A blueprint for detecting dark matter in the halo of the Milky Way

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Testing the cold dark matter theory

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The ultimate test:

Testing the cold dark matter theory

The ultimate test:

find the bloody thing!

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A blueprint for detecting halo CDM

Supersymmetric particles annihilate and lead to production of γ-rays which may be observable by GLAST/FERMI

Intensity of annihilation radiation at $\boldsymbol{x}$ depends on:

$$\int \rho^2(\boldsymbol{x}) \, \langle\sigma v\rangle \, dV$$

halo density at $\boldsymbol{x}$ cross-section

$\Longrightarrow$ Theoretical expectation requires knowing $\rho(\boldsymbol{x})$

$\Longrightarrow$ Accurate high resolution N-body simulations of halo formation from CDM initial conditions

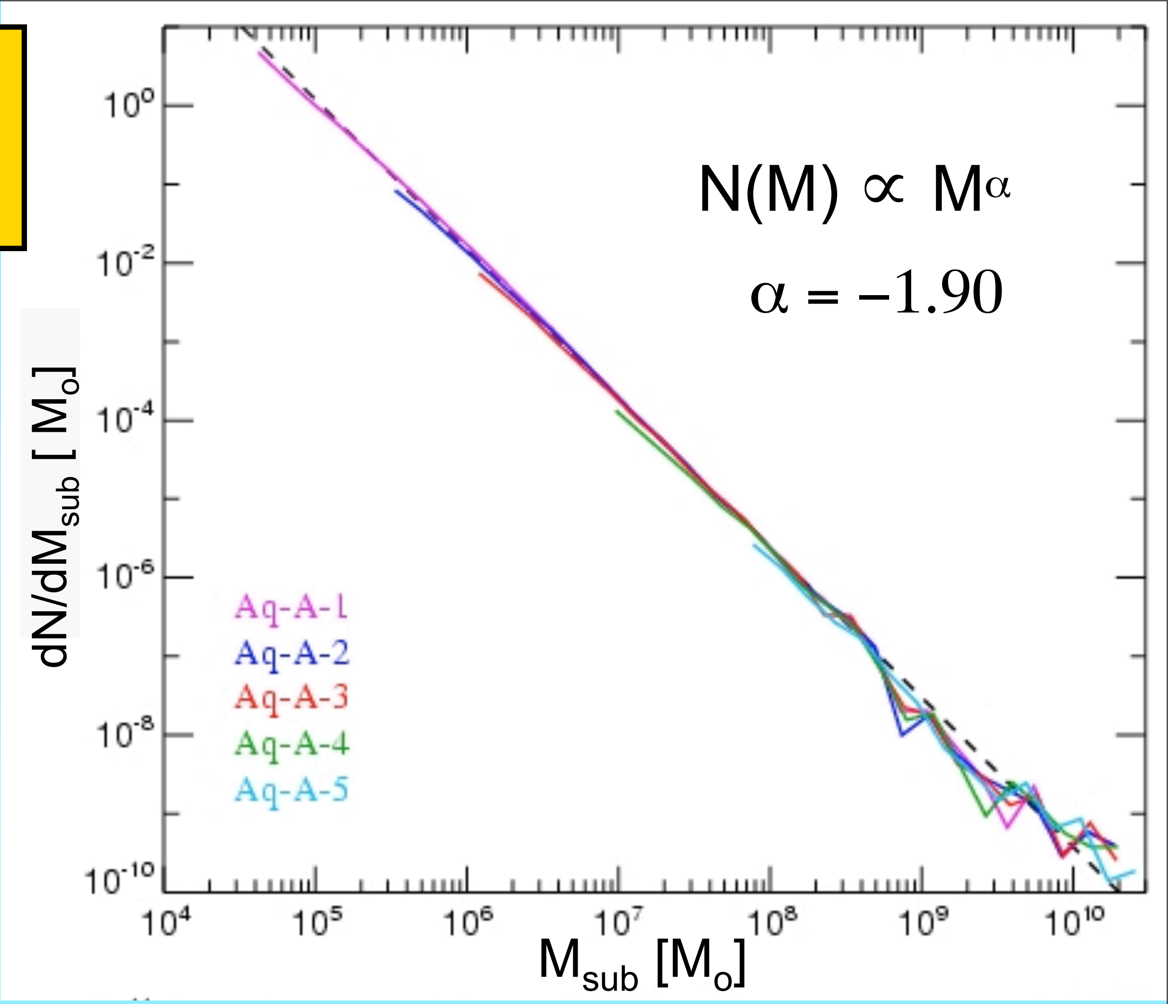

z = 0.1
A galactic dark matter halo
1.1 billion particles inside r_{vir}
Springel, Wang, Volgensberger, Ludlow, Jenkins, Helmi, Navarro, Frenk & White '08
2400^3 run

The mass function of substructures

The subhalo mass function is shallower than M^2

- Most of the substructure mass is in the few most massive halos
- The total mass in substructures converges well even for moderate resolution

Virgo consortium
Springel et al 08



300,000 subhalos within virialized region in Aq-A-1

Springel, Wang, Vogelsberger, Ludlow, Jenkins, Helmi, Navarro, Frenk & White '08

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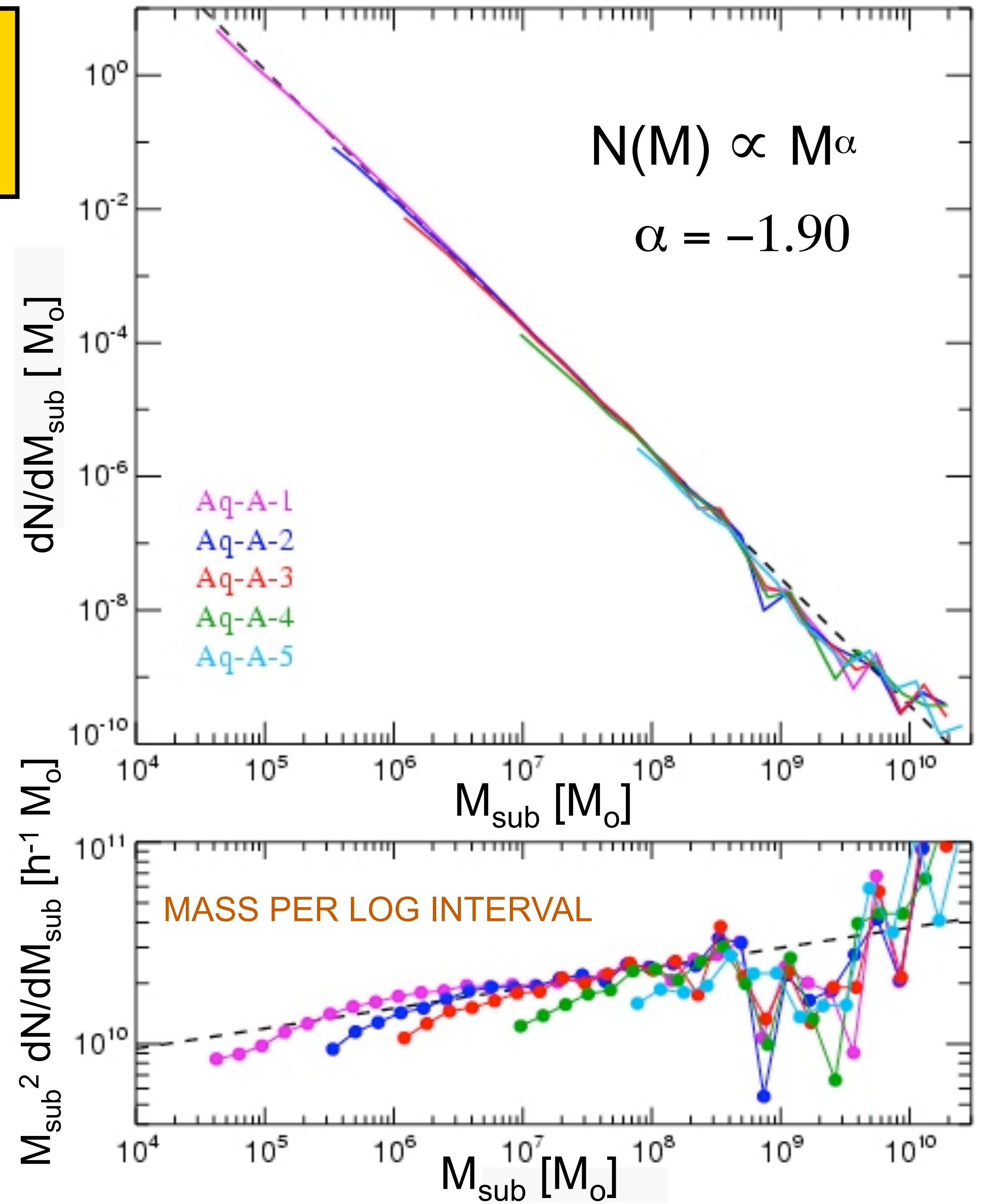

The substructure circ velocity function

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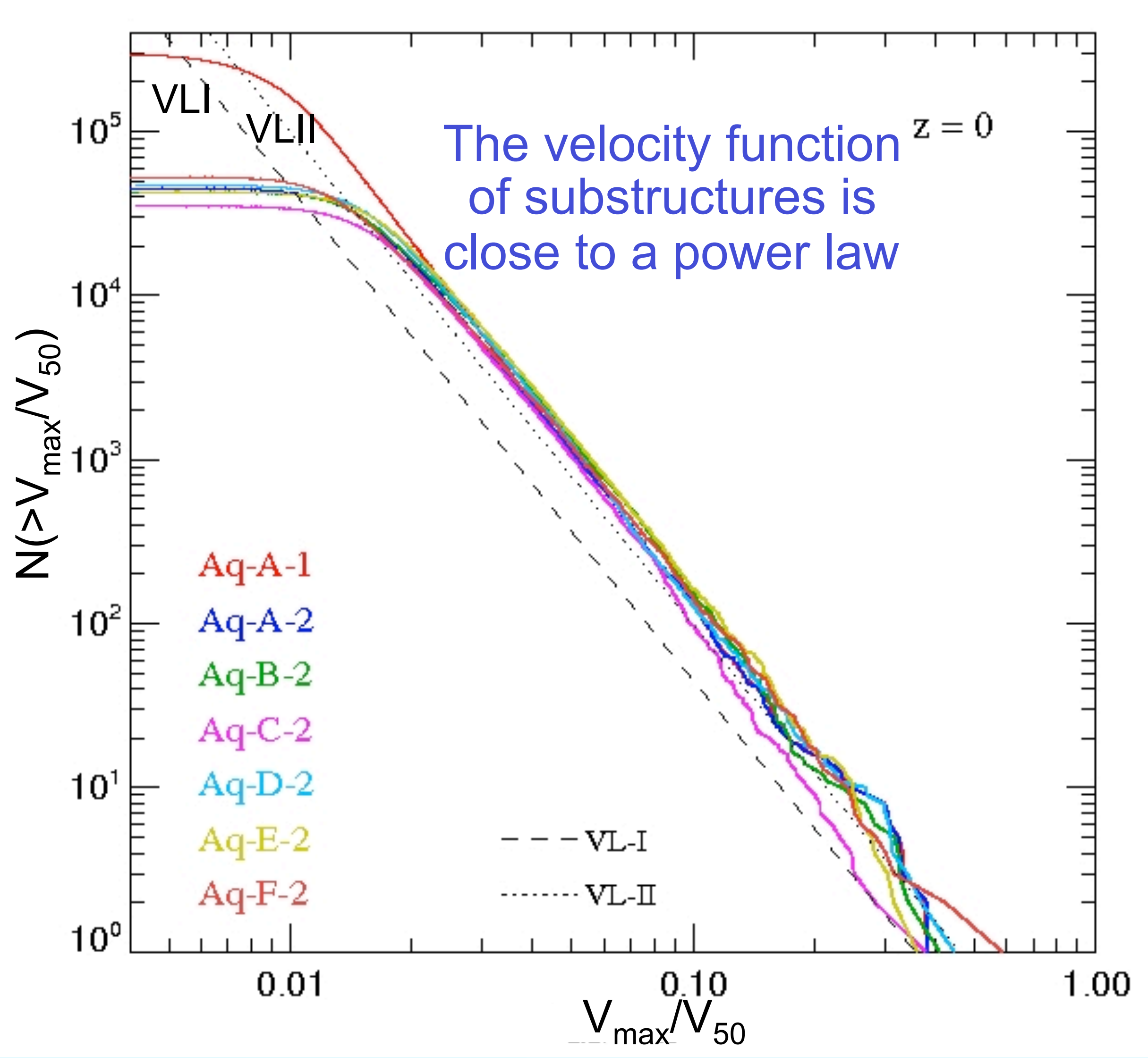
CUMULATIVE NUMBER OF SUBSTRUCTURES AS A FUNCTION OF VMAX

We find *3 times* as many subhalos as Diemand et al find for VL I, but VLII is close to our ensemble

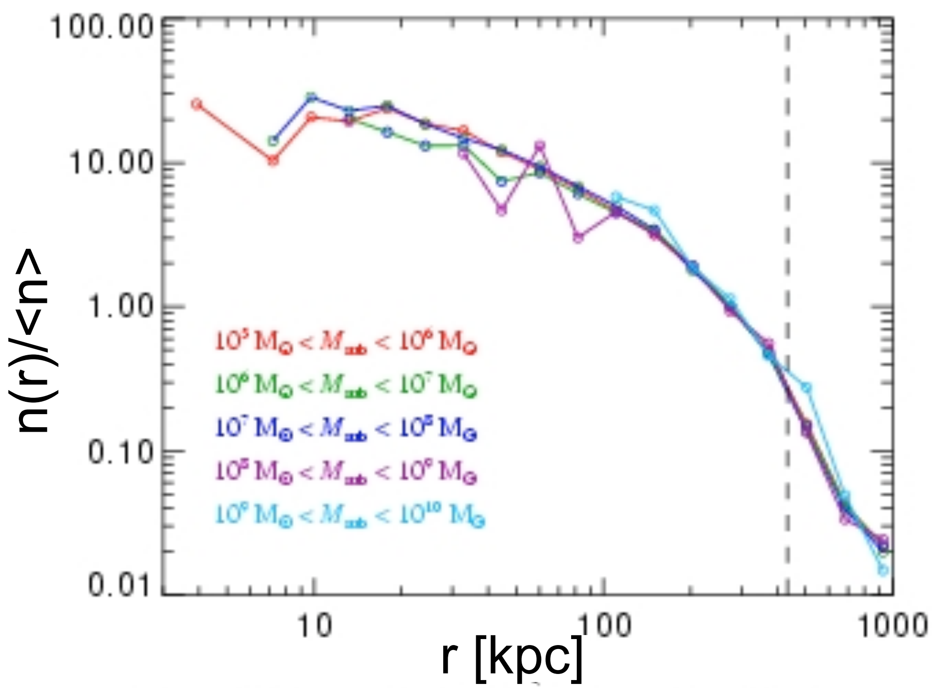
Differences in the DM distributions of VLII and Aquarius are NOT significant for the problem at hand

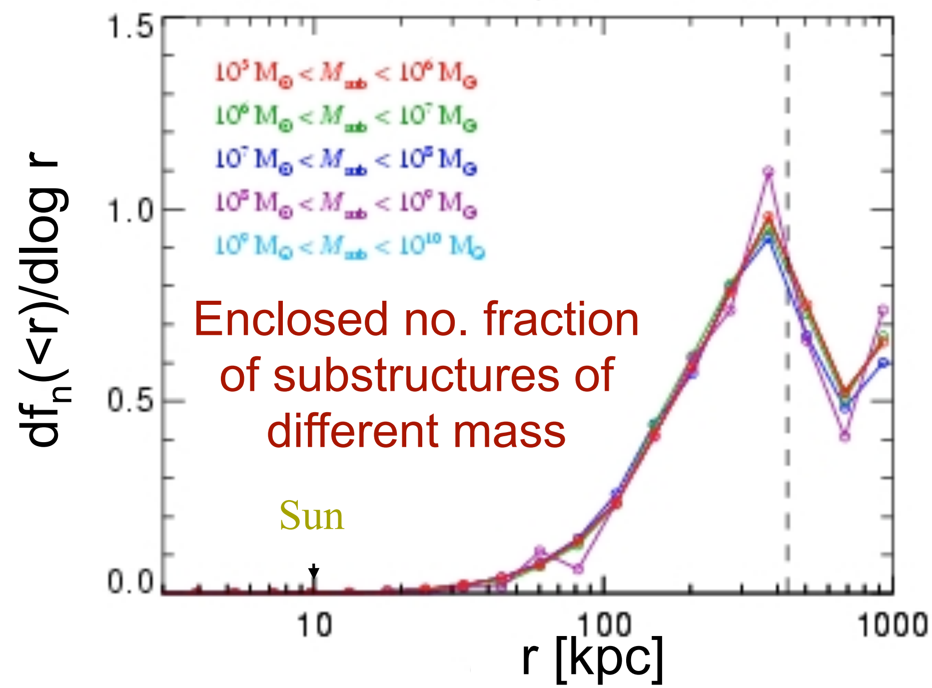
The differences in our conclusions about γ-ray radiation stem from different assumptions about visibility of clumps



The subhalo number density profile

- The spatial distribution of subhalos (except for the few most massive ones) is independent of mass
- Most subhalos are at large radii -- subhalos are more effectively destroyed near the centre
- Most subhalos have completed only a few orbits; dynamical friction unimportant below a subhalo mass threshold
- Subhalos are far from the Sun





How lumpy is the MW halo?

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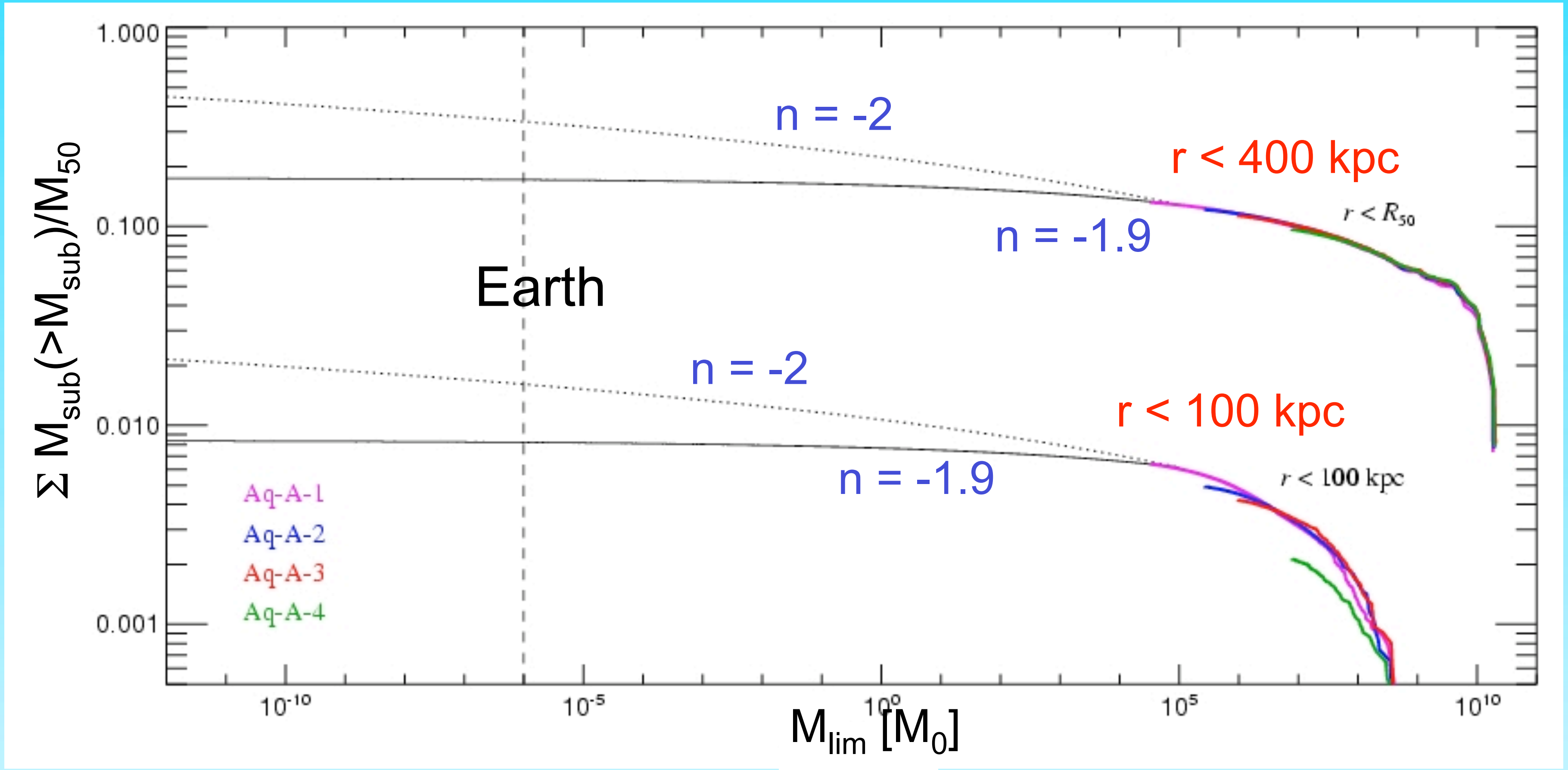
Mass fraction in subhalos as a fn of cutoff mass in CDM PS

The Milky Way halo is expected to be quite smooth!



Substructure mass fraction within R_{sun} < 0.1%

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A blueprint for detecting halo CDM

Supersymmetric particles annihilate and lead to production of γ-rays which may be observable by GLAST/Fermi

Intensity of annihilation radiation at ***x*** depends on:

$$L \propto \int \rho^2(\boldsymbol{x}) \, \langle \sigma v \rangle \, dV$$

halo density at ***x*** — cross-section

Converges for $\rho(r)$ with slope shallower than -1.5

For NFW:
- 95% of L from r_{max}
- 50% of L from $0.1r_{max}$

For a smooth halo: $L \propto \frac{V^4_{\max}}{r_{\max}}$

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More on substructure convergence

Convergence in the size and maximum circular velocity for individual subhalos cross-matched between simulation pairs.

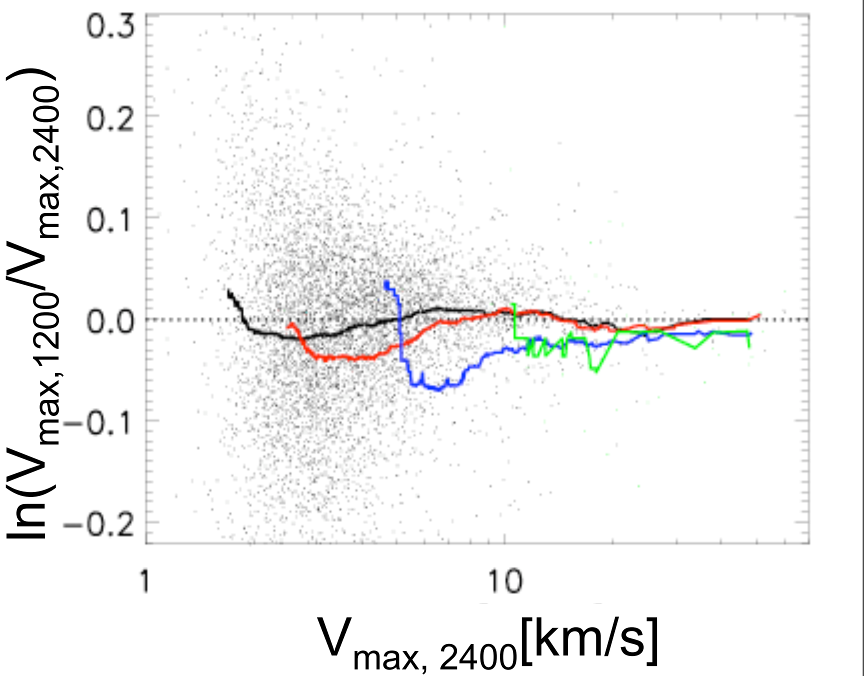
Biggest simulation gives convergent results for

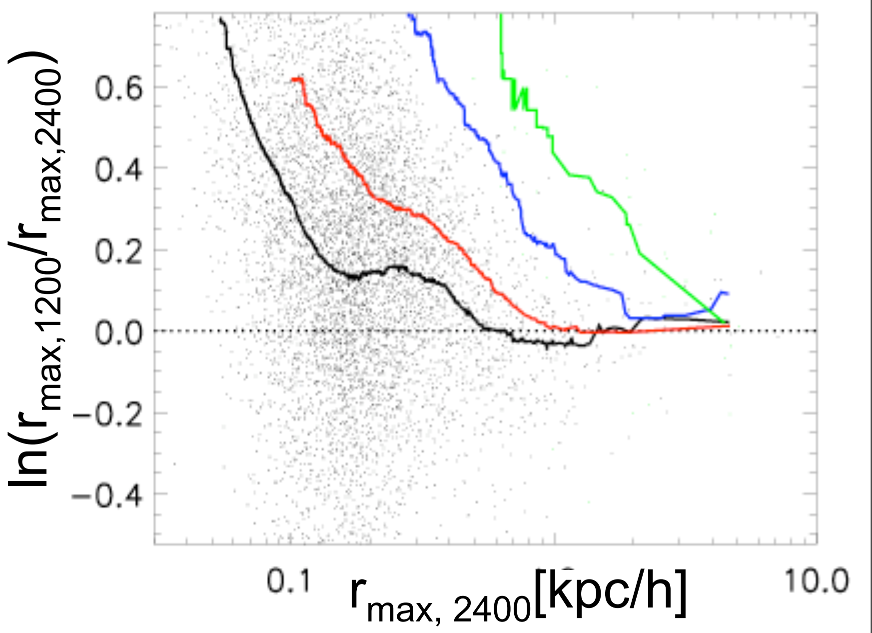
$V_{max} > 1.5$ km/s

$r_{max} > 165$ pc

Much smaller than the halos inferred for even the faintest dwarf galaxies

Virgo Consortium 2008





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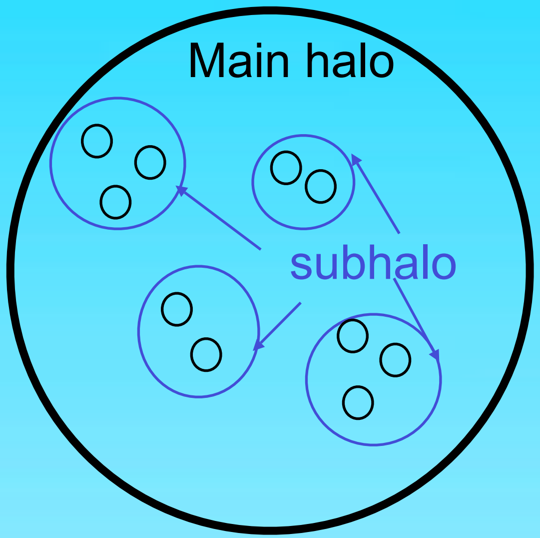
A blueprint for detecting halo CDM

Springel, White, Frenk, Navarro, Jenkins, Vogelsberger, Wang, Ludlow, Helmi

Nature - Nov/08

A blueprint for detecting halo CDM

To calculate L need contribution from 4 components:



1. Smooth emission from main halo
2. Smooth emission from resolved subhalos
3. Emission from unresolved subhalos in main halo
4. Emission from substructure of subhalos

Mass and annihilation radiation profiles of a MW halo

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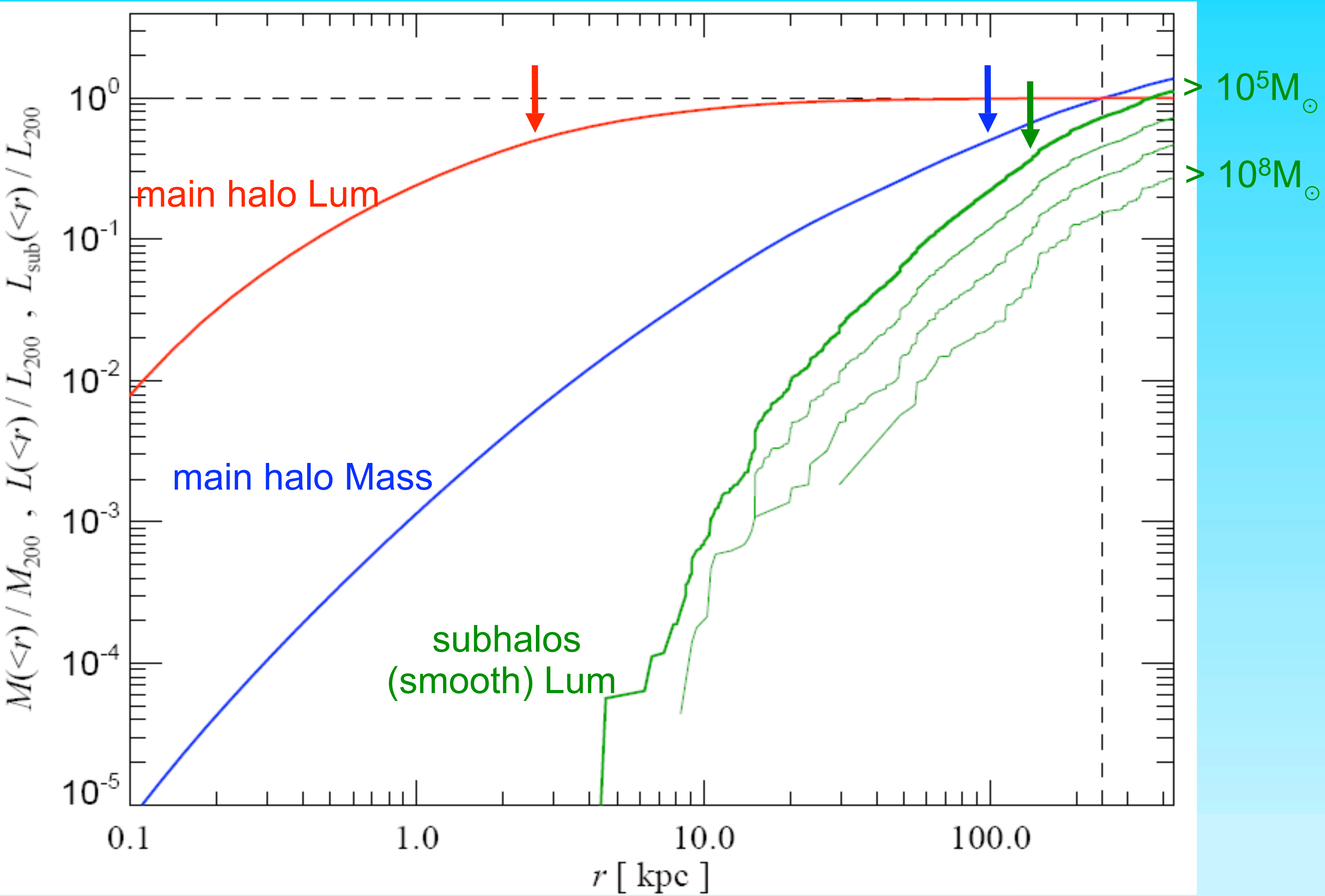

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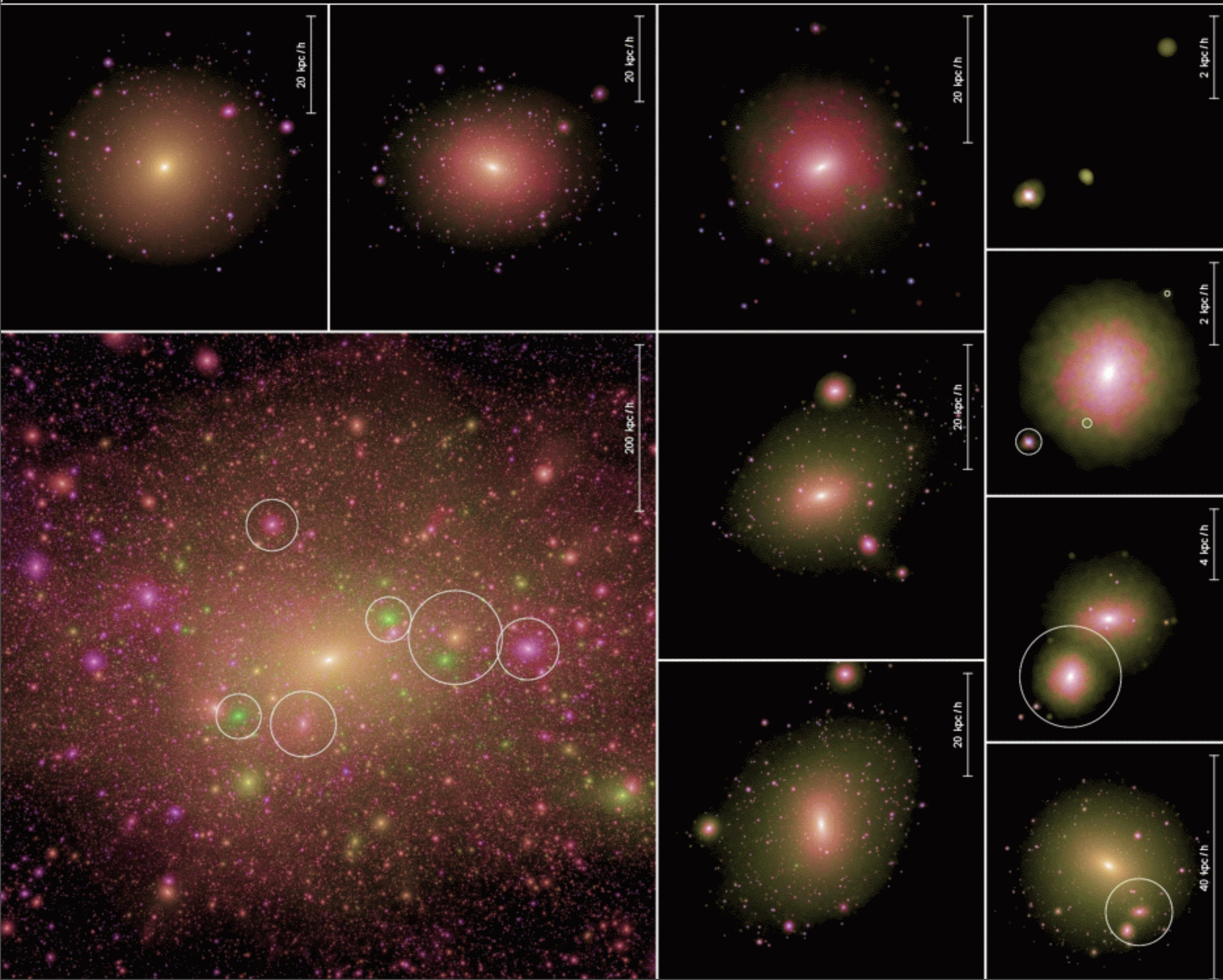
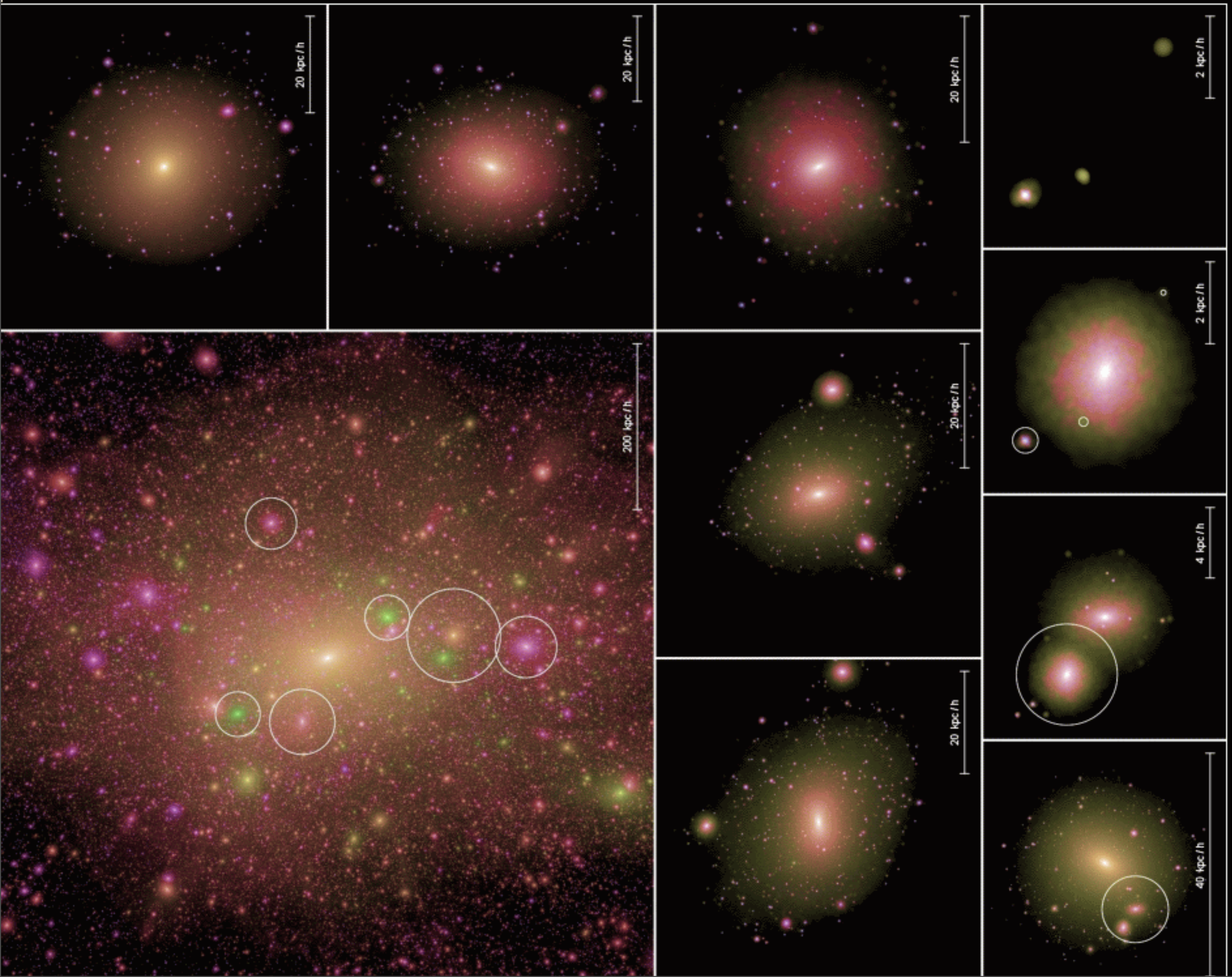
Substructures within substructures



There are substructures embedded within other structures.
We detect 4 generations

Substructures within substructures

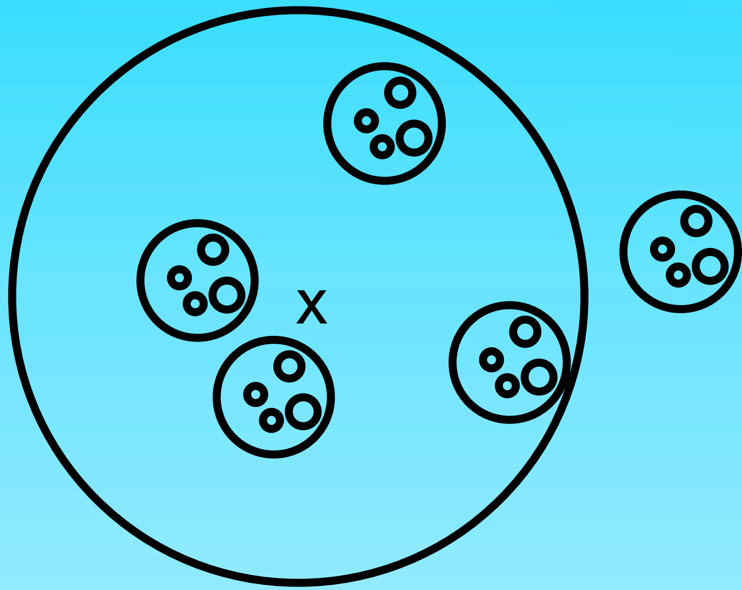


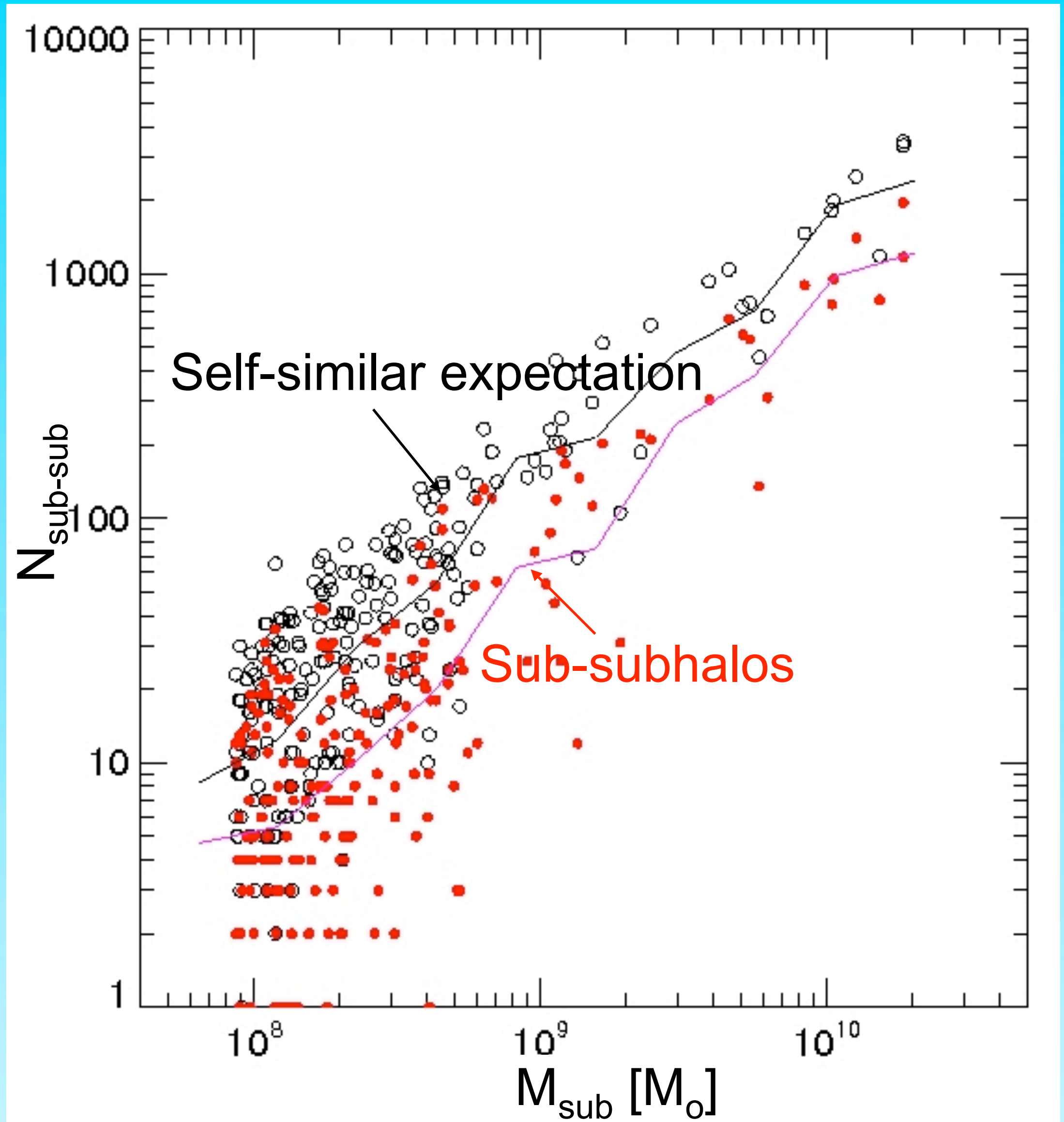
There are substructures embedded within other structures. We detect 4 generations

The hierarchy clearly is NOT self-similar and is heavily dependent on the degree of tidal stripping of the subhalo

Substructures within substructures

No of (sub-)substructures





Self-similar expectation assumes subhalos are scaled down copies of main halo (corrected for resolution)

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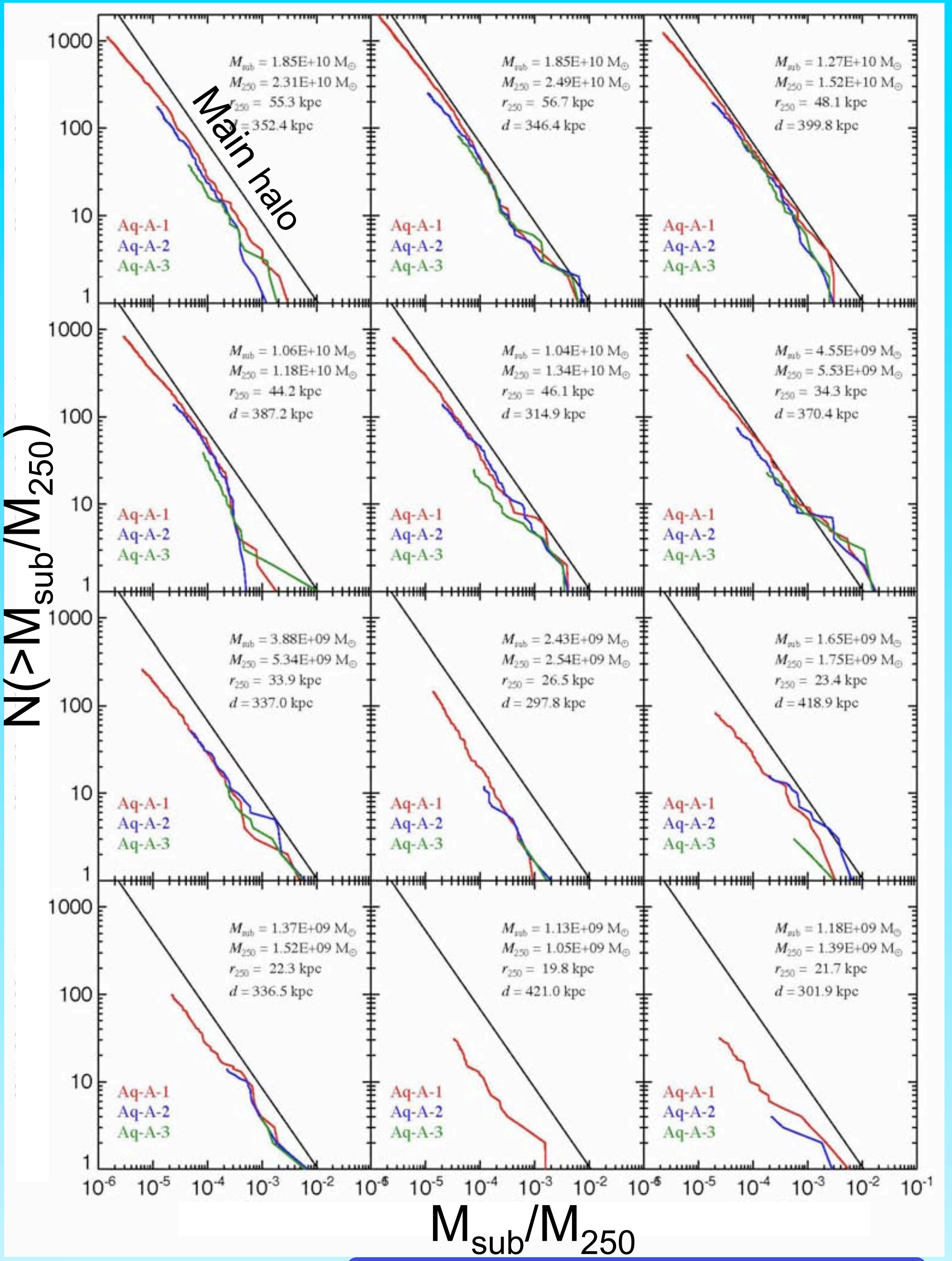
Substructures within substructures

Cumulative number of (sub-) subhalos within subhalos



substructure mass fraction in subhalos is much lower than in the main halo

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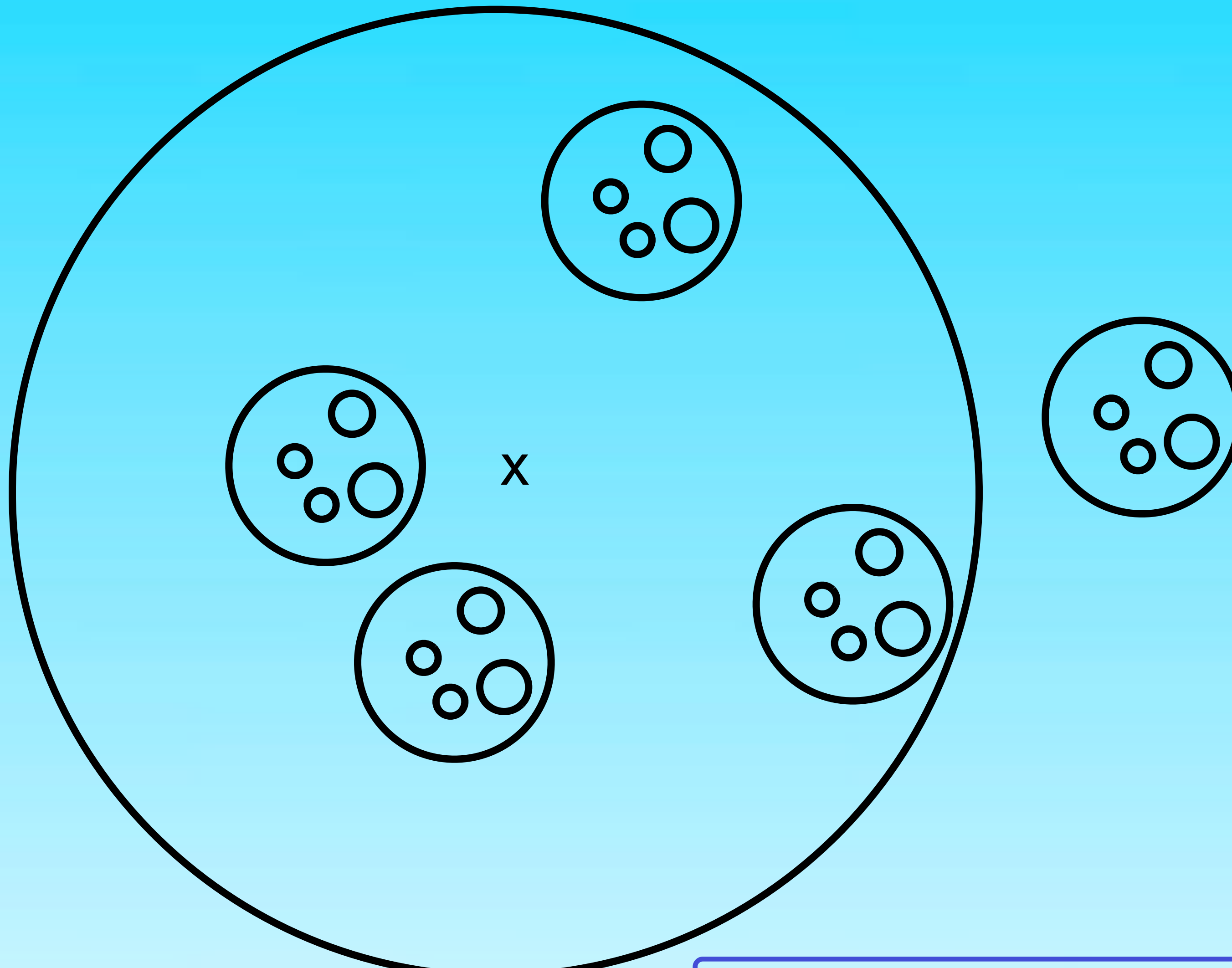

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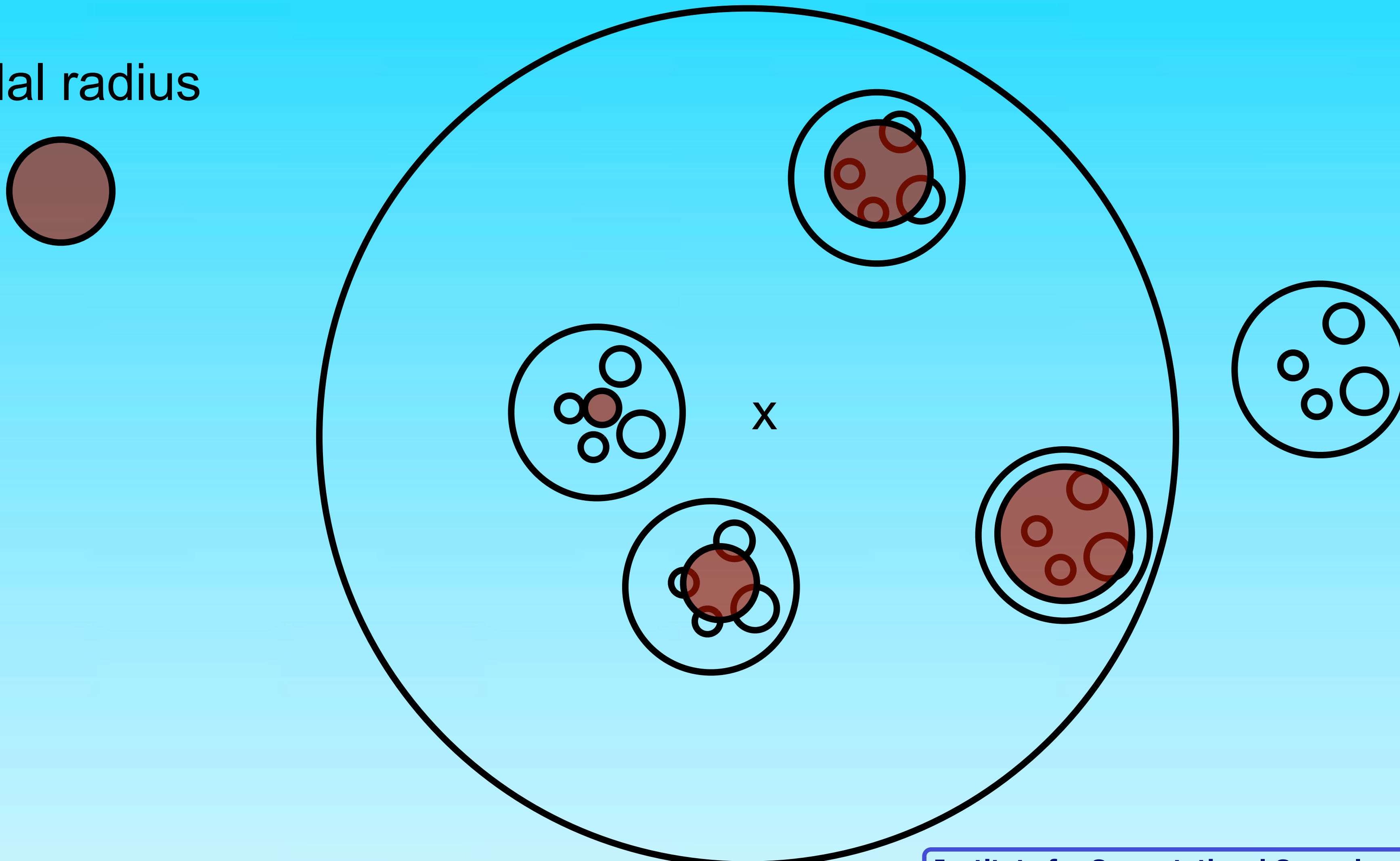
Tidal radius



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Substructures within substructures

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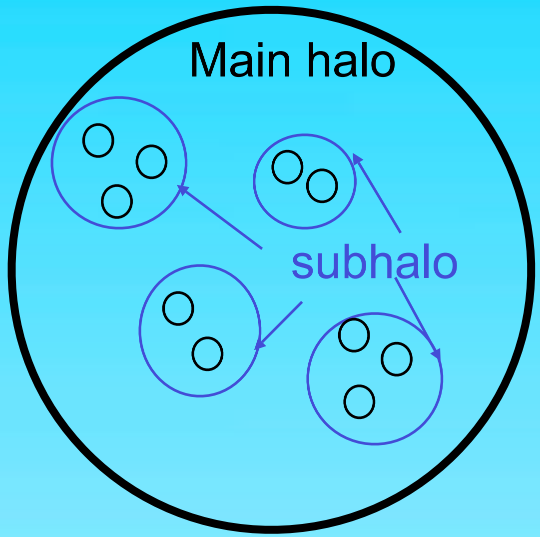
Sub-substructure abundance in subhalos is NOT, in general, a scaled-down version of that in the main halo



because:

- substructure abundance reduced by tidal truncation
- sub-subs continue to loose mass through tides
- sub-subs not replenished by infall of fresh halos

$\Longrightarrow$ Distribution of sub-substructure is NOT self-similar

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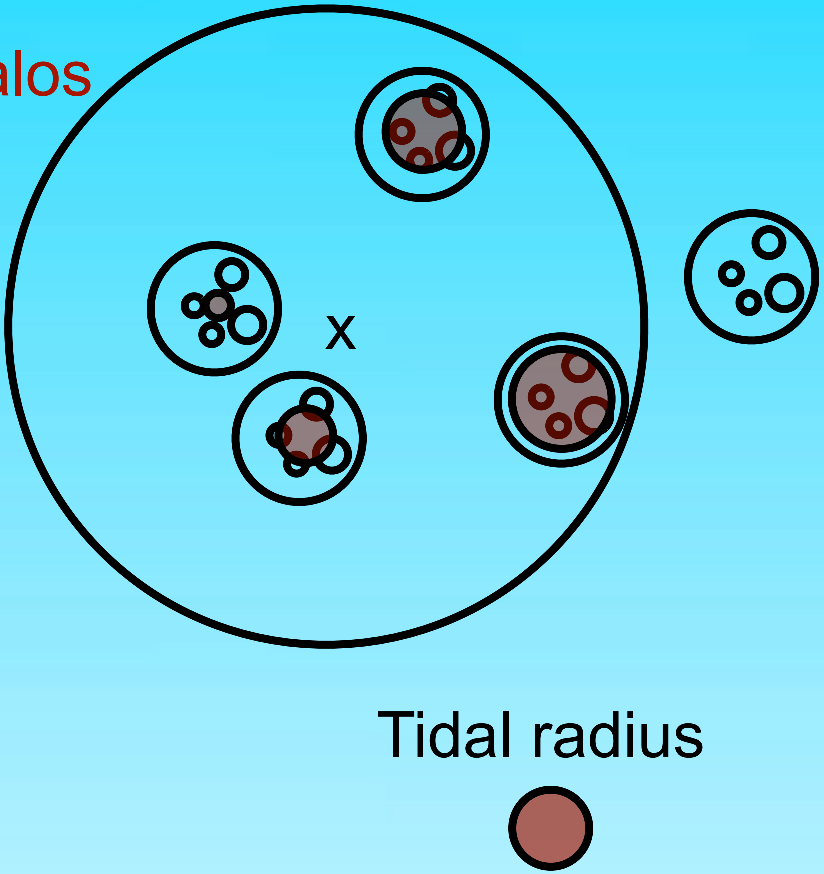
Emission from substructure of subhalos

- Assume all material beyond r_t is removed
- Scale from main halo (within scaled r_t)
- Correct for luminosity below (scaled) mass limit



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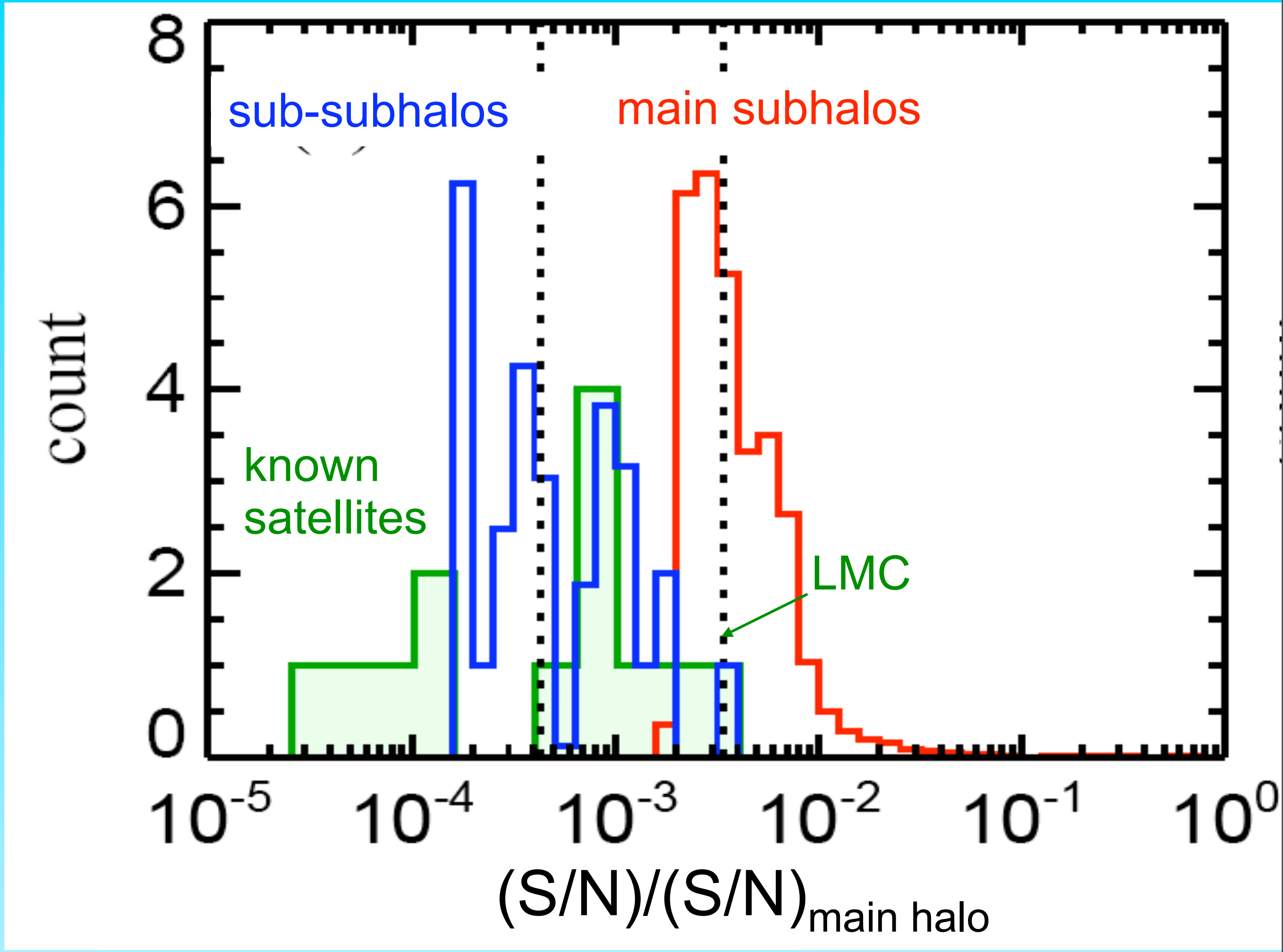
$S/N = F/(\theta^2_h + \theta^2_{psf})^{1/2}$

S/N for detecting subhalos in units of that for detecting the main halo.

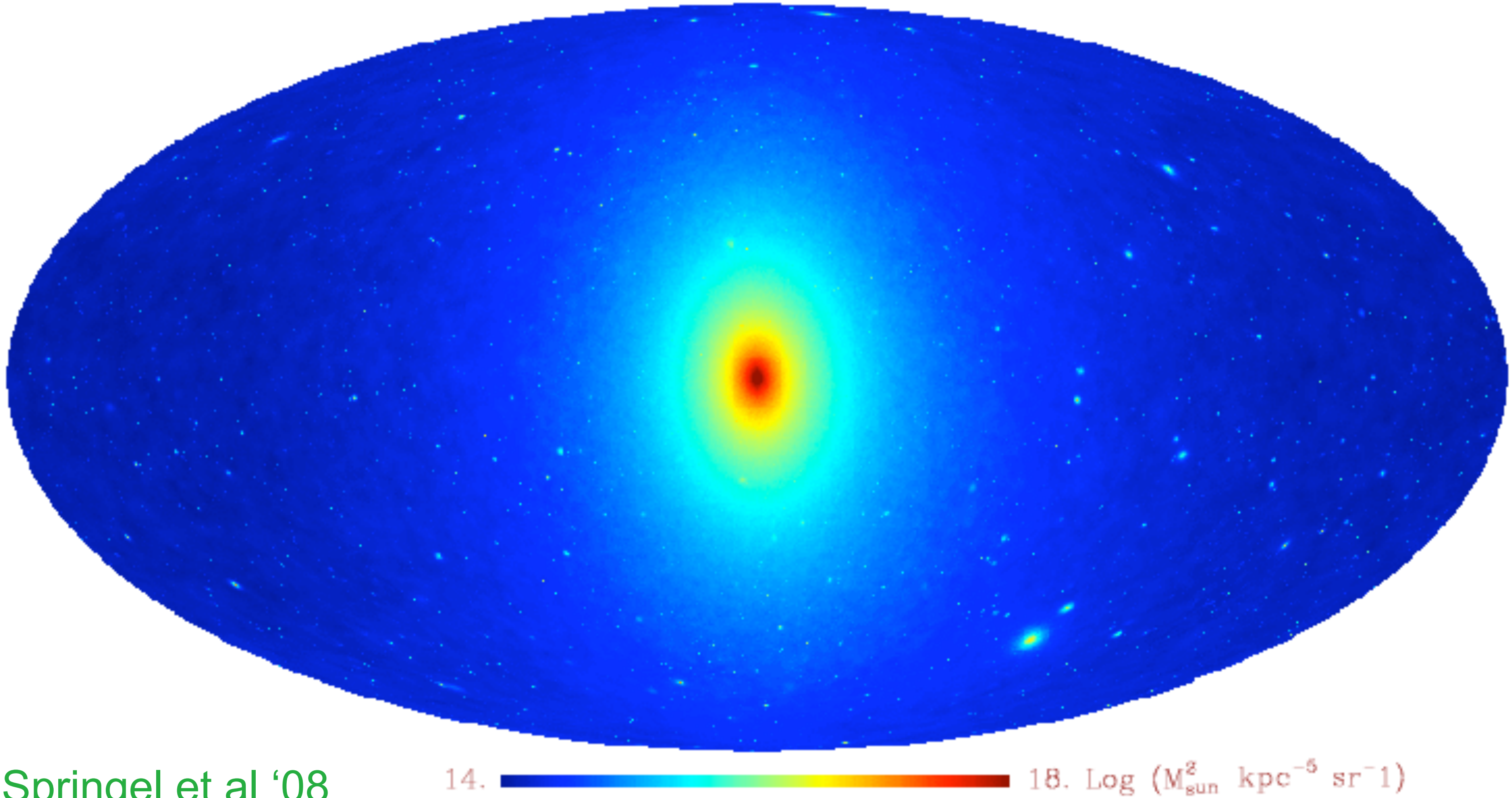
30 highest S/N objects, assuming use of optimal filters



- Highest S/N subhalos have 1% of S/N of main halo
- Highest S/N subhalos have 10 times S/N of known satellites
- Substructure of subhalos has no influence on detectability

Milky Way halo seen in DM annihilation radiation

Aquarius simulation: $N_{200} = 1.1 \times 10^9$



Springel et al '08

A galactic CDM halo

5 Myths about the galactic halo & annihilation signal from the Milky Way

- Halo DM is mostly in small (e.g. Earth mass) clumps
- Halo DM is self-similar distribution of nested subhalos (fractal)
- Small (Earth mass) clumps dominate observable γ-ray signal
- Dwarf spheroidals/subhalos are best targets for detecting signal
- Subhalo γ-ray emission boosted by sub-substructure

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Conclusions: ΛCDM on small scales

- Predictions for galactic dark matter in ΛCDM well established
- N-body simulations of ΛCDM predict:
  – many small substructures, with convergent mass fraction
  – the distribution of DM is not fractal nor is it dominated by Earth-mass objects
- γ-ray annihilation may be detectable by FERMI which should:
  – First detect smooth halo (if background can be subtracted)
  – Then (perhaps) detect dark subhalos with no stars
  – Sub-substructure boost irrelevant for detection

→ Confirm fundamental prediction of CDM model

Galactic dark matter halos

The inner halo is remarkably smooth

Galactic dark matter halos

The inner halo is remarkably smooth

Is the subhalo distribution a fractal?