

Non-linear Structure in Cold and Warm Dark Matter Cosmologies

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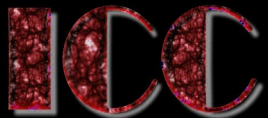
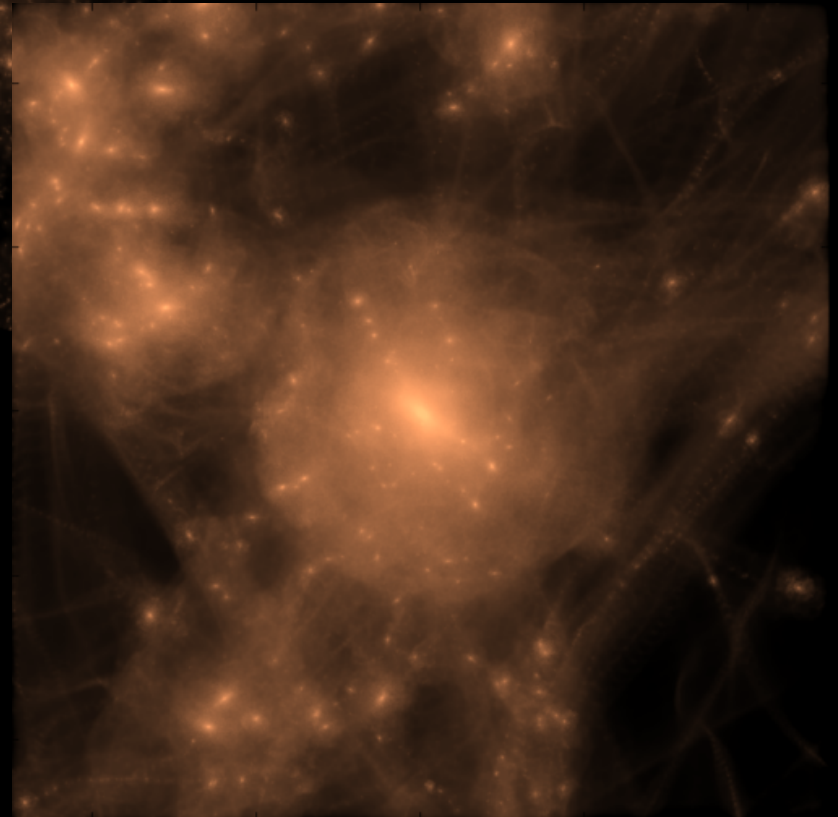
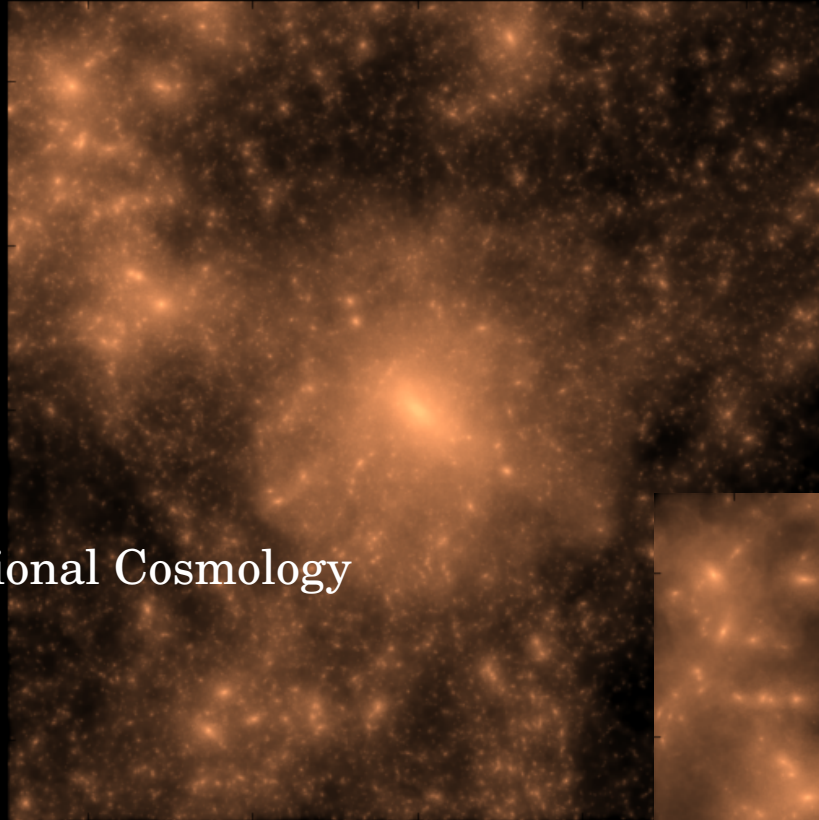
Raul Angulo (CEFCA)

Wojtek Hellwing

Carlos Frenk

Shaun Cole

Julio Navarro



Durham
University

Outline

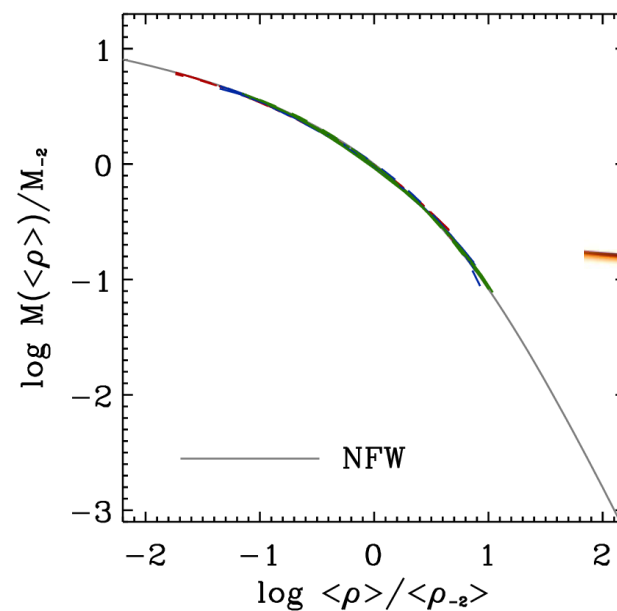
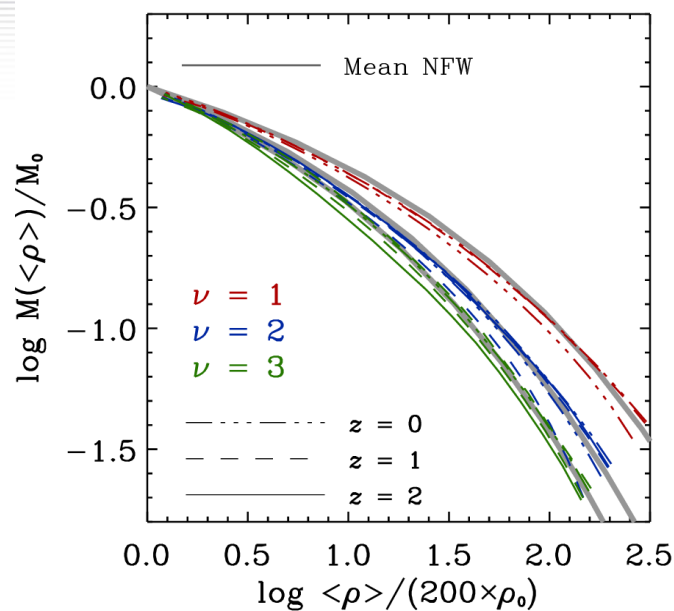
I. Modeling the $c(M,z)$ relation in CDM

- The origin of halo mass profiles: NFW, Einasto...
- Relationship between halo assembly and structure
- Comparison with simulations

II. Extensions to WDM

- Imprint of WDM cut-off on assembly histories and mass profiles
- Modification of “formation times”
- Predicting halo structure from the linear power spectrum

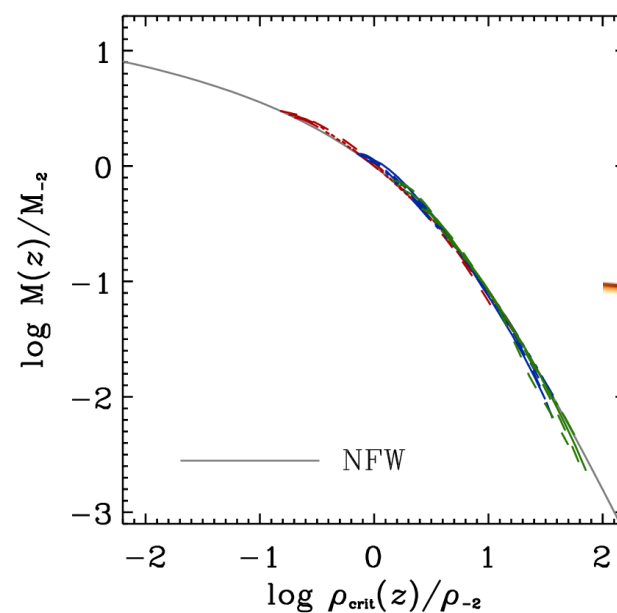
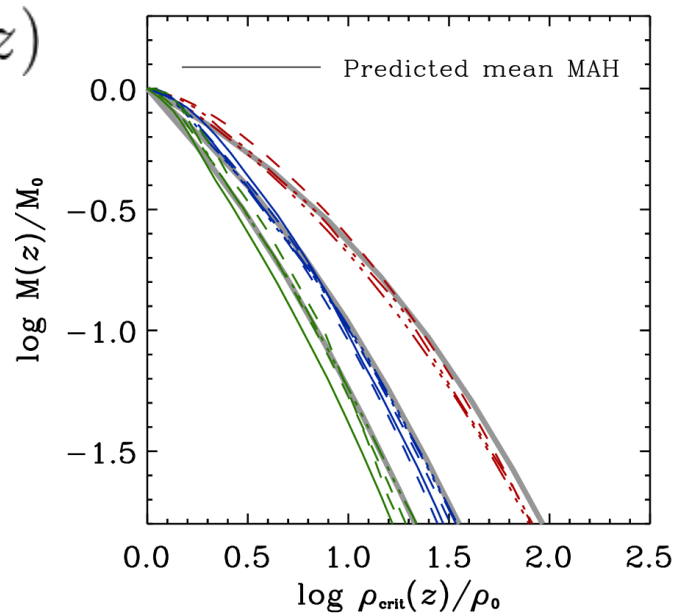
Mass profiles and Accretion Histories



Mass Profiles



$$\nu = \delta_{\text{sc}}(z)/\sigma(M, z)$$

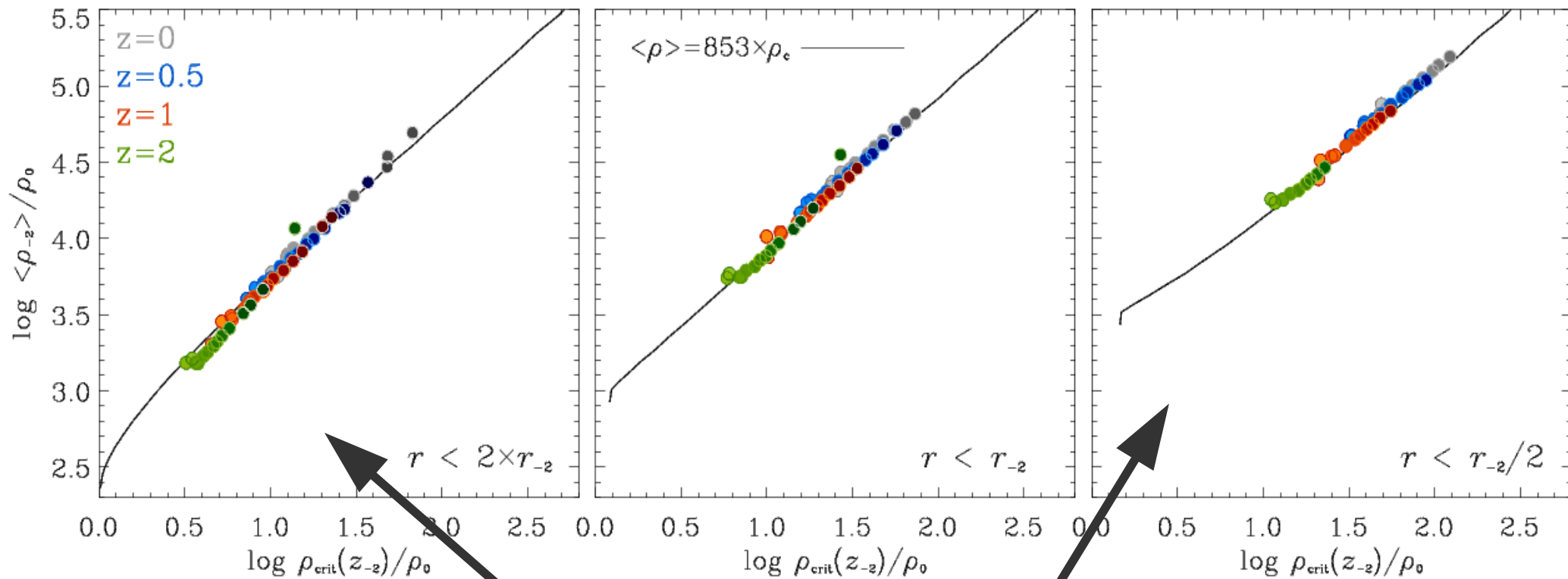


Accretion Histories



Concentration-formation time relation

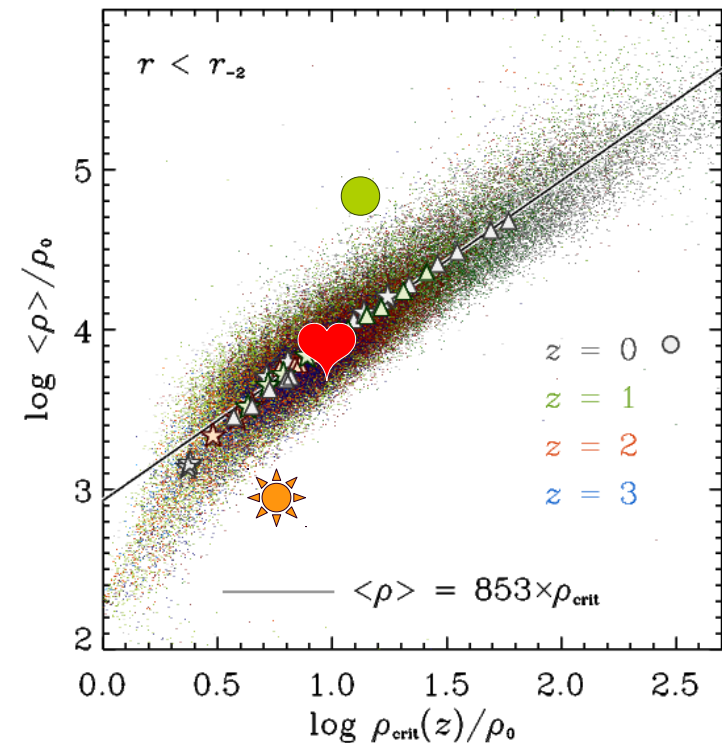
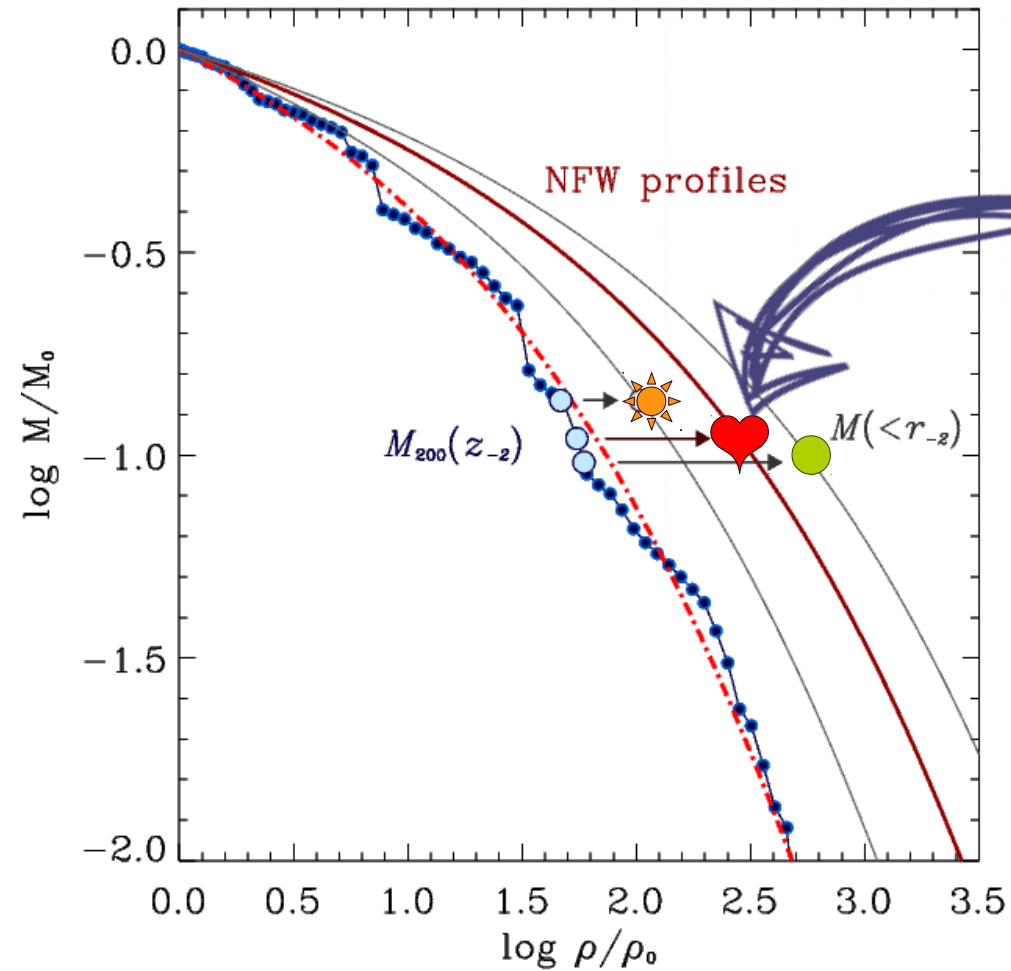
$$\langle \rho(< r_{-2}) \rangle \approx 853 \times \rho_{\text{crit}}(z_{-2})$$



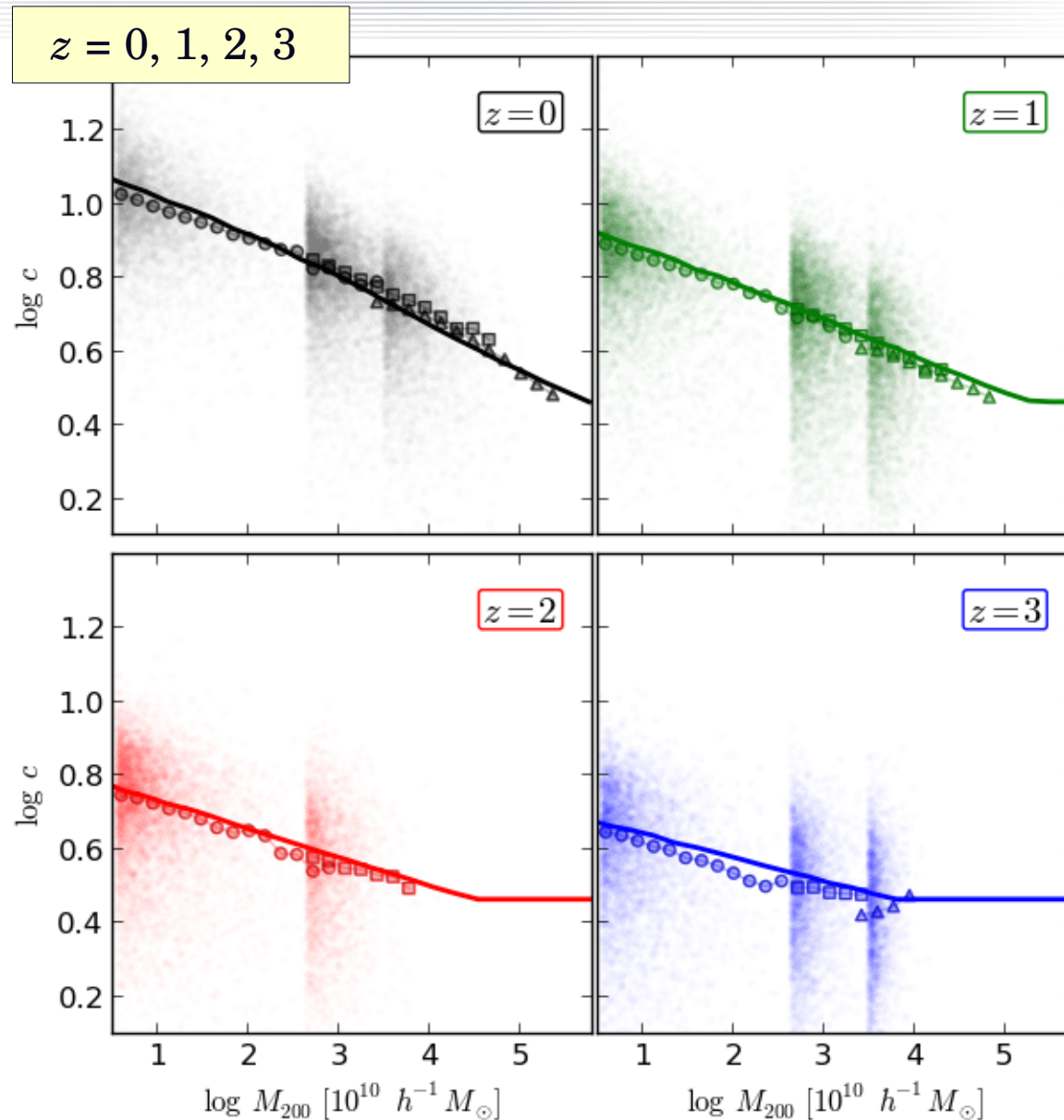
Predicted relations

CDM halos: Mass profile & accretion history

Parkinson, Cole & Helly (2008)



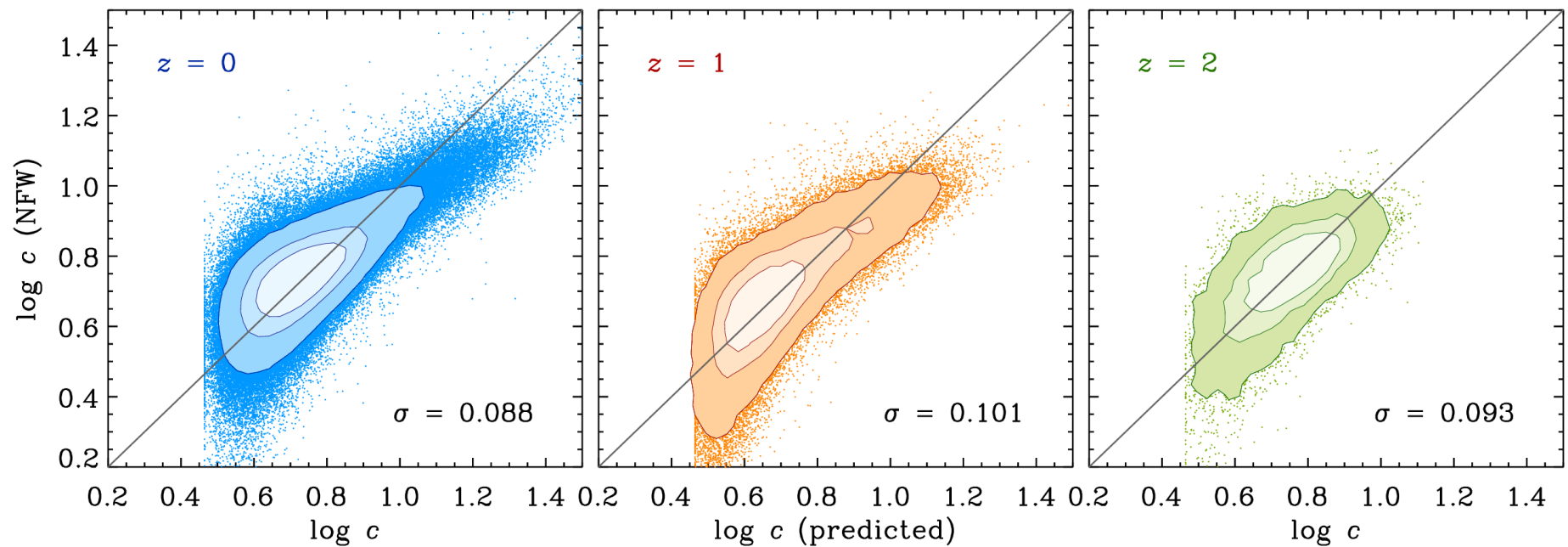
The mean $c(M,z)$ relation: *The Millennium Simulations*



Mean $c(M,z)$ based on
assembly histories calculated
from excursion set theory
(Parkinson, Cole & Helly, 2008)

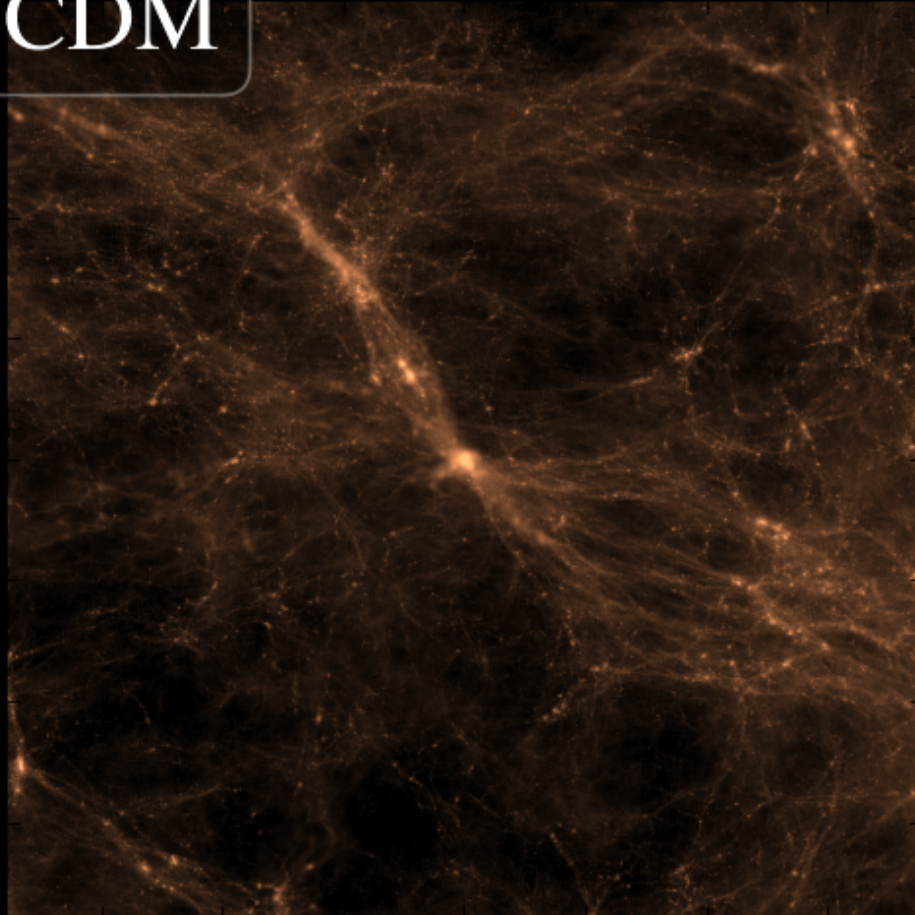
The mean $c(M,z)$ relation: *Individual halos*

Predictions for individual halos: accurate to $\sim 25\%$

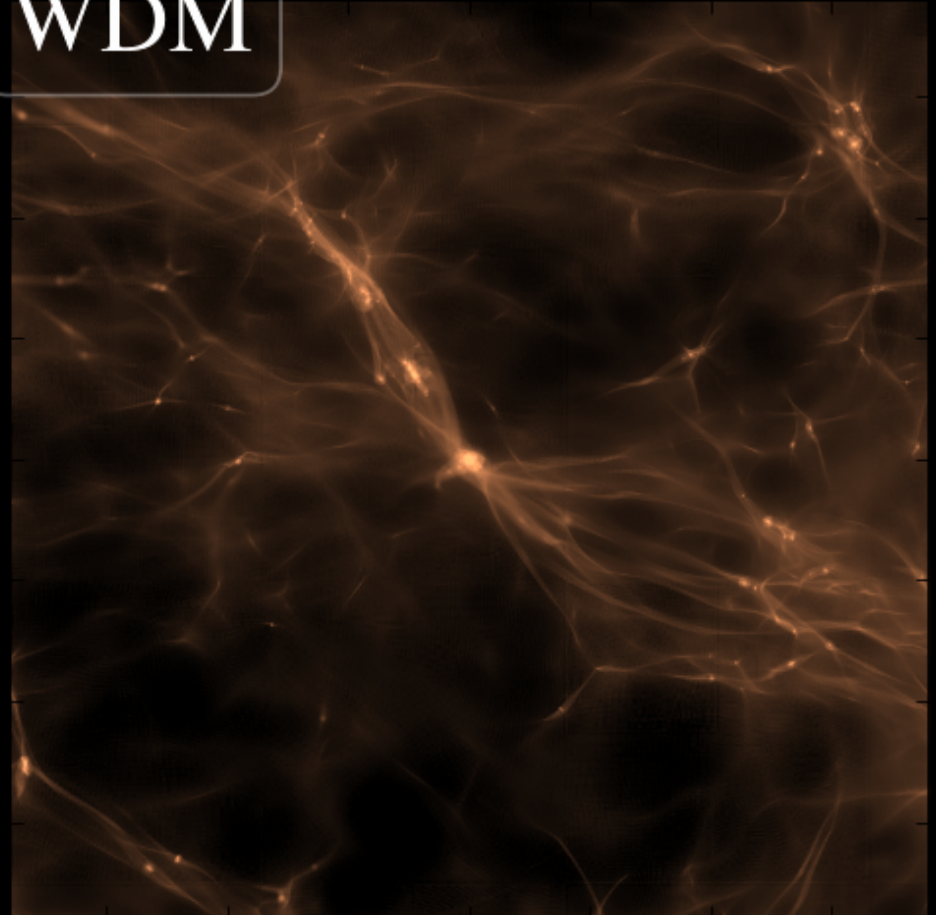


The structure of WDM halos

CDM



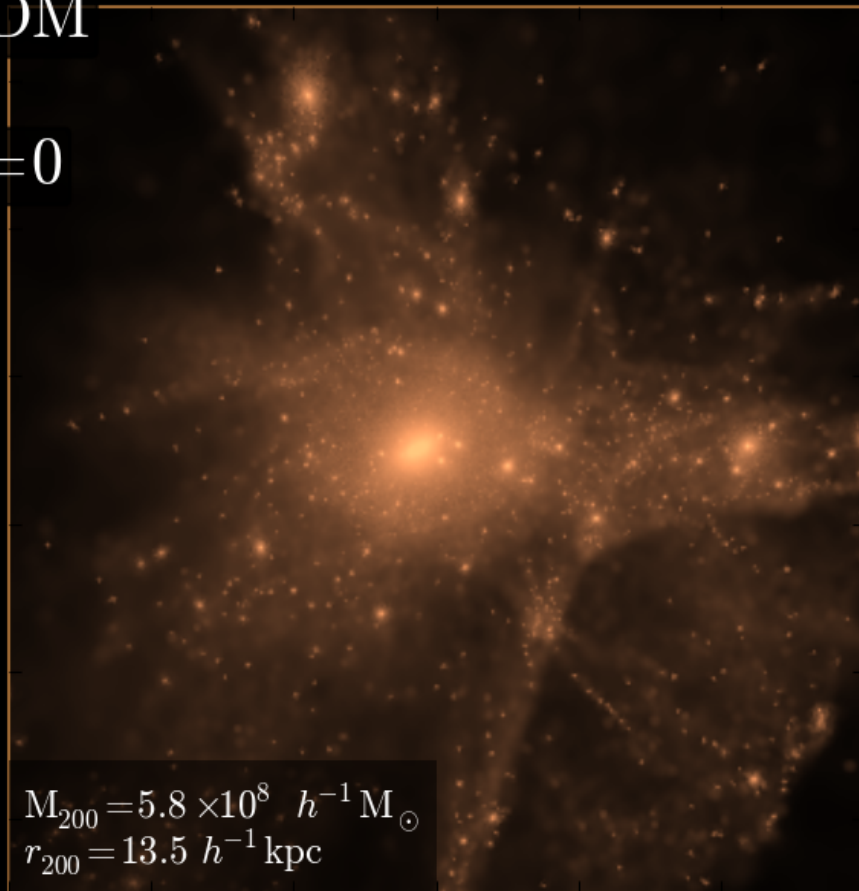
WDM



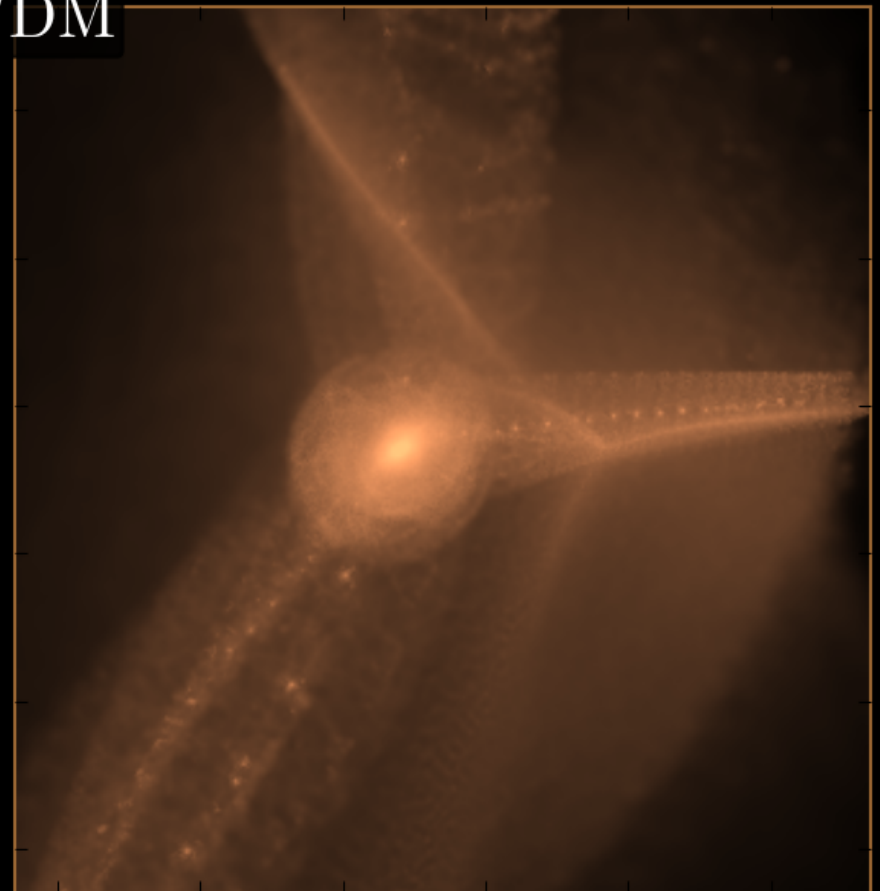
The structure of WDM halos

CDM

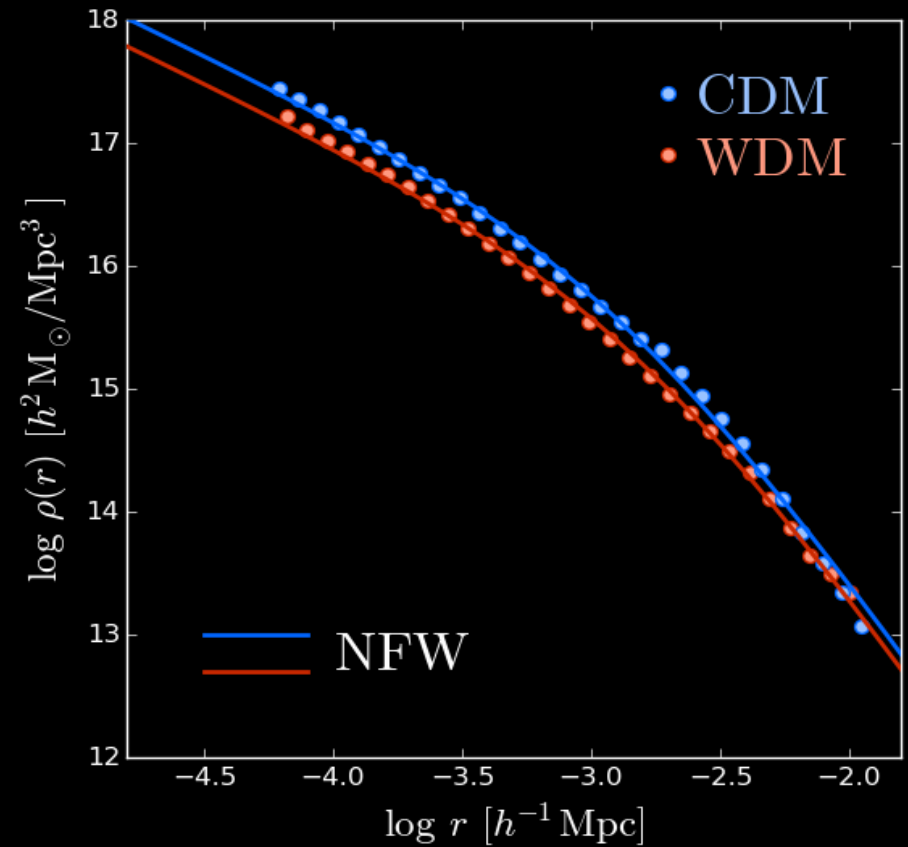
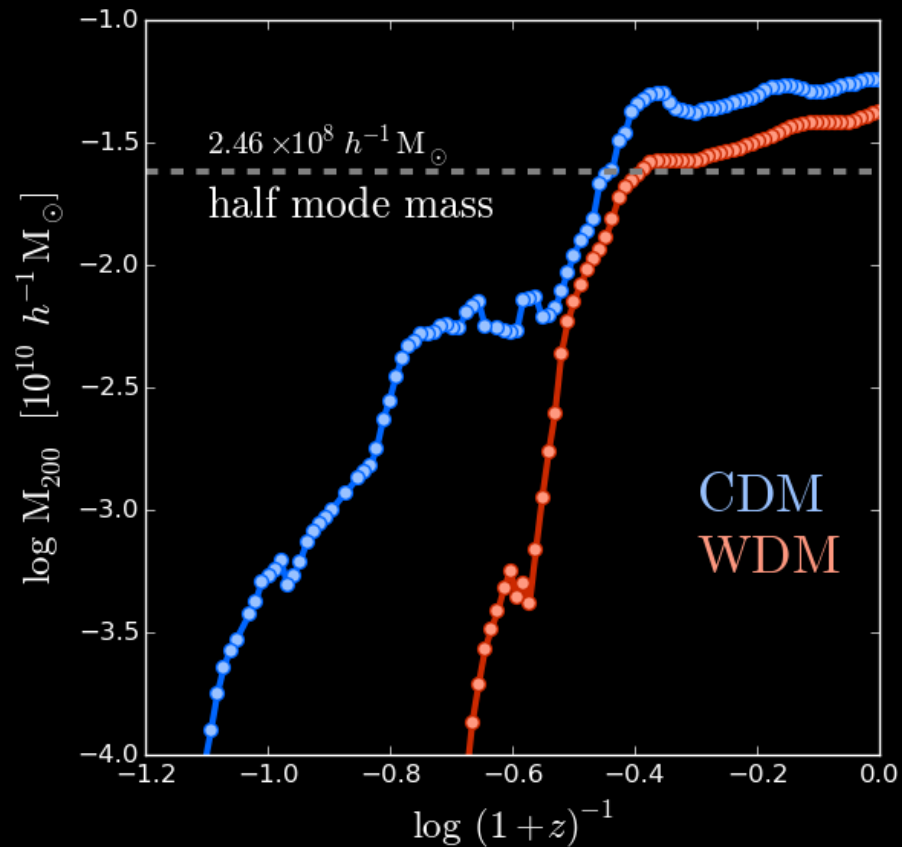
$z=0$



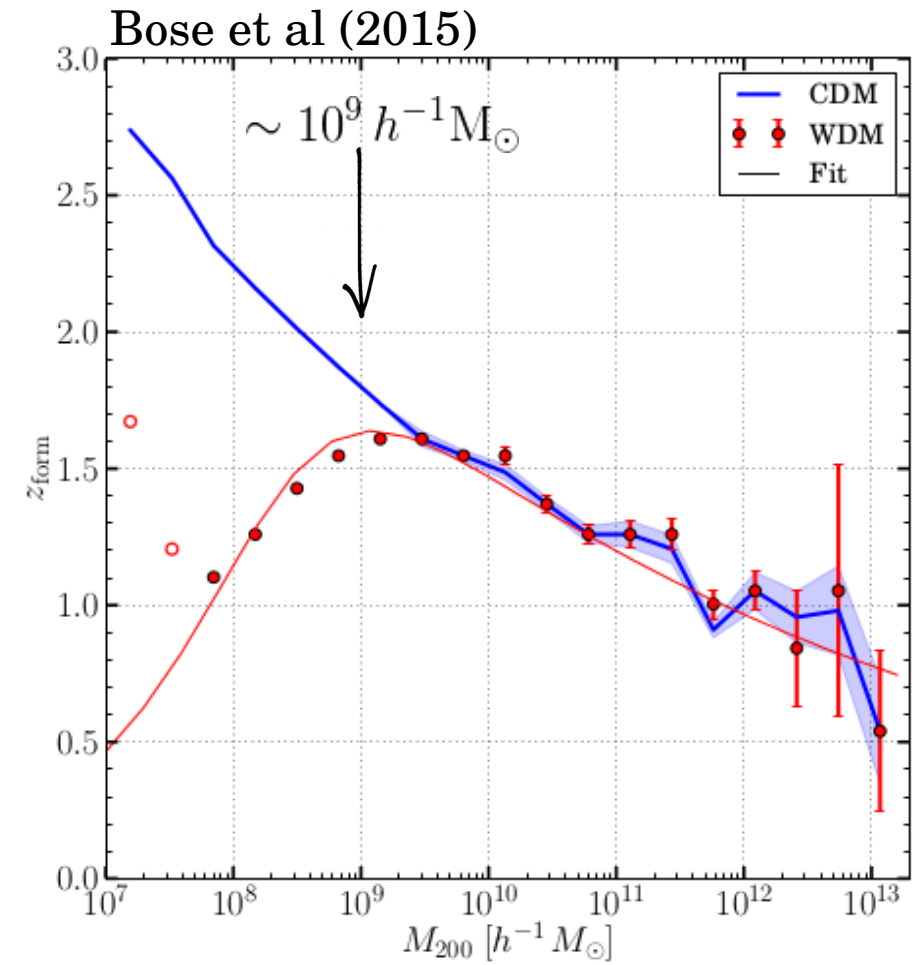
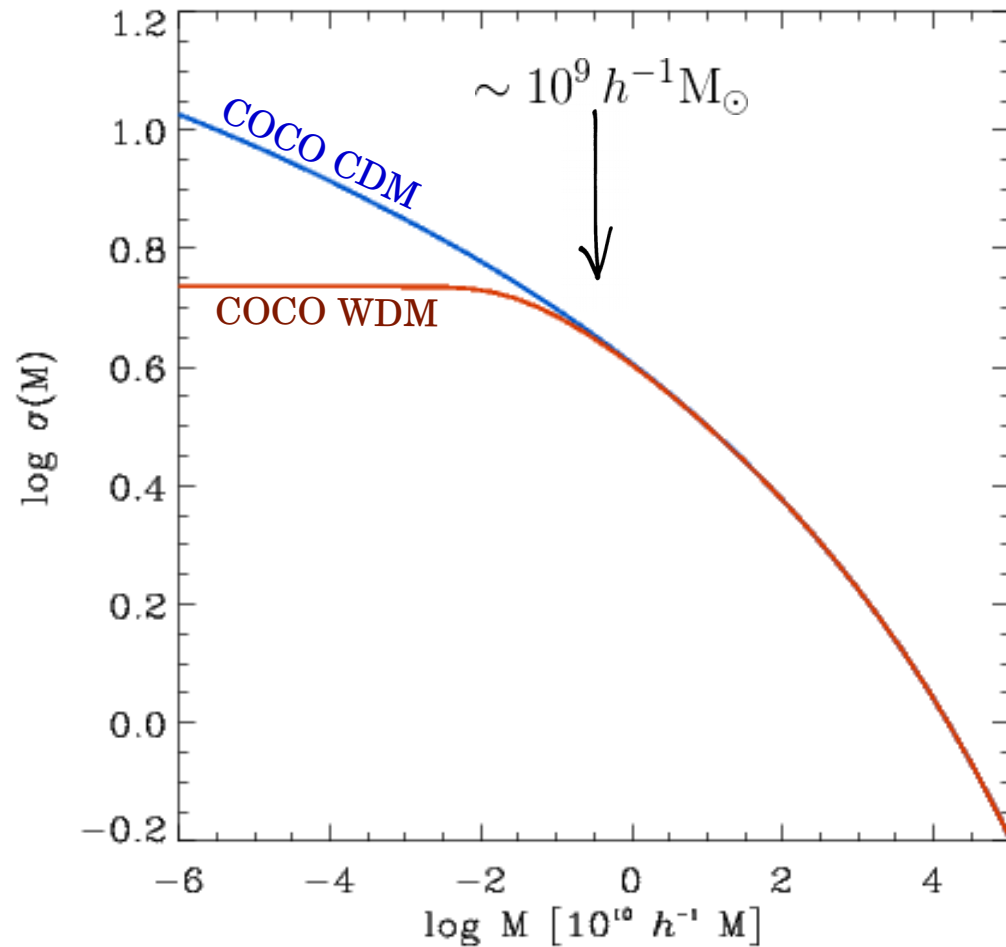
WDM



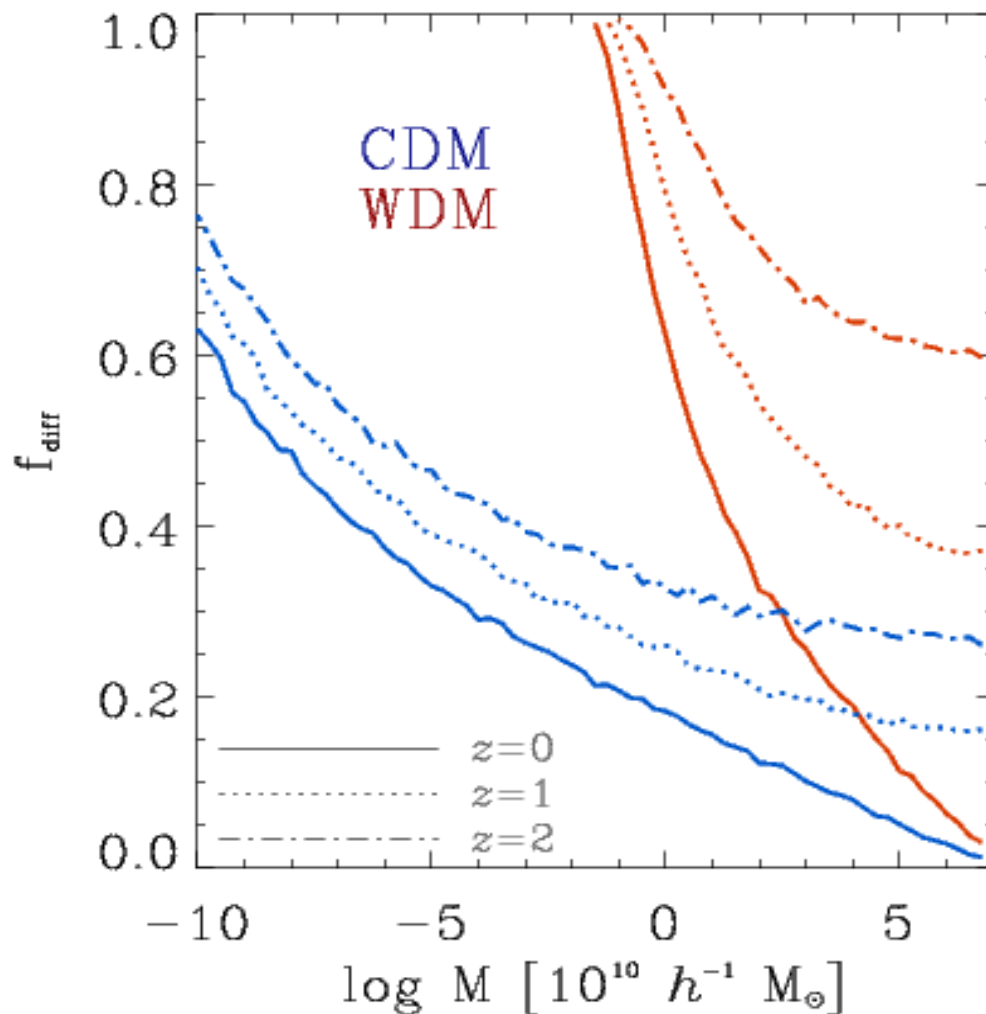
WDM halos: Mass profiles and accretion histories



WDM halos: formation times



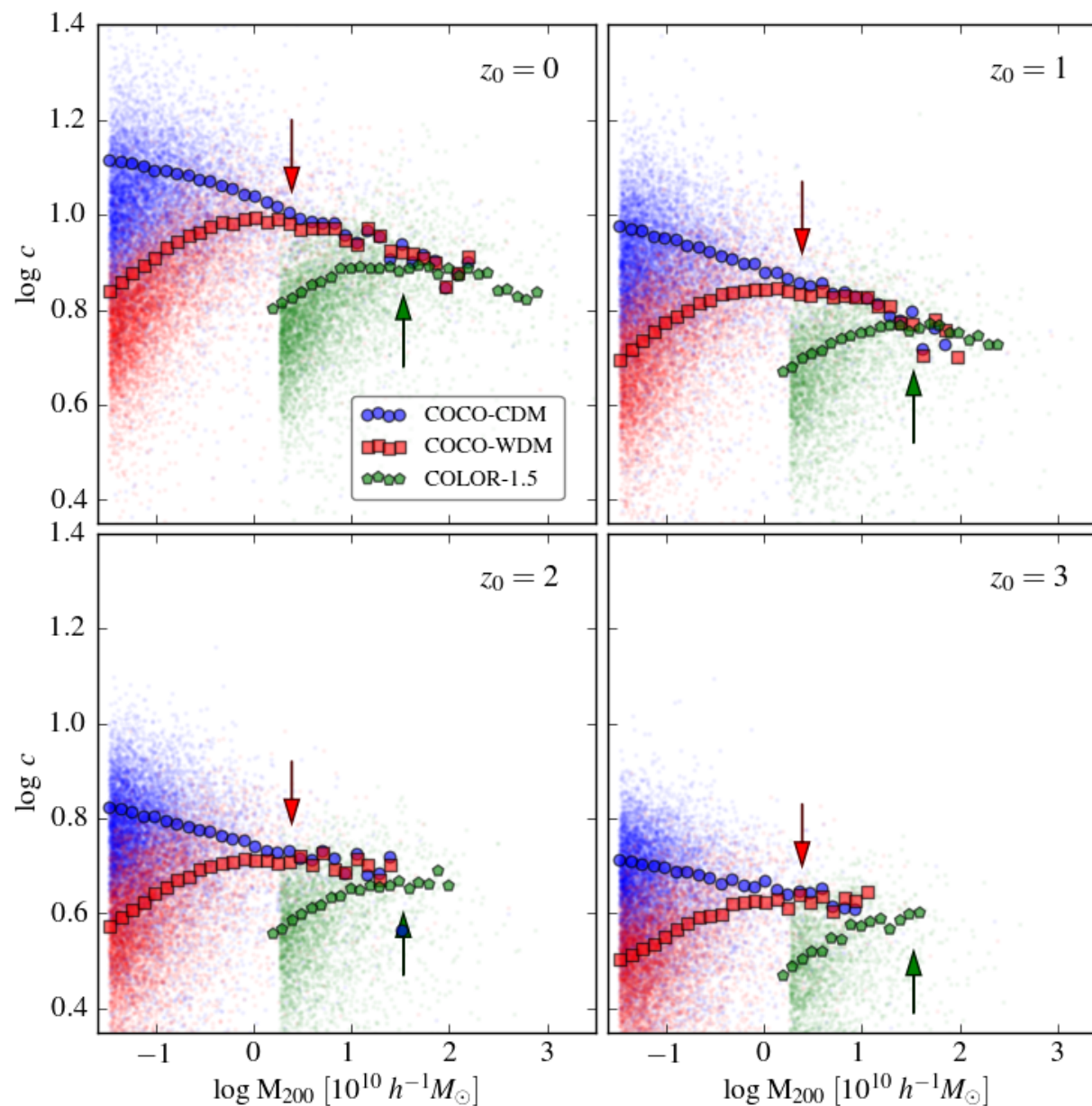
Warm dark matter's footprint: *diffuse accretion*



Excursion set theory suggests that WDM halos of any mass have accreted have much more diffuse dark matter

Clumpy Accretion in Extended Press-Schechter...

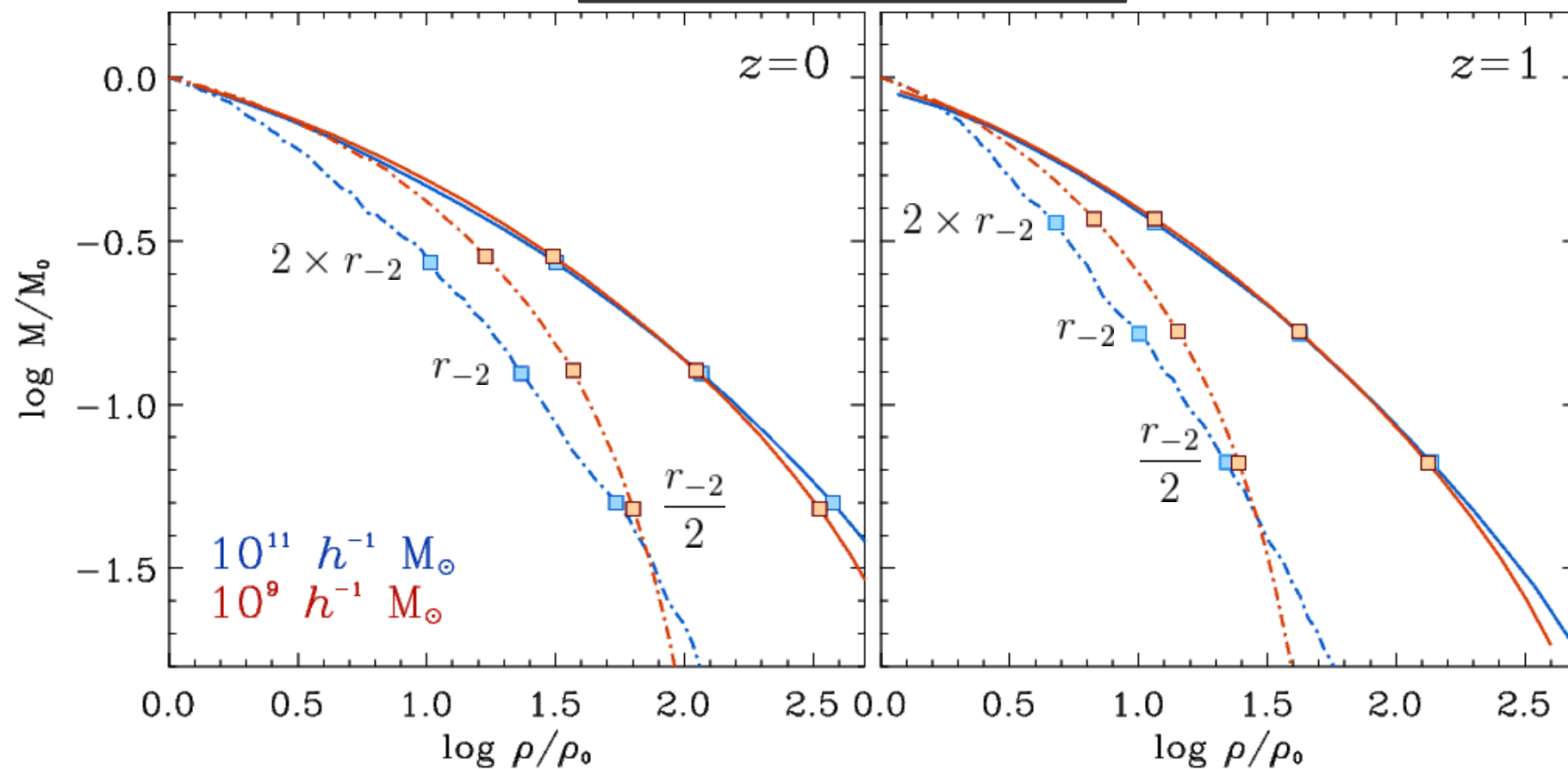
WDM halos: the $c(M,z)$ relation



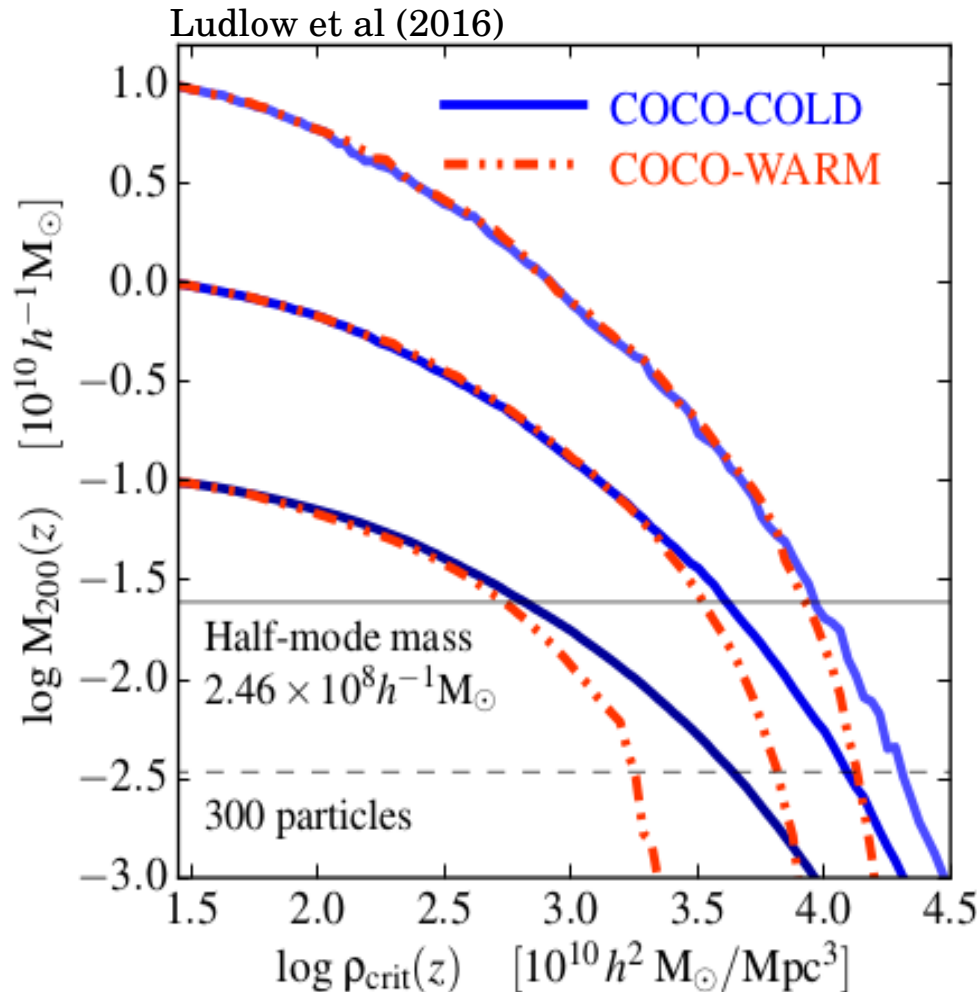
Ludlow et al (2016)

Warm dark matter's footprint

$$M(z) = M_{200}(z)$$



WDM halos: Mass profiles and accretion histories

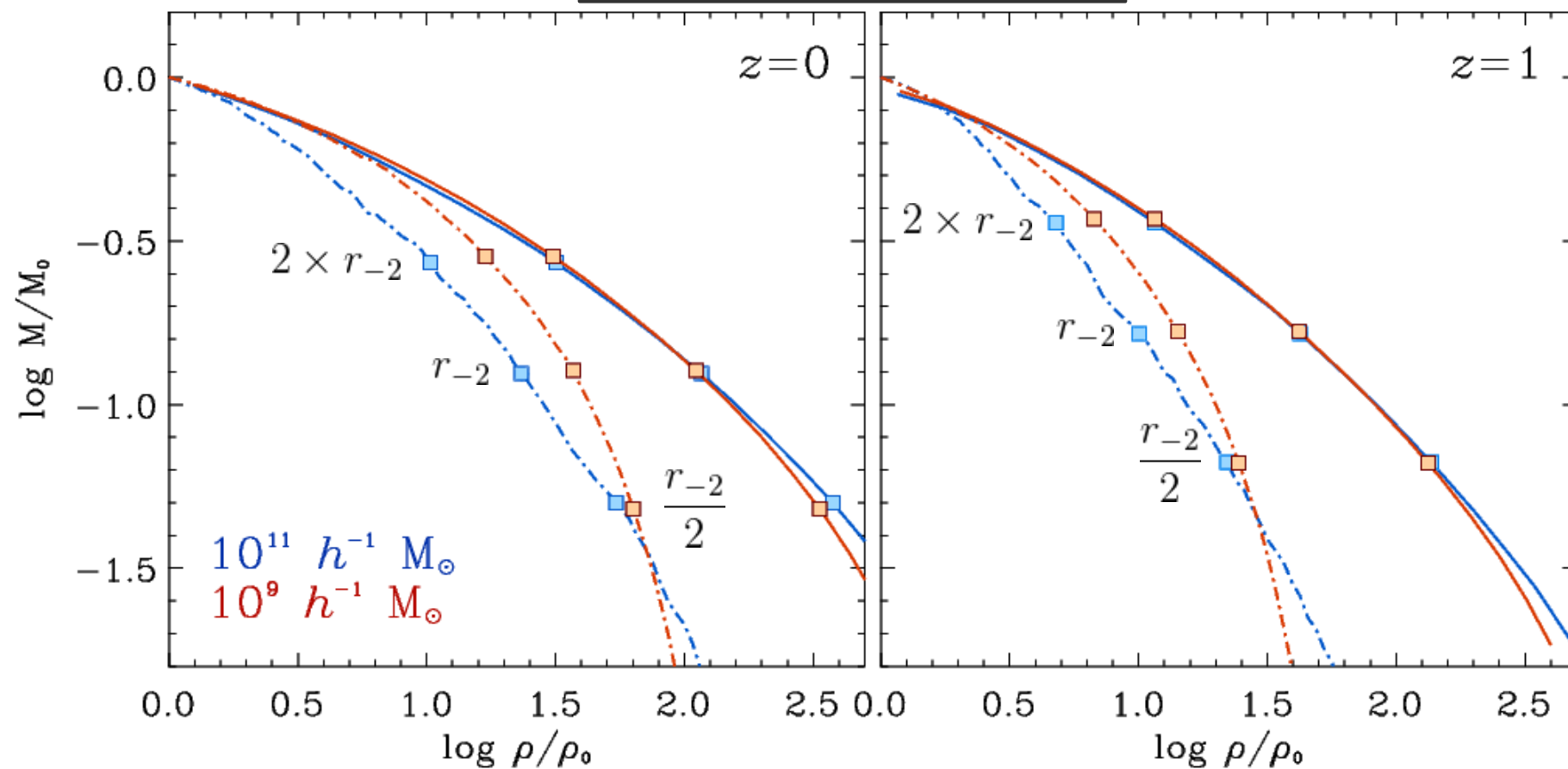


Mass accretion onto WDM halos is suppressed below a characteristic “free-streaming” mass scale

MAHS OF WDM HALOS ARE NOT SELF-SIMILAR

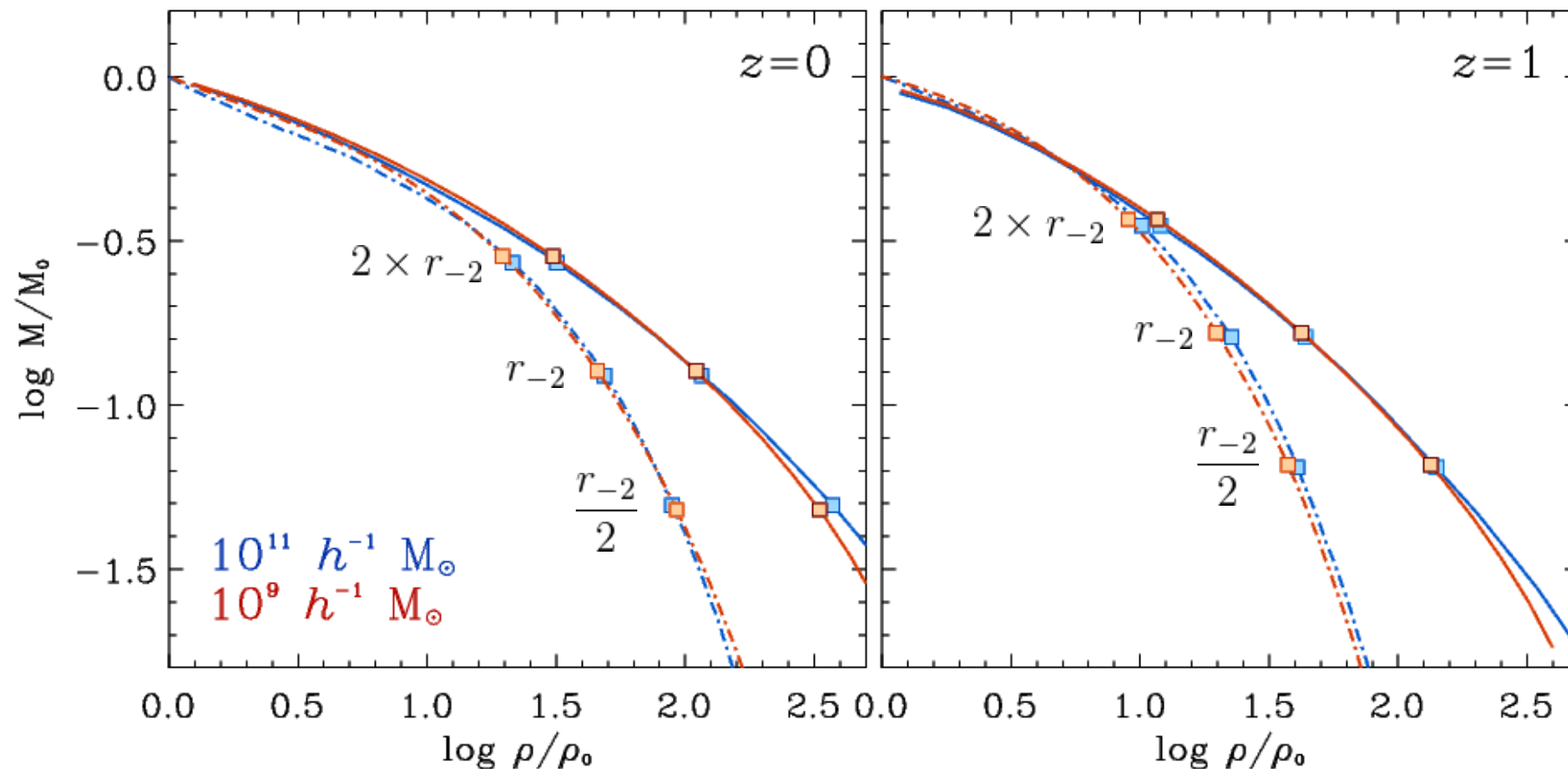
Warm dark matter's footprint

$$M(z) = M_{200}(z)$$



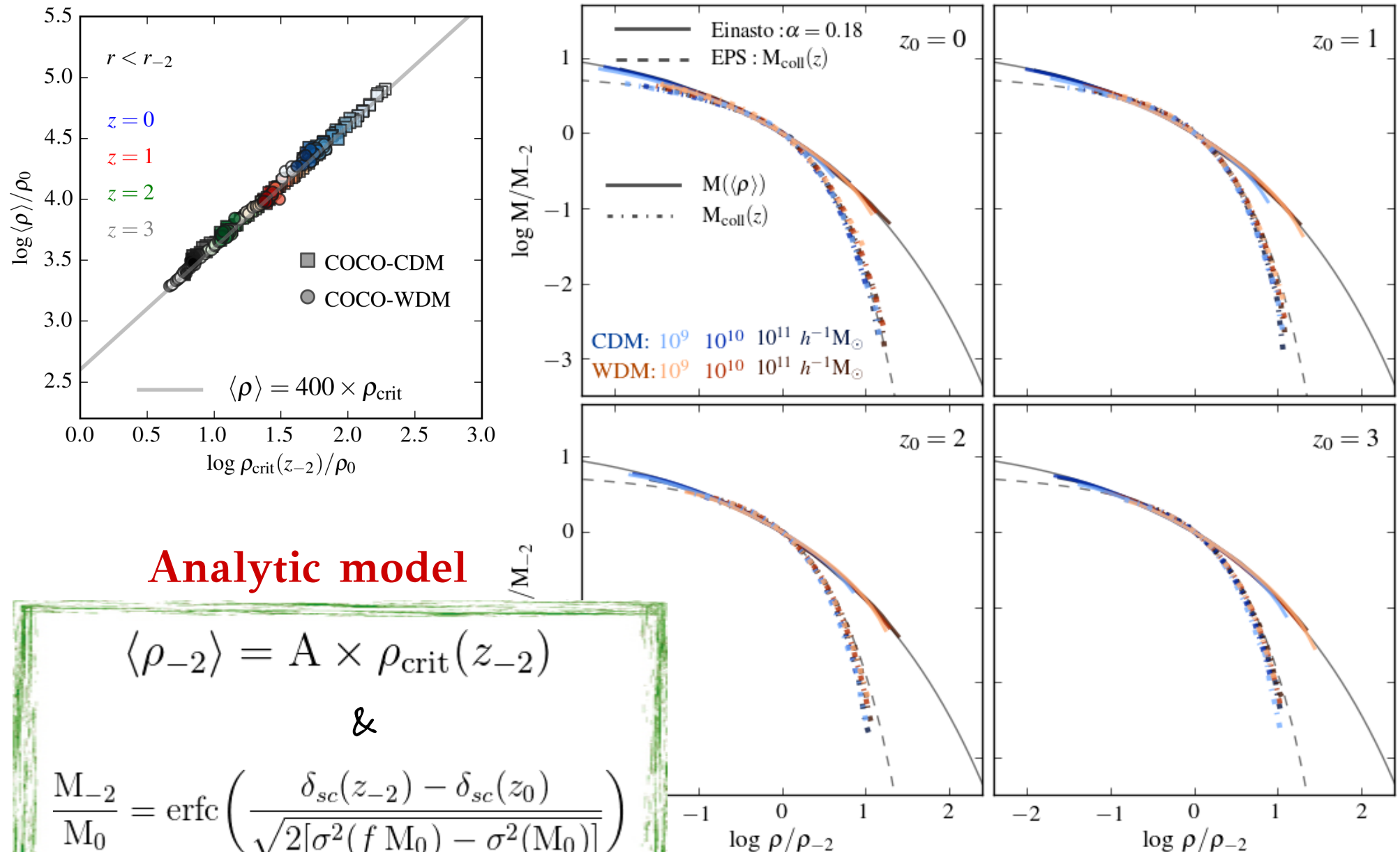
Warm dark matter's footprint

$$M(z) = \sum M_{\text{prog}}(> f \times M_0)$$

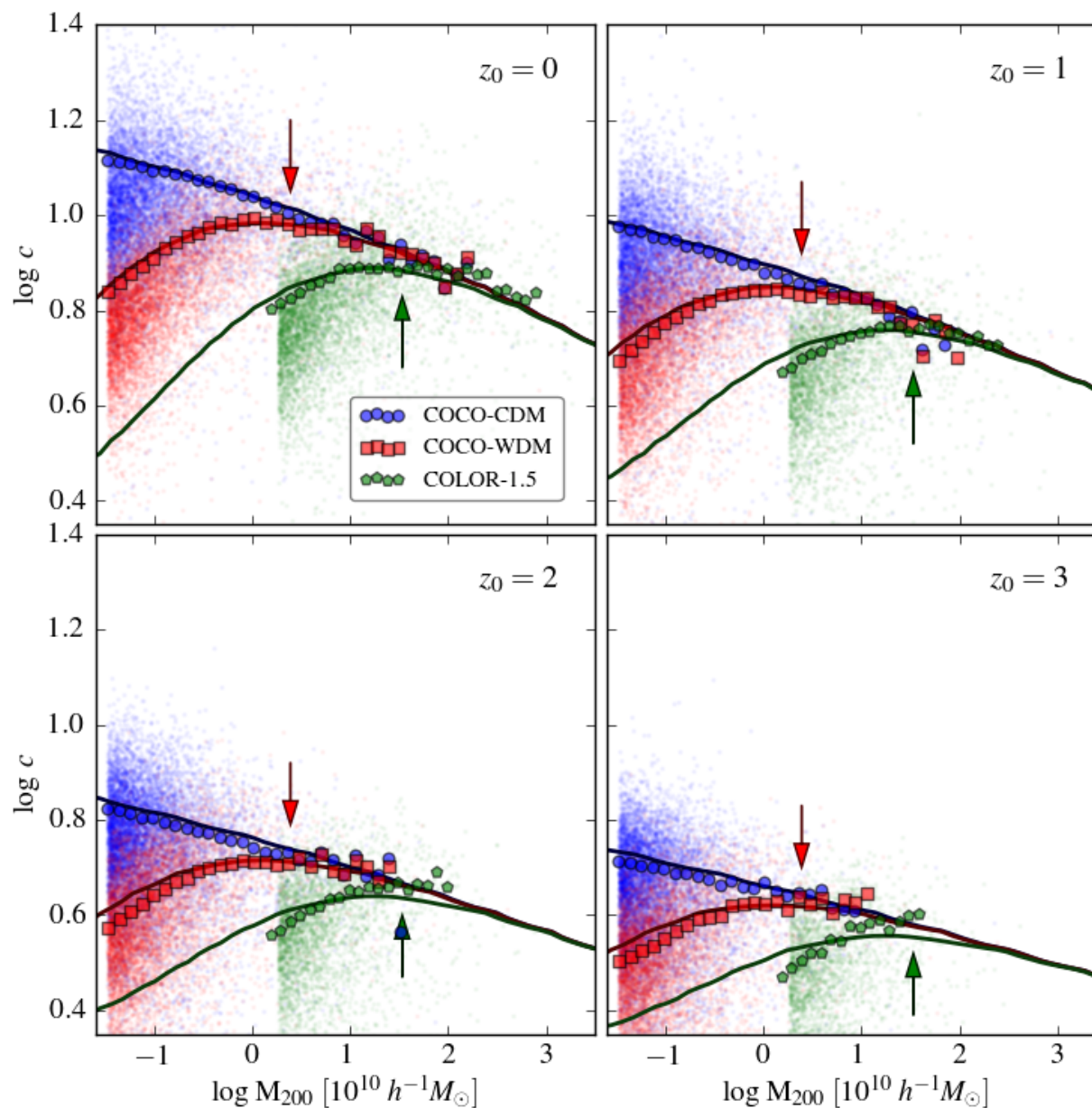


$$\frac{M(z)}{M_0} = \text{erfc} \left(\frac{\delta_{\text{sc}}(z) - \delta_{\text{sc}}(z_0)}{\sqrt{(2[\sigma^2(f \times M_0) - \sigma^2(M_0)])}} \right)$$

WDM halos: Mass profiles and accretion histories



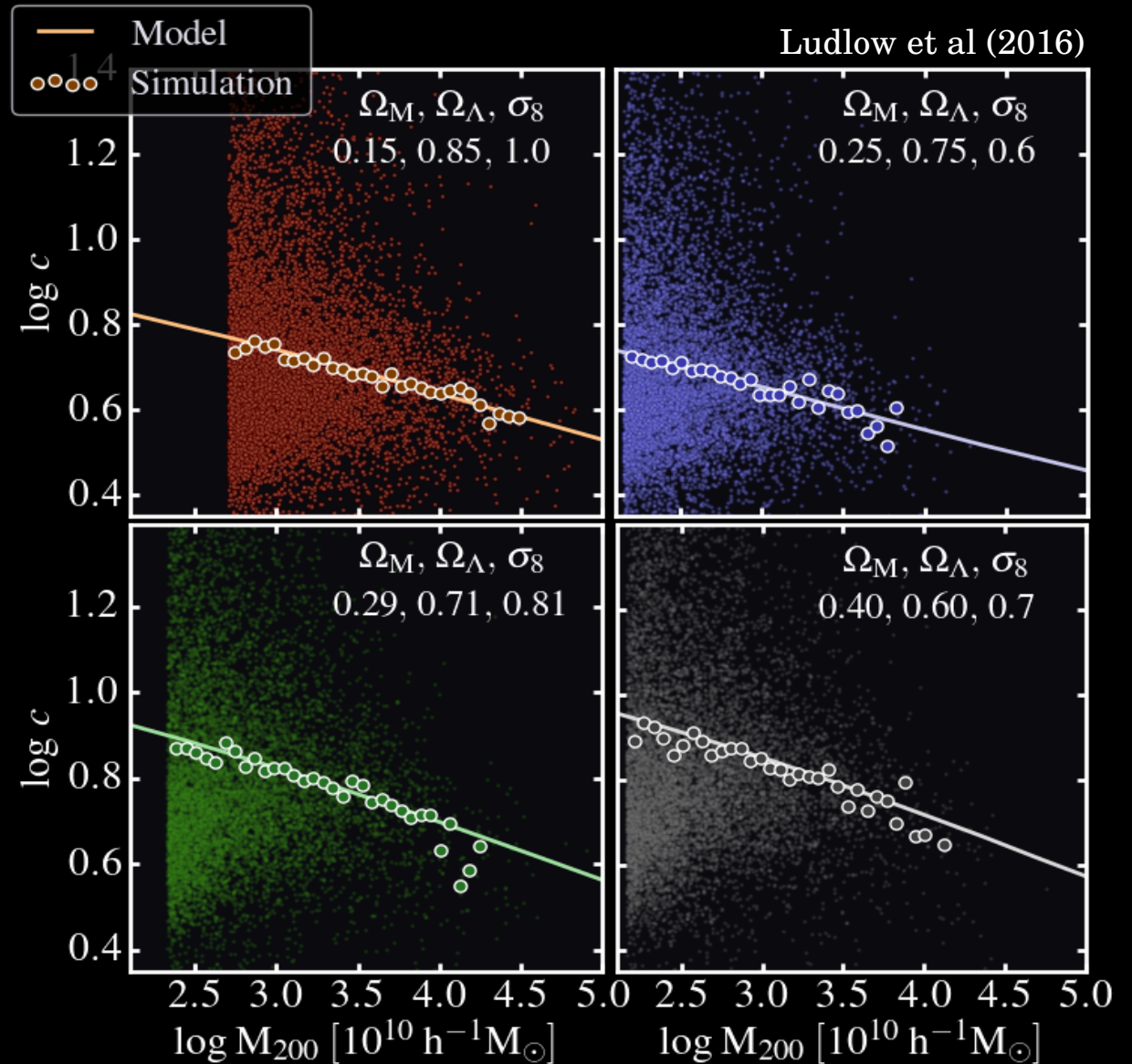
WDM halos: the $c(M,z)$ relation



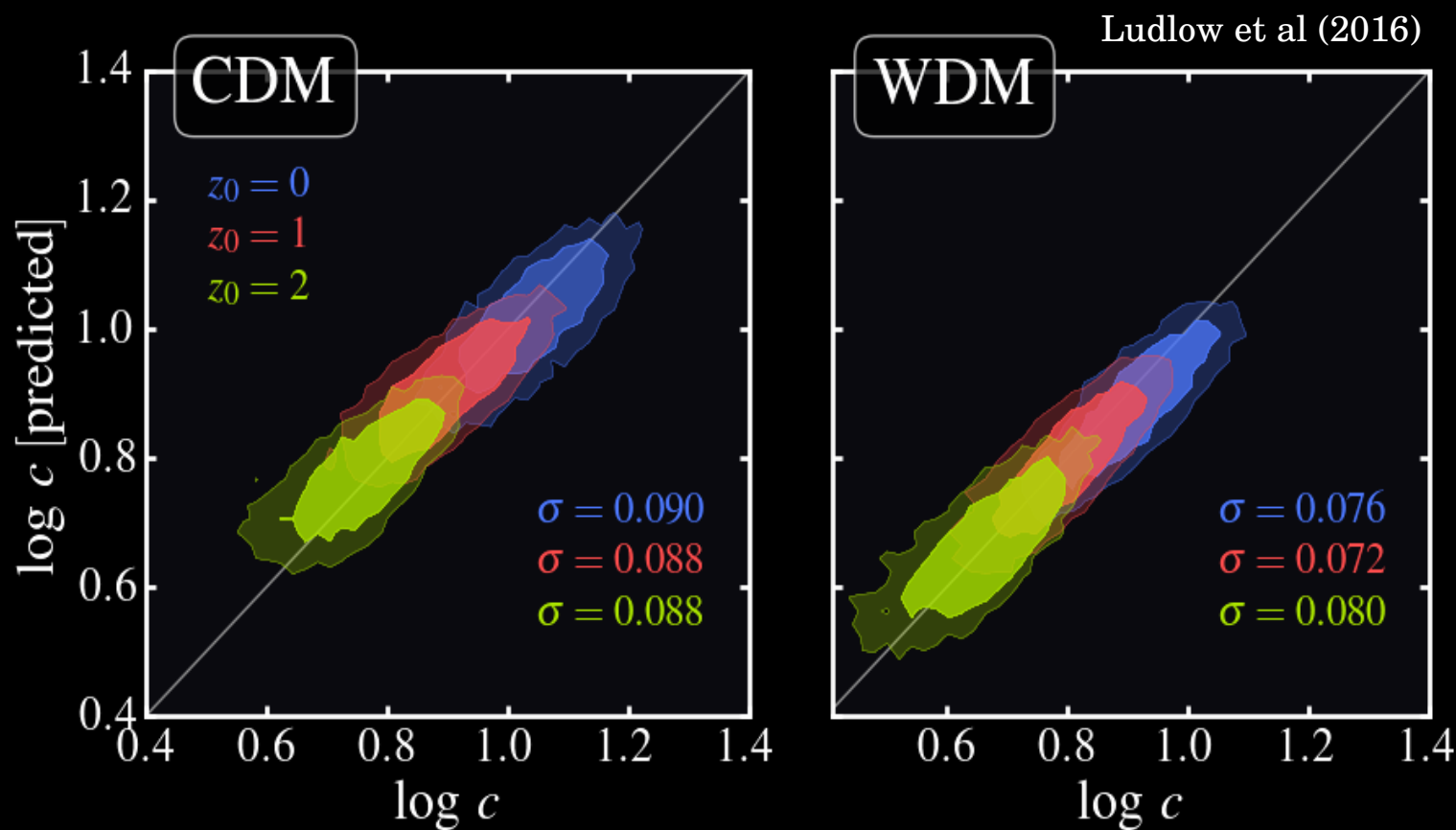
Ludlow et al (2016)

Additional tests of the model

Works for different
cosmologies with no
fine-tuning



Additional tests of the model



Individual halo concentrations predicted within $\sim 20\%$

Summary

- CDM halo mass profiles, expressed in terms of enclosed density, and accretion histories, expressed in terms of background density, are self-similar: *both follow an NFW profile*
- For WDM, “collapsed mass history” (CMH) is also self-similar and a tight scaling relation between the characteristic halo density and its formation time

$$\langle \rho(r_{-2}) \rangle \propto \rho_{\text{crit}}(z_{-2})$$

- Can be used to construct a simple analytic model for halo structure:
 - Independent of power spectrum
 - Works for various cosmological models
 - Accurate to ~20% for *individual halos*