CHARACTERIZATION OF SUBHALO STRUCTURAL PROPERTIES

and implications for

DM ANNIHILATION SIGNALS

[arXiv: 1603.04057]

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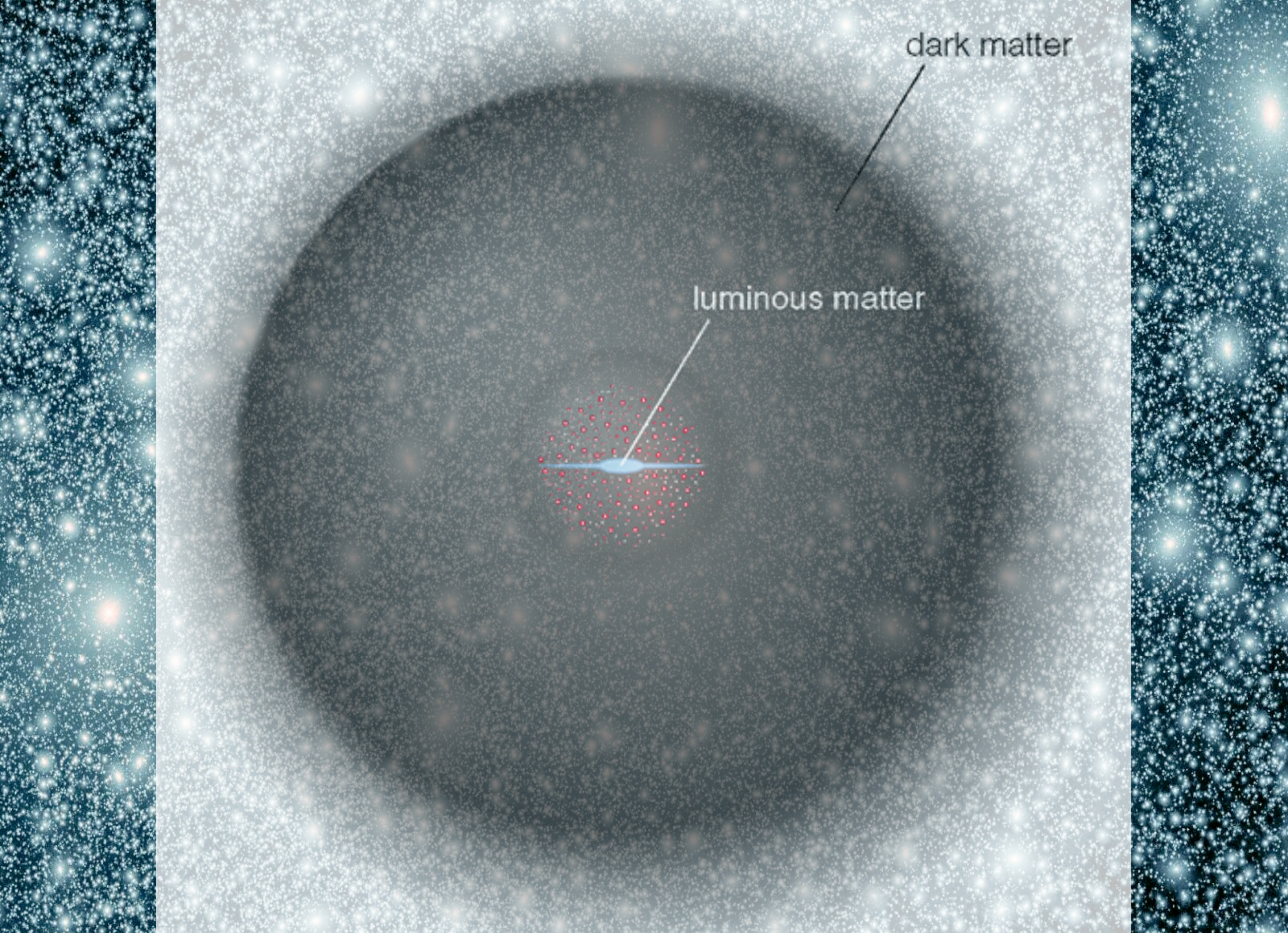
2nd Anisotropic Universe Workshop

GRAPPA, Amsterdam, April 11-13 2016

GHALO simulation [Stadel+09]



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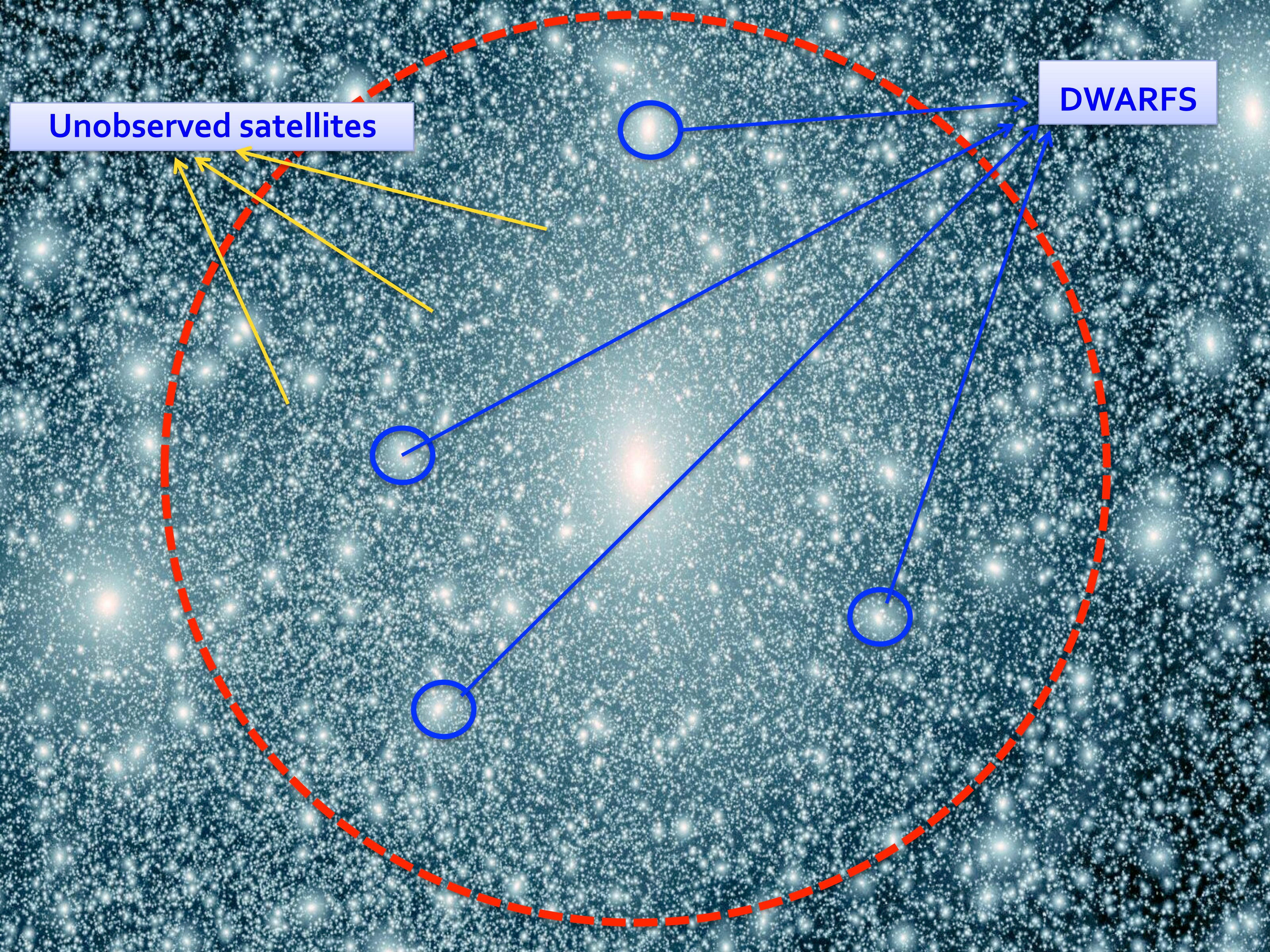
Unobserved satellites
DWARFS

The role of DM substructure in γ-ray DM searches

Both *dwarfs* and *dark satellites* are highly DM-dominated systems

→ GOOD TARGETS

The *clumpy distribution* of subhalos inside larger halos may boost the annihilation signal importantly.

→ SUBSTRUCTURE BOOSTS

The role of DM substructure in γ-ray DM searches

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→ SUBSTRUCTURE BOOSTS

DM annihilation boost factor from substructure

Since DM annihilation signal is proportional to the DM density squared
→ *Enhancement of the DM annihilation signal expected due to subhalos.*

Substructure **BOOST FACTOR**: $L = L_{host} * [1+B]$, so $B=0$ → no boost
$B=1$ → $L_{host} \times 2$ due to subhalos

$$B(M) = \frac{1}{L(M)} \int_{M_{min}}^{M} (dN/dm)\ [1 + B(m)]\ L(m)\ dm$$

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Subhalo mass function

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Subhalo luminosity

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M_{min}: Minimum halo mass

(dN/dm): Subhalo mass function

$L(m)$: Subhalo luminosity

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- M_{min}: Minimum halo mass
- (dN/dm): Subhalo mass function
- $[1 + B(m)]$: Other levels of sub-substructure
- $L(m)$: Subhalo luminosity

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Host halo luminosity

Minimum halo mass

Subhalo mass function

Other levels of sub-substructure

Subhalo luminosity

B(M) depends on the internal structure of the subhalos and their abundance

→ N-body cosmological simulations

- Integration down to the minimum predicted halo mass ~10^{-6} Msun.
- Current Milky Way-size simulations "only" resolve subhalos down to ~10^{5} Msun.

→ ***Extrapolations below the mass resolution*** *needed.*

Subhalo mass function

$$dN/dm = A/M(m/M)^{-\alpha}$$

α = -1.9 in Aquarius
α = -2 in VL-II

Subhalo annihilation luminosity

J-factor $\propto \rho_s^2 r_s^3 \propto M \frac{c^3}{f(c)^2}$ with

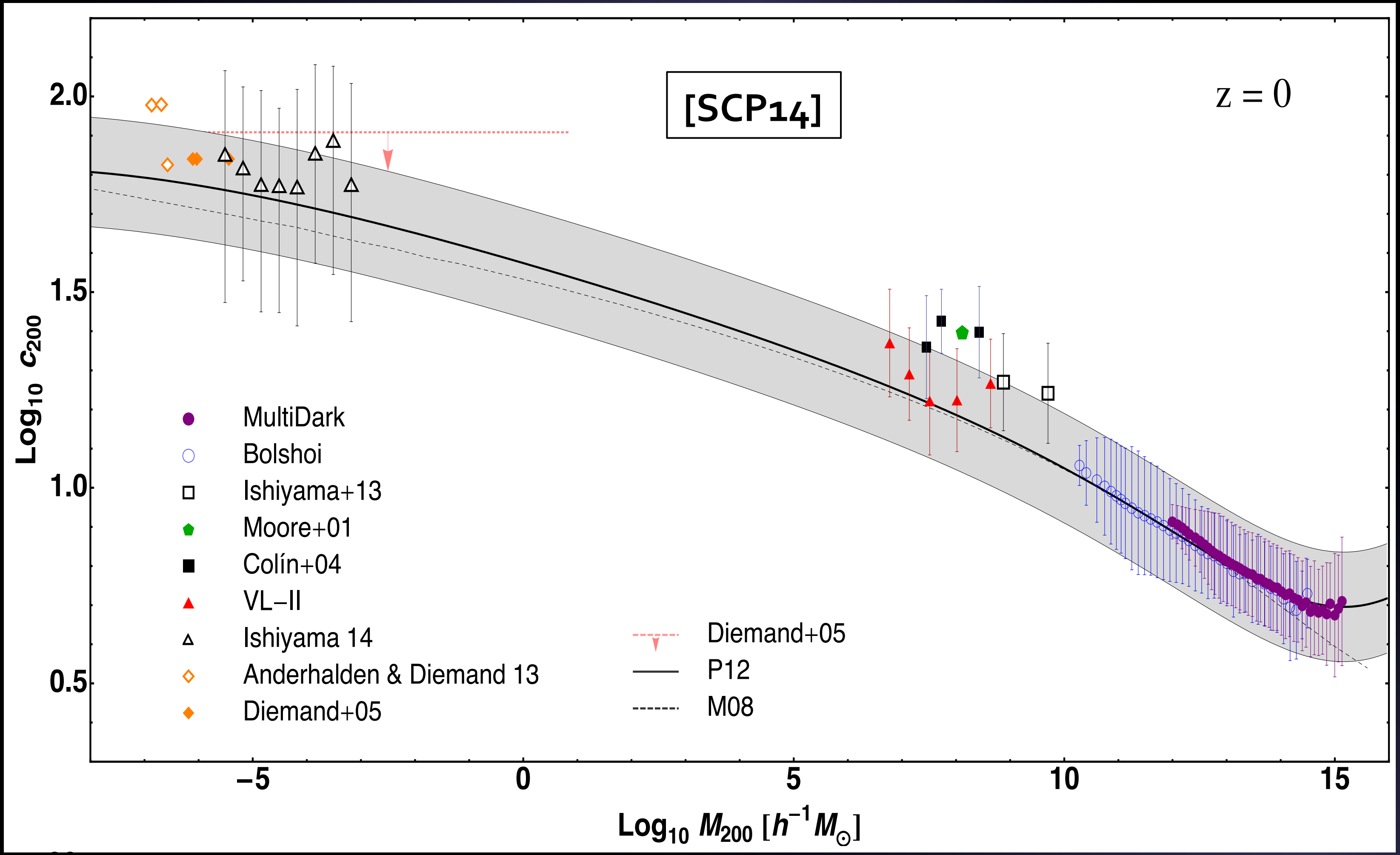
Concentration $c = R_{vir} / r_s$

$$f(c) = ln(1+c) - c/(1+c)$$

→ Results very sensitive to the c(M) extrapolations down to M_{min}

Current knowledge of the c(M) relation at z=0

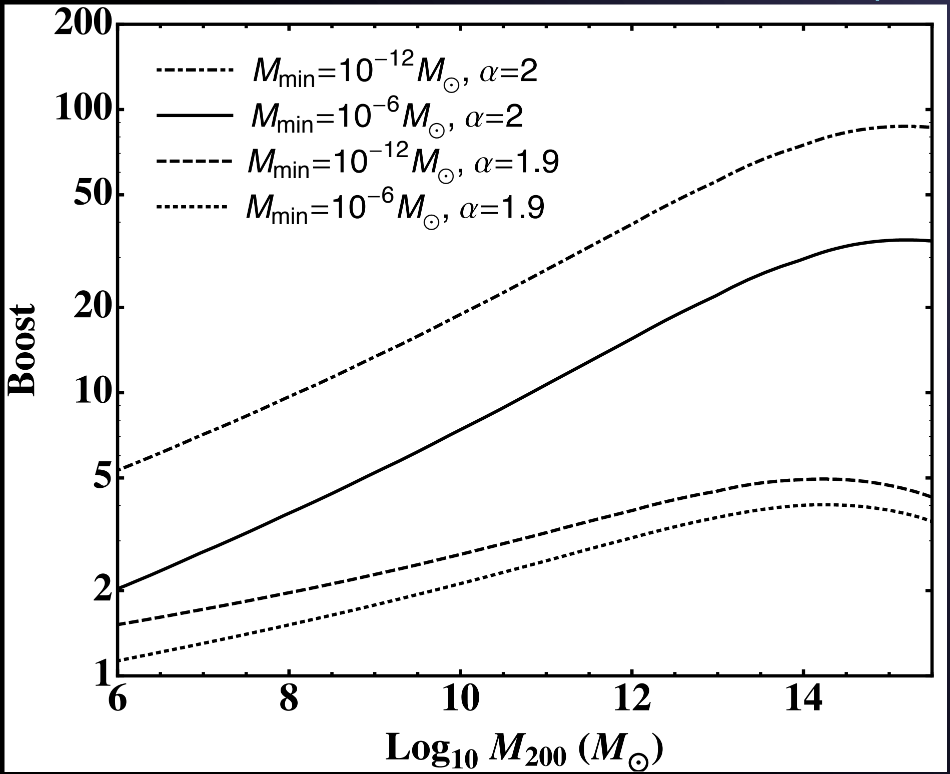
Concentration $c = R_{vir} / r_s$

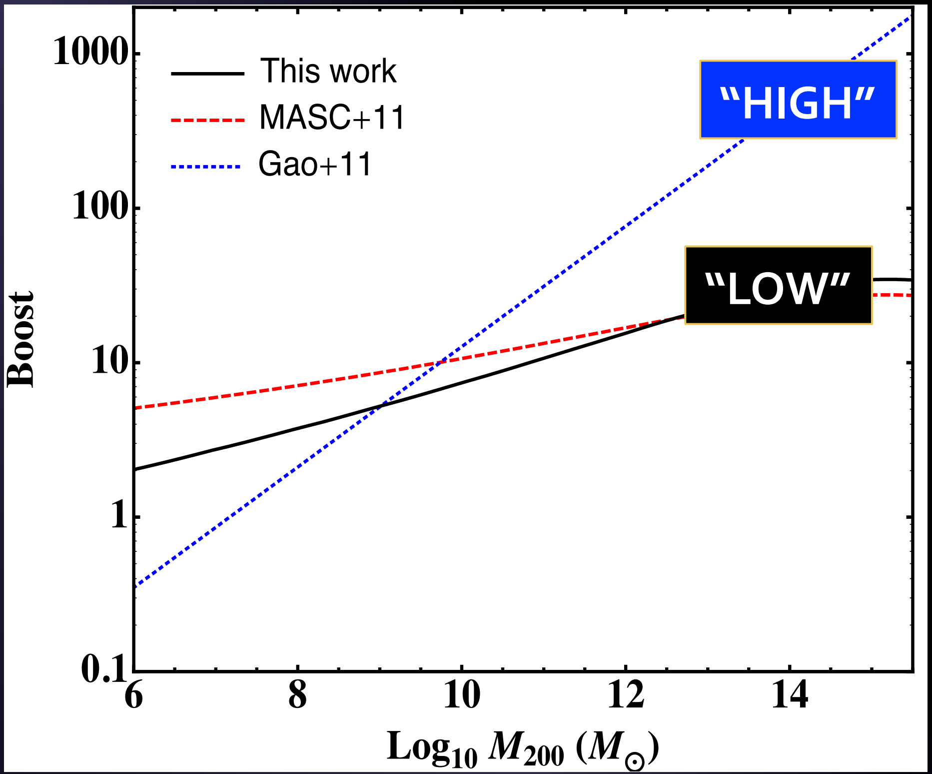


MASC & Prada, MNRAS, 442, 2271 (2014) [astro-ph/1312.1729]

SCP14 substructure boosts

MASC & Prada, MNRAS, 442, 2271 (2014) [astro-ph/1312.1729]





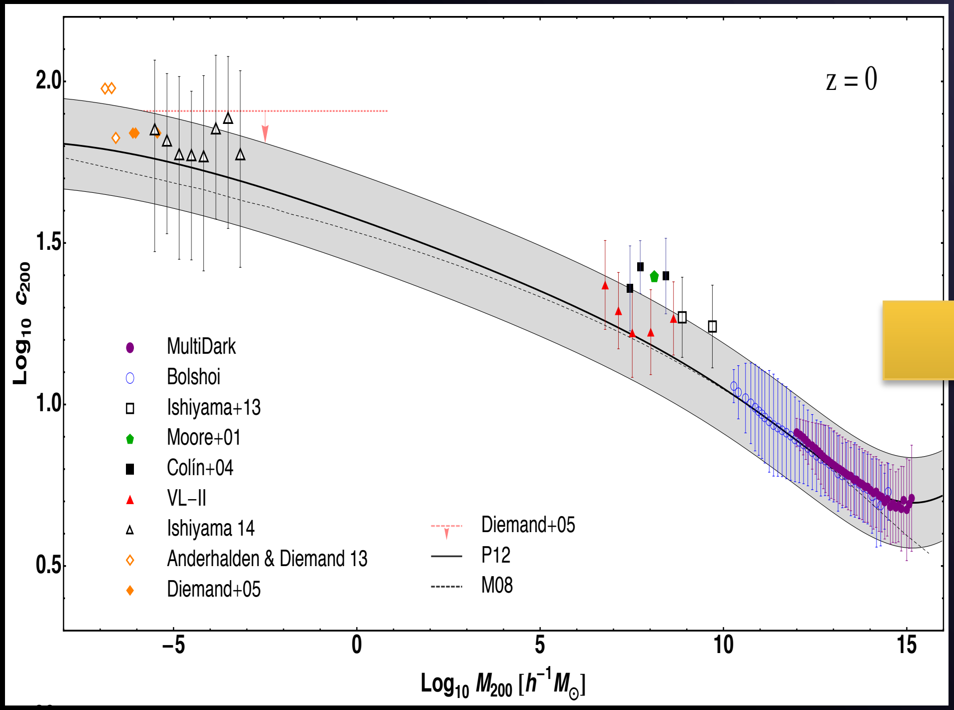
Variation with M_{min} and α
[only first two substructure levels included]

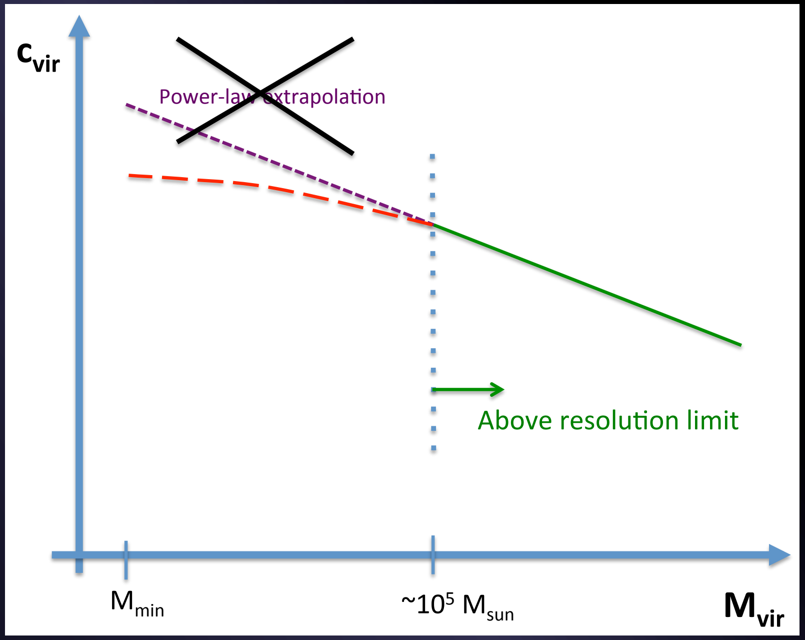
Comparison with previous boost models

Reminder: they all assume that both main halos and subhalos possess similar structural properties!

No more simple power-law c(M) extrapolations!

Our current knowledge of the c(M) relation from simulations also support the theoretical expectations.





SCP14: caveats

1) Strictly valid only for field DM halos (i.e., no subhalos).

→ Not easily applicable to e.g. Milky Way satellites.
→ Subhalo concentrations are larger → *lower limits* to actual boost values.
→ Tidal forces will remove material from the outskirts → *upper limits*

2) Total integrated boosts for the whole object.

→ No radial information.
→ *Suggestion*: follow 3k10 formalism (Kamionkowski+10) with the recipe in MASC+11, assuming the total boost given by MASC+14.

[Slide taken from my presentation at the UCLA DM 14]

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Subhalo concentrations? Yes.

- Difficulty in defining them:
  - More complex evolution compared to field halos.
  - Tidal forces modify the DM density profile (e.g. Kazantzidis+04)
  - Reduced R_{max}, i.e. the radius at which the maximum circular velocity V_{max} is reached (e.g. Bullock+01).

- Solution: choose a definition independent of the profile

$$c_{\rm V} = \frac{\bar{\rho}(R_{\rm max})}{\rho_c} = 2\left(\frac{V_{\rm max}}{H_0\, R_{\rm max}}\right)^2$$

See also Diemand+08

- Still useful to compare to the standard c_{200}:

For NFW:

$$c_{\rm V} = \left(\frac{c_\Delta}{2.163}\right)^3 \frac{f(R_{\rm max}/r_s)}{f(c_\Delta)}\,\Delta$$

c_v from N-body simulations

BOTH PUBLIC!

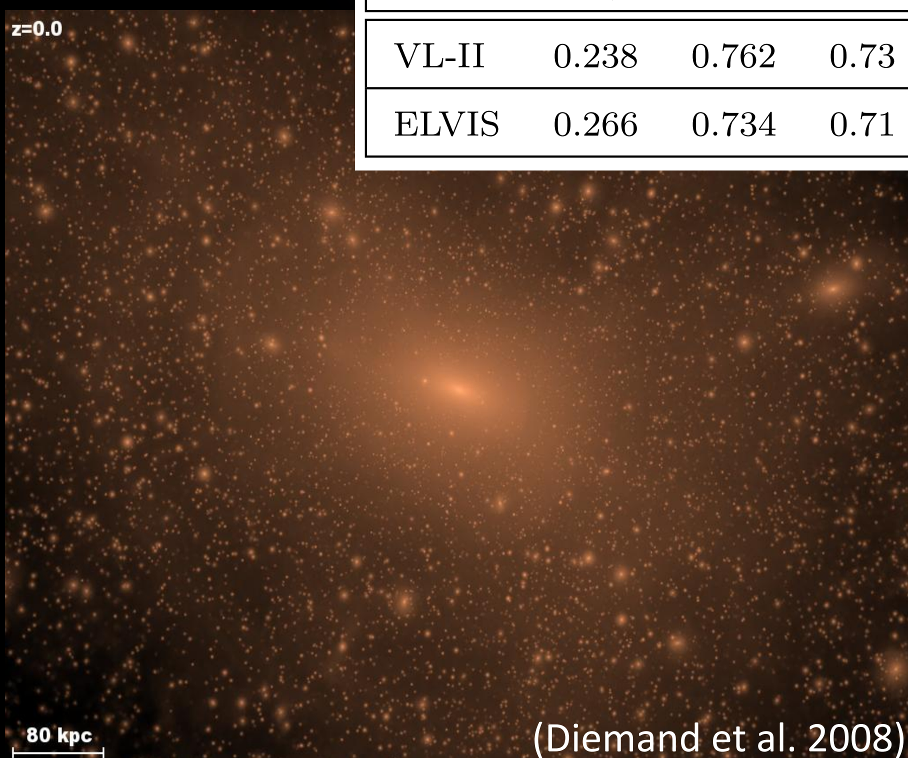
VIA LACTEA II

One MW-size halo.
WMAP3 cosmology.
4100 Msun mass resolution.
Over one billion particles.

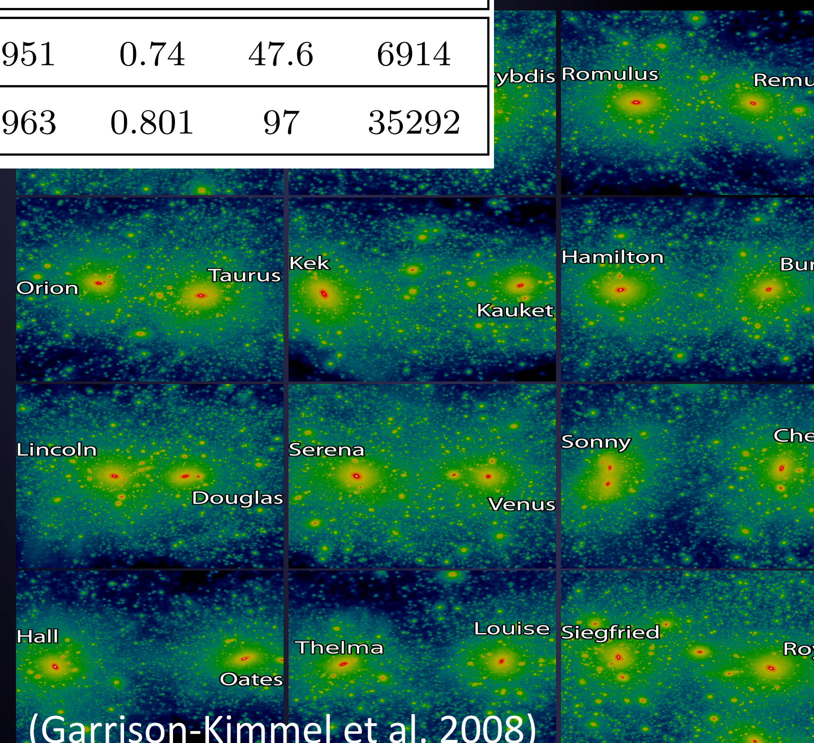
ELVIS

48 MW-size halos. Half in paired configurations.
3 additional MW with higher resolution.
WMAP7 cosmology.
10^5 Msun mass resolution for the 48 MW.

	$\Omega_{m,0}$	Ω_Λ	h	n_s	σ_8	Δ	N_{sub}
VL-II	0.238	0.762	0.73	0.951	0.74	47.6	6914
ELVIS	0.266	0.734	0.71	0.963	0.801	97	35292



(Diemand et al. 2008)



(Garrison-Kimmel et al. 2008)

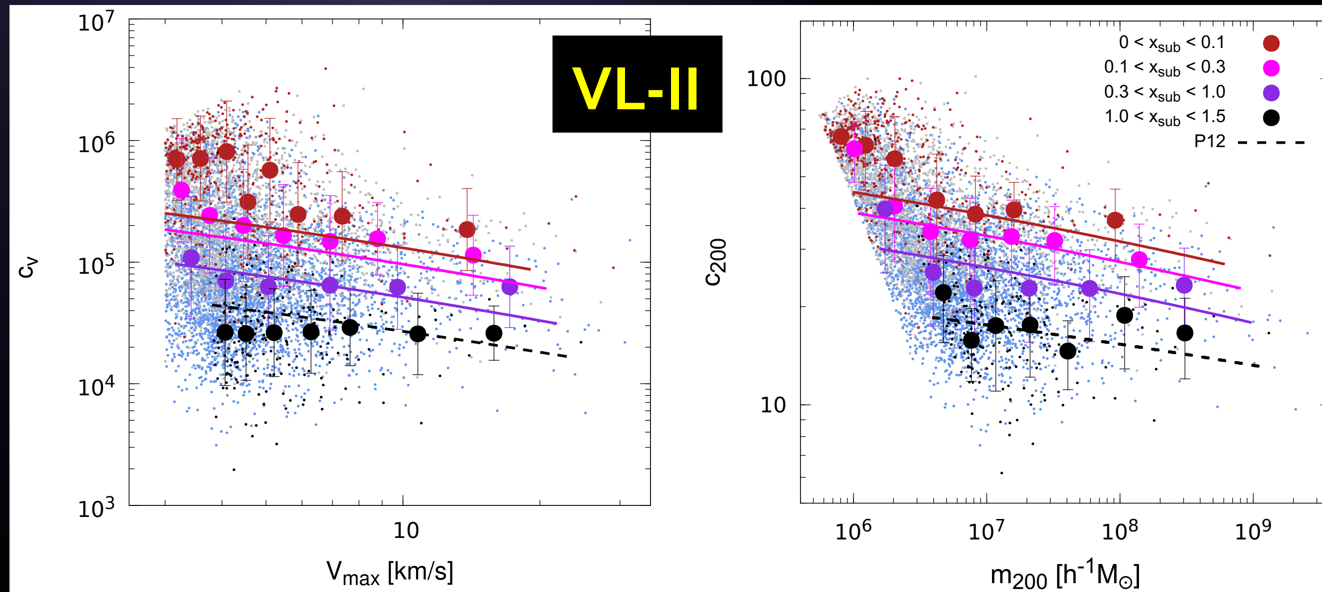
c_v results from VL-II and ELVIS

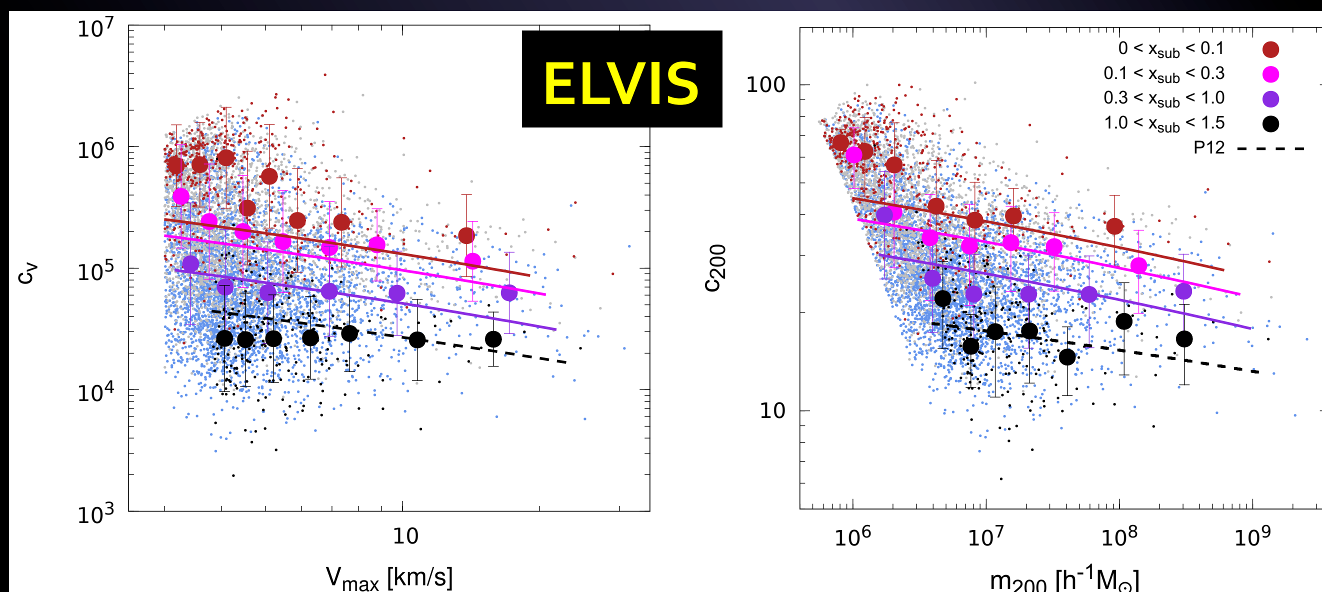
Median values

Four radial bins:

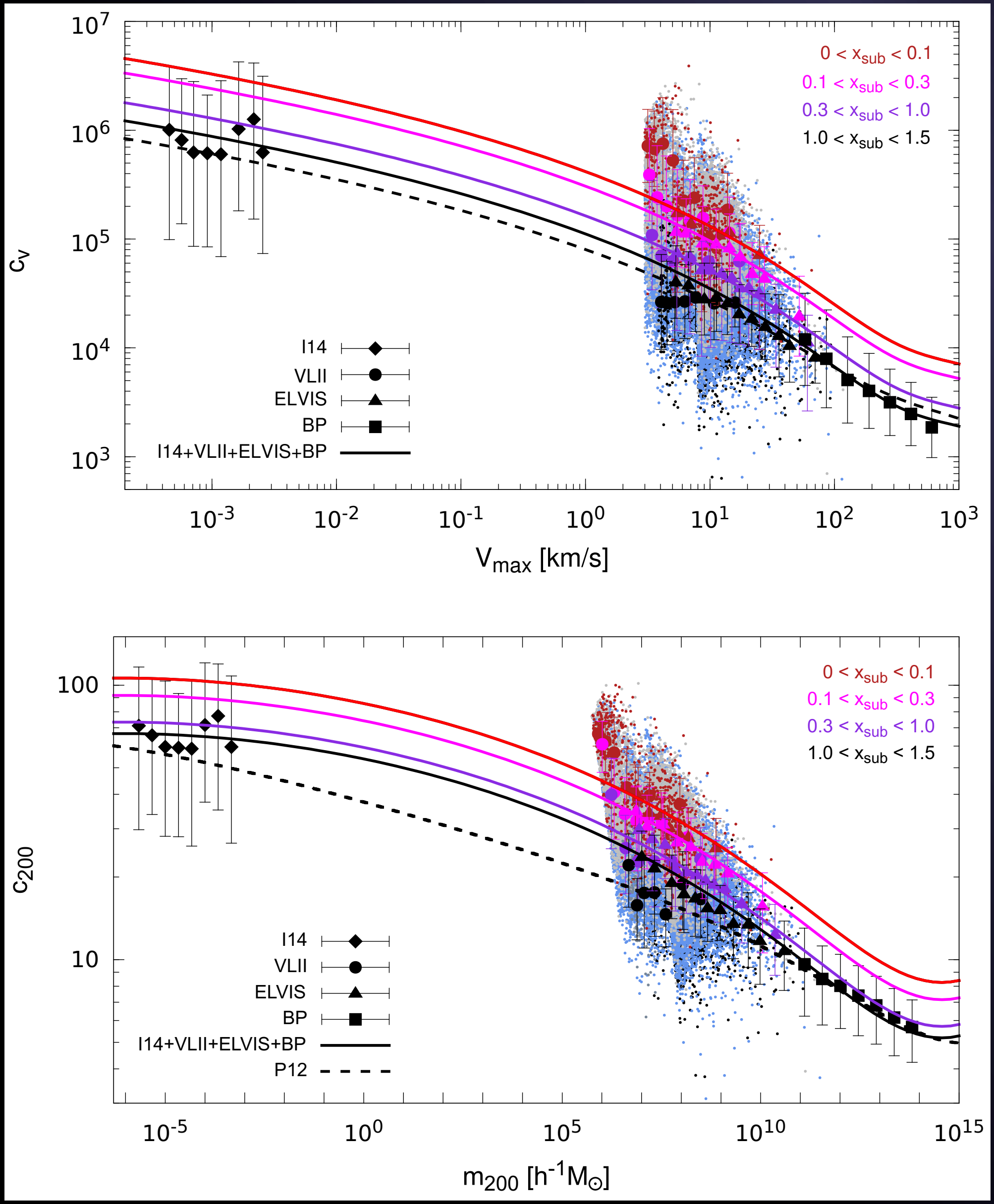
Clear **increase** of subhalo concentration as we approach the host halo center

Scatter similar to that of main halos





Subhalo concentrations at all masses



Provide **fits for c_v and c_{200}**:

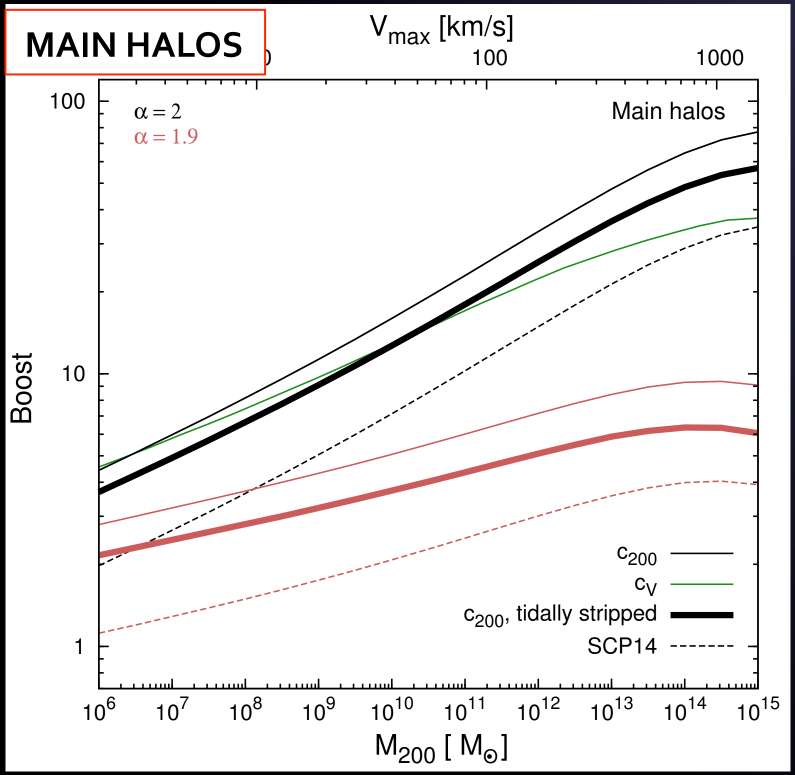
- VL-II and ELVIS between $10^6 - 10^{10}$ Msun.
- Ishiyama (2014) main halos at the lowest masses
- BolshoiP main halos at the largest masses

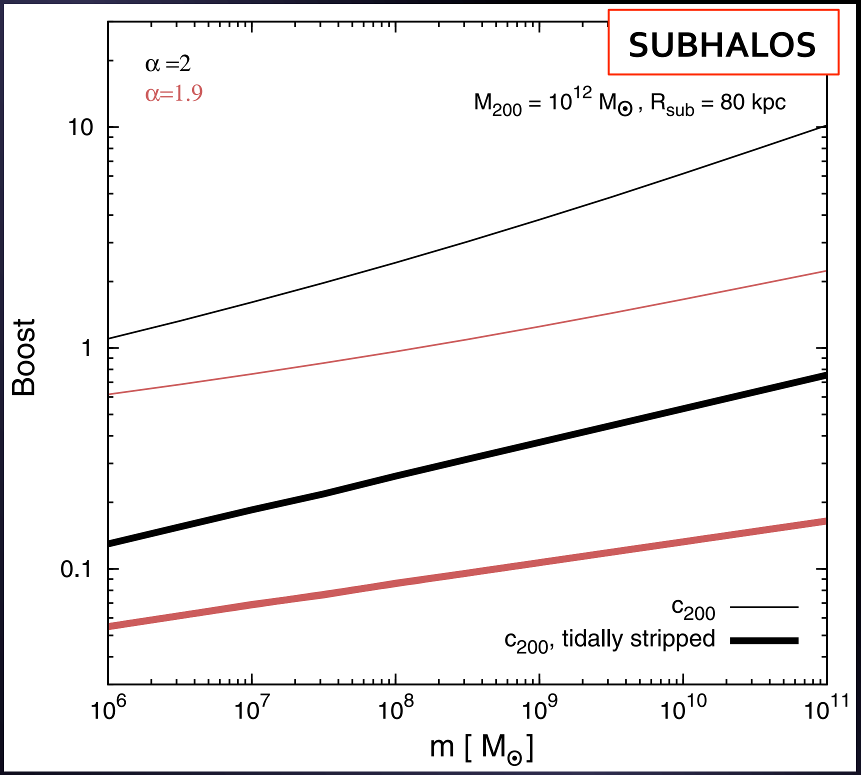
Clear **increase** of subhalo concentrations as we approach the host halo center.

Future: add BolshoiP, MultidDark, Ishiyama subhalos.

Improved subhalo boost model

1. Make use of our best knowledge on subhalo concentrations.
2. Tidal stripping included (Roche criterium).





Factor 2-3 larger boosts

Very small boost for subhalos, e.g. **dwarfs**

Agrees also with Bartels & Ando (2015) and Zavala & Afshordi (2015)

Remarks

- Subhalo concentrations:
  - Used VL-II and ELVIS.
  - Used a concentration parameter independent of the profile.
  - The closer to the host halo center the more concentrated.
  - Substantially larger (factor ~2) than field halos.

- Substructure boosts factors:
  - Improved the model in Sánchez-Conde & Prada (2014).
  - More accurate subhalo concentrations + tidal stripping.
  - About a factor 2-3 larger than before (main halos).
  - Negligible for dwarf galaxies of the Milky Way.

MULTIDARK

Multimessenger Approach for Dark Matter Detection

STAY TUNED

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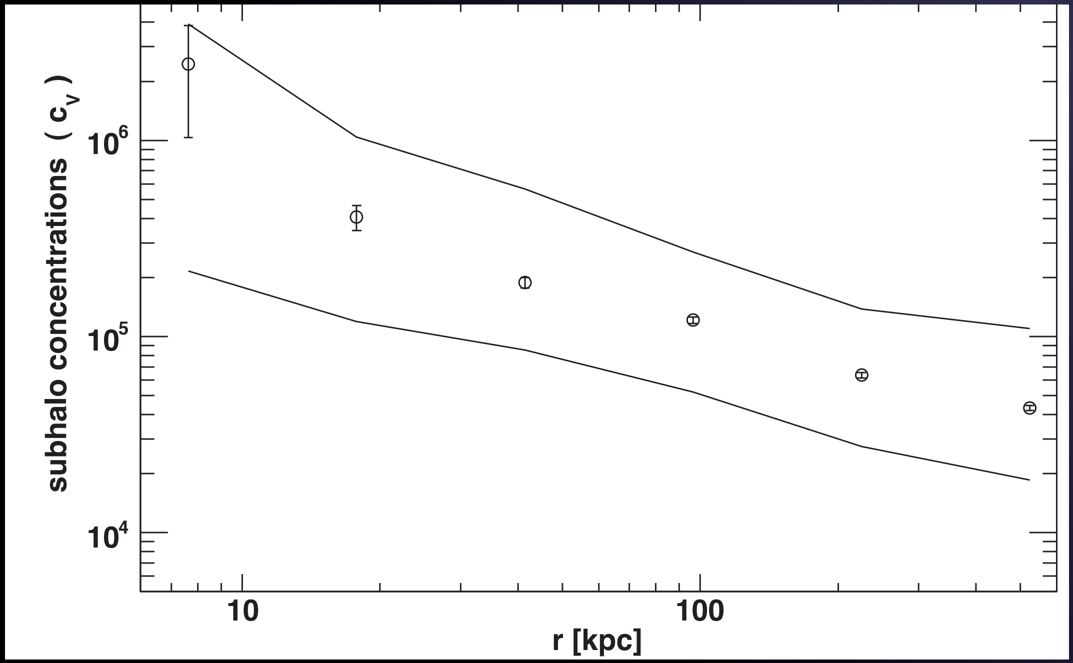
Oskar Klein centre

ADDITIONAL MATERIAL

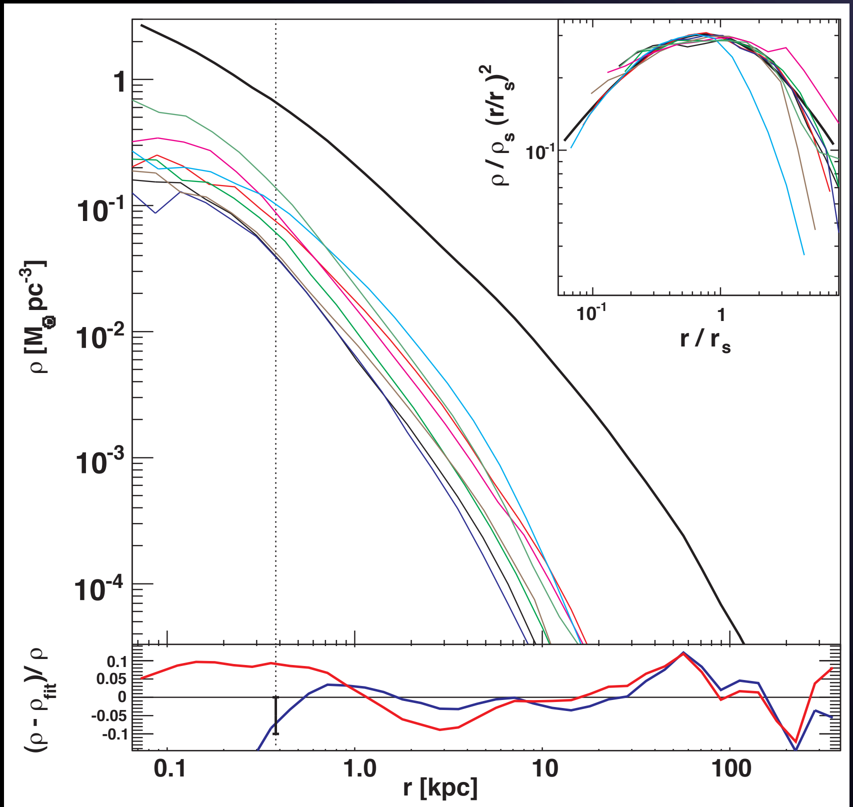
Subhalo c(M) = halo c(M)?

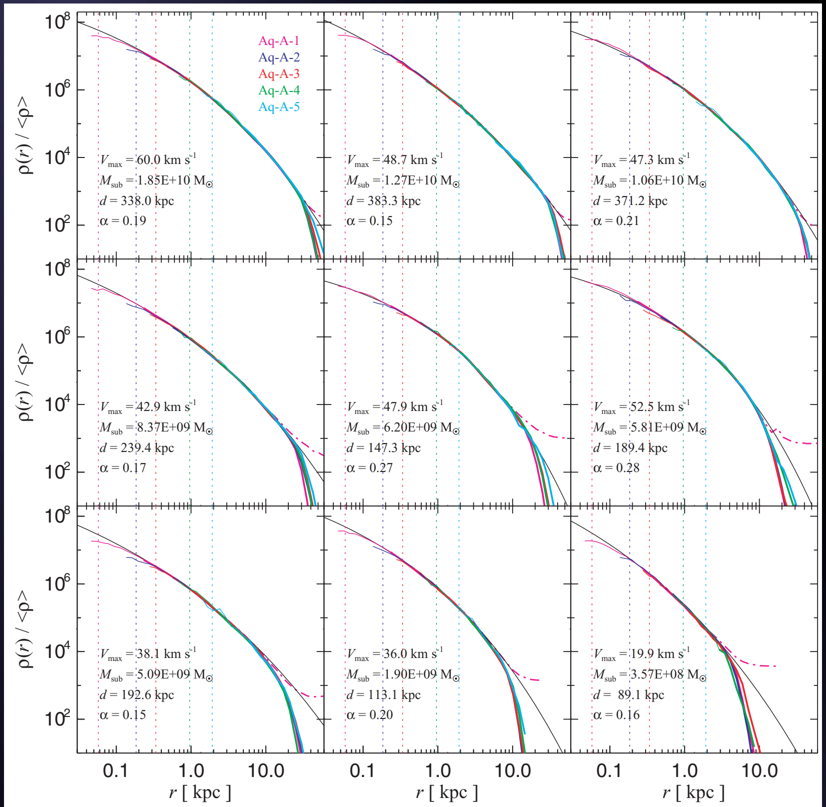


VL-II (Diemand+08)

Subhalo c(M) is actually c(M,R)
→P12 boosts are a lower limit!

Subhalo DM density profiles

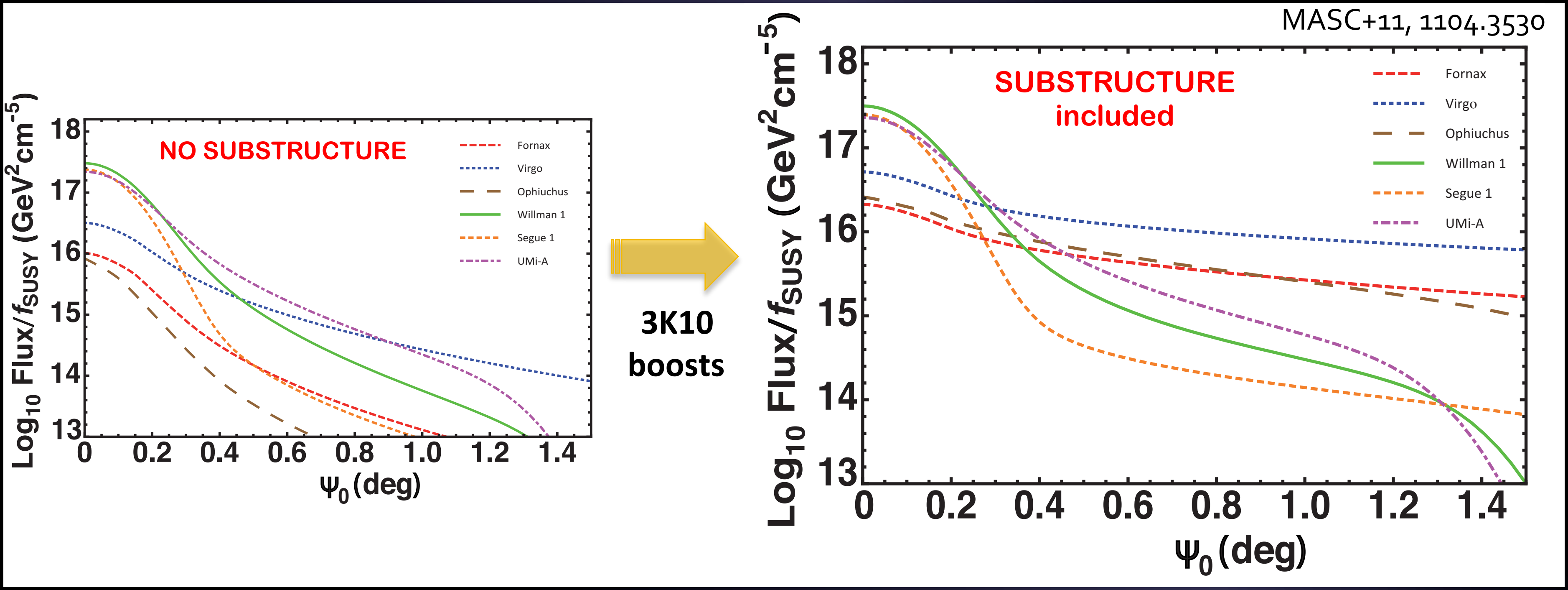




AQUARIUS, Springel+08

Substructure modifies the annihilation flux profile

[MASC, Cannoni, Zandanel et al., JCAP 12 (2011) 011]



Annihilation signal becomes *more spatially extended*.

→ Instrumental sensitivity is worse for extended sources.

→ More relevant for galaxy clusters; probably irrelevant for dwarfs.

How can we know about the concentration of the smallest halos?

Two approaches taken so far:

1) Power-law extrapolations below the resolution limit.

2) Physically motivated c(M) models that take into account the growth of structure in the Universe.

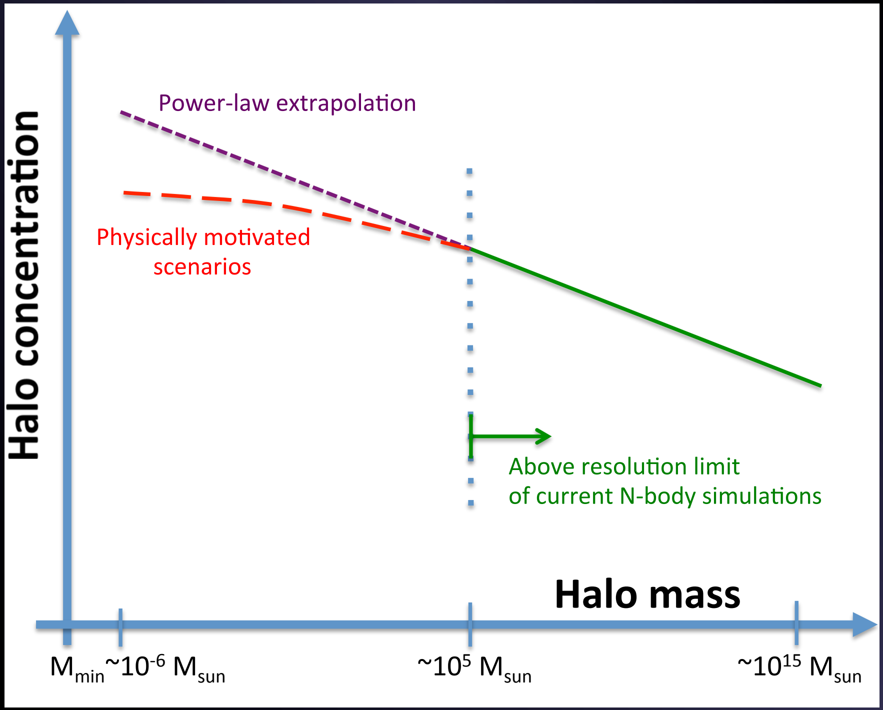
→ tuned to match simulations above resolution limit.

__Power-law extrapolations, e.g.:__
Springel+08, Zavala+10, Pinzke+11, Gao+11

__Non power-law extrapolations, e.g.:__
Lavalle+08, Kuhlen+08, Kamionkowski+10, Pieri+11

See also Zavala+13

Large impact on boost factors!



What does ΛCDM tell us about c(M) at the smallest scales?

- Natal concentrations are mainly set by the halo formation time.
- Given the CDM power spectrum , the smallest halos typically collapse *nearly* at the same time:

  → Concentration is nearly the same for the smallest halos over a wide range of masses.

  → power-law c(M) extrapolations not correct!