Modeling Subhalos and Satellites in Milky Way-like Systems

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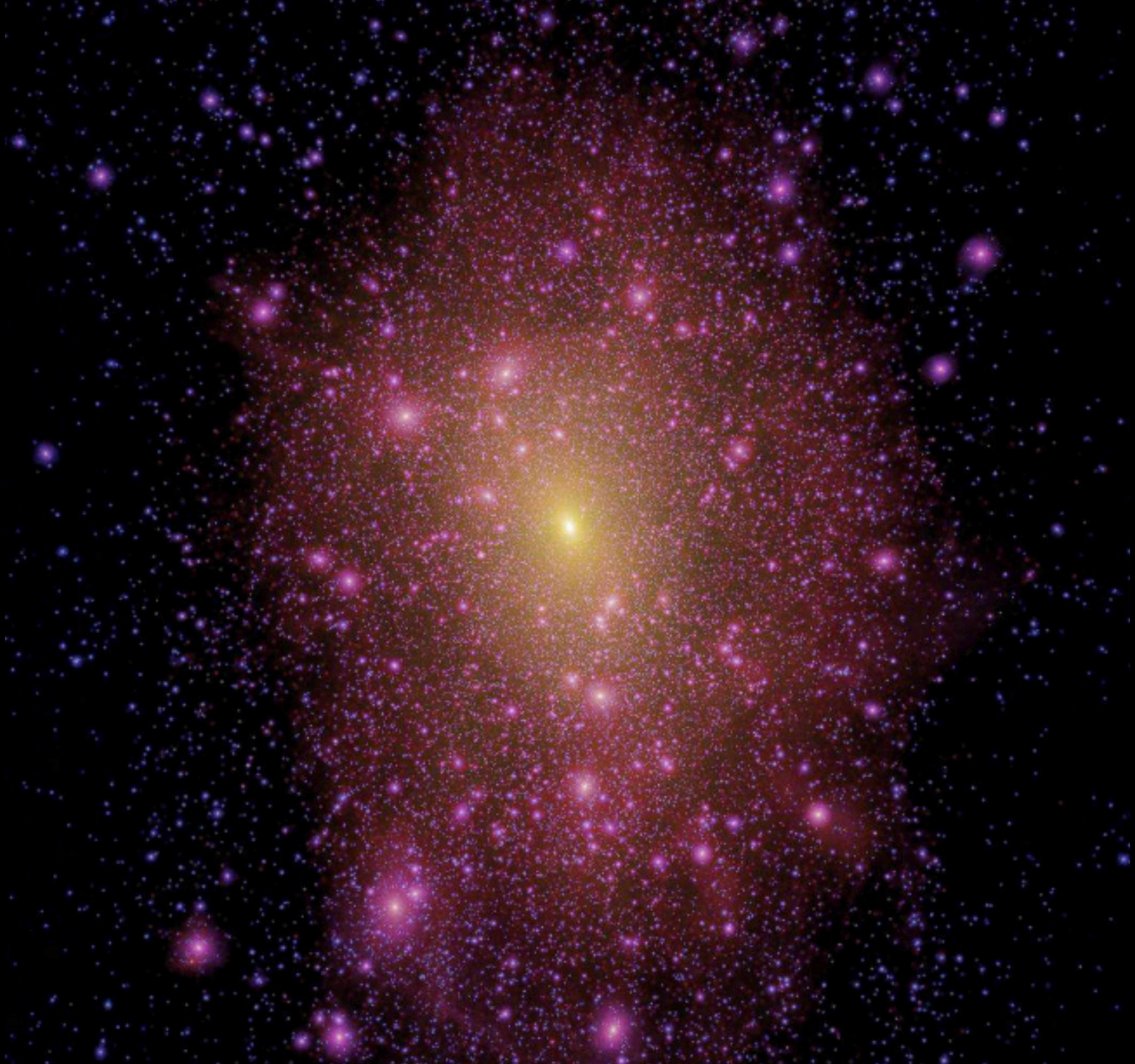
6/28/18

KIPAC



Lovell et al. 2011

Modeling Milky Way Satellites

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

Physical Ingredient	Assumptions	Parameterization	Fixed for this analysis?
3.1 Host Halo Properties	Fixed by zoom-in simulations	None	Yes ($M = 10^{12.1\pm0.03}\ M_\odot$)
3.2 Satellite Luminosities	Abundance match to GAMA survey	Non-parametric	Yes
	Extrapolate subhalo $V_{\rm peak}$ function	Faint-end slope α	No (α is free)
	Lognormal magnitude distribution	Constant scatter σ_M	No (σ_M is free)
	Subhalos below $M_{\rm peak}$ threshold are dark	Cut on $M_{\rm peak} < \mathcal{M}_{\rm min}$	No ($\mathcal{M}_{\rm min}$ is free)
3.3 Satellite Locations	On-sky positions set by subhalos	None	Yes
	Distances set by scaled subhalo radii	$r_{\rm sat} = \chi r_{\rm sub}$	Yes ($\chi = 0.93$)
3.4 Satellite Sizes	Jiang et al. (2018) sizes at accretion	$r_{1/2} = A(c/10)^{\gamma} R_{\rm vir}$	Yes ($A = 0.02$, $\gamma = -0.7$)
	Size reduction set by stripping	$r'_{1/2} = r_{1/2}(V_{\rm max}/V_{\rm acc})^{\beta}$	Yes ($\beta = 0$)
	Lognormal size distribution	Constant scatter σ_R	Yes ($\sigma_R = 0.01$ dex)
3.5 Baryonic Effects	Nadler et al. (2018) disruption model	$p_{\rm disrupt} \rightarrow p_{\rm disrupt}^{1/\mathcal{B}}$	No ($\mathcal{B}$ is free)
3.6 Orphan Satellites	Correspond to disrupted subhalos	None	Yes
	NFW host + dynamical friction	$\ln\Lambda = -\ln(m/M)$	Yes
	Stripping after pericentric passages	$\dot{m}_{\rm outgoing} \sim -\frac{m}{\tau_{\rm dyn}}\left(\frac{m}{M}\right)^{0.07}$	Yes
	Disruption probability set by stripping	$p_{\rm disrupt} = (1 - V_{\rm max}/V_{\rm acc})^{\mathcal{O}}$	Yes ($\mathcal{O} = 0.5$)

Nadler et al. in prep.

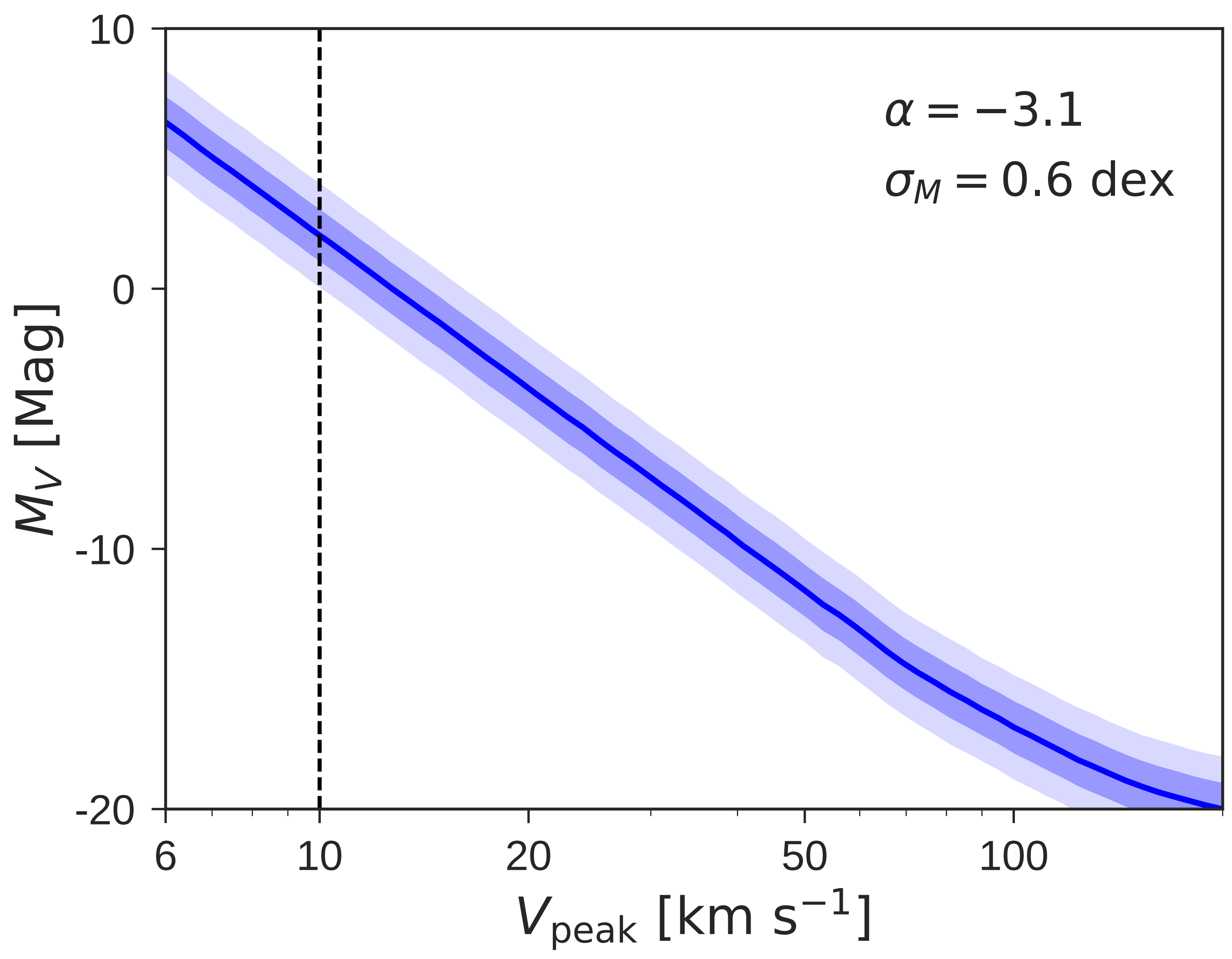
Model Building: Luminosities

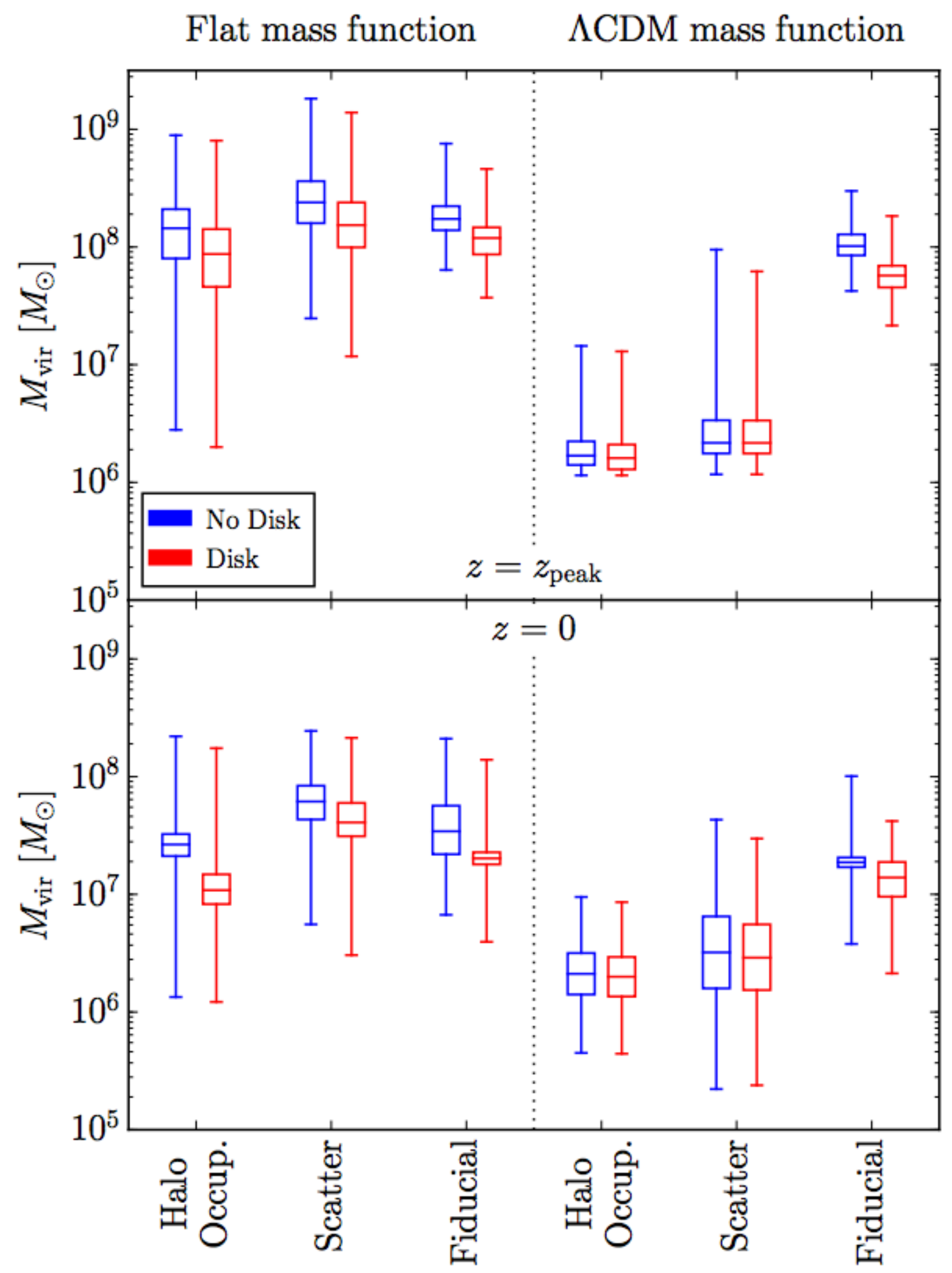
- Abundance match to GAMA luminosity function (measured down to $M_r \sim -12$)
- Parameters: abundance matching slope, scatter, galaxy formation threshold

α : abundance matching slope

σ_M : abundance matching scatter

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





Jethwa et al. 2018

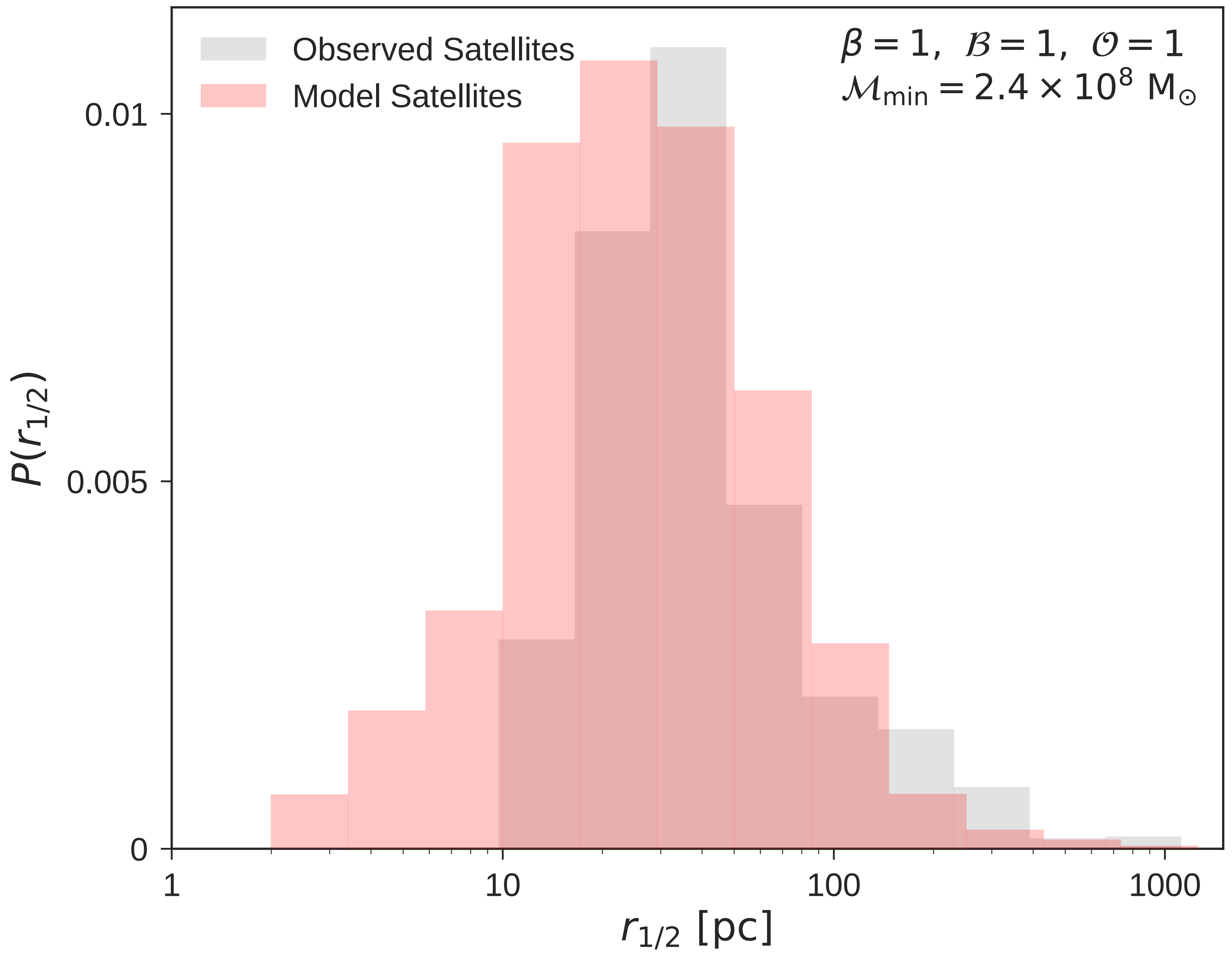
Model Building: Sizes

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

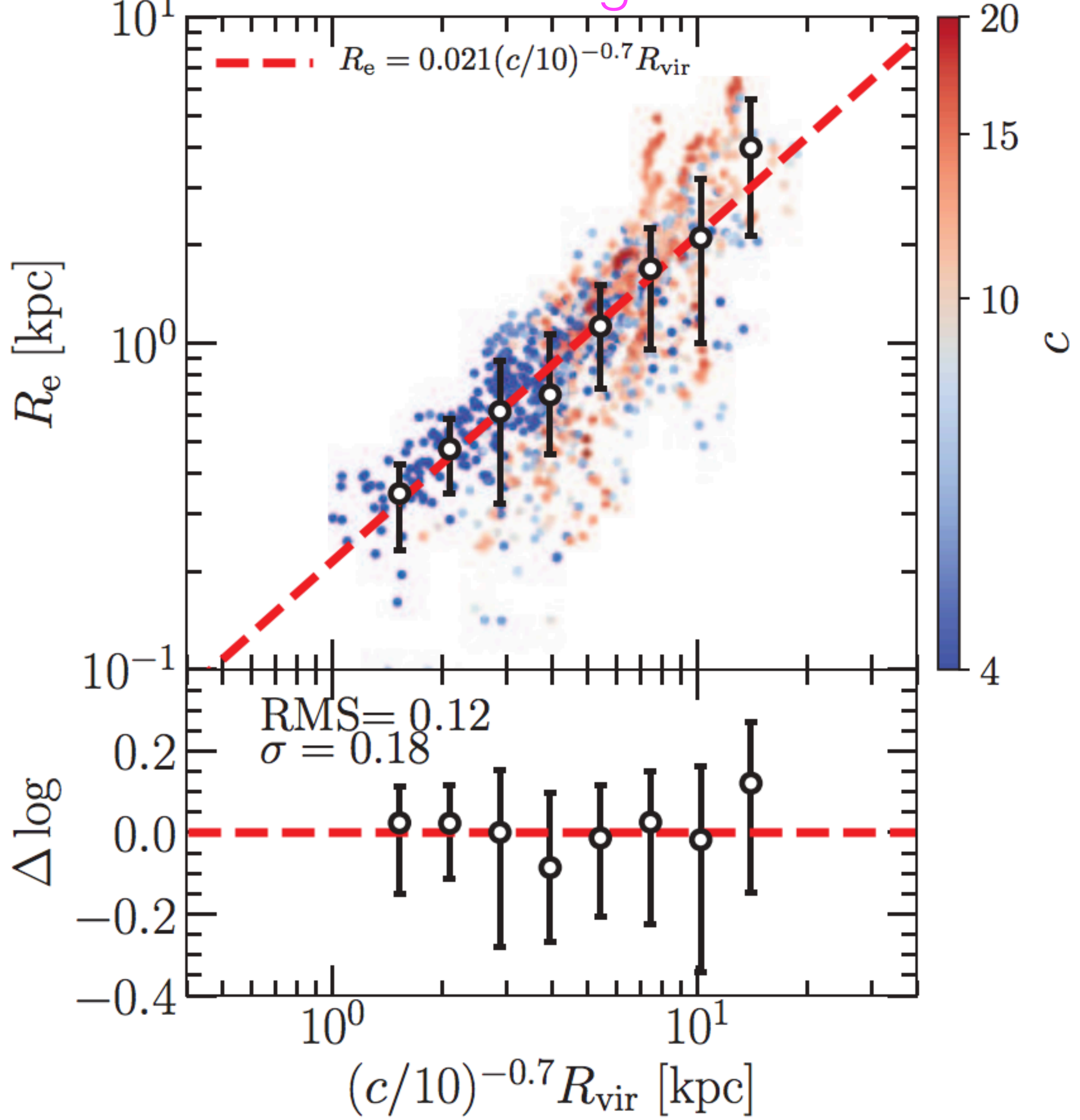
$$\beta : r'_{1/2} = r_{1/2}\left(\frac{V_{\rm max}}{V_{\rm acc}}\right)^{\beta}$$

σ_R : size scatter

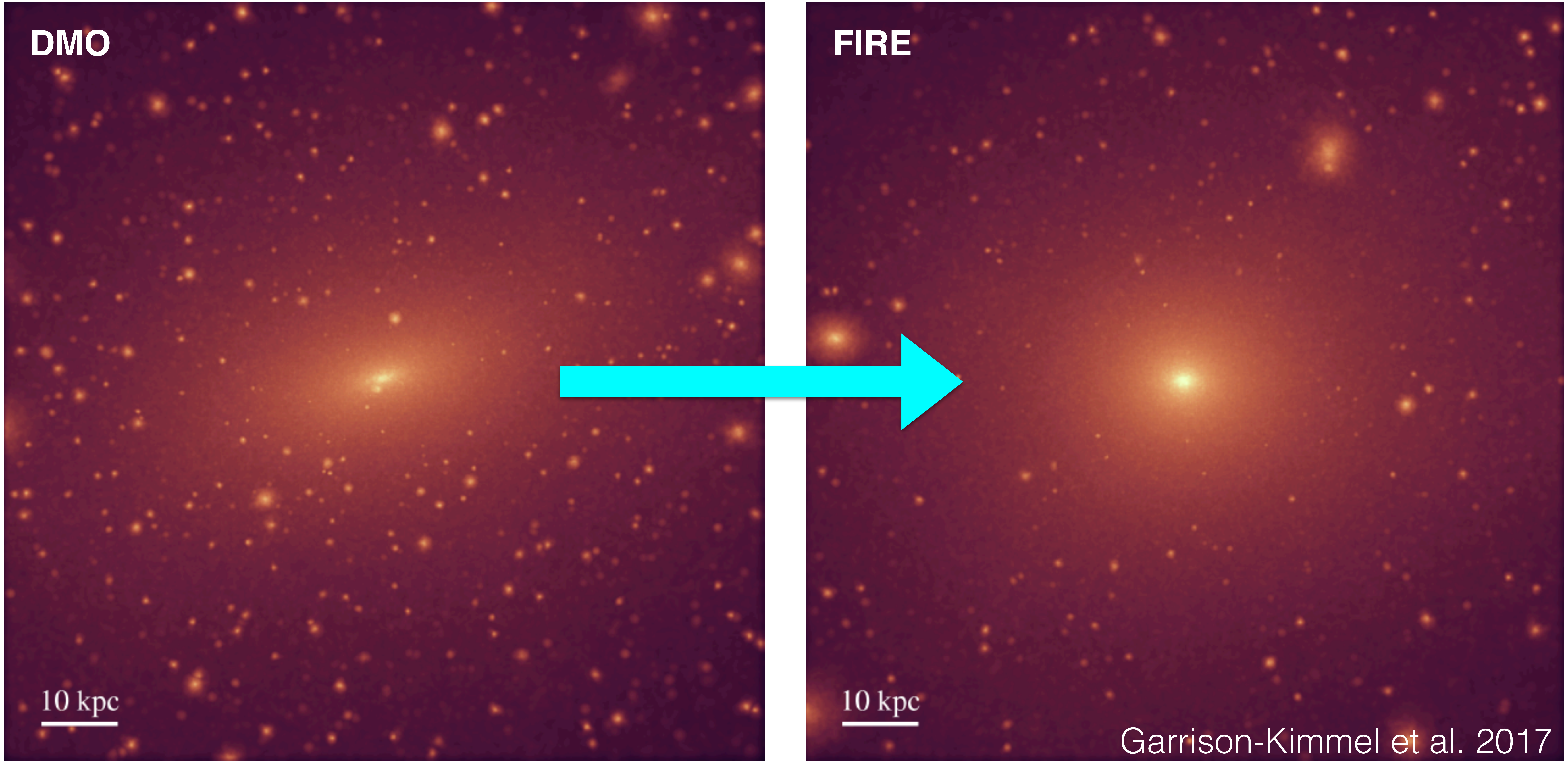
Sizes Set at $z = 0$



Jiang et al. 2018



Baryonic Subhalo Disruption



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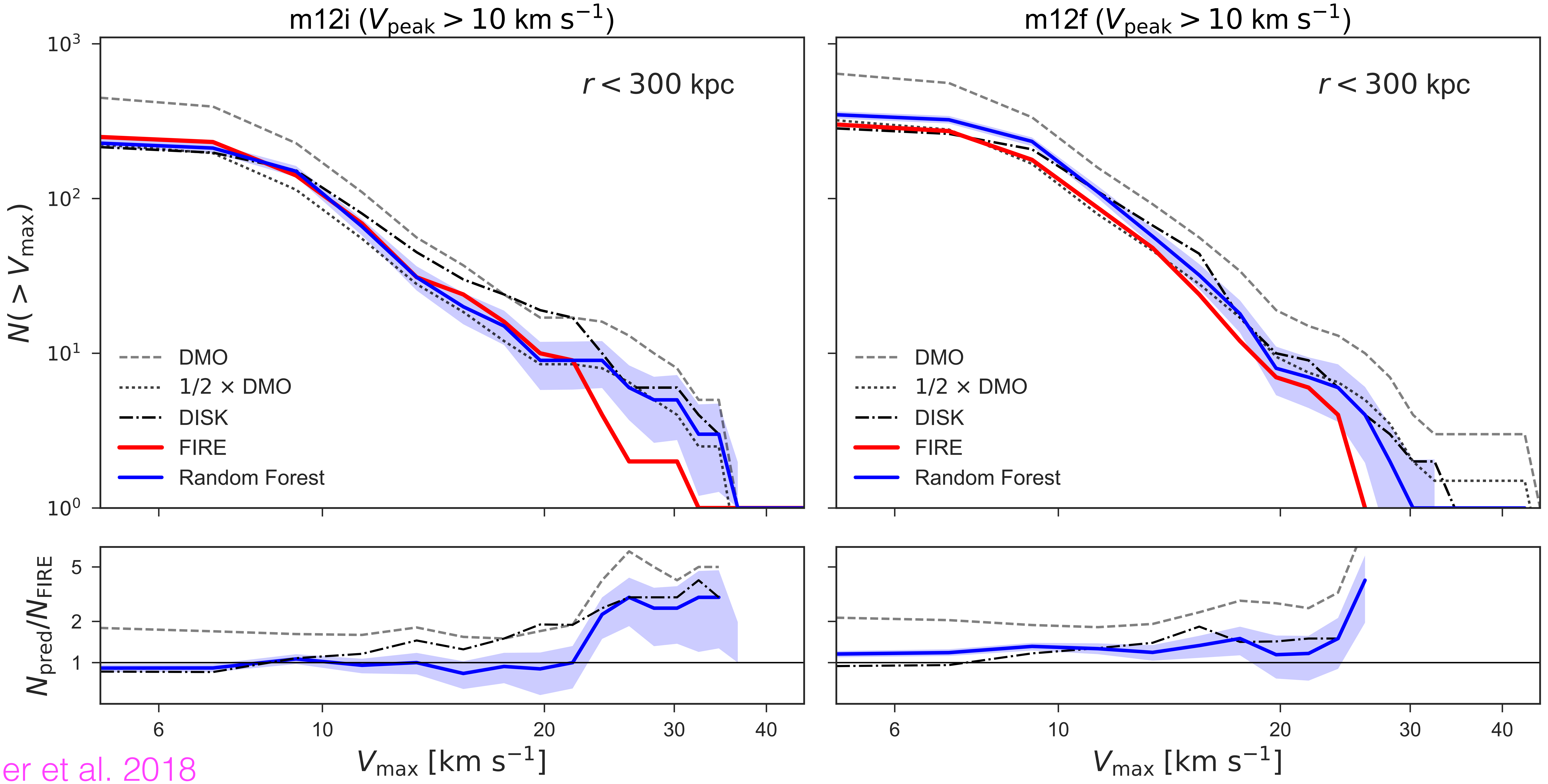
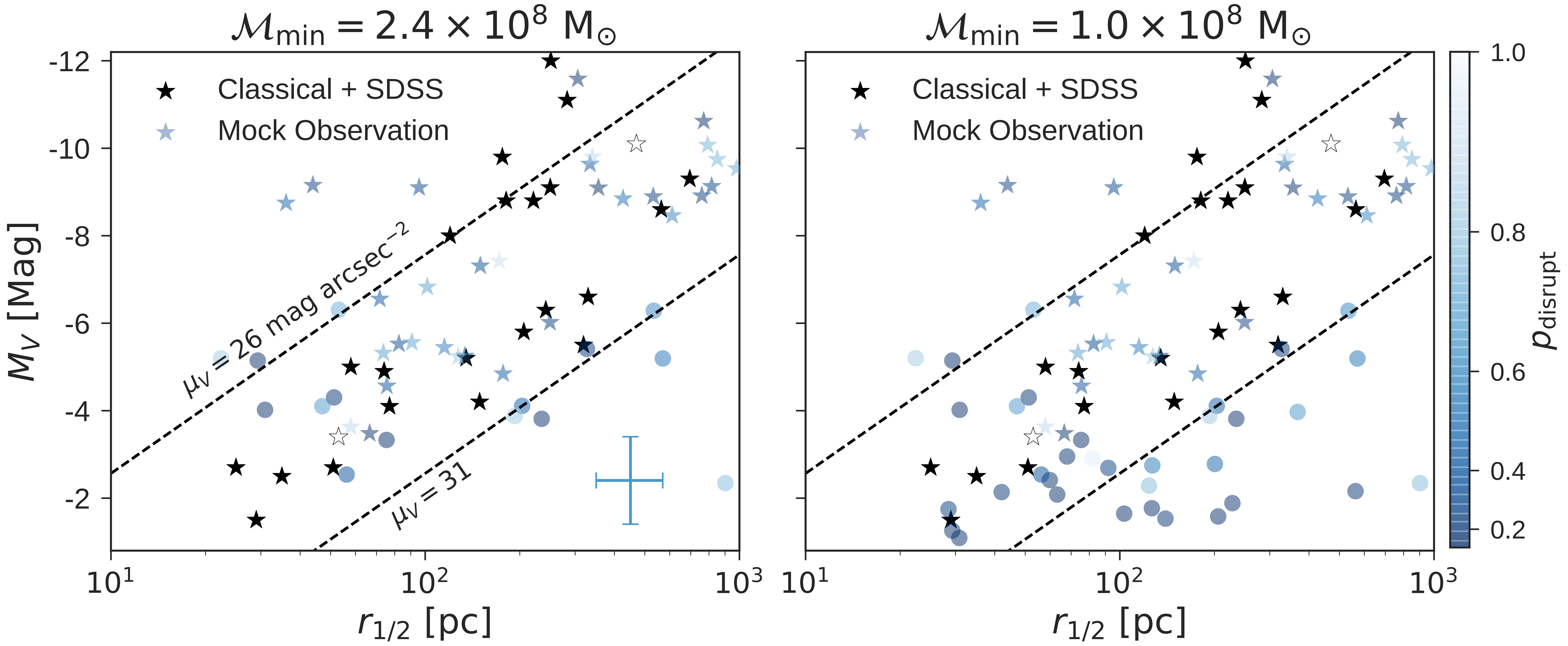


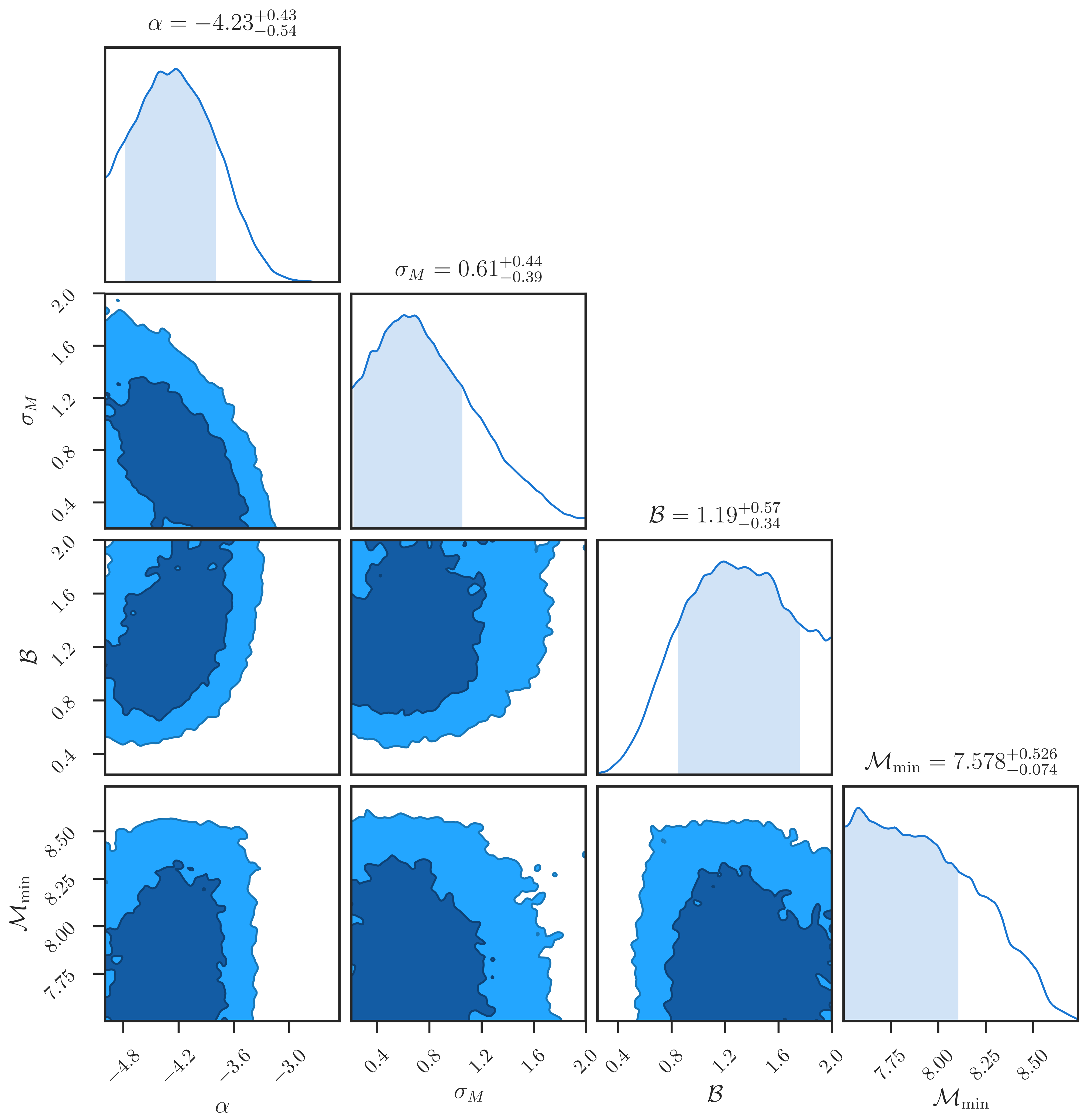
Nadler et al. 2018

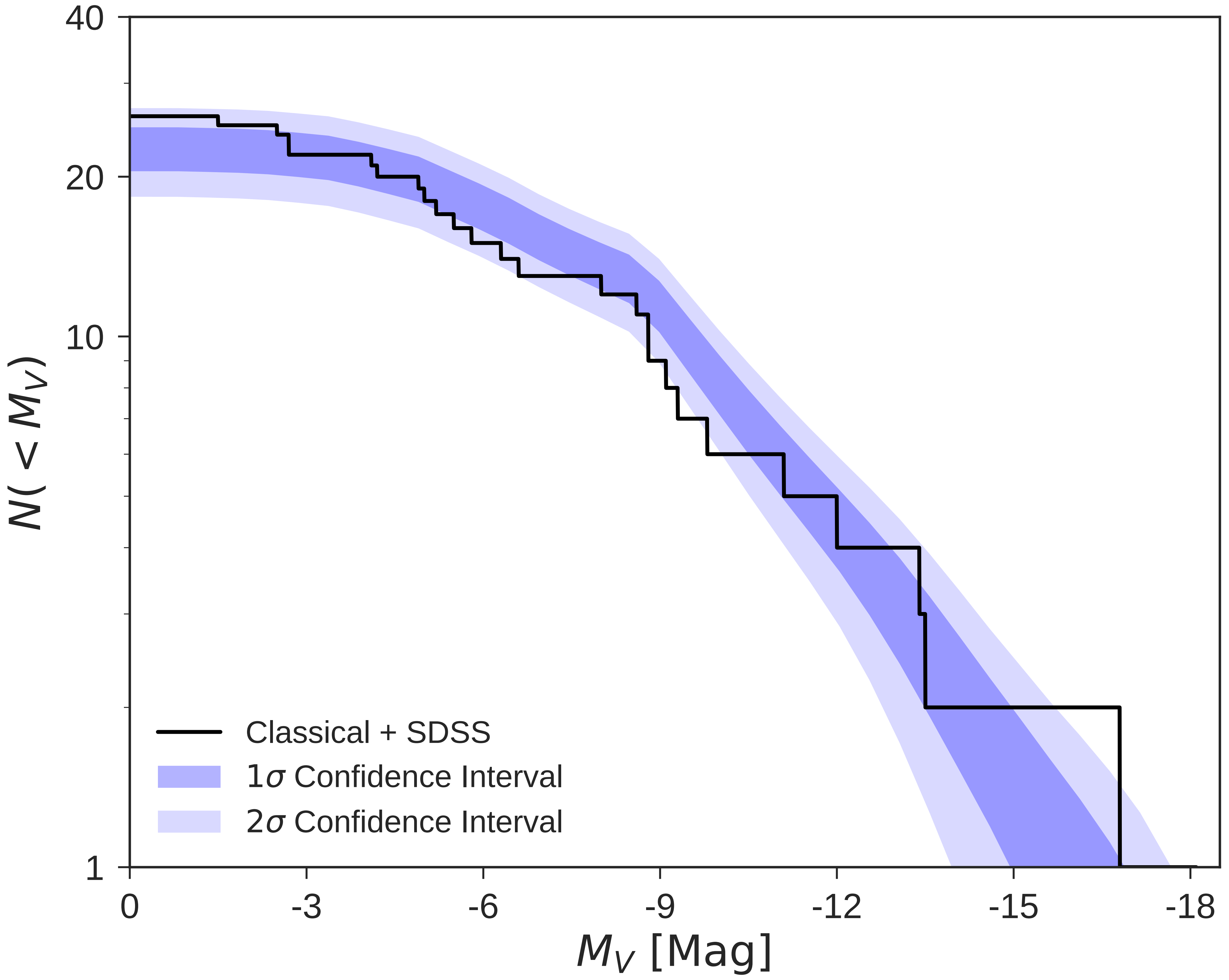
Example: Classical + SDSS Satellites



Example: Classical + SDSS Satellites

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





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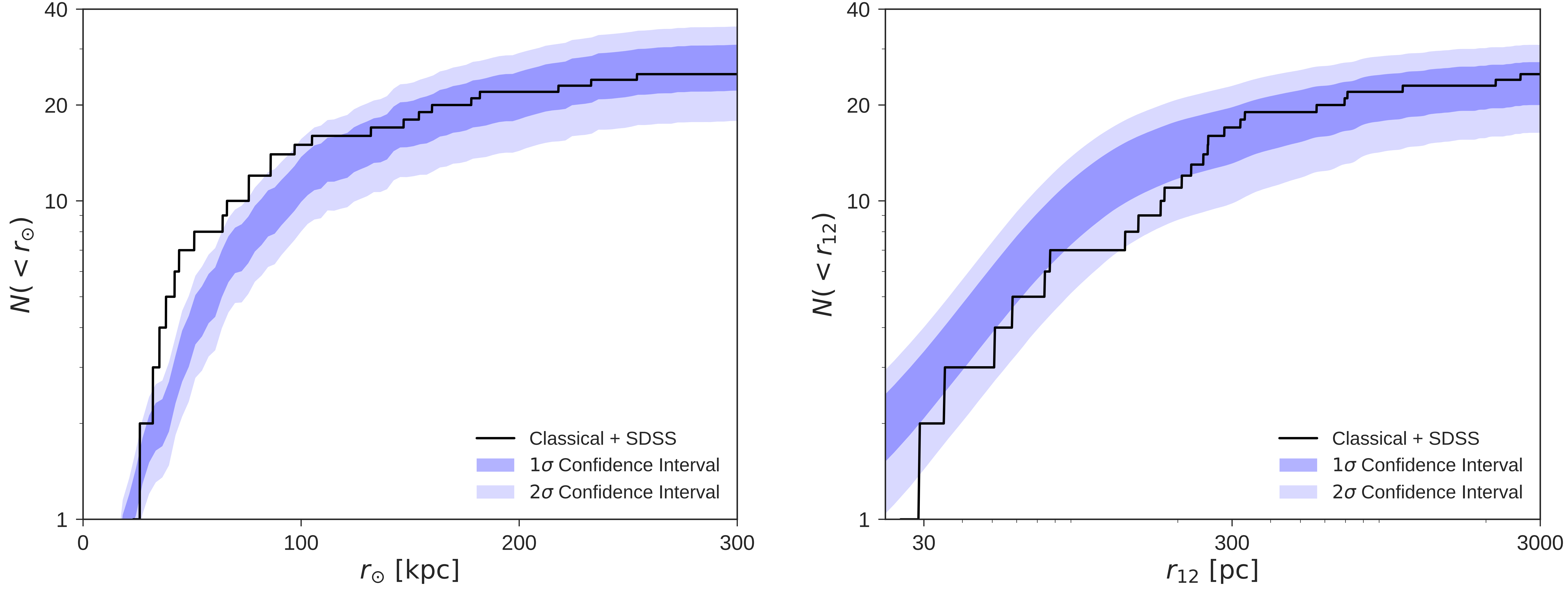
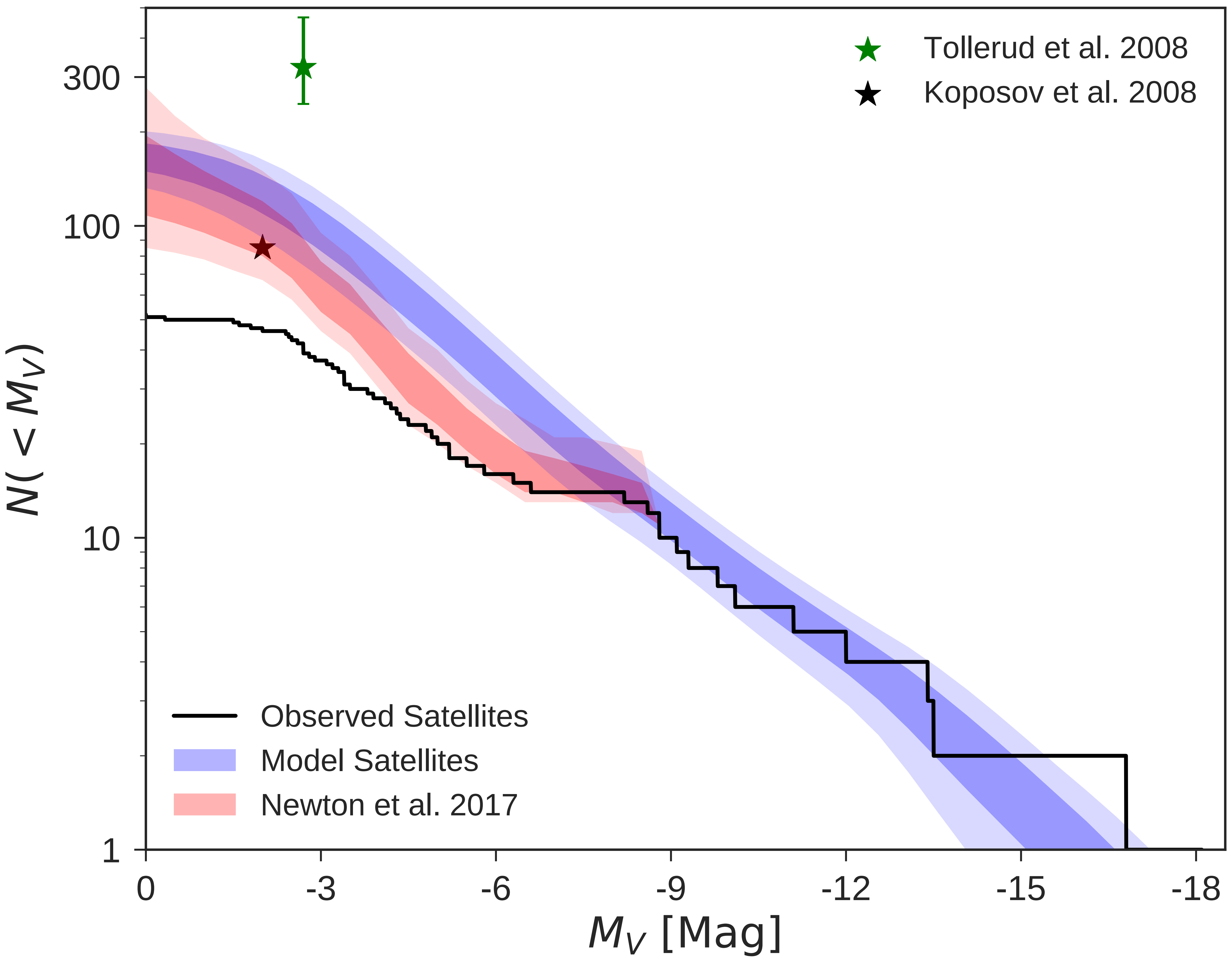
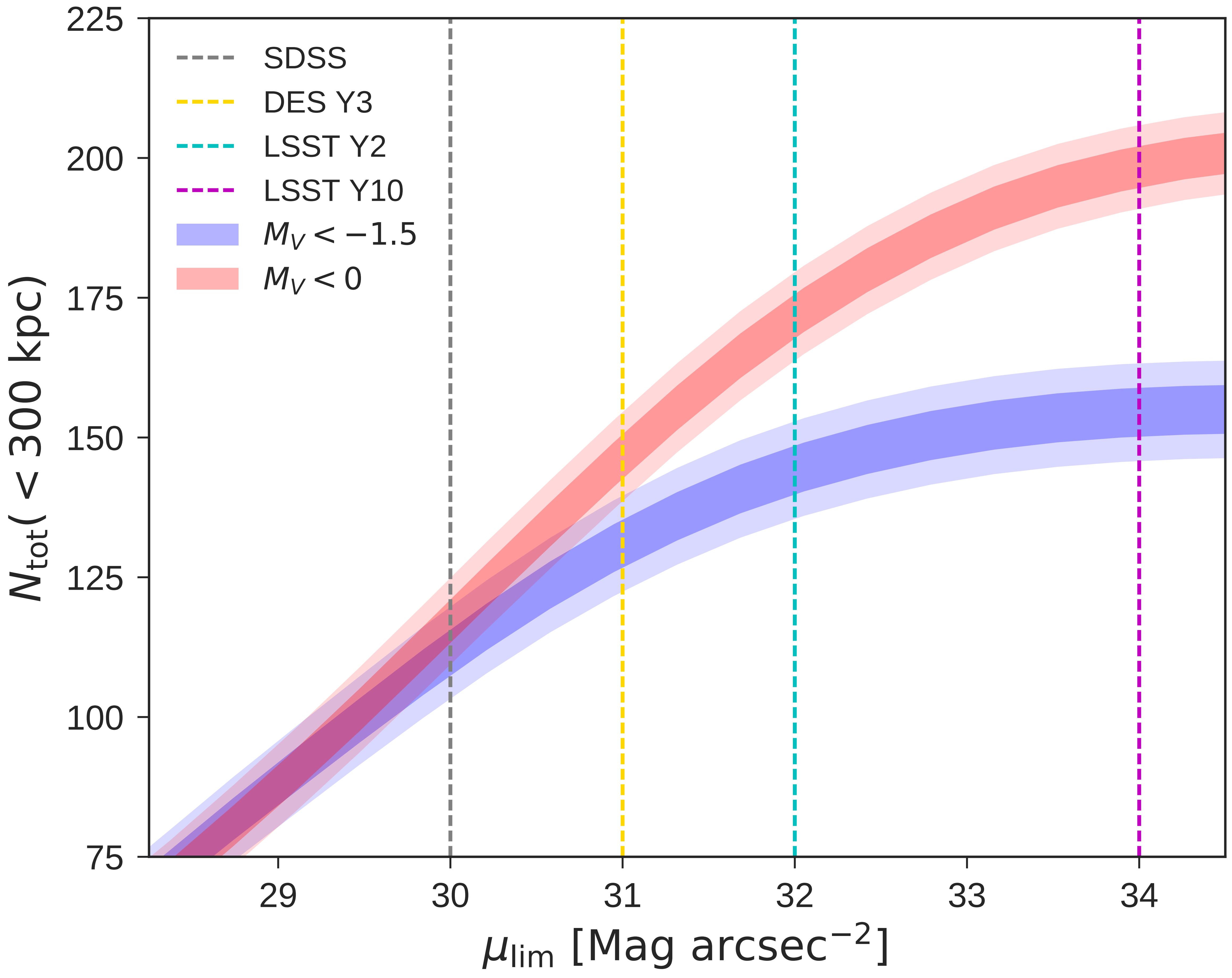
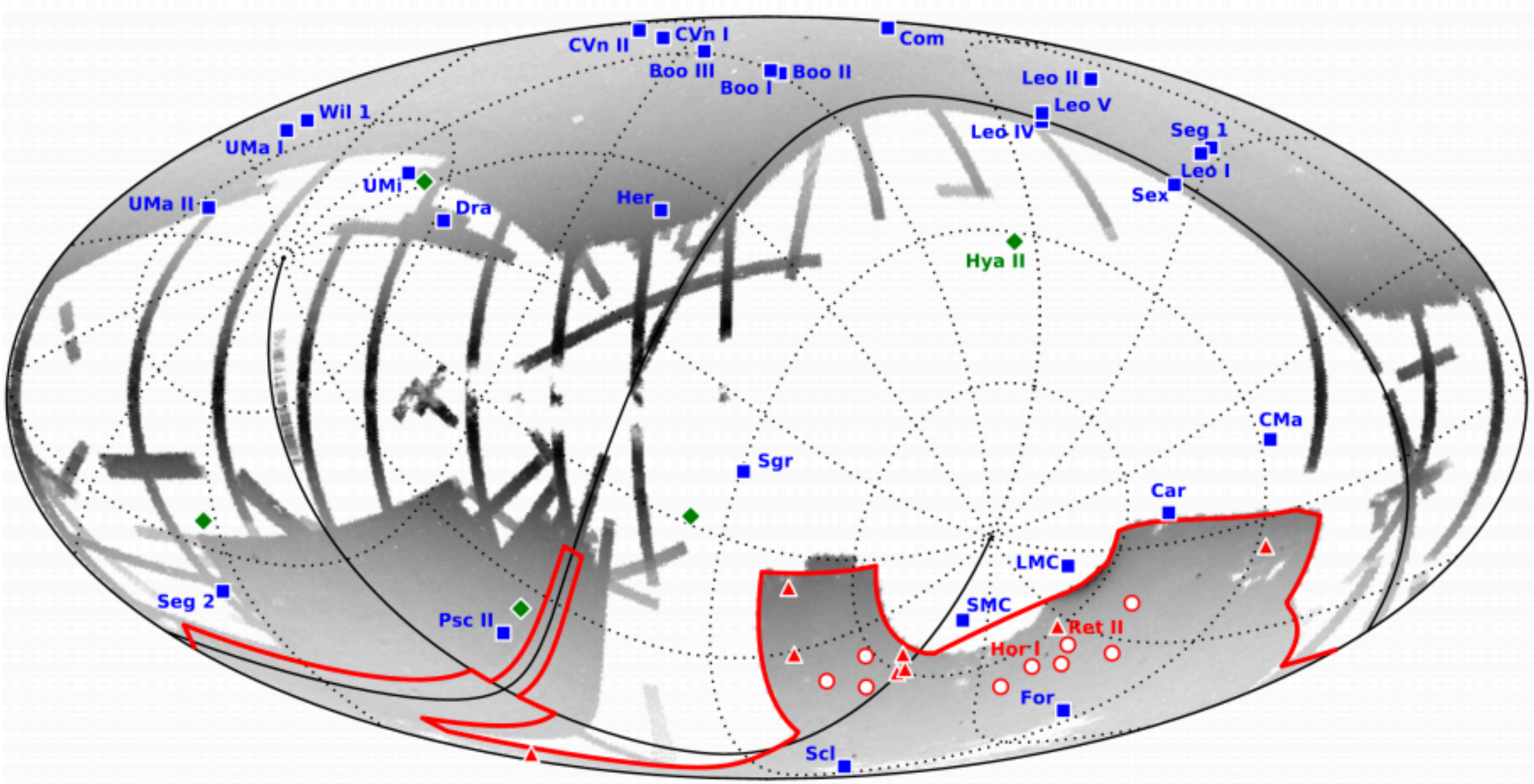


Predictions for Future Surveys





DES Y3 Milky Way Satellites

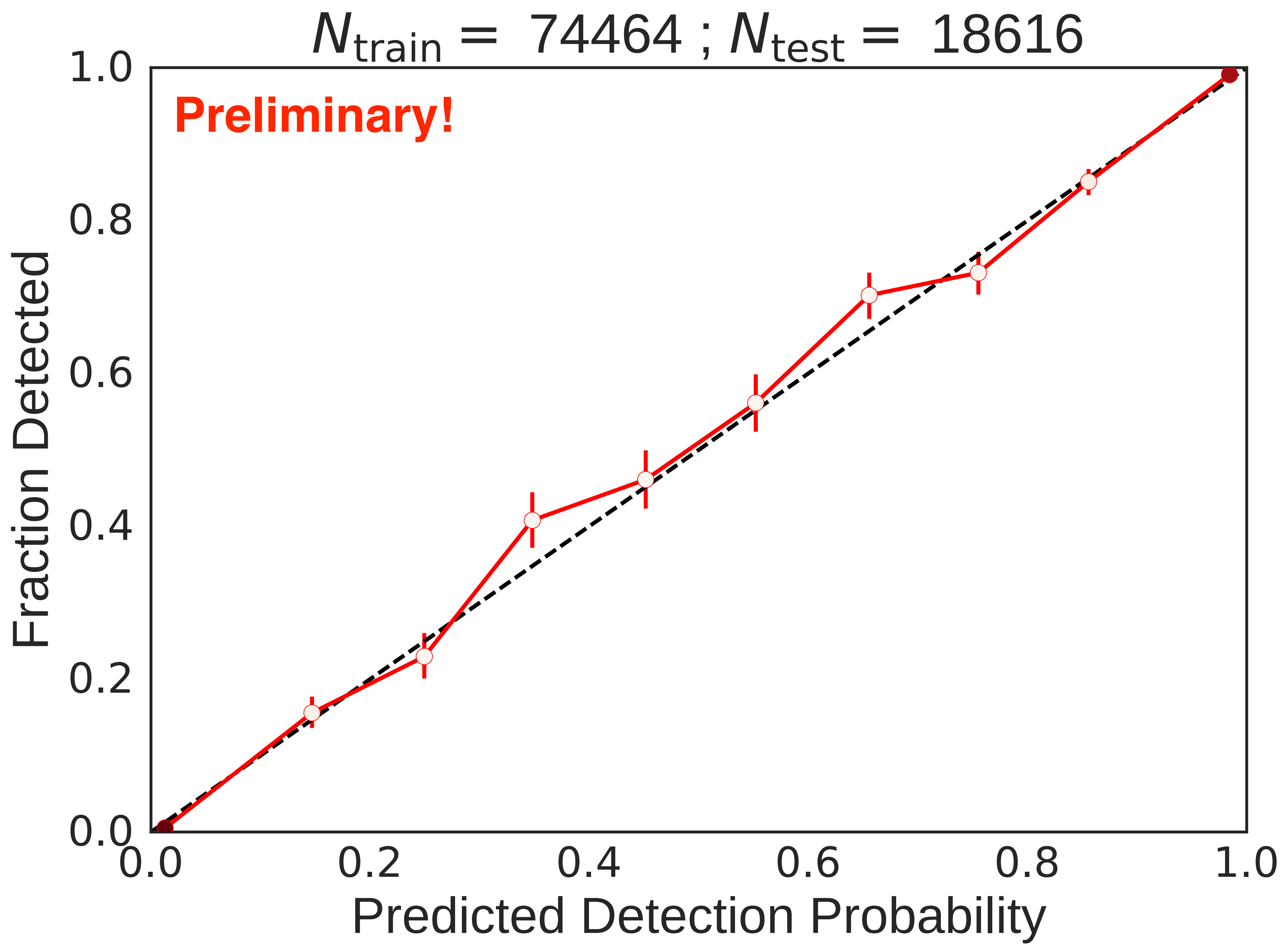


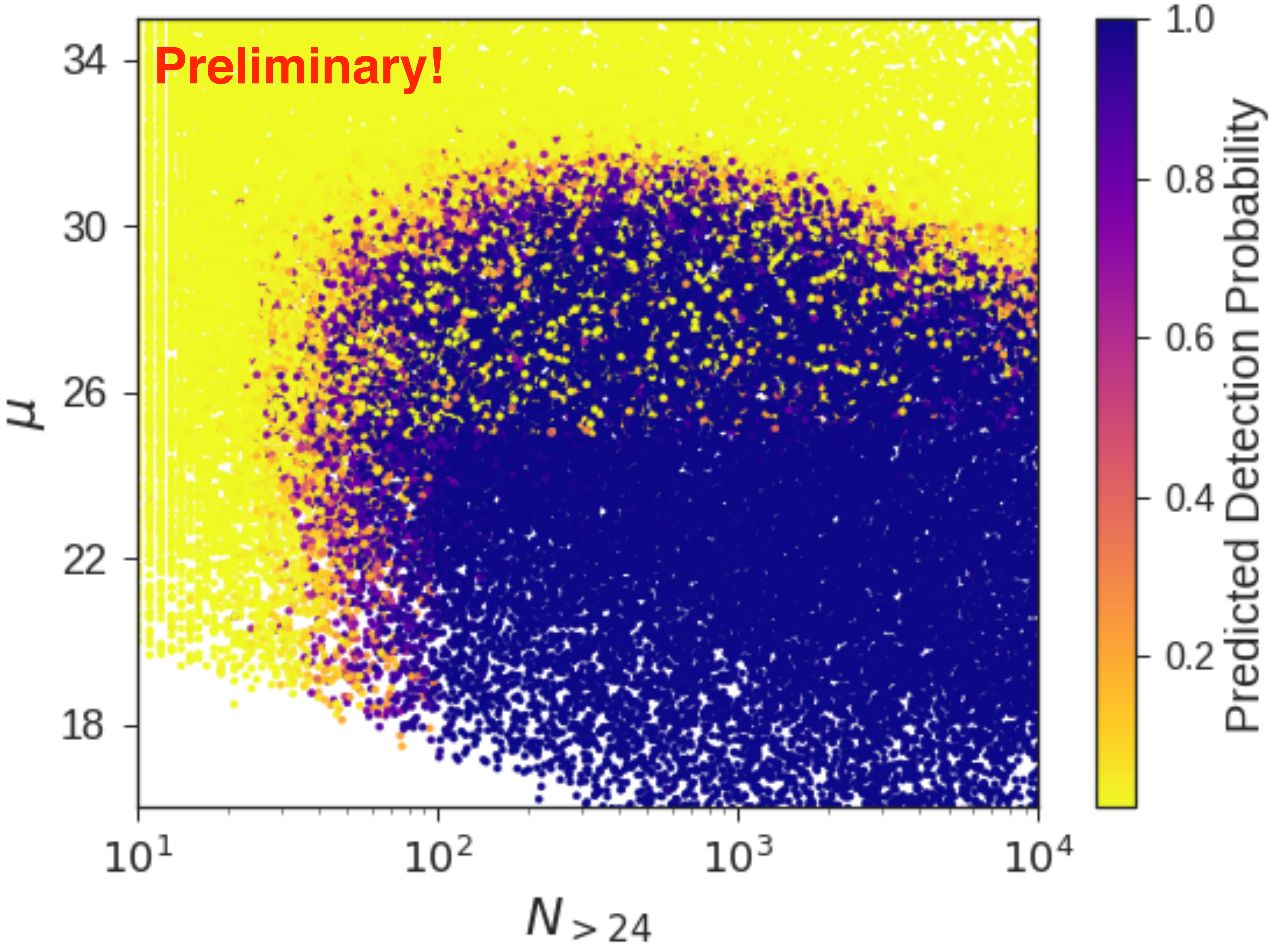
Drlica-Wagner et al. 2015

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

DES Survey Selection Function

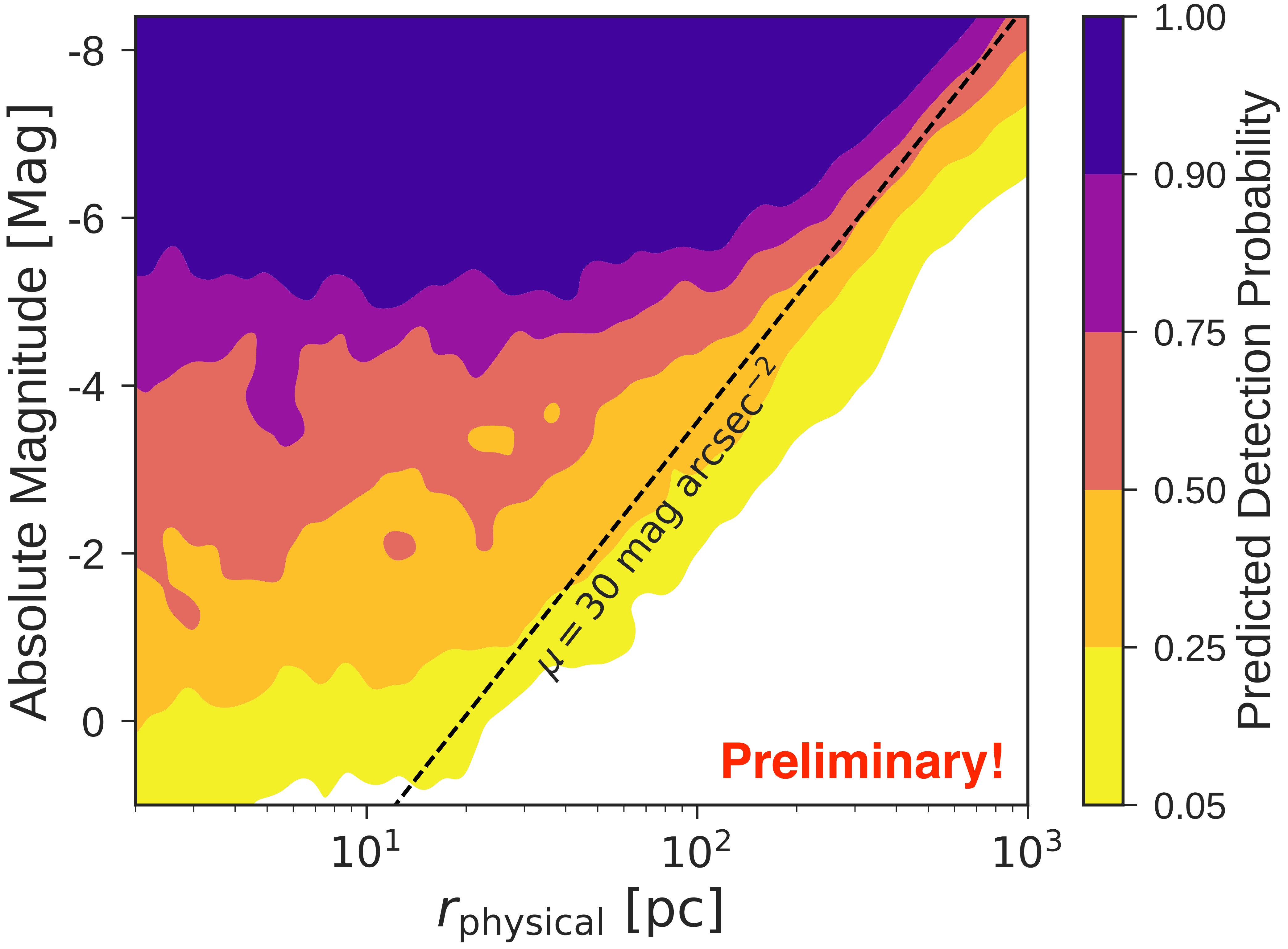
- Inject fake satellites into DES data; train algorithm to model detection efficiency
- Surface brightness, number of detected stars drive satellite detectability

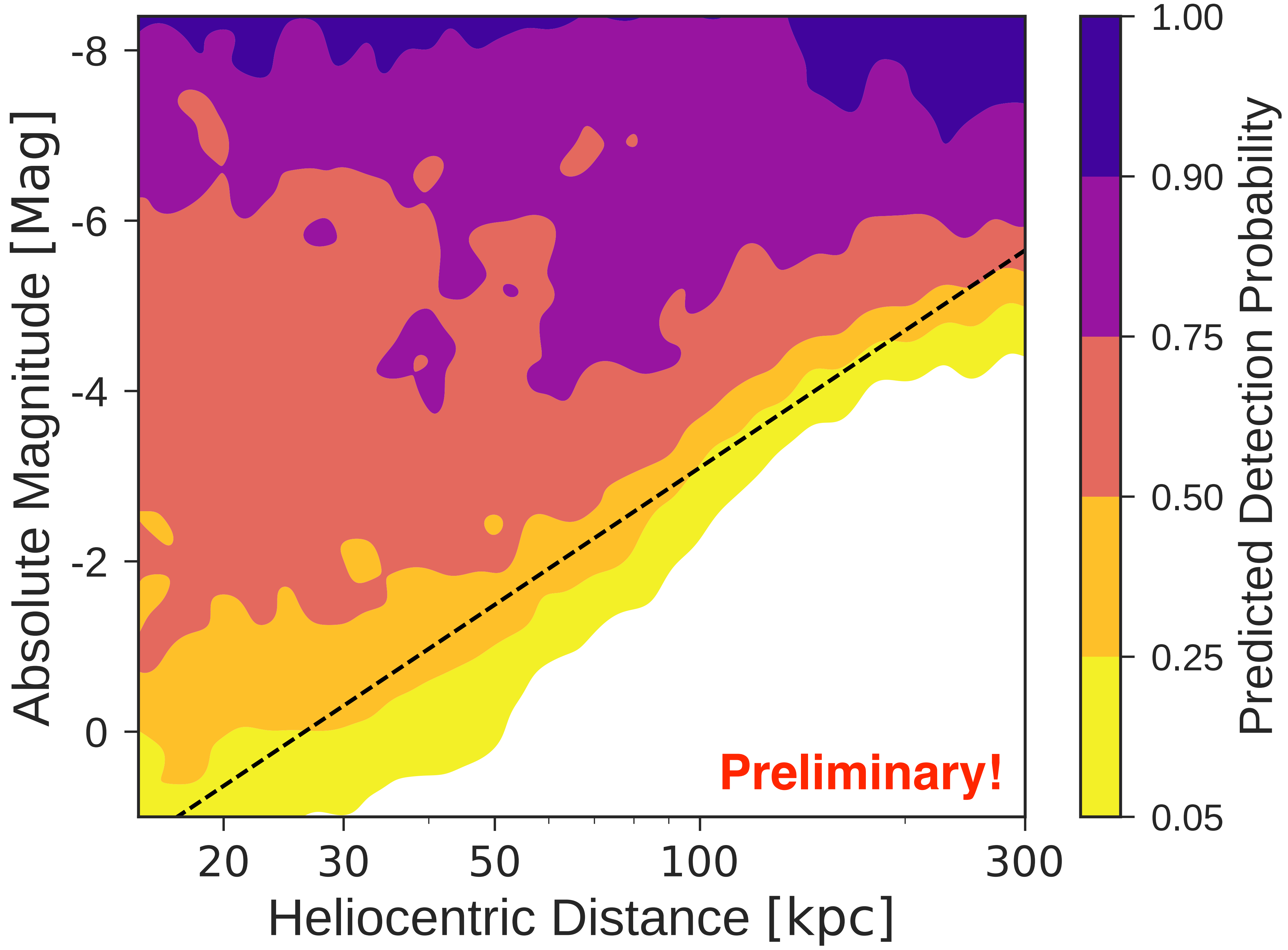




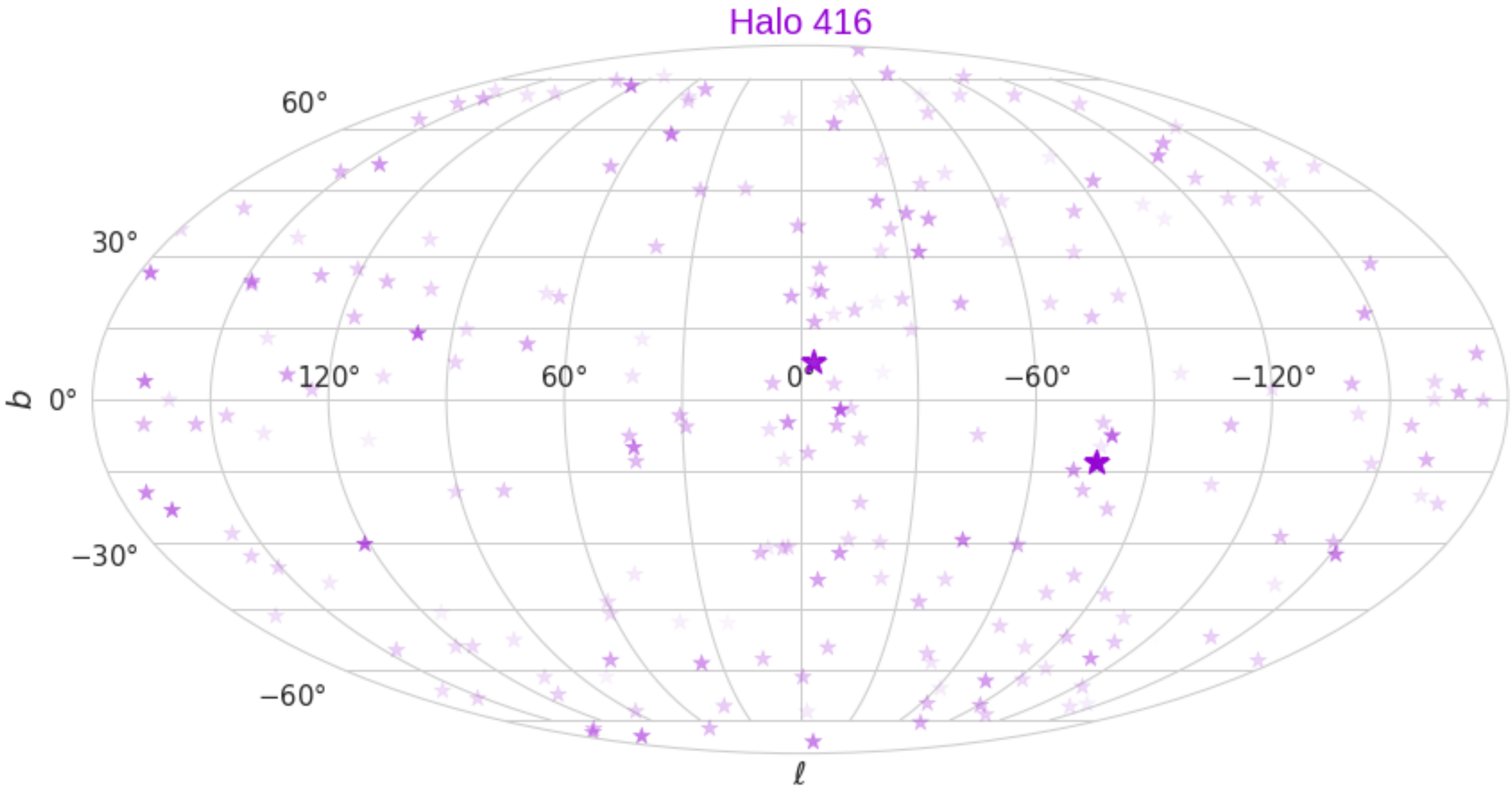
DES Survey Selection Function

- Algorithm trained on satellite magnitude + size + distance remains accurate
- Projections of detection probability in physical parameter space:





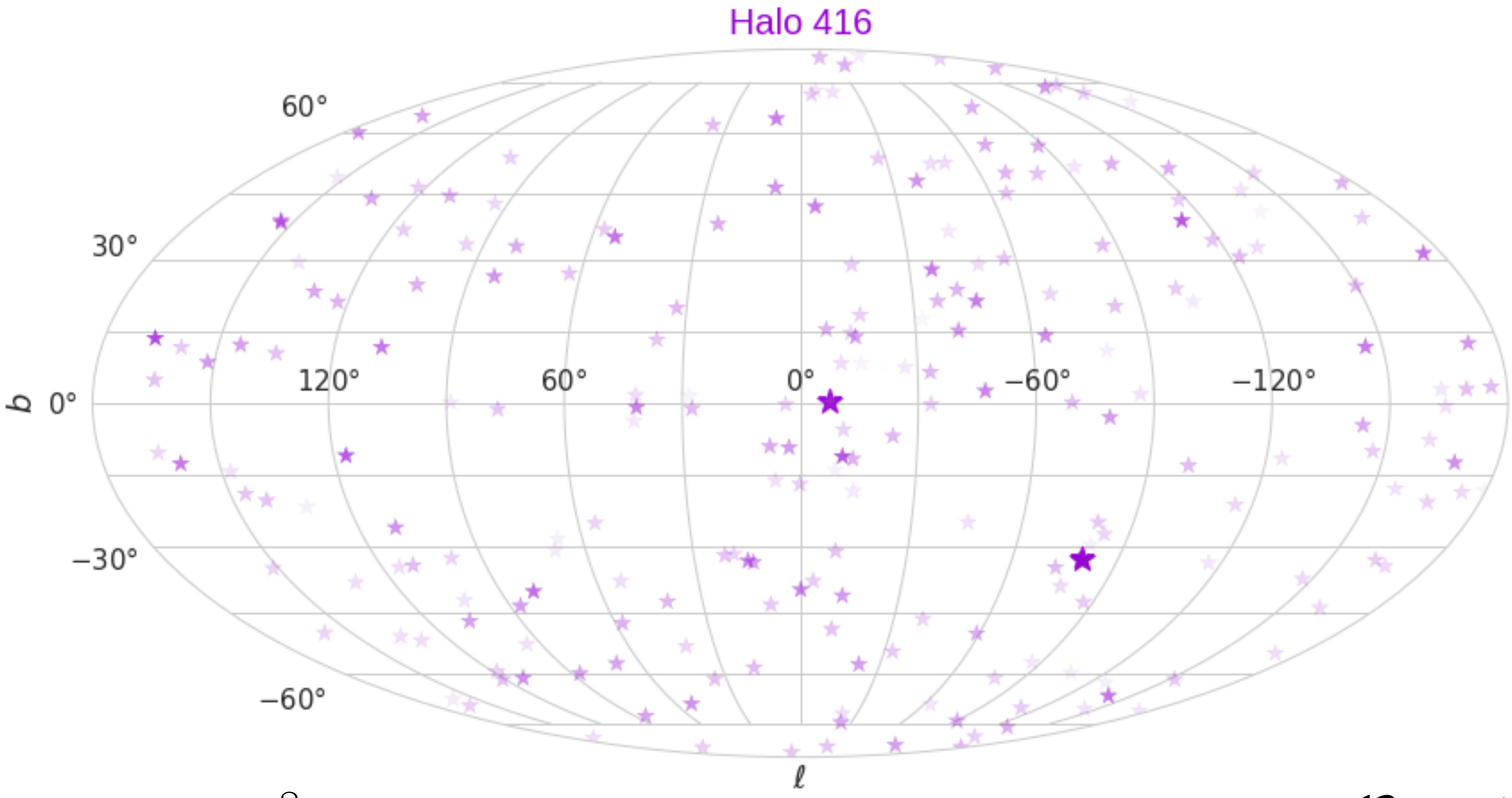
Modeling DES Satellites



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

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

Modeling DES Satellites



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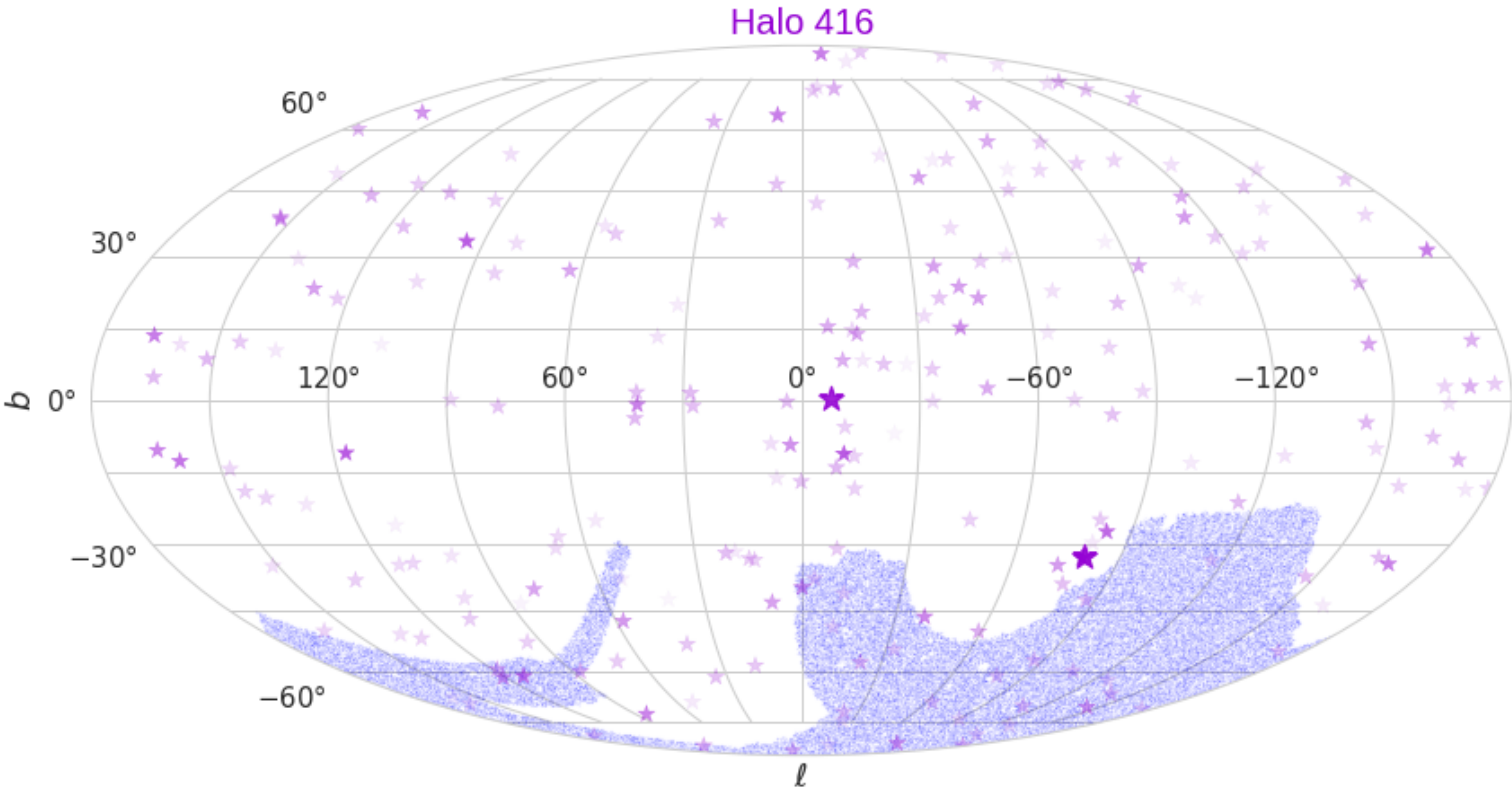
Modeling DES Satellites



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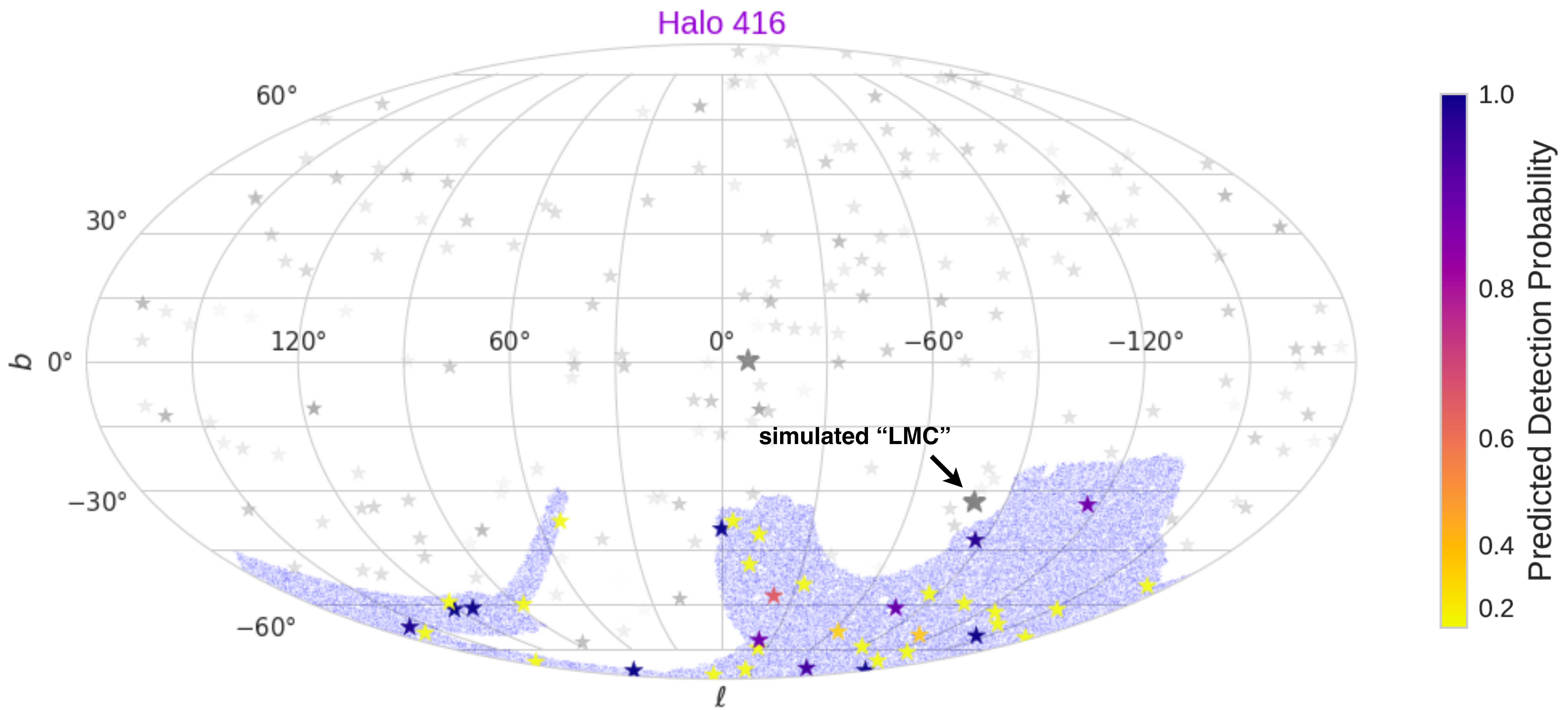
Modeling DES Satellites



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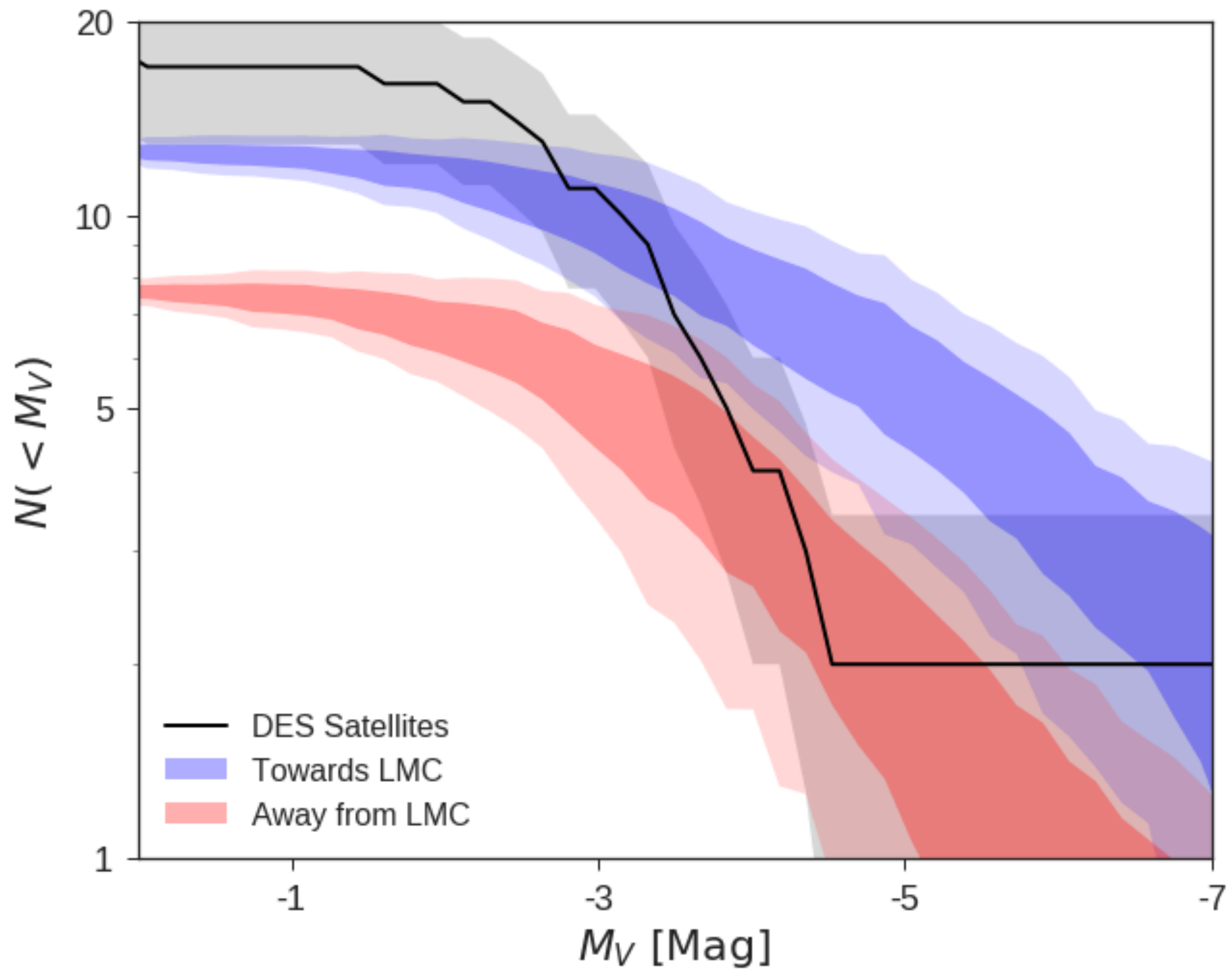
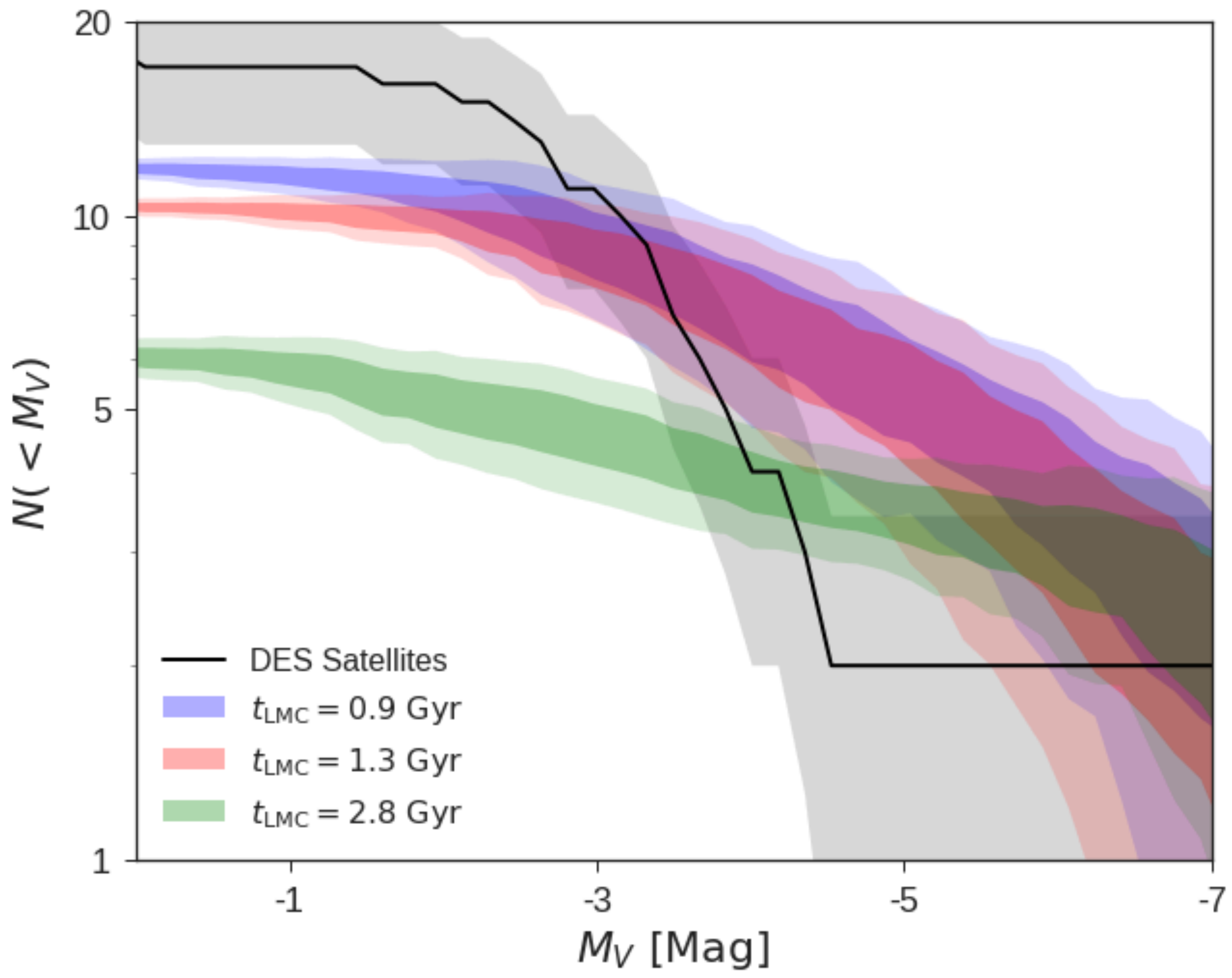
Modeling DES Satellites

- Fold cosmological model through DES footprint + survey selection function
- Predicted luminosity function is sensitive to LMC position and accretion time





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, …

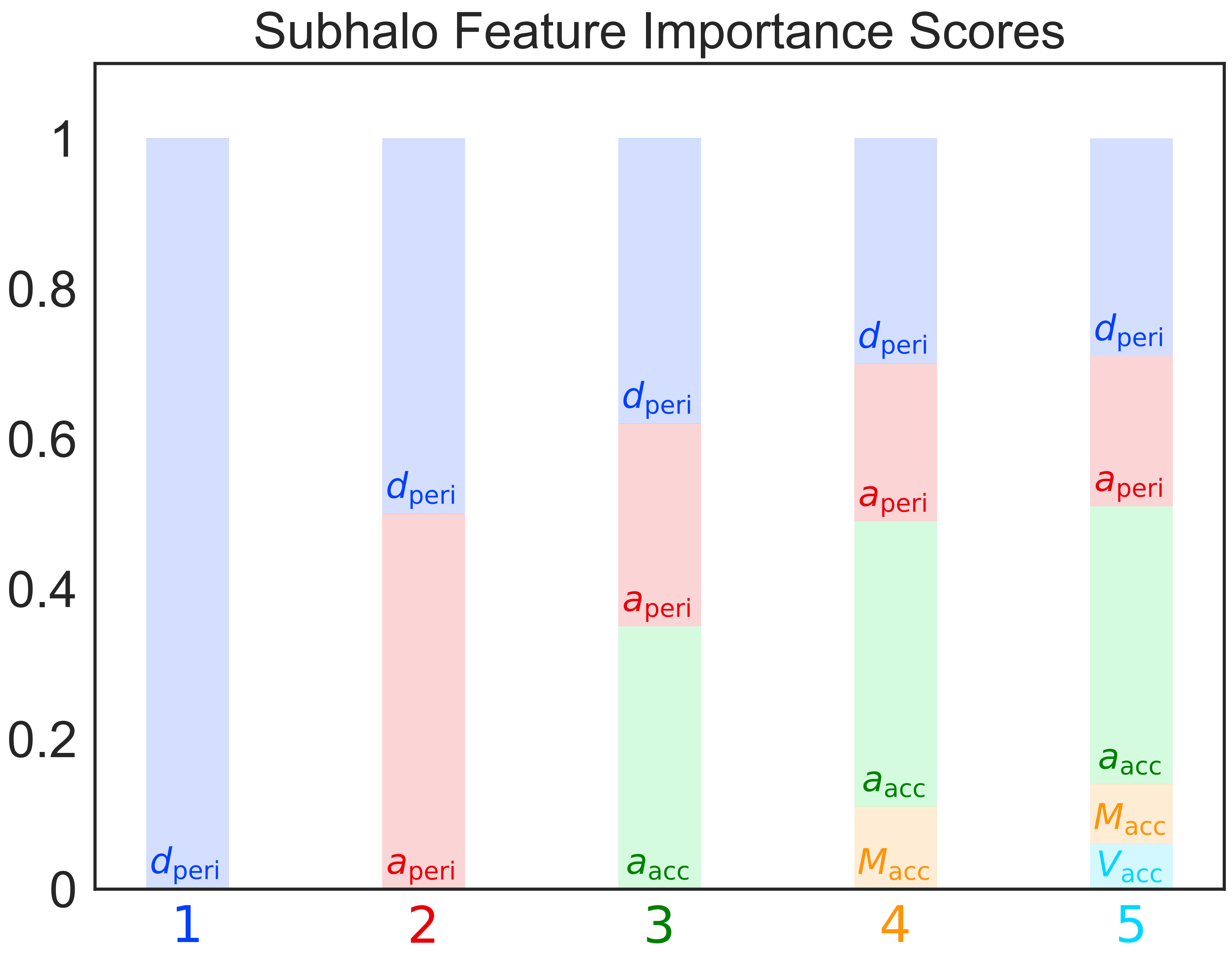
Some data-driven questions:

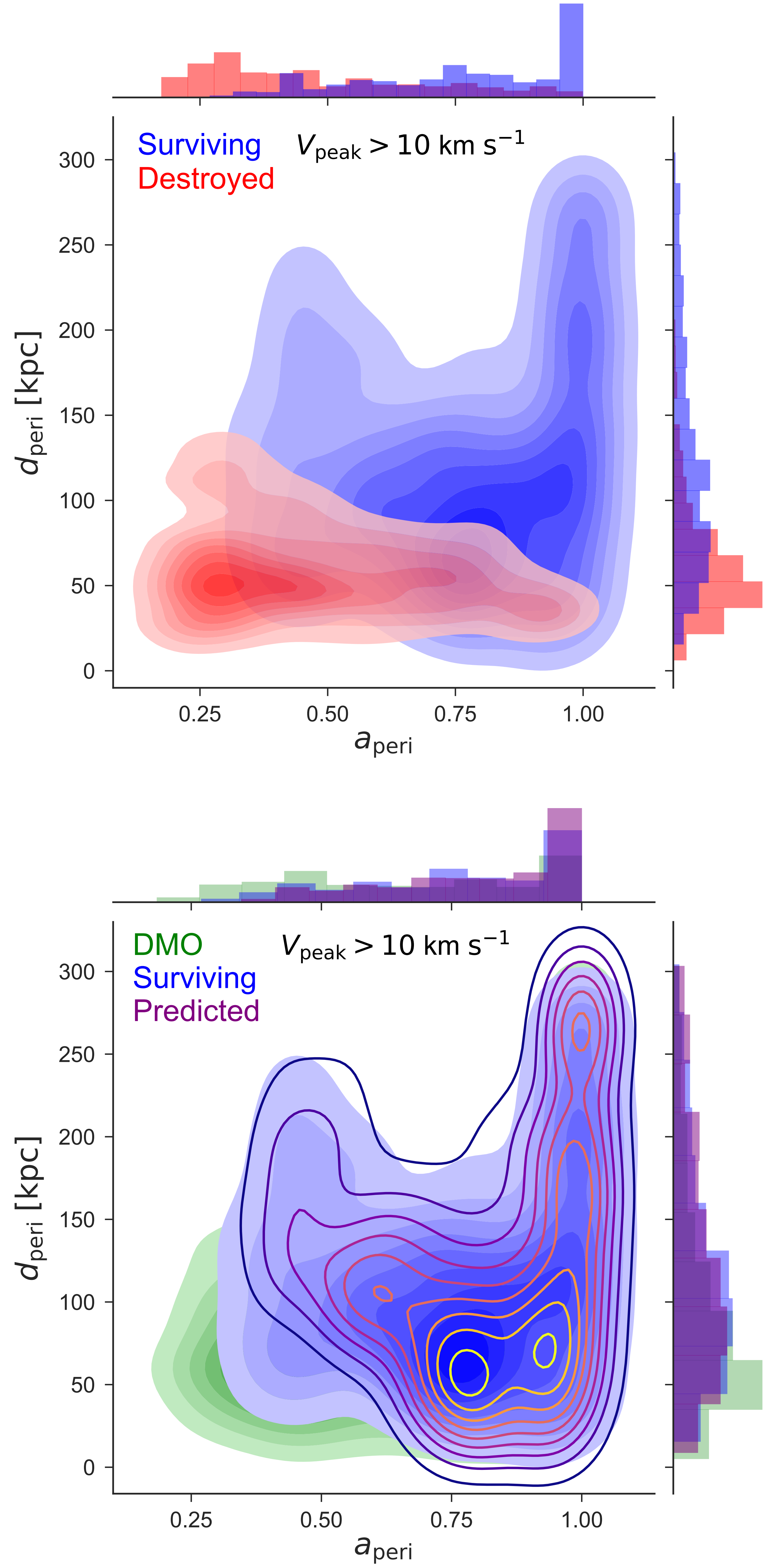
- Are observed/predicted satellite distributions consistent with isotropy?
- Is there evidence for a distinct LMC/SMC satellite population?
- What can we infer about the properties of subhalos that host DES satellites?
- Are the orbits of simulated satellites consistent with results from GAIA?

Bonus Slides

Baryonic Subhalo Disruption

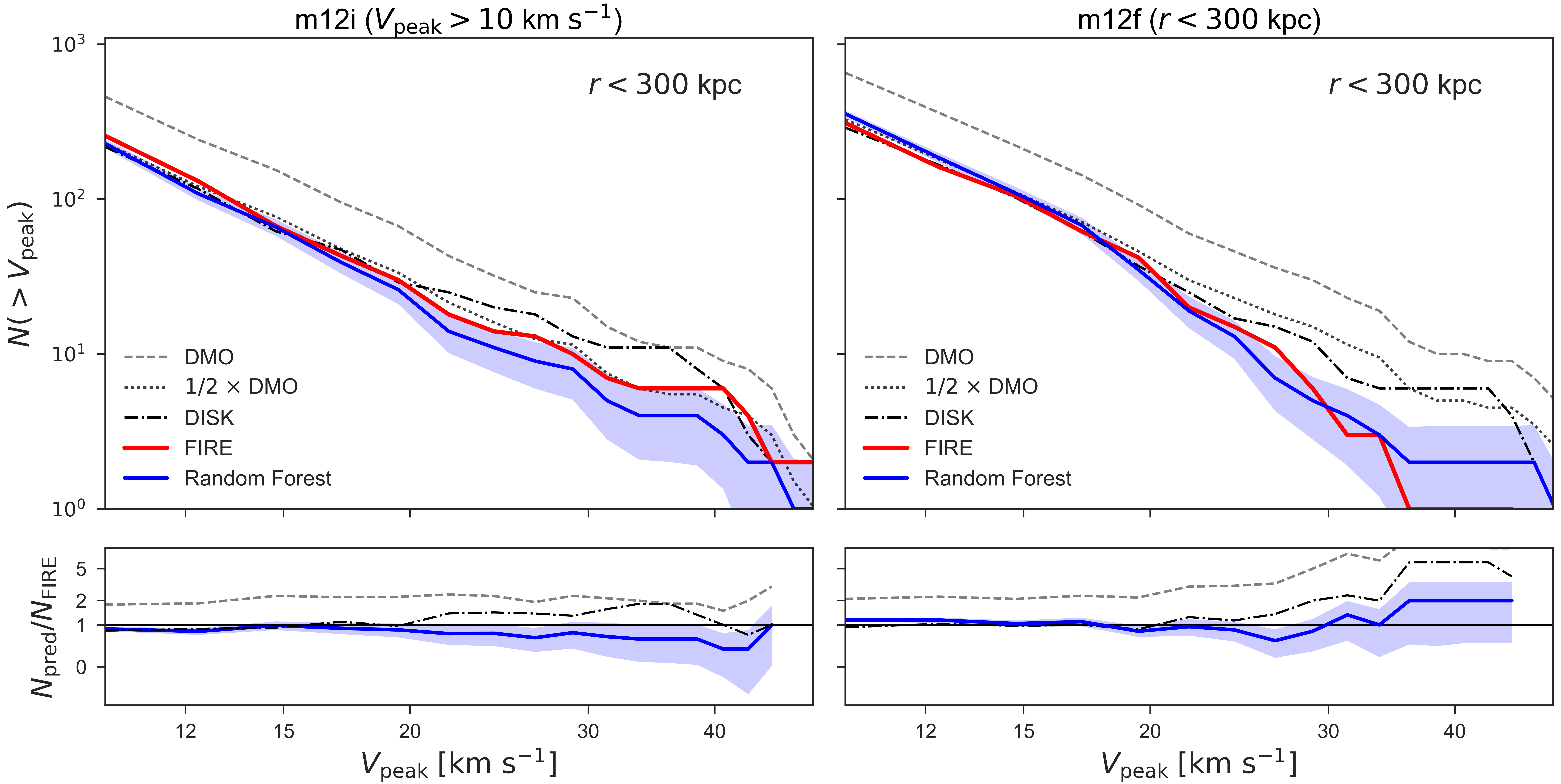
- Five subhalo features encode ~90% of disruption
- Predicted subhalo properties consistent with FIRE



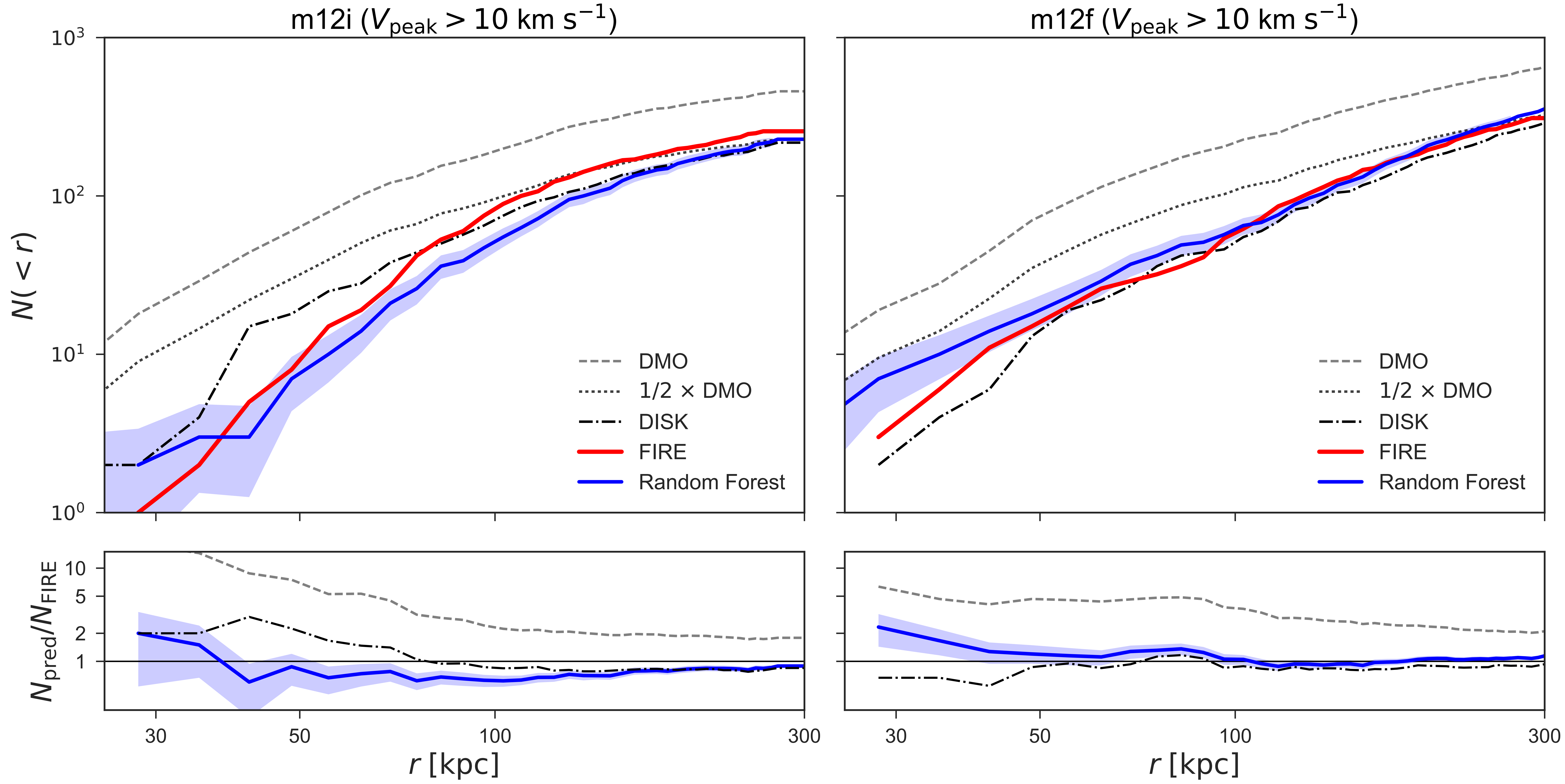


Nadler et al. 2018

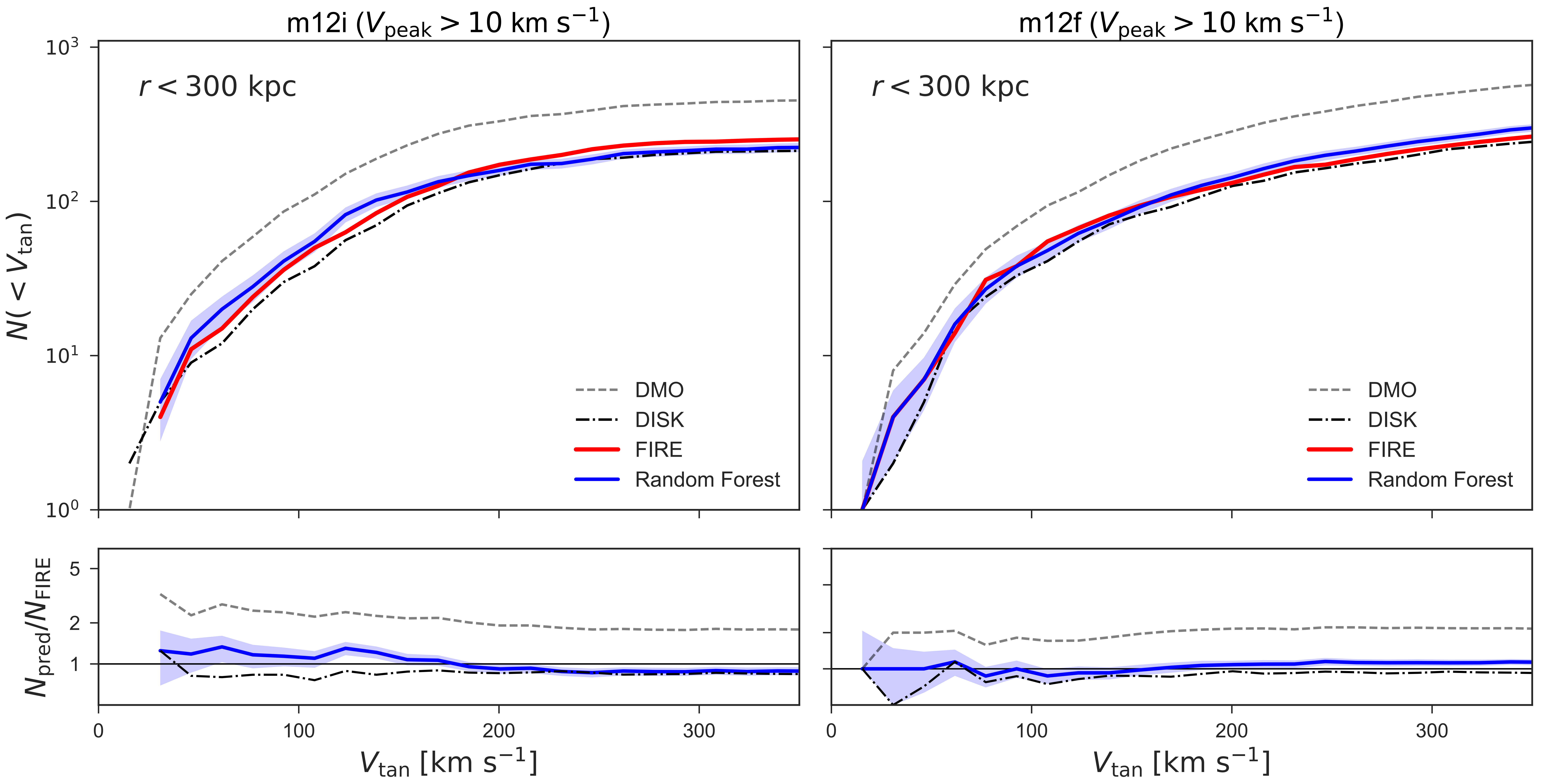
Peak Velocity Functions



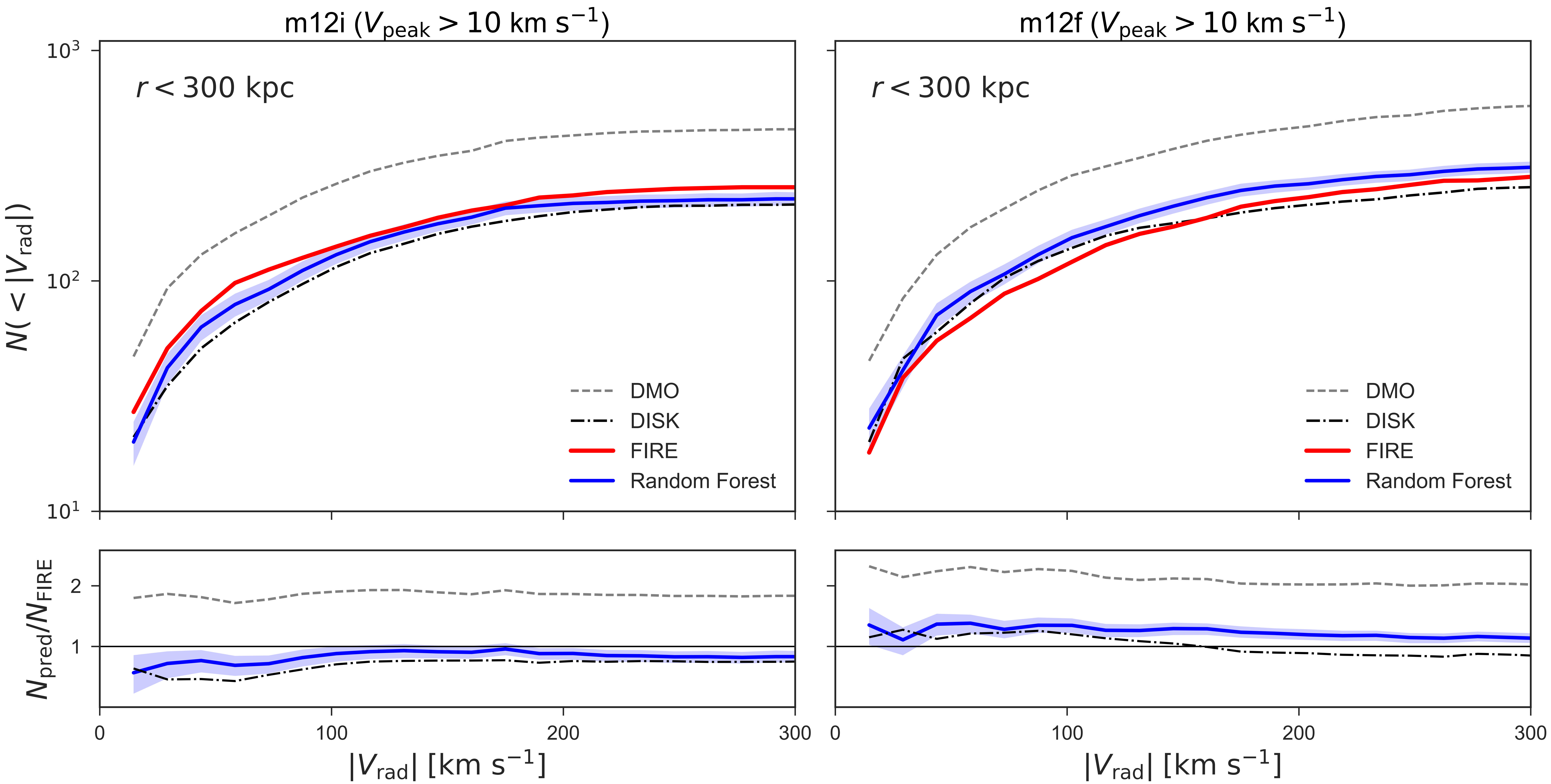
Radial Distributions



Orbital Velocity Distributions



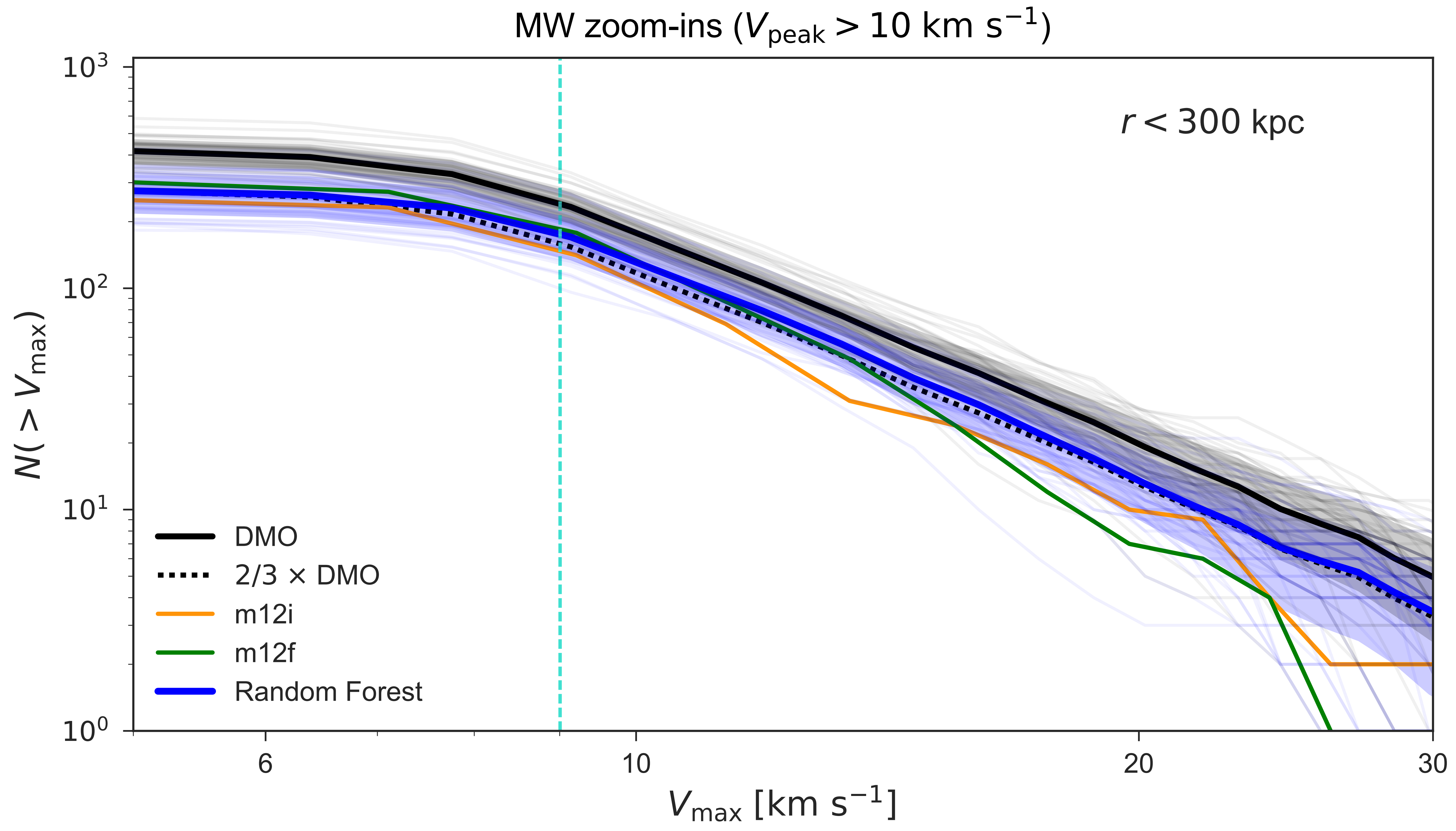
Radial Velocity Distributions

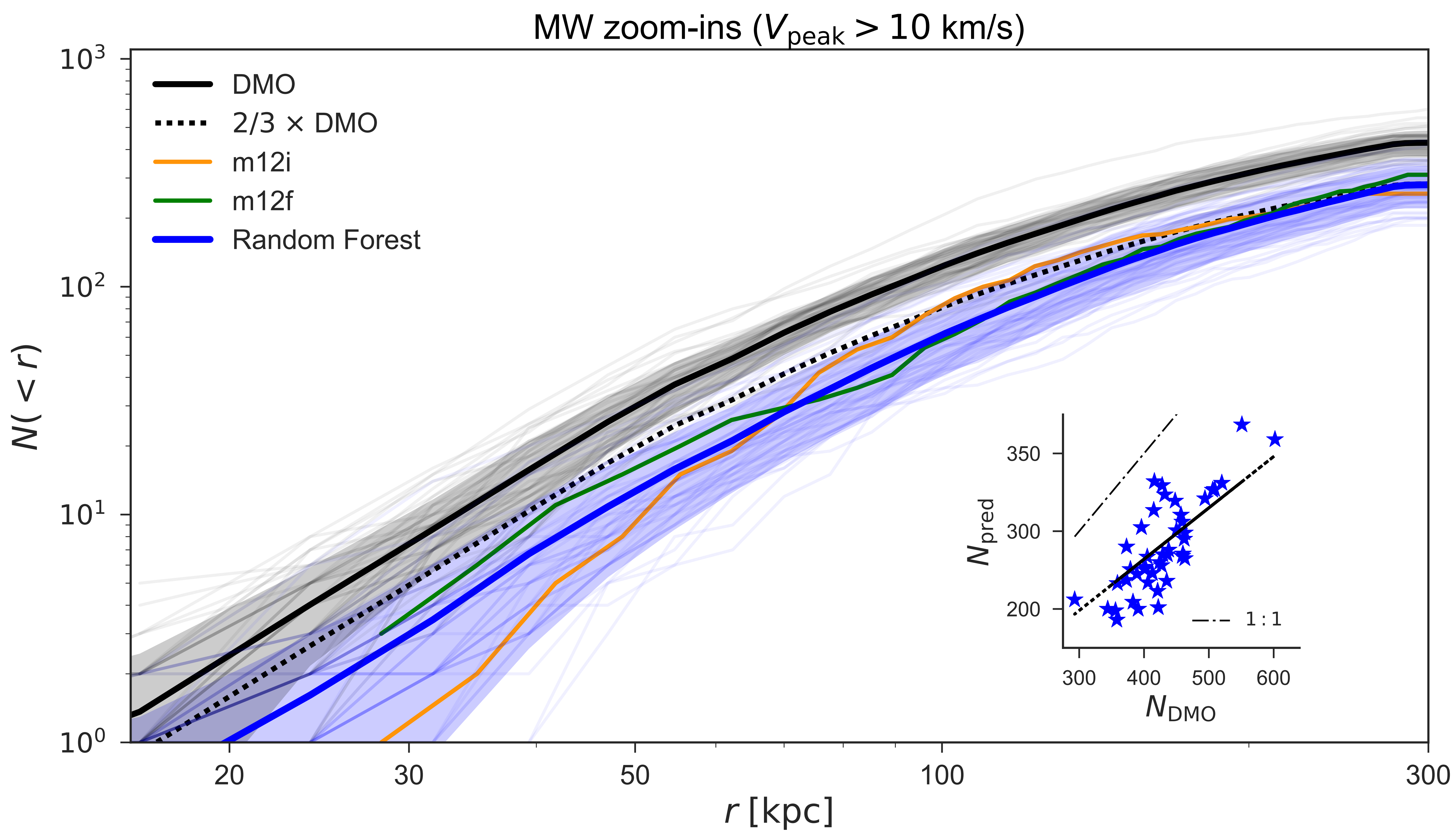


Applications and Extensions

Trained model (github/eonadler) predicts subhalo disruption probabilities

Example: 45 MW zoom-ins with range of formation histories (Mao et al. 2015)

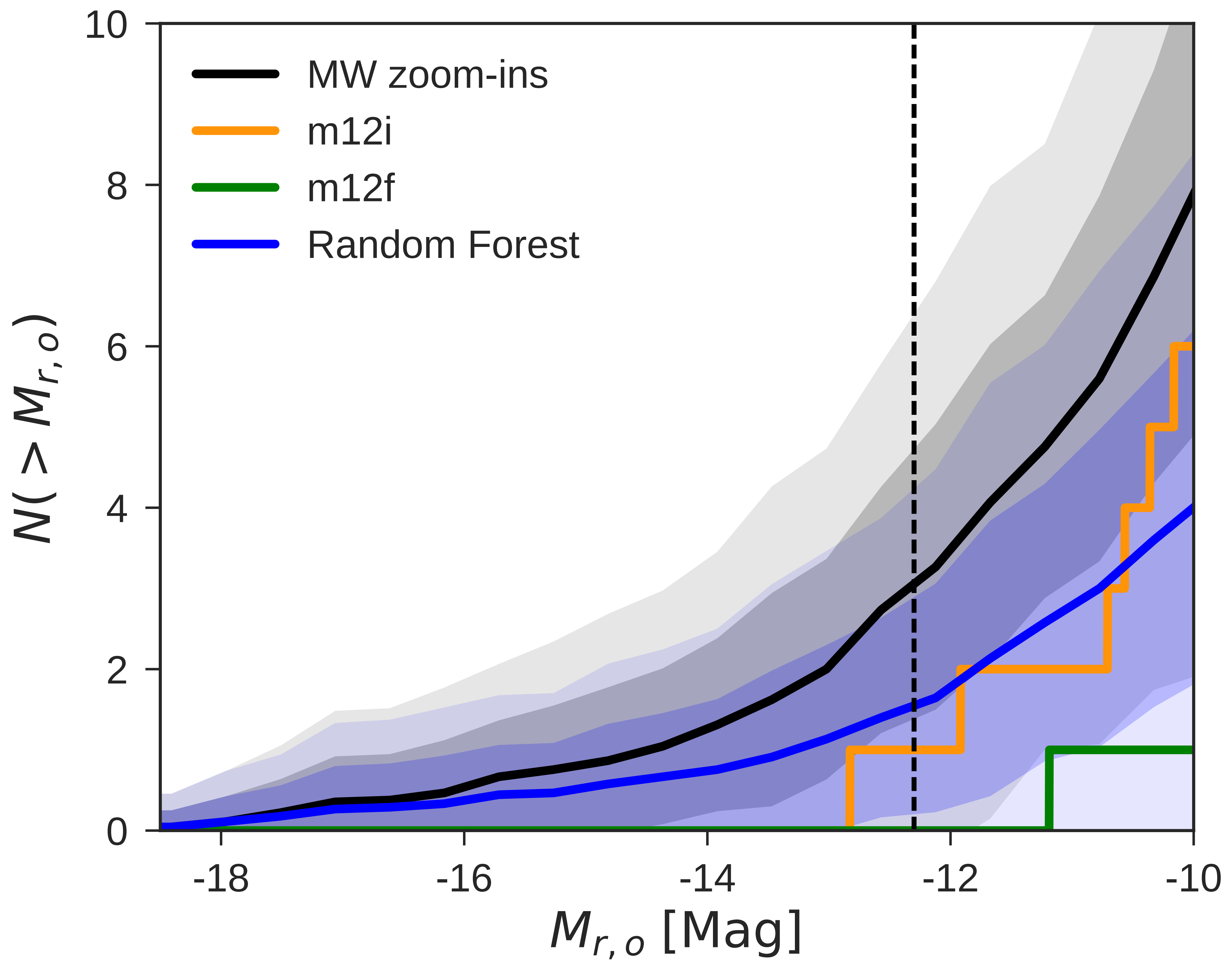


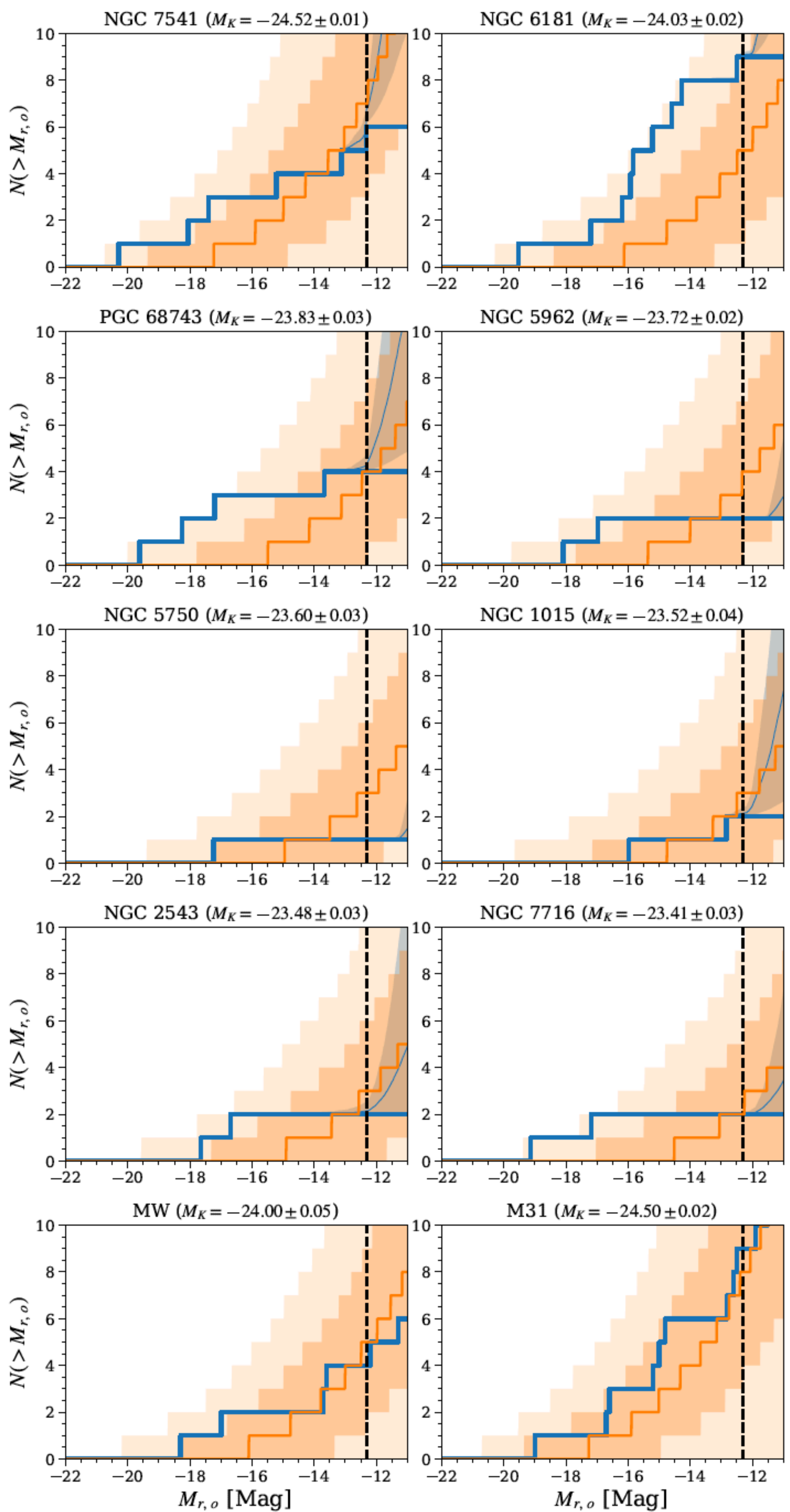


Predicted disruption is larger than halo-to-halo scatter!

Modeling Milky Way Analogs

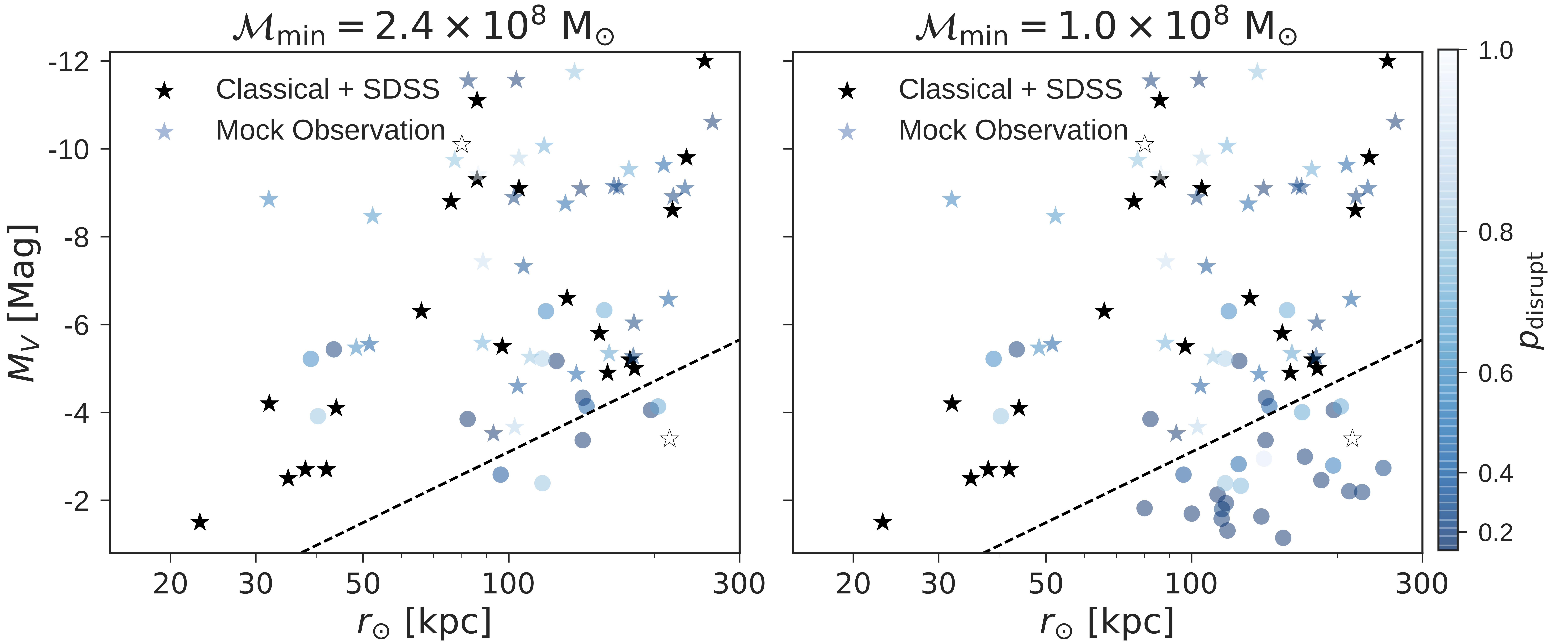
- Ensemble of MW analog LFs measured by SAGA
- Generalize model for variable host halo mass





Geha et al. 2017

Example: Classical + SDSS Satellites



Example: DES Satellites