

# BLOODHOUND: TESTING $\Lambda$ CDM WITH DARK MATTER SUBHALOS

HYUNSU KONG

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[hyunsukong.github.io](https://hyunsukong.github.io)

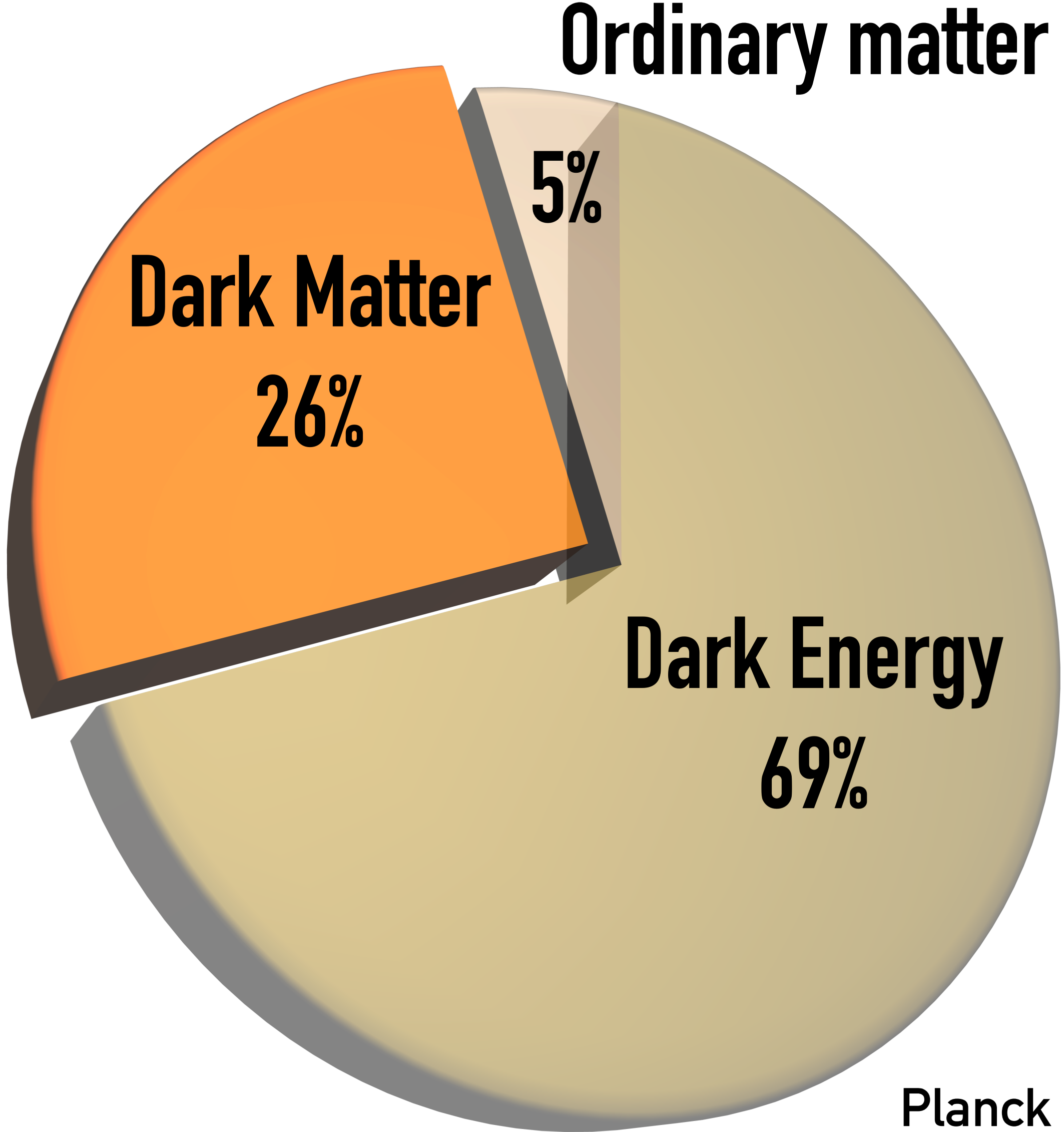
PMA 16.212



11/02/2023

PHYSICS CONCERTO

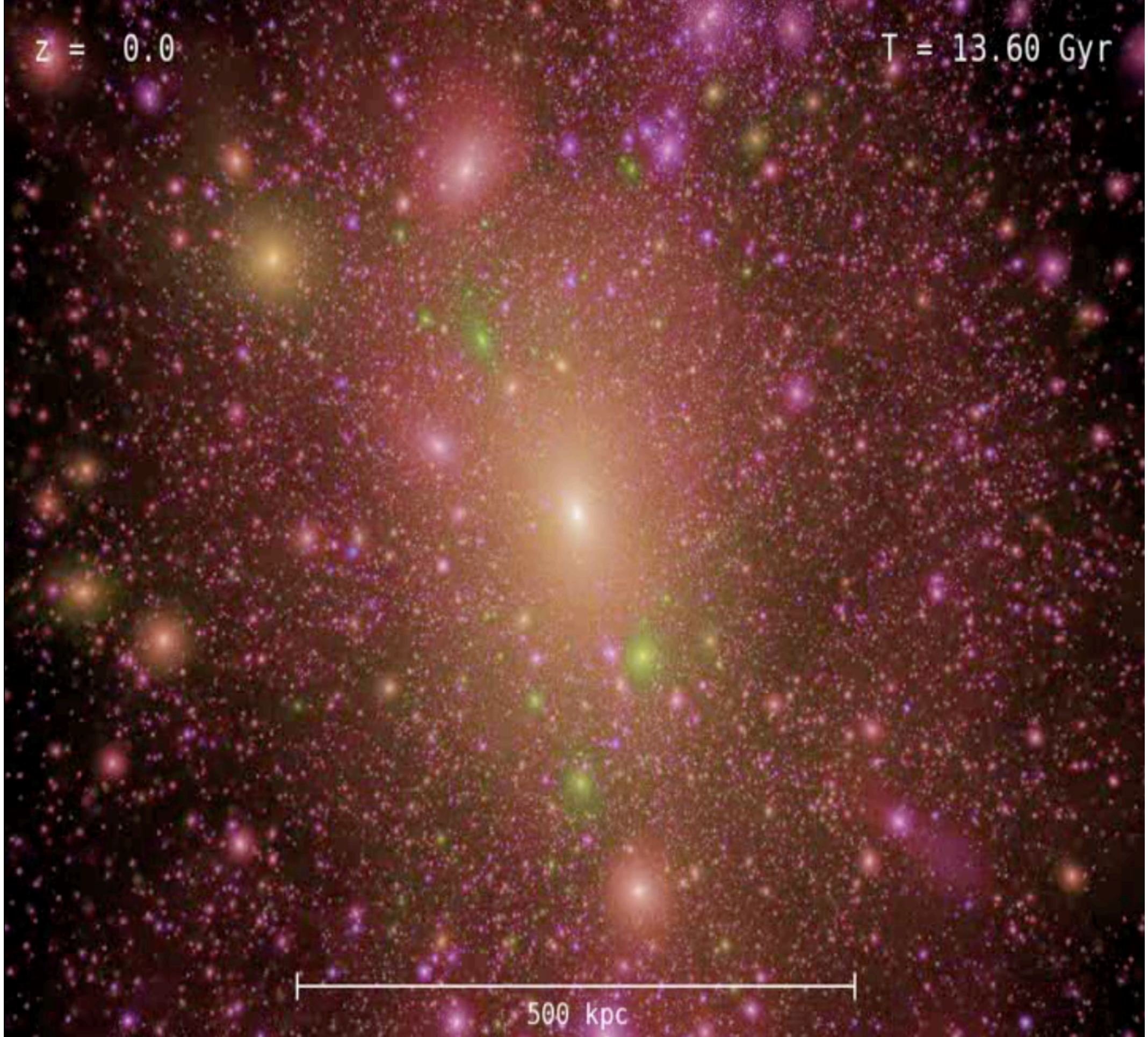
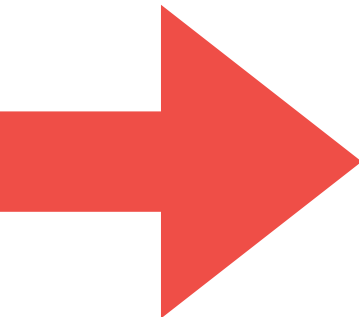
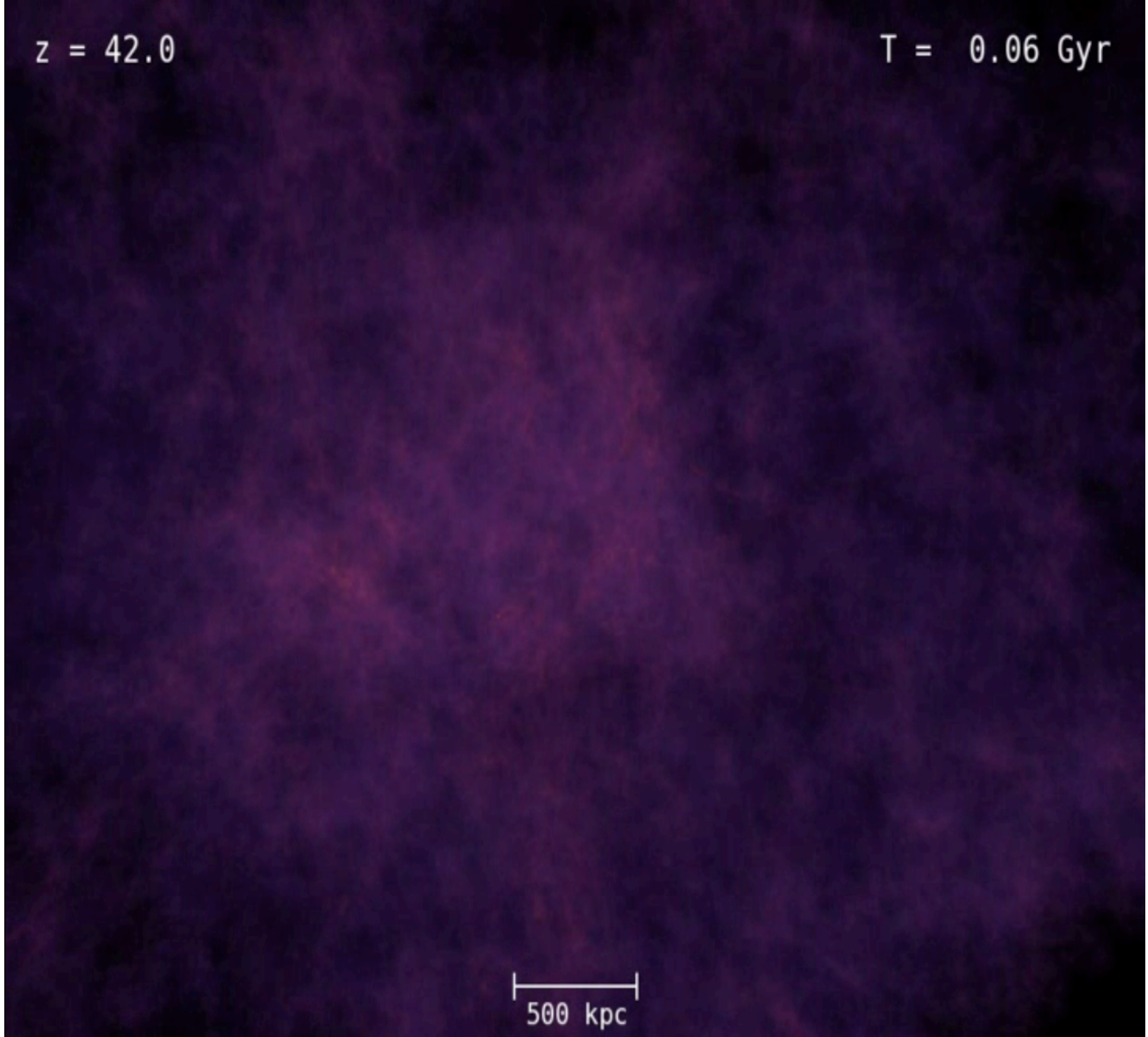
# $\Lambda$ CDM: A MOSTLY DARK UNIVERSE



Planck Collaboration 2018

# $\Lambda$ CDM: STRUCTURE FORMATION

From this

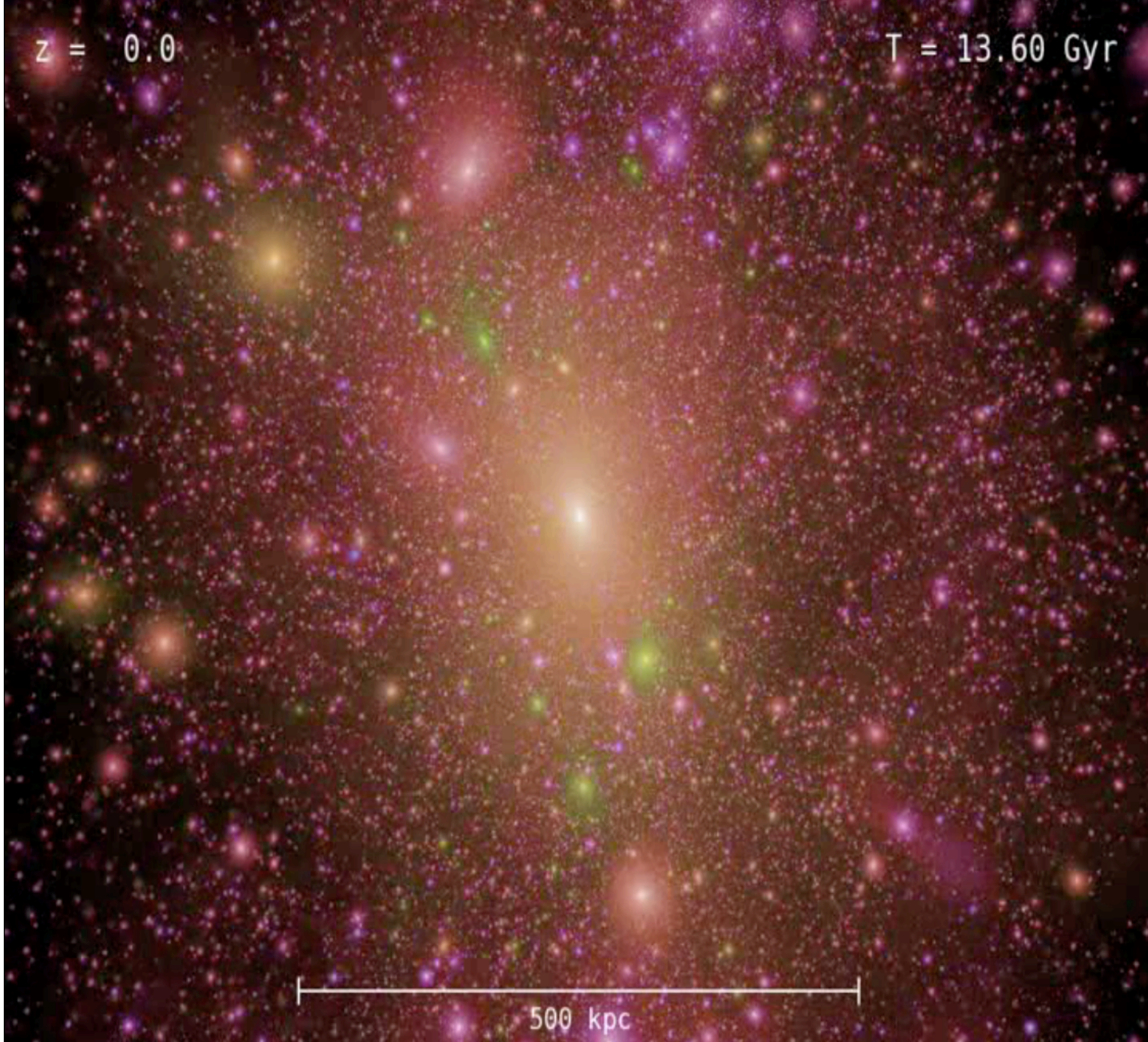
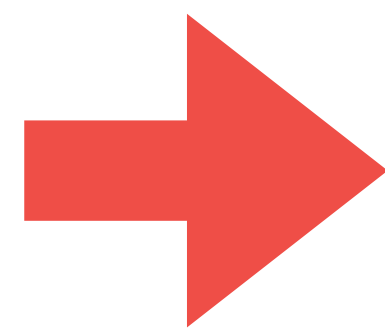
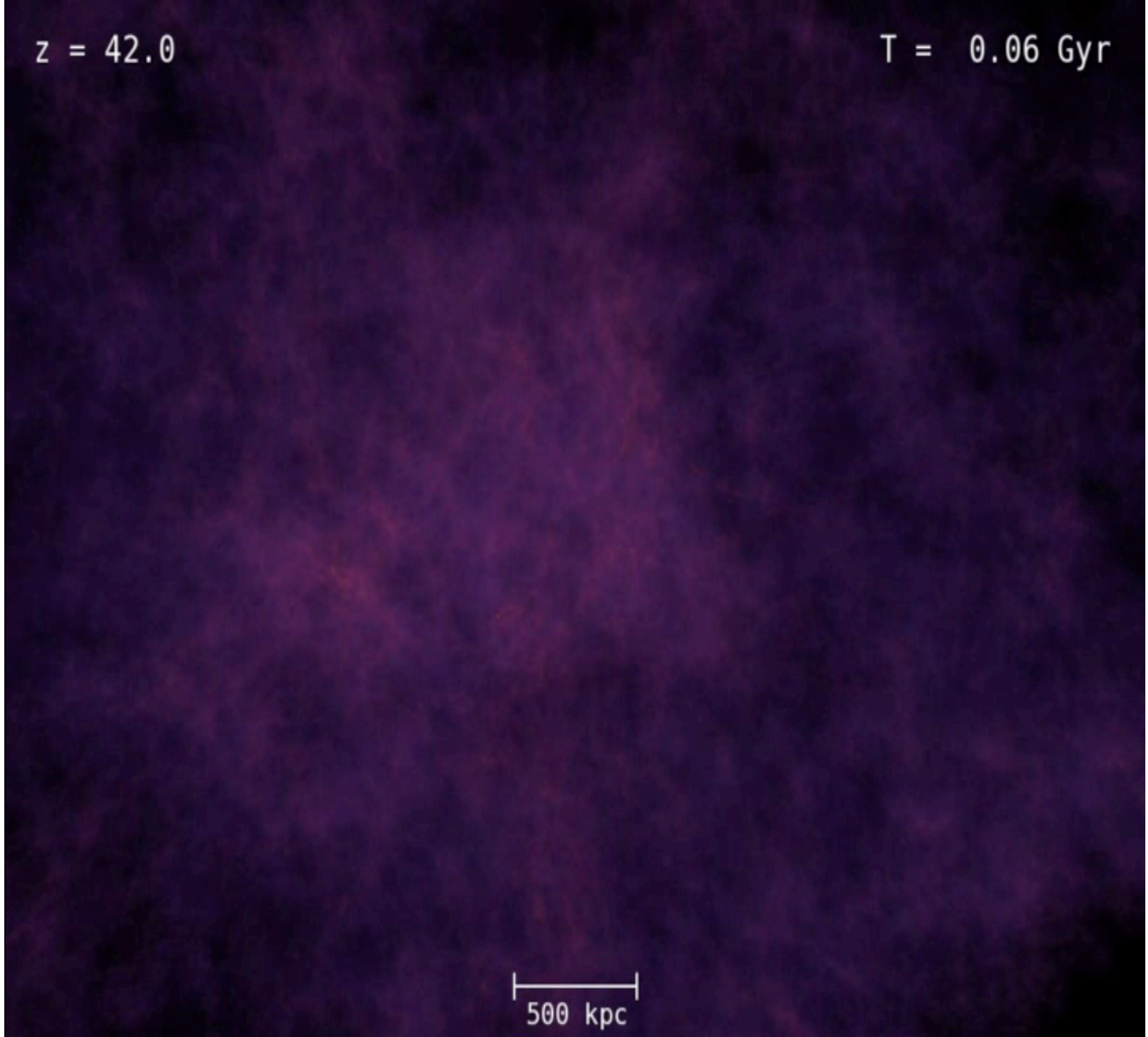


The Aquarius Project

# $\Lambda$ CDM: STRUCTURE FORMATION

From this

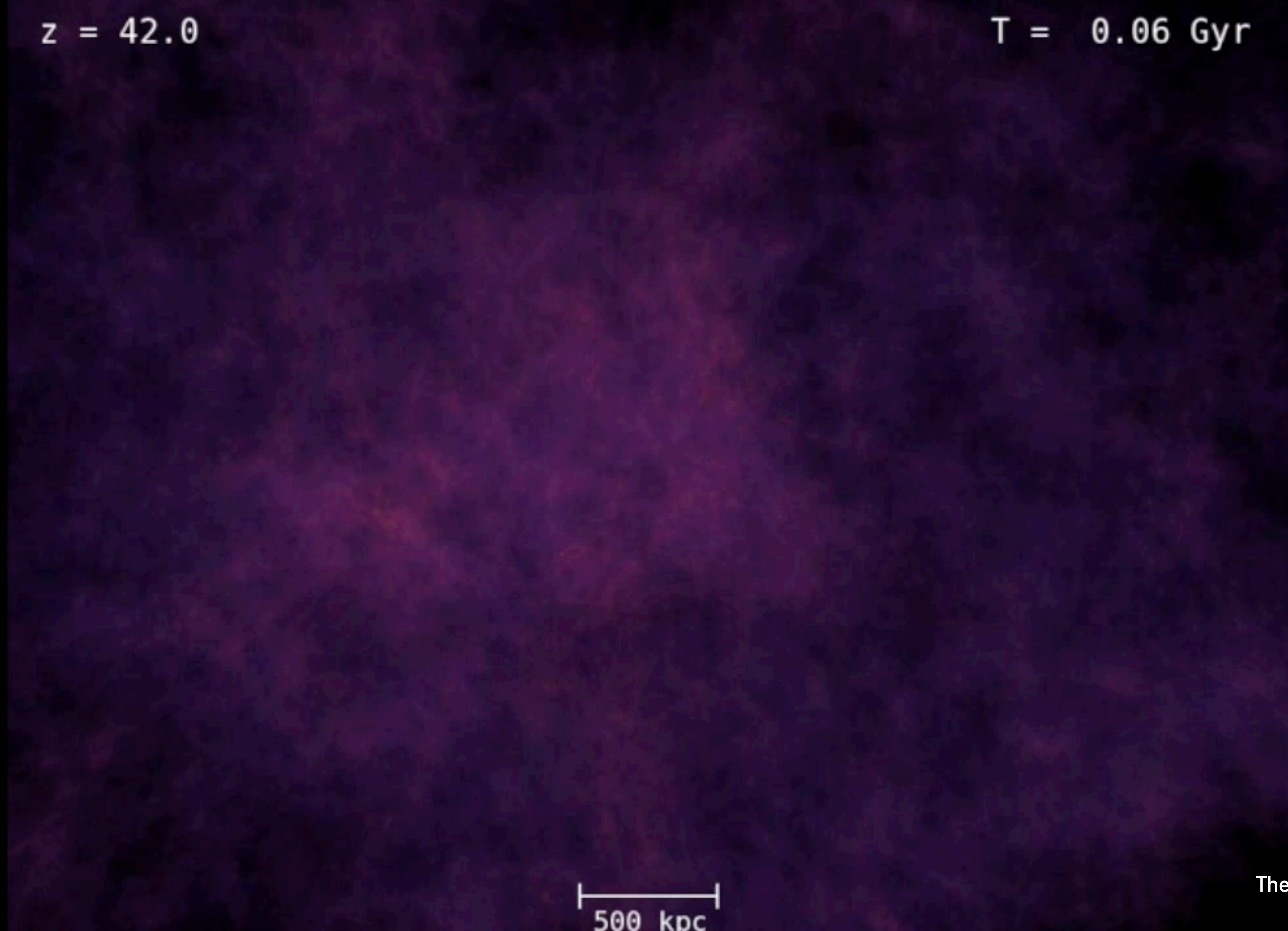
To this



The Aquarius Project

$z = 42.0$

$T = 0.06 \text{ Gyr}$

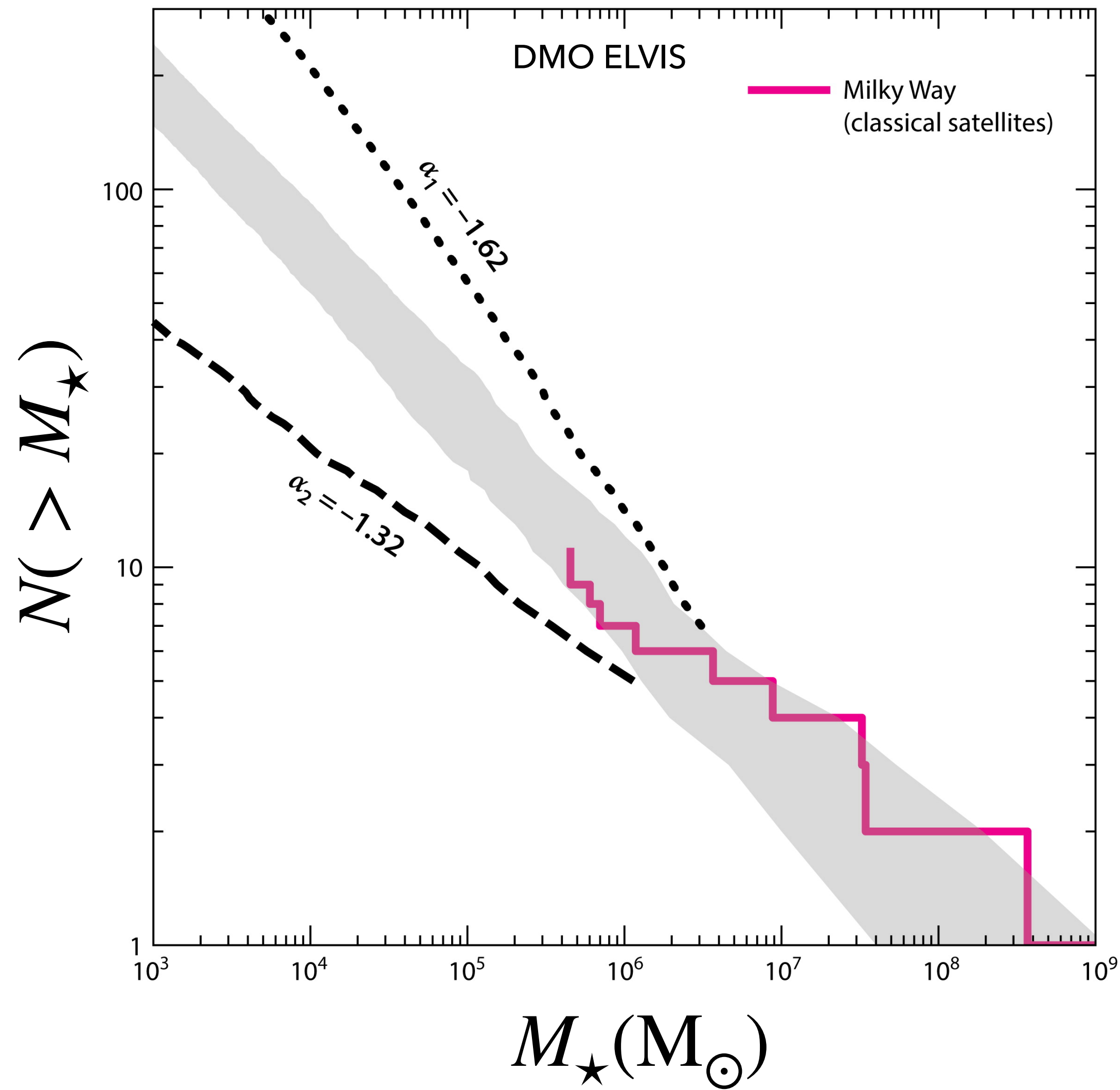


500 kpc

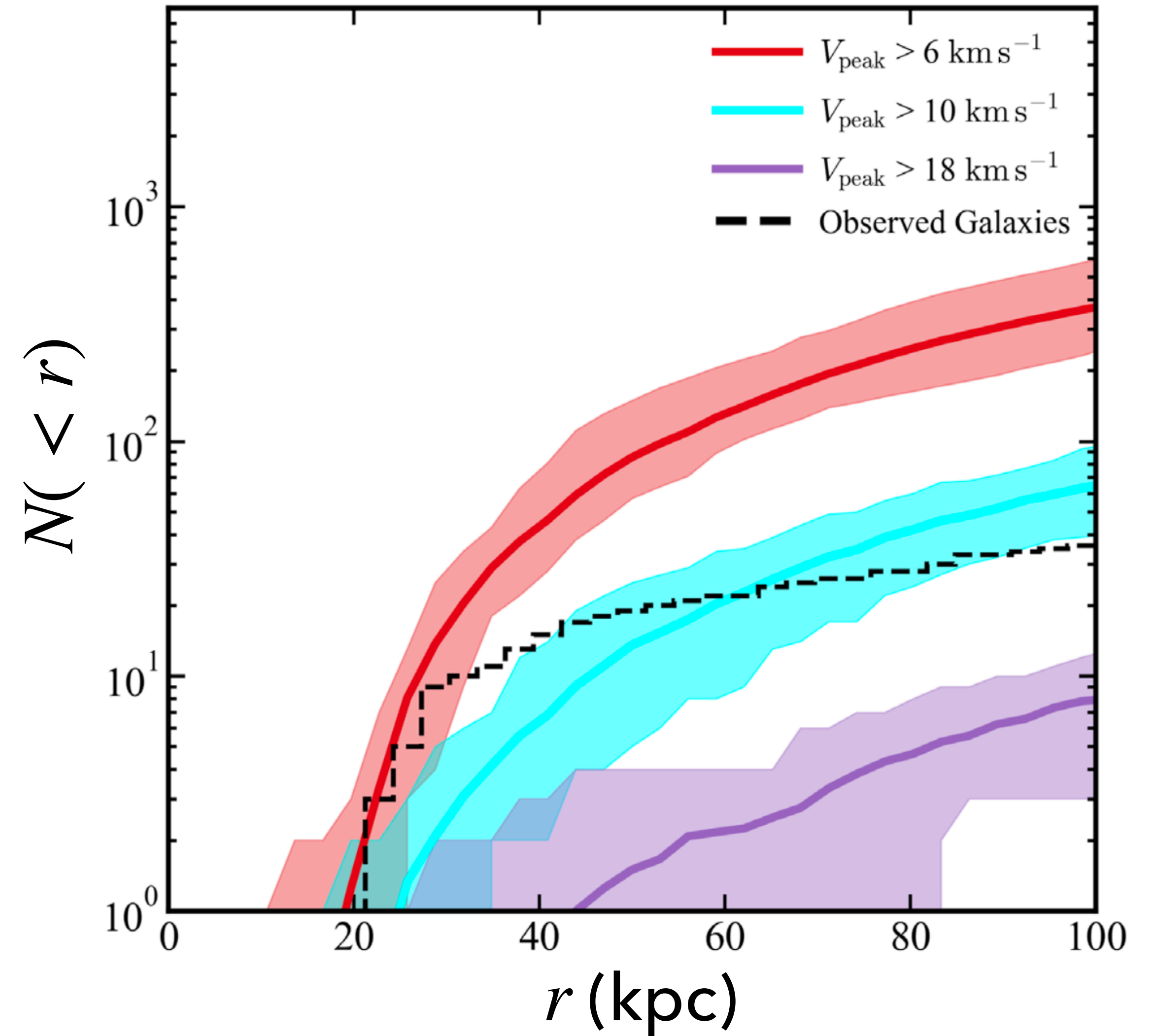
$$V_{\max} = \sqrt{\frac{GM(< R_{\max})}{R_{\max}}}$$

$V_{\text{peak}}, V_{\text{infall}}, V_{\text{disrupt}} \dots$

# MW SATELLITE COUNTS

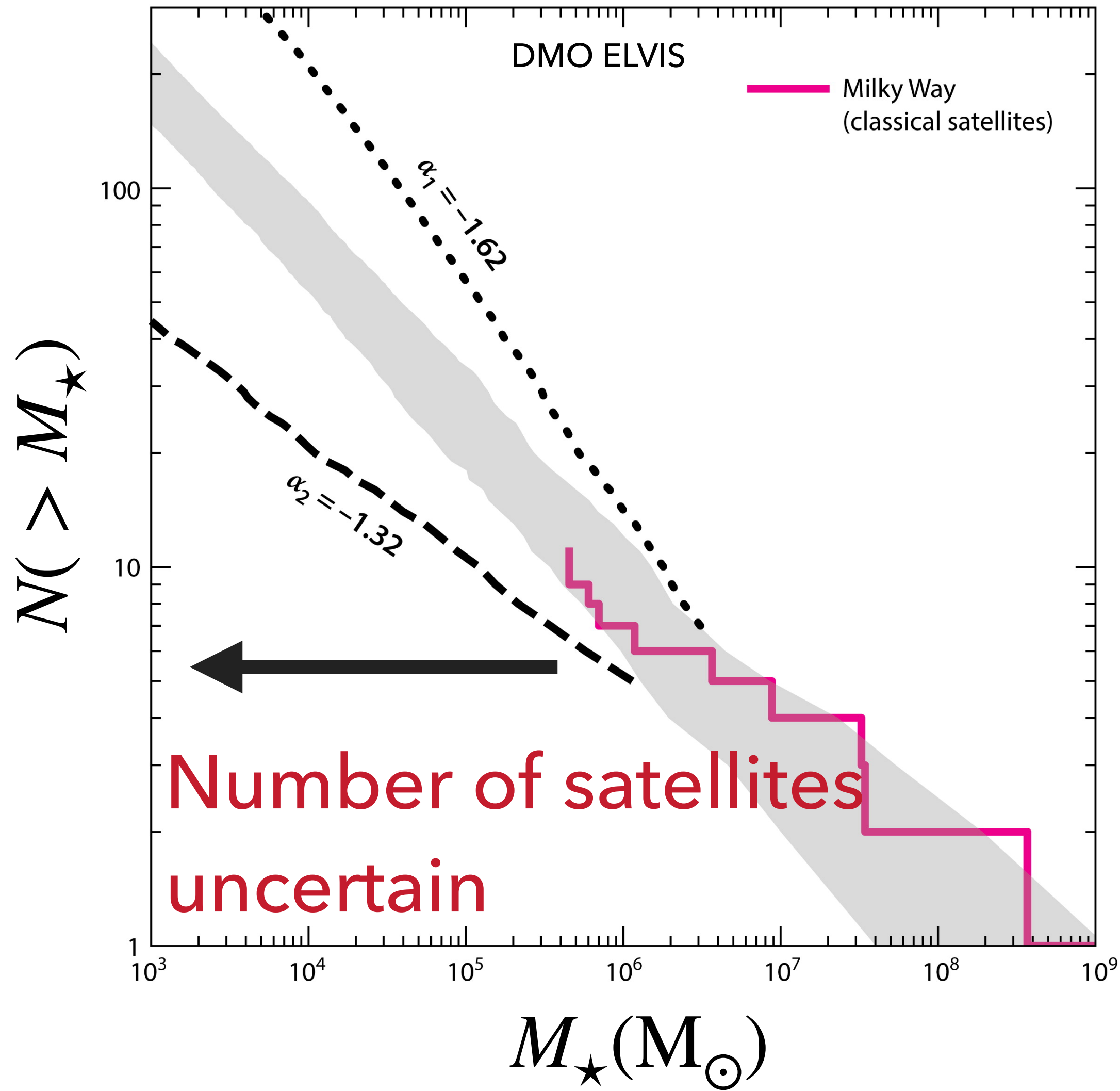


Bullock & Boylan-Kolchin 2017

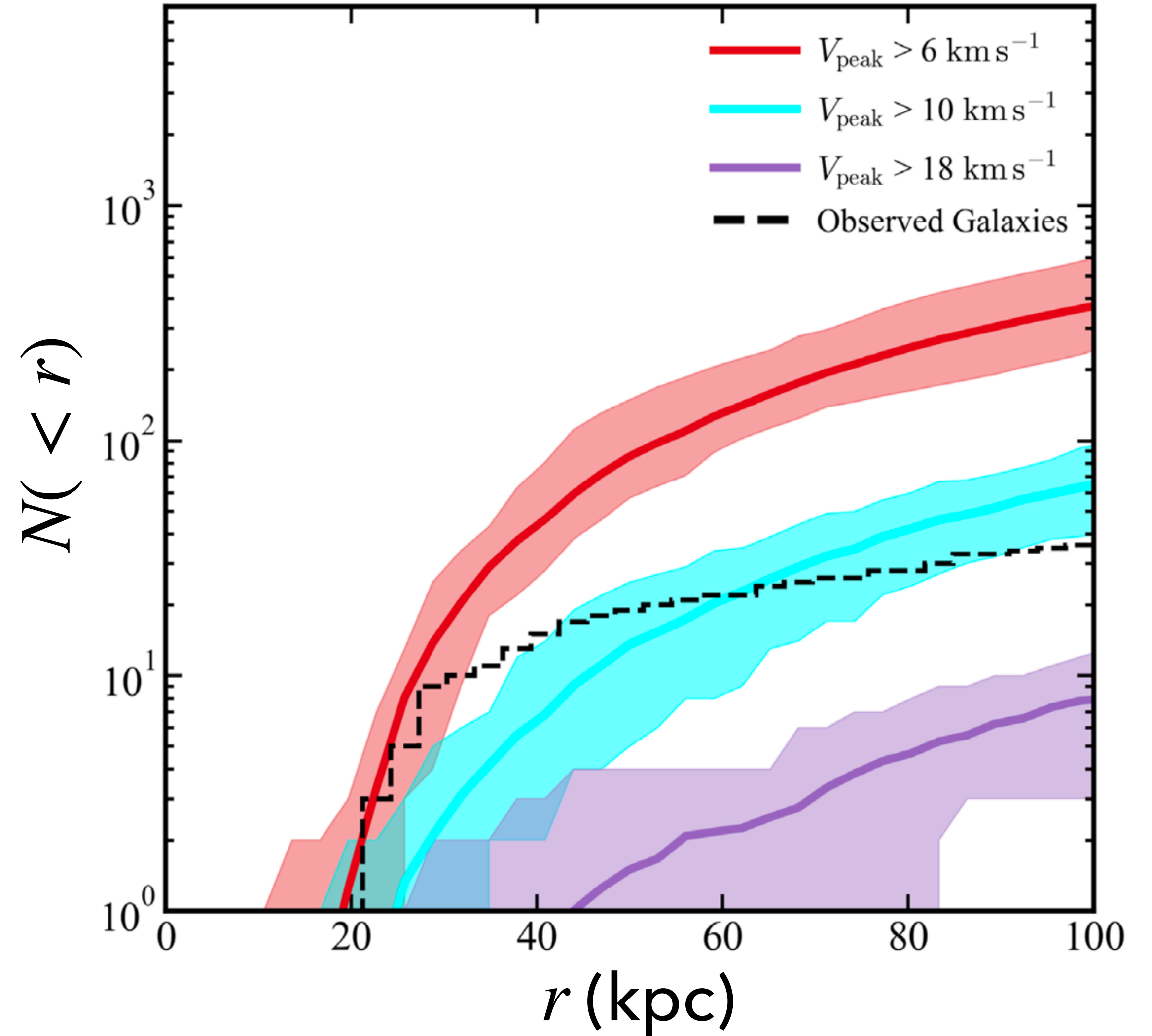


Graus et al. 2019

# MW SATELLITE COUNTS



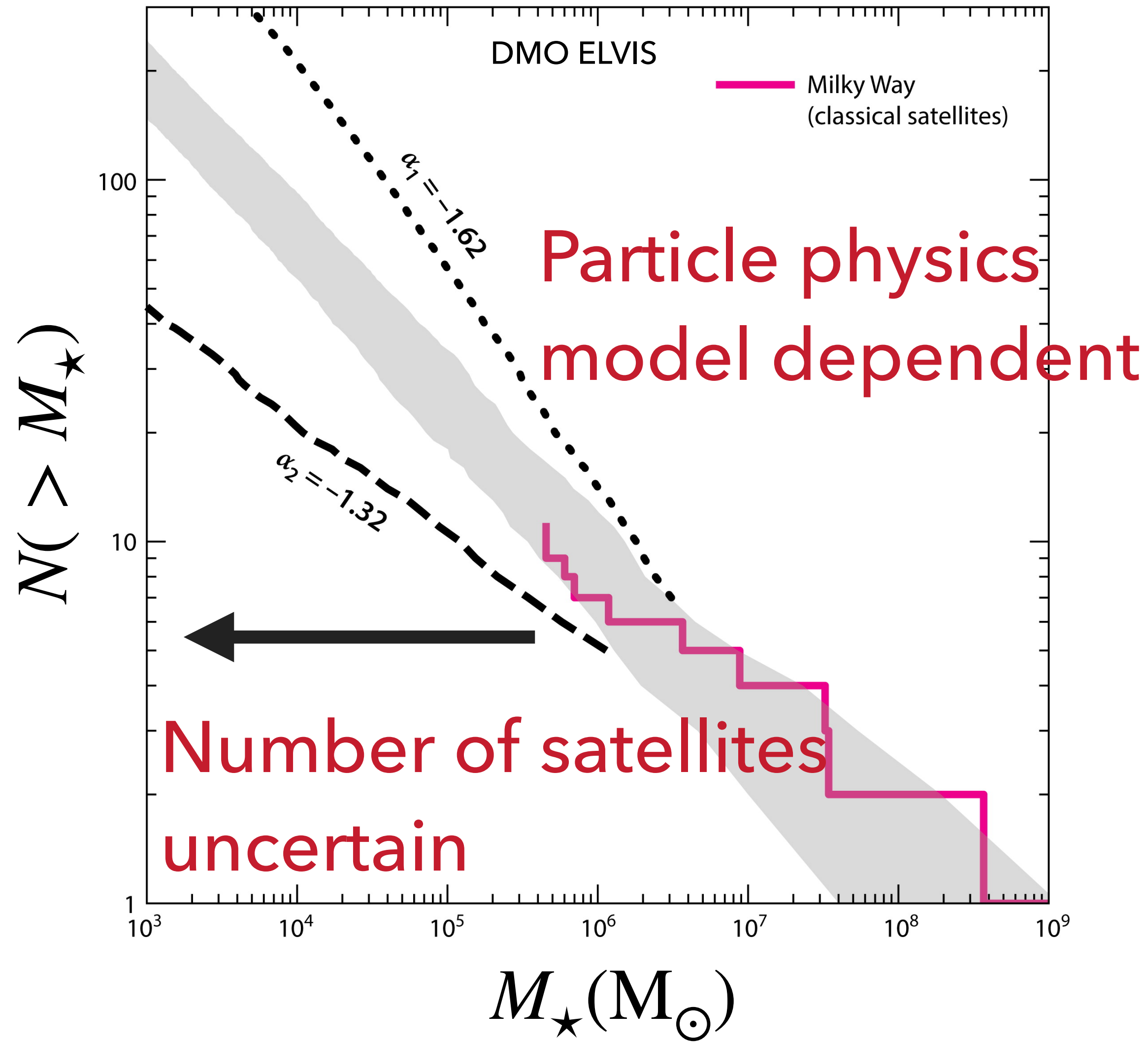
Bullock & Boylan-Kolchin 2017



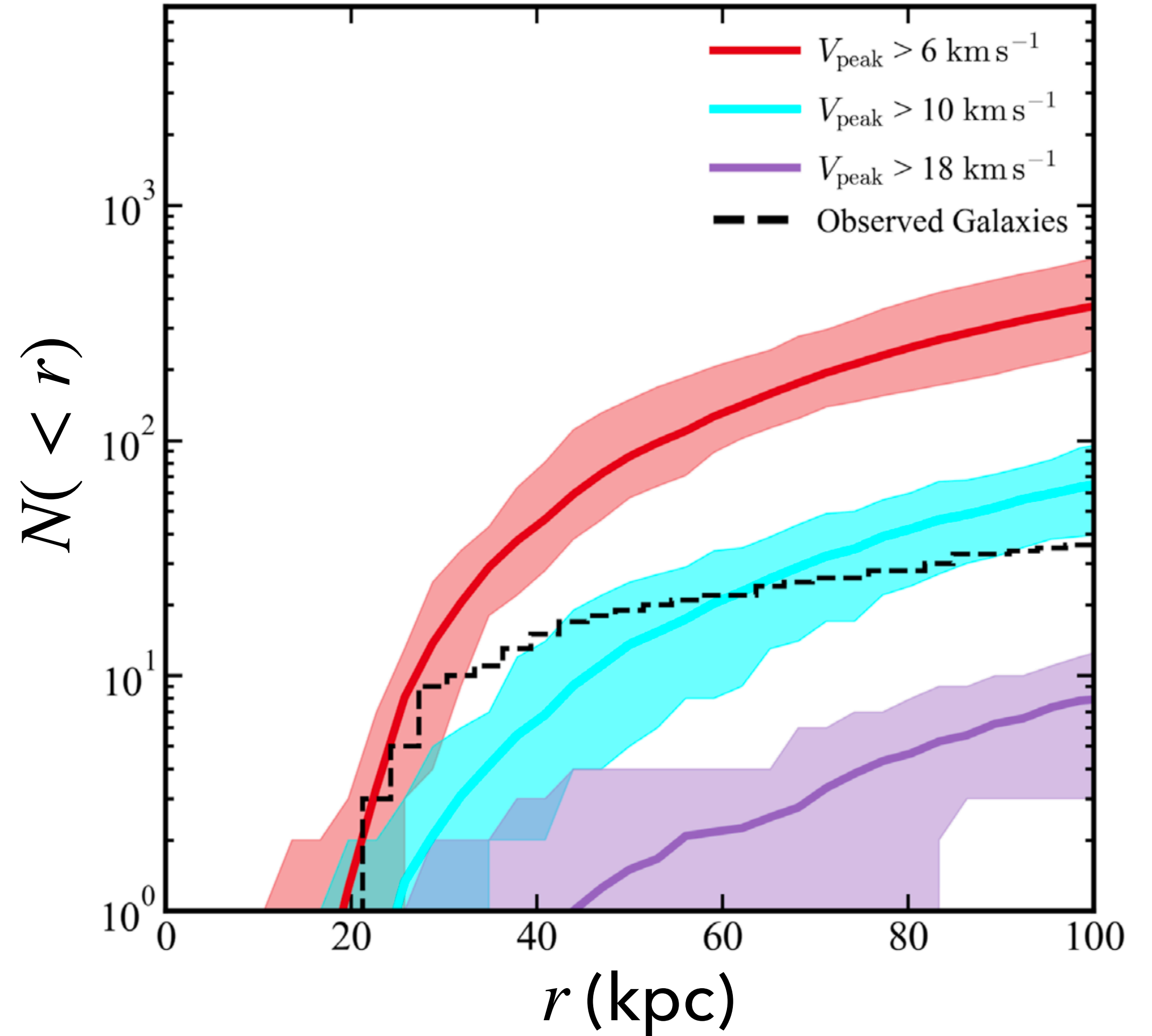
Graus et al. 2019



# MW SATELLITE COUNTS

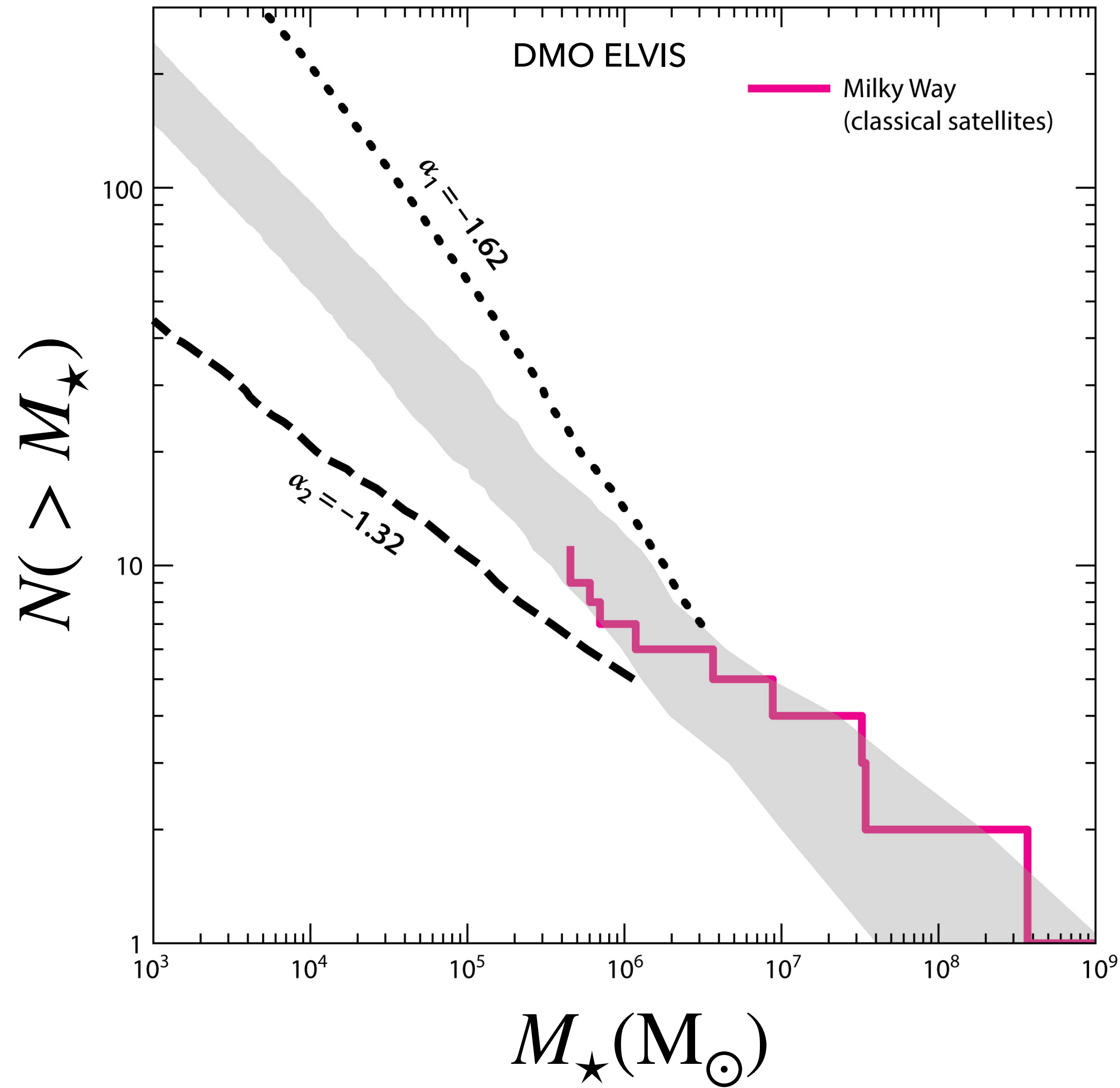


Bullock & Boylan-Kolchin 2017

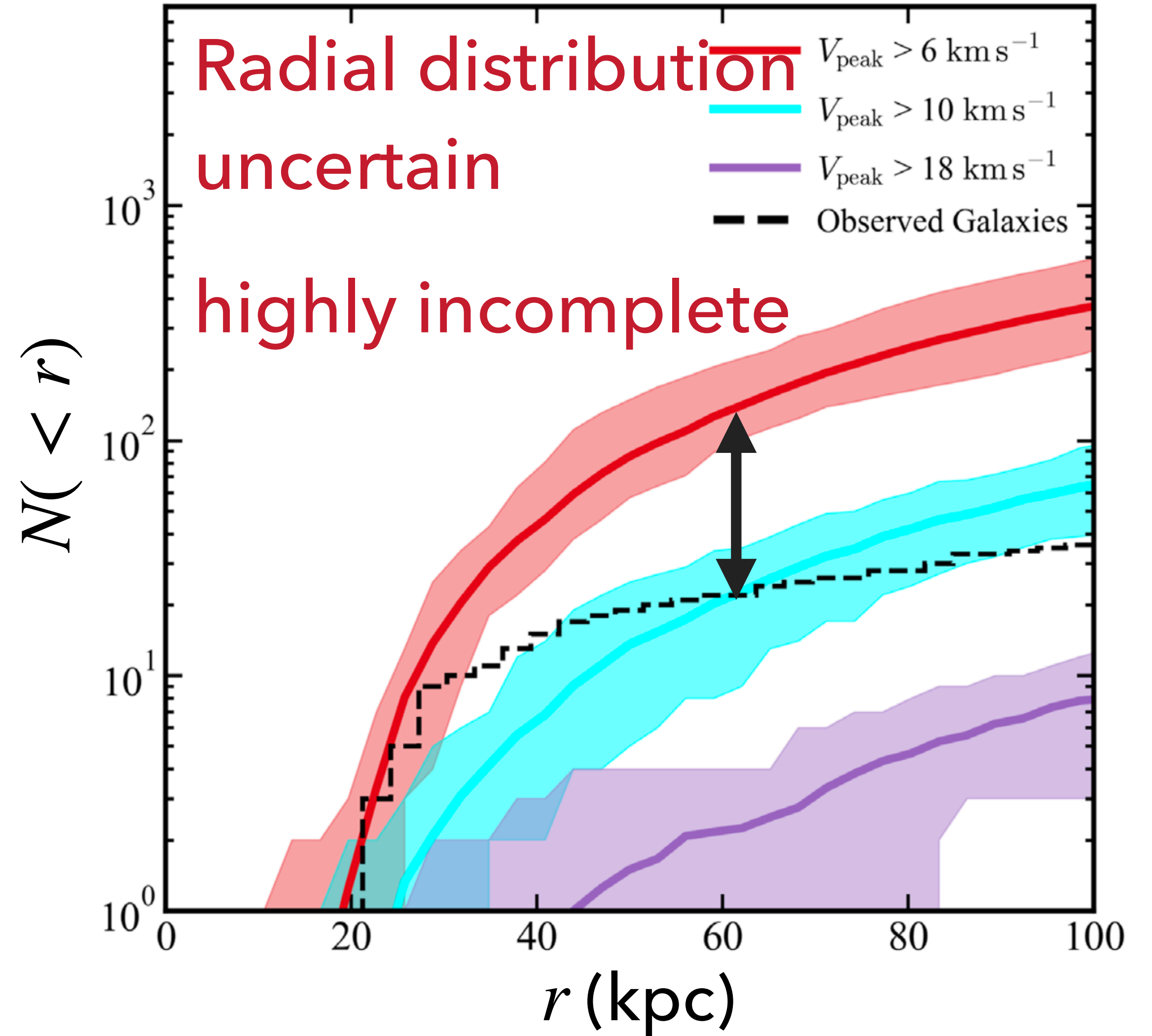


Graus et al. 2019

# MW SATELLITE COUNTS

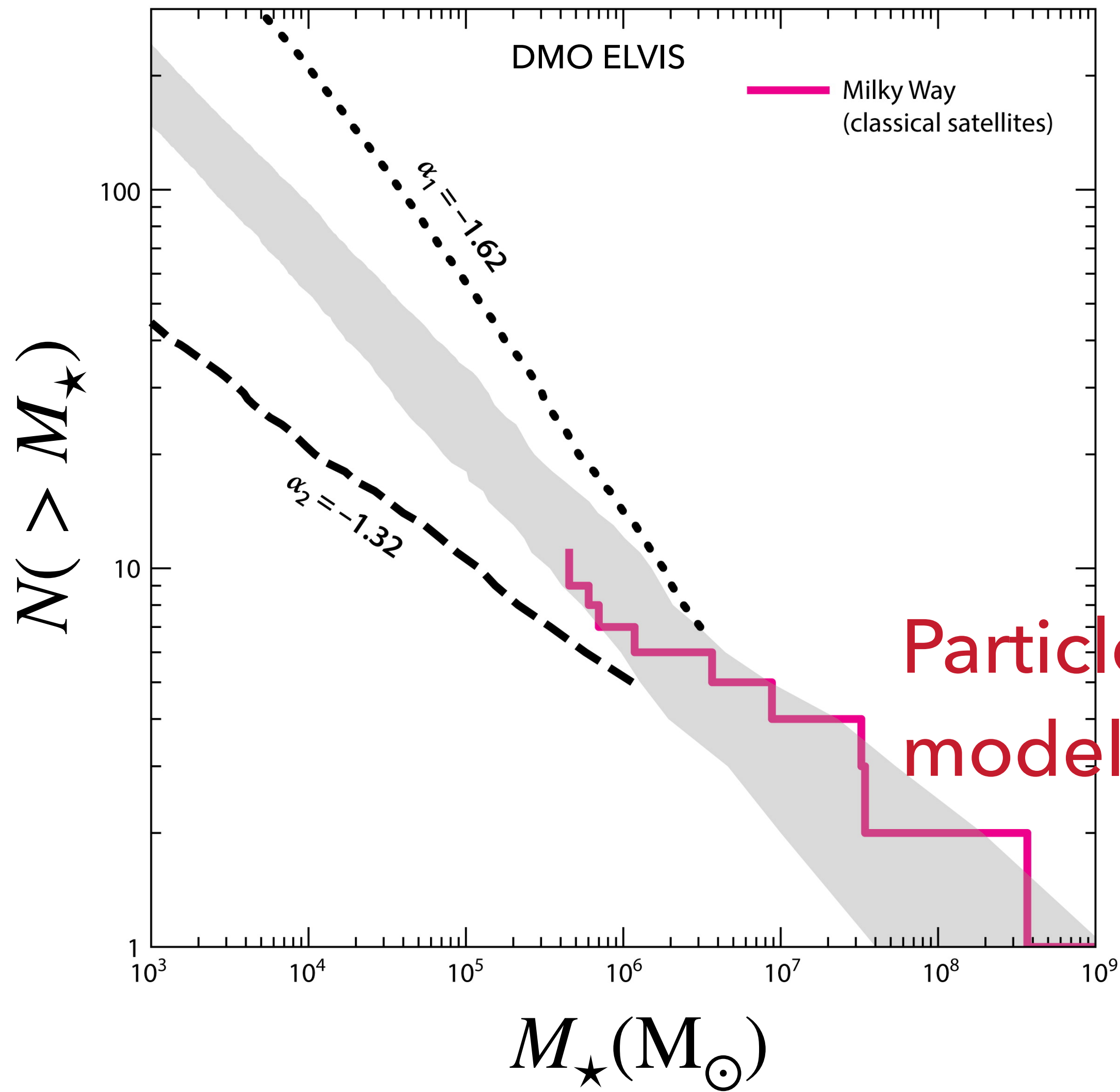


Bullock & Boylan-Kolchin 2017

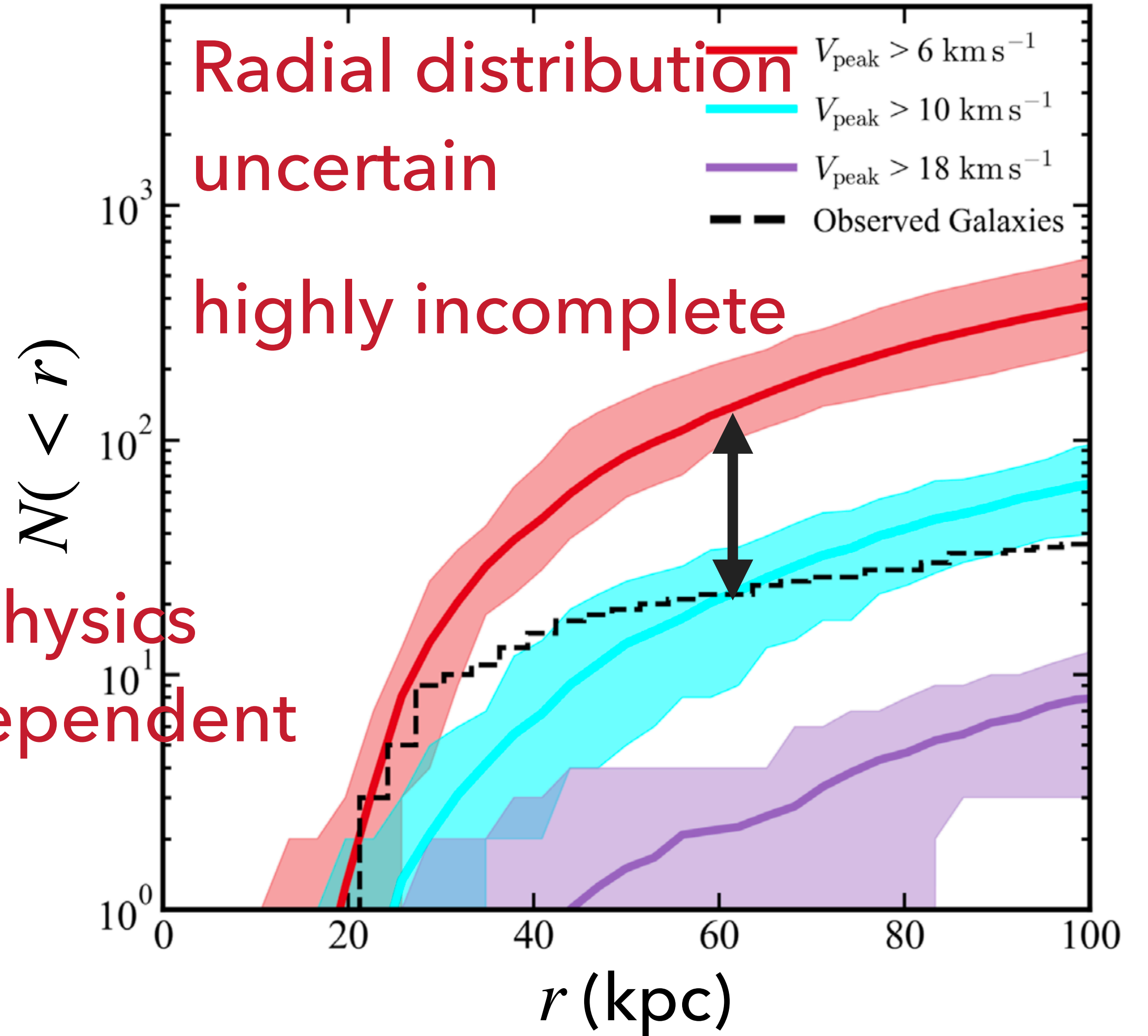


Graus et al. 2019

# MW SATELLITE COUNTS



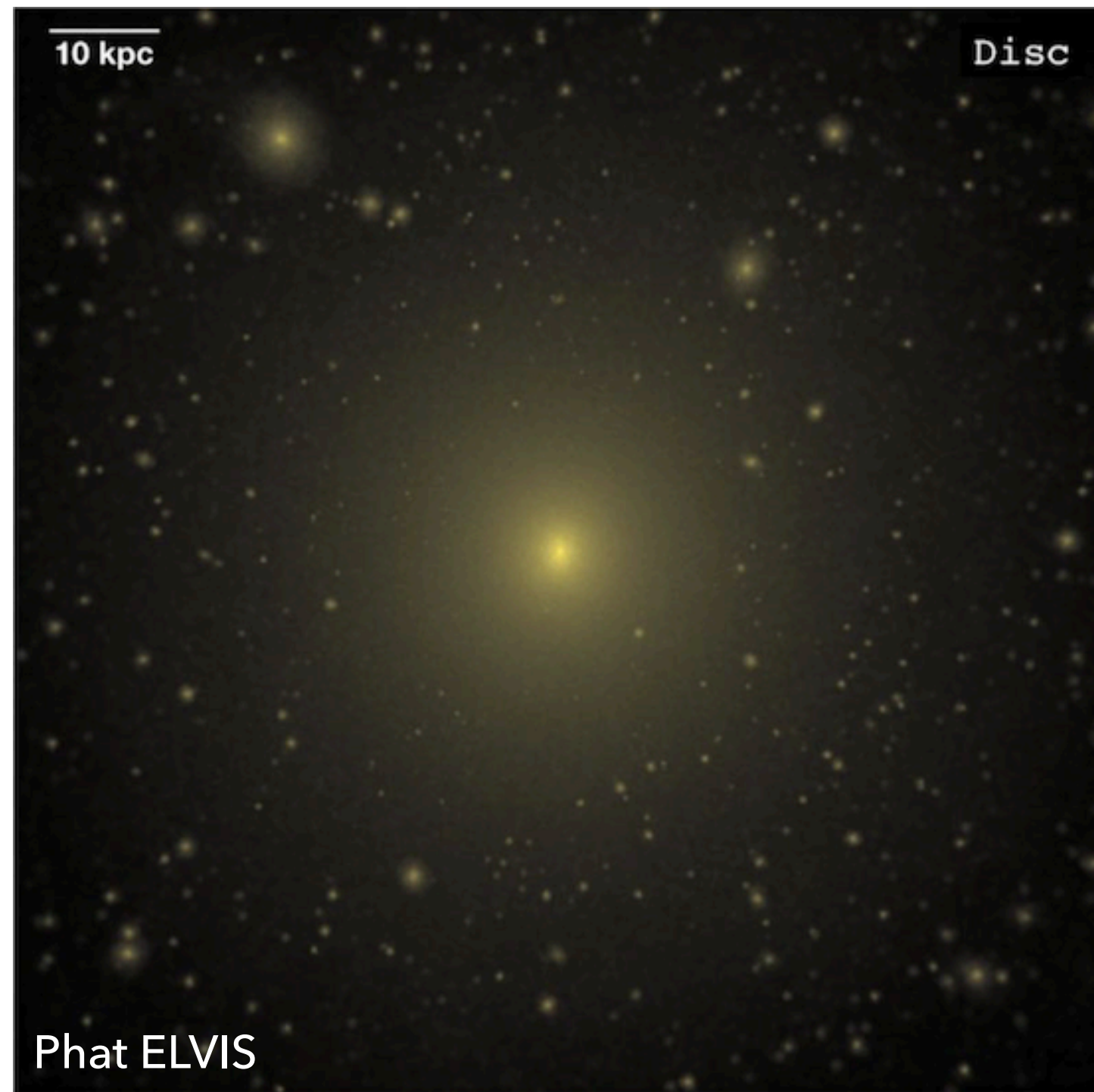
Bullock & Boylan-Kolchin 2017



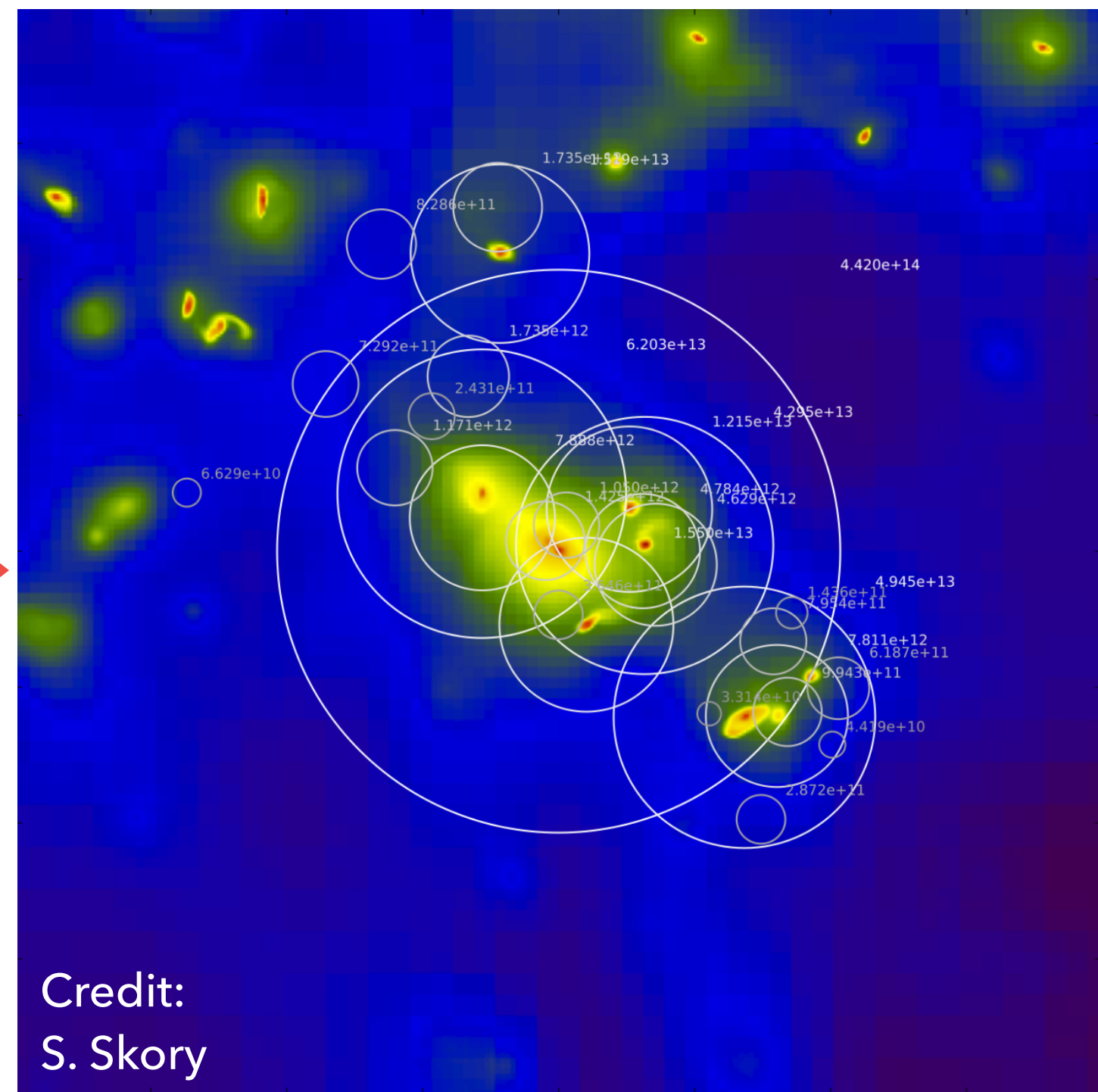
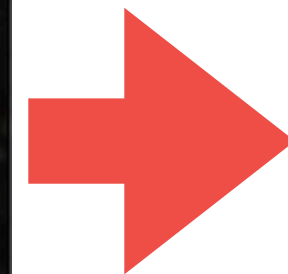
Graus et al. 2019

Particle physics model dependent

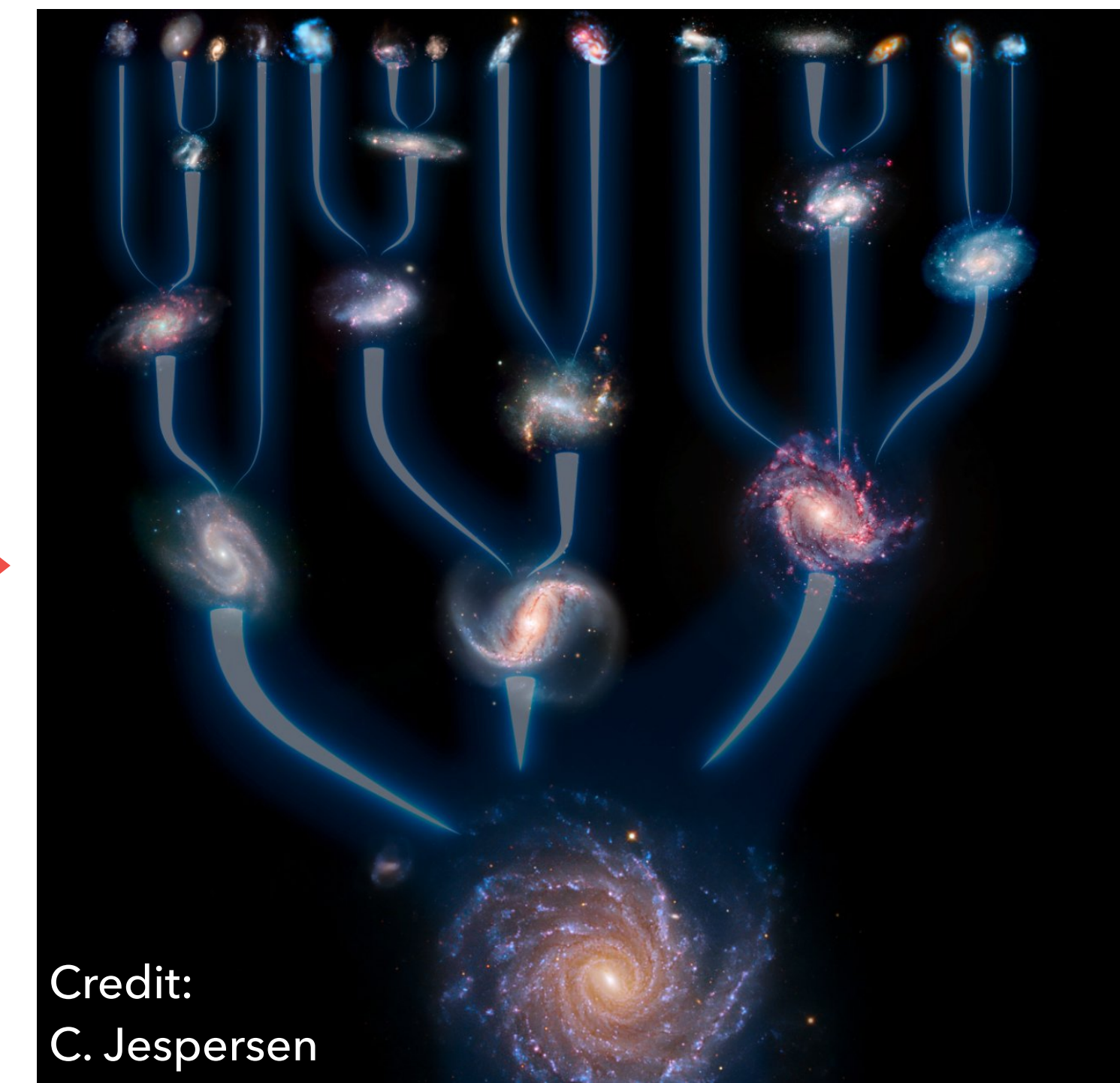
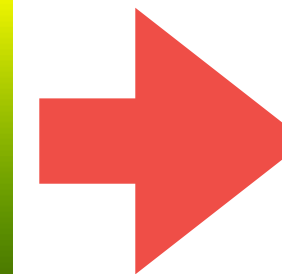
## "Standard" pipeline



Simulation

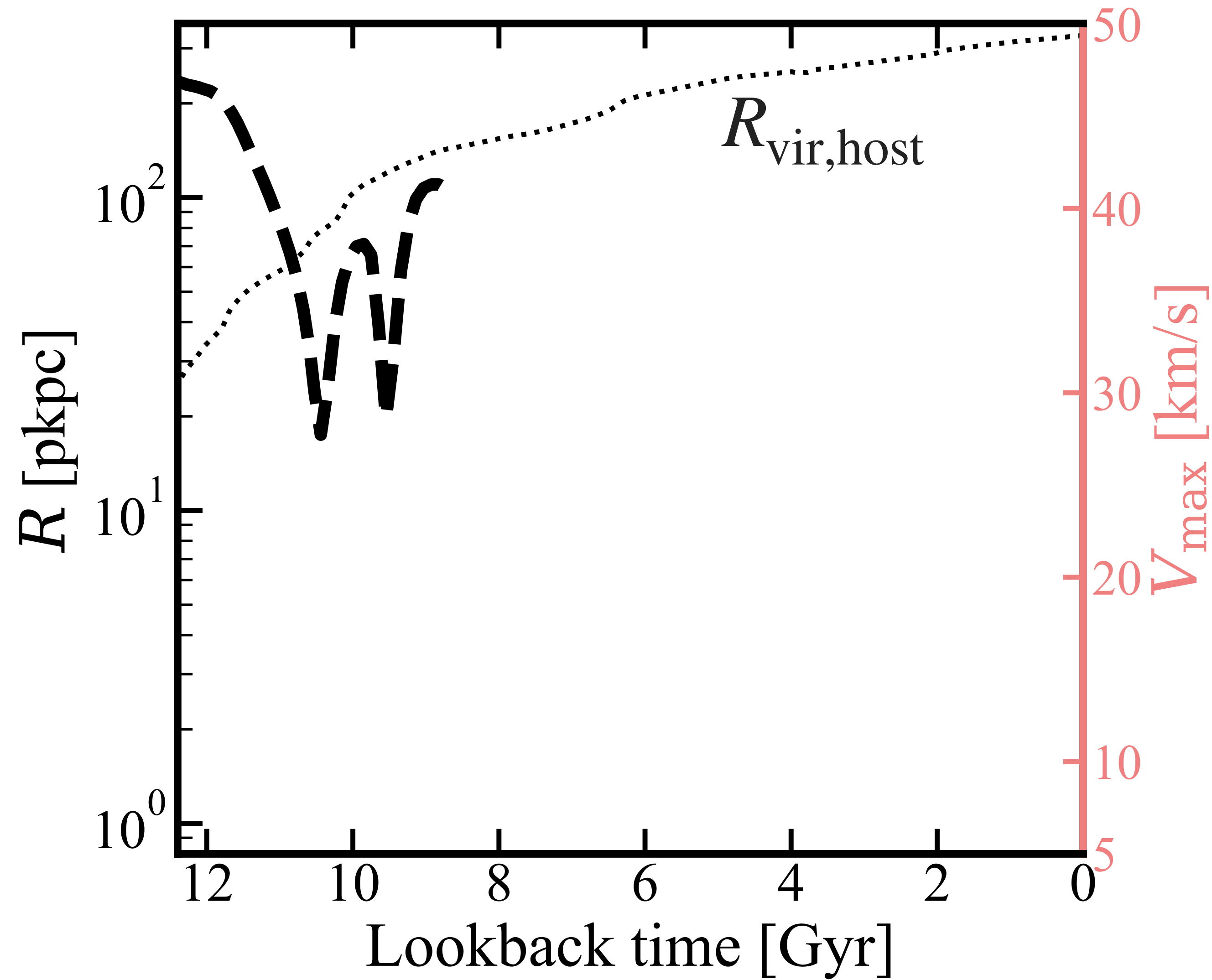


Halo finder

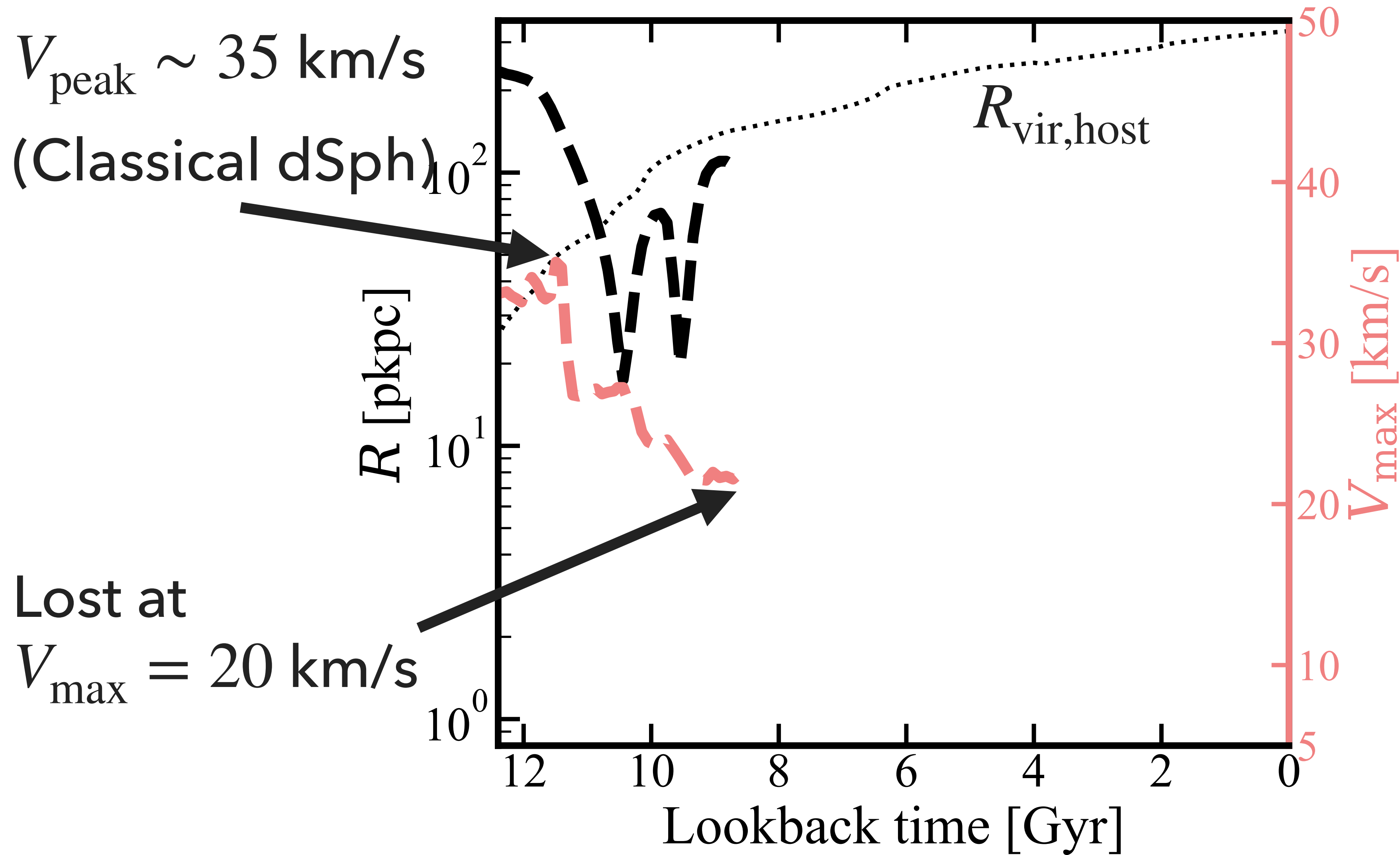


Merger tree

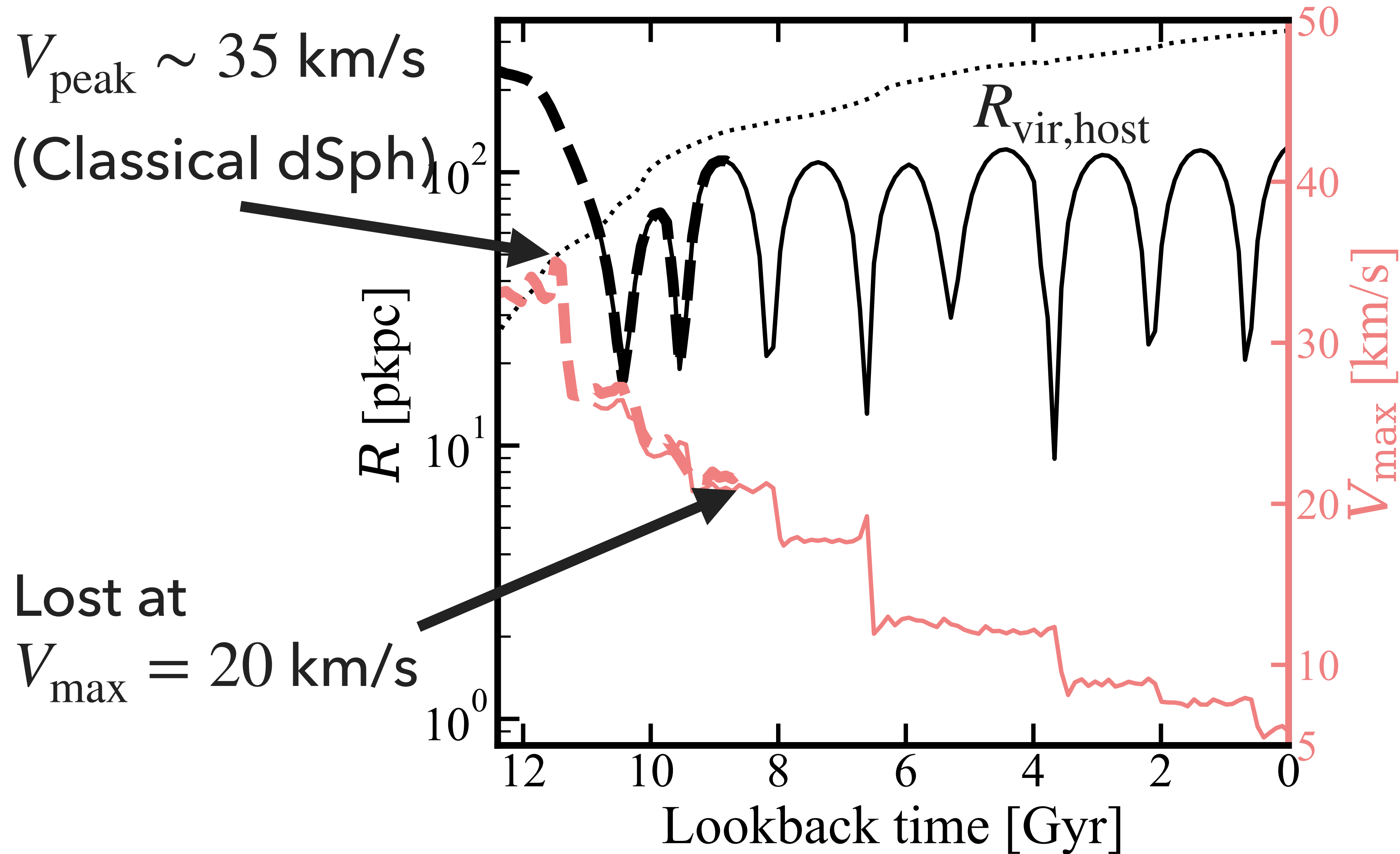
# MERGER-TREE VS. PARTICLES



# MERGER-TREE VS. PARTICLES



# MERGER-TREE VS. PARTICLES



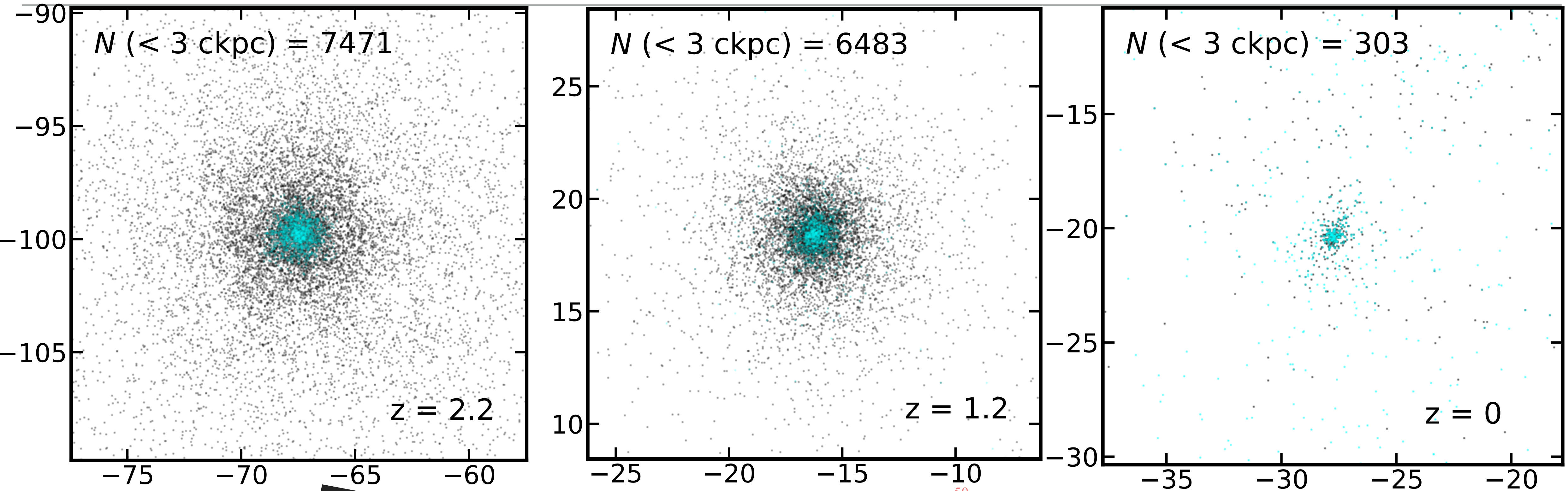
## Bloodhound:

- ▶ Tracked all the way to  $z=0$
- ▶  $\sim 9 \text{ Gyr}$  longer
- ▶ 6 additional pericenters
- ▶  $V_{\text{max}} = 5 \text{ km/s}$

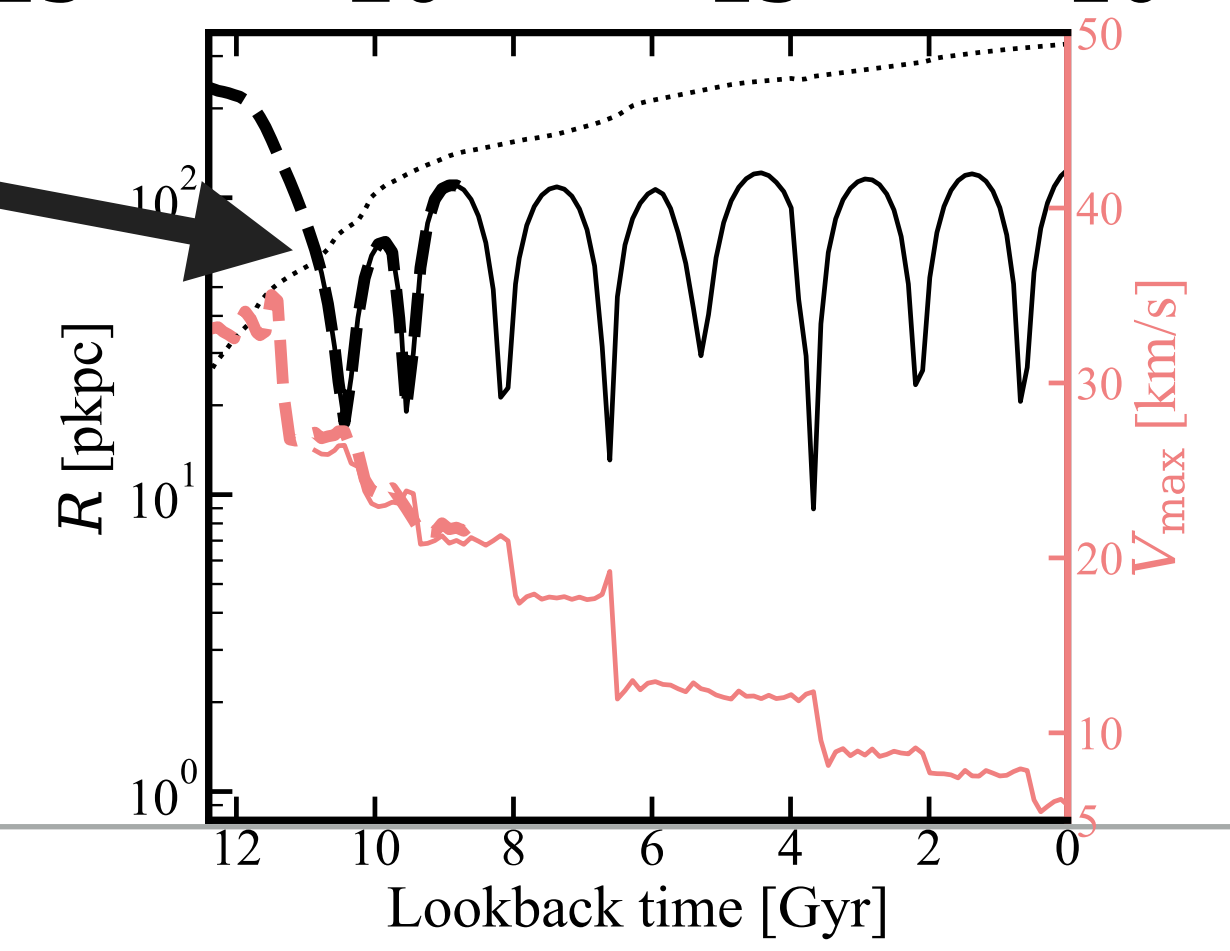
**BLOODHOUND**



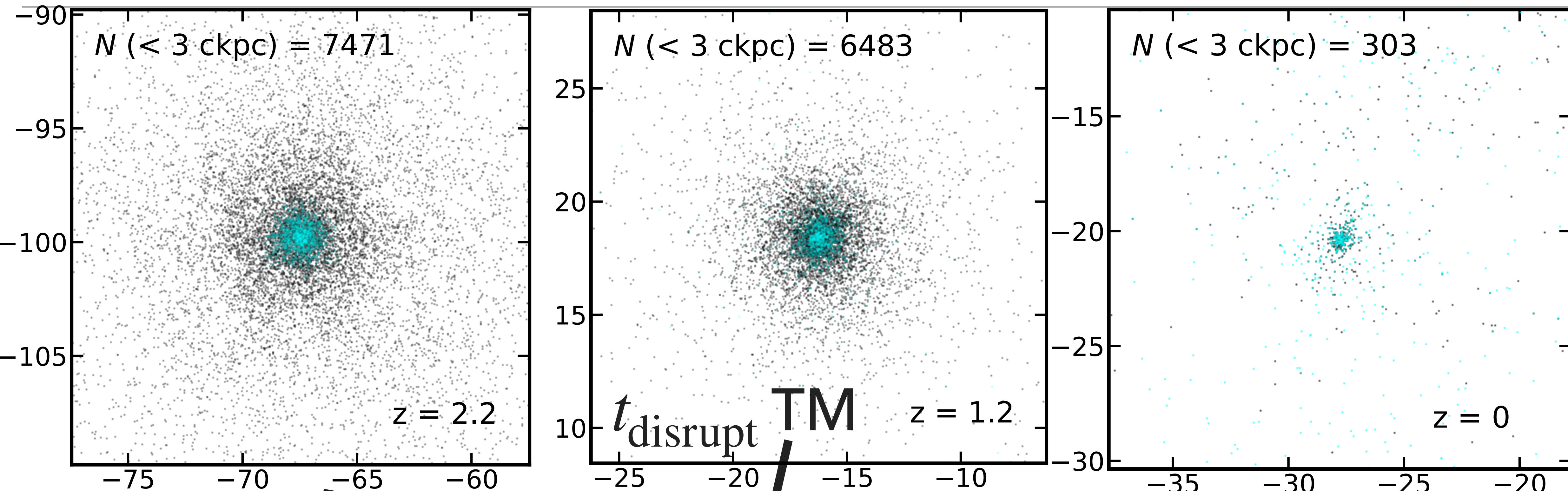
# BLOODHOUND



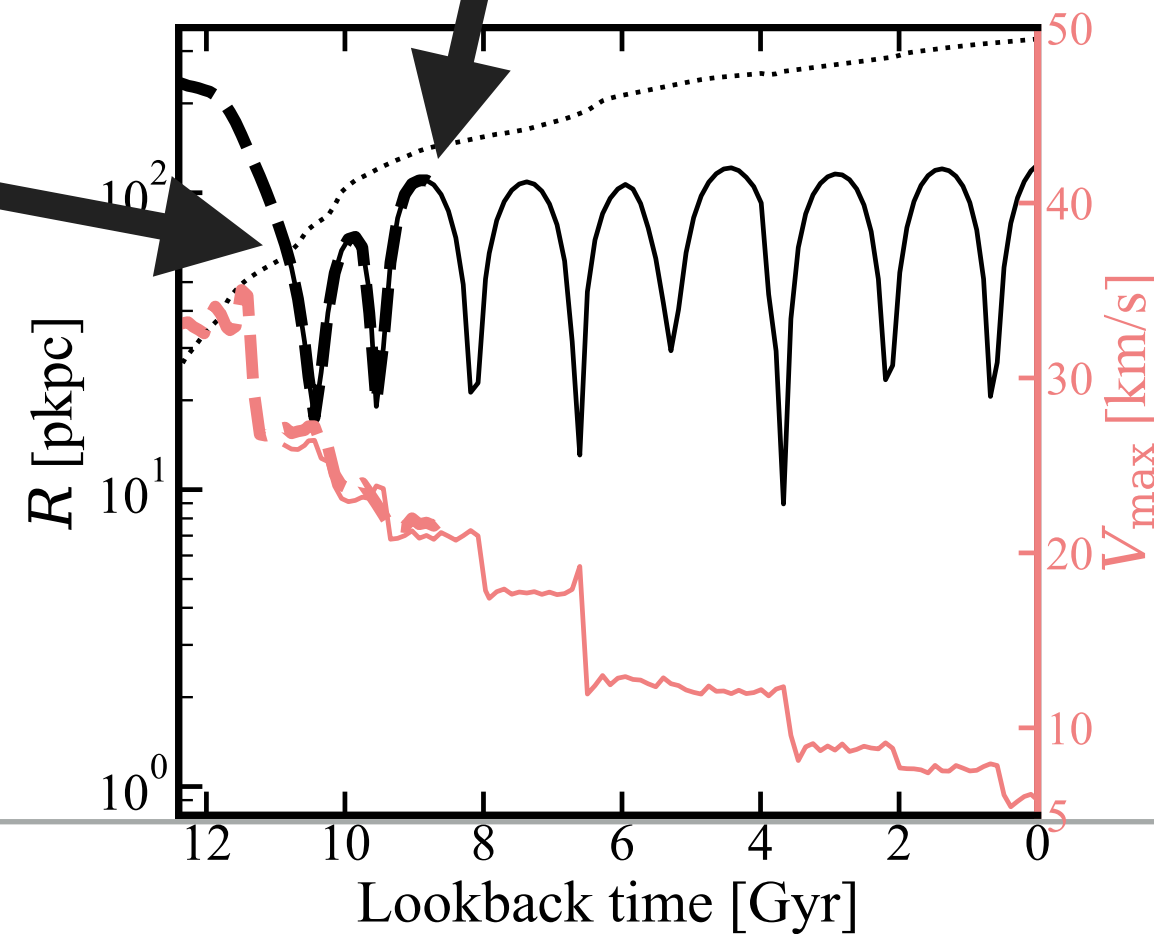
Infall



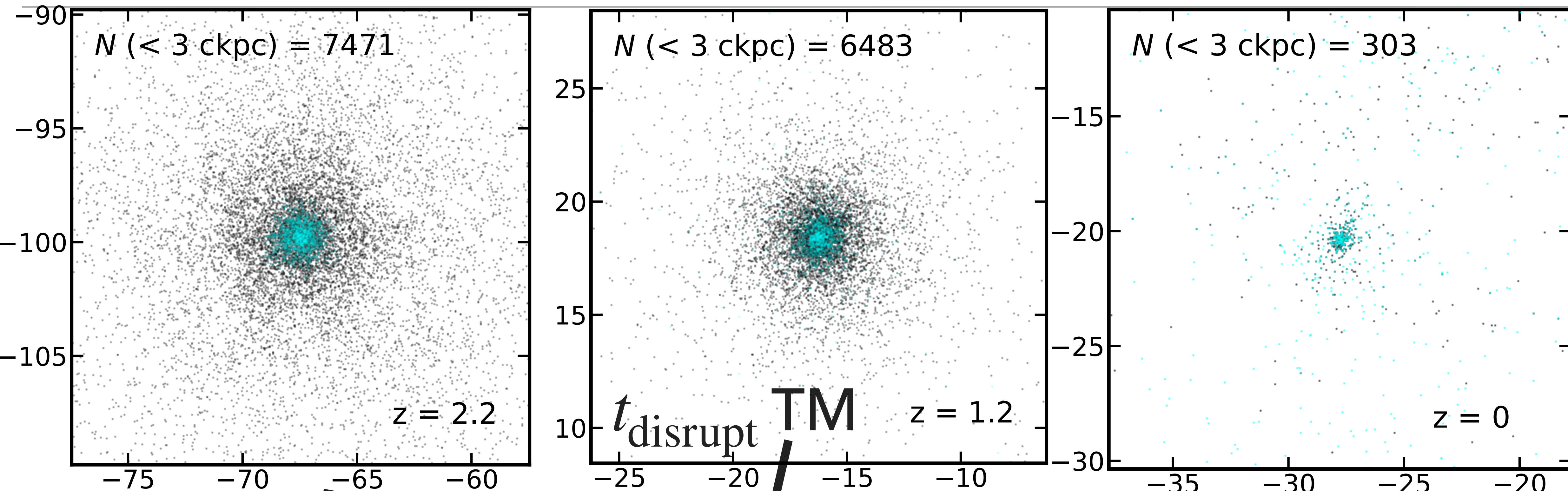
# BLOODHOUND



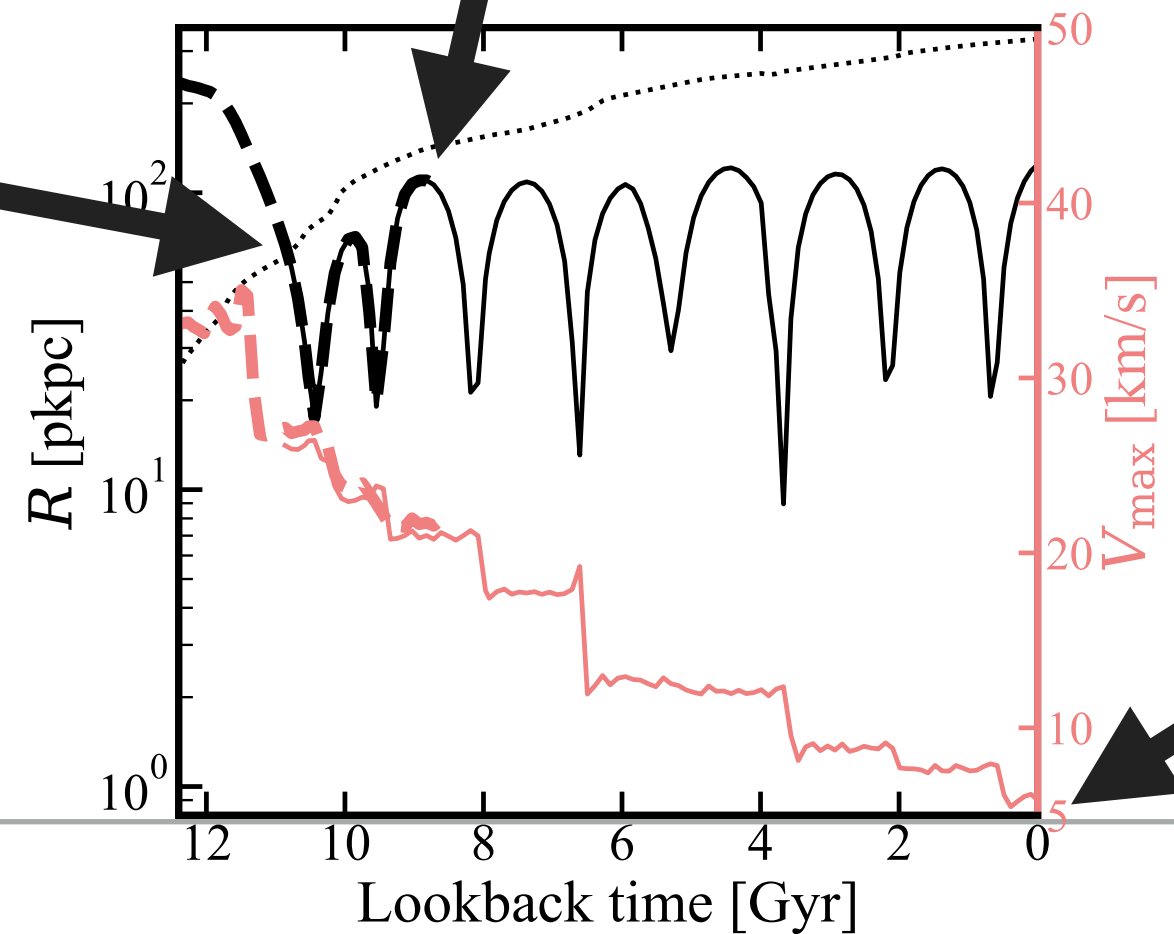
Infall



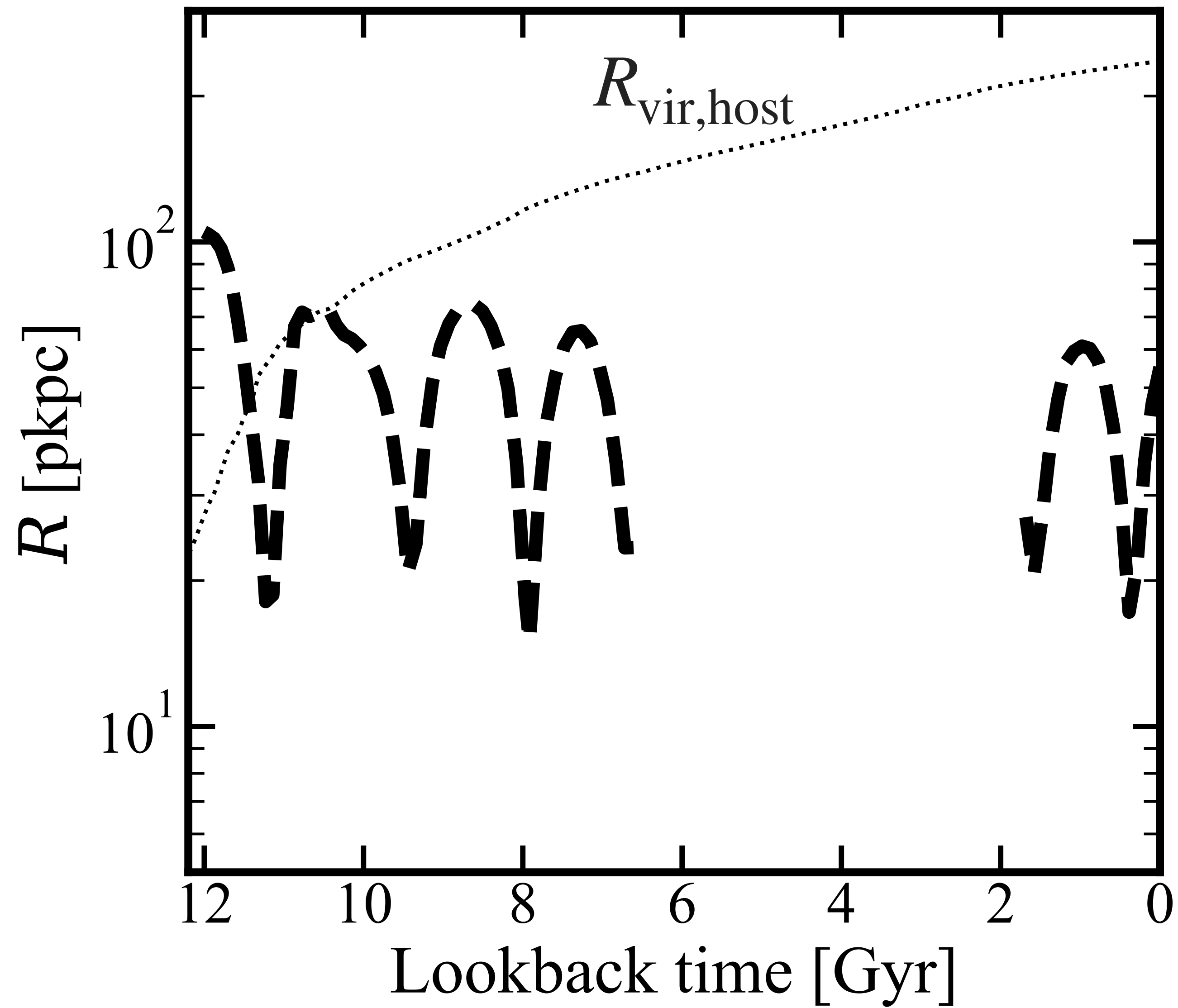
# BLOODHOUND



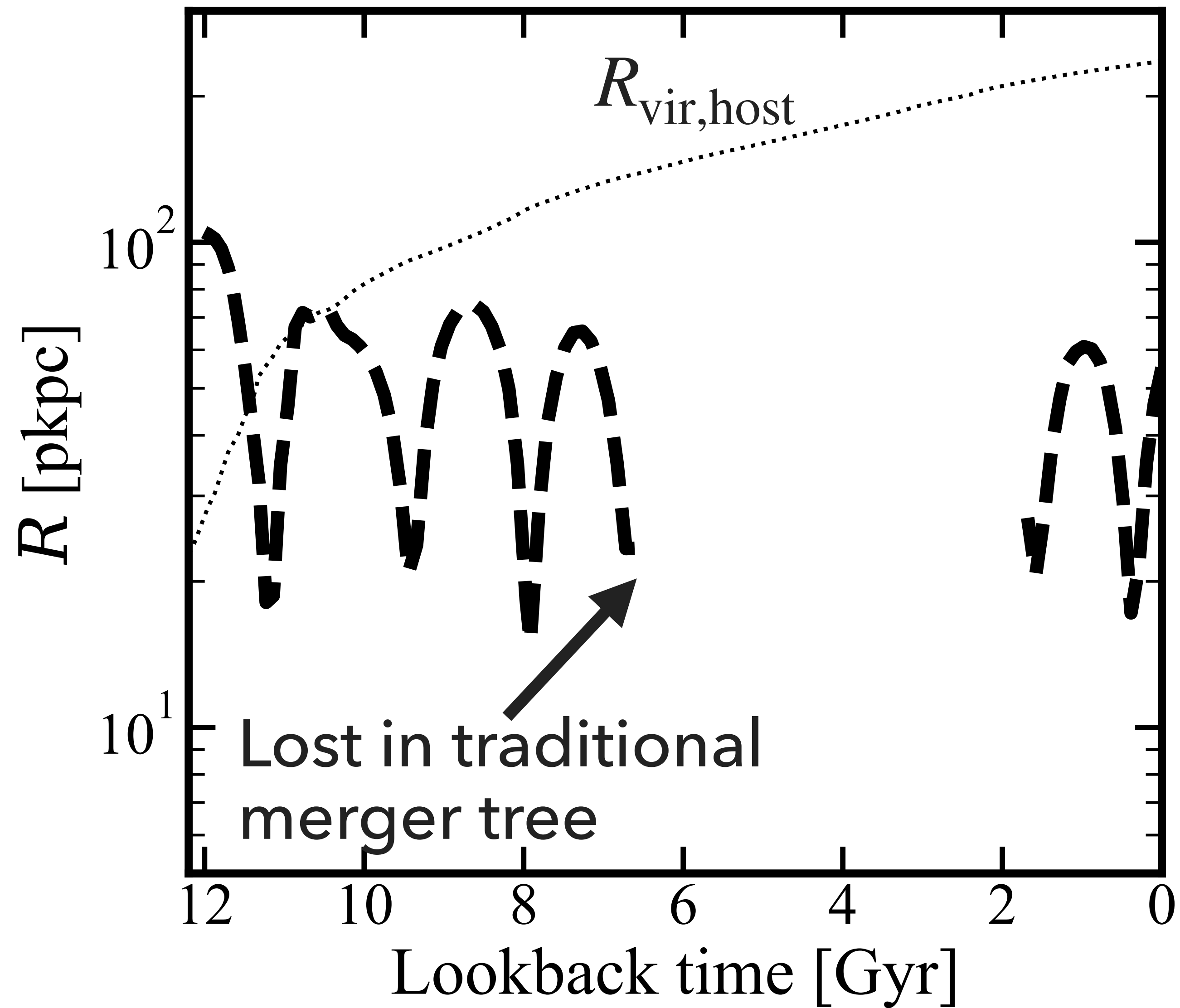
Infall



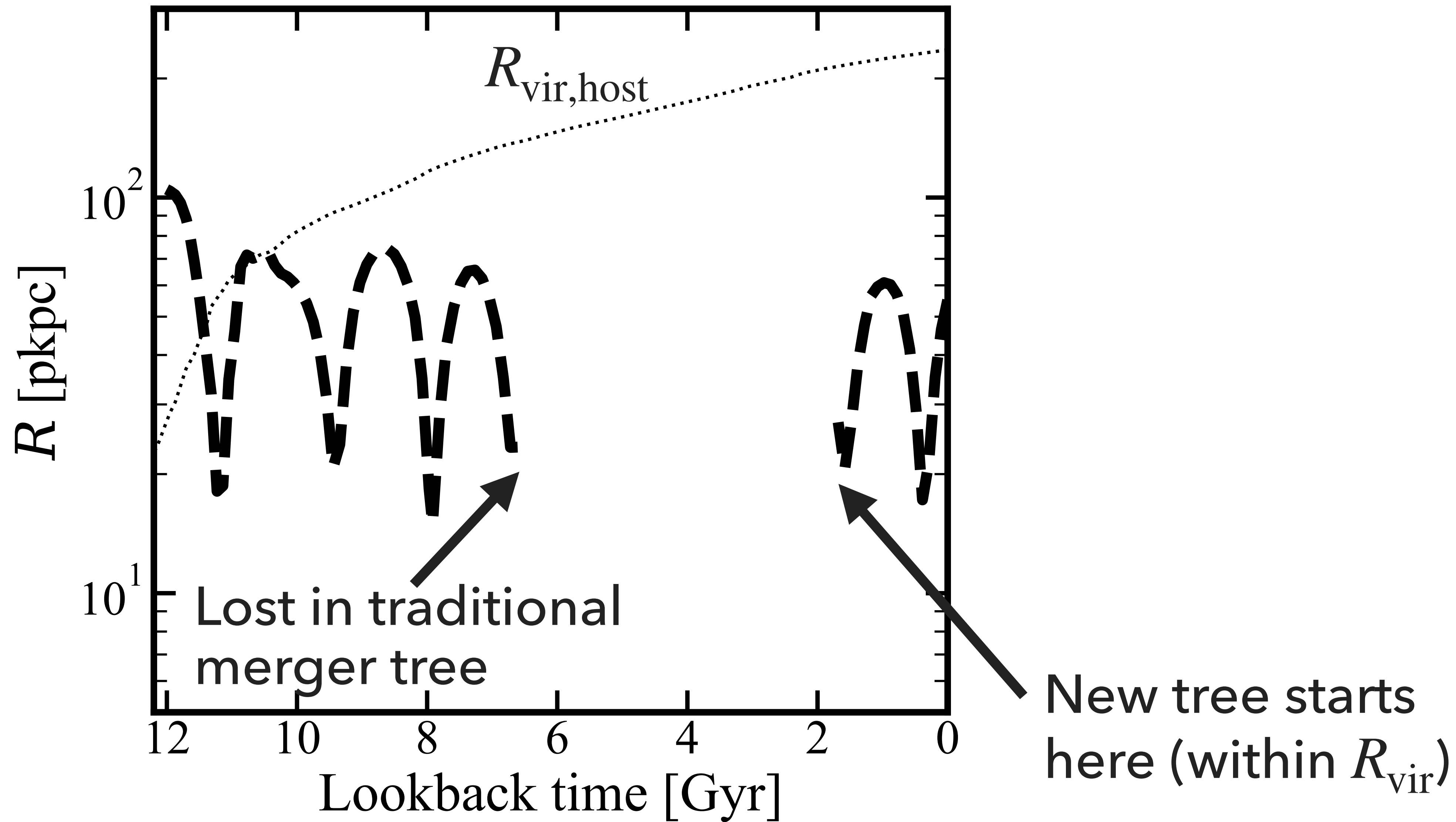
# MISSING-LINK TREES



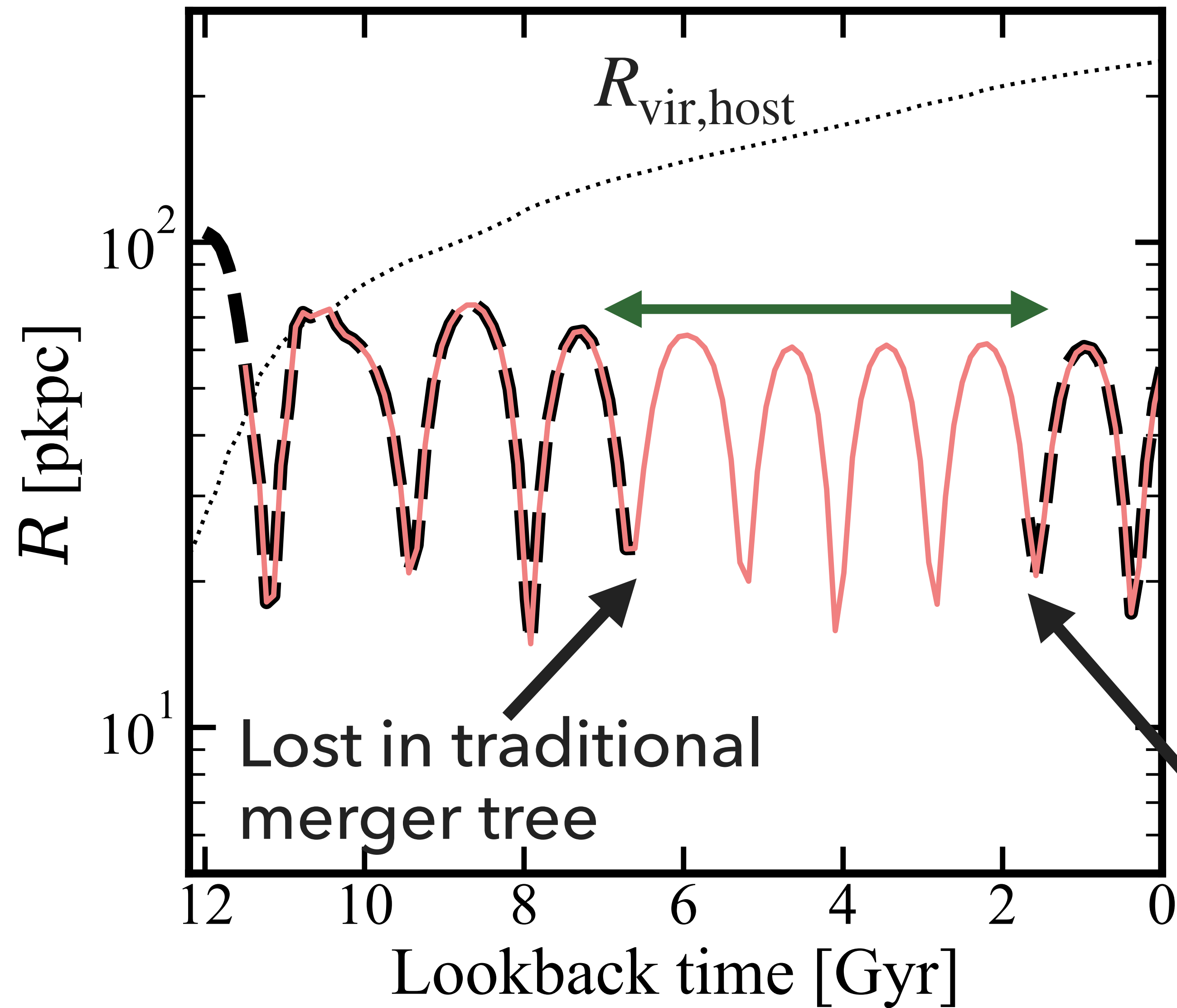
# MISSING-LINK TREES



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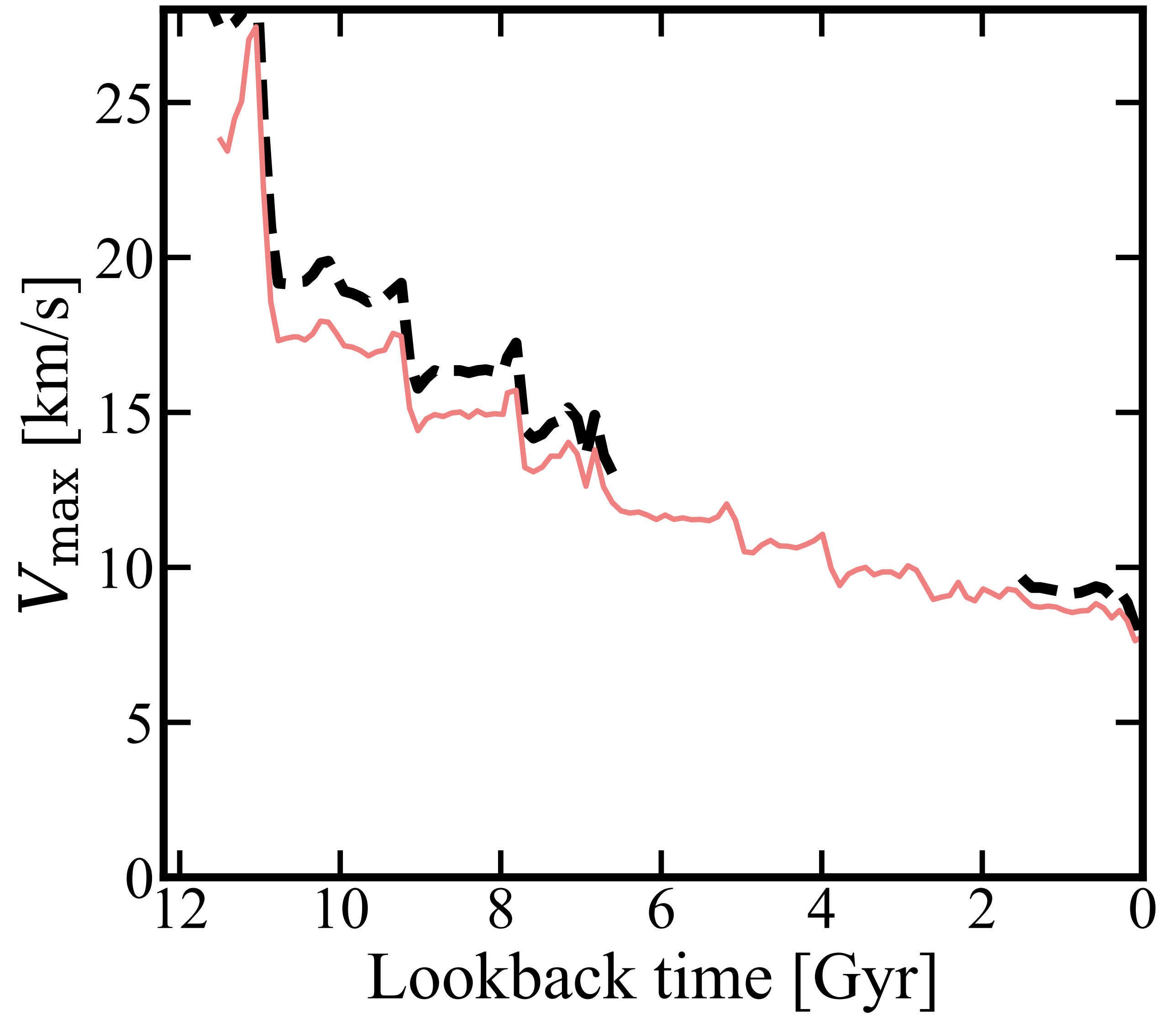
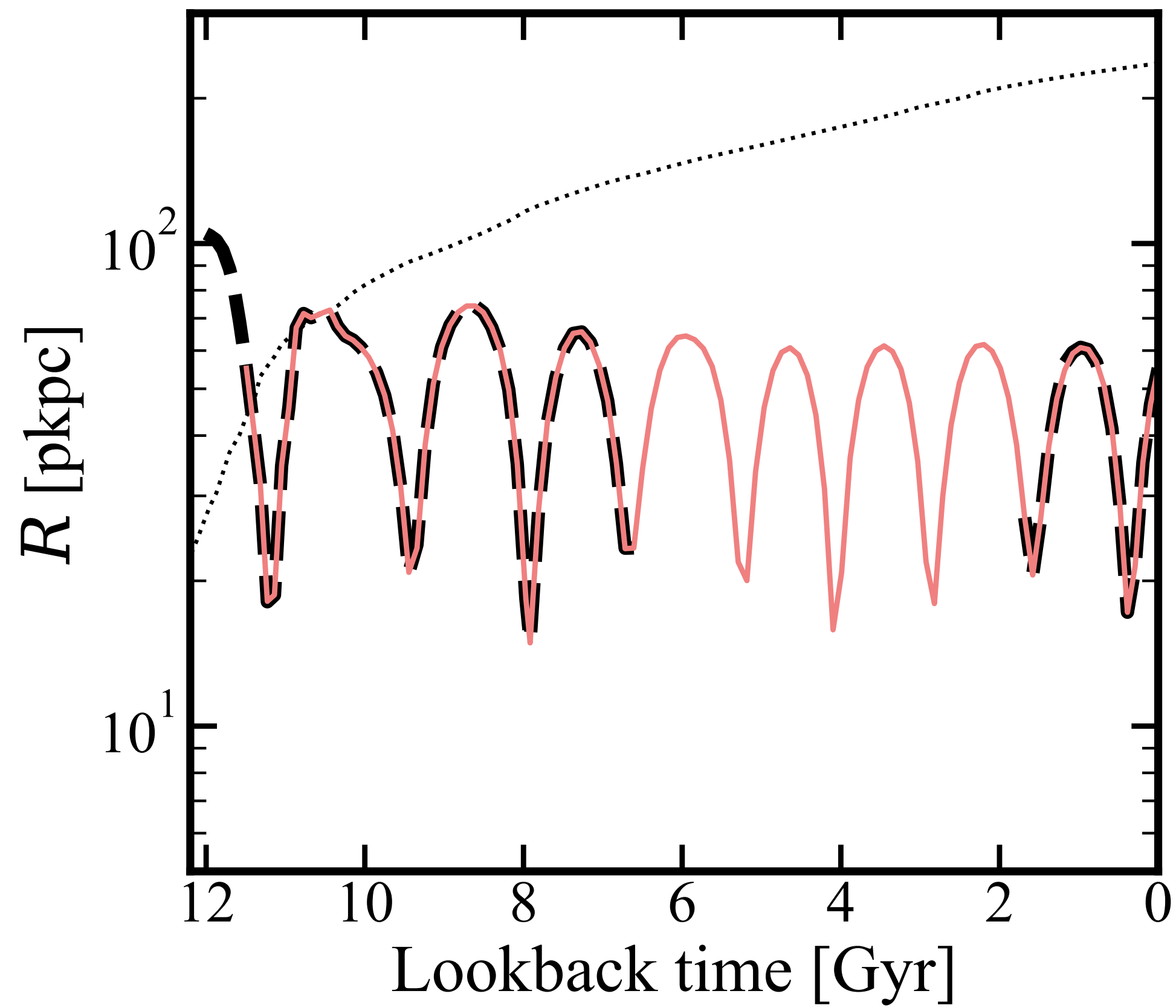
# MISSING-LINK TREES



**Bloodhound continuously tracks it as 1 halo, never lost**

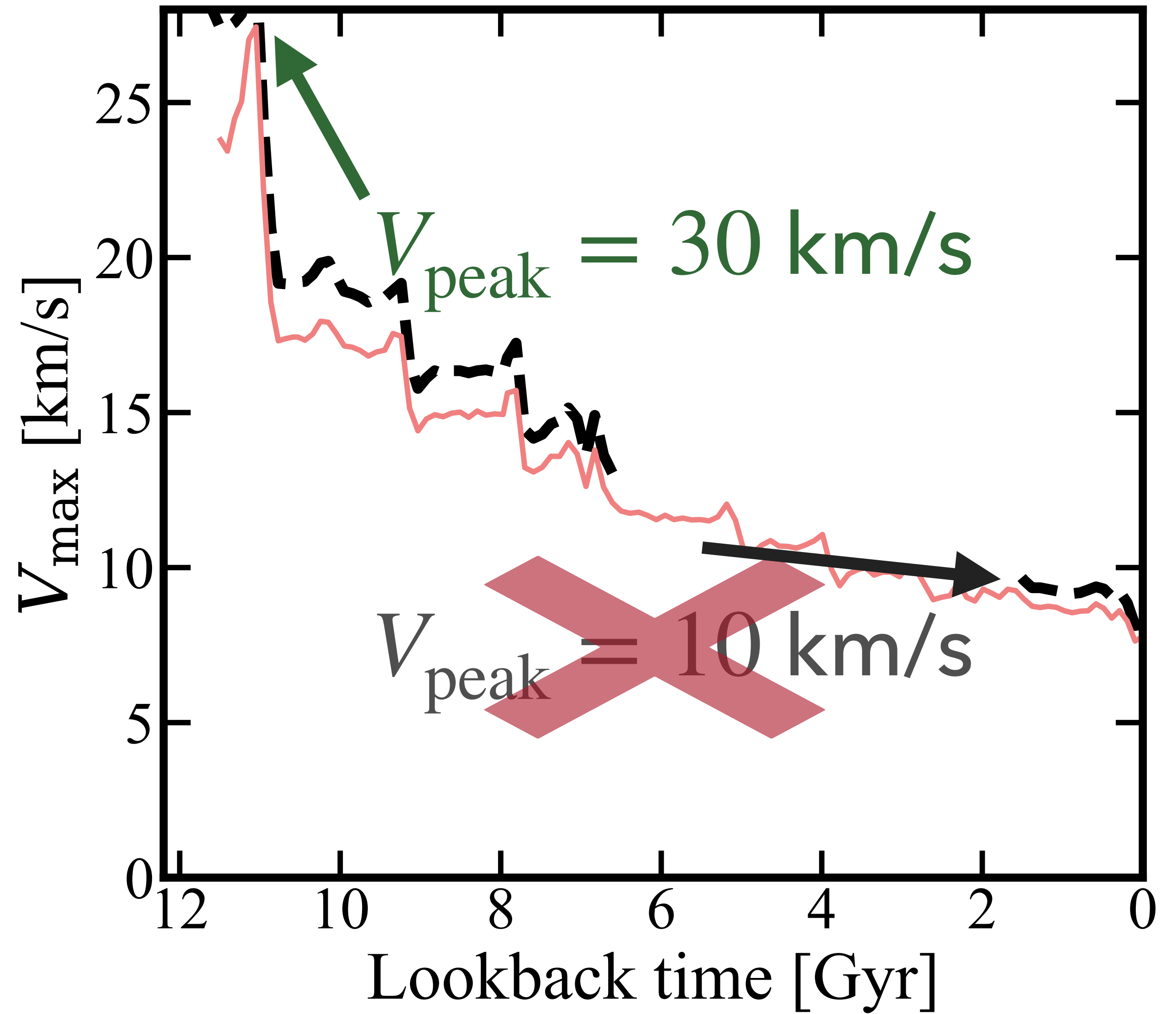
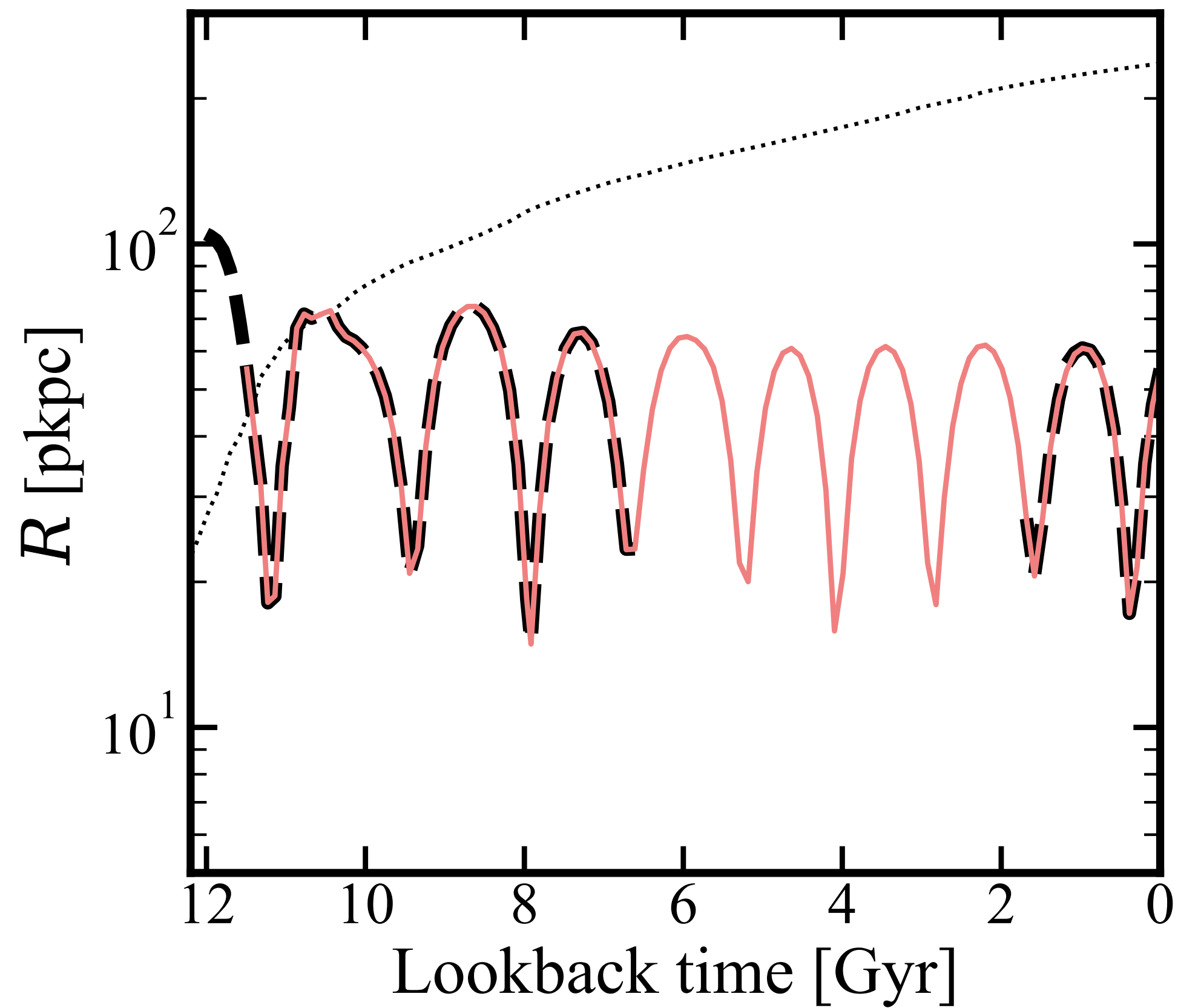
New tree starts here (within  $R_{vir}$ )

# MISSING-LINK TREES

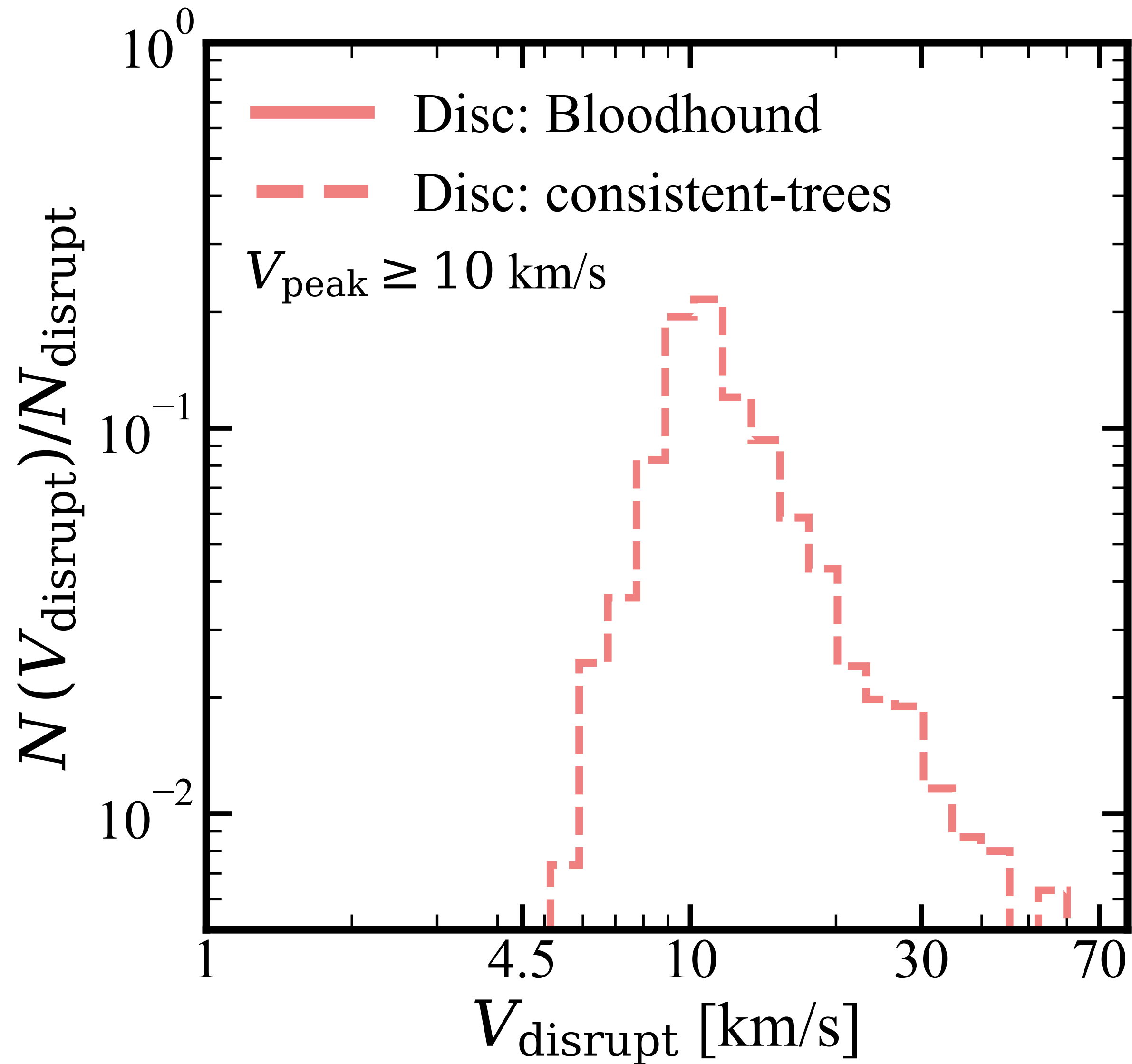


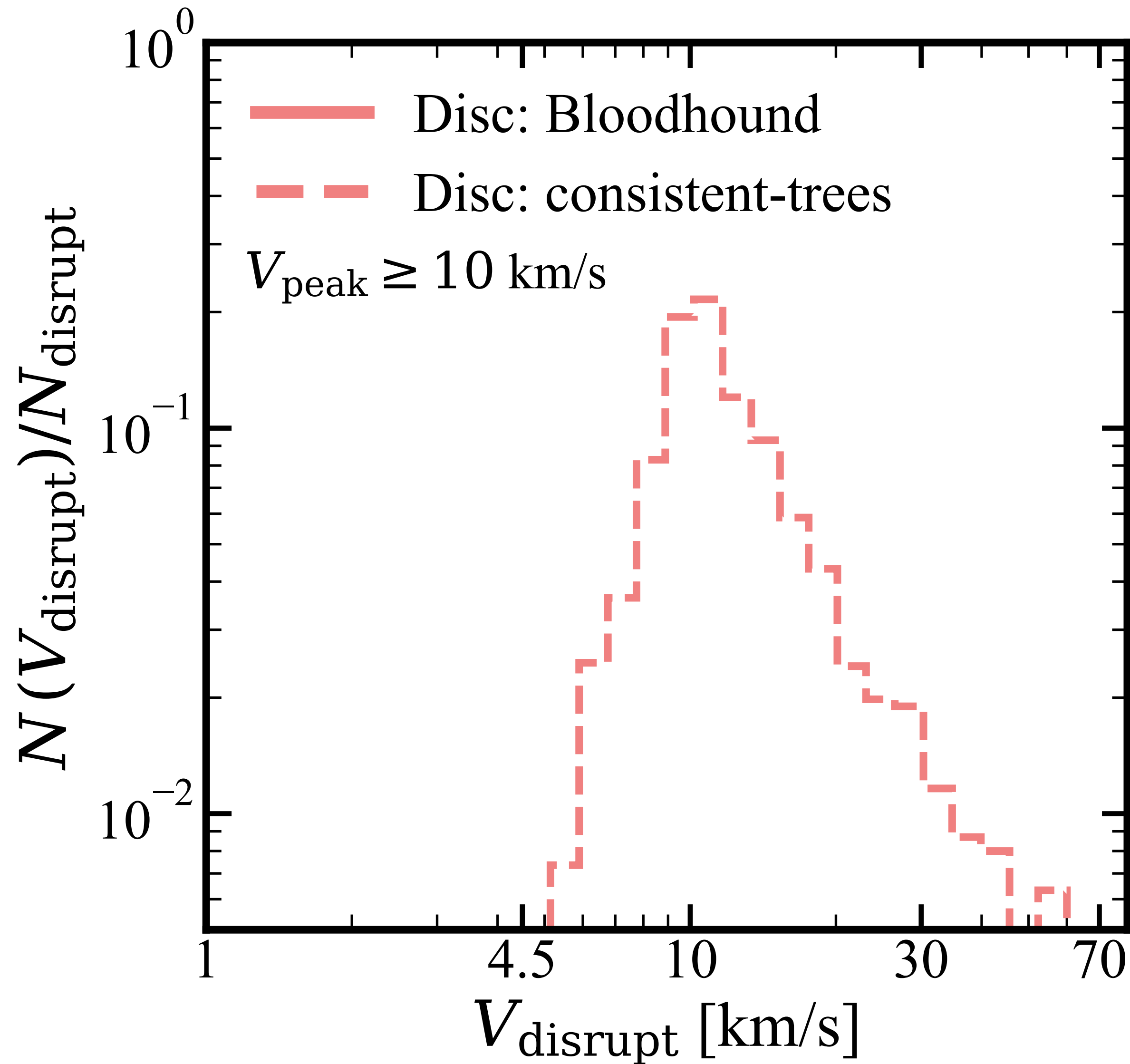


# MISSING-LINK TREES



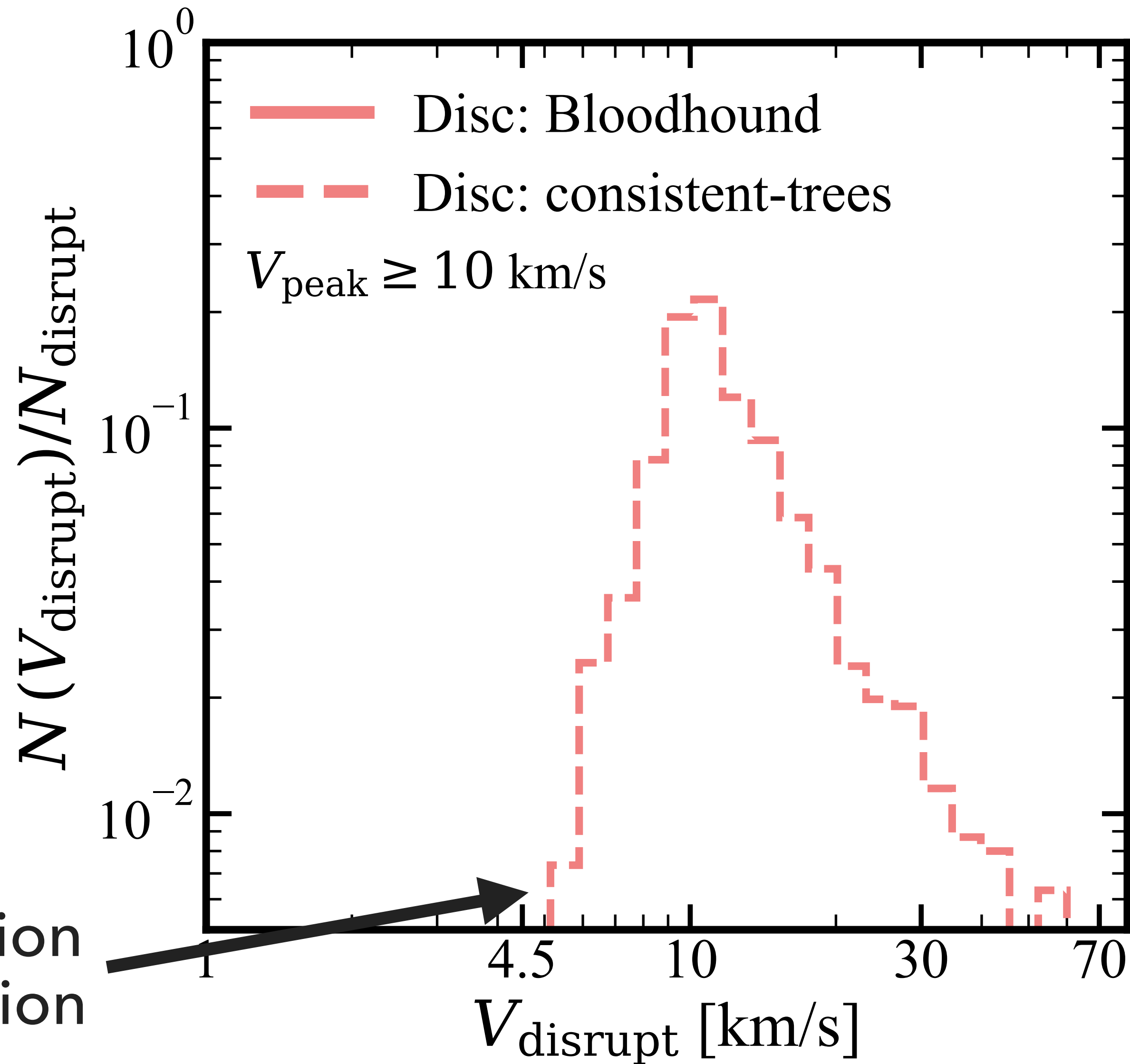
# SUBHALO TRACKING IMPROVEMENTS





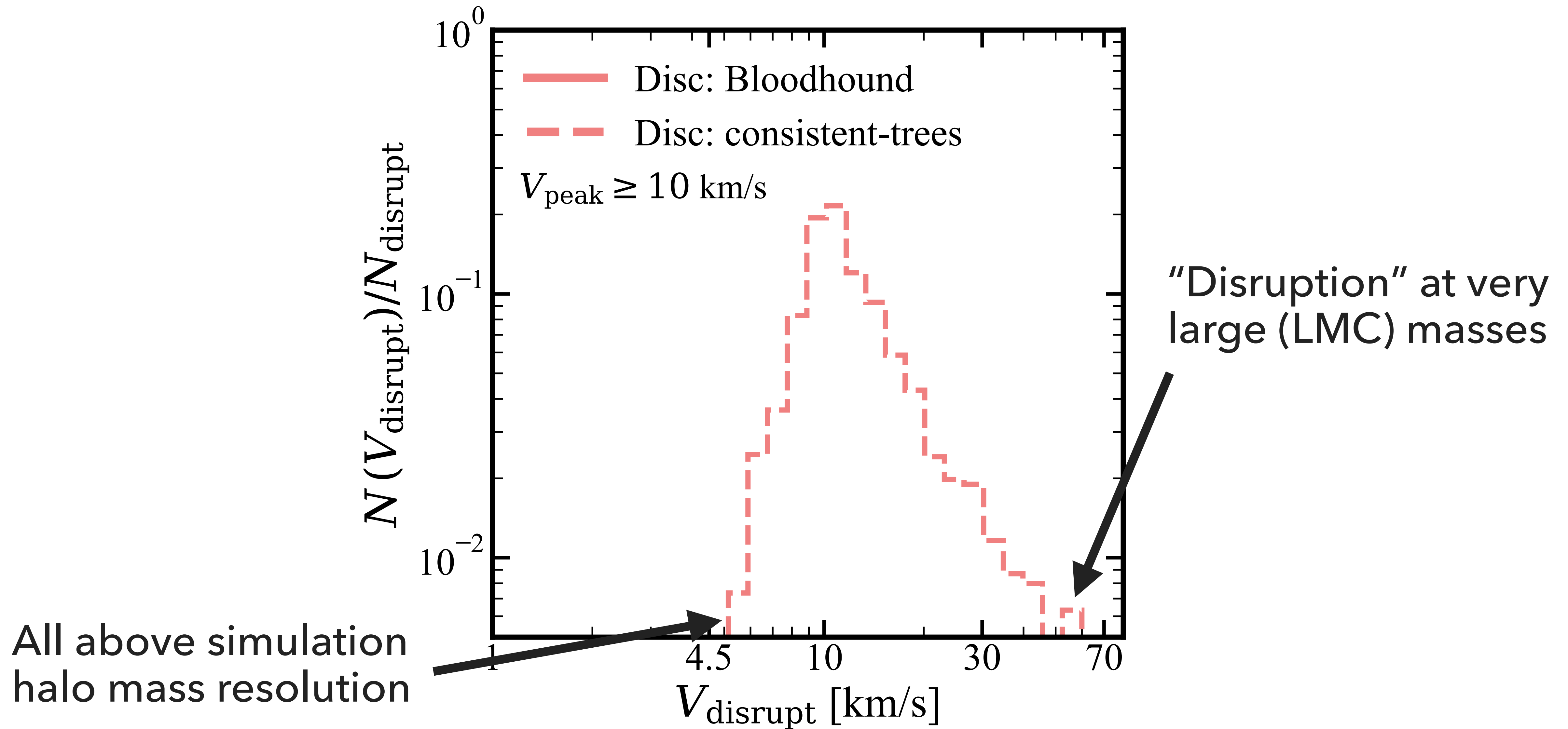
$V_{\text{disrupt}} = V_{\text{max}}$   
at disruption

# SUBHALO TRACKING IMPROVEMENTS

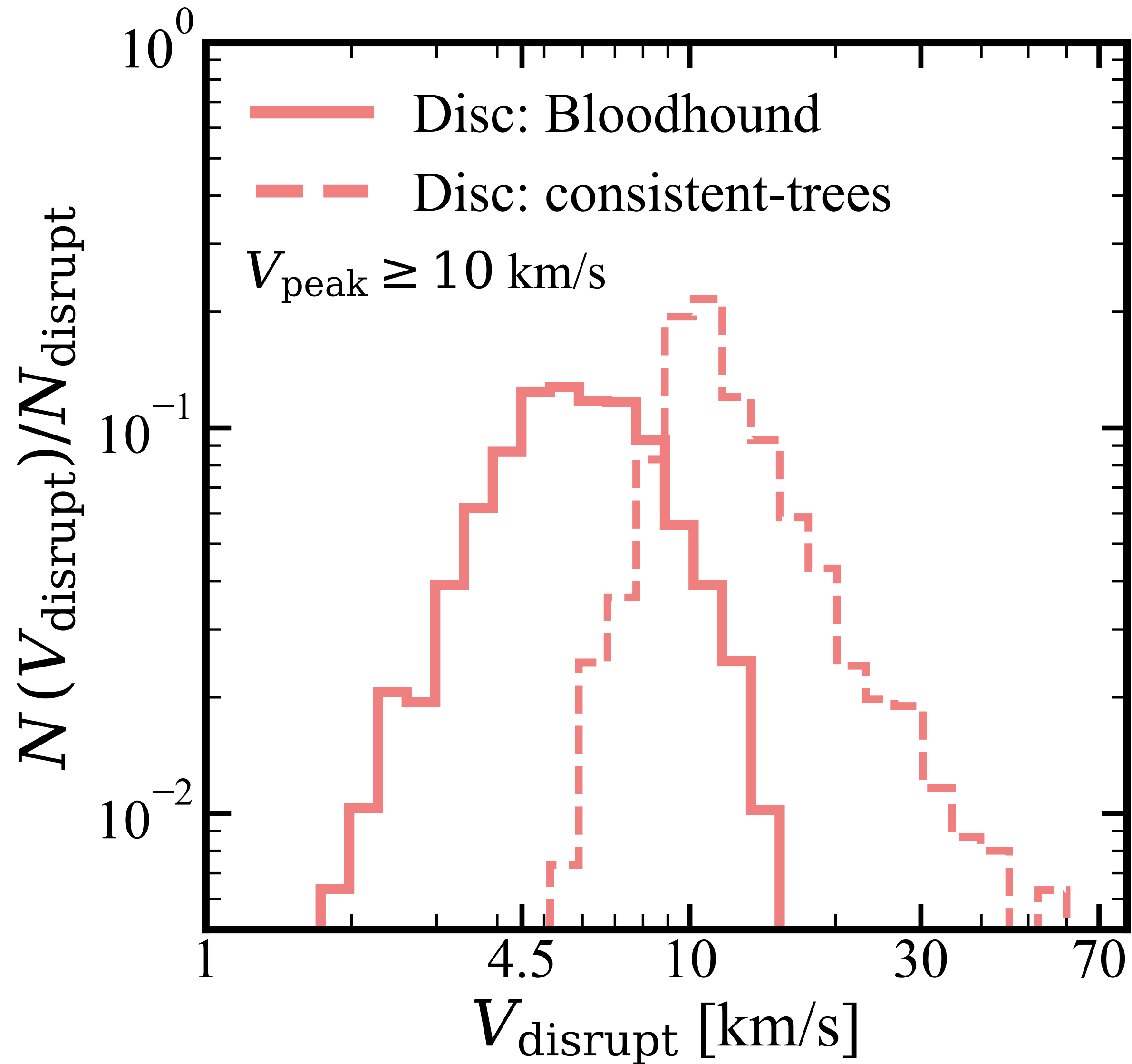


All above simulation  
halo mass resolution

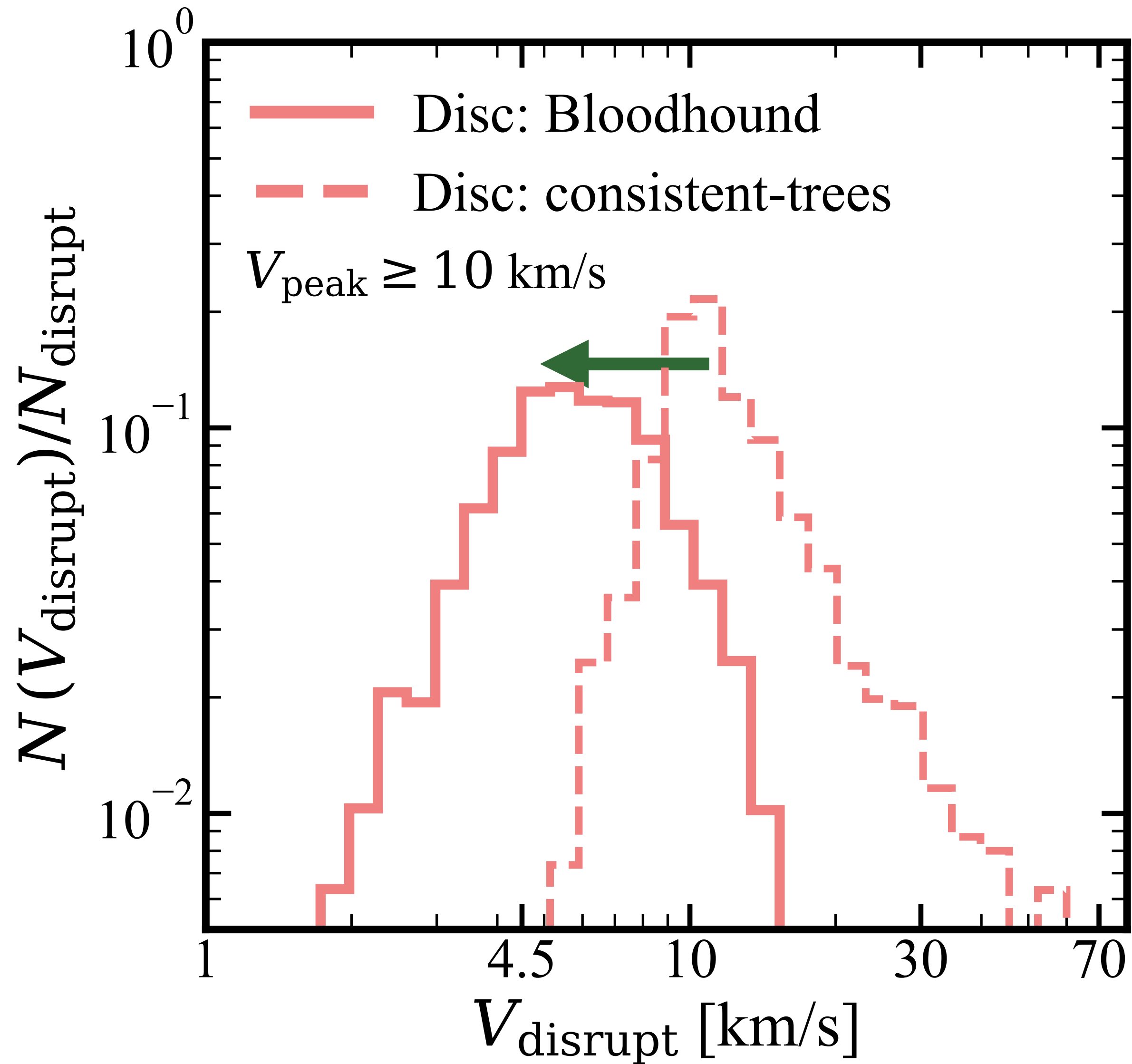
# SUBHALO TRACKING IMPROVEMENTS



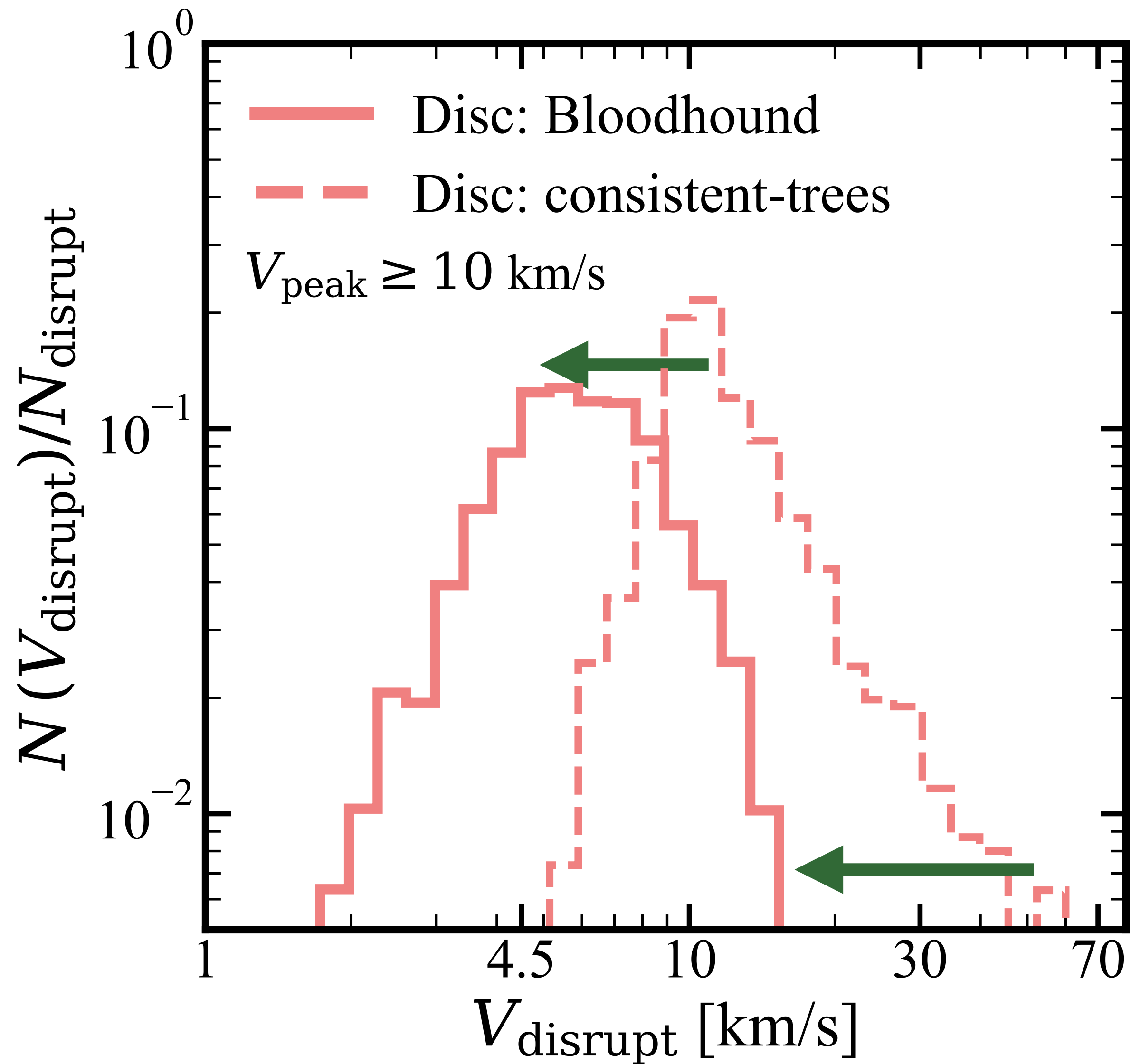
# SUBHALO TRACKING IMPROVEMENTS



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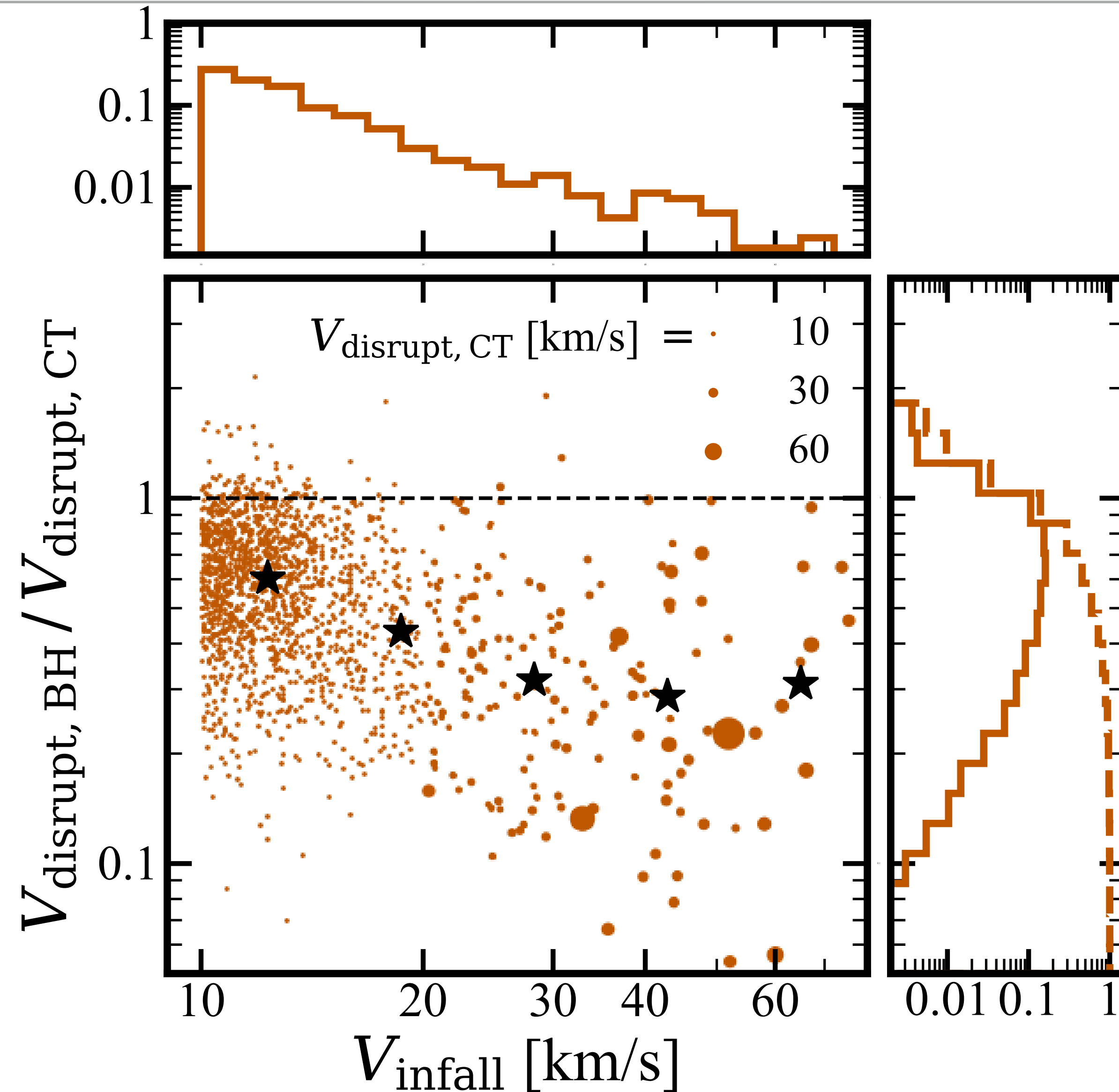


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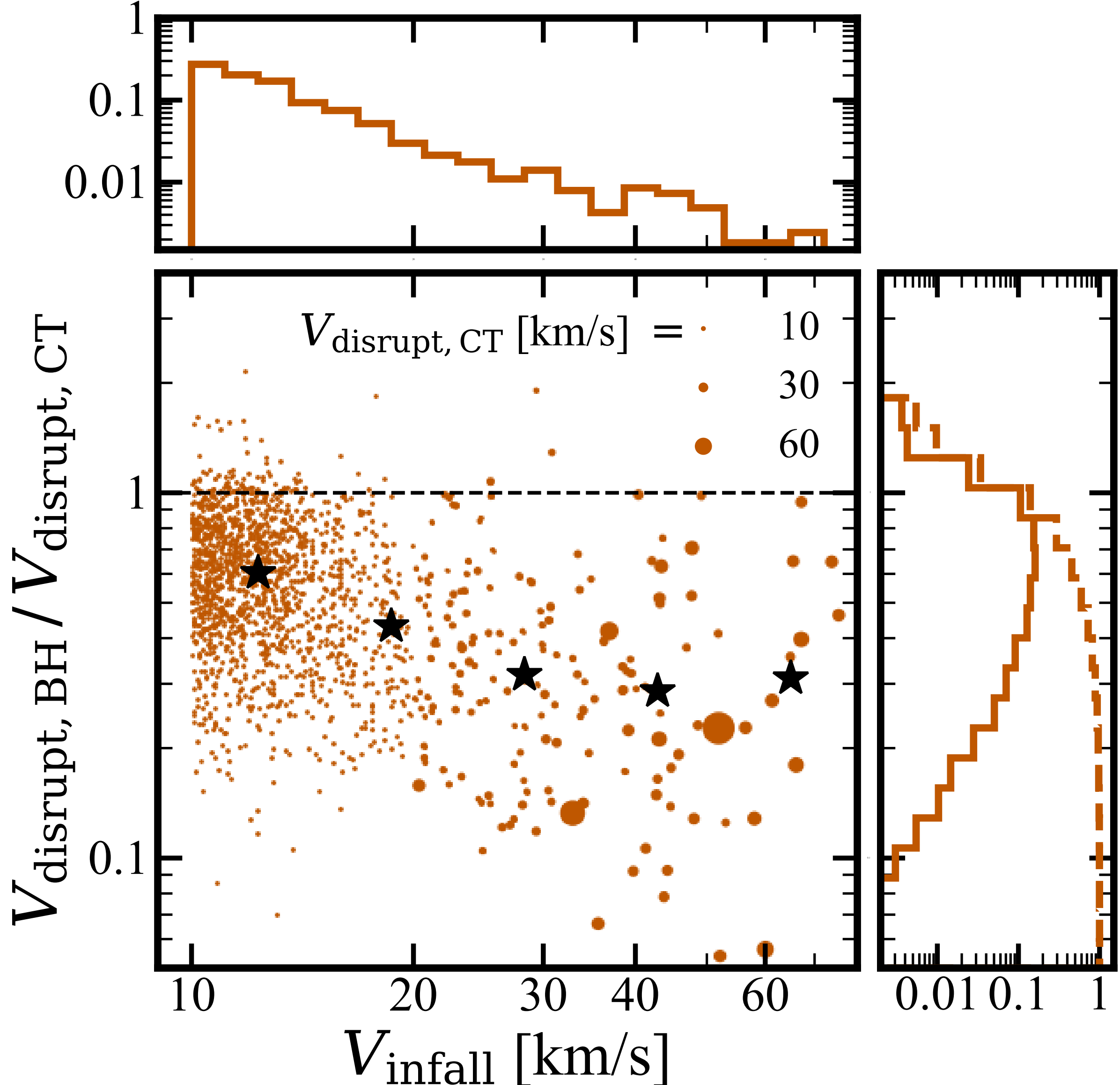




# AT WHAT MASS ARE THEY DISRUPTING?



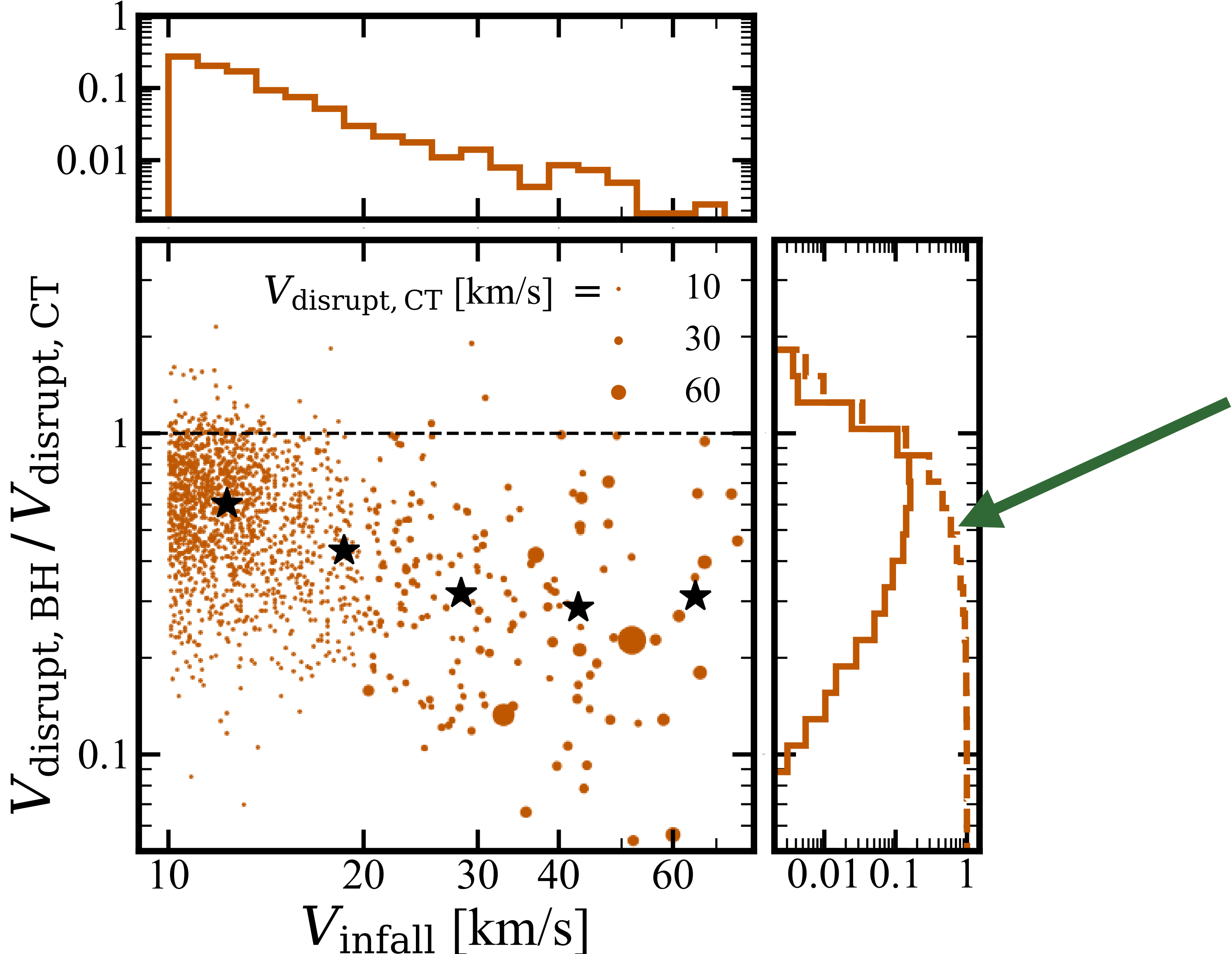
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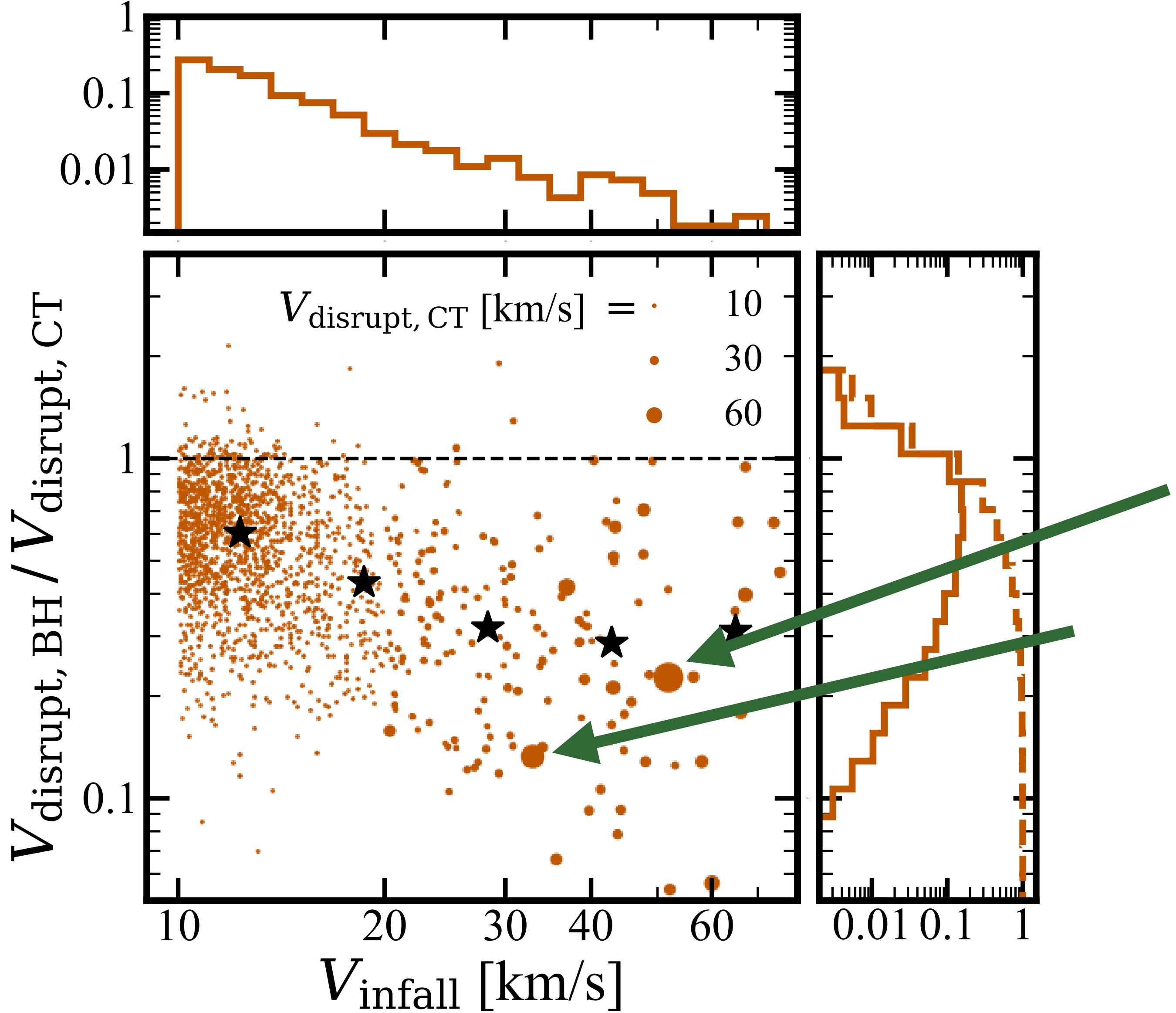
Smaller  $V_{\text{disrupt}}$  in almost all cases



# SUBHALO TRACKING IMPROVEMENTS

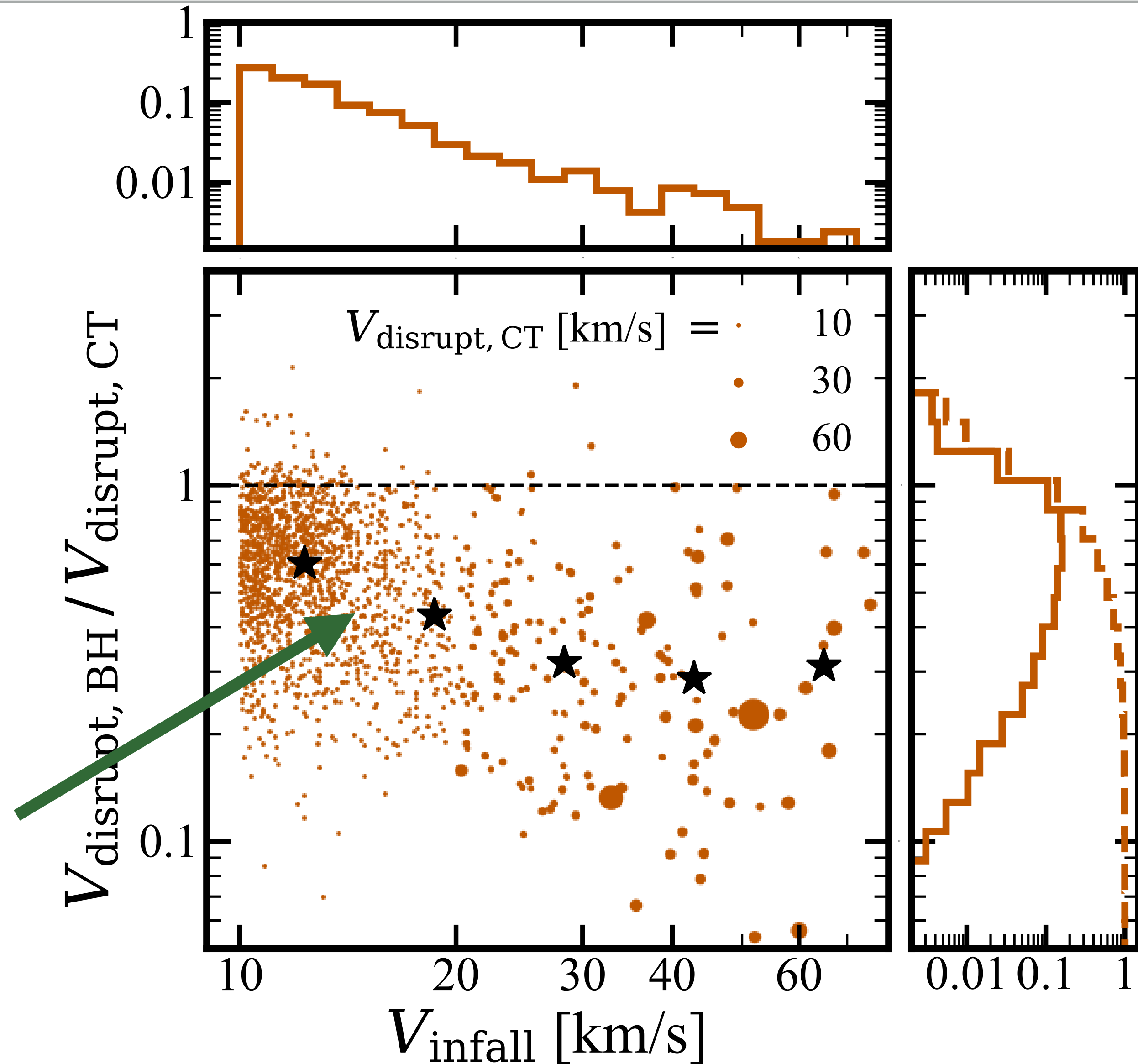


# SUBHALO TRACKING IMPROVEMENTS

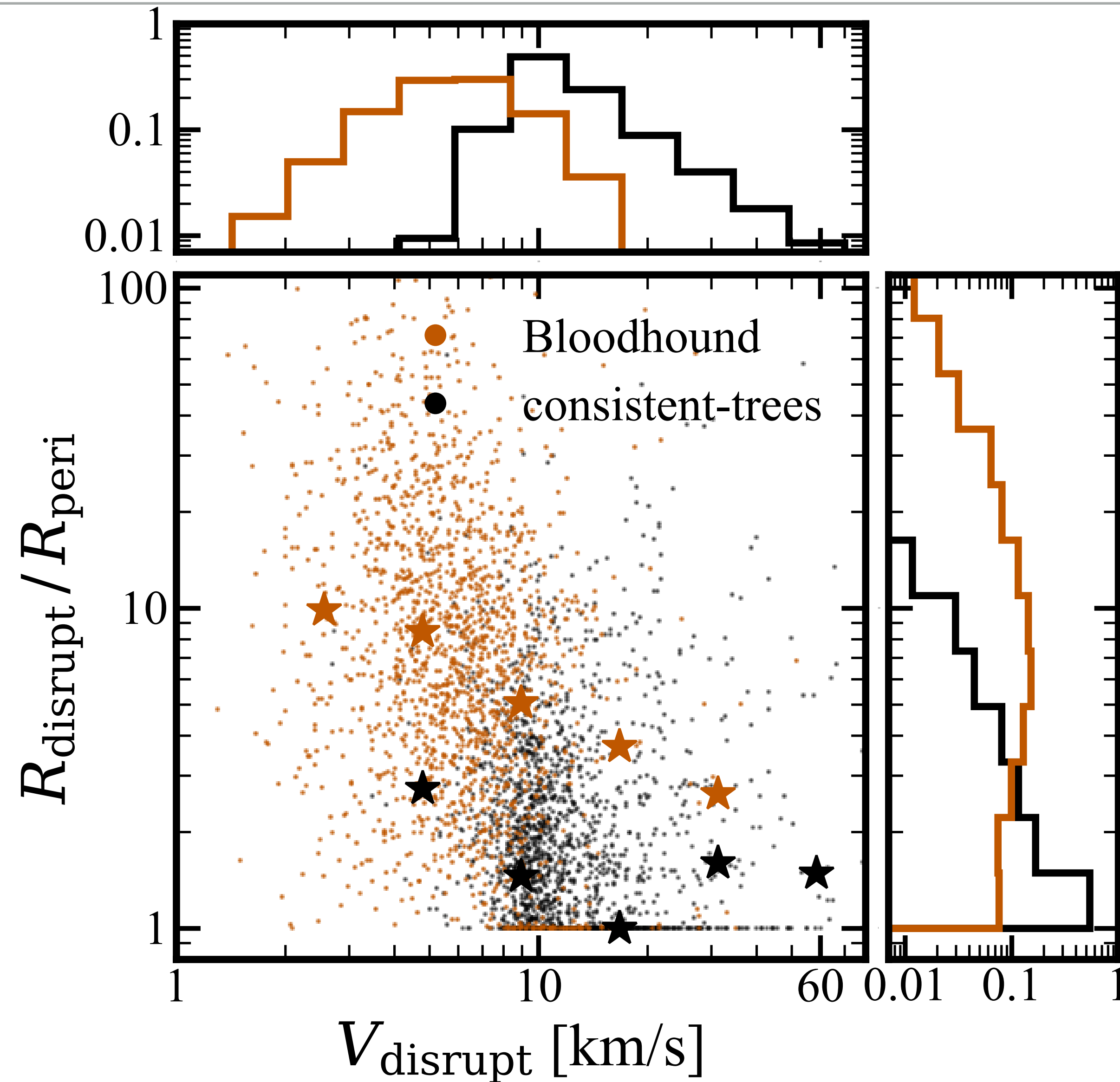


# SUBHALO TRACKING IMPROVEMENTS

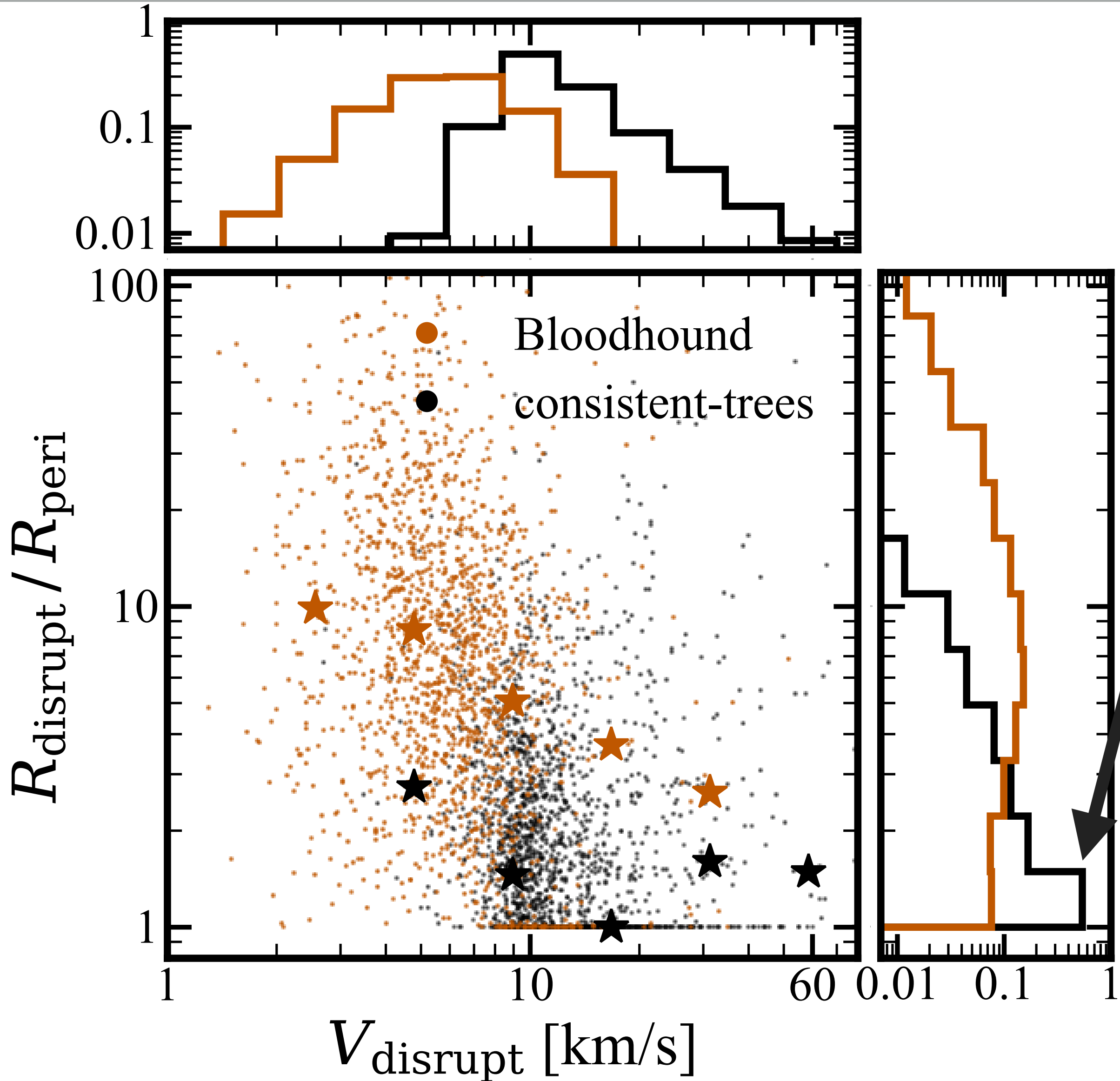
Bloodhound:  
resolution  
dependent



# WHERE ARE THEY DISRUPTING?



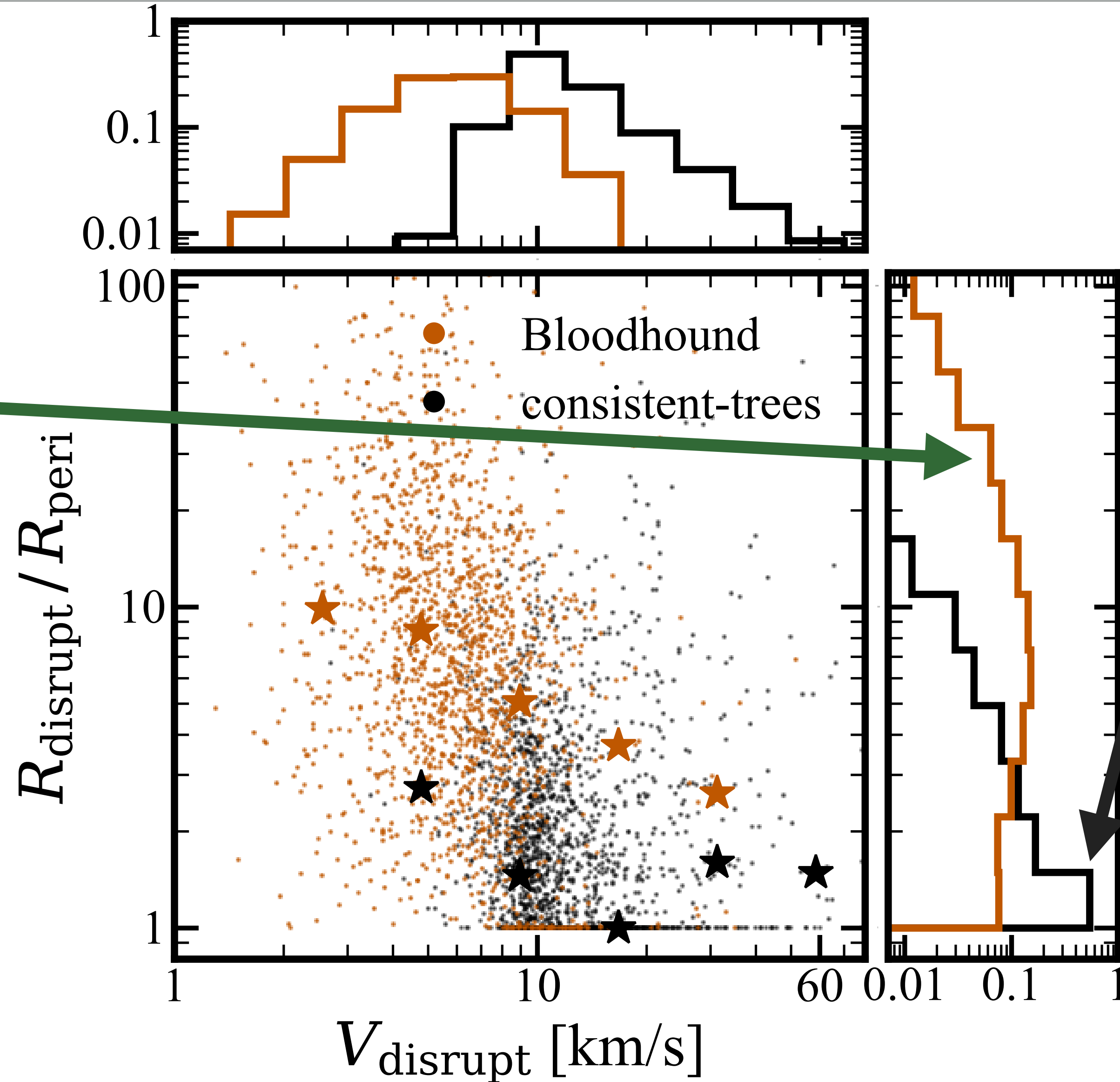
# WHERE ARE THEY DISRUPTING?



Standard method:  
Most of them disrupt  
at the pericenter

# WHERE ARE THEY DISRUPTING?

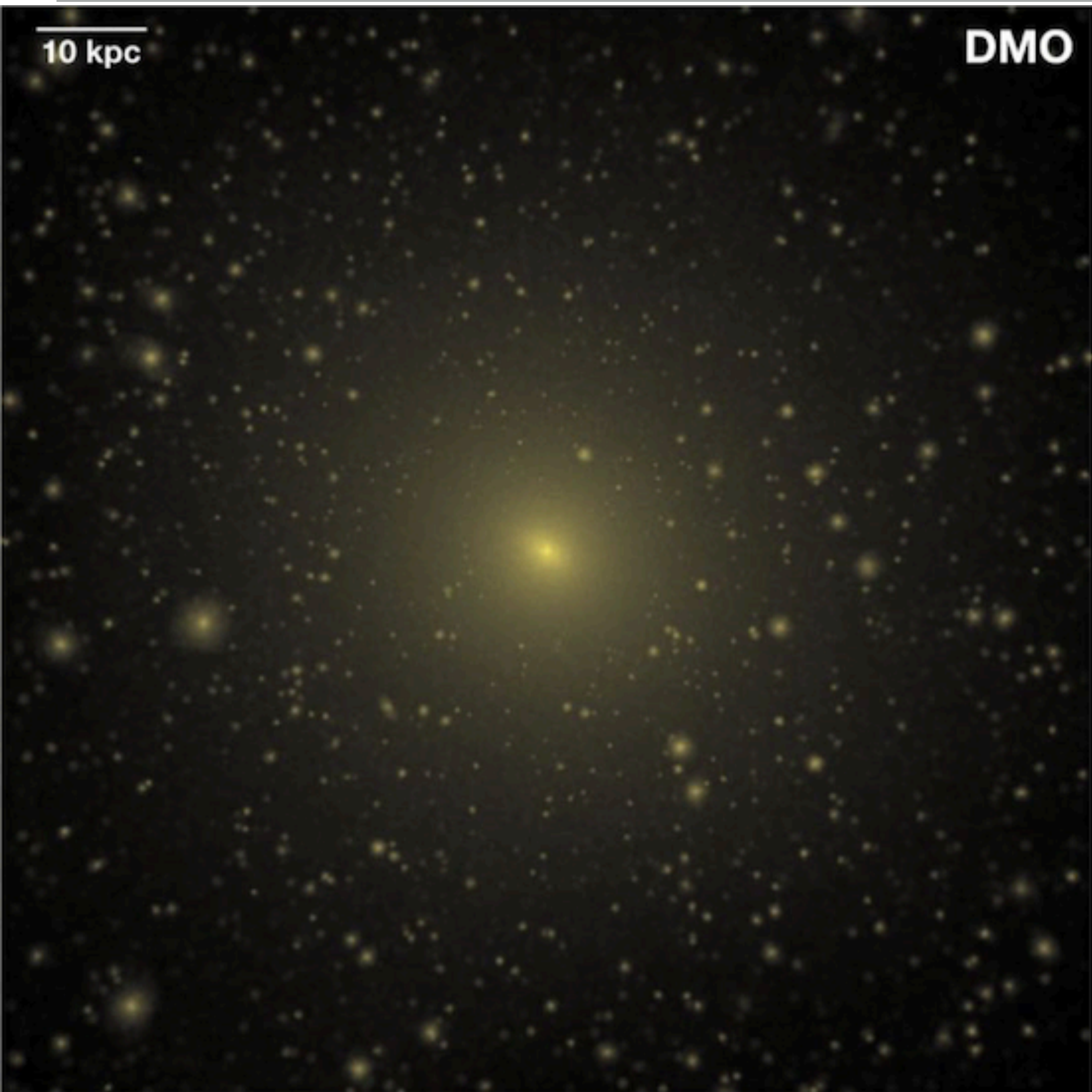
Bloodhound:  
A lot of them survive past the pericenter



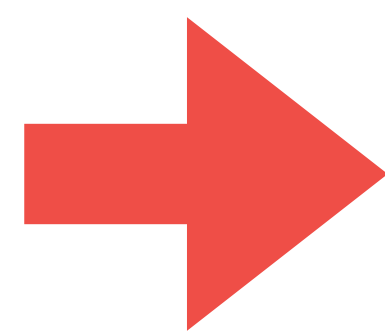
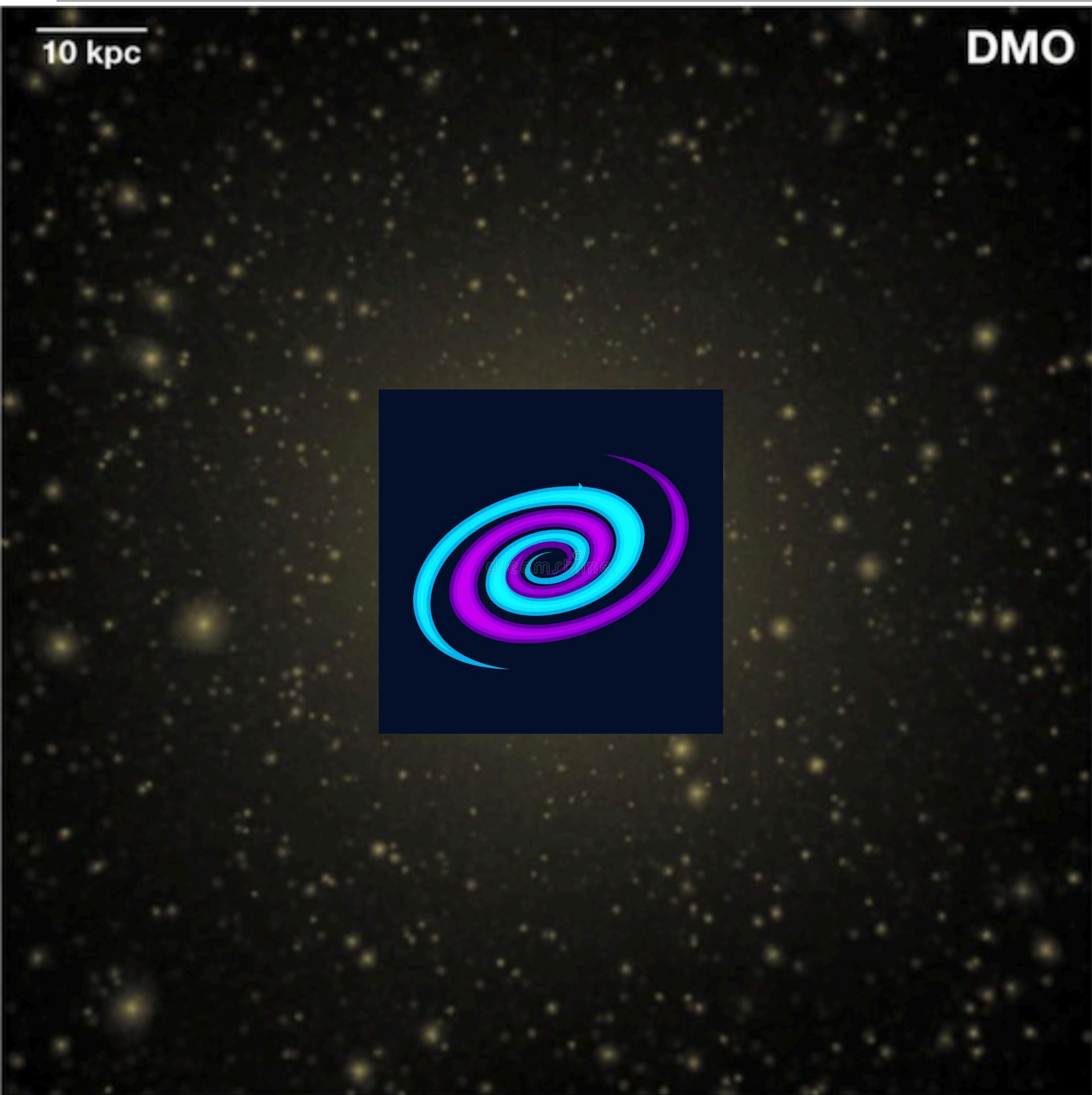
Standard method:  
Most of them disrupt at the pericenter



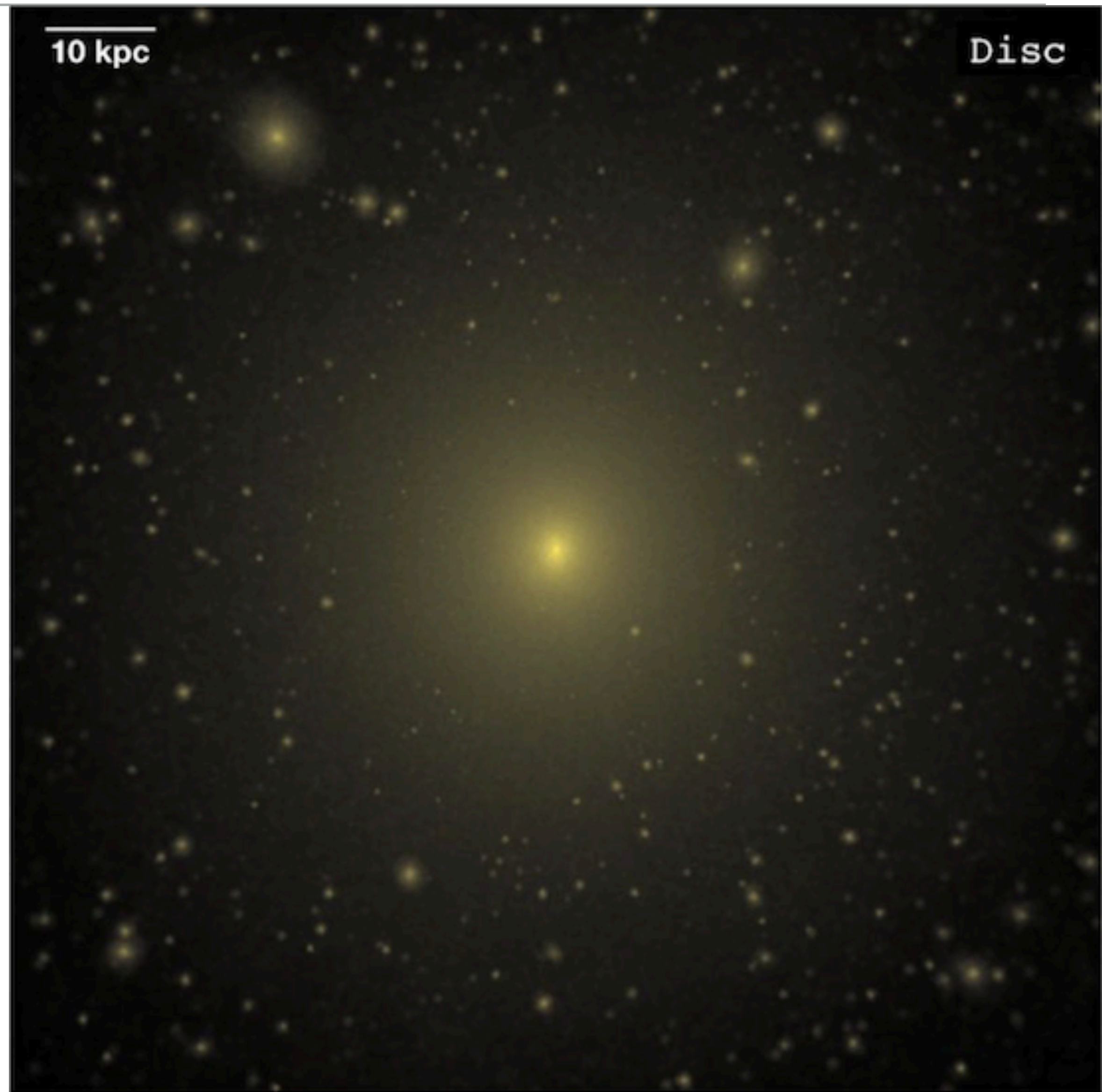
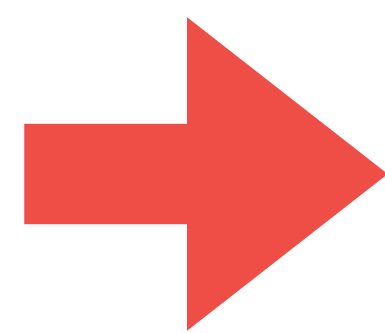
# PHAT ELVIS: DMO VS. DISC



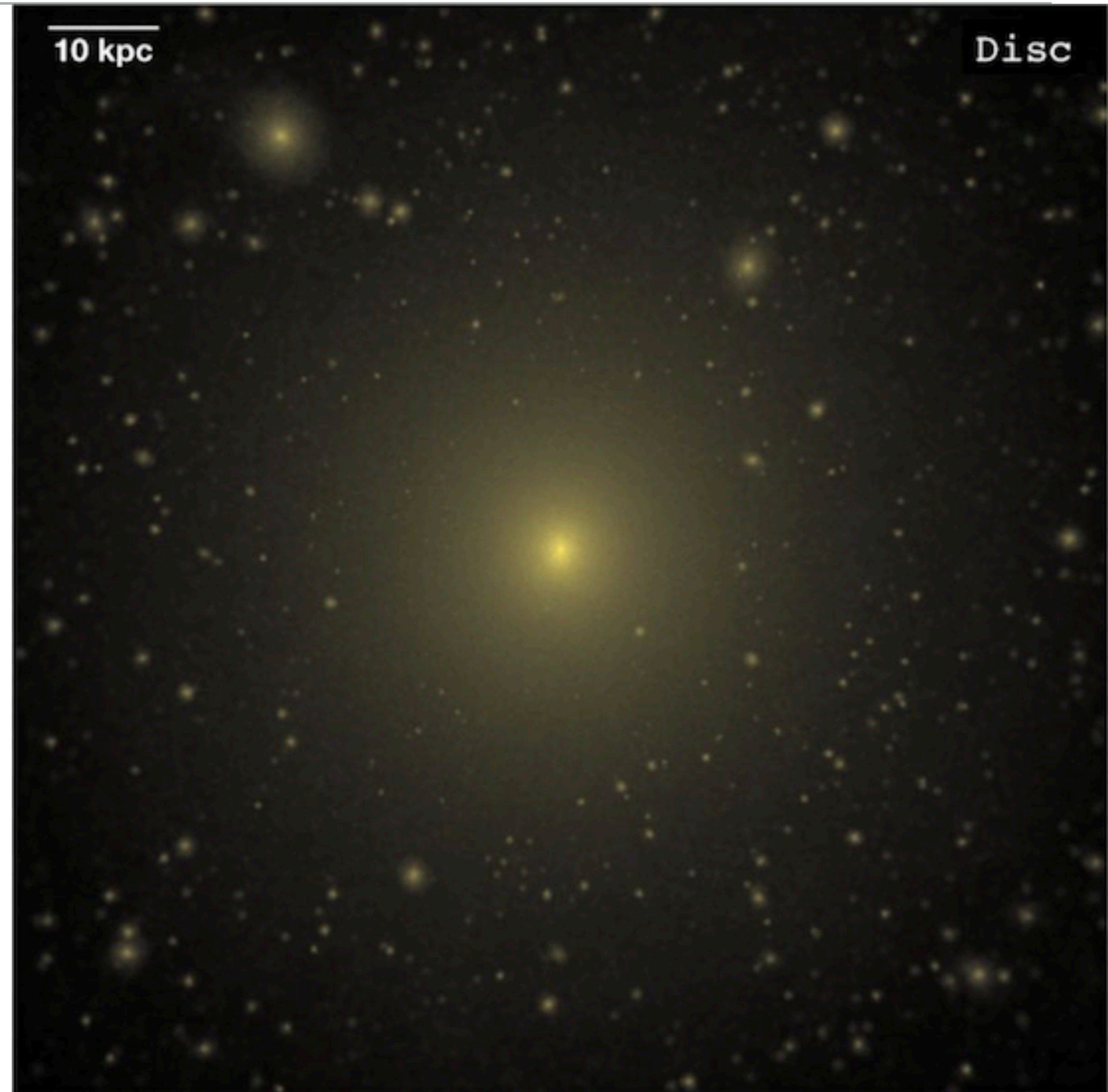
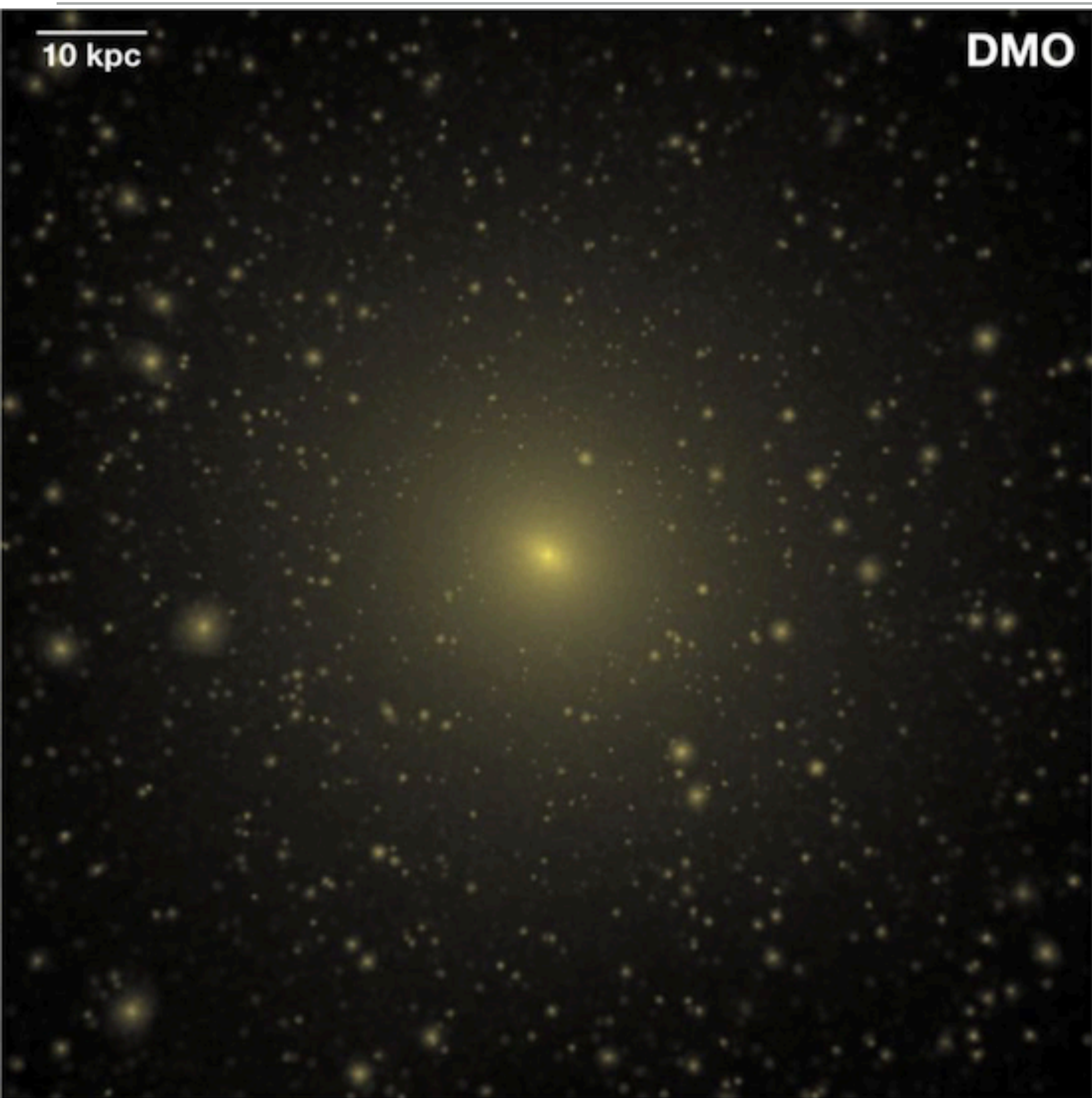
# PHAT ELVIS: DMO VS. DISC



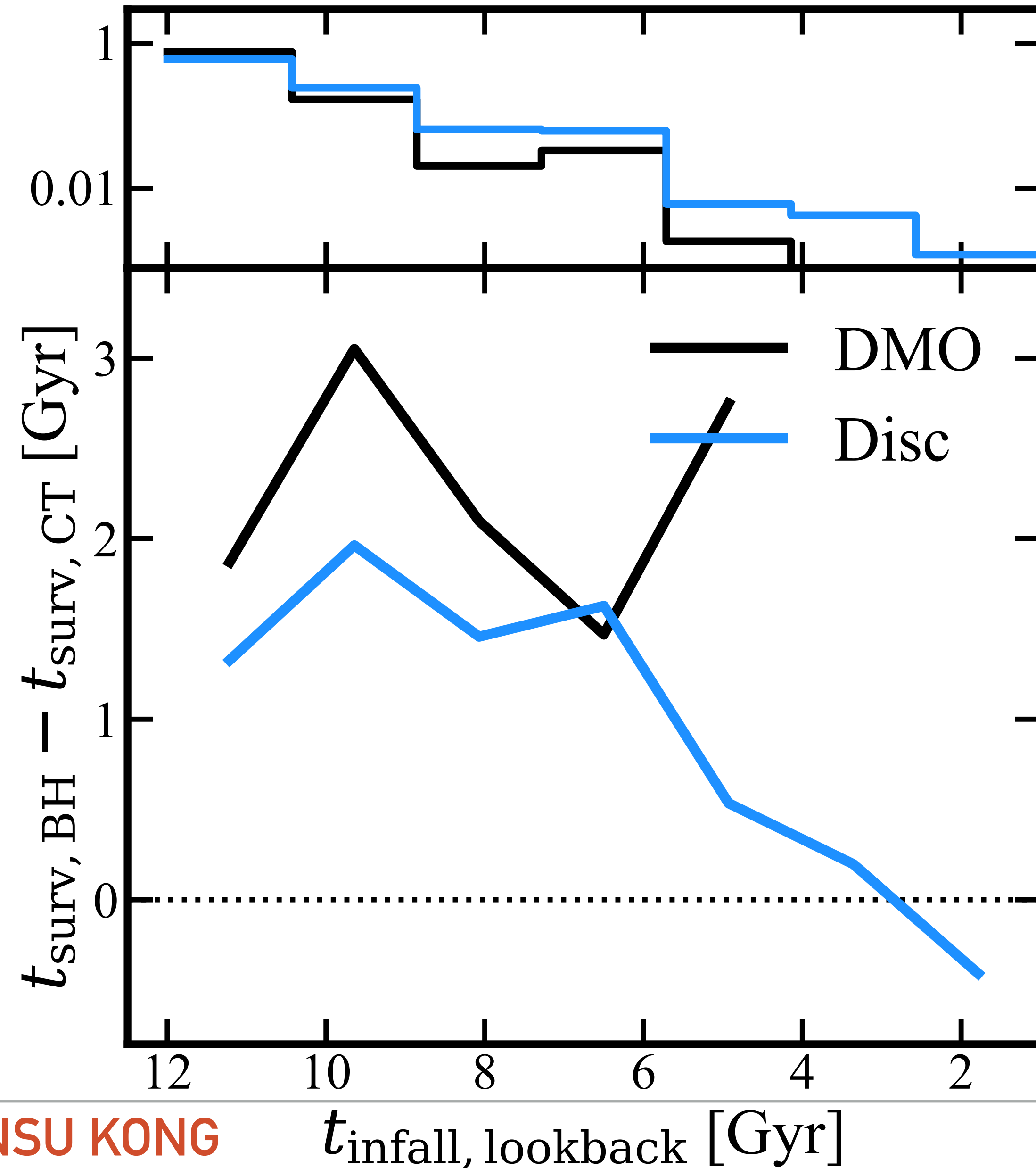
# PHAT ELVIS: DMO VS. DISC



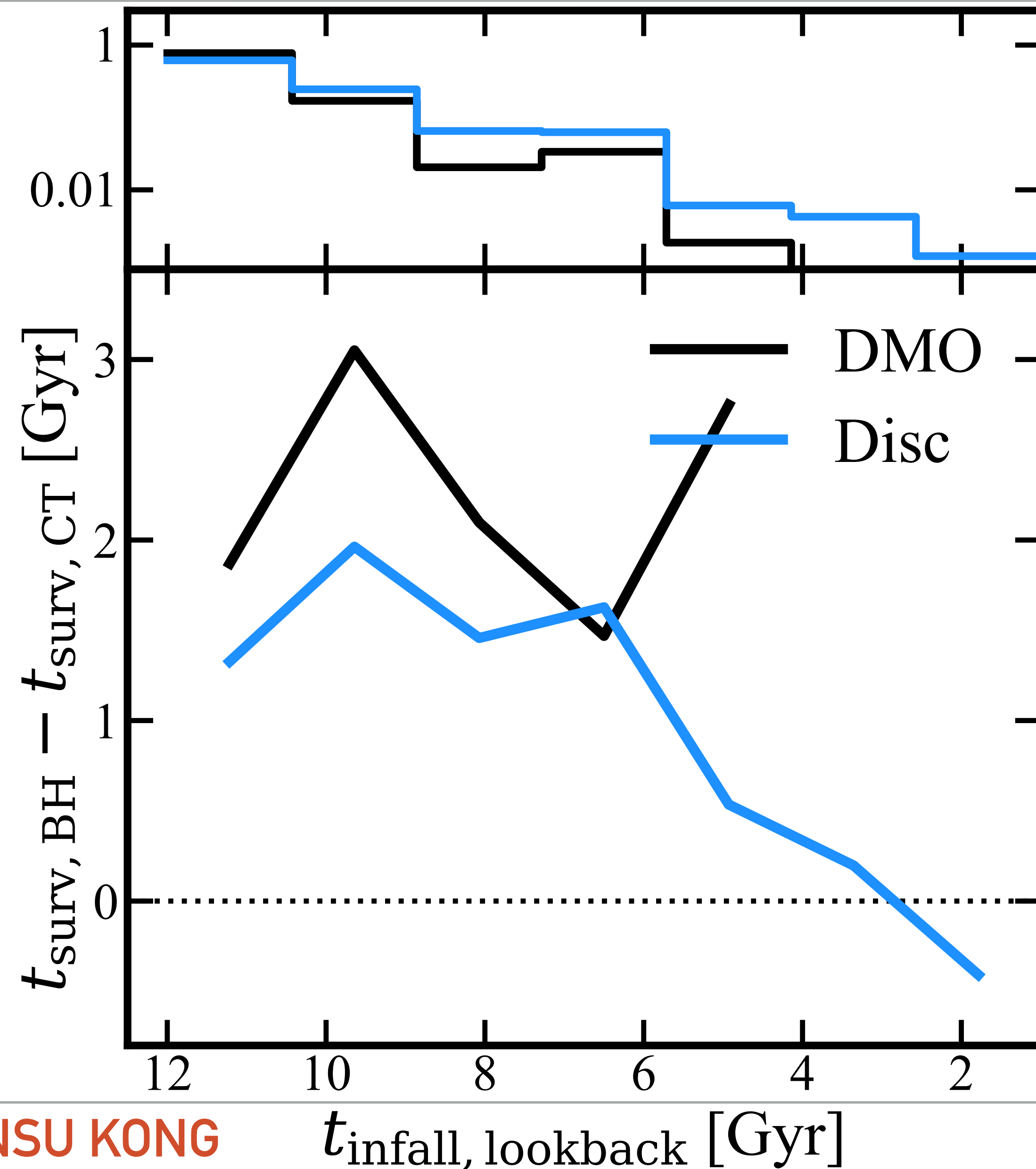
# PHAT ELVIS: DMO VS. DISC



# SUBHALO TRACKING TIME

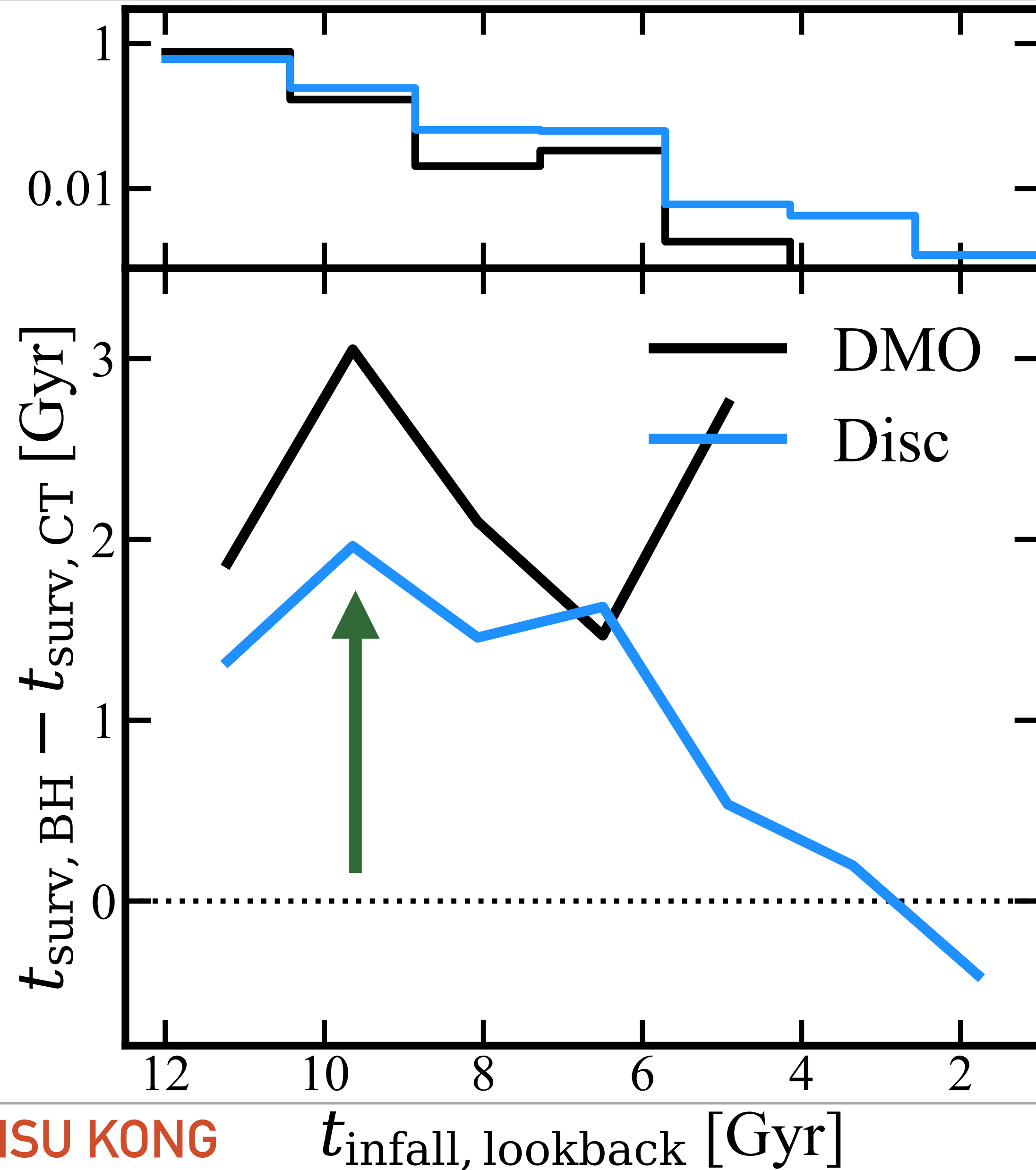


# SUBHALO TRACKING TIME



$$t_{\text{surv}} = t_{\text{infall, lb}} - t_{\text{disrupt, lb}}$$

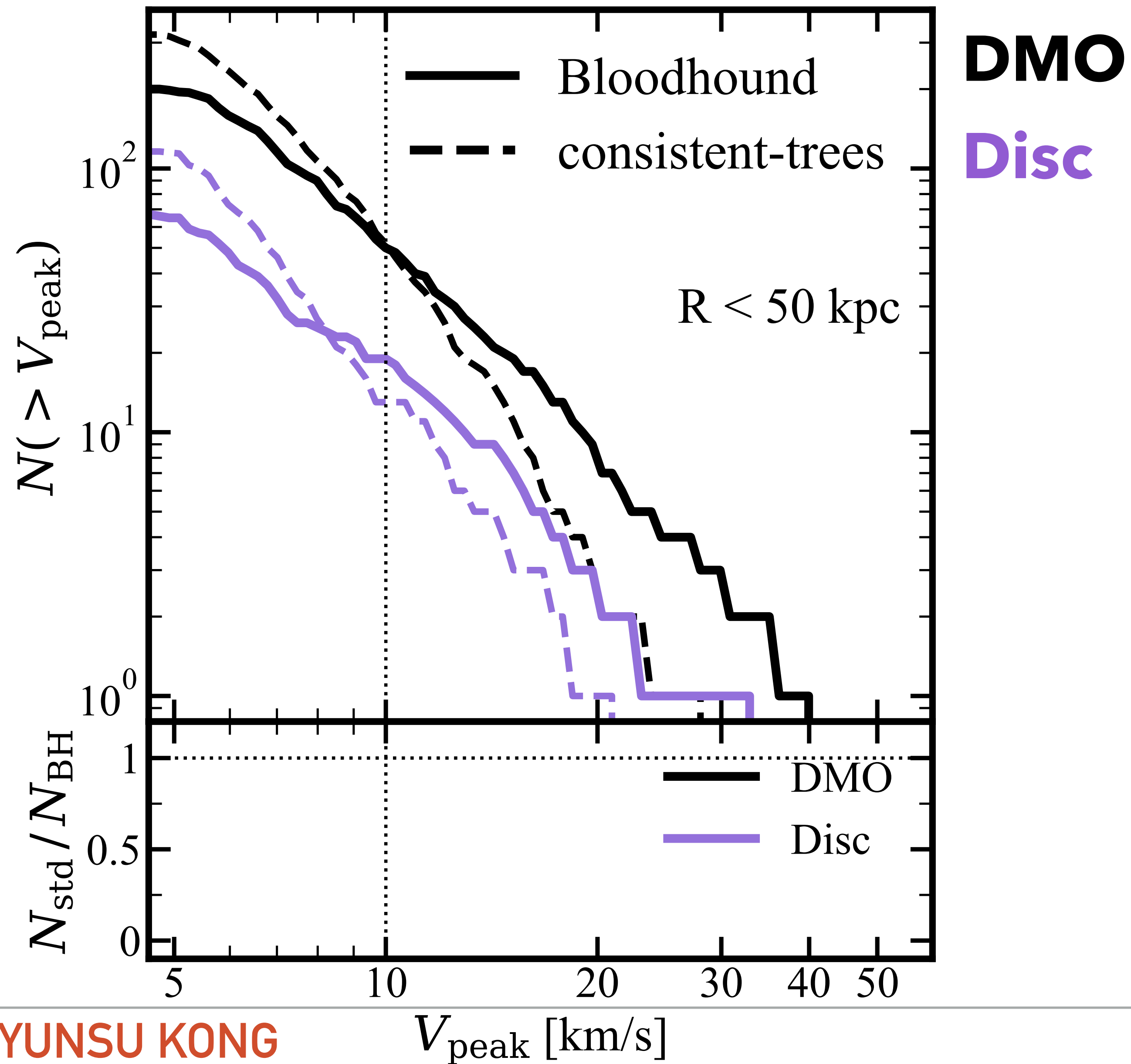
# SUBHALO TRACKING TIME



+ ~2.5 Gyr DMO

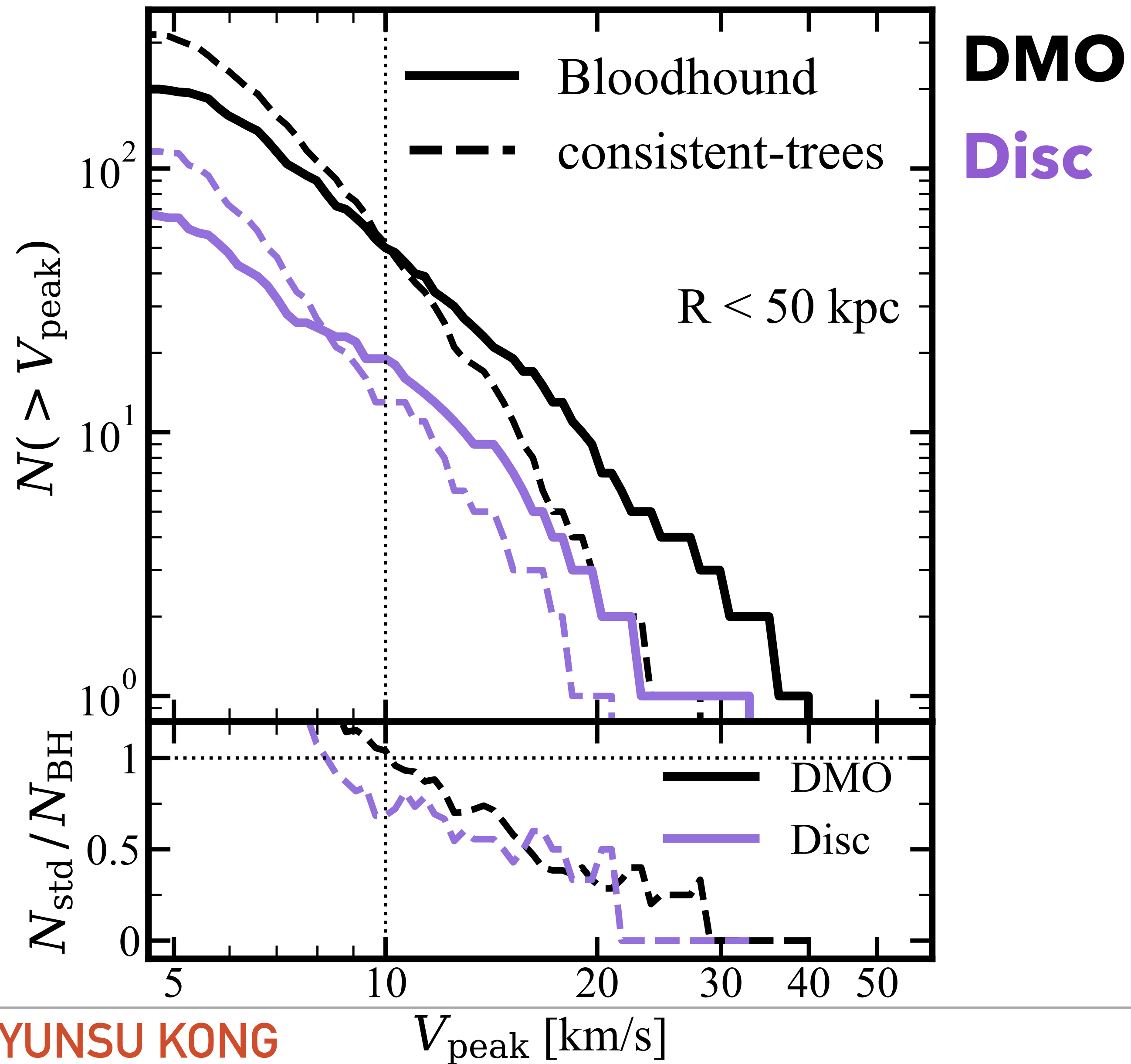
+ ~1.5 Gyr Disc

# VELOCITY FUNCTIONS

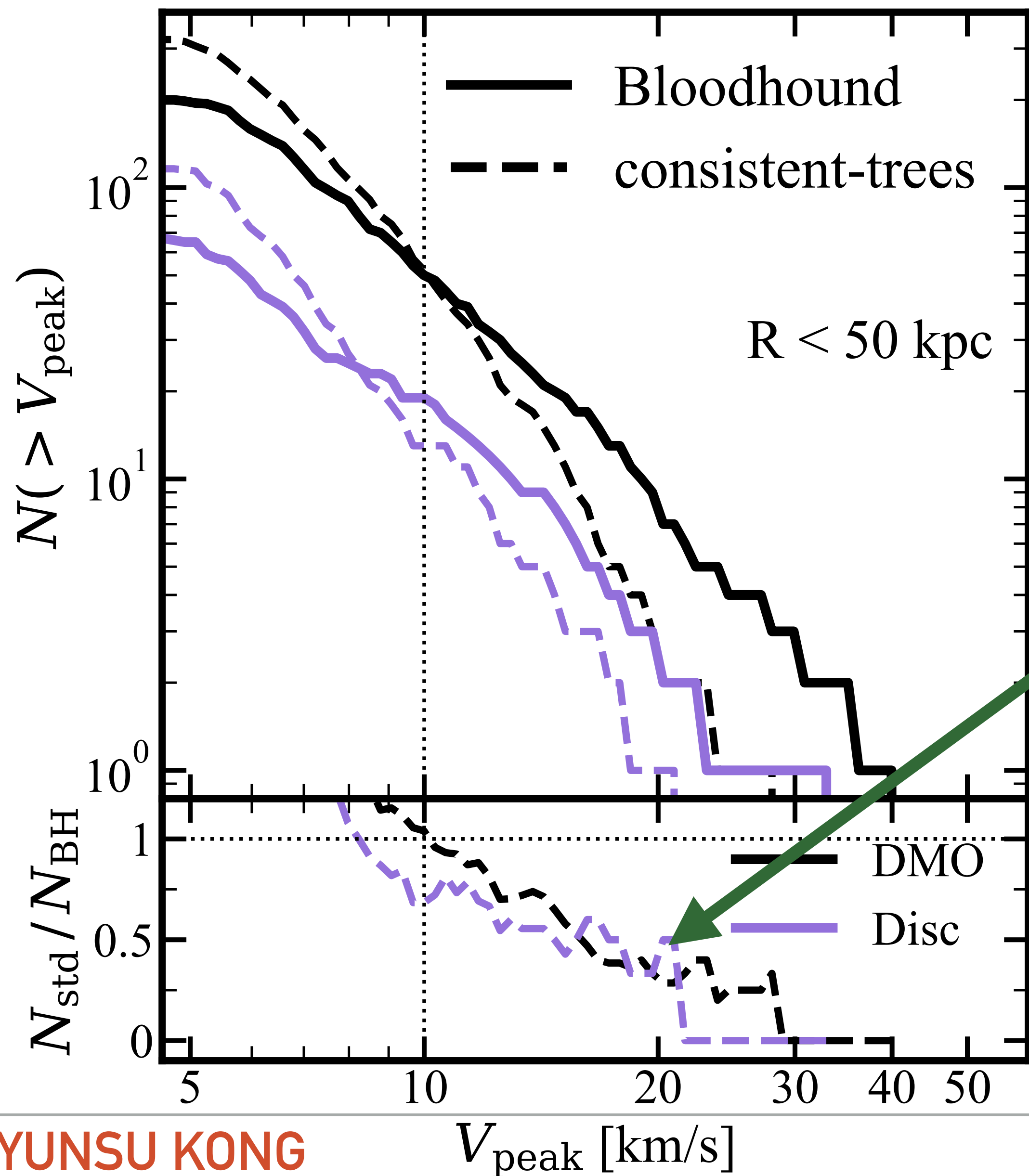




# VELOCITY FUNCTIONS



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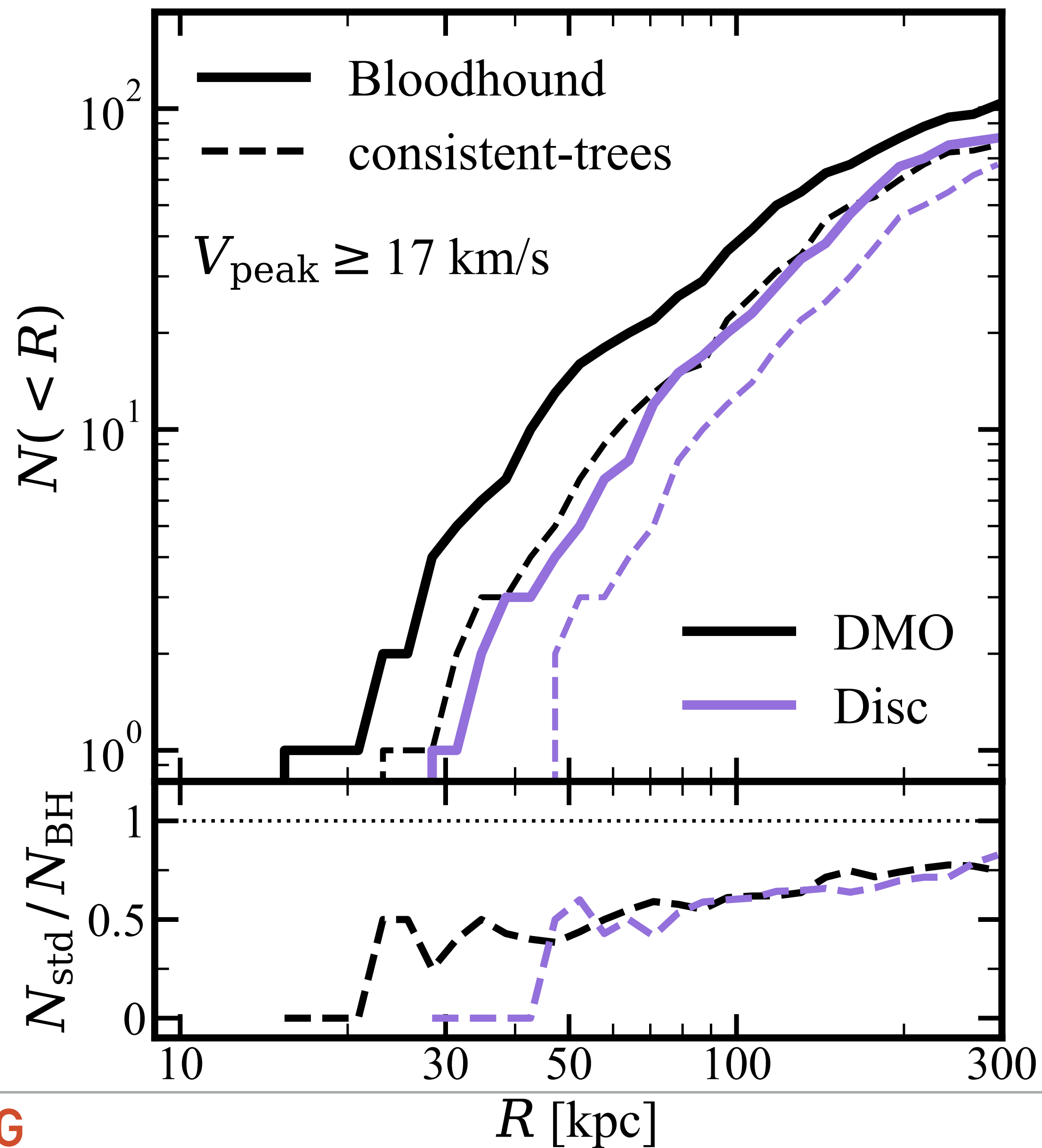


**DMO**

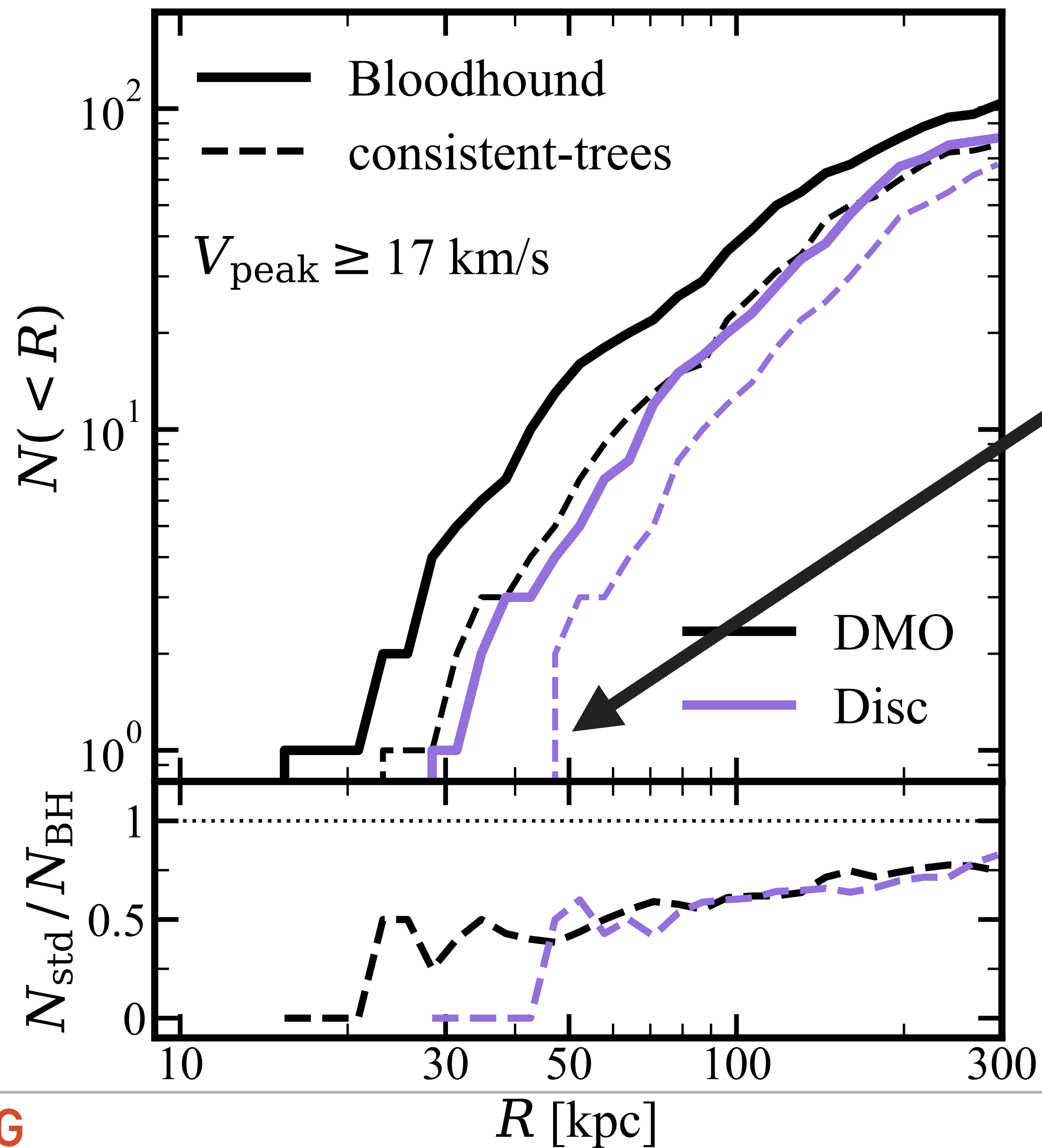
**Disc**

2x more surviving subhalos of  $V_{\text{peak}} > 20$  km/s (atomic cooling limit) within 50 kpc

# RADIAL DISTRIBUTIONS

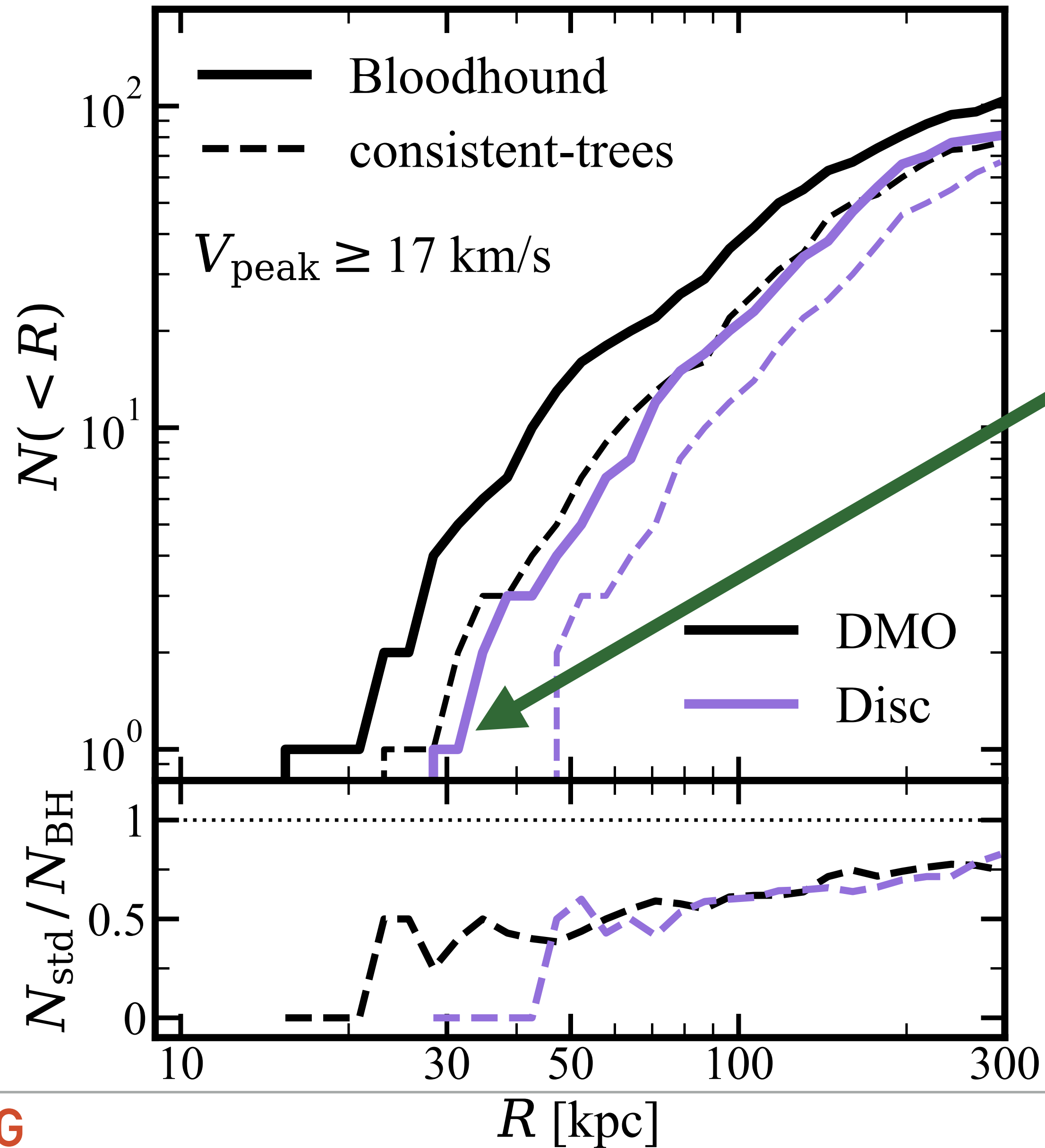


# RADIAL DISTRIBUTIONS



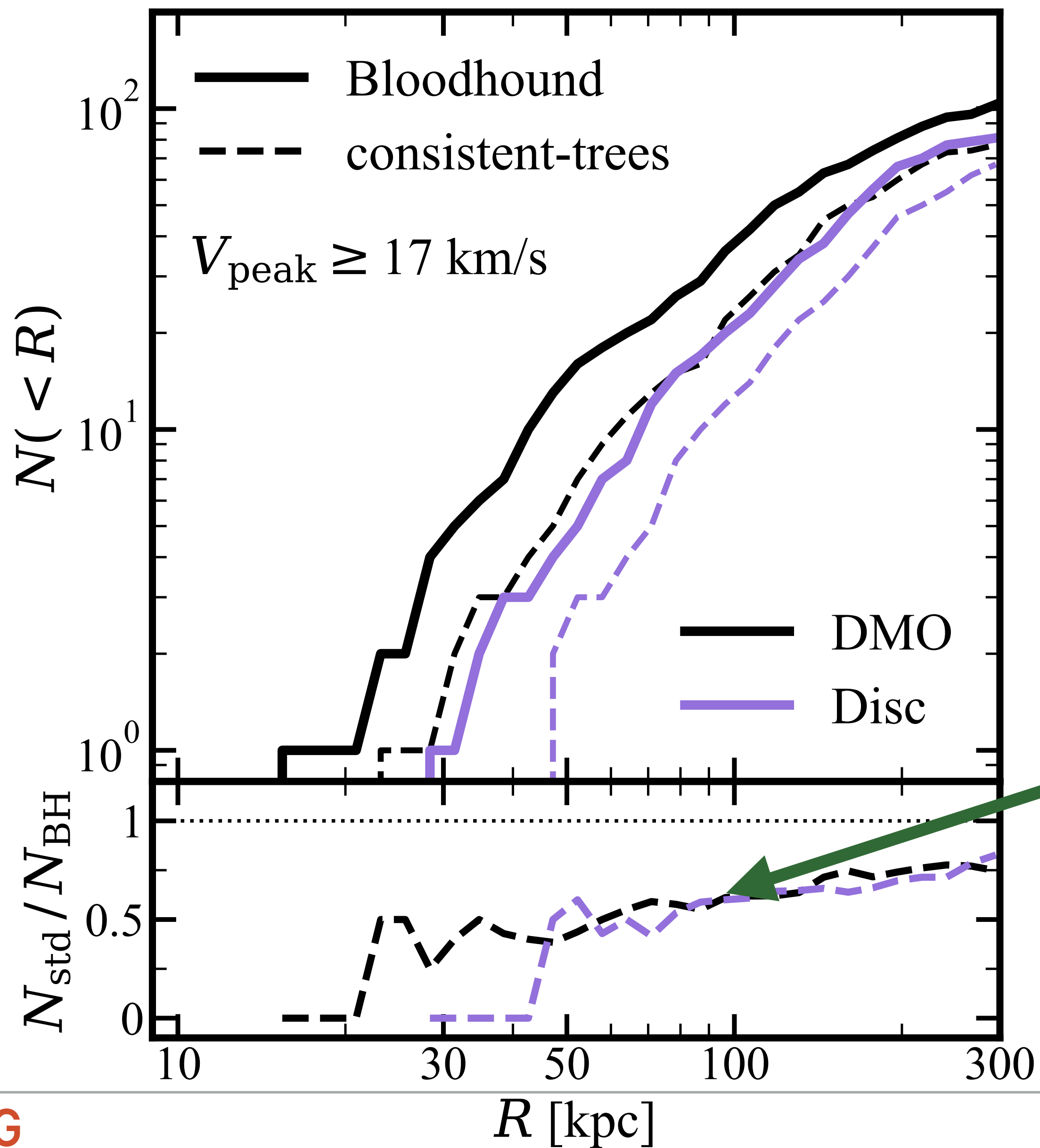
Depleted  $R < 50 \text{ kpc}$   
in traditional method

# RADIAL DISTRIBUTIONS



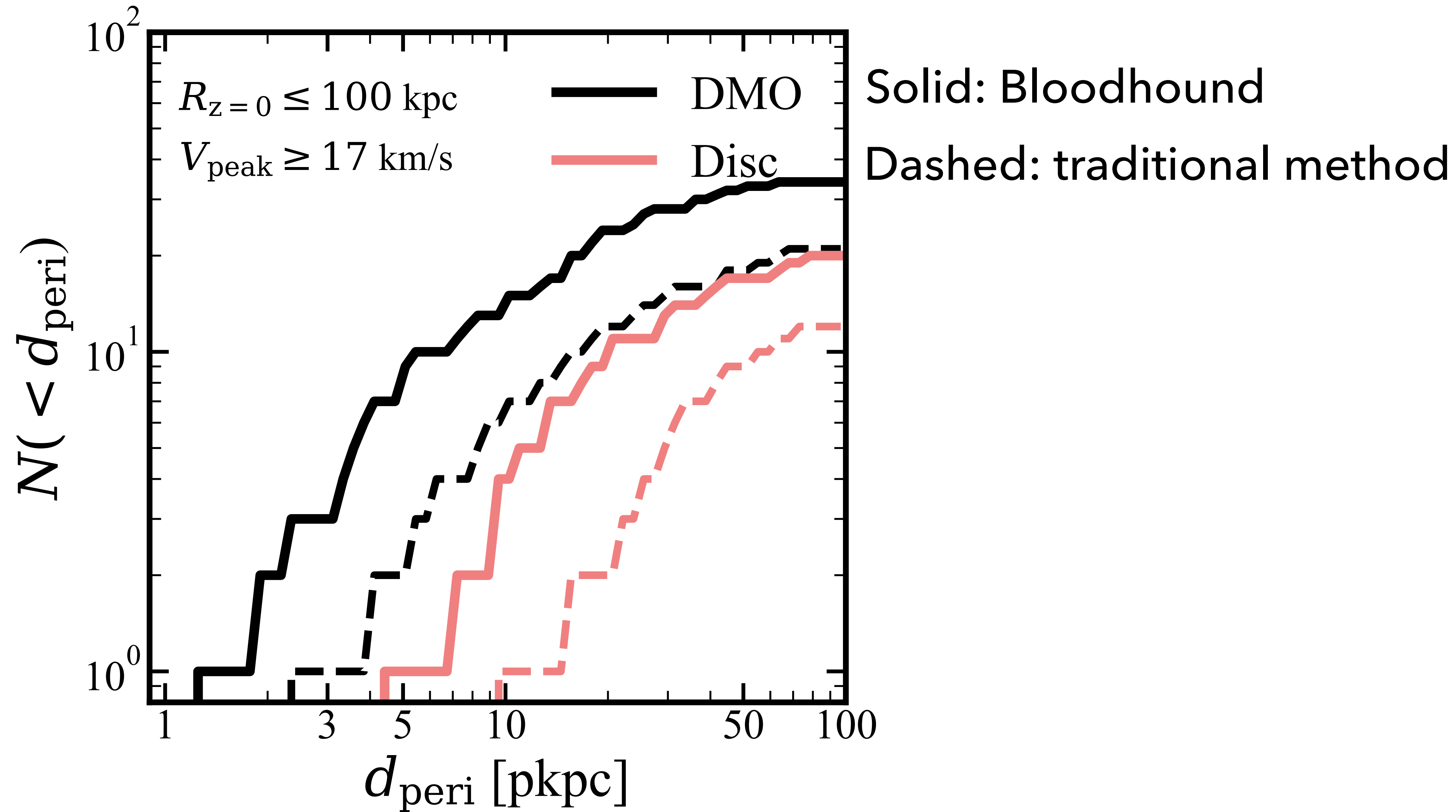
Bloodhound:  
As close as 30 kpc

# RADIAL DISTRIBUTIONS

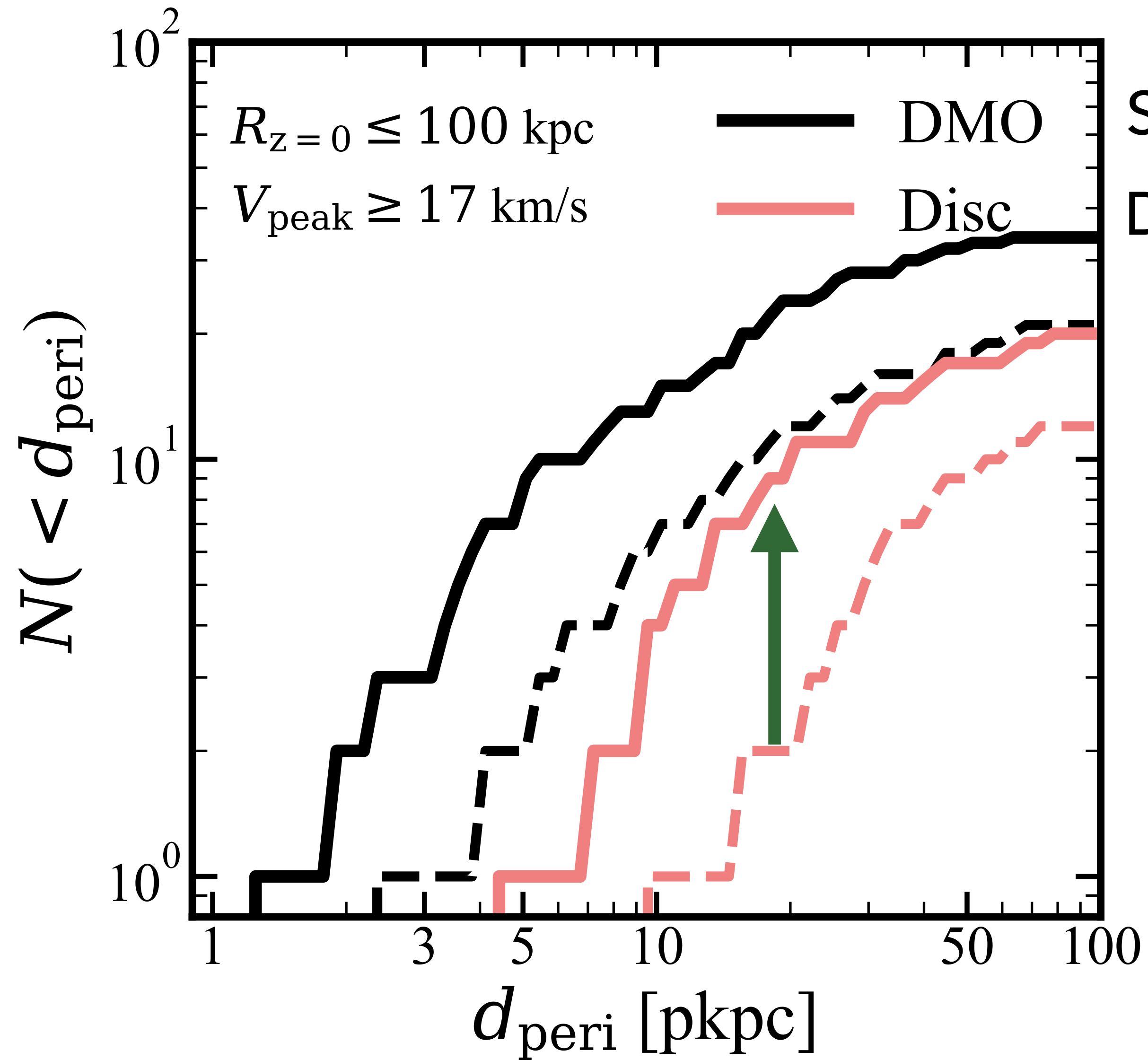


2x more subhalos  
with  $V_{\text{peak}} > 17 \text{ km/s}$   
out to 100 kpc

# PERICENTER DISTRIBUTION



# PERICENTER DISTRIBUTION



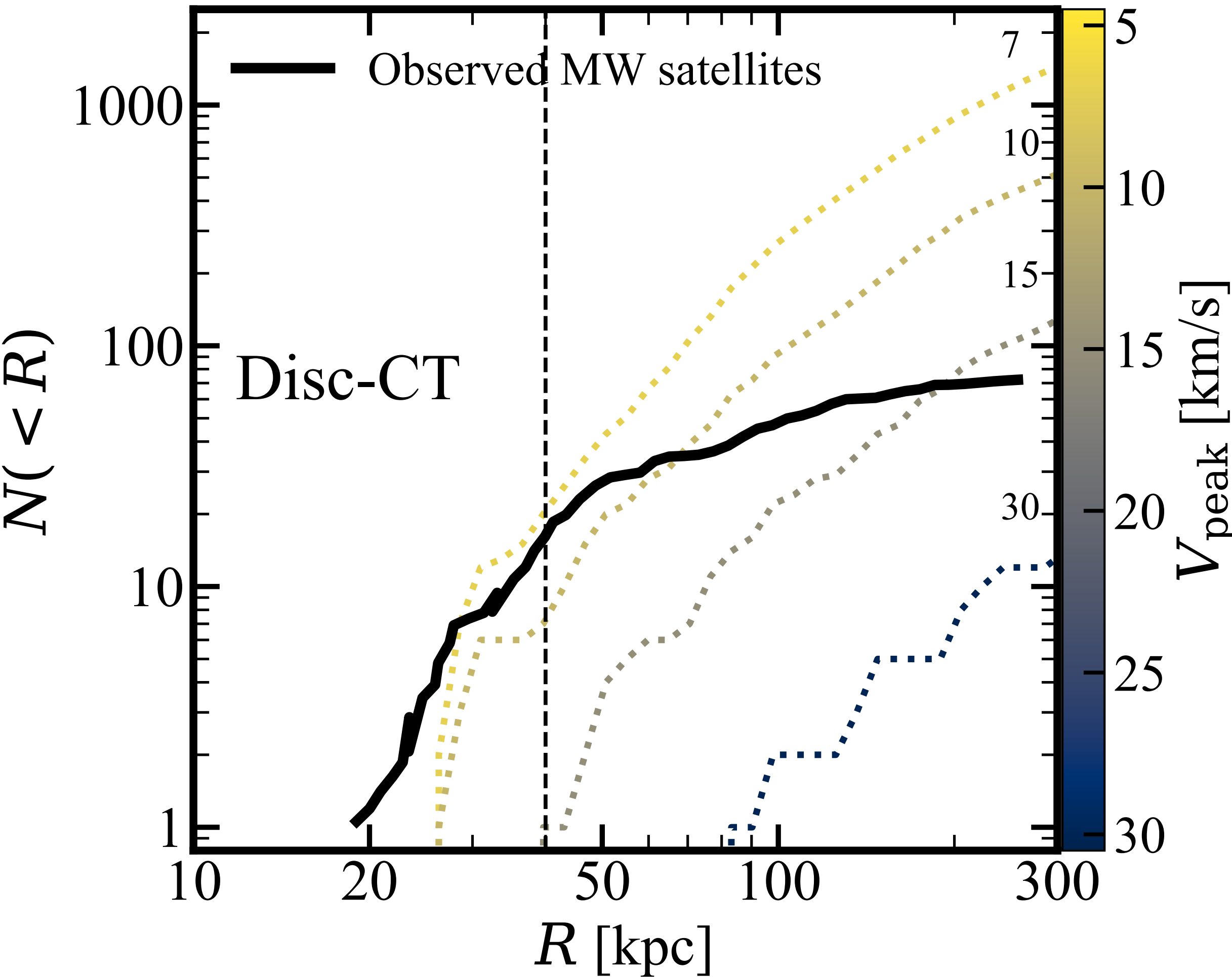
Solid: Bloodhound

Dashed: traditional method

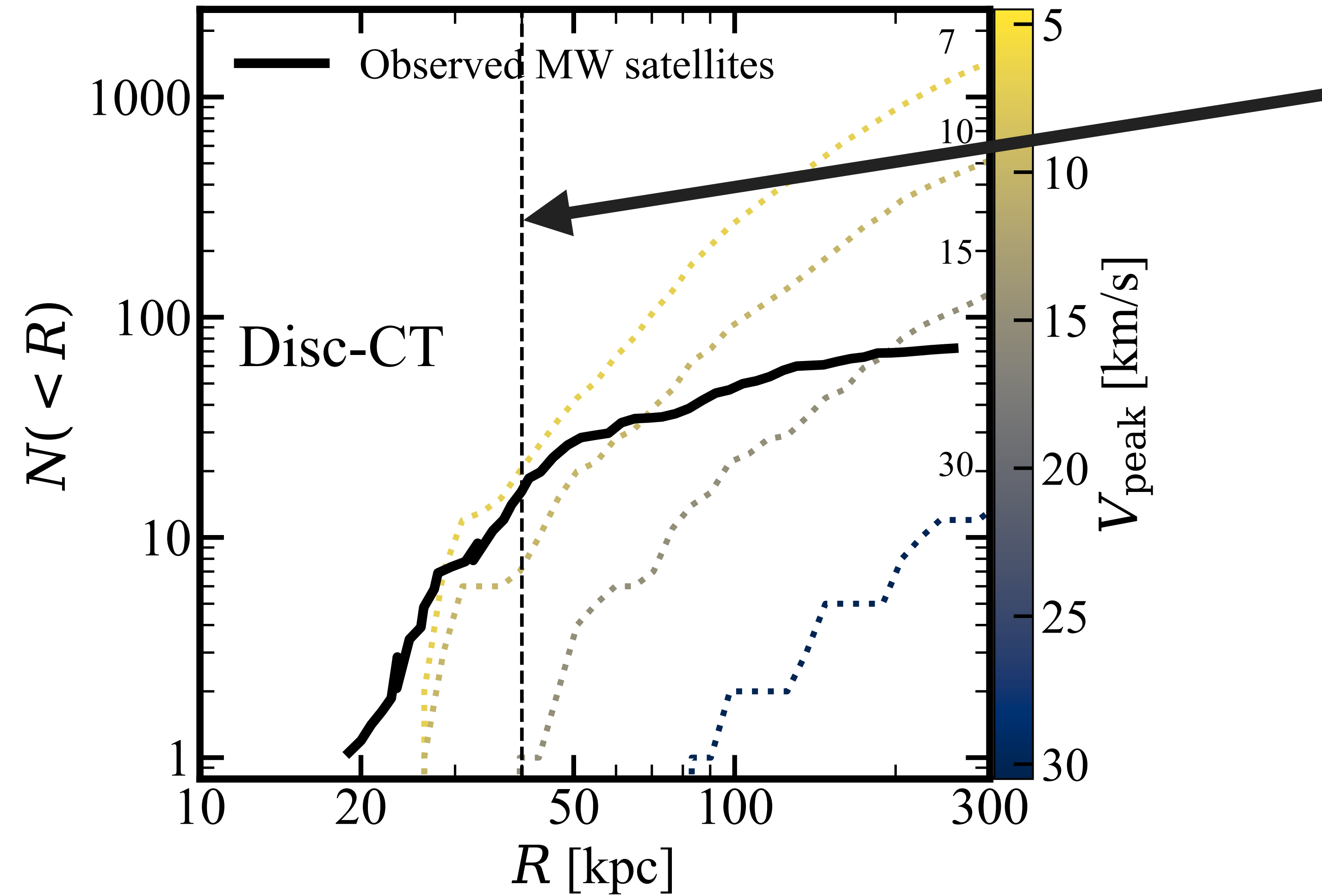
× 3 more surviving subhalos  
with  $d_{\text{peri}} < 20$  kpc found in  
Bloodhound



# HOW MANY ULTRA-FAINTS ARE THERE?

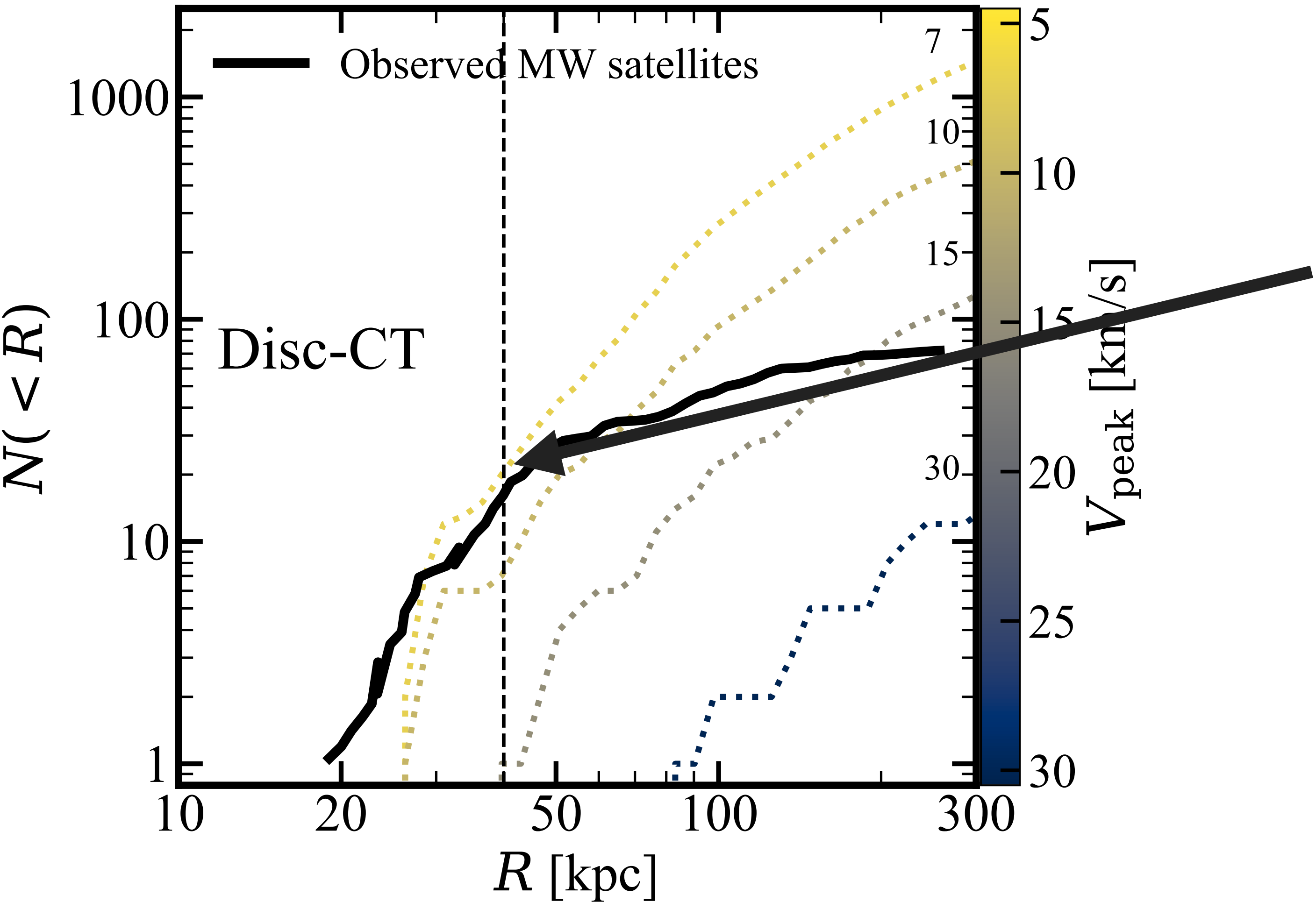


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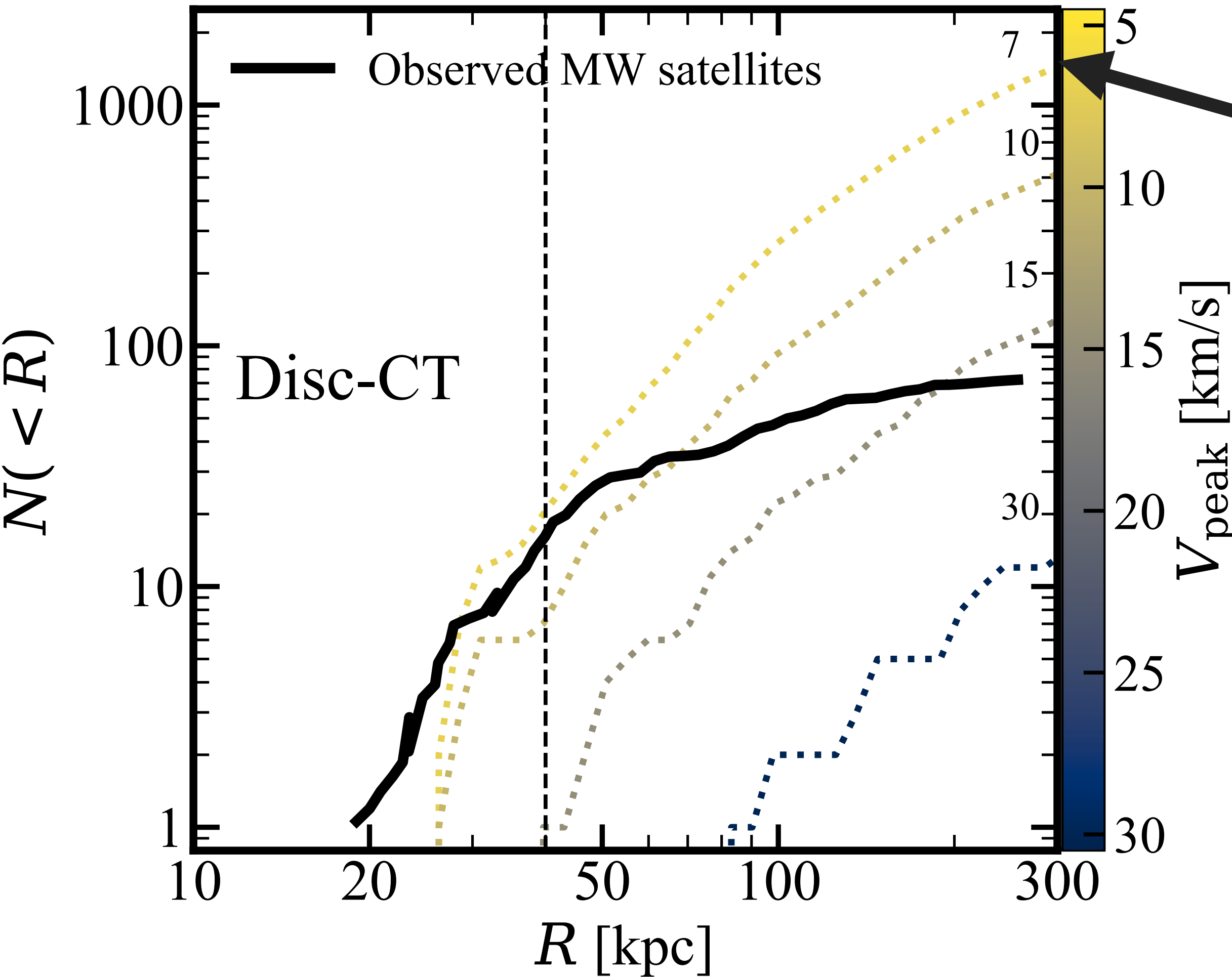


~ 40 kpc: where we think MW observations are complete

# HOW MANY ULTRA-FAINTS ARE THERE?

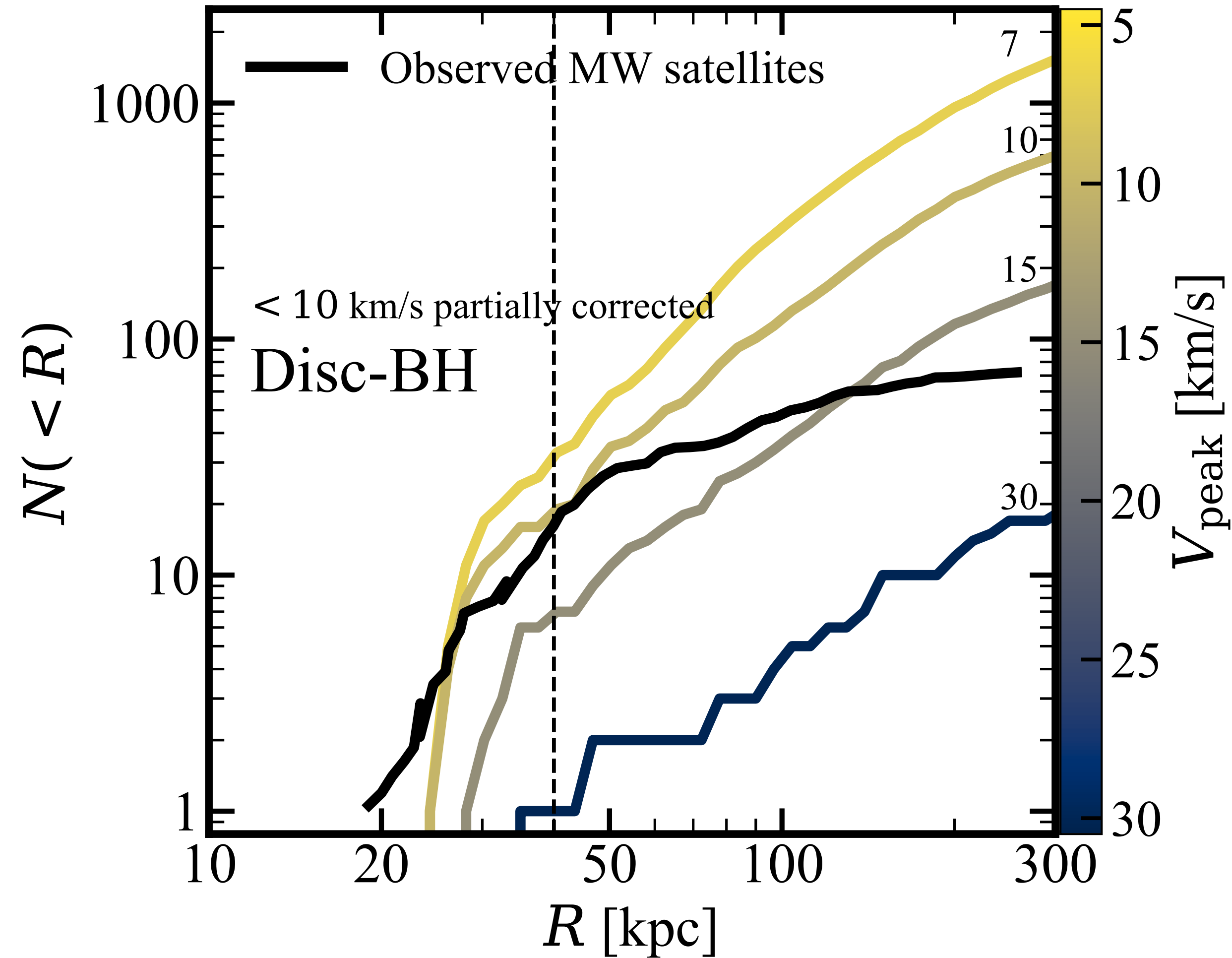


# HOW MANY ULTRA-FAINTS ARE THERE?



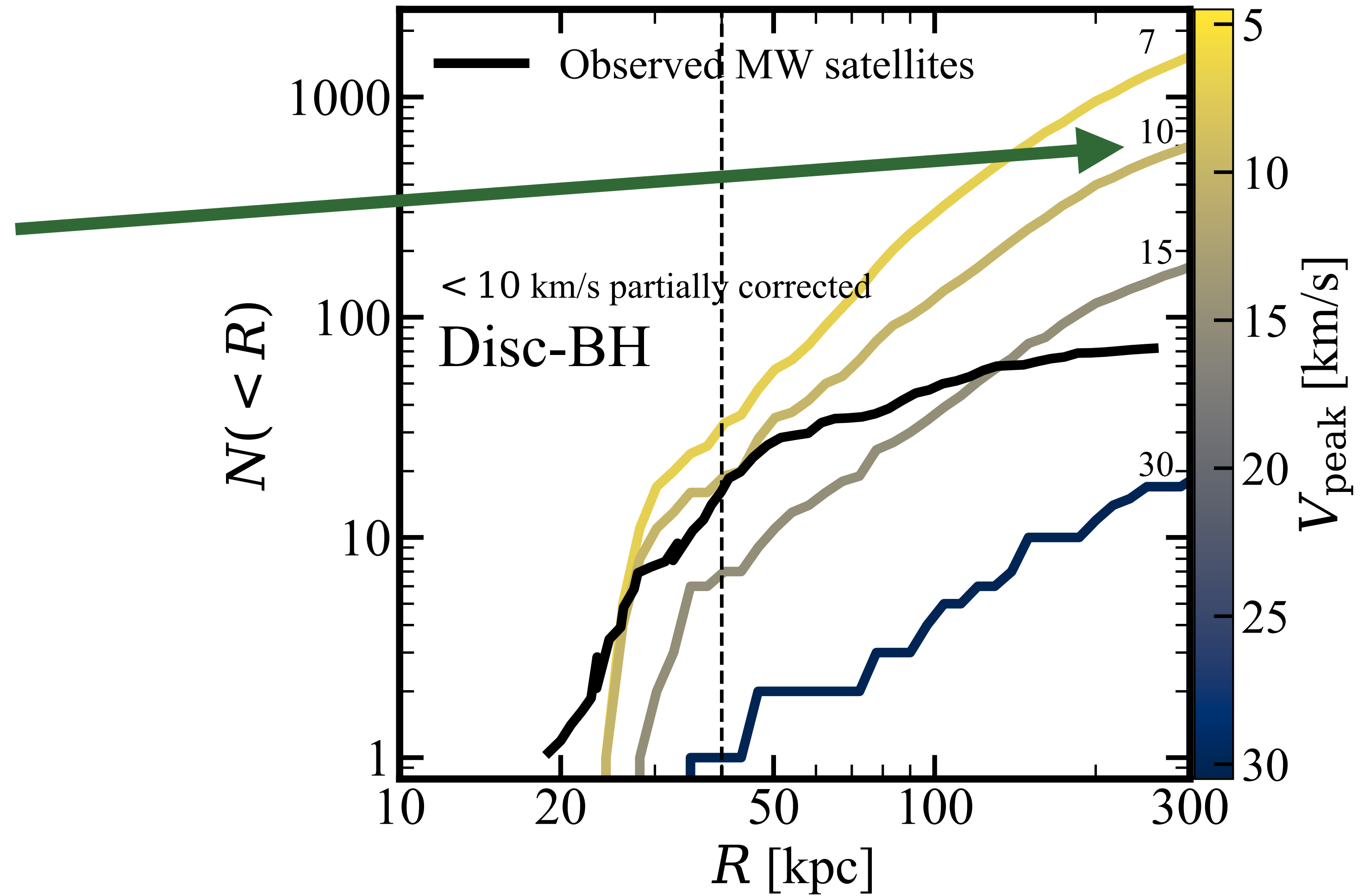
>1200 undetected ultra-faints?

# HOW MANY ULTRA-FAINTS ARE THERE?



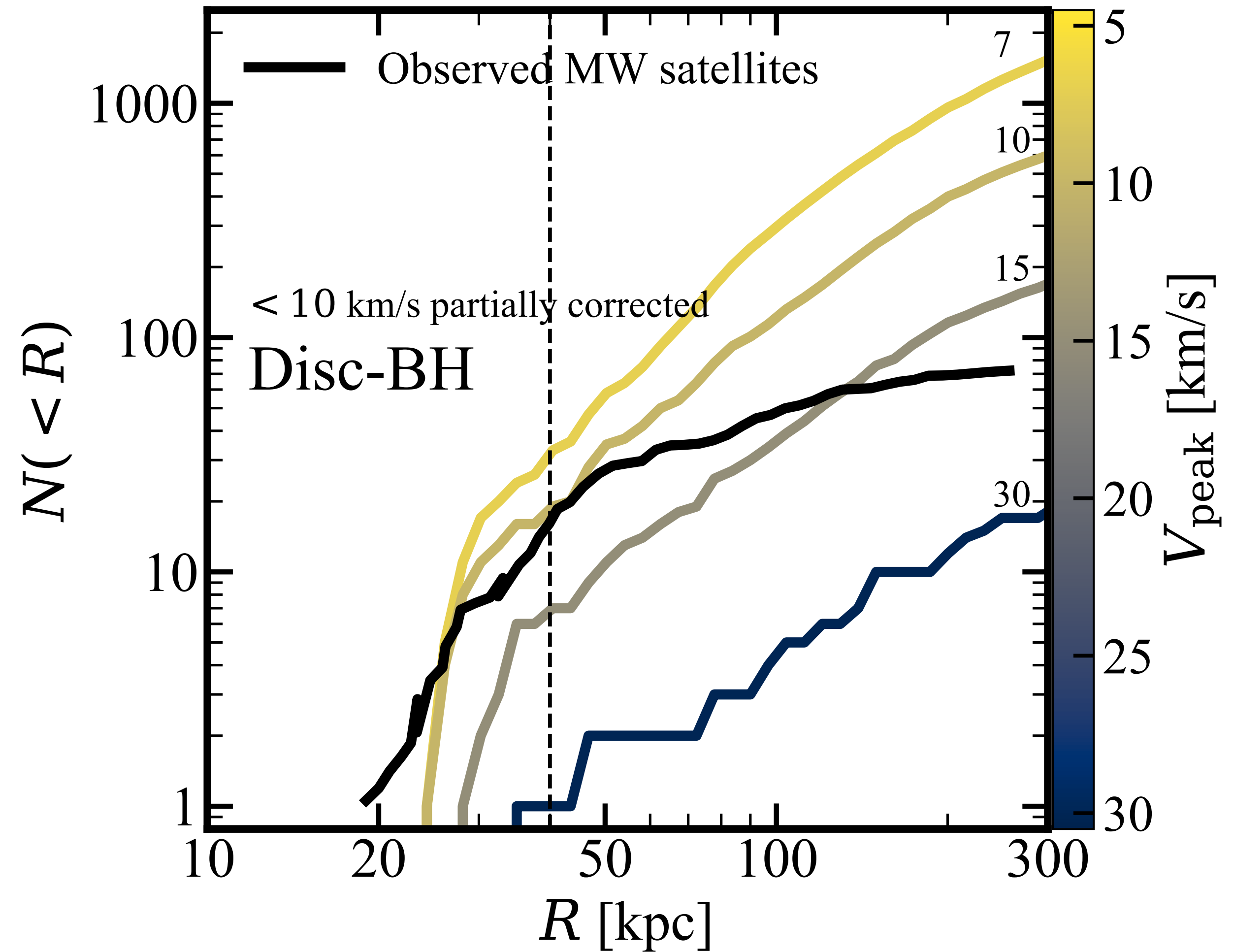
# HOW MANY ULTRA-FAINTS ARE THERE?

~500 undetected  
ultra-faints?



# HOW MANY ULTRA-FAINTS ARE THERE?

Rubin observatory is  
expected to complete the  
counts out to 300 kpc  
2025



- ▶ Missing a lot of low-mass things, Gyrs of information
- ▶ DM substructure detection: MW stellar streams, subhalo lensing anomalies
- ▶ Tidal disruption due to the host galaxy
- ▶ Galaxy formation:
  - ▶ UDG: FIRE II, Jenna Samuel and Courtney Reed (Summer NSF REU)
  - ▶ Ultra-faint galaxies, completeness correction
- ▶ Making a prediction requires a statistical sample of subhalos with sufficient resolution and **faithful tracking**
- ▶ Applying to alternative DM models, higher-res simulations



# ADDITIONAL FIGURES

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- ▶ Gravitational effects of DM substructure
- ▶ Subhalos' effect on MW stellar streams
- ▶ DM substructure lensing anomalies
- ▶ Making a prediction requires a statistical sample of subhalos with sufficient resolution and **faithful tracking**

You can just say that thin streams may be sensitive to low-mass subhalos (and same for lensing), but current predictions don't have correct estimates of frequency of subhalo-stream interactions because subhalos aren't tracked well

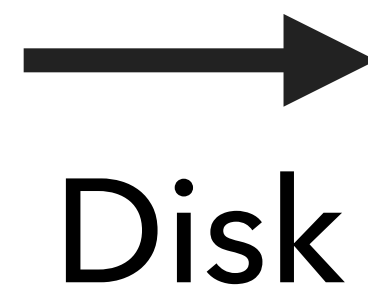
- ▶ Stripped/disrupted galaxies: Ultra-diffuse satellite galaxies
  - ▶ With FIRE II simulations, in progress
- ▶ Threshold of galaxy formation: Ultra-faint galaxies
- ▶ Completeness correction: we only see ones close to us

- ▶ Missing a lot of low-mass things: implications - predicting detectability of things, maybe threshold of galaxy formation
- ▶ Ultra-diffuse galaxies: simulations have trouble producing the same variety of things we observe, this could be because we are losing them, Courtney's research note.
- ▶ Better estimates of tidal disruption due to the host disc
- ▶ We are losing Gyrs of information about dynamical evolution of low-mass objects
- ▶ Applying to new DM models, higher resolution simulations
- ▶ DM detectability

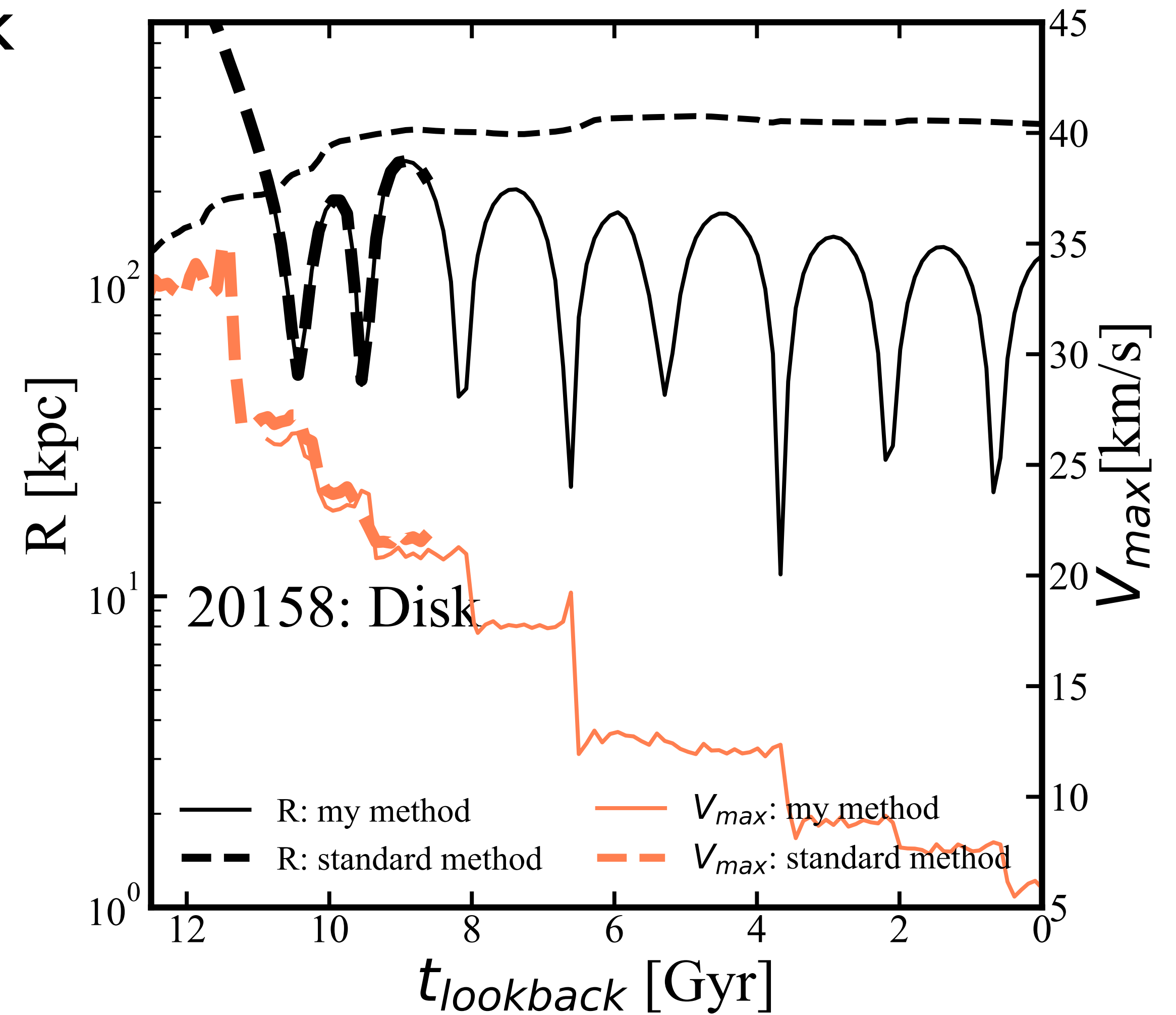
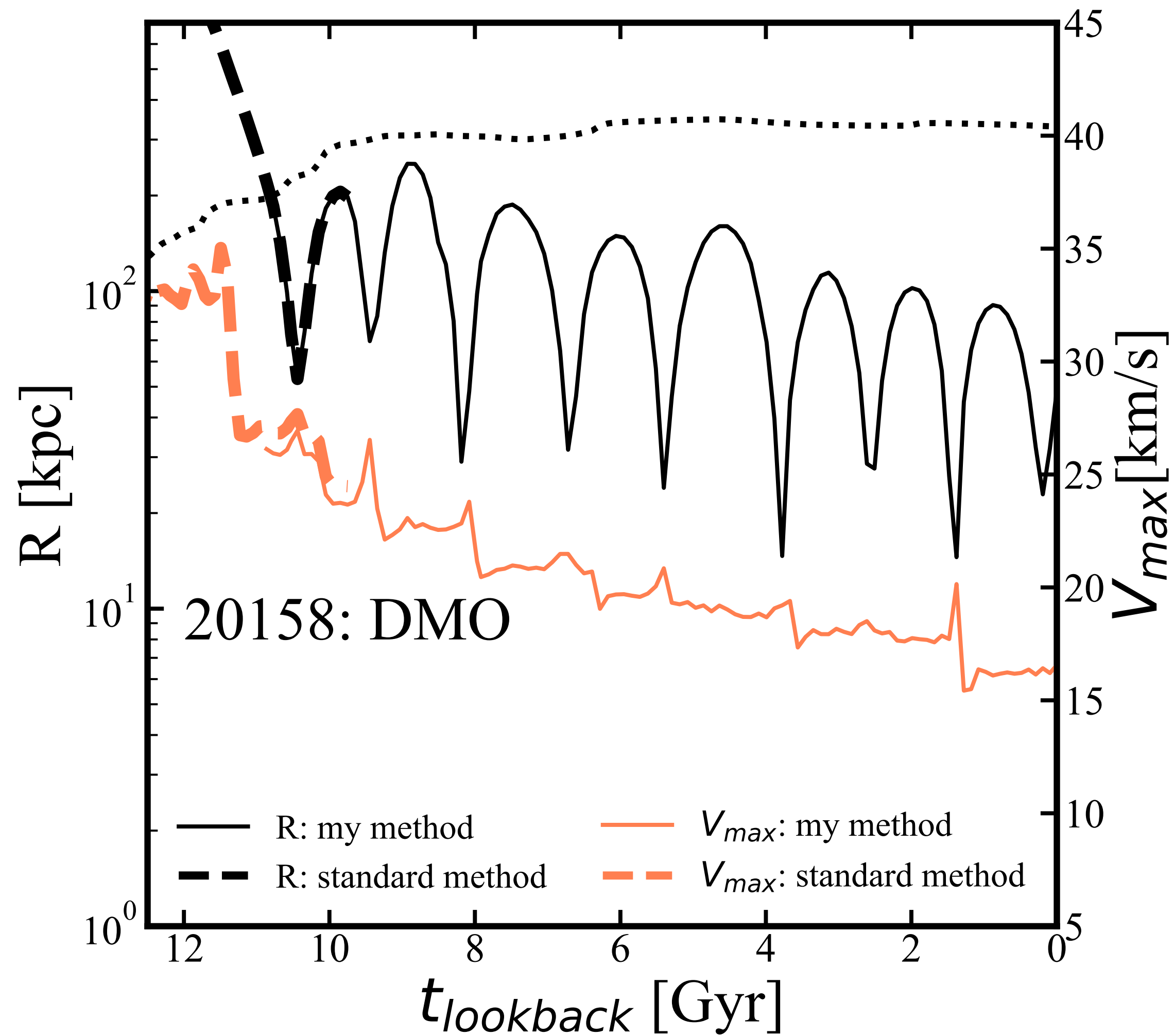
[hyunsukong@utexas.edu](mailto:hyunsukong@utexas.edu)

# MERGER-TREE VS. PARTICLES

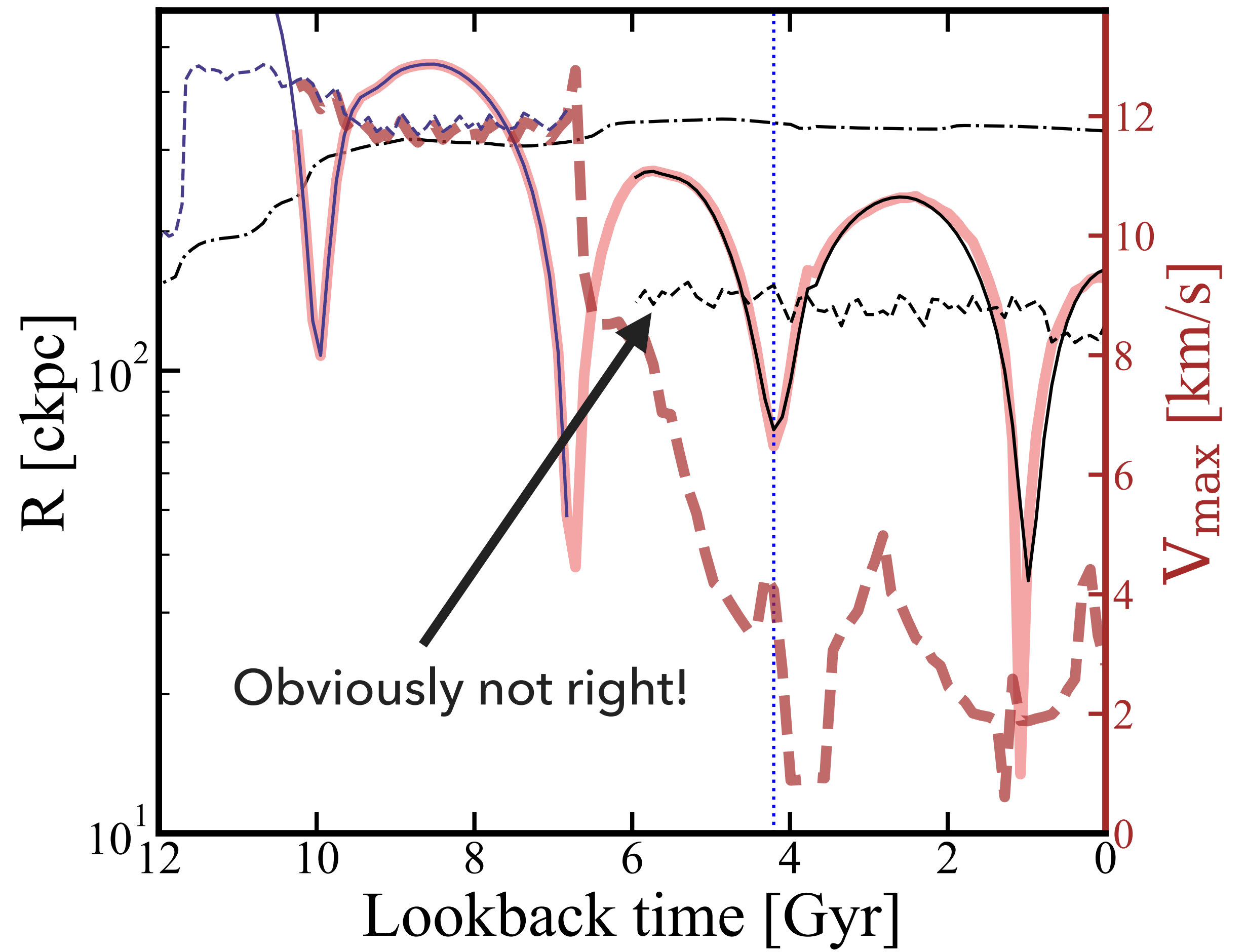
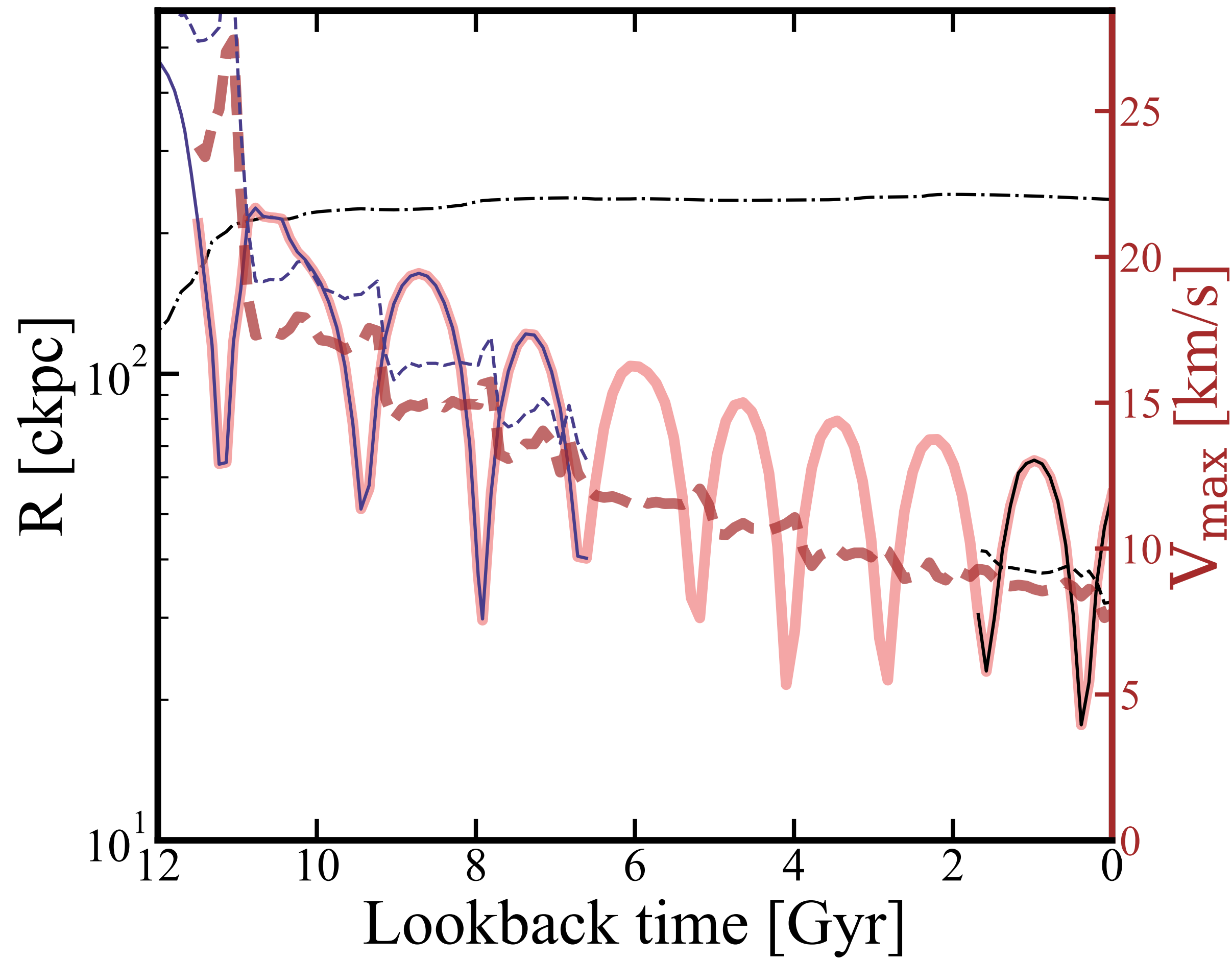
$$V_{\max,0} = 16 \text{ km/s}$$



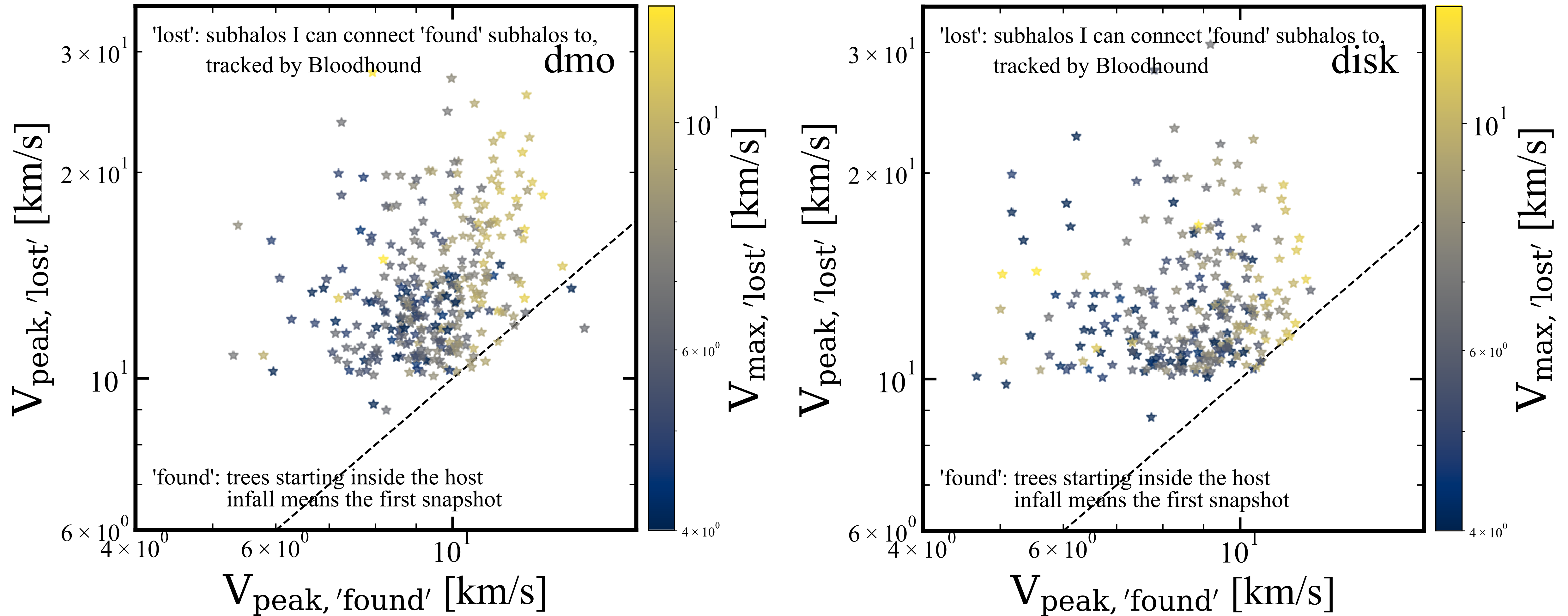
$$V_{\max,0} = 6 \text{ km/s}$$

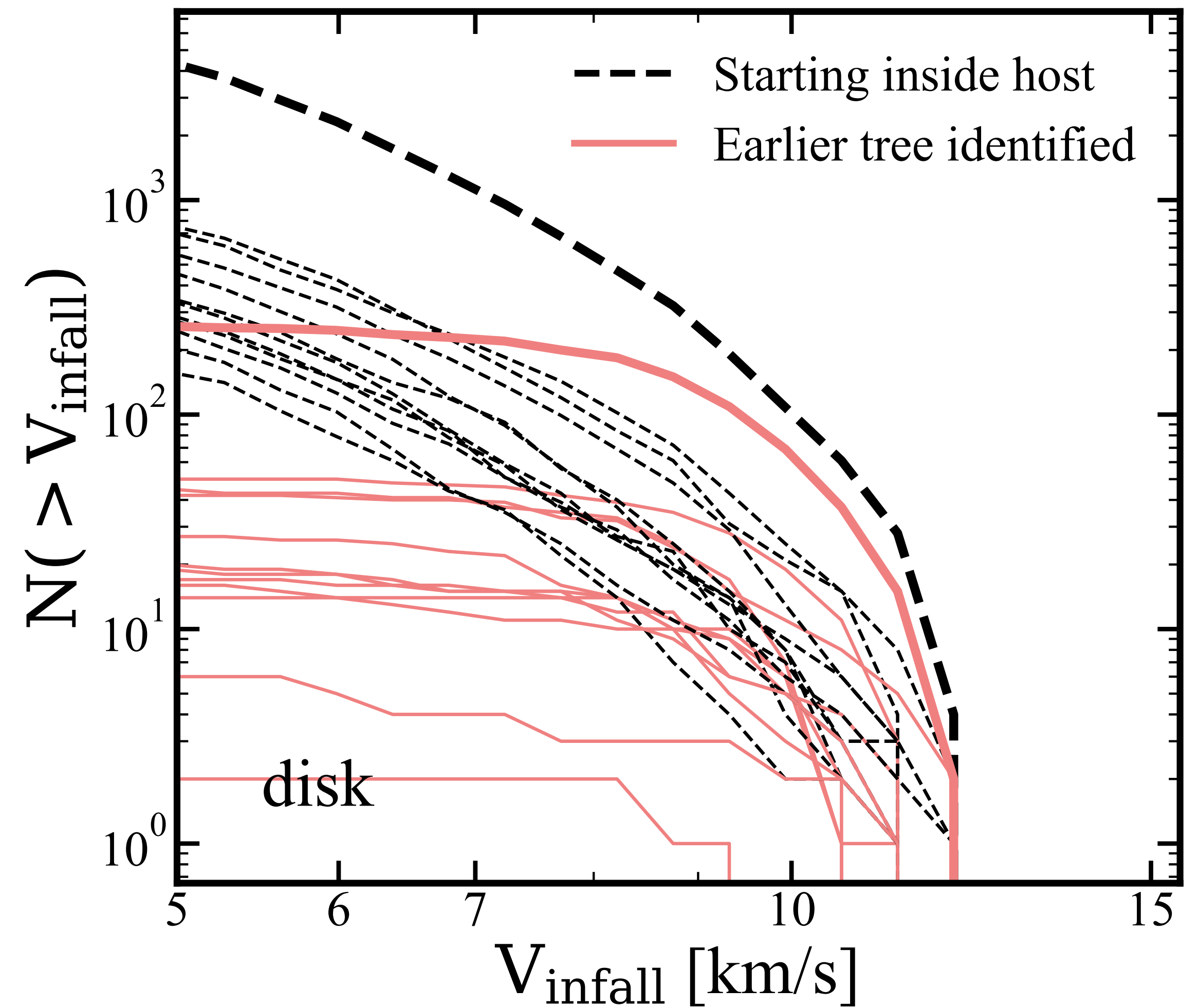
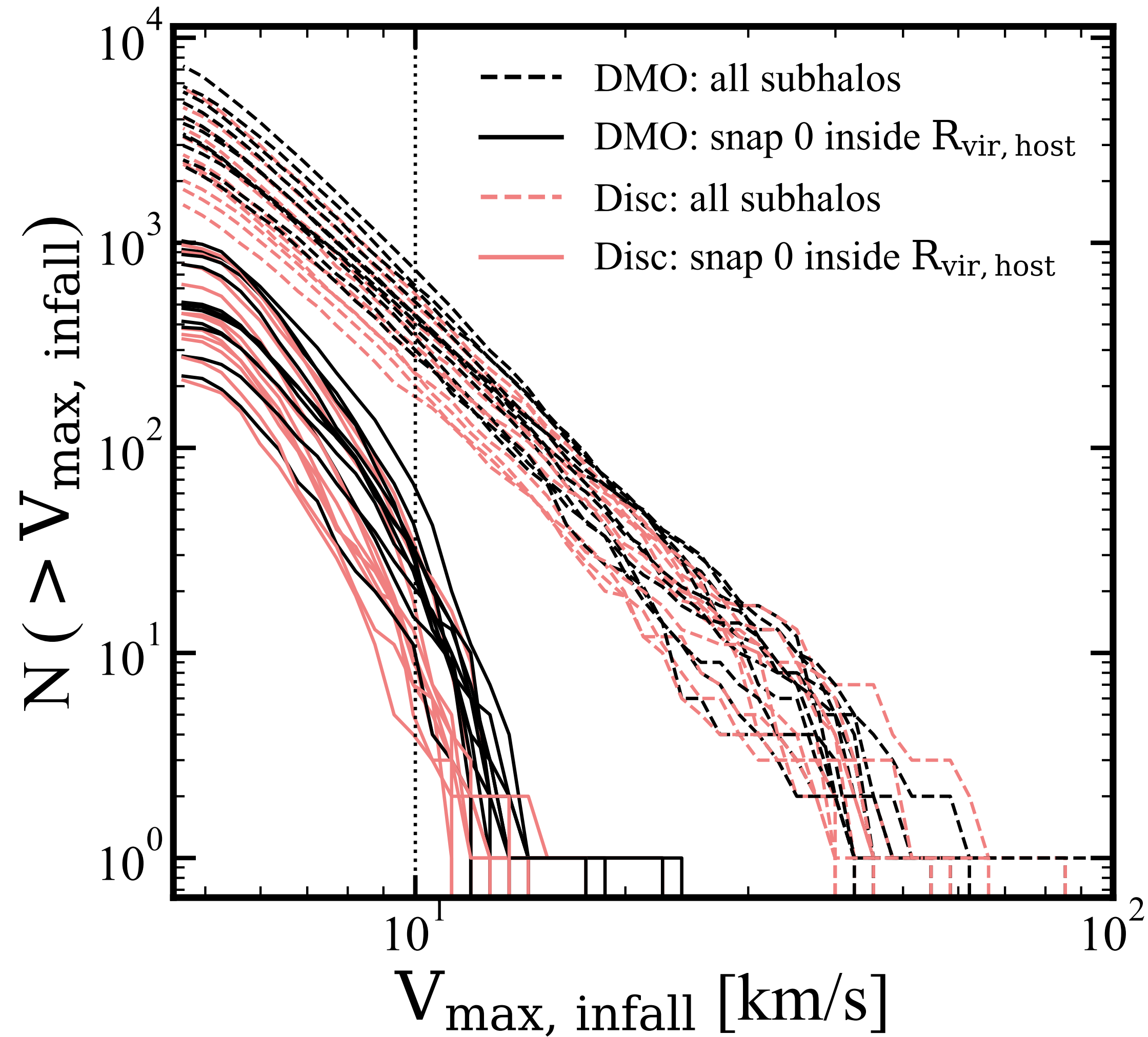


# MISSING-LINK TREES



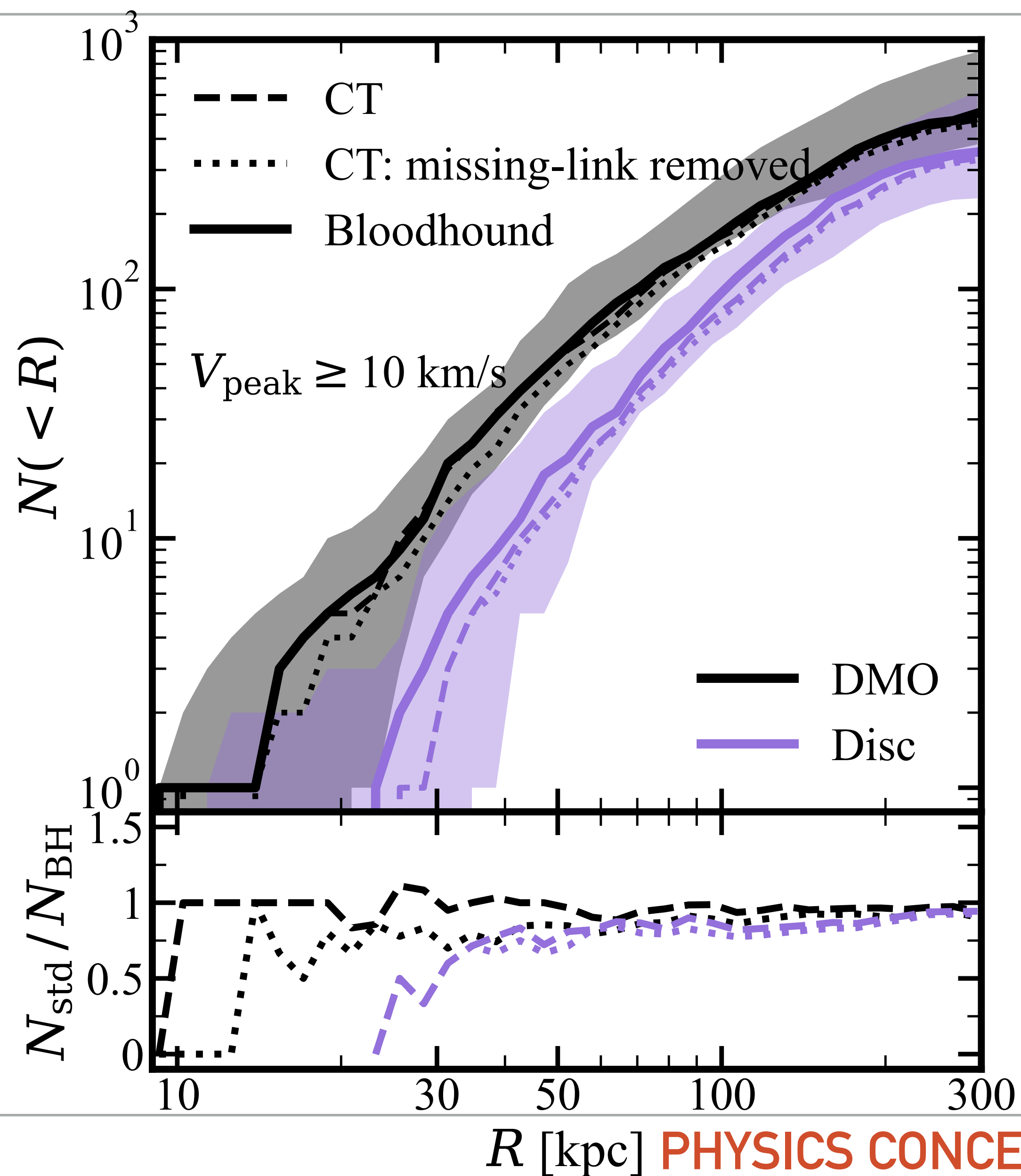
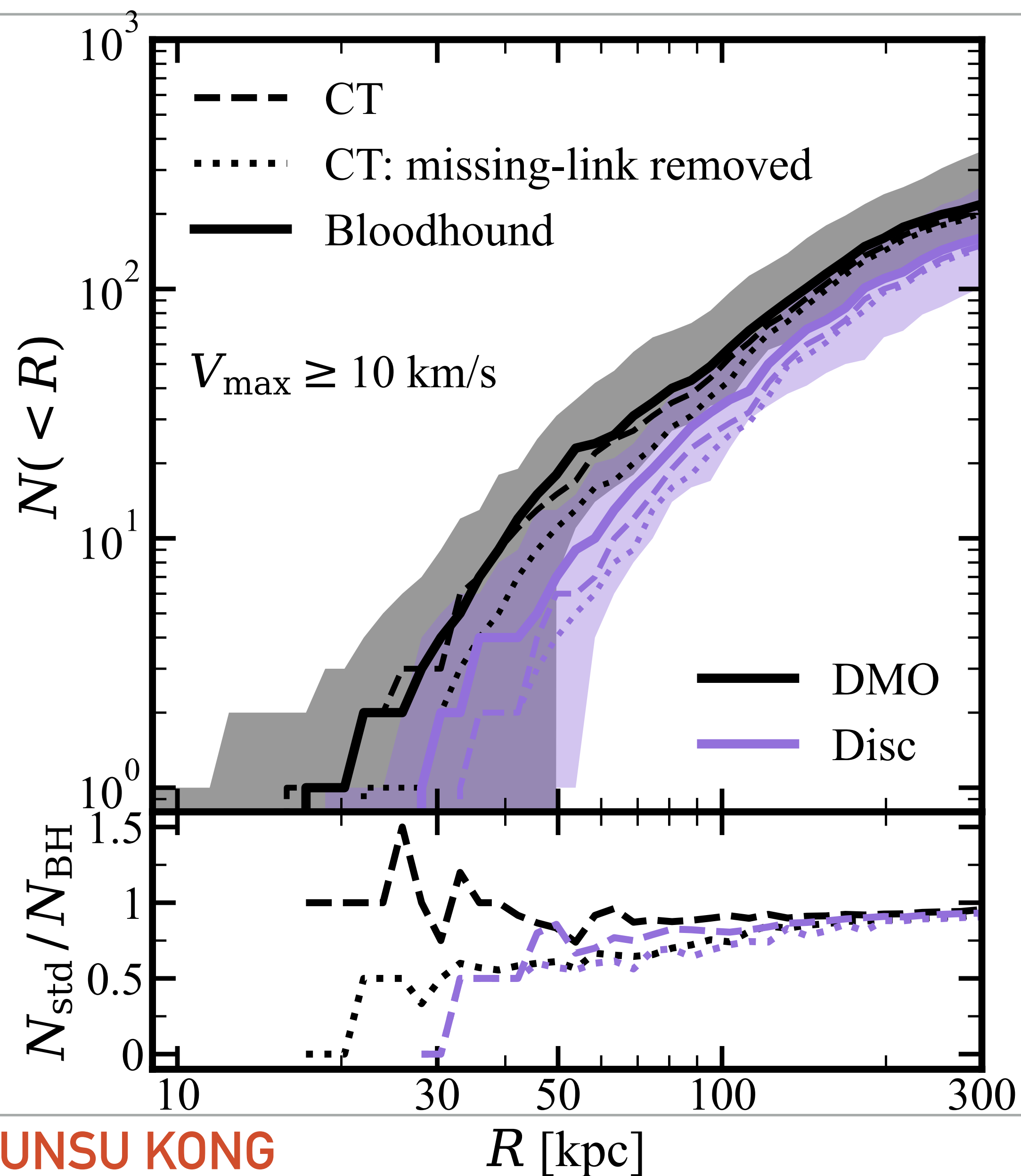
# MISSING-LINK TREES: RENAME LABELS



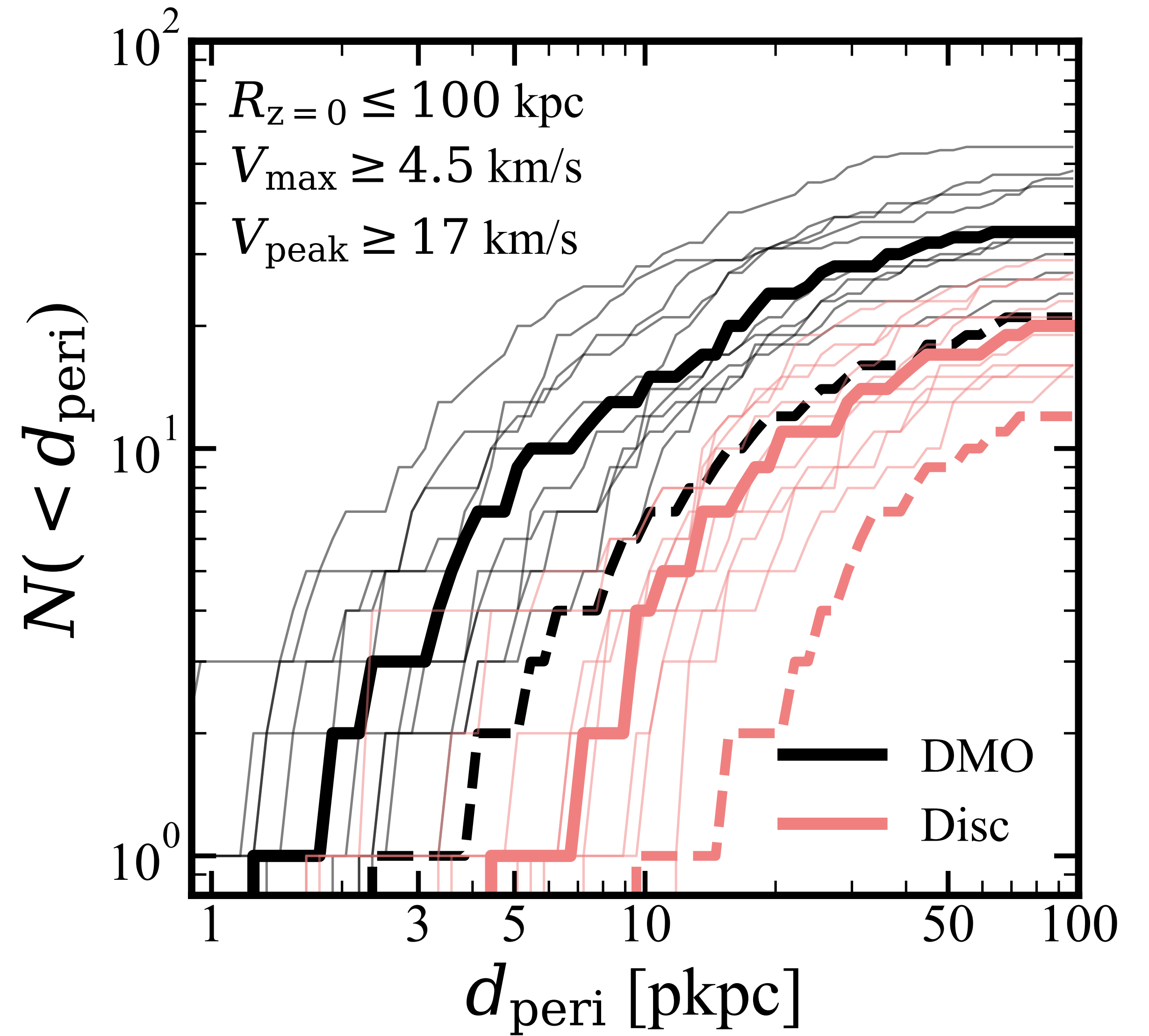
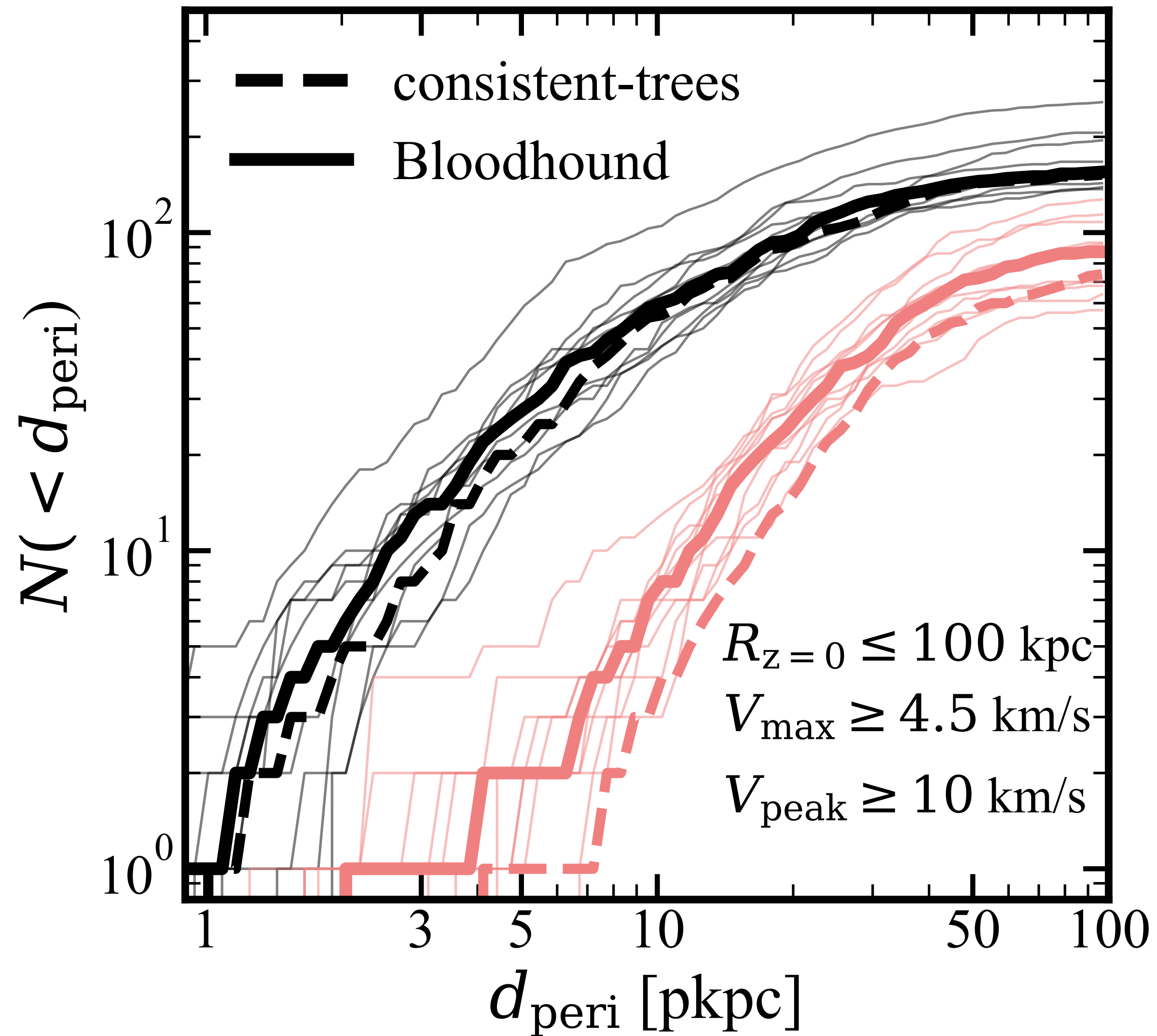




# RADIAL DISTRIBUTIONS

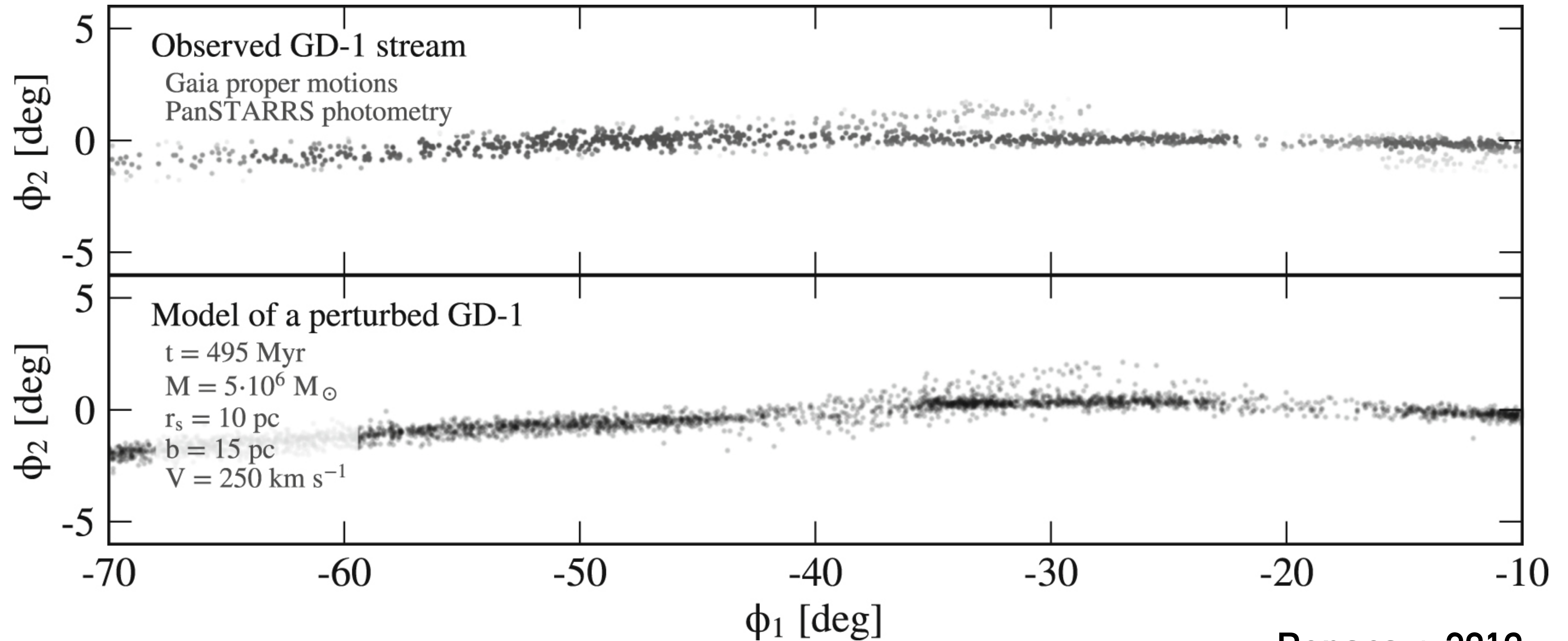


# PERICENTER DISTRIBUTION



- ▶ People start right from the halo catalog/merger tree side, assuming they are correct, but there's a nuance.
- ▶ At each step, we lose something.
- ▶ And that something is very important for what I am interested in.

- ▶ Inevitable effect of the MW without doing full hydrodynamics
- ▶ Cosmological box: 74 Mpc
- ▶ Zoom-in: 3 Mpc
- ▶ 12 MW halos:  $M_{\text{halo}} = (0.7 - 2) \times 10^{12} M_{\odot}$
- ▶  $m_{\text{dm}} = 3 \times 10^4 M_{\odot}$
- ▶ 152 snapshots:  $z=125$  to  $z=0$
- ▶ Growing MW potential: stellar disk, gas disk & bulge



Bonaca + 2019

# FUTURE PLANS: HIGHER RESOLUTION

