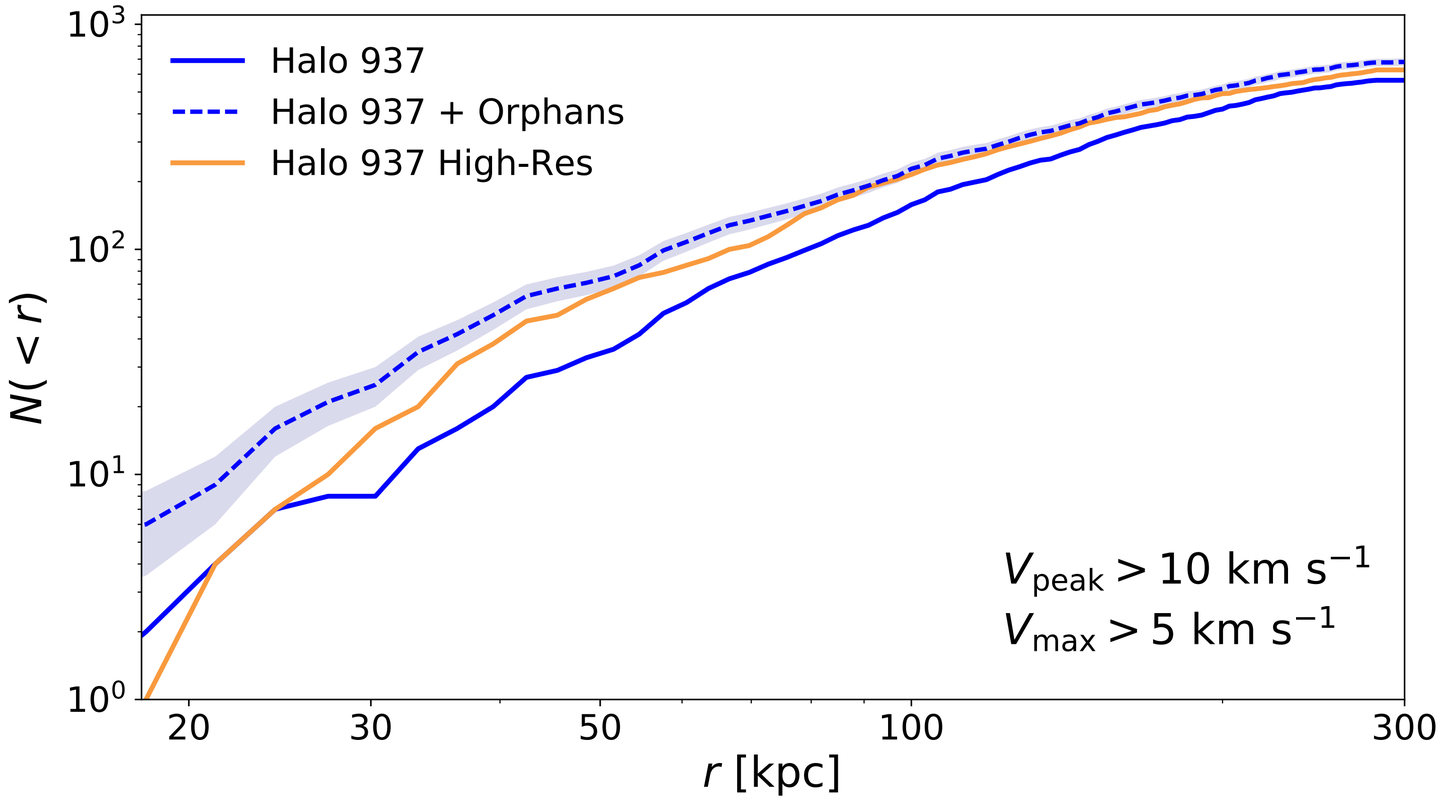


Model Building: Disruption & Orphans

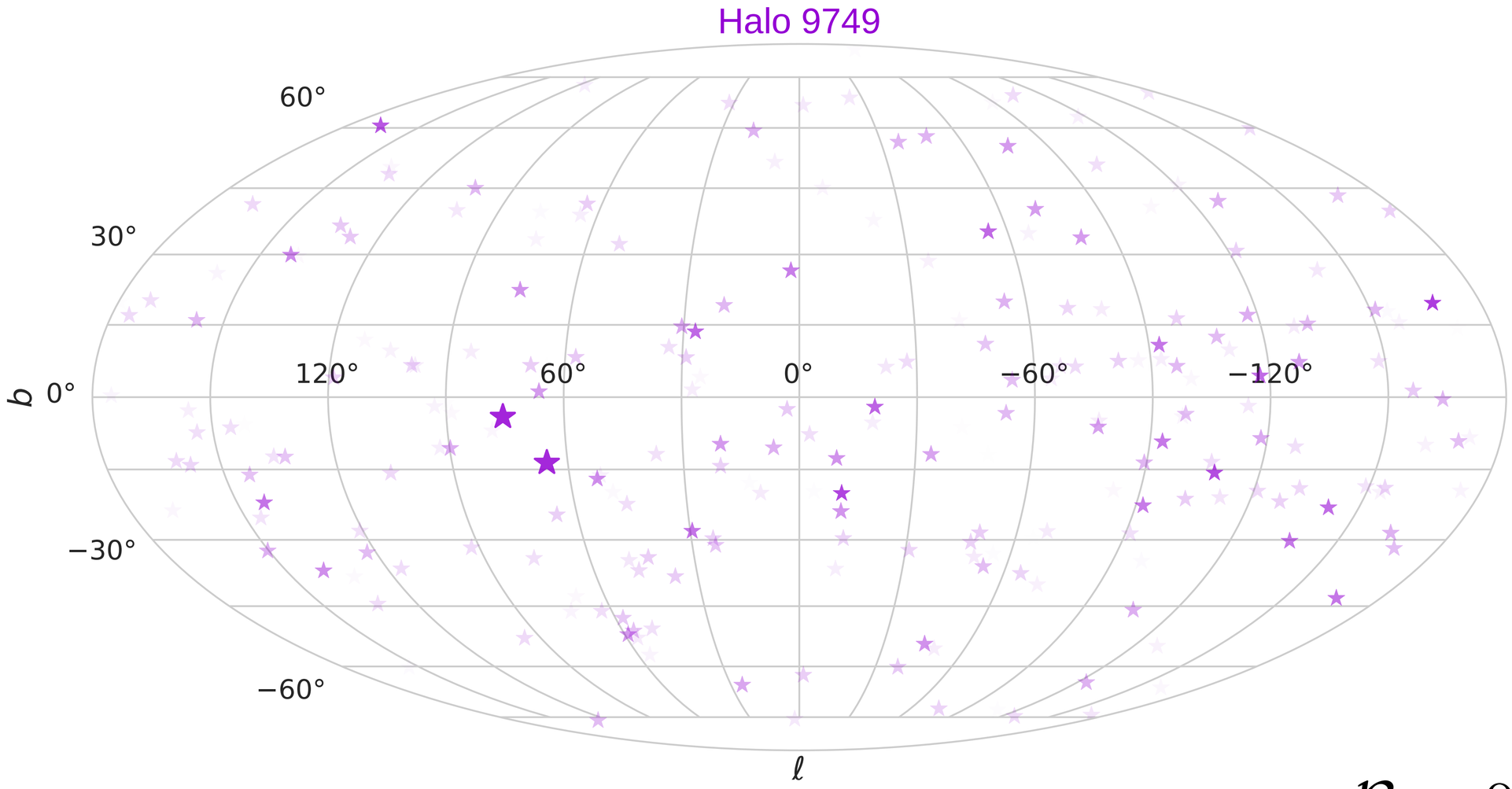
- Baryonic disruption: parameterize random forest disruption probability
- Orphans: track disrupted subhalos with dynamical friction, stripping models

$$\mathcal{B}: \; p_{\rm disrupt} \rightarrow p_{\rm disrupt}^{1/\mathcal{B}}$$

$$\mathcal{O}: p_{\rm disrupt} = (1 - V_{\rm max}/V_{\rm peak})^{\mathcal{O}}$$

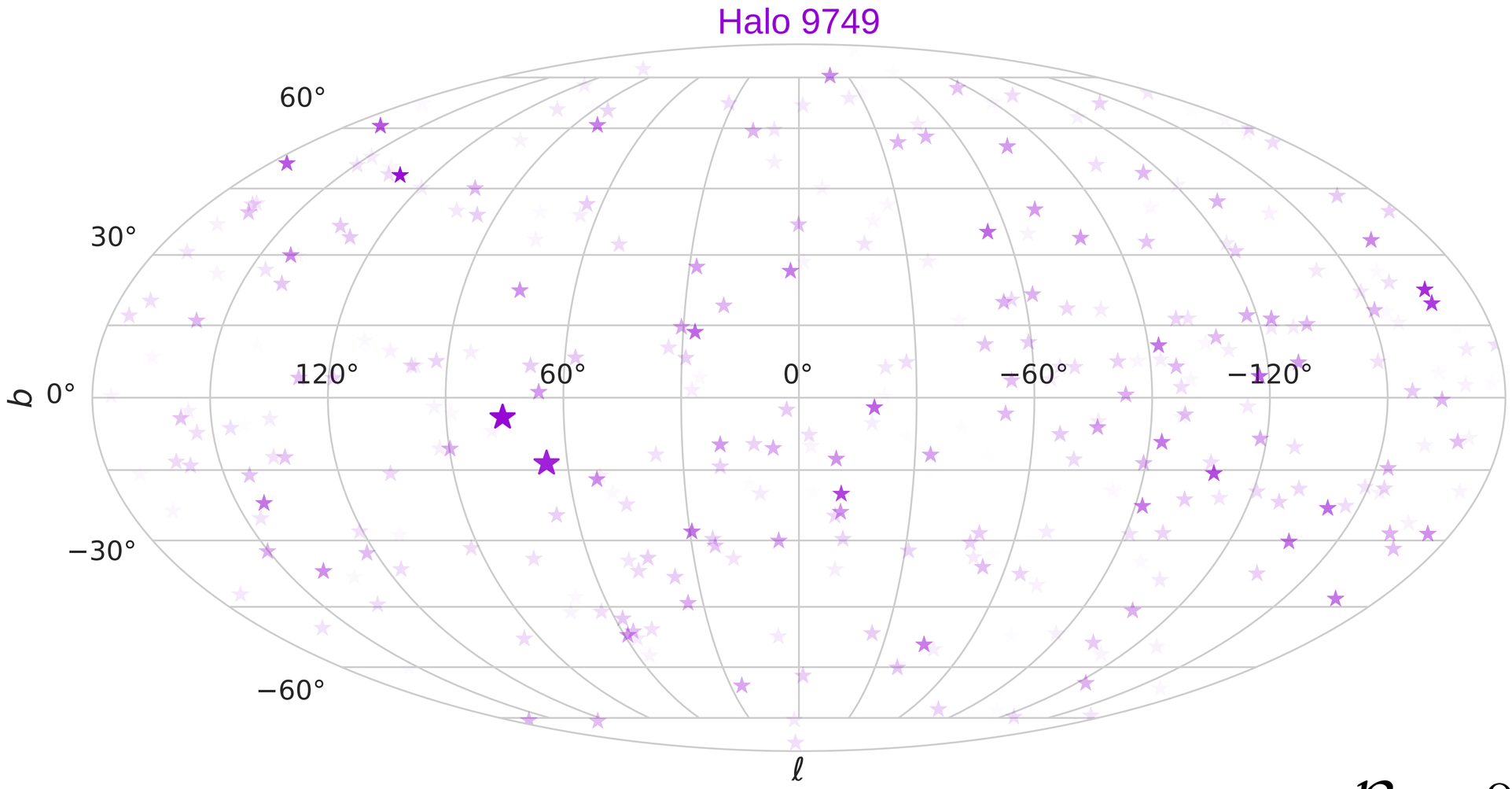


Satellite Distributions



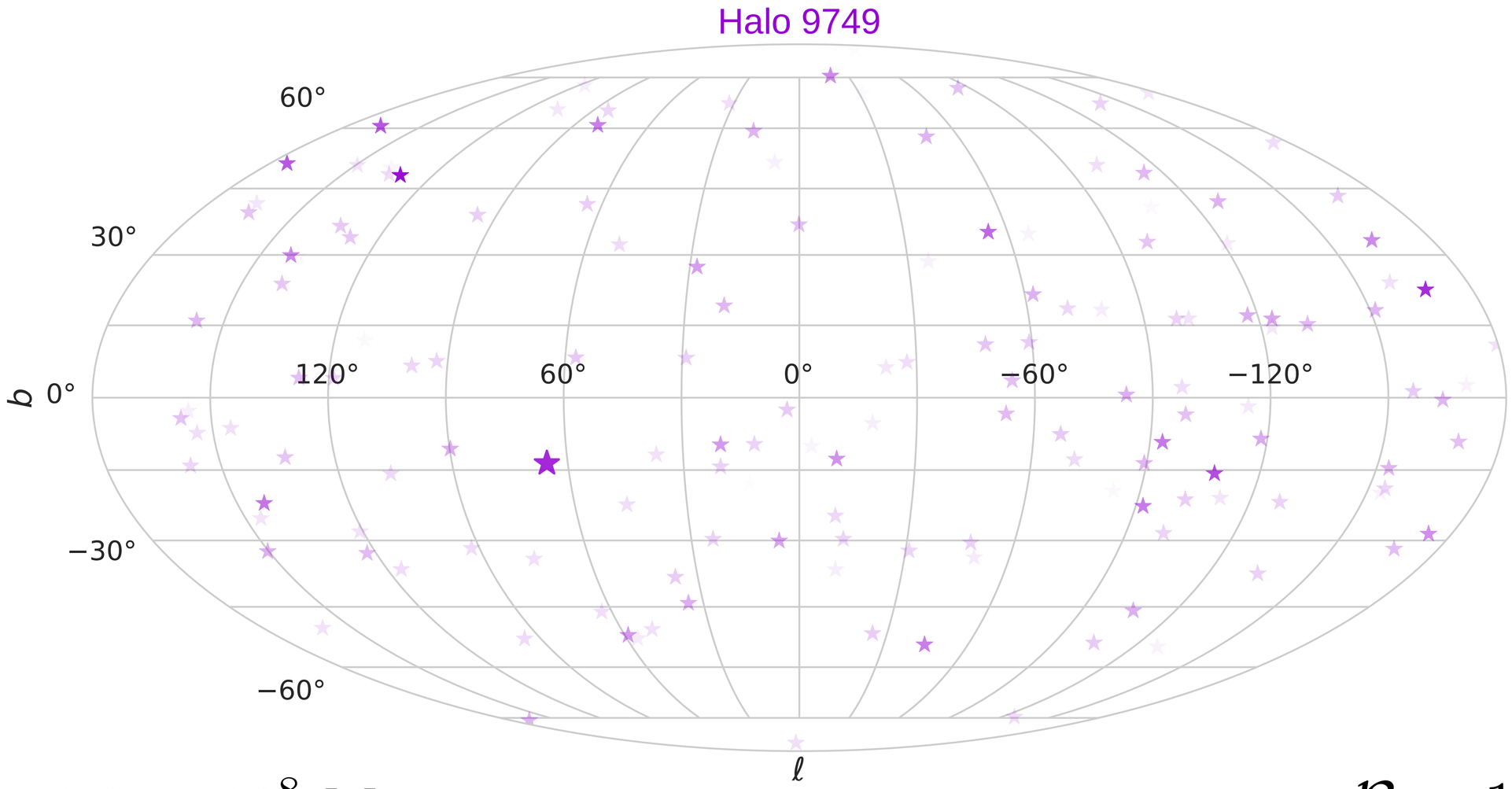
$\mathcal{B} = 0, \ \mathcal{O} = 0$

Satellite Distributions



$\mathcal{B} = 0, \ \mathcal{O} = 1$

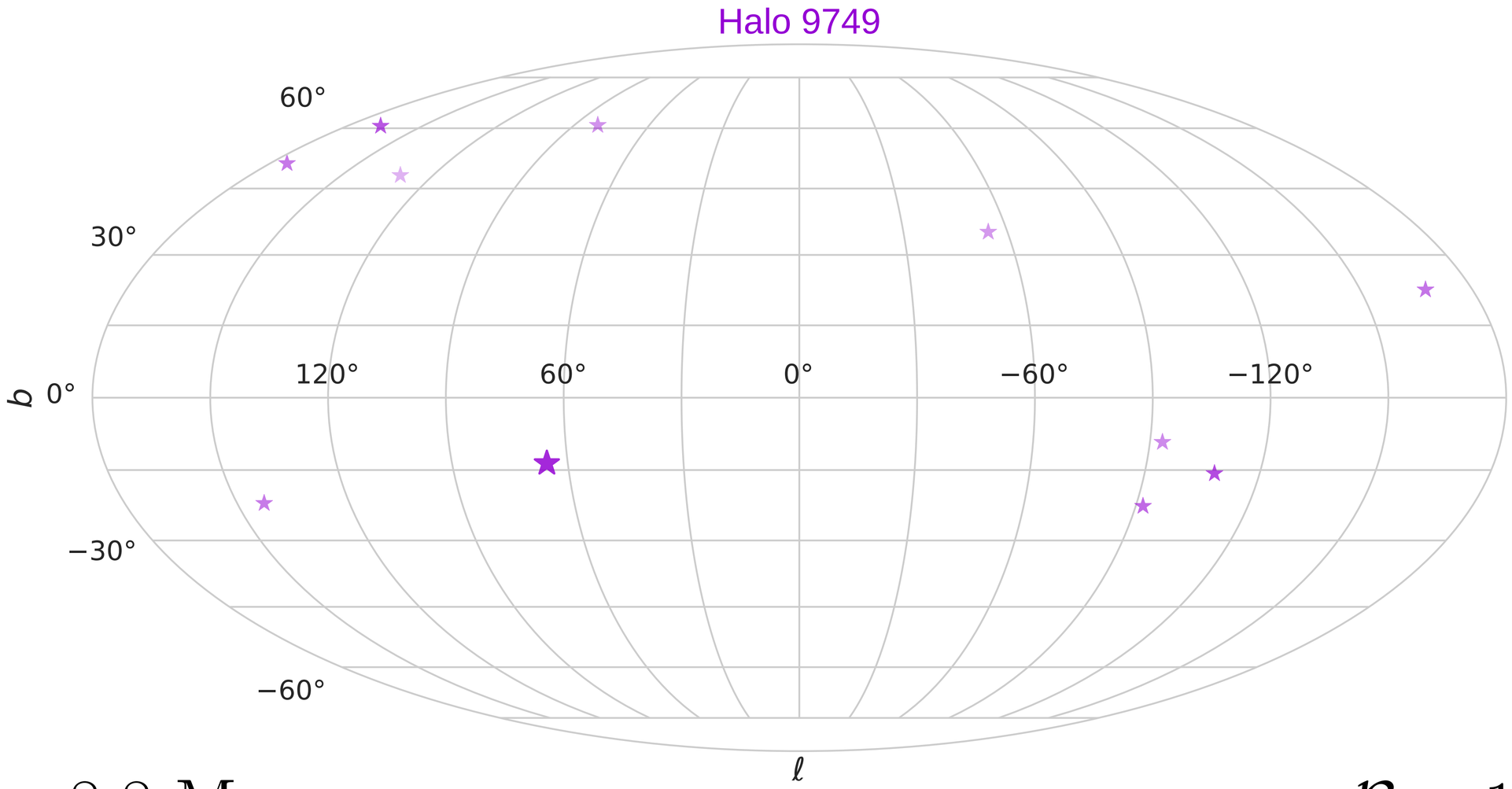
Satellite Distributions



$\mathcal{M}_{\rm min} = 1.0 \ \times 10^8 \ {\rm M}_\odot$

$\mathcal{B} = 1, \ \mathcal{O} = 1$

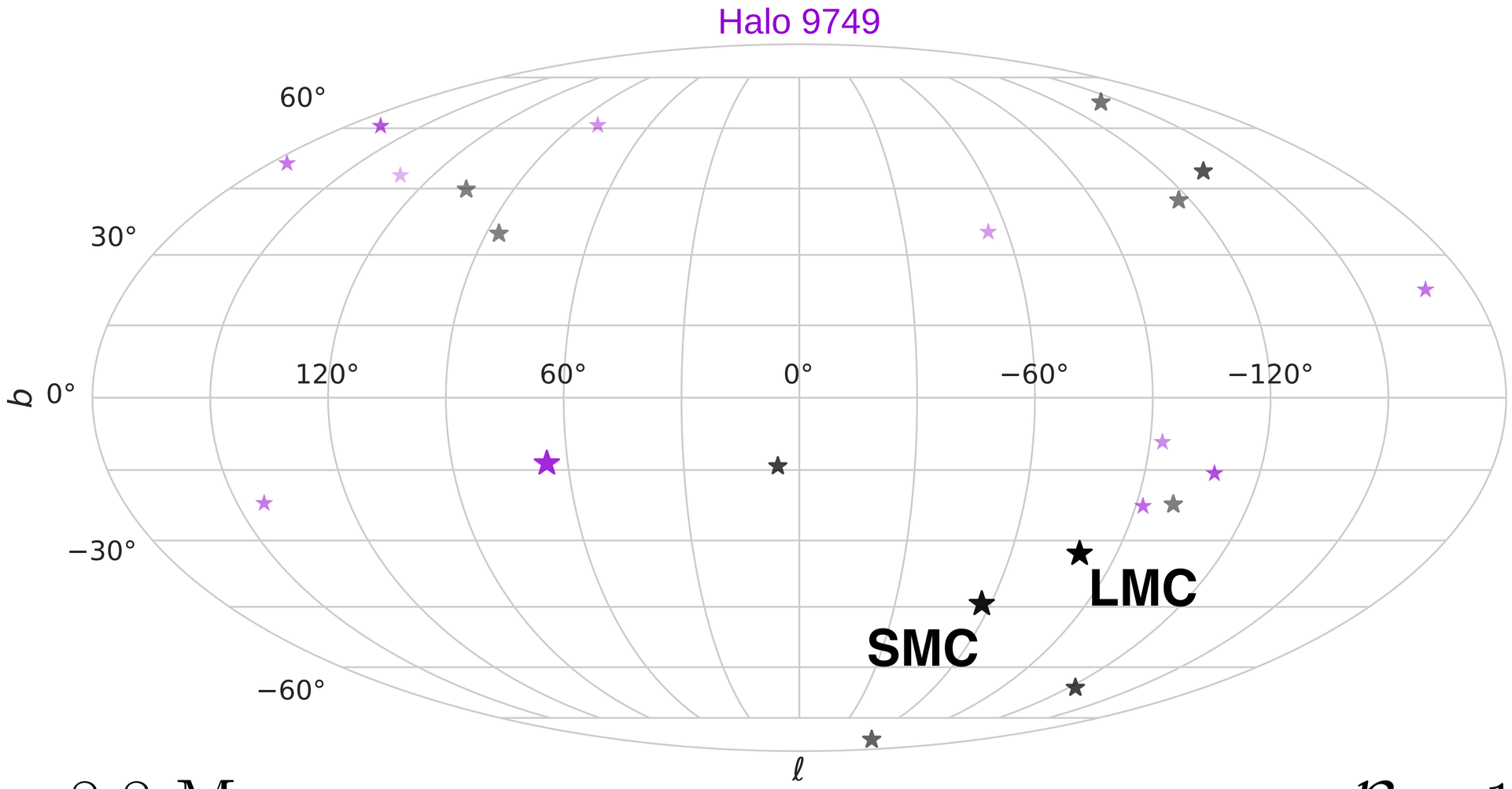
Classical Satellite Distributions



$M_V \leq -8.8$ Mag

$\mathcal{B} = 1,\ \mathcal{O} = 1$

Classical Satellite Distributions



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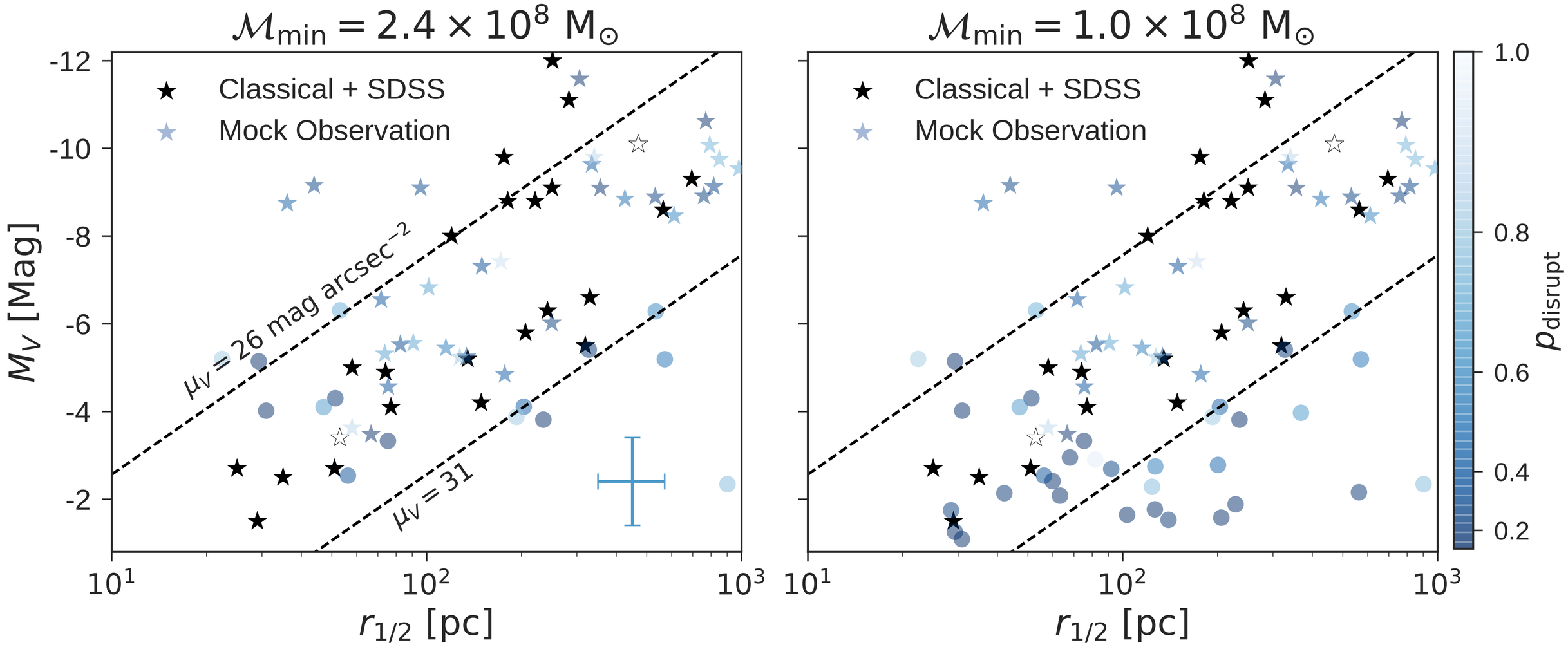
Mock Observations of Milky Way Satellites



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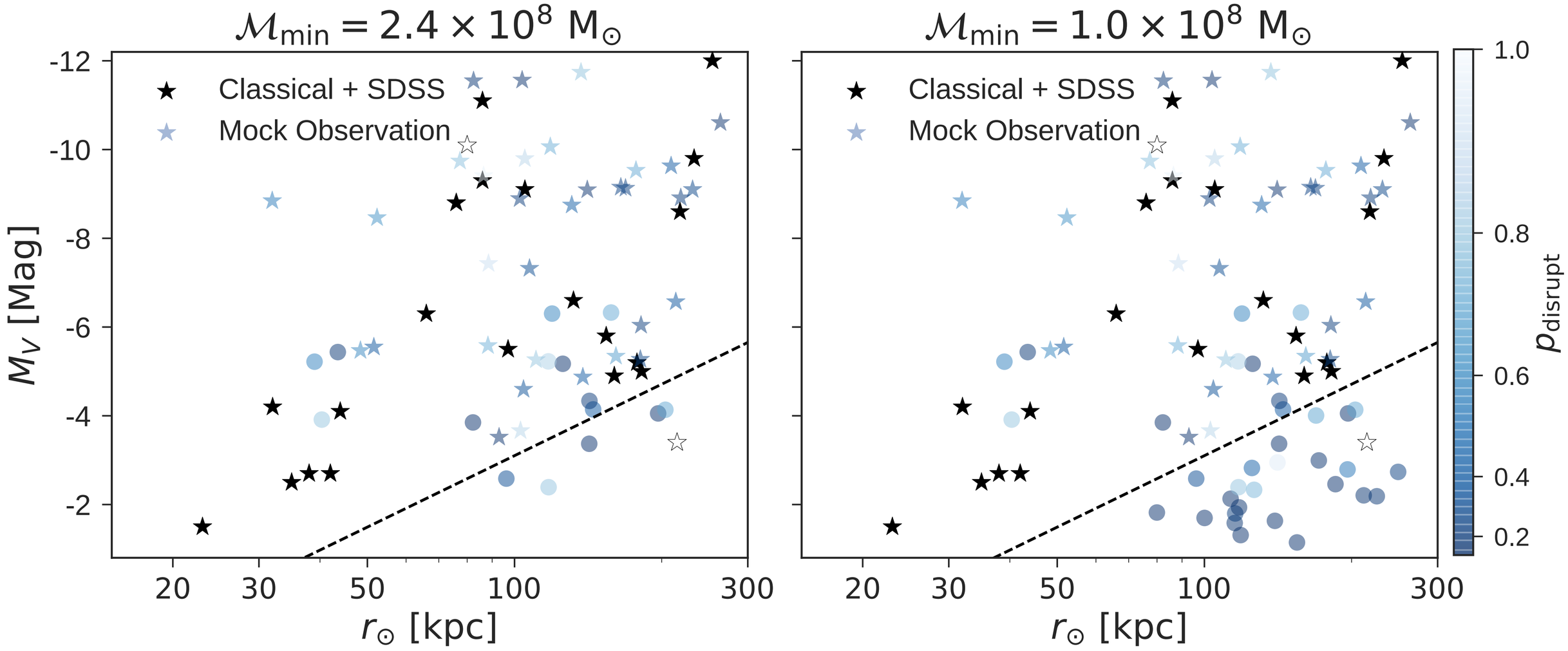
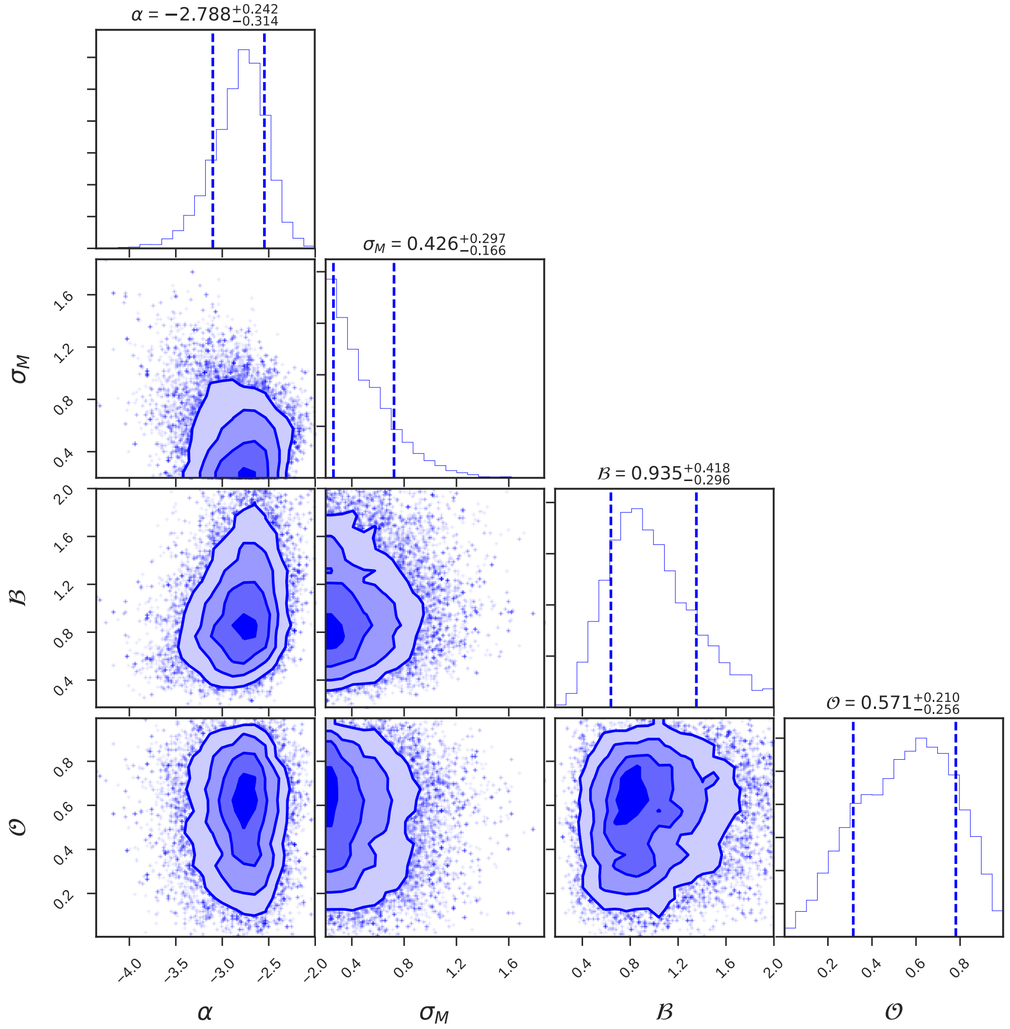
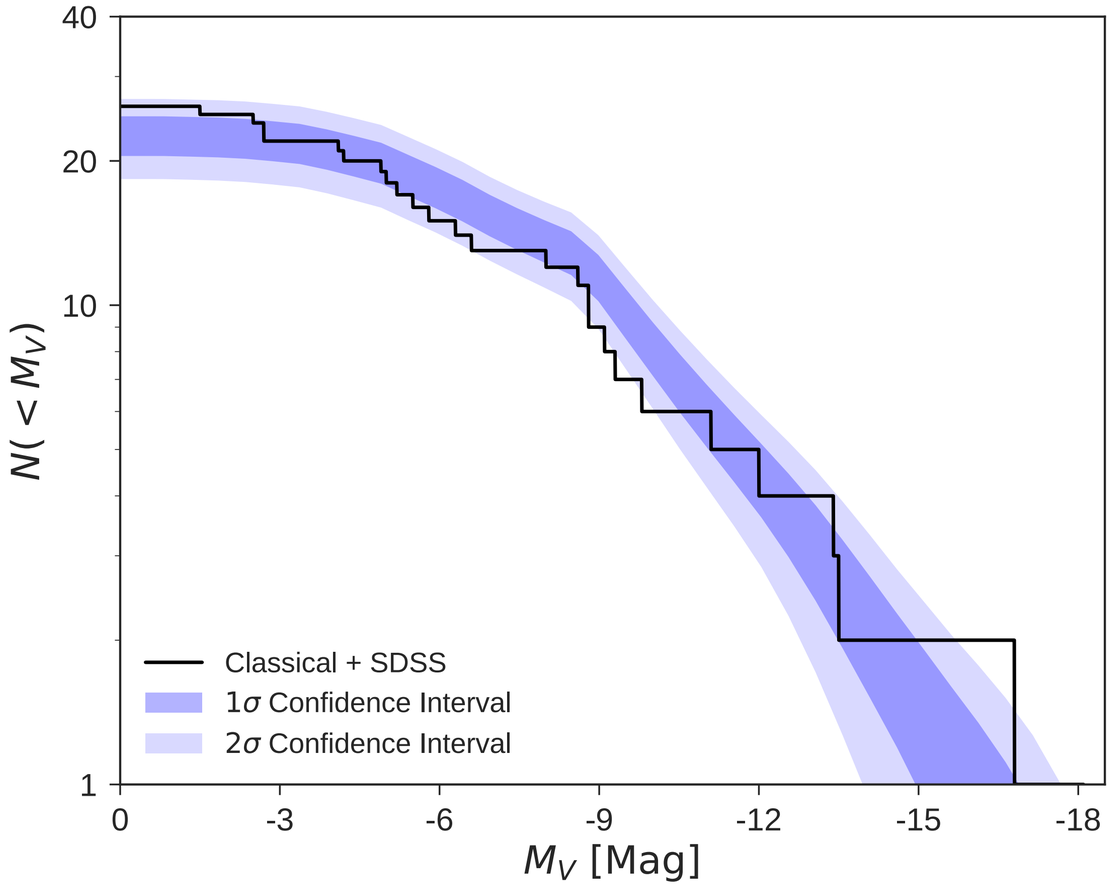


Mock Observations of Milky Way Satellites

Fit to observed satellites (Poisson process): $P(\{M_V, r_\odot, r_{1/2}\}|\theta) = e^{-\langle N_{\rm mock}(\theta)\rangle} \prod_{\rm bins\ } \frac{\lambda_i(\theta)^{N_{{\rm obs},i}}}{N_{{\rm obs},i}!}$





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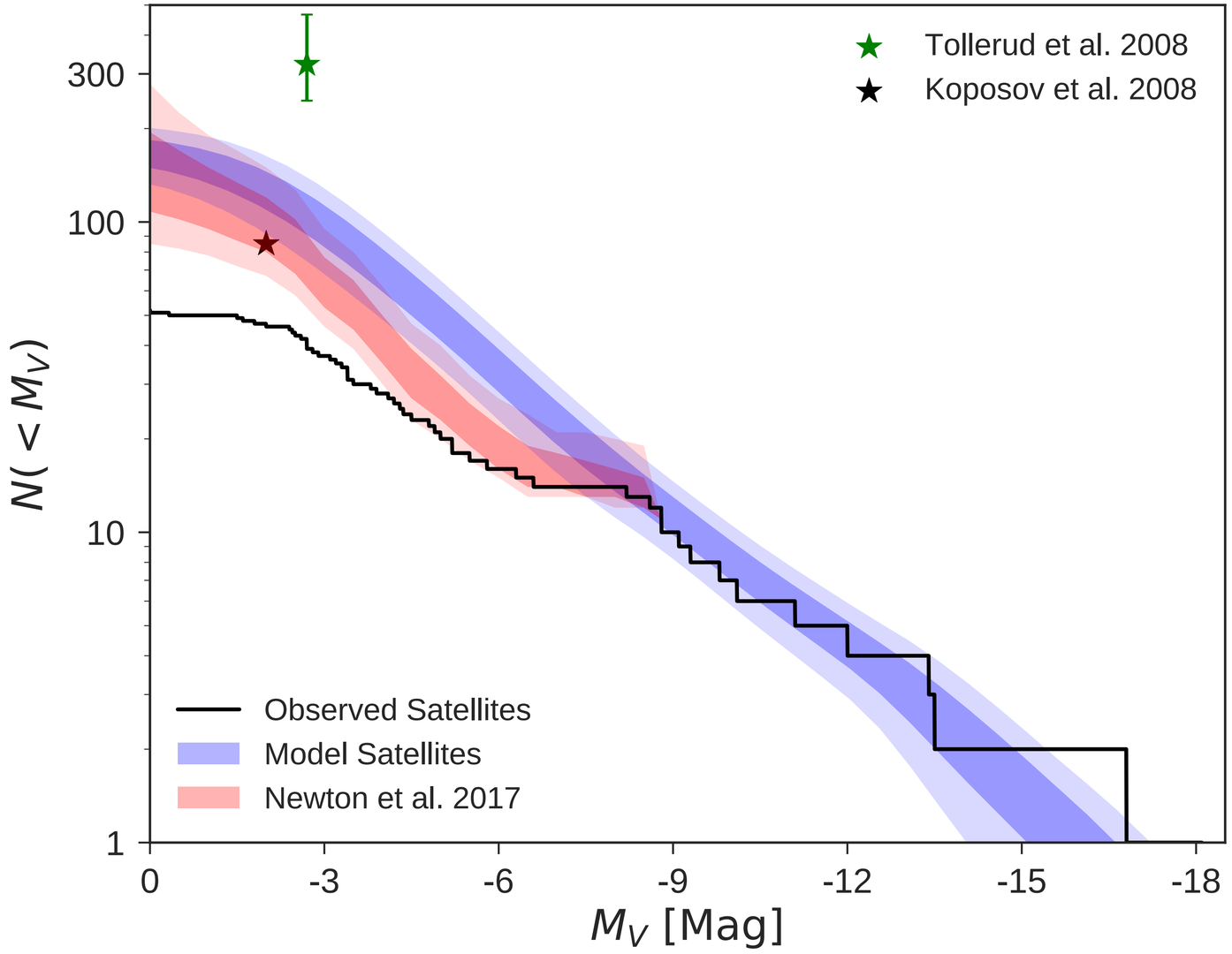
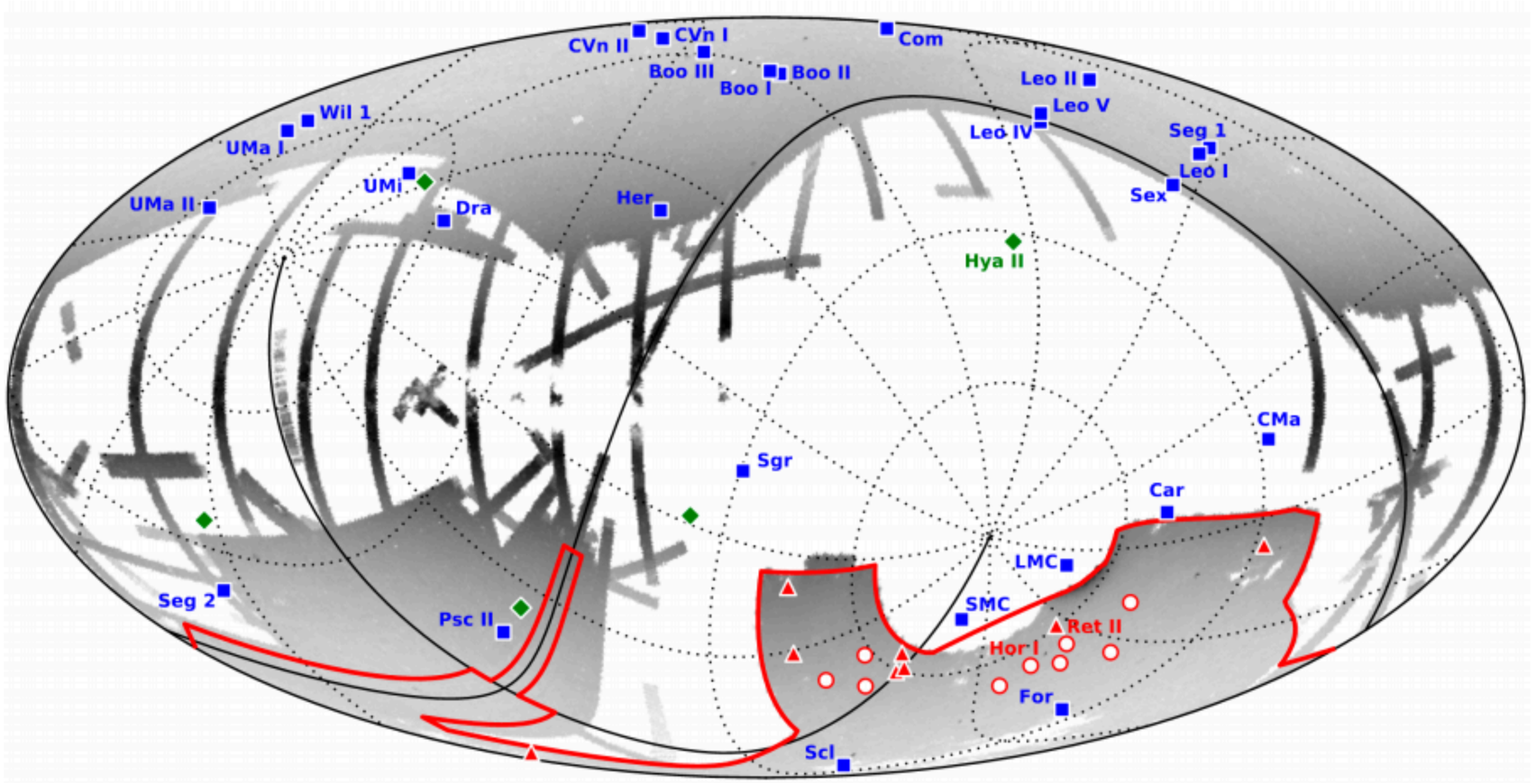


DES Y3 Milky Way Satellites

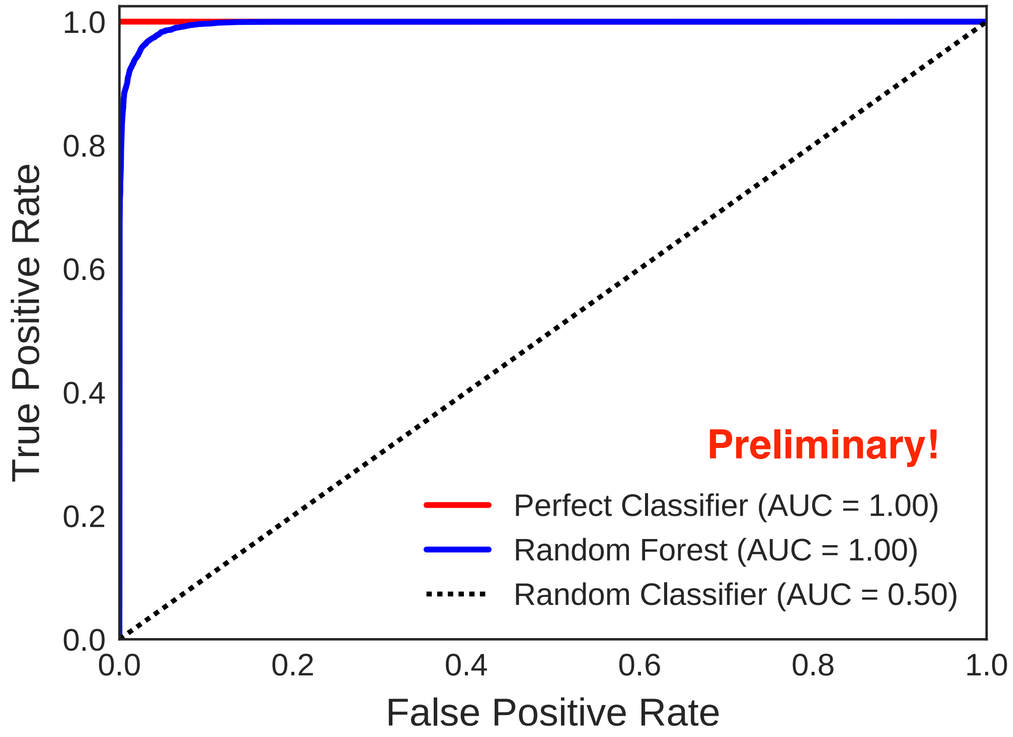


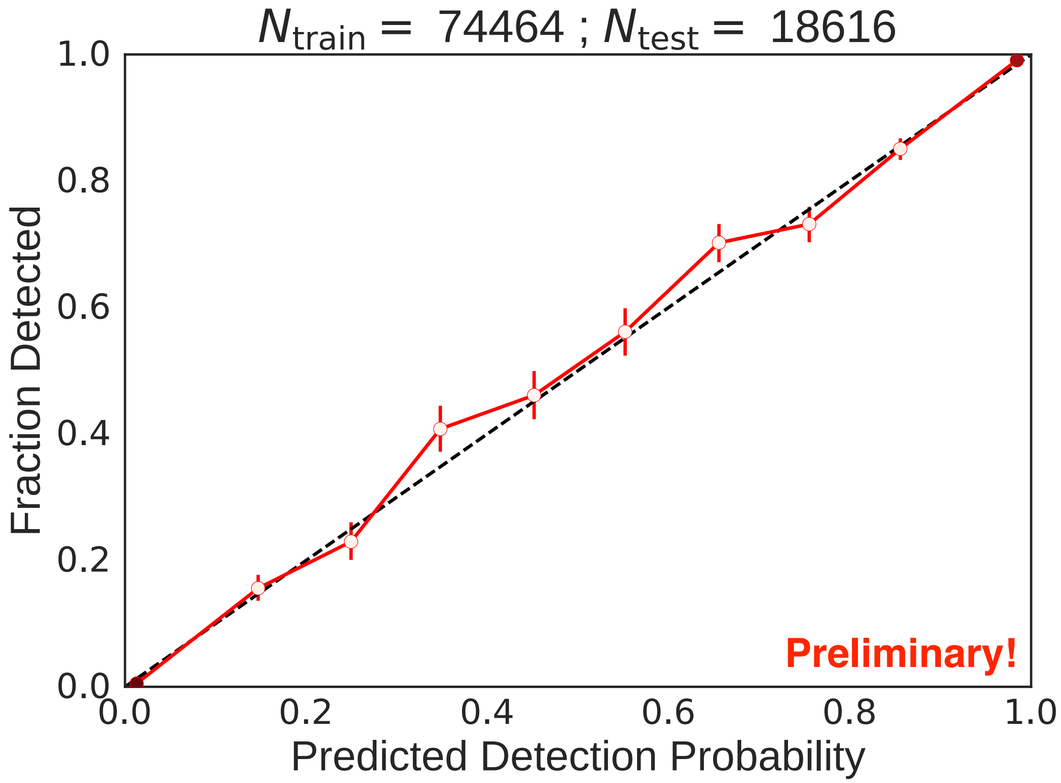
Drlica-Wagner et al. 2015

with Keith Bechtol, Alex Drlica-Wagner, Sidney Mau, Risa Wechsler

DES Y3 Milky Way Satellites

- Inject satellites into DES pipeline; train algorithm to model selection function
- Forward-model DES satellite population using footprint + detection efficiency





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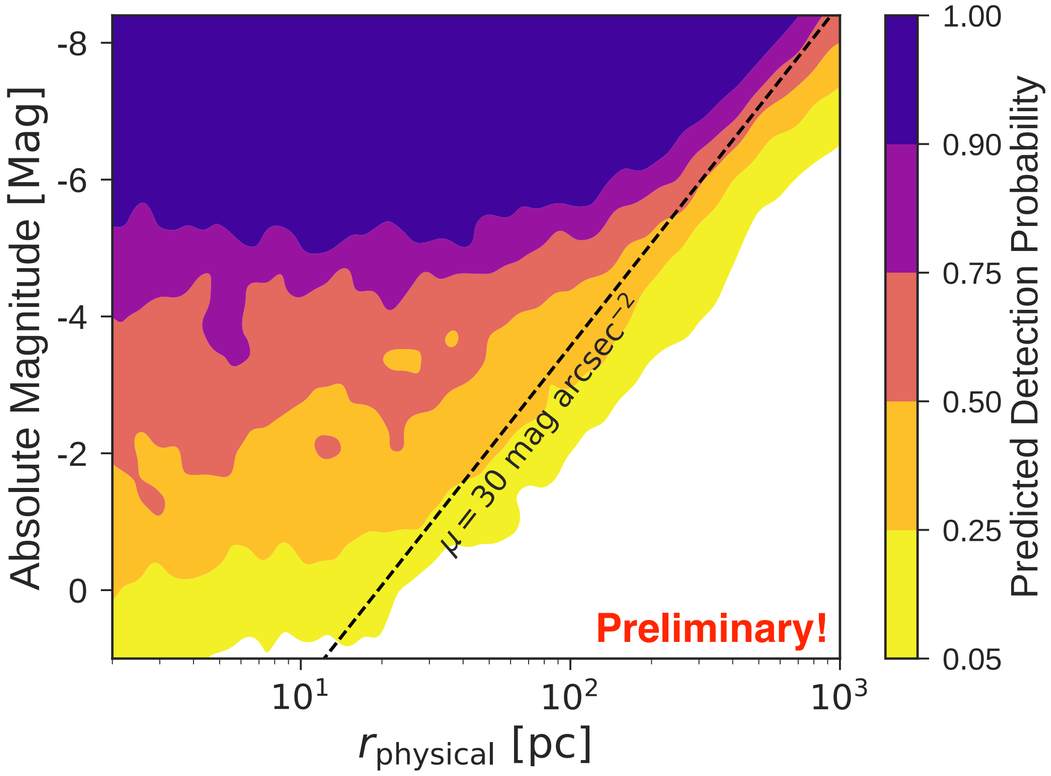
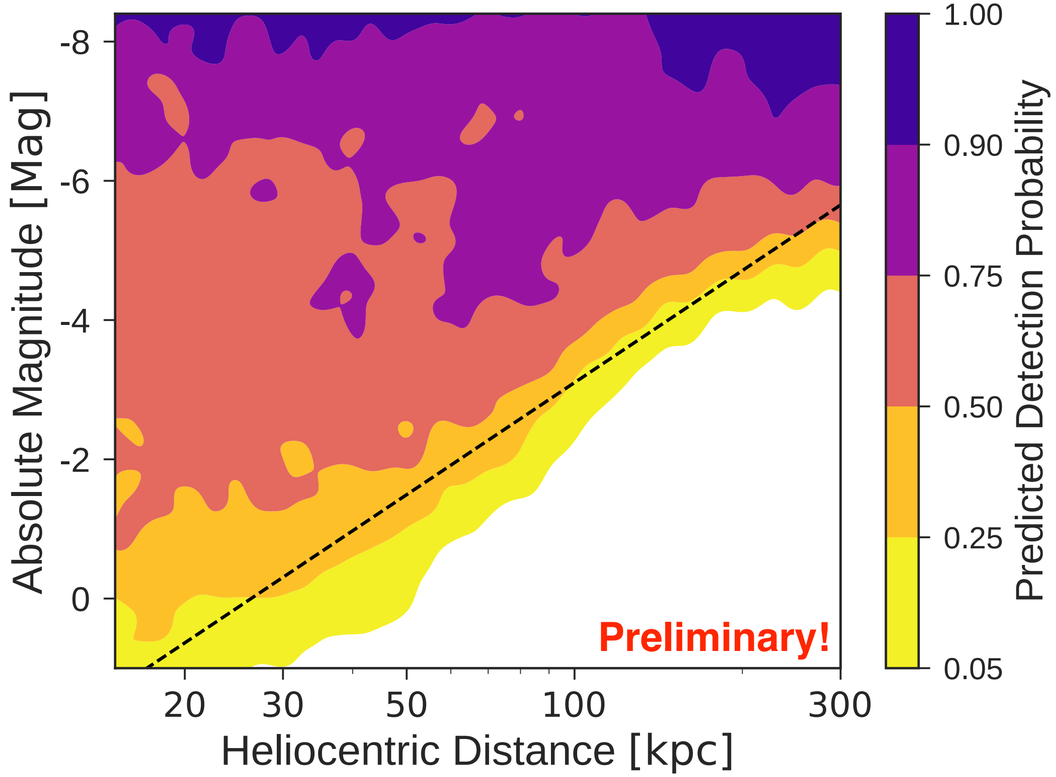
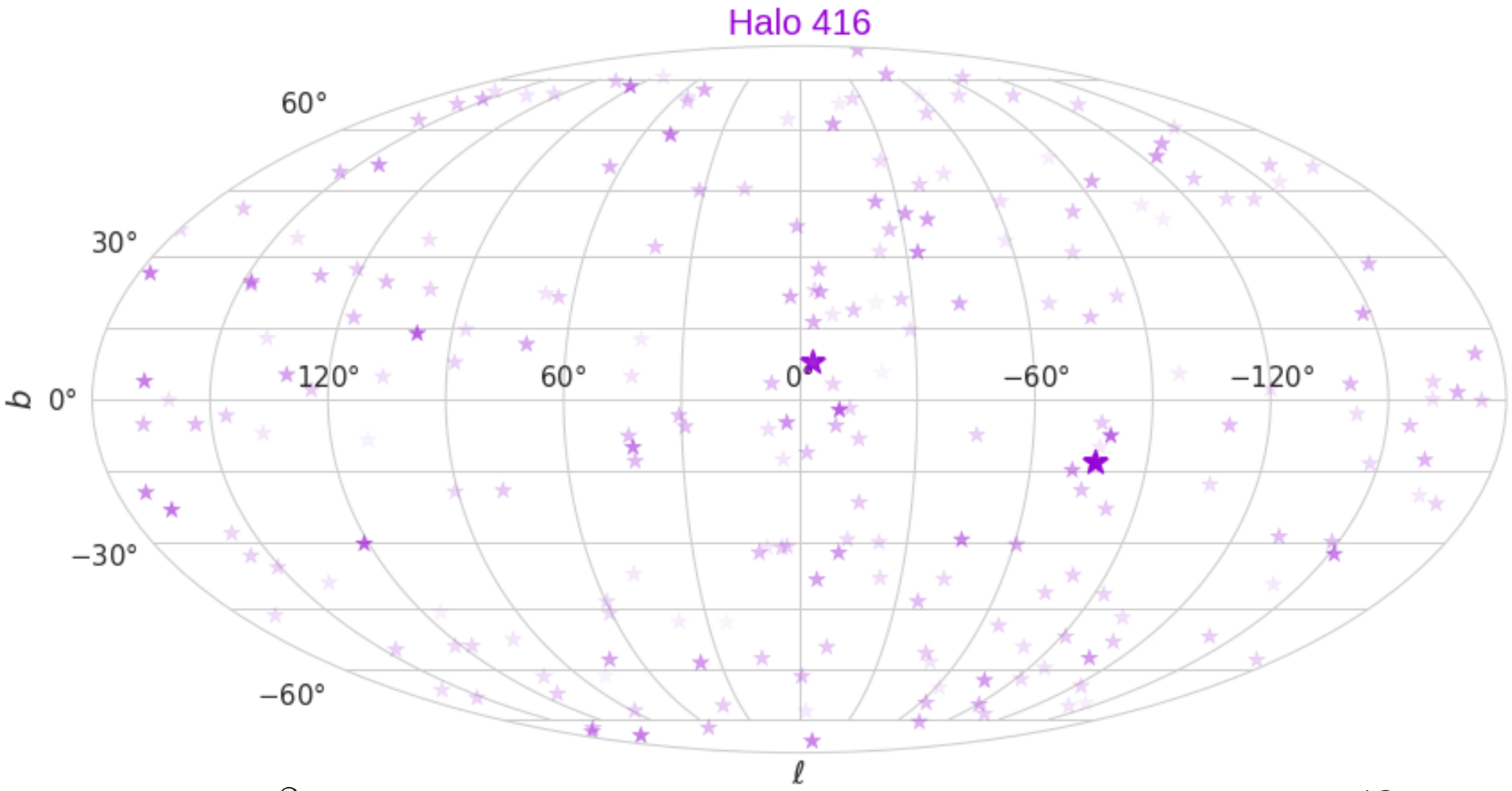




DES Y3 Milky Way Satellites



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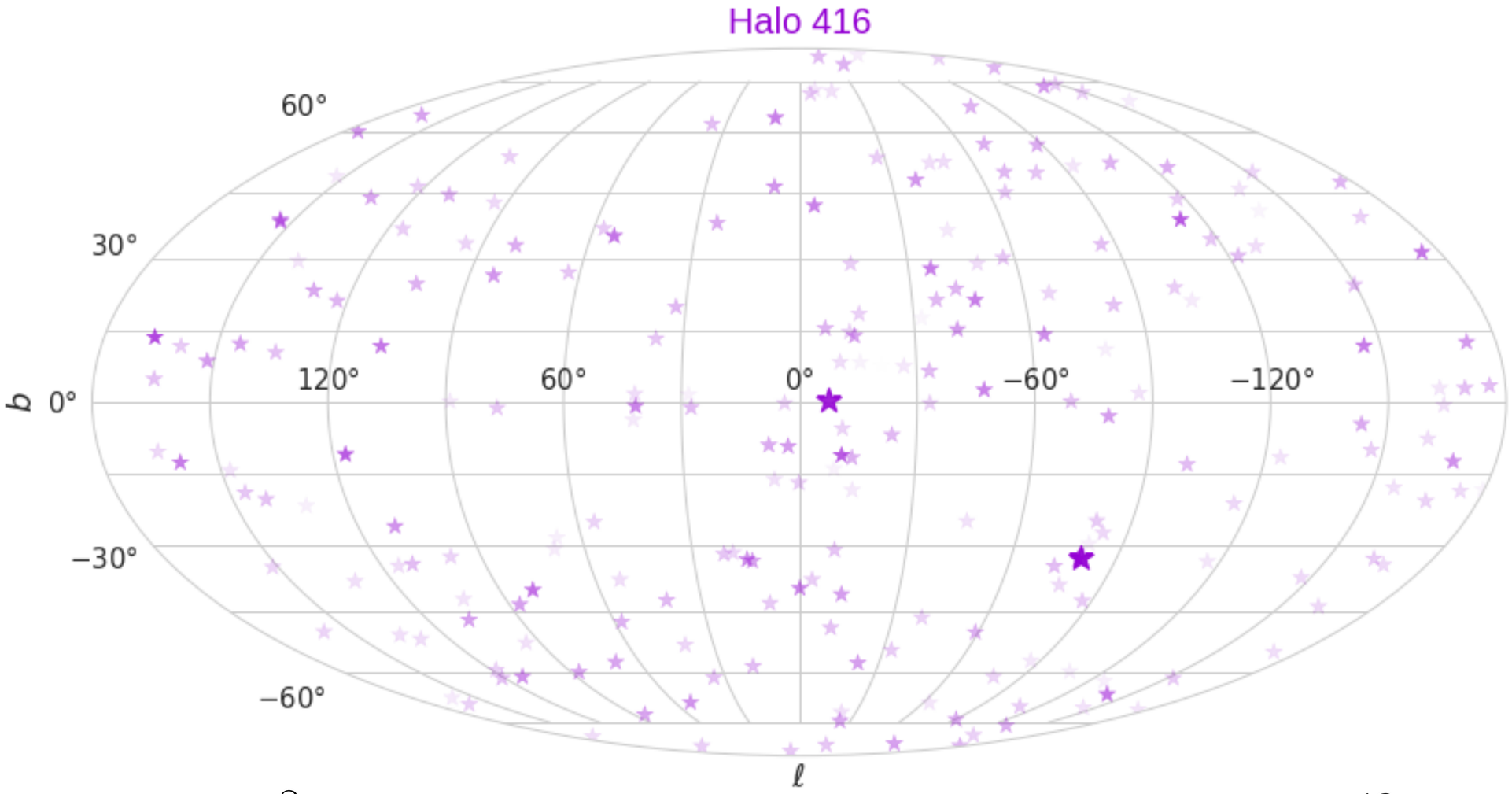
$\mathcal{B} = 1, \ \mathcal{O} = 1$

DES Y3 Milky Way Satellites



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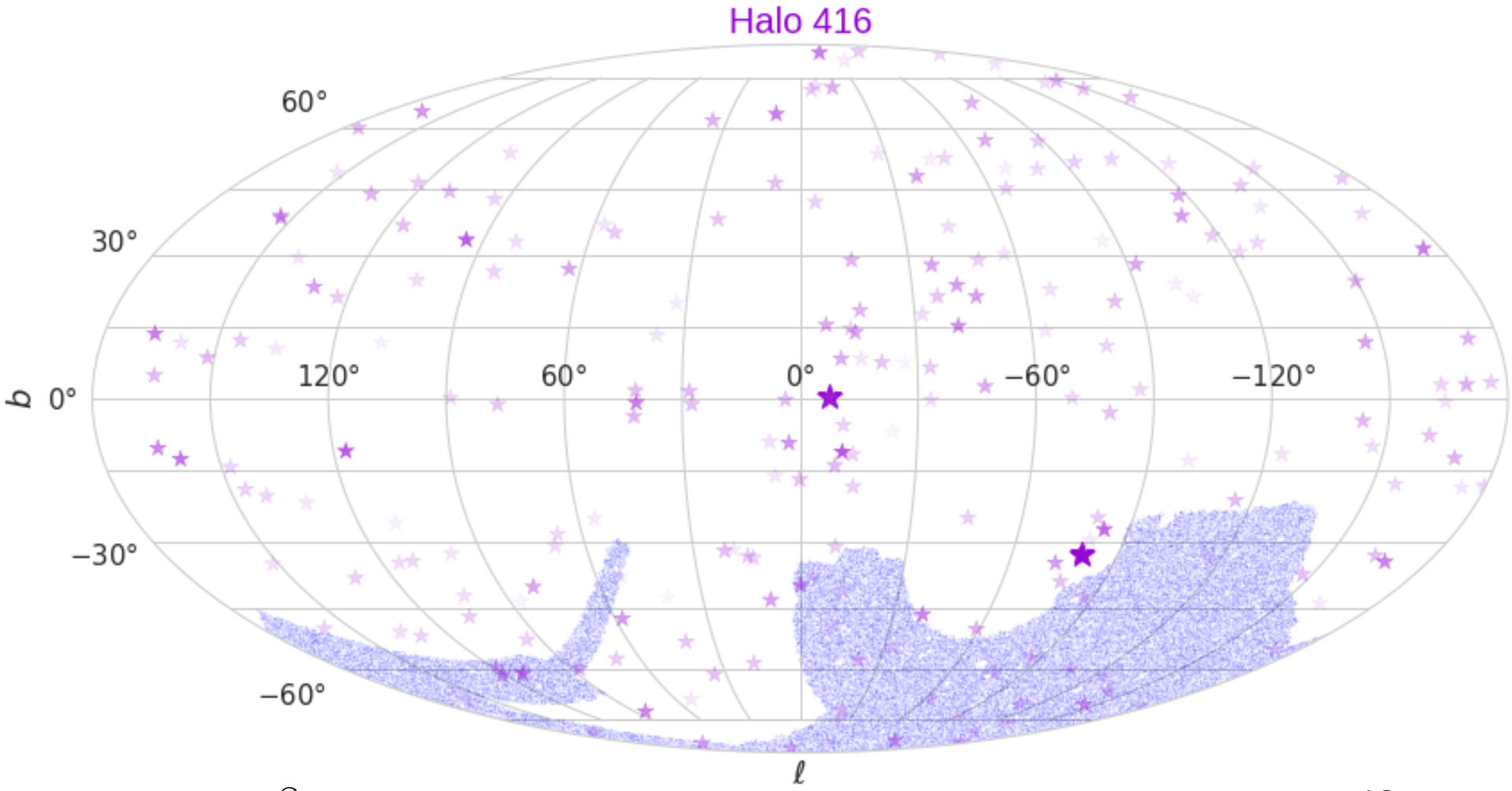
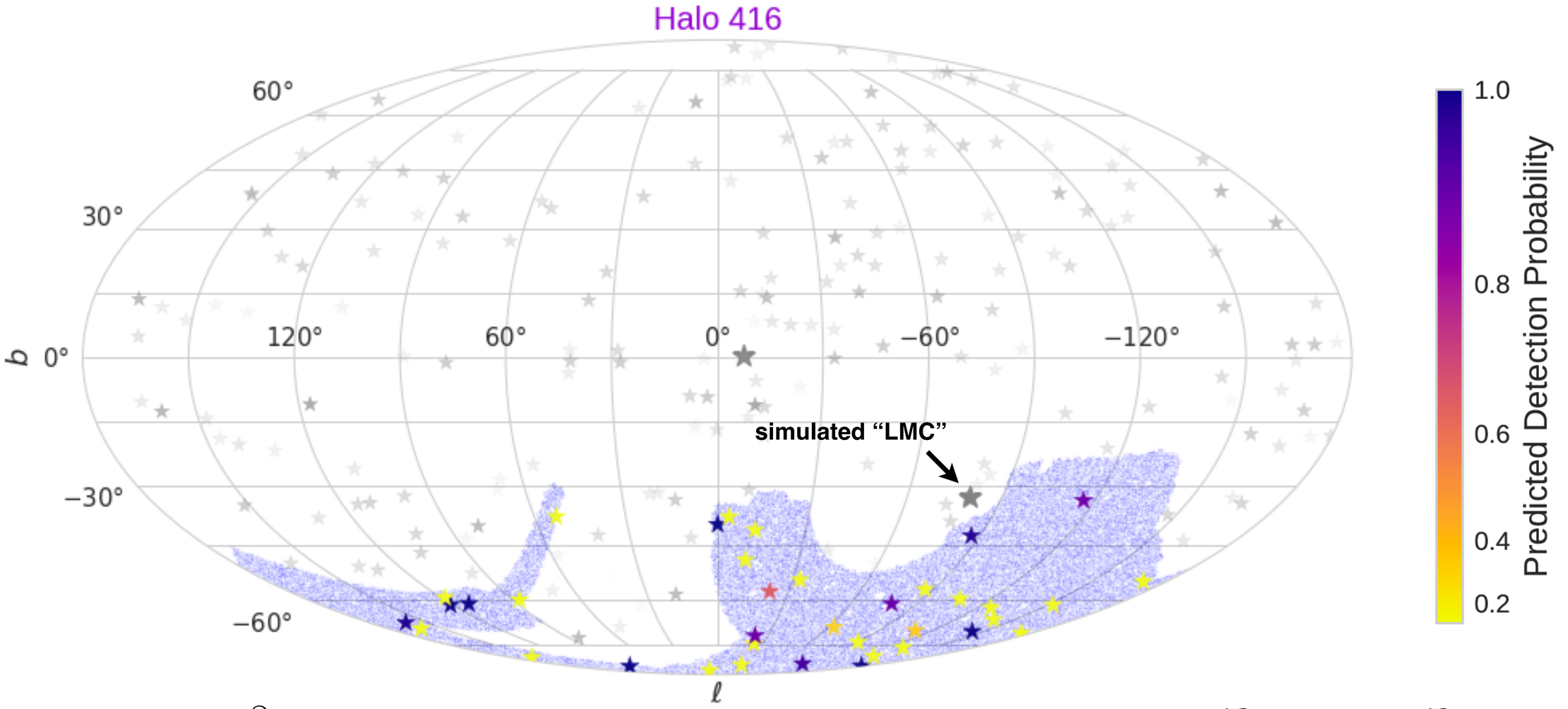
DES Y3 Milky Way Satellites



$\mathcal{M}_{\rm min} = 1.0 \ \times 10^8 \ {\rm M}_\odot$

$\mathcal{B} = 1, \ \mathcal{O} = 1$

DES Y3 Milky Way Satellites



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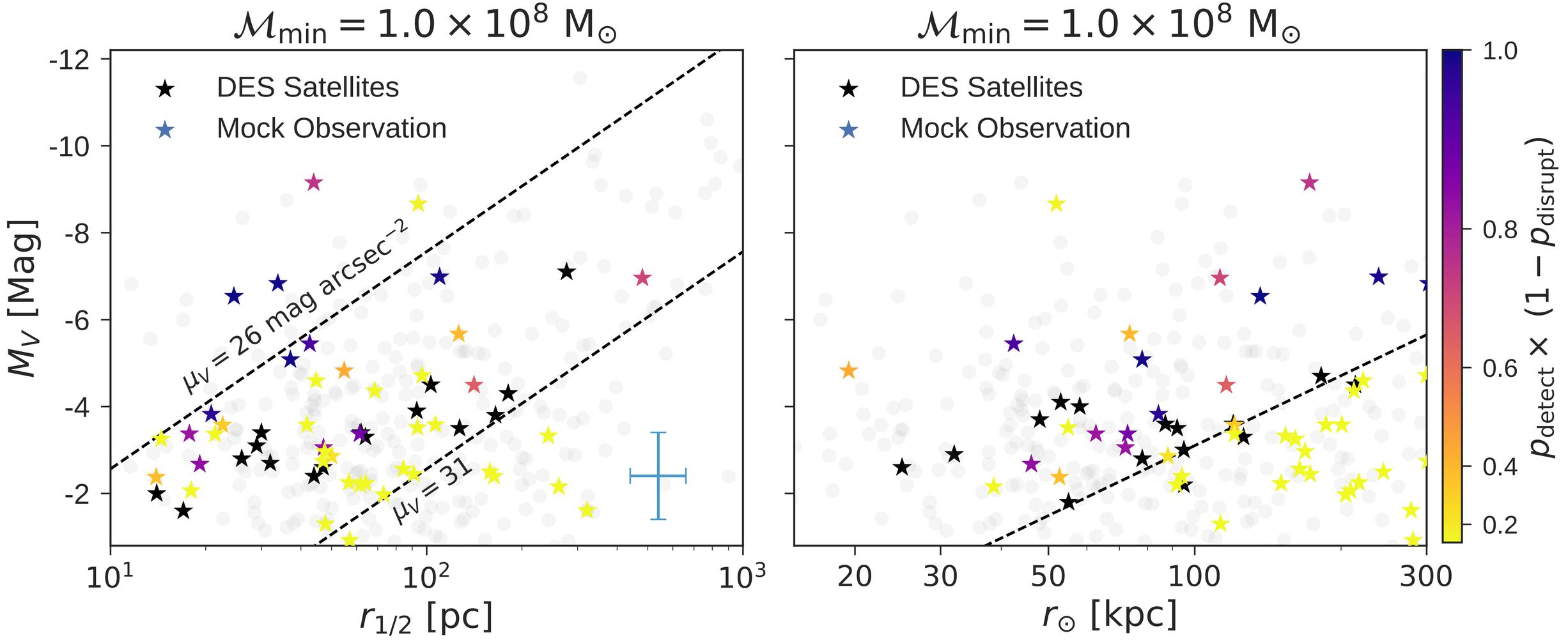
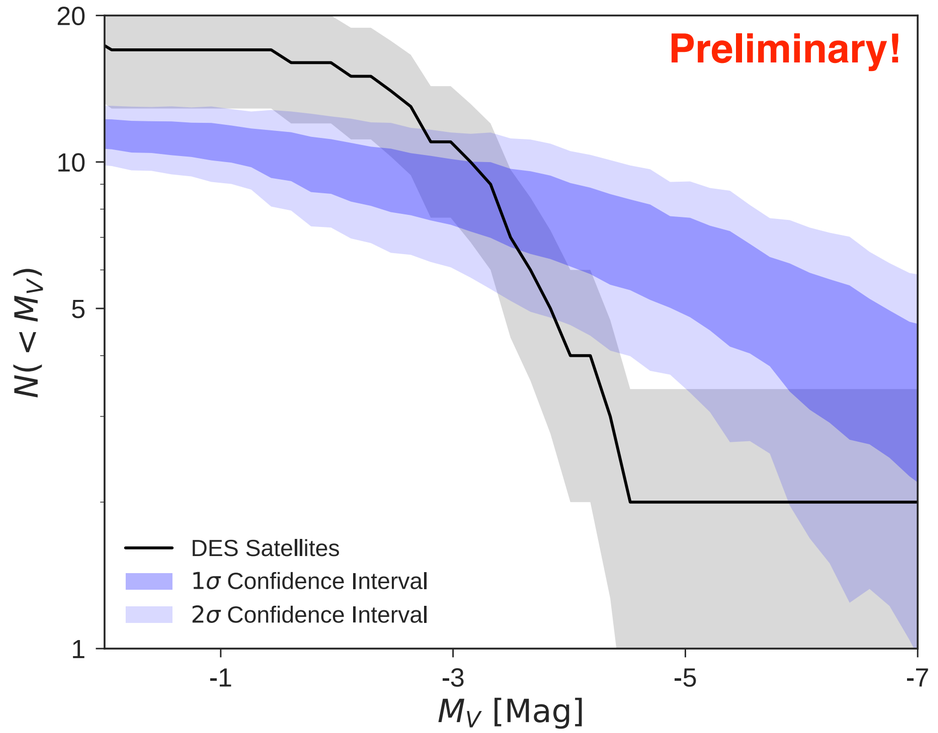
DES Y3 Milky Way Satellites



DES Y3 Milky Way Satellites

- Luminosity function in DES footprint folded through selection function using model fit to SDSS + classical satellites (not a fit to DES satellites!)



Interpreting Full-Sky Observations

SDSS + DES + Pan-STARRS + … —> full-sky satellite luminosity function

There are significant modeling uncertainties: luminosity/size models, tidal stripping, baryonic effects, orphans, LMC/SMC, …

Some data-driven questions:

- Are observed/predicted satellite distributions consistent with isotropy?
- Is there evidence for a distinct LMC/SMC satellite population?
- How will DES constrain the mass threshold for subhalos that host ultra-faints?
- Are the orbits of modeled satellites consistent with results from GAIA?