High resolution cosmological simulations for cold and self-interacting dark matter halos

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With
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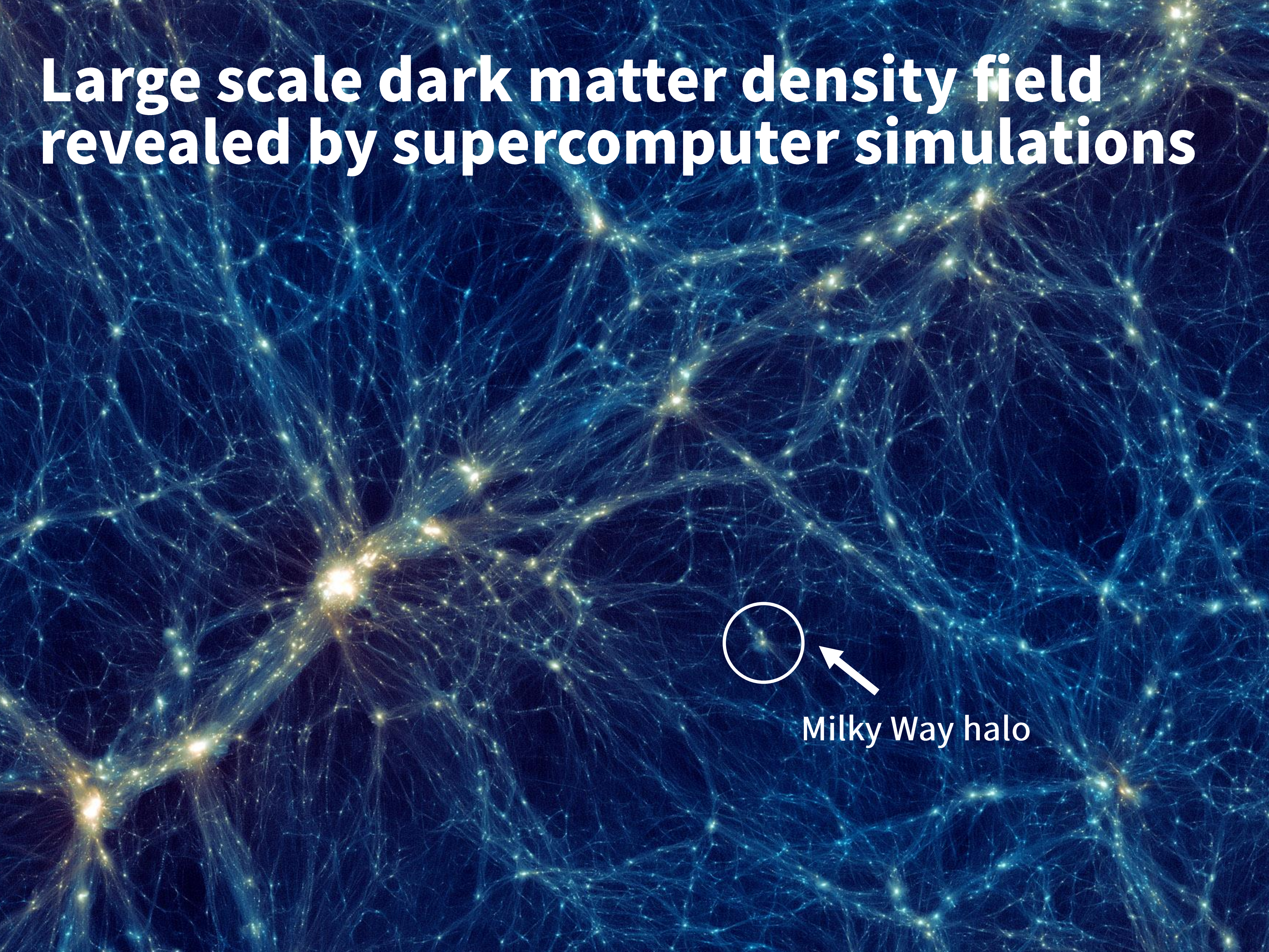
- The Uchuu Simulations: Data Release 1 and Dark Matter Halo Concentrations
  - Ishiyama, Prada, Klypin et al., submitted to MNRAS (arXiv: 2007.14720)

- High resolution cosmological simulations for cold and self-interacting dark matter halos
  - Ebisu, Ishiyama, and Hayashi, to be submitted soon


Large scale dark matter density field
revealed by supercomputer simulations
Milky Way halo

Structures of cold dark matter halos

- **Central Cusp**
  - Not core, the density continues to increase toward the halo center
  - Well fitted by NFW and Einasto profile

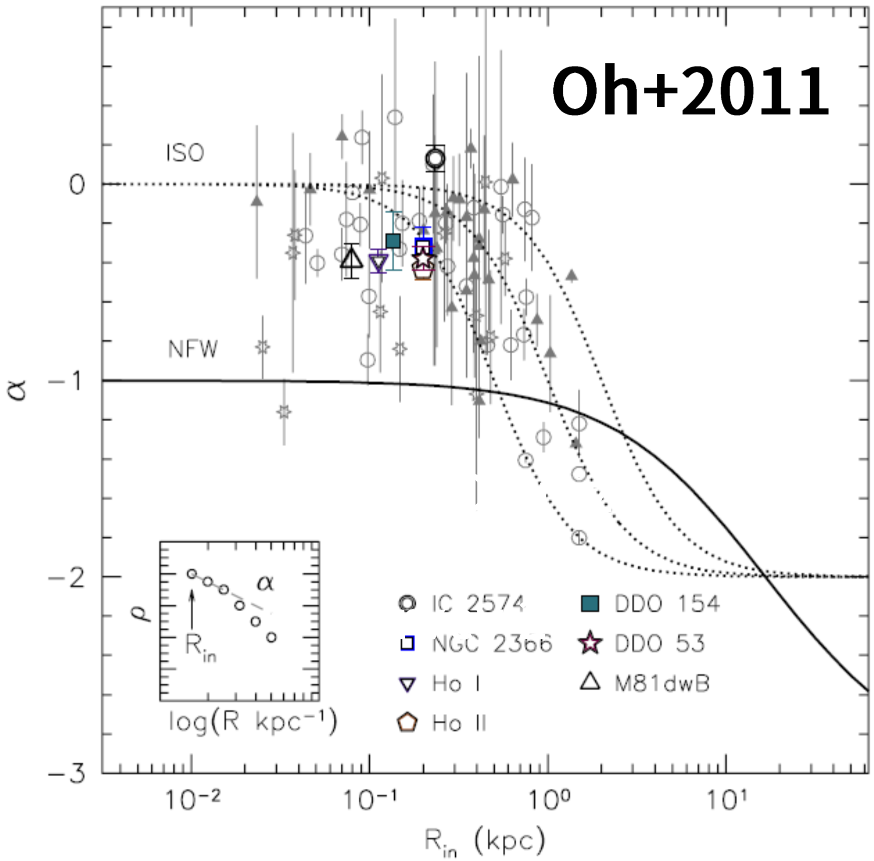
$$\boxed{\rho(r) = \frac{\rho_{\rm s}}{(r/r_{\rm s})[1+(r/r_{\rm s})]^2}}$$

- **Numeraous subhalo**
  - dn/dm ~ $m^{-(1.8\text{-}2)}$
- **Triaxial**

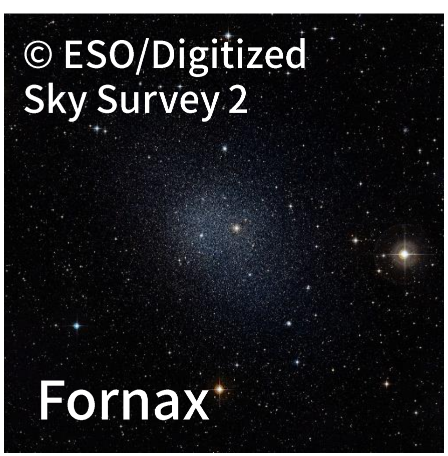
- **Non Universality**
  - Weak dependence on the halo mass
  - Halo to halo variation
    - Halo formation epoch

Impact on the galaxy formation, Dark matter detection experiment

Observation



- The central slopes of LSBs and dwarf galaxies are around -0.2 ~ 0
- Inconsistent with simulations ? (Core cusp problem)
  - Baryonic effect ?
  - CDM Alternative?
    - Warm dark matter
    - Self-Interacting dark matter



Both mechanisms can coincide and interplay. To remove this degeneracy, it is ideal to study dark matter dominated system such as dwarf spheroidal (dSph) and ultra faint (UFD) galaxies

This work

- Investigating density structures of dSph and UFD scale subhalos (10^{7-9} Msun) using high-resolution cosmological N-body simulations
- Most of previous works are limited in a few MW halos and poor mass resolution (> 10^5 Msun)
  - Improve to ~ ten halos and ~10^{3-5} Msun resolution
- Utilizing both CDM and SIDM
  - Comparing with observational data, we can constrain the nature of dark matter

Cosmological simulations

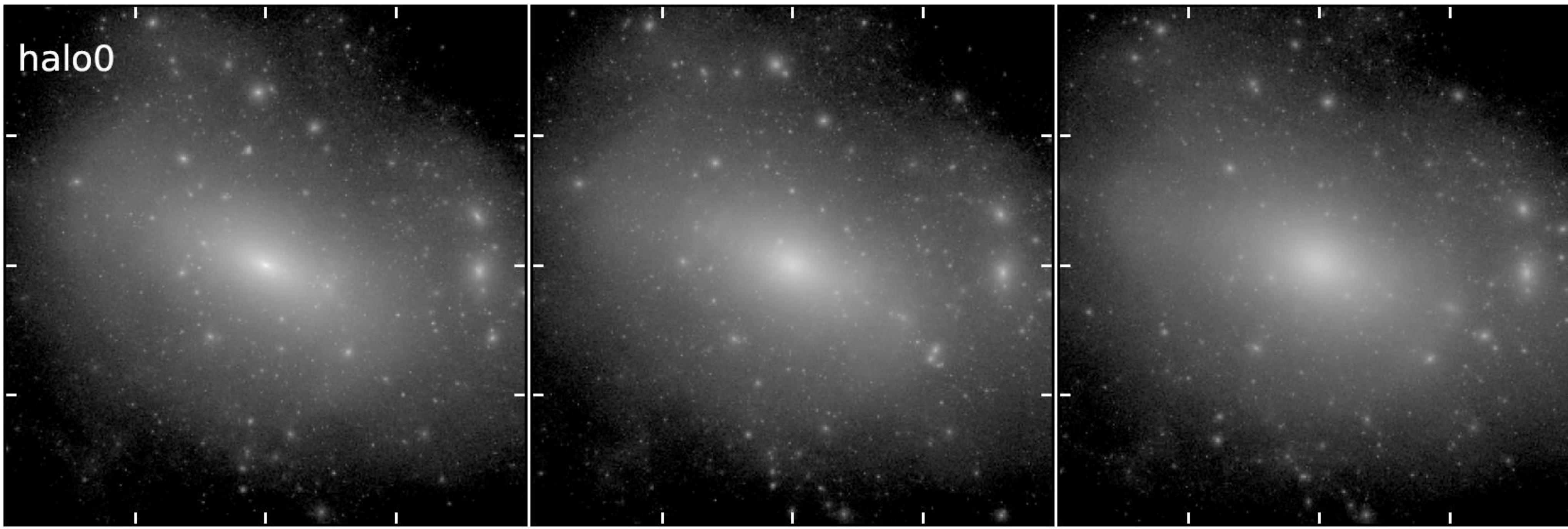
N	1024^3
box size	8 Mpc/h
mass resolution	4.1×10^4 Msun/h
force resolution	100 pc/h

- Three simulations with the same initial cosmological condition
  - CDM
  - SIDM1 (σ/m=1.0 $cm^2\ g^{-1}$)
  - SIDM3 (σ/m=3.0 $cm^2\ g^{-1}$)

- We adopt the SIDM implementation used in Vogelsberger+ 2012 (velocity independent, isotropic, elastic)

- We performed three simulations on Aterui-II supercomputer using GreeM TreePM code

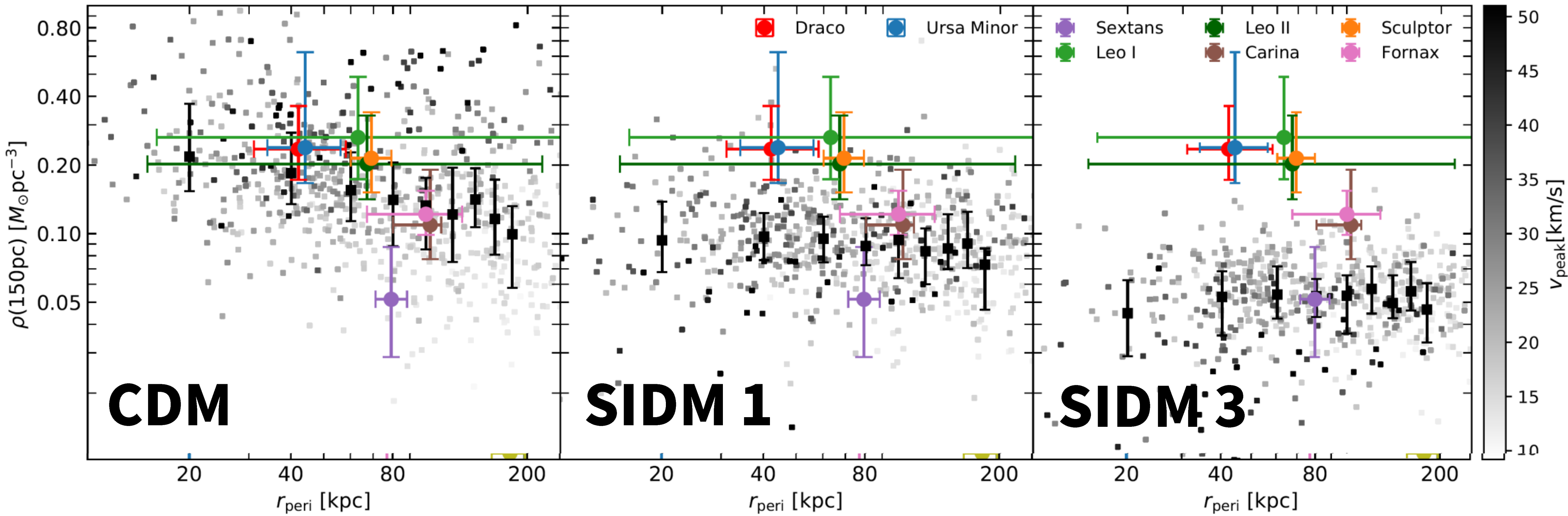
Visual comparison of a Milky Way sized halo



CDM **SIDM 1** **SIDM 3**

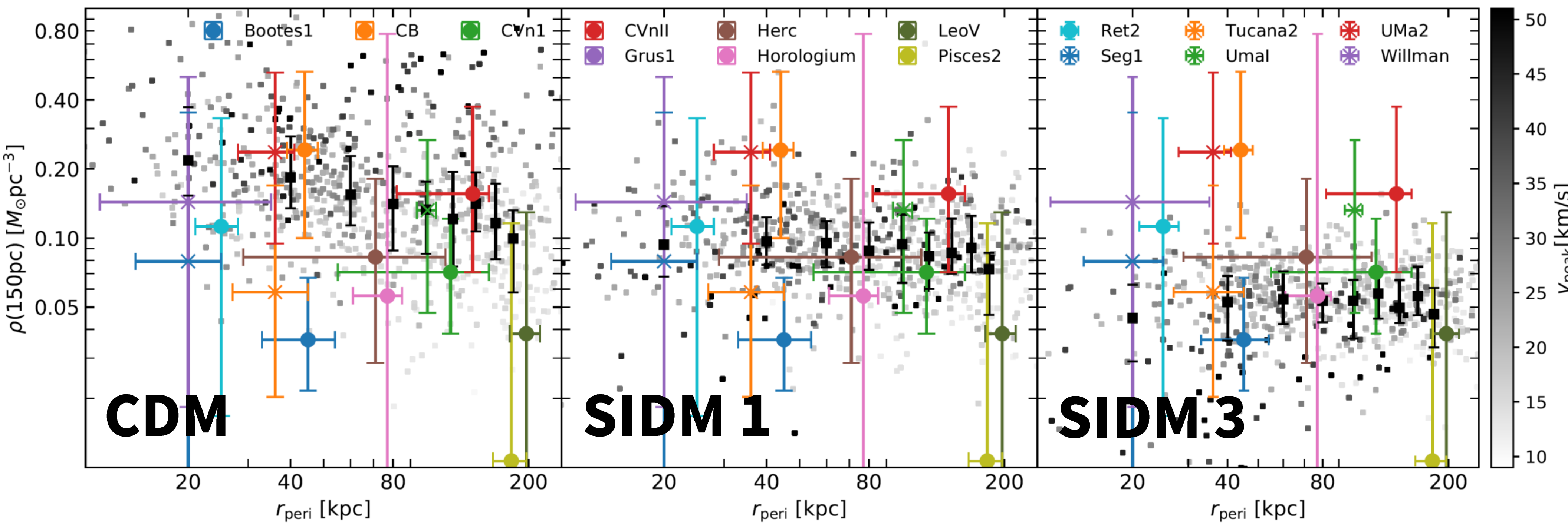
- We quantify the central density at 150 pc from the center of each subhalo (Read et al., 2019)
- The number of host MW halos is nine

Central density versus pericenter



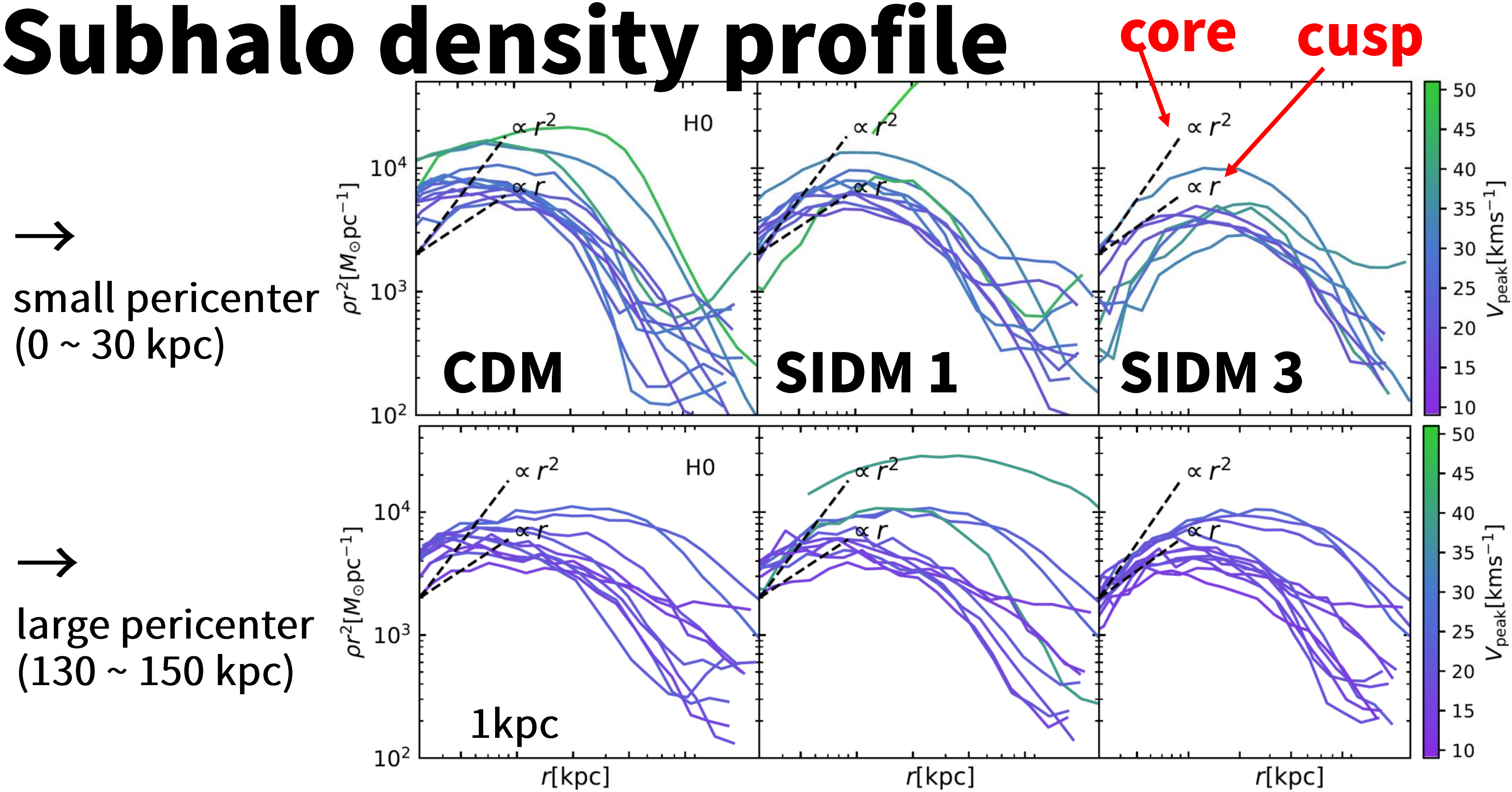
- In CDM, central density correlates with pericenter (see also Kaplinghat+ 2019, Hayashi+ 2020), whereas no correlation in SIDM1 and SIDM3
- Comparing with the classical dSphs, the SIDM scattering cross section of $\sigma/m < 1$ cm^2 g^{-1} is favored

Central density versus pericenter



- Comparing with ultra faint dwarfs, the SIDM scattering cross section of $\sigma/m < 3$ cm^2 g^{-1} is favored
- Note that observational uncertainty is large
  - Good data are going to be provided by PFS

Subhalo density profile



- At small pericenter, dense subhalos tend to survive
- Self-interactions work effectively in such dense subhalos, and hence, the central densities tend to be lower in the SIDM simulations
- Statistically the difference is small at large pericenter because less dense subhalos are plenty

Summary and future

- By high resolution cosmological N-body simulations, we are testing whether (how) we can use dSphs to constrain the nature of dark matter
- Comparing with available observational data, we find that the self-interacting cross section of $\sigma/m < 3\ \mathrm{cm^2\,g^{-1}}$ is favored
- Dwarf galaxies with small pericenter are ideal sites to further constrain the nature of dark matter by future large spectroscopic surveys such as PFS

- Higher resolution simulations by Fugaku supercomputer in future
- Effect of other SIDM implementations? (e.g., velocity dependent, anisotropic, inelastic...)