Probing Atomic Dark Matter (ADM) using Simulated Subhalo Populations

Caleb Gemmell
University of Toronto

Collaborators:
D.Curtin, T. Li, M. Lisanti, N. Murray, S.Roy, and X. Shen

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Outline:

1. How do we identify subhalos ?
2. How does ADM change DM subhalo structure ?
3. Do these differences affect satellite galaxies ?

Quickly Recap Motivation:

- ΛCDM does a good job at matching data on large astrophysical scales
- Variety of structure problems still exist on small, sub galactic scales
  - Want to probe how ADM behaves at this scale
  - Can we distinguish a MW-like galaxy of CDM vs ADM ?
- Additionally, ADM as an implementation of a complex dark sector / hidden valley model
  - Can address naturalness issues, e.g. Little Hierarchy Problem
  - Inspired by the complexity of the SM

How do we identify subhalos ?

ADM-1

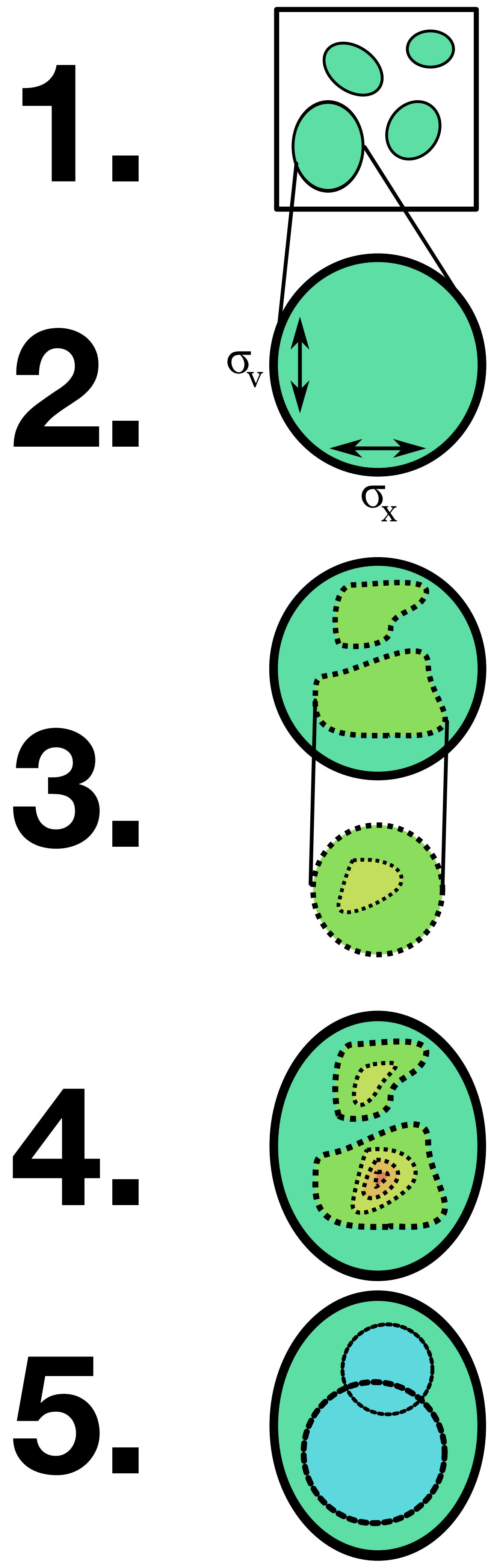
(DM and ADM clumps)

Rockstar

Behroozi et al [1110.4372]

- **Only consider DM and ADM clump particles**
- **How do we find subhalos in an N-body simulation?**

1. Simulation box is divided into groups using Friends-of-friends algorithm with fixed linking length
2. For each subgroup, positions and velocities are normalised by their dispersions to give a distance metric
3. Linking length is adaptively chosen such that 80% of particles are linked with a sub-sub group
4. Process is repeated until sub^n groups with minimum number of particles (10) are identified
5. “Seed” halos are generated from the deepest sub groups, and particles are associated to the seed halo closest in phase space



- **Quality Cuts**
  - Host distance < 300 kpc (~ viral radius)
  - Mass quality error, statistical tolerance

$$\sigma = \frac{\sqrt{\sum m_i^2}}{\sum m_i} \sim \frac{1}{\sqrt{N}} < \frac{1}{\sqrt{50}}$$

ADM-1

(DM and ADM clumps)

ADM-1

(DM and ADM clumps)

How does ADM change subhalo structure?

CDM
CDM-NF
ADM-1
ADM-2
Concentration (R200m / R1/2)
M200m [M⊙]
ADM Mass Percentage

CDM
CDM-NF
ADM-1
ADM-2
*CDM like
Concentration ($R_{200m}/R_{1/2}$)
M_{200m} [$M_\odot$]
ADM Mass Percentage
10^0
10^1
10^2
10^3
10^4
10^6
10^7
10^8
10^9
10^{10}
0.0
0.2
0.4
0.6
0.8
1.0


*Dense objects
in the disk
(ADM-1 only)
Concentration ($R_{200m}/R_{1/2}$)
ADM Gas Distribution
y [kpc]
x [kpc]
NF
1
2
like
ADM Mass Percentage


*Dense objects
in the disk
(ADM-1 only)
Focus of this talk,
ADM 'enhanced' subhalos
are more concentrated
*CDM like
CDM
CDM-NF
ADM-1
ADM-2
Concentration ($R_{200m}/R_{1/2}$)
M_{200m} [$M_\odot$]
ADM Mass Percentage
10^0
10^1
10^2
10^3
10^4
10^6
10^7
10^8
10^9
10^{10}
0.0
0.2
0.4
0.6
0.8
1.0

How does having more concentrated DM subhalos affect satellite galaxies ?

Identifying Satellite Galaxies:

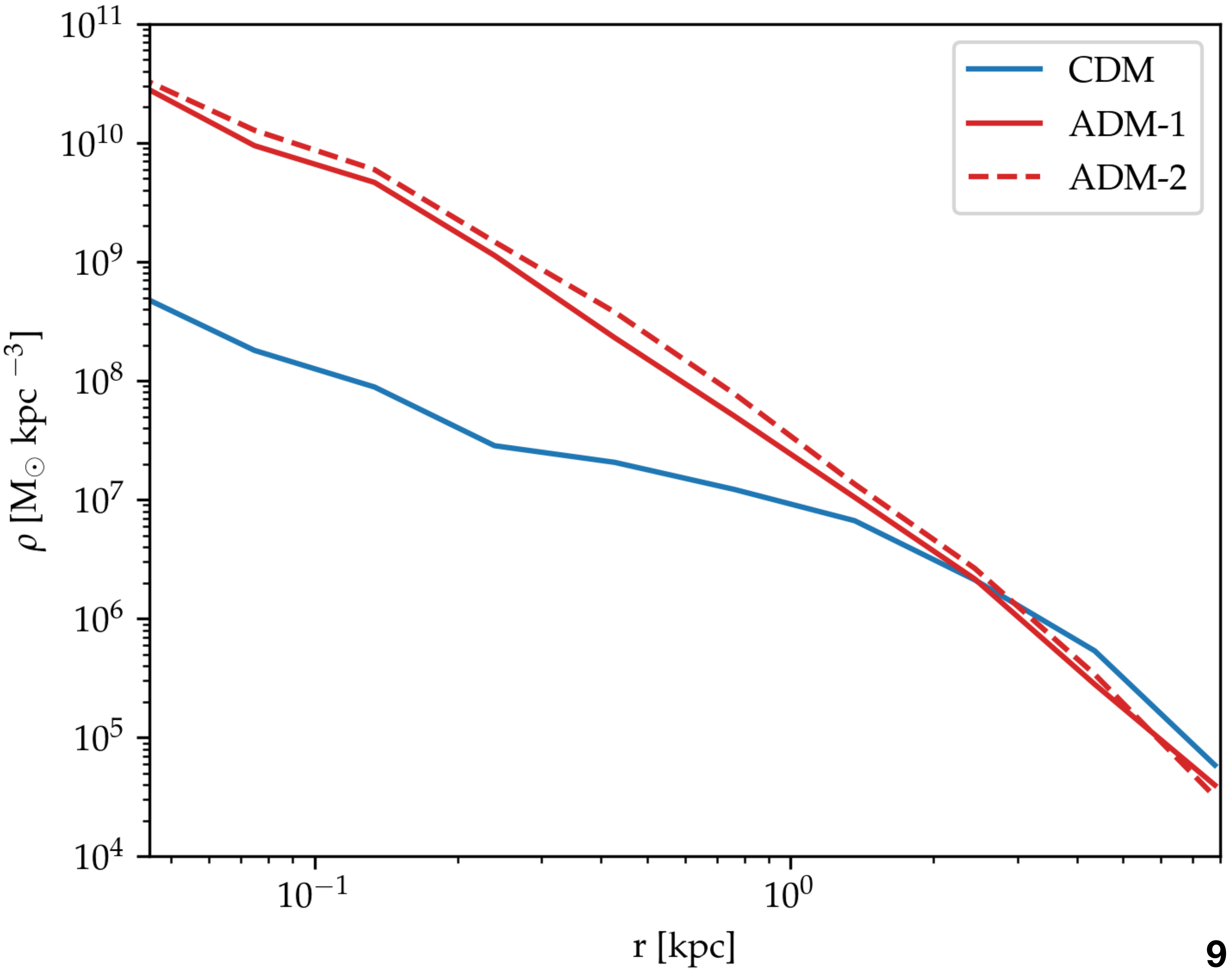
- Use HaloAnalysis to find SM baryon containing DM subhalos

Wetzel A., Garrison-Kimmel S., 2020

  - Initial phase space cut: $r \leq 0.8R_{200,m}$ and $v \leq 2V_{circ}^{max}$
  - Iteratively: $r \leq 1.5R_{90}$ and $v \leq 2\sigma_v$ (until stellar mass converges)
- Apply additional quality cuts
  - # of SM star particles > 10 (~ 4 * 10 ^5 stellar mass threshold)
  - Lie outside the host disk: $r > 10$ kpc, $z > 3$ kpc
- Across simulations, ~10-25 satellite galaxies identified

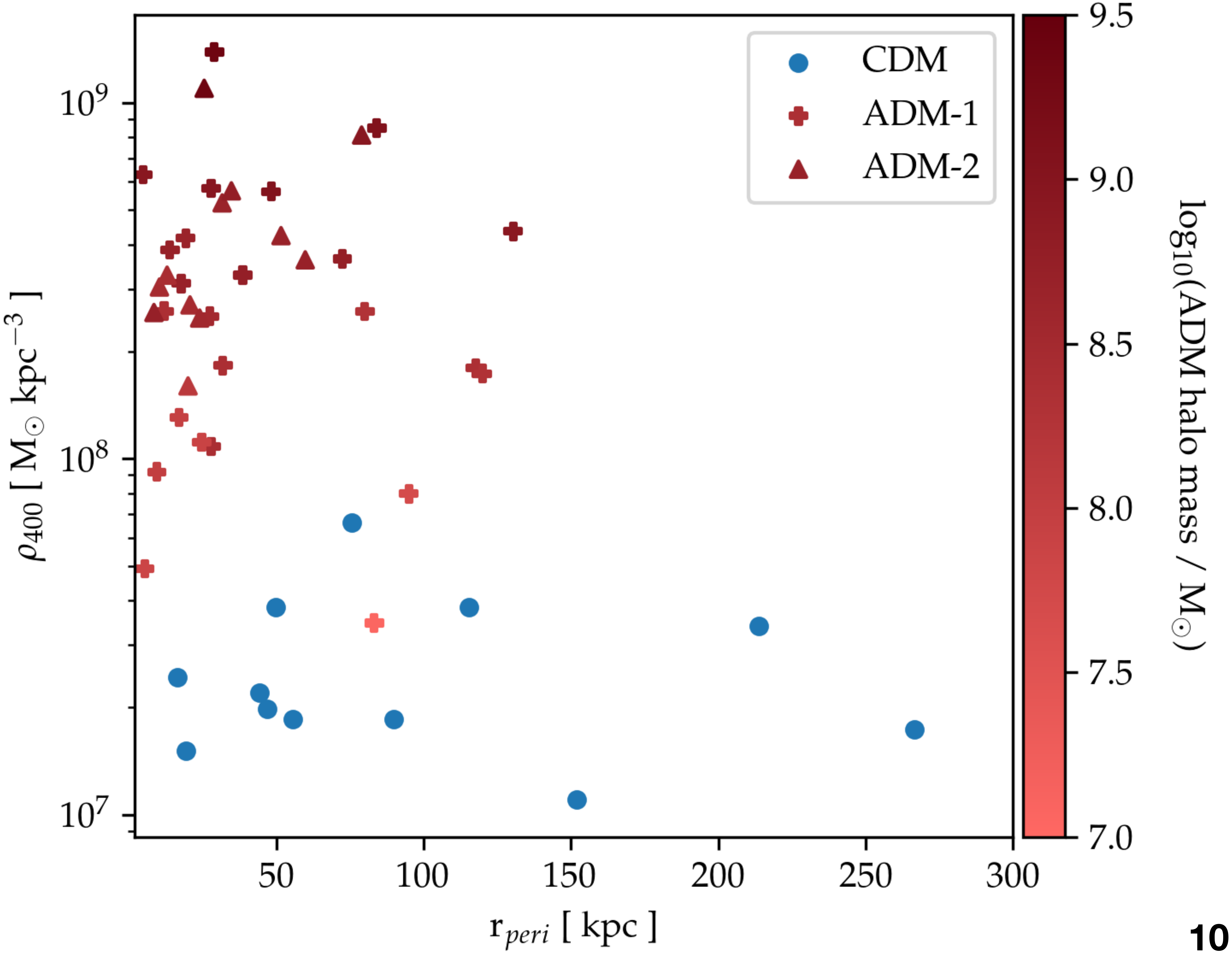
Density Profile

(Median value across satellite galaxy population per radial bin)



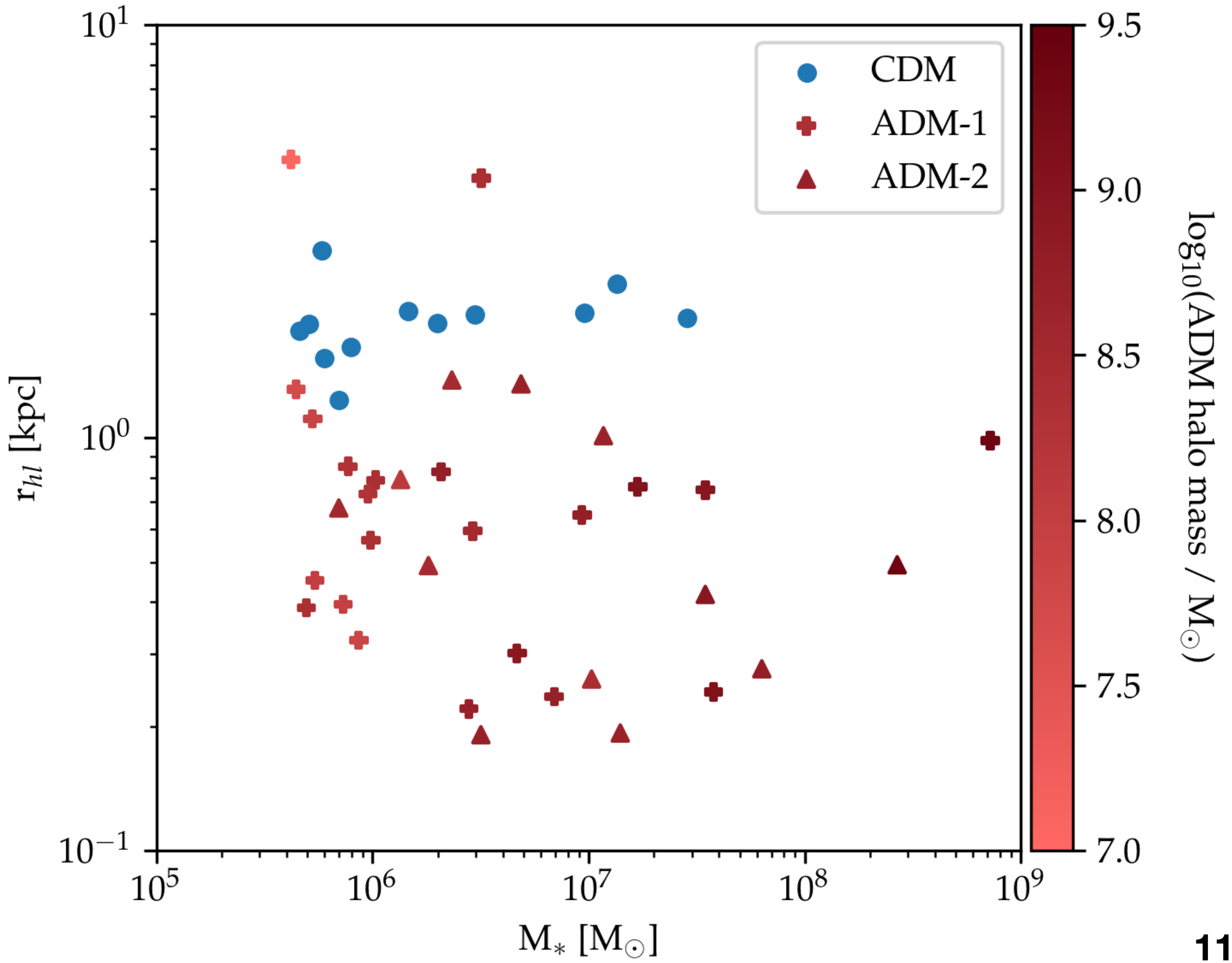
ADM is able to form a cuspier density profile. This is due to its ability to efficiently cool, dissipate energy and collapse.

Pericenter Distribution



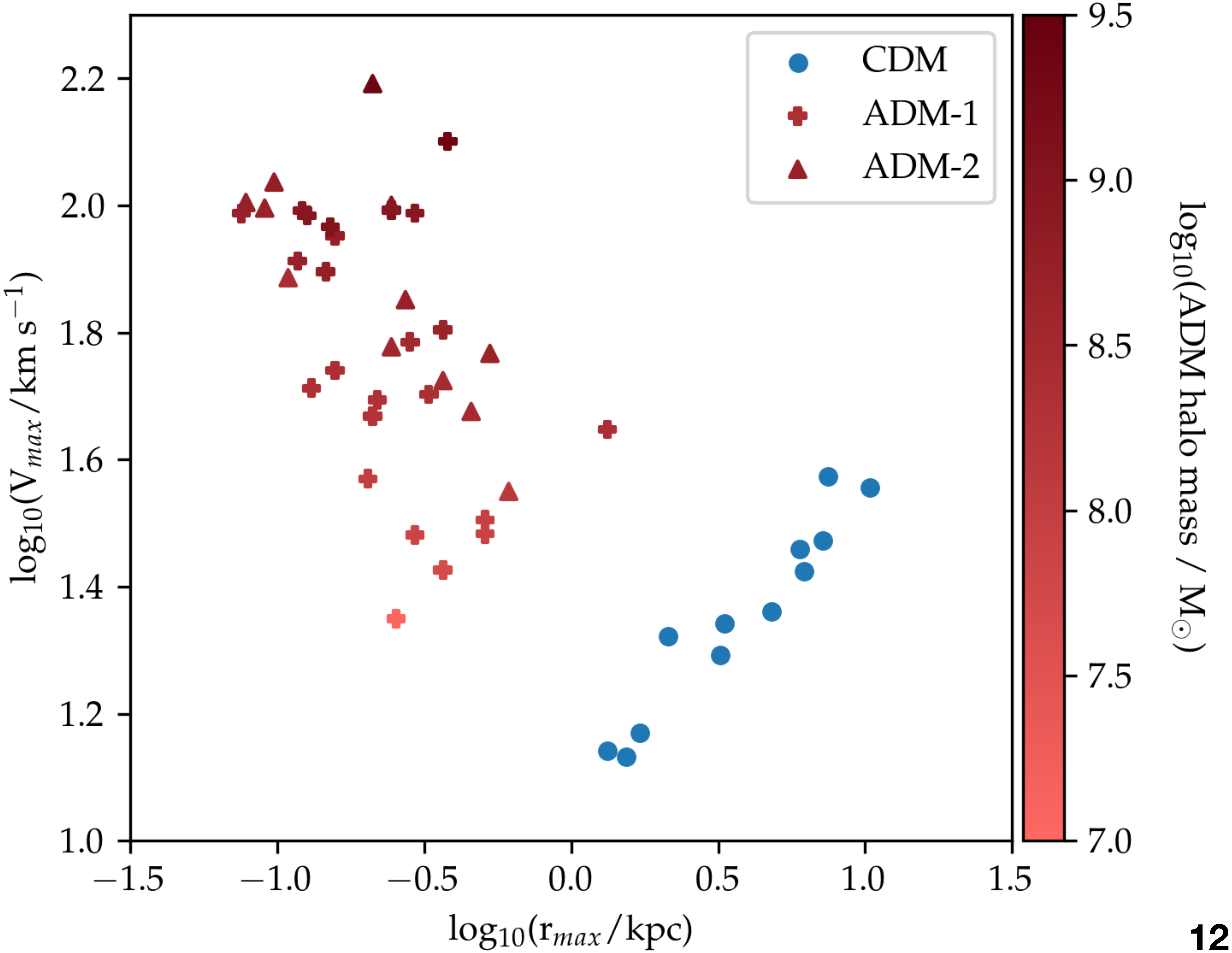
The increased central density in ADM satellite galaxies could make them more resistant to tidal stripping, changing the distribution of percenters.

Half-light Radii



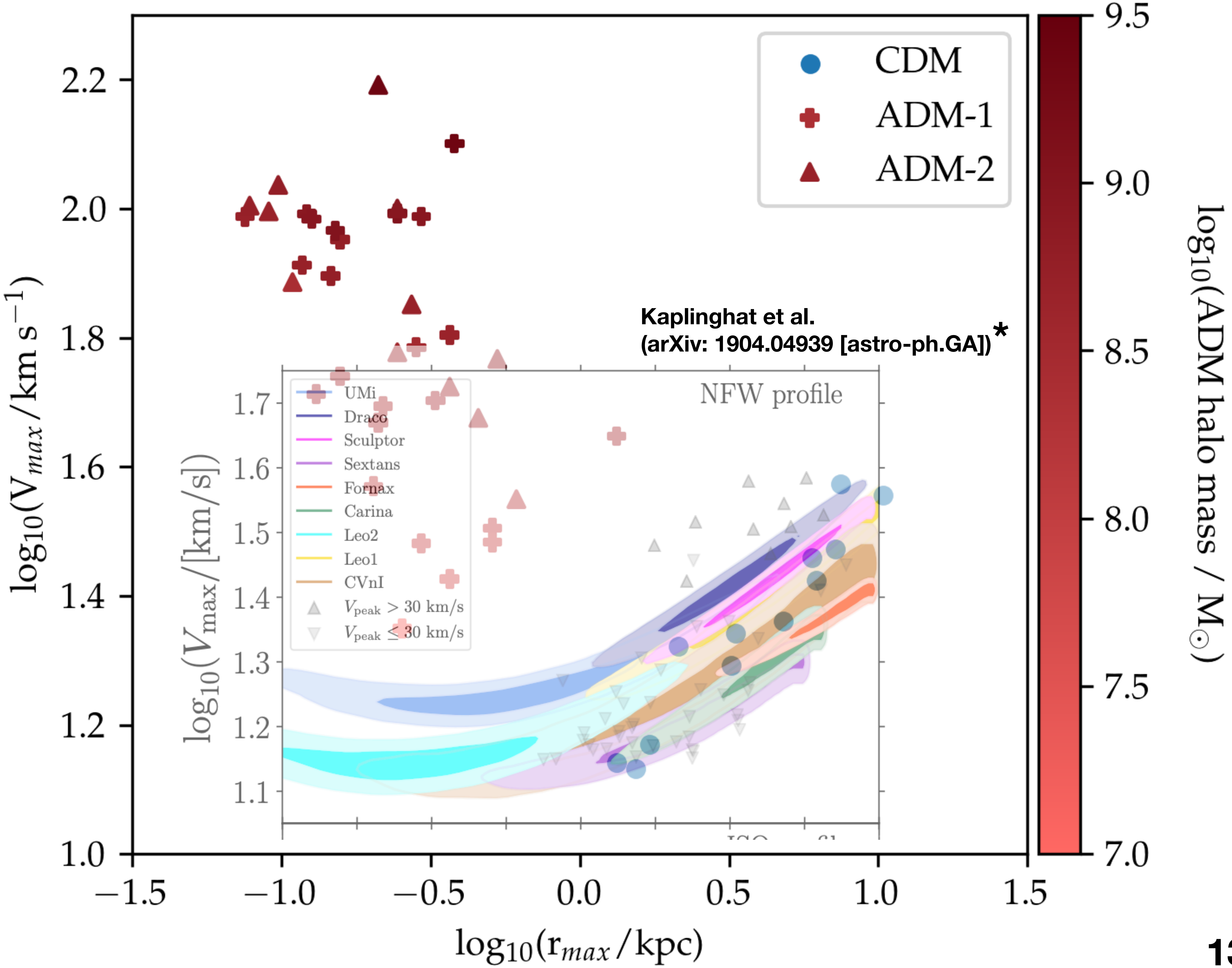
Increased central density could also lead to smaller observed satellite galaxies.

Circular Velocities



Increased central density could also lead to increased circular velocity maximums.

* Data not provided for direct comparison, merely providing context for parameter space



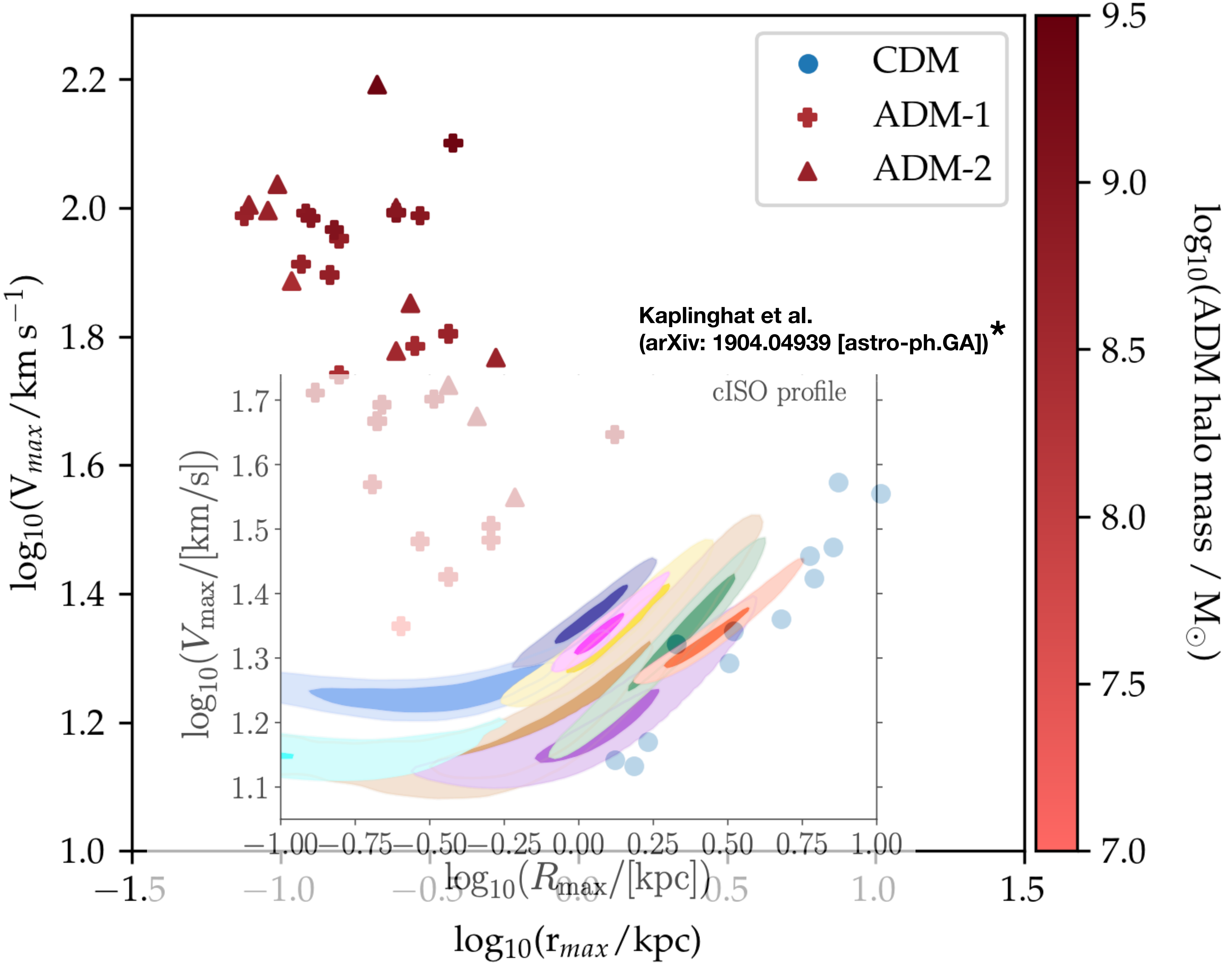
Increased central density could also lead to increased circular velocity maximums.

Conclusions:

- In the parameter points we have simulated, ADM is able to cool efficiently, enhancing the central densities of DM subbhalos
- Also can form dense, concentrated ADM-only subhalos in the disk
- This is having a large influence over a variety of satellite galaxy properties (AT ONLY 5% ADM FRACTION)
- Future investigations into high-res simulation of isolated/field dwarf galaxy to support this study, able to explore more of the ADM parameter space

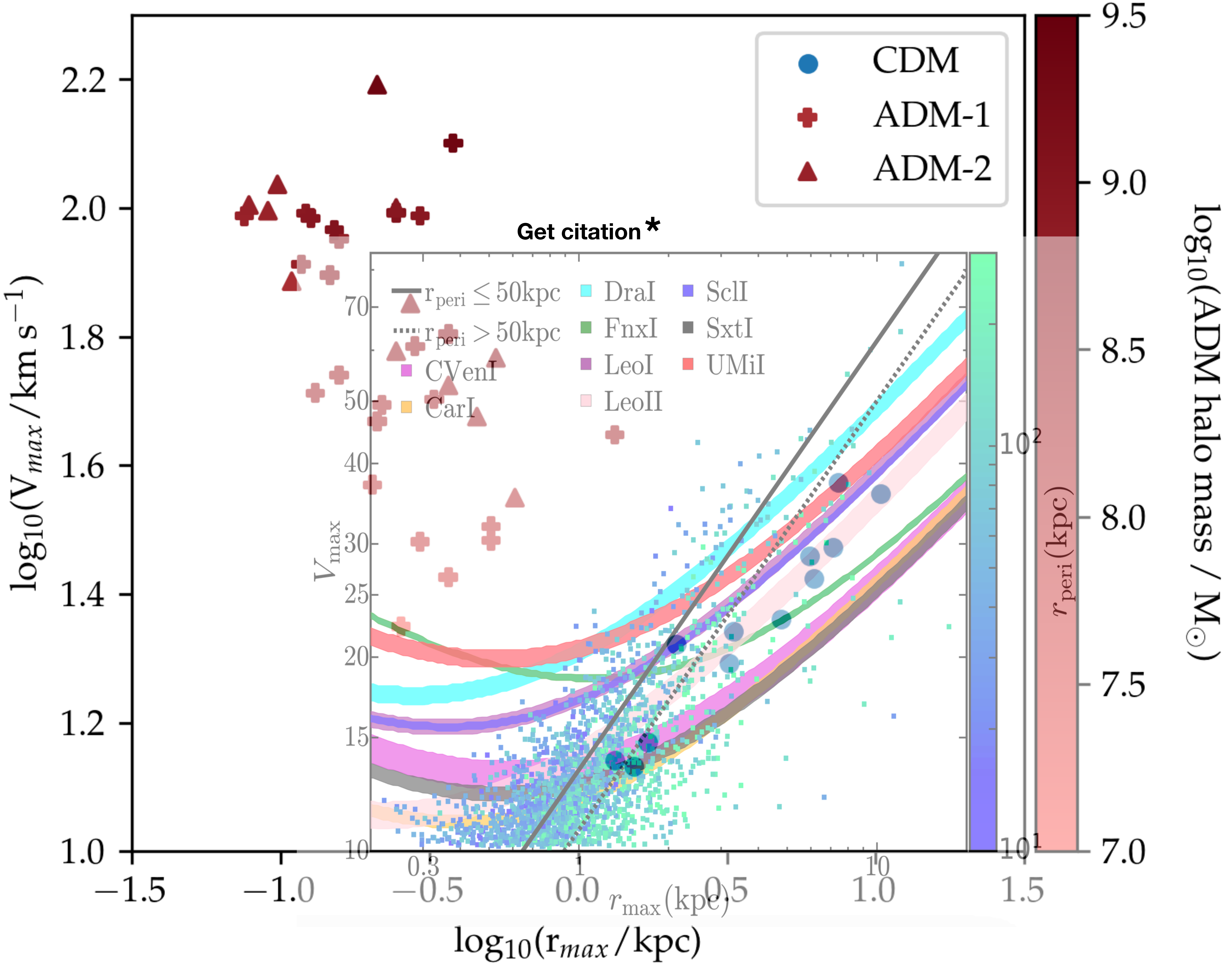
Supplementary Slides

*** Data not provided for direct comparison, merely providing context for parameter space**

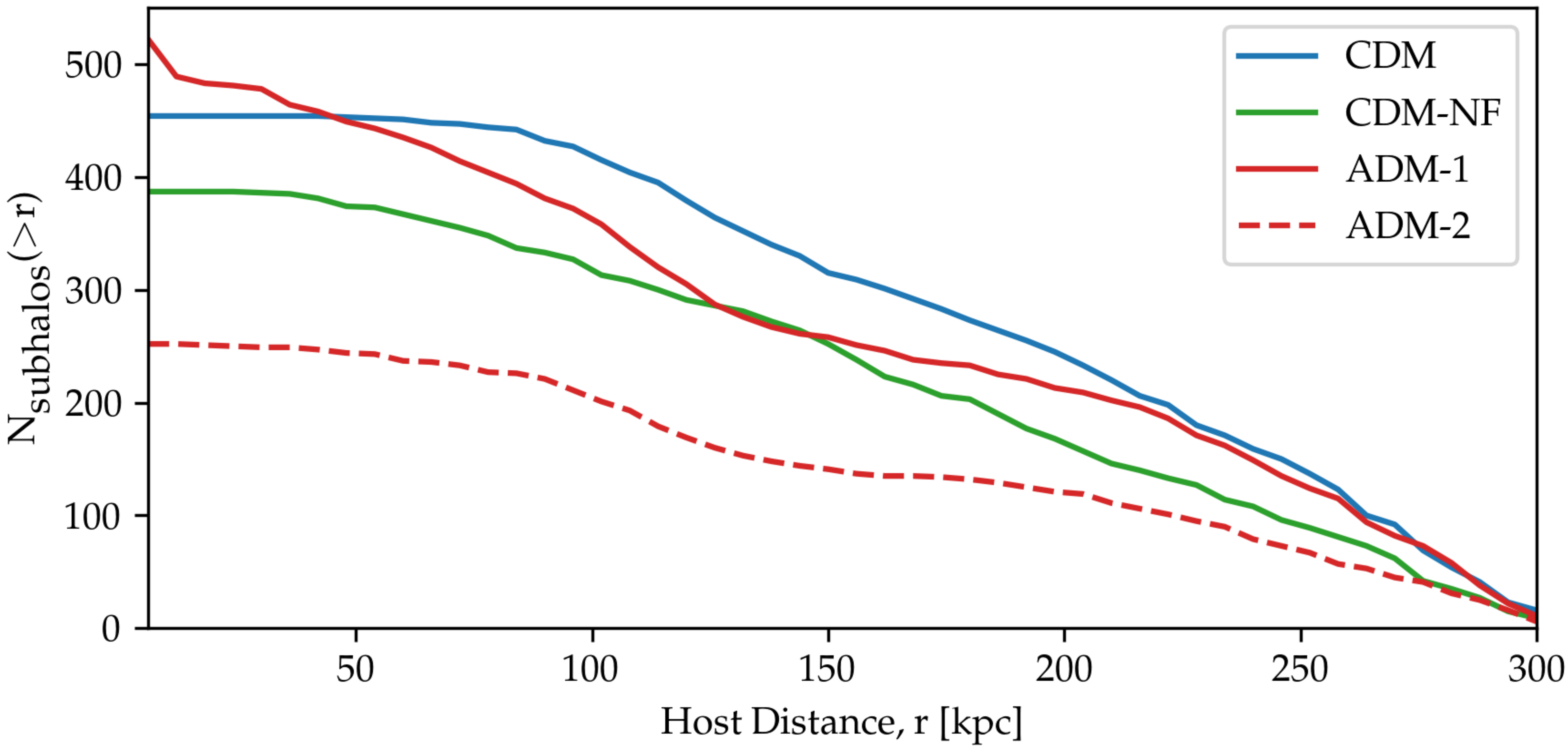


Increased central density could also lead to increased circular velocity values

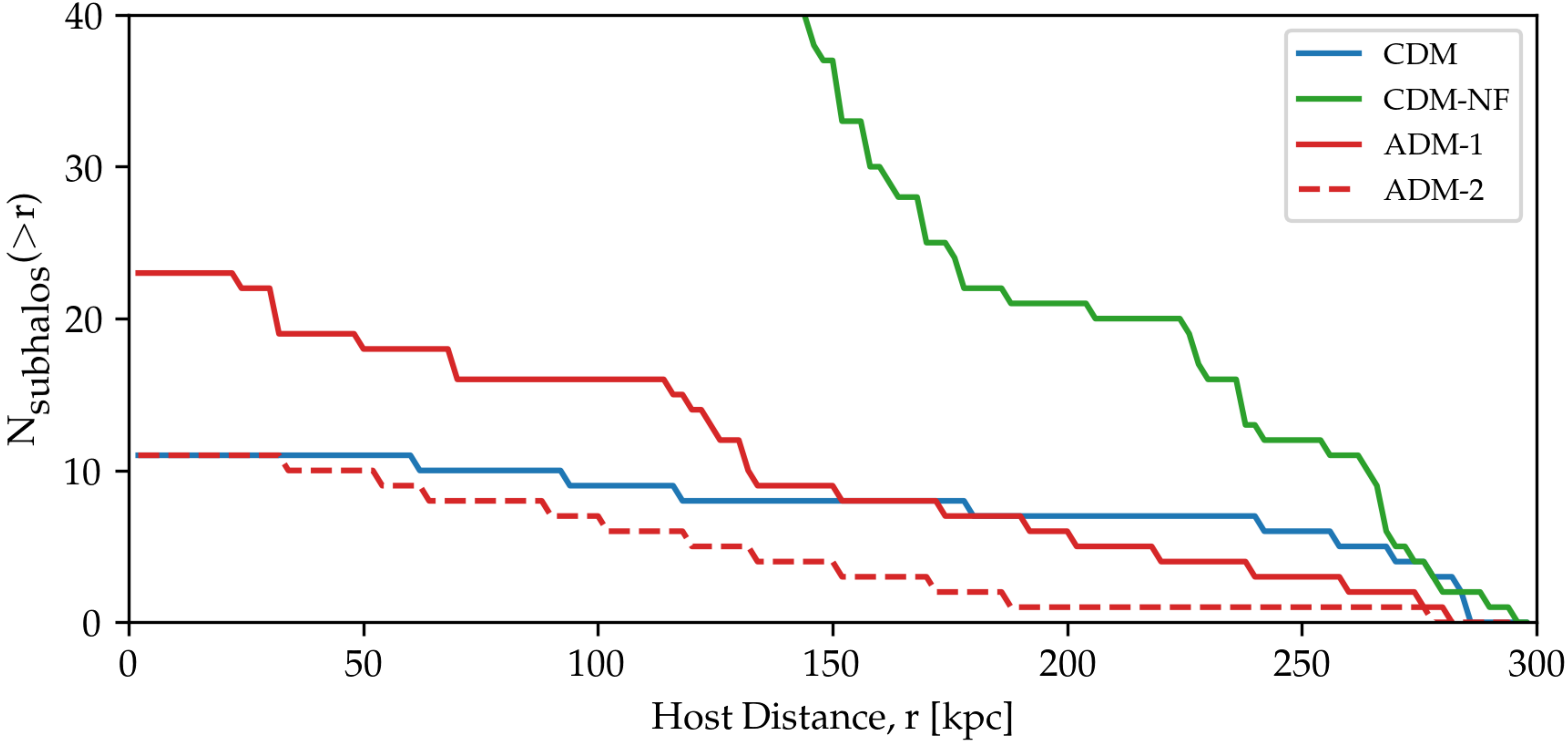
* Data not provided for direct comparison, merely providing context for parameter space



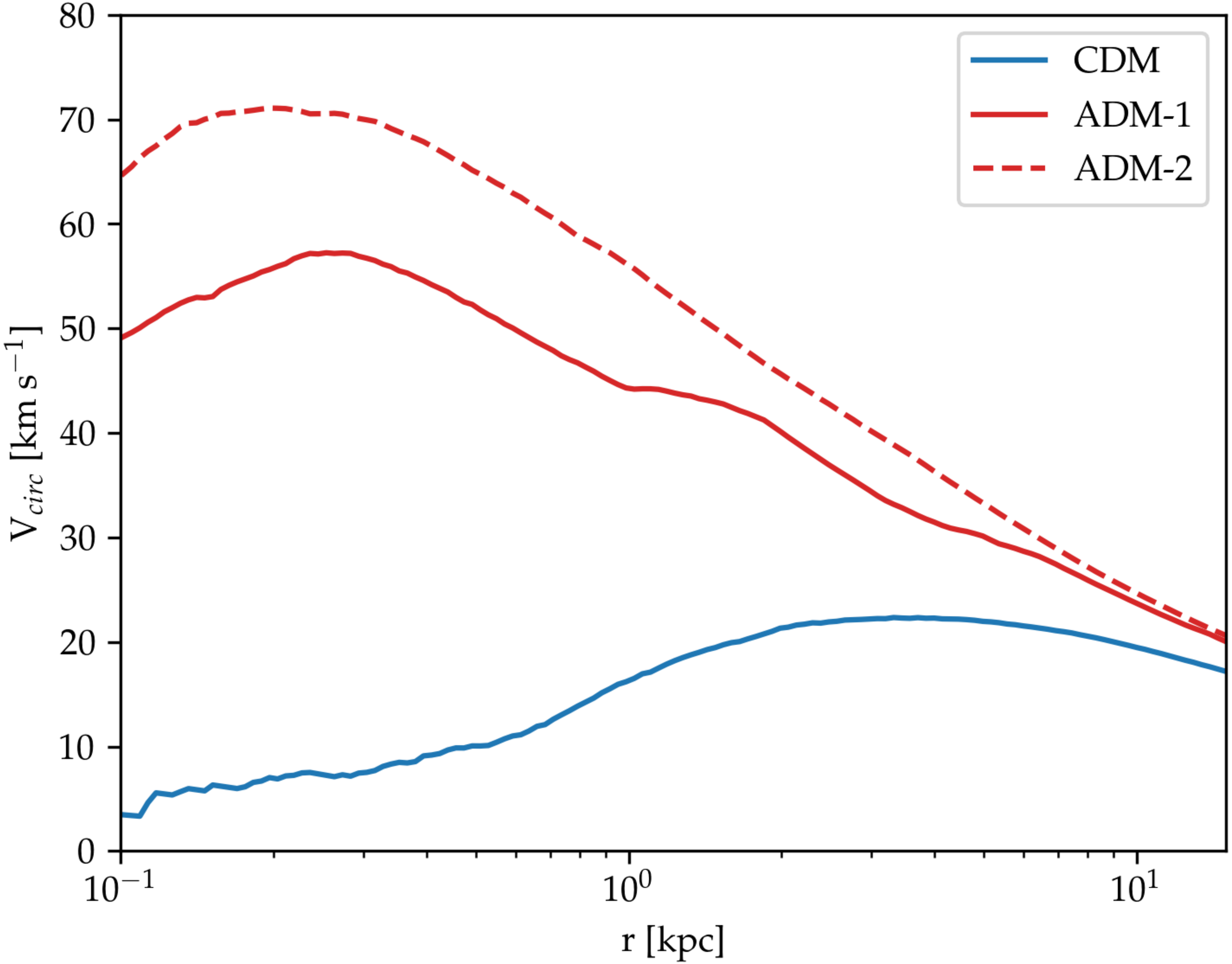
Increased central density could also lead to increased circular velocity values



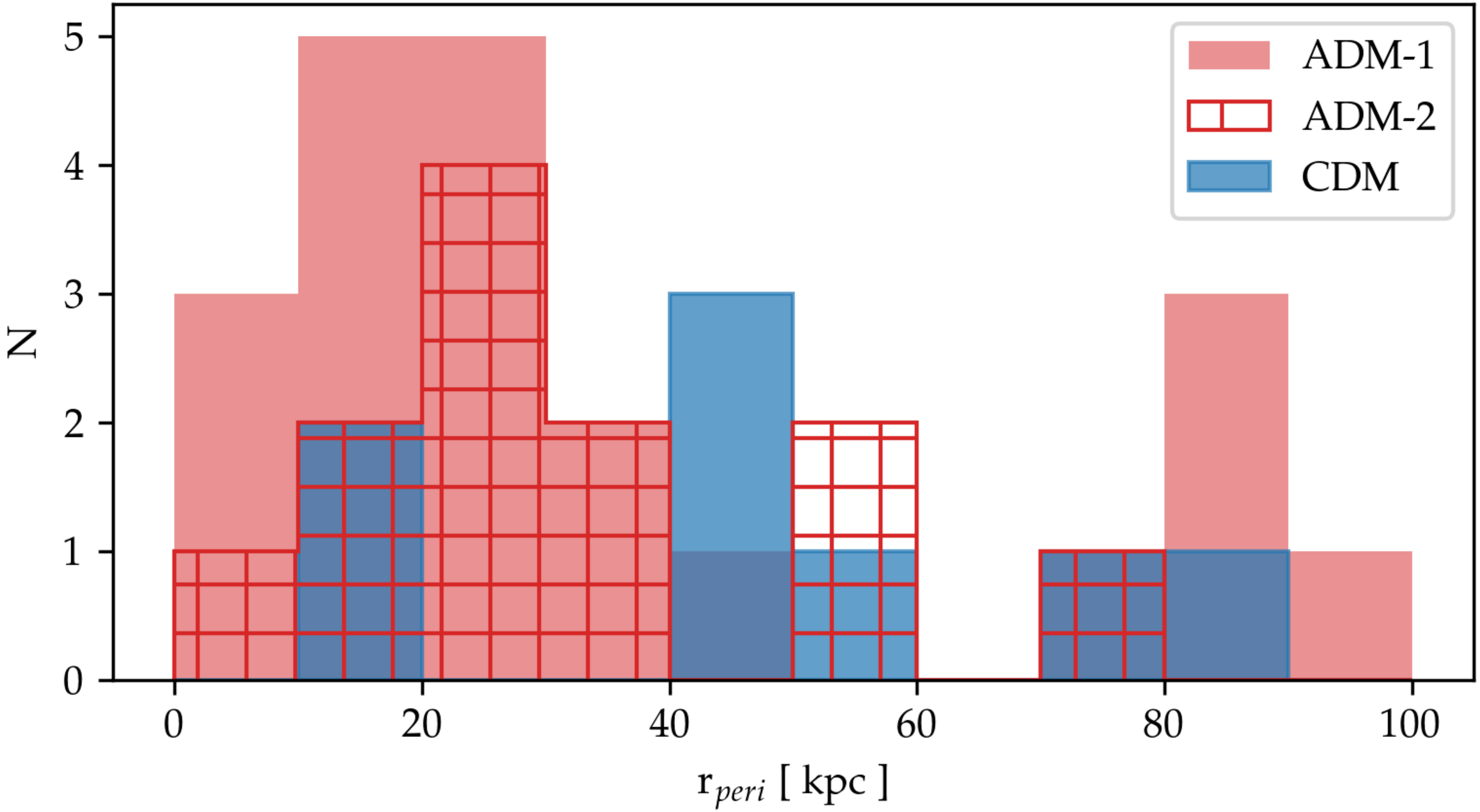
CDM
CDM-NF
ADM-1
ADM-2
0
100
200
300
400
500
50
100
150
200
250
300
$N_{subhalos}(>r)$
Host Distance, r [kpc]



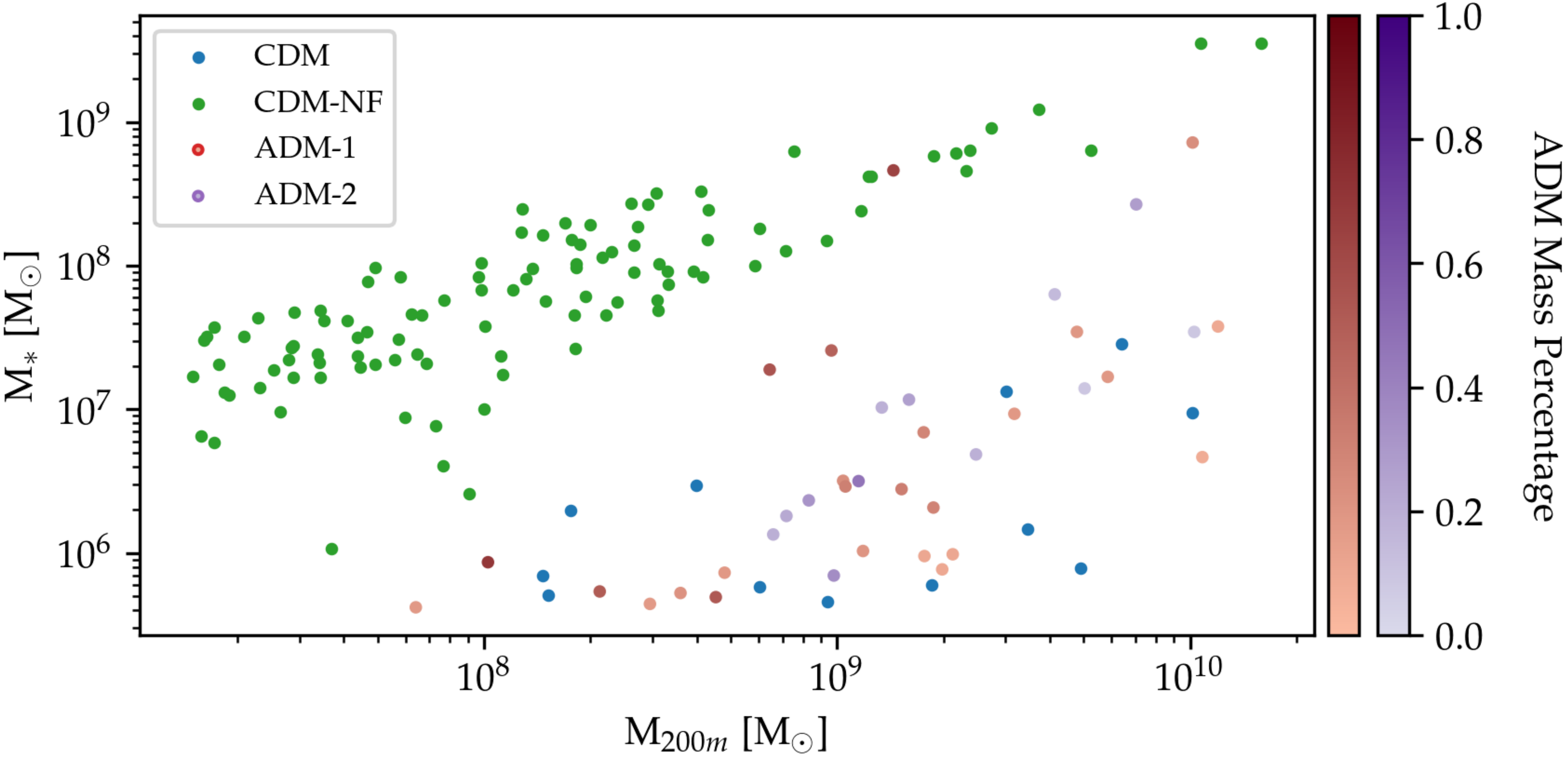
40
30
20
10
0
0
50
100
150
200
250
300
$N_{subhalos}(>r)$
Host Distance, r [kpc]
CDM
CDM-NF
ADM-1
ADM-2



CDM
ADM-1
ADM-2
V_{circ} [km s^{-1}]
r [kpc]
0
10
20
30
40
50
60
70
80
10^{-1}
10^{0}
10^{1}



ADM-1
ADM-2
CDM
N
0
1
2
3
4
5
0
20
40
60
80
100
r_peri [kpc]



CDM
CDM-NF
ADM-1
ADM-2
10^9
10^8
10^7
10^6
M_* [$M_\odot$]
10^8
10^9
10^{10}
M_{200m} [$M_\odot$]
1.0
0.8
0.6
0.4
0.2
0.0
ADM Mass Percentage