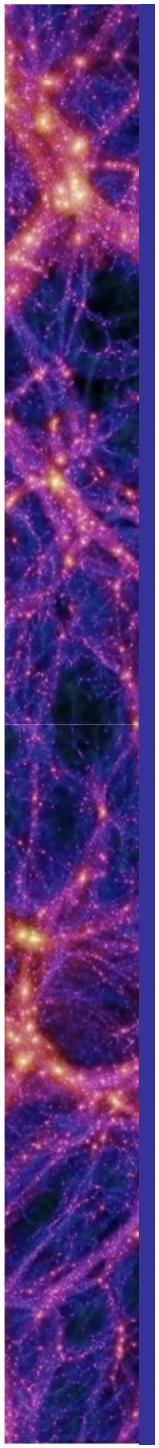

HIERARCHICAL STRUCTURE FINDER

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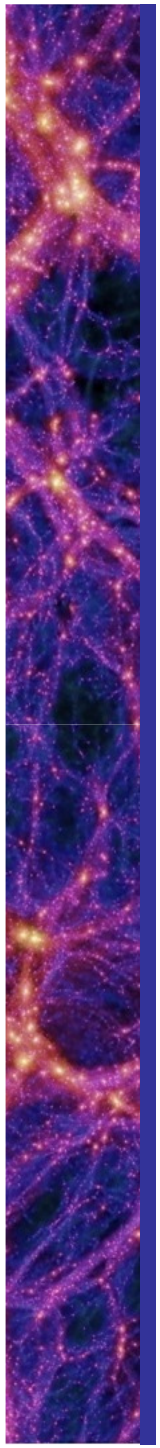
Max Planck Institute for Astrophysics

UC HIPACC 2010 Summer School on Astro-Computing July 26 – August 13 2010



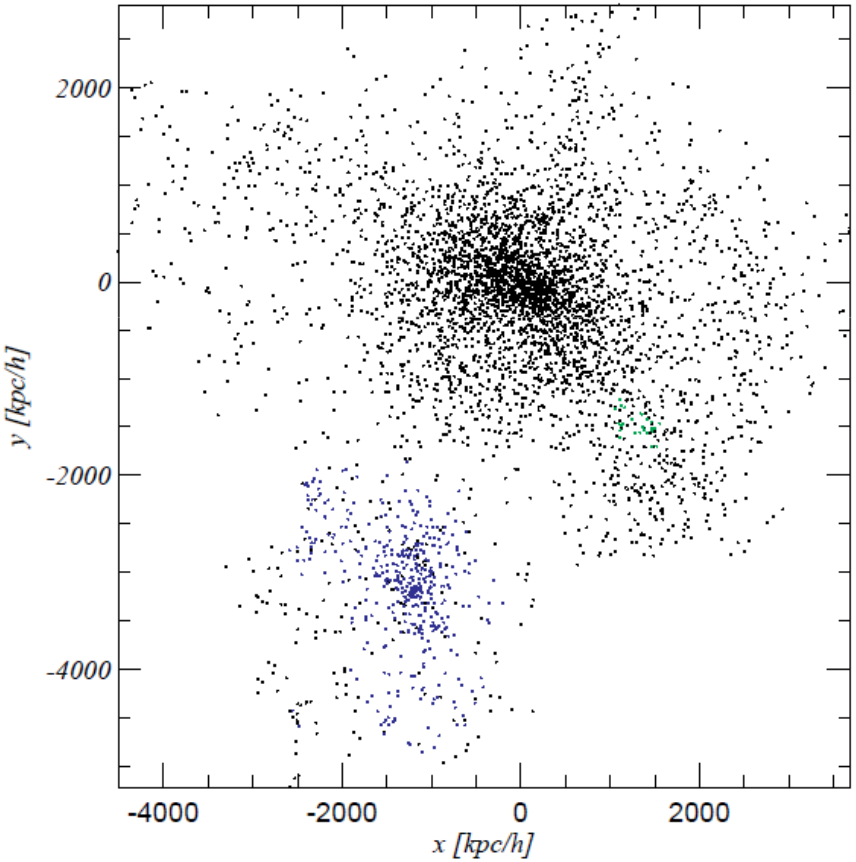
Finding Dark Matter Haloes

1. Cosmological simulation with Dark Matter particles
2. Analysis and comparison with observations
3. Dark Matter Haloes
   - FOF
4. Dark Matter Substructures
   - SKID, DENMAX, SO, BDM, VOBOZ, PSB
   - HOP, ADAPTAHOP, VOBOZ, SUBFIND, HSF, AHF
5. Two haloes definitions
   1. Overdesity peak (FOF)
   2. Gravitationally self-bound object

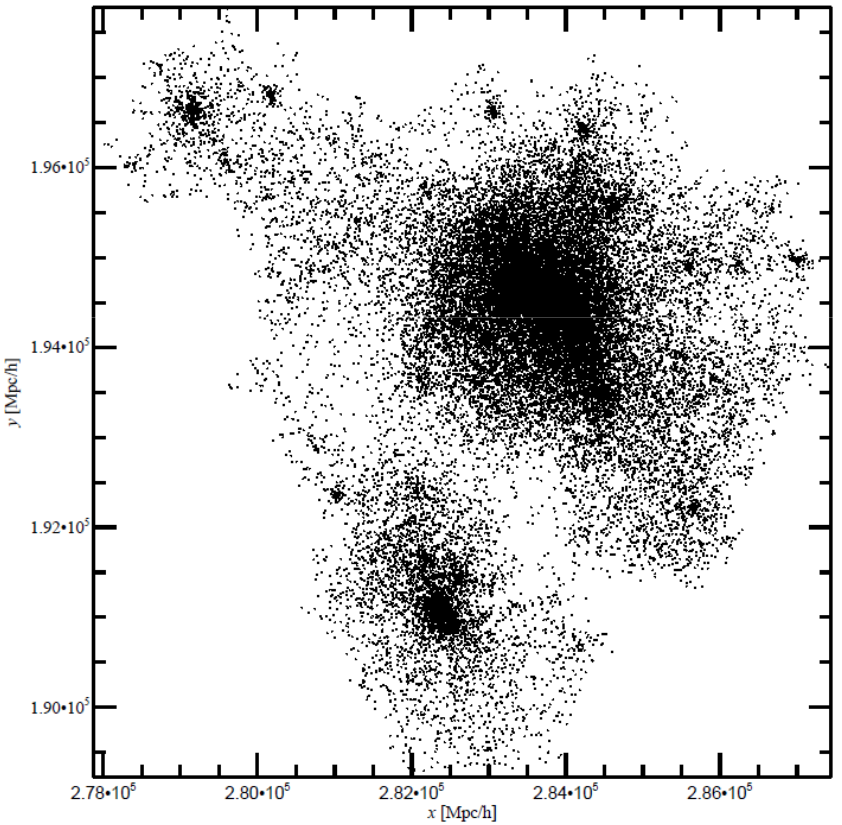
Finding Dark Matter Haloes

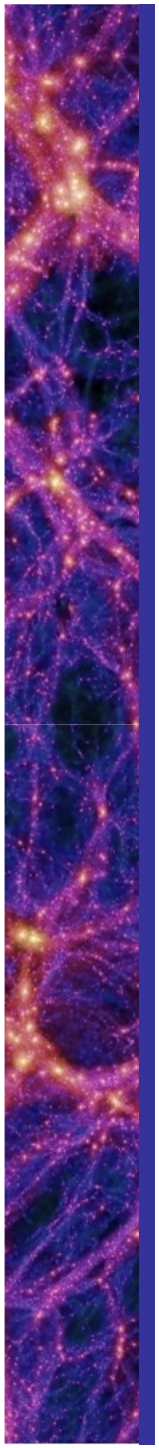
- FOF

256x256x256



512x512x512





Finding Dark Matter Subhaloes 4

1. Dark Matter Substructures

   SKID DENMAX SO BDM VOBOZ PSB
   HOP ADAPTAHOP VOBOZ SUBFIND HSF AHF

2. Hierarchical Structure Finder
   1. Estimate density by SPH (in phase-space)
   2. Find local maxima
   3. Grow structures around local maxima
   4. Self-bound structures
      - Check the total energy of each particles
      - Escape velocity

Hierarchical structure finder

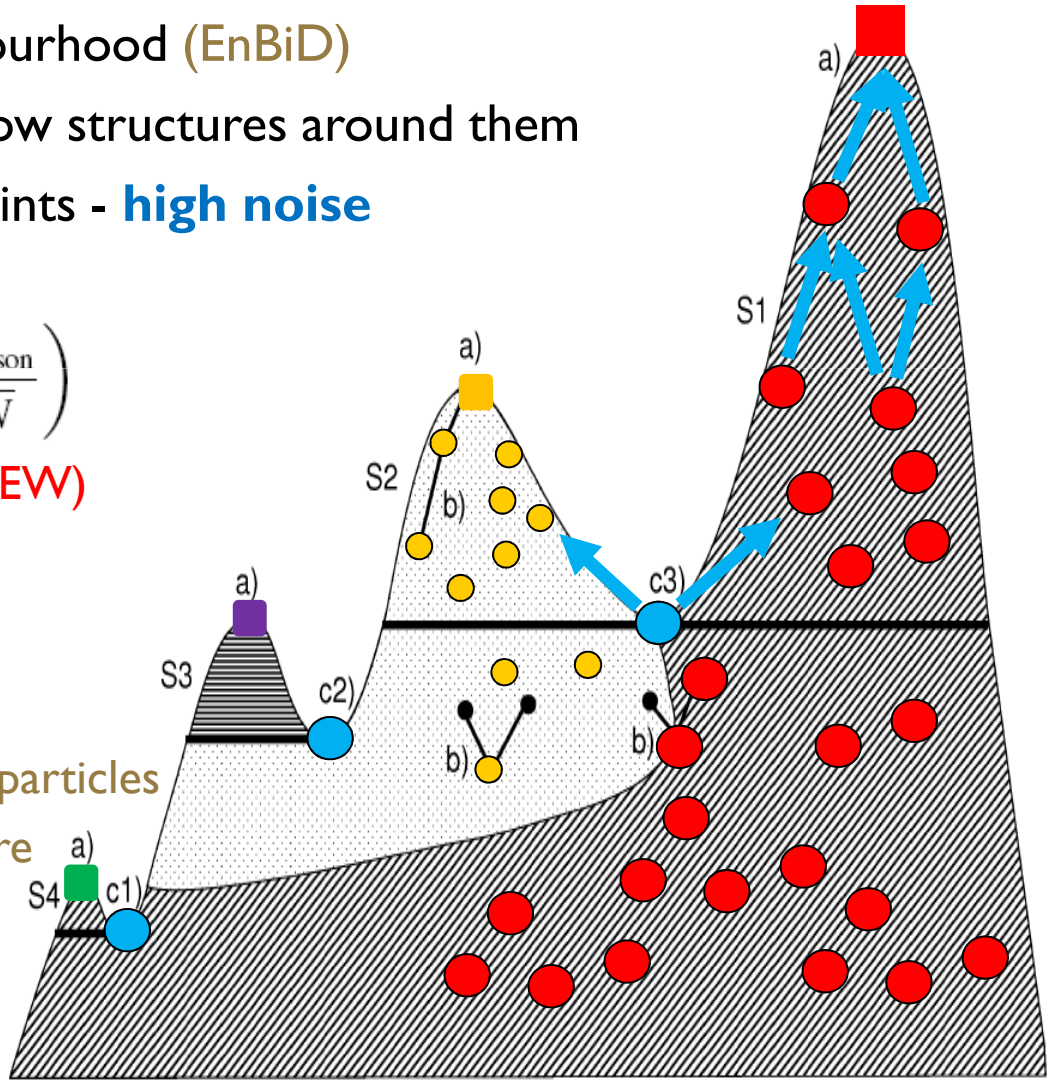
- **Multidimensional Hierarchical Structure Finder (HSF)**
  (Maciejewski et al. 2009)
  - Density and local neighbourhood (EnBiD)
  - Find local maxima and grow structures around them
  - What to do on saddle points - **high noise**
    - Poisson noise criterion

$$\langle \rho \rangle_{\text{substructure}} > \rho_t \left(1 + \frac{f_{\text{Poisson}}}{\sqrt{N}} \right)$$

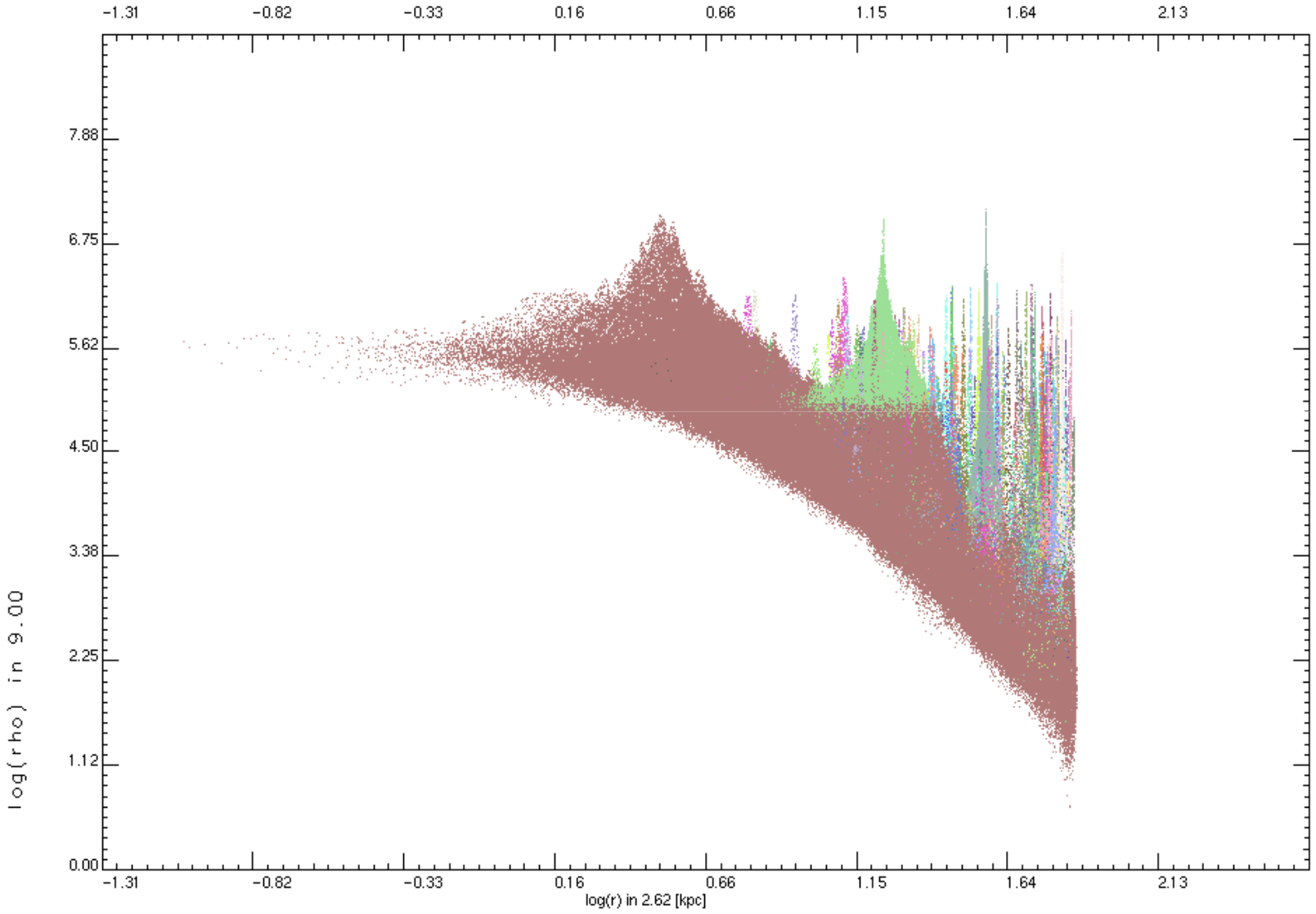
    - Cut or grow criterion (NEW)

$$|S_m|\alpha > |S_n|$$

  - Unbinding
    - Calculate total energy of particles relative to structure centre
    - Move particles to bigger structure

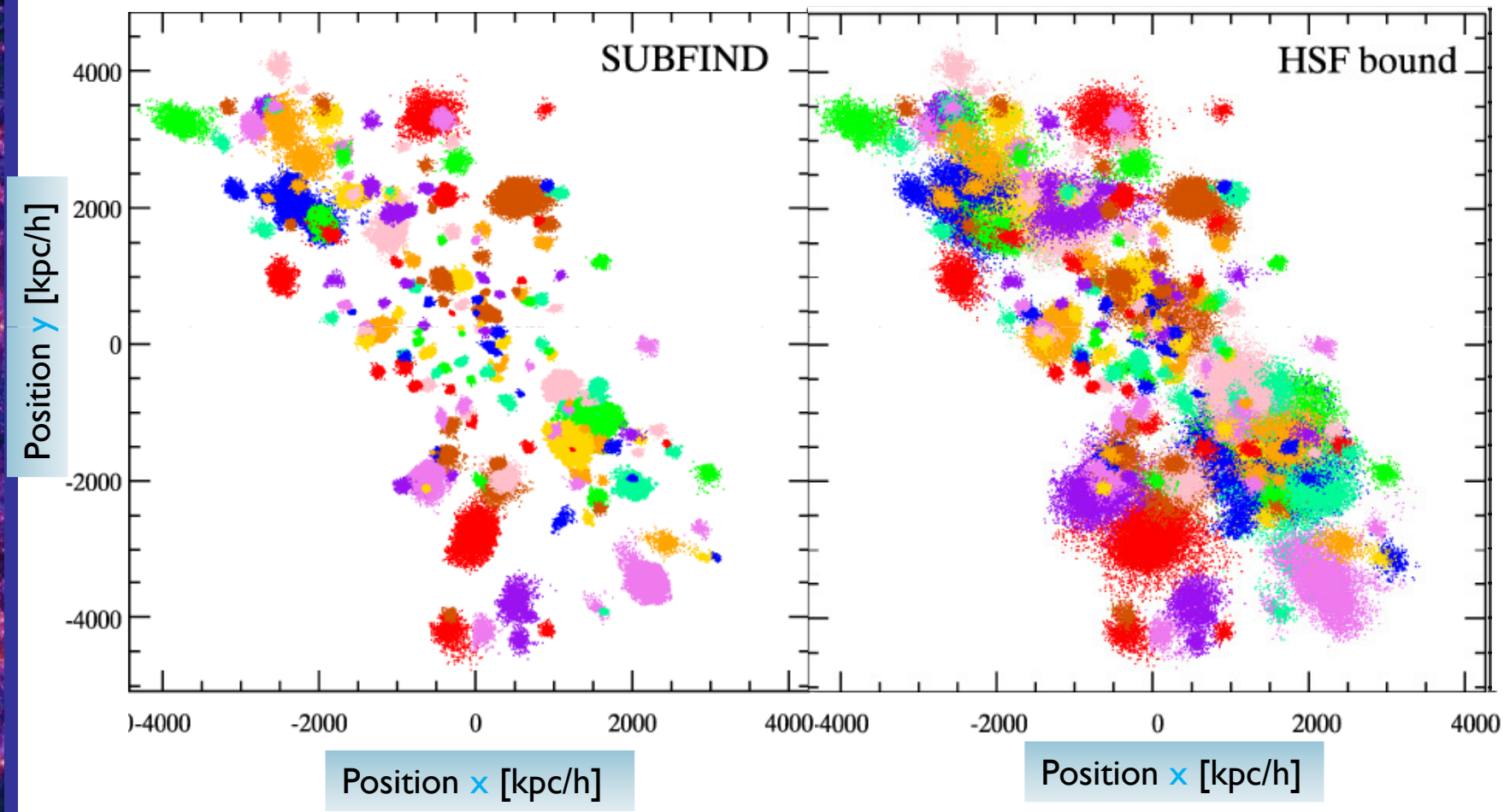


Hierarchical Structure Finder



Hierarchical Structure Finder

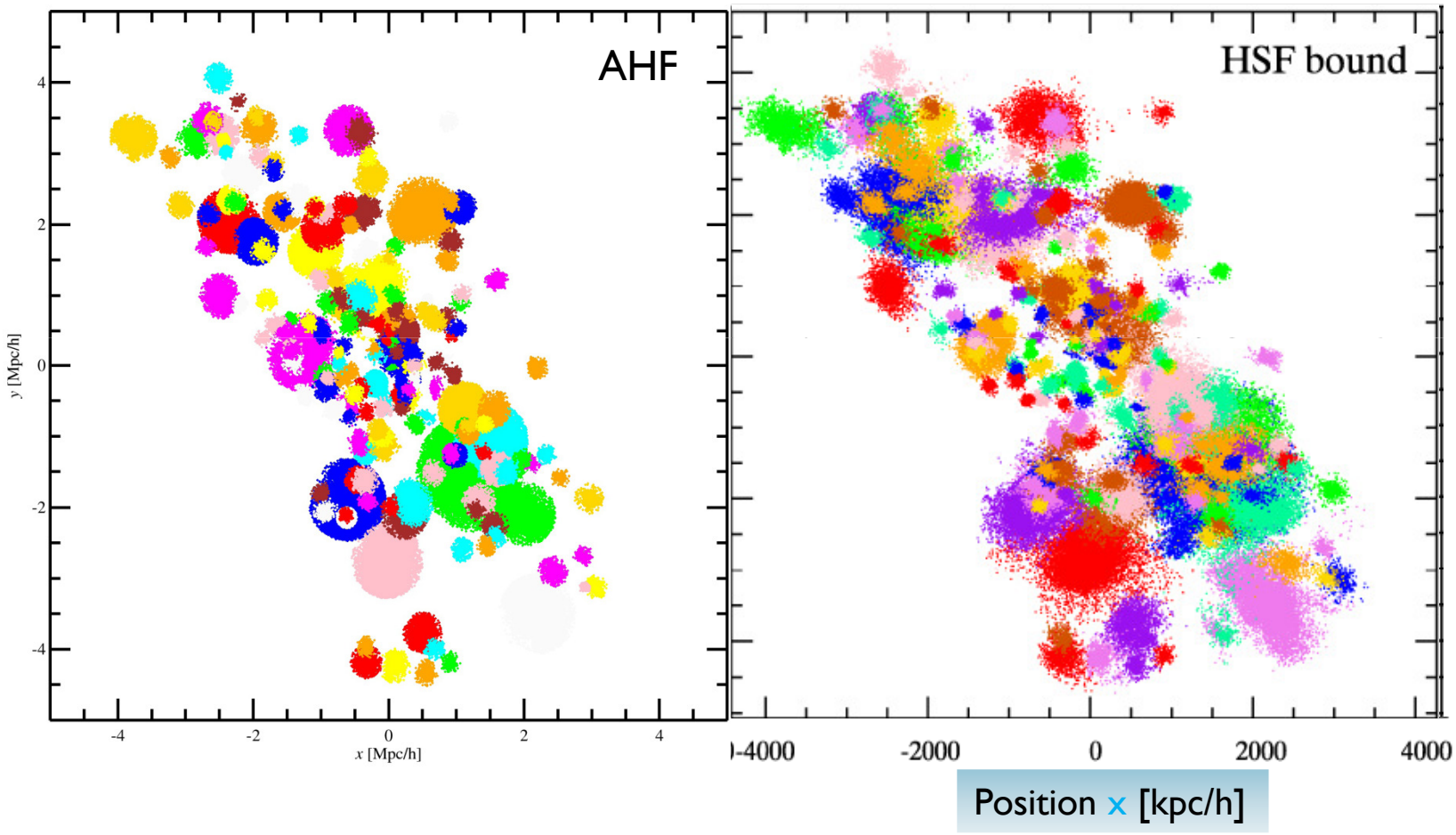
- What is the distribution of bound dark matter structures?



The area of a circle is proportional to the structure mass.

Hierarchical Structure Finder 8

- What is the distribution of bound dark matter structures?



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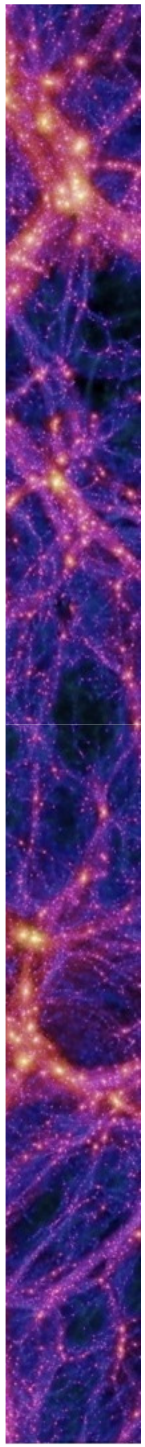


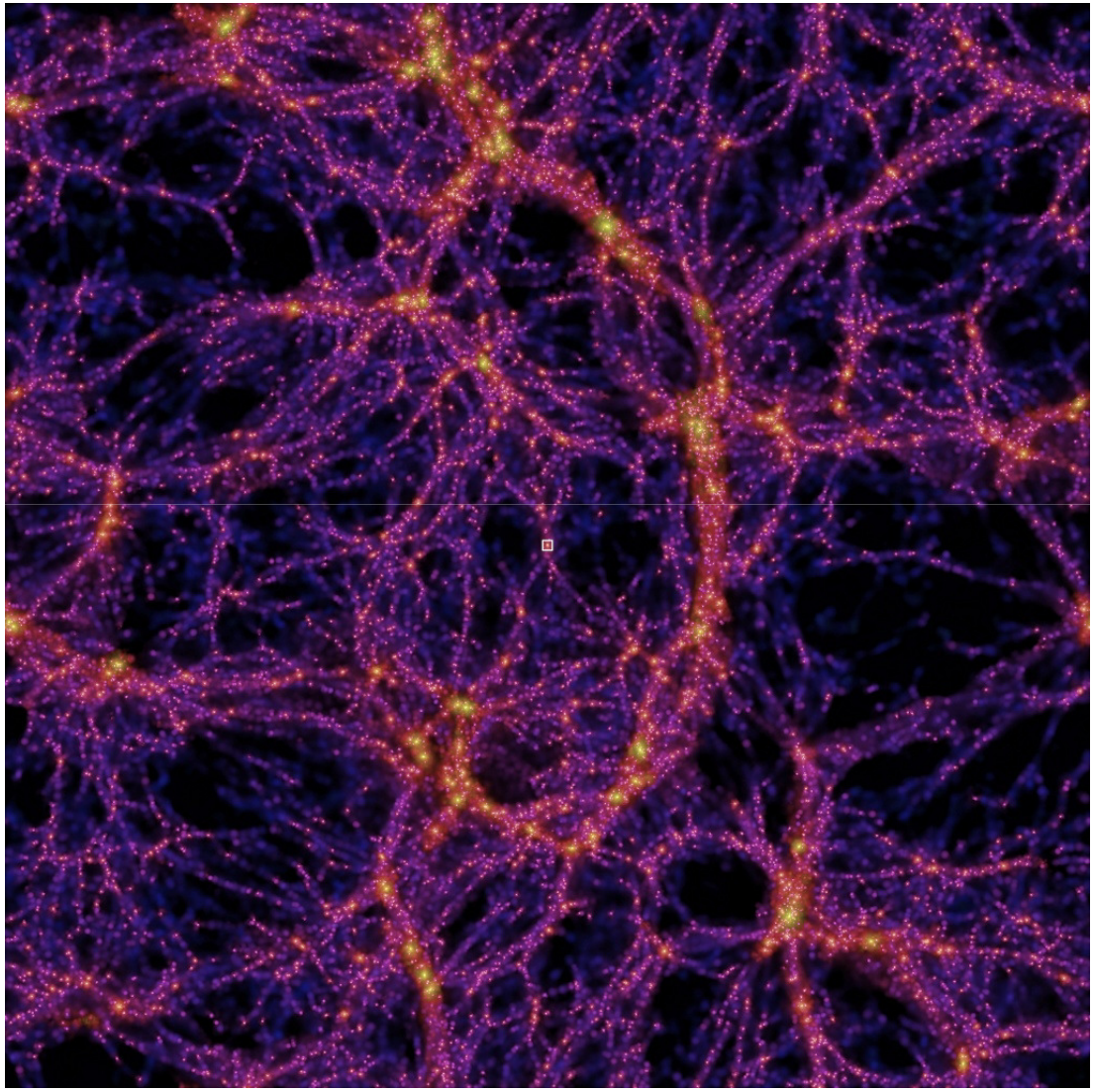
Dark matter structures of the Milky-Way type Galaxies

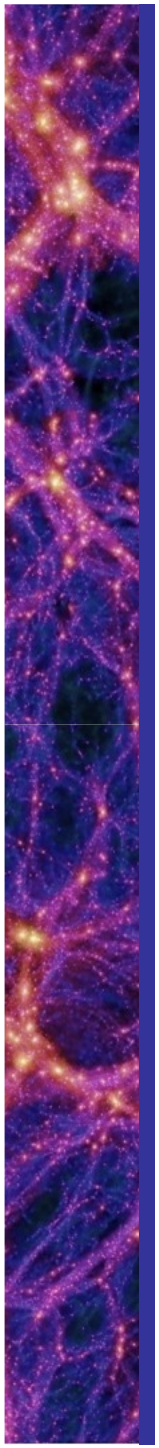
AQUARIUS SIMULATIONS

VOLKER SPRINGEL
SIMON D.M. WHITE
MARK VOGELSBERGER

Aquarius simulations

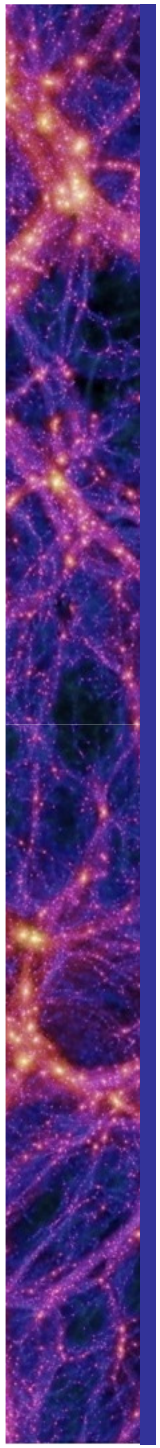
- 100 Mpc/h box
- Zoom simulation
- 6 Milky-Way size haloes Aq-A – Aq-F
- Aq-A-5 – Aq-A-1





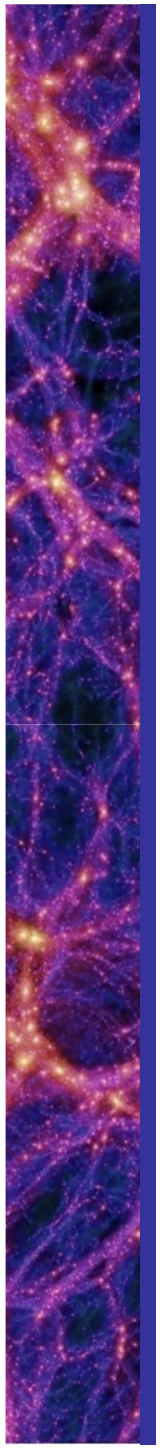
Aquarius simulations

Aq-A-5 808,479 particles



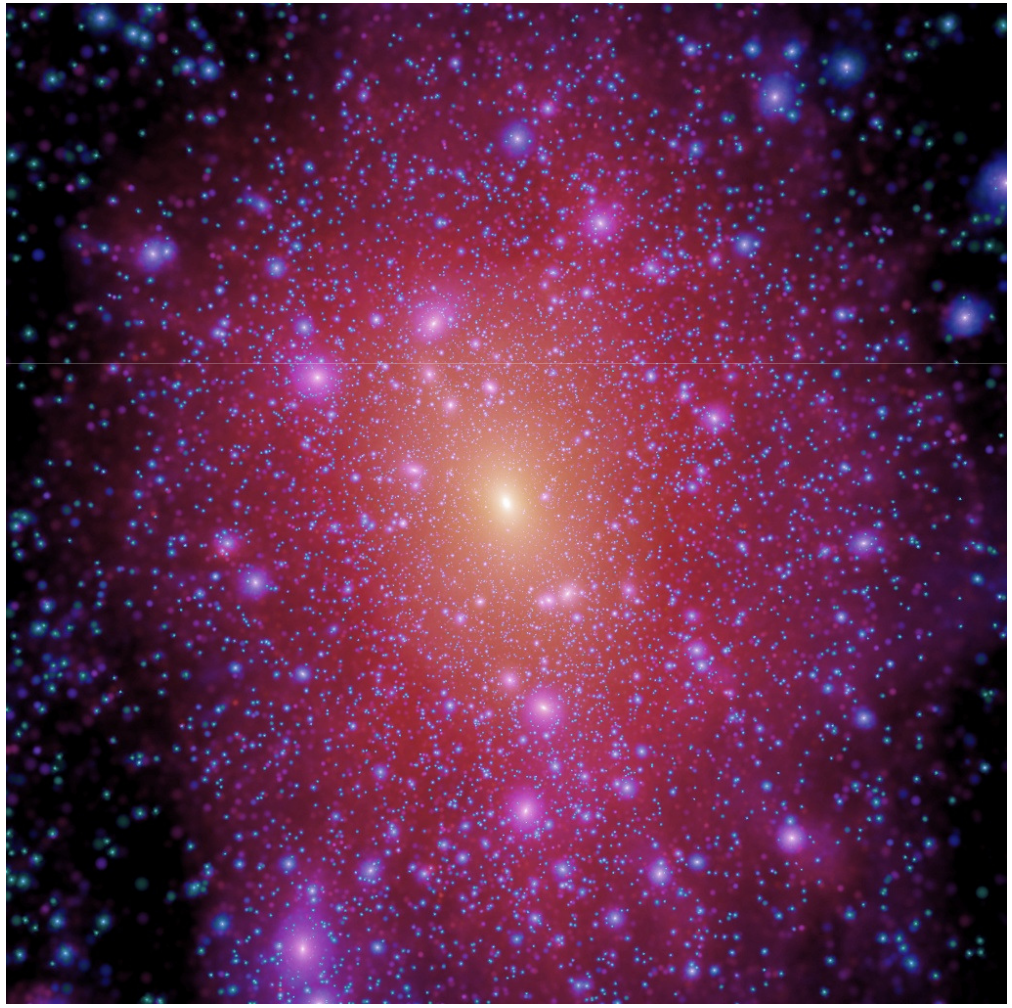
Aquarius simulations

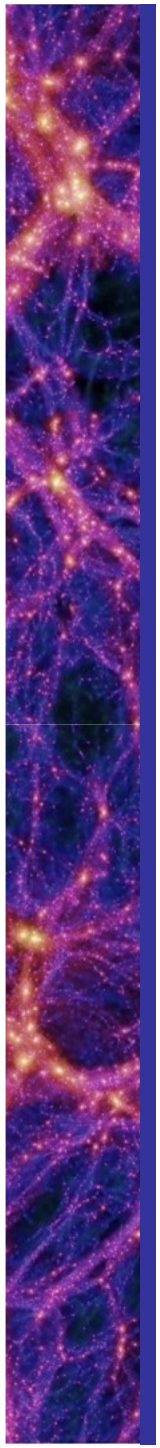
Aq-A-4 6,424,399 particles



Aquarius simulations

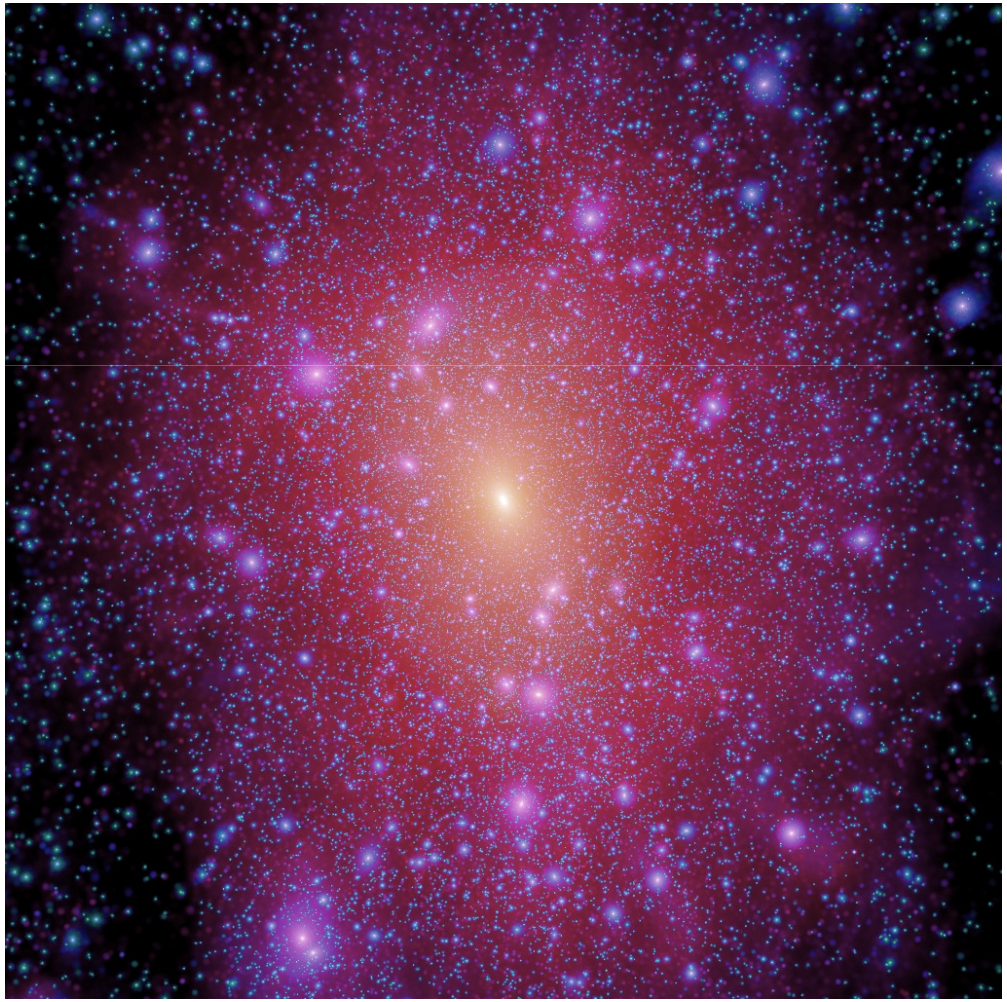
Aq-A-3 51,391,468 particles

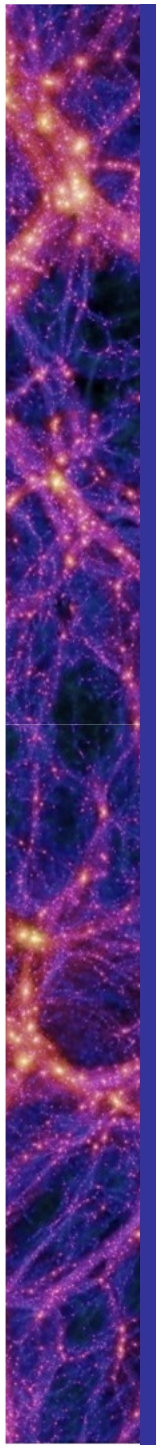




Aquarius simulations

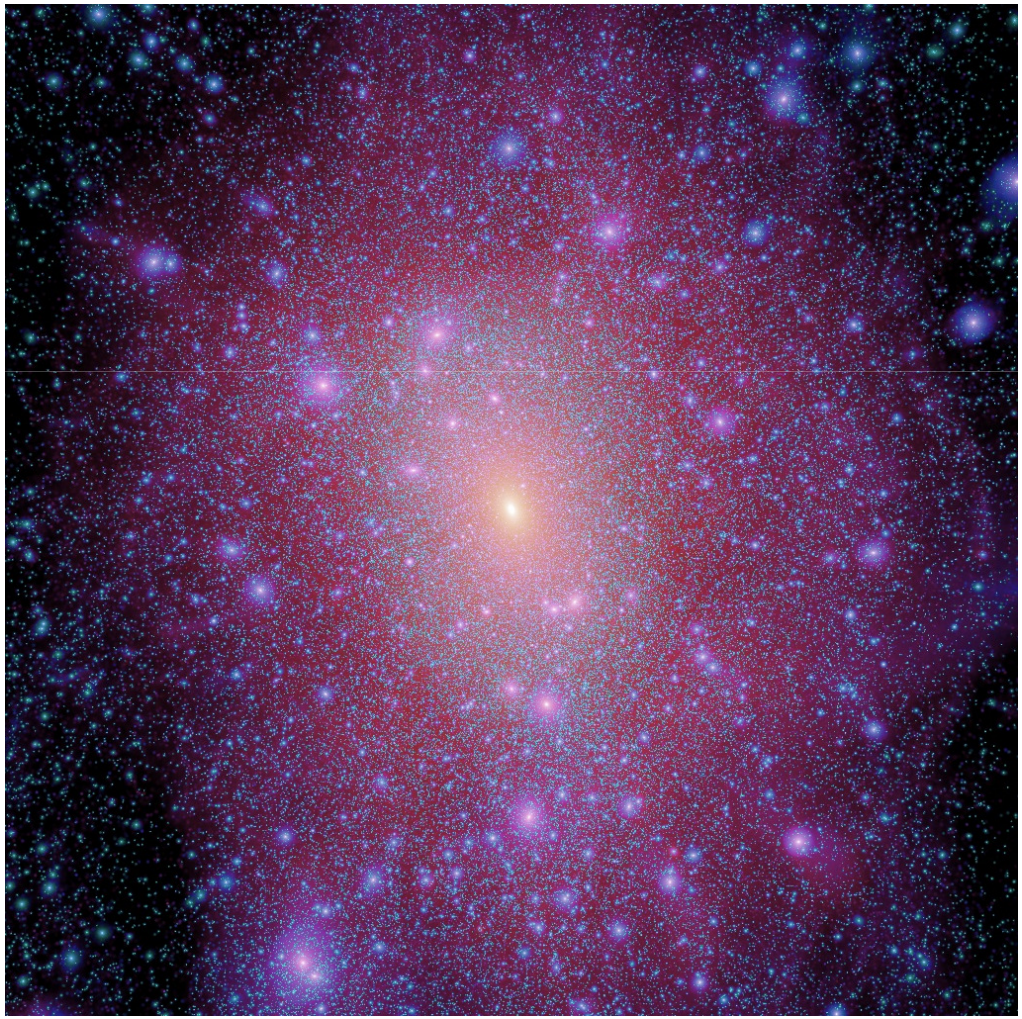
Aq-A-2 184,243,536 particles





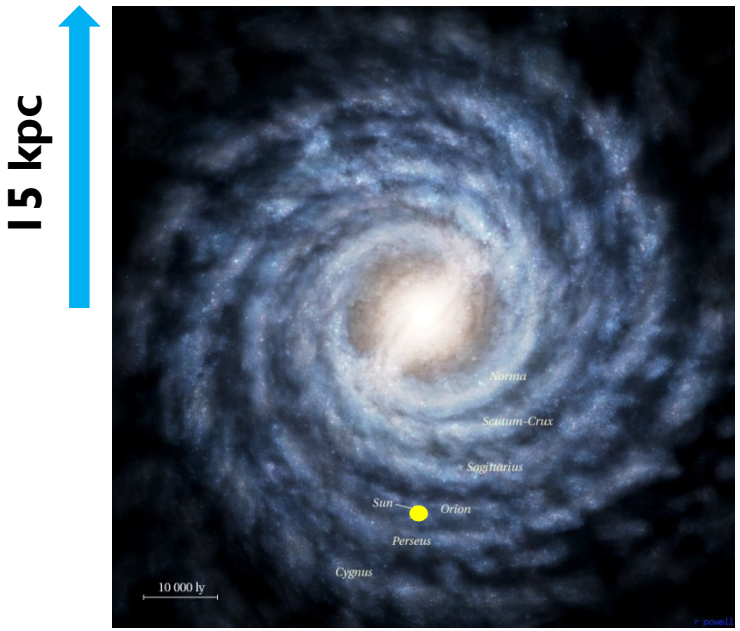
Aquarius simulations

Aq-A-1 1,473,568,512 particles



Aquarius simulations

- The AQUARIUS project – study properties of dark matter in our galaxy (White, Springel, Vogelsberger)
  - Particle mass equal 1712 Solar Mass
  - 35 kpc slice
  - 200 million particles
  - 0.05 % of mass in bound structures
  - trace of dark matter streams near the Sun
  - 0.5 % of mass in all structures found by HSF



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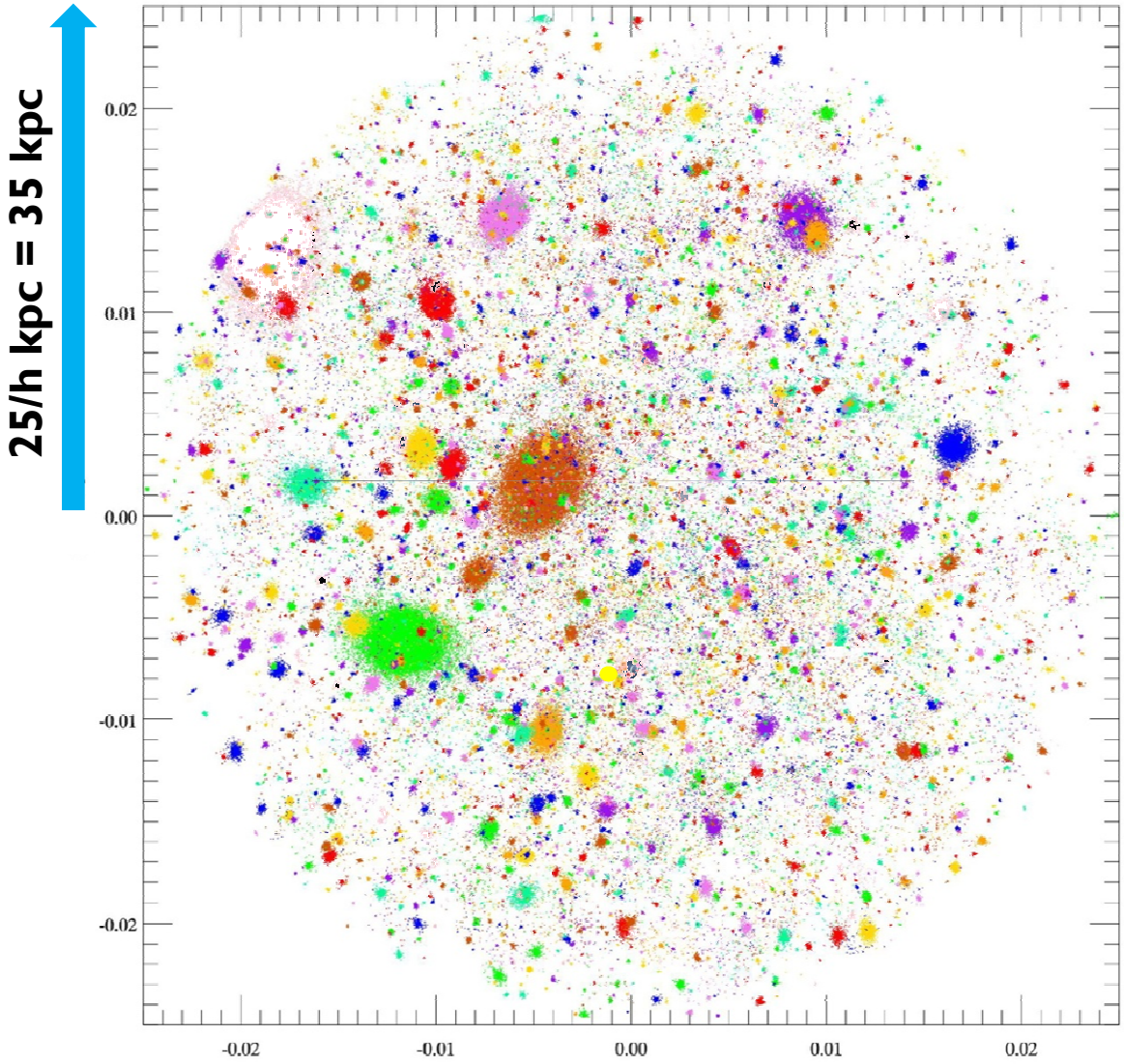

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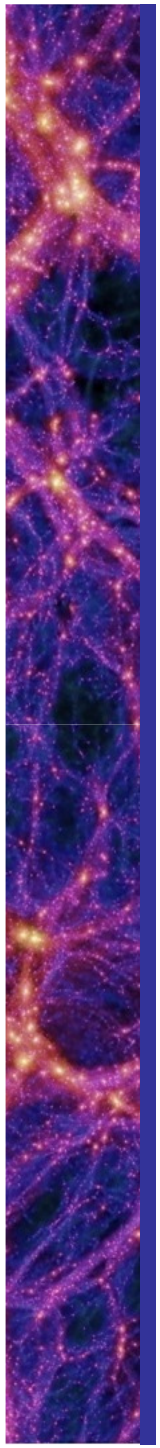

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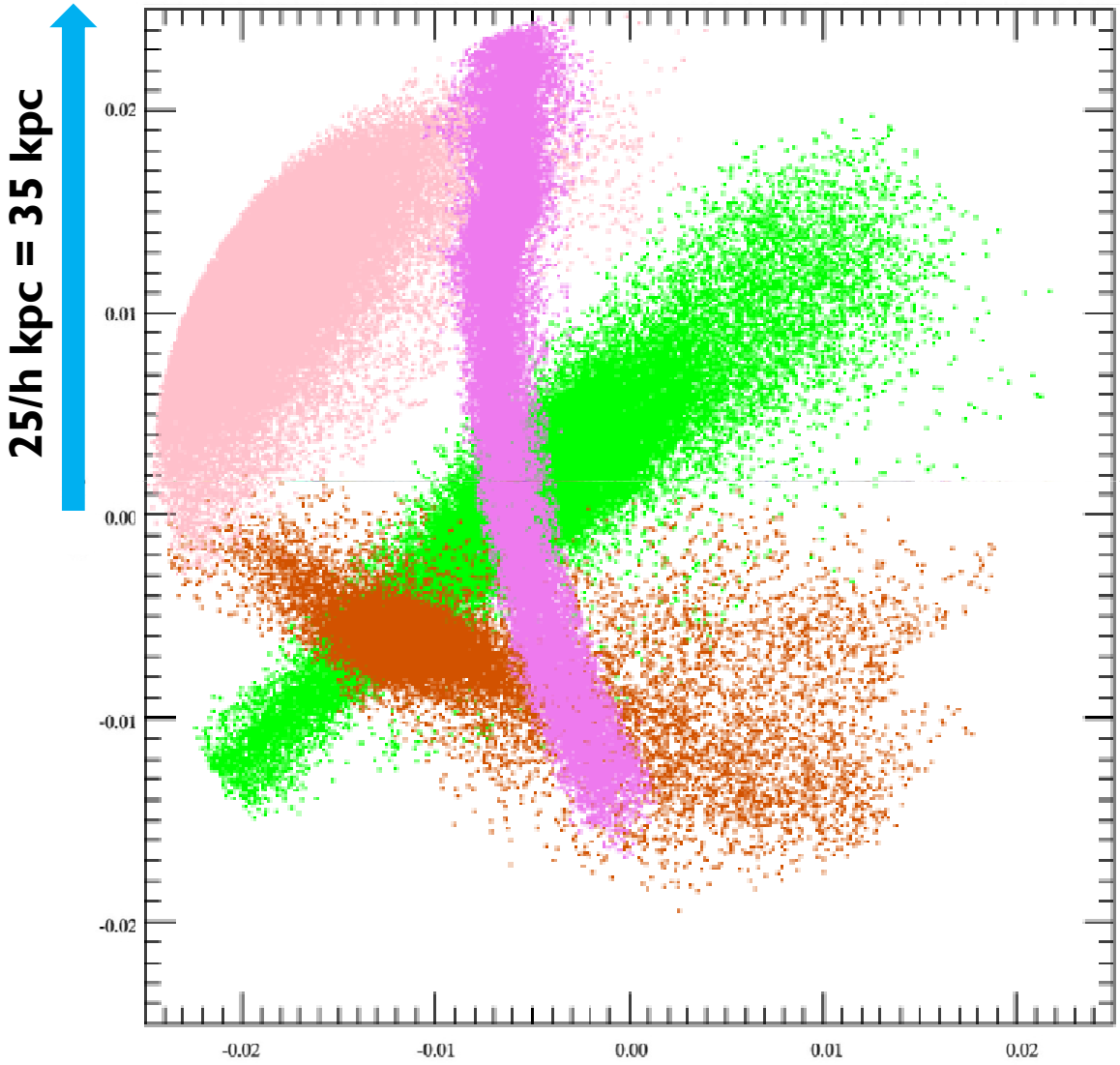
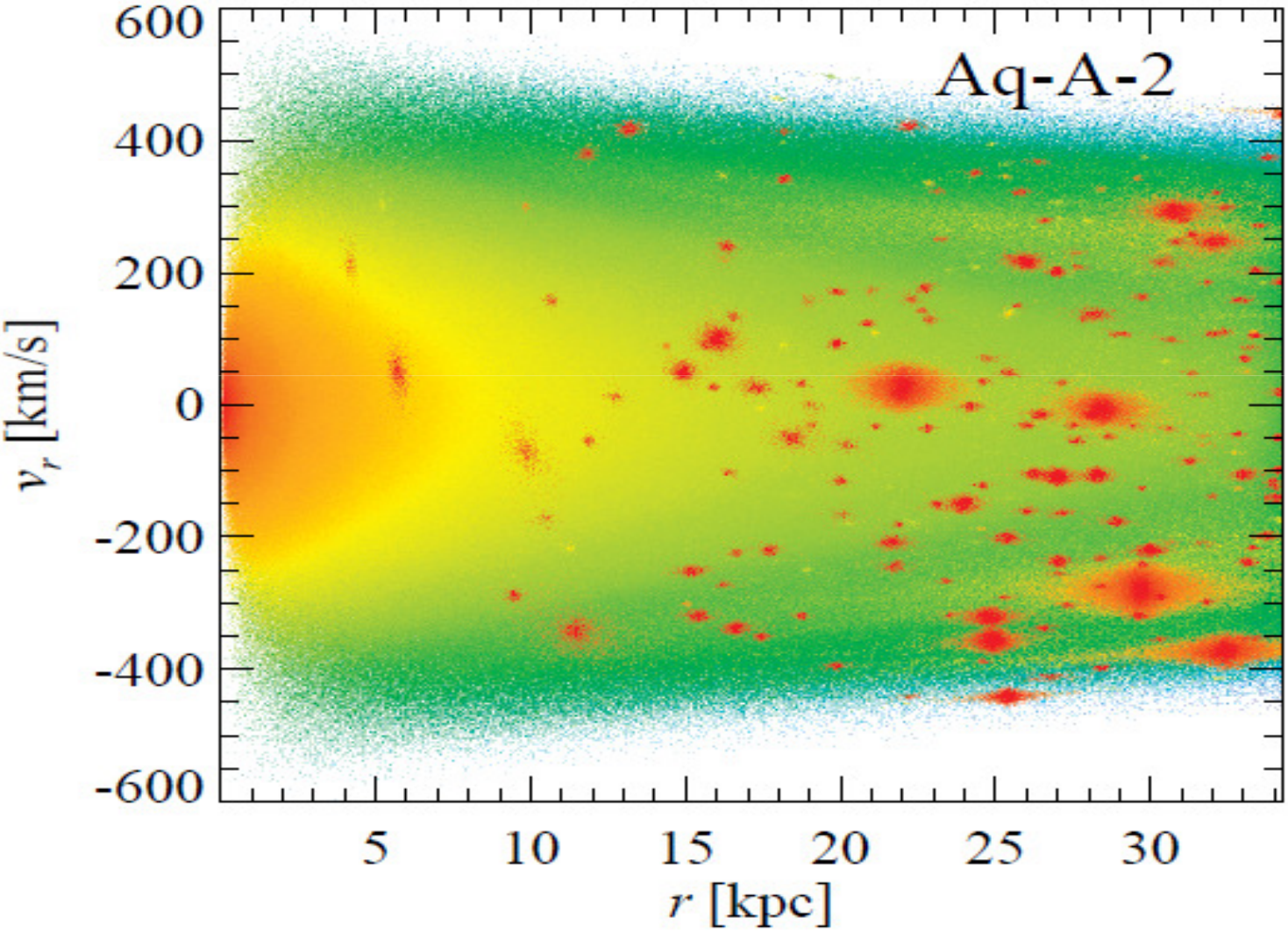


Aquarius simulations

- AQUARIUS project - trace of dark matter streams near the Sun



Aquarius simulations

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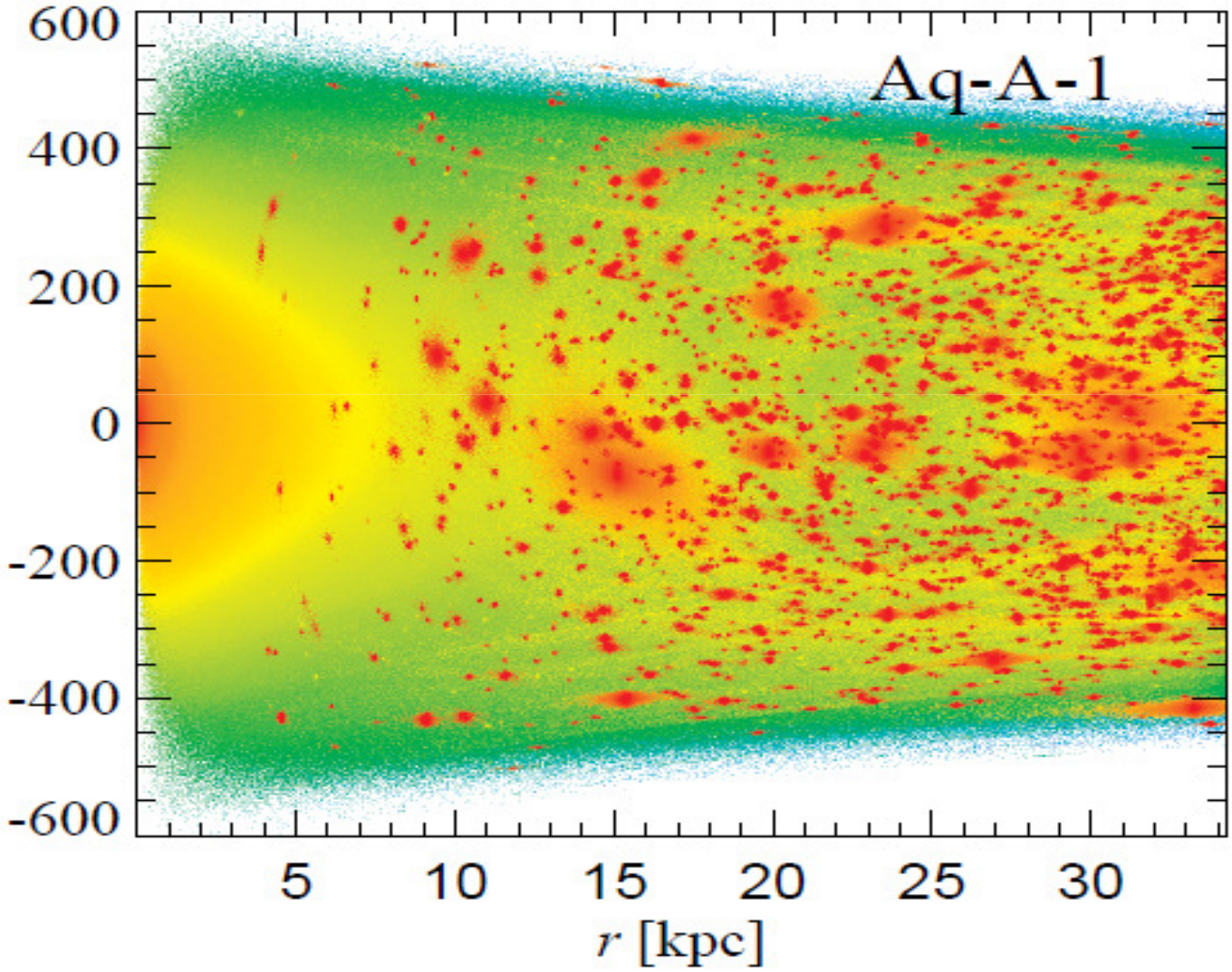

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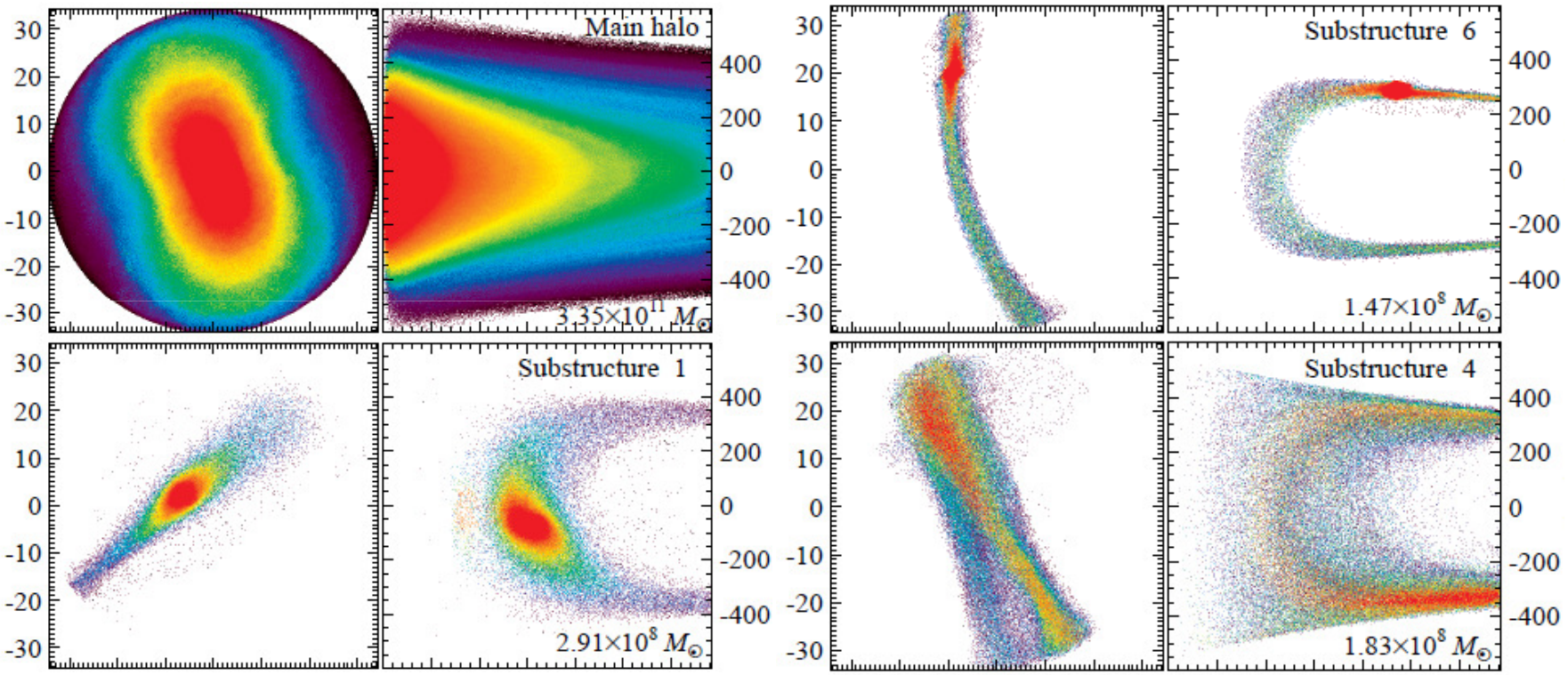
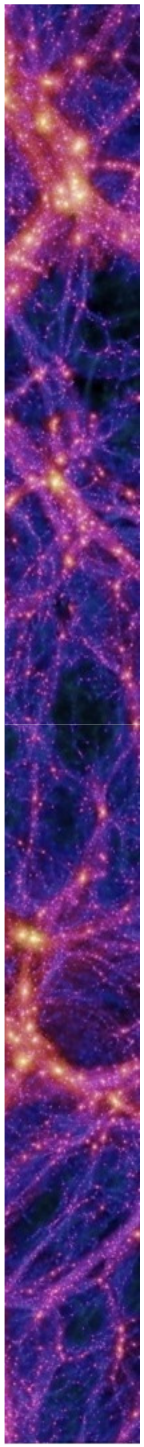
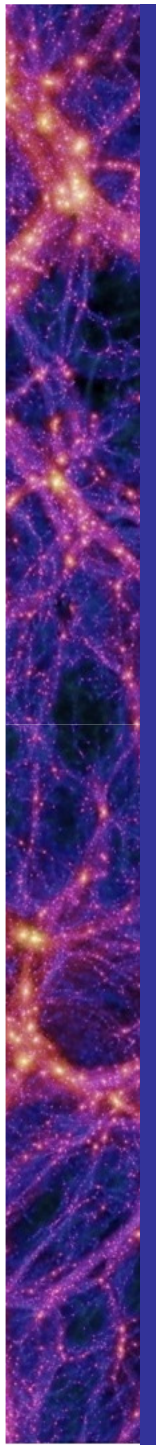




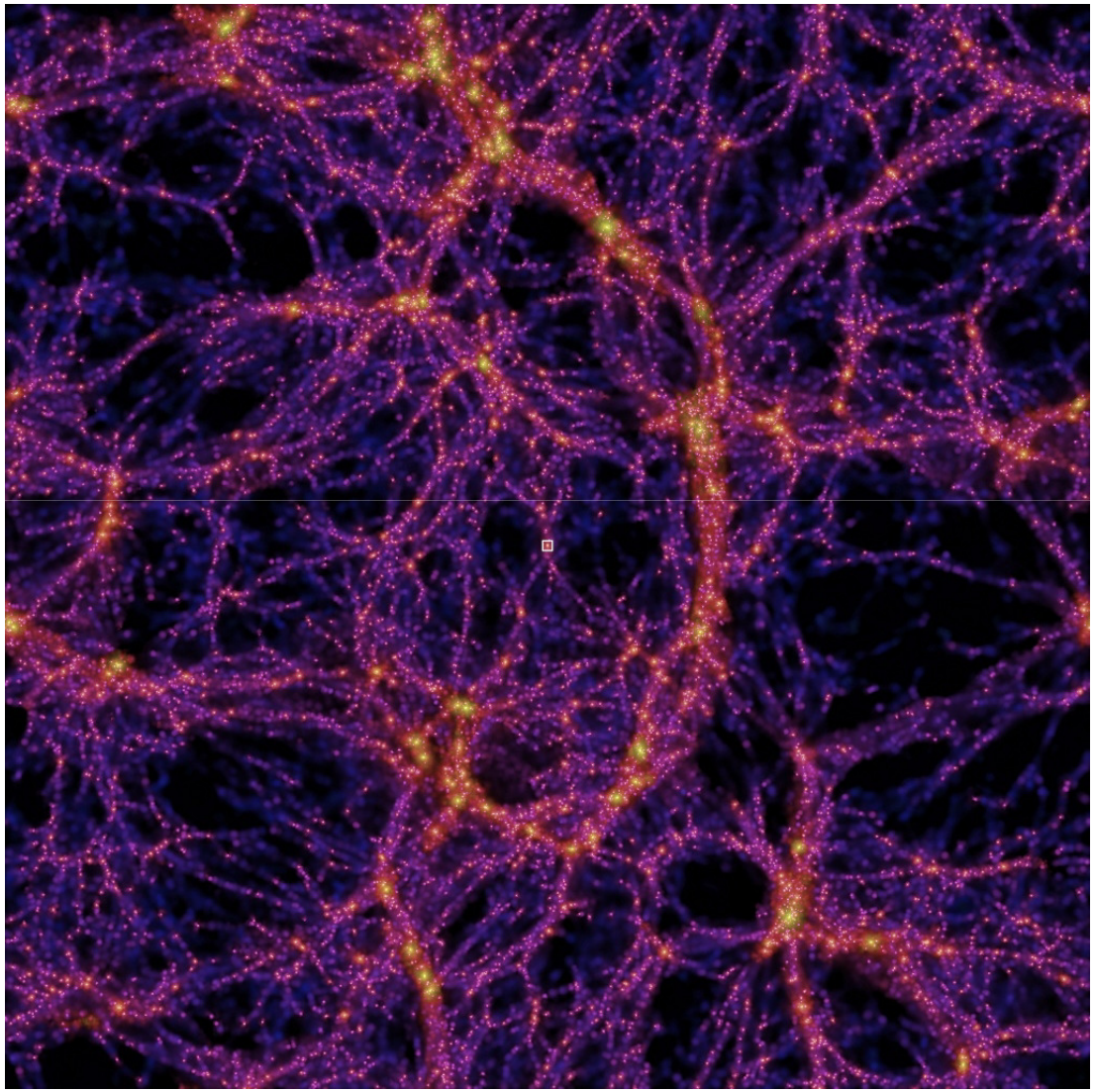
High resolution ΛCDM with 10 bln particles in 100 Mpc/h box

MILLENNIUM II

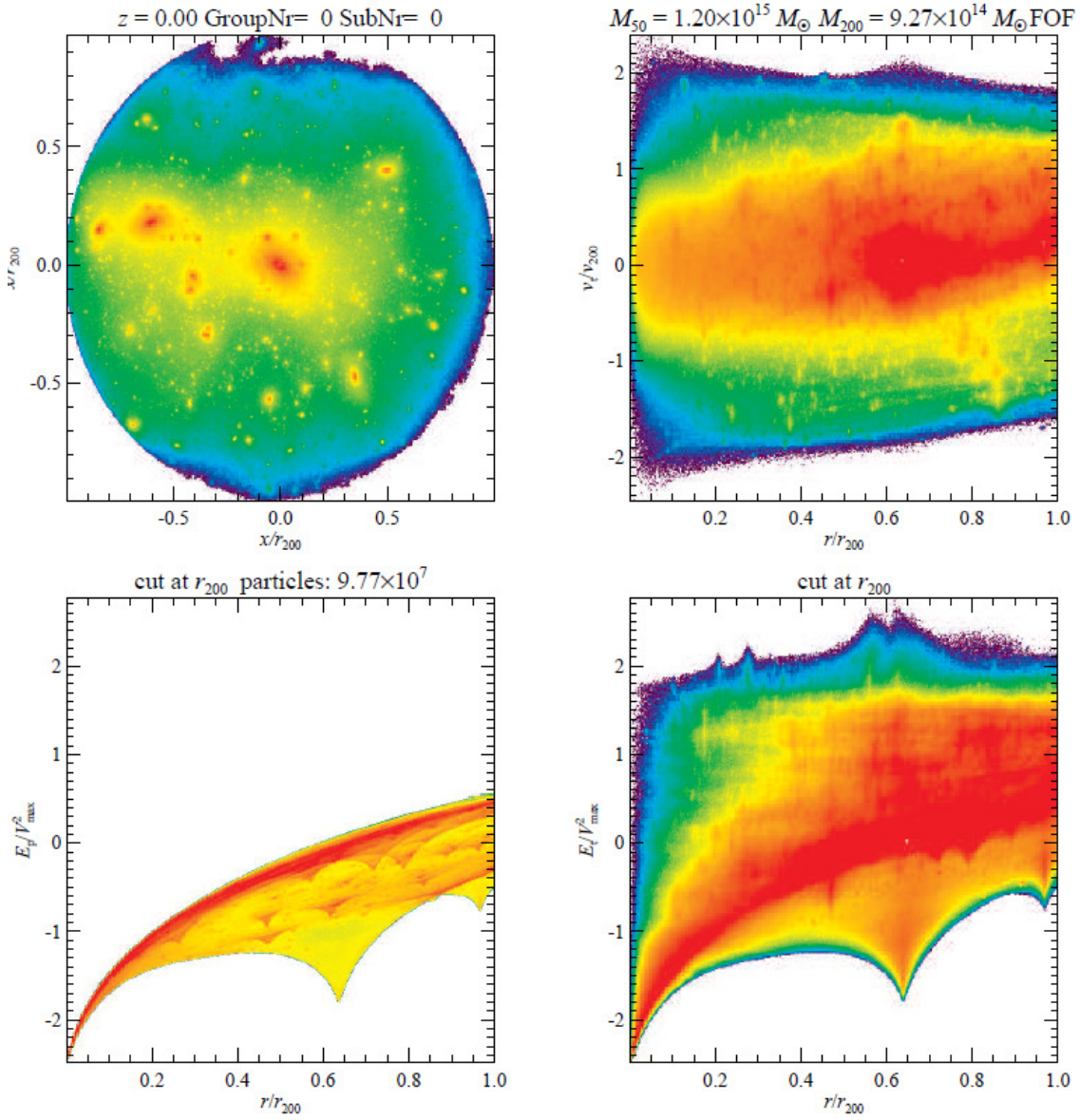
MIKE BOYLAN-KOLCHIN



Millennium II



Millennium II - SUBFIND



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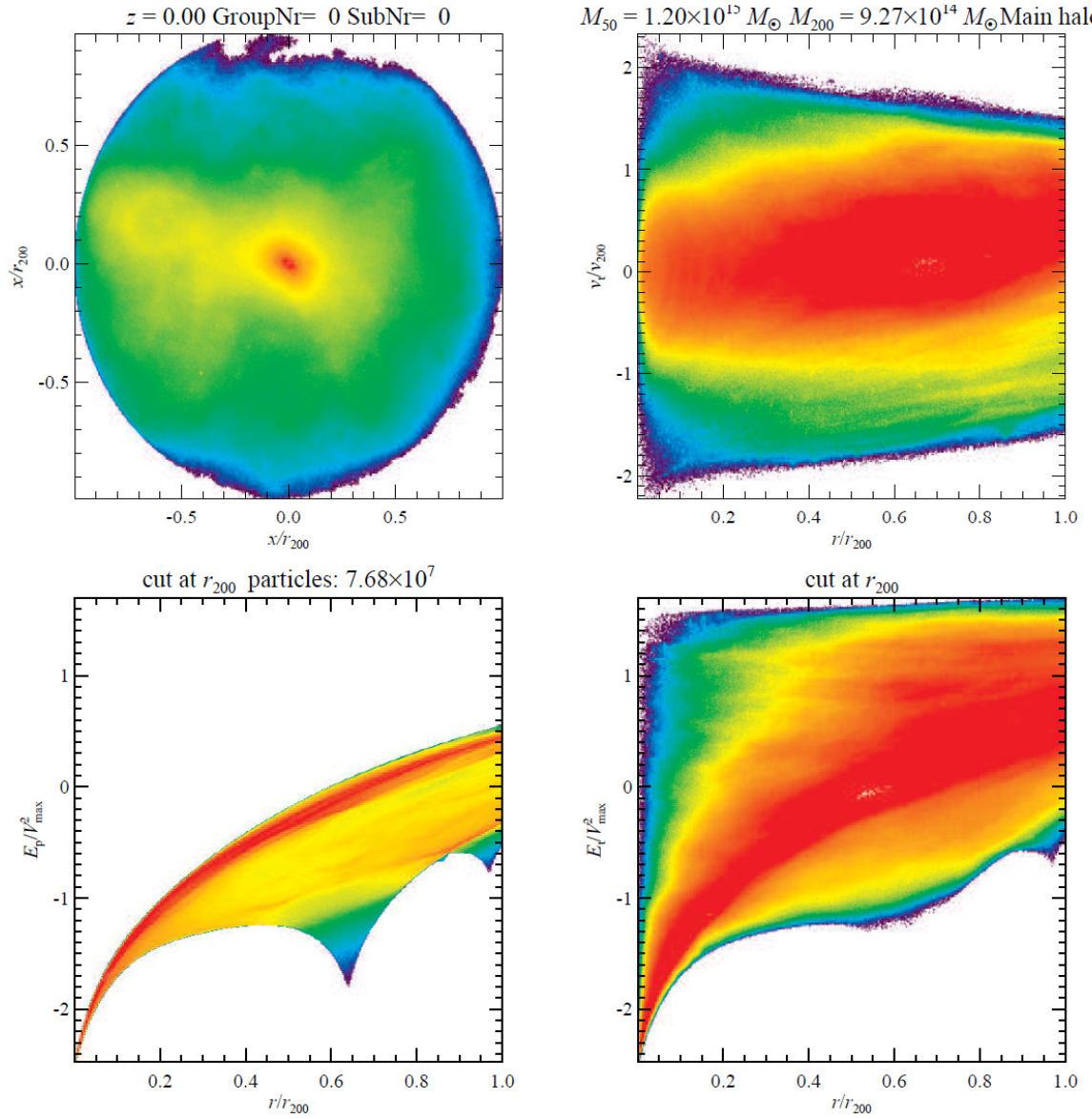

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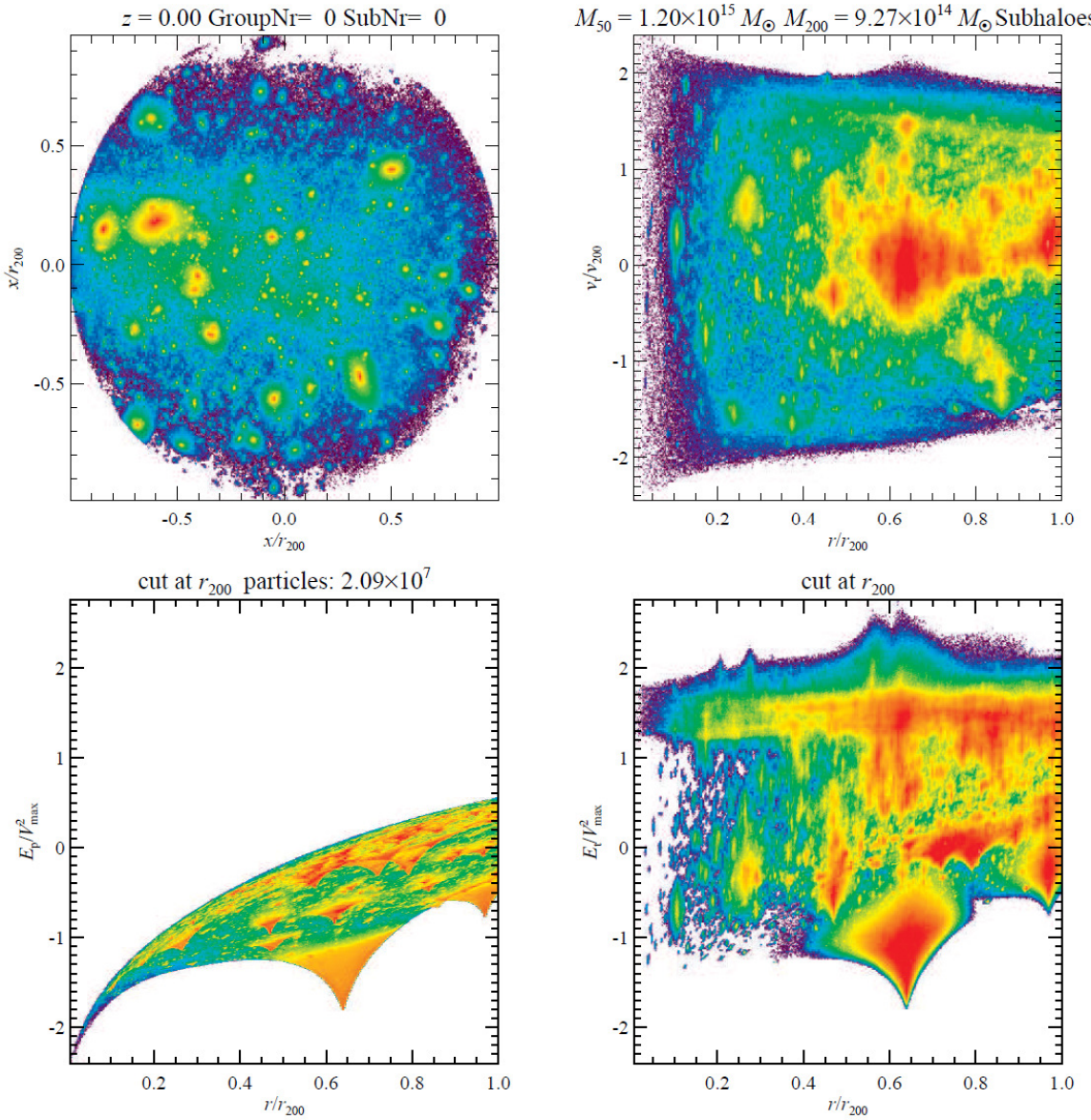

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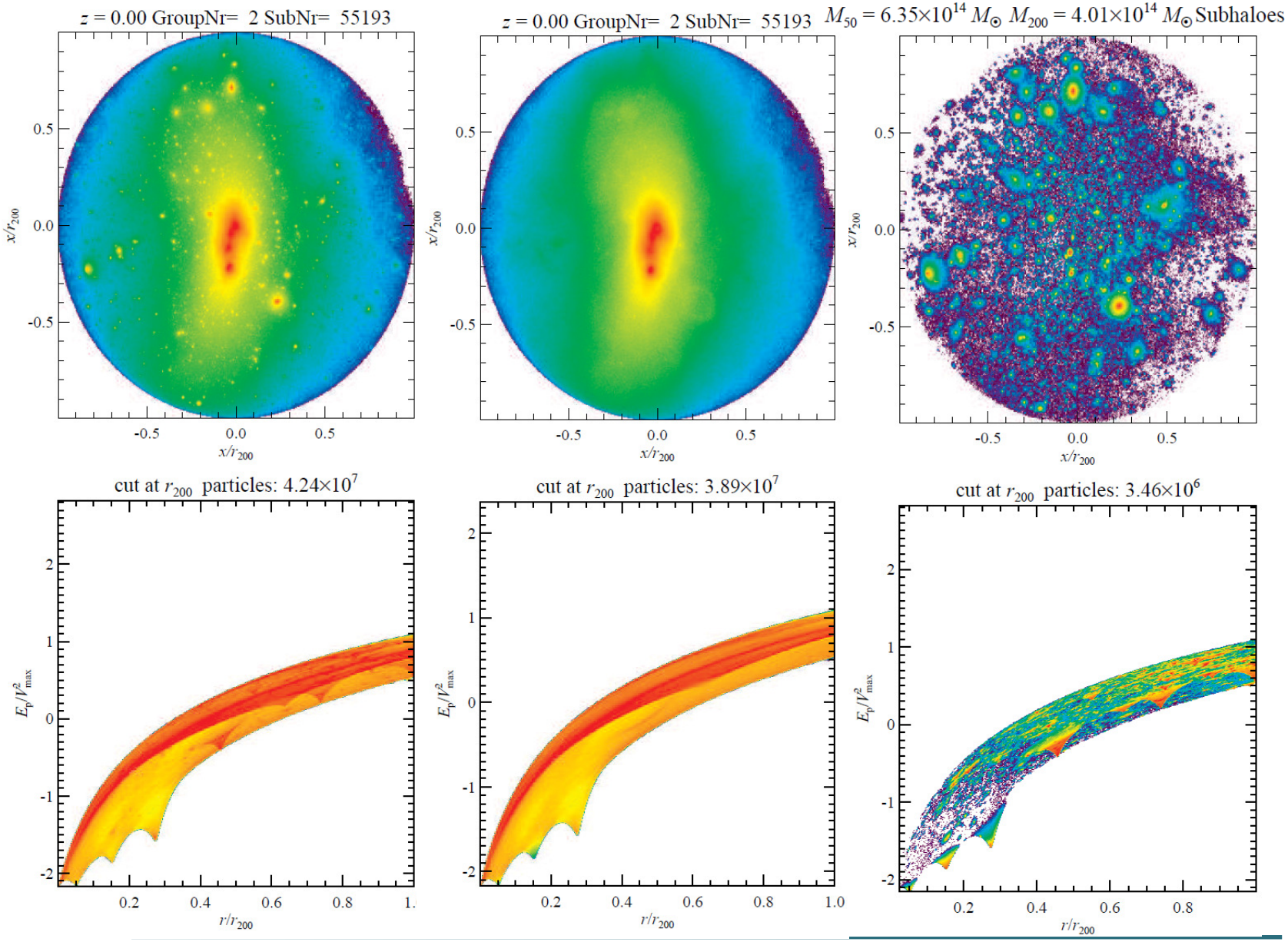

Millennium II - HSF