Dark Matter

ASTR 333/433

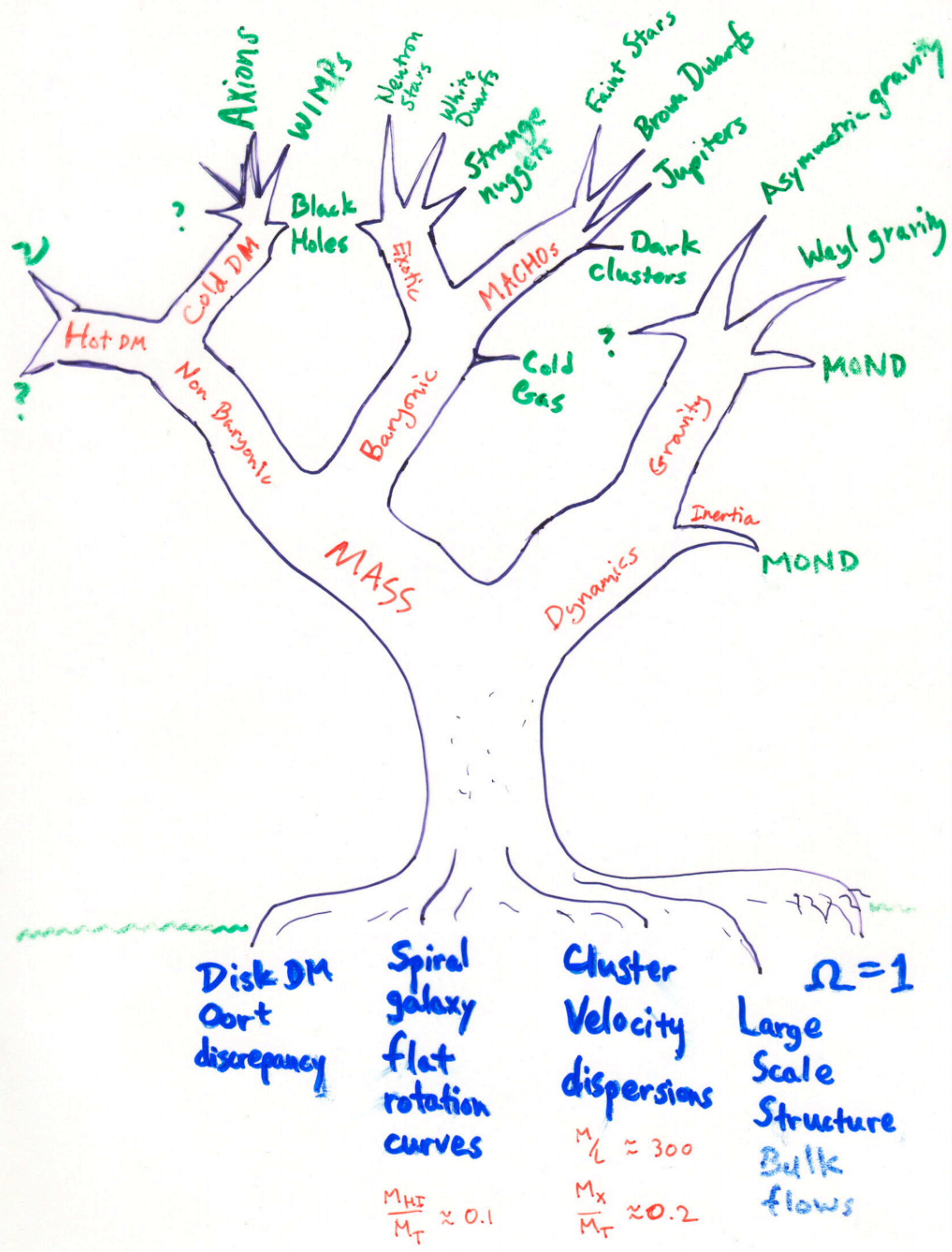
TODAY

Dark Matter Halo Models

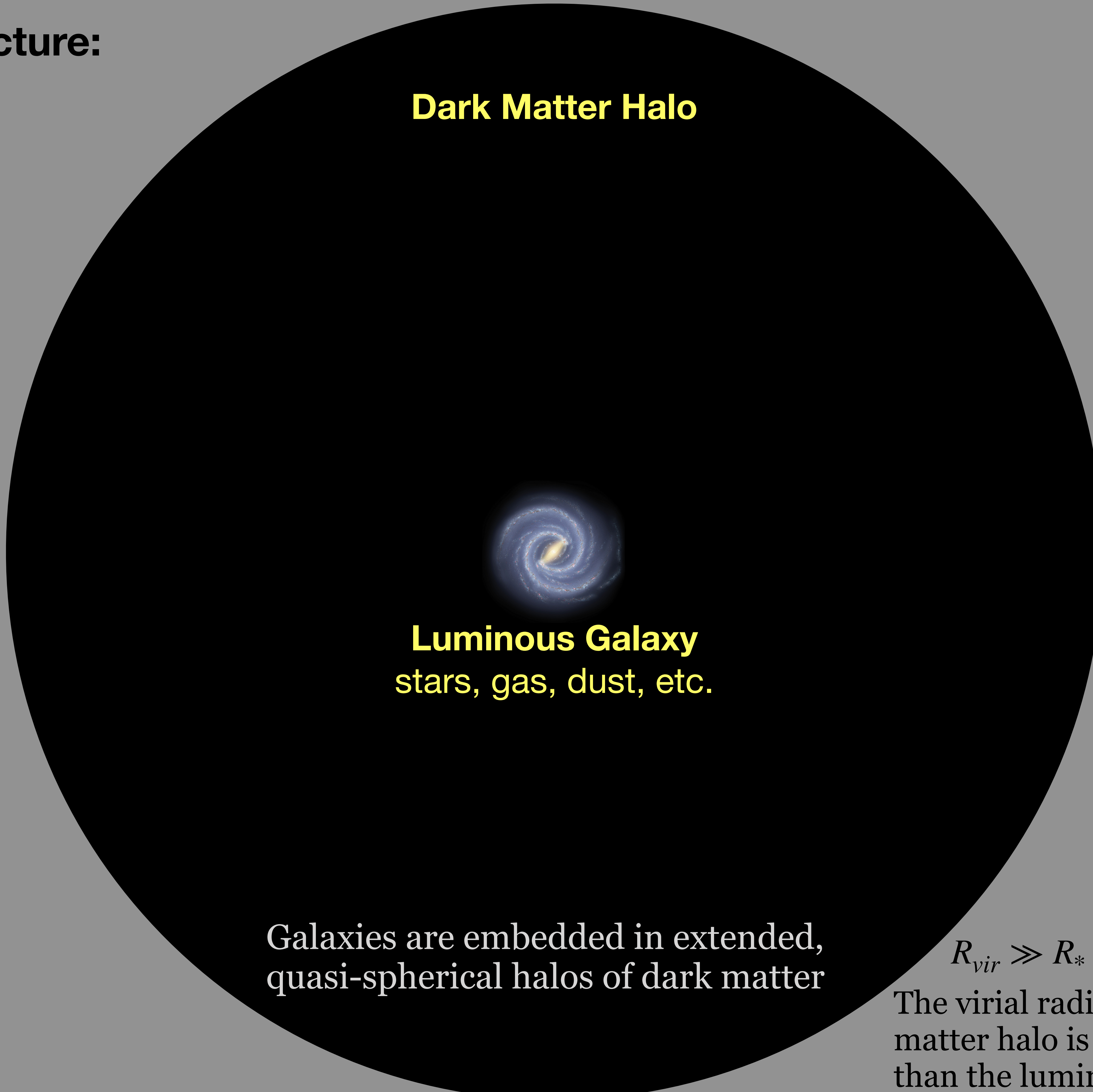
Next time

Homework 1 due

hard copy at beginning of class



Basic Picture:



Galaxies are embedded in extended, quasi-spherical halos of dark matter

$R_{vir} \gg R_*$

The virial radius of the dark matter halo is much larger than the luminous galaxy

Dark Matter Halo models

pseudo-isothermal

older
empirically motivated

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

theoretically reminiscent of an isothermal distribution

Both models have 2 parameters - a characteristic density and scale radius

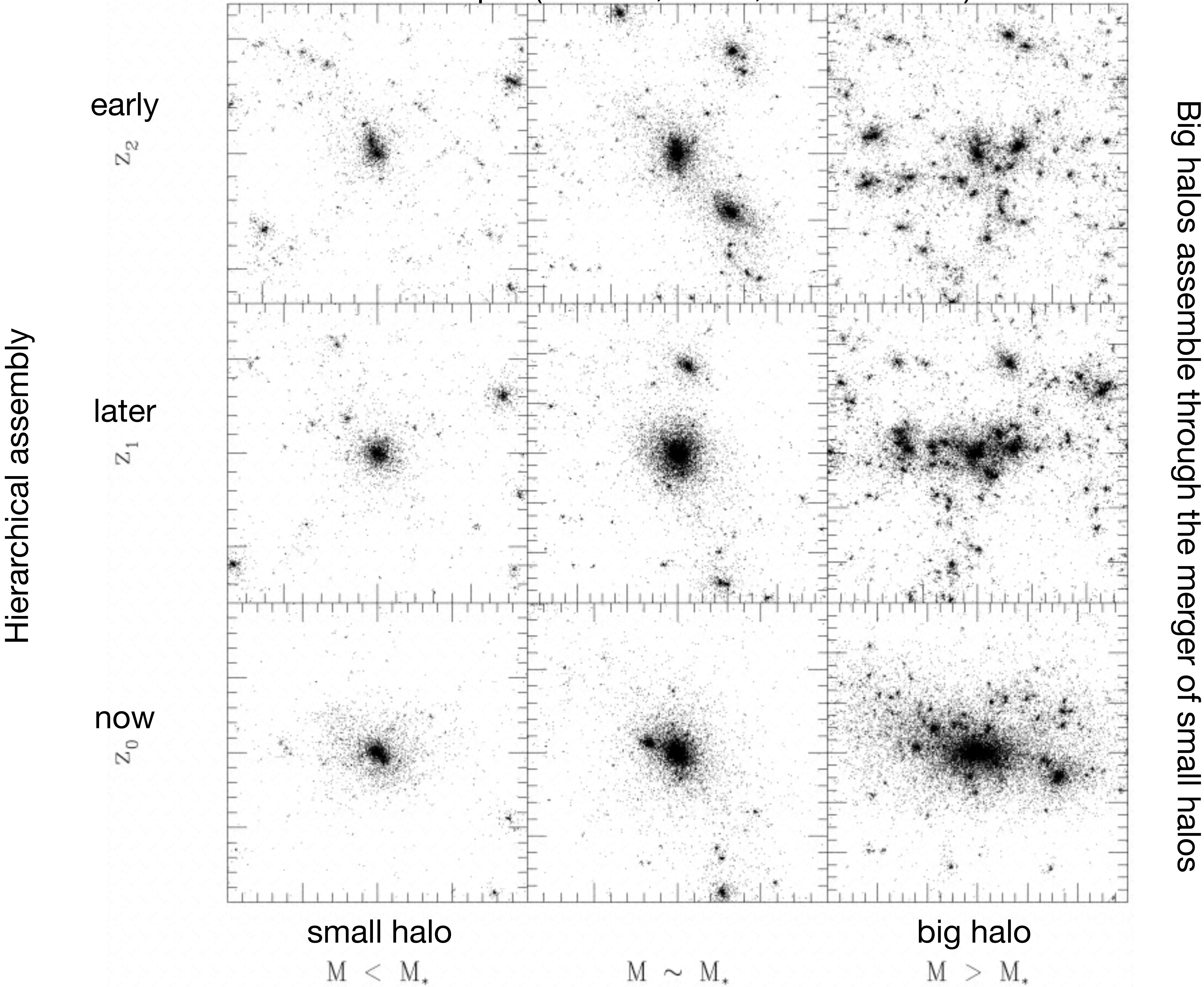
NFW

now old new normal
theoretically motivated

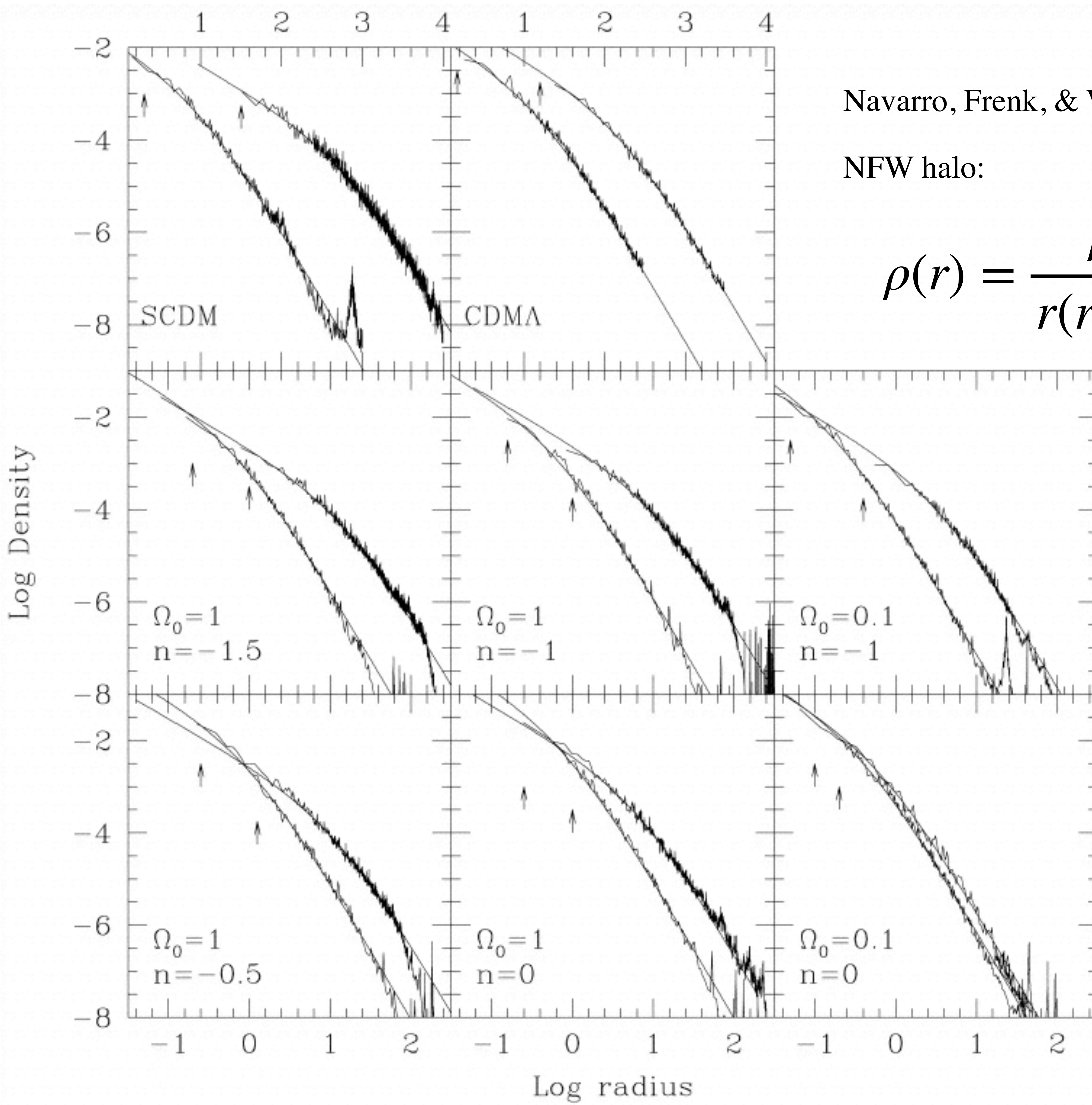
$$\rho(r) = \frac{\rho_s r_s^3}{r(r + r_s)^2}$$

an analytic approximation to the results of numerical simulations

Simulation output (Navarro, Frenk, & White 1997)



Density profiles of simulated dark matter halos



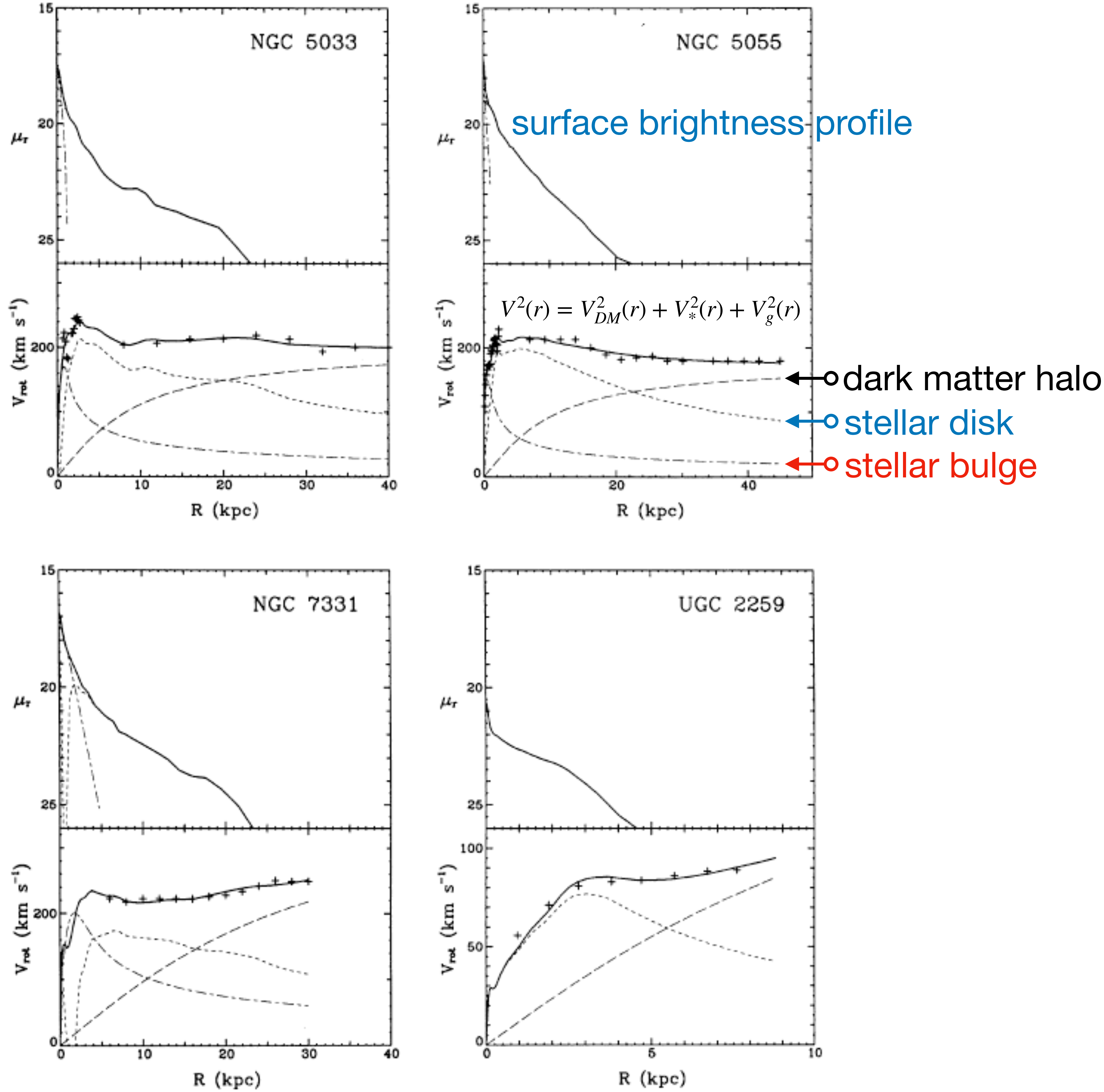
Navarro, Frenk, & White (1997)

NFW halo:

$$\rho(r) = \frac{\rho_s r_s^3}{r(r + r_s)^2}$$

Mass models

Kent (1987)



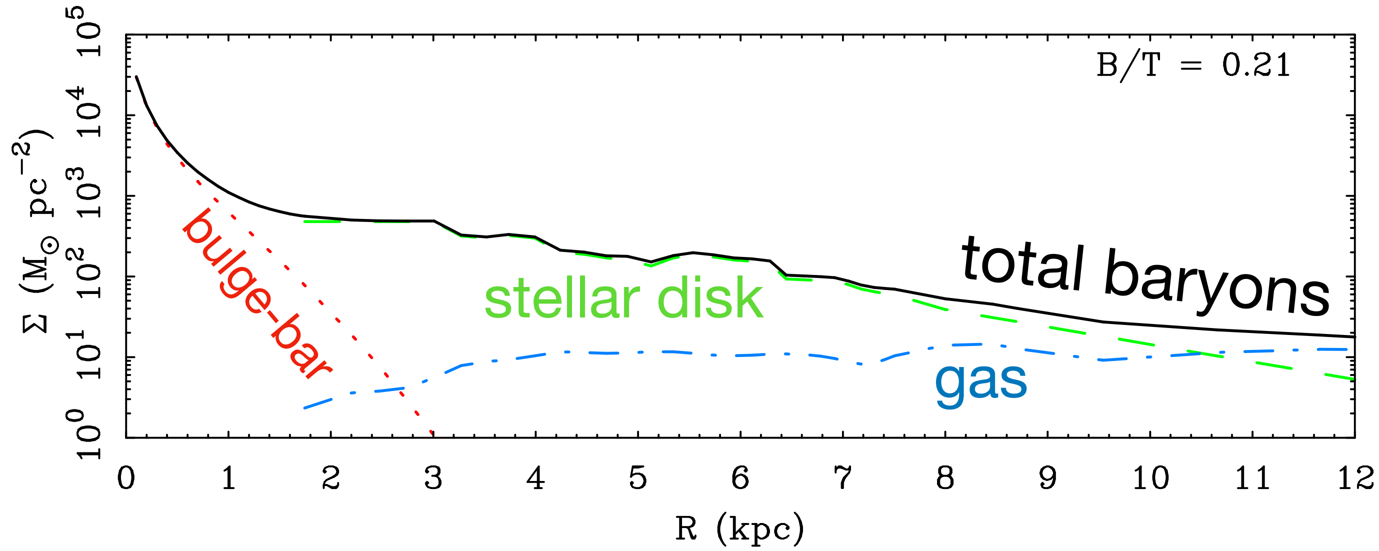
Rotation curves fit with pseudo-isothermal halos

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

$$V_{\rm iso}(r) = V_\infty \sqrt{1 - \frac{R_c}{r} \tan^{-1}\left(\frac{r}{R_c}\right)}$$

$$V_\infty = \sqrt{4\pi G \rho_0 R_c^2}$$

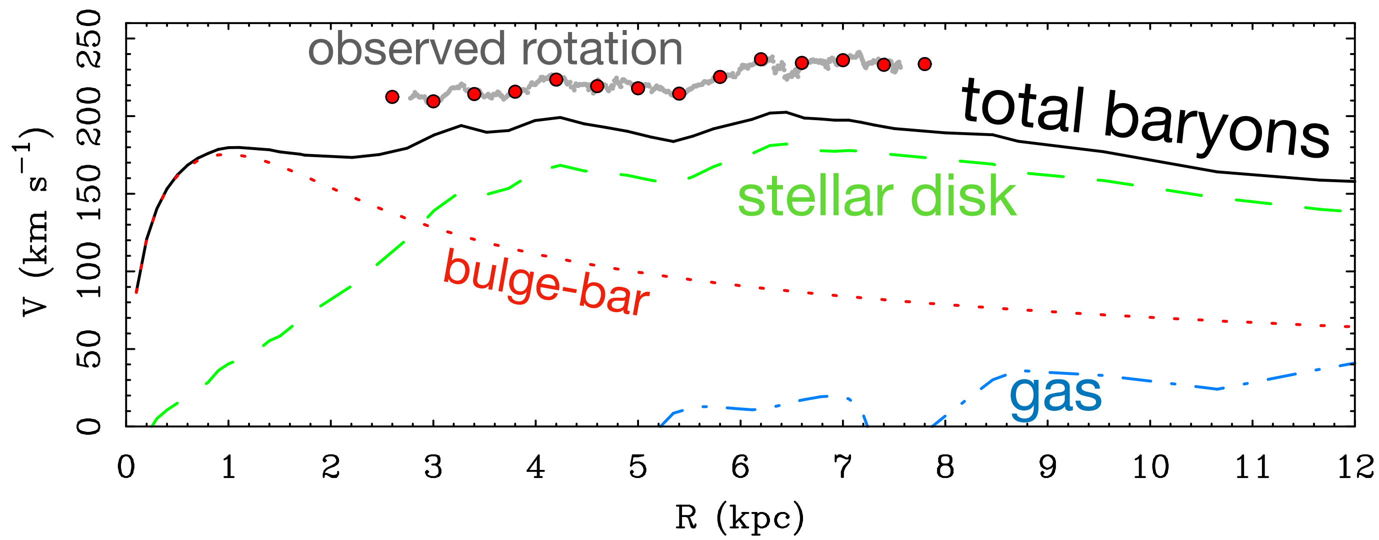
Mass modeling - Milky Way example



Surface density profile

$\Sigma(R)$ *from observed surface brightness profile*

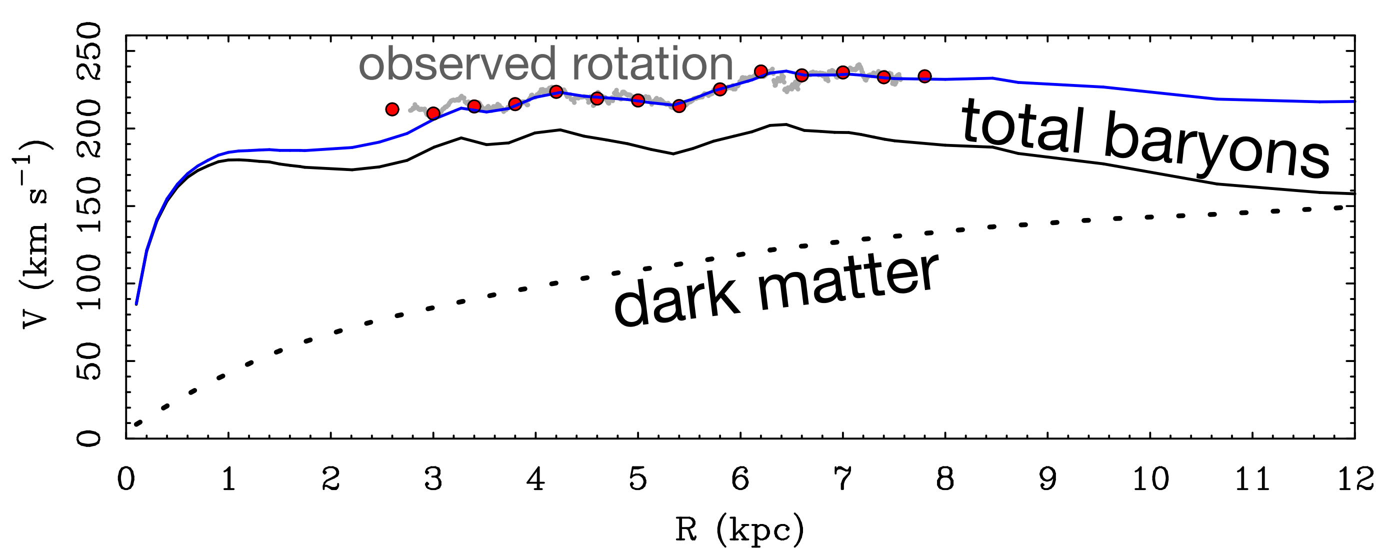
The main uncertainty is the mass-to-light ratio of the stars.



Mass model

$$\frac{V^2}{R} = -\frac{\partial \Phi}{\partial R} = 2\pi G \Sigma(R)$$

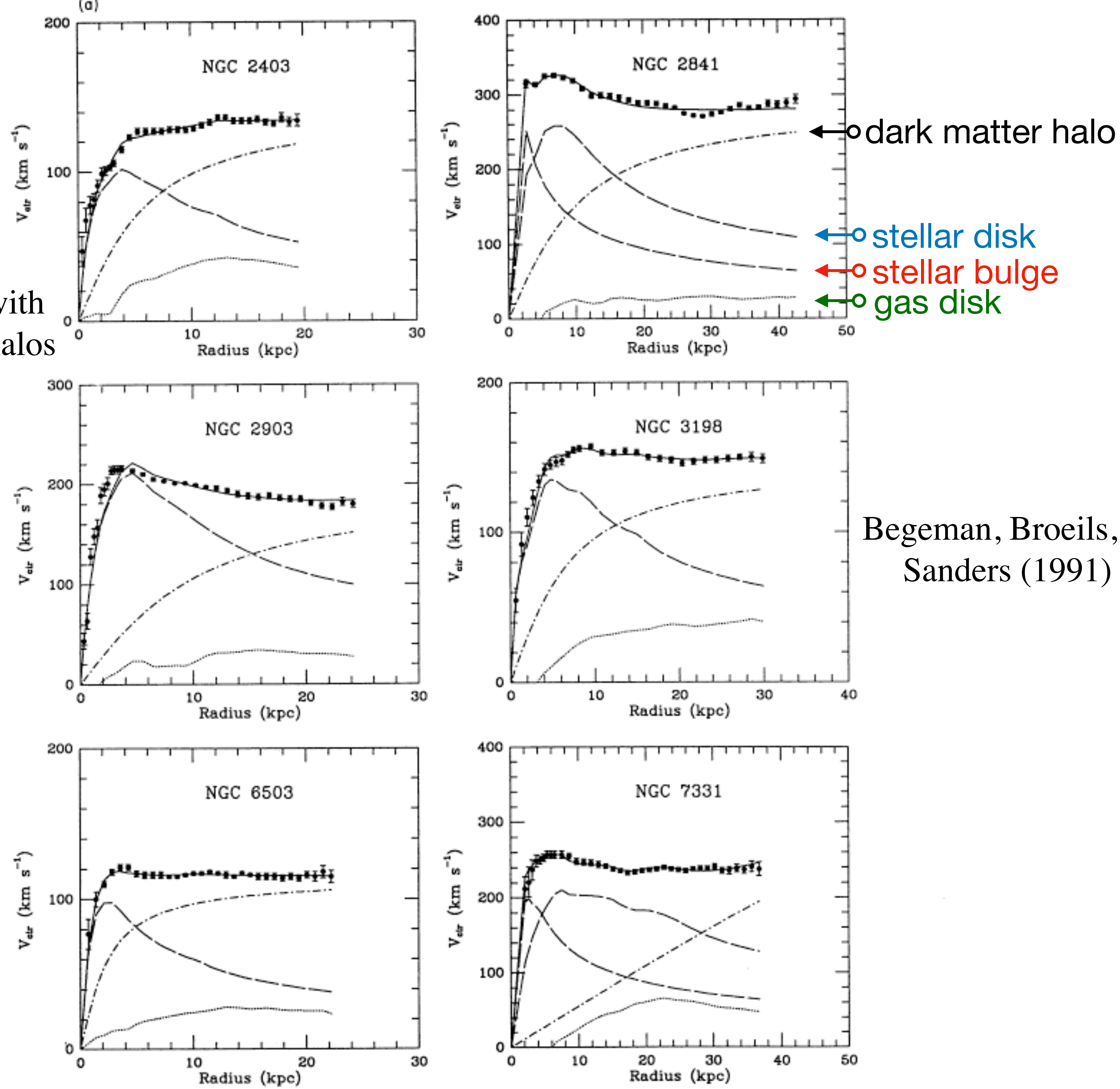
$$V_{DM}^2 = V_{obs}^2 - V_{bar}^2$$



Mass model with DM halo

Total rotation decomposed into baryonic and dark components

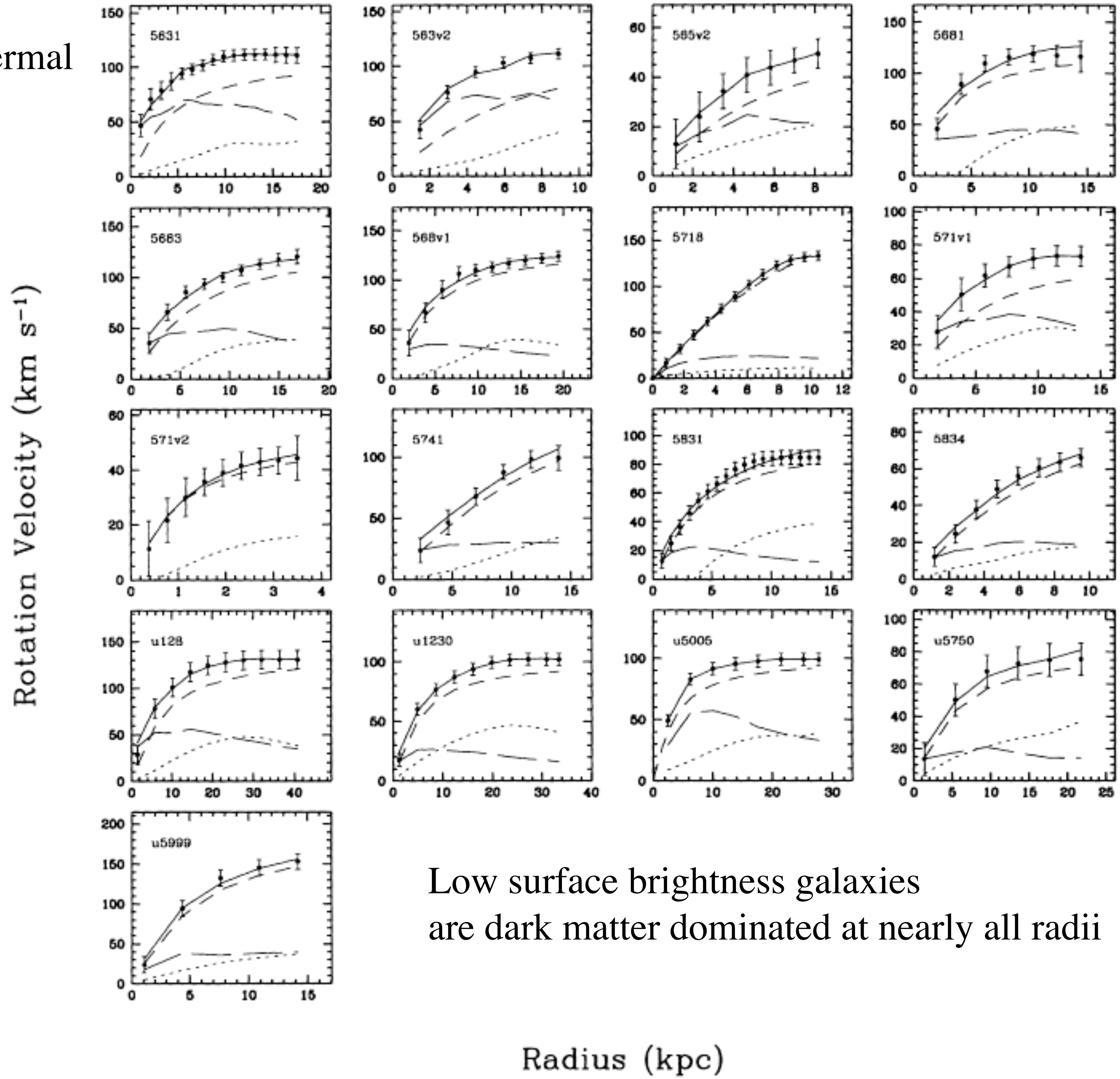
Rotation curves fit with pseudo-isothermal halos



Begeman, Broeils, & Sanders (1991)

 (1997) - low surface brightness galaxies

pseudo-isothermal fits



Low surface brightness galaxies
are dark matter dominated at nearly all radii

Figure 5. Maximum disc rotation curve decompositions of the final sample of LSB galaxies. The dotted lines represent the rotation curves of the gas; the long-dashed line those of the scaled stellar disc; the short-dashed lines the rotation curves of the halo. The full line represents the total model rotation curve. Error bars are based on a combination of profile width in the position–velocity diagrams (BMH96) and the asymmetries between the rotation curves of both sides of the

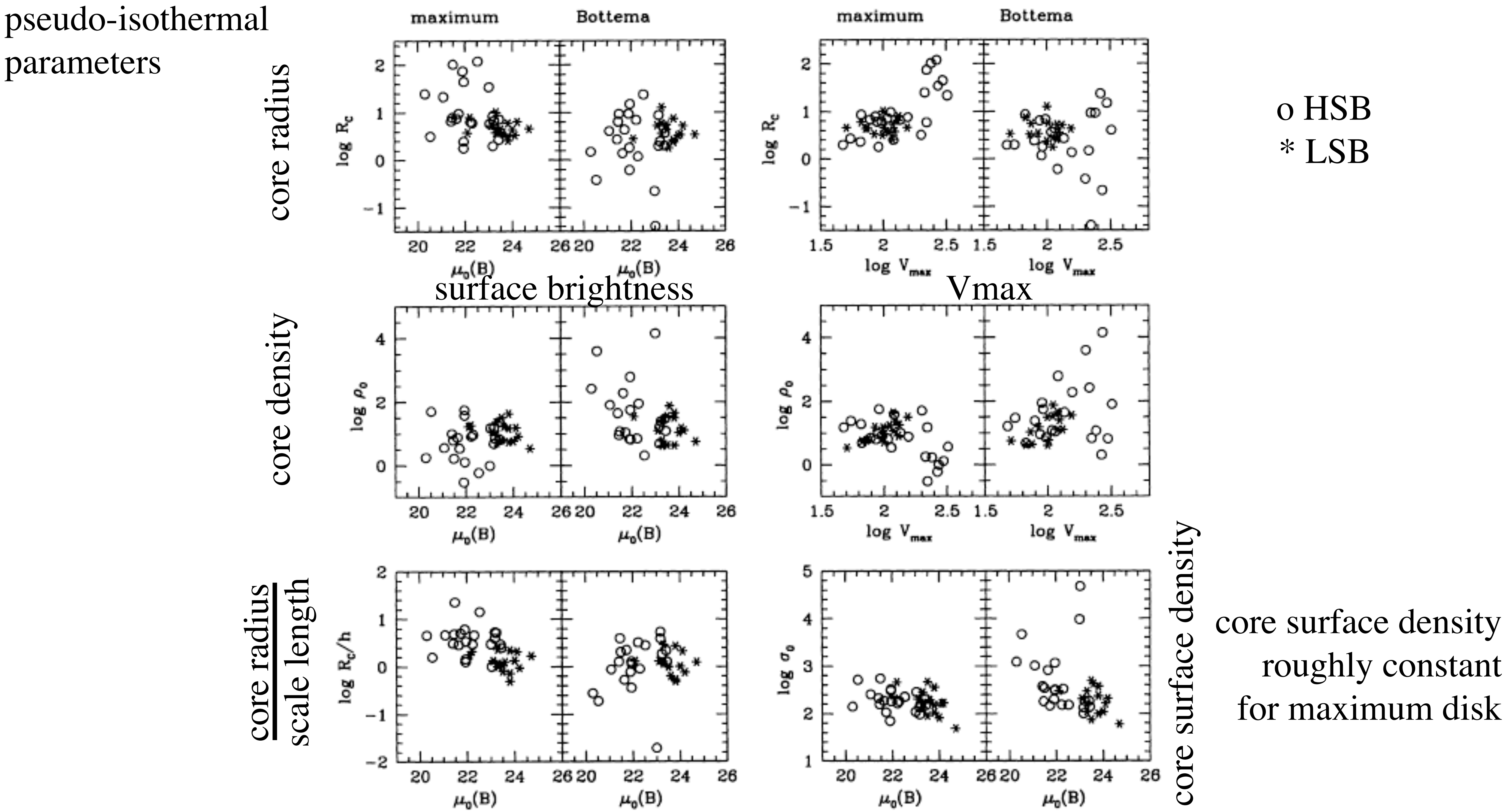


Figure 9. Isothermal halo fitting parameters for maximum disc fits (left panels) and Bottema disc fits (right panels). The open circles represent the HSB sample, the asterisks the LSB sample. ρ_0 is expressed in units of 10^{-3} M$_\odot$ pc^{-3}; R_C in kpc; σ_0 in 10^{-3} M$_\odot$ pc^{-2}; V_{max} in km s^{-1}; and $\mu_0(B)$ in mag arcsec^{-2}.

5.4 Minimum disc

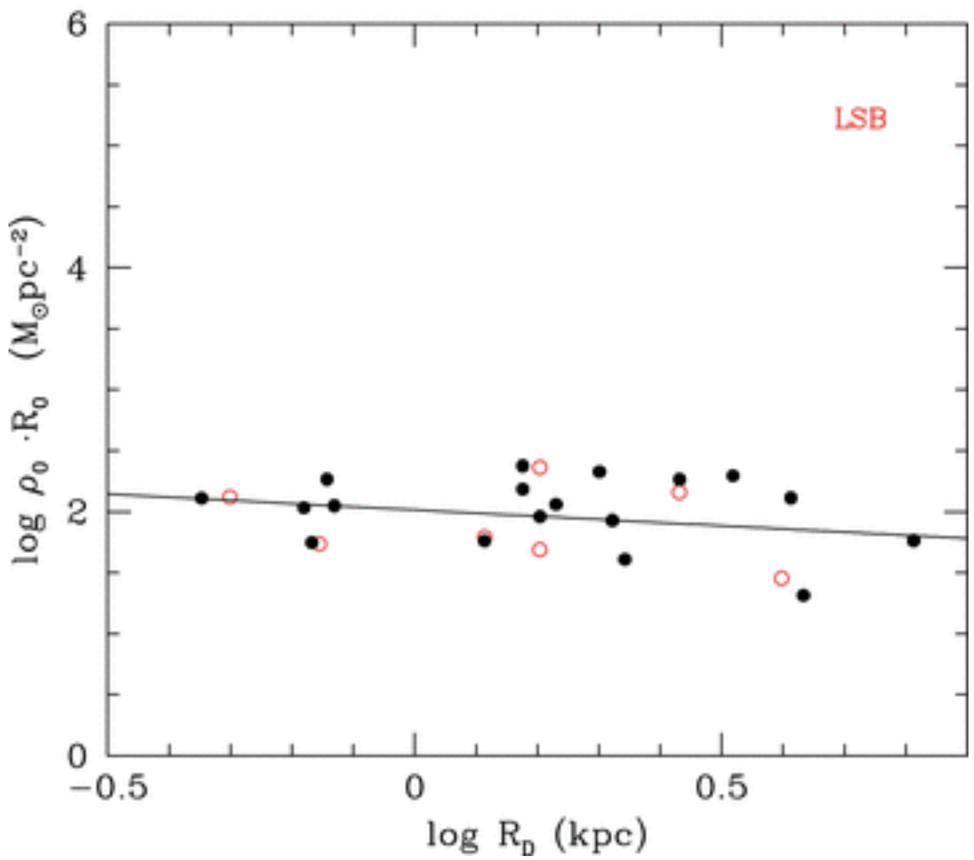
We can illustrate that the halo parameters derived for the LSB galaxies are robust values by comparing the values derived for maximum disc and minimum disc. This is done in Fig. 10, where the core radii and central densities as derived using these two extreme hypotheses are compared. The difference in maximum and minimum disc–halo parameters is clearly a strong function of surface

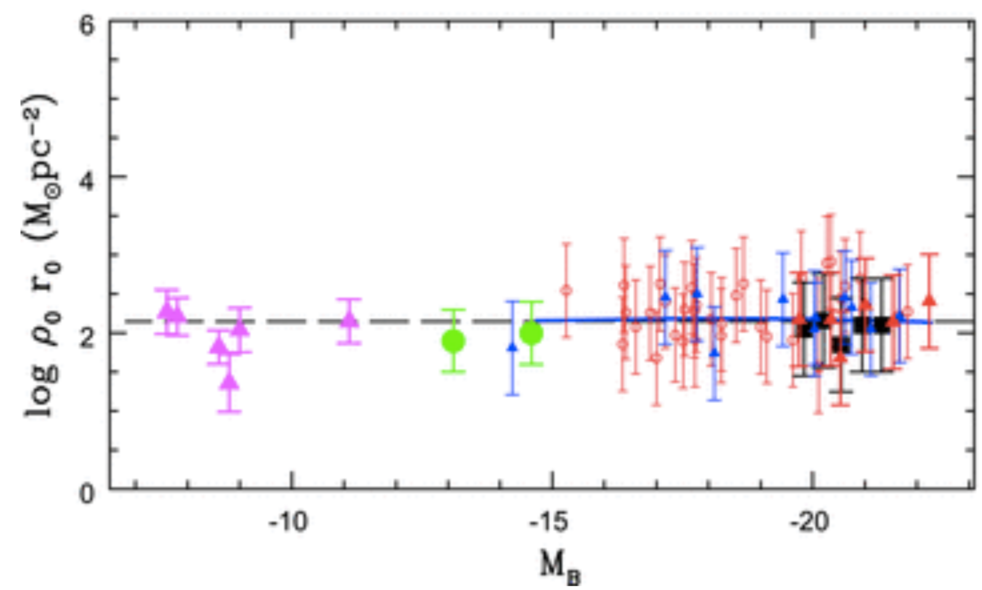
5.5 Bottema disc mass-to-light ratios

The most important property that distinguishes the Bottema disc from the maximum disc is its small range of $(M/L_B)_\star$. This is immediately apparent in Fig. 8. The Bottema disc typically implies values of $(M/L_B)_\star$ between 1 and 2. In general the reddest galaxies have the highest mass-to-light ratios.

The striking systematic offset in $(M/L)_\star$ at fixed V_{max} between

Halo core surface density (product of core density and core radius)
is nearly constant (Donato et al 2009)



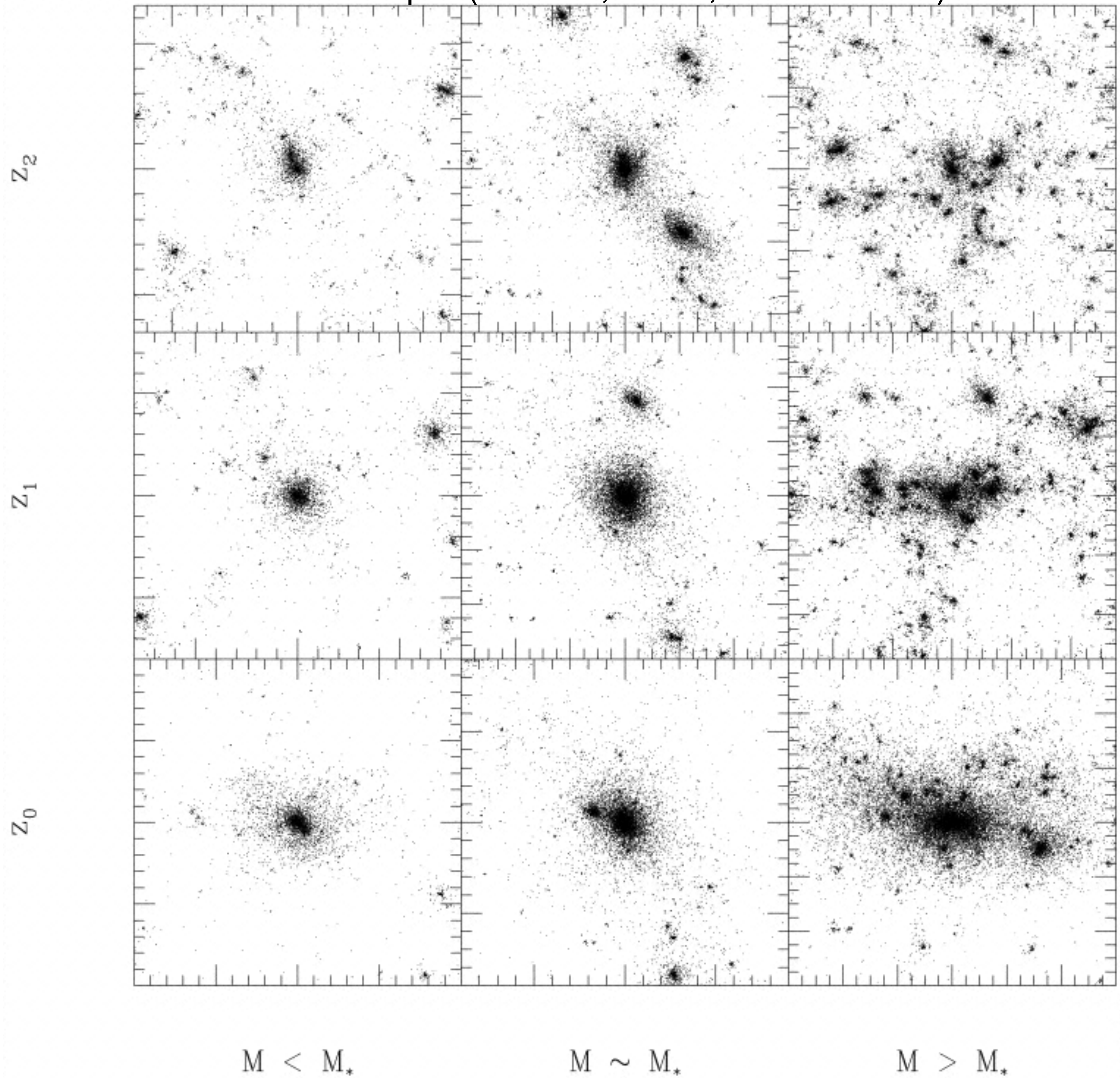


$$\mu_{0D} = \rho_0 R_C$$

$$\log \mu_{0D} = 2.2 \pm 0.25 \text{ M}_\odot \text{ pc}^-2$$

Simulation output (Navarro, Frenk, & White 1997)

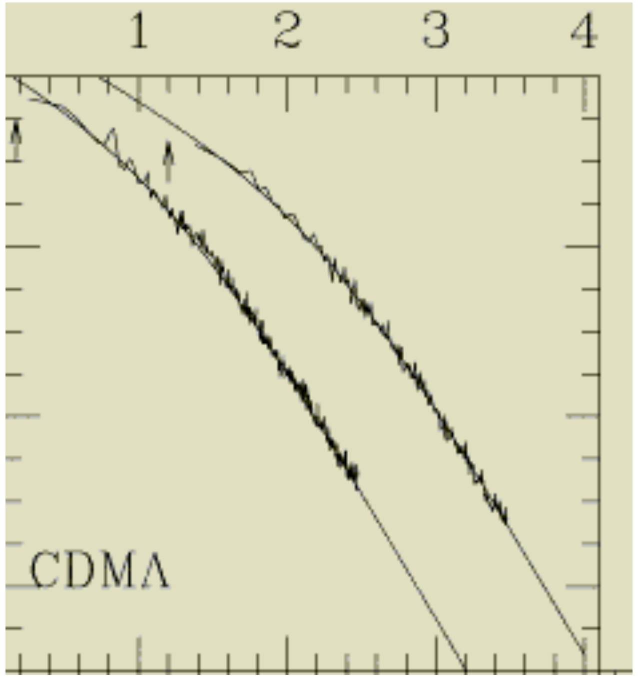
NFW



Aquarius large scale structure simulation

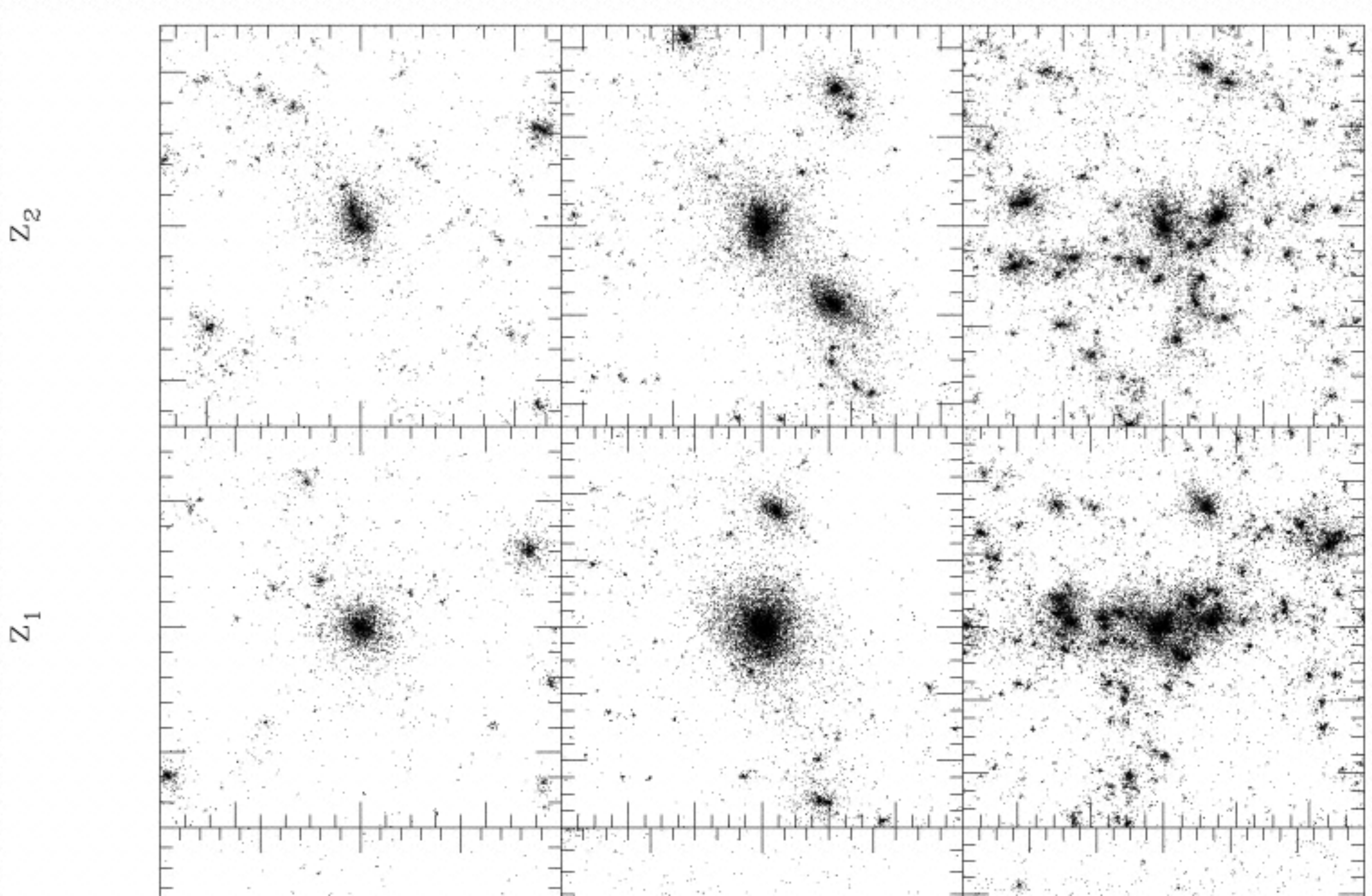
http://www.youtube.com/watch?v=2qeT4DkEX-w

NFW



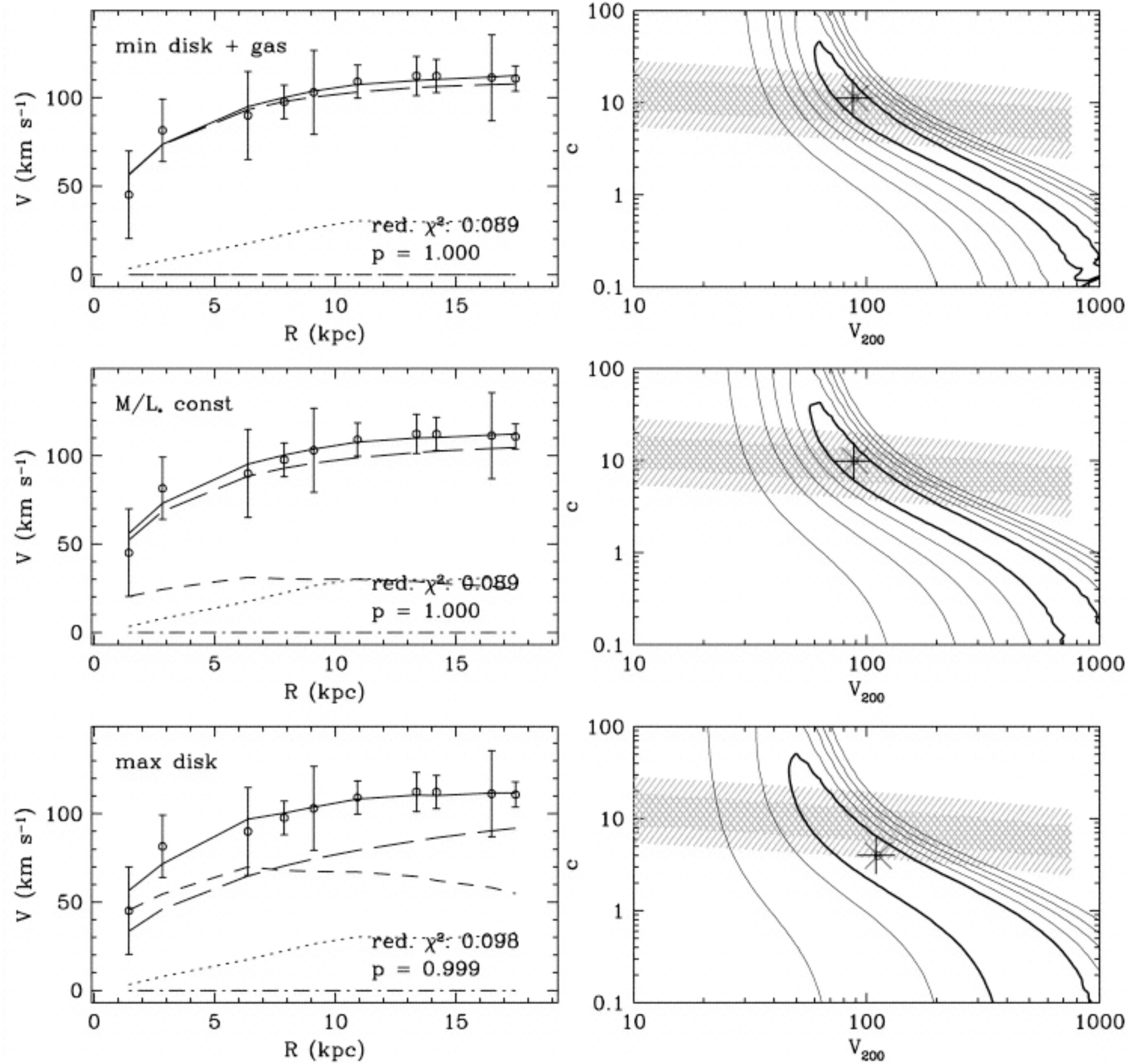
NFW halo

$$\rho(r) = \frac{\rho_s r_s^3}{r(r + r_s)^2}$$



NFW
fits

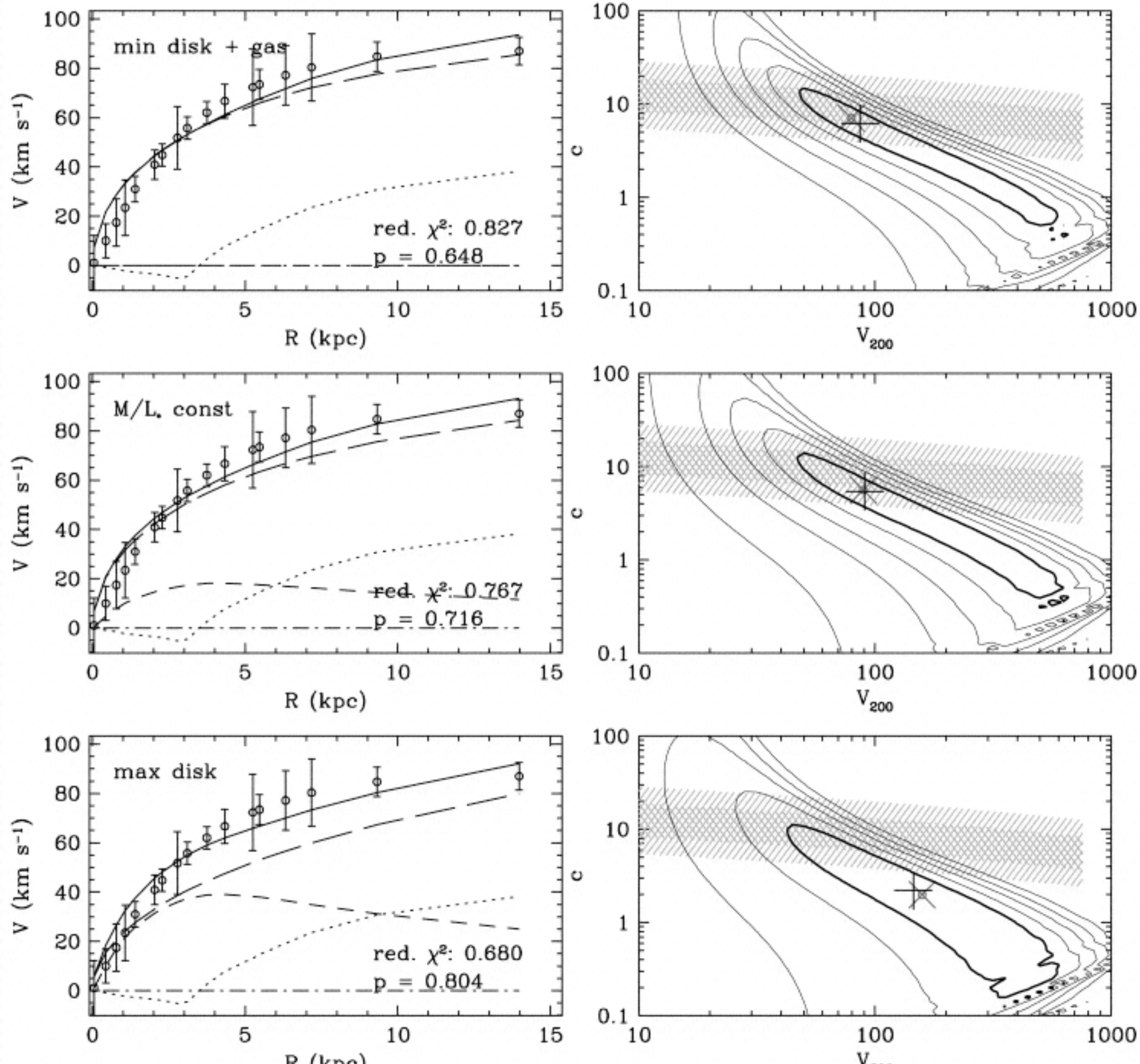
LSB
F563-1



considerable parameter degeneracy!

NFW fits

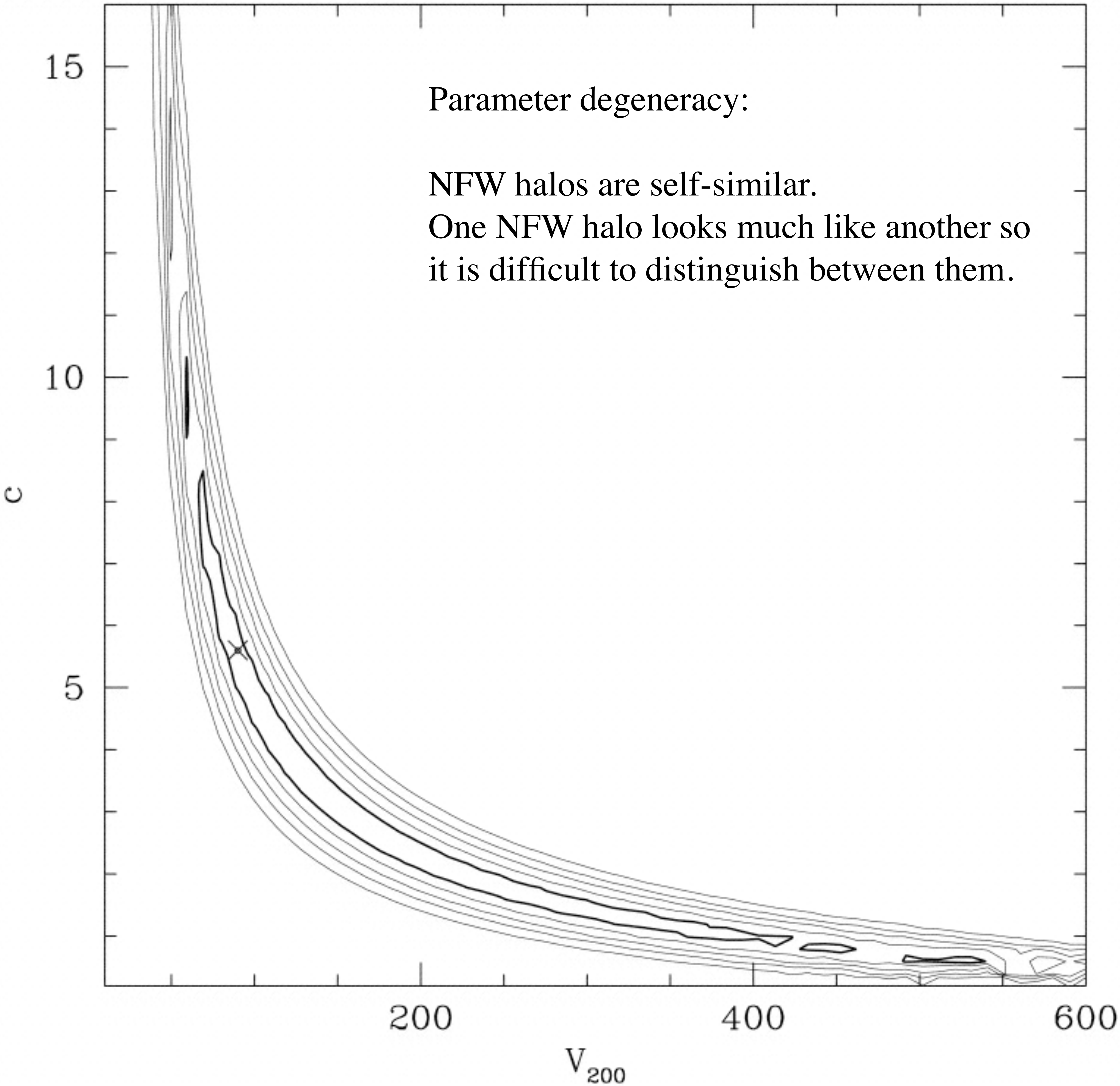
LSB F583-1



considerable parameter degeneracy!

NFW
fits

LSB
F583-4



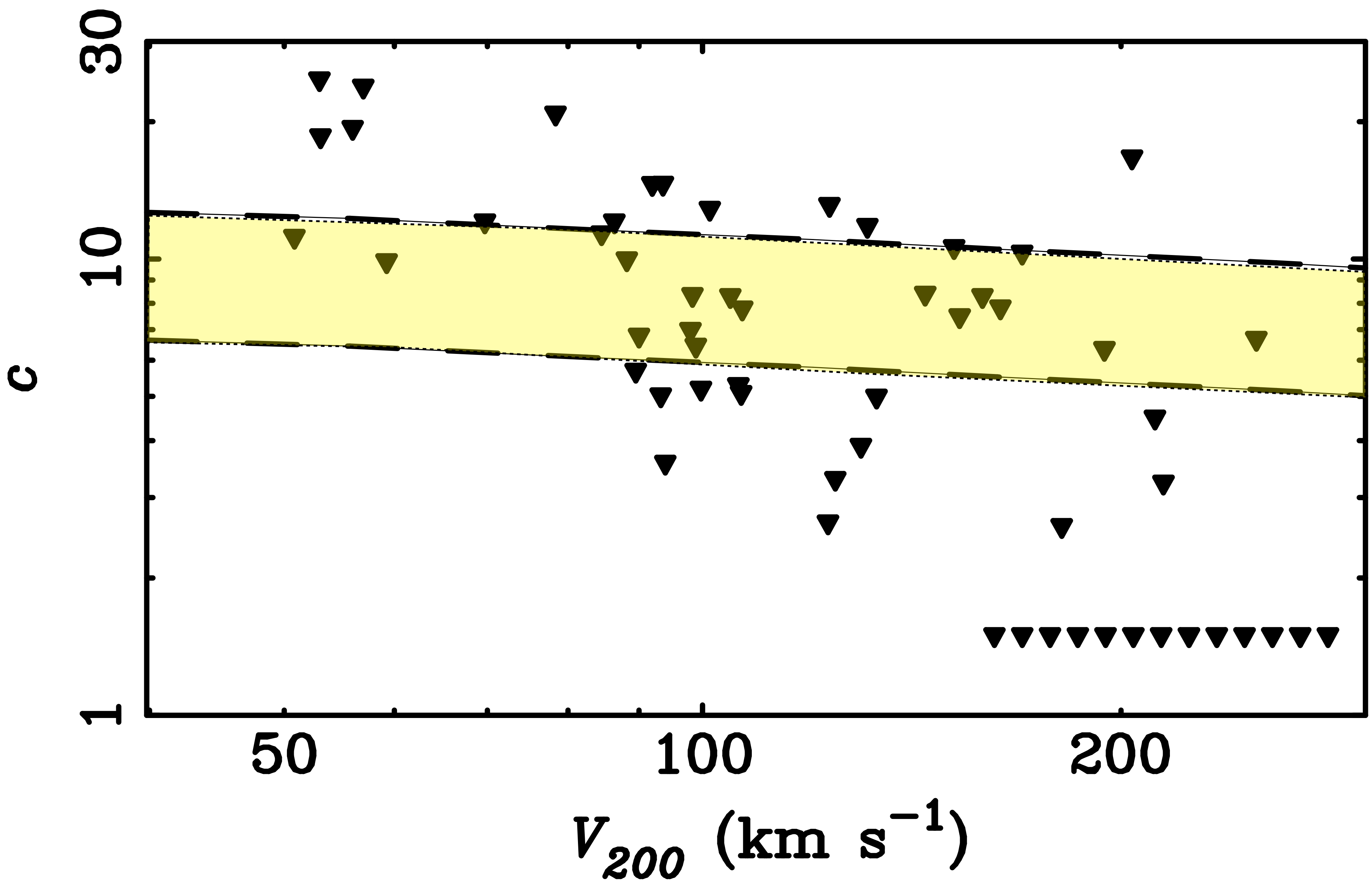
Parameter degeneracy:

NFW halos are self-similar.
One NFW halo looks much like another so it is difficult to distinguish between them.

considerable parameter degeneracy!

NFW
c-V200
relation

LCDM predicts a specific mass-concentration relation



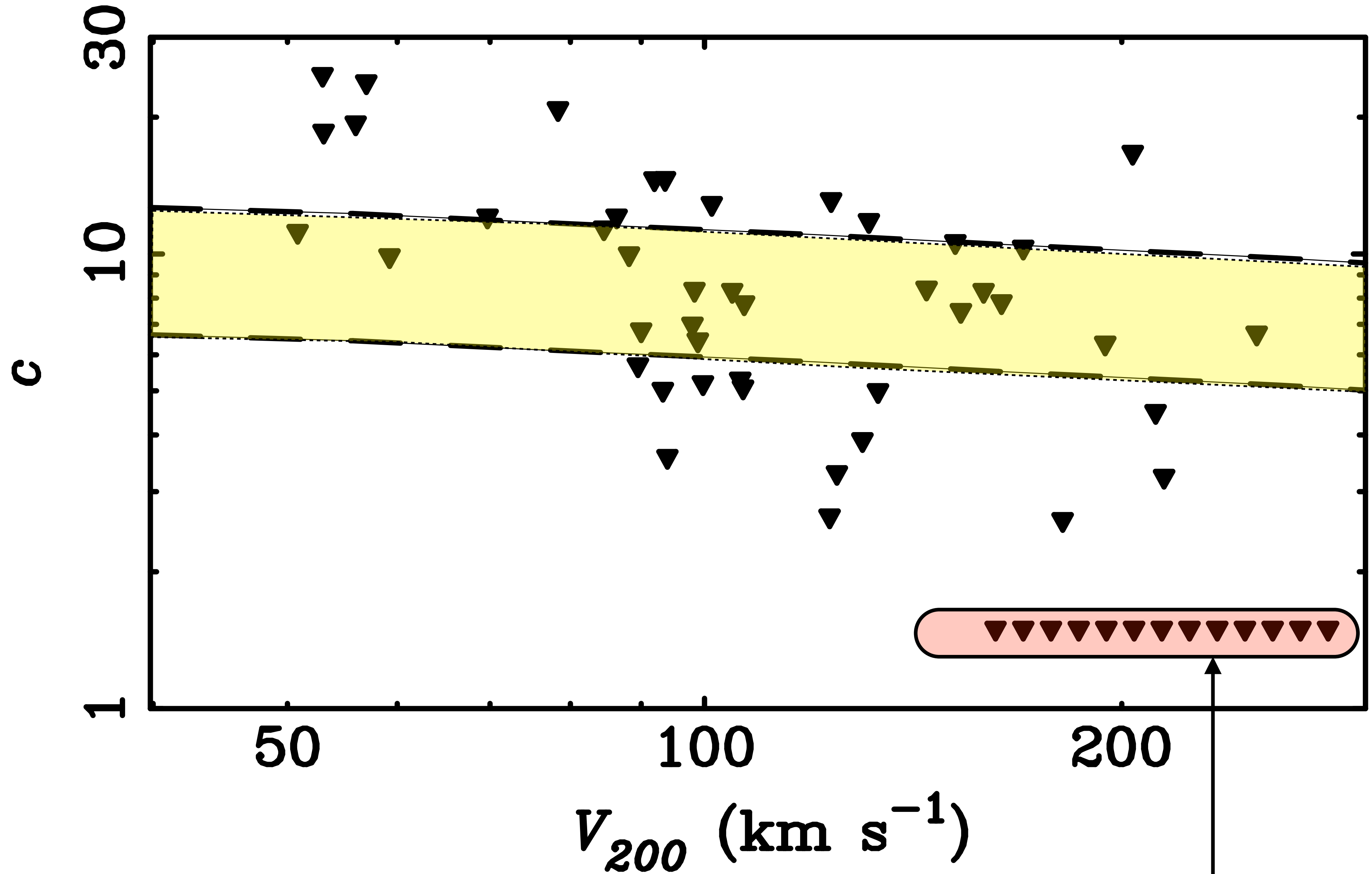
$$\log c = 0.844 - 0.098 \log \left(\frac{M_{200}}{10^{12}\ \mathrm{M}_\odot} \right)$$

This LCDM mass-concentration relation is mildly cosmology dependent

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

NFW
c-V200
relation

NFW halos are a one parameter family with some scatter



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).