Title: Probing Atomic Dark Matter using Simulated Galactic Subhalo Populations

Speakers: Caleb Gemmell

Collection: Dark Matter, First Light

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Abstract: Atomic dark matter (ADM) is a simple extension to the Standard Model that is motivated by considerations in both particle and astrophysics. ADM can alter structure formation on subgalactic scales due to its ability to dissipate energy through cooling mechanisms, but is also one realisation of a possible complex dark sector. These dark sectors have been previously studied as a solution to the little hierarchy problem. Recently the first N-body simulations were completed, studying the effects of cold dark matter with a ADM subcomponent (6%) and are only beginning to be analysed. In this talk I present how the dissipative nature of ADM affects both the distribution and structure of subhalos in a Milky Way analogue, and outline how we may hope to constrain and probe the ADM parameter space.

Probing Atomic Dark Matter (ADM) using Simulated Subhalo Populations

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arXiv: 2311.02148

Dark Matter, First Light
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Outline:

1. ADM and N-body simulations recap
2. How does ADM change DM subhalo structure ?
3. Do these differences affect subhalo distributions ?
4. Do these differences affect satellite galaxies ?

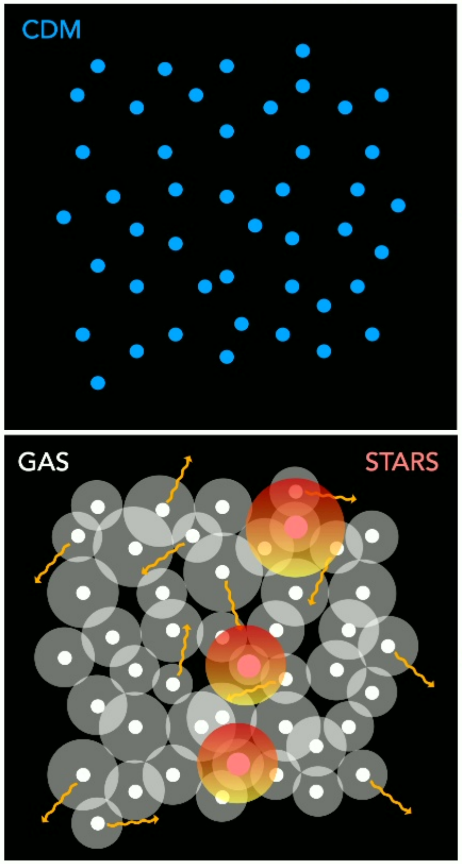
Quickly Recap Motivation:

- 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, dark U(1)
  - Can address naturalness issues, e.g. Little Hierarchy Problem
  - Inspired by the complexity of the SM

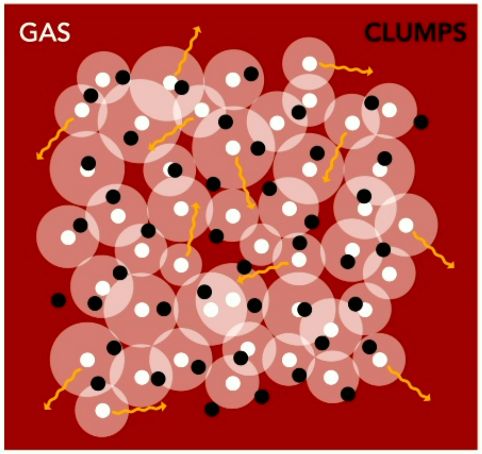
ADM in GIZMO (summary)

GIZMO: N-Body Hydrodynamics Code

Hopkins et al. (1409.7395 & 1702.06148)



ADM



Credit: Sandip Roy

Physics	Particles
Gravity	All
Cooling & fragmenting	Gas & ADM Gas
Supernovae feedback	Stars (& Gas)

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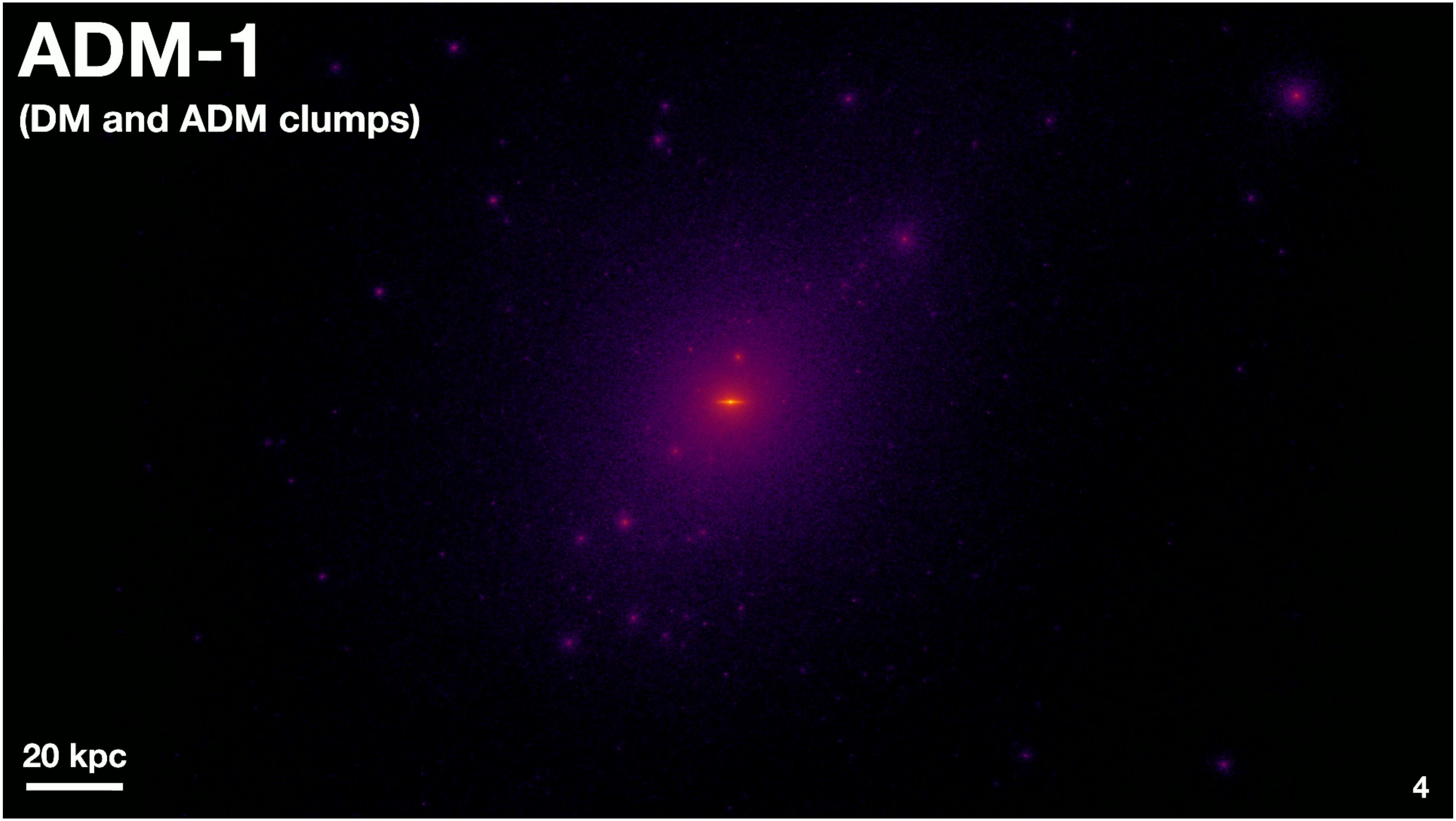
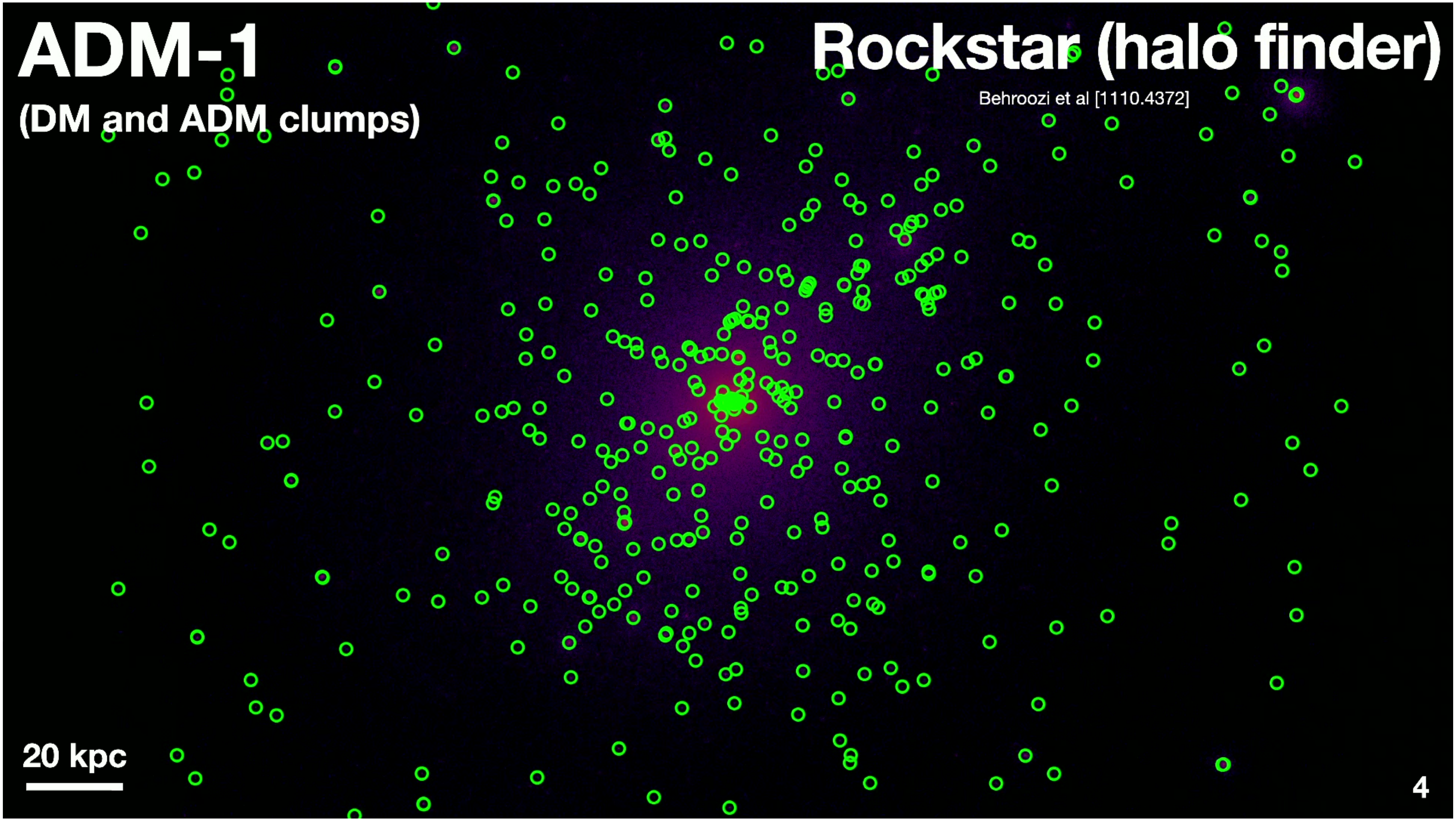
ADM in GIZMO (summary)

GIZMO: N-Body Hydrodynamics Code

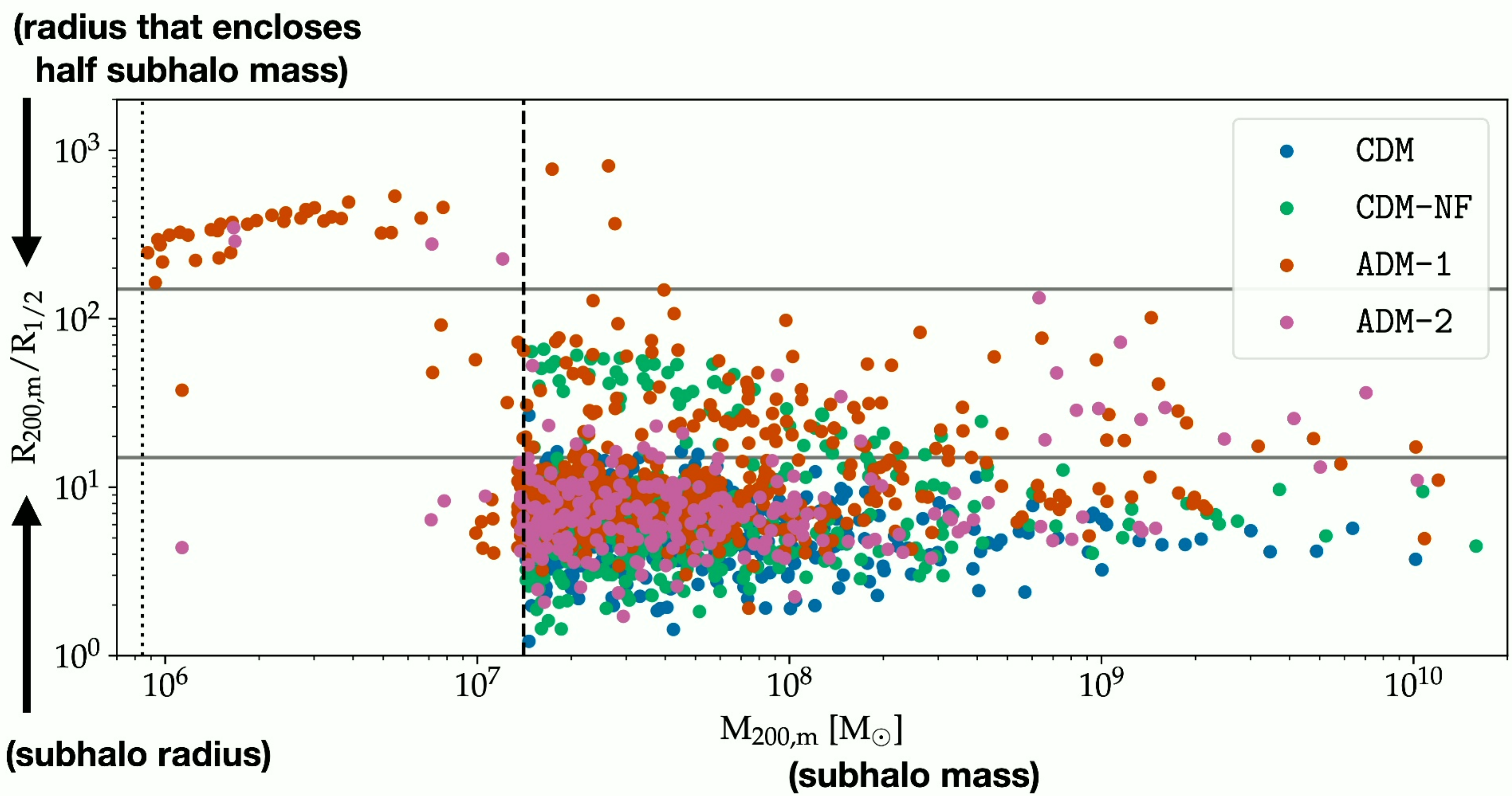
Hopkins et al. (1409.7395 & 1702.06148)

Simulation	Included Species	$\frac{\Omega_{cdm}}{\Omega_m}$	$\frac{m_{cdm}}{M_\odot}$	$\frac{\Omega_{adm}}{\Omega_{dm}}$	$\frac{m_{adm}}{M_\odot}$	$\frac{\Omega_b}{\Omega_m}$	$\frac{m_b}{M_\odot}$	$\frac{\alpha'}{\alpha}$	$\frac{m_{p'}}{m_p}$	$\frac{m_{e'}}{m_e}$	$\frac{T_{cmb'}}{T_{cmb}}$
CDM	CDM+Bar.	0.83	2.79×10^5	0	-	0.17	5.6×10^4	-	-	-	-
CDM-NF	CDM+Bar., no FB	0.83	2.79×10^5	0	-	0.17	5.6×10^4	-	-	-	-
ADM-1	CDM+ADM-1+Bar.	0.78	2.62×10^5	0.06	1.67×10^4	0.17	5.6×10^4	$1/\sqrt{0.55}$	1.3	0.55	0.39
ADM-2	CDM+ADM-2+Bar.	0.78	2.62×10^5	0.06	1.67×10^4	0.17	5.6×10^4	2.5	1.3	0.55	0.39


ADM-1
(DM and ADM clumps)
20 kpc
4



ADM-1
(DM and ADM clumps)
Rockstar (halo finder)
Behroozi et al [1110.4372]
20 kpc
4



(radius that encloses half subhalo mass)
$R_{200,m}/R_{1/2}$
10^3
10^2
10^1
10^0
10^6
10^7
10^8
10^9
10^{10}
$M_{200,m}$ $[M_\odot]$
CDM
CDM-NF
ADM-1
ADM-2
(subhalo radius)
(subhalo mass)

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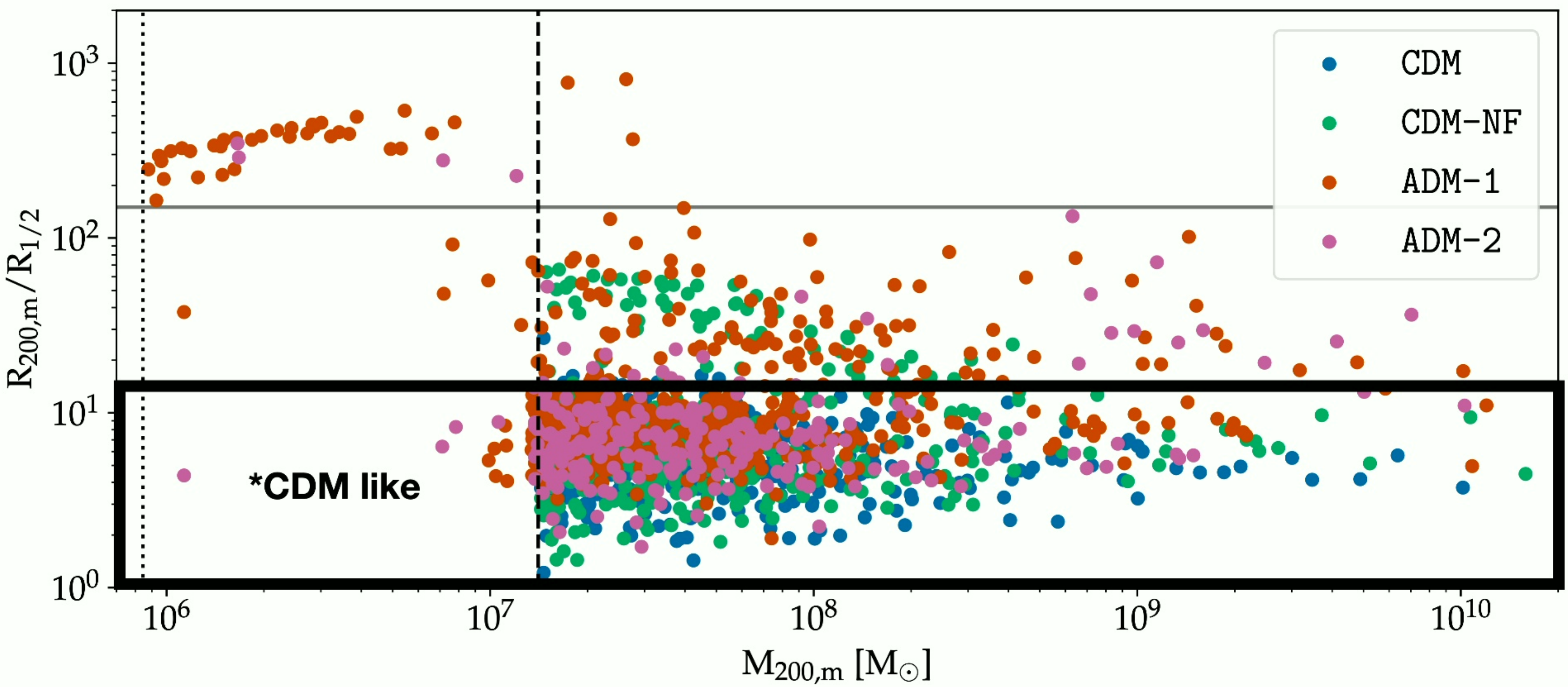

10^3
10^2
10^1
10^0
$R_{200,m}/R_{1/2}$
10^6
10^7
10^8
10^9
10^{10}
$M_{200,m}$ [$M_\odot$]
CDM
CDM-NF
ADM-1
ADM-2
*CDM like

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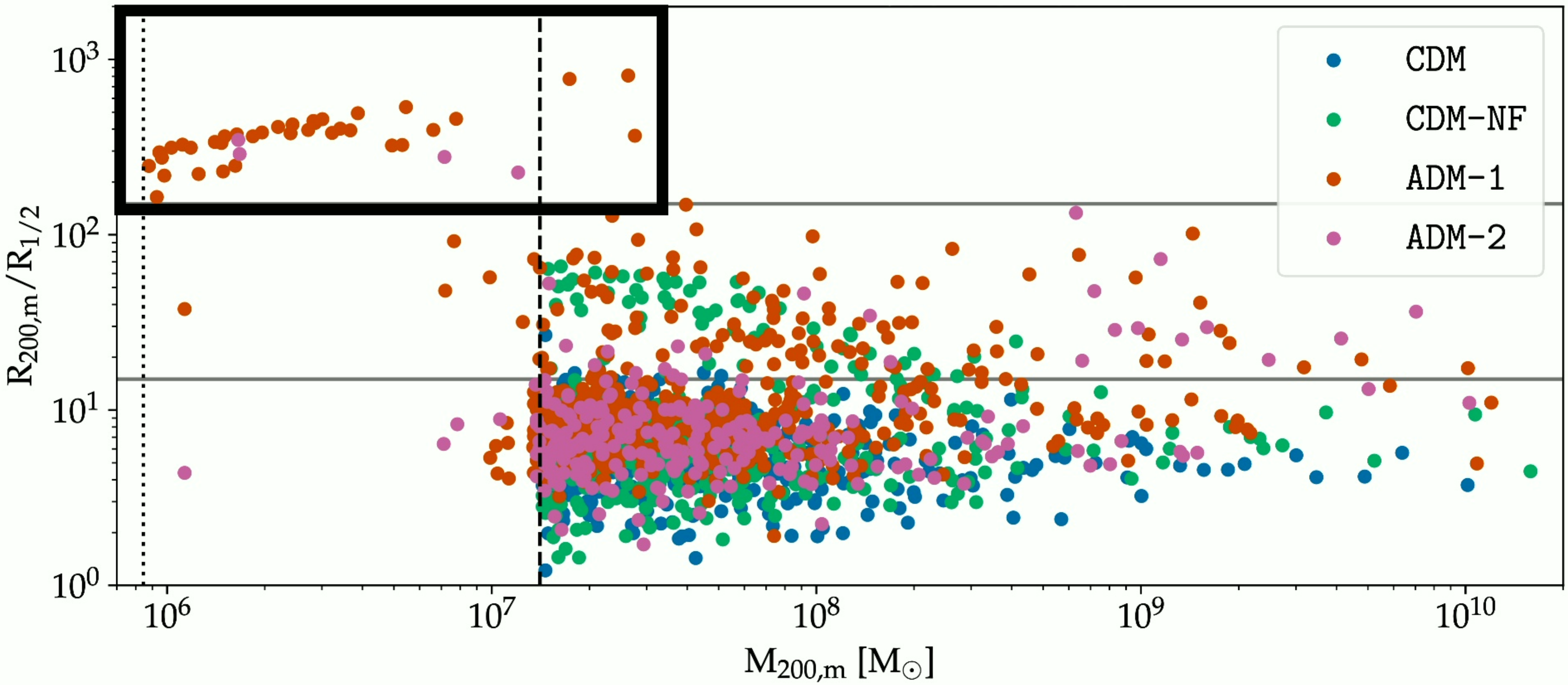
*ADM dominated
(Mostly found in disk)



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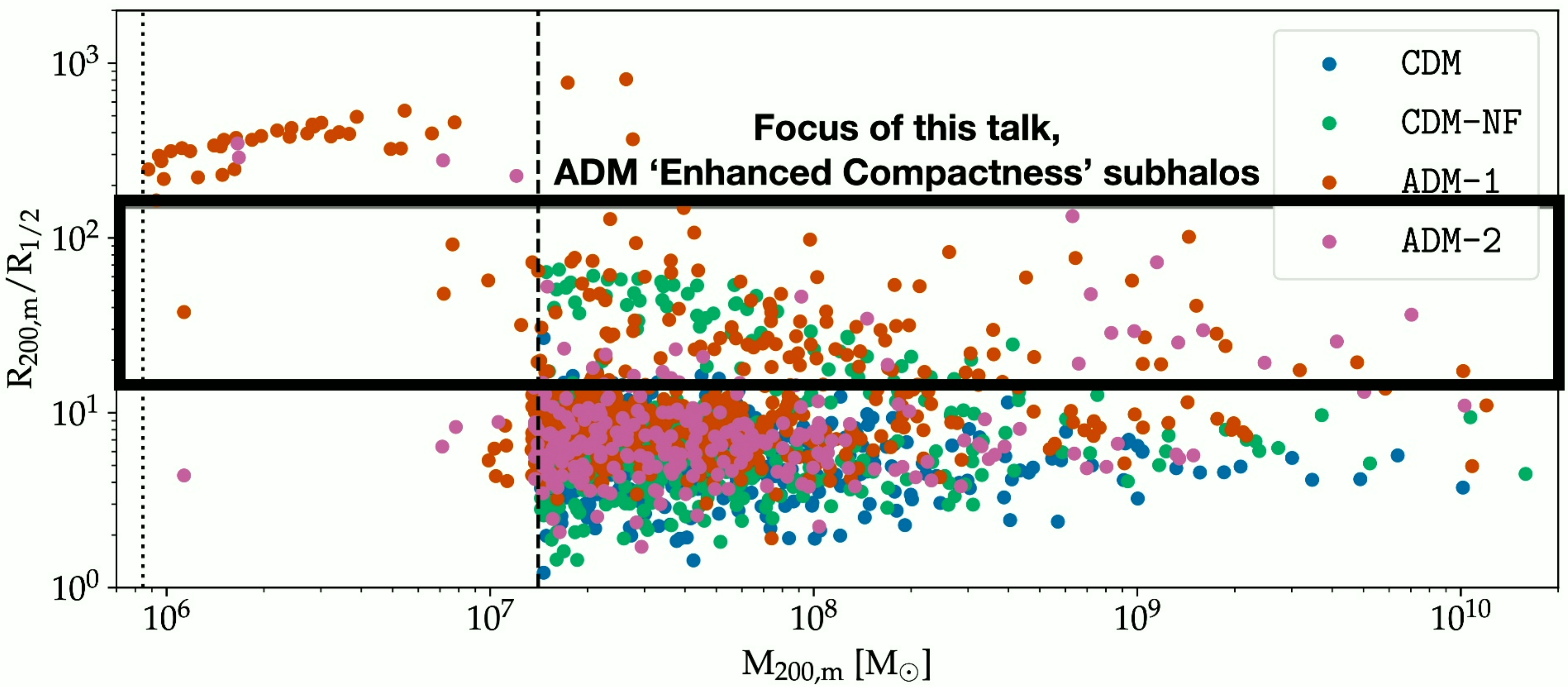
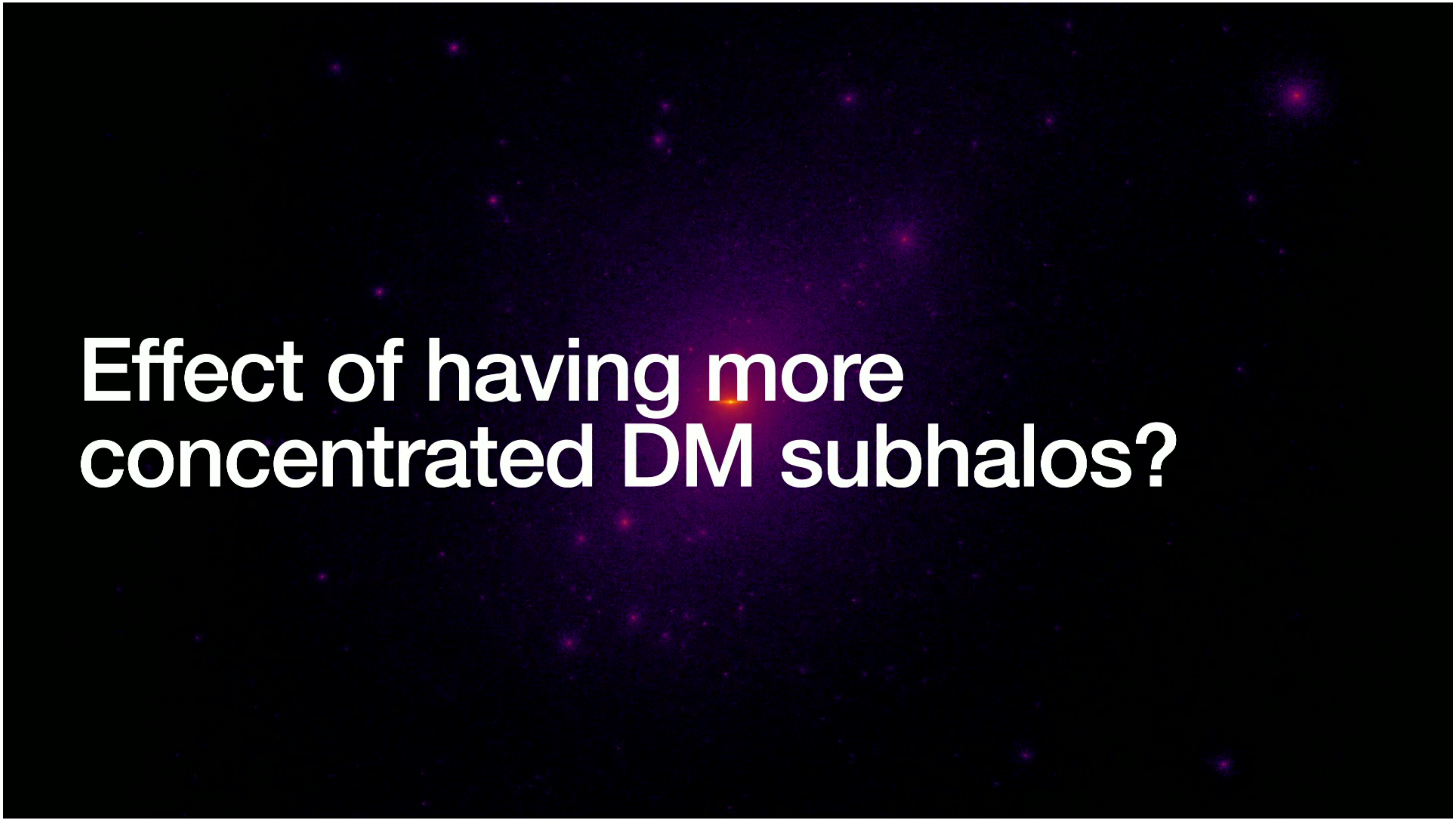
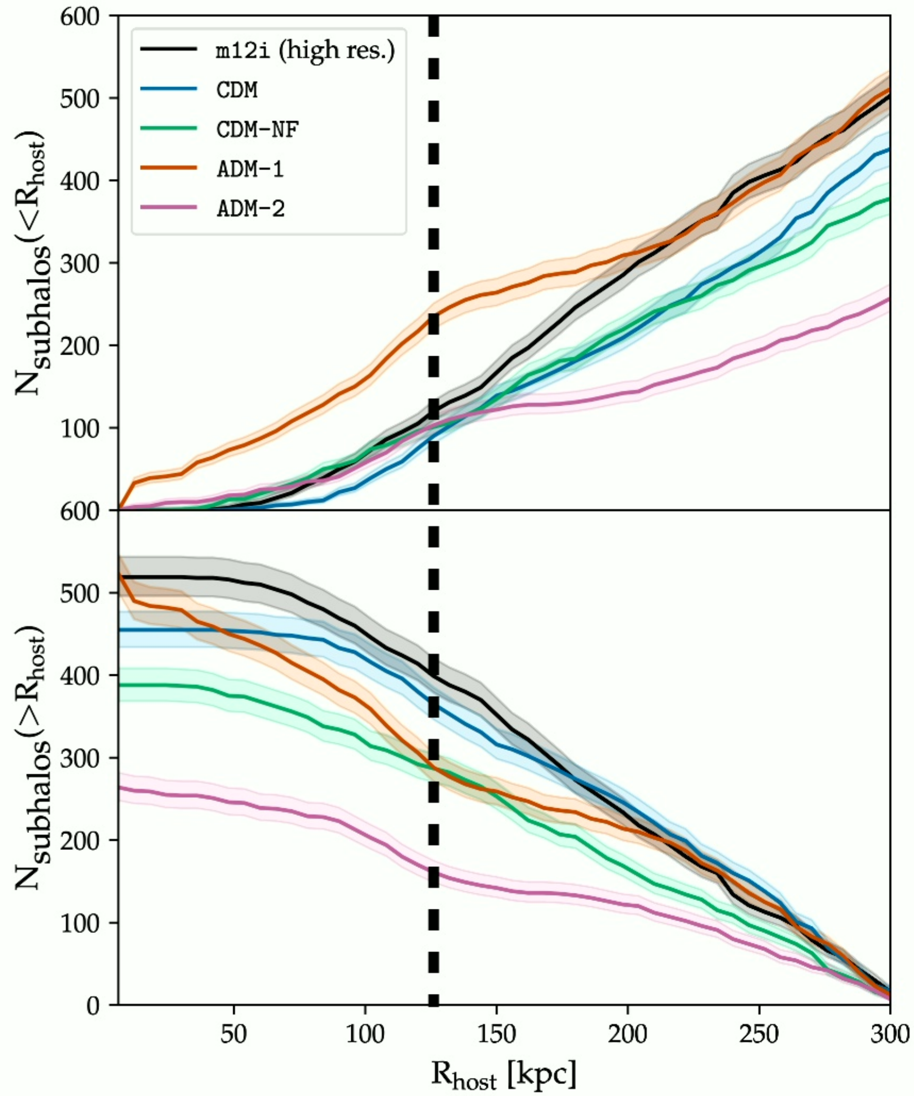

Focus of this talk,
ADM 'Enhanced Compactness' subhalos
CDM
CDM-NF
ADM-1
ADM-2
10^3
10^2
10^1
10^0
$R_{200,m}/R_{1/2}$
10^6
10^7
10^8
10^9
10^{10}
$M_{200,m}$ [$M_\odot$]

8

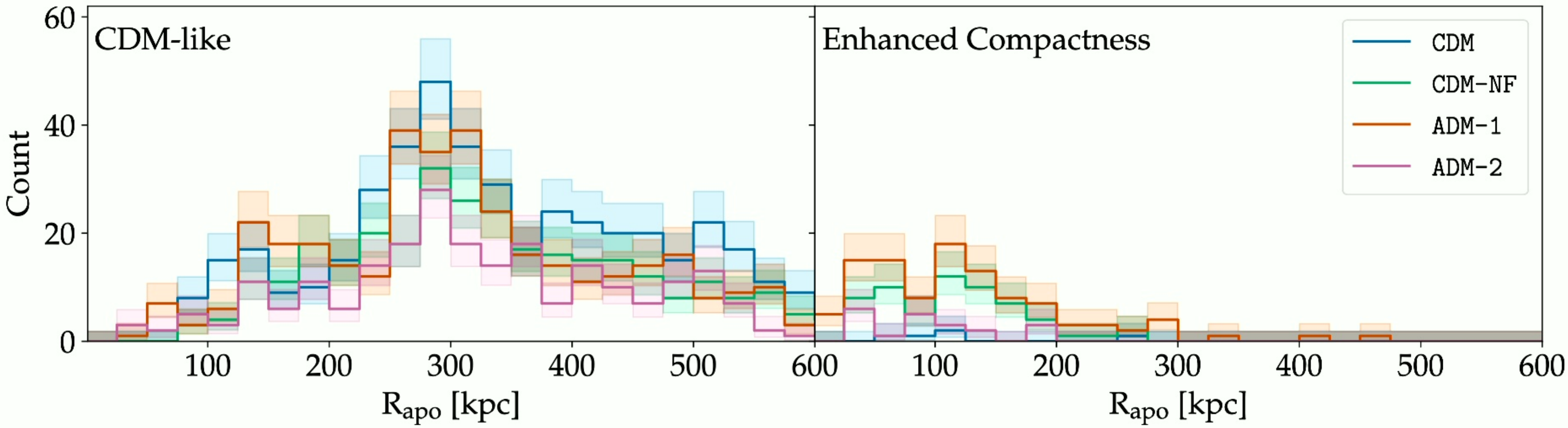

Effect of having more concentrated DM subhalos?

Radial Distribution



ADM appears to increase the relative fraction of subhalos at closer host distances.

Orbital Parameters



Subhalos with enhanced compactness are likely surviving small pericentric passages, resulting in smaller apocenters.

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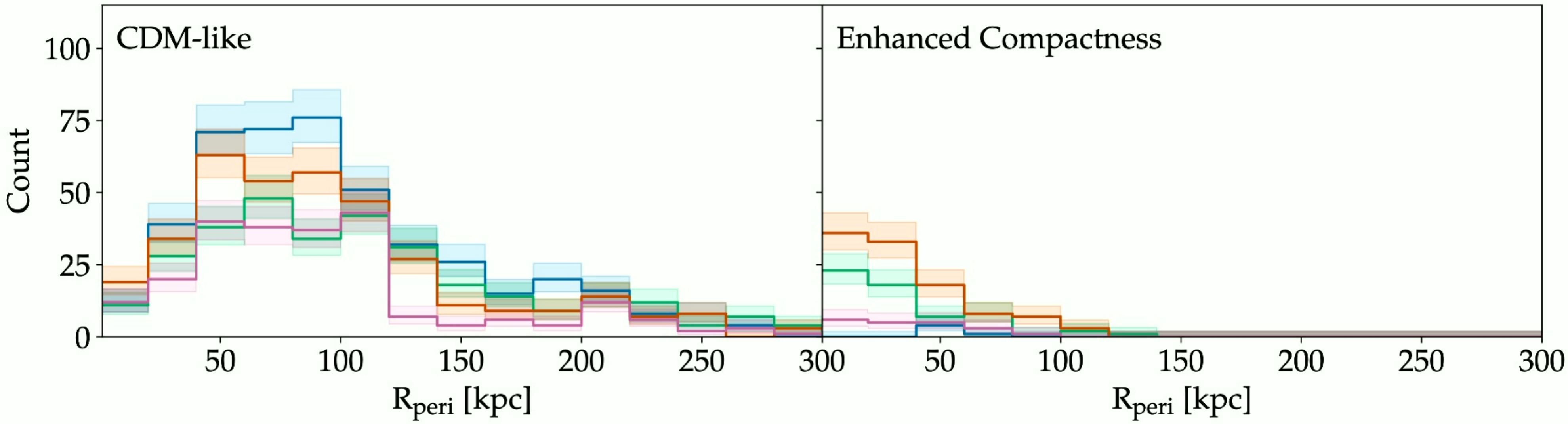
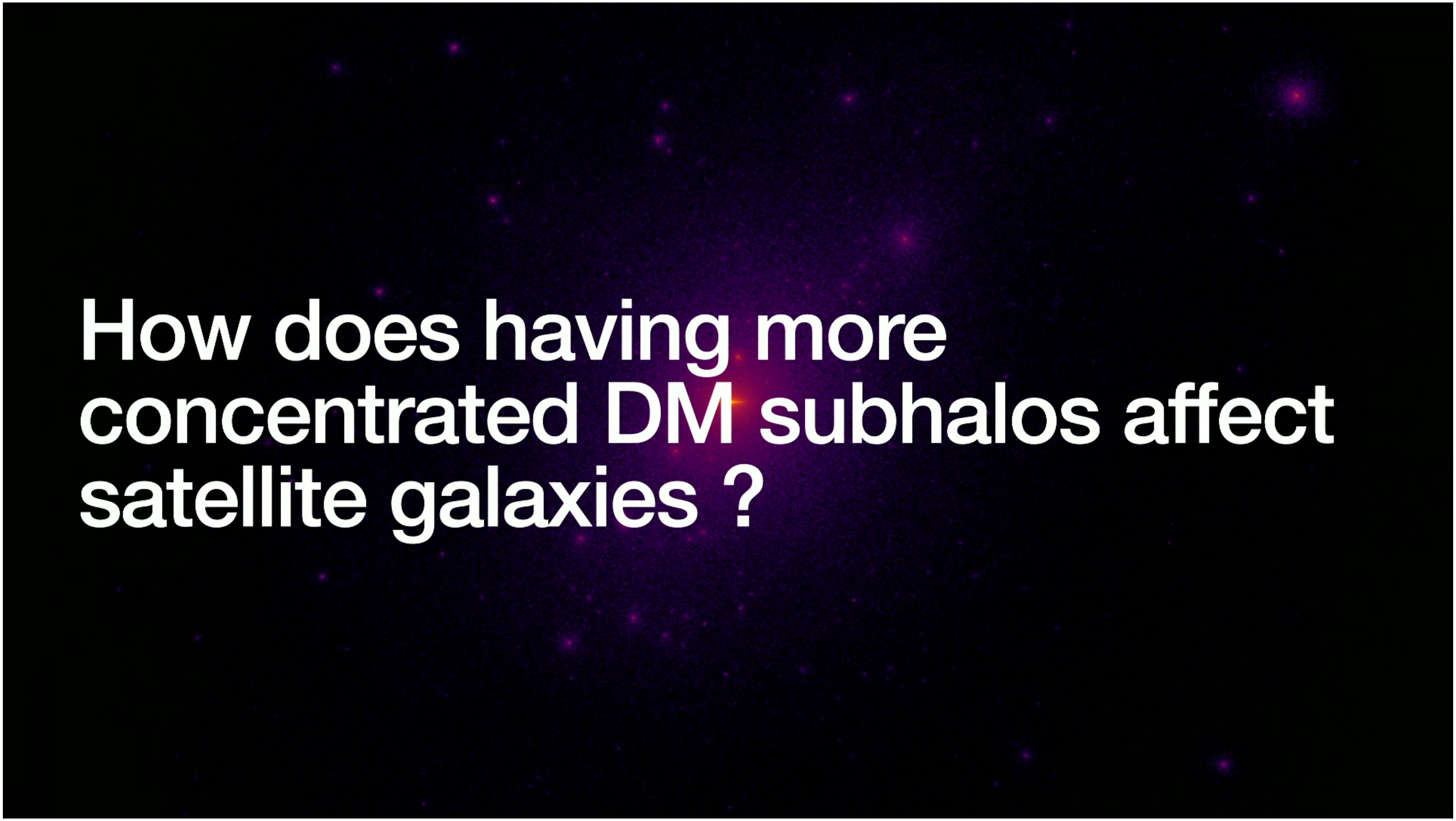
Orbital Parameters

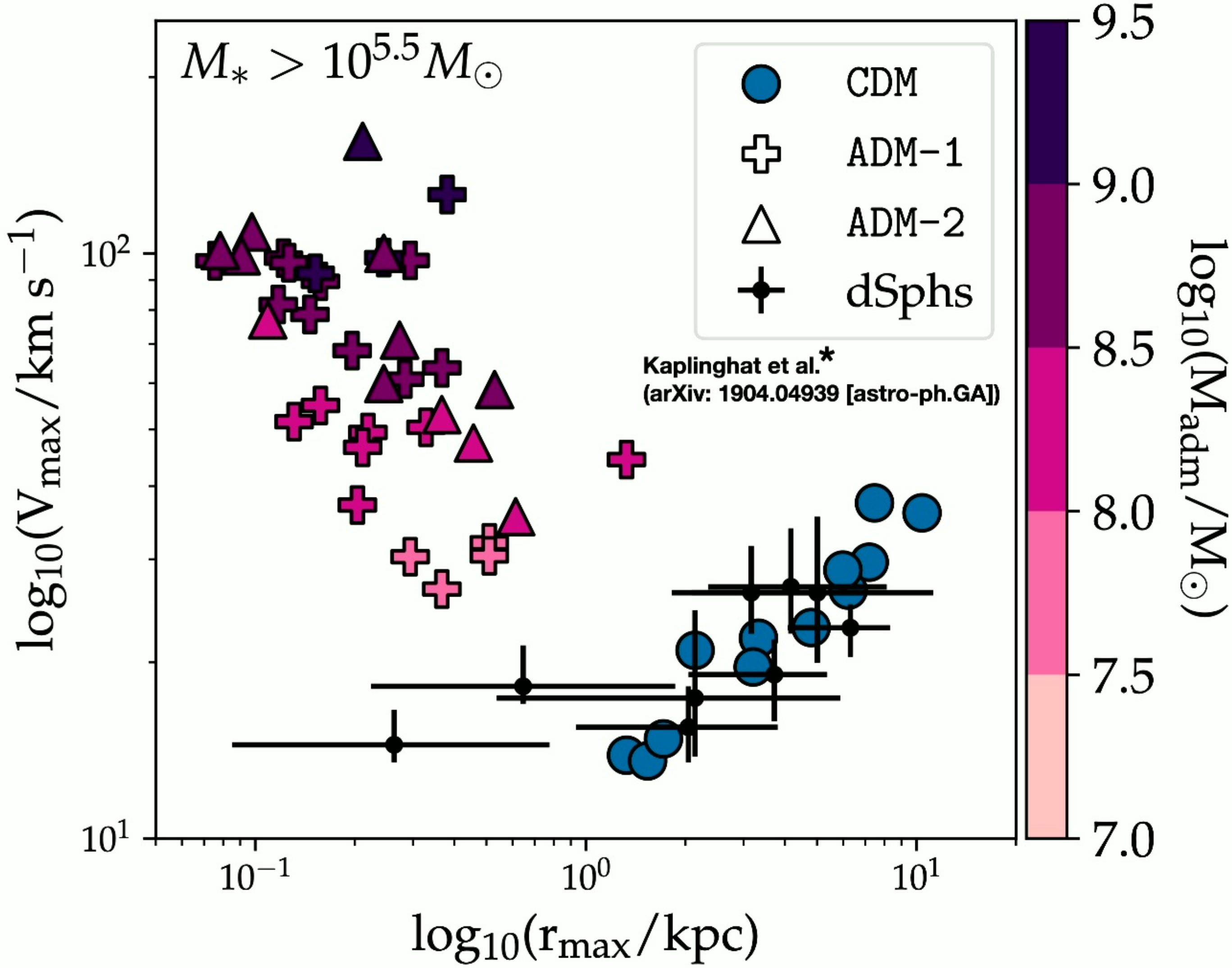


Subhalos with enhanced compactness are likely surviving small pericentric passages, resulting in smaller apocenters.

This is also supported by the pericenter distribution.
Interesting for future stellar stream studies.


How does having more concentrated DM subhalos affect satellite galaxies ?

Circular Velocities



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

Conclusions:

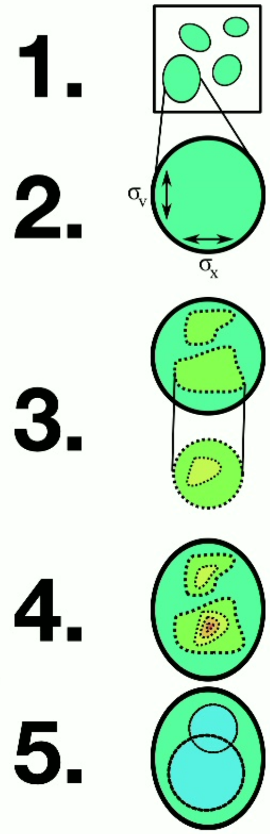
- In the parameter points we have simulated, ADM is able to cool efficiently, enhancing the central densities of DM subbhalos
- Also can form dense, concentrated ADM dominated subhalos in the disk
- This is having a large influence over a variety of galactic observables (AT ONLY 6% ADM FRACTION)
- Future investigations into high-res simulation of isolated/field dwarf galaxy to support this study… stellar streams…

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

$$\sigma = \left[\left(\frac{f_{\rm adm}}{N_{\rm adm}^{1/2}}\right)^2 + \left(\frac{f_{\rm cdm}}{N_{\rm cdm}^{1/2}}\right)^2\right]^{1/2} < \frac{1}{\sqrt{N_{\rm cut}}} < \frac{1}{\sqrt{50}}$$



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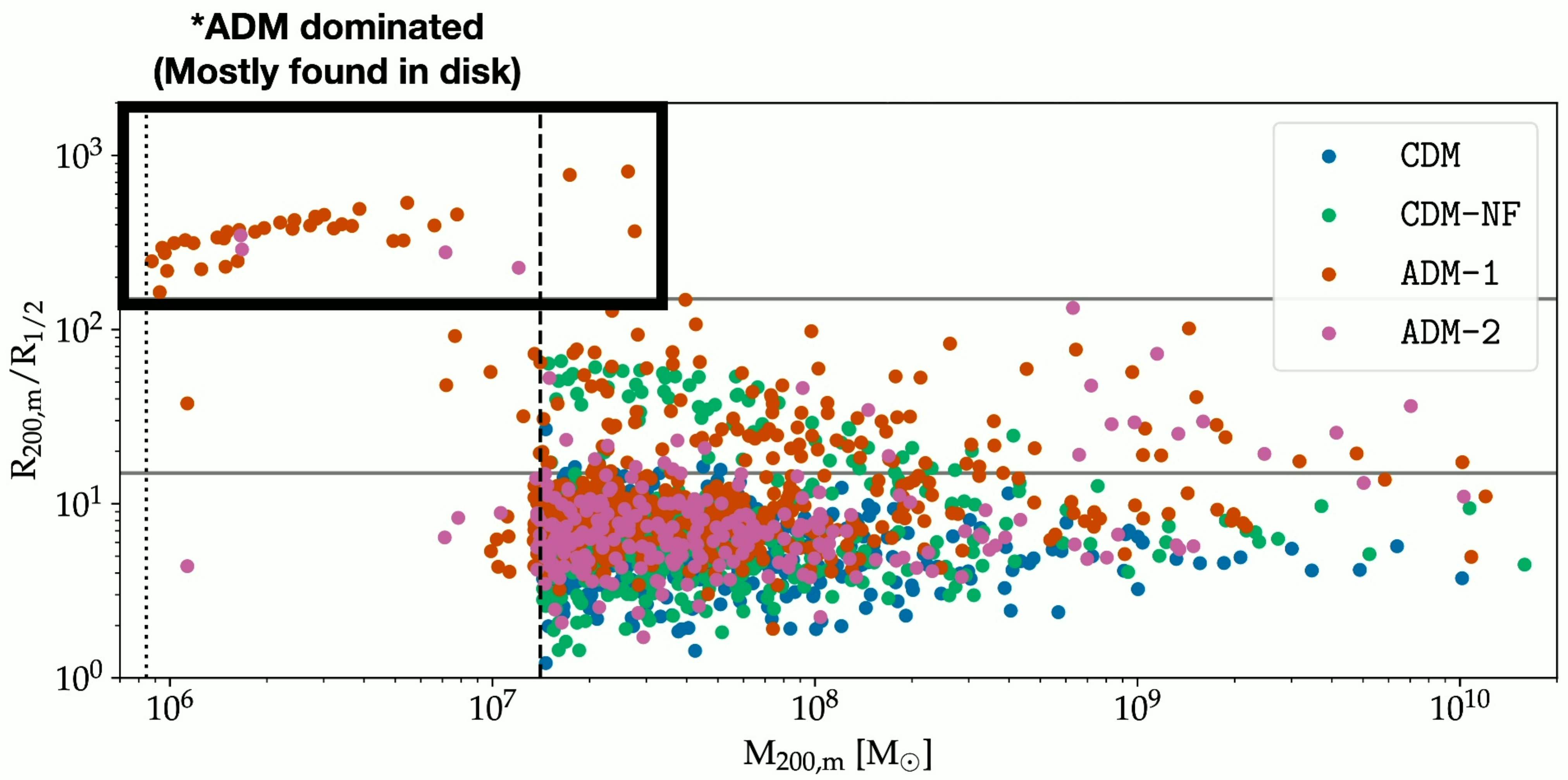

*ADM dominated
(Mostly found in disk)
CDM
CDM-NF
ADM-1
ADM-2
$R_{200,m}/R_{1/2}$
$M_{200,m}$ [$M_\odot$]

7