

BLOODHOUND: TESTING Λ CDM WITH DARK MATTER SUBHALOS

HYUNSU KONG

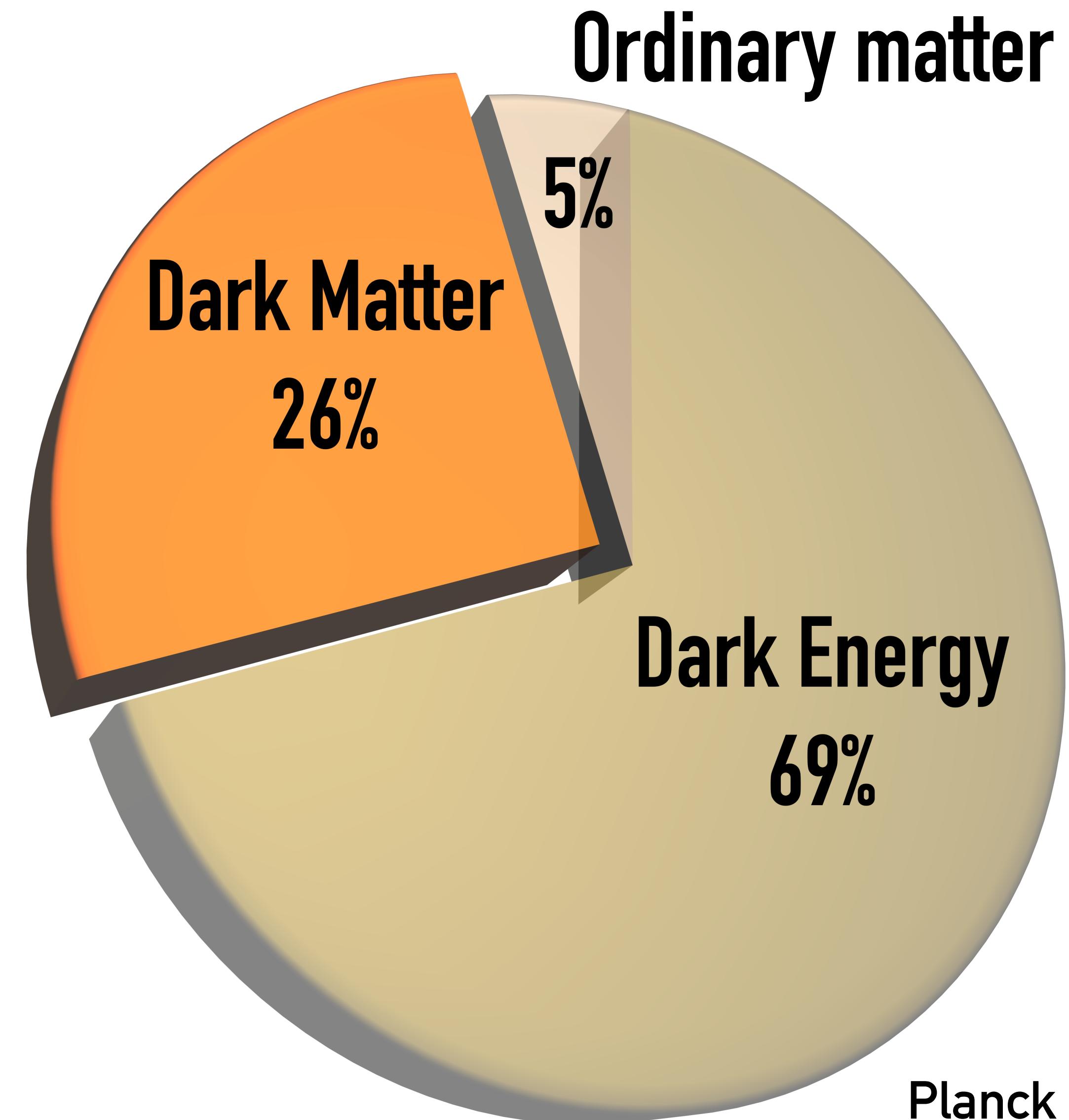
hyunsukong@utexas.edu

hyunsukong.github.io

PMA 16.212



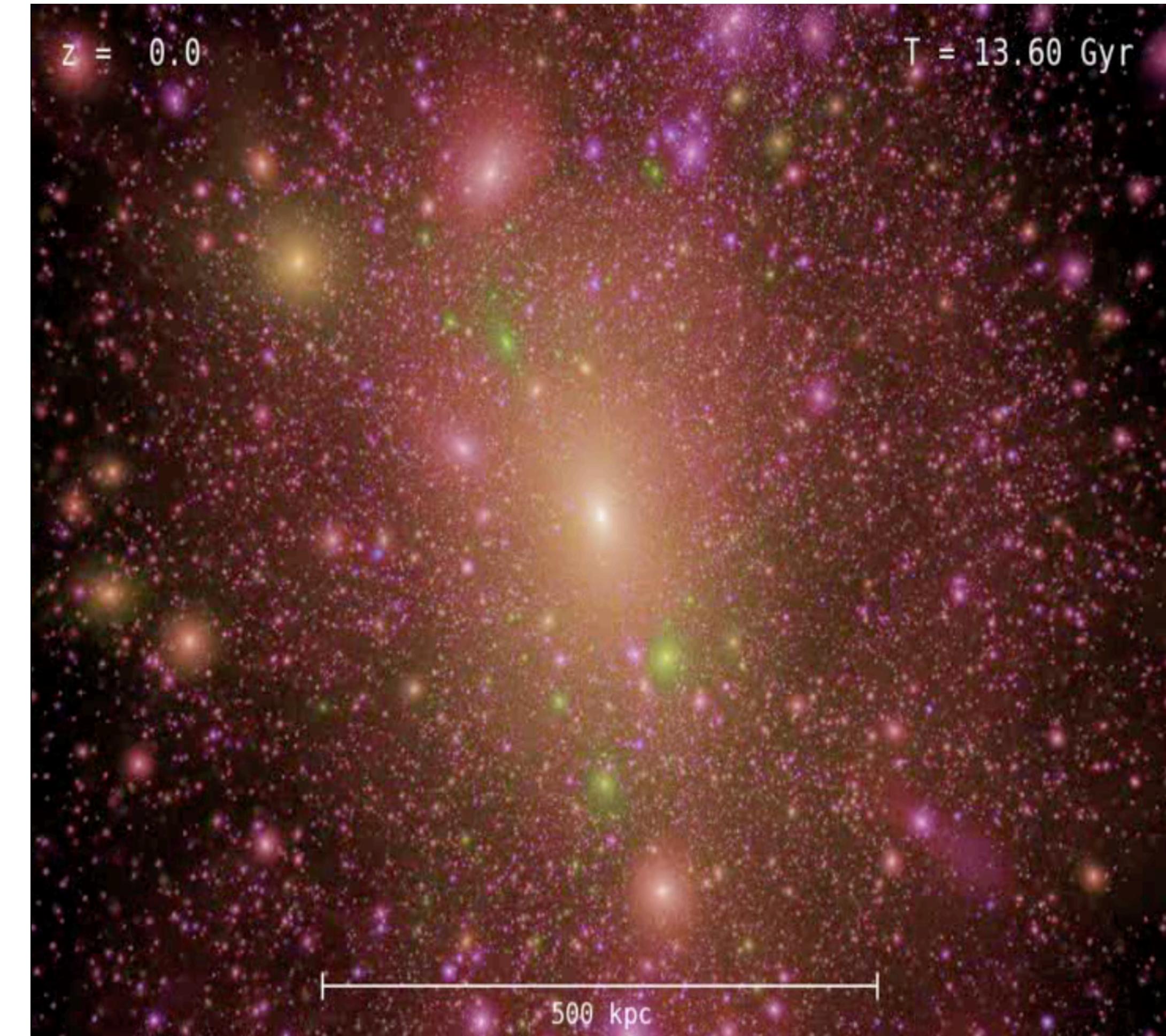
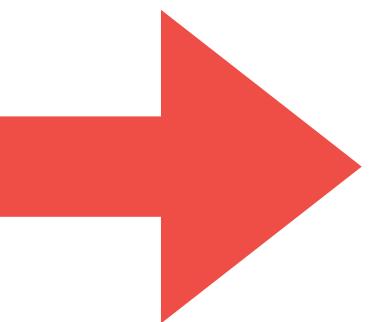
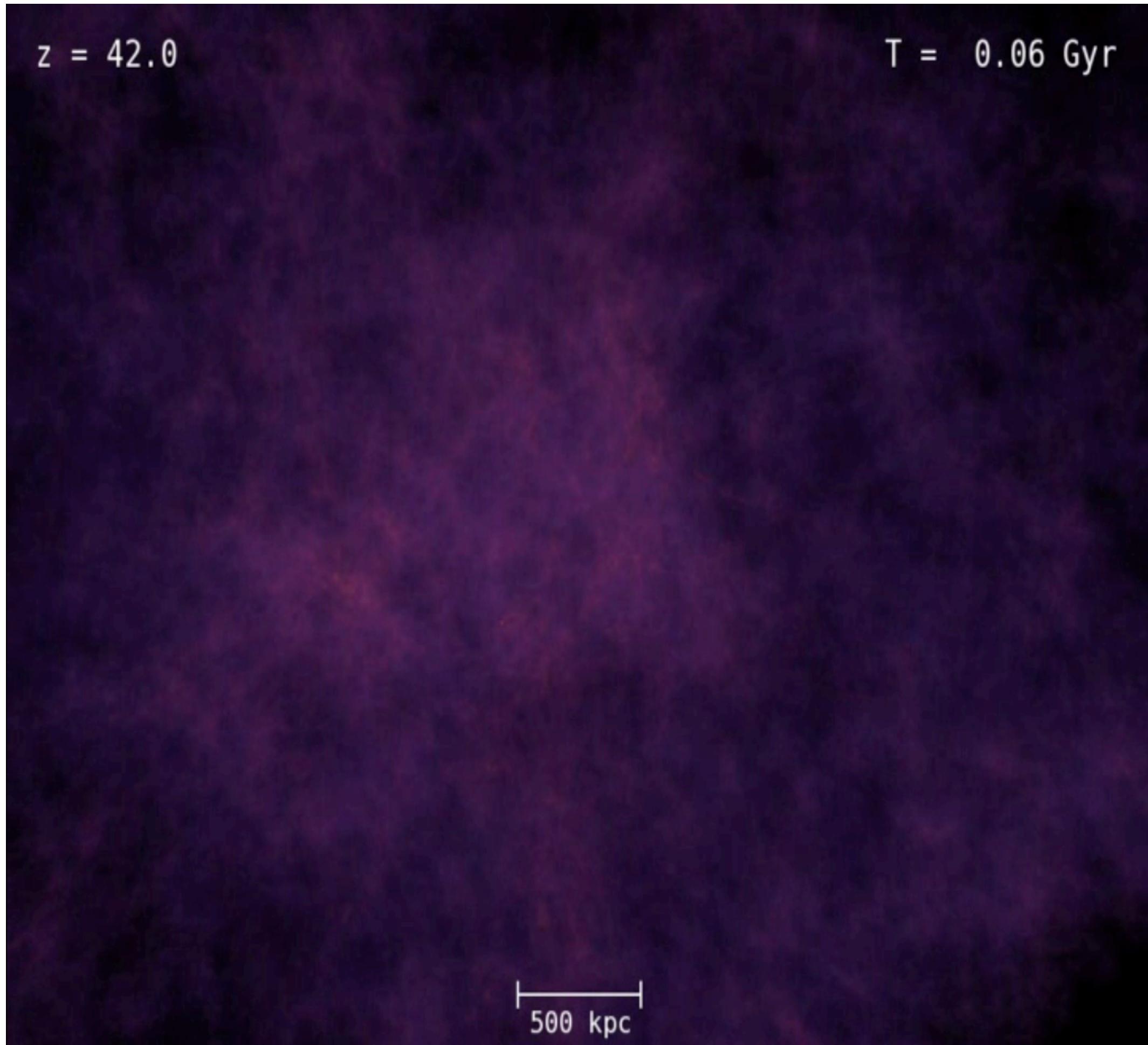
Λ CDM: A MOSTLY DARK UNIVERSE



Planck Collaboration 2018

Λ CDM: STRUCTURE FORMATION

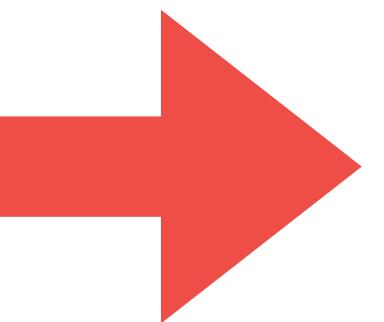
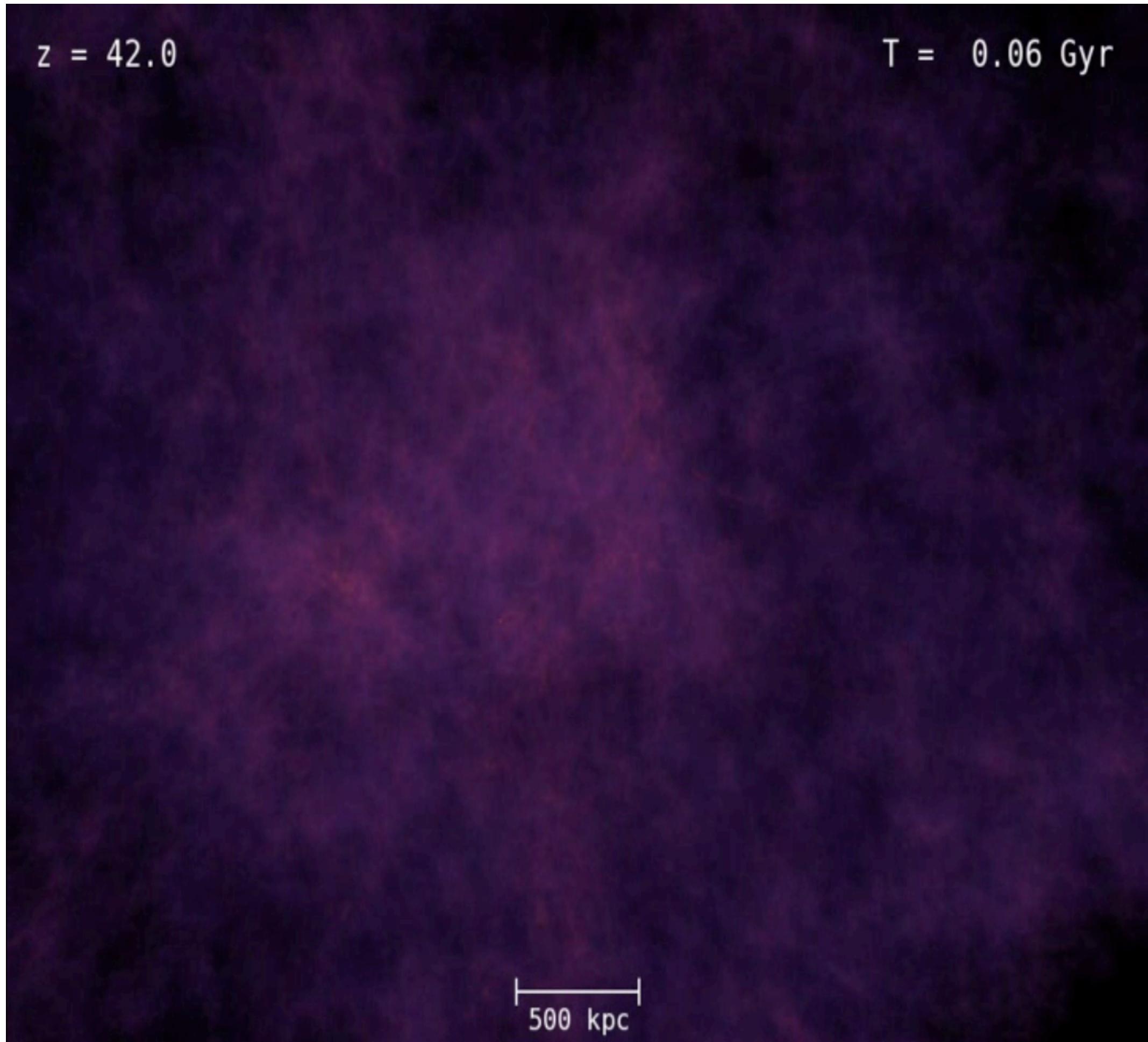
From this



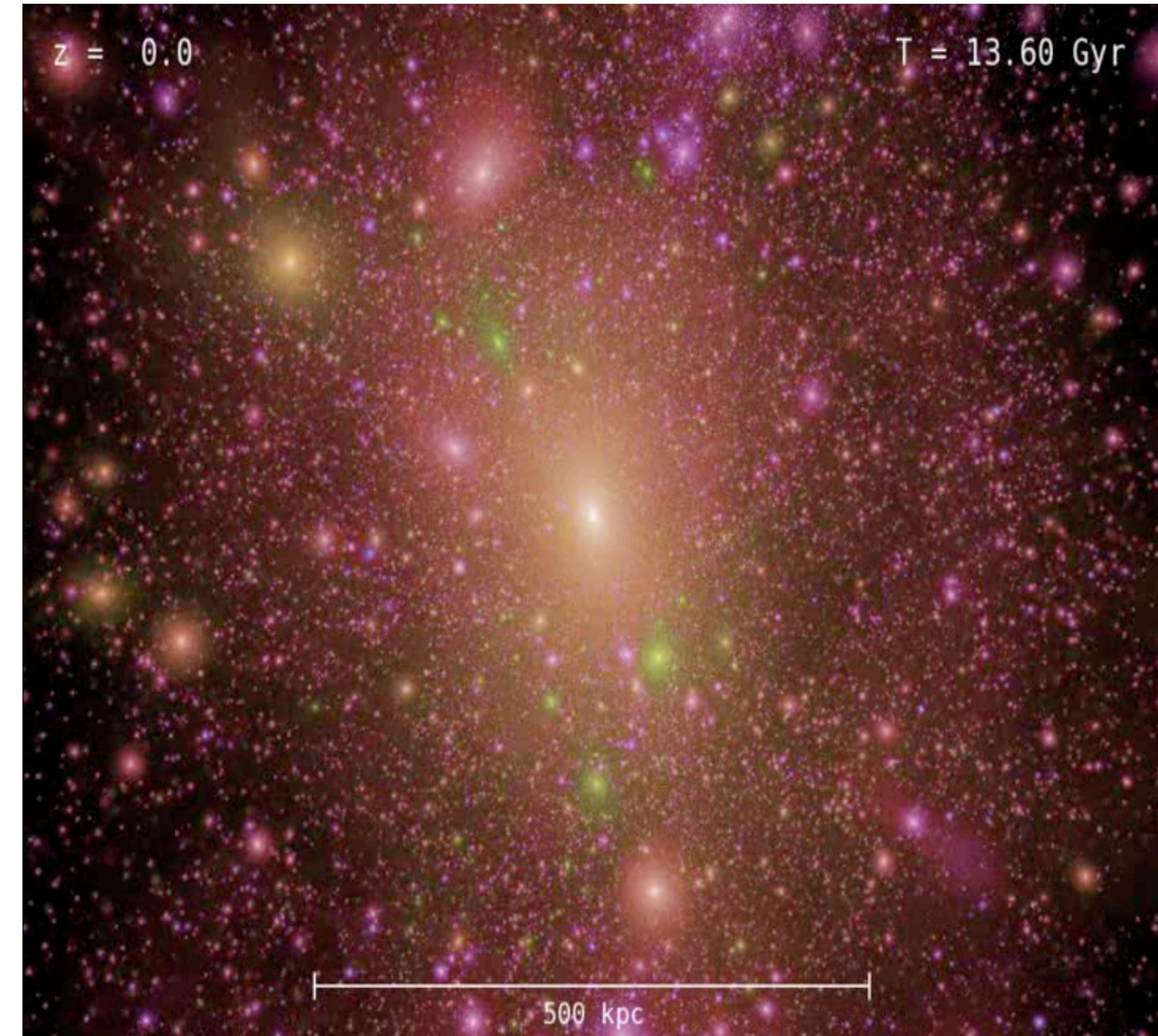
The Aquarius Project

Λ CDM: STRUCTURE FORMATION

From this



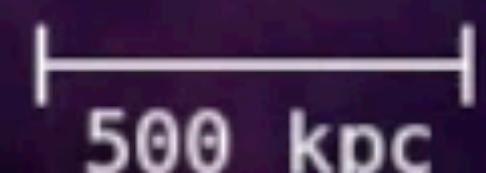
To this



The Aquarius Project

$z = 42.0$

$T = 0.06 \text{ Gyr}$



500 kpc

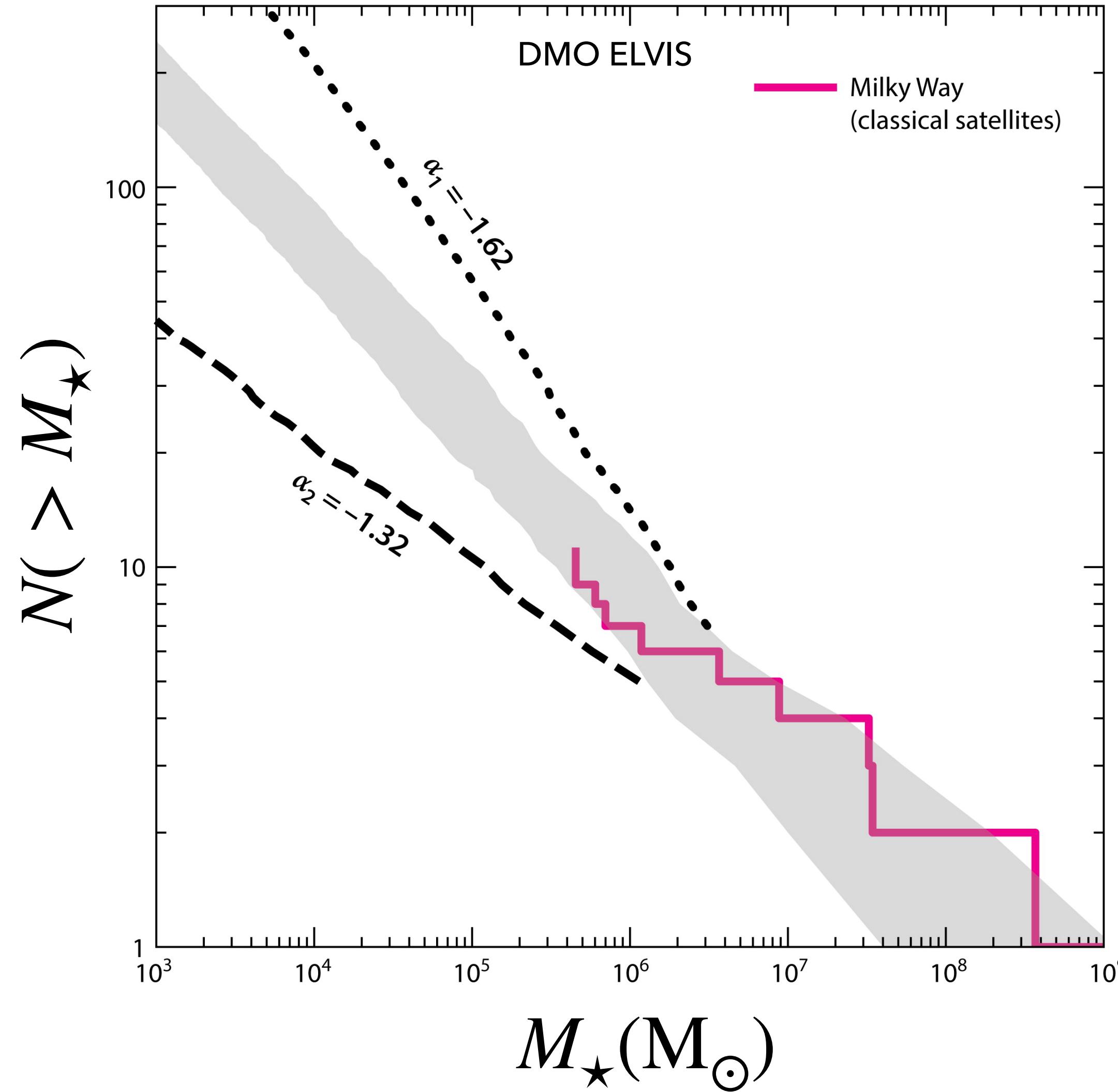
The Aquarius Project

CHARACTERIZING SUBHALOS

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

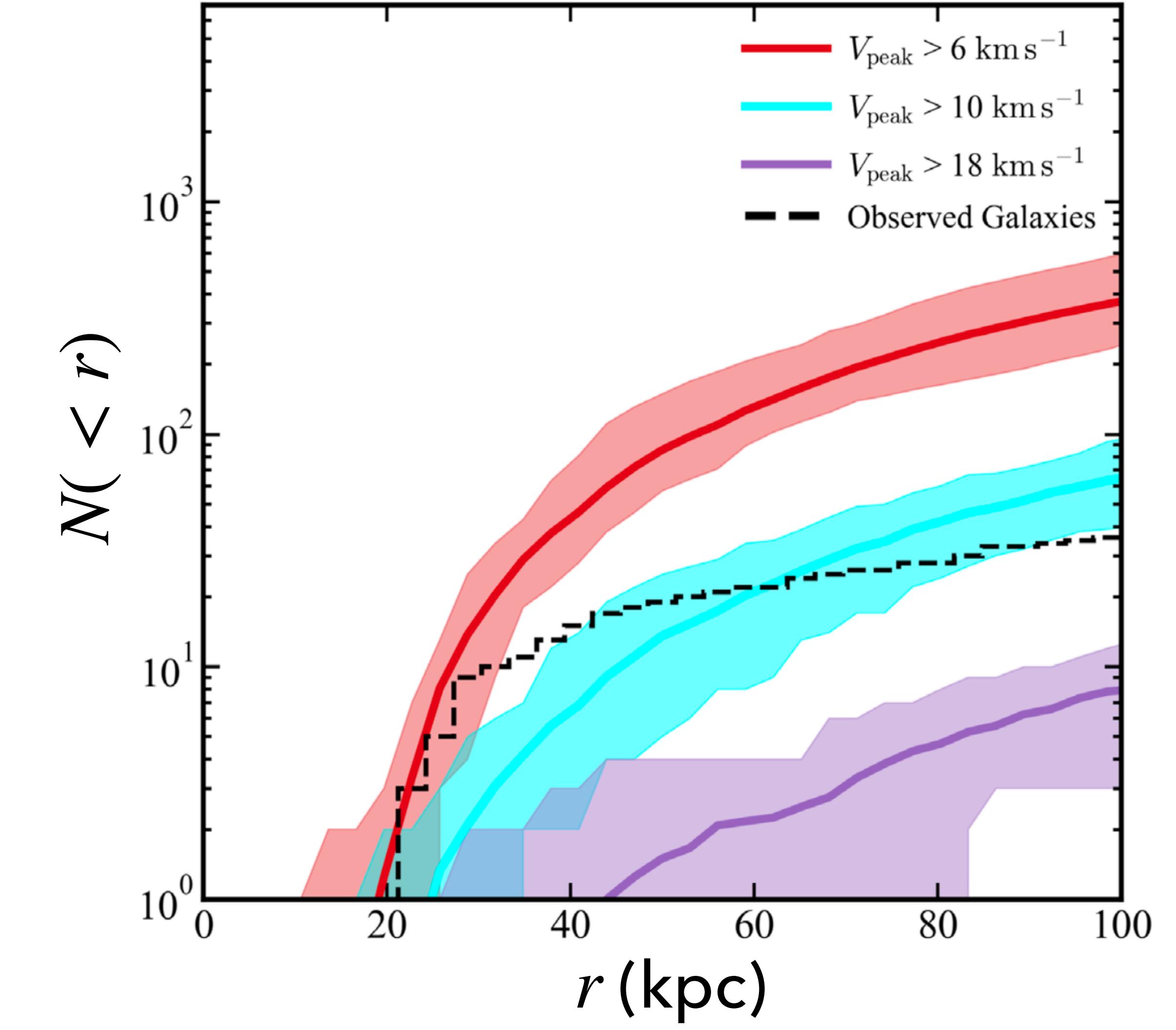
$V_{\text{peak}}, V_{\text{infall}}, V_{\text{disrupt}} \cdots$

MW SATELLITE COUNTS



Bullock & Boylan-Kolchin 2017

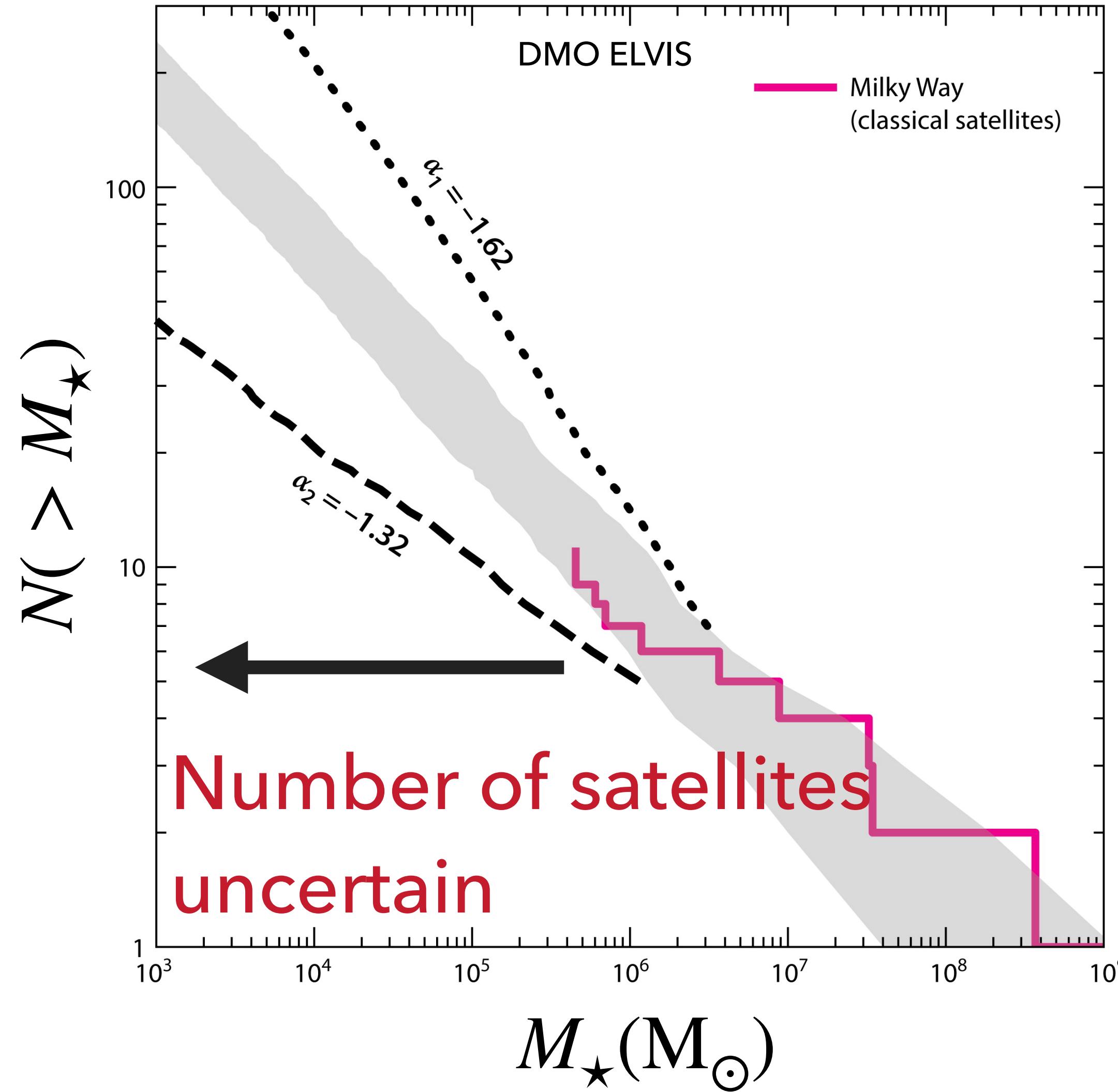
HYUNSU KONG



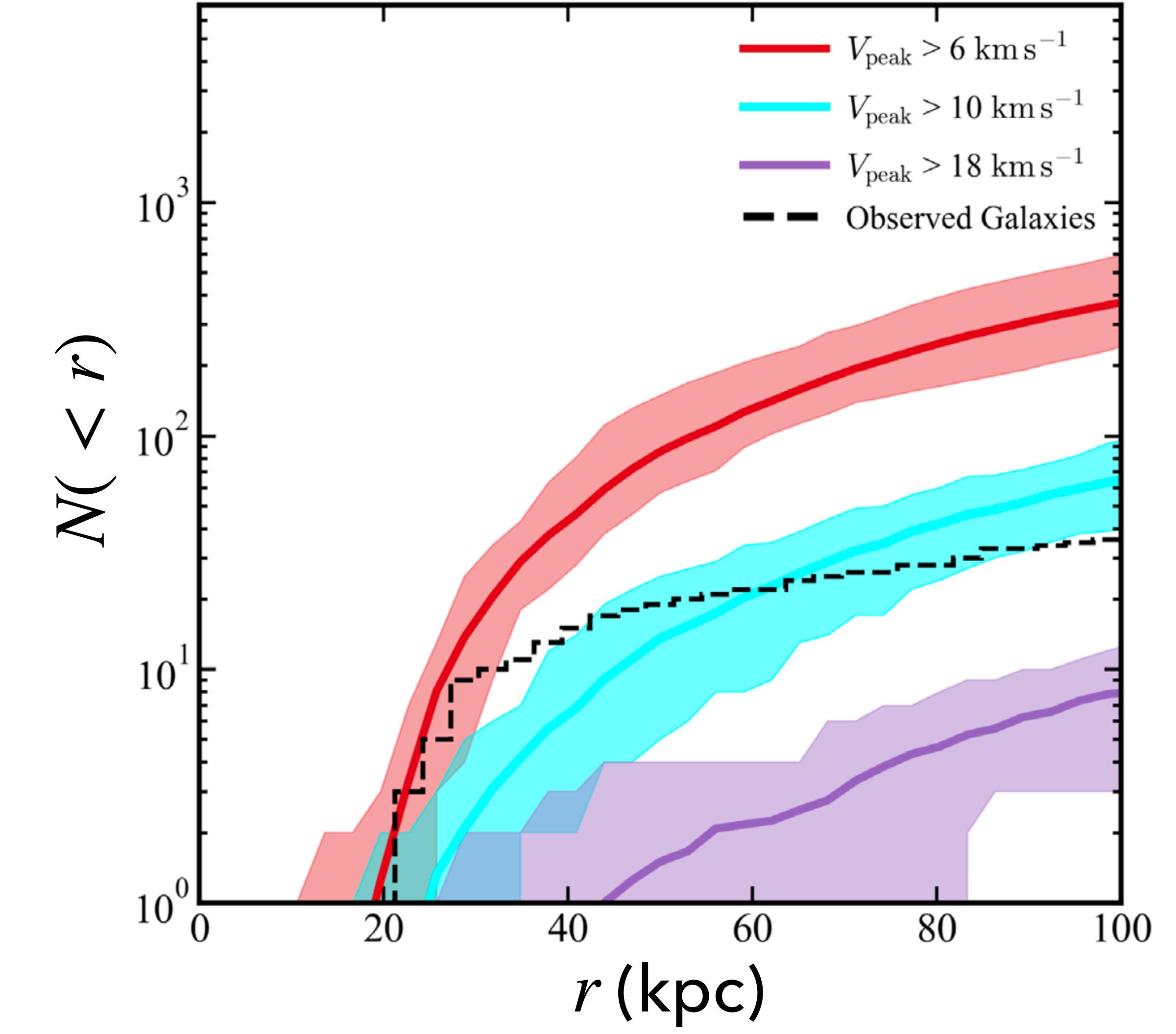
Graus et al. 2019

PHYSICS CONCERTO

MW SATELLITE COUNTS

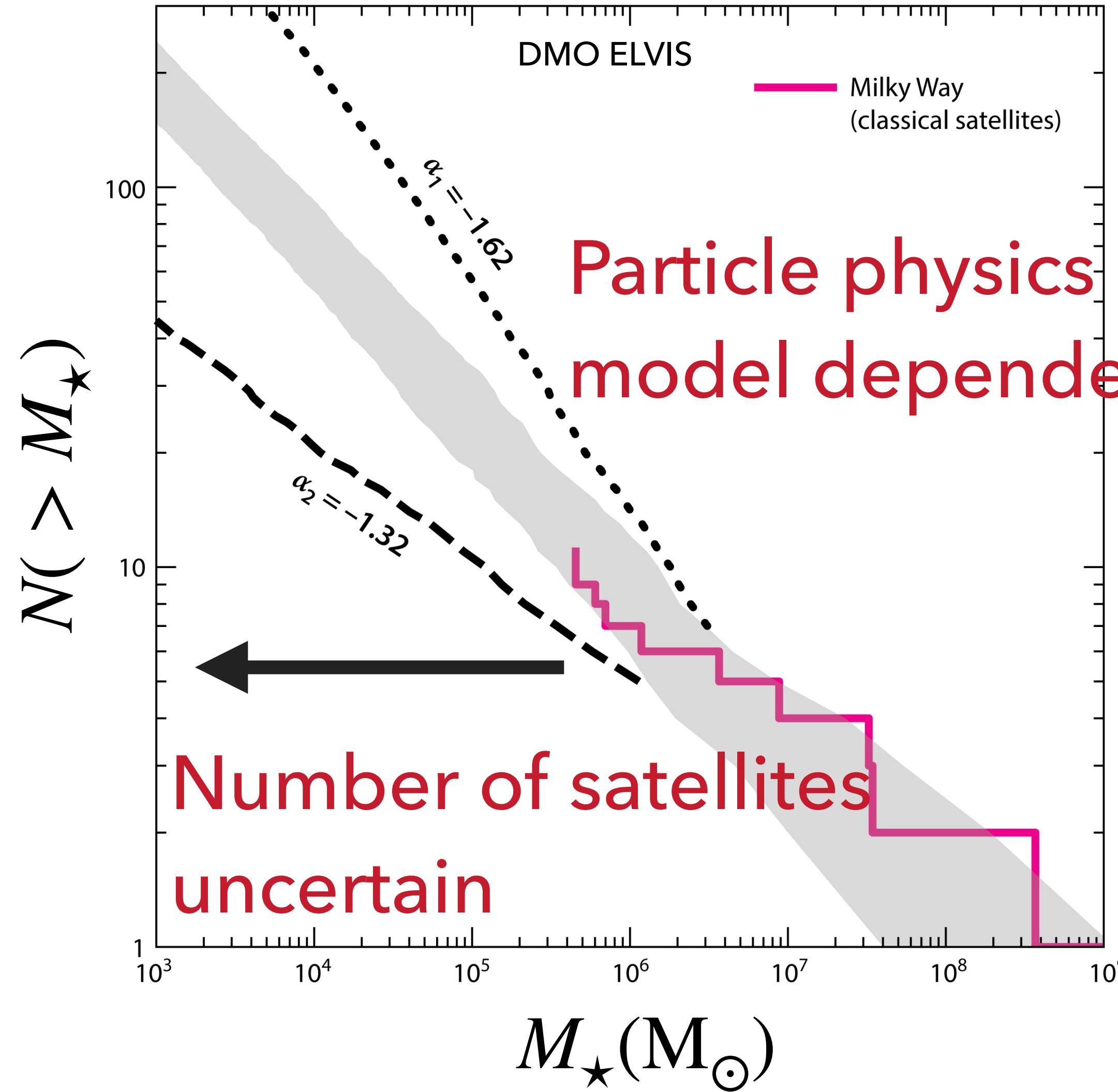


Bullock & Boylan-Kolchin 2017

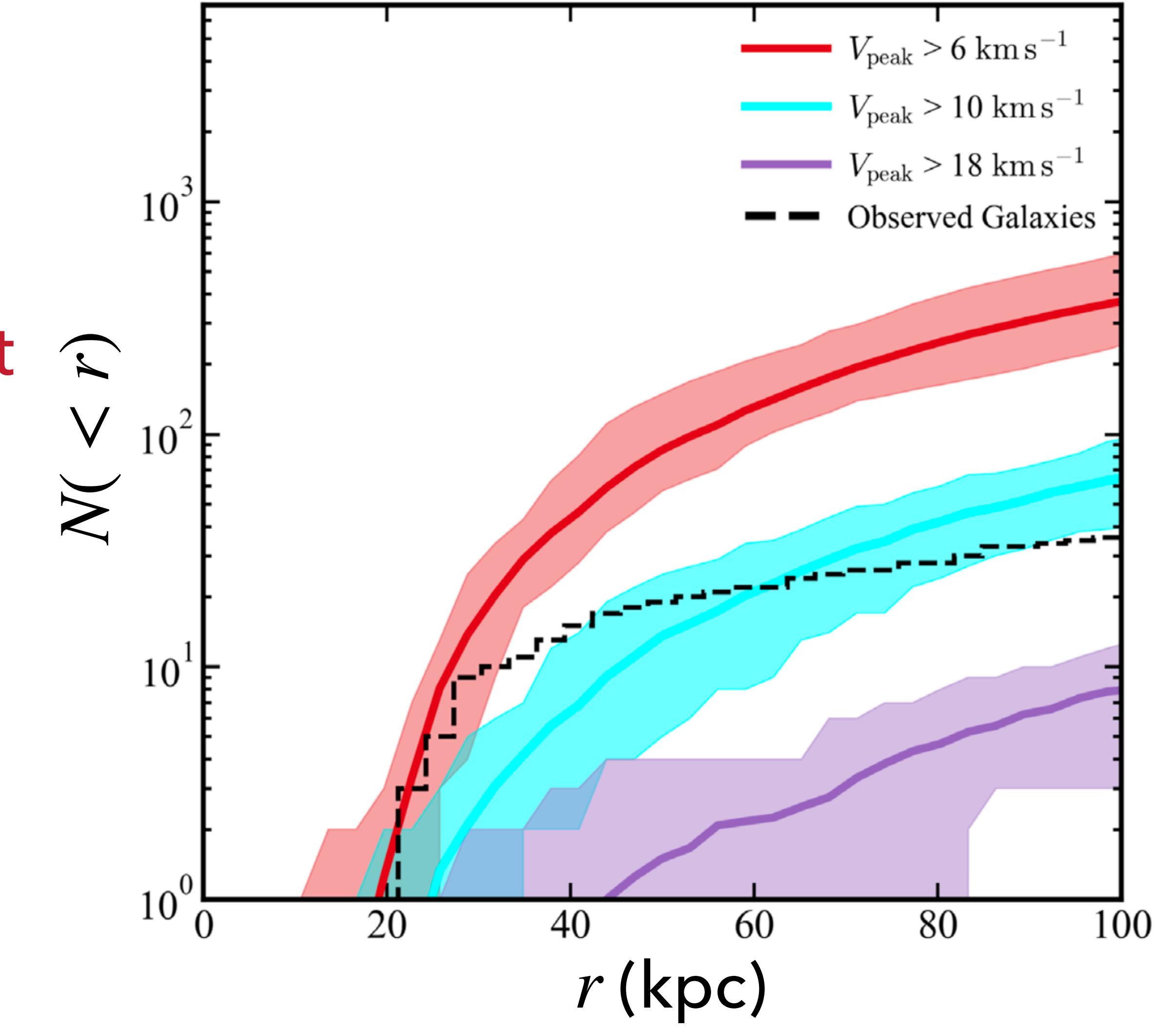


Graus et al. 2019

MW SATELLITE COUNTS



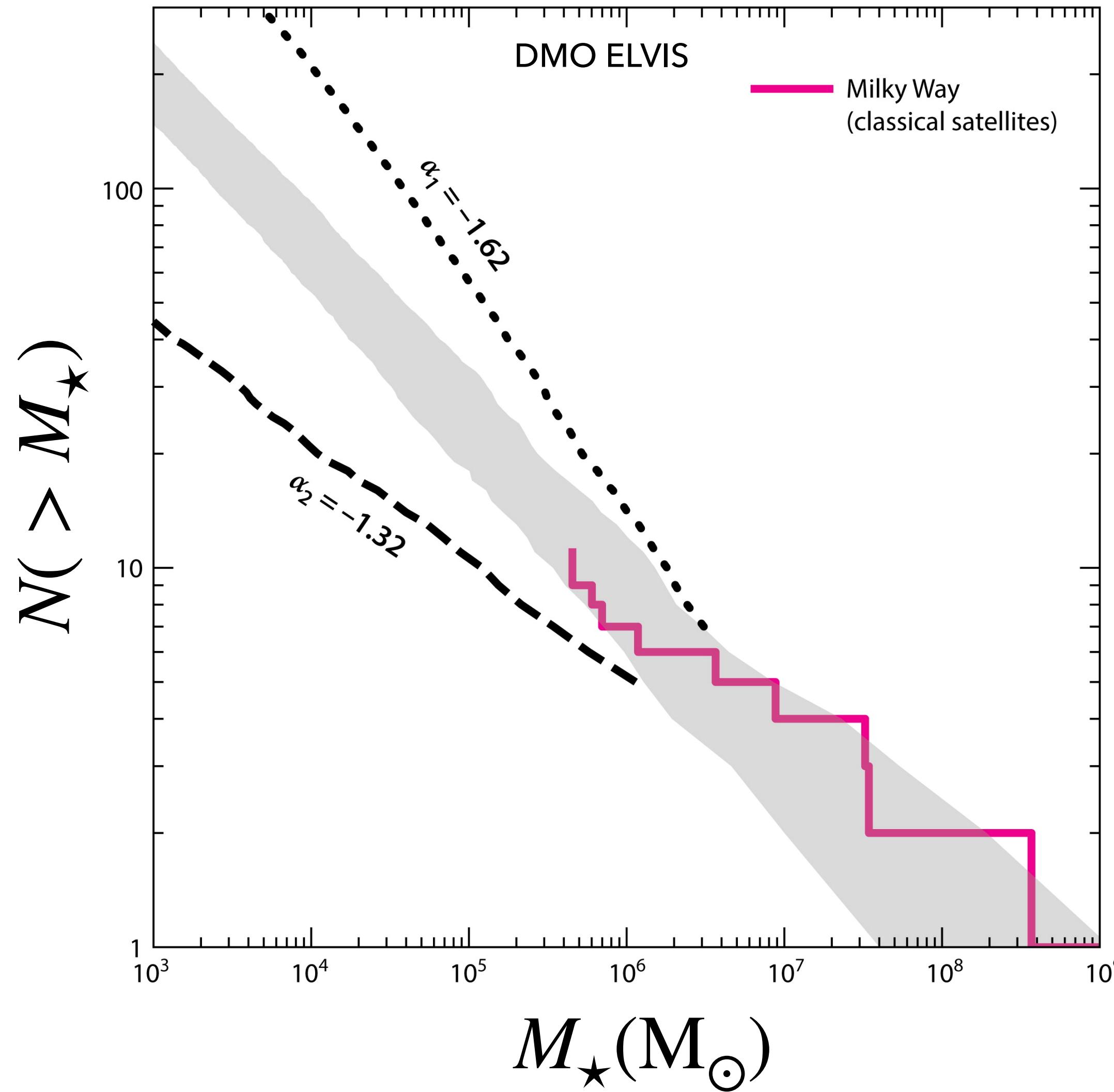
Bullock & Boylan-Kolchin 2017



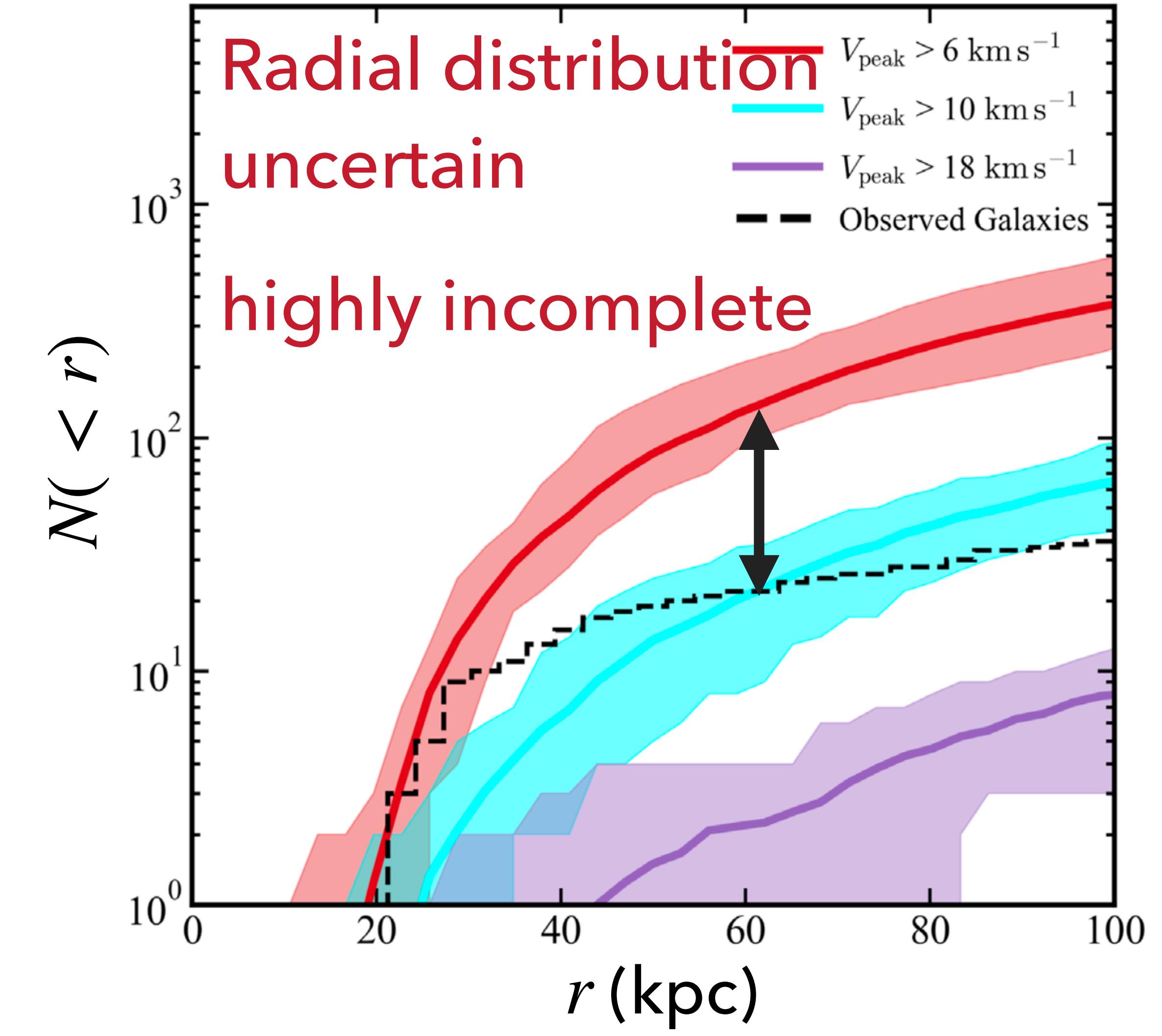
Graus et al. 2019

MW SATELLITE COUNTS

10



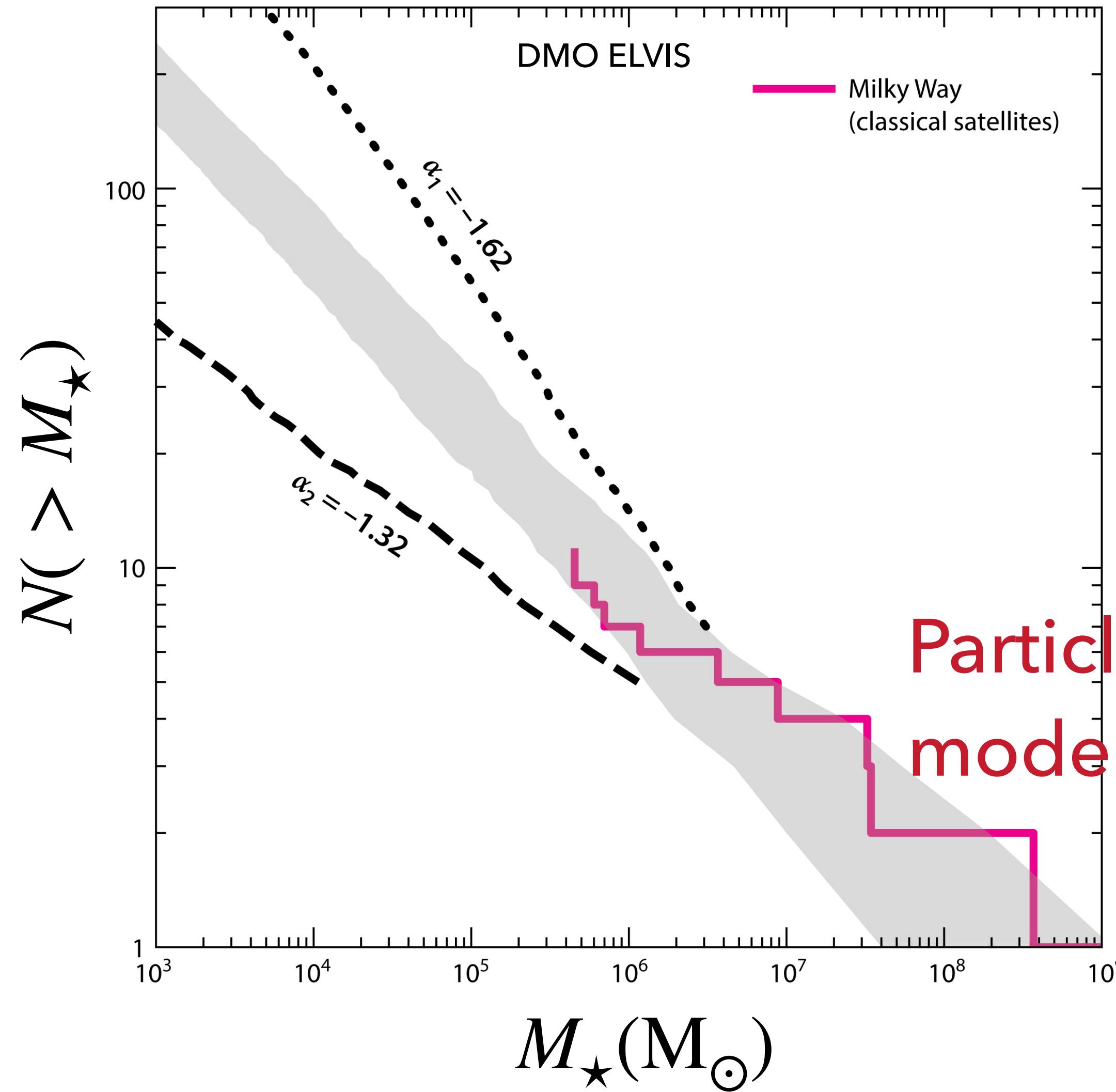
Bullock & Boylan-Kolchin 2017



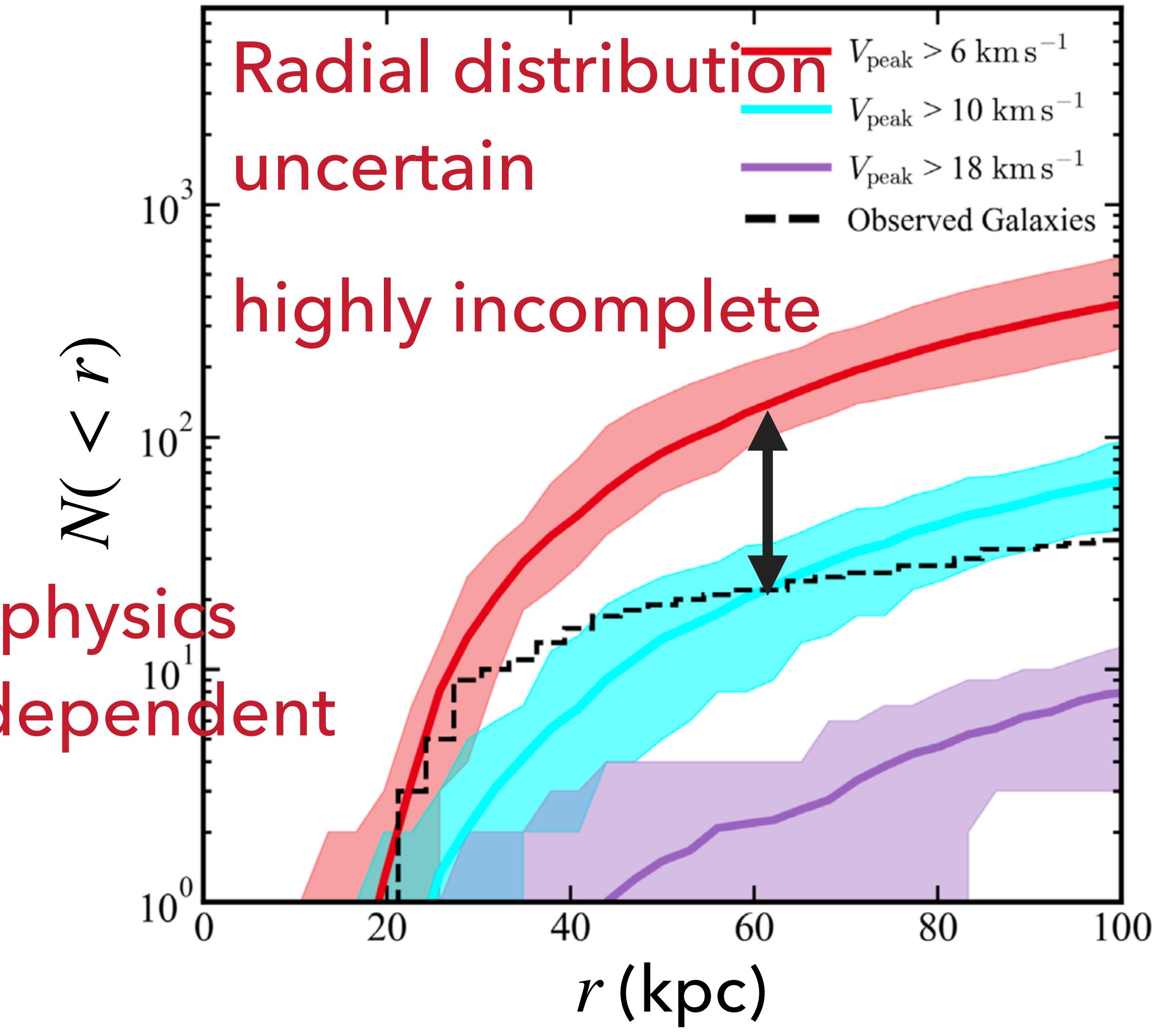
Graus et al. 2019

MW SATELLITE COUNTS

11

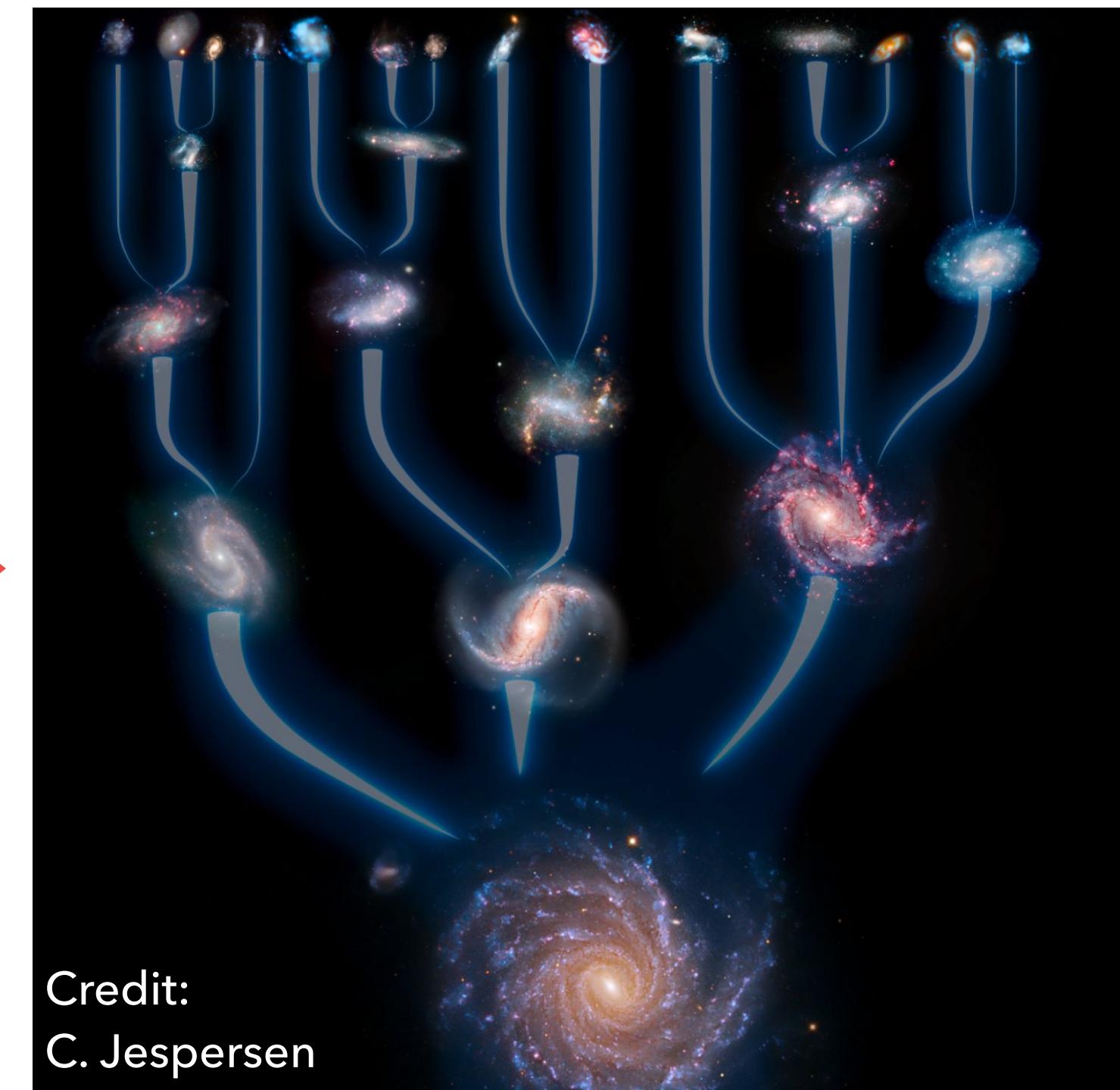
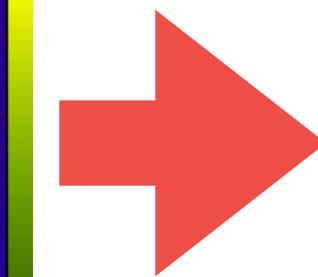
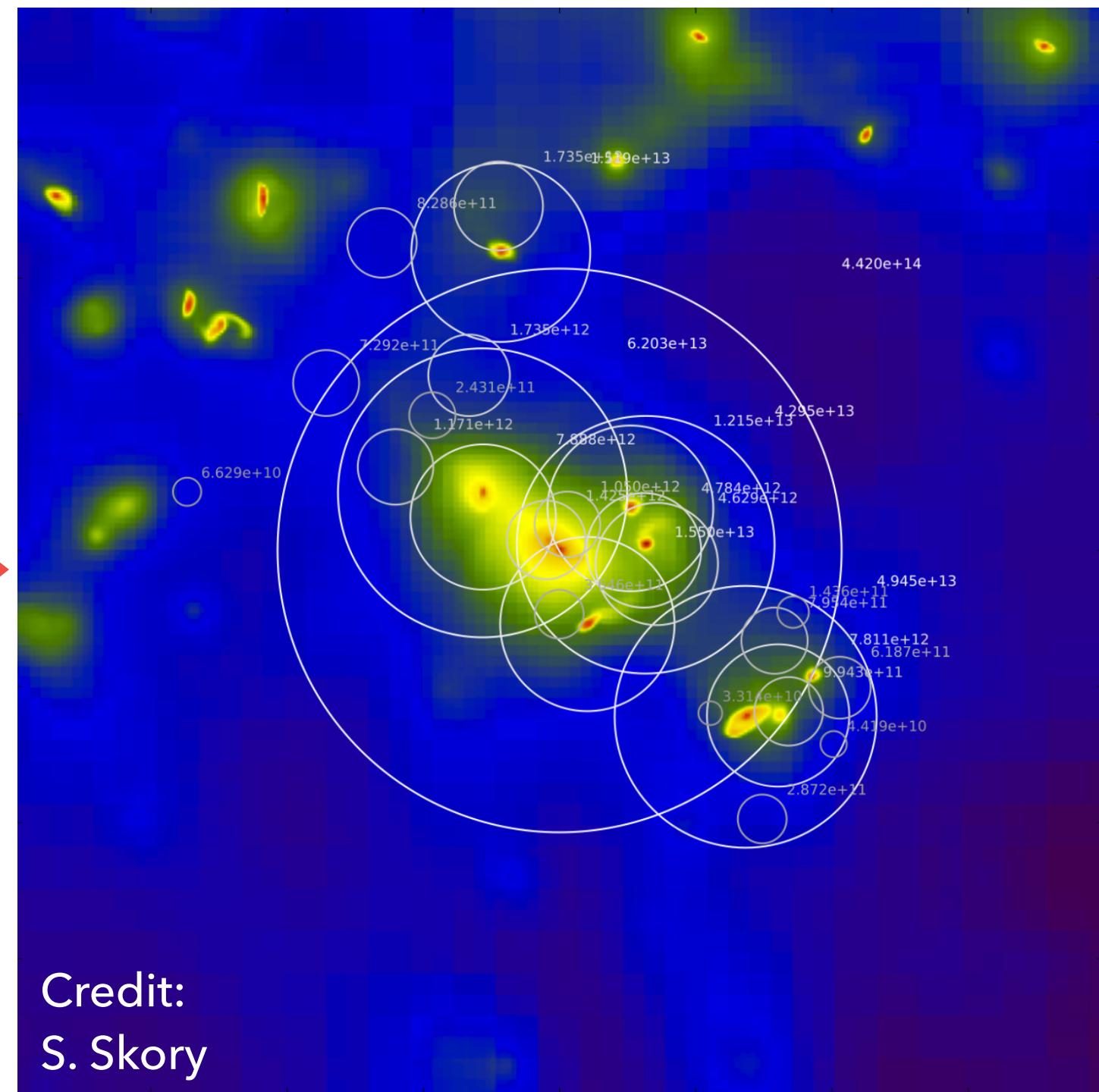
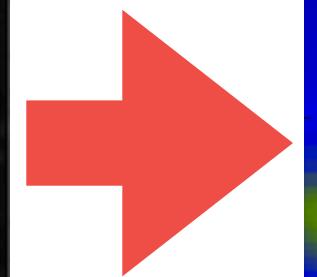
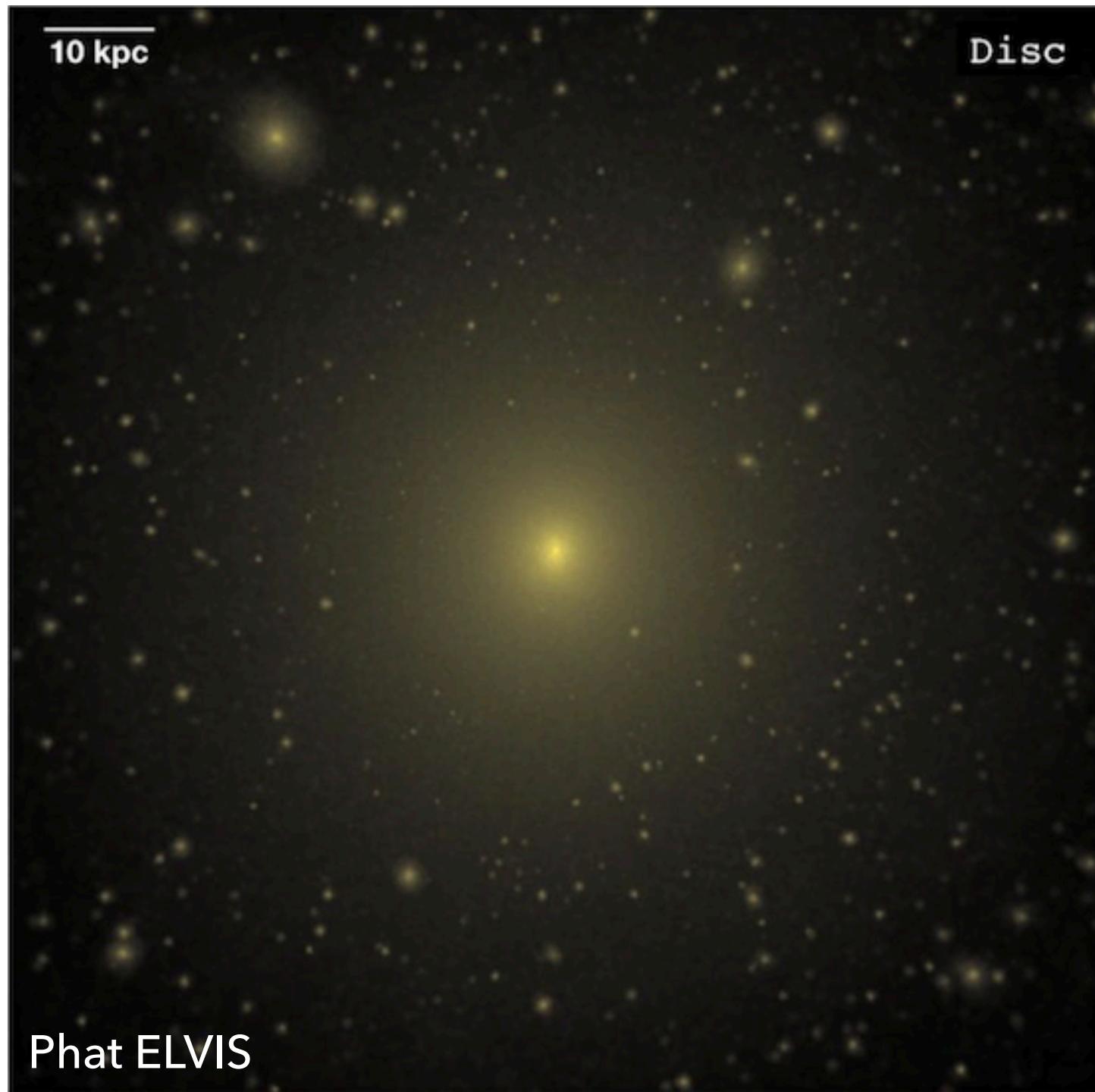


Bullock & Boylan-Kolchin 2017



Graus et al. 2019

“Standard” pipeline

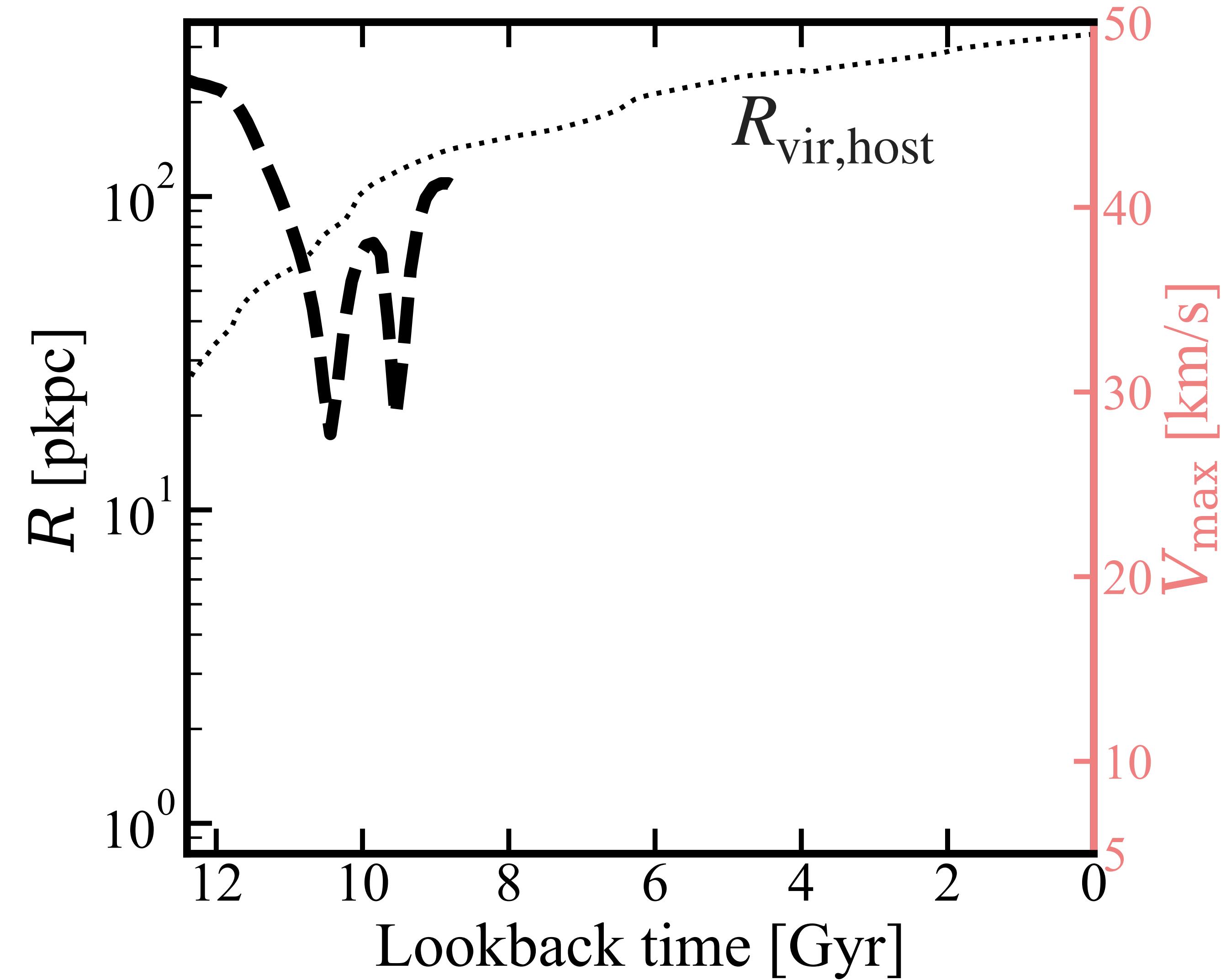


Simulation

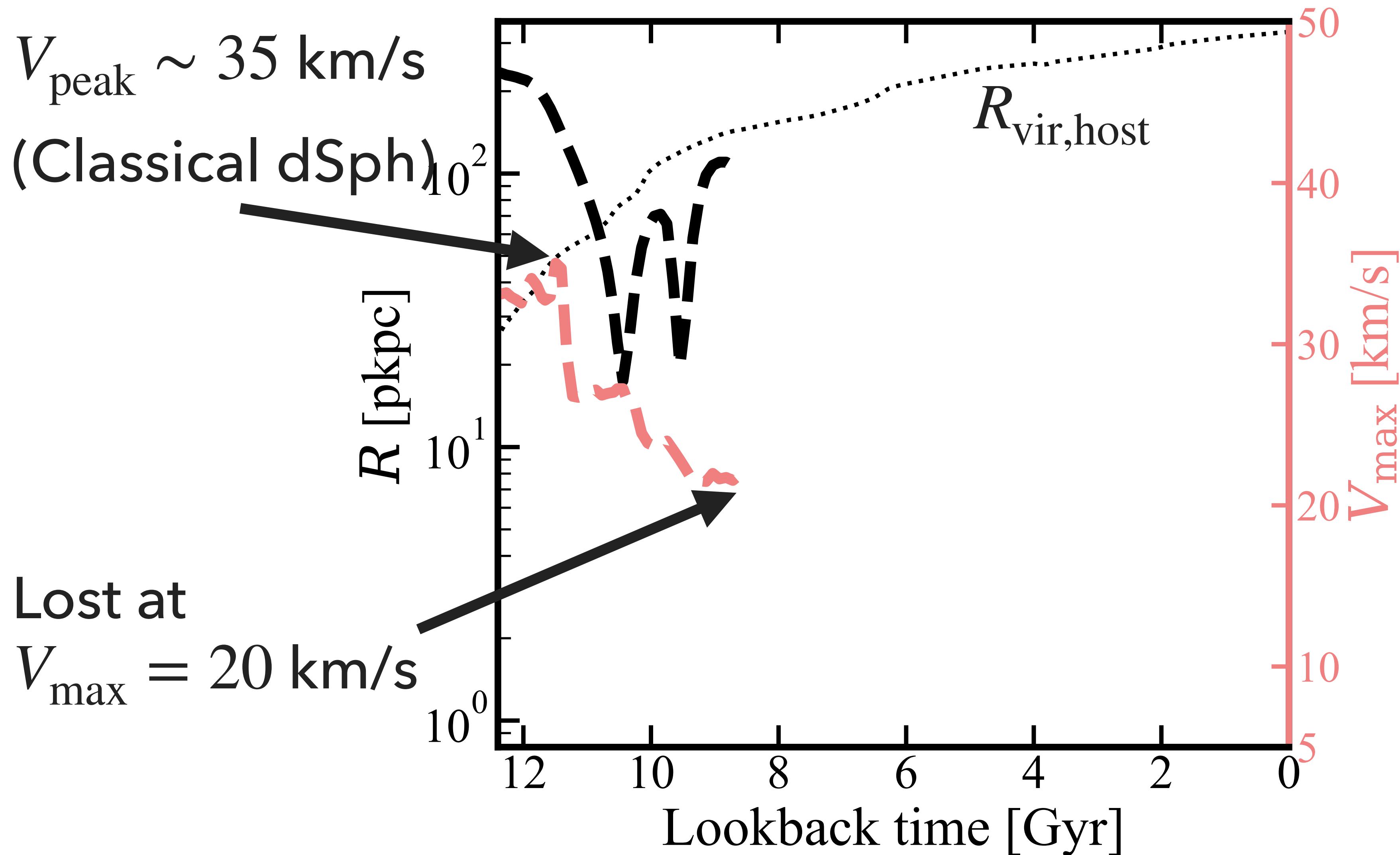
Halo finder

Merger tree

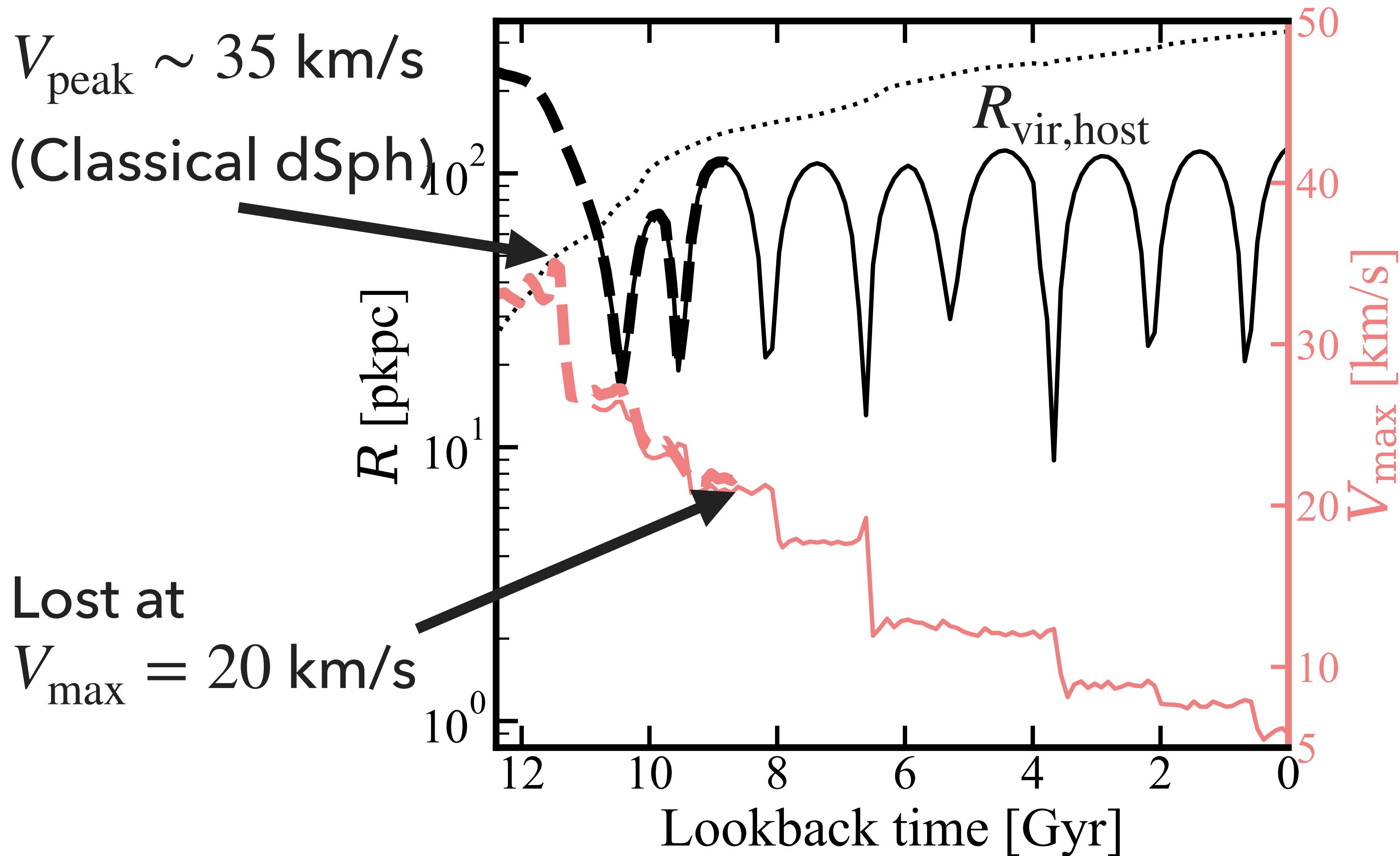
MERGER-TREE VS. PARTICLES



MERGER-TREE VS. PARTICLES



MERGER-TREE VS. PARTICLES

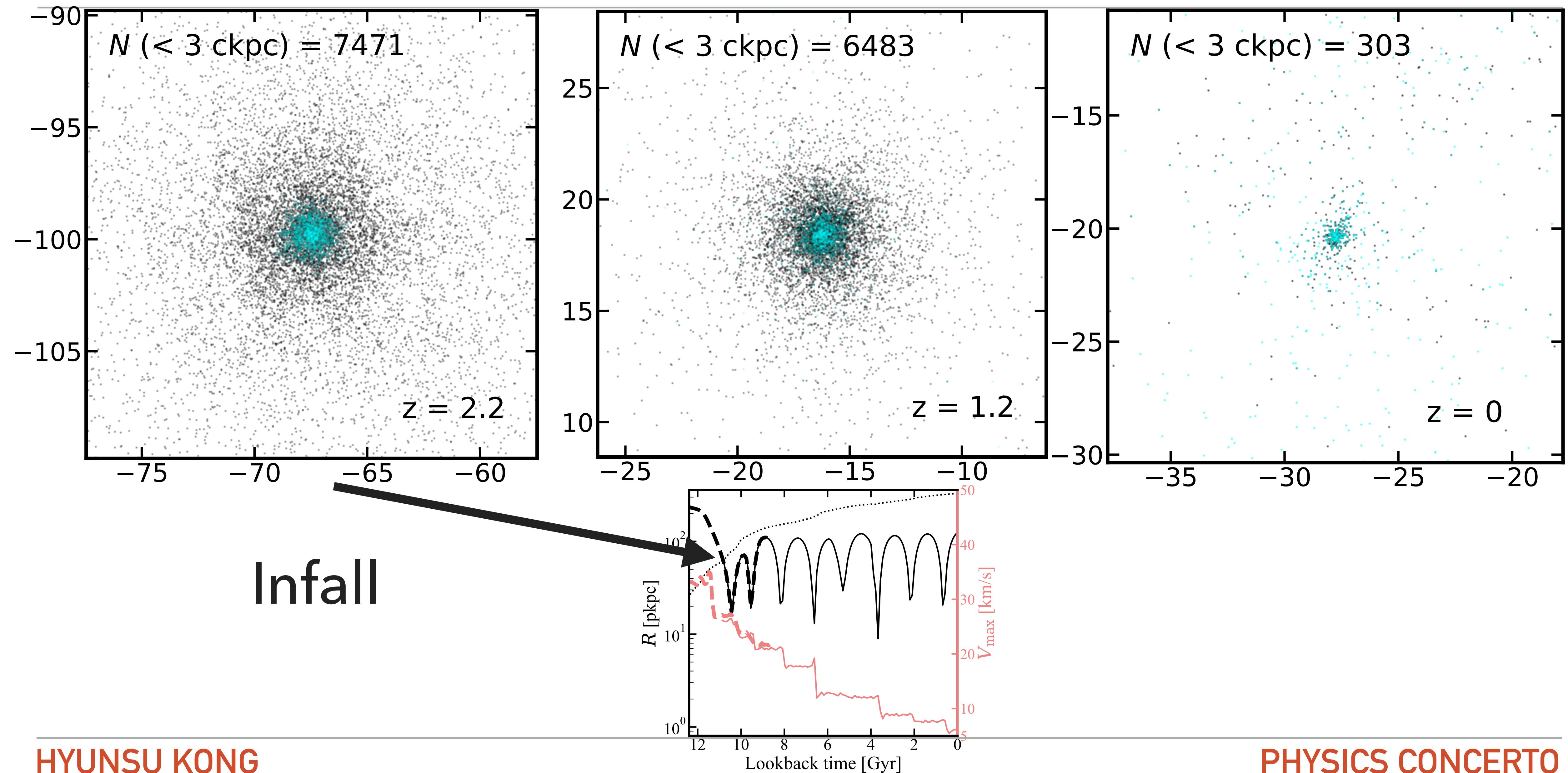


- Bloodhound:**
- Tracked all the way to $z=0$
 - $\sim 9 \text{ Gyr}$ longer
 - 6 additional pericenters
 - $V_{\text{max}} = 5 \text{ km/s}$

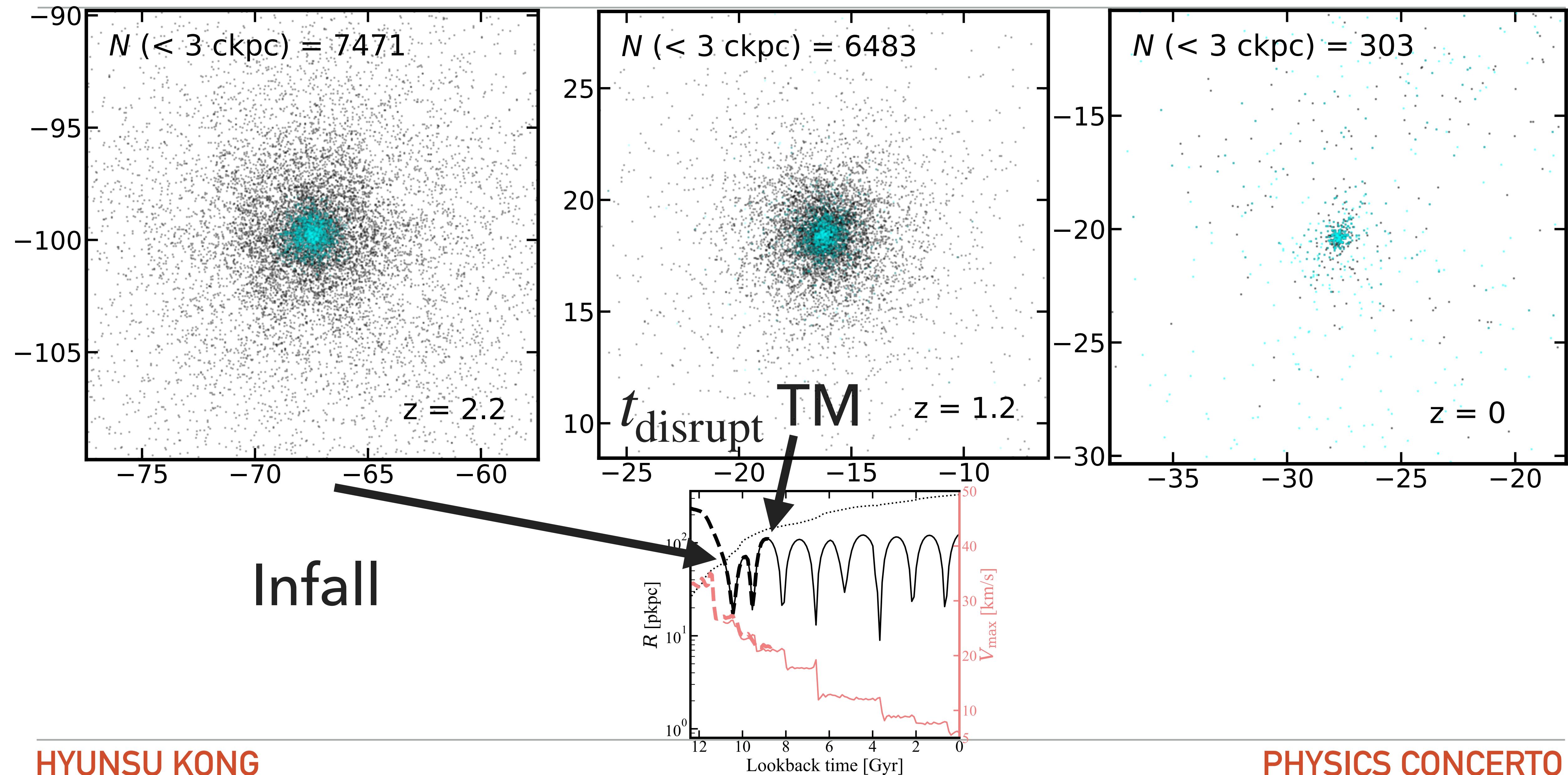
BLOODHOUND

BLOODHOUND

17

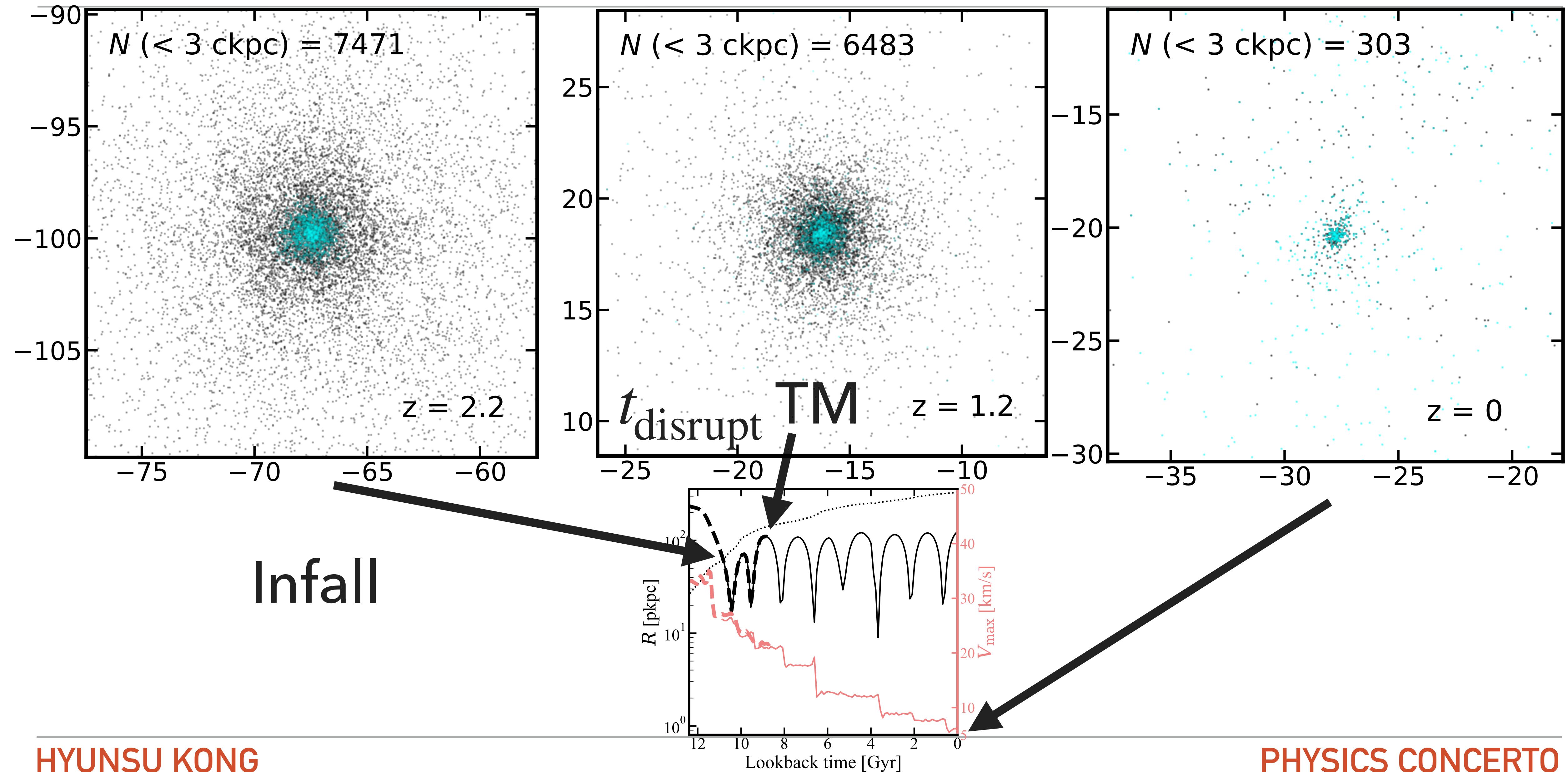


BLOODHOUND



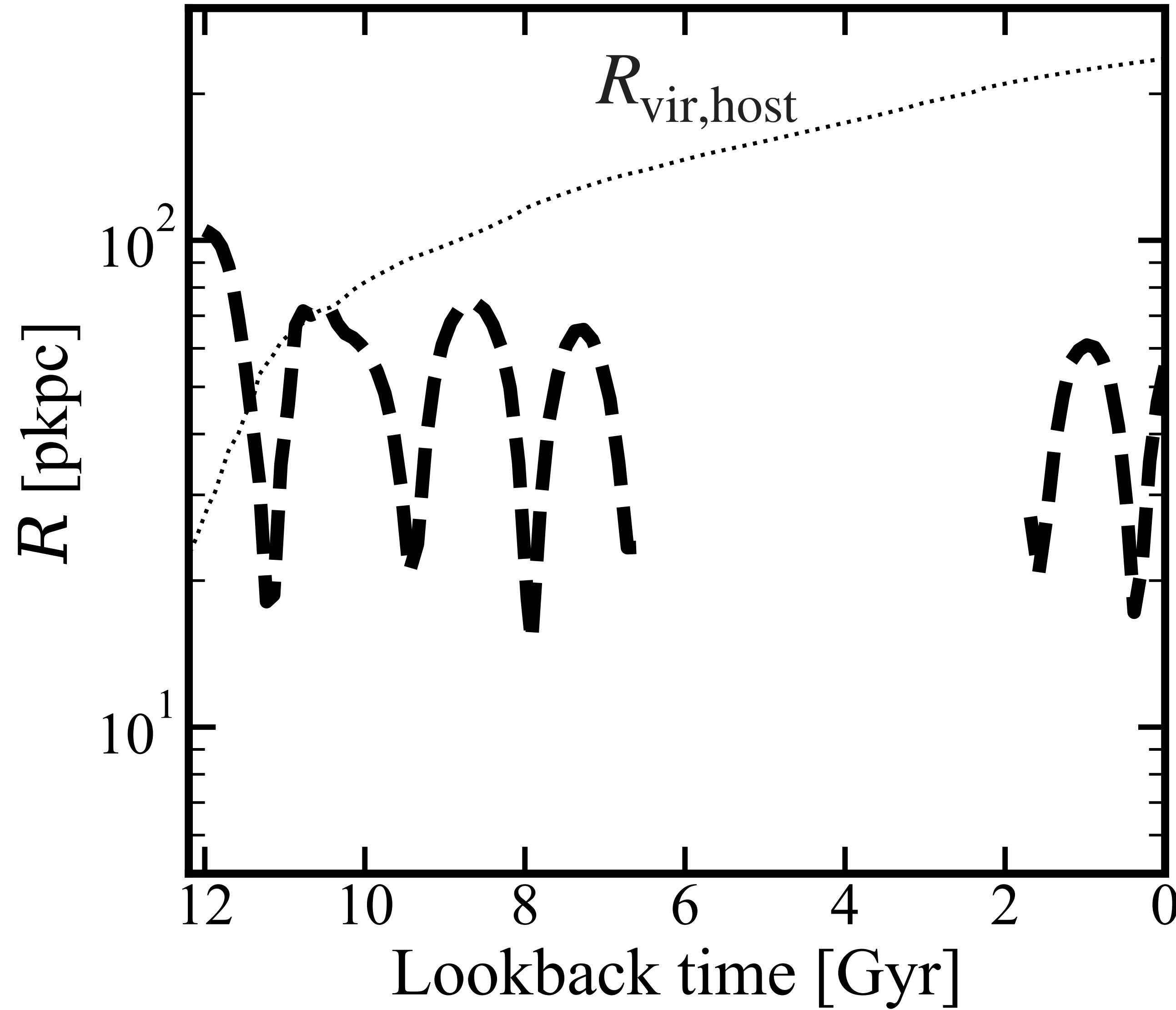
BLOODHOUND

19



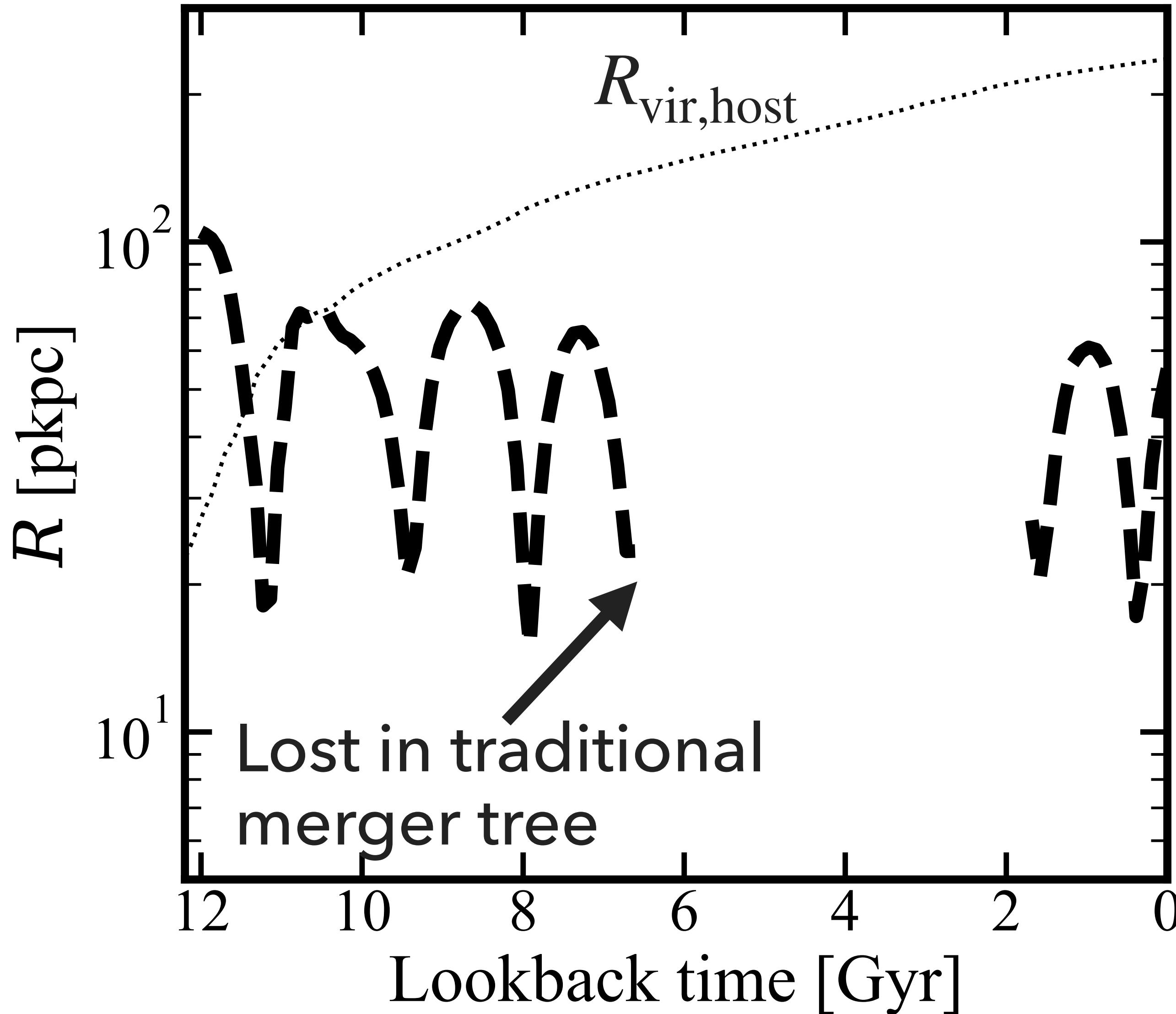
MISSING-LINK TREES

20



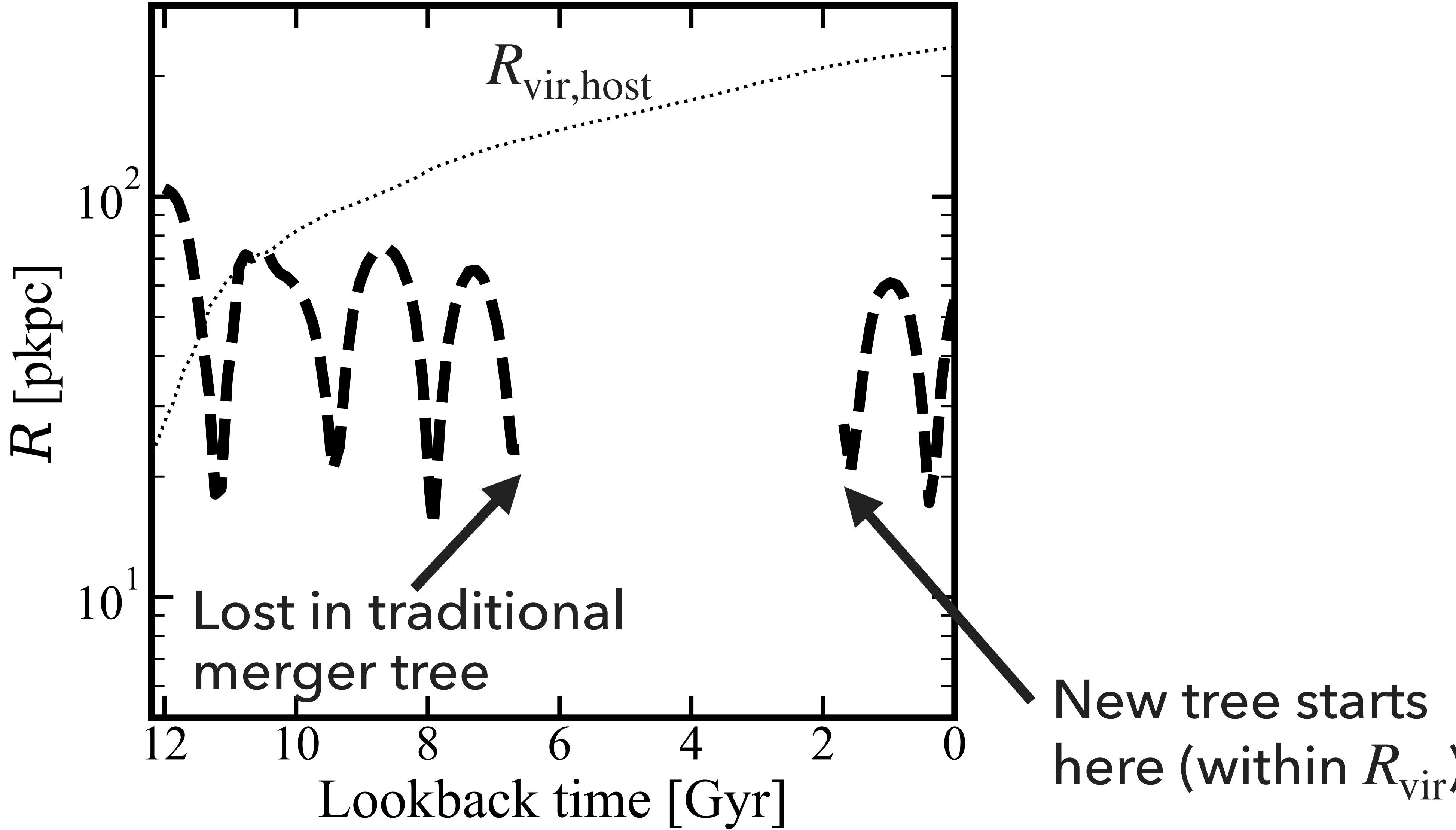
MISSING-LINK TREES

21



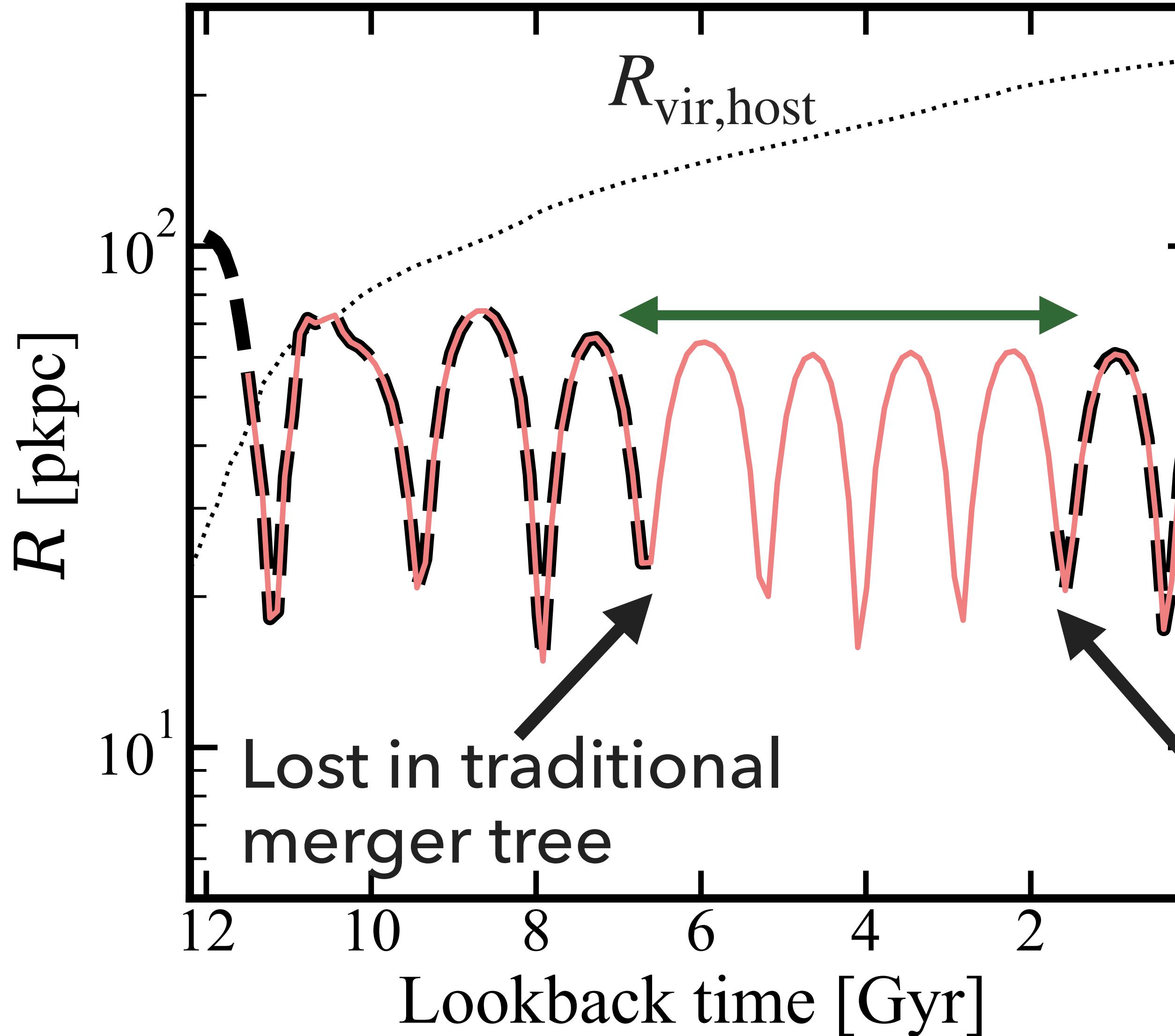
MISSING-LINK TREES

22



MISSING-LINK TREES

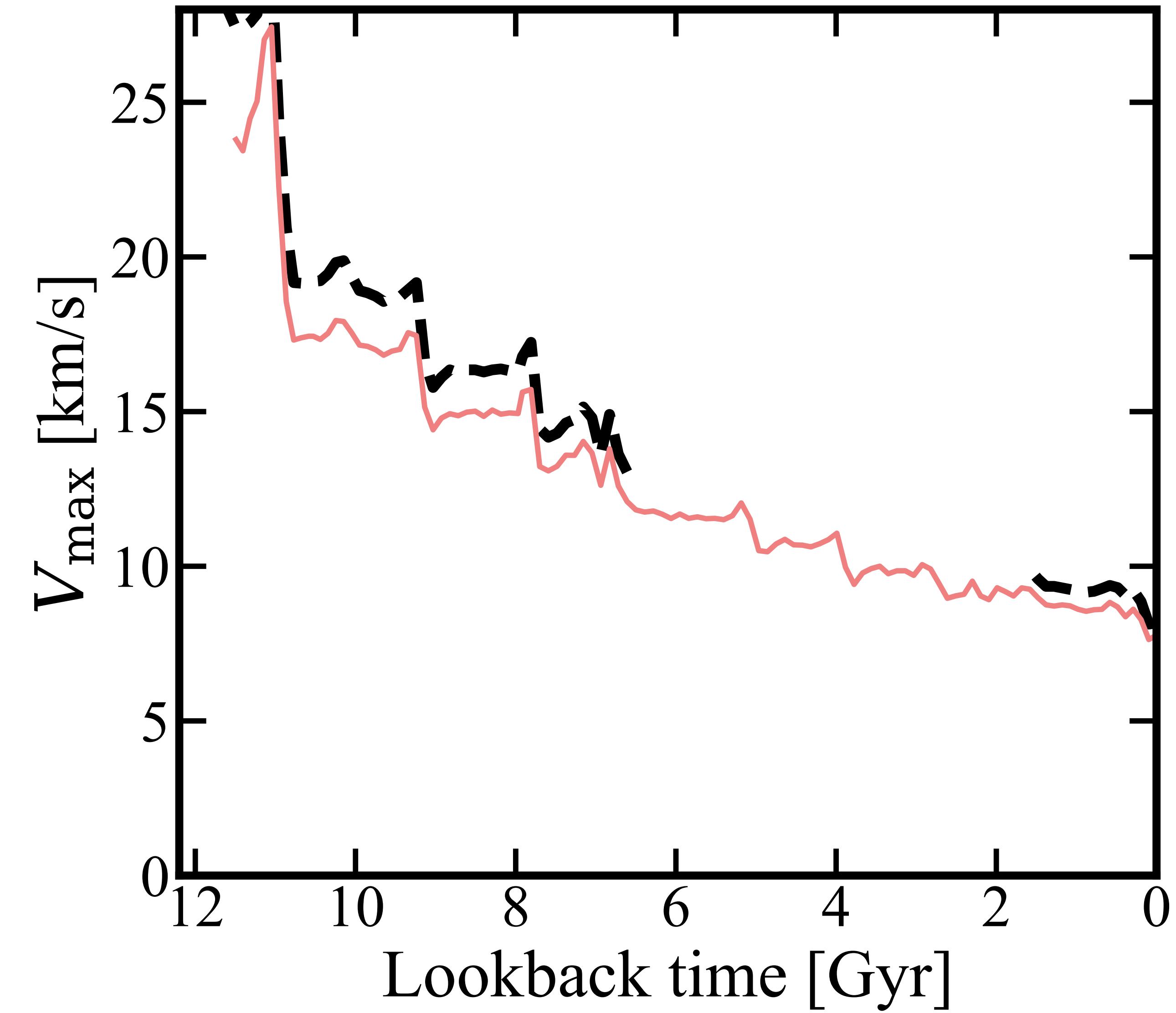
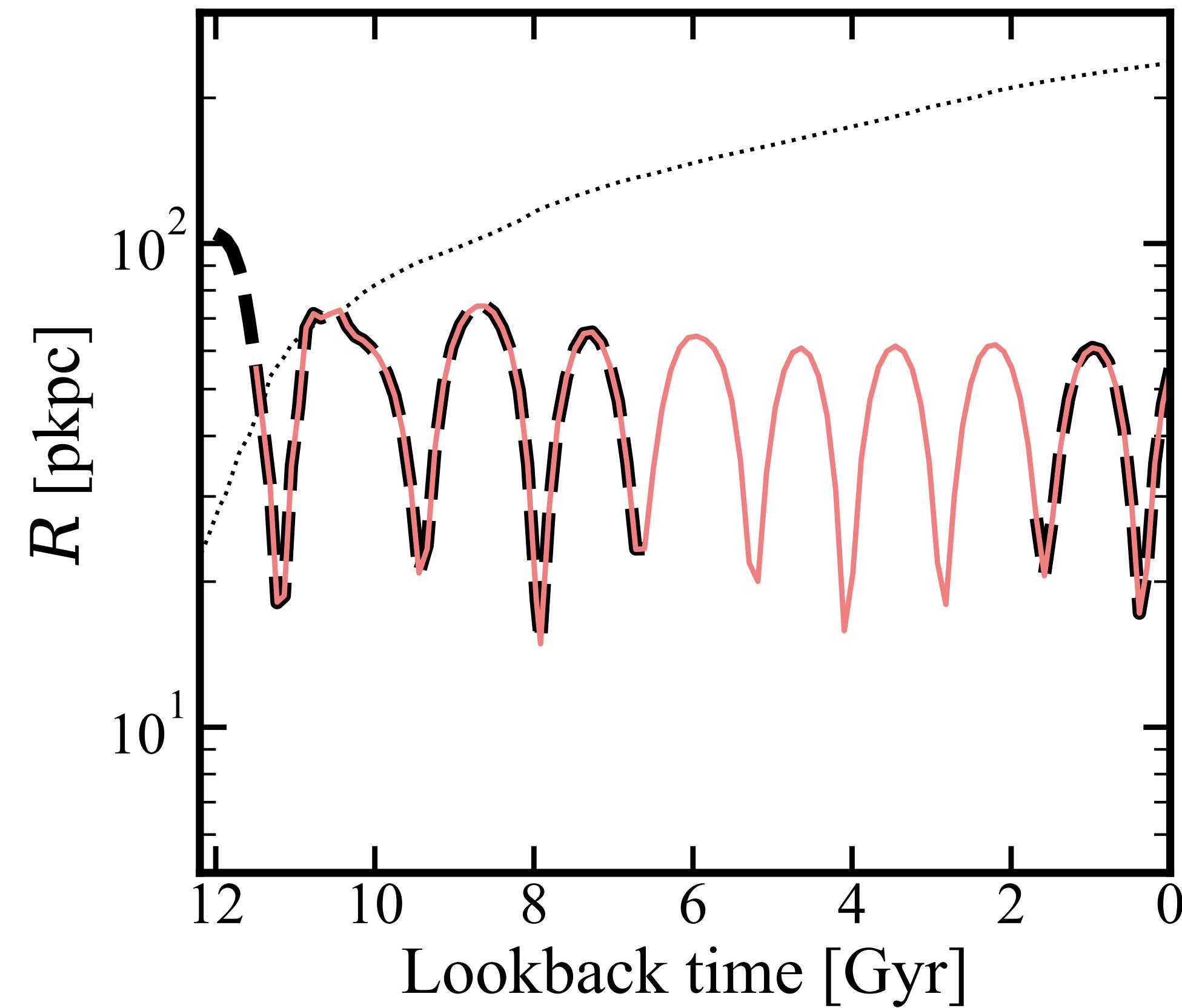
23



Bloodhound
continuously tracks it as
1 halo, never lost

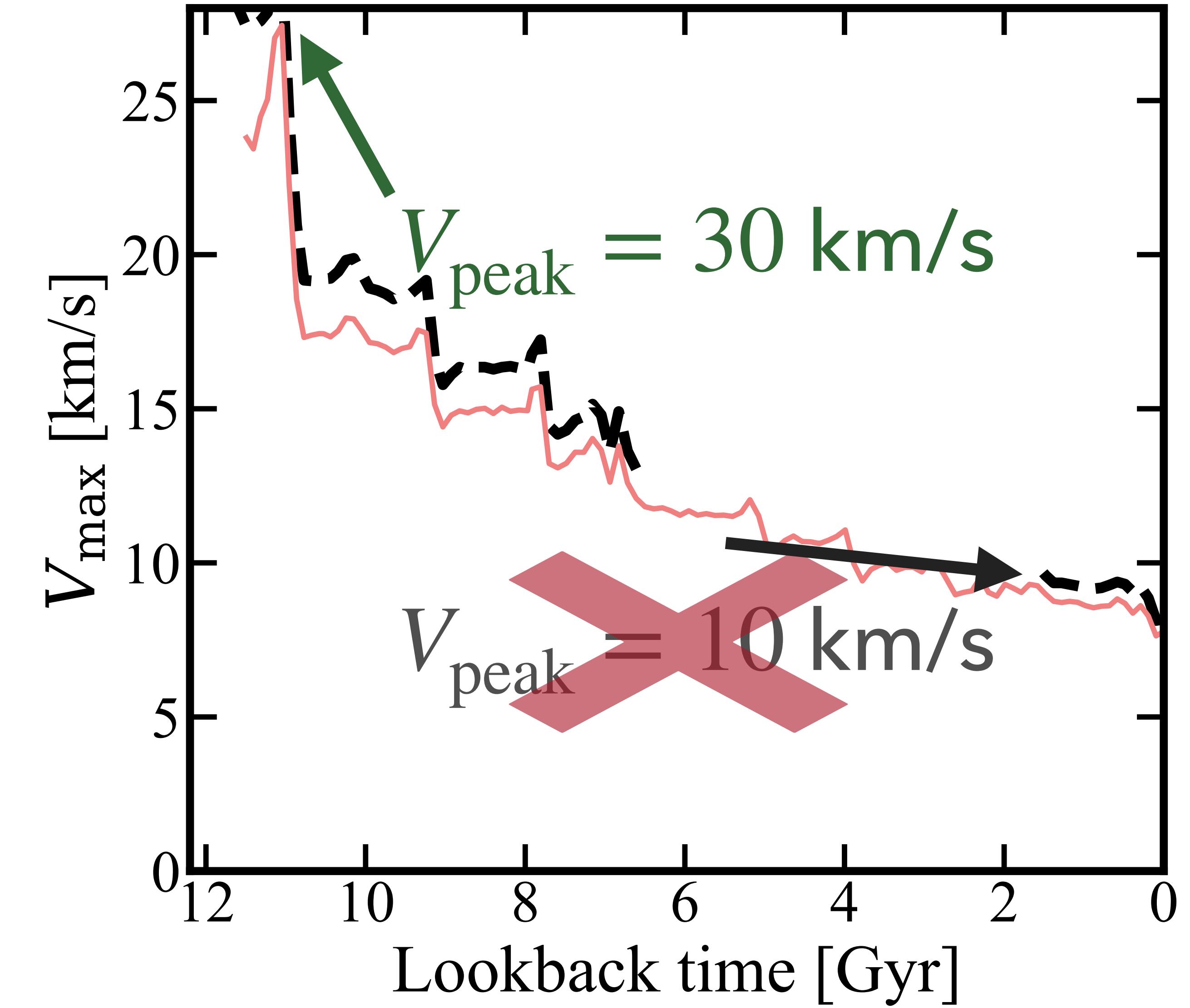
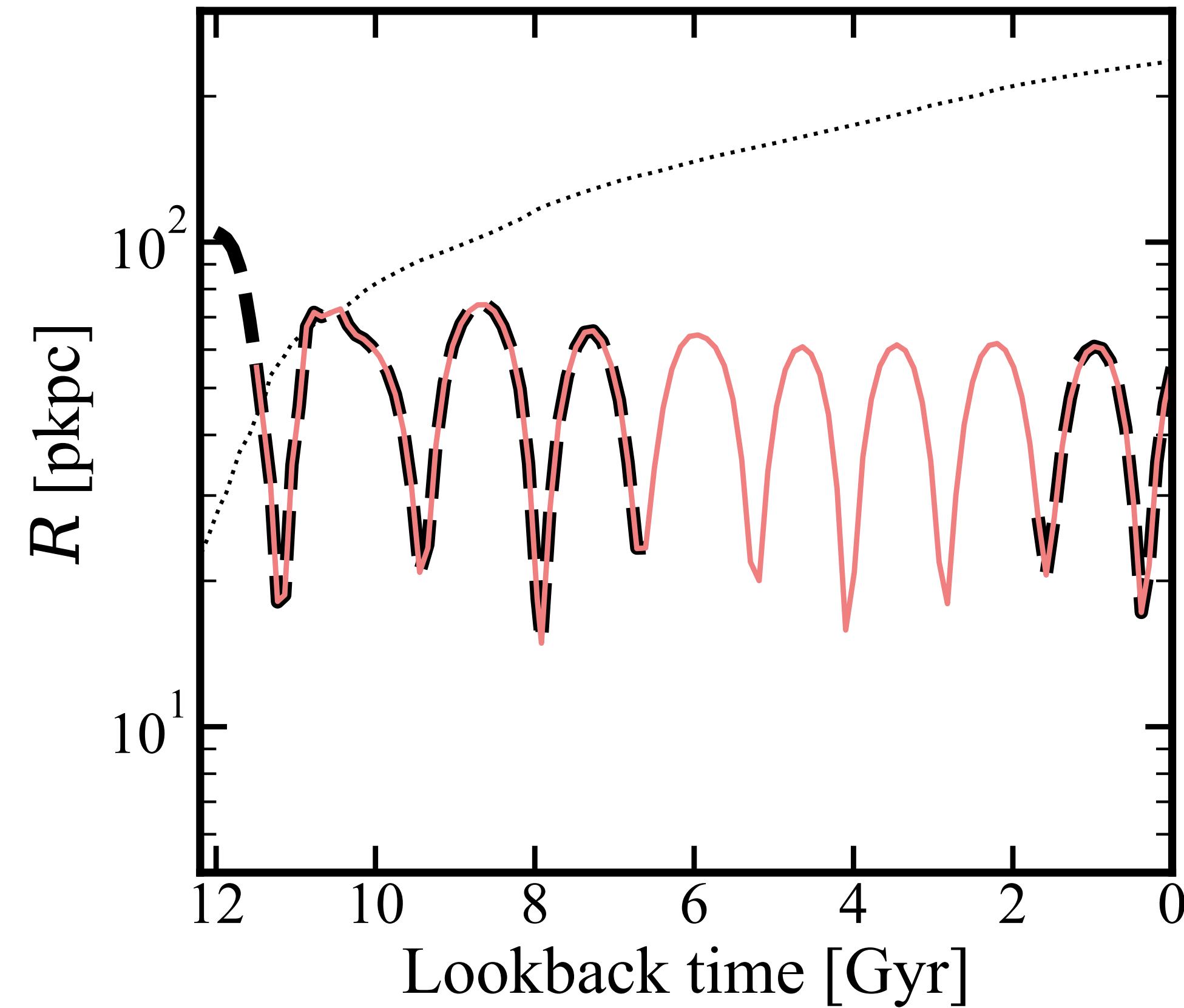
MISSING-LINK TREES

24



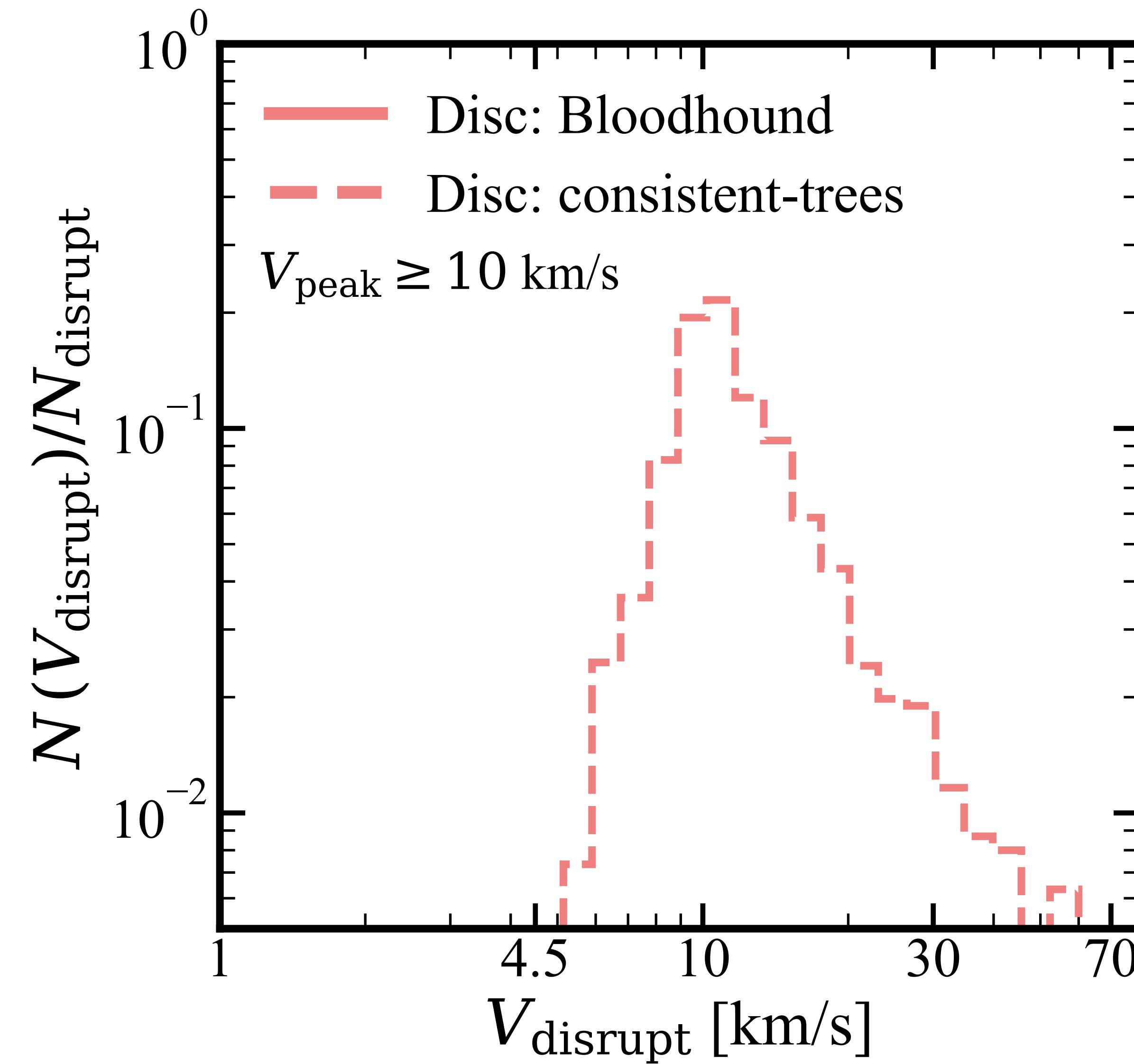
MISSING-LINK TREES

25



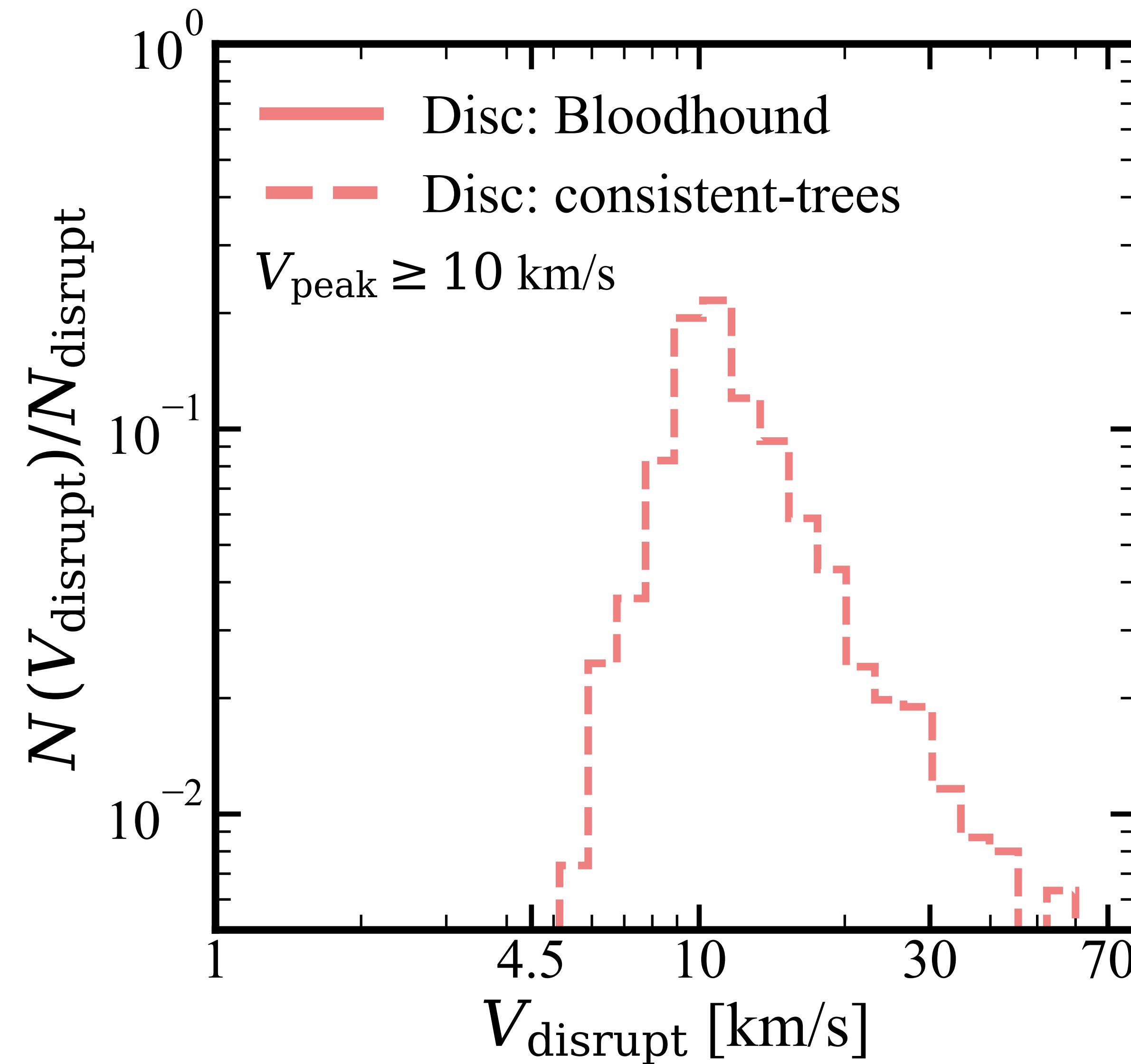
SUBHALO TRACKING IMPROVEMENTS

26



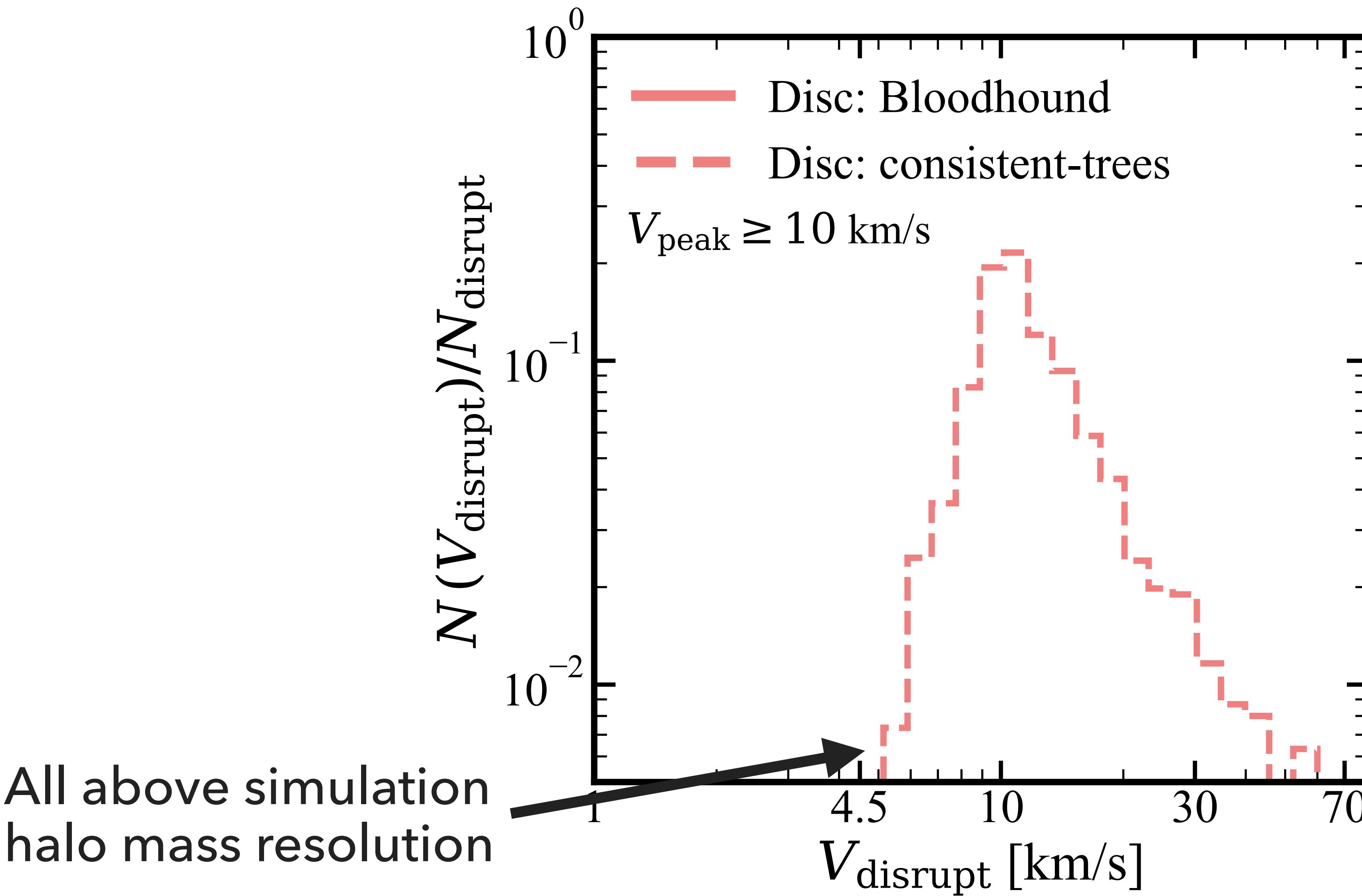
SUBHALO TRACKING IMPROVEMENTS

27



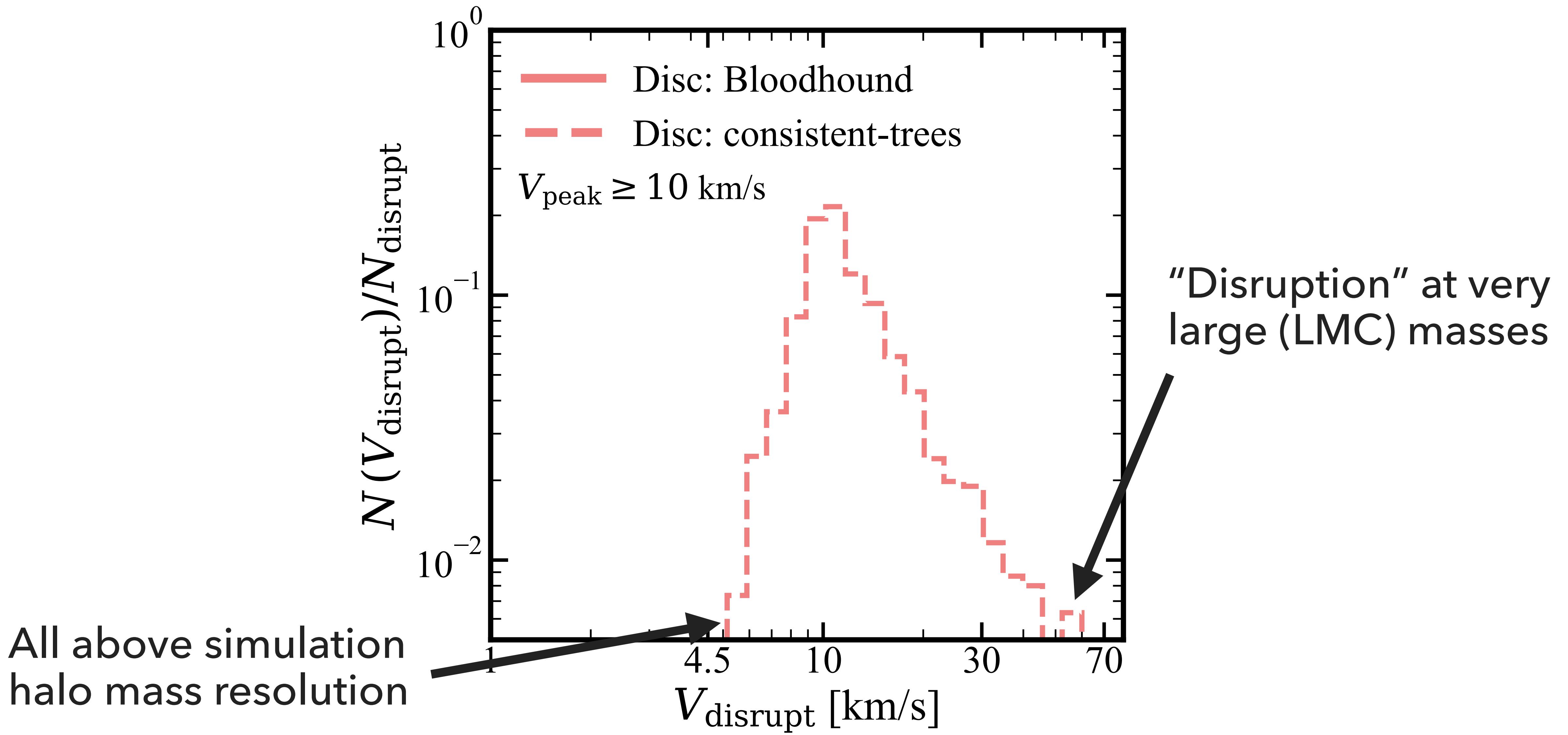
$V_{\text{disrupt}} = V_{\text{max}}$
at disruption

SUBHALO TRACKING IMPROVEMENTS

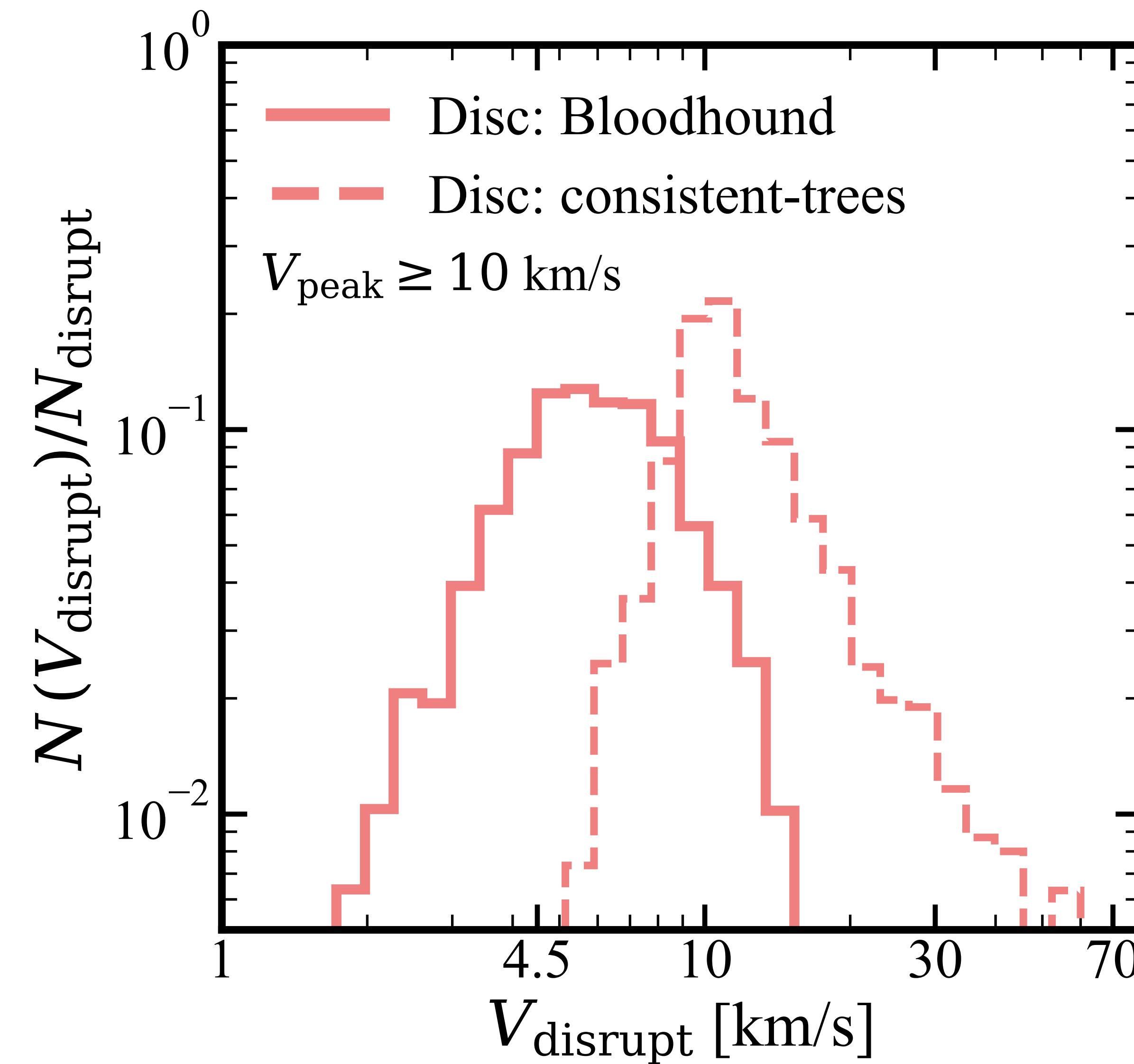


SUBHALO TRACKING IMPROVEMENTS

29

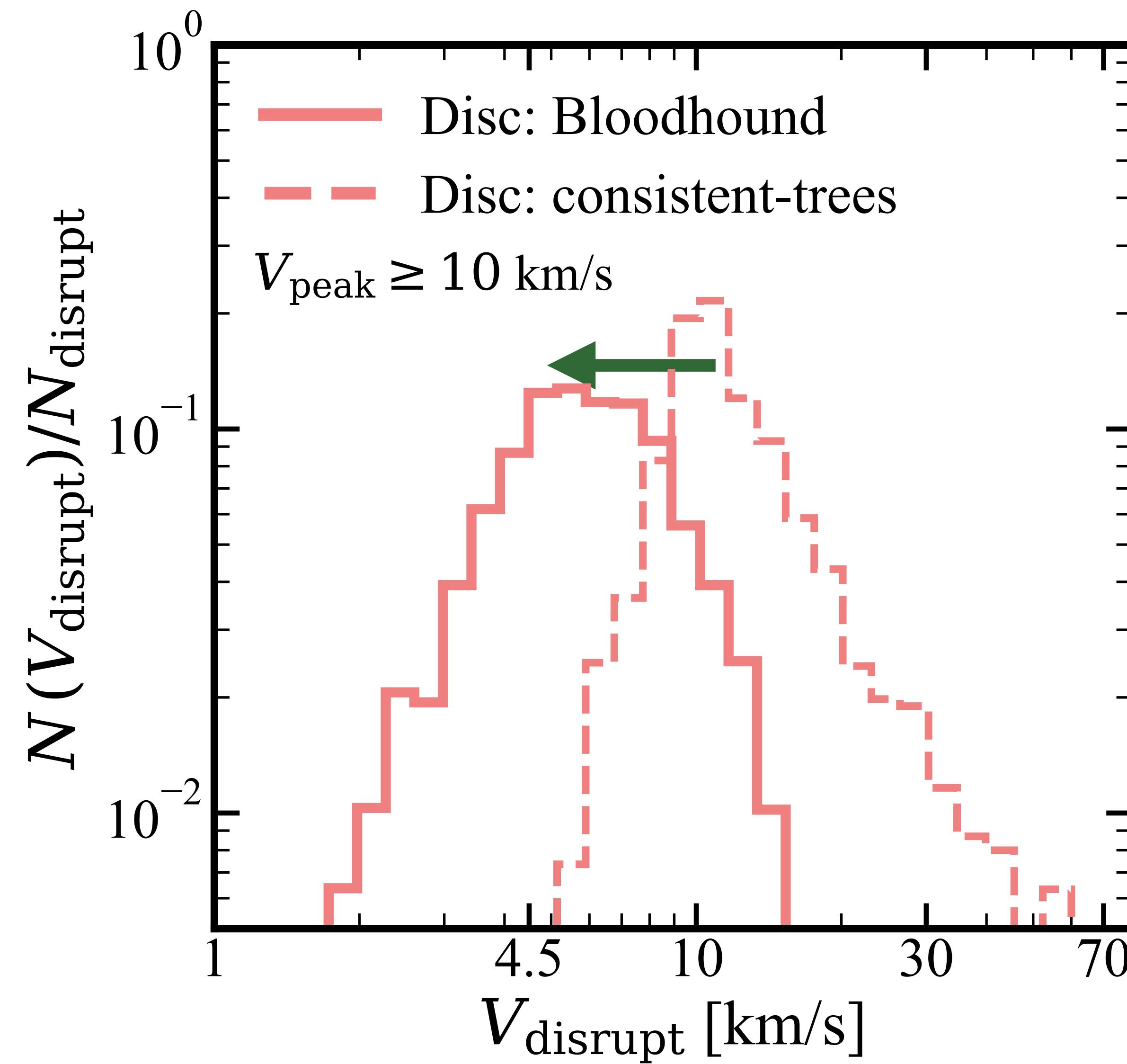


SUBHALO TRACKING IMPROVEMENTS

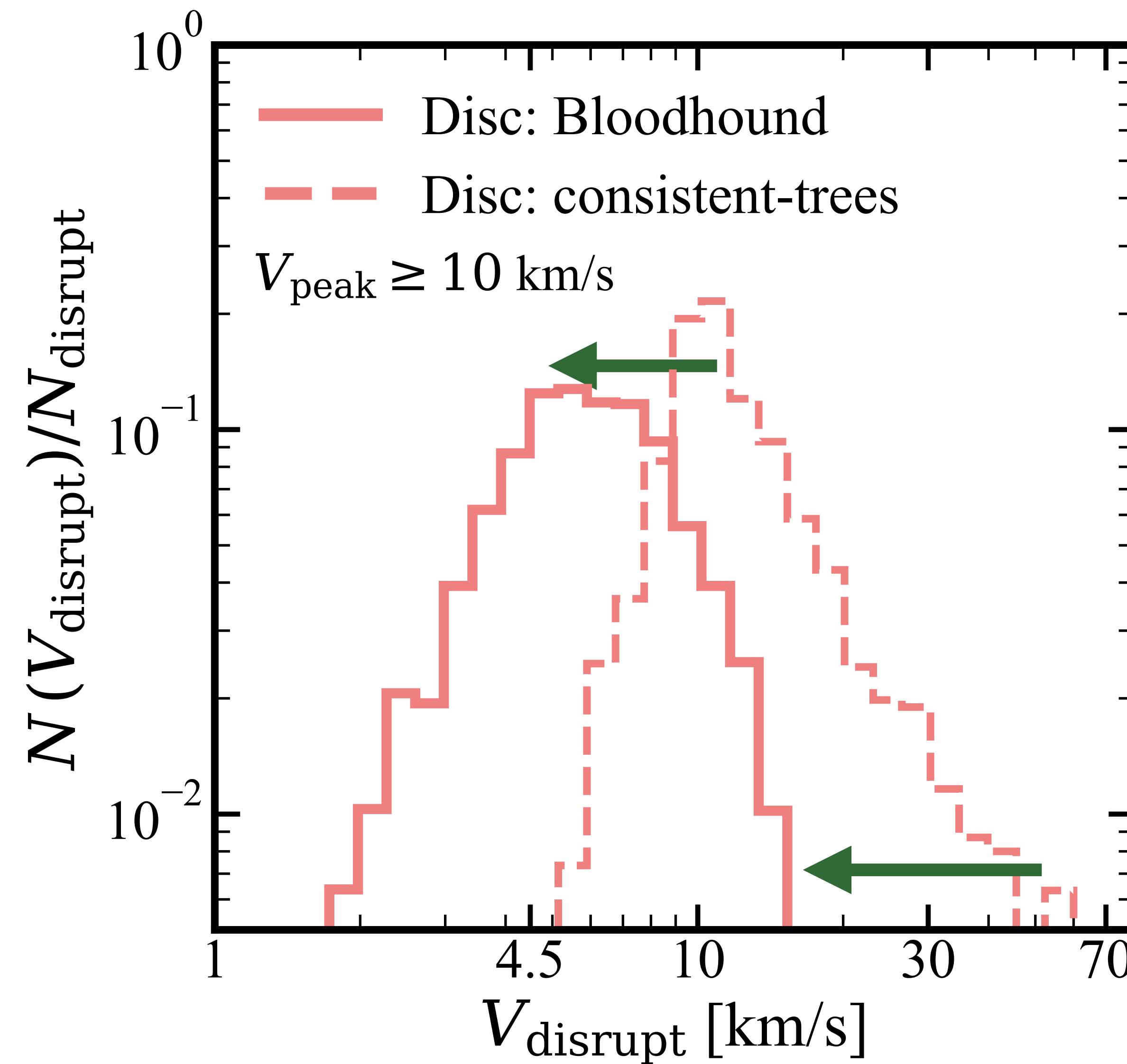


SUBHALO TRACKING IMPROVEMENTS

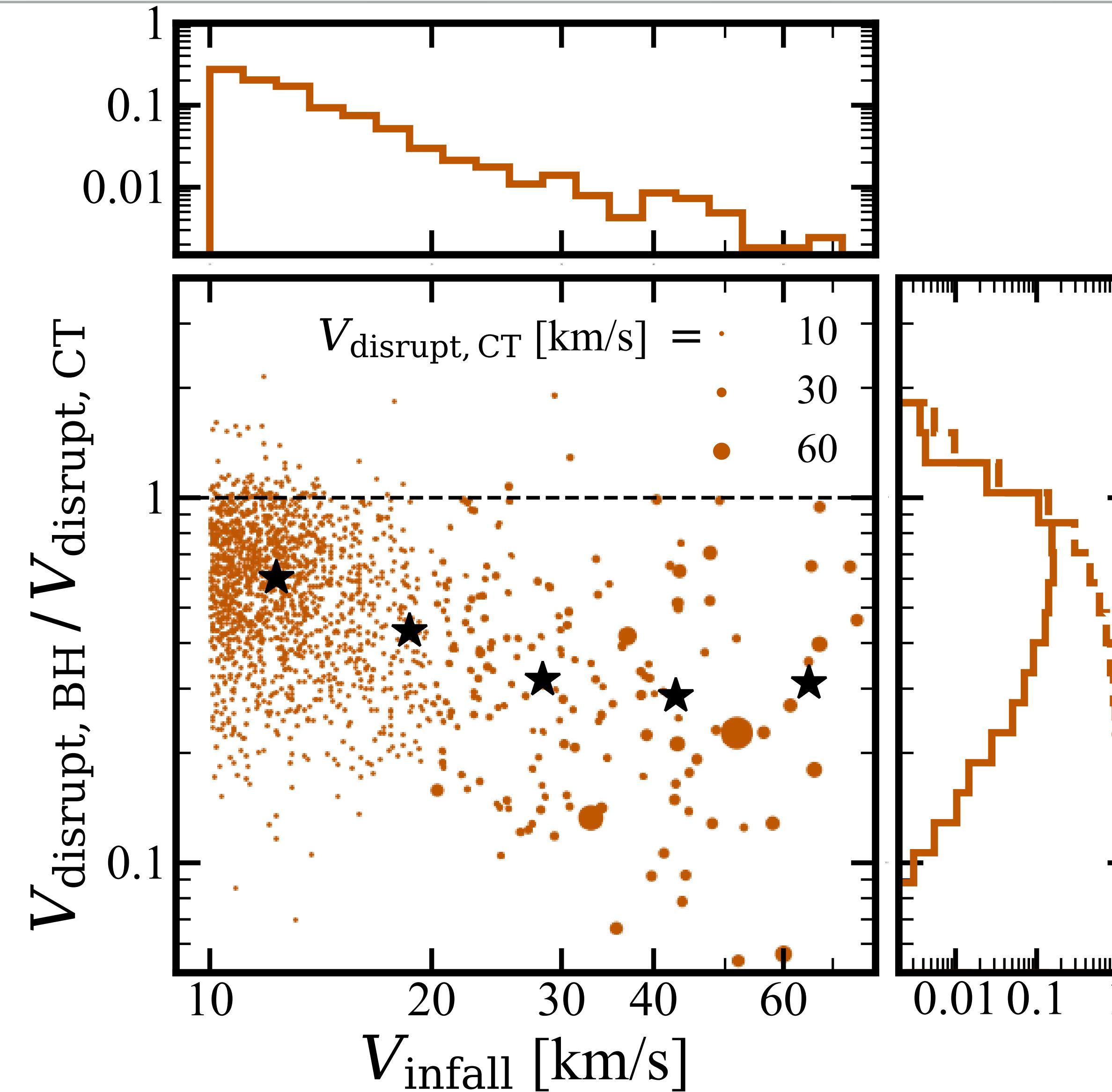
31



SUBHALO TRACKING IMPROVEMENTS

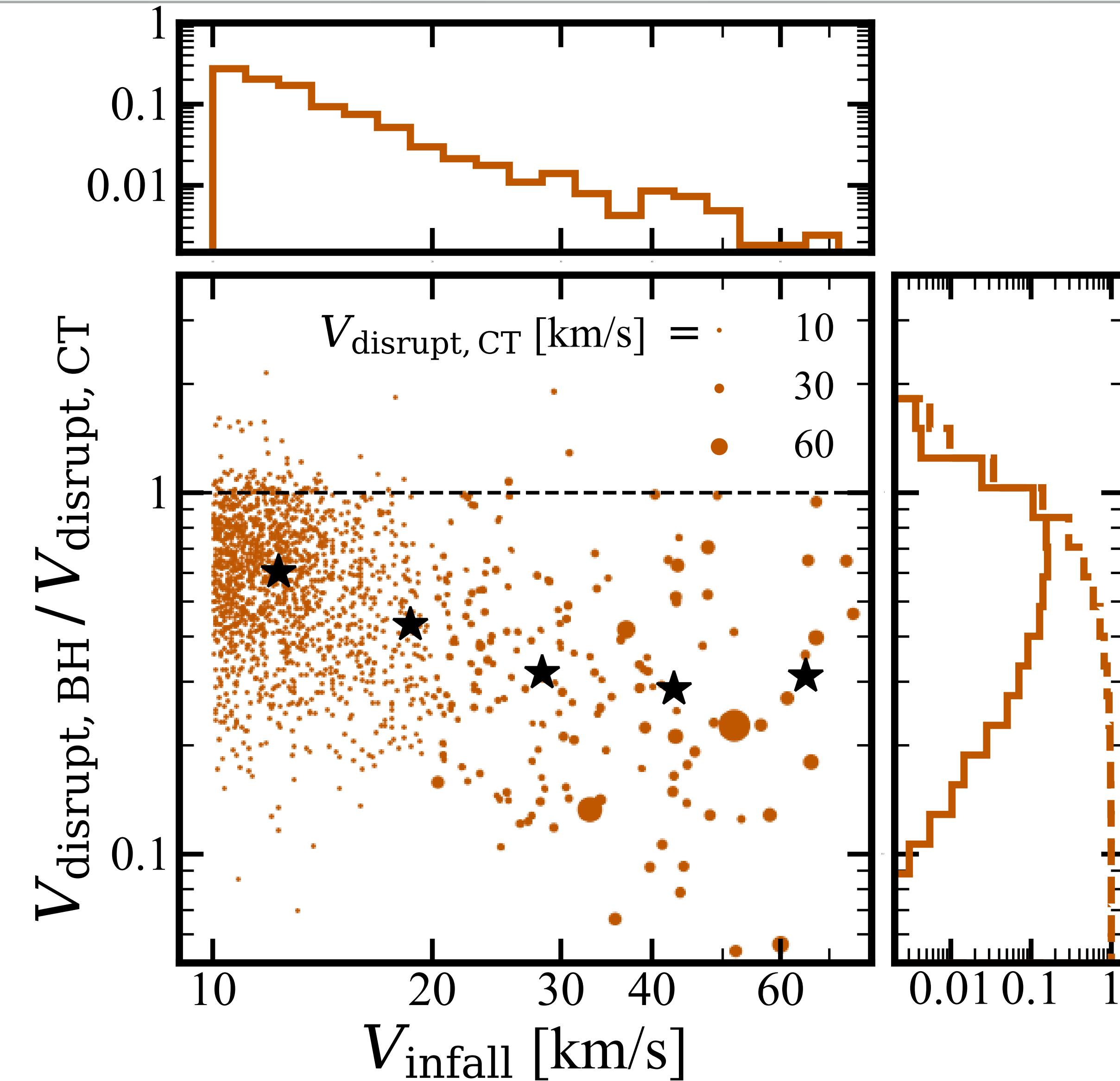


AT WHAT MASS ARE THEY DISRUPTING?



SUBHALO TRACKING IMPROVEMENTS

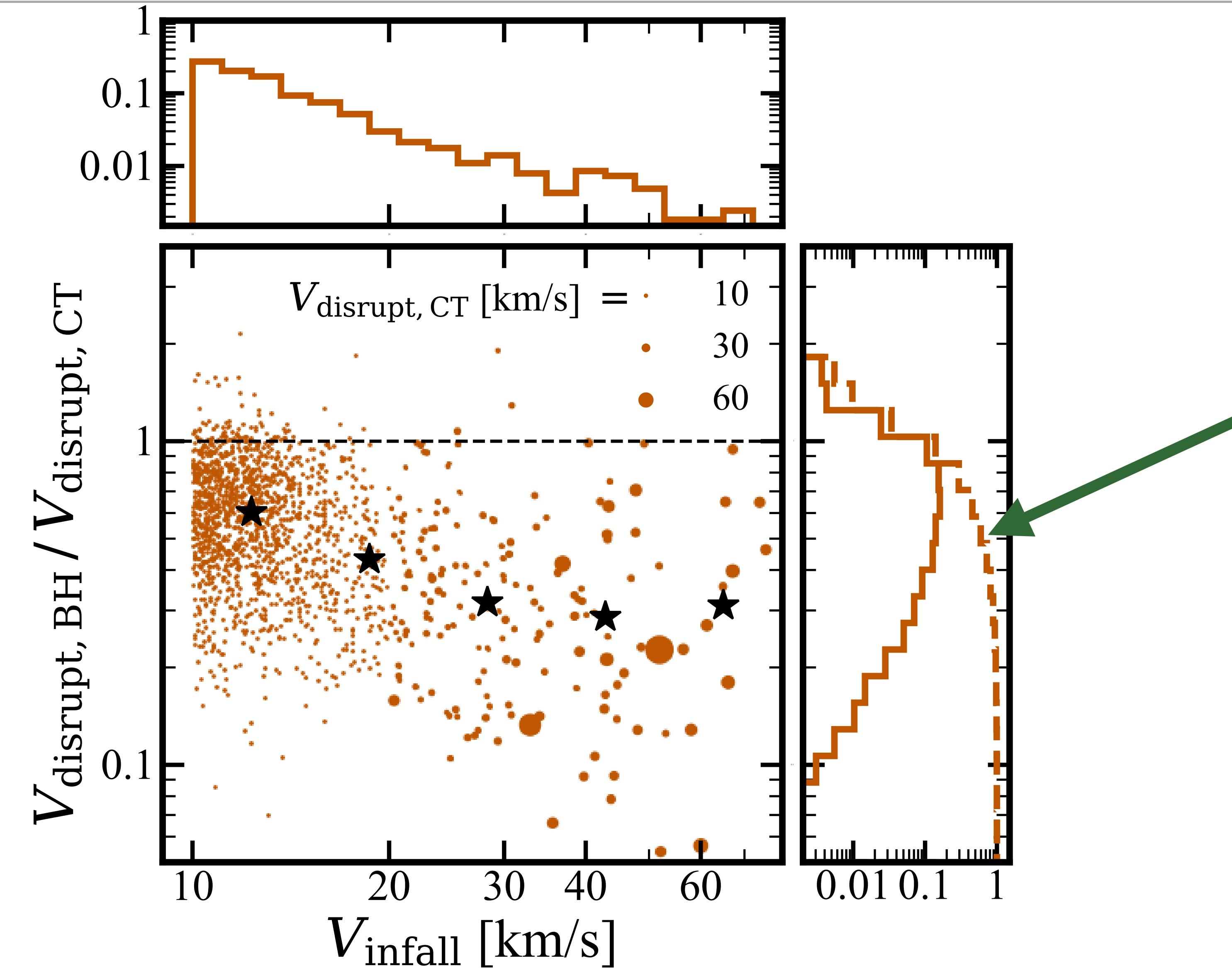
34



Smaller V_{disrupt} in
almost all cases

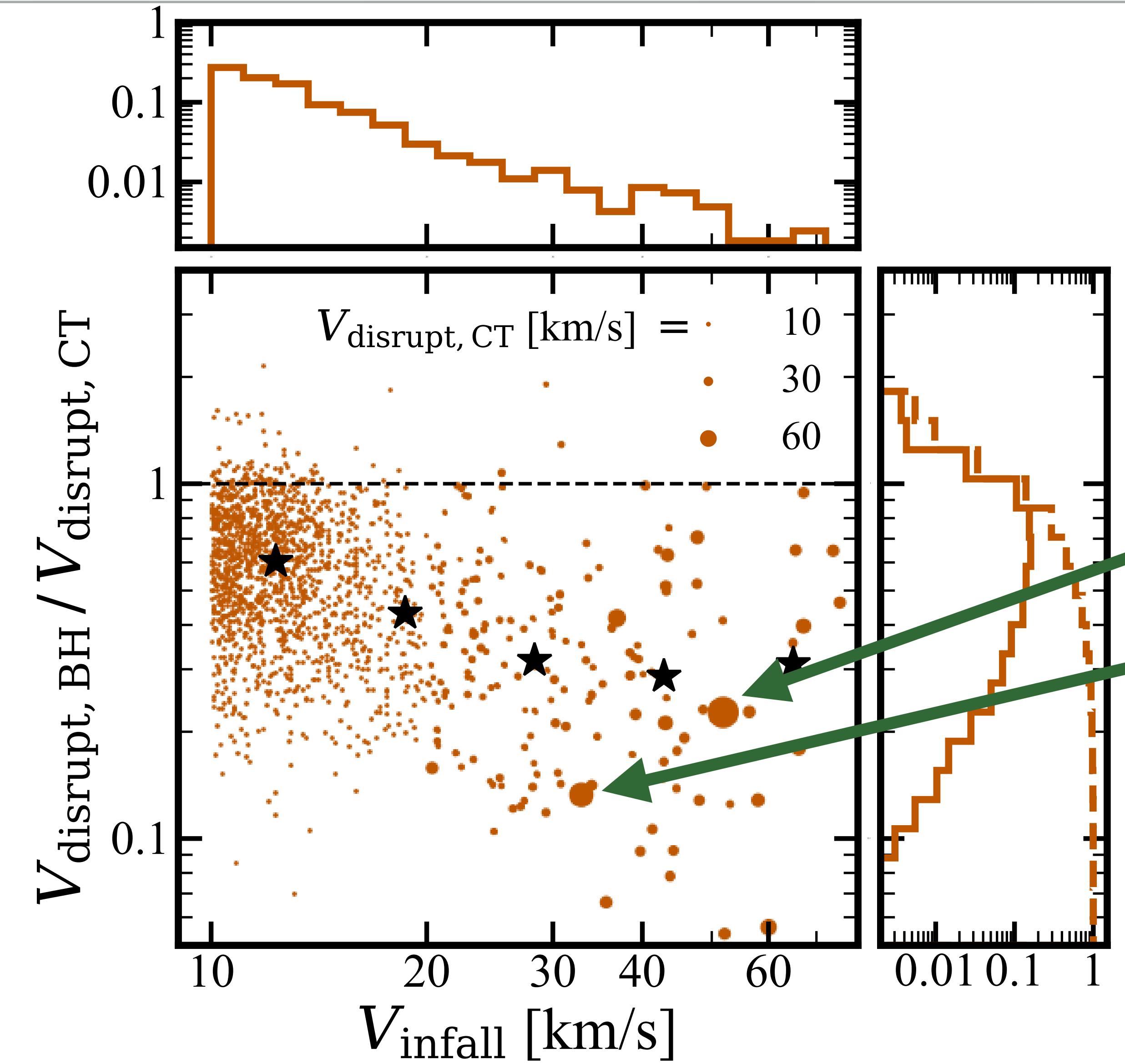
SUBHALO TRACKING IMPROVEMENTS

35



SUBHALO TRACKING IMPROVEMENTS

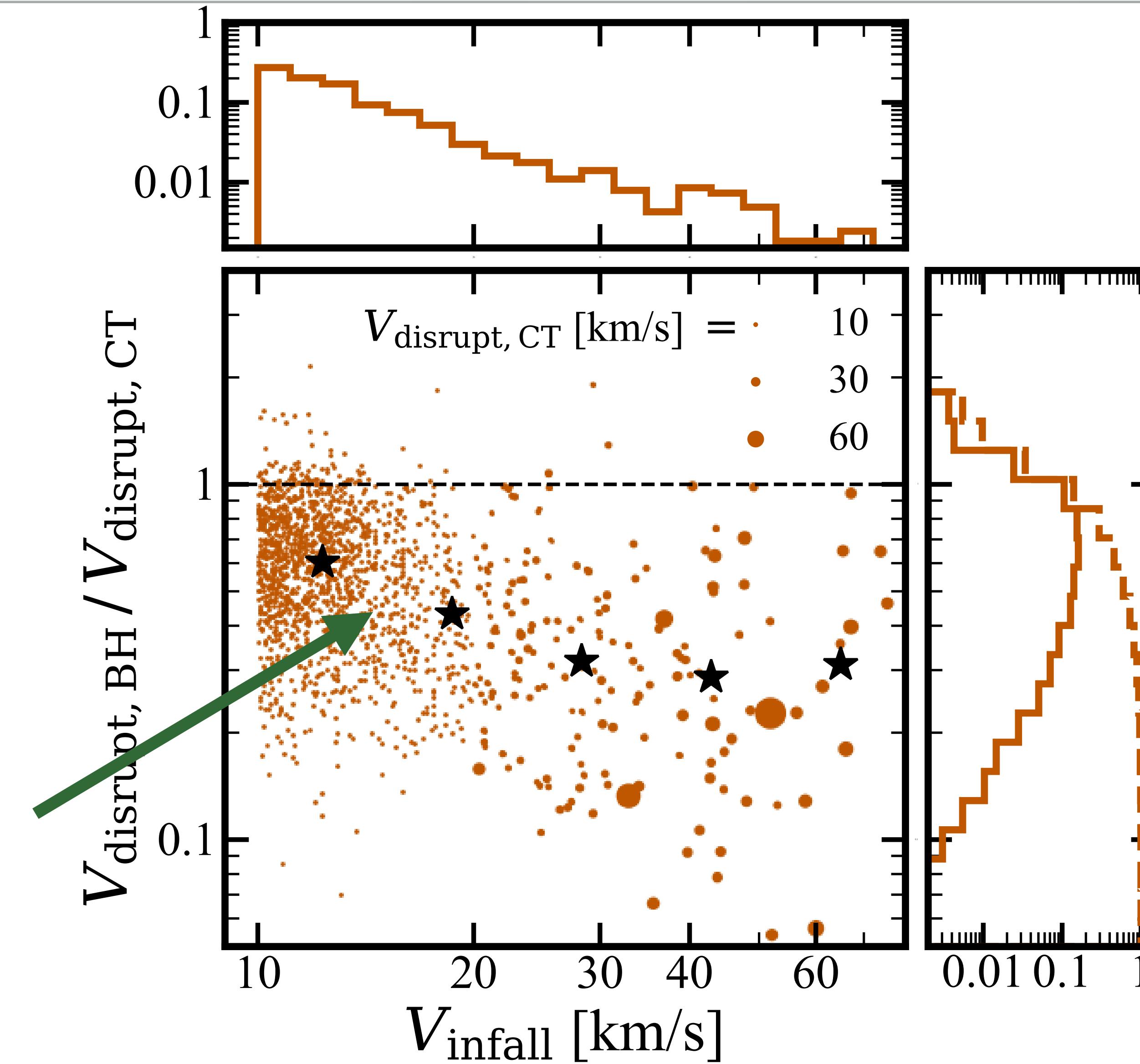
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SUBHALO TRACKING IMPROVEMENTS

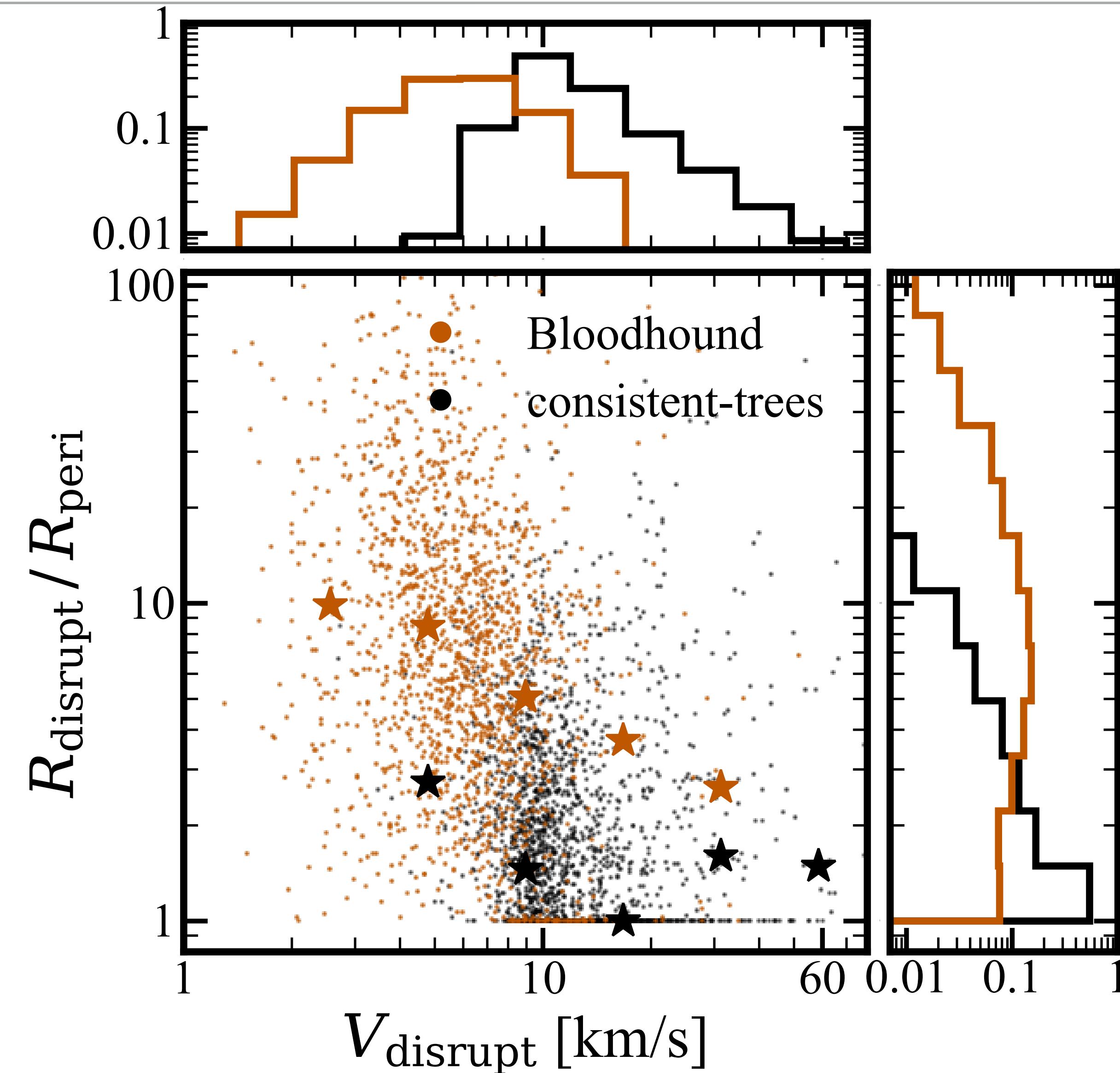
37

Bloodhound:
resolution
dependent



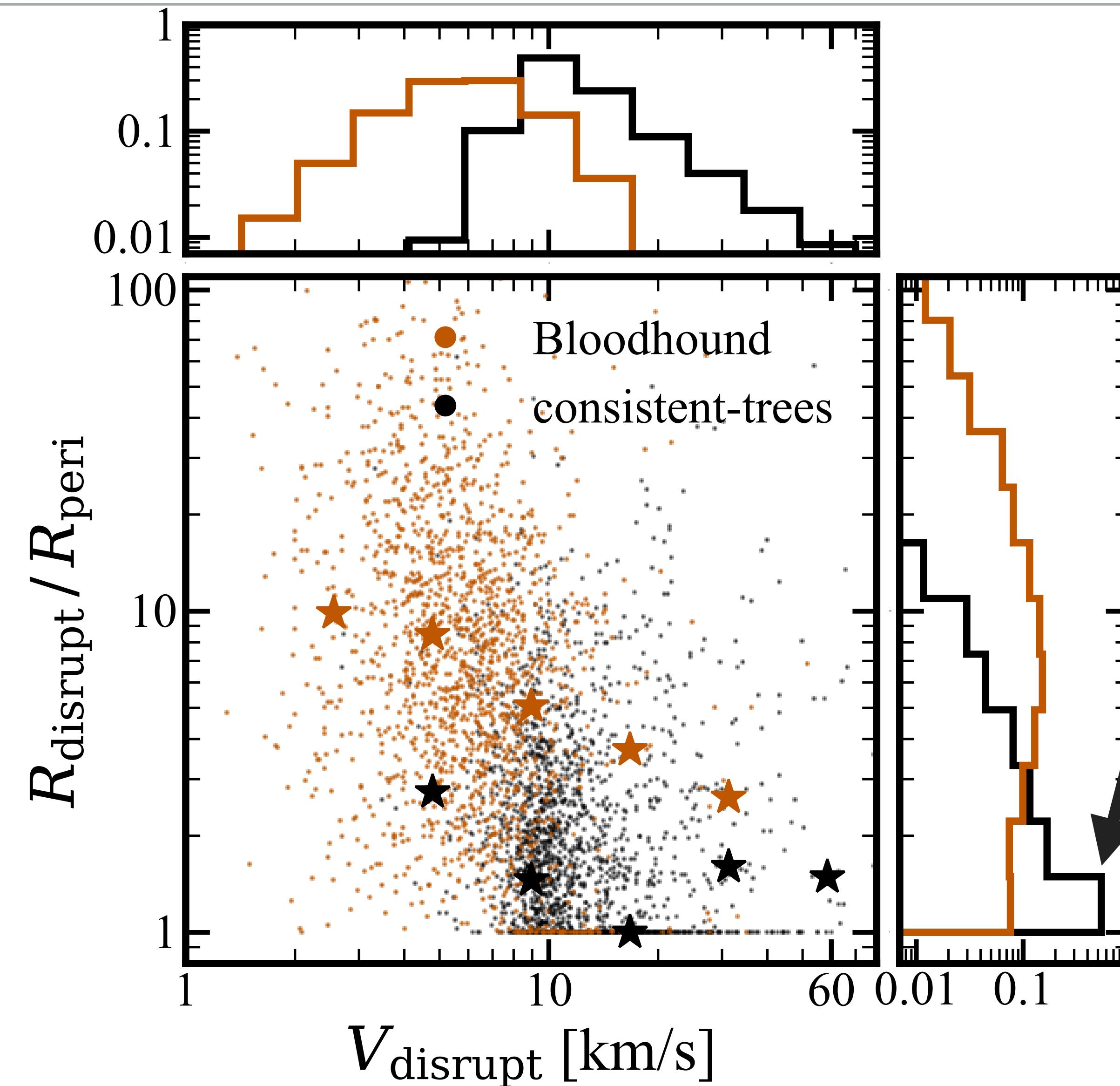
WHERE ARE THEY DISRUPTING?

38



WHERE ARE THEY DISRUPTING?

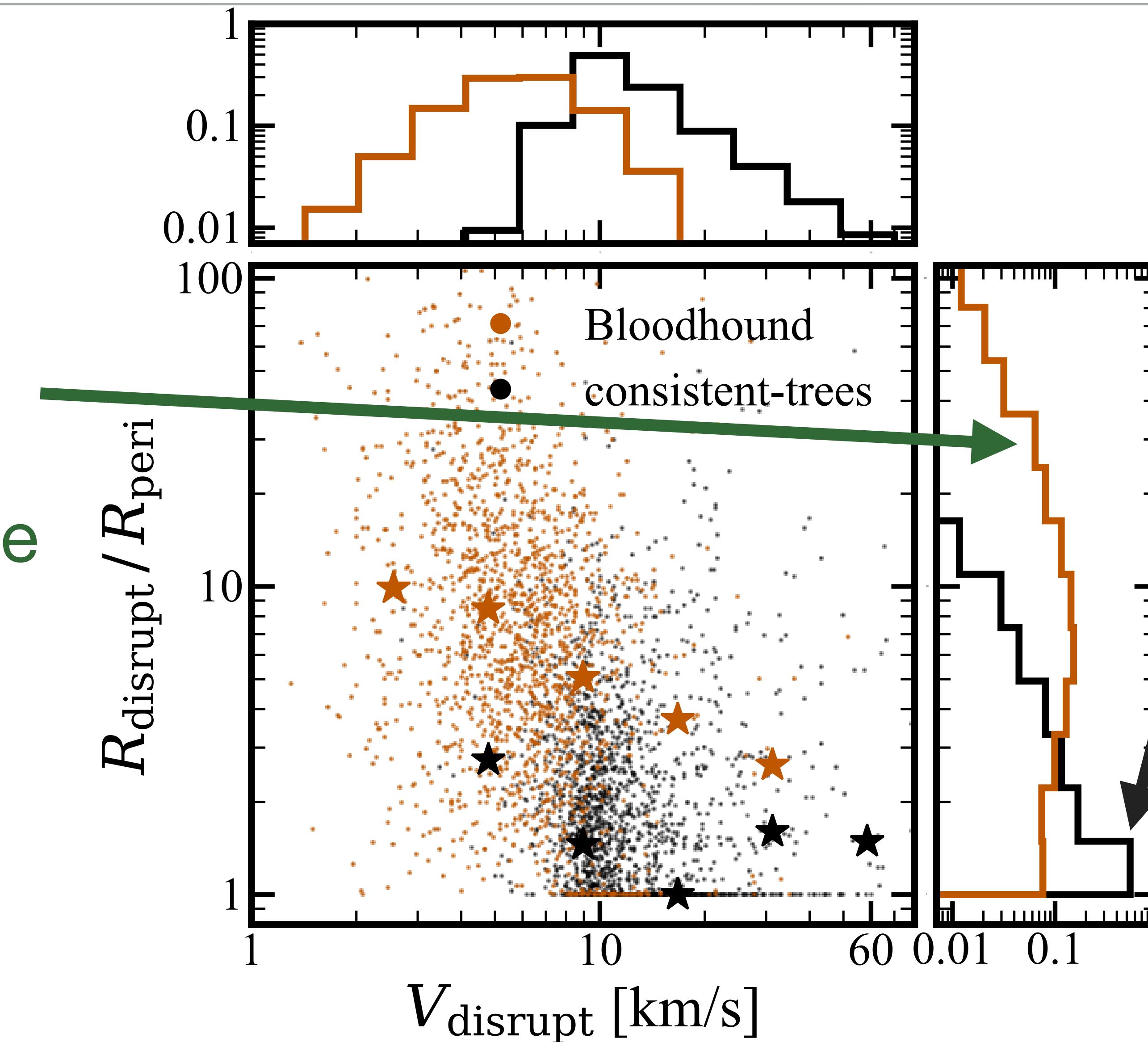
39



Standard method:
Most of them disrupt
at the pericenter

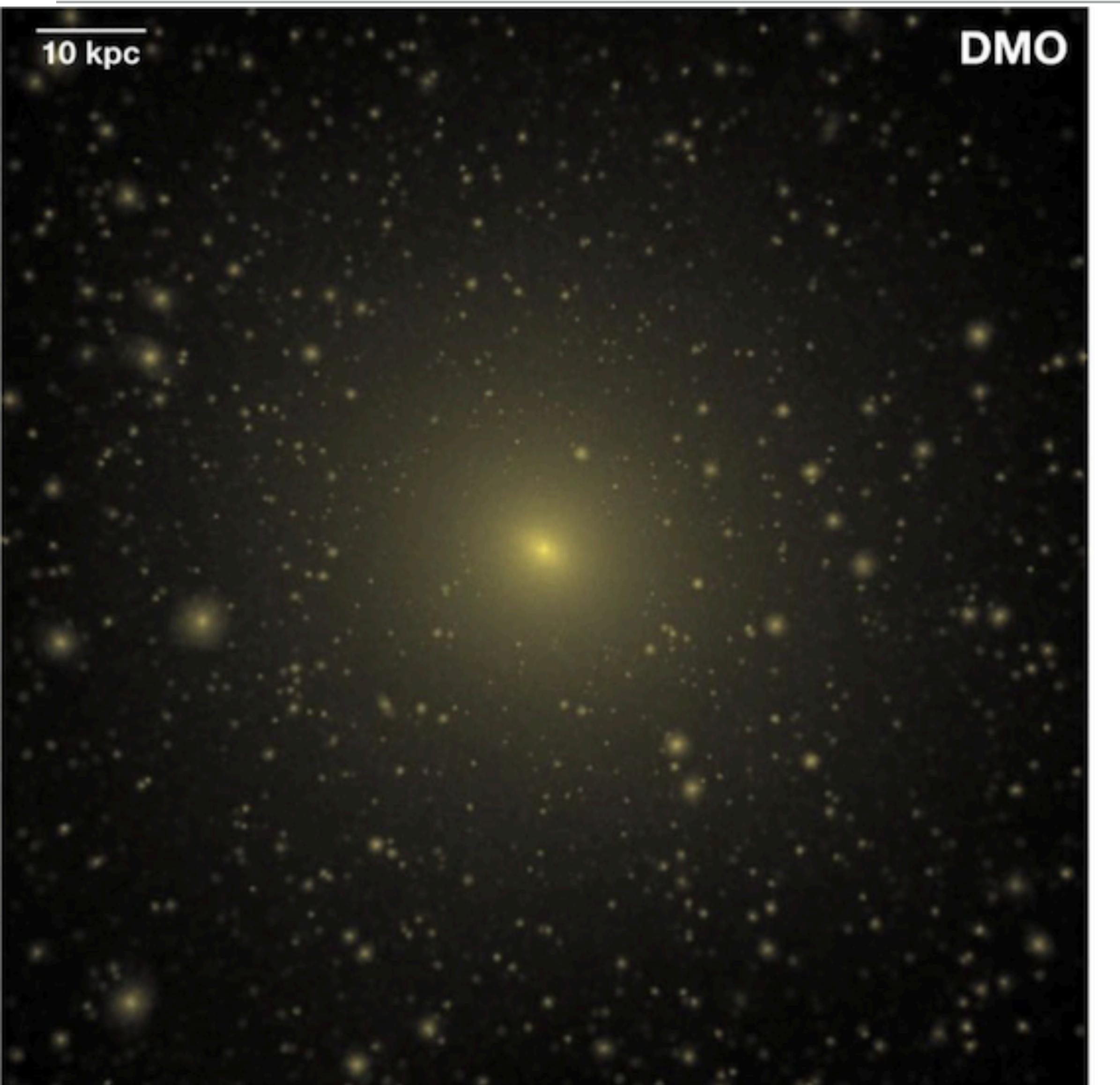
WHERE ARE THEY DISRUPTING?

Bloodhound:
A lot of them
survive past the
pericenter

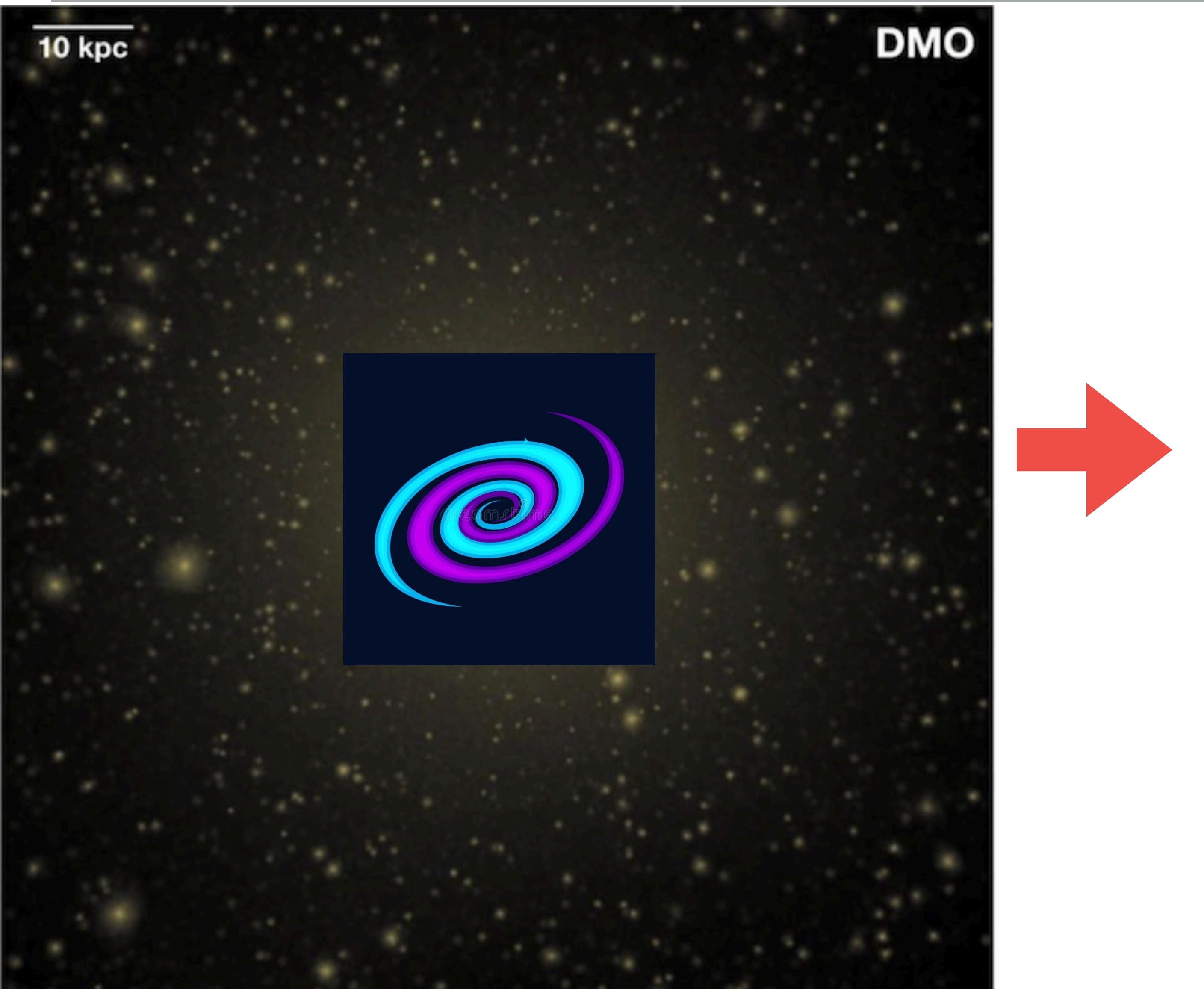


Standard method:
Most of them disrupt
at the pericenter

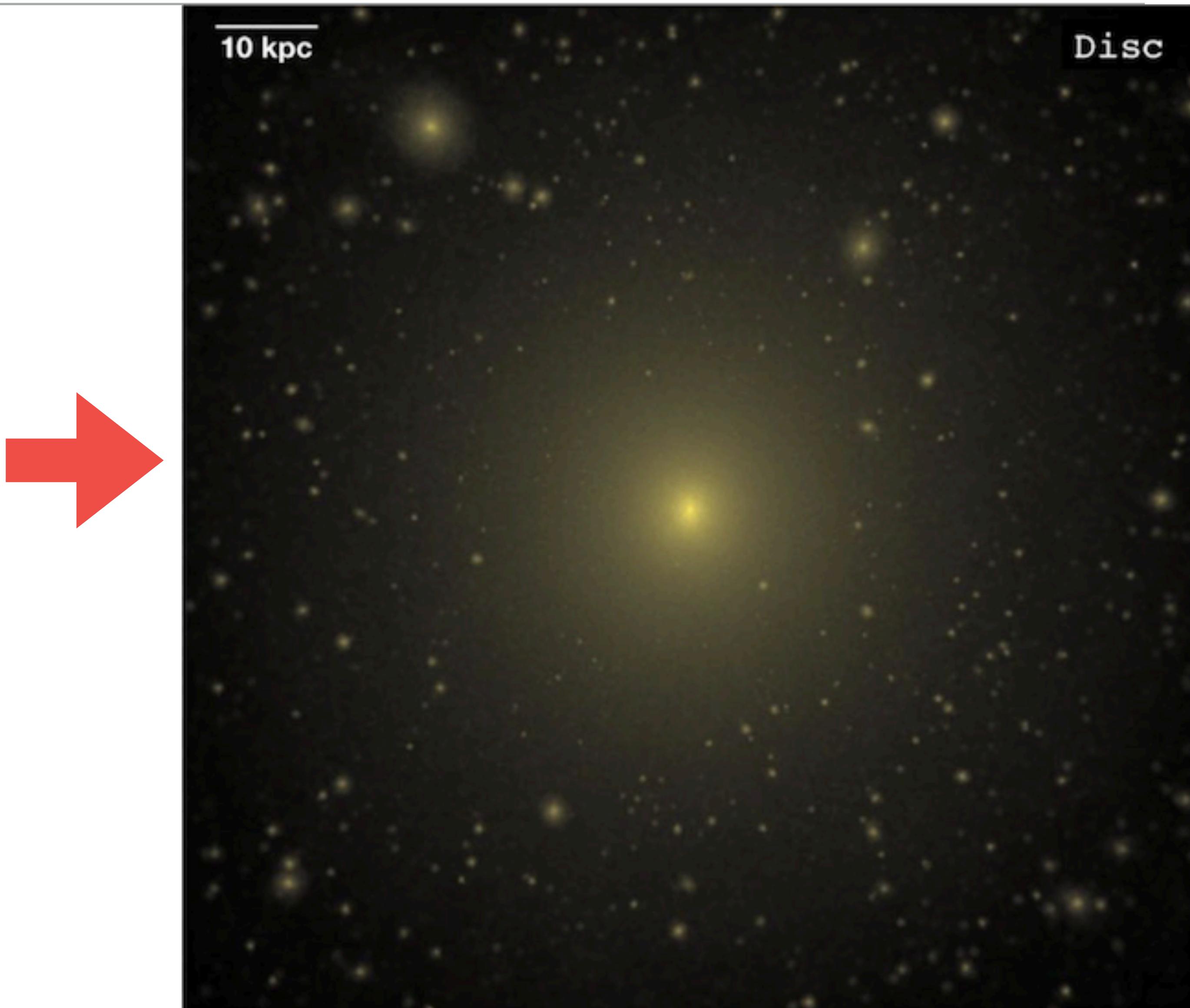
PHAT ELVIS: DMO VS. DISC



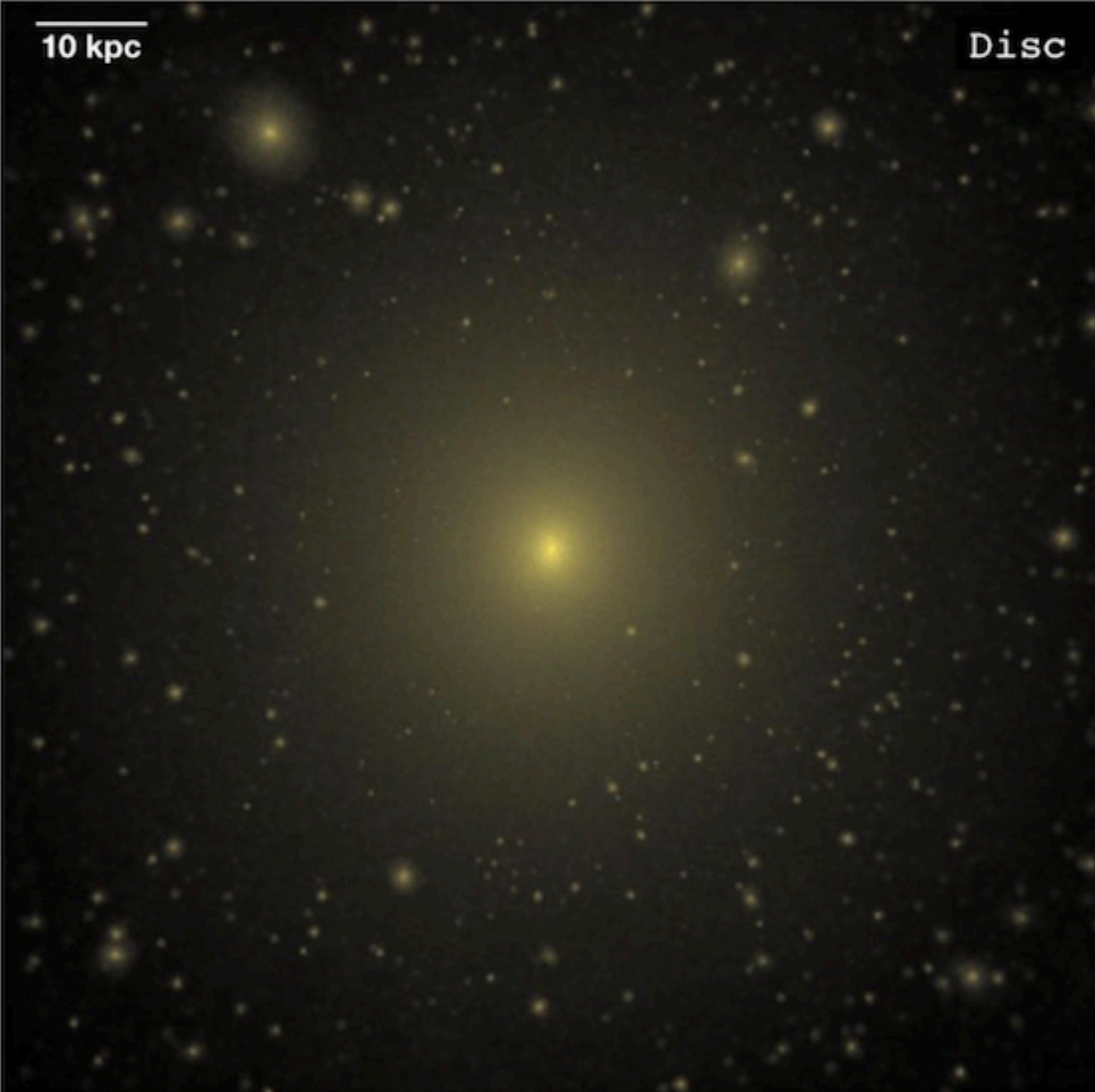
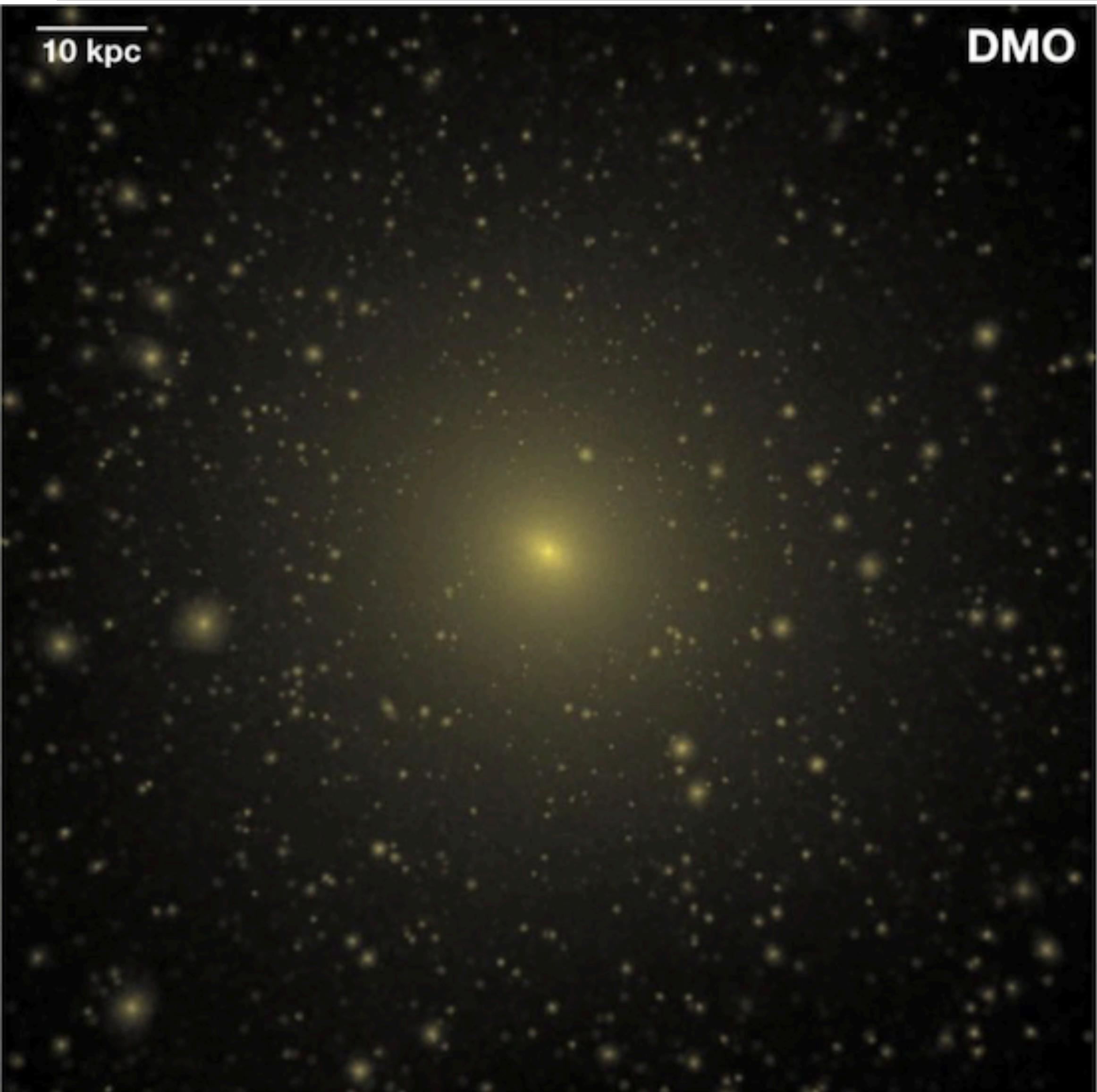
PHAT ELVIS: DMO VS. DISC



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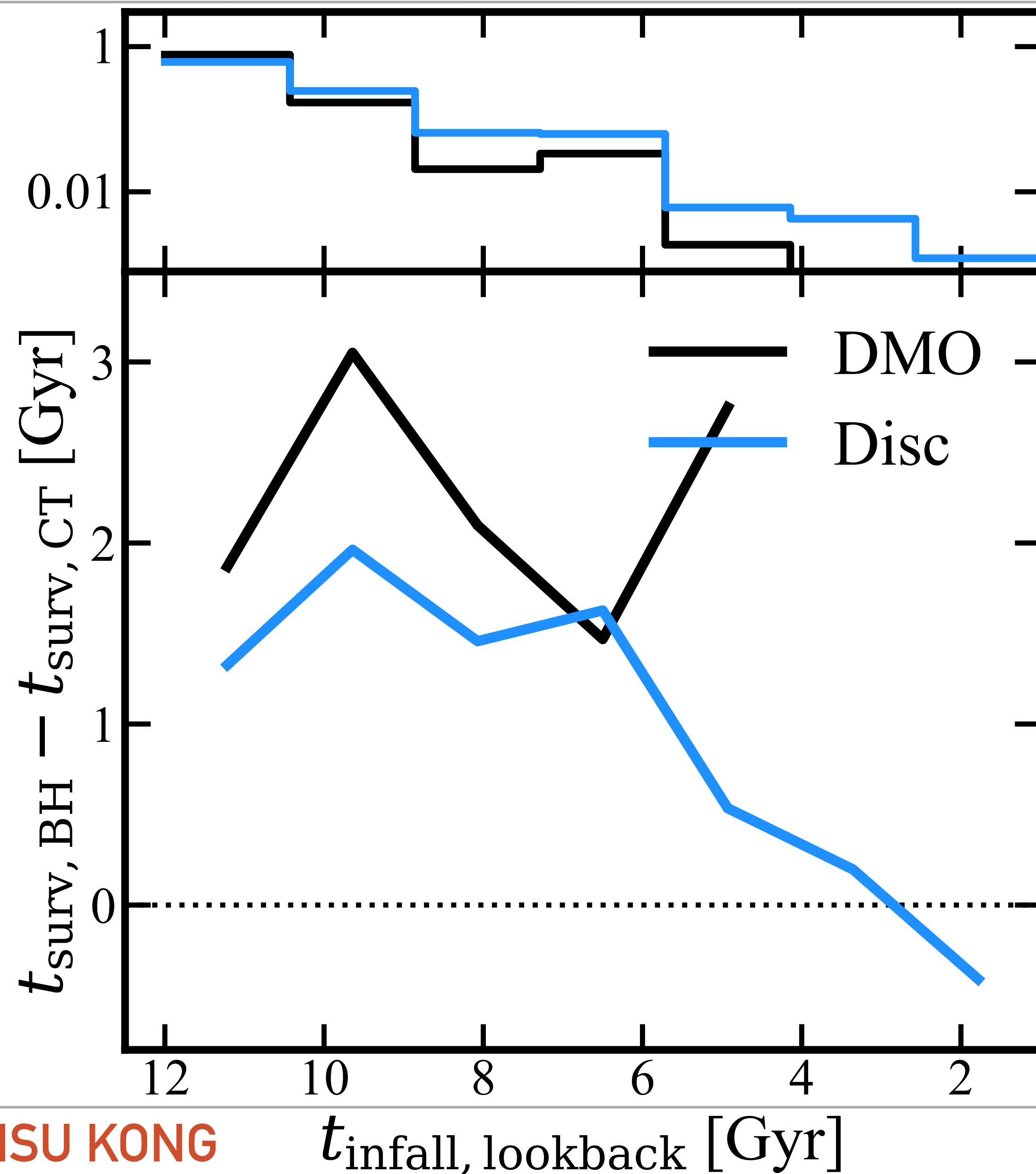


PHAT ELVIS: DMO VS. DISC



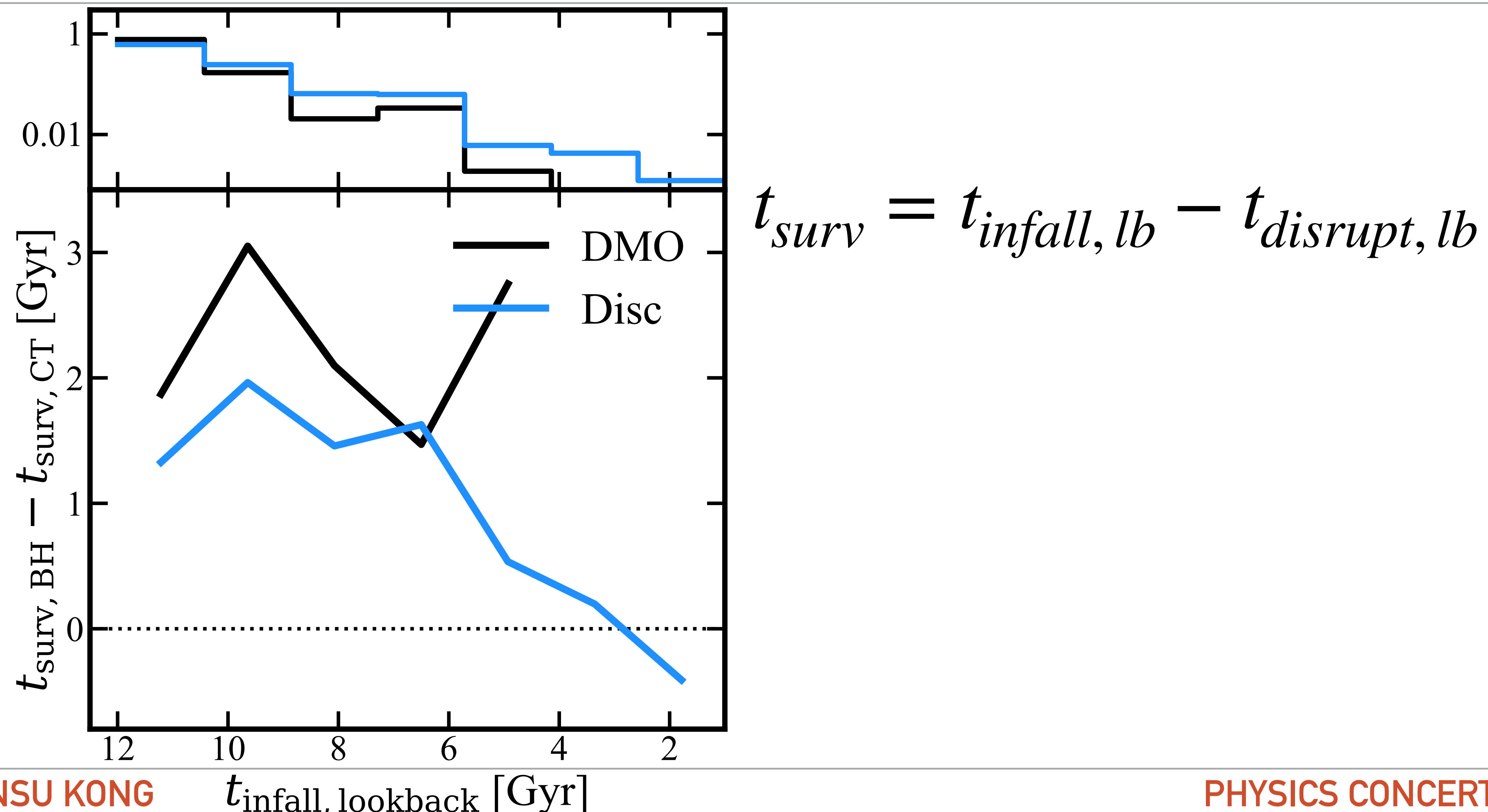
SUBHALO TRACKING TIME

45



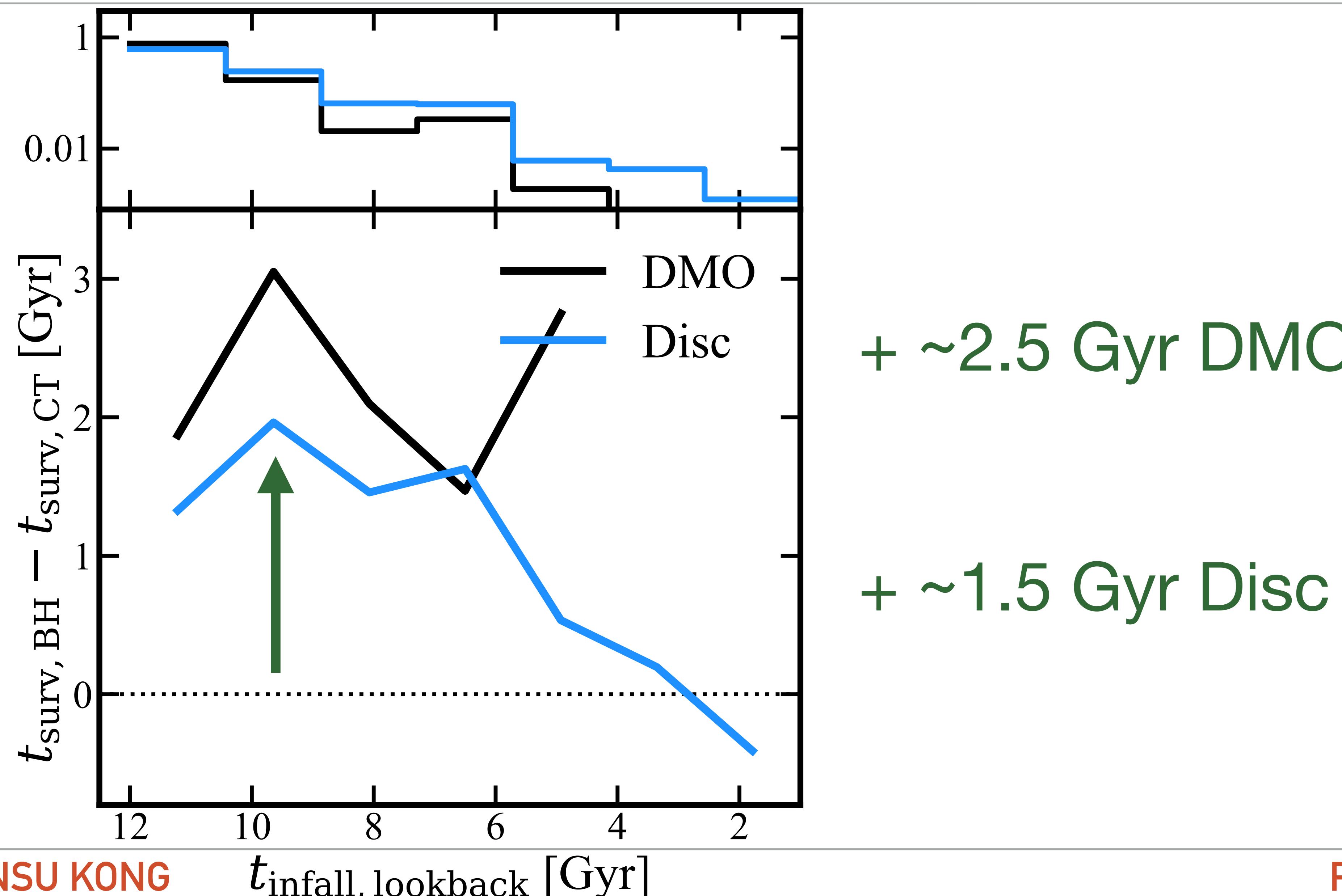
SUBHALO TRACKING TIME

46

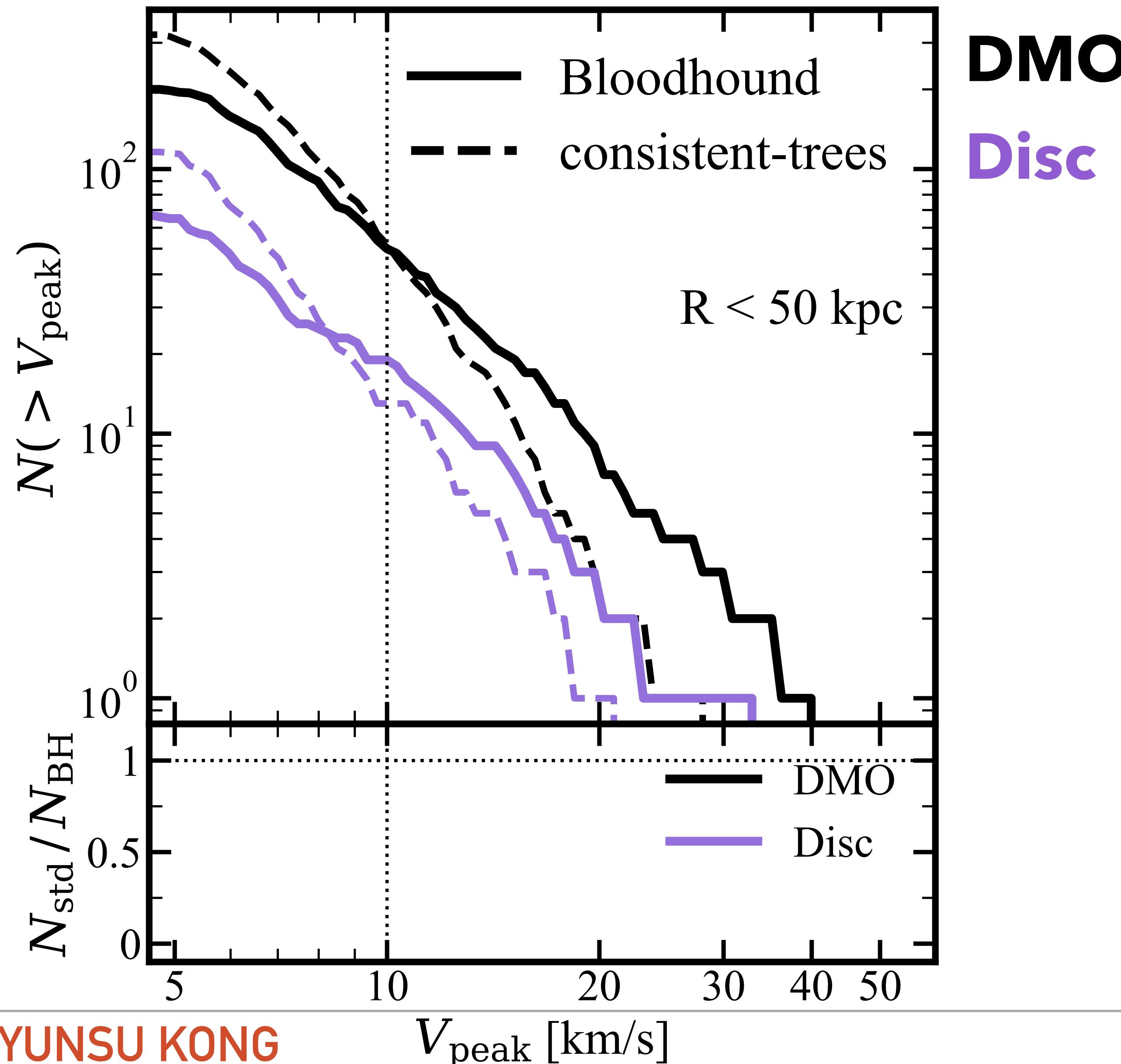


SUBHALO TRACKING TIME

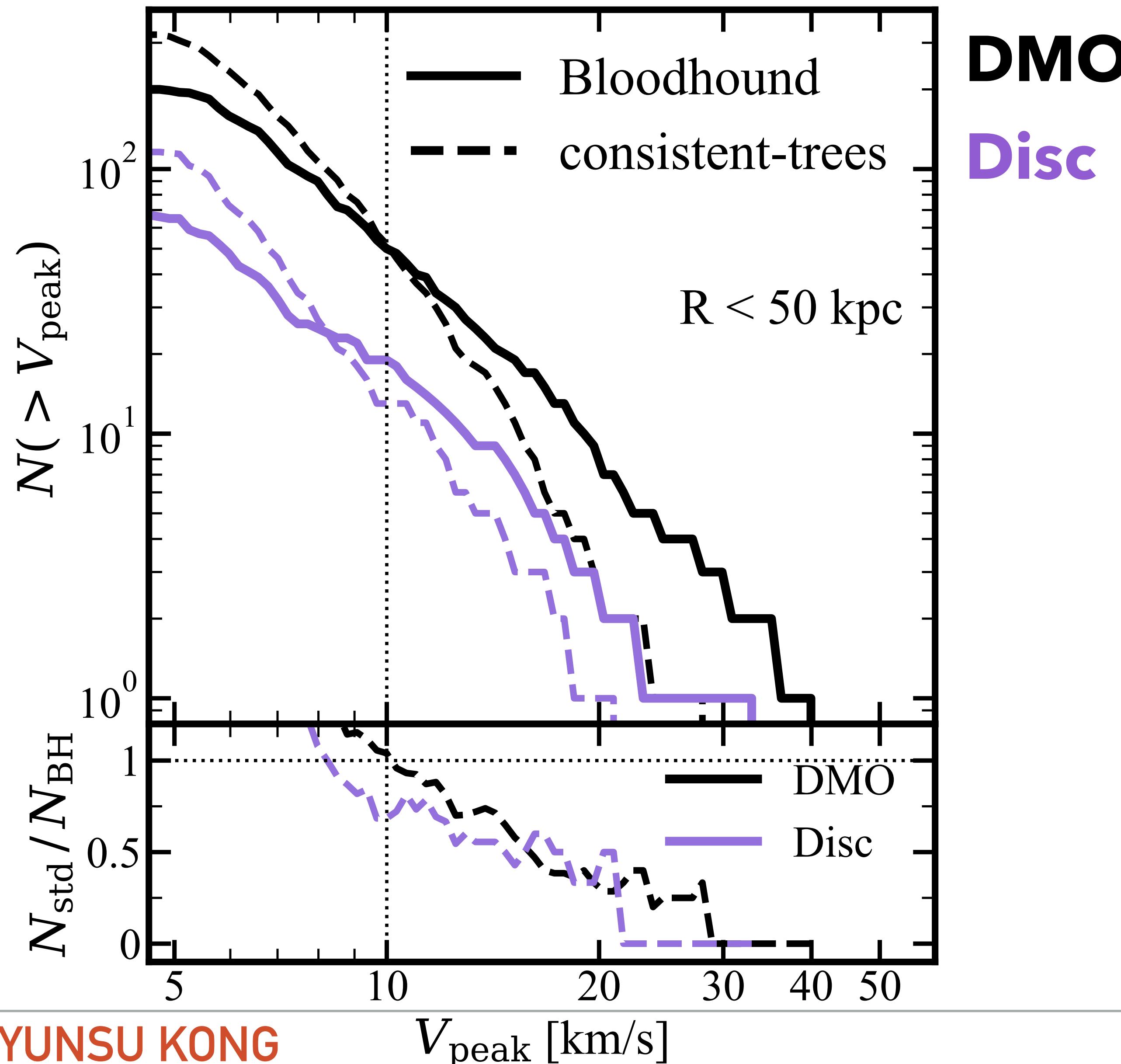
47



VELOCITY FUNCTIONS

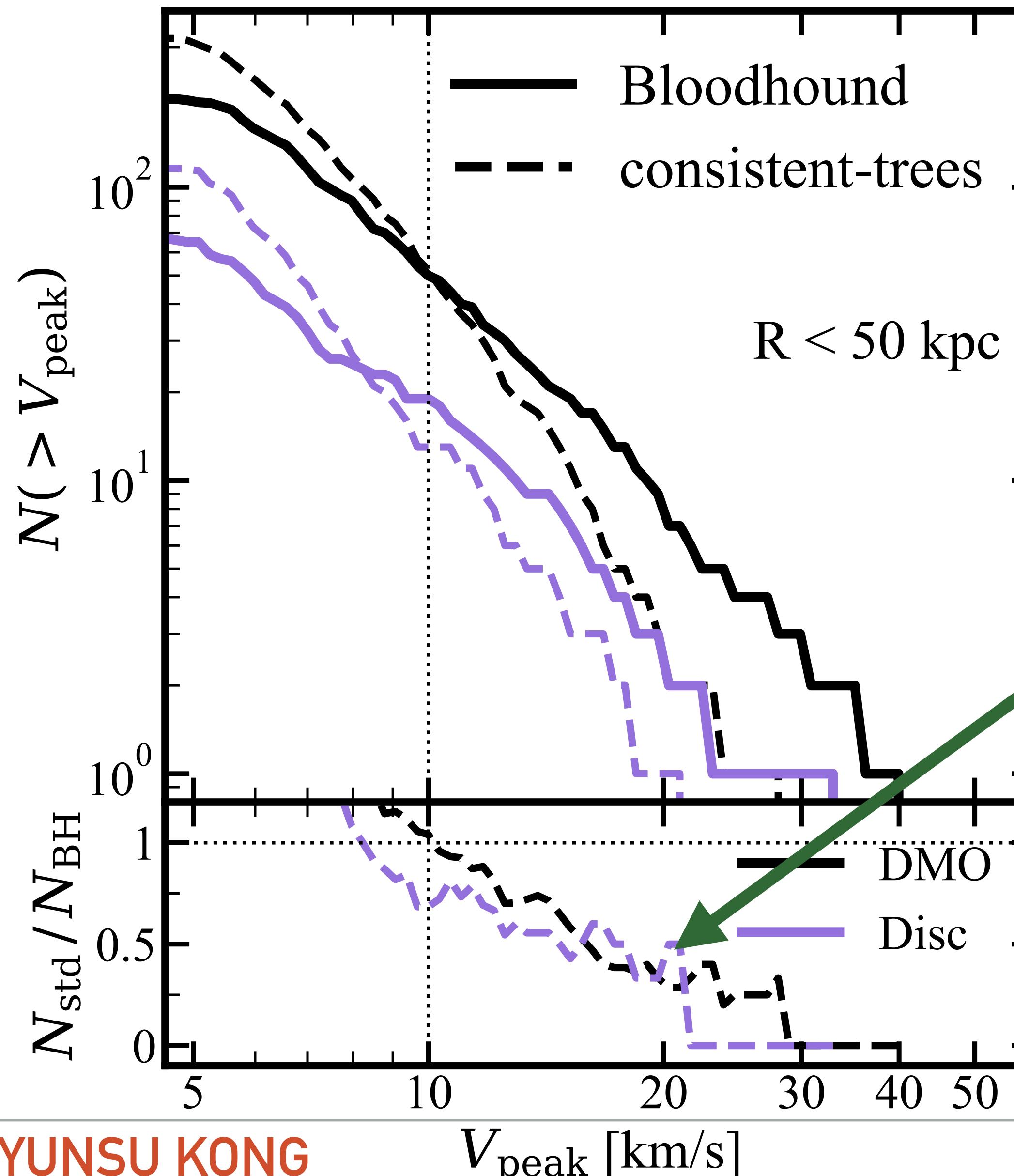
**DMO****Disc**

VELOCITY FUNCTIONS



VELOCITY FUNCTIONS

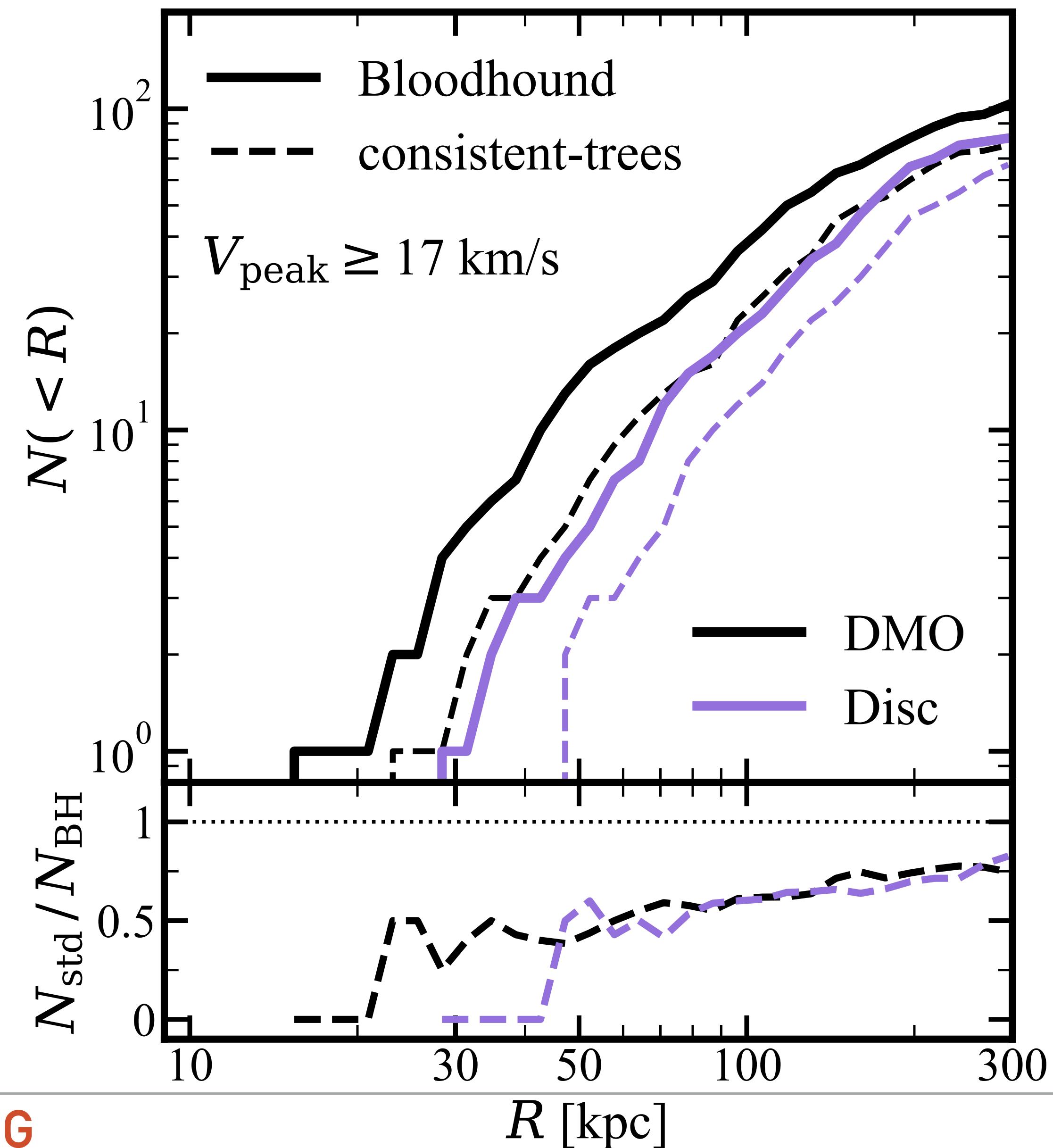
50

**DMO****Disc**

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

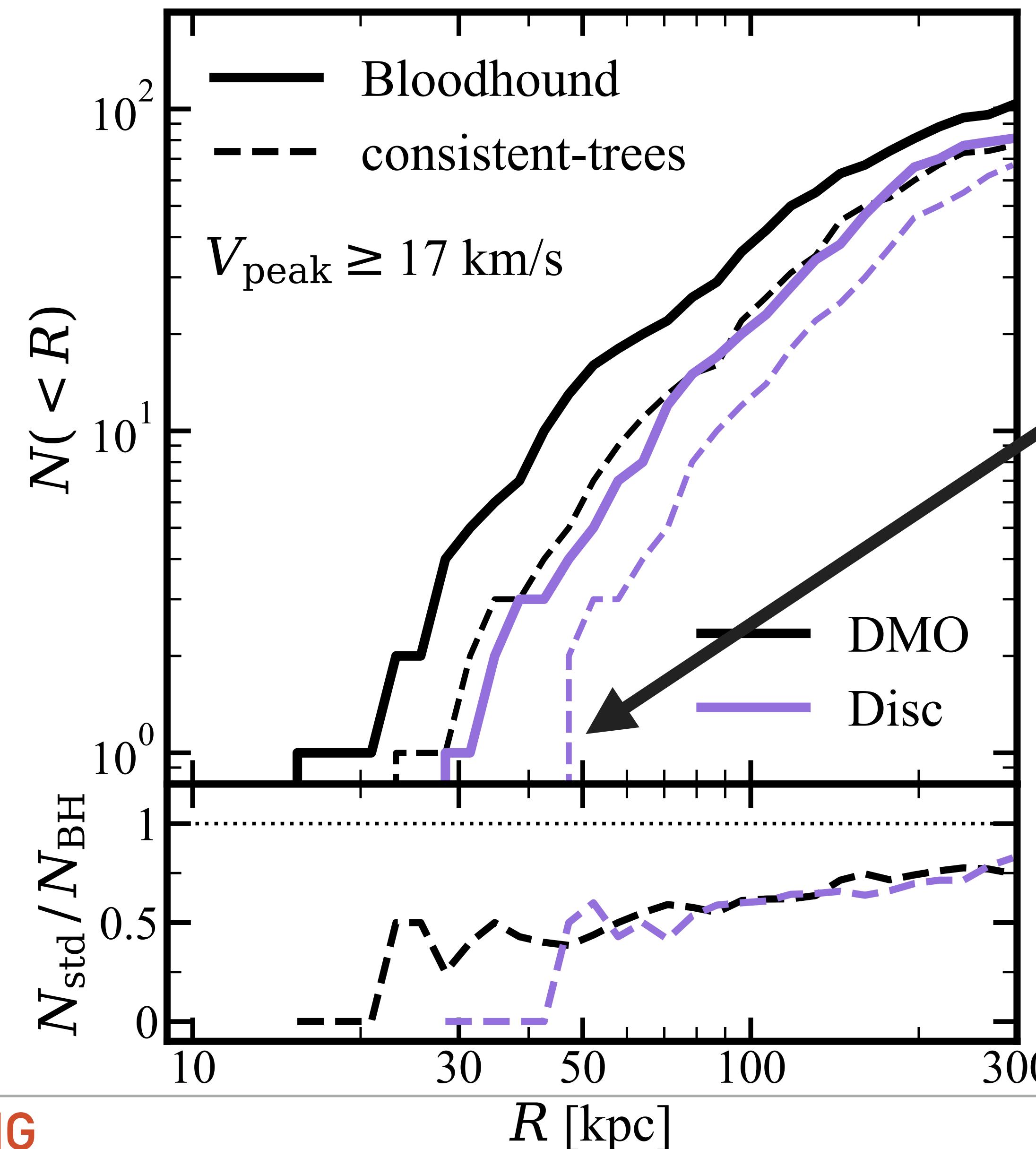
RADIAL DISTRIBUTIONS

51



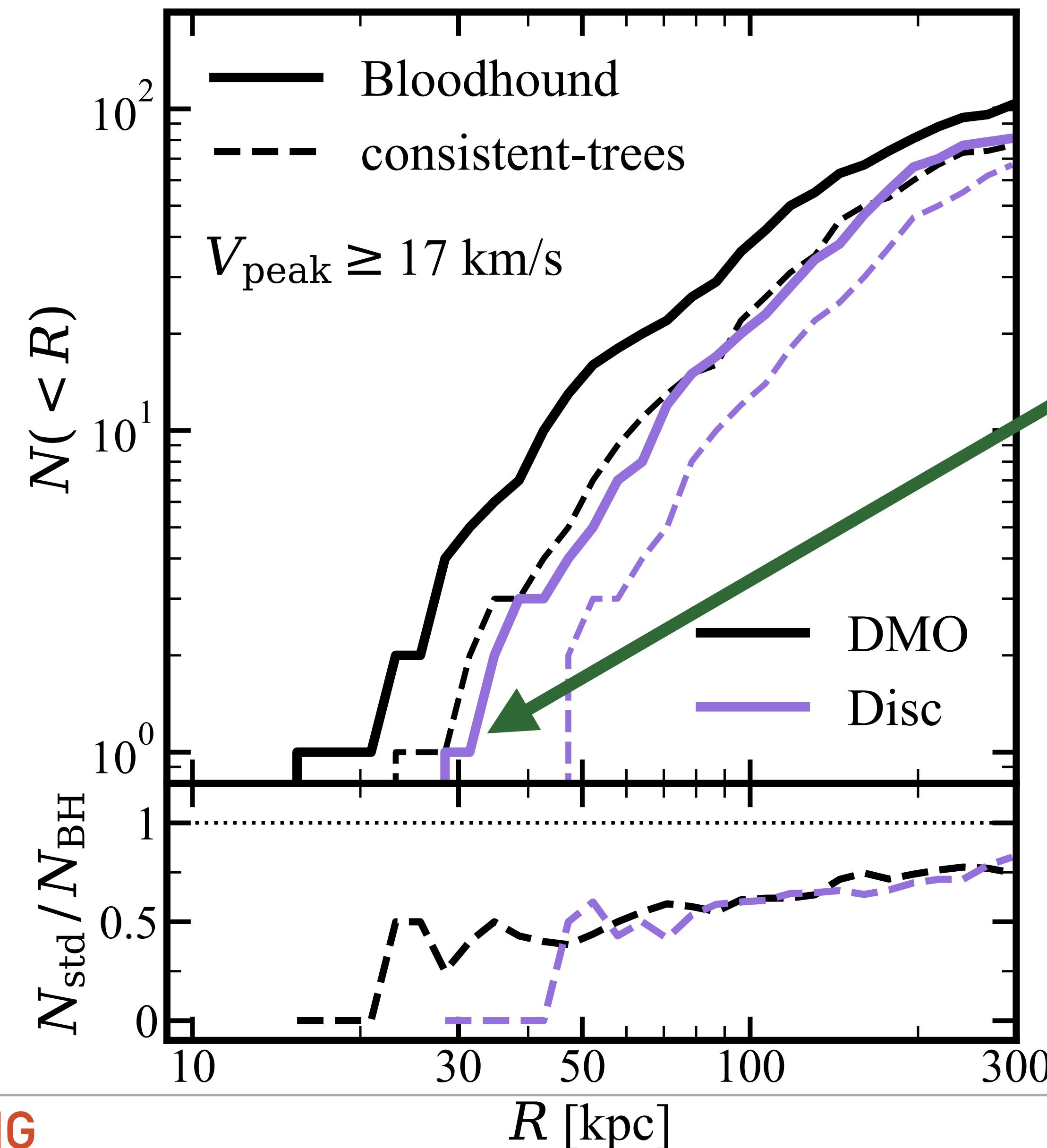
RADIAL DISTRIBUTIONS

52



RADIAL DISTRIBUTIONS

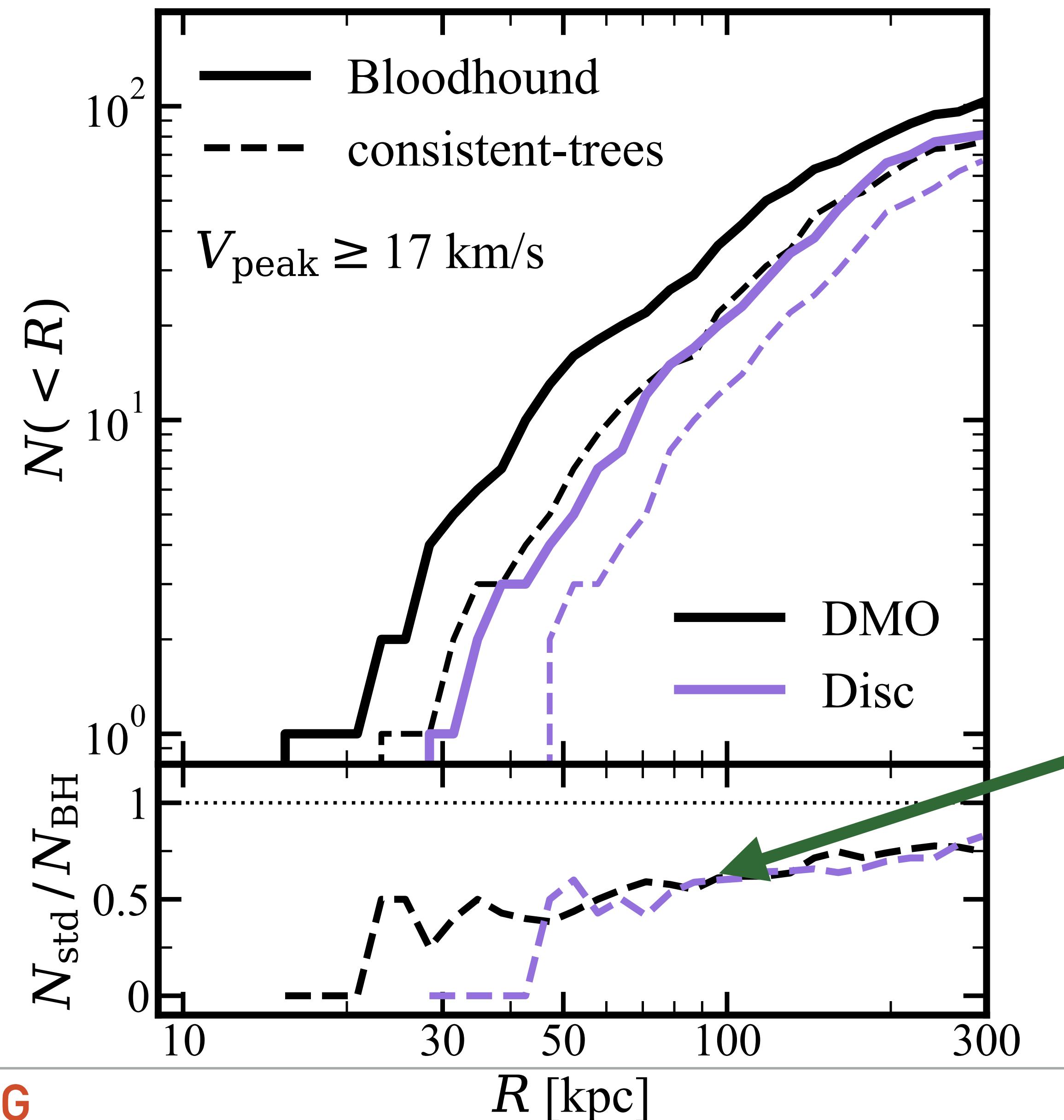
53



Bloodhound:
As close as 30 kpc

RADIAL DISTRIBUTIONS

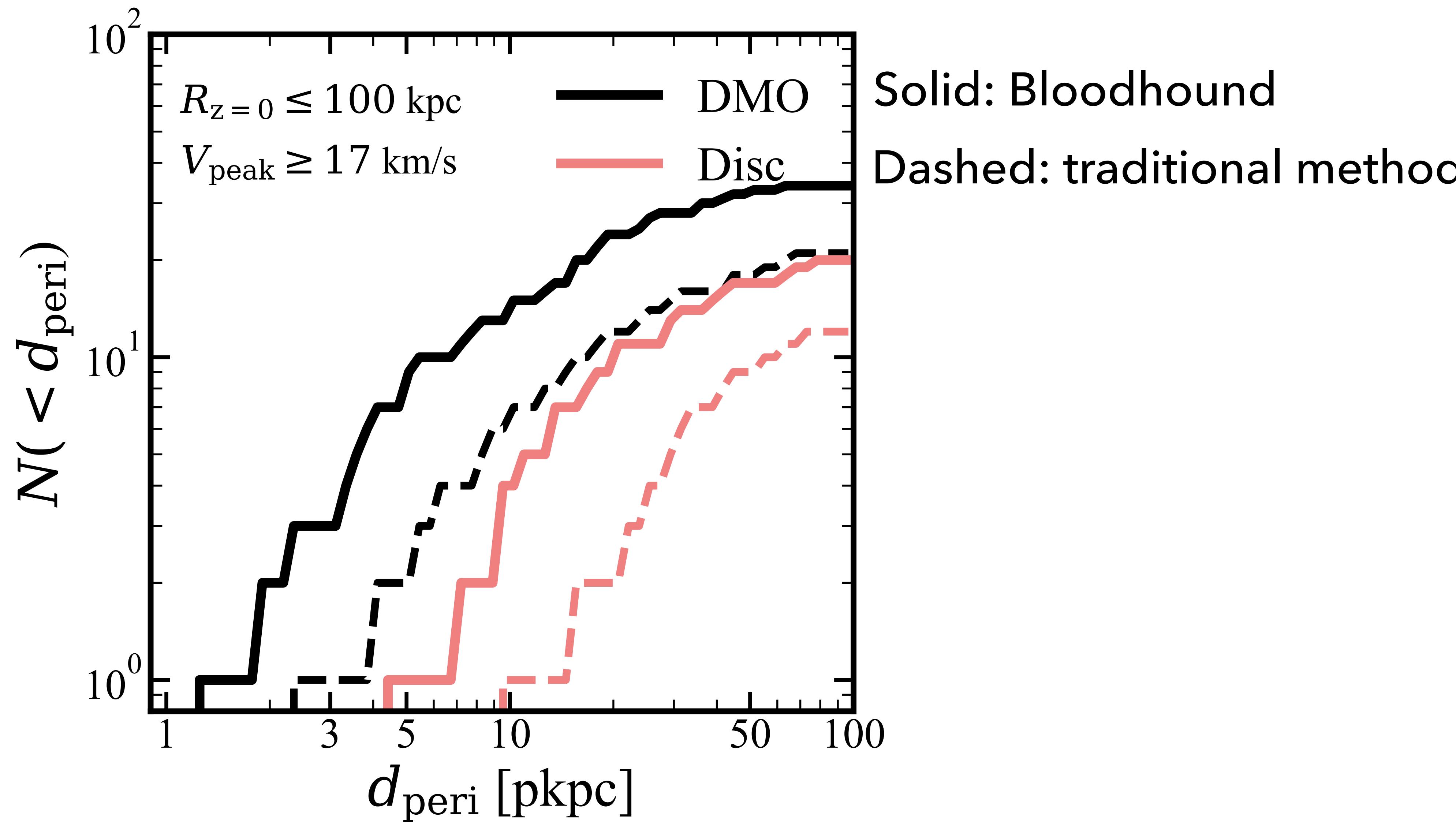
54



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

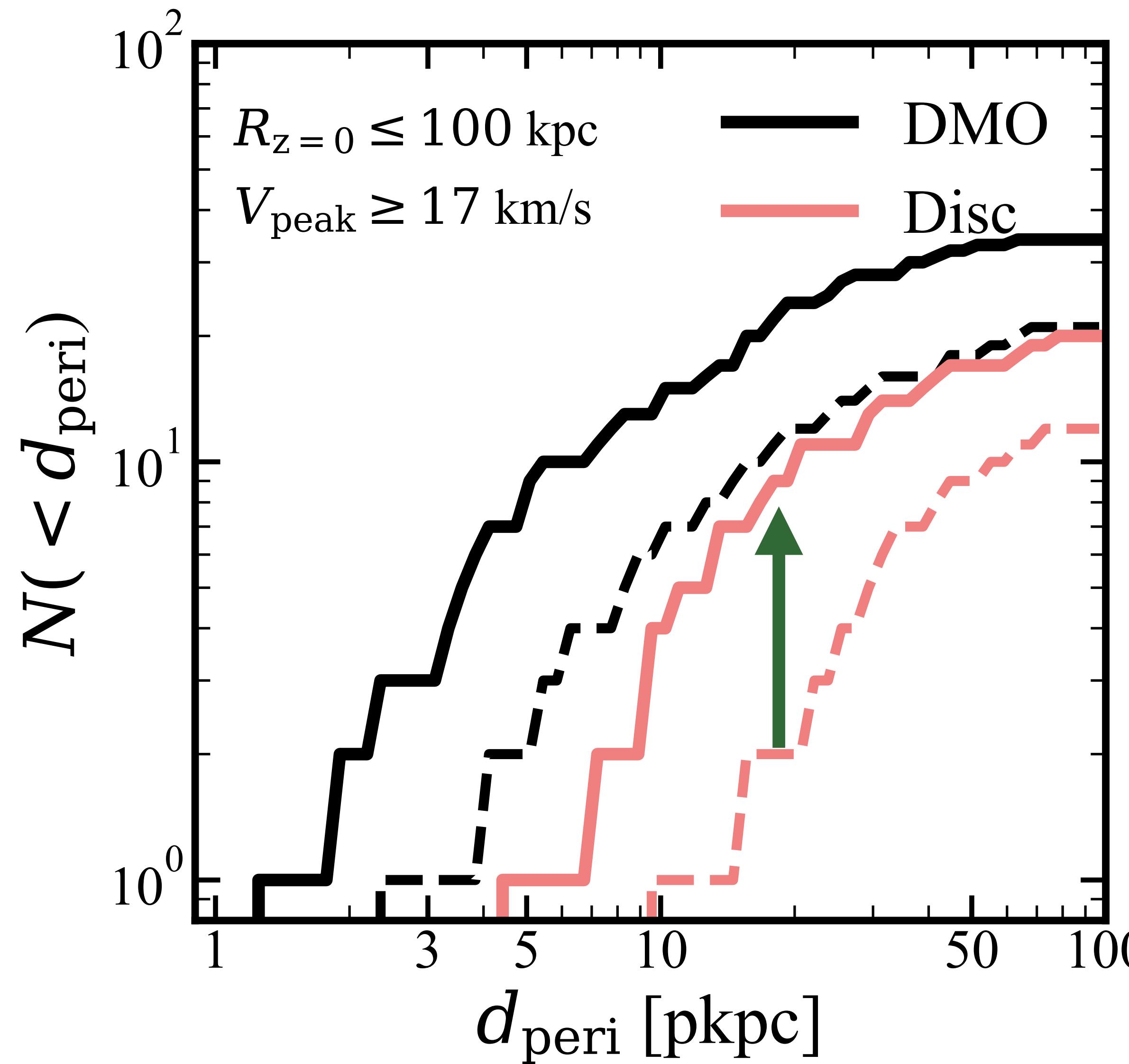
PERICENTER DISTRIBUTION

55



PERICENTER DISTRIBUTION

56

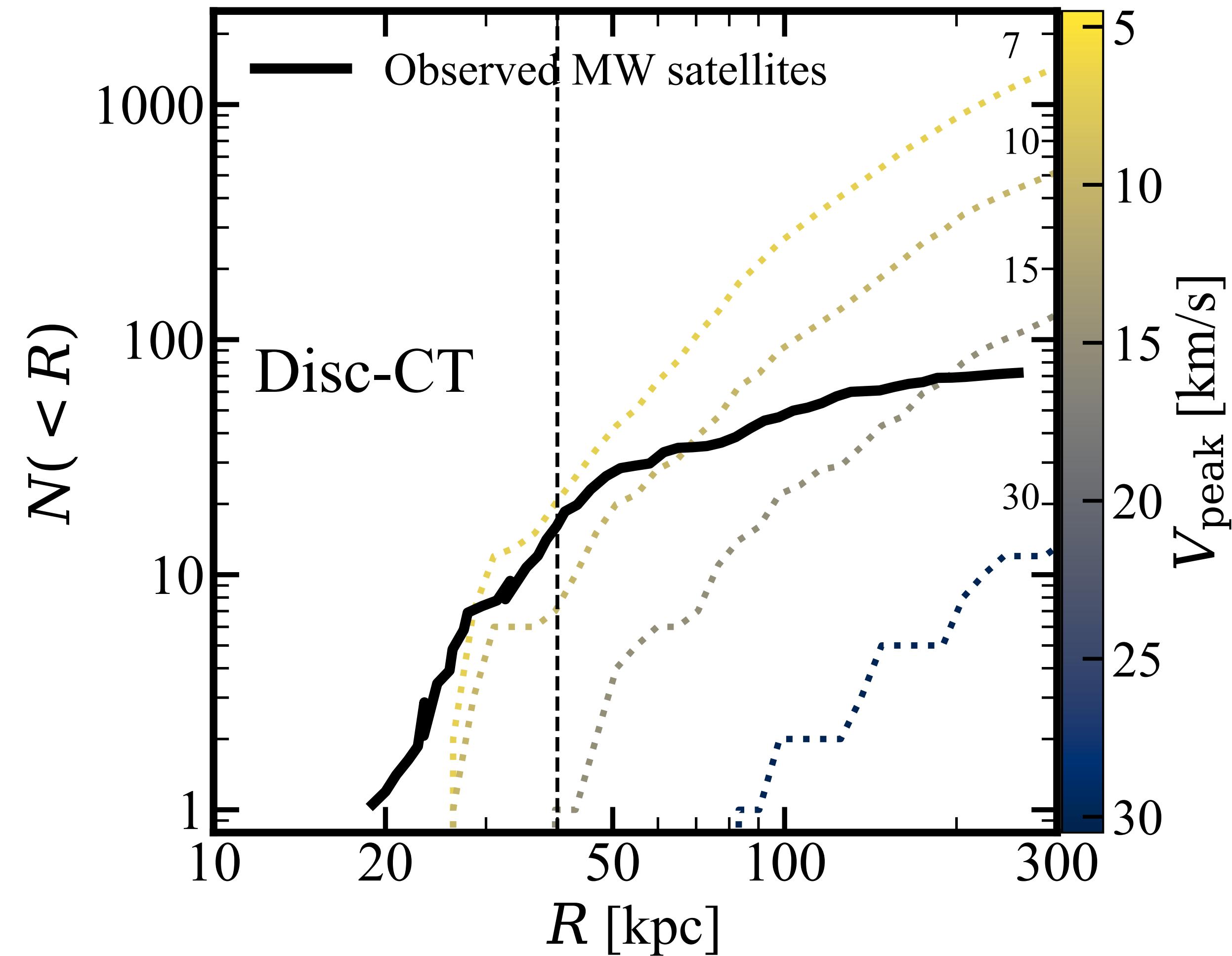


Solid: Bloodhound
Dashed: traditional method

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

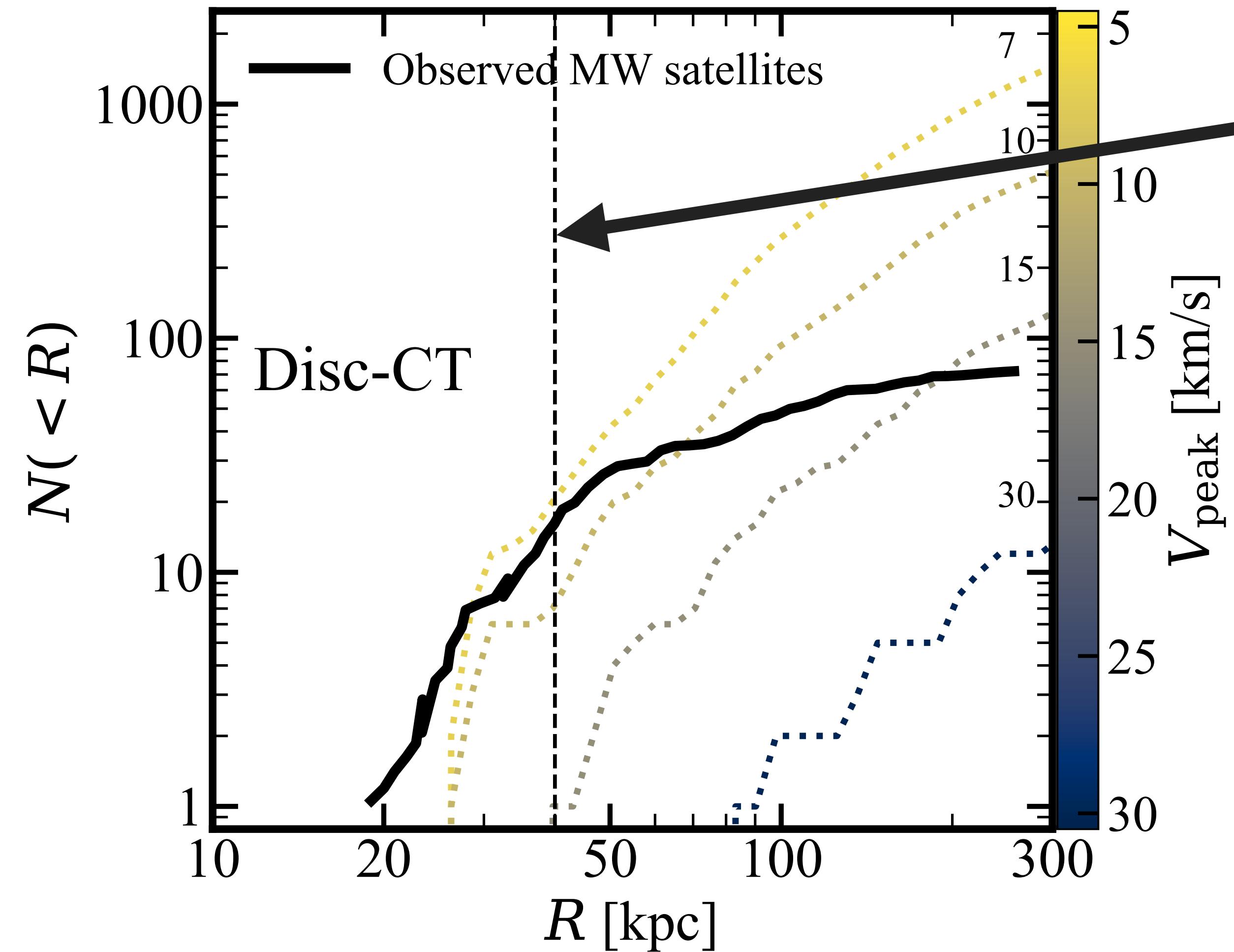
HOW MANY ULTRA-FAINTS ARE THERE?

57



HOW MANY ULTRA-FAINTS ARE THERE?

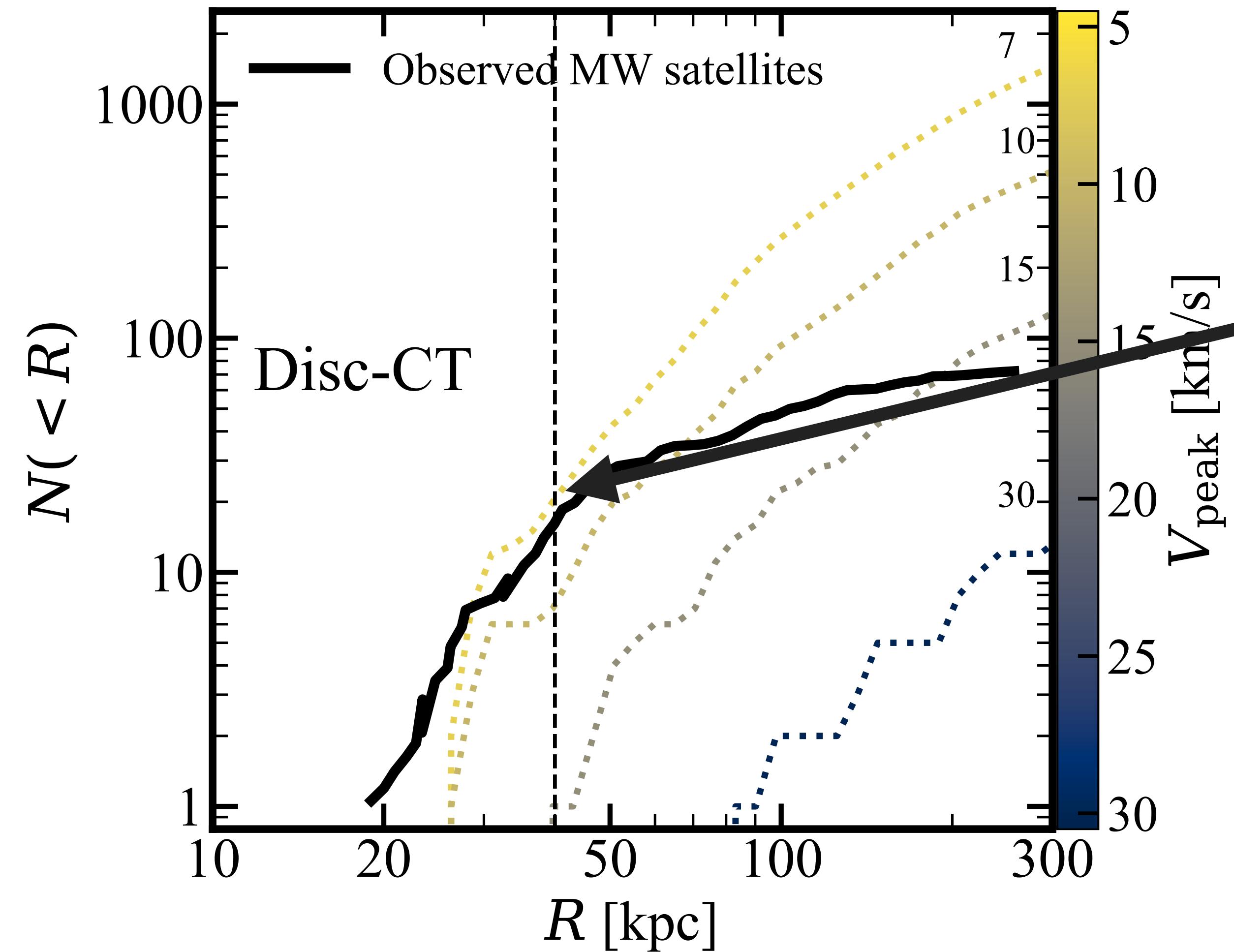
58



~ 40 kpc: where we think MW observations are complete

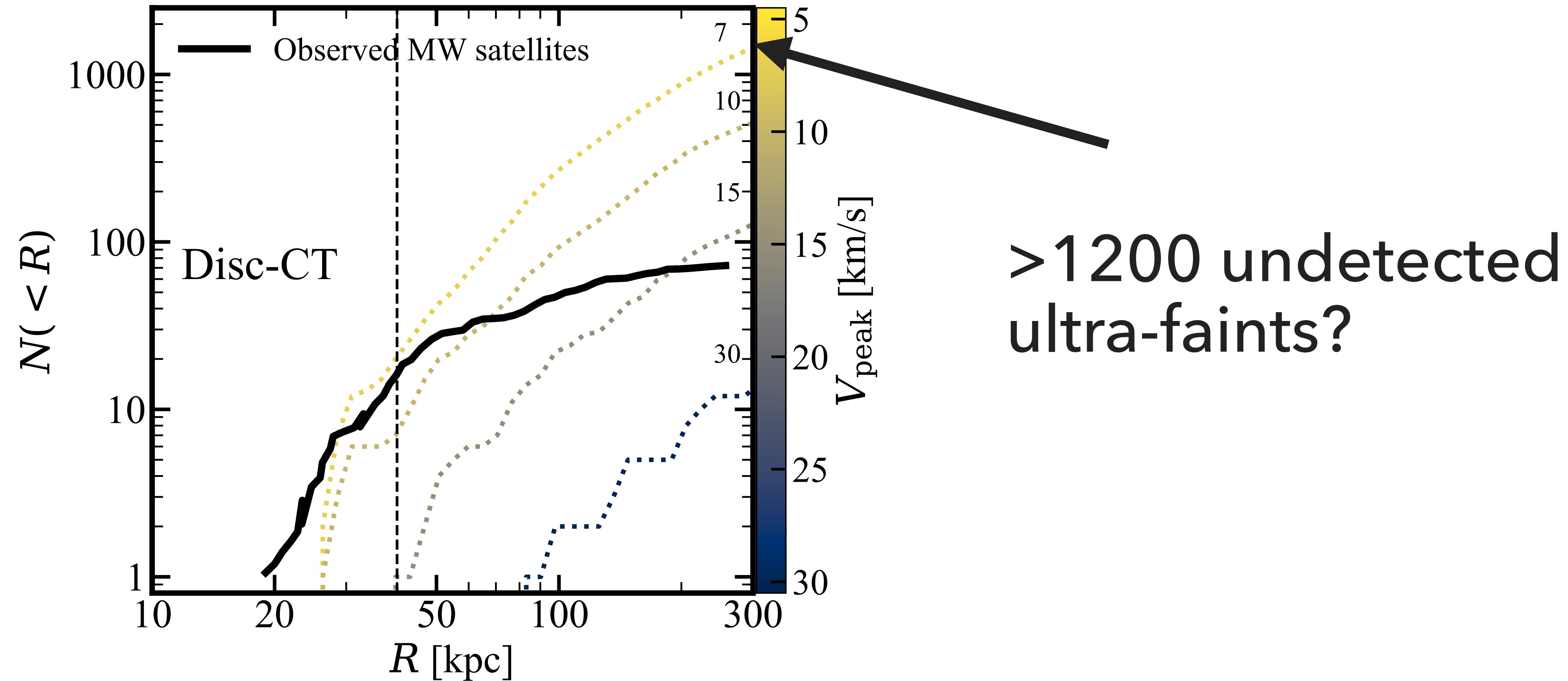
HOW MANY ULTRA-FAINTS ARE THERE?

59



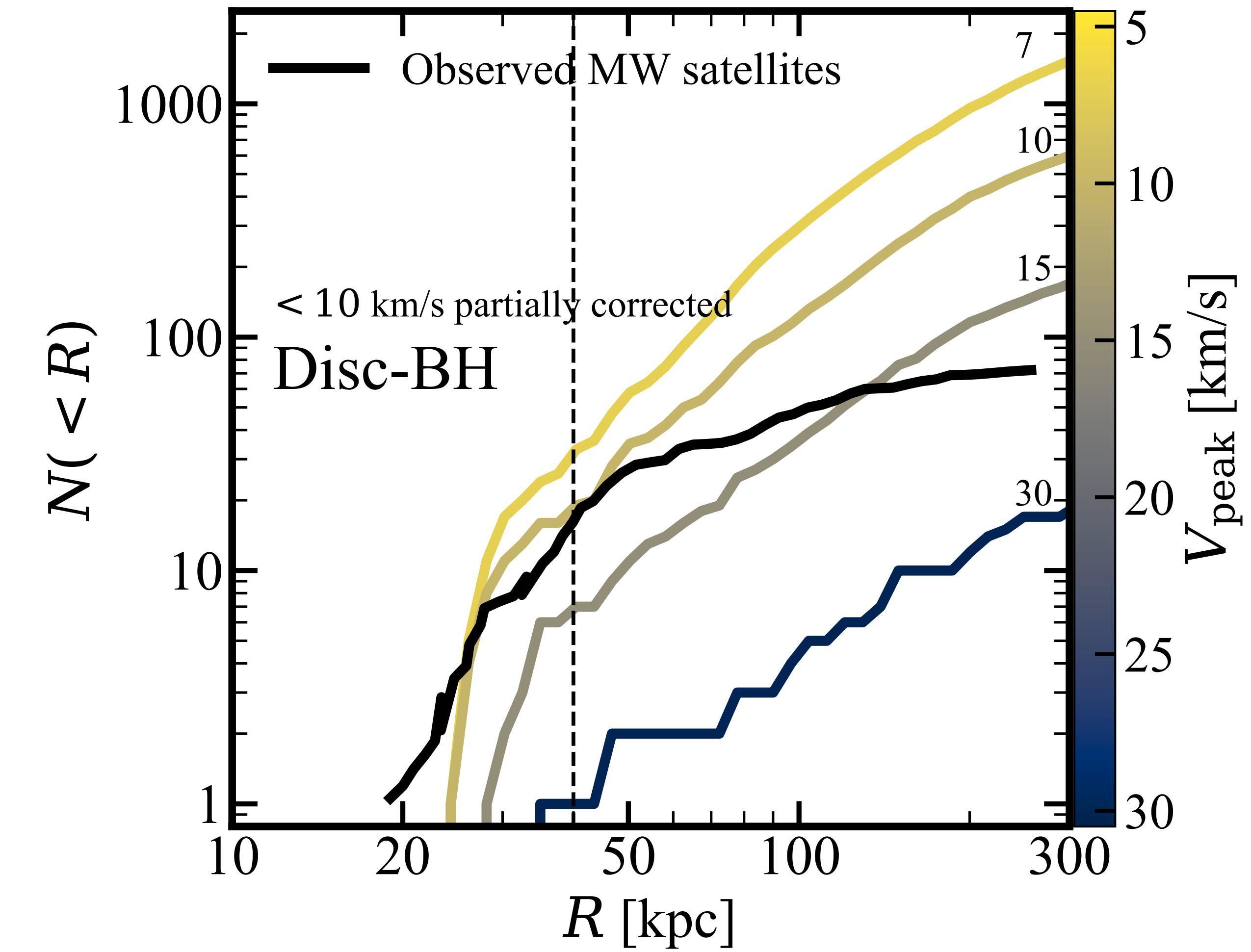
HOW MANY ULTRA-FAINTS ARE THERE?

60



HOW MANY ULTRA-FAINTS ARE THERE?

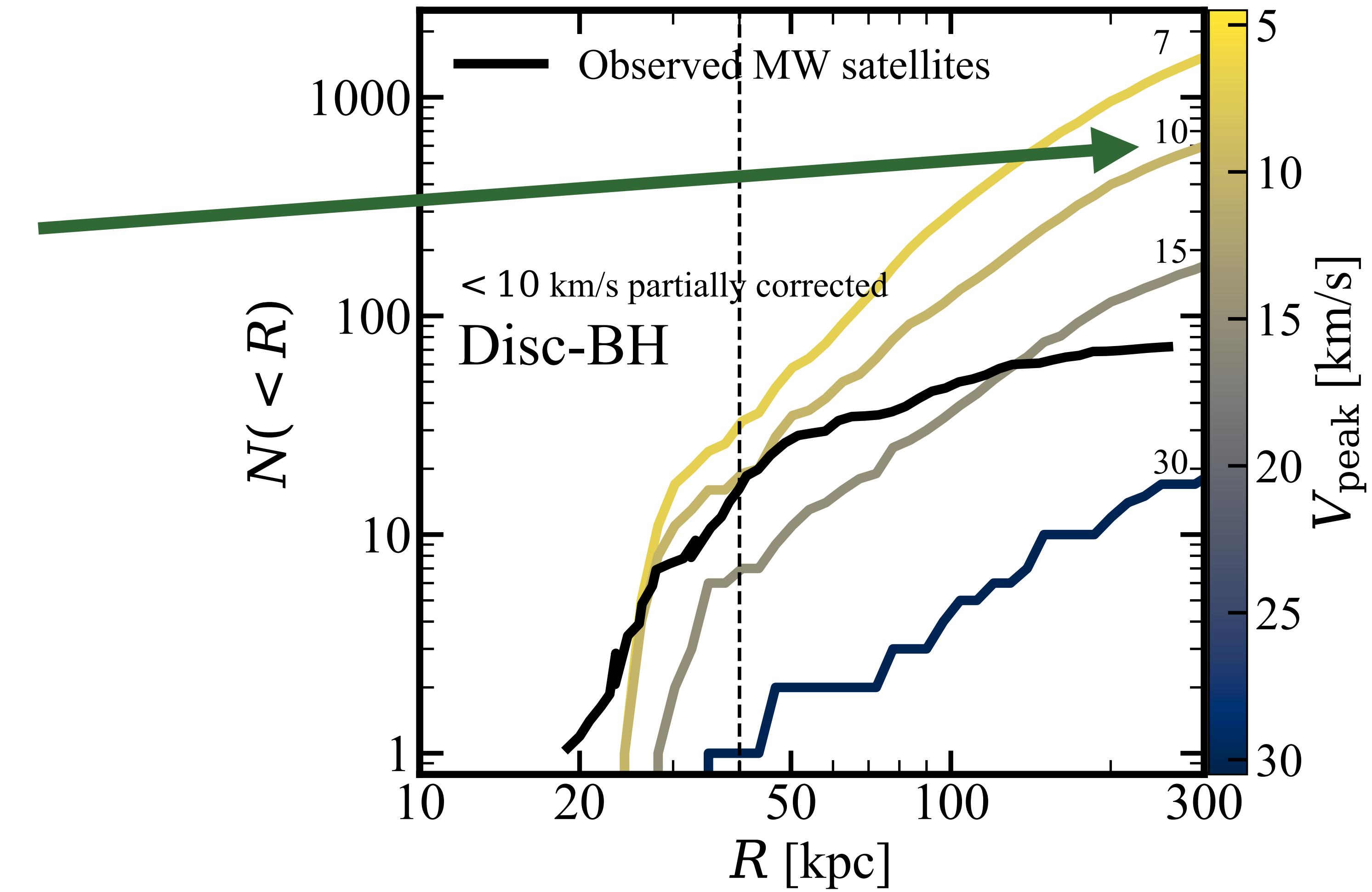
61



HOW MANY ULTRA-FAINTS ARE THERE?

62

~500 undetected
ultra-faints?

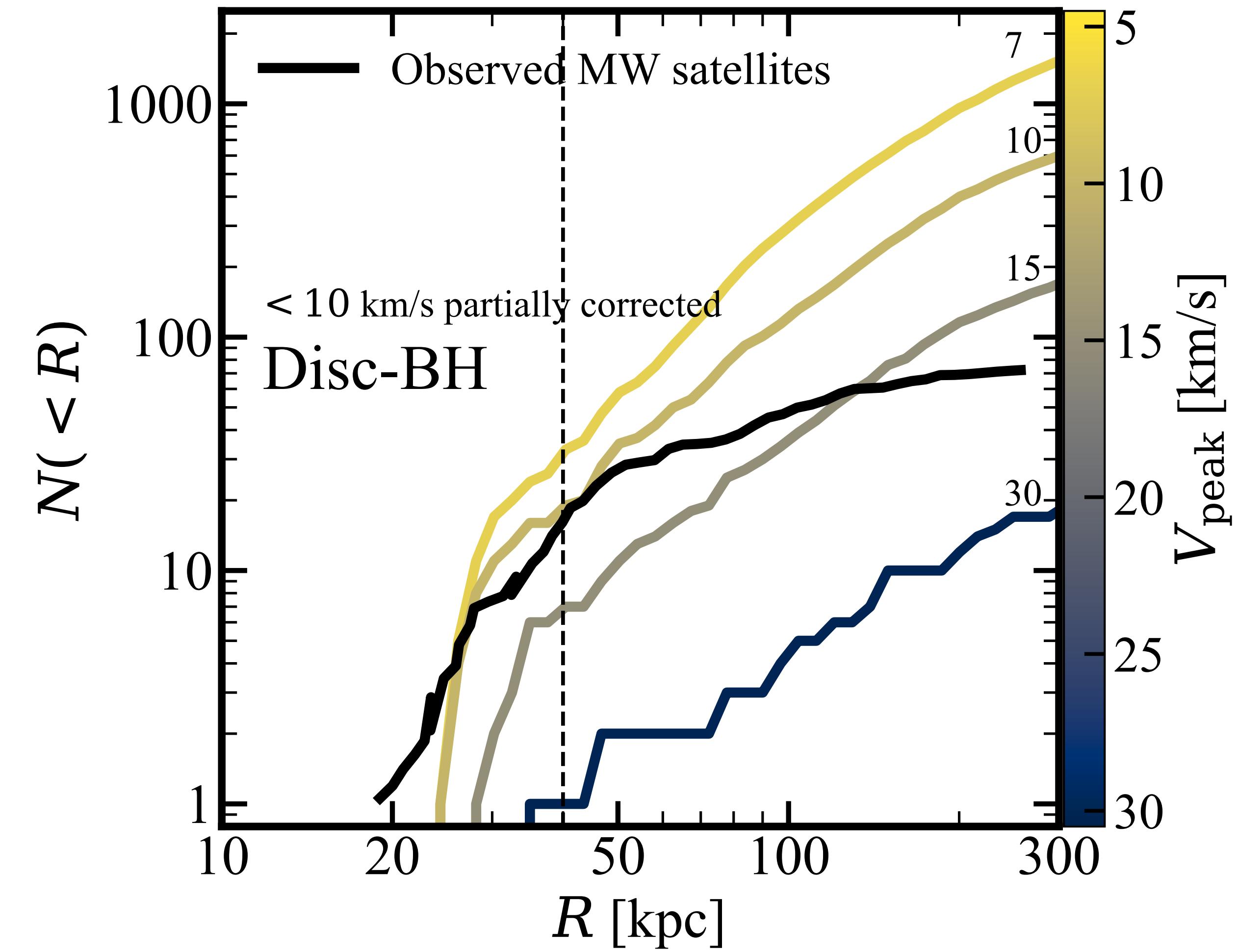


HOW MANY ULTRA-FAINTS ARE THERE?

63

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

2025



SUMMARY

- ▶ 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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DM SUBSTRUCTURE DETECTION

- ▶ 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

GALAXY FORMATION

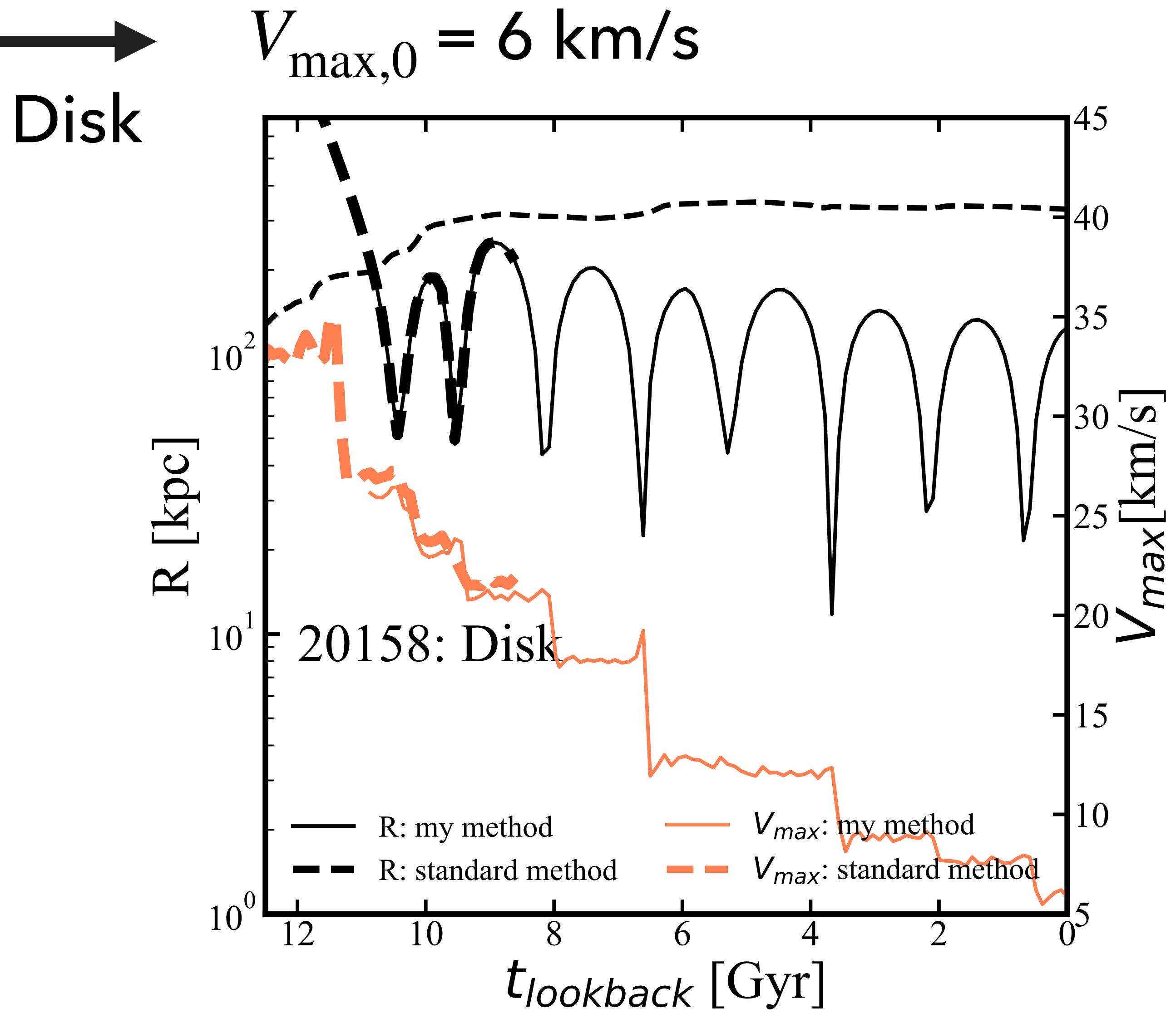
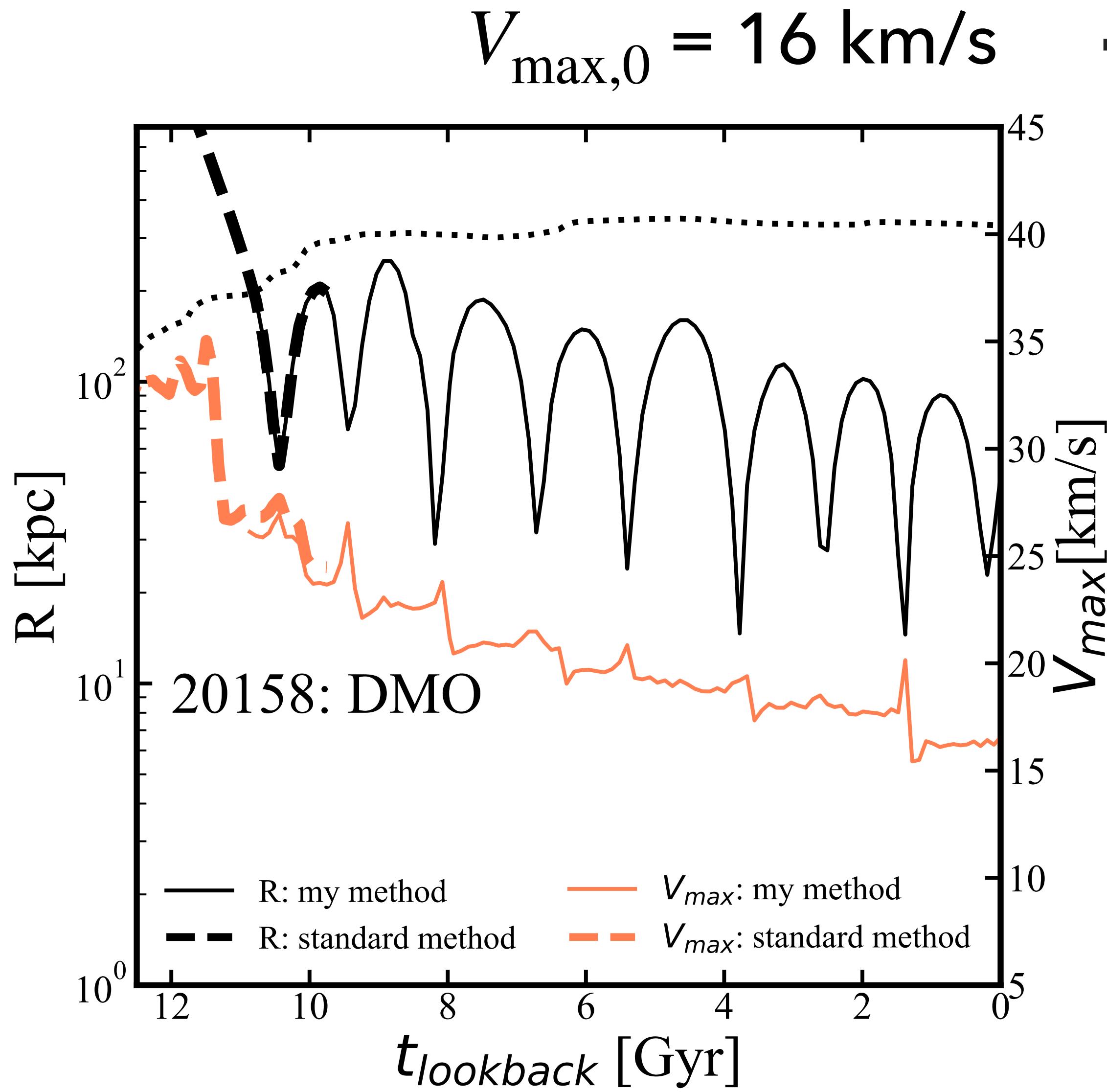
- ▶ Stripped/disrupted galaxies: Ultra-diffuse satellite galaxies
- ▶ With FIRE II simulations, in progress
- ▶ Threshold of galaxy formation: Ultra-faint galaxies
- ▶ Completeness correction: we only see ones close to us

SUMMARY

- ▶ 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

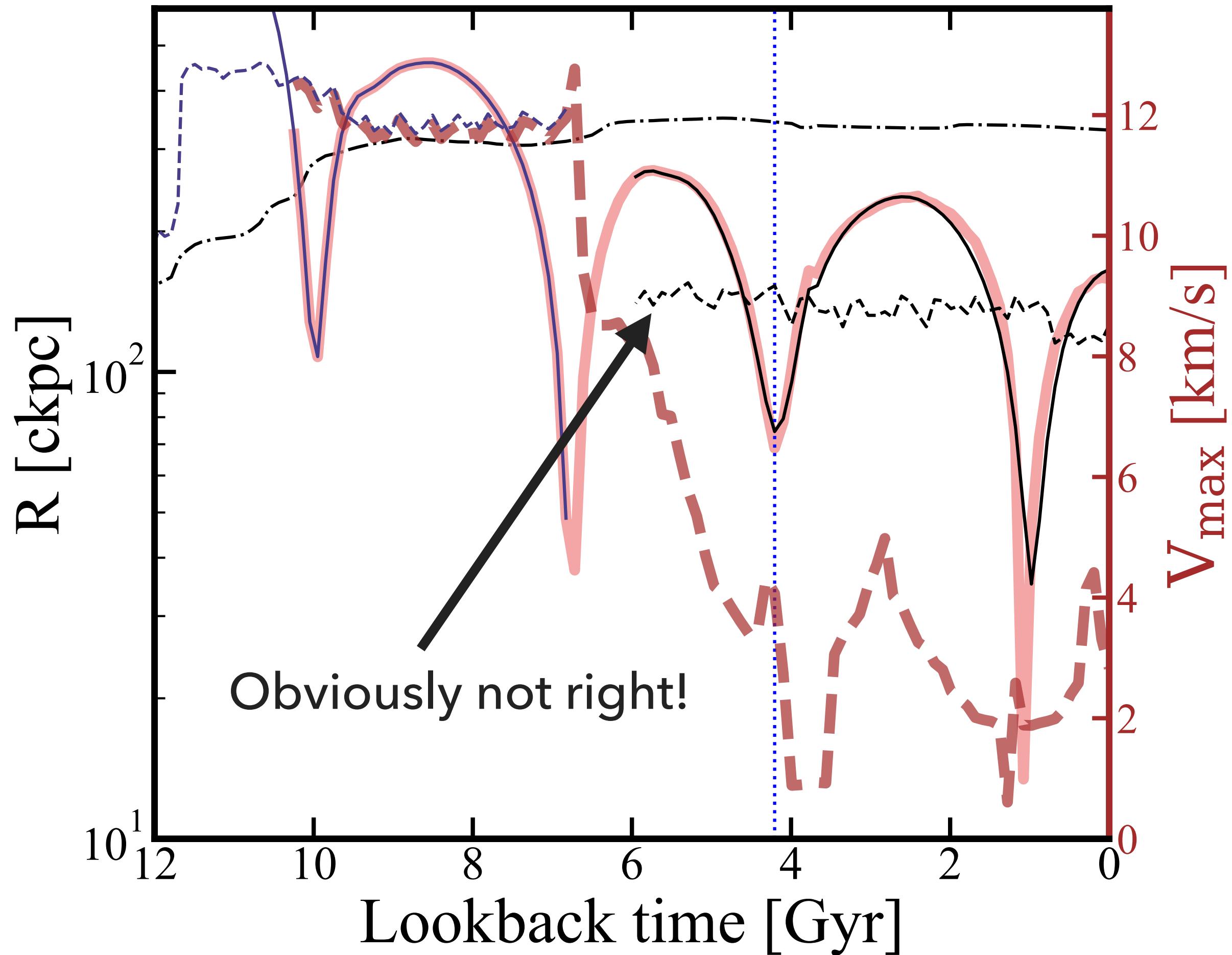
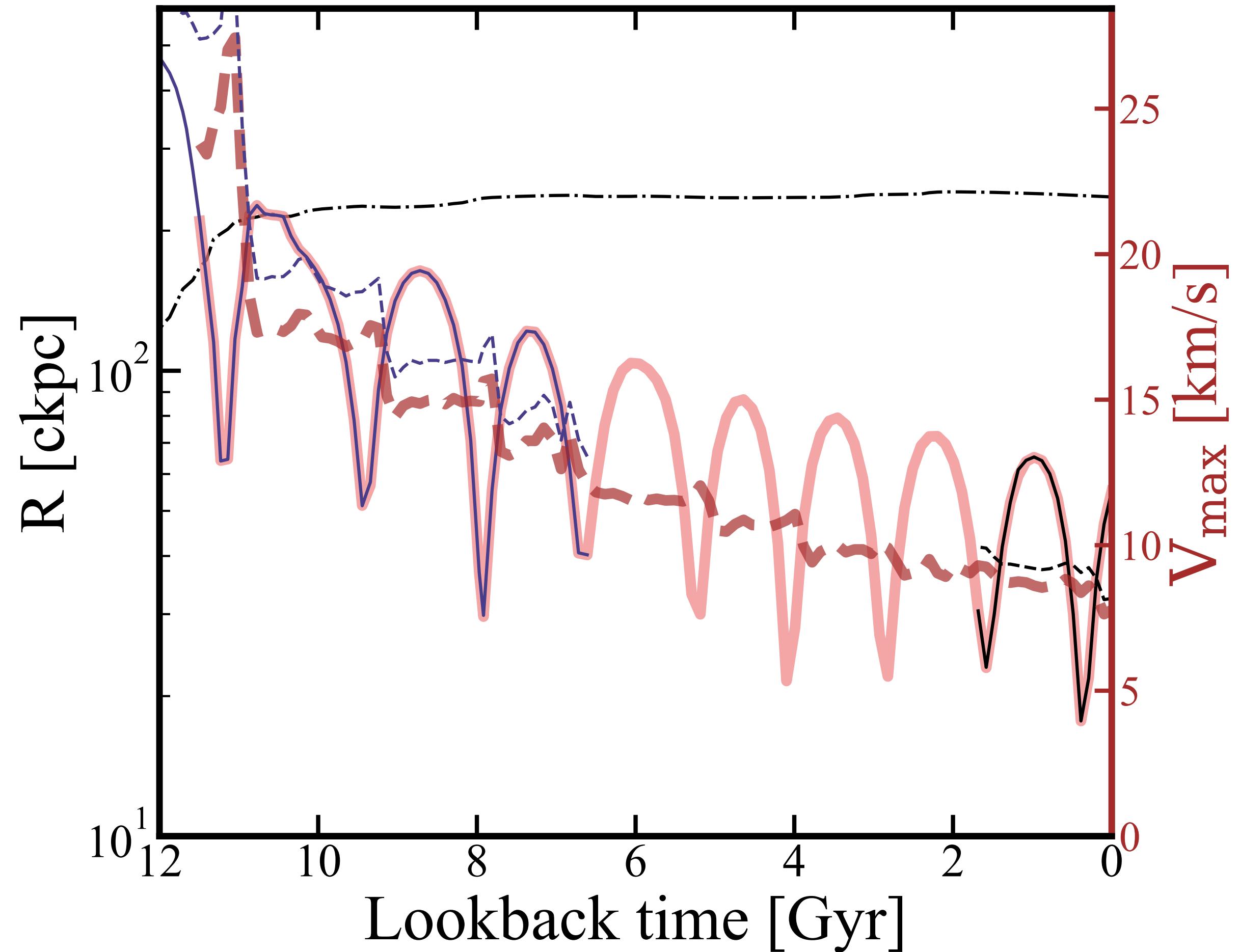
hyunsukong@utexas.edu

MERGER-TREE VS. PARTICLES

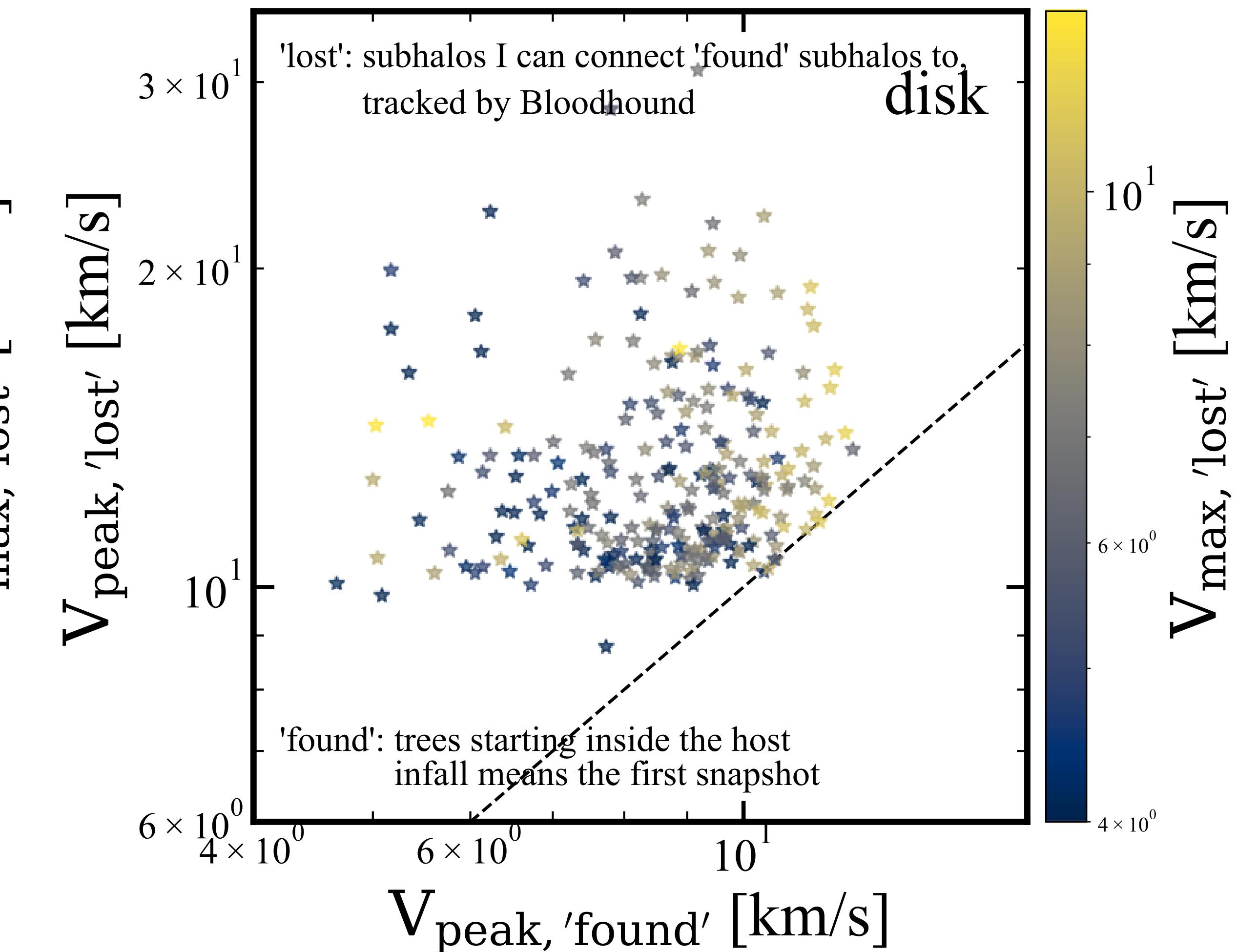
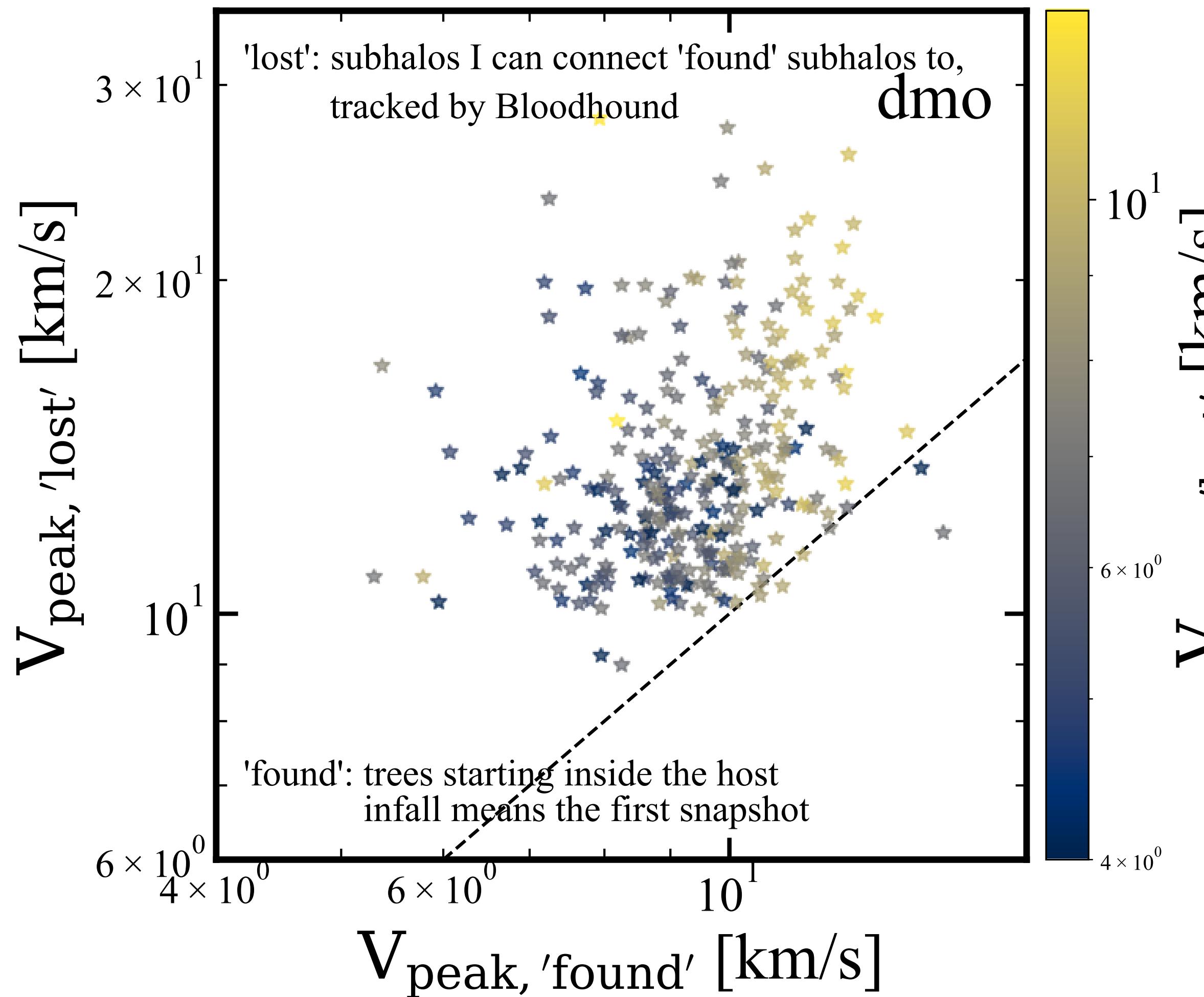


MISSING-LINK TREES

70

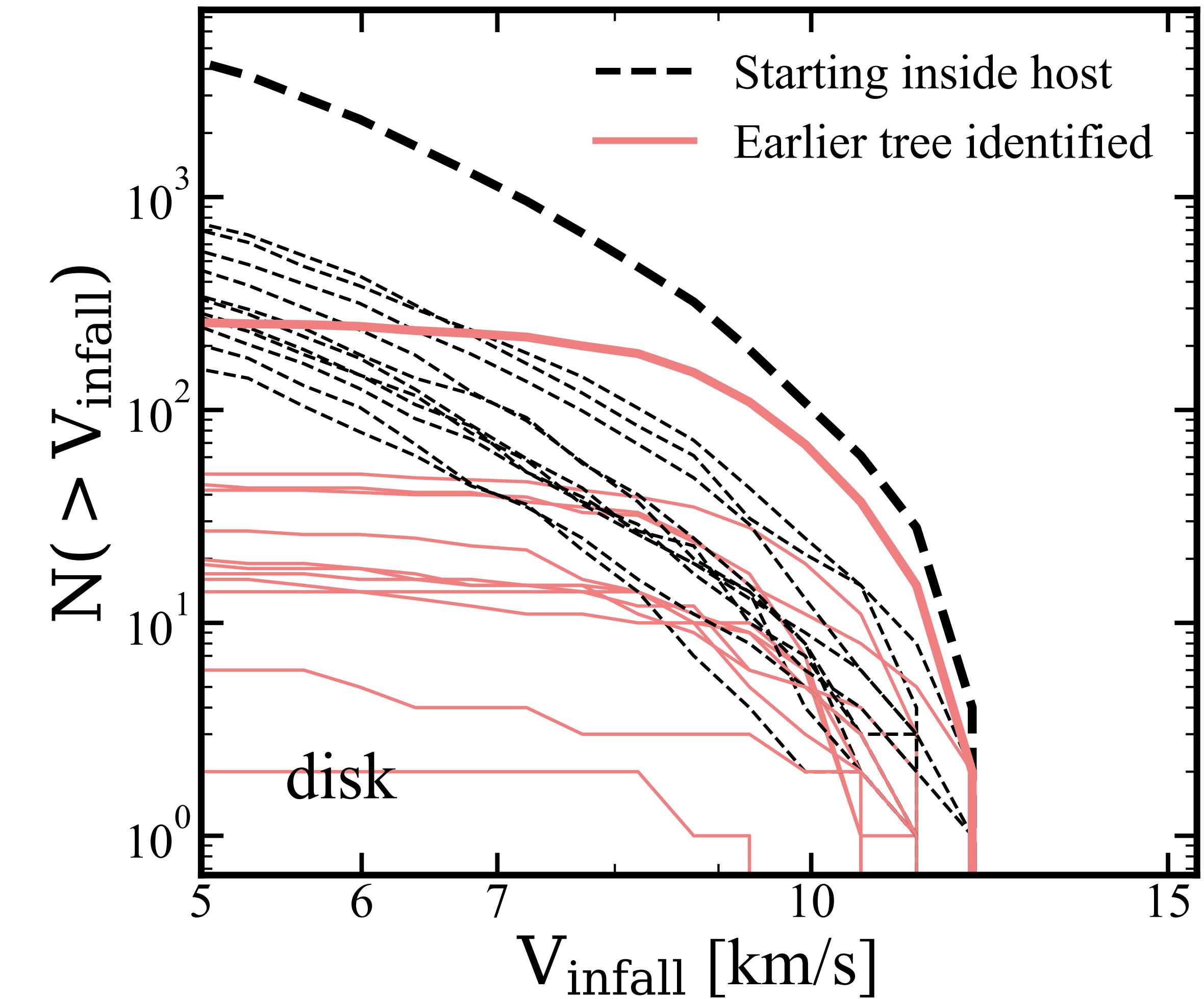
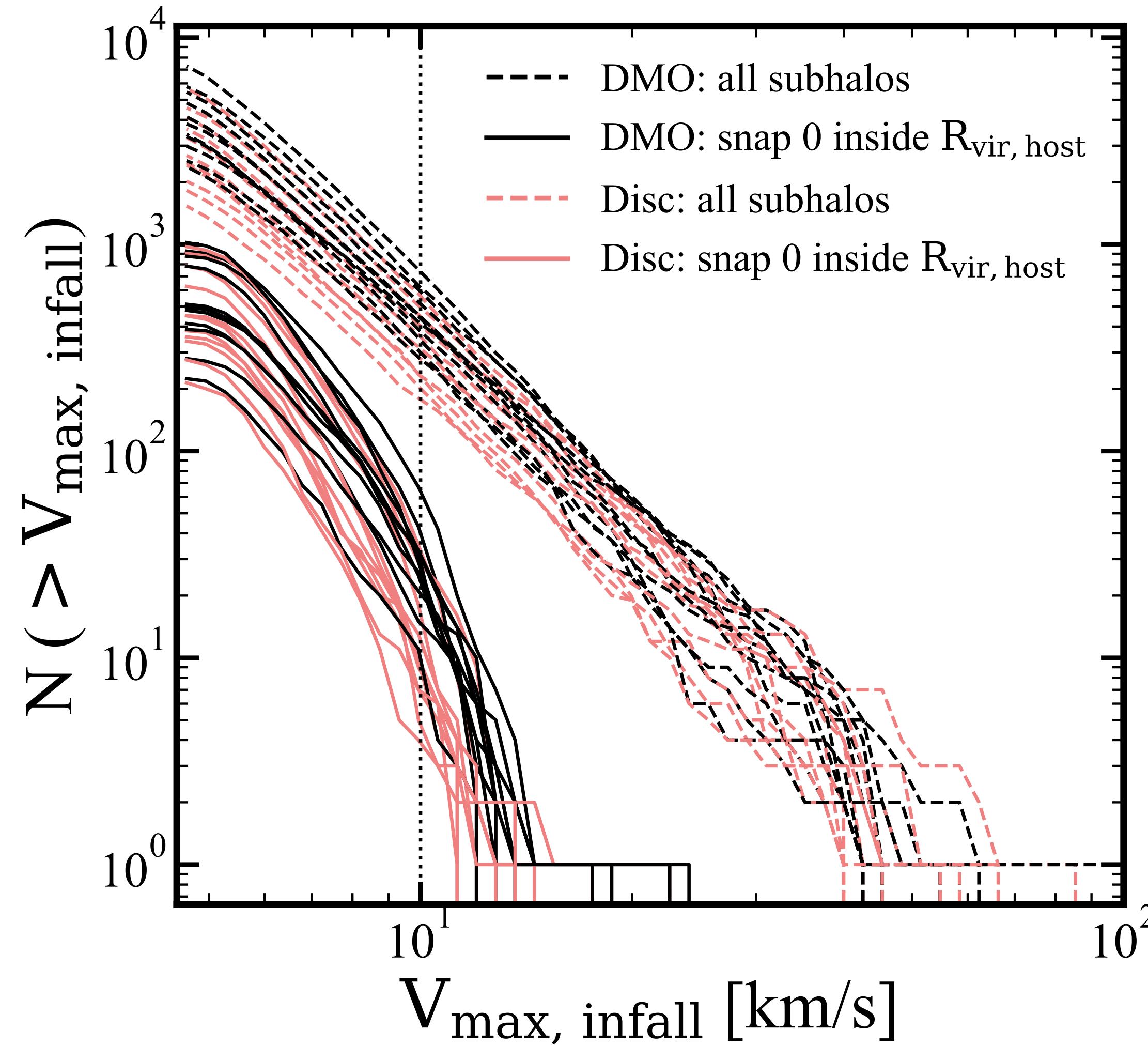


MISSING-LINK TREES: RENAME LABELS

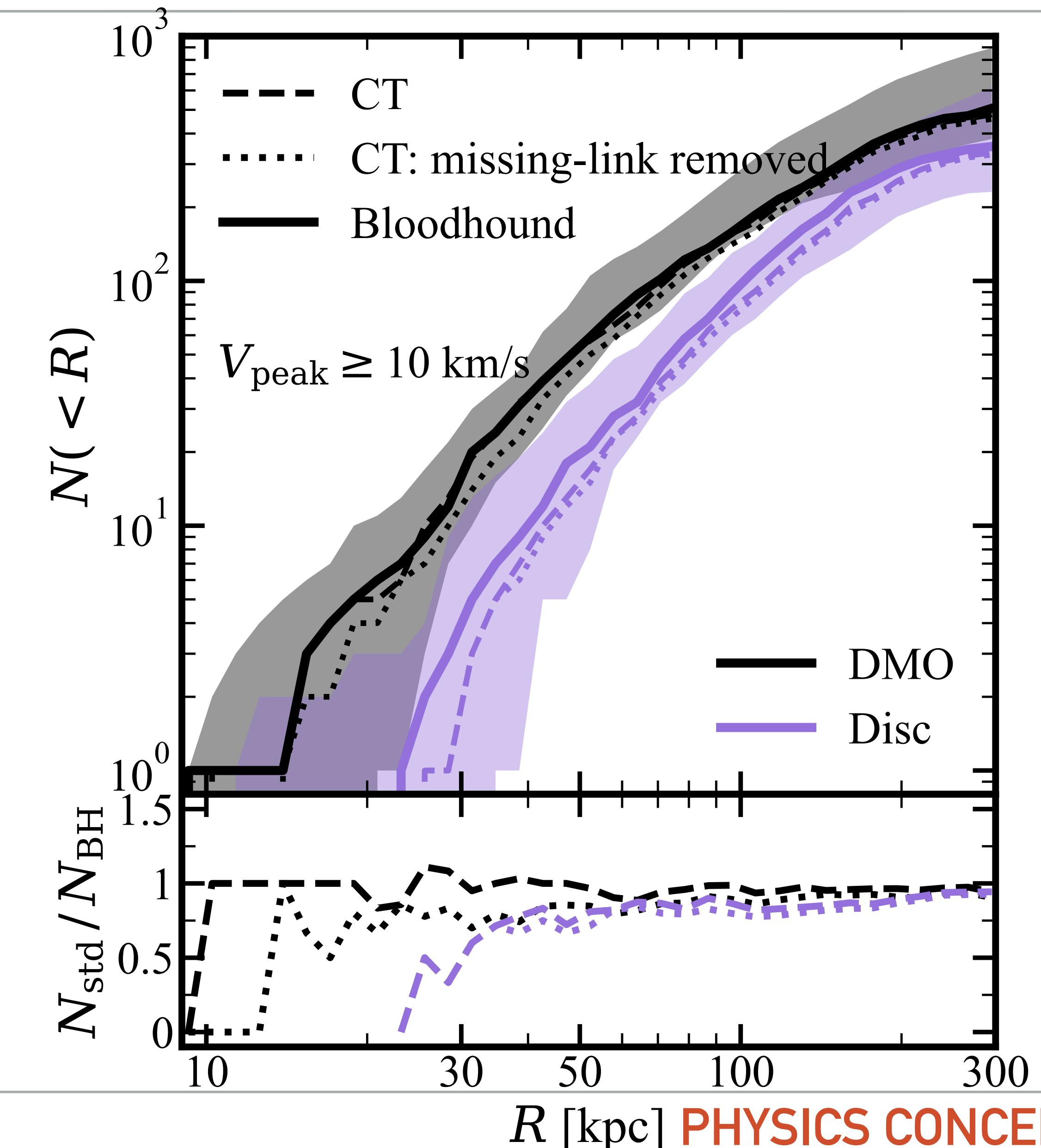
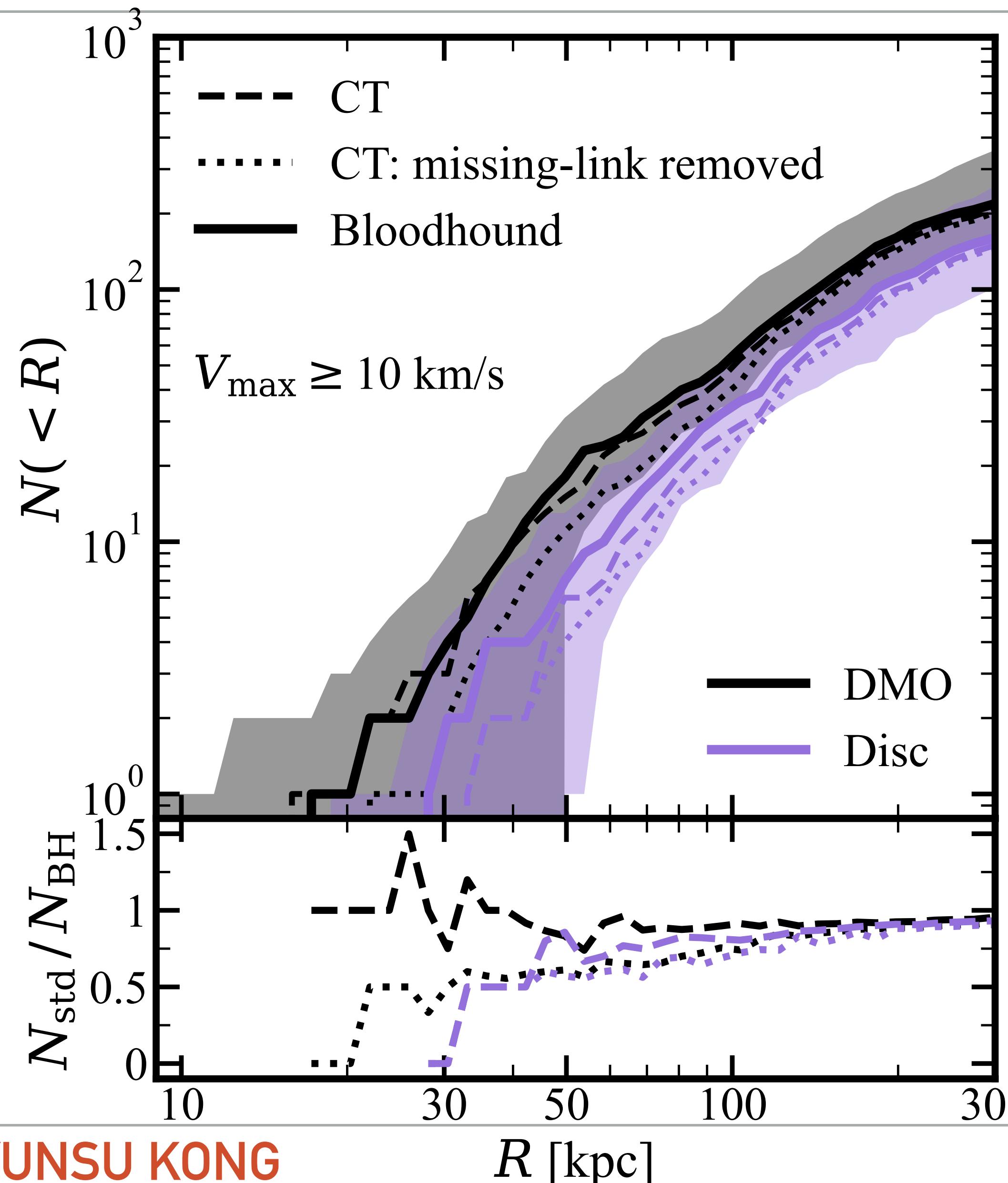


MISSING-LINK TREES

72

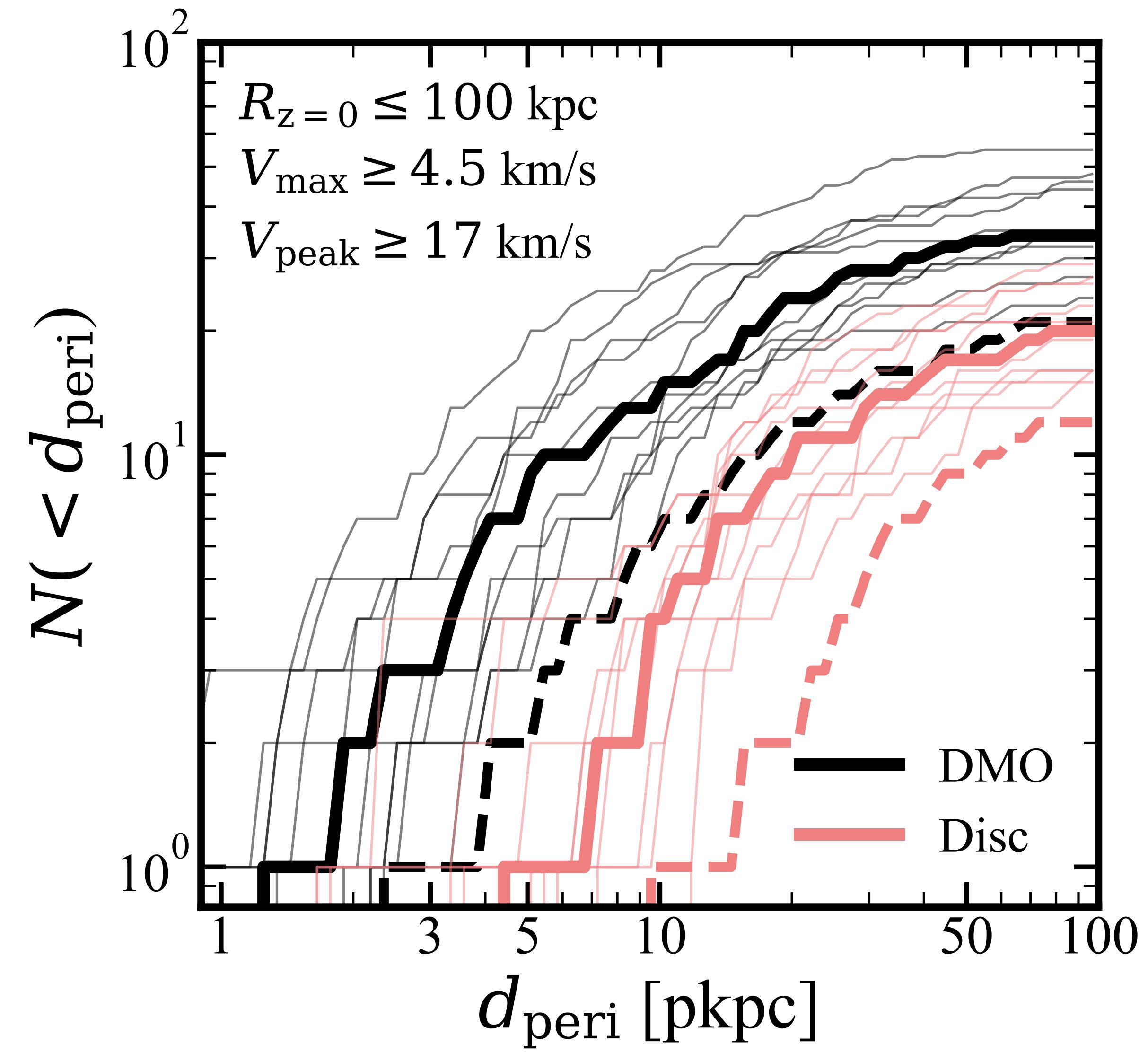
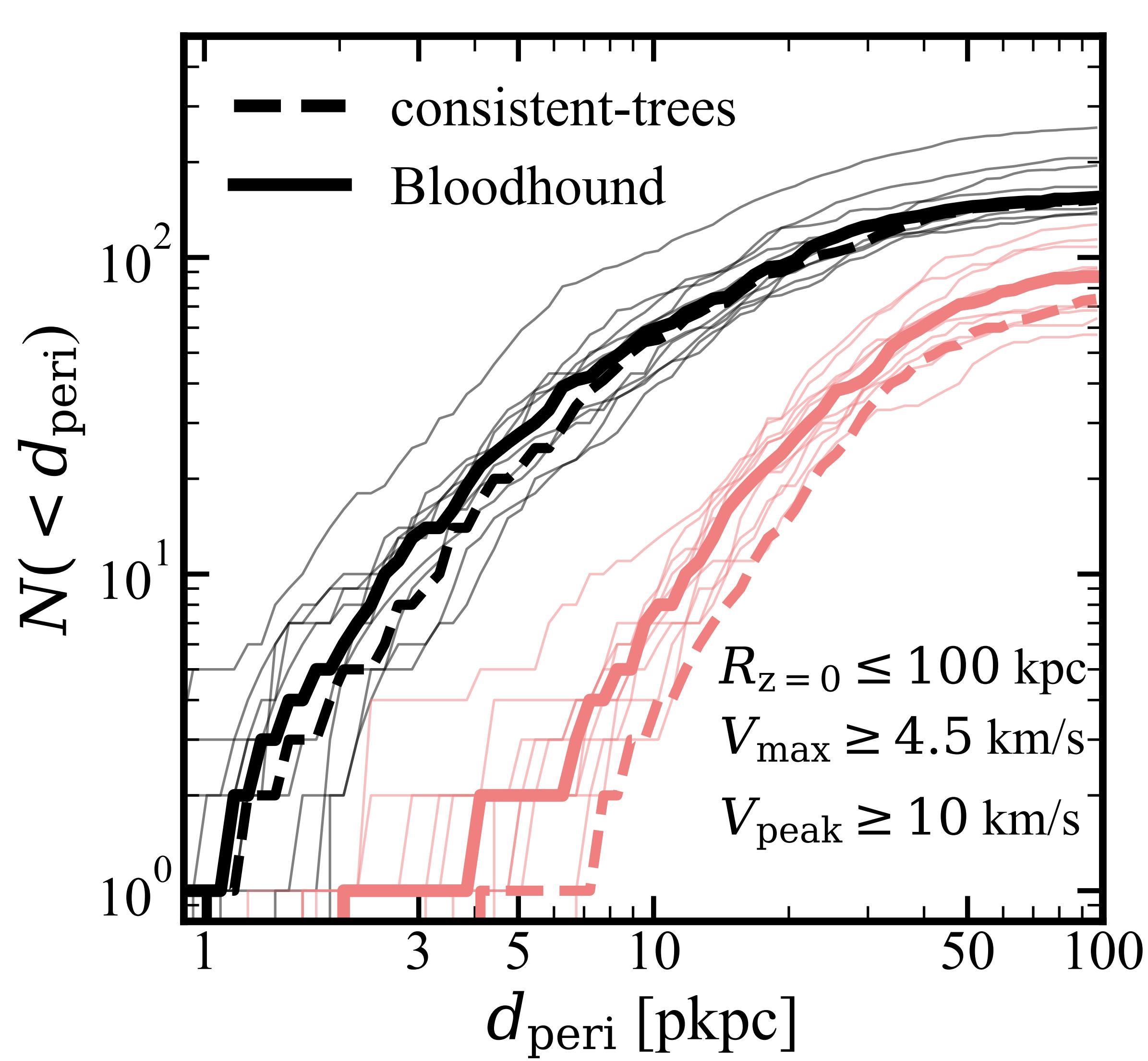


RADIAL DISTRIBUTIONS



PERICENTER DISTRIBUTION

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FLAWED TOOLS

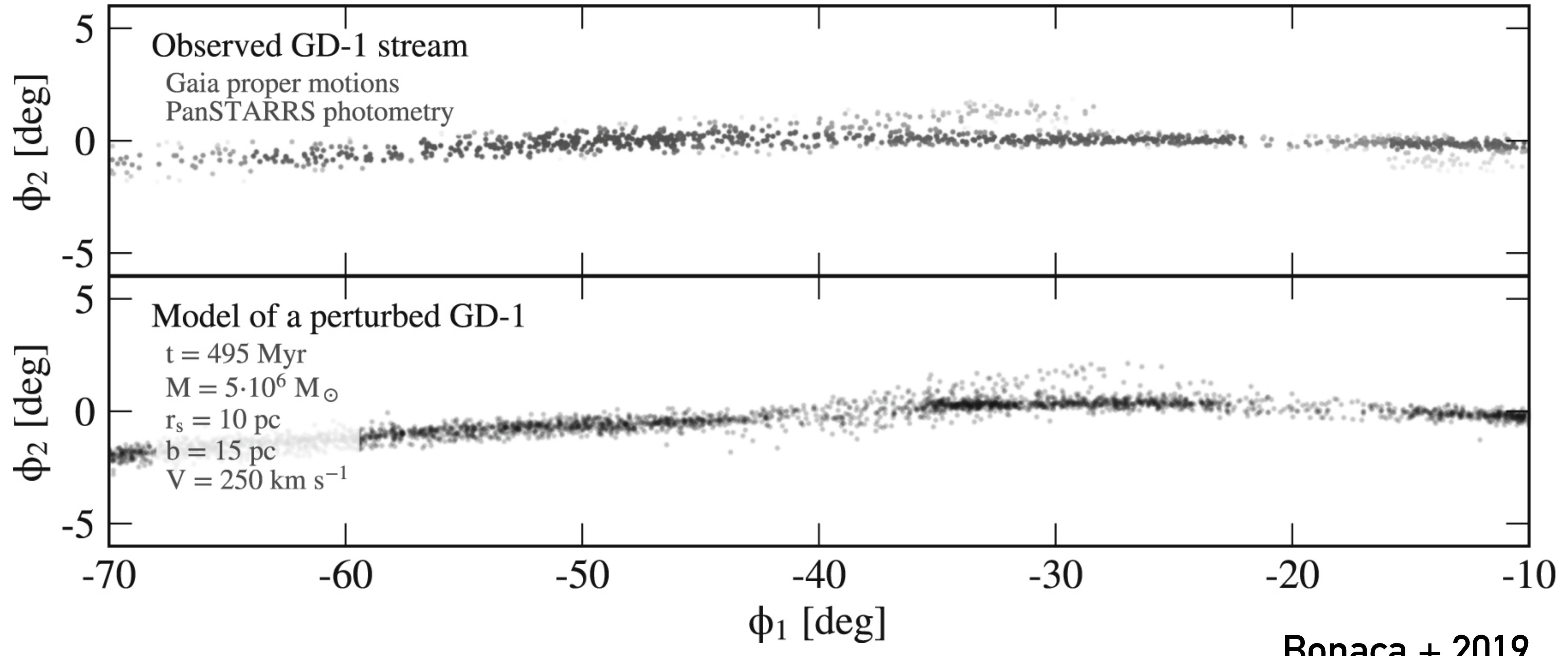
- ▶ People start right from the halo catalog/merger tree side, assuming they are correct, but there's a nuance.
- ▶ At each step, we lose something.
- ▶ And that something is very important for what I am interested in.

PHAT ELVIS

- ▶ 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

DM SUBSTRUCTURE DETECTION

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FUTURE PLANS: HIGHER RESOLUTION

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