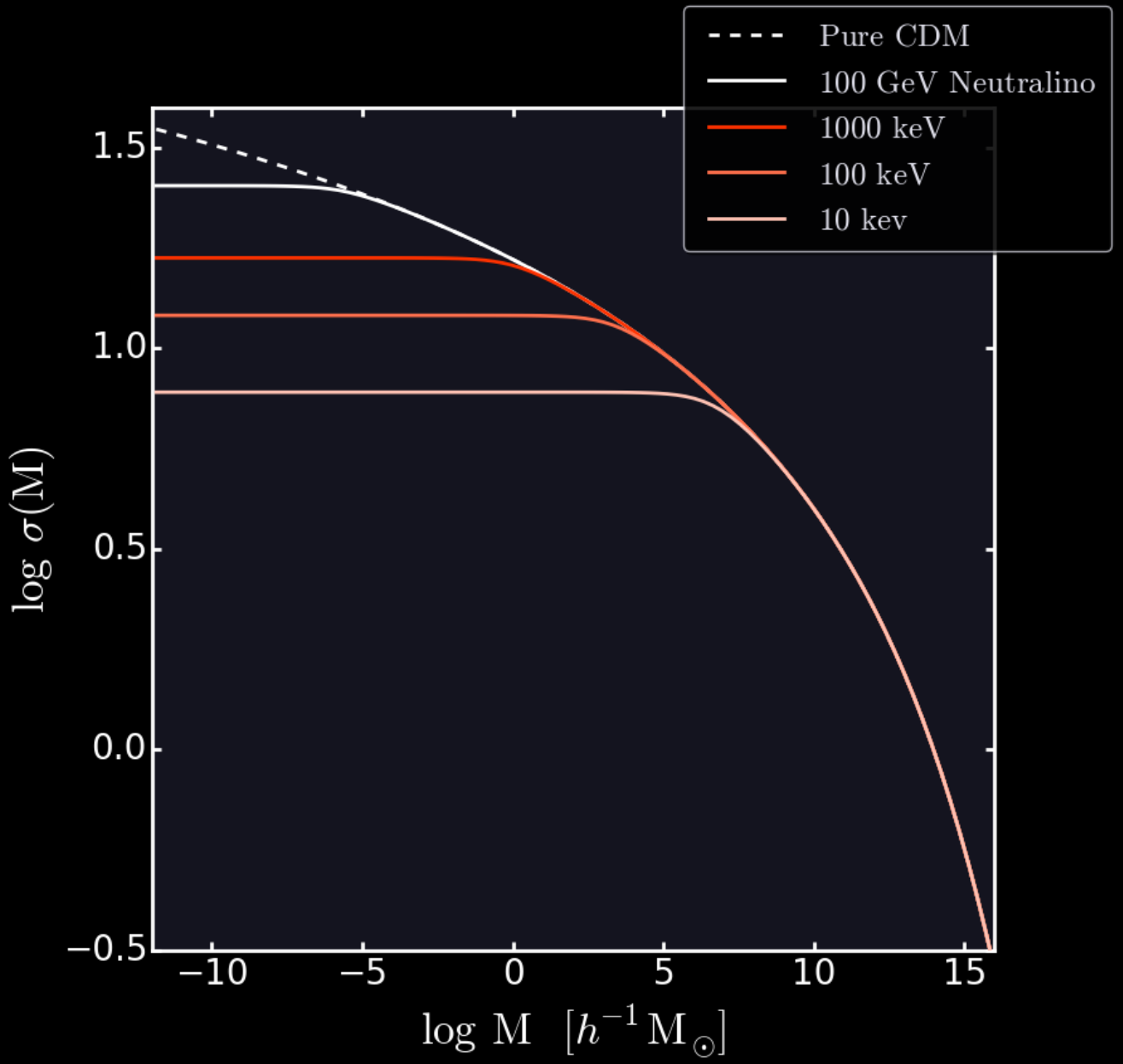
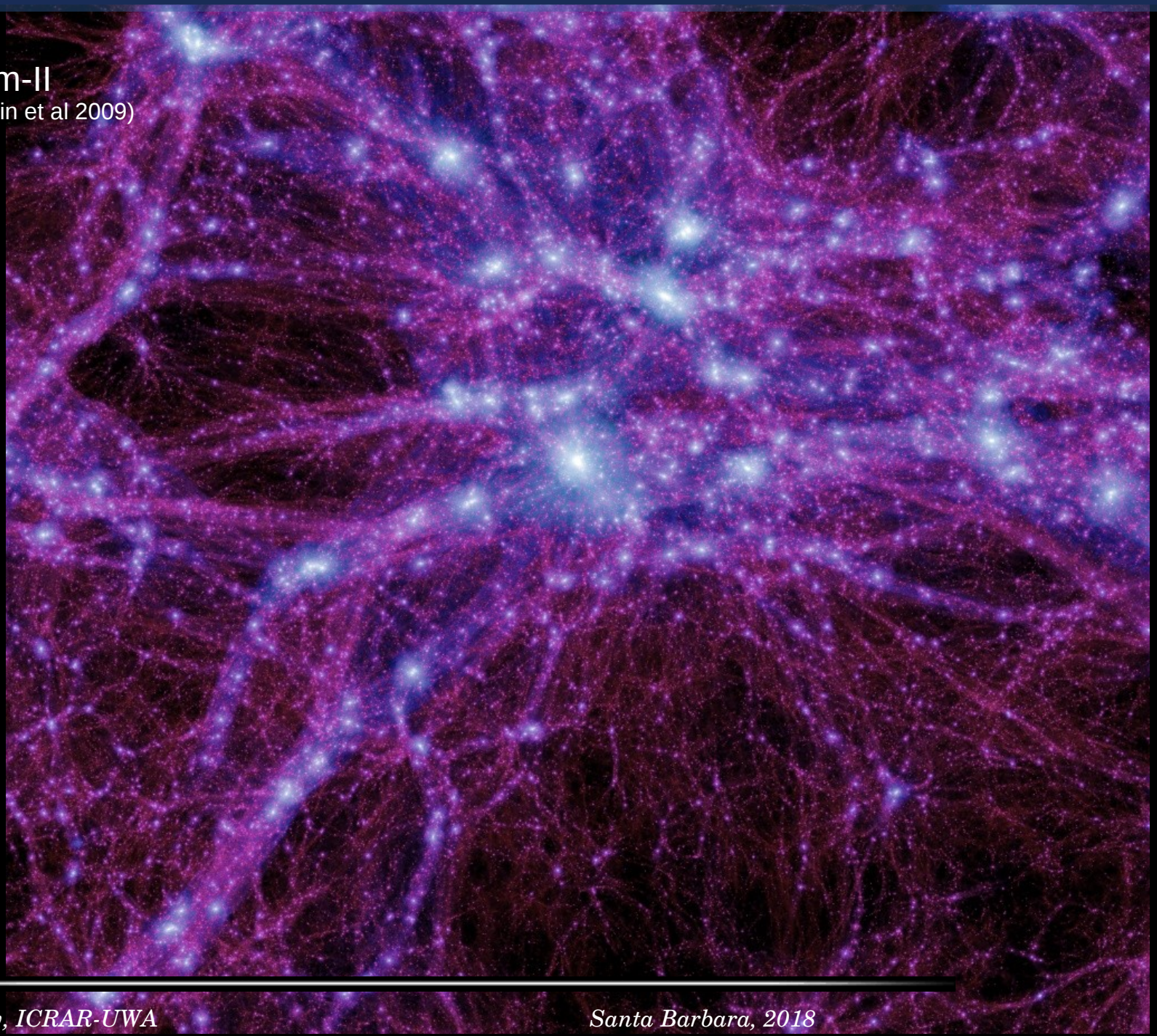
Cold, Warm and Neutralino DM halos



Cold DM halos

Millennium-II
(Boylan-Kolchin et al 2009)

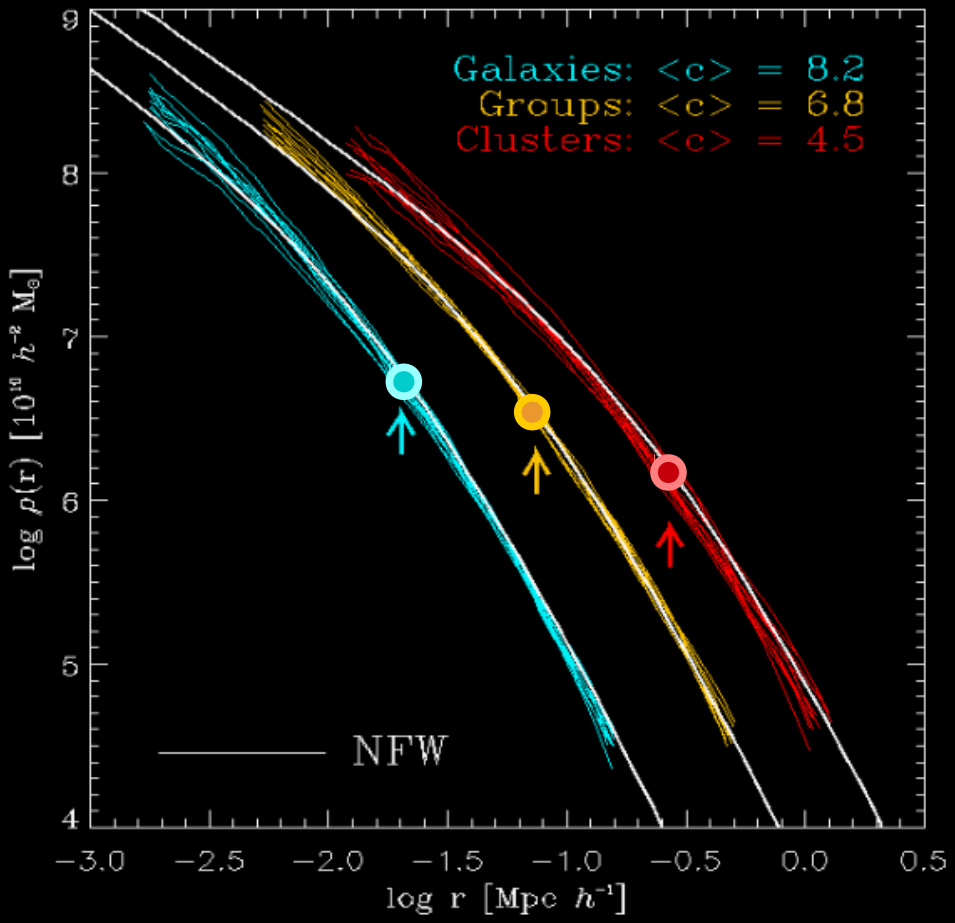


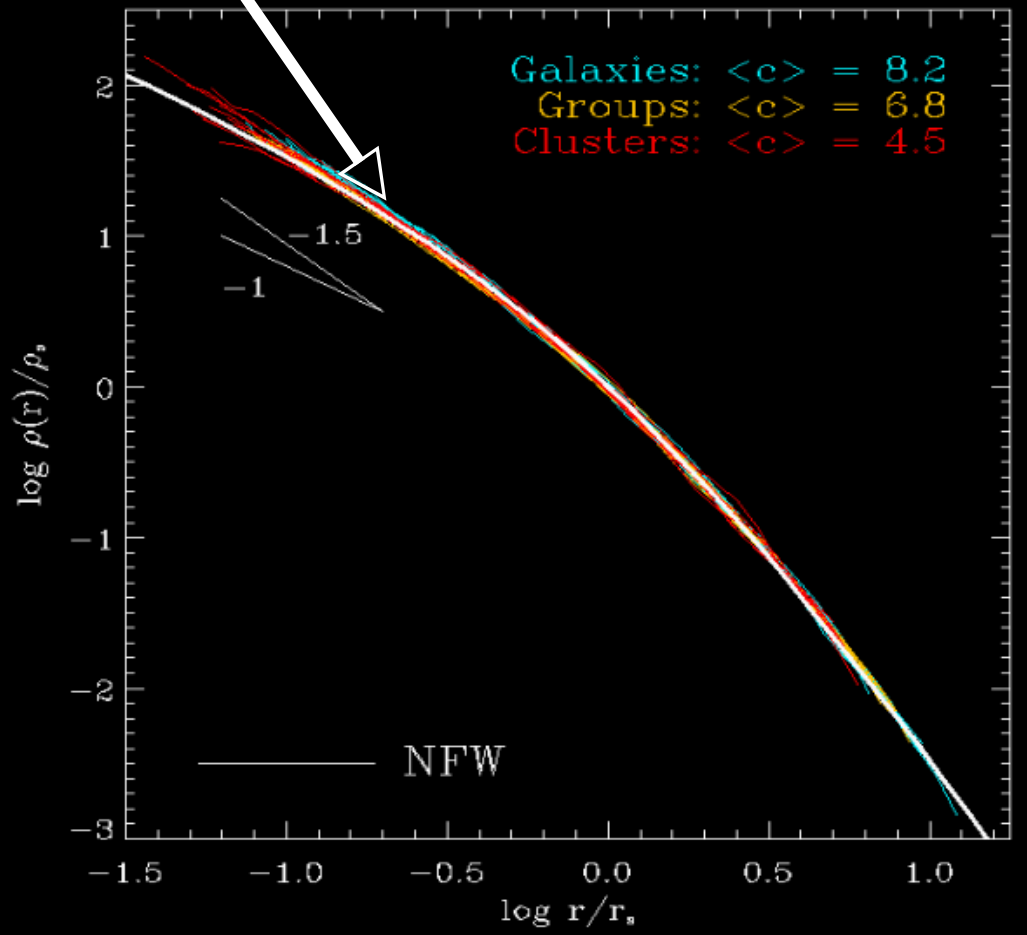
Start with CDM: Navarro, Frenk & White "NFW" profile

Universal

"NFW profile" : $\rho(r) = \dfrac{\rho_{\rm crit}\,\delta_c}{\frac{r}{r_s}\left(1+\frac{r}{r_s}\right)^2}$

concentration: $c \equiv \dfrac{r_{200}}{r_s}$





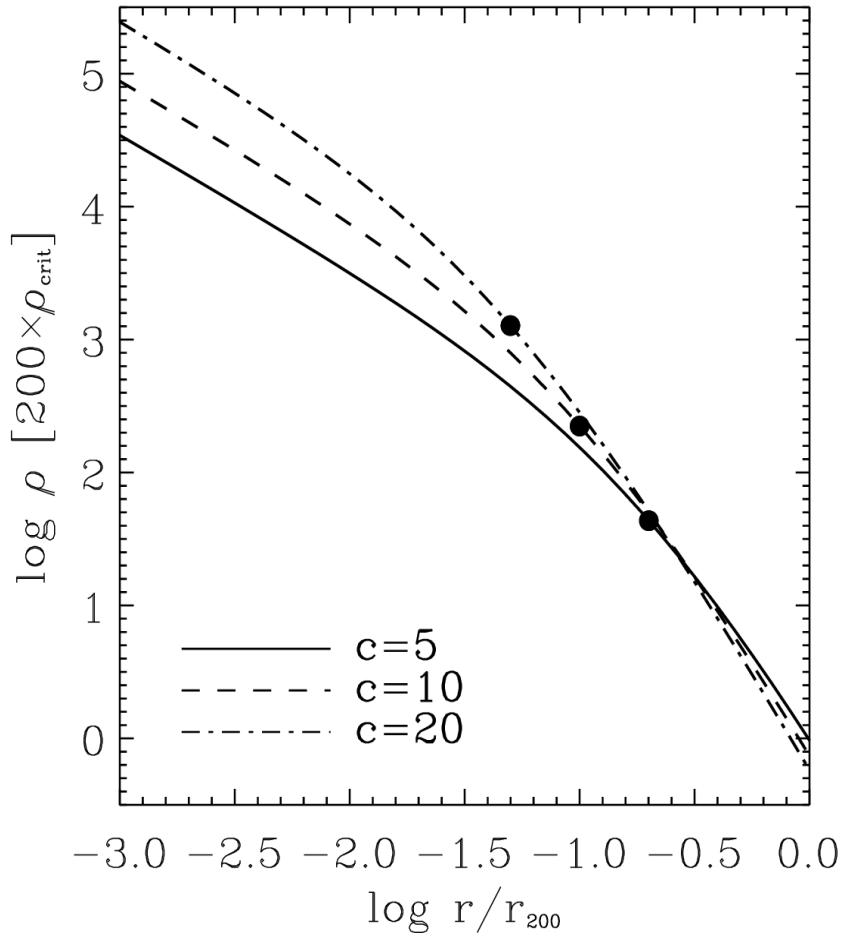
Start with CDM: Navarro, Frenk & White "NFW" profile

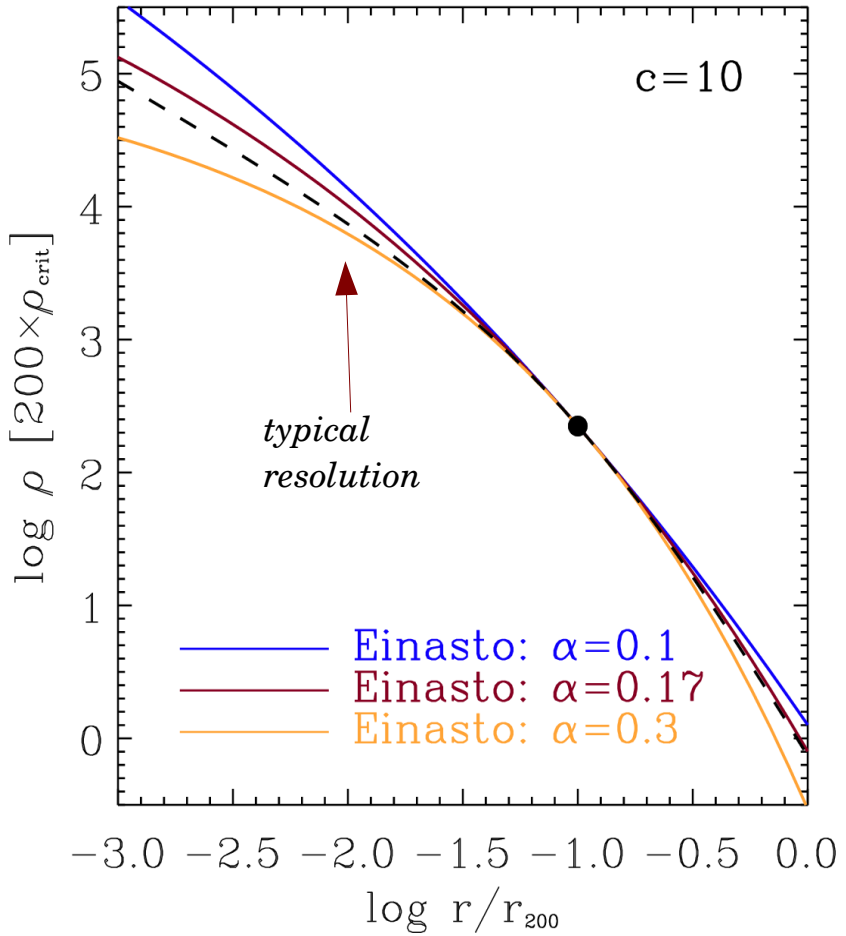
"concentration"

$$\rho(r) = \frac{\rho_0}{cx(1+cx)^2}$$

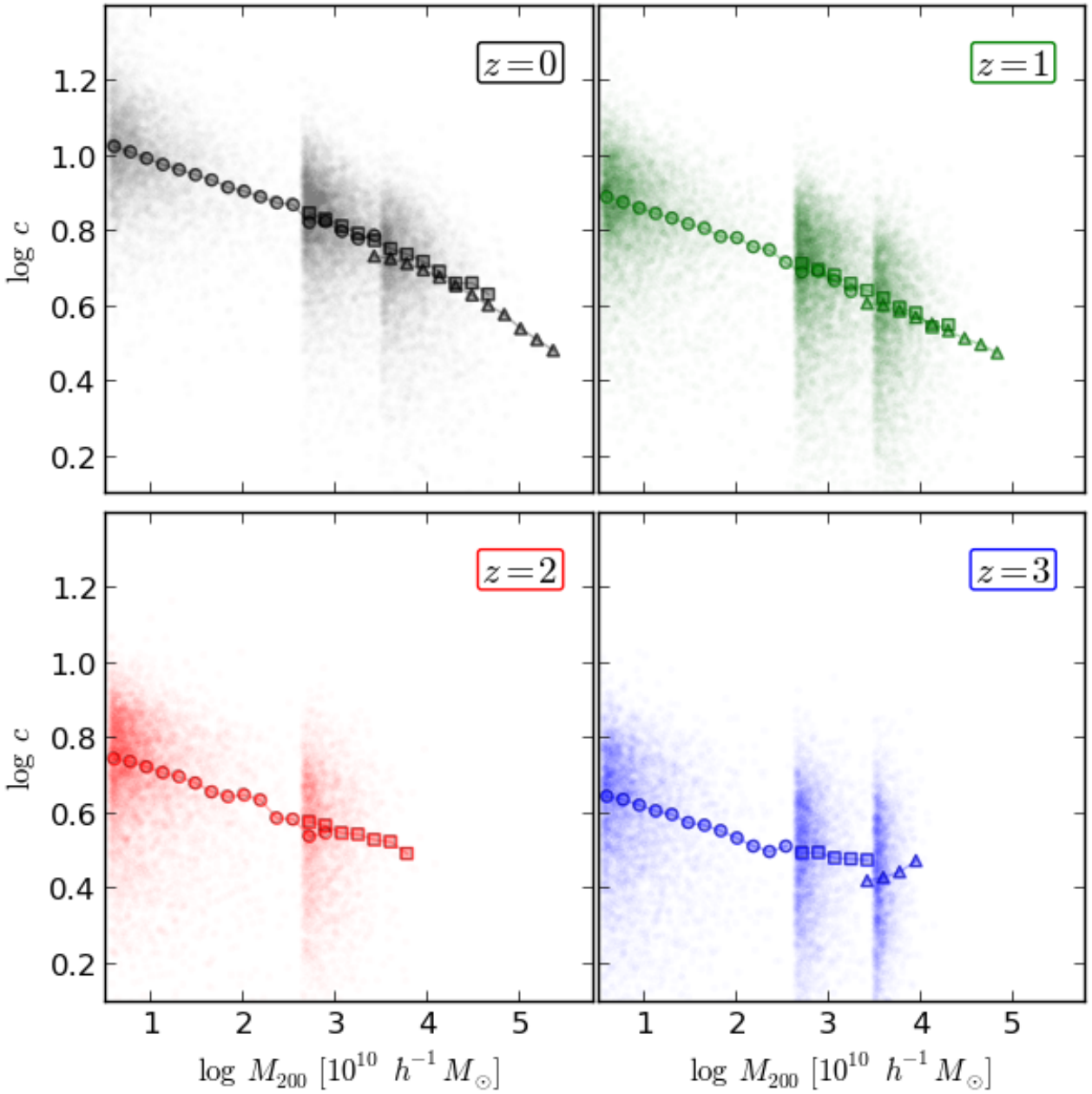
$$\frac{d\ln\rho}{d\ln r} \propto -2(cx)^{\alpha}$$

"Shape"



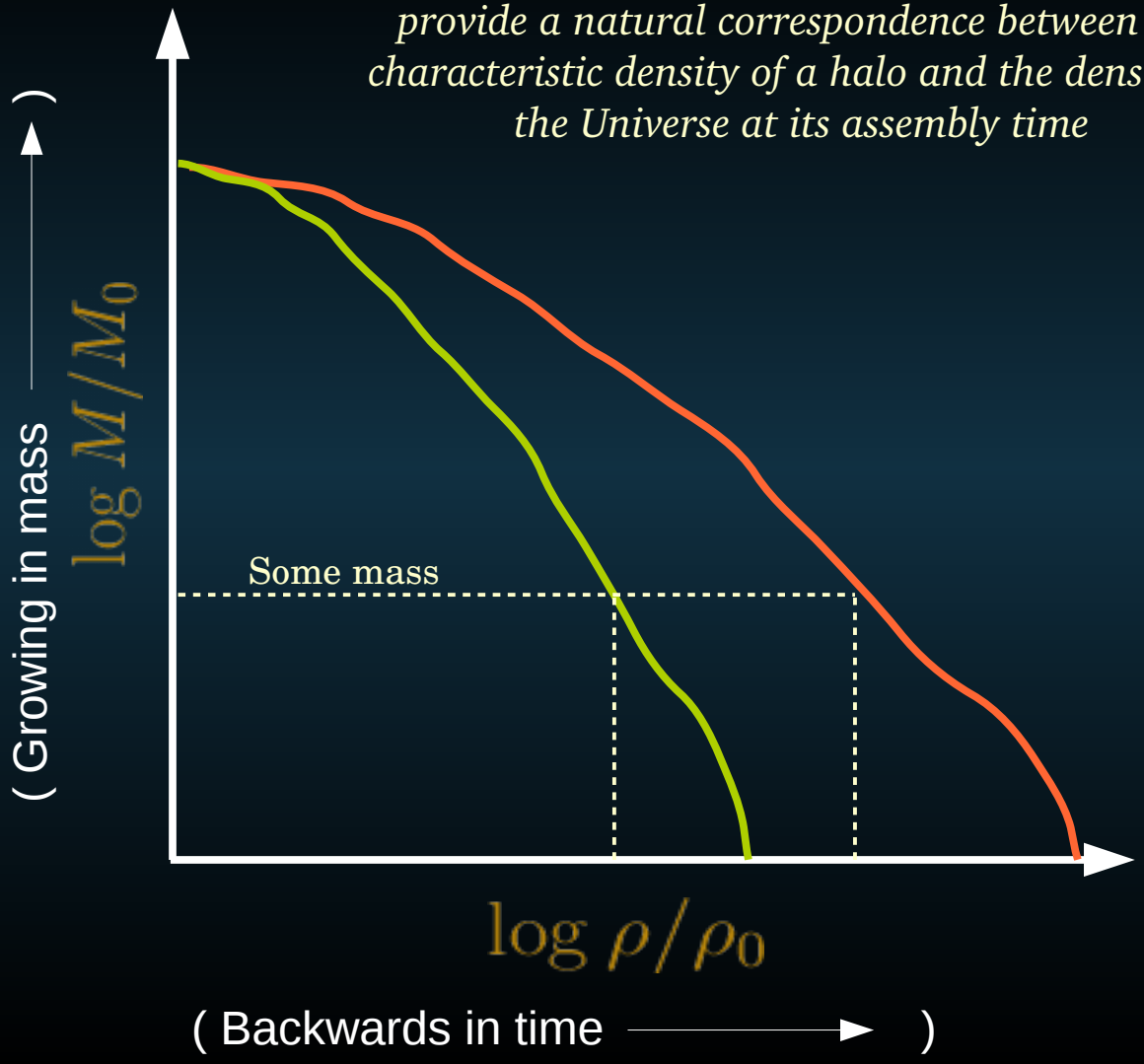


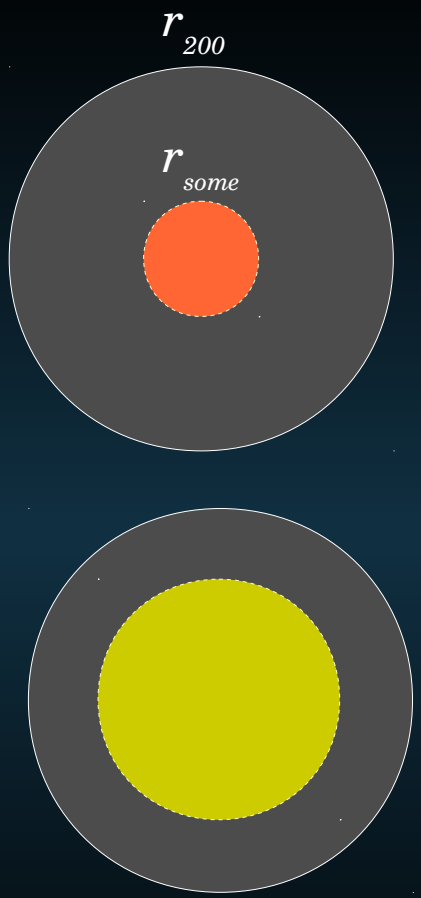
CDM halos: The concentration-mass-redshift relation



Mass Profiles and Accretion Histories

An ideal definition of "formation time" would provide a natural correspondence between the characteristic density of a halo and the density of the Universe at its assembly time





Mass Profiles and Accretion Histories

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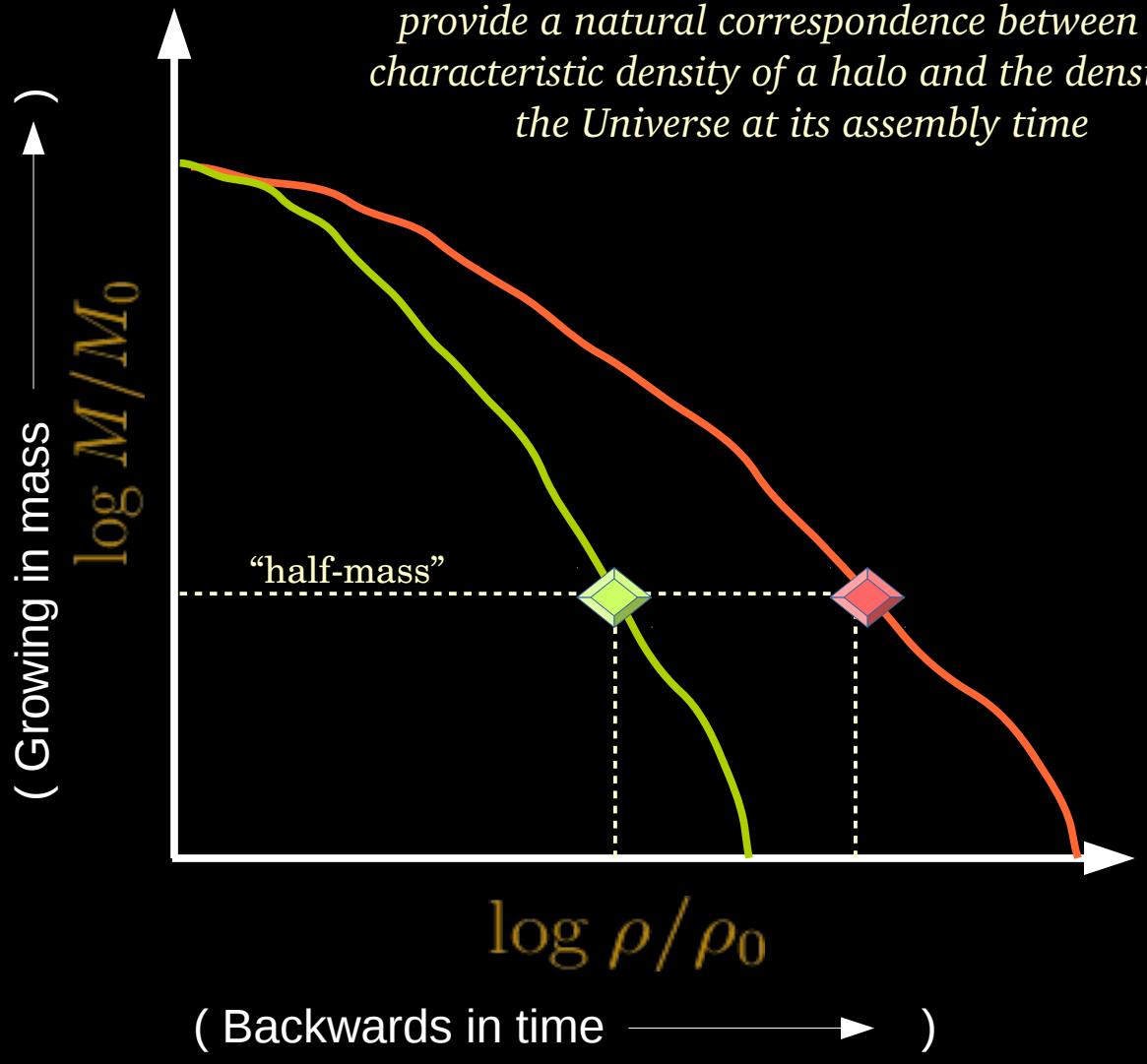

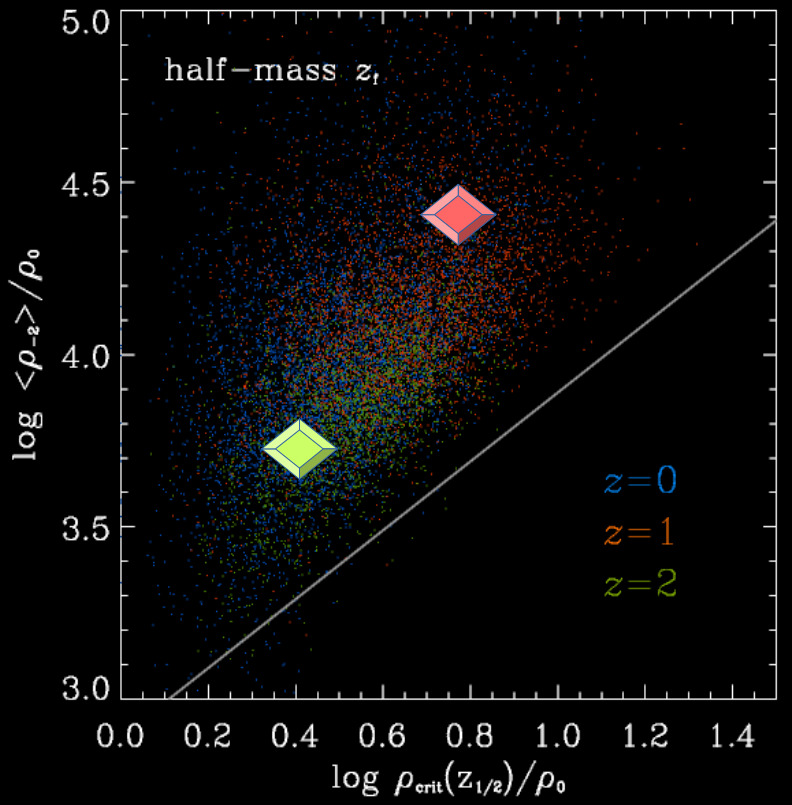

Mass Profiles and Accretion Histories

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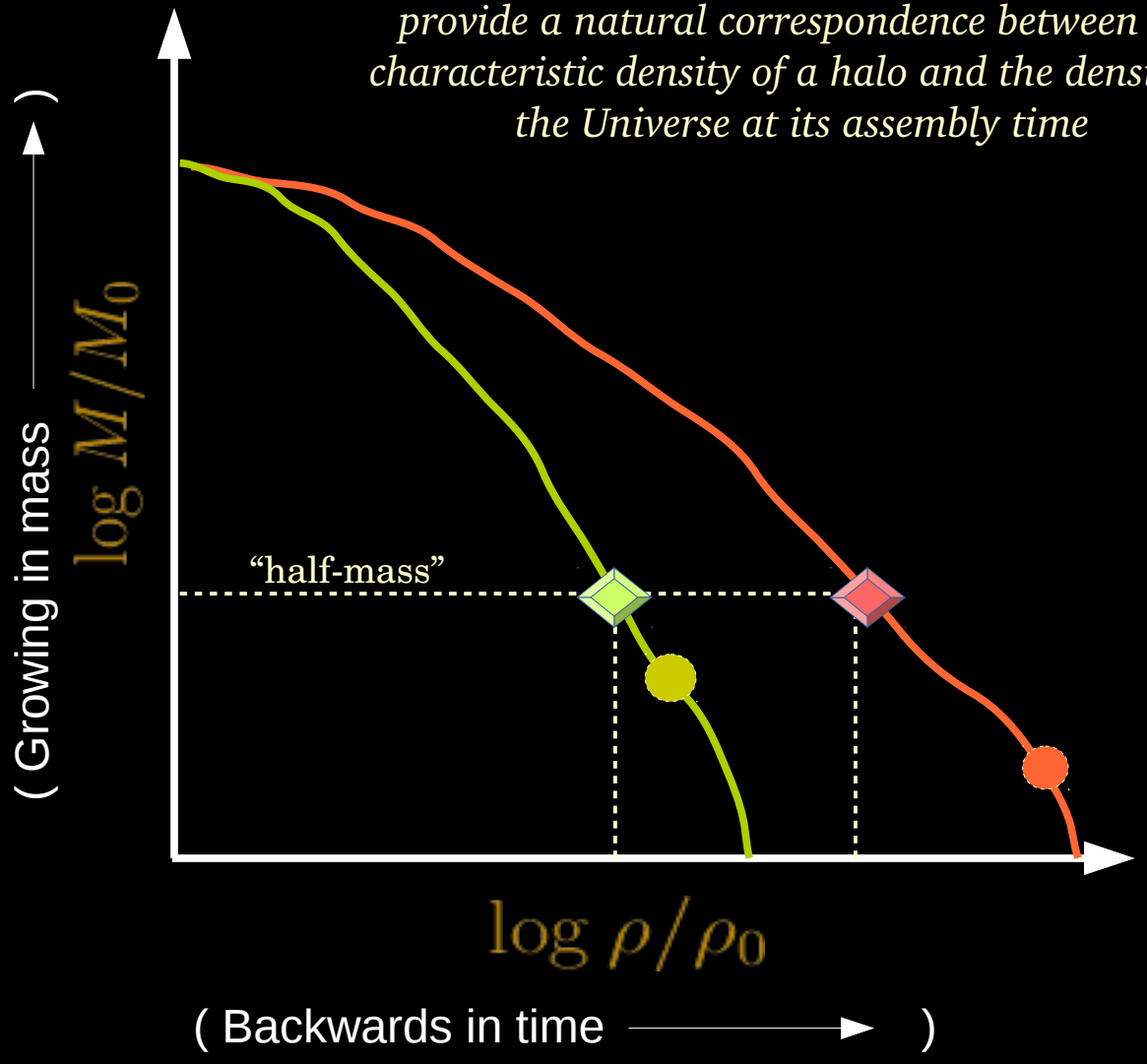
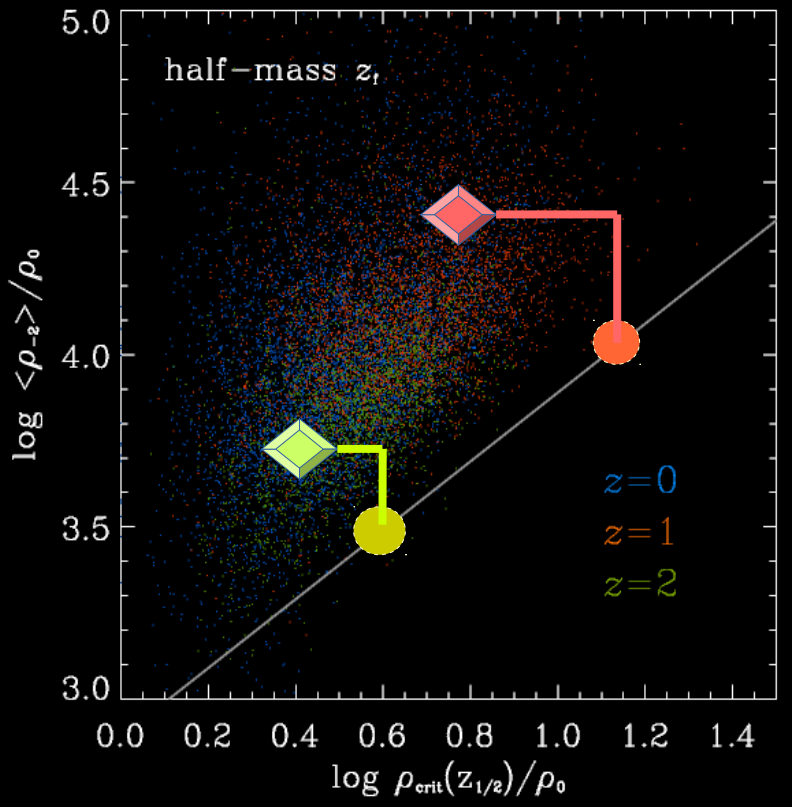
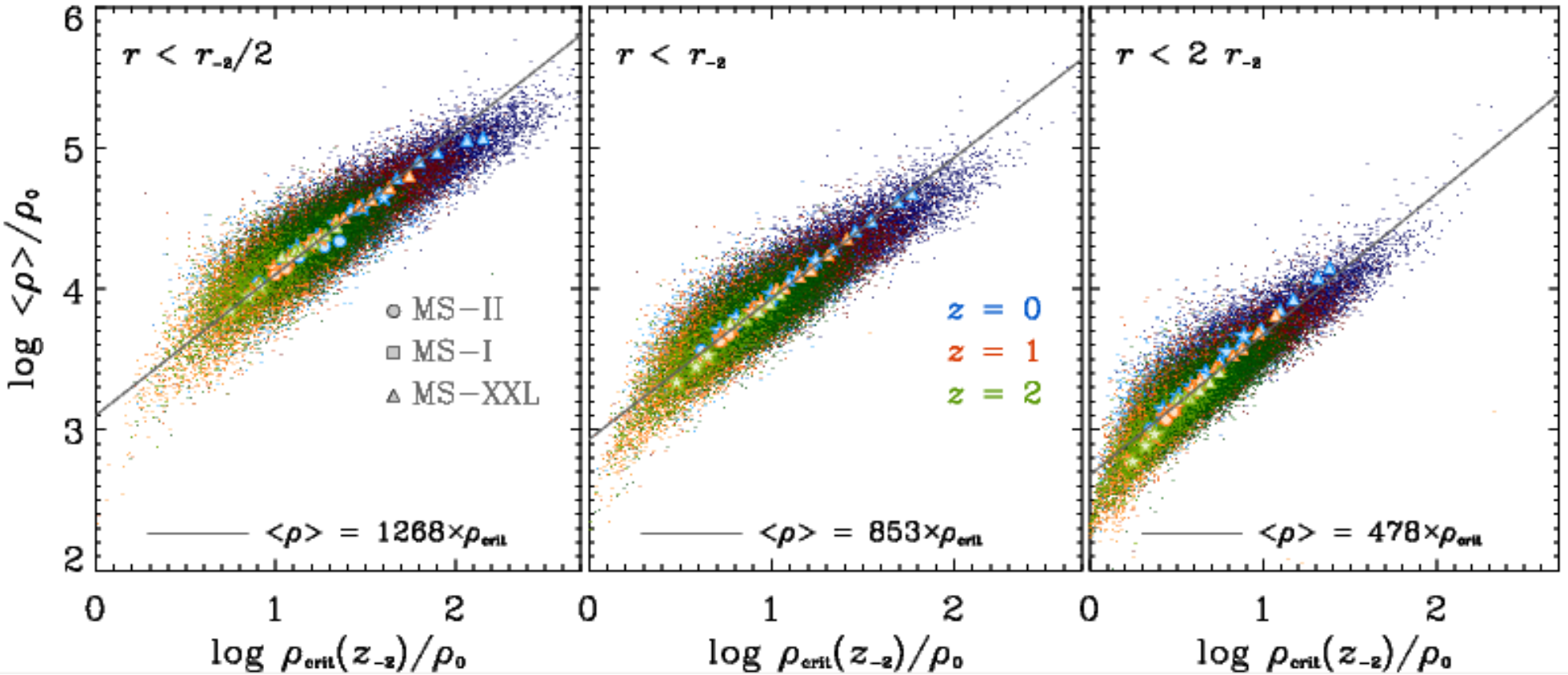
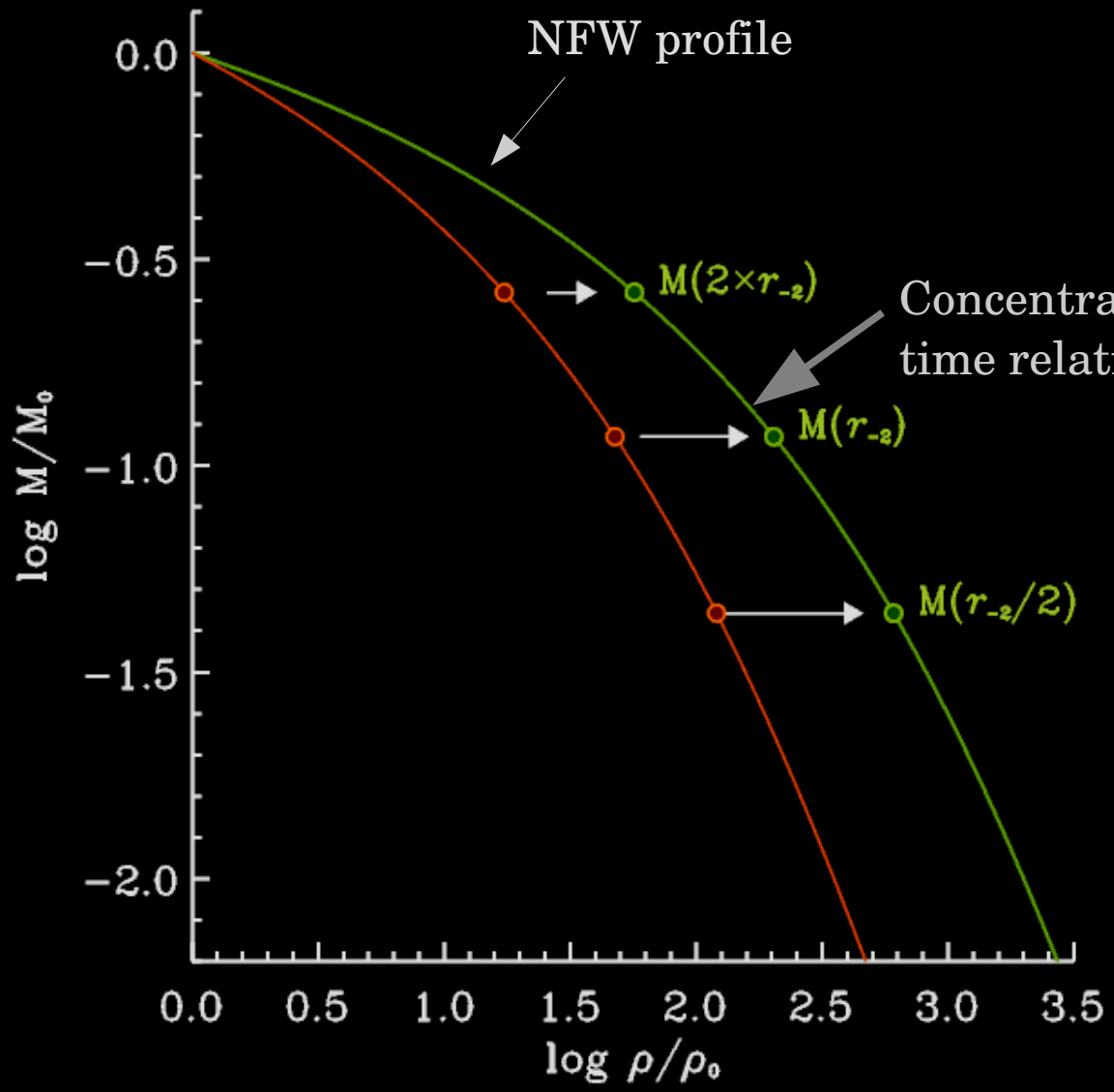


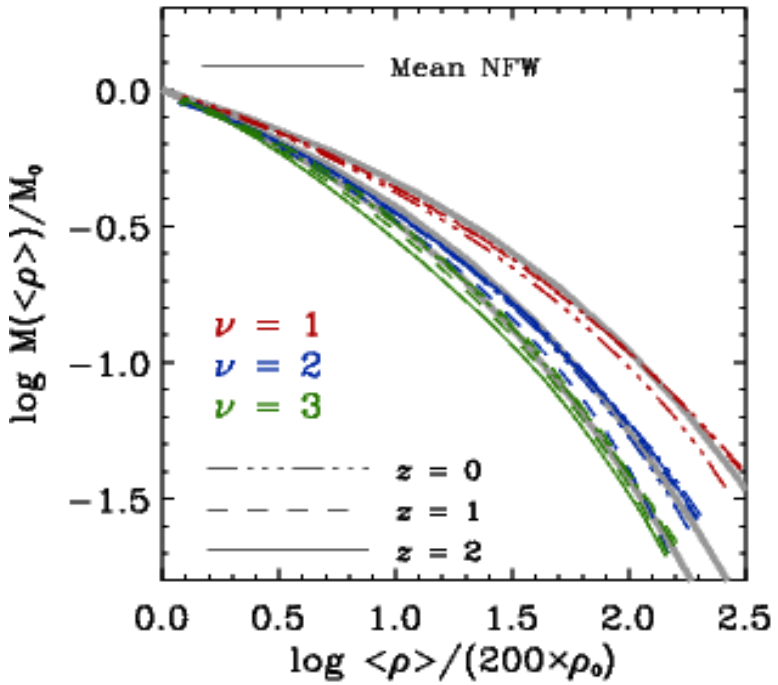


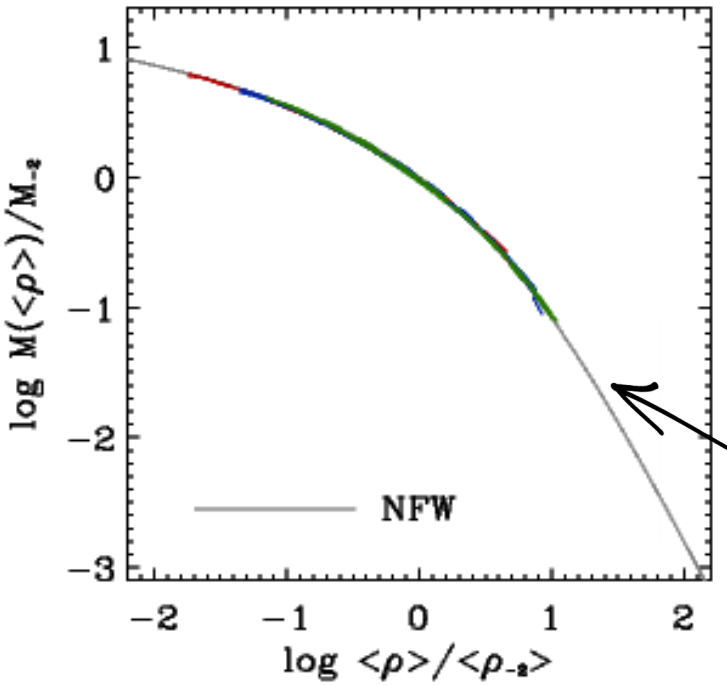
CDM: concentration-formation time relation

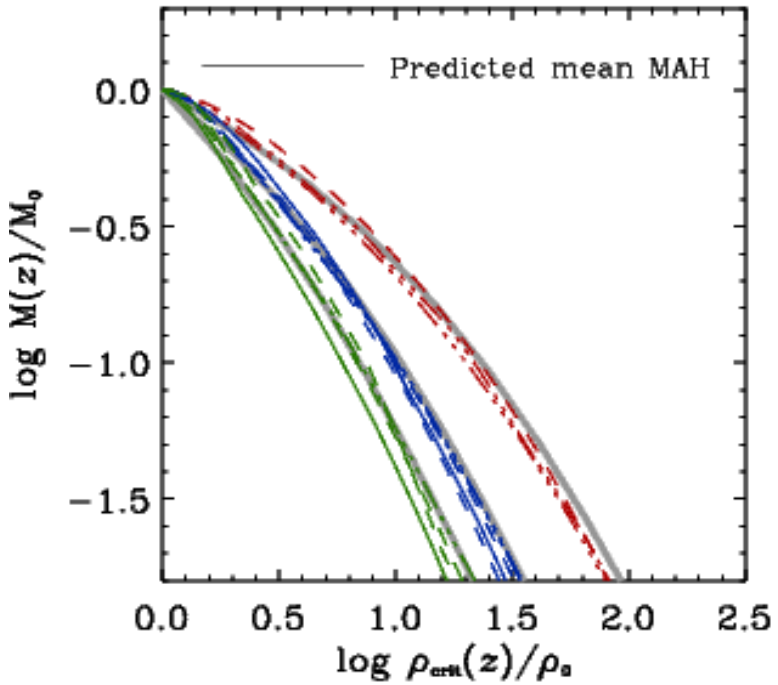


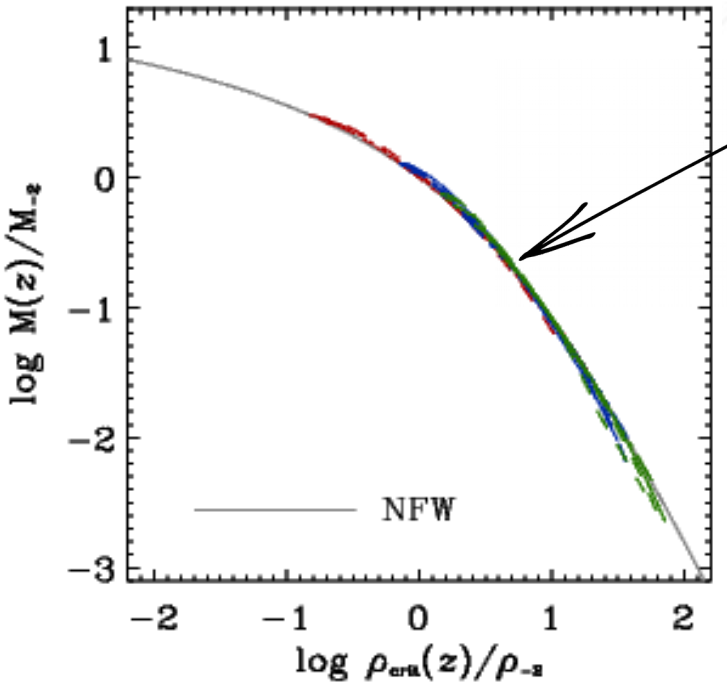
Accretion Histories can be mapped to mass profiles...





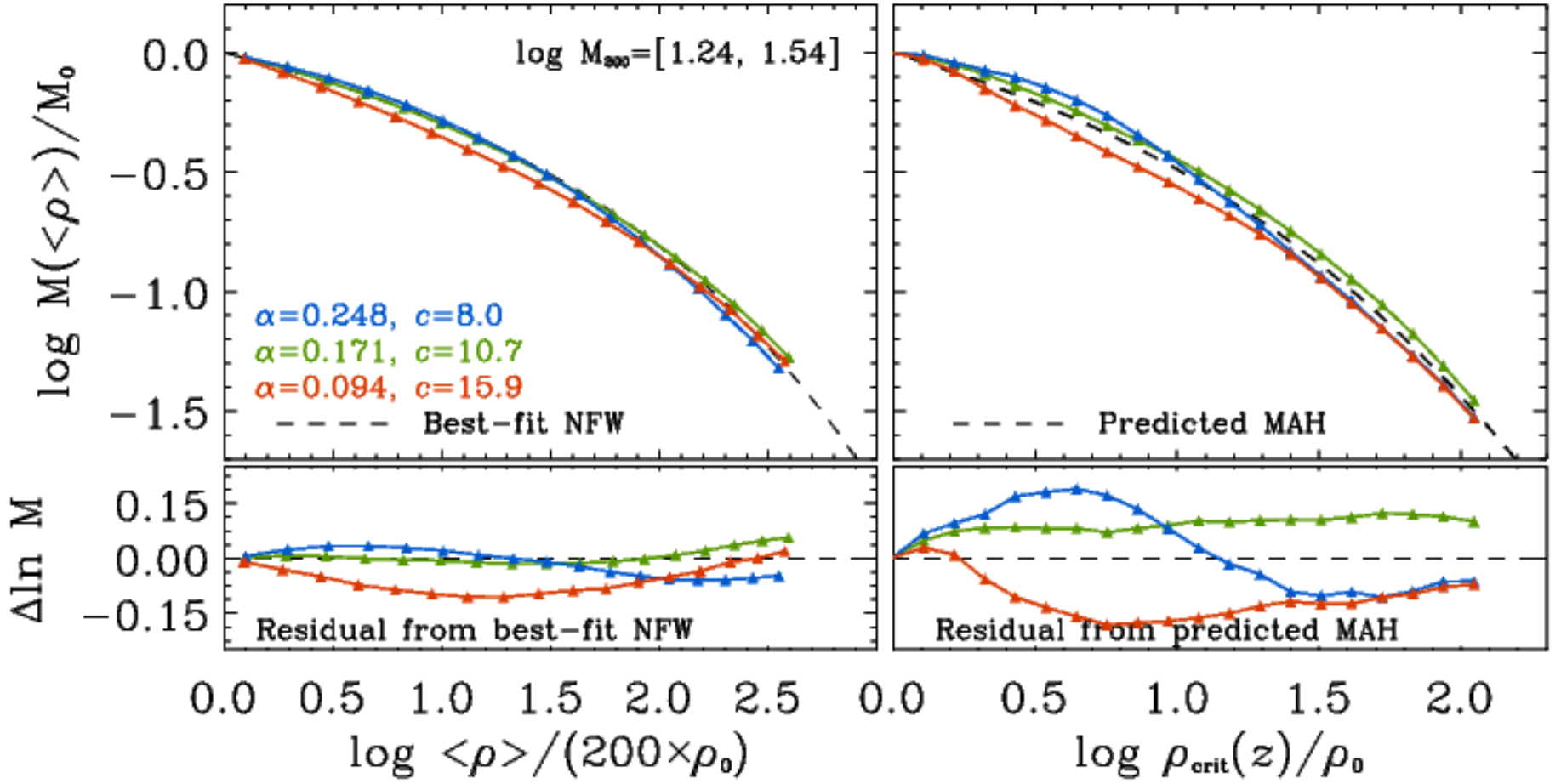






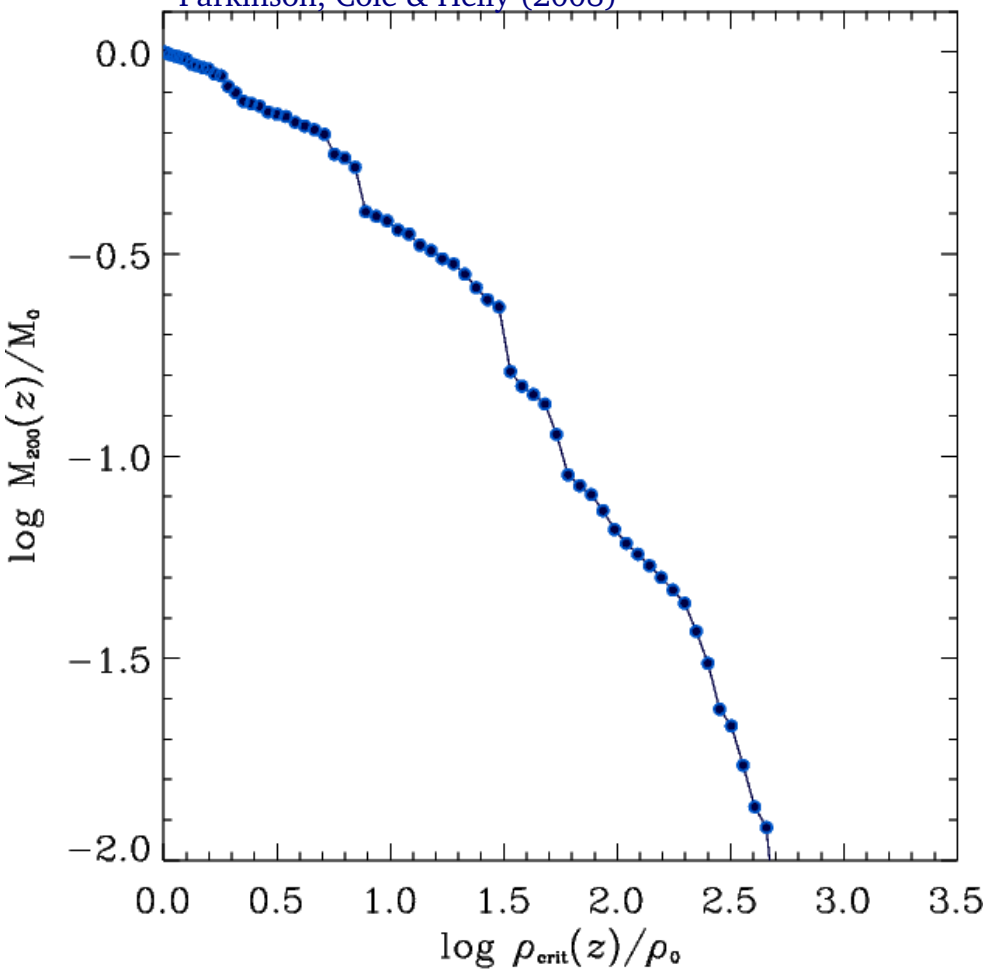
Universal NFW profile

Departure from universal NFW...



Predicting mass profiles in practice

Parkinson, Cole & Helly (2008)



Extended Press-Schechter formalism (Bond *et al* 1991, Bower 1991) predicts the conditional probability

$$P(M_1, z_1|M_0, z_0)\, dM_1$$

that a halo of mass M_0 at z_0 had a progenitor at $z_1 > z_0$ in the range

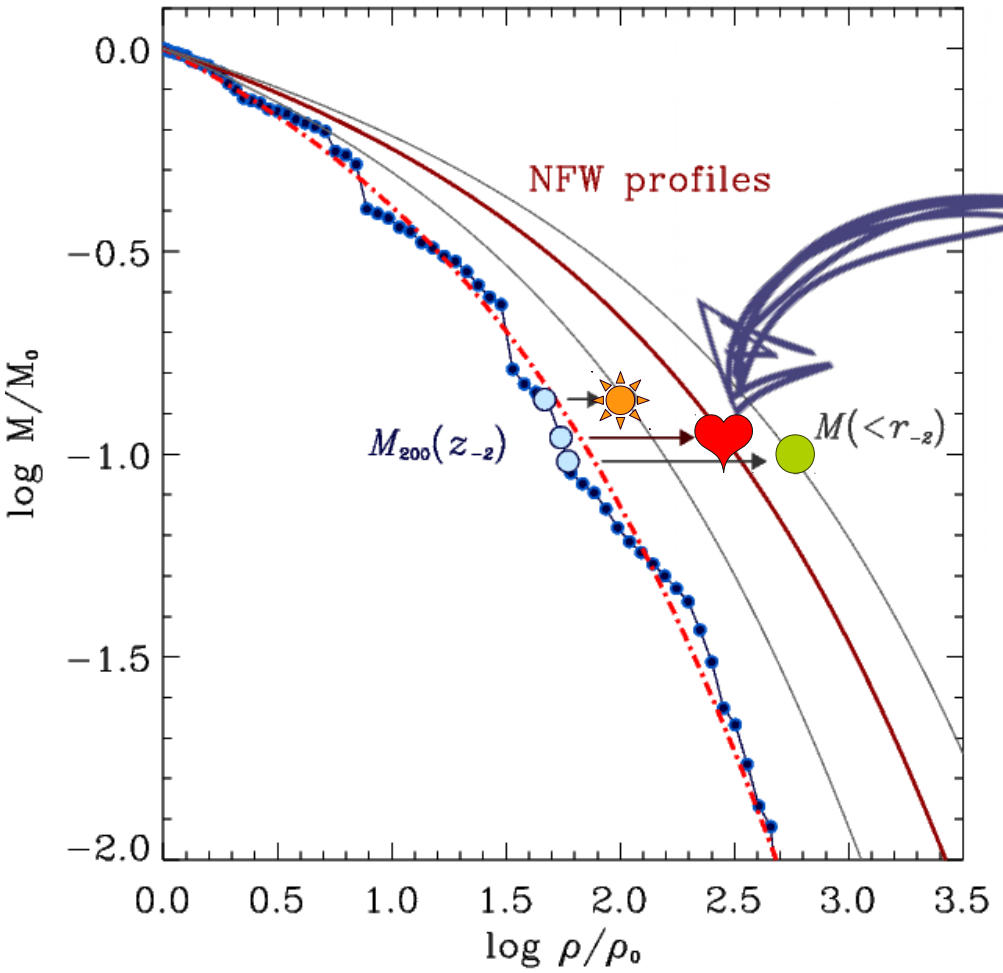
$$[M_1, M_1 + dM_1]$$

The "progenitor mass function" is the mass-weighted conditional probability

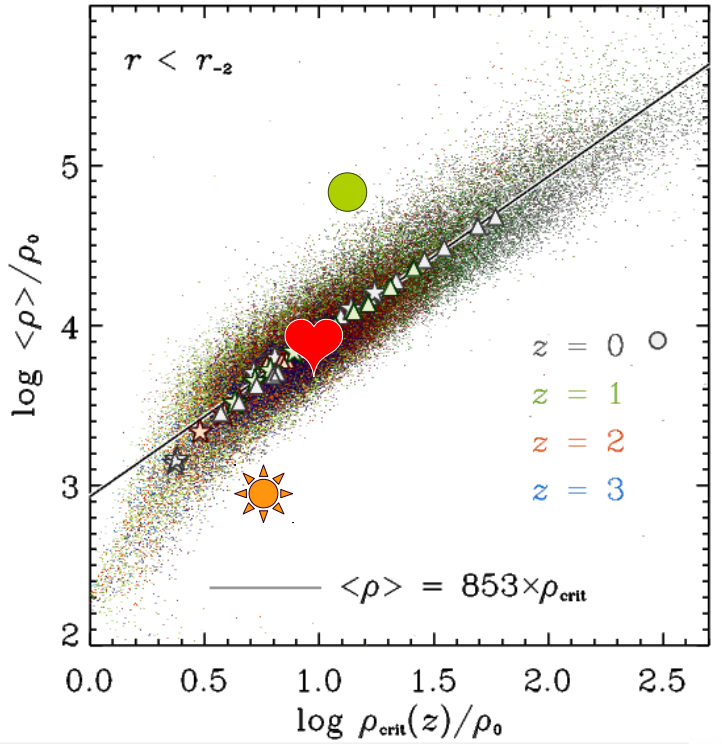
$$n(M_1, z_1|M_0, z_0)\, dM_1 = \frac{M_0}{M_1} P(M_1, z_1|M_0, z_0)\, dM_1$$

Predicting mass profiles in practice

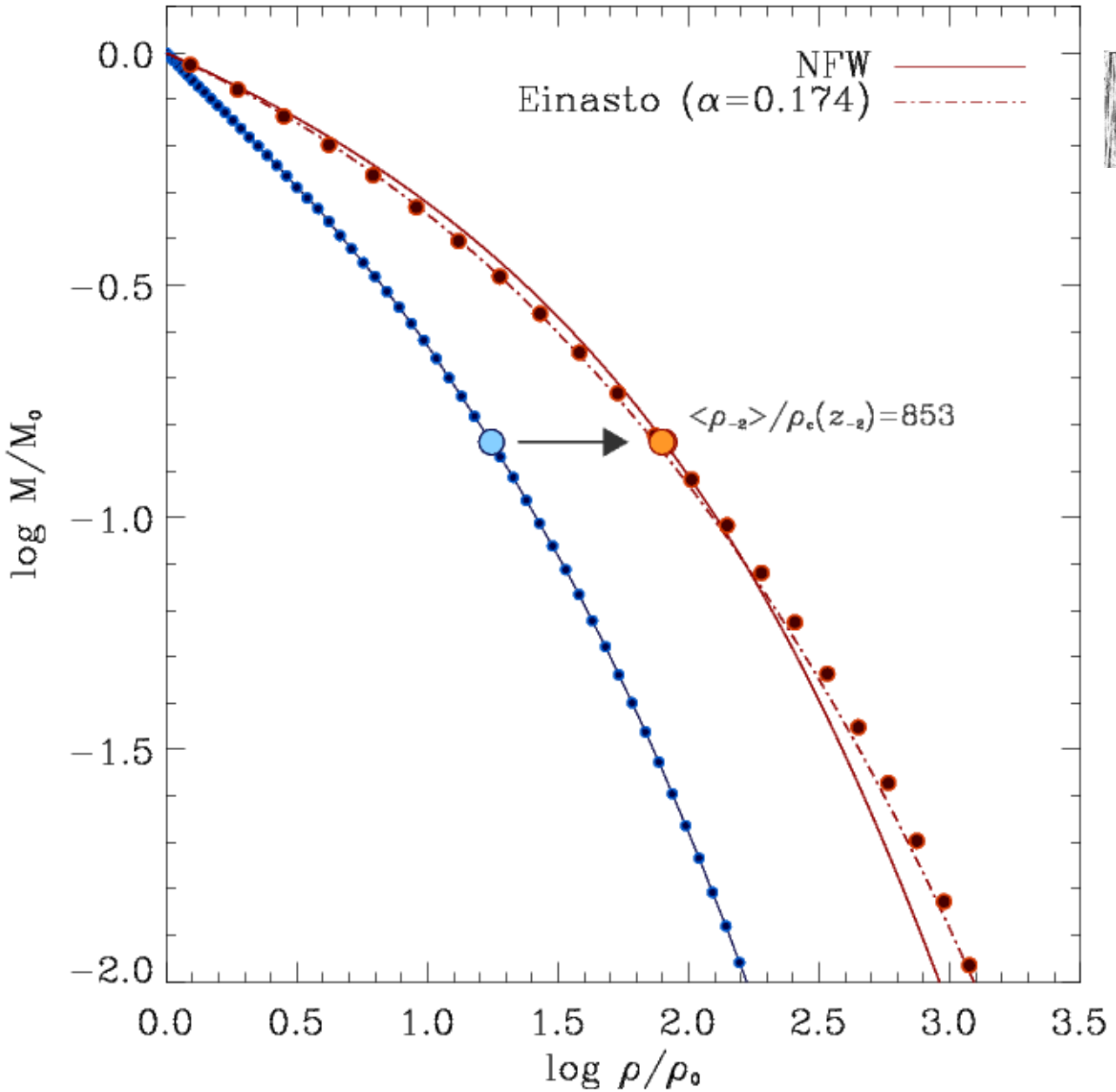
Parkinson, Cole & Helly (2008)



$$\langle \rho(r_{-2}) \rangle = 853 \times \rho_{\rm crit}(z_{-2})$$

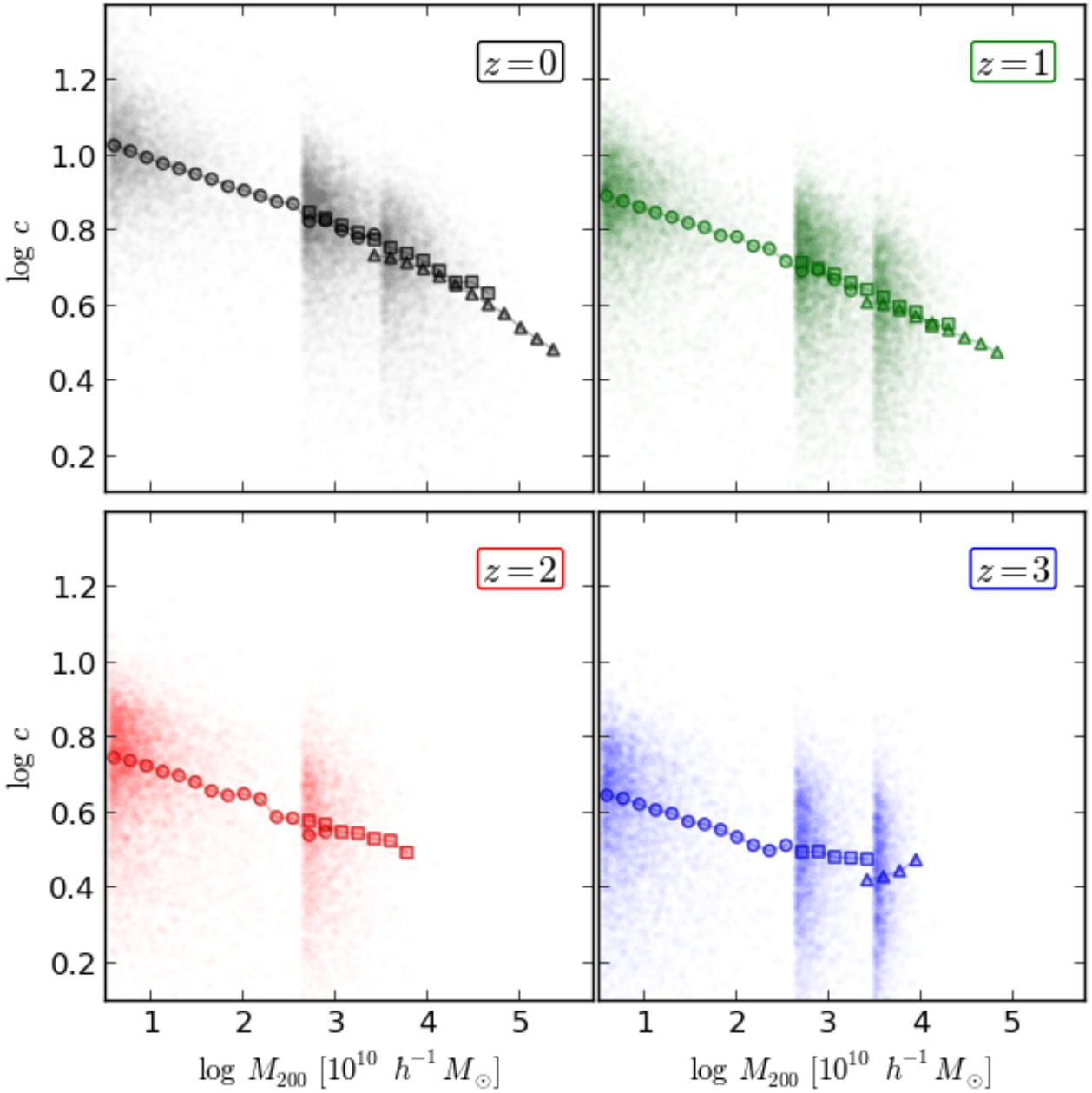


Predicting mass profiles in practice

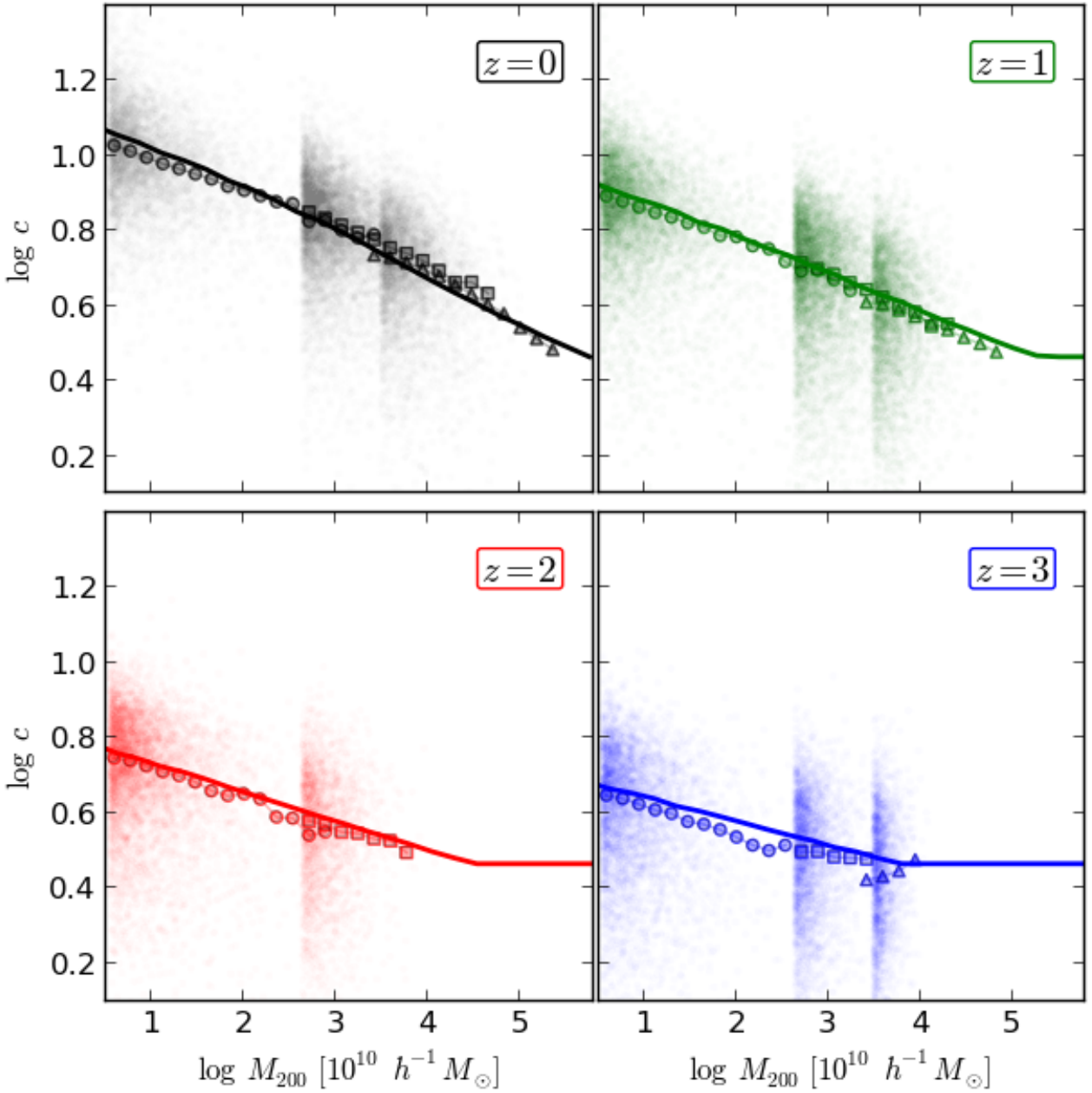


$\sim 10^{10}\, h^{-1} M_\odot$

A simple model for the c(M,z) relation



A simple model for the c(M,z) relation



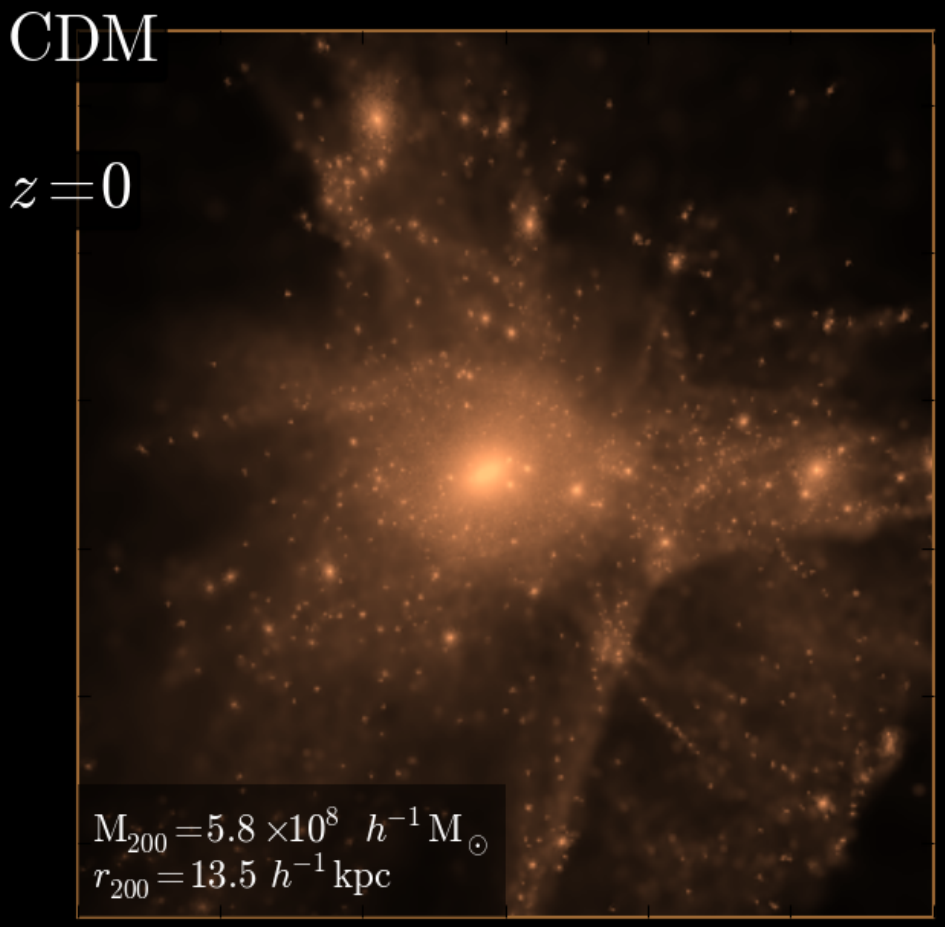
CDM summary...

- CDM mass profiles and mass accretion histories are self-similar:
- Both follow an NFW profile and are linked by a simple scaling law:

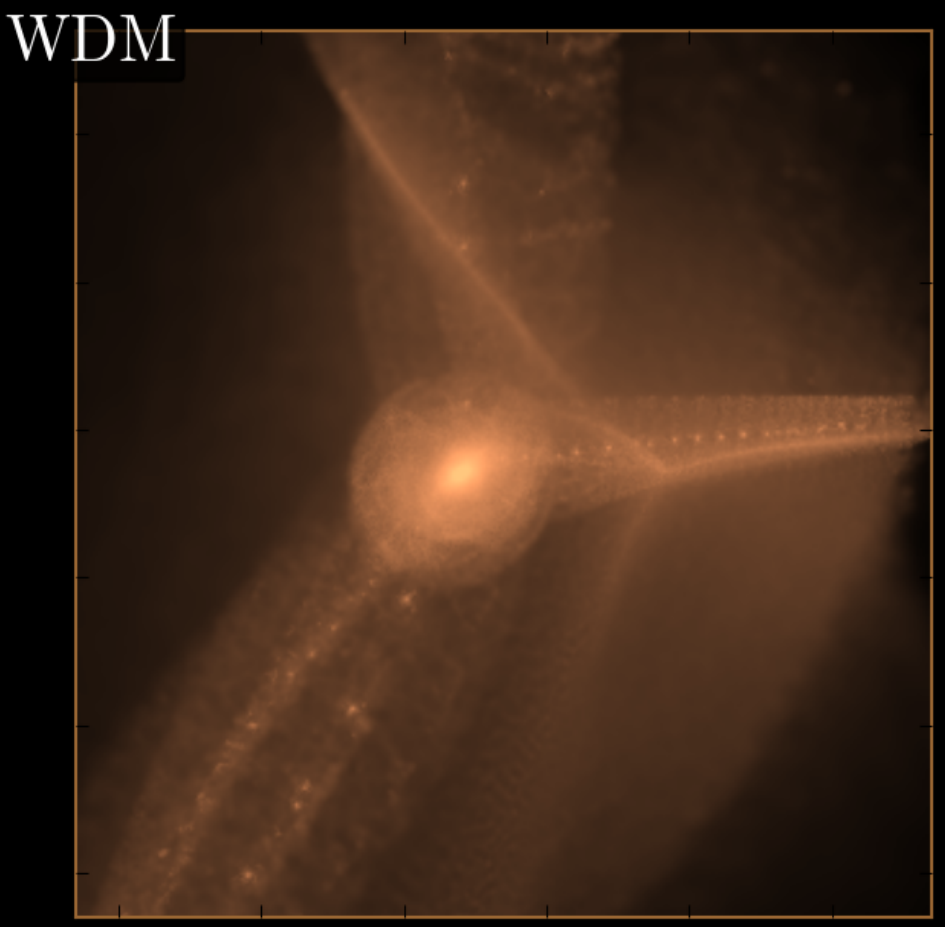
$$\langle \rho(< r_{-2}) \rangle \approx 853 \times \rho_{\rm crit}(z_{-2})$$

- This allows halo concentrations to be predicted from MAHs alone
- Mass accretion histories that depart from the self-similar form give rise to mass profiles that depart from NFW in a correlated way giving rise to a third structural parameter

What about Warm DM...

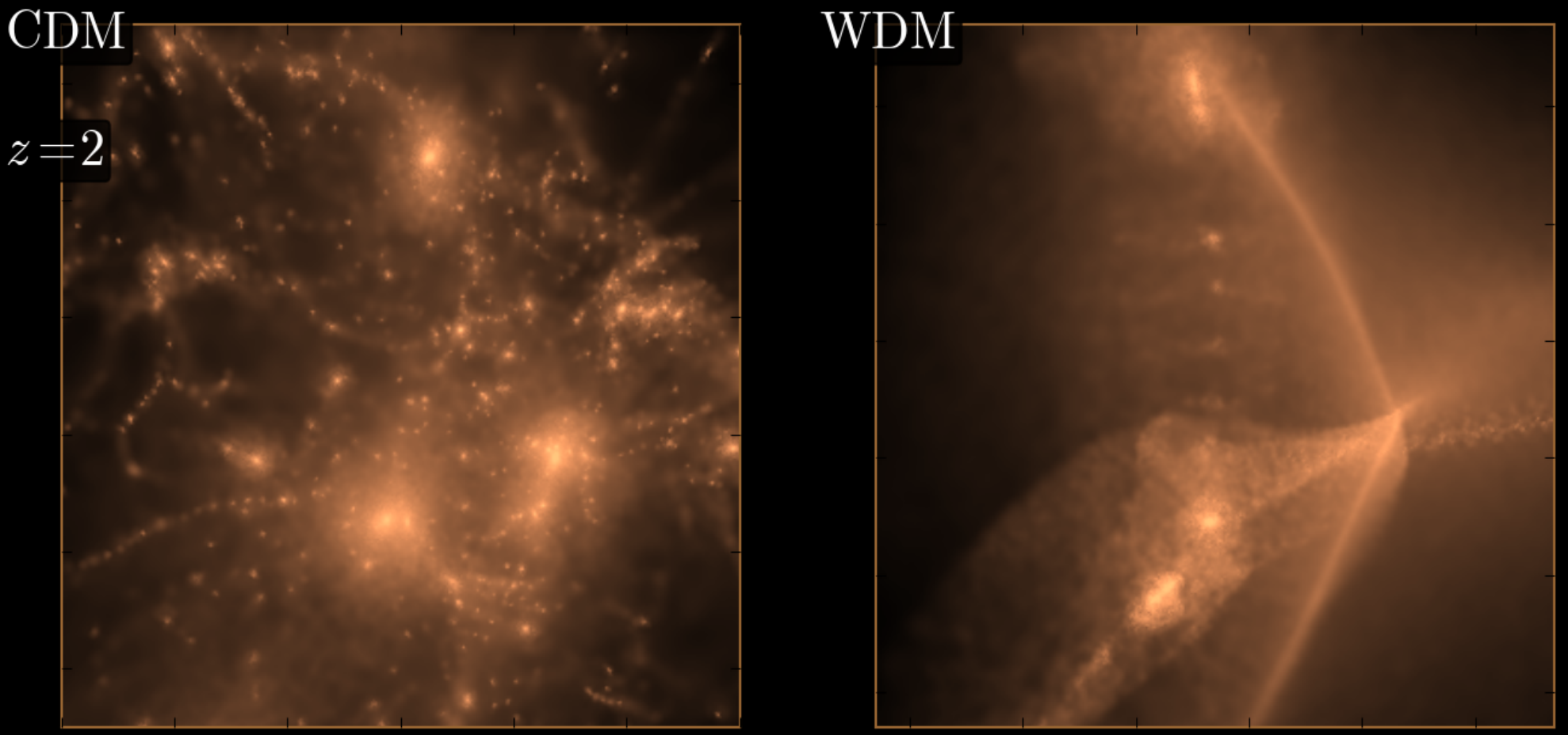


Clumpy



Smooth

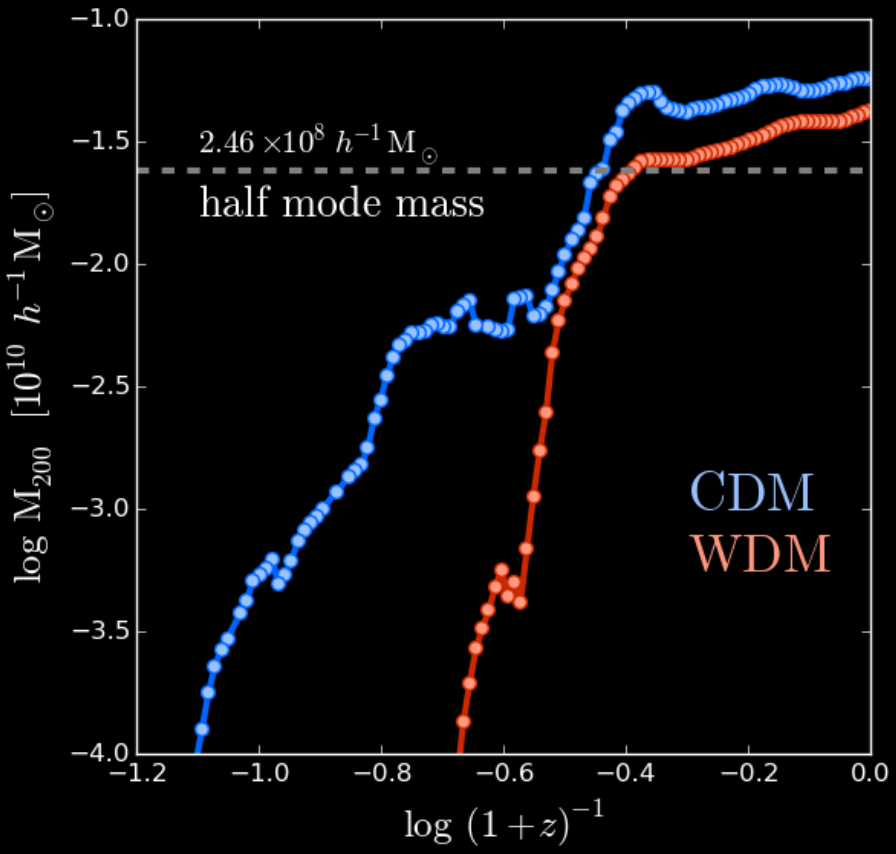
What about Warm DM...

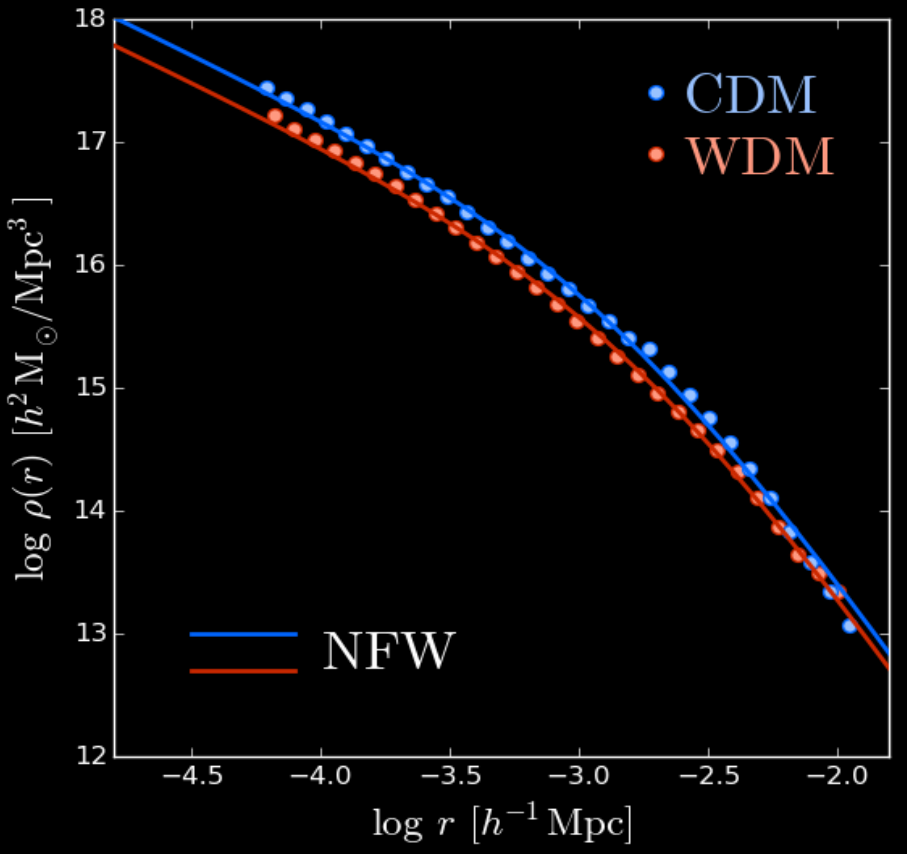


Clumpy

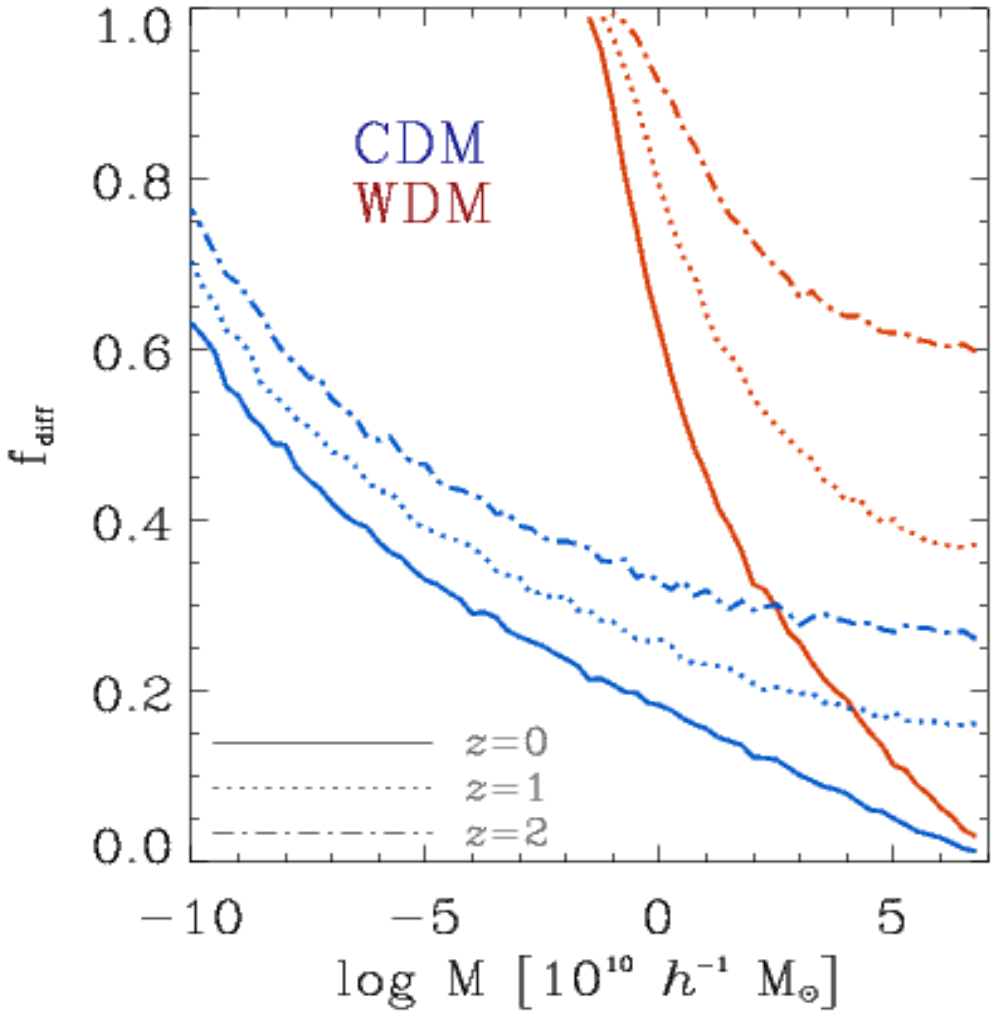
Smooth

What about Warm DM...

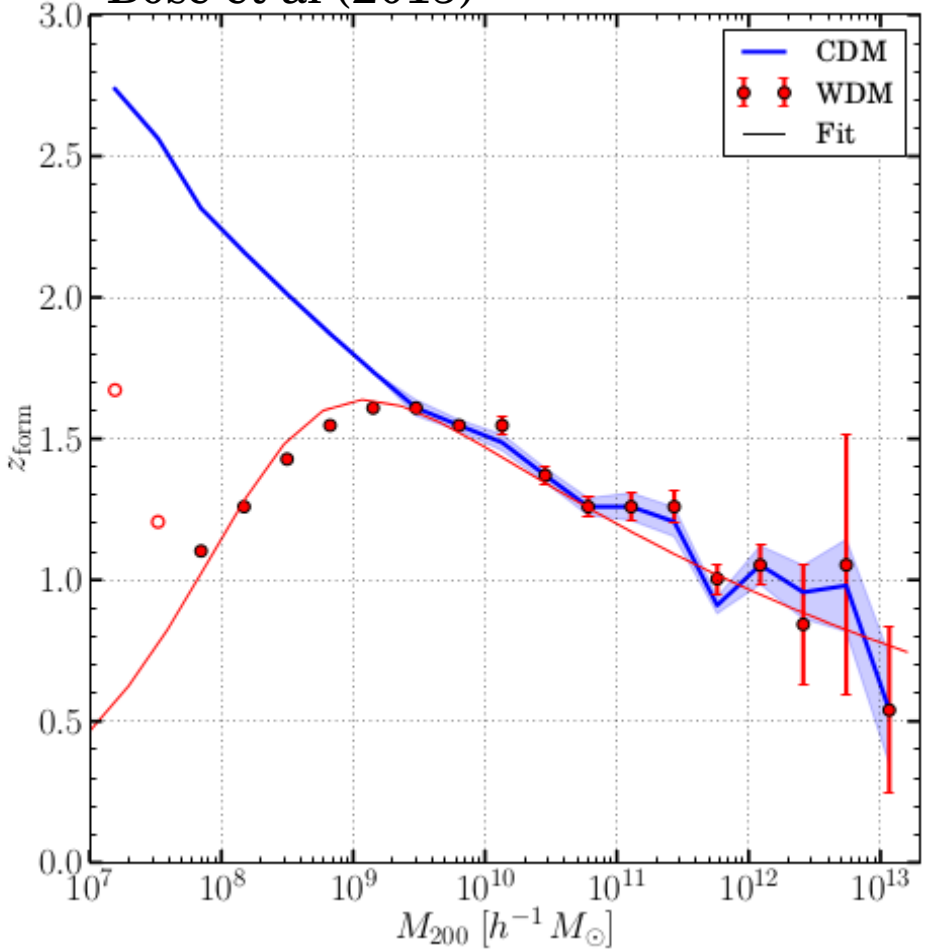




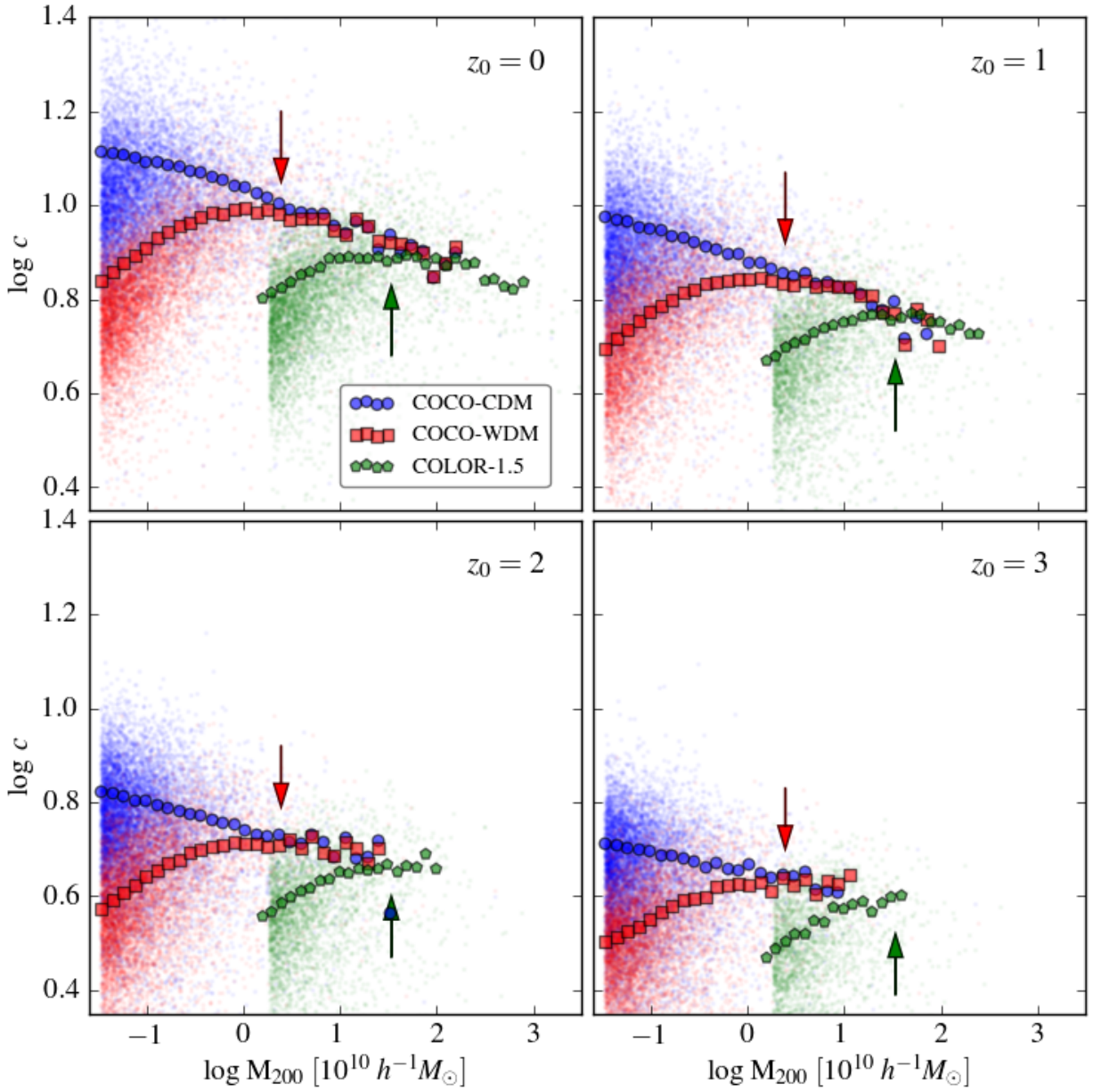
Diffuse versus clumpy accretion



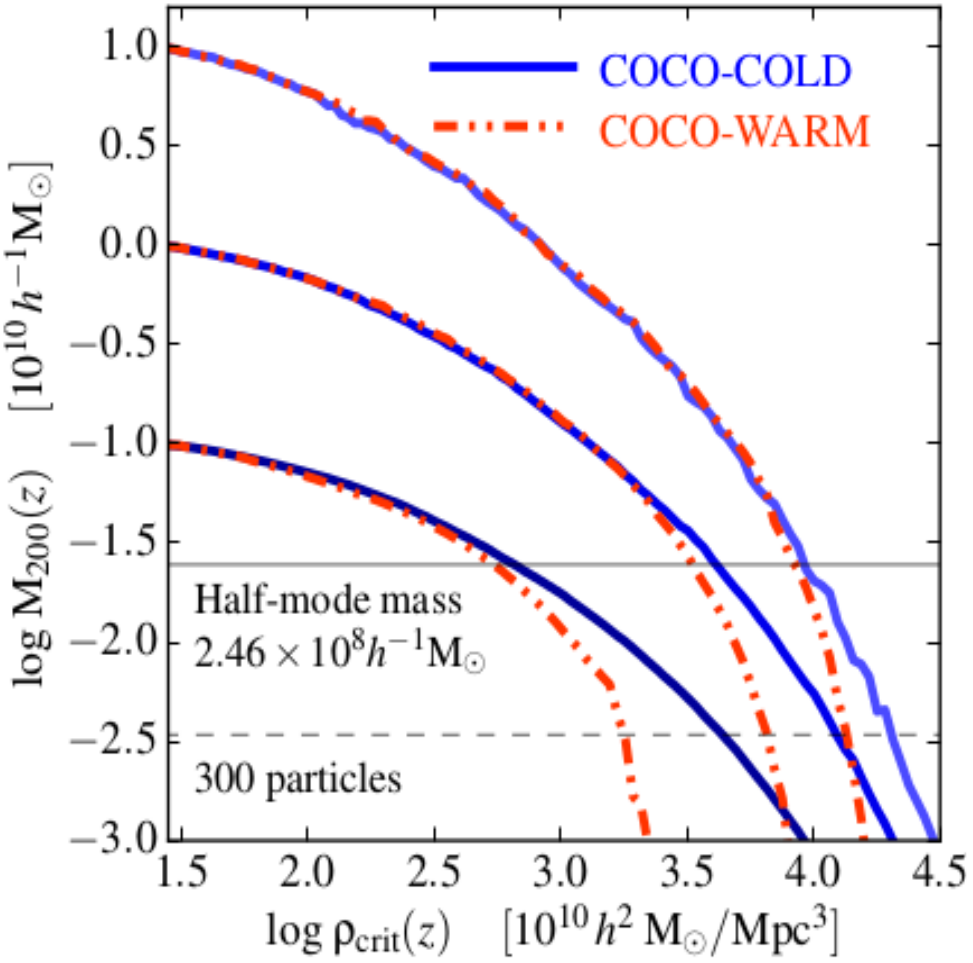
Bose et al (2015)



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

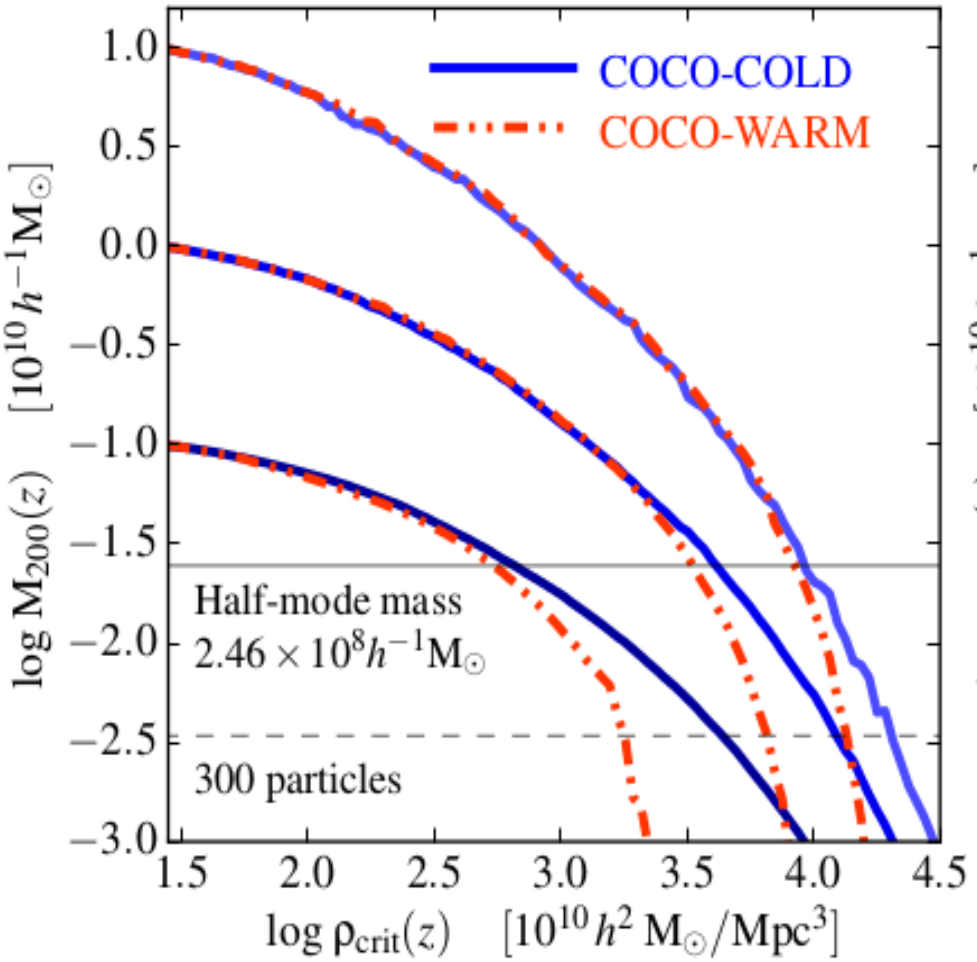


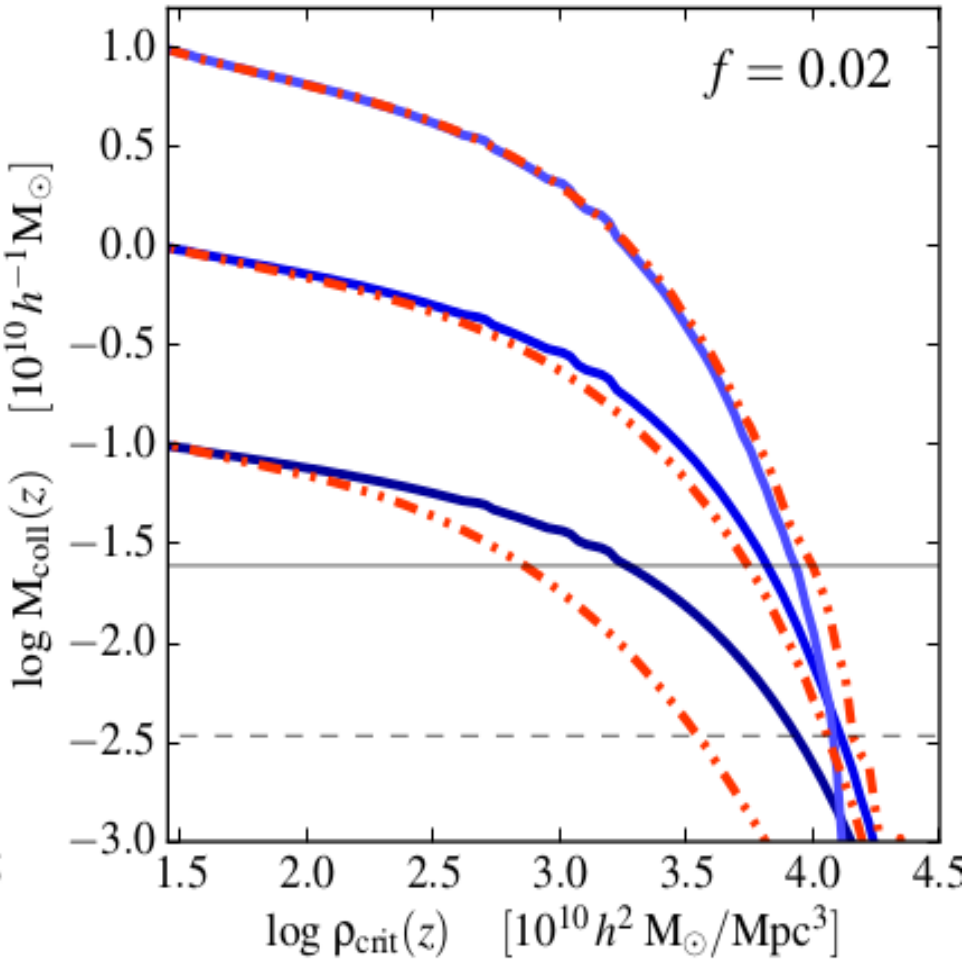
Mass accretion histories of WDM halos



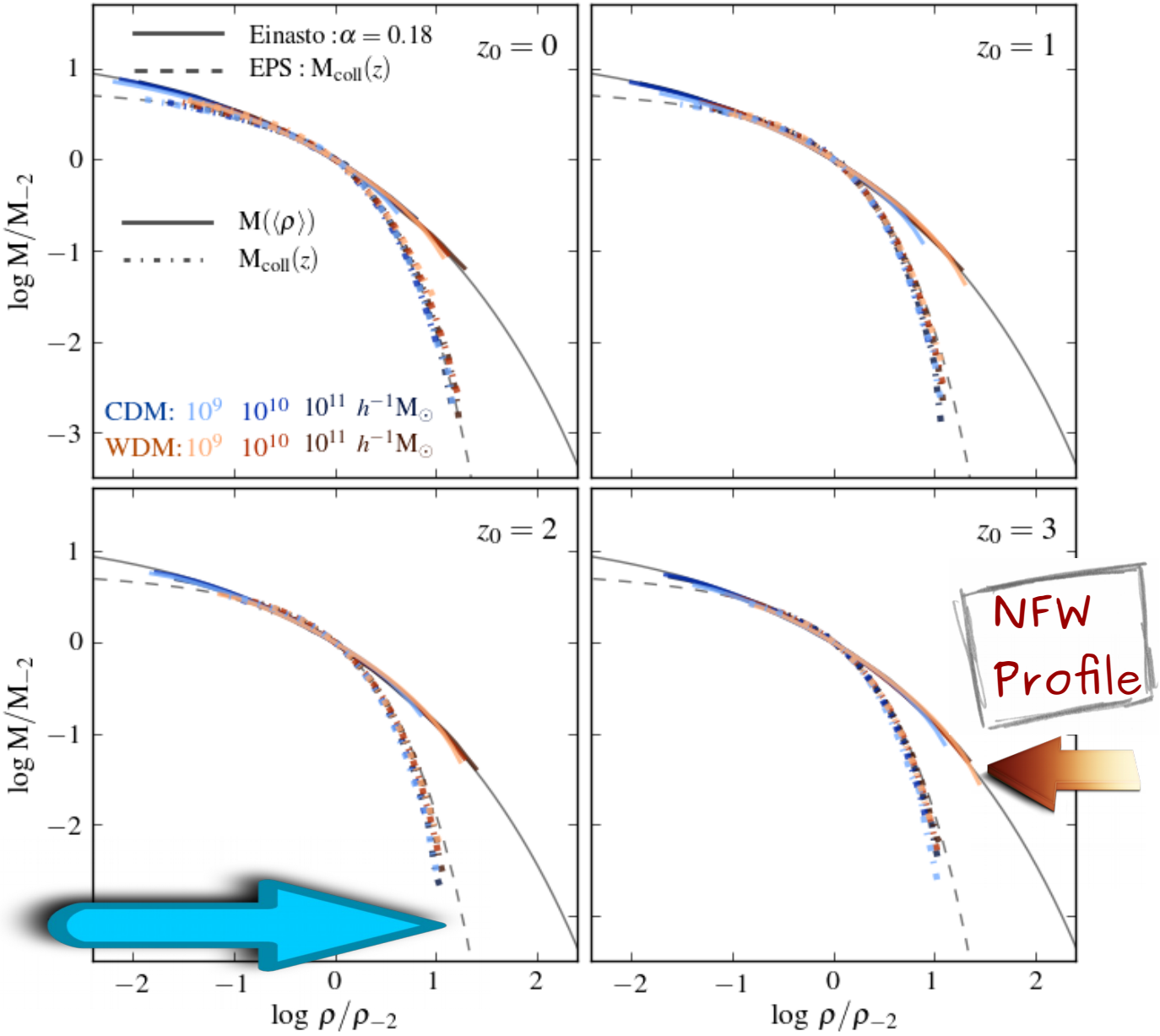
Mass accretion histories of WDM halos

$$\frac{\mathrm{M_{coll}}(z)}{\mathrm{M_0}} = \mathrm{erfc}\left(\frac{\delta_{sc}(z_{\mathrm{coll}}) - \delta_{sc}(z_0)}{\sqrt{2[\sigma^2(f\ \mathrm{M_0}) - \sigma^2(\mathrm{M_0})]}}\right)$$



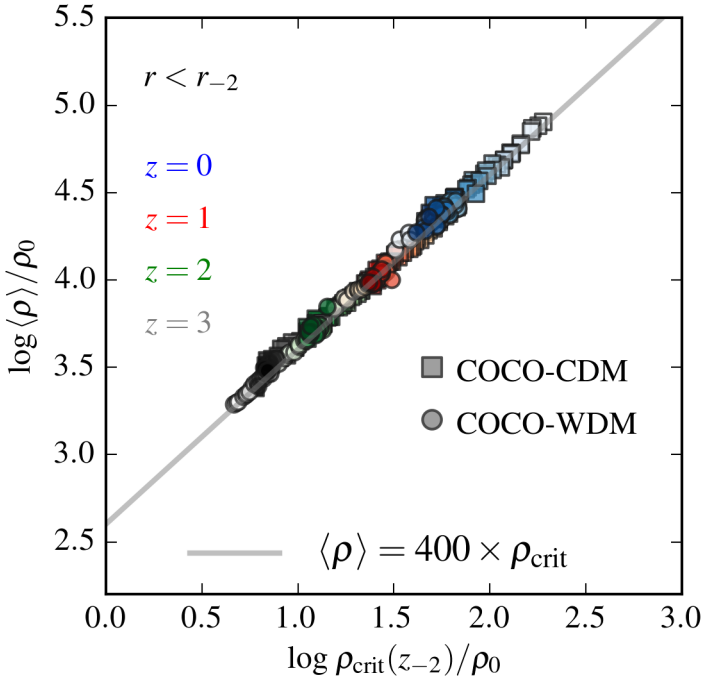


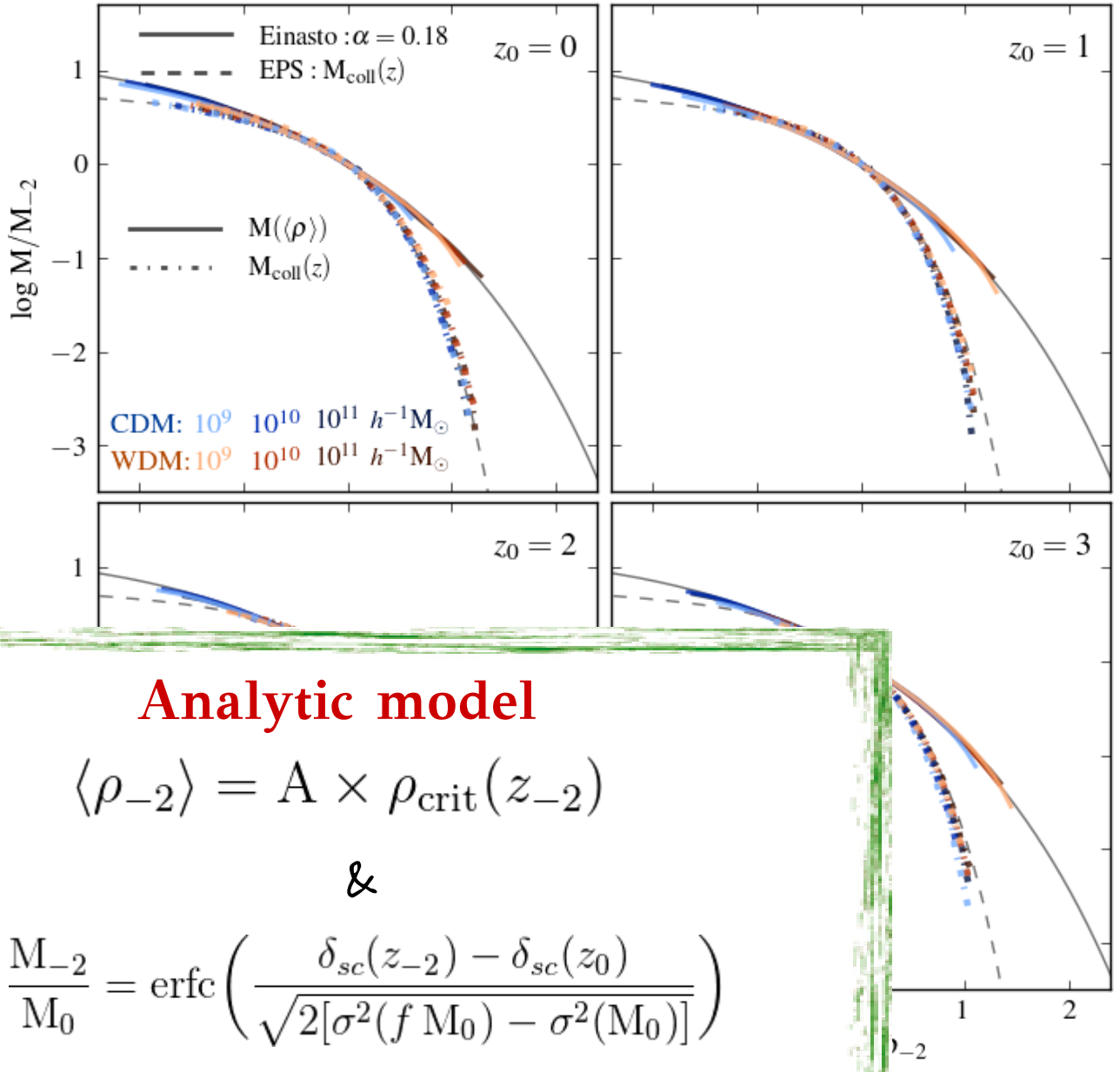
Mass accretion histories of CDM & WDM halos



$$\frac{M_{coll}(z)}{M_0} = \mathrm{erfc}\left(\frac{\delta_{sc}(z_{coll}) - \delta_{sc}(z_0)}{\sqrt{2[\sigma^2(f\,M_0) - \sigma^2(M_0)]}}\right)$$

Mass accretion histories of CDM & WDM halos





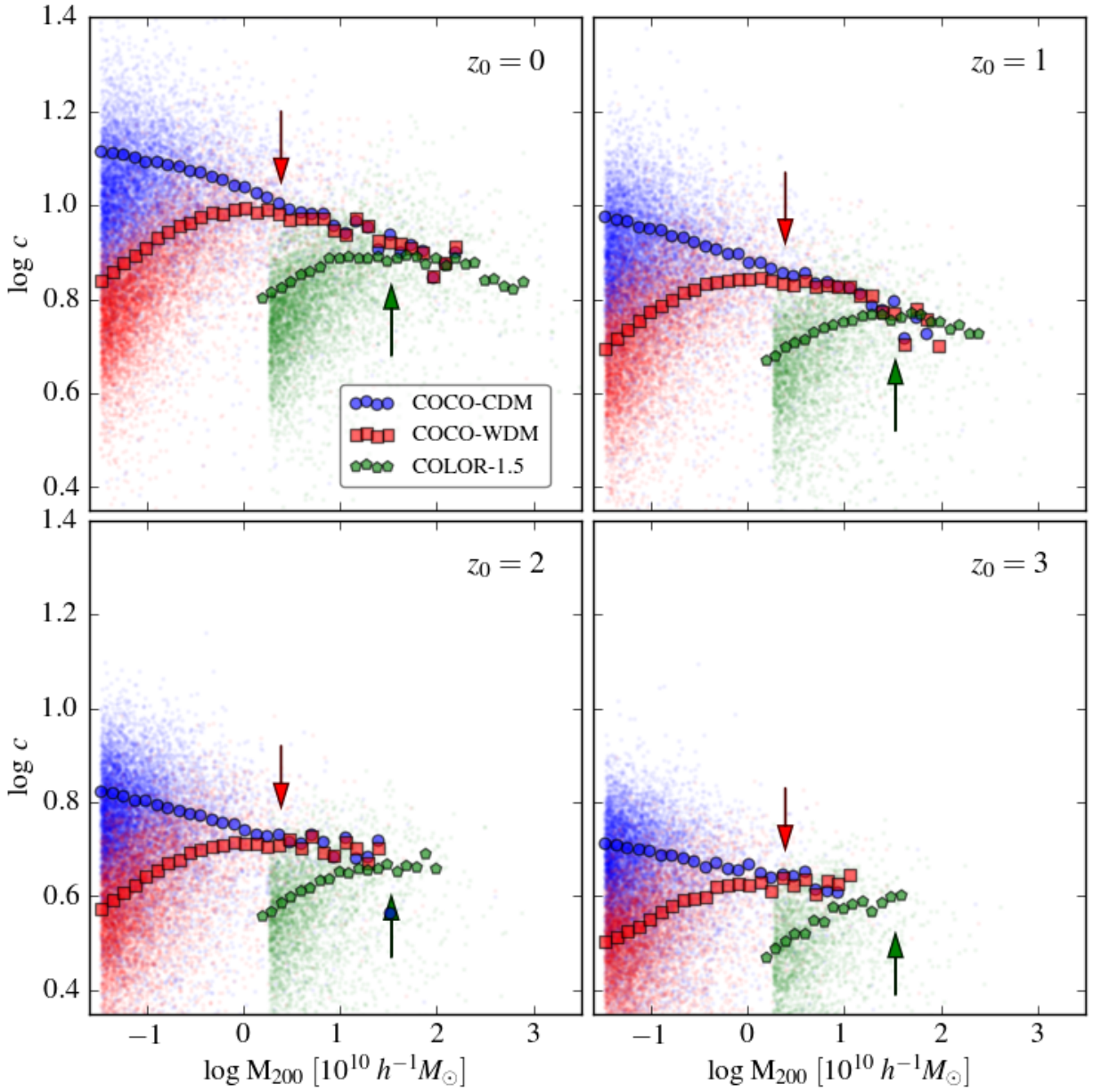
Analytic model

$$\langle\rho_{-2}\rangle = \mathrm{A} \times \rho_{\rm crit}(z_{-2})$$

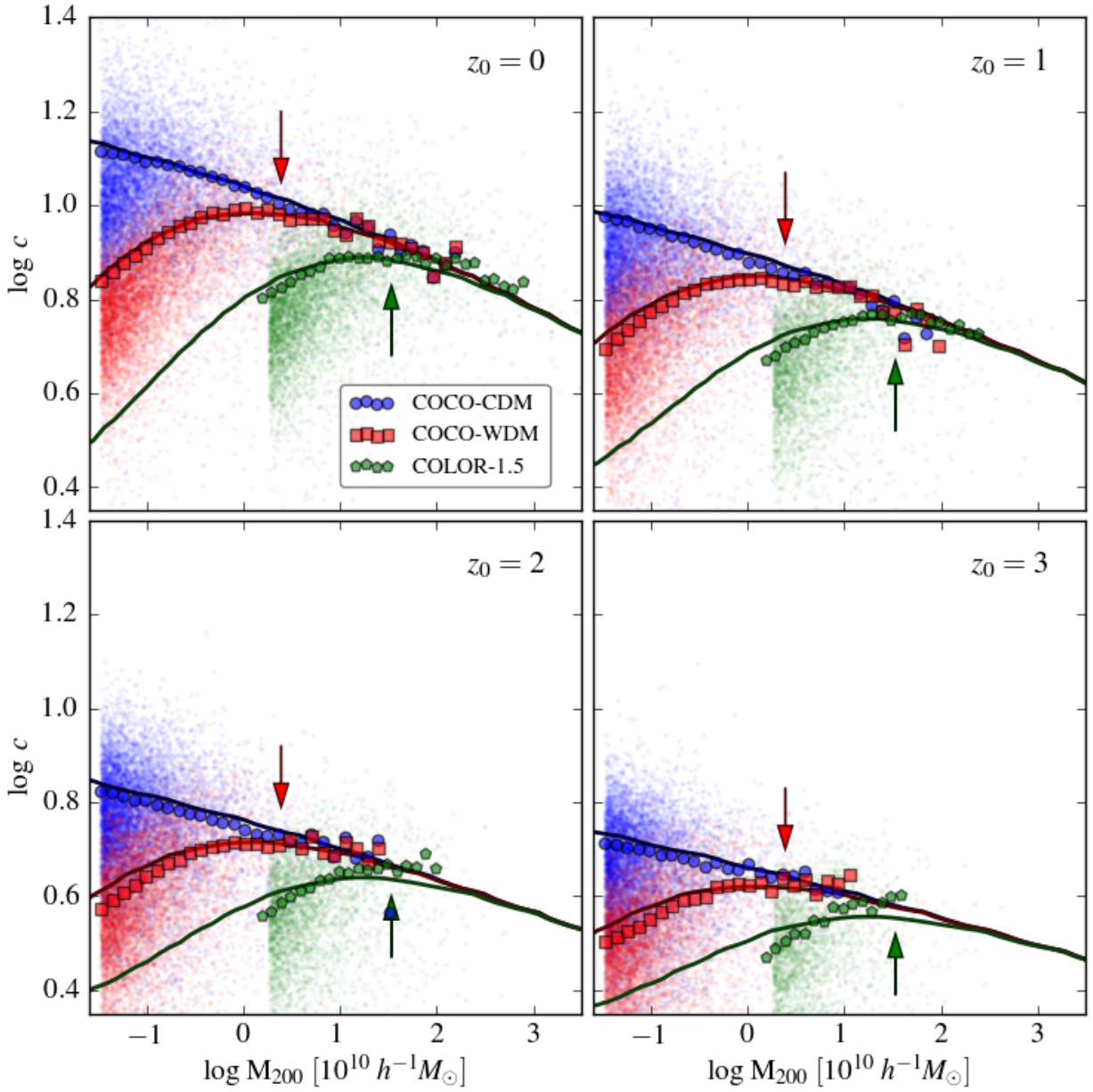
&

$$\frac{\mathrm{M}_{-2}}{\mathrm{M}_0} = \mathrm{erfc}\left(\frac{\delta_{sc}(z_{-2}) - \delta_{sc}(z_0)}{\sqrt{2[\sigma^2(f\,\mathrm{M}_0) - \sigma^2(\mathrm{M}_0)]}}\right)$$

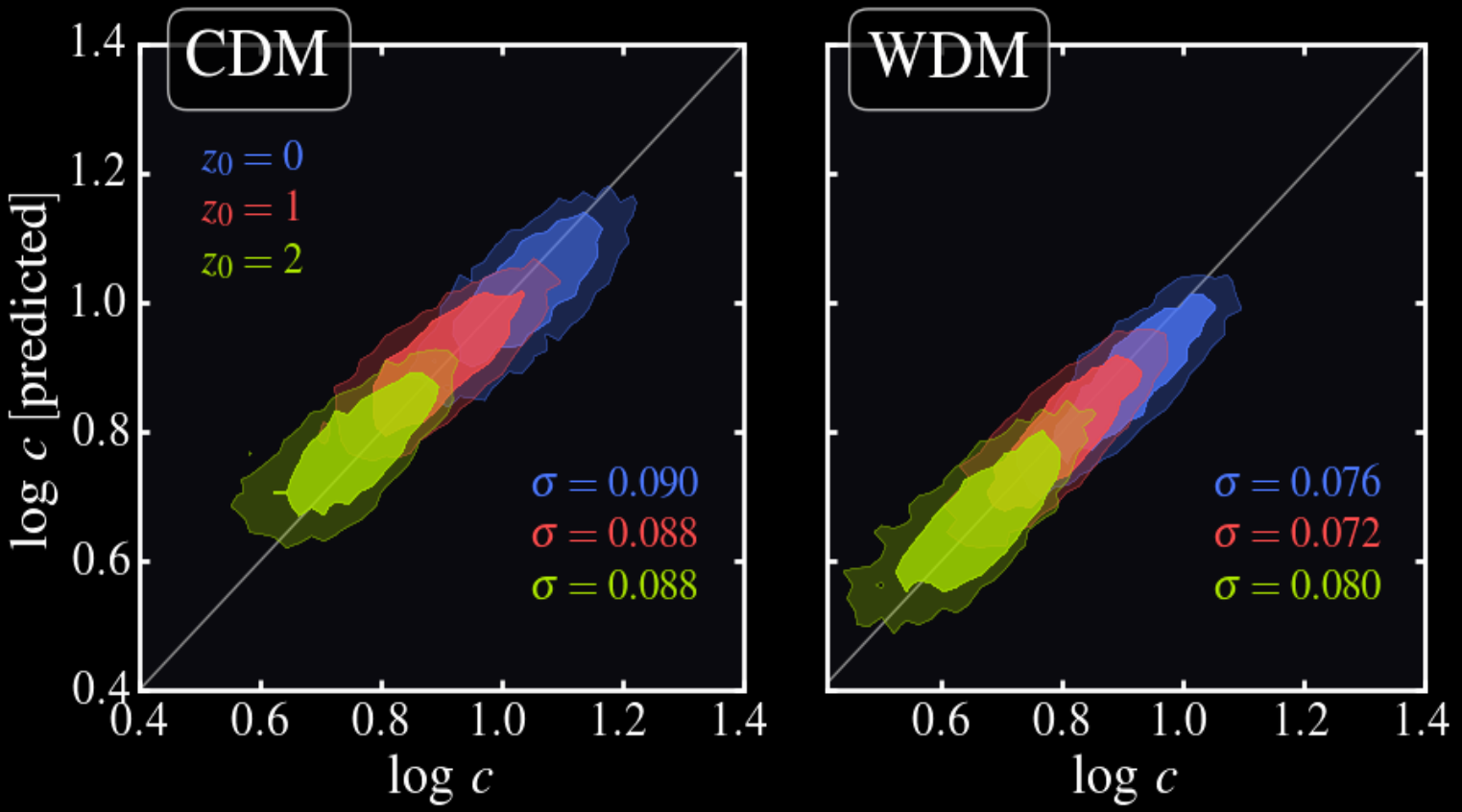
WDM halos: the $c(M,z)$ relation



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



Works for individual halos...

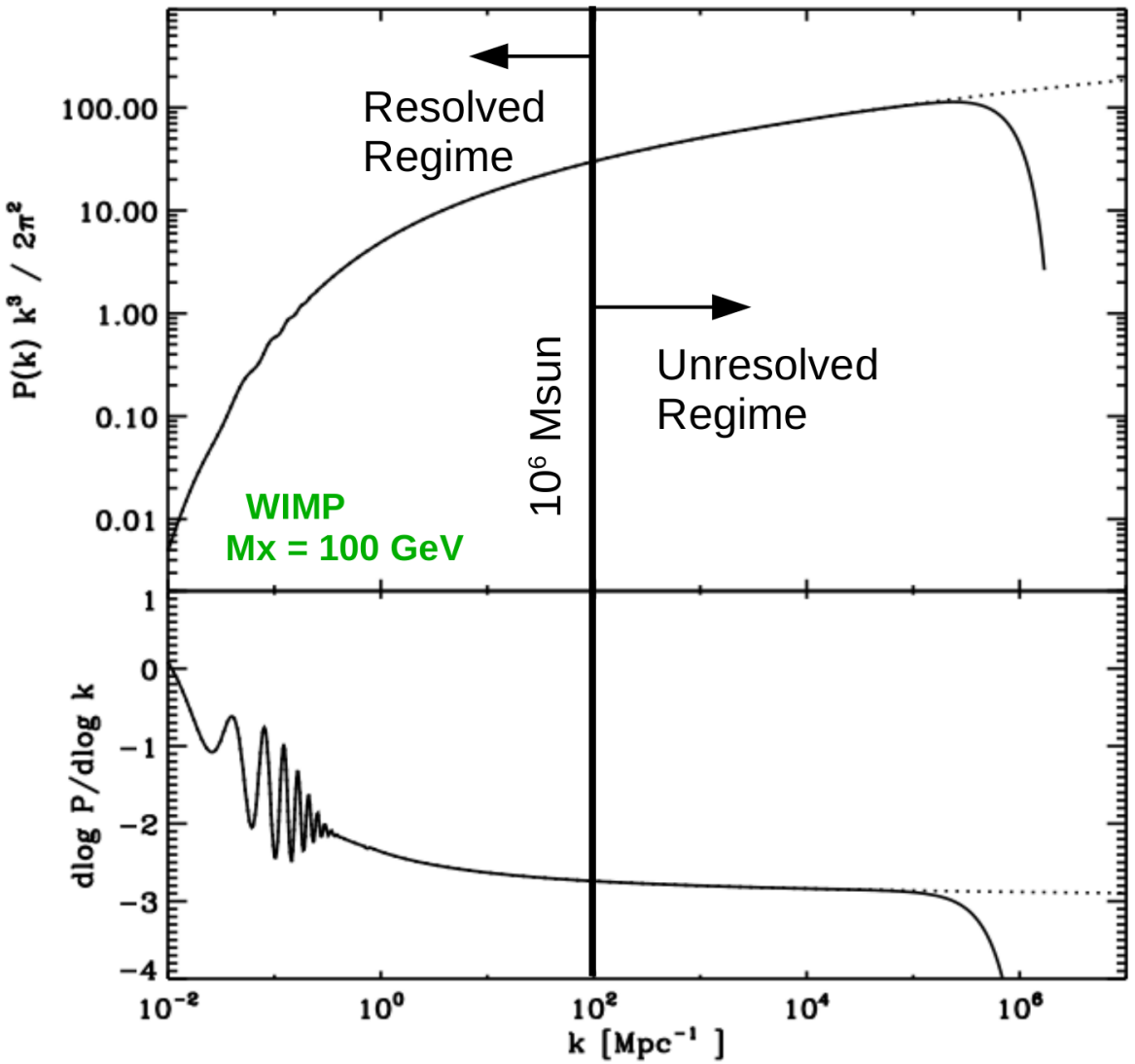


Individual halo concentrations predicted within ~20%

Structure formation for neutralino DM

A simulation of the full DM hierarchy might require 10^{21} particles

14 orders of magnitude in mass



Slides from Raul Angulo (Based on Angulo, Hahn, Ludlow & Bonoli, 2017)

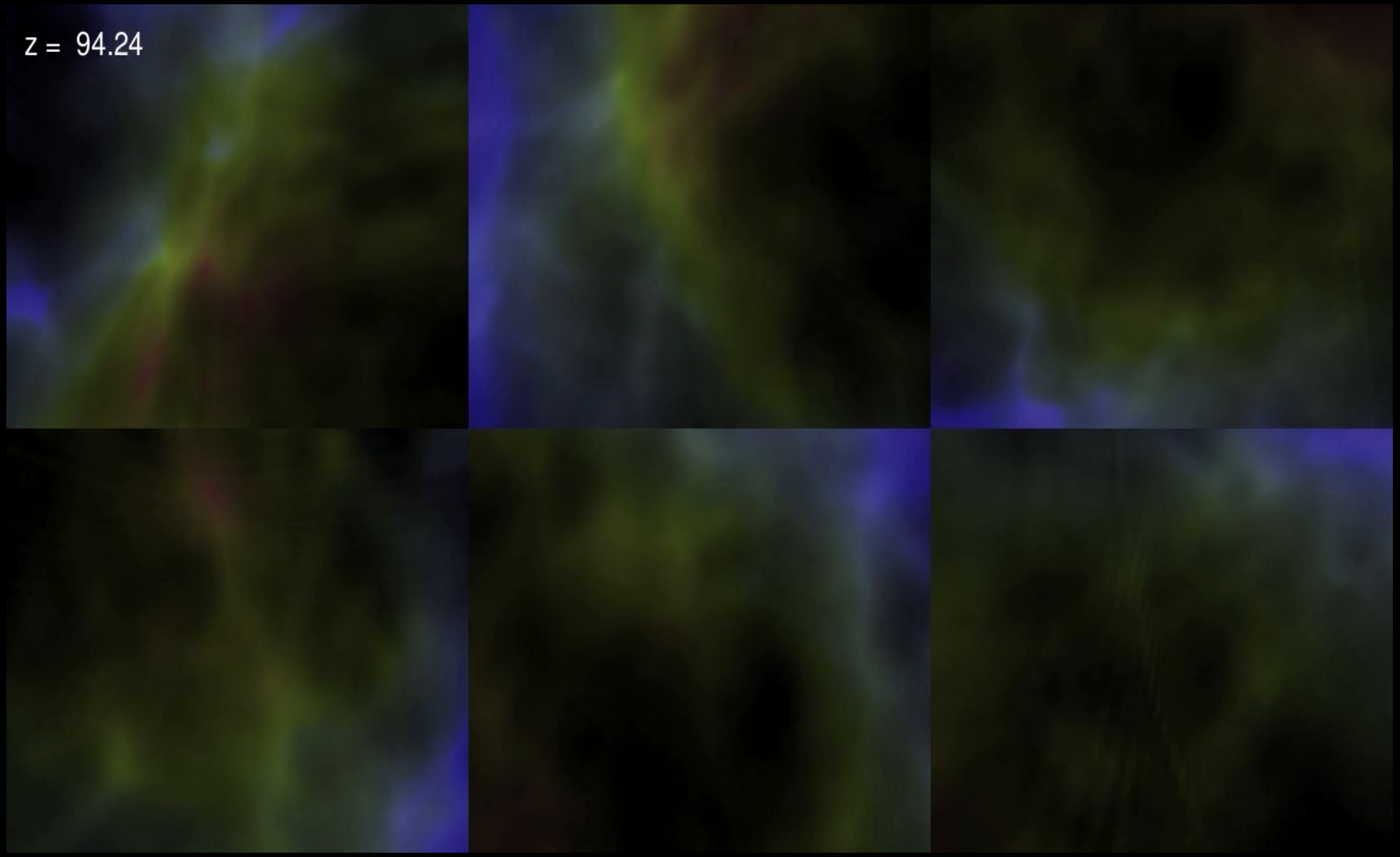
Collapse times scale like...

$$\sigma^2 \propto \int k^2 P(k) dk$$

$$= \int k^{2-n} dk \propto k^{3-n}$$

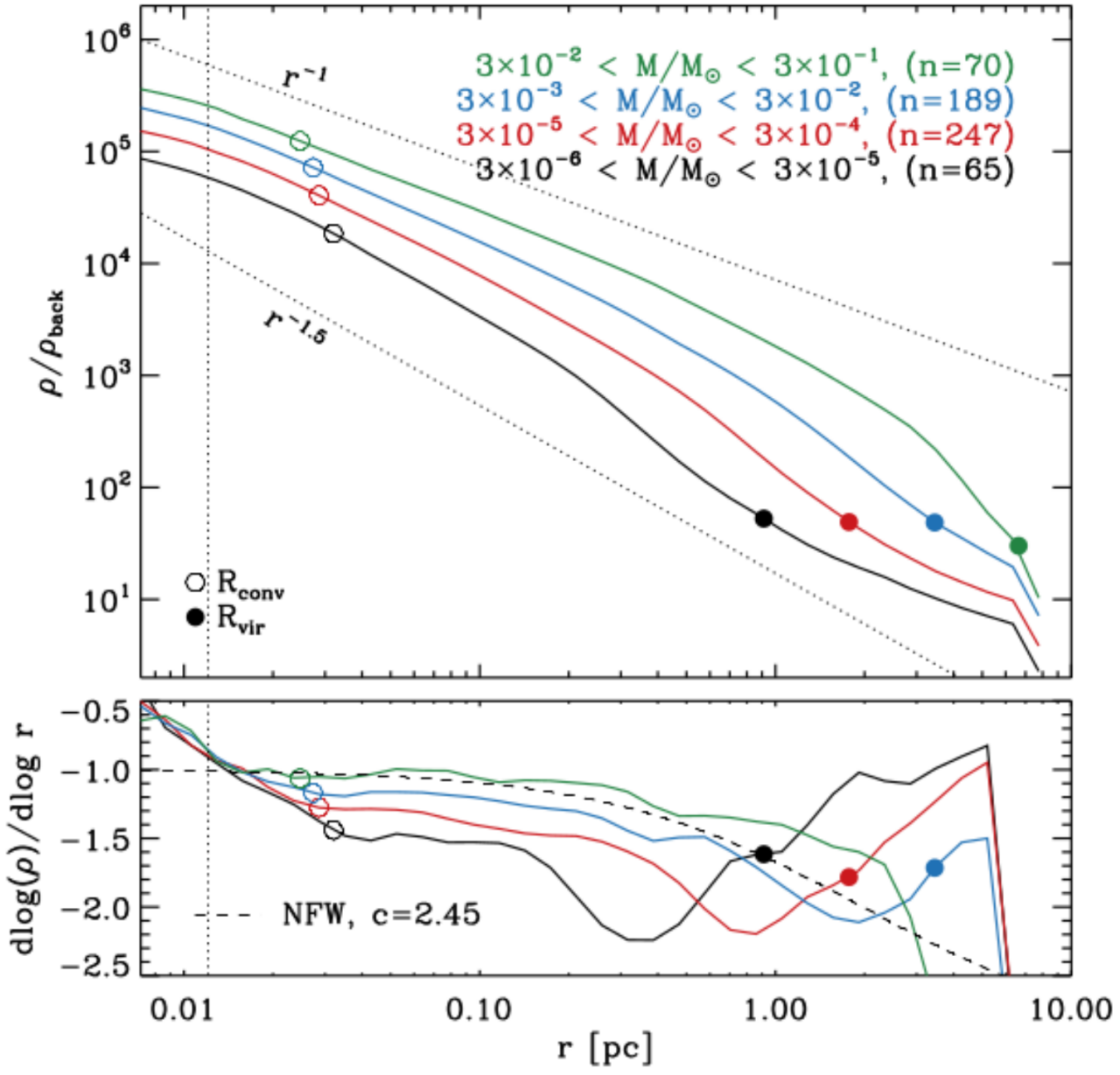
Lowest masses in CDM have $n \sim 3$…

⇒ all strucure collapses at once



Structure formation at the free streaming mass

The density profile of microhalos is steeper than a NFW



Structure formation at the free streaming mass

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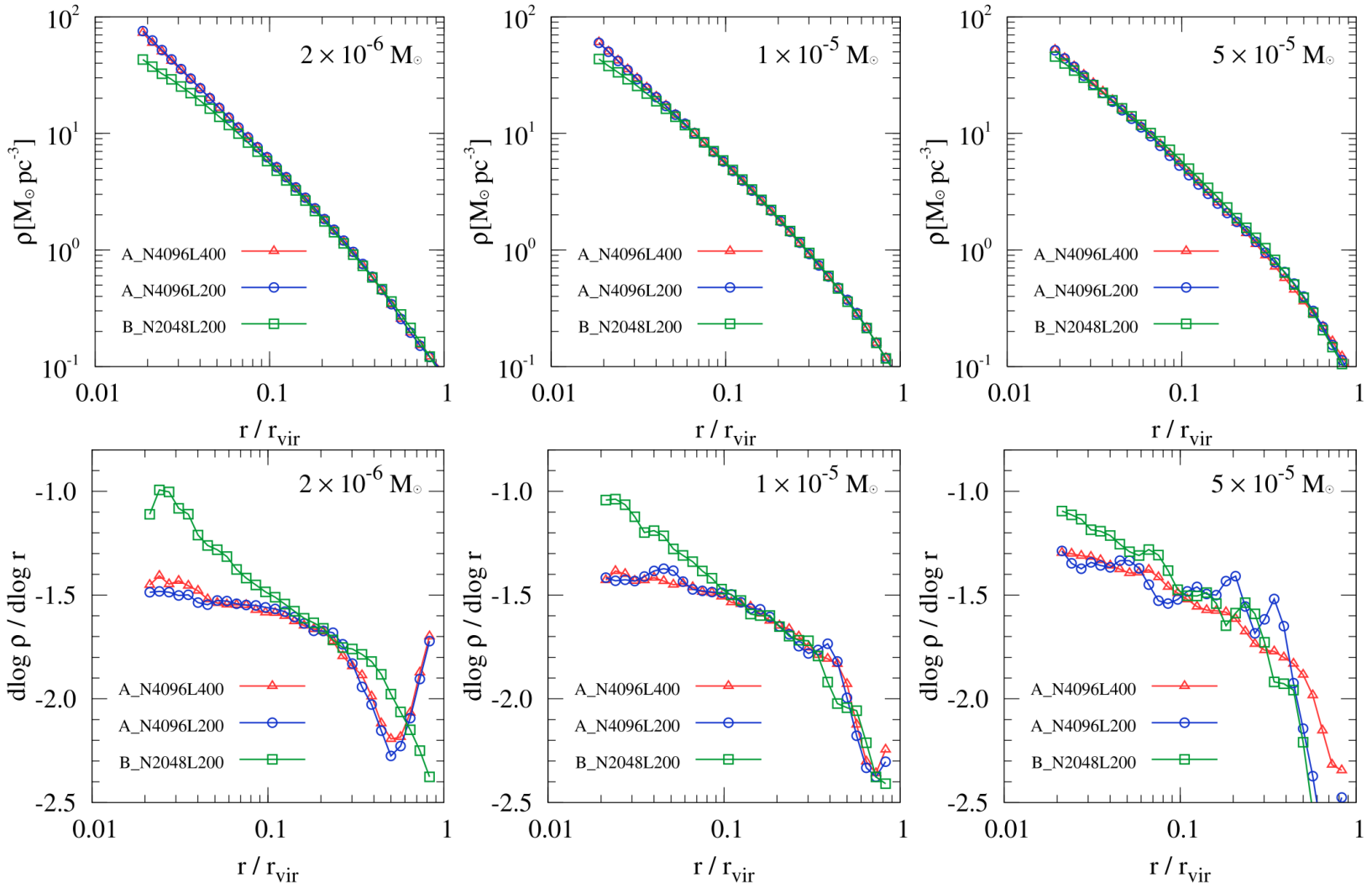
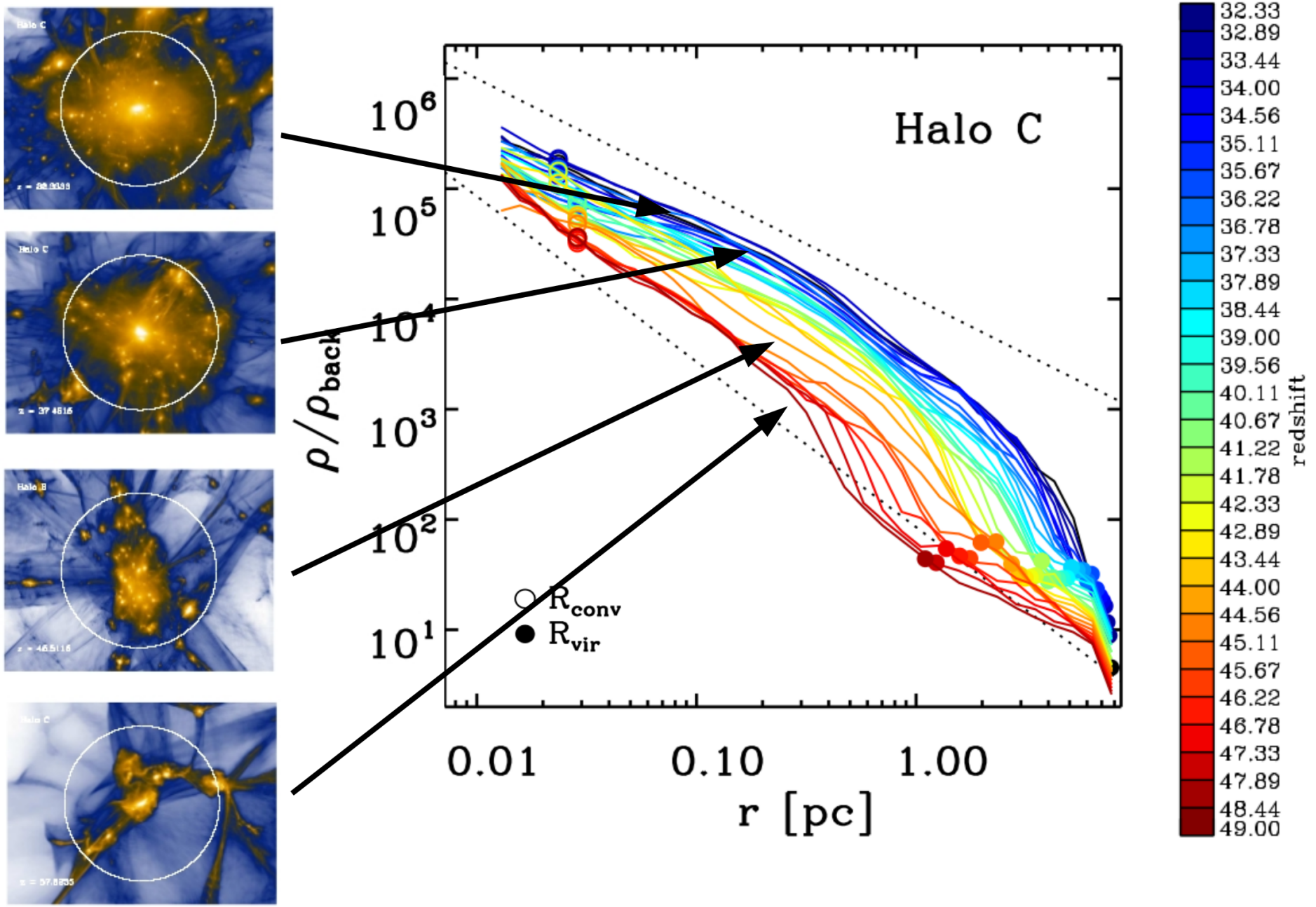
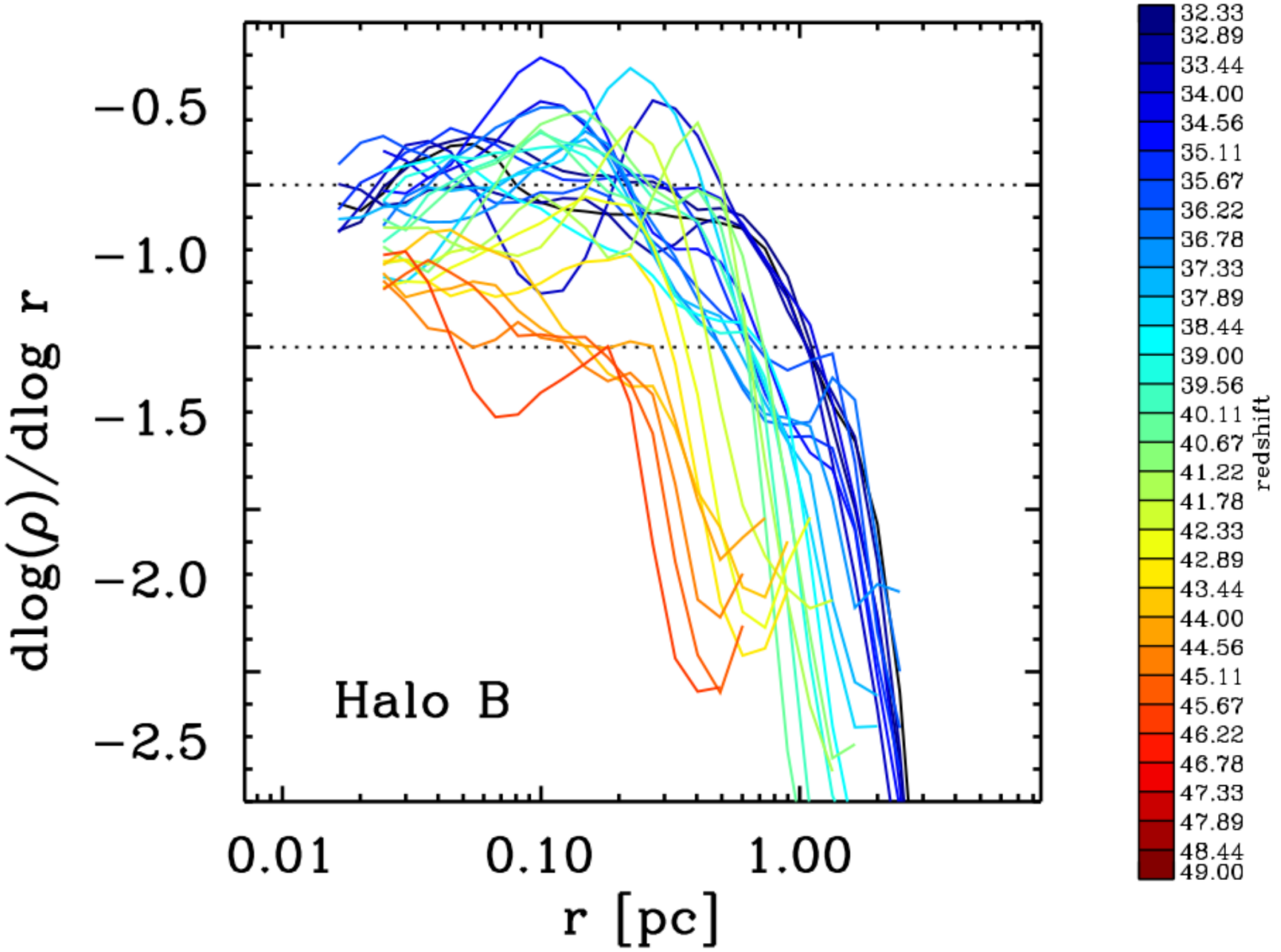


Colors: No cut-off in PS
With cut-off
With cot-off

Ishiyama 2014





Controlled simulations of equal-mass mergers

With an explicit calculation of the exact phase-space distribution

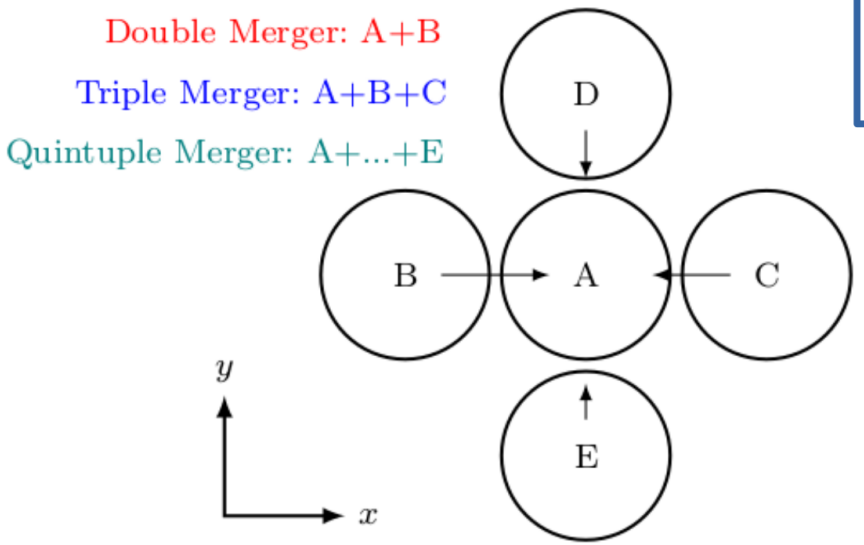


Figure 10.

Initial density profiles

$$\rho = \rho_s x^{-\gamma} \begin{cases} 1 & \text{for } 0 \leqslant x \leqslant 1 \\ x^{\kappa} \exp\left[-\kappa(x-1)\right] & \text{for } x \geqslant 1 \end{cases}$$

$$x \equiv r/r_s = r/R_{vir}$$

- Isotropic velocity profile
- One million particles
- Softening = 0.05% of Rvir
- Evolution for 15 Gyrs

Controlled simulations of equal-mass mergers

Multiple mergers change the density profile (and mass is not conserved)

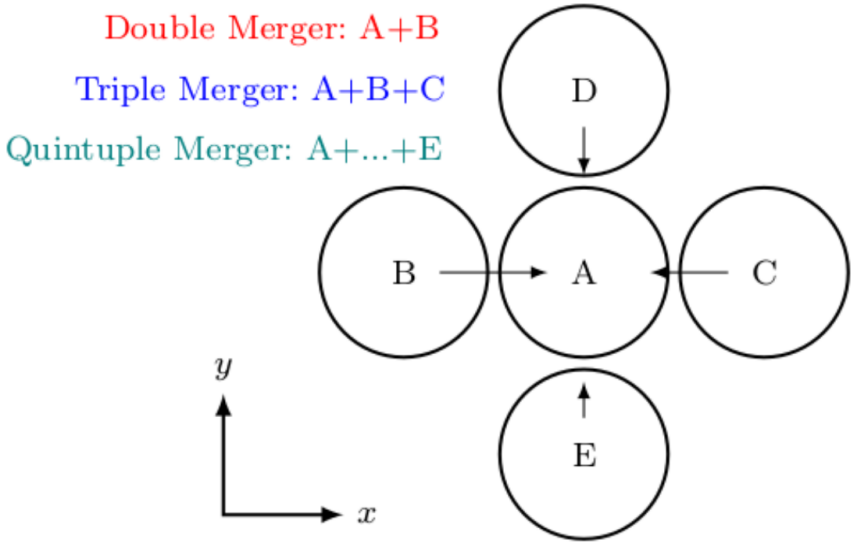
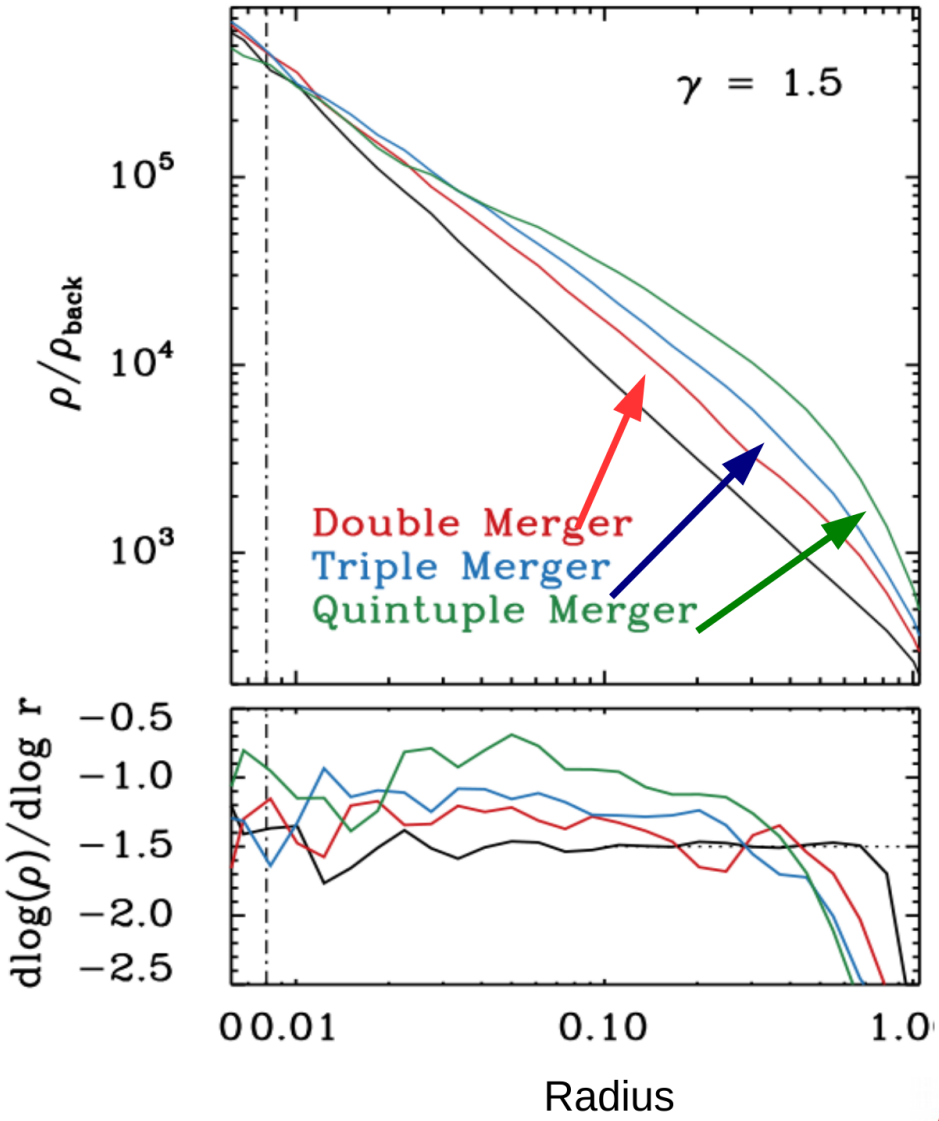


Figure 10.



End result depends on the initial profile