Novel Challenges in Tracking Self-Interacting Dark Matter Subhalos

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Based on arXiv:2506.xxxxx

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Background

- For N-body simulations, we need tools to determine what are the (sub)halos and follow them across simulation times.
- Finding field halos is mostly a solved problem, while multiple groups still actively working on subhalo finders.
- A complete subhalo population is necessary to compare with observations.

Many Tools with Many Methods

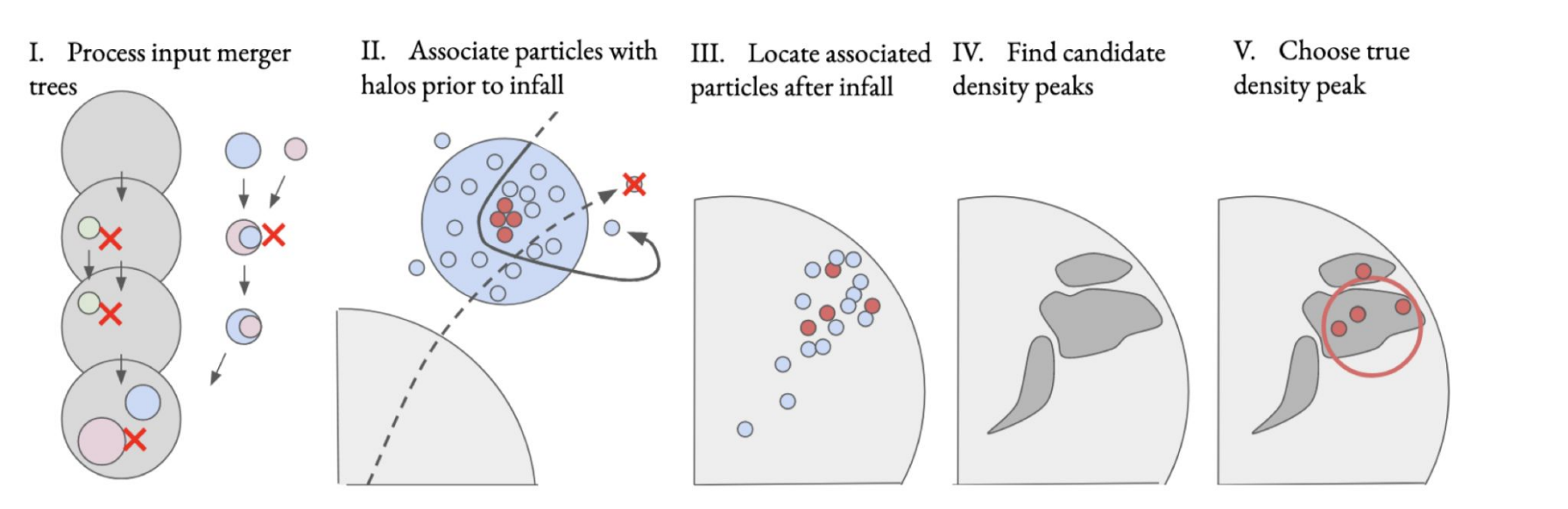
- Many methods: Configuration-Based; Phase Space (velocity + position); Particle-Based

- Many Tools: Subfind (Springel+01), AHF (Knollmann & Knebe+09), SURV (Giocoli+10), Rockstar (Behroozi+11), HBT/HBT+ (Han+11, Han+17), SPARTA (Diemer+17, Diemer+20),VELOCIraptor (Elahi+19), Symfind (Mansfield+24), Bloodhound (Kong+25), and more..

Revisiting with SIDM N-body Simulations

- Most of these tools are built with CDM simulations.
- Many particle-based tools are very successful in recovering more subhalos in CDM simulations by tagging the most-bound particle(s) as core particles.
- Thus, the evolution of core particles is very important to the success of halo finder.
- We revisited the particle-based tool Symfind using the SIDM Concerto simulations in comparison with Rockstar+Consistent-Trees.

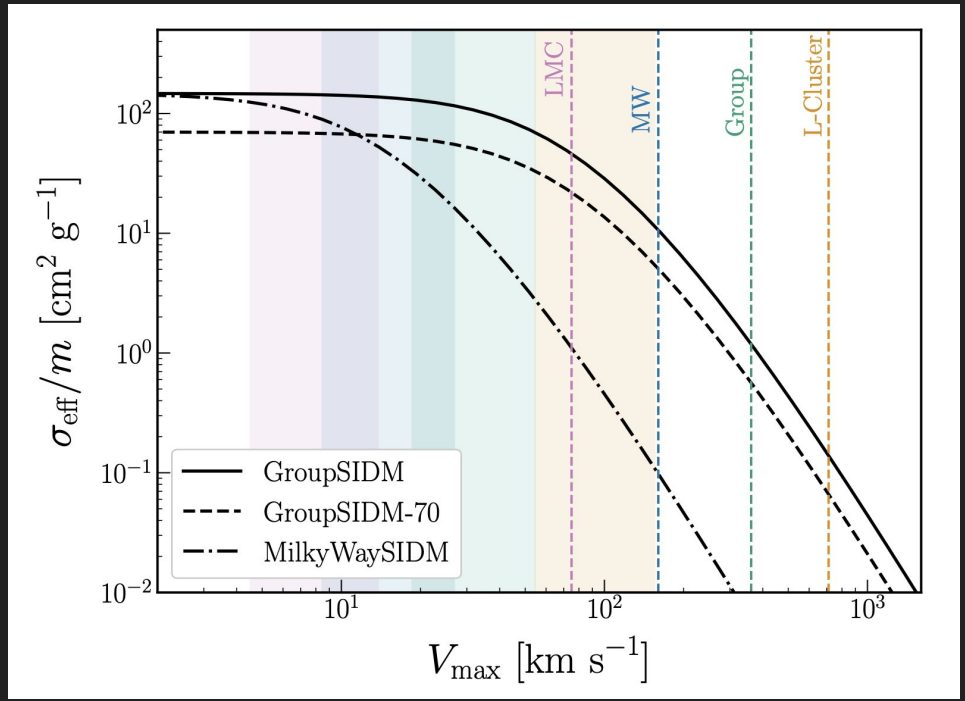
Symfind Overview



Credit: Mansfield+24

Zoom-in Simulations

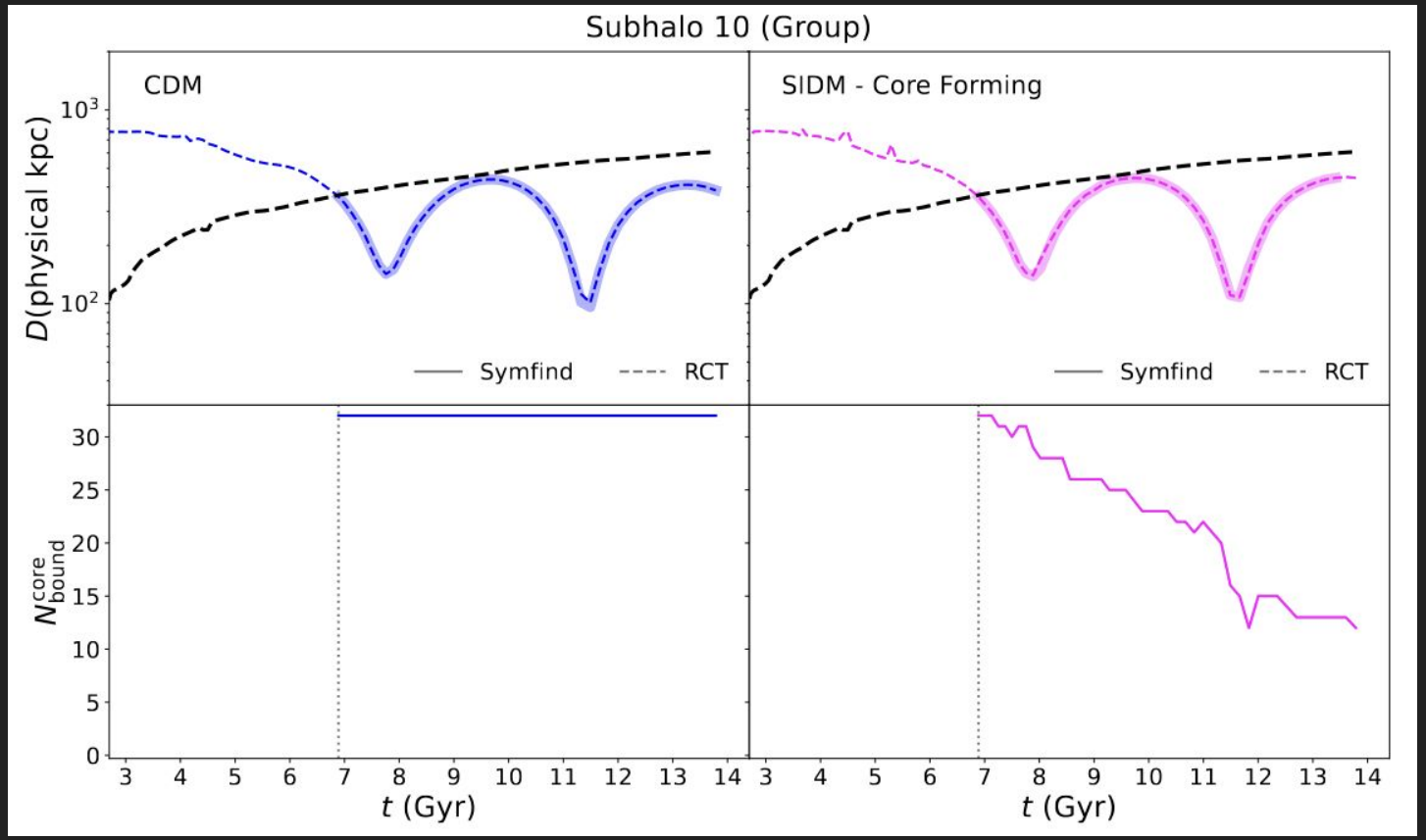
- We used SIDM zoom-in simulation suite: SIDM Concerto.
  - Resimulated from CDM zoom-ins
  - One-to-One subhalo comparison
  - One-to-One catalog comparison
  - Multiple velocity-depend SIDM models
- We focus on the Group Scale System (10^13 Solar Mass) with GroupSIDM model for case studies.



Credit: Nadler, Kong...+2503.10748

14 high-resolution simulations and data are publicly released

Subhalos with a Large Core



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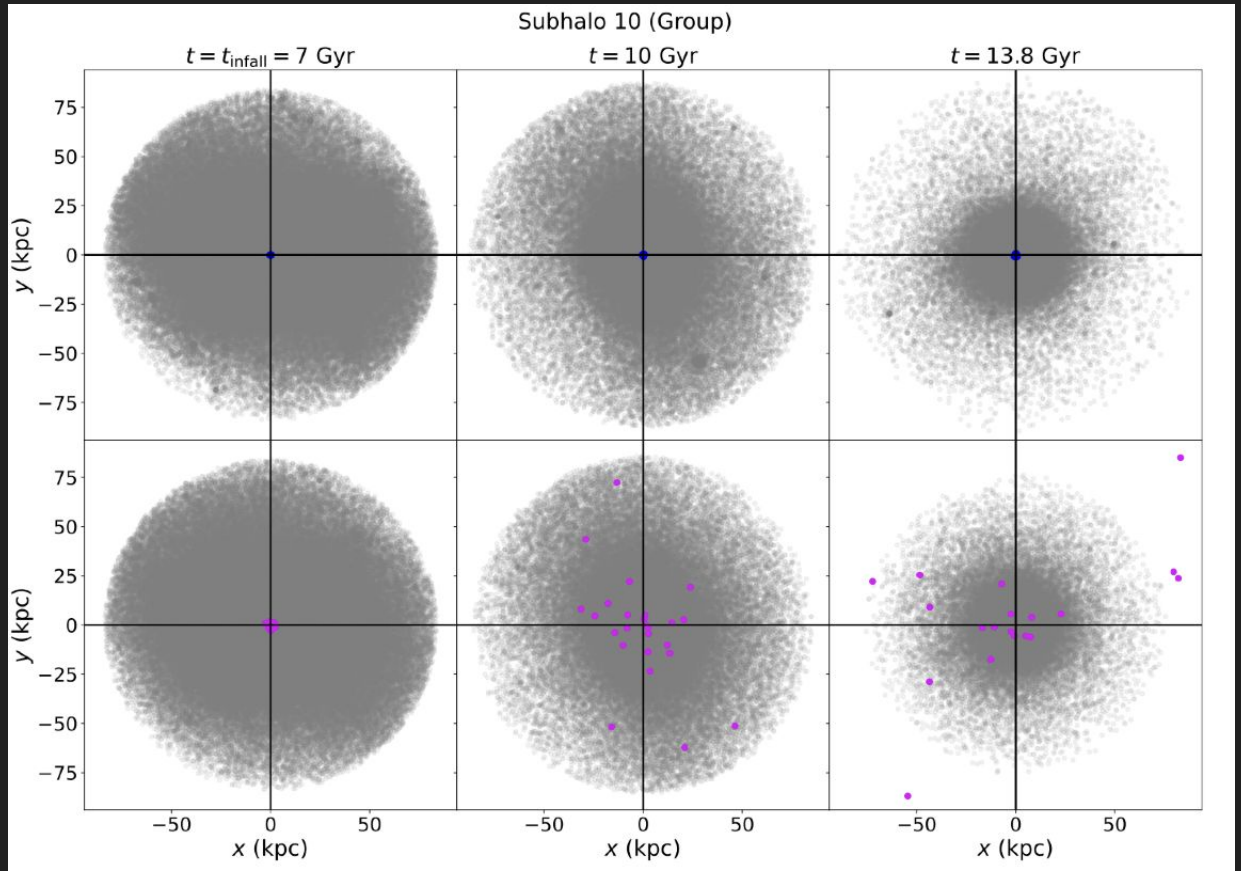
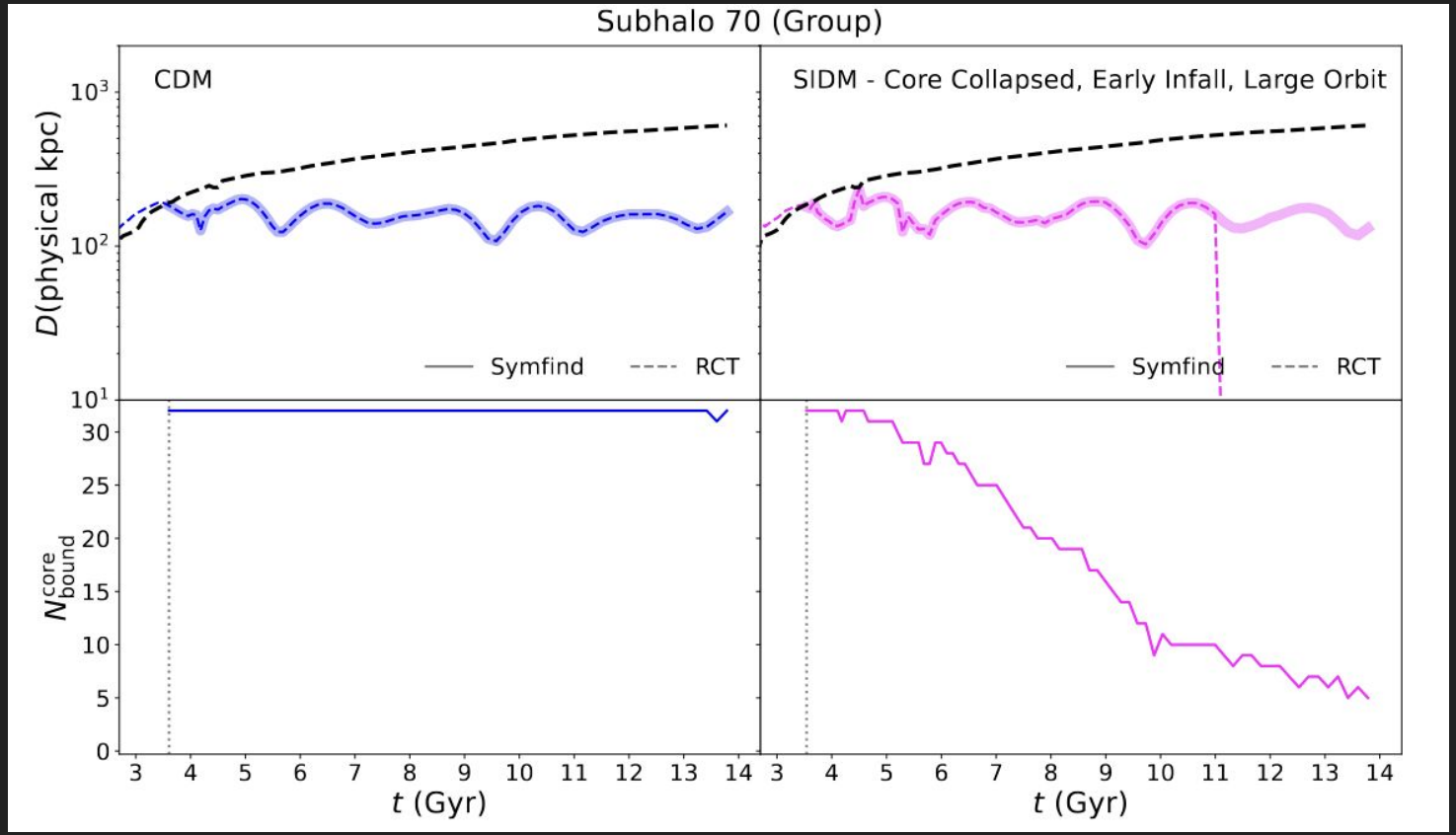
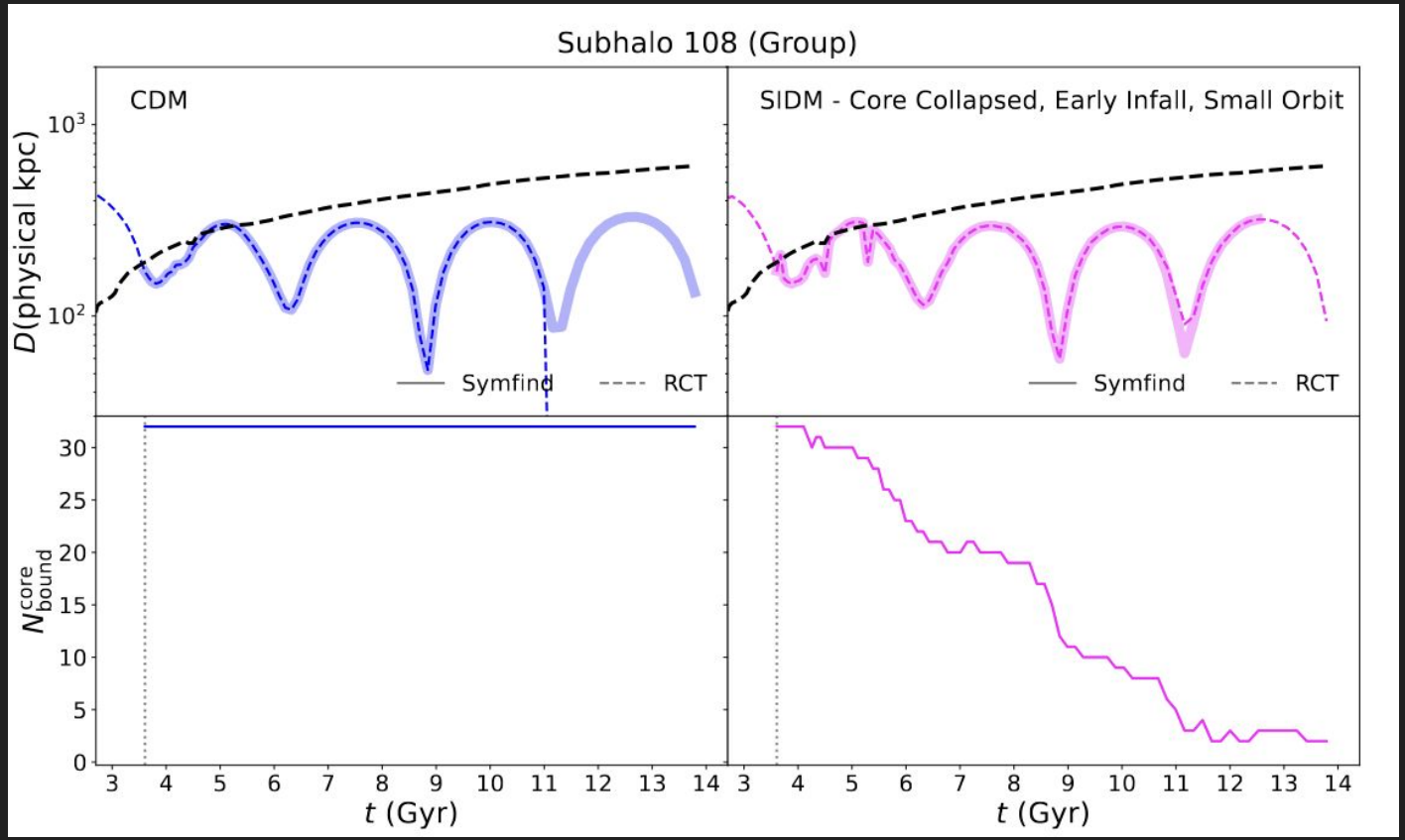


Core Collapsed Subhalos



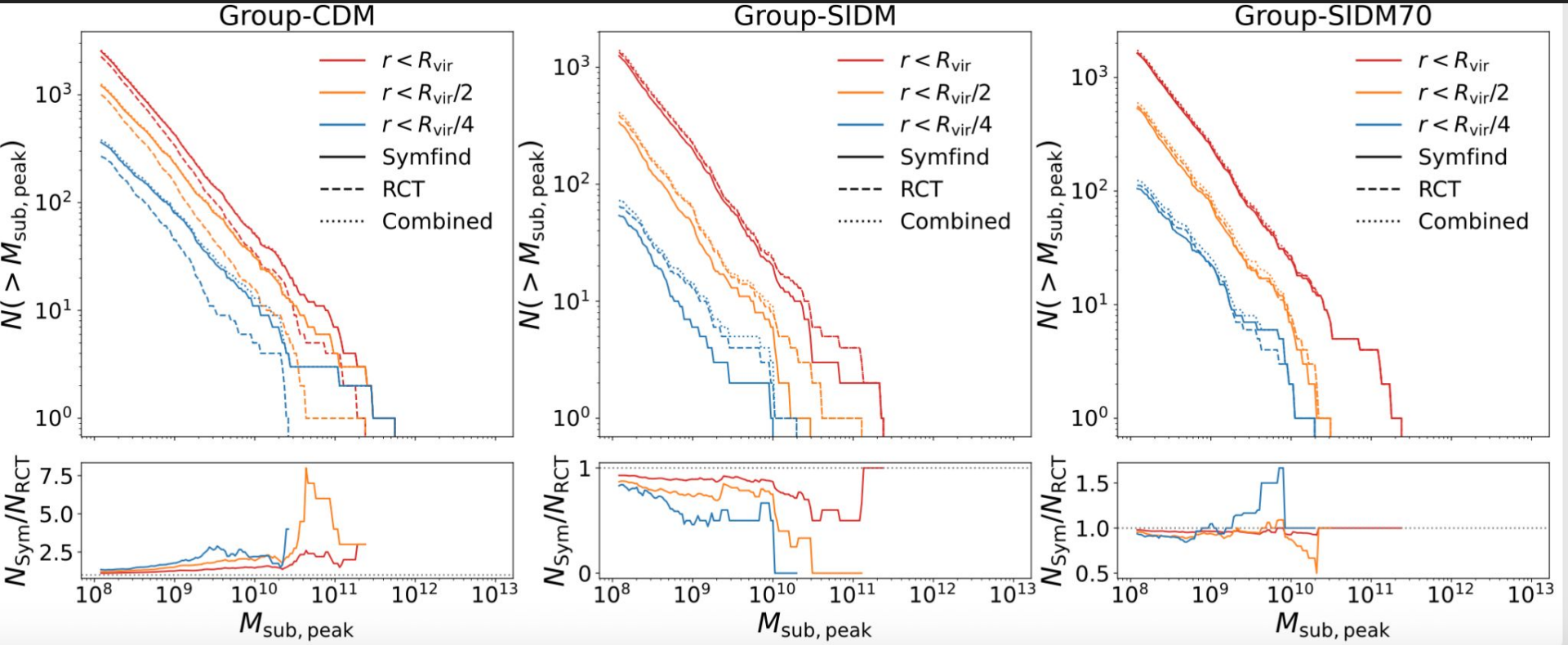
Core Collapsed Subhalos



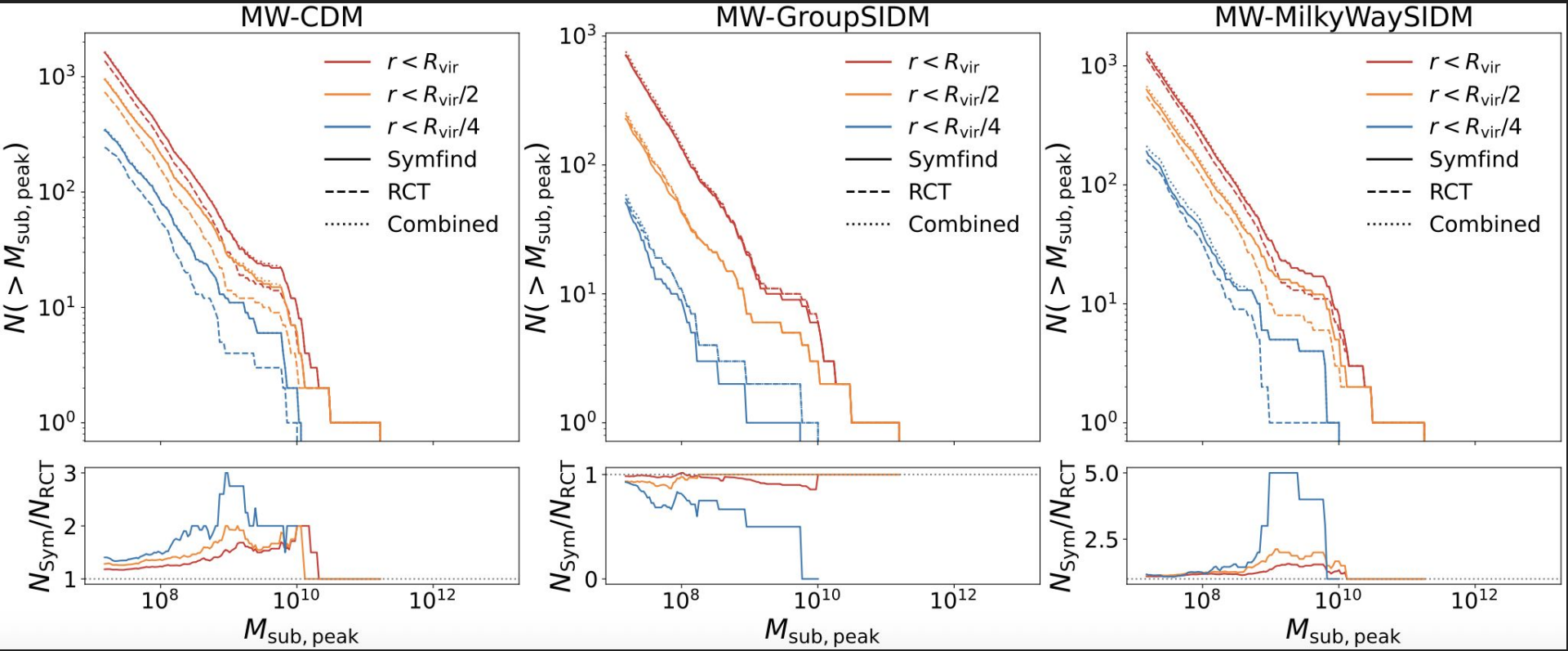
Take away

- For large mergers, which are likely core-forming in the context of velocity-dependent SIDM models, the use of a core-particle method is not preferred.
- For smaller subhalos, more likely to be core-collapsed, the particle-based method may have an advantages for long-surviving subhalos.
- The reliability is heavily influenced by the exact tidal evolution history and velocity-dependent SIDM models.

Subhalo Mass Function - Group



Subhalo Mass Function - MW



Summary

- Tagged core particles in SIDM N-body can be lost due to collisions (momentum transfer) and tidal stripping, leading to incorrect disruption determination.
- Lost tracking is more severe for core-forming subhalos than core-collapsed subhalos, while still highly influenced by exact orbital evolution.
- **For SIDM, combined halo catalogs can leverage both methods (phase space + particle), leading to 5-10% more subhalos overall and up to 30% in the innermost region (r < Rvir/4) compared to either method alone.**