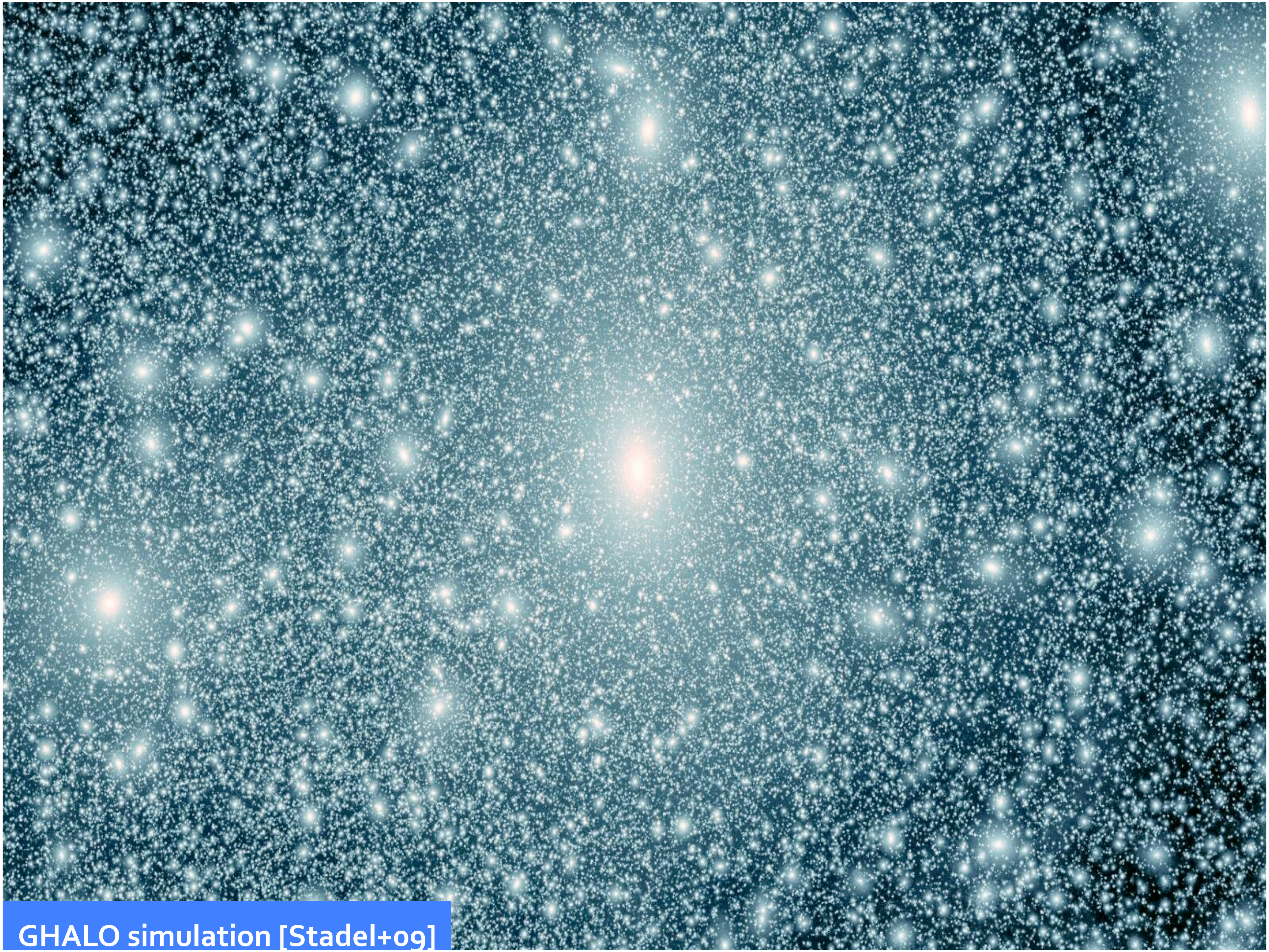
MULTIDARK
Multimessenger Approach for Dark Matter Detection

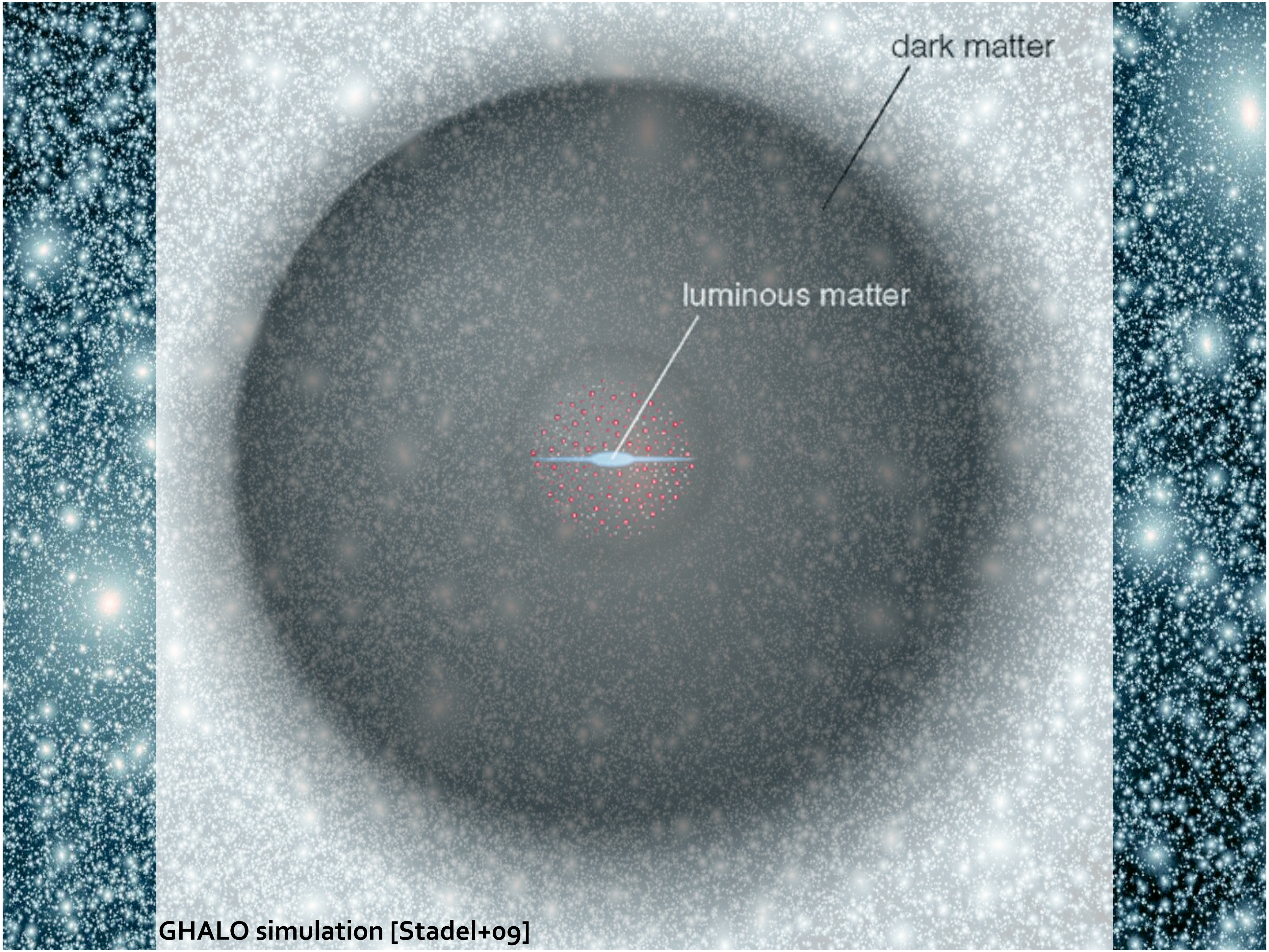
CDM HALO CONCENTRATIONS
AND
[IMPLICATIONS FOR]
DM ANNIHILATION SUBSTRUCTURE BOOSTS

Miguel A. Sánchez-Conde

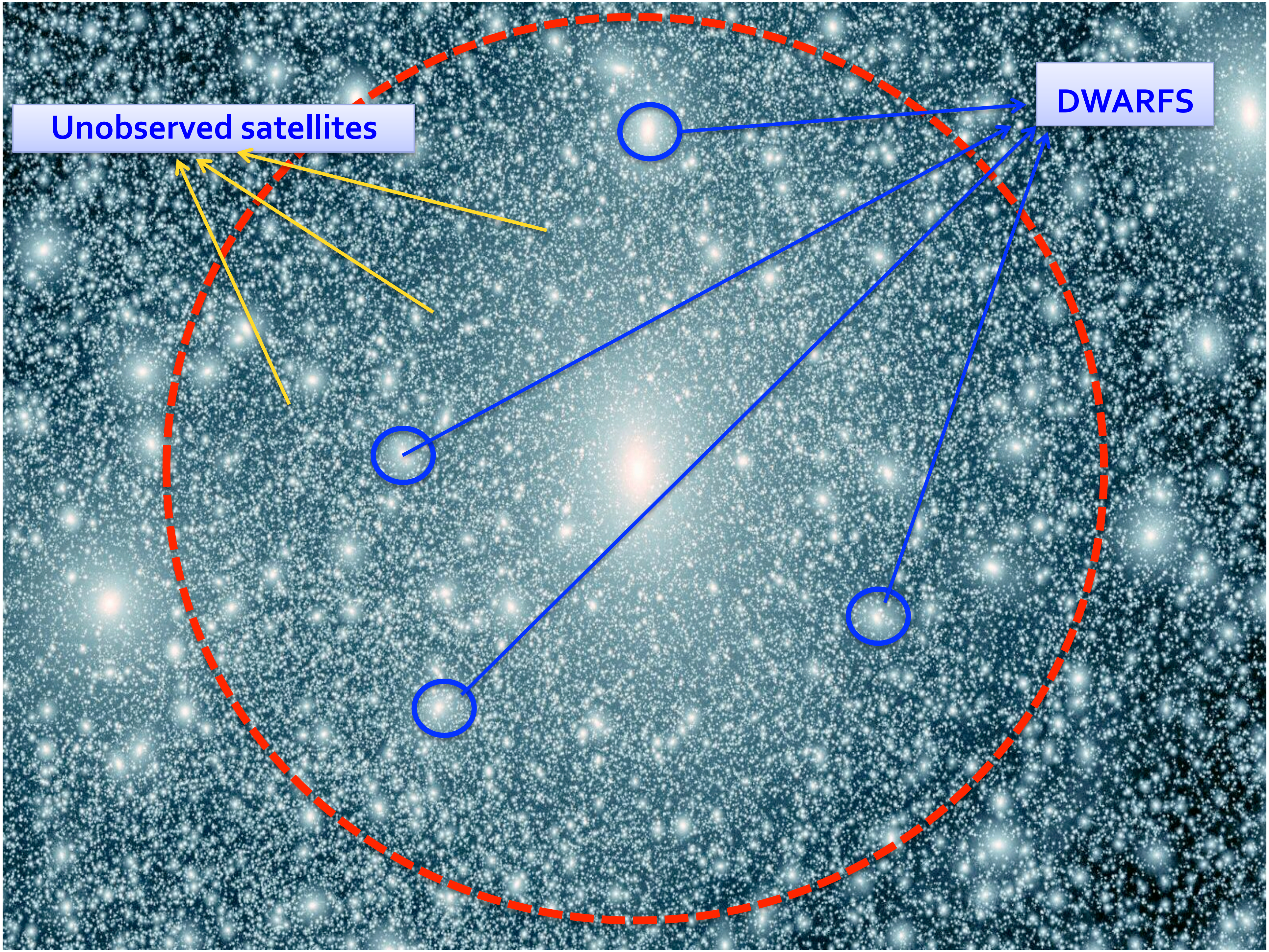
SLAC KIPAC STANFORD UNIVERSITY

TeVP Particle Astrophysics 2013, Irvine CA– August 28th 2013


GHALO simulation [Stadel+09]



GHALO simulation [Stadel+09]


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

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

→ GOOD TARGETS

THIS TALK

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

→ SUBSTRUCTURE BOOSTS

The DM annihilation γ-ray flux

$$F(E_\gamma > E_{th}, \Psi_0) = J(\Psi_0) \times f_{PP}\left(E_\gamma > E_{th}\right)$$

photons cm^{-2} s^{-1}

Astrophysics | **Particle physics**

Integration of the squared DM density

J-FACTOR

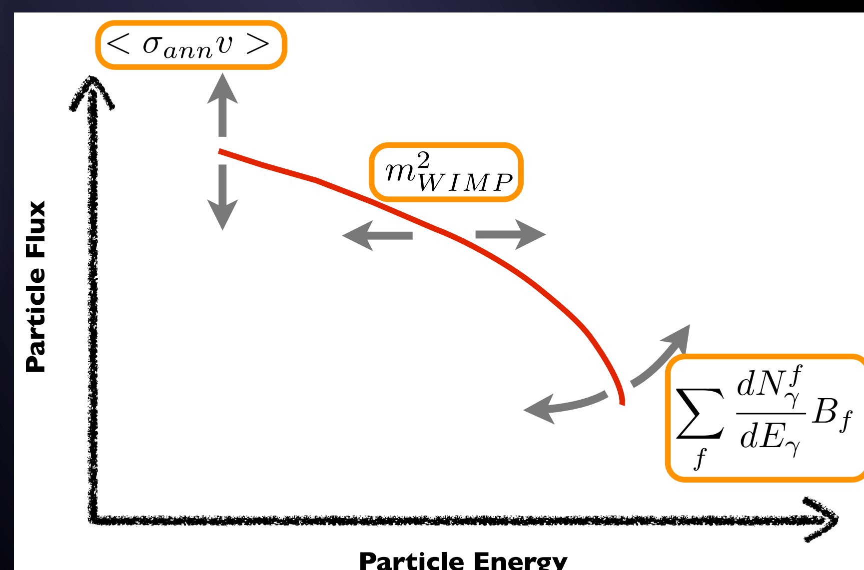
$$J(\Psi_0) = \frac{1}{4\pi} \int_{\Delta\Omega} d\Omega \int_{l.o.s.} \rho^2_{DM}[r(\lambda)]\, d\lambda$$

SMOOTH + SUBSTRUCTURE

J-factor can be expressed in terms of (v_{max},r_{max}) or (c,M) or (ρ_s,r_s)

$$f_{PP} \propto \sum_f \frac{dN_\gamma^f}{dE_\gamma} B_f \frac{\langle \sigma \cdot v \rangle}{m_\chi{}^2}$$

- N_g : number of photons per annihilation, E >E_{th}
- <σ v>: cross section
- m_χ: neutralino mass



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} x 2 due to subhalos

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

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} x 2 due to subhalos

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

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 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}

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

Two approaches taken so far:

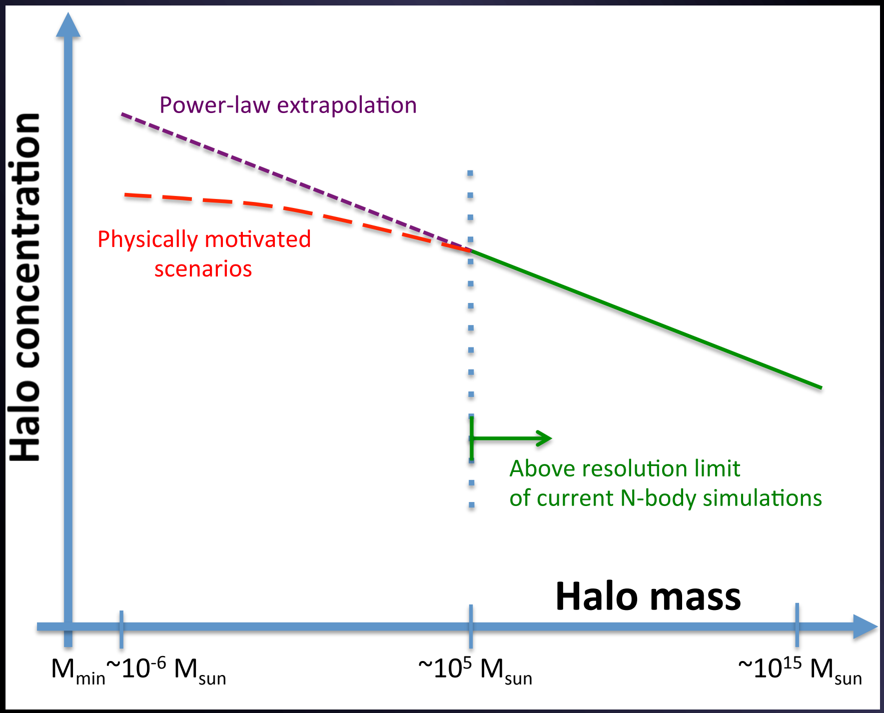
1) Power-law extrapolations below the resolution limit.

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, Han+12

Non power-law extrapolations, e.g.:
Bullock+01, Kuhlen+08, Macció+08, Kamionkowski+10, Pieri+11

Large impact on boost factors!

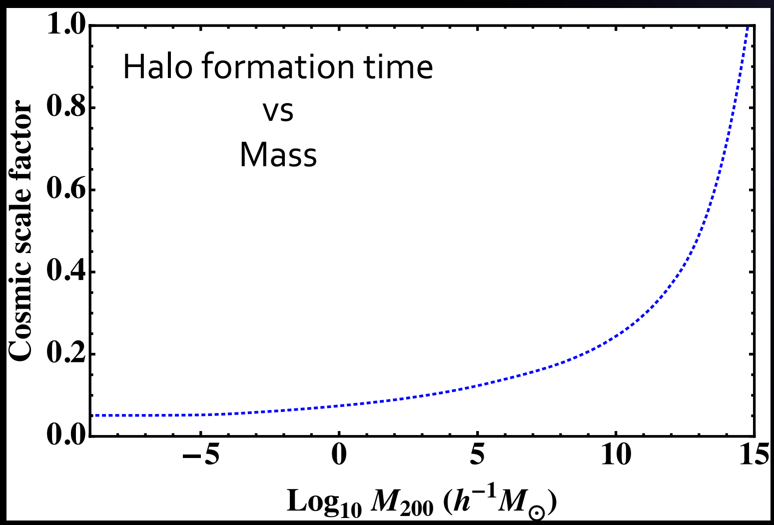


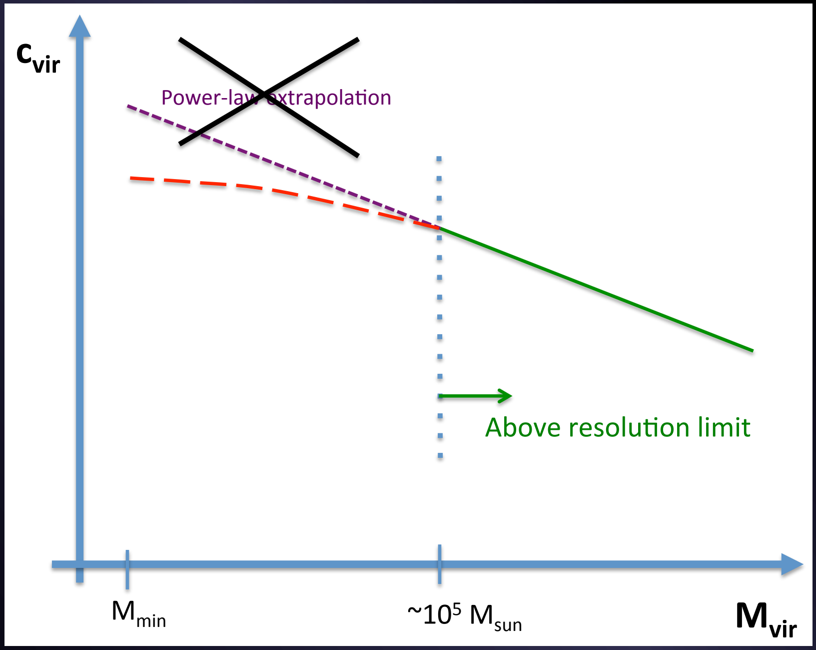
What does ΛCDM tell us about c(M) at the smallest scales?

- 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!

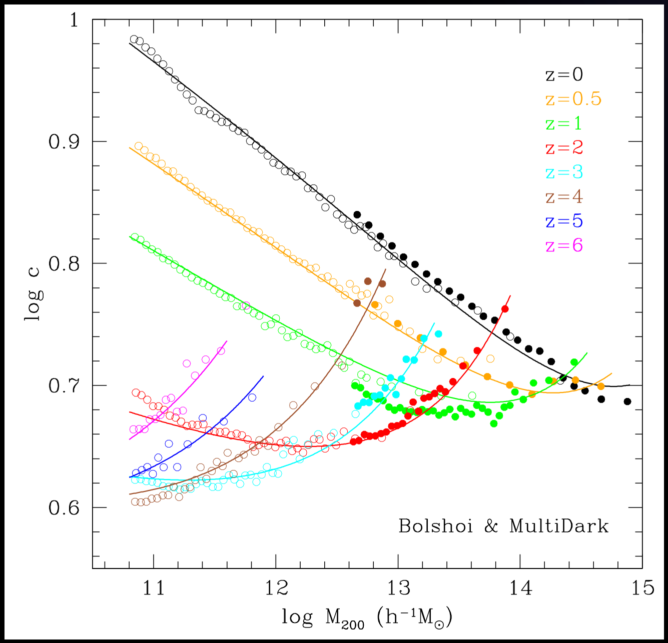


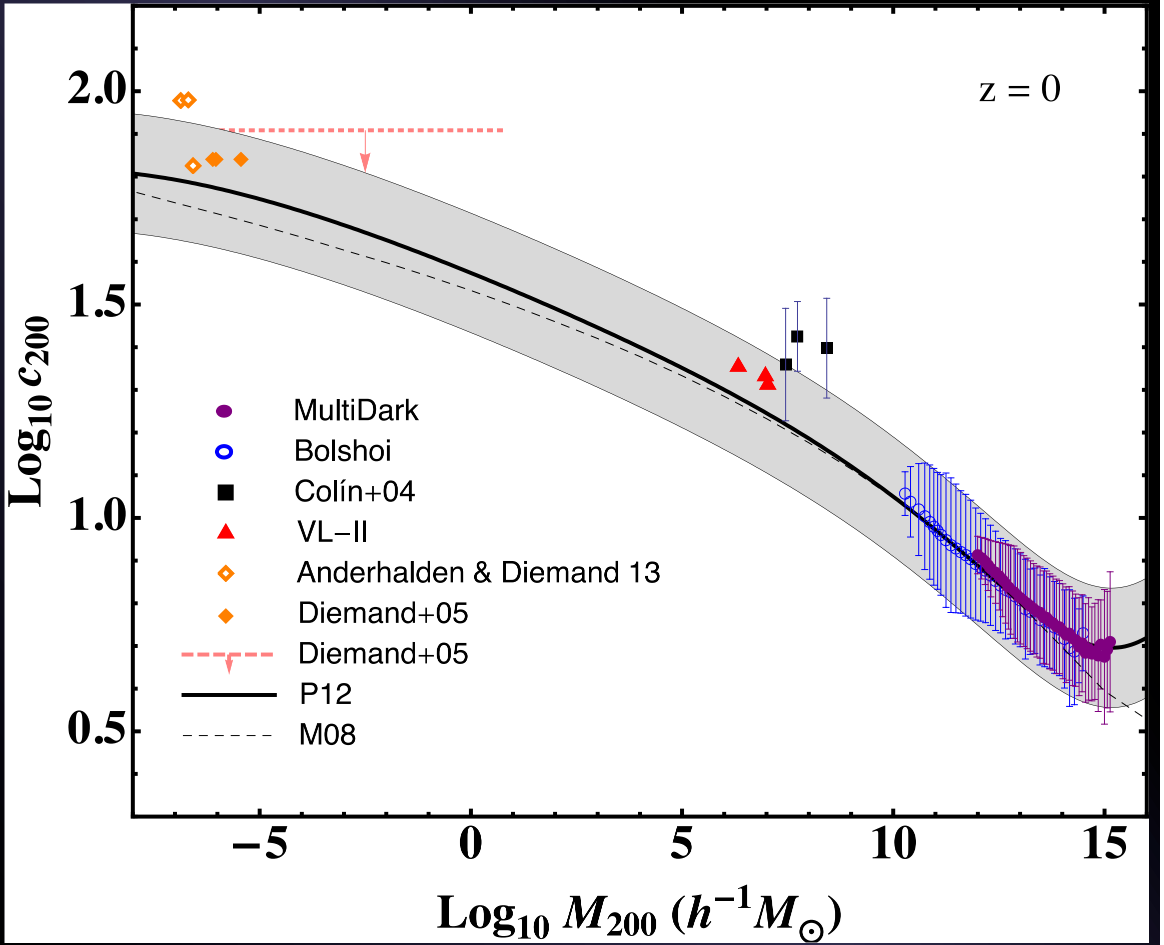


Current knowledge of the c(M) relation at z=0

Concentration $c = R_{vir} / r_s$

c scales with mass and redshift (e.g., Bullock+01, Zhao+03,08; Maccio+08, Gao+08, Prada+12)





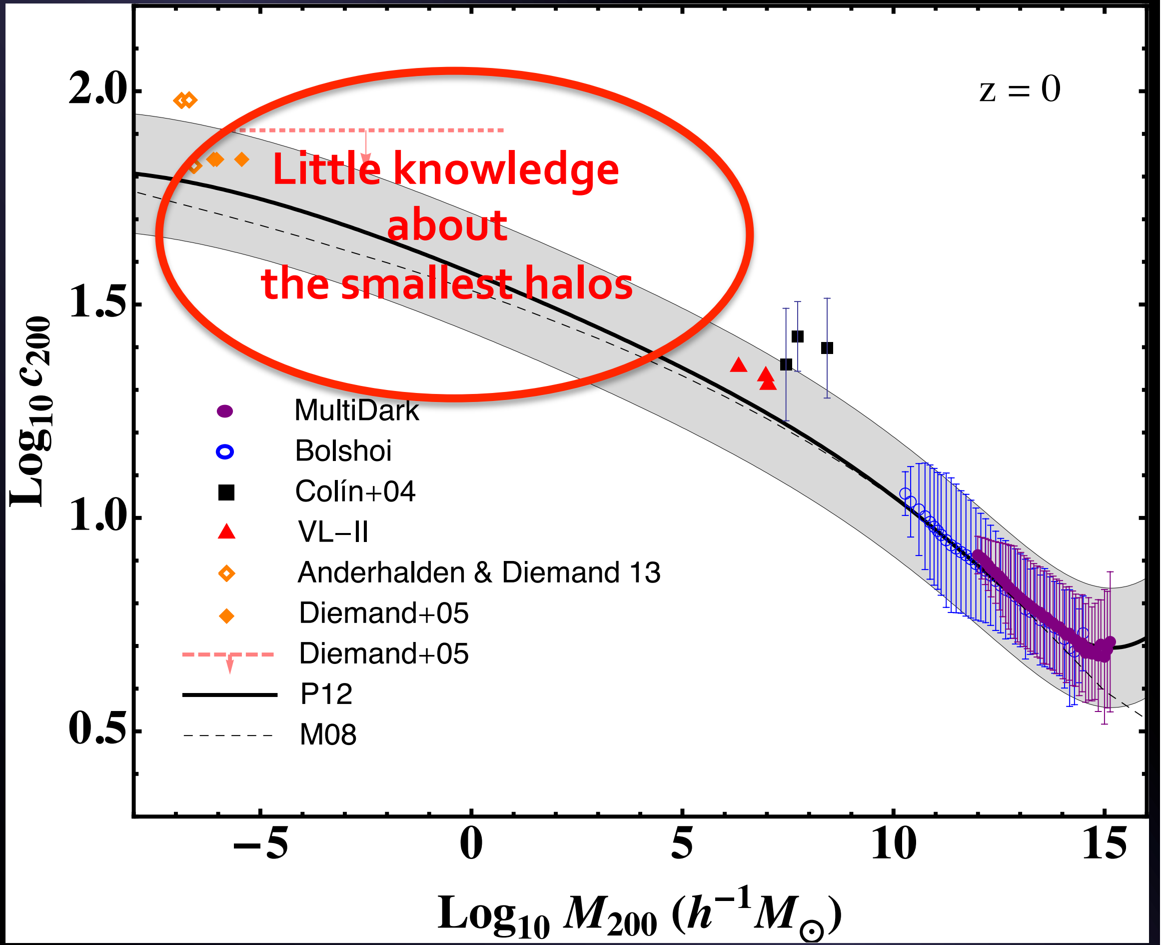
[MASC & Prada, in prep.]

Prada+12 → P12

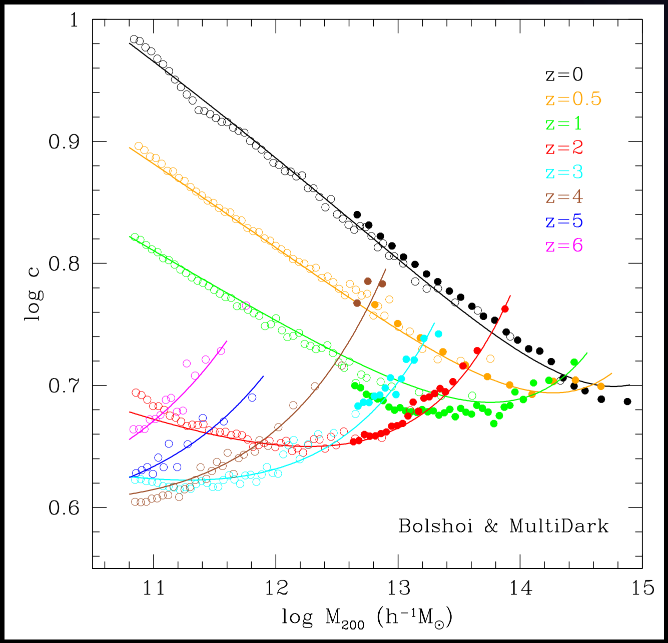
Current knowledge of the c(M) relation at z=0

Concentration $c = R_{vir} / r_s$

c scales with mass and redshift (e.g., Bullock+01,Zhao+03,08; Maccio+08,Gao+08, Prada+12)



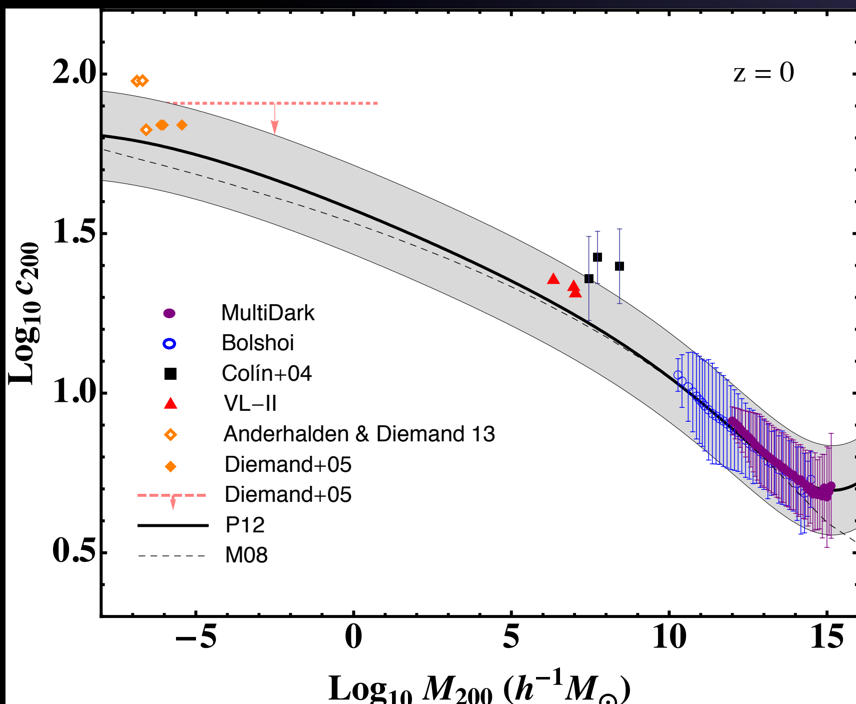
[MASC & Prada, in prep.]



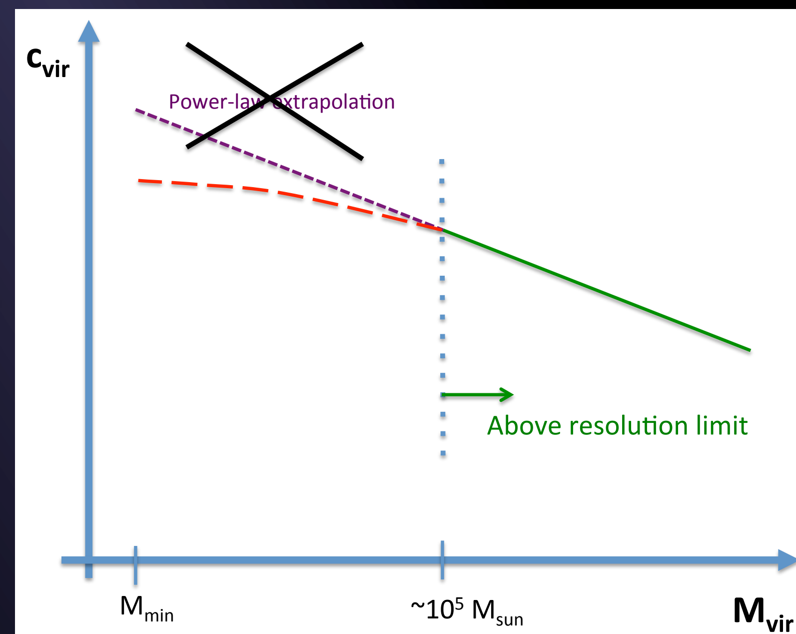
Prada+12

No more simple power-law c(M) extrapolations

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

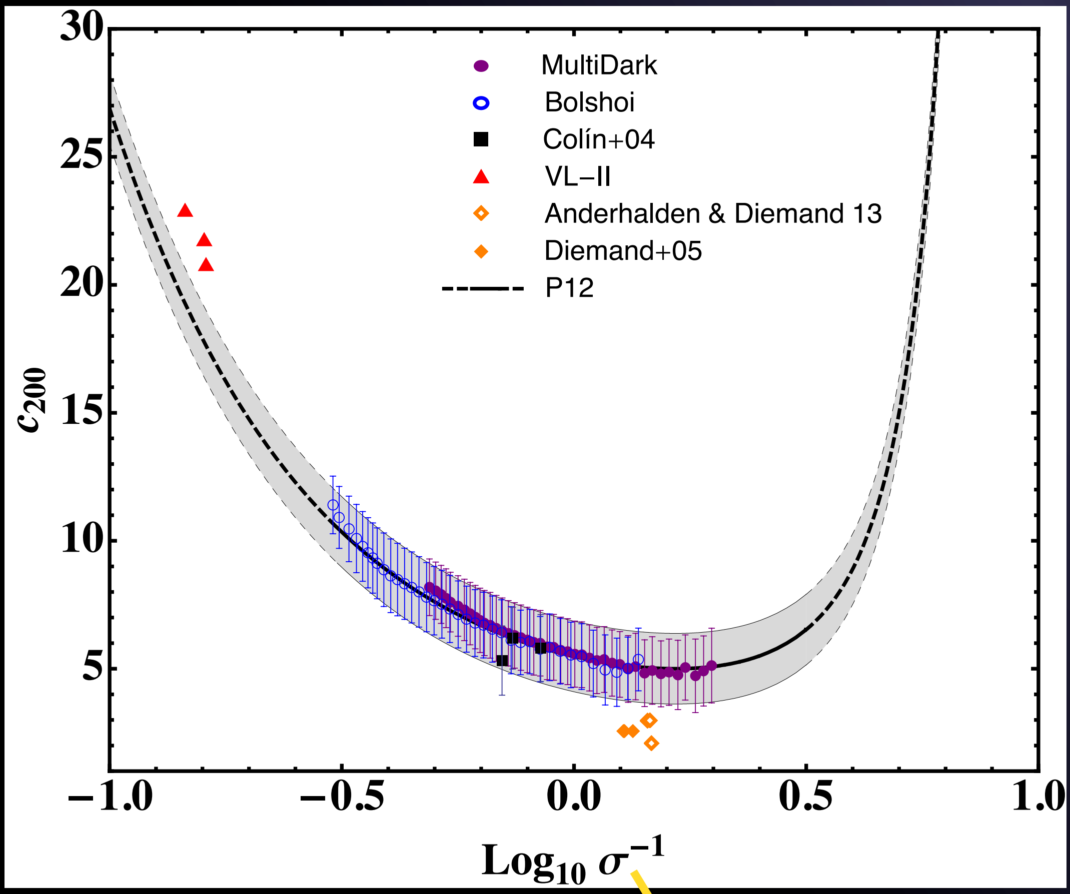


[MASC & Prada, in prep.]



The *U-shape plot*

[Is the use of P12 below the mass resolution entirely justified?]



[MASC & Prada, in prep.]

r.m.s. of the matter power spectrum

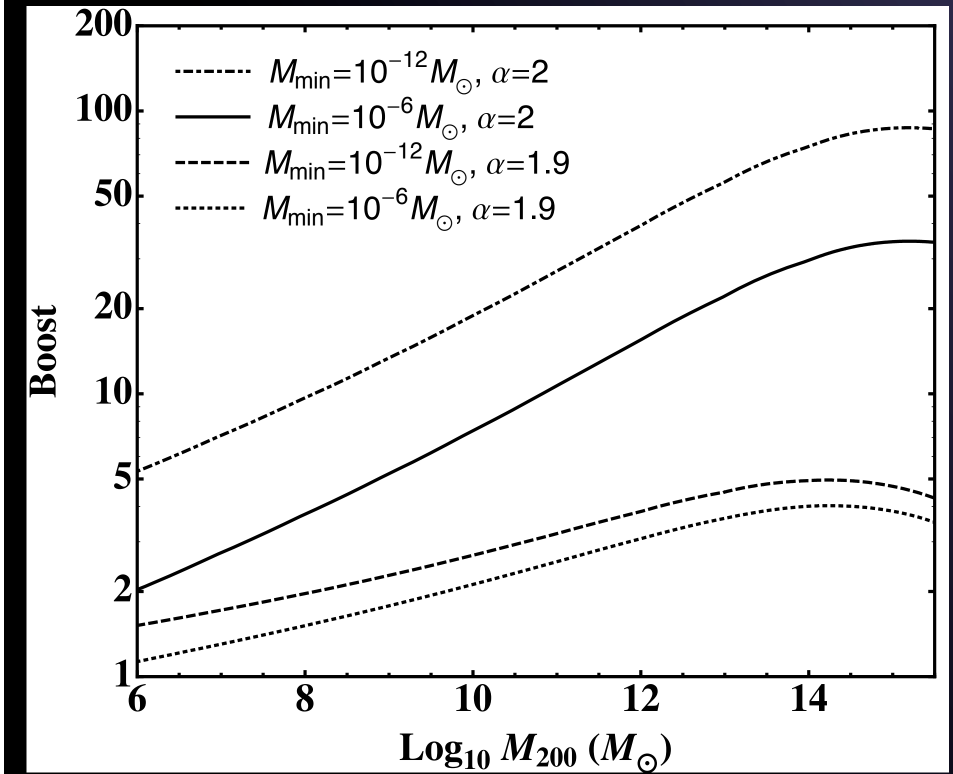
P12 links the concentration with the r.m.s. of the matter power spectrum.

All data sets but VL-II lie within the range tested by P12

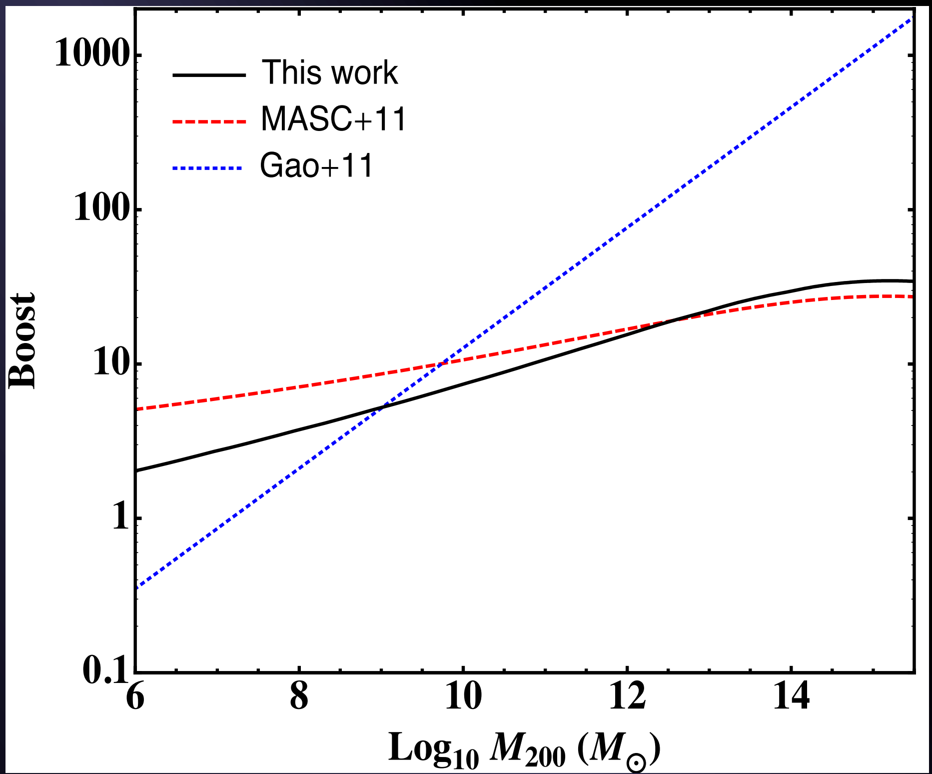
→ No extrapolations indeed

Substructure boosts

[MASC & Prada, in prep.]



Variation with M_{min} and α



Comparison with previous boosts in the literature

O(1000) boost factors for galaxy clusters given by simple power-law c(M) extrapolations clearly ruled out.

SUMMARY

- ΛCDM substructure key component for planning gamma-ray search strategies:
  - Some of them excellent targets.
  - Boost to the DM annihilation signal expected.
- Substructure boosts factors:
  - Very sensitive to extrapolations below the mass resolution.
  - Specially relevant for clusters; moderate values <50.
  - O(10) for MW-sized halos.
- Halo concentrations:
  - P12 c(M) model in remarkable agreement with N-body simulations at all halo masses.
  - Power-law extrapolations to low masses clearly ruled out.


MULTIDARK
Multimessenger Approach
for Dark Matter Detection
STAY TUNED
masc@stanford.edu
KIPAC