Dark Matter

ASTR 333/433

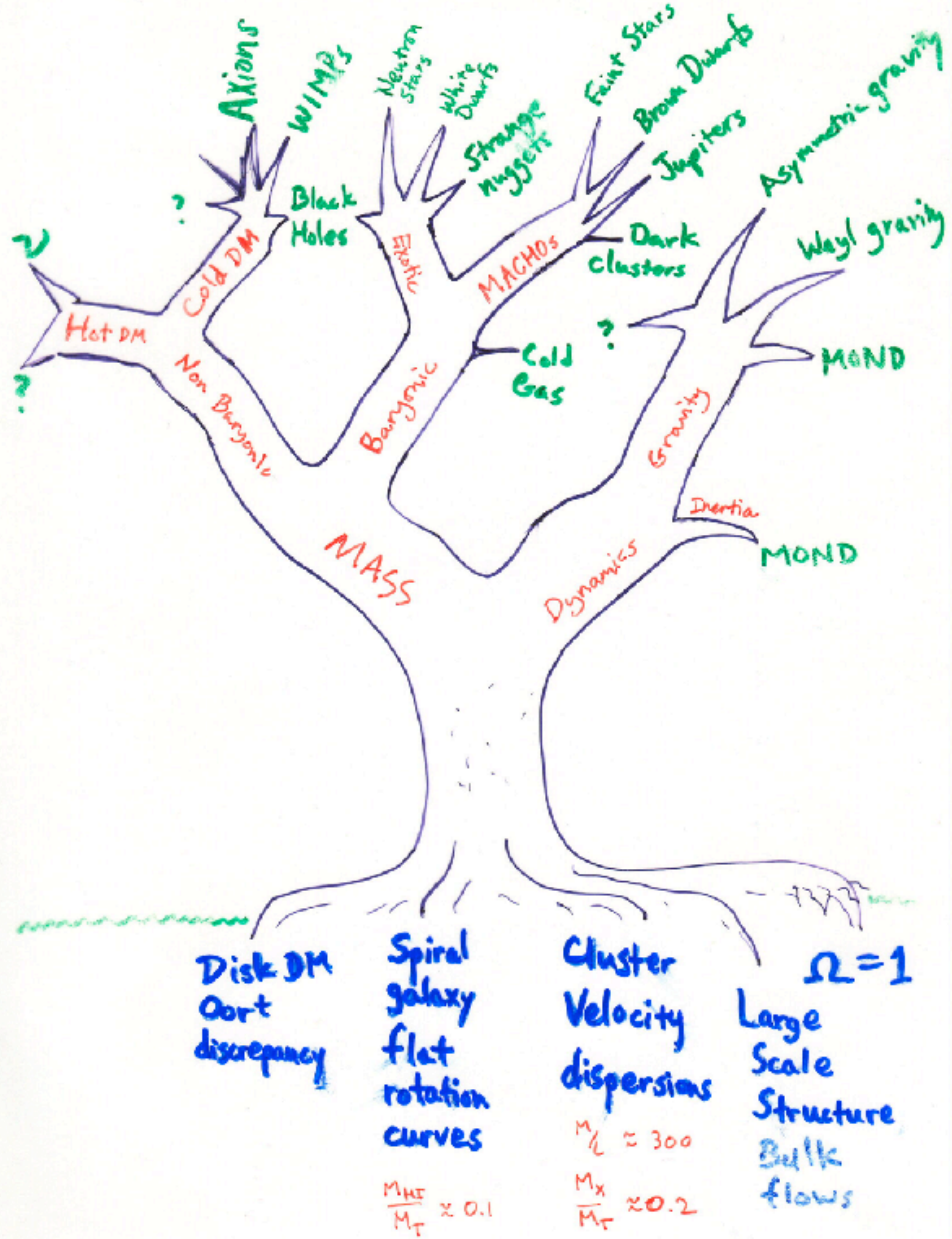
Today

Hierarchical galaxy formation

Halo shapes & profiles
cusp-core problem

adiabatic compression
feedback

Homework 3 due April 5



Hierarchical galaxy formation (*not* monolithic)

Small objects conglomerate to make big ones

Gas dissipates and cools to form thin disks.

Stars cannot cool: if hot coming in, stay hot.

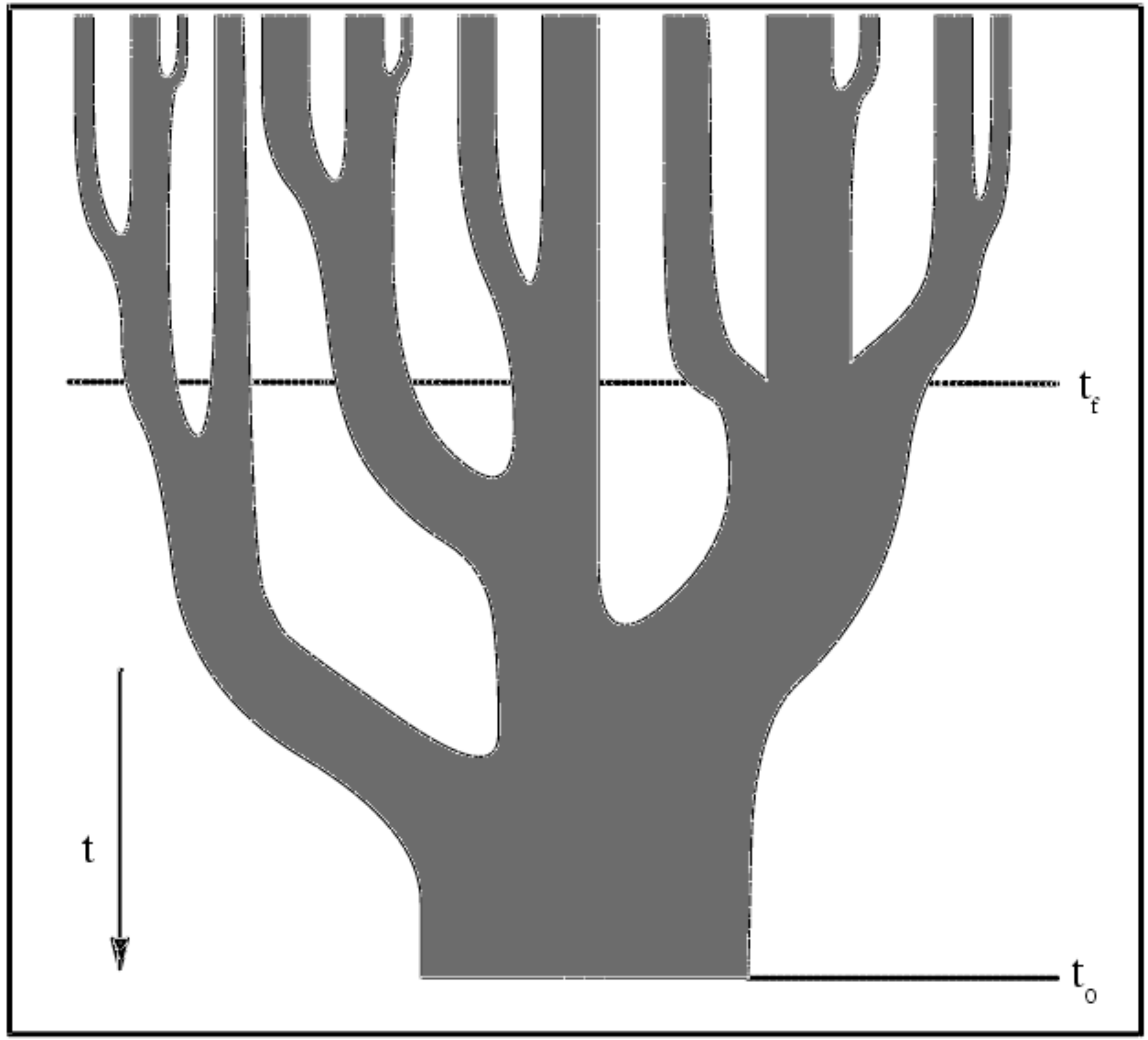


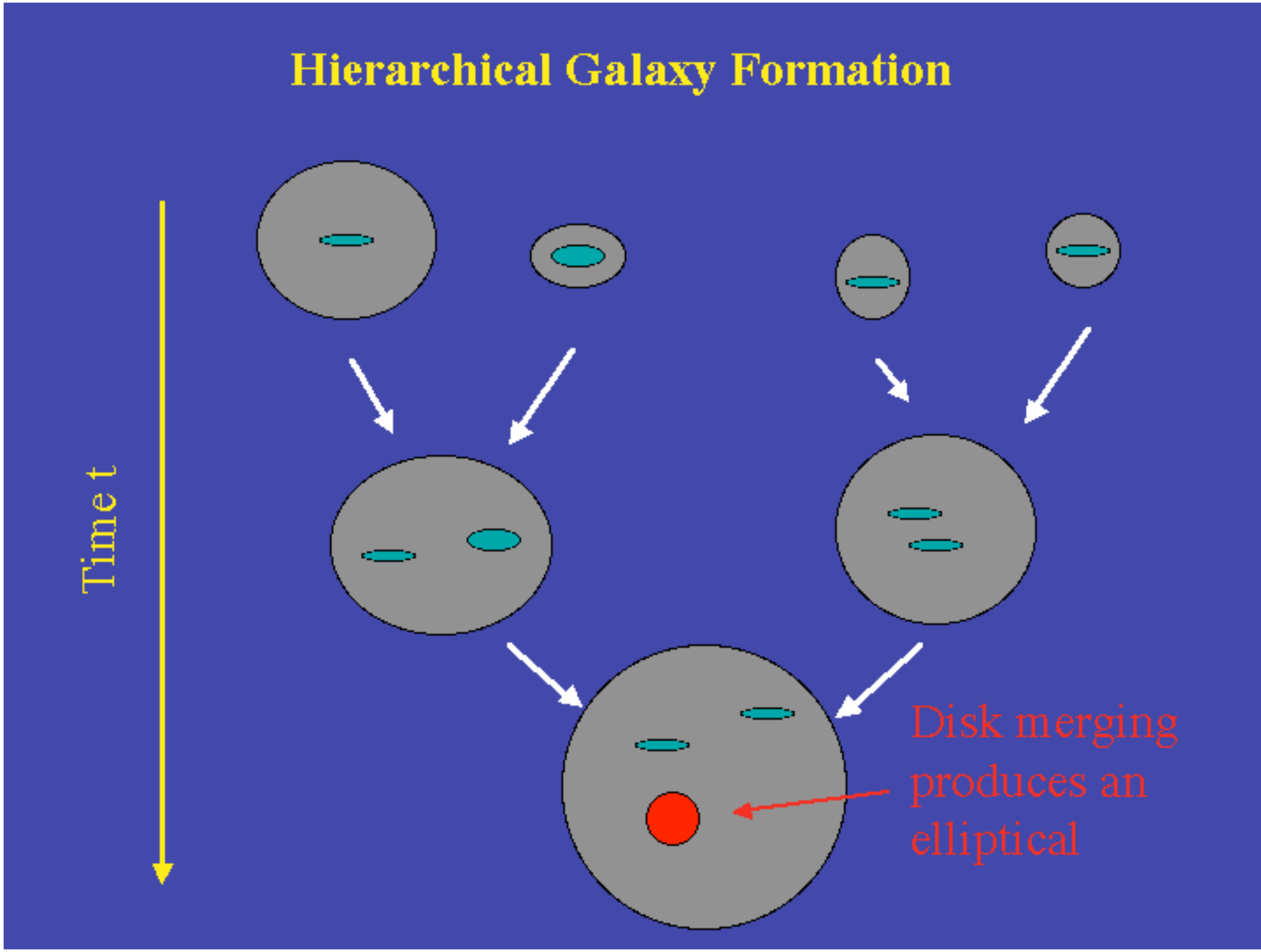
Figure 6. A schematic representation of a "merger tree" depicting the growth of a halo as the result of a series of mergers. Time increases from top to bottom in this figure and the widths of the branches of the tree represent the masses of the individual parent halos. Slicing through the tree horizontally gives the distribution of masses in the parent halos at a given time. The present time t_0 and the formation time t_f are marked by horizontal lines, where the formation time is defined as the time at which a parent halo containing in excess of half of the mass of the final halo was first created.

Gray: dark matter halos

Blue: gas rich disks

Red: elliptical merger remnant

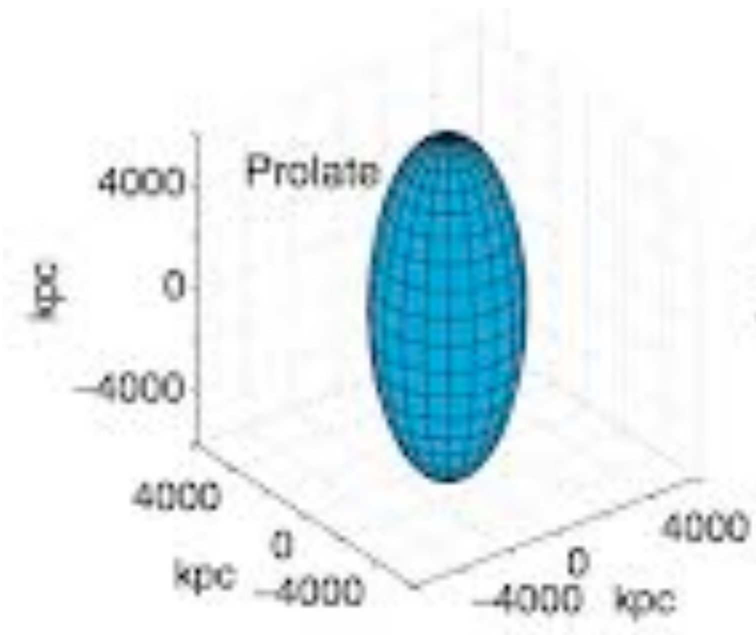
sometimes it is imagined that a disk re-forms around an elliptical to form a bulge+disk system like and Sa galaxy



NFW halos use 2 parameters to describe their azimuthally averaged density profile.
The density profiles of halos in dark matter-only simulations are not spherically symmetric.
They tend to be triaxial, with the axis ratios and position angle varying with radius.
This must get rounded-out by the process of galaxy formation, or the dynamics of galaxies would look different from different viewing angles and induce scatter in Tully-Fisher, etc.

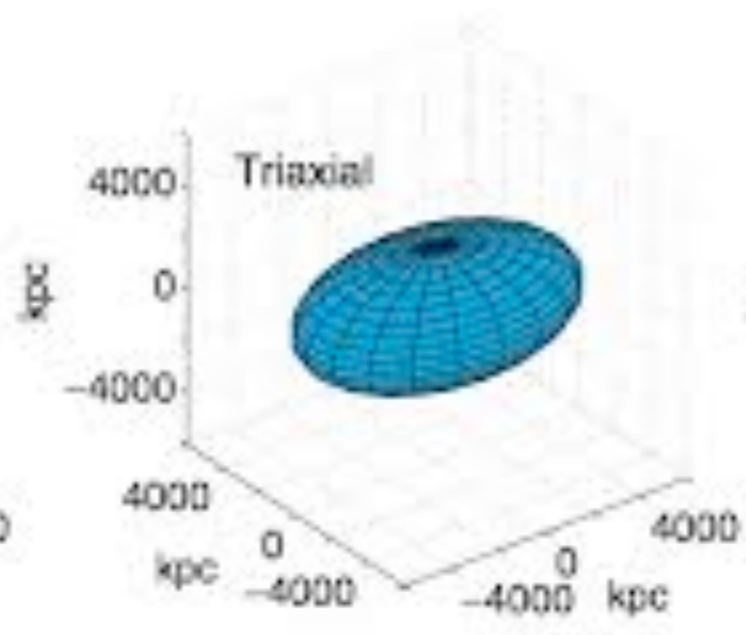
shape

prolate



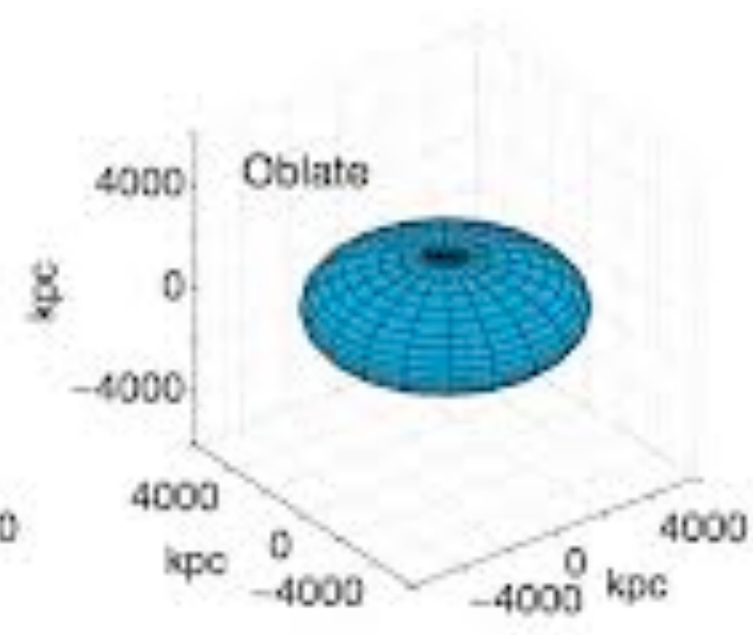
$$a > b = c$$

triaxial



$$a > b > c$$

oblate



$$a = b > c$$

Simulations blobby and even more complicated

NFW shape

NFW halos triaxial. More massive halos less round

perhaps because they are still building up hierarchically ?

Maccio et al (2007)

Concentration, spin and shape of dark haloes 63

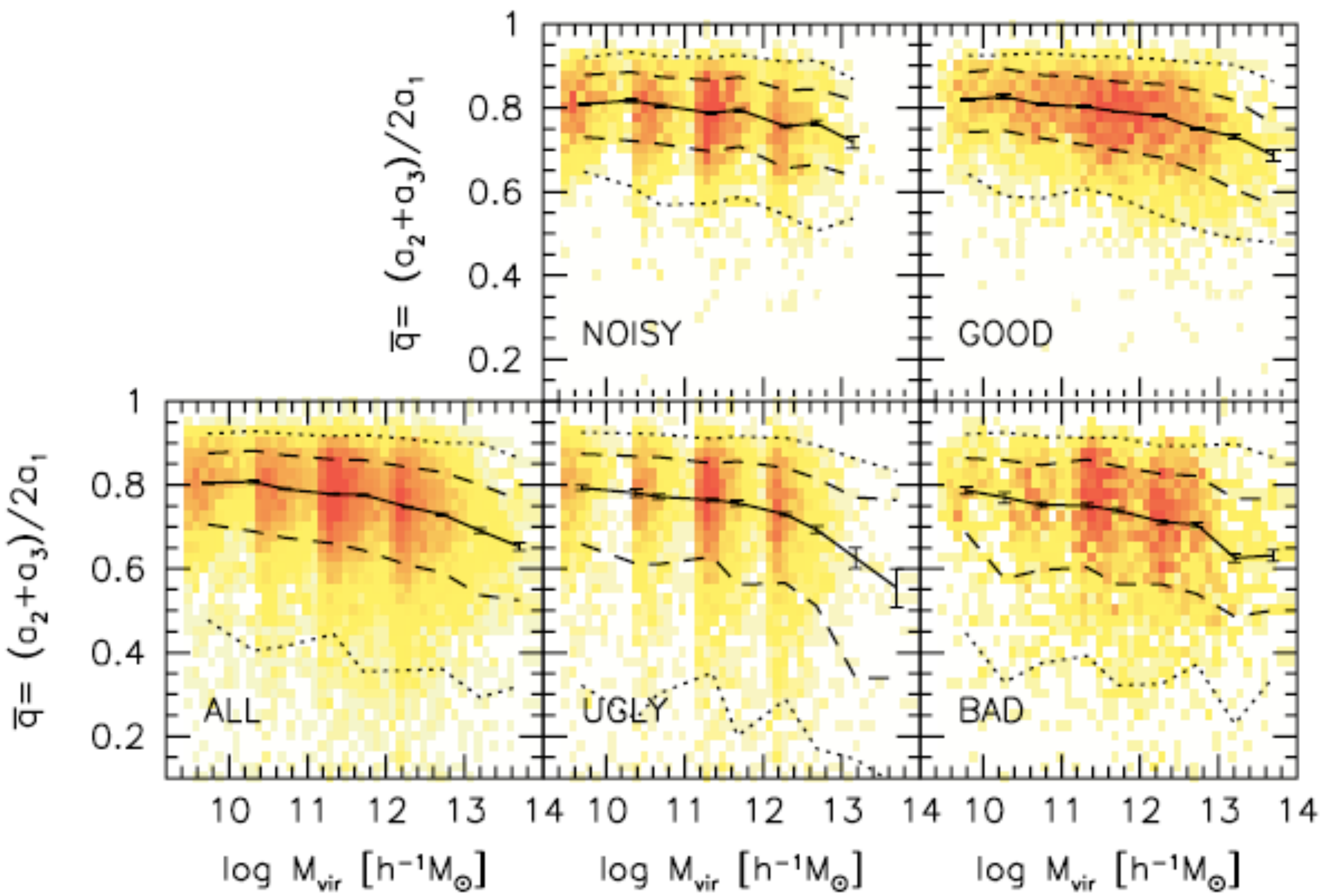
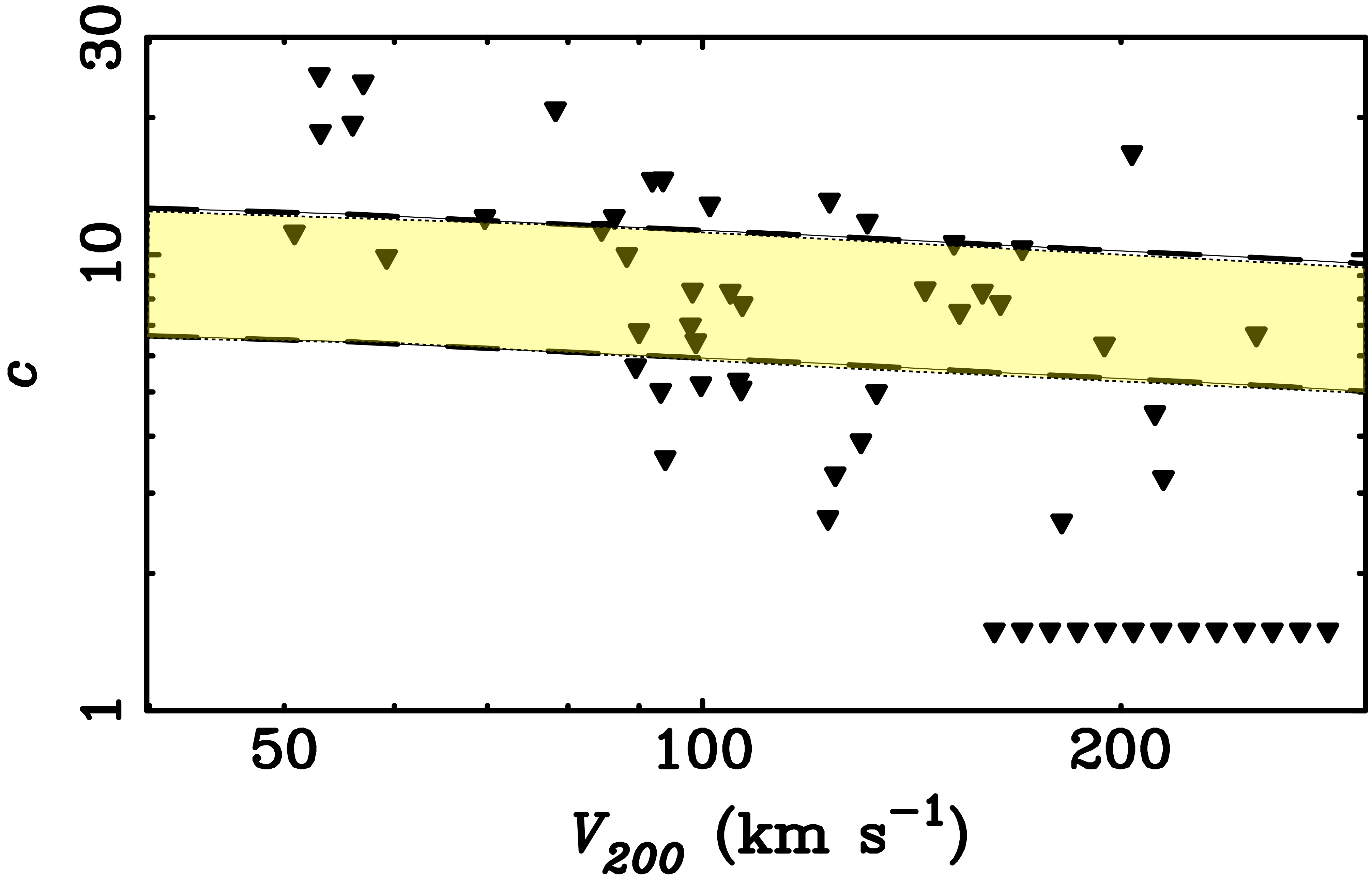


Figure 6. Relation between $\bar{q}$ and $M_{\rm vir}$ for different subsamples of haloes. The solid lines show the 50th percentile, dashed lines show the 16th and 84th percentiles, and the dotted lines show the 2.5th and 97.5th percentiles. The error bar gives the Poisson error on the median.

NFW
c-V200
relation

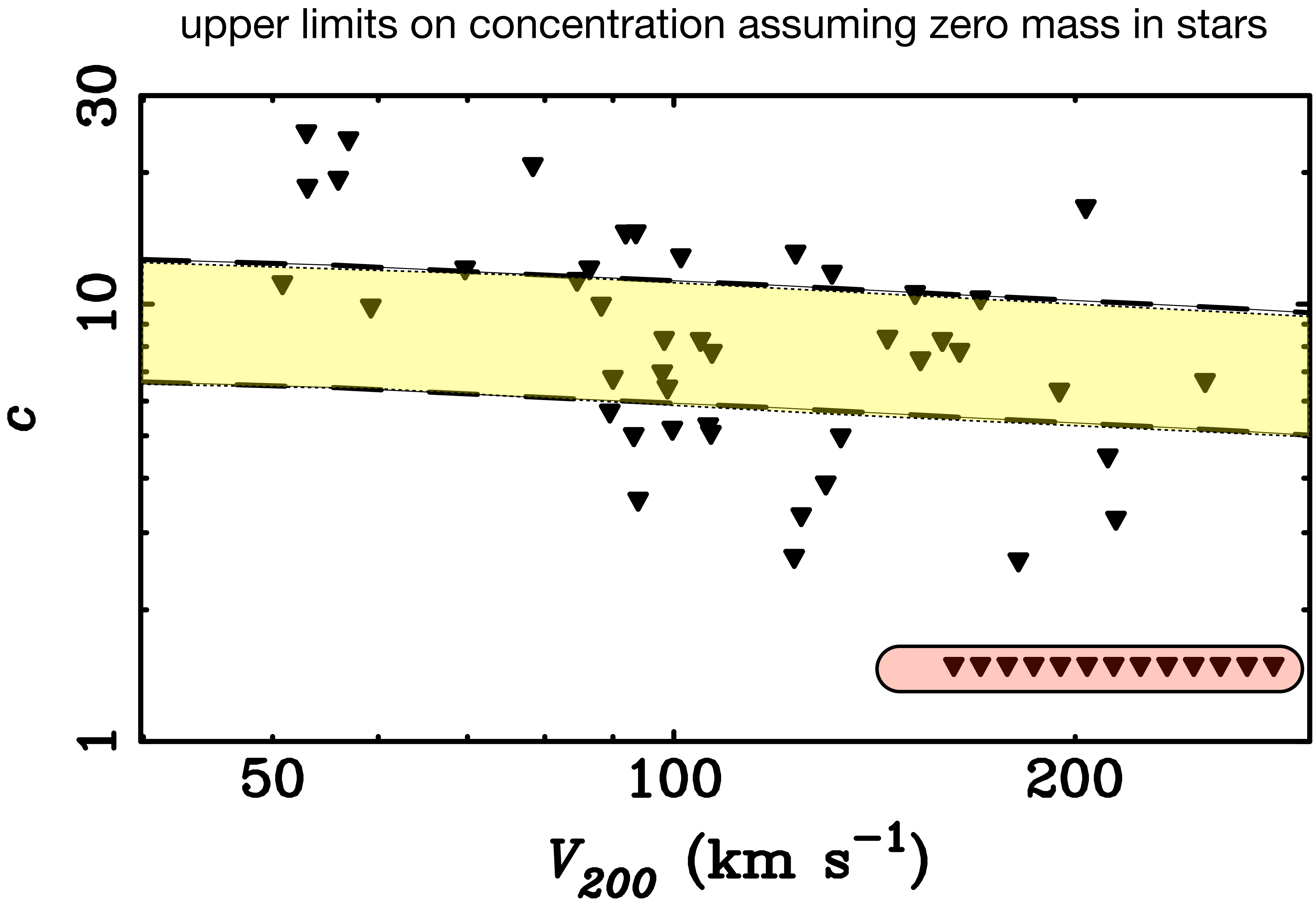
upper limits on concentration assuming zero mass in stars



$$\log c = 0.844 - 0.098 \log \left(\frac{M_{200}}{10^{12}\ \mathrm{M}_\odot} \right)$$

$\sigma_{\ln c} = 0.25$ Maccio, Dutton, & van den Bosch 2008

NFW
c-V200
relation

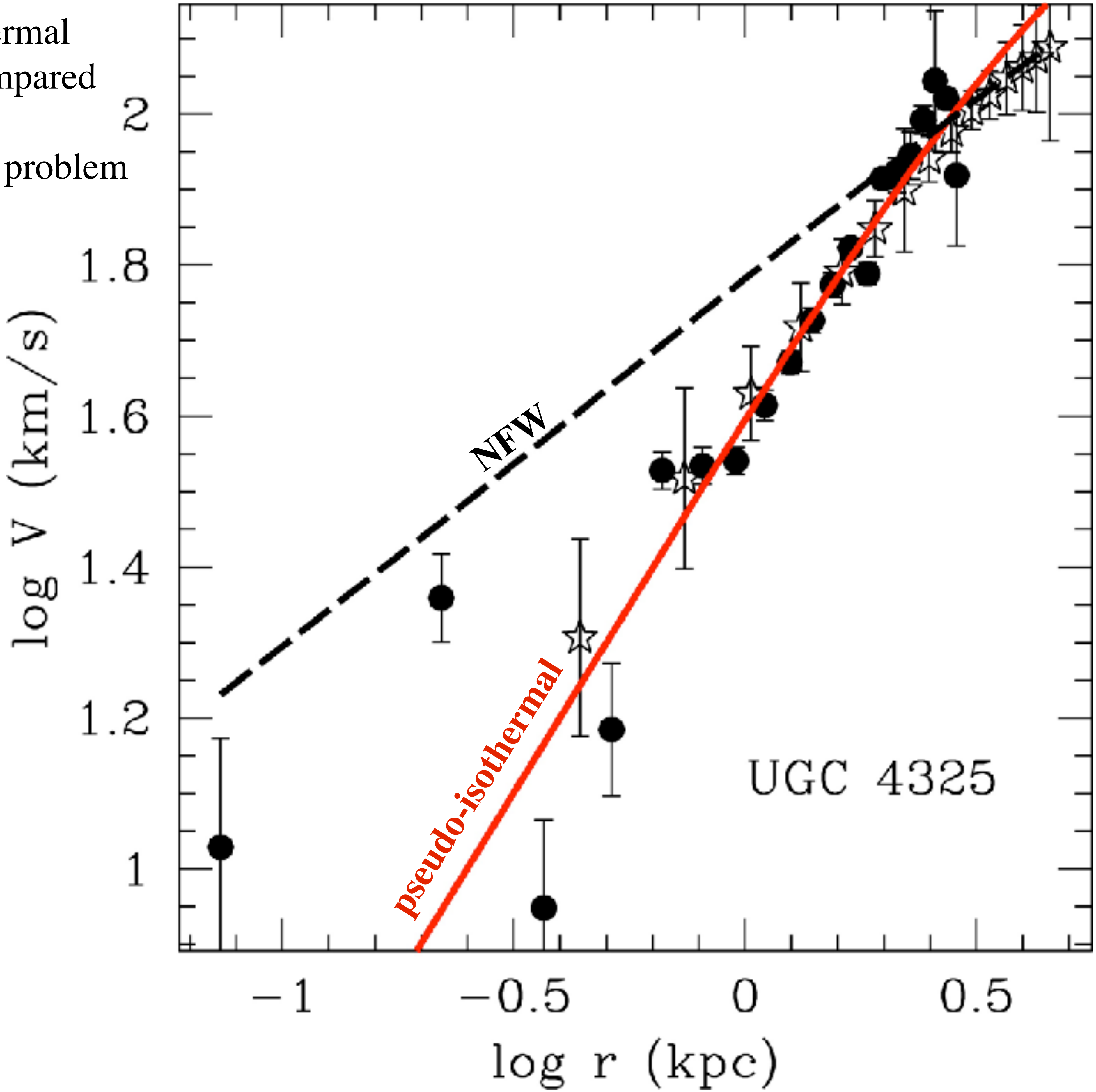


Many galaxies - especially LSBs - have upper limits on c that are unacceptably low. This is one indication of the “cusp-core problem.”

The central “cuspy” profiles predicted for dark matter halos are not always observed; much of the data prefer a nearly constant density core (like a pseudo-isothermal halo).

pseudo-isothermal
and NFW compared

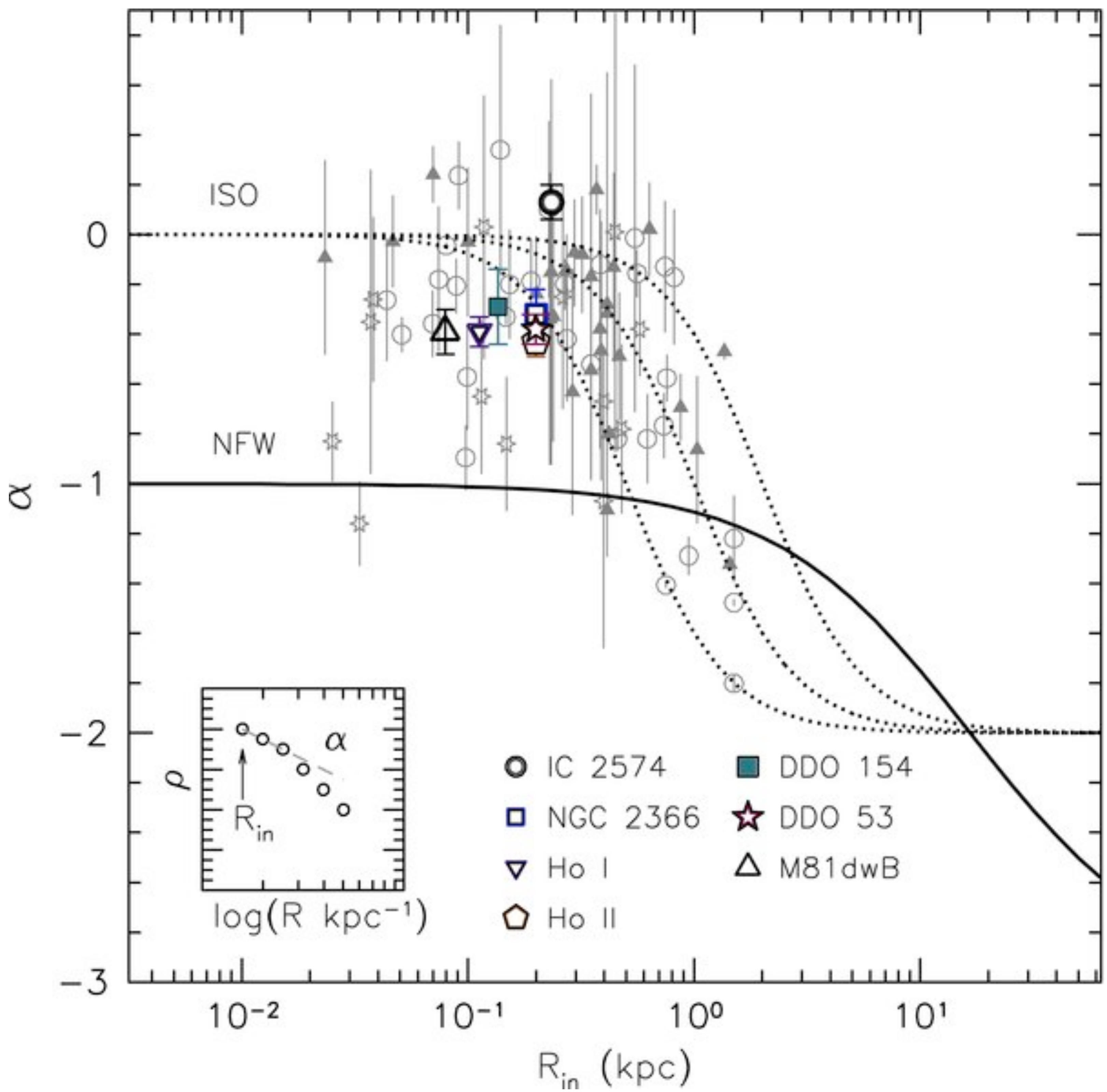
the cusp-core problem



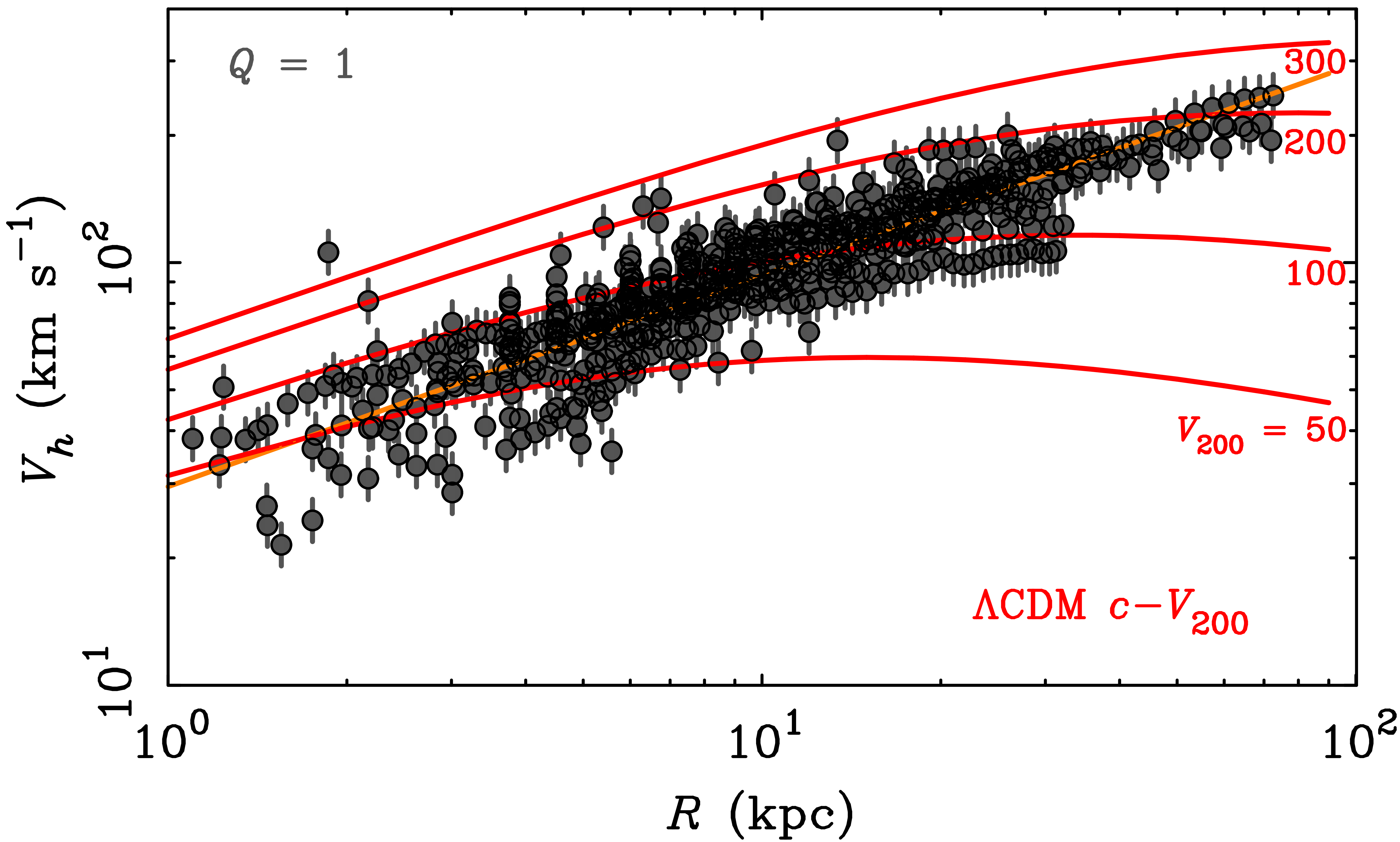
Kuzio de Naray et al. (2008)

Inner density profiles of dark matter halos

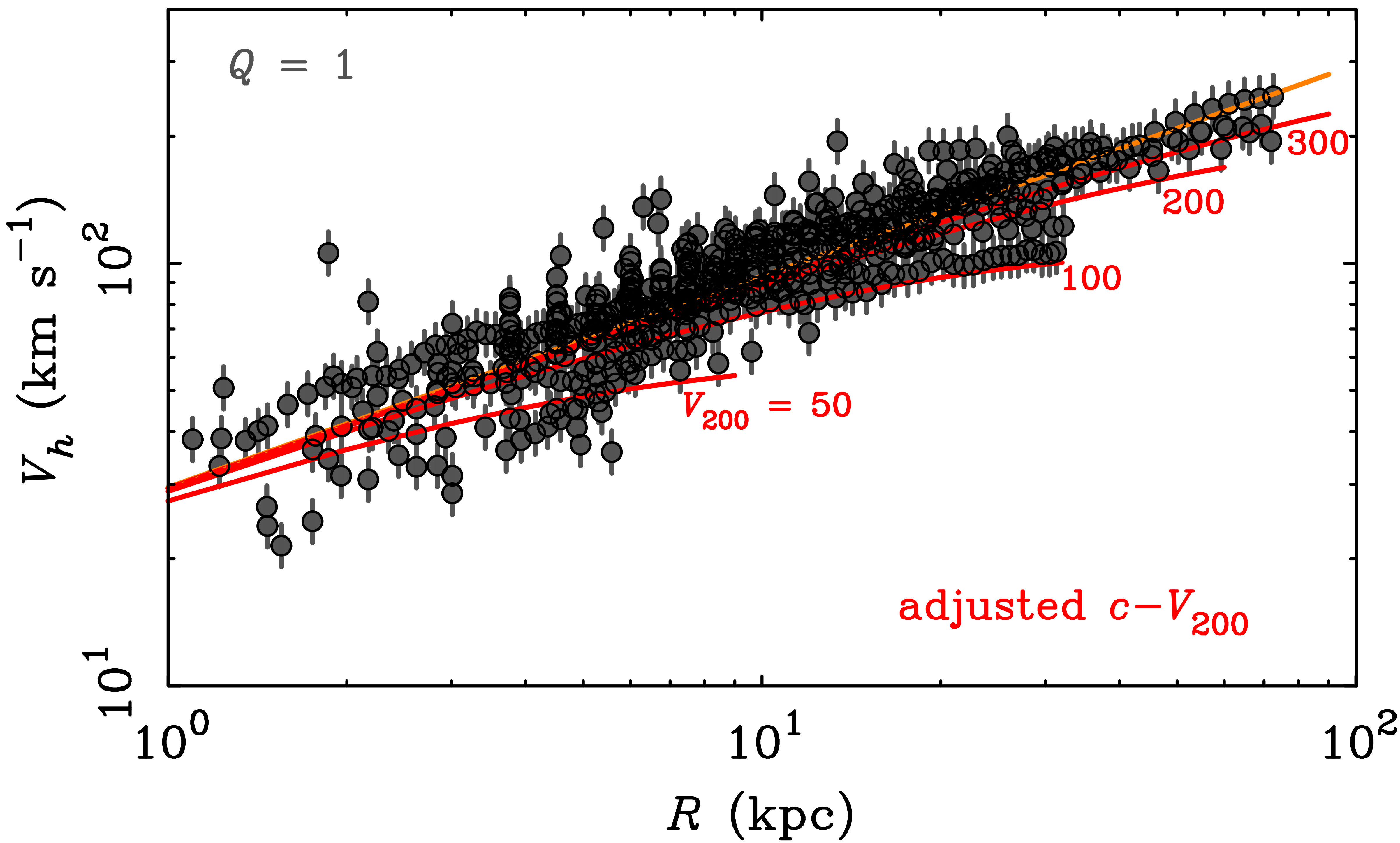
$$\rho \sim r^{\alpha}$$



Oh et al (2011) AJ, 141, 193

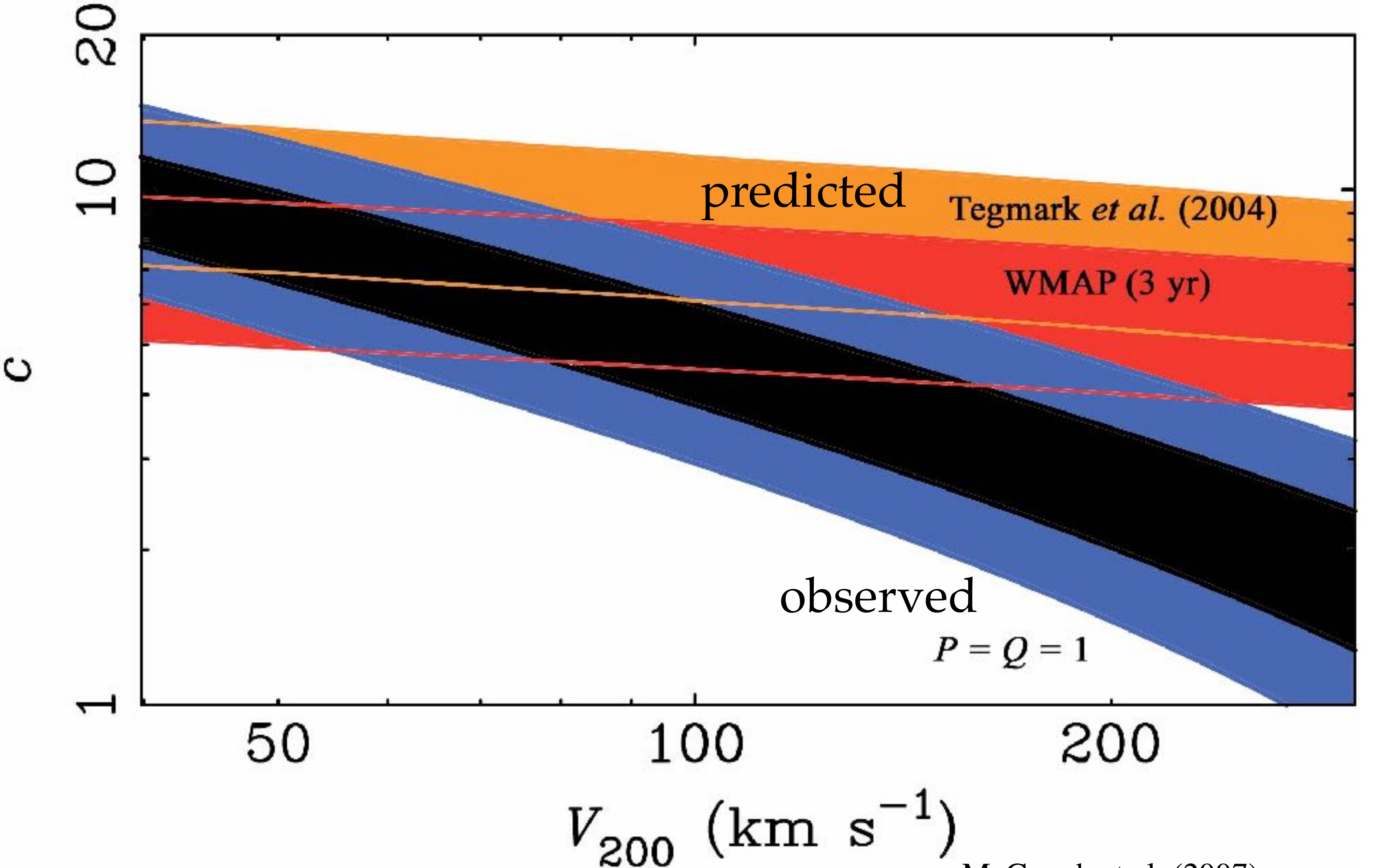


McGaugh et al. (2007)



McGaugh et al. (2007)

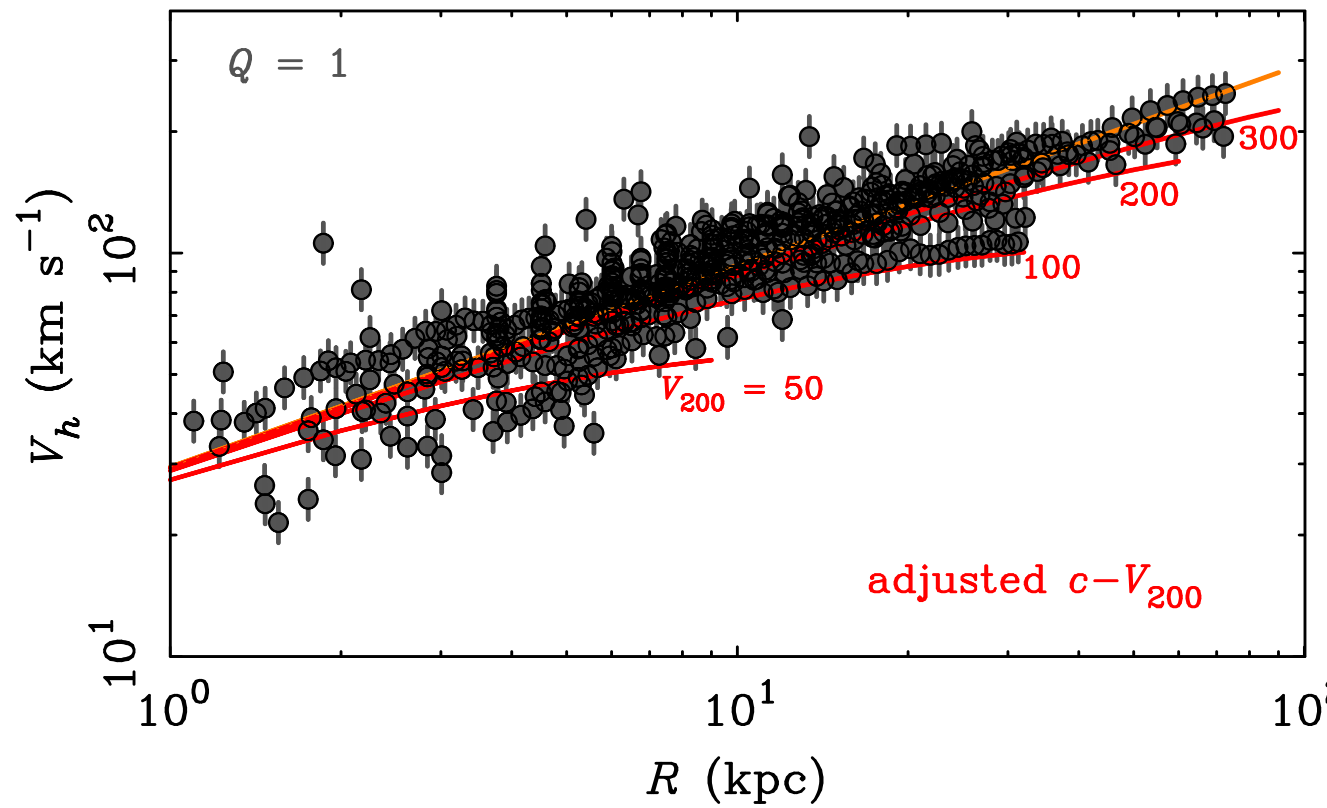
NFW c-V200 relation



McGaugh et al. (2007)

Empirical DM halo

$$\frac{M_{DM}}{\mathrm{M}_\odot} = 200\left(\frac{R}{\mathrm{pc}}\right)^2$$



McGaugh et al. (2007)
Walker et al. (2010)

$$\log\left(\frac{V_{DM}}{\mathrm{km\,s^{-1}}}\right) = 1.47 + \frac{1}{2}\log\left(\frac{R}{\mathrm{kpc}}\right)$$

$$g_{DM} = 3\times 10^{-11}\ \mathrm{m\,s^{-2}}$$

Roughly constant acceleration - equivalent to constant surface density

Empirical DM halo

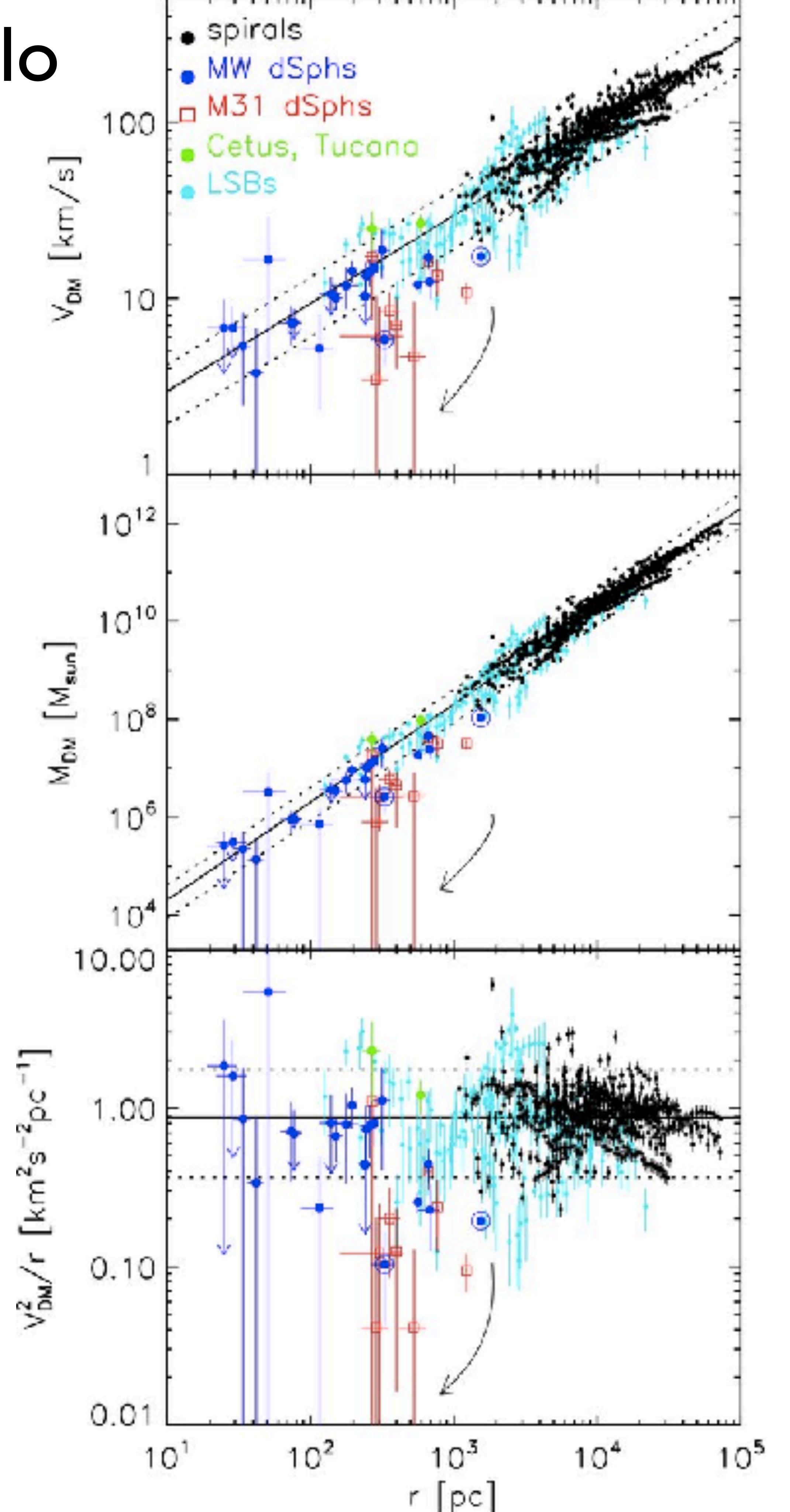
$$\frac{M_{DM}}{\mathrm{M}_\odot} = 200 \left(\frac{R}{\mathrm{pc}}\right)^2$$

McGaugh et al. (2007)
Walker et al. (2010)

$$\log\left(\frac{V_{DM}}{\mathrm{km\,s^{-1}}}\right) = 1.47 + \frac{1}{2}\log\left(\frac{R}{\mathrm{kpc}}\right)$$

$$g_{DM} = 3 \times 10^{-11}\ \mathrm{m\,s^{-2}}$$

Roughly constant acceleration -
equivalent to constant surface density



Adiabatic Compression

In a spherical potential, the squared angular momentum of a circular orbit is $L^2 = rGM(r)$, and if this quantity is conserved as a disk with the mass profile $M_d(r)$ grows slowly, we have

$$r_i M_i(r_i) = r_f \left[M_d(r_f) + (1 - f_d) M_f(r_f)\right], \qquad (1)$$

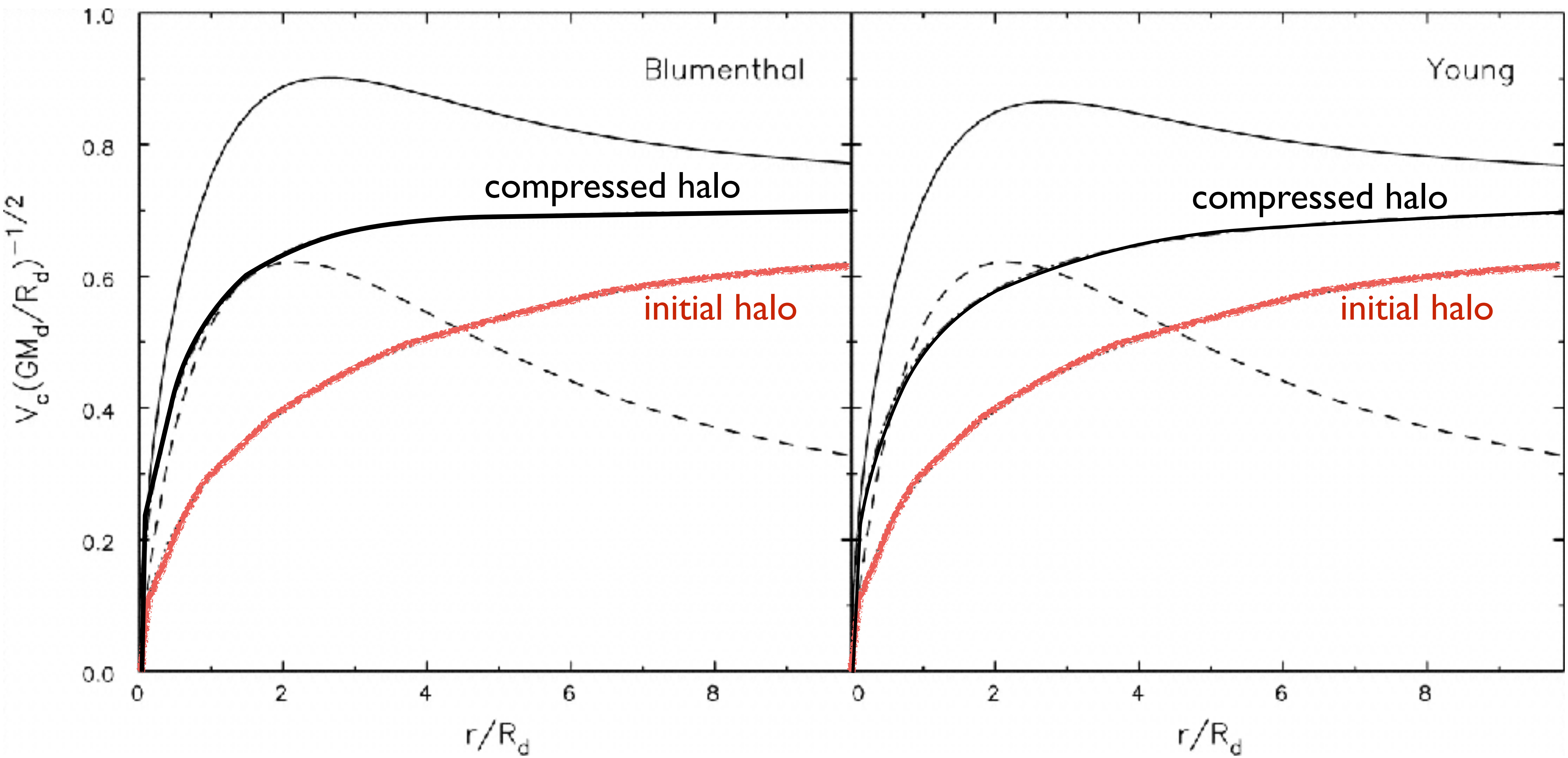
where M_i is the initial total mass (dark plus baryonic) profile, $(1 - f_d)M_f$ is the desired final dark matter mass profile, and r_f is the final radius of the mass shell initially at radius r_i. The quantity f_d is the fraction of the initial total mass, assumed to be independent of radius, that condenses to form the disk. We can substitute for $M_f(r_f)$ by making use of the assumption

$$M_i(r_i) = M_f(r_f), \qquad (2)$$

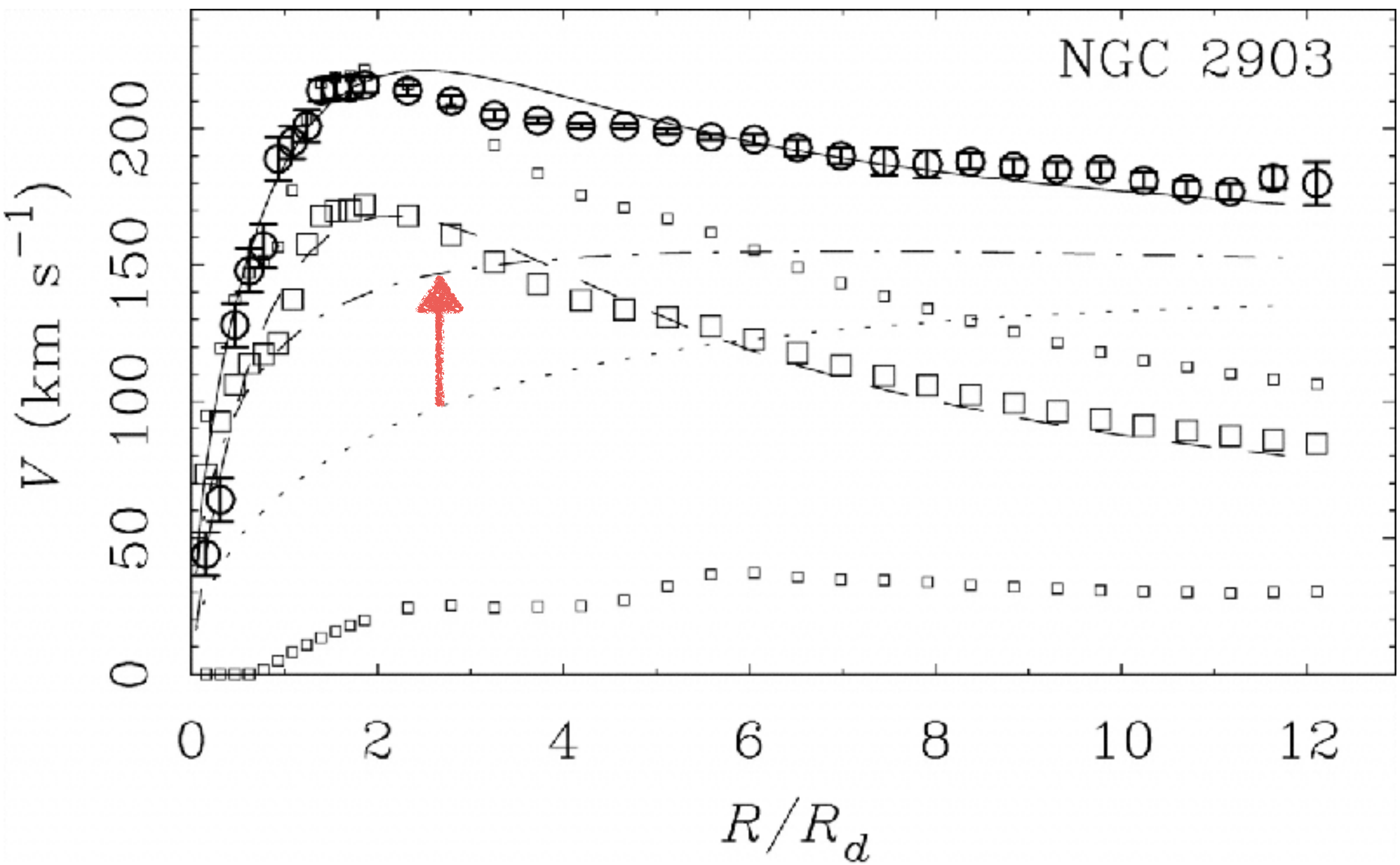
which is sometimes stated as "shells of matter do not cross." We can then find r_i for any desired r_f, and through equation (2), we can obtain the mass profile of the compressed dark matter halo. For convenience, we denote this the Blumenthal algorithm.

The Blumenthal algorithm only conserves angular momentum. Young's algorithm conserves the adiabats of the orbit, but is harder to implement (Sellwood & McGaugh 2005).

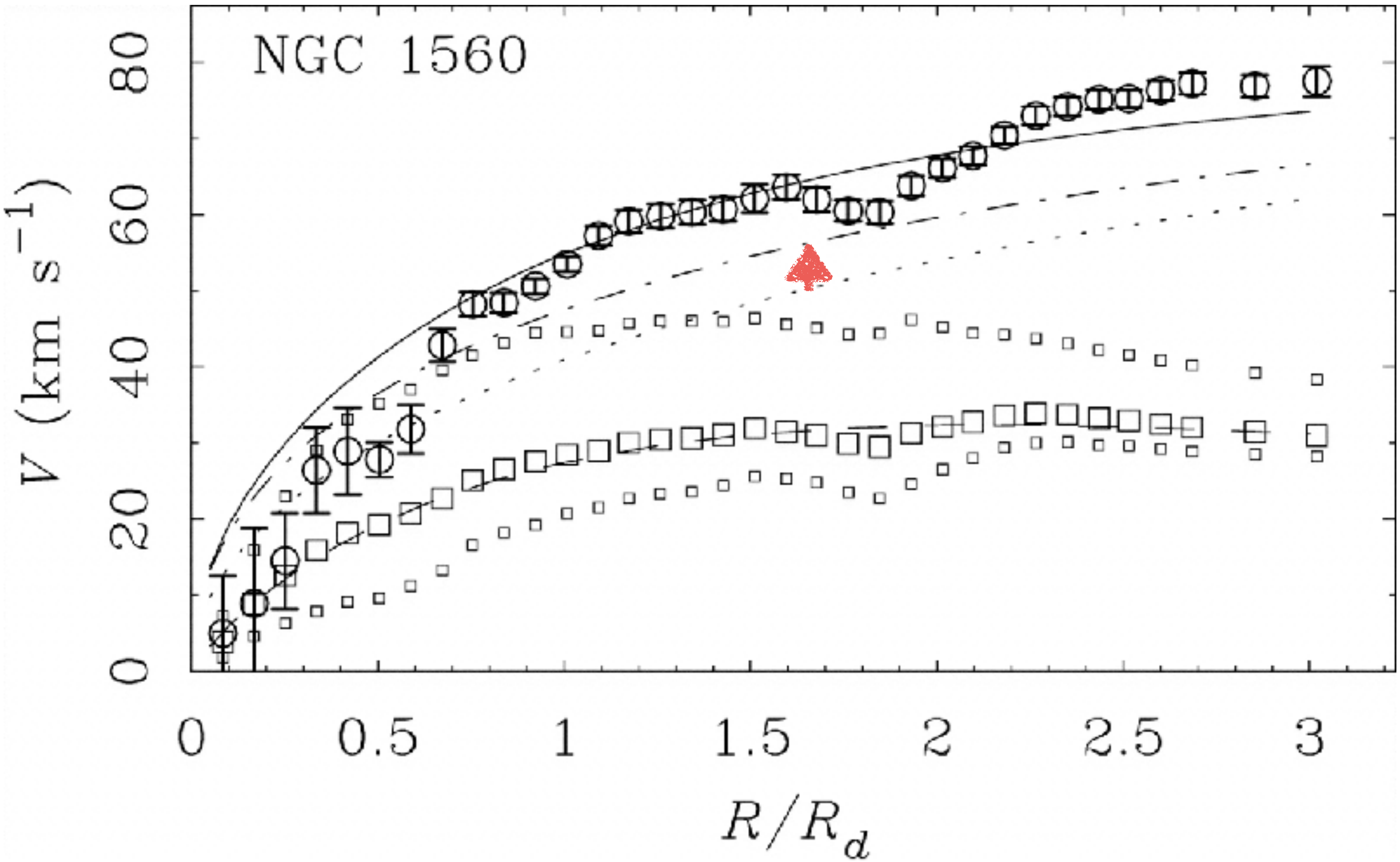
Adiabatic compression



The Blumenthal algorithm over-compresses. Young's algorithm allows for more nearly maximal disks.

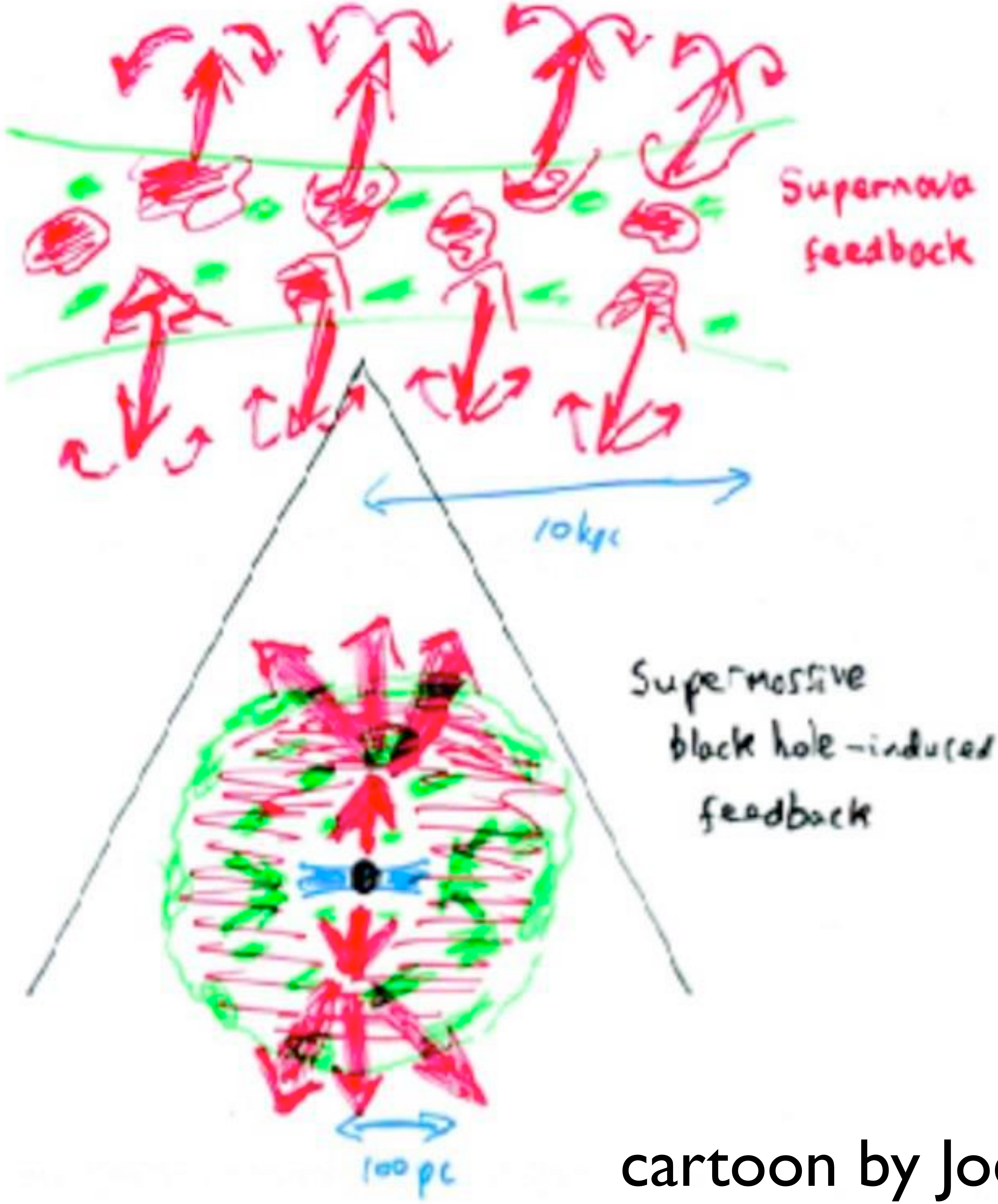


High surface density disks cause noticeable compression; tend to steepen halo profile. The current-day halo isn't the same as the primordial halo prior to galaxy formation.



Low surface density disks cause only minor compression; don't affect profile much

Feedback



cartoon by Joe Silk