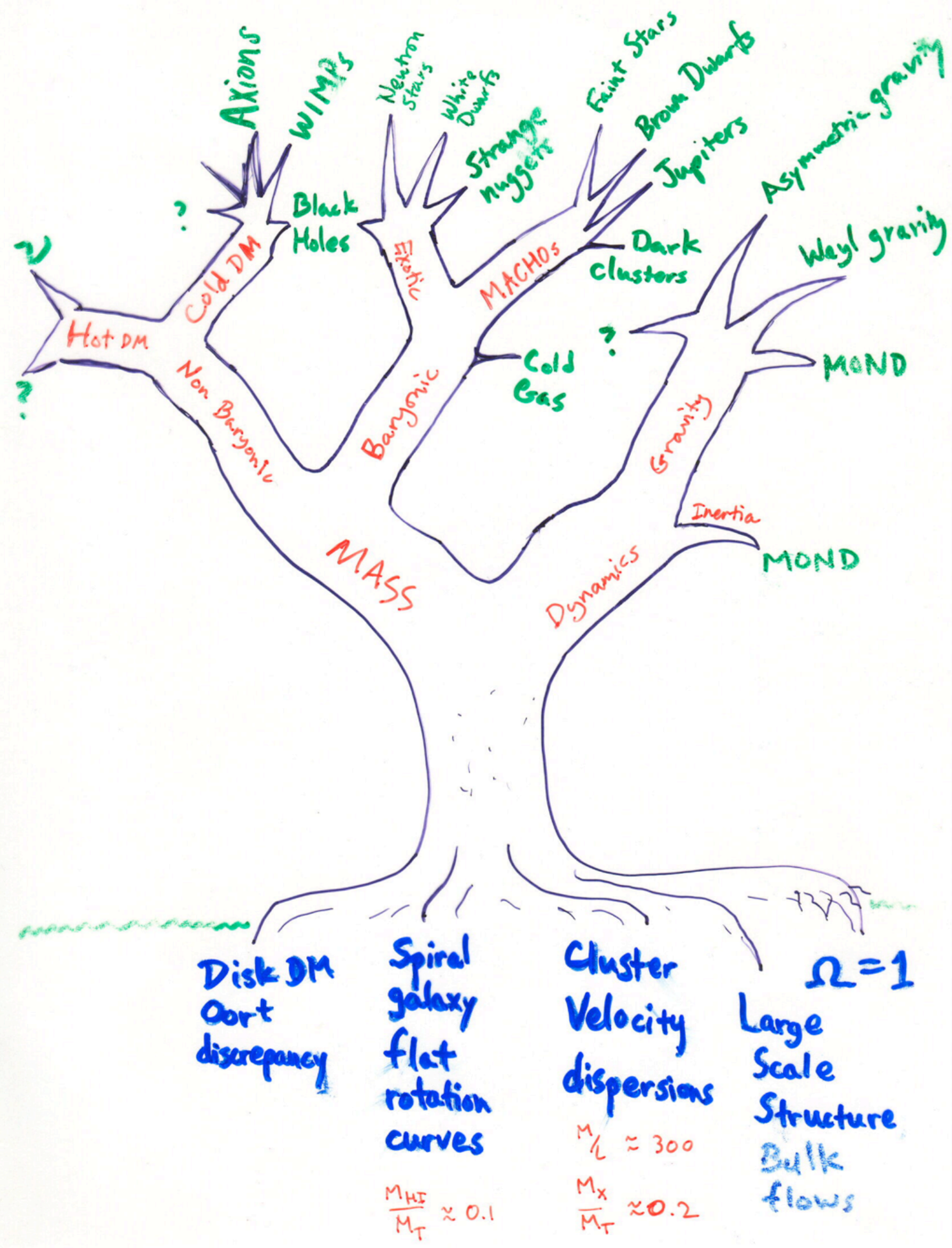
Dark Matter

ASTR 333/433

TODAY

Dark Matter Halo Models



Halo models

pseudo-isothermal

older
empirically motivated

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

theoretically reminiscent of an isothermal distribution

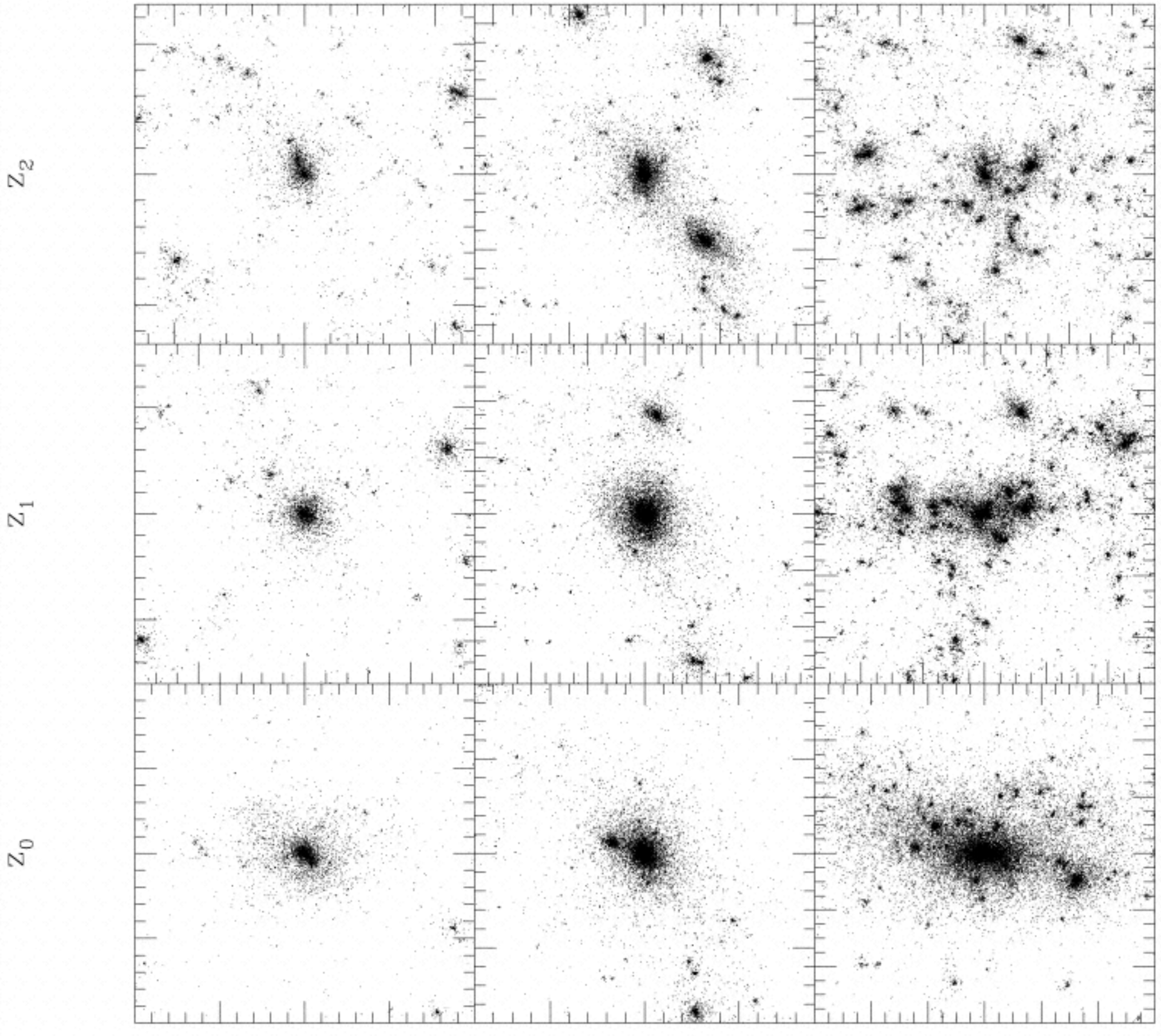
Both models have 2 parameters - a characteristic density and scale radius

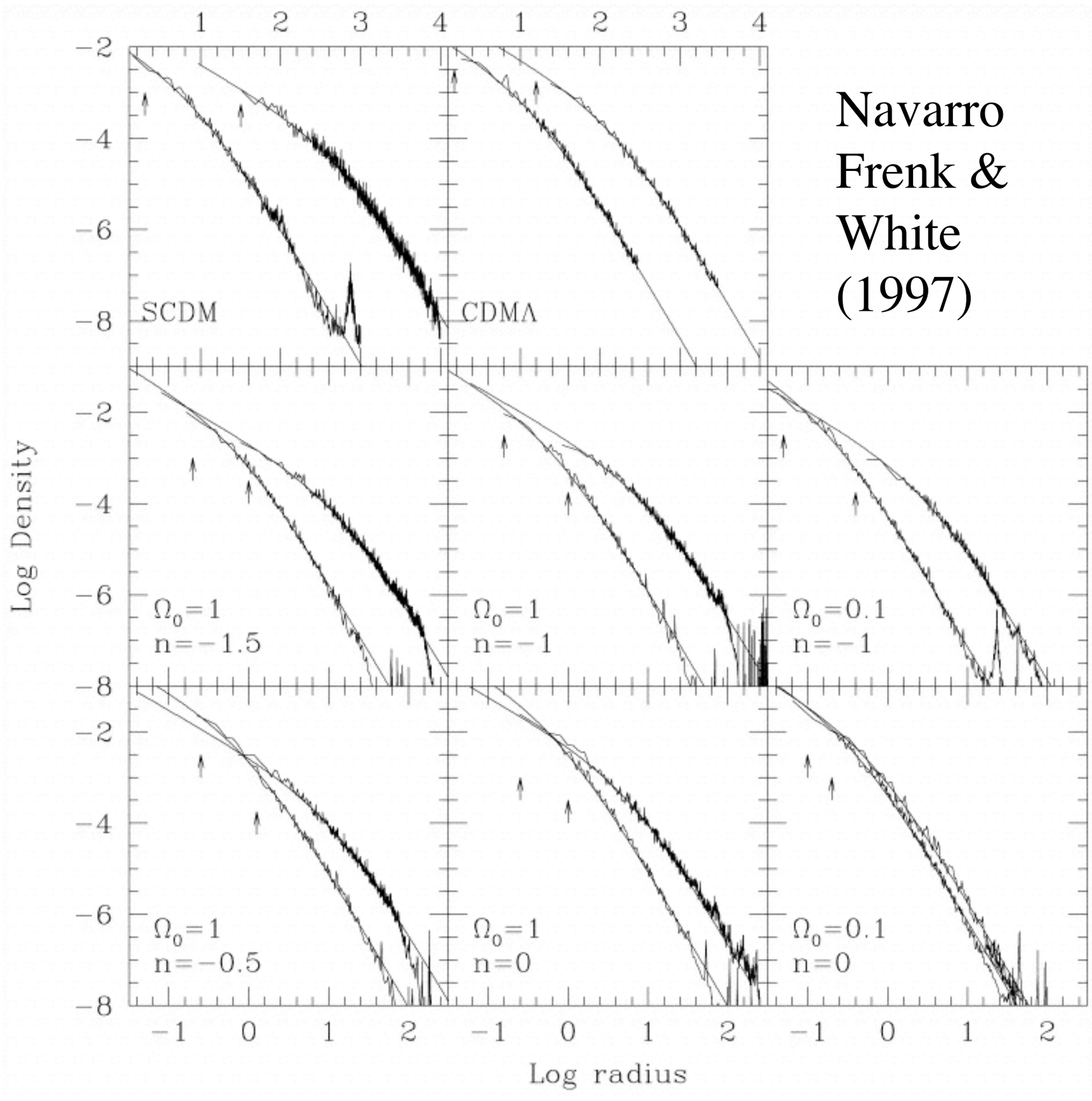
NFW

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

motivated by simulations

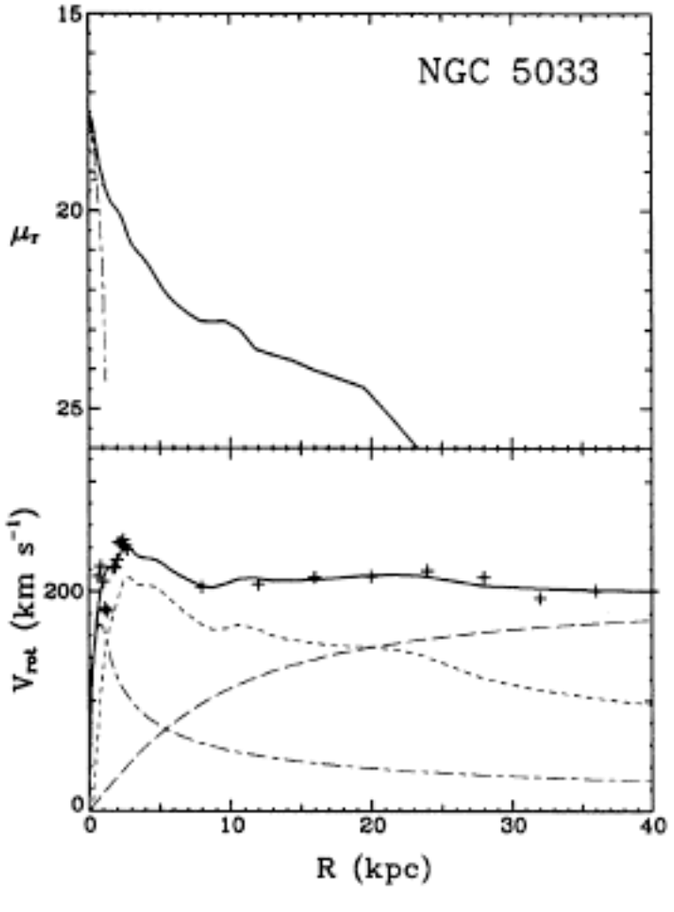
see “NFW halos” on review literature page

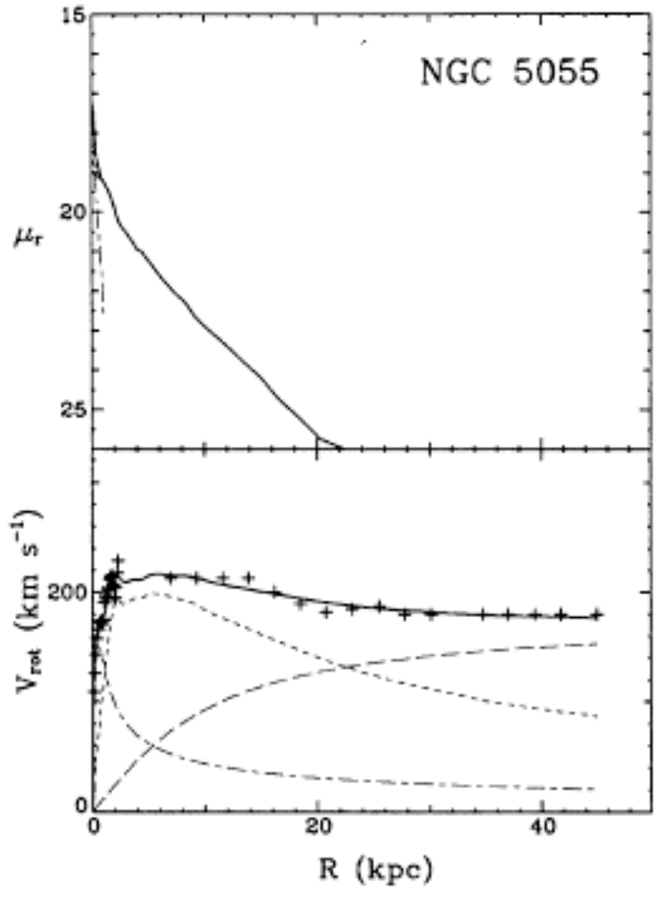

z_2
z_1
z_0
$M < M_*$
$M \sim M_*$
$M > M_*$



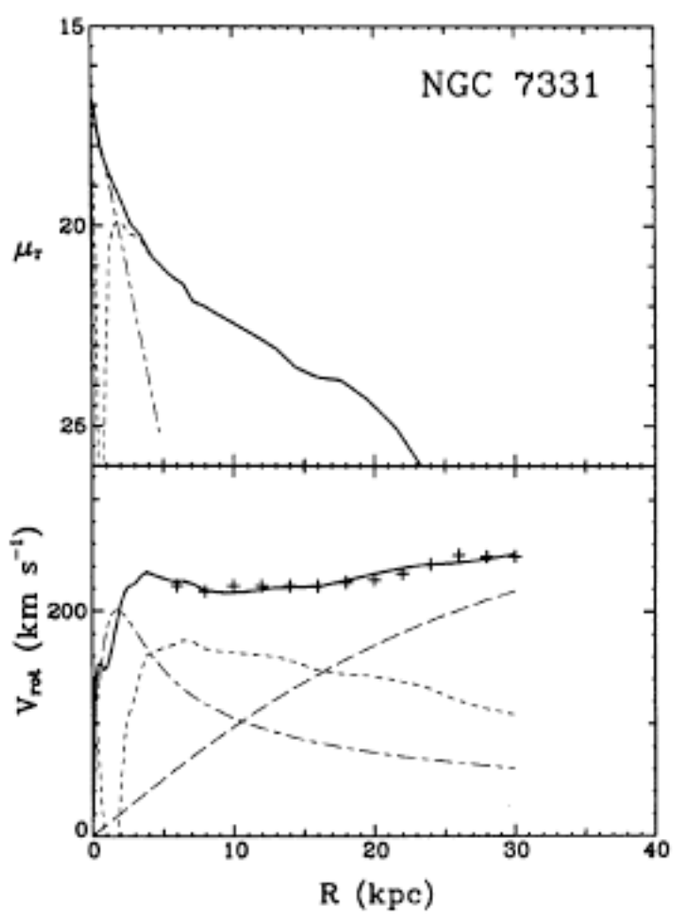
Navarro Frenk & White (1997)

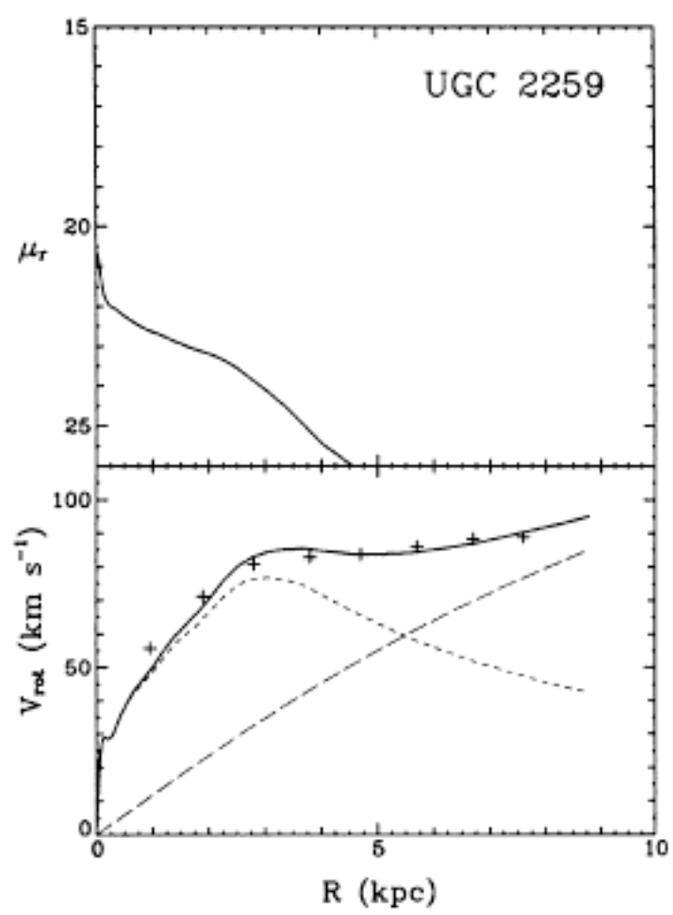
pseudo-isothermal fits



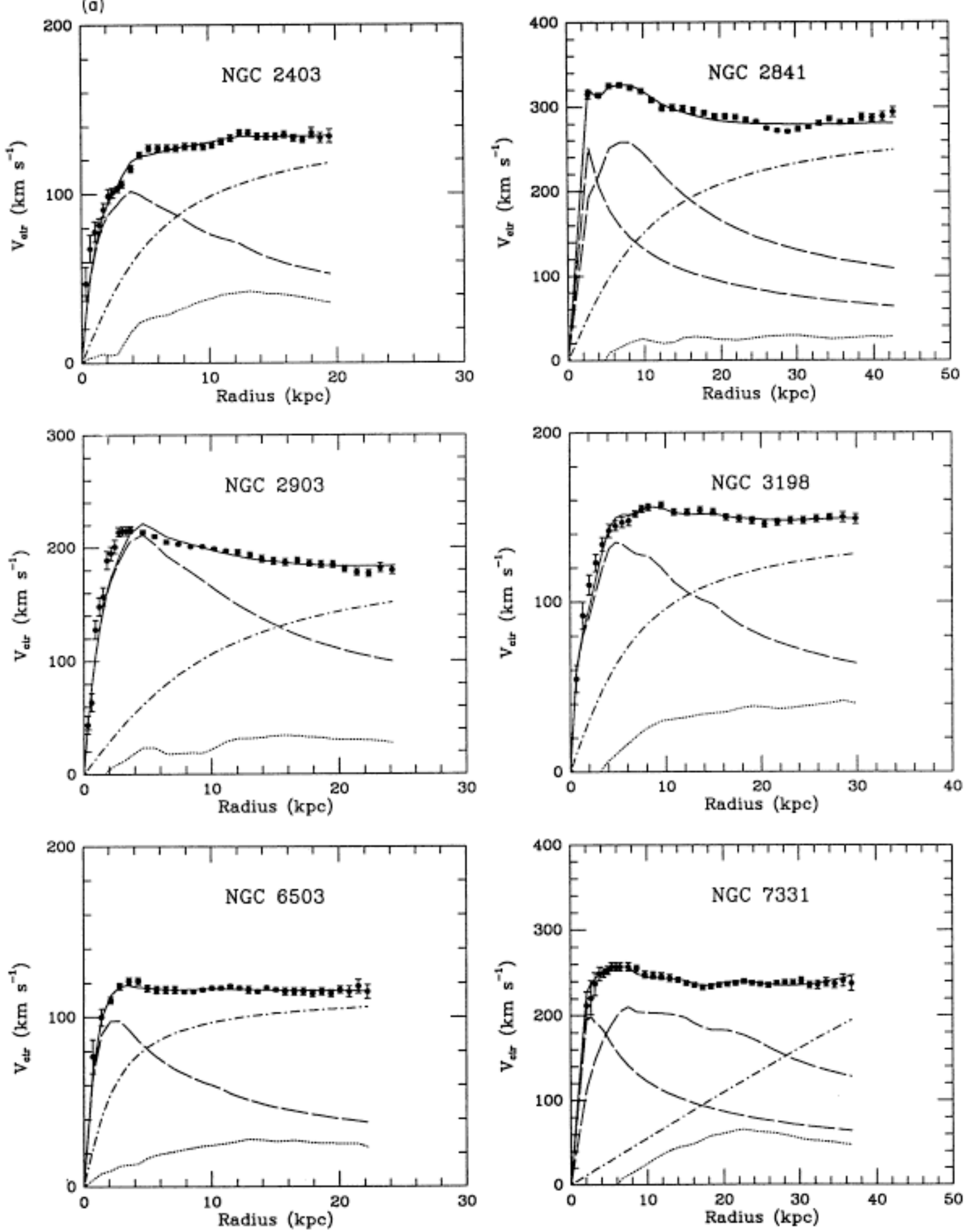


Kent (1987)



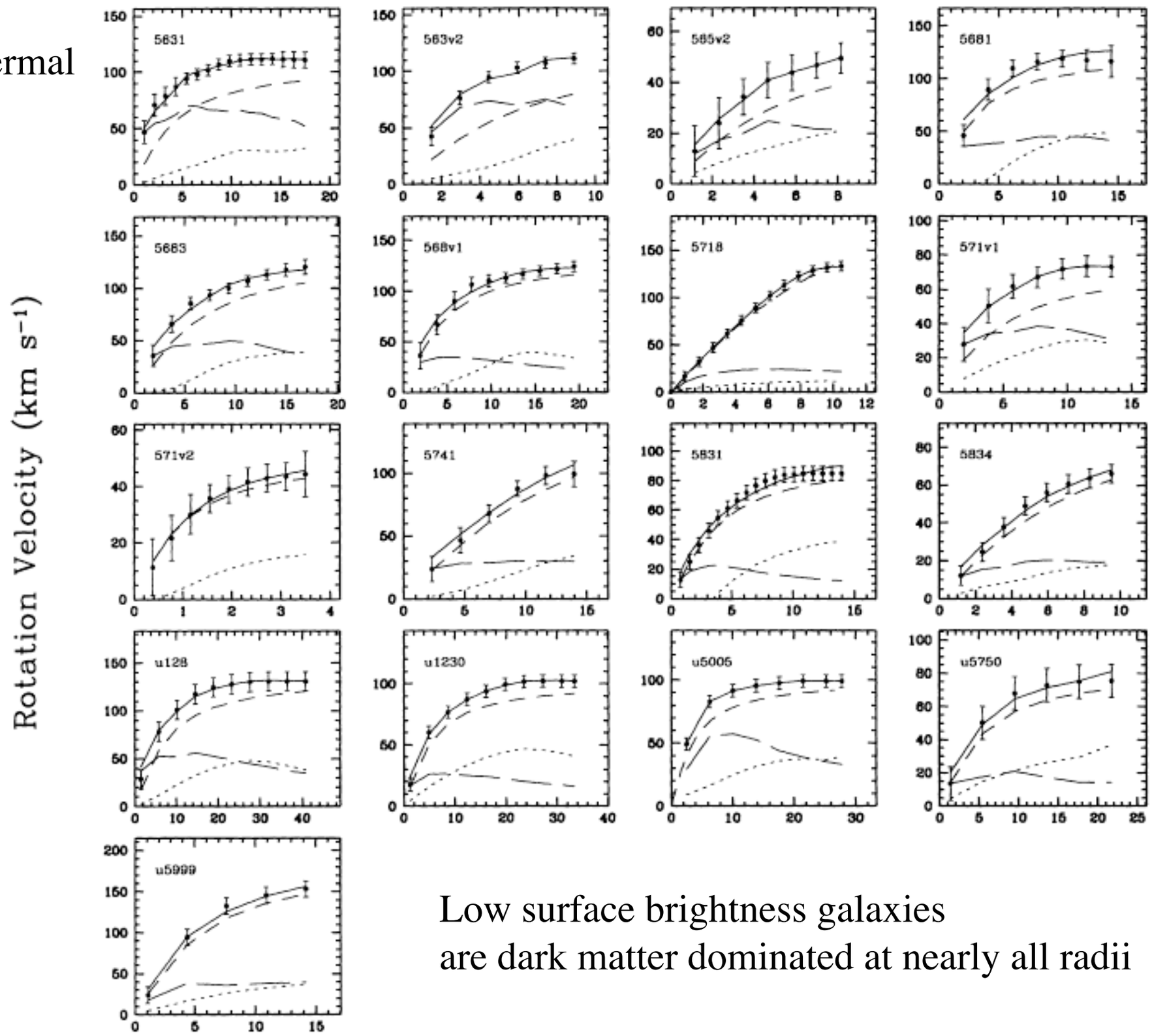


pseudo-isothermal fits



Begeman, Broeils, & Sanders (1991)

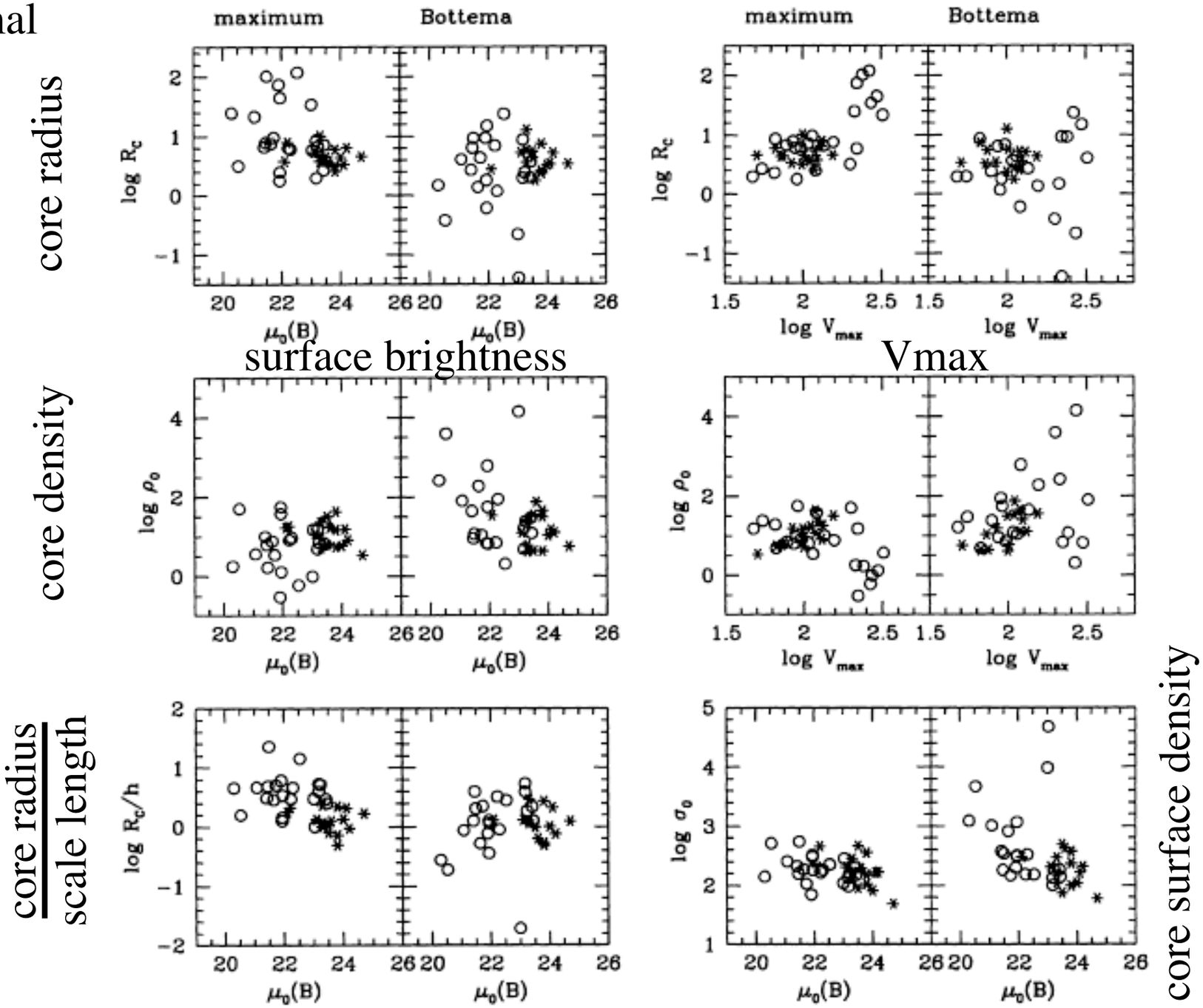
pseudo-isothermal fits



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

pseudo-isothermal parameters



o HSB
* LSB

core surface density roughly constant for maximum disk

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

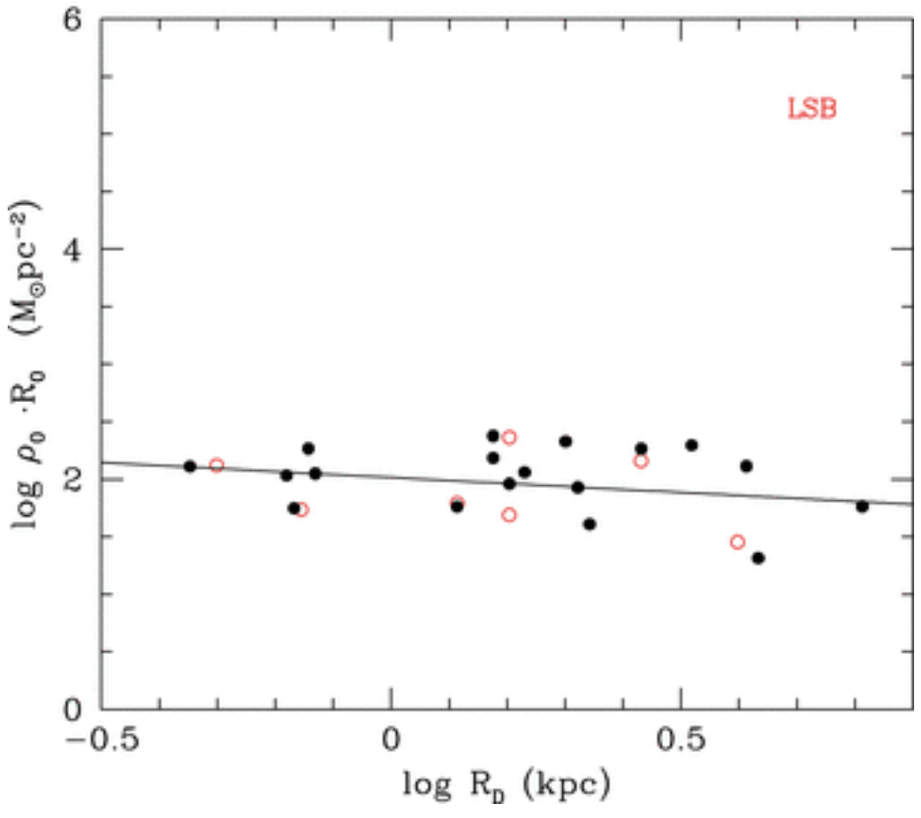
We can illustrate that the halo parameters derived for the LSB galaxies are robust values by comparing the values derived for maximum disc and minimum disc. This is done in Fig. 10, where the core radii and central densities as derived using these two extreme hypotheses are compared. The difference in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

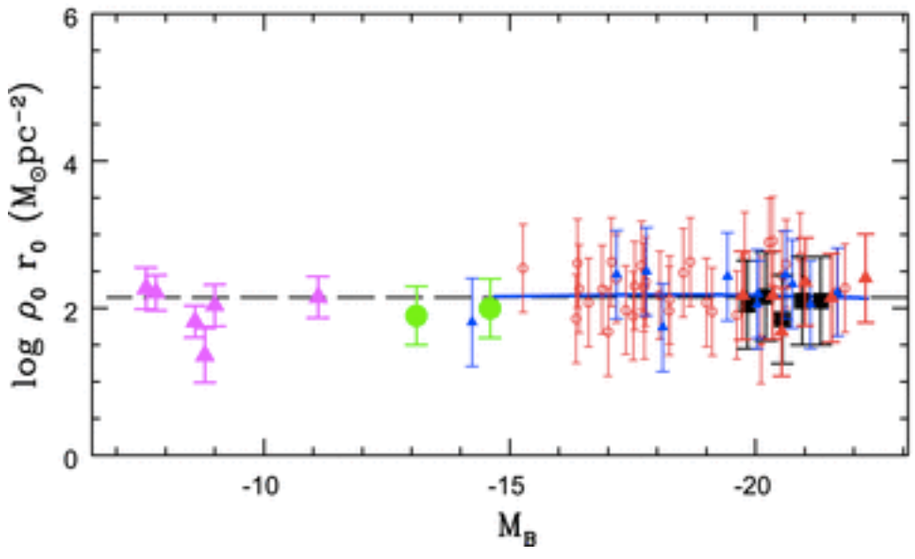
5.5 Bottema disc mass-to-light ratios

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)

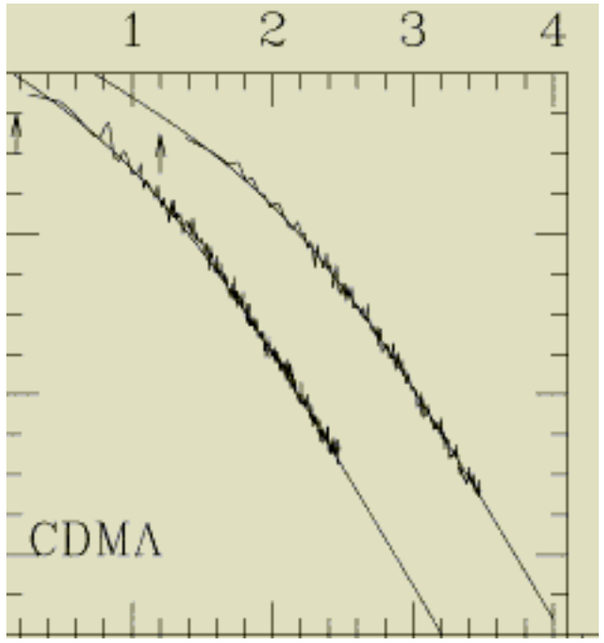


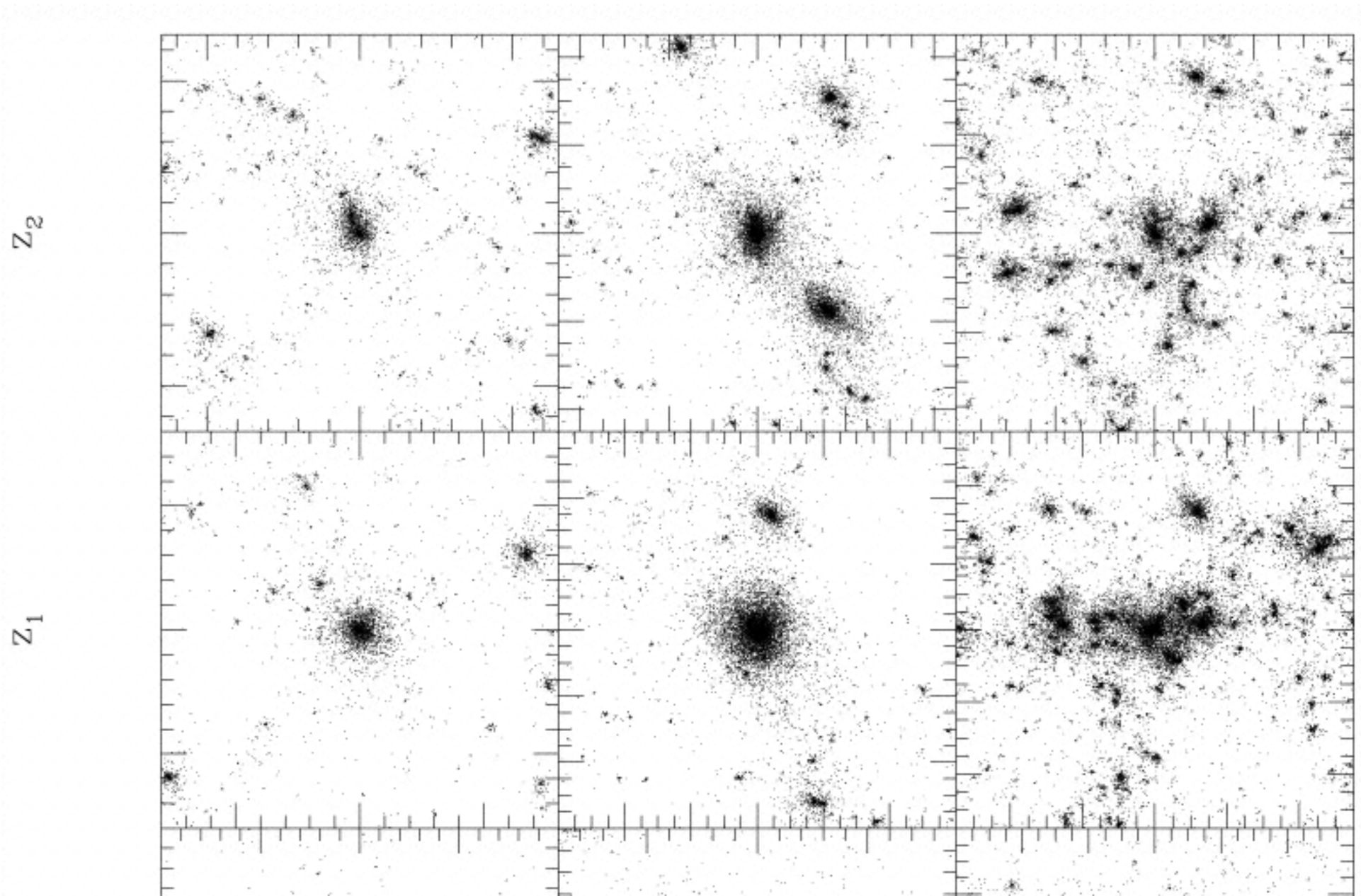


$$\mu_{0D} = \rho_0 R_C$$

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

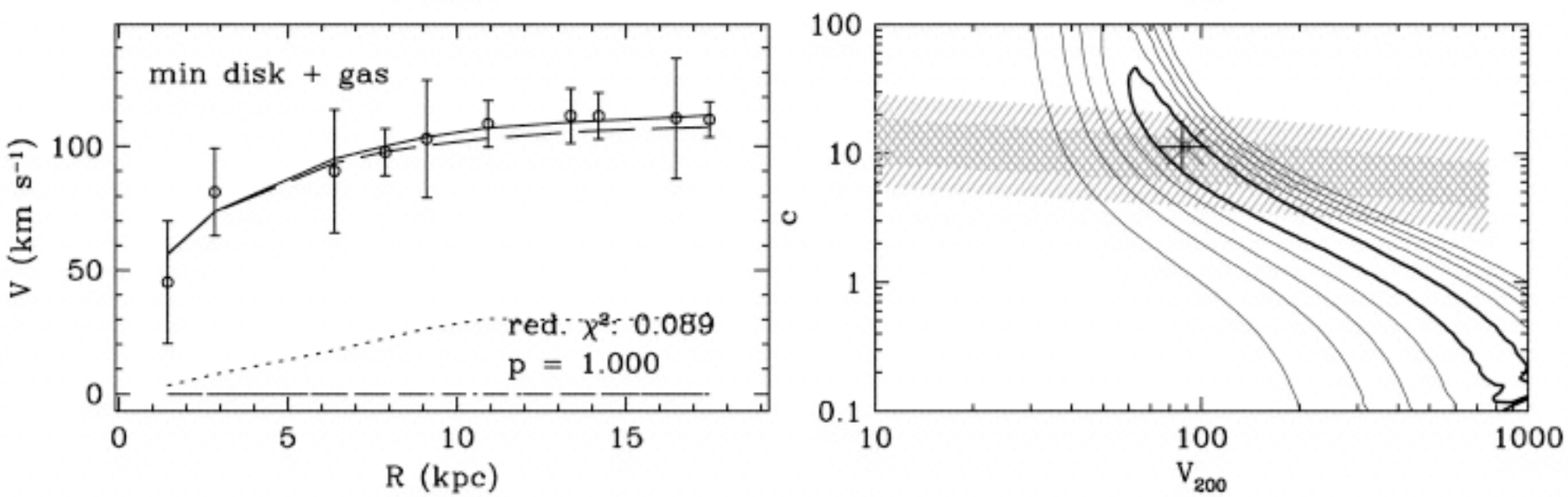
NFW

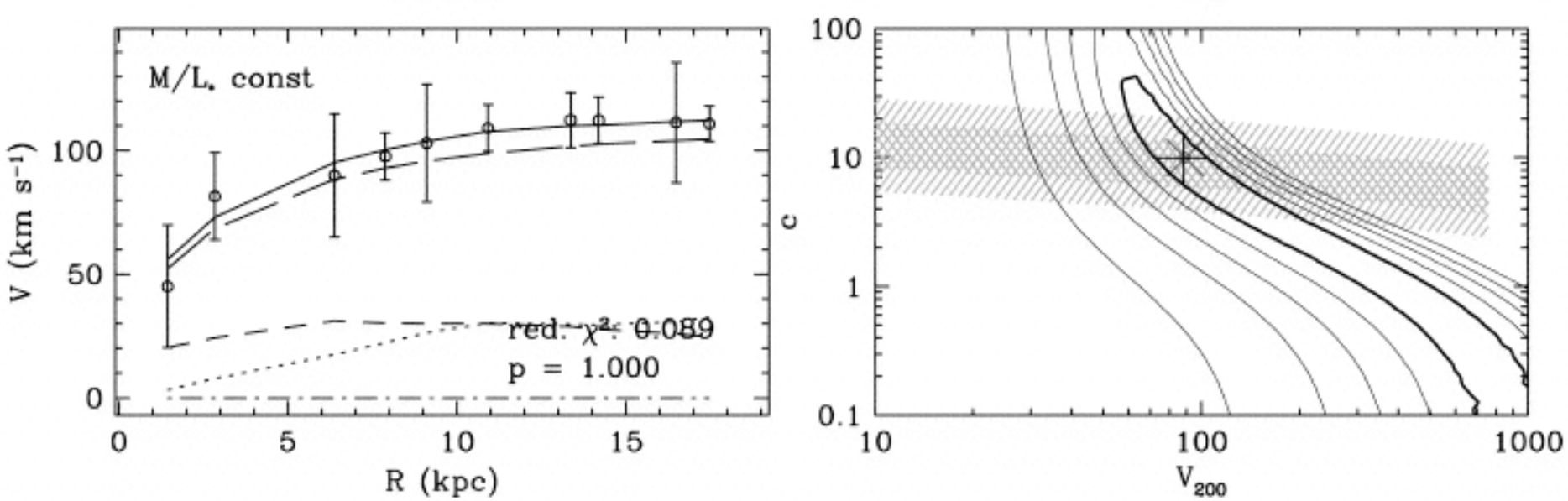


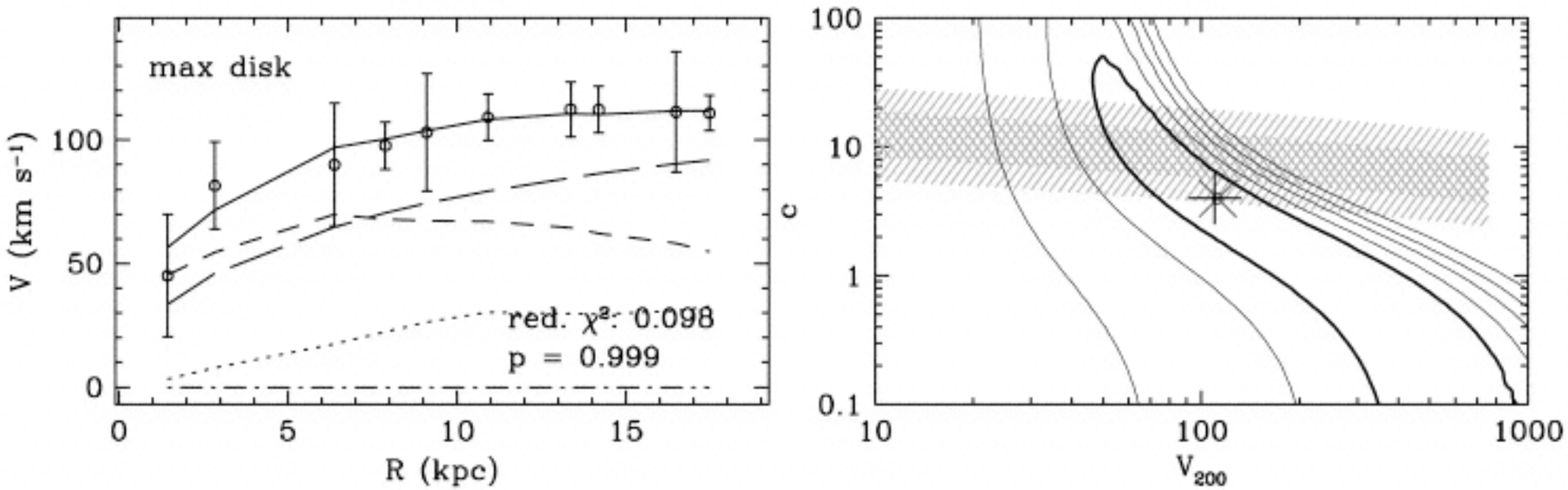


NFW fits

LSB F563-1

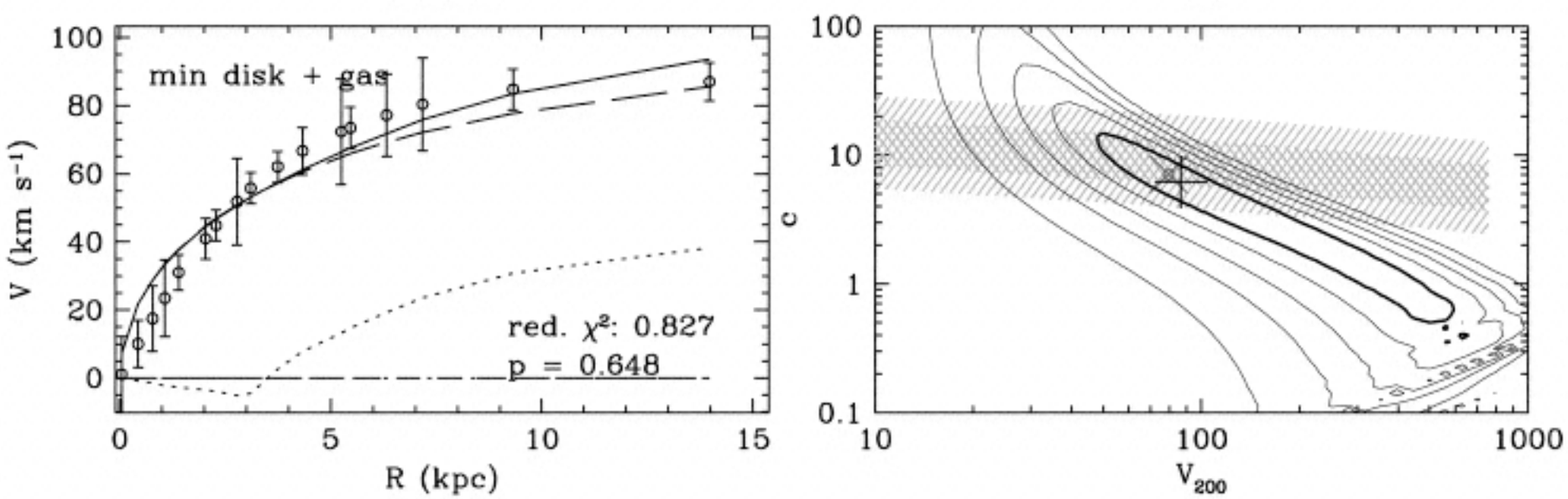


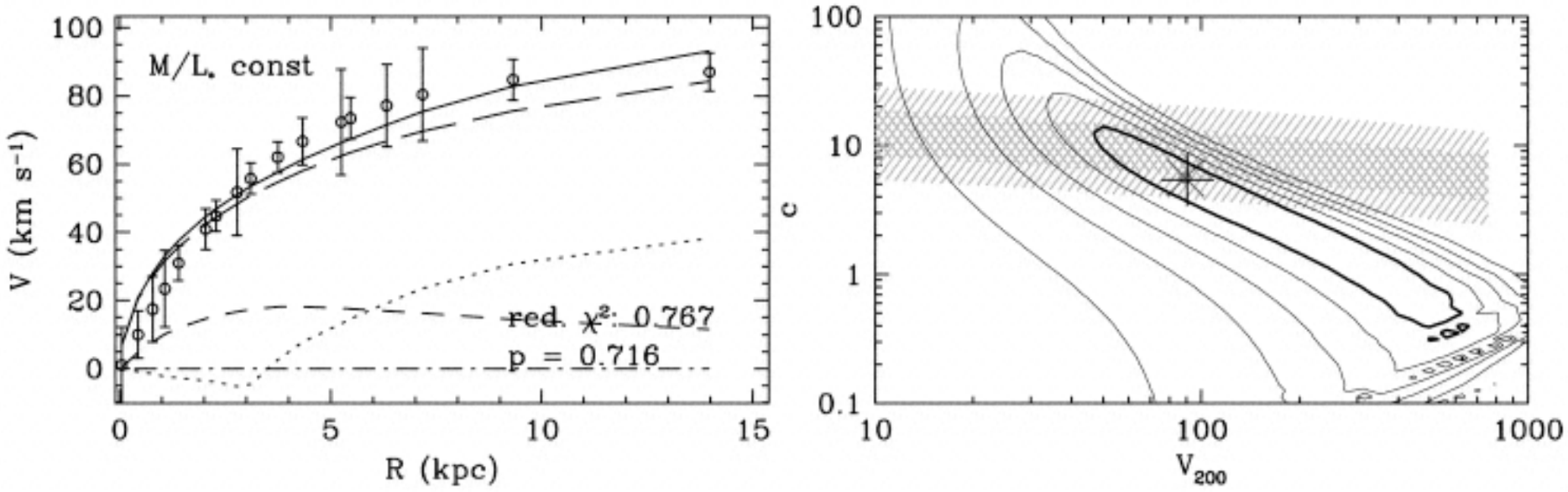


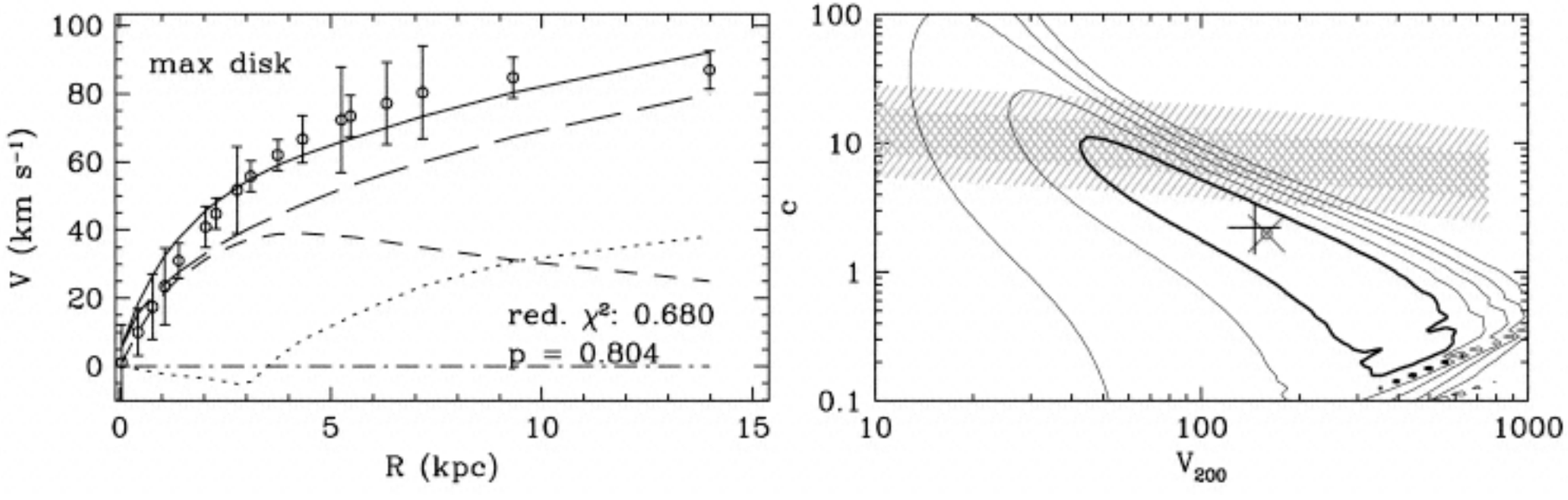


NFW
fits

LSB
F583-1

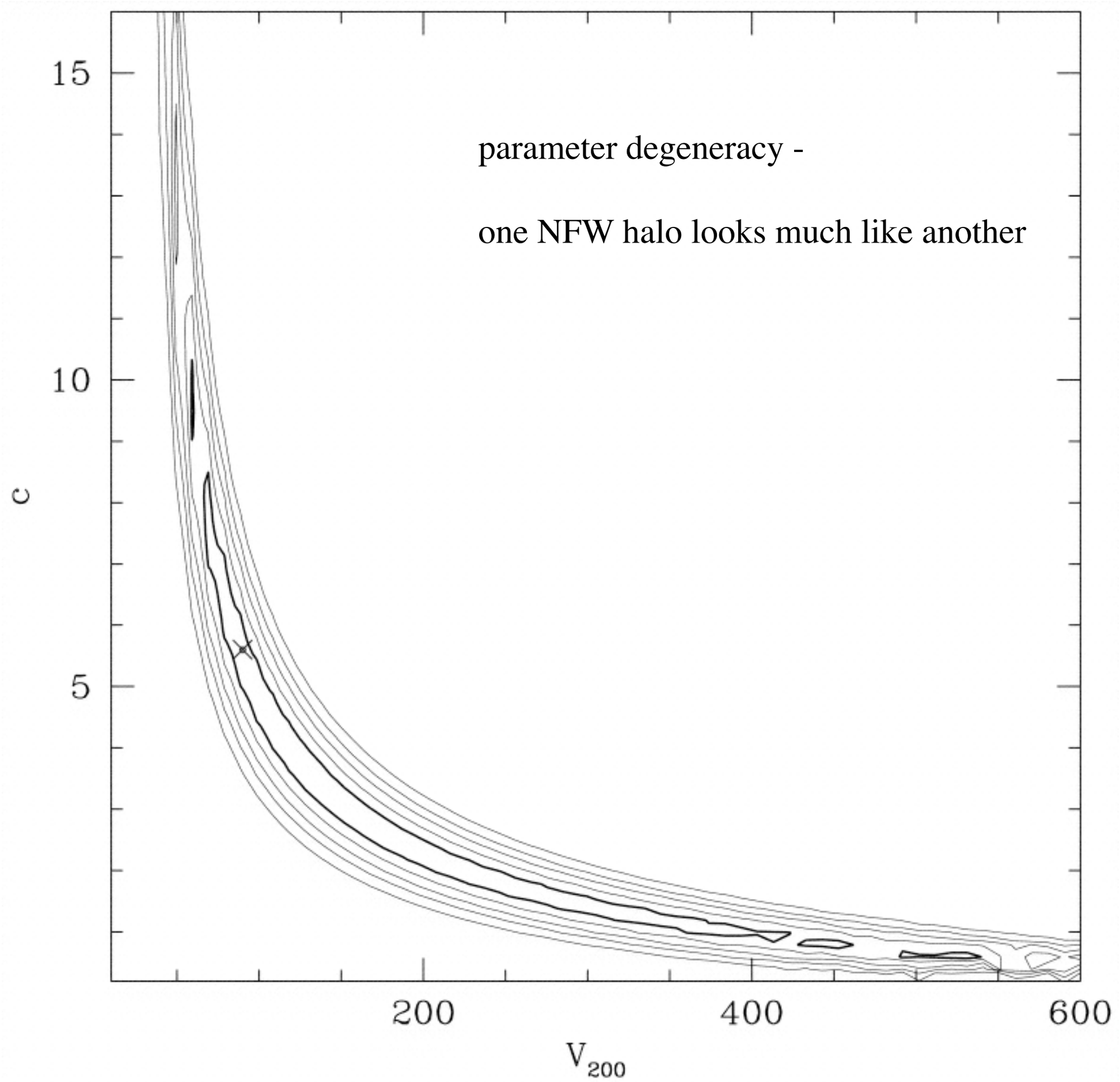






NFW
fits

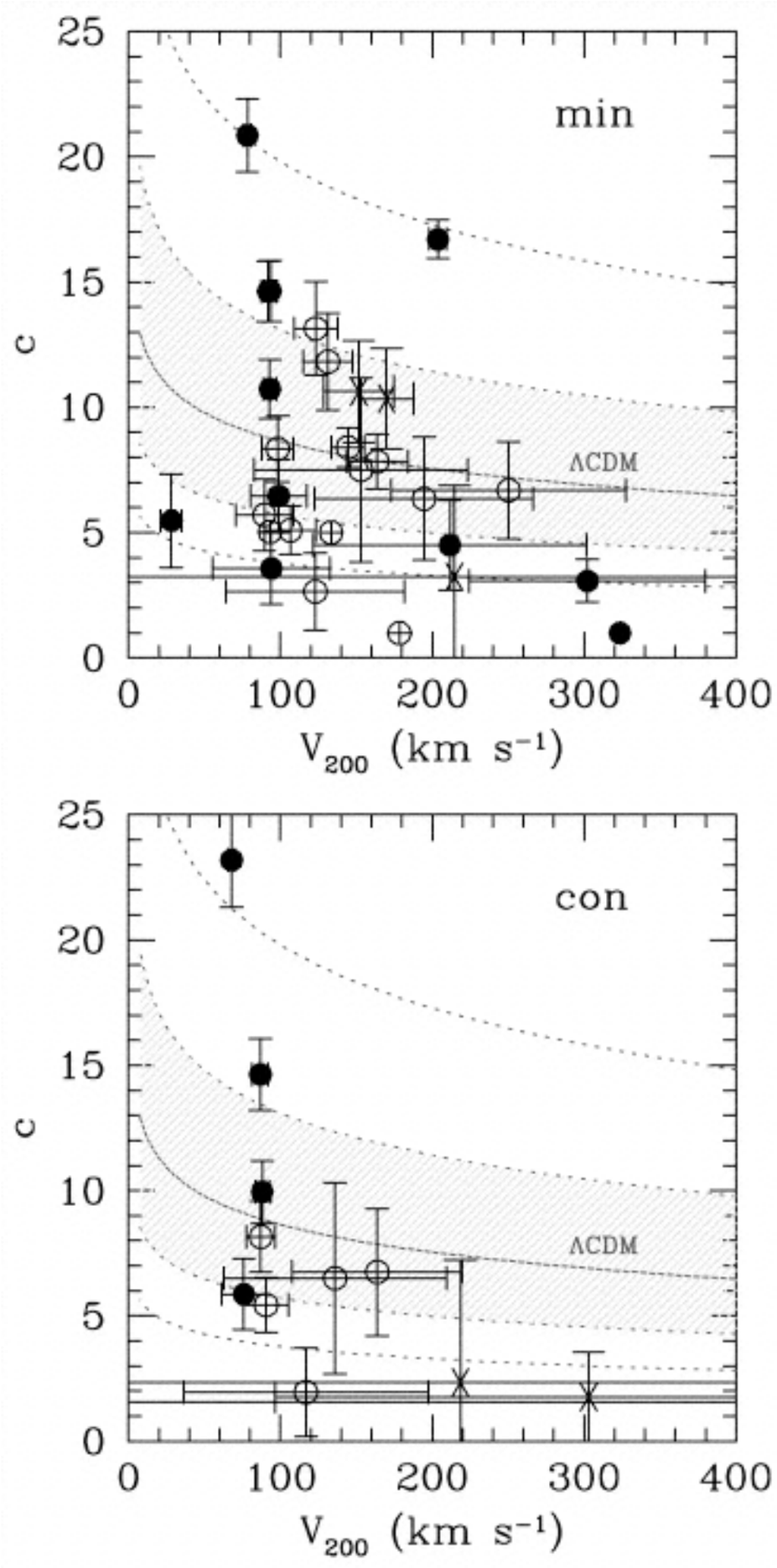
LSB
F583-4

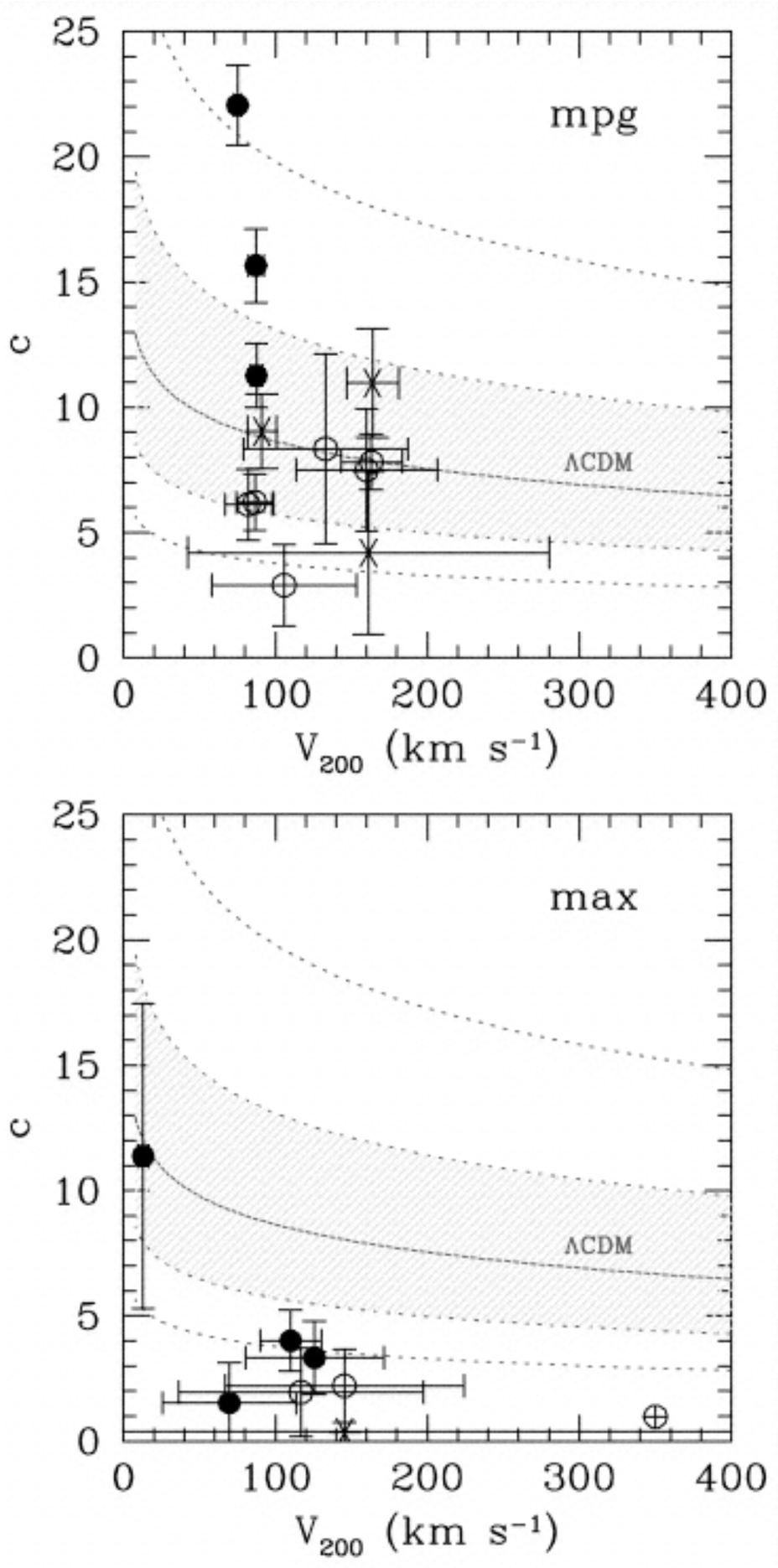


parameter degeneracy -

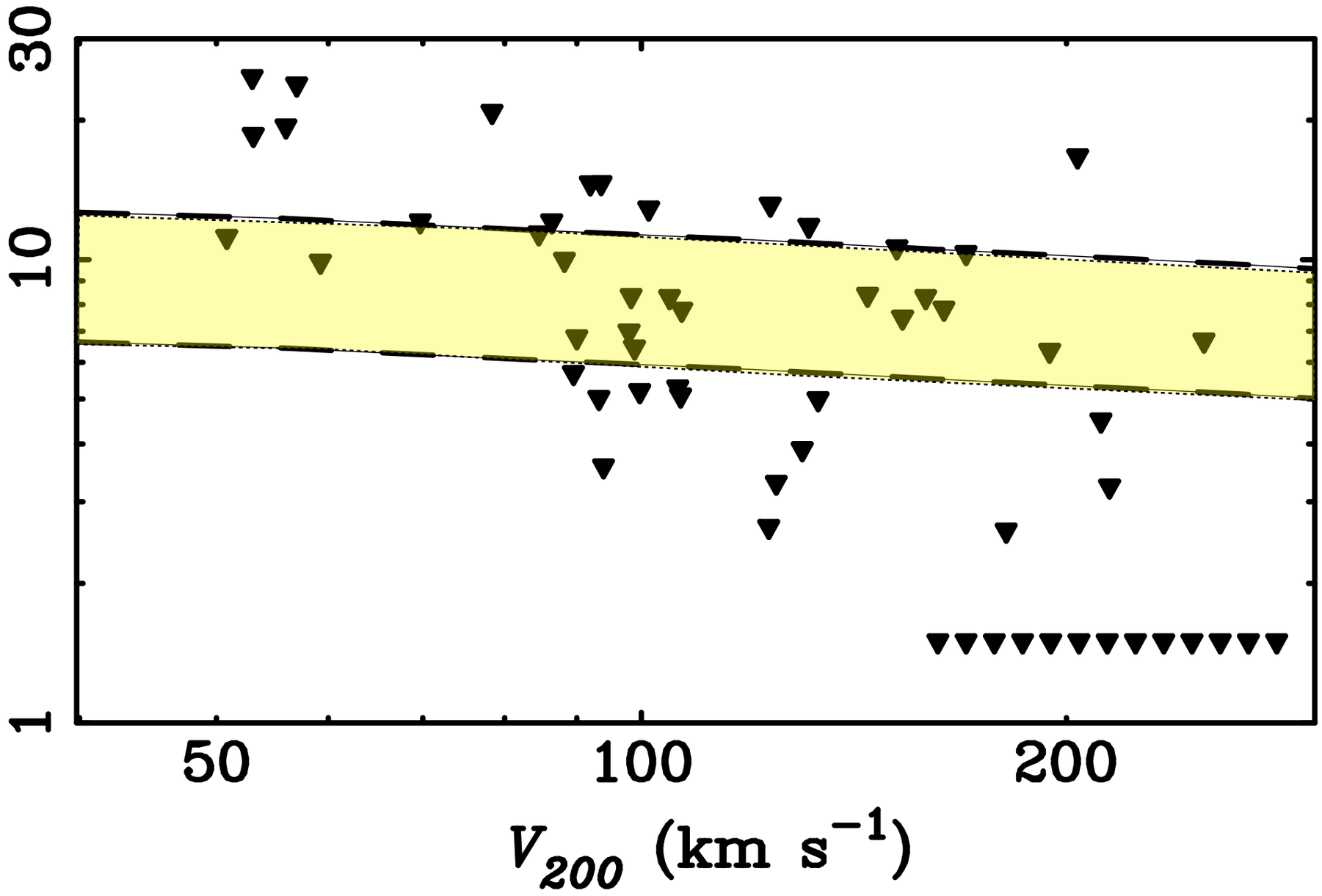
one NFW halo looks much like another

NFW
c-V200
relation





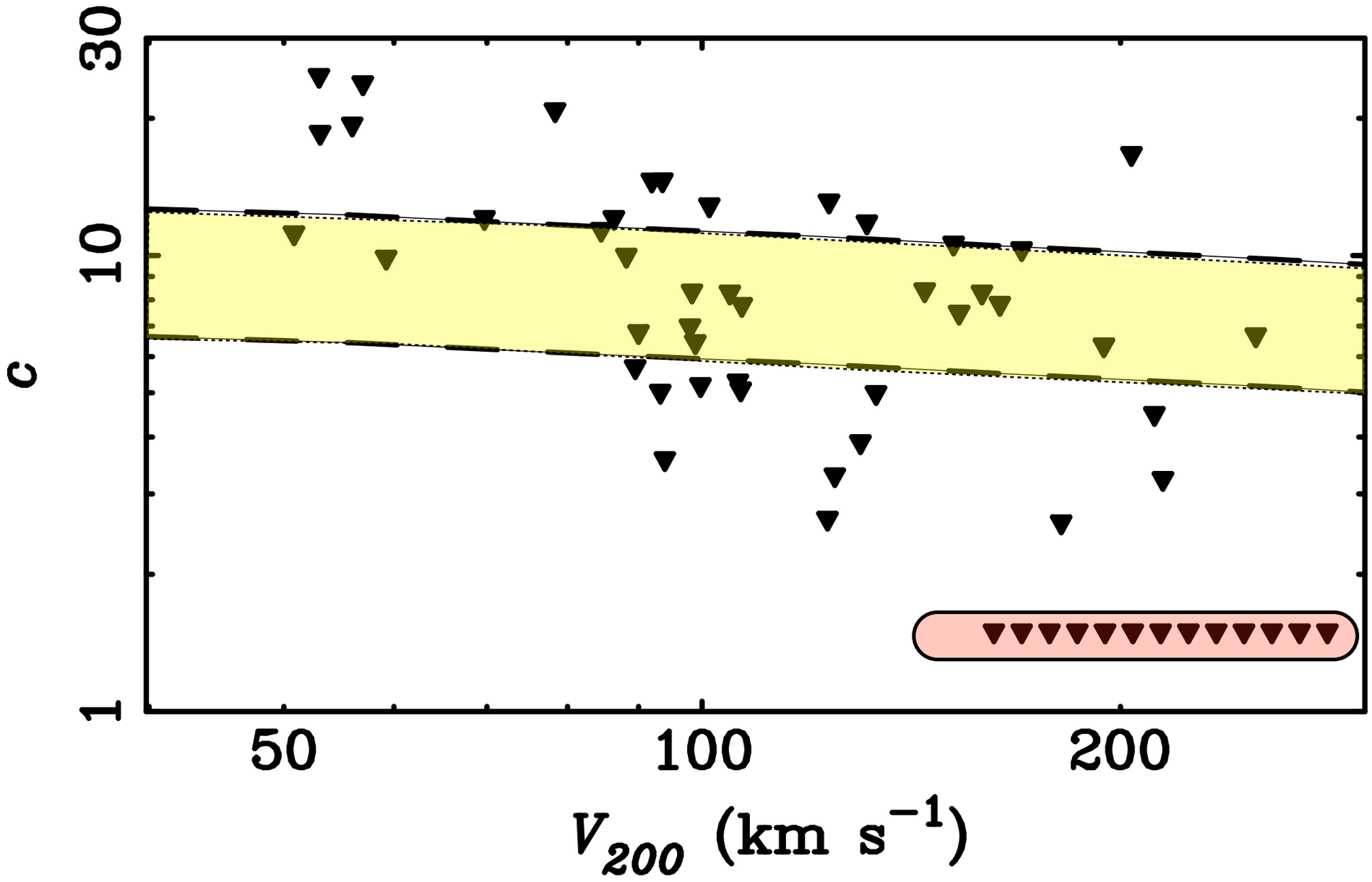
NFW
c-V200
relation



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

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

NFW
c-V200
relation

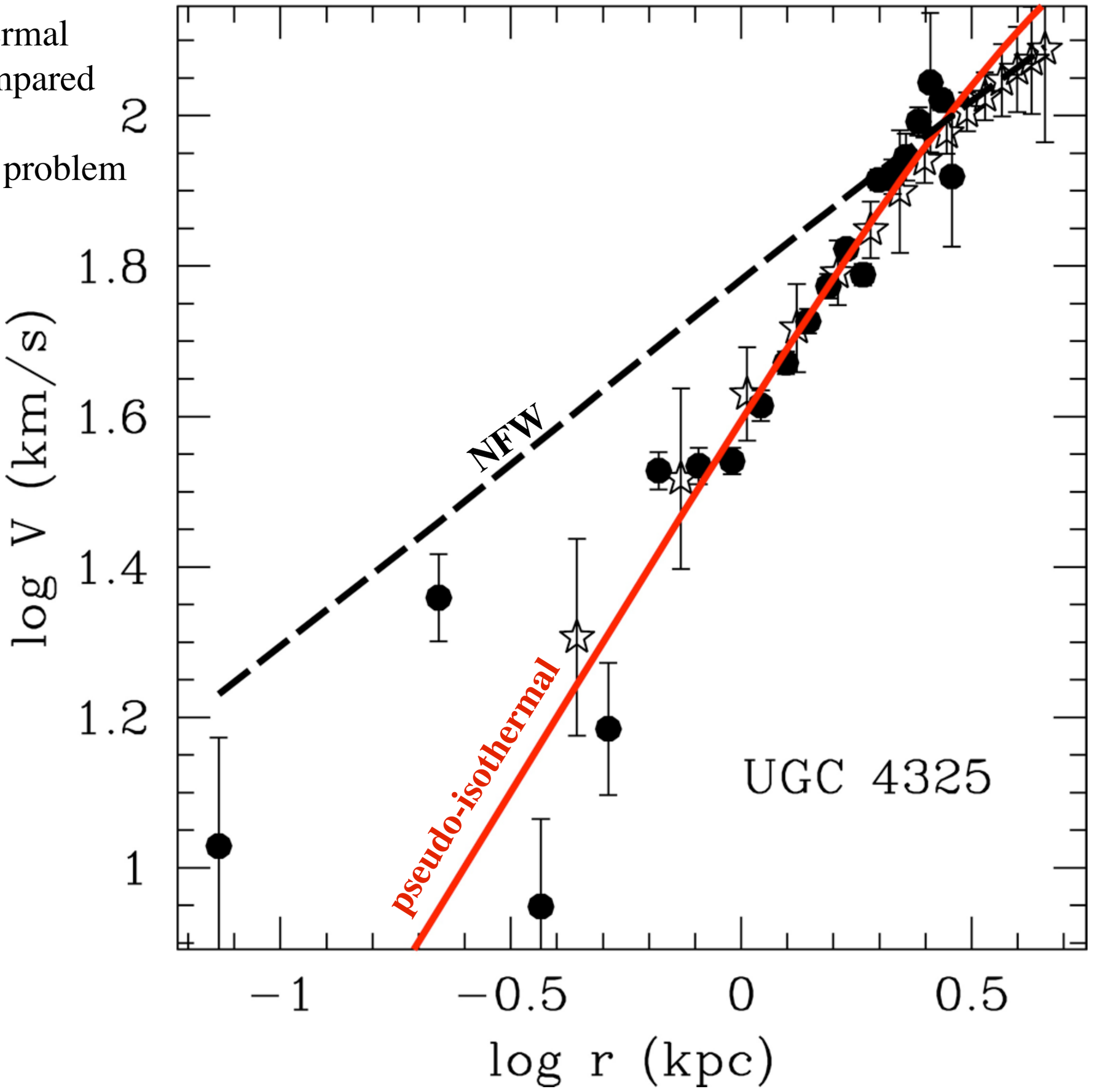


Many galaxies - especially LSBs - have upper limits on c that are unacceptably low.
This is one indication of the “cusp-core problem.”

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

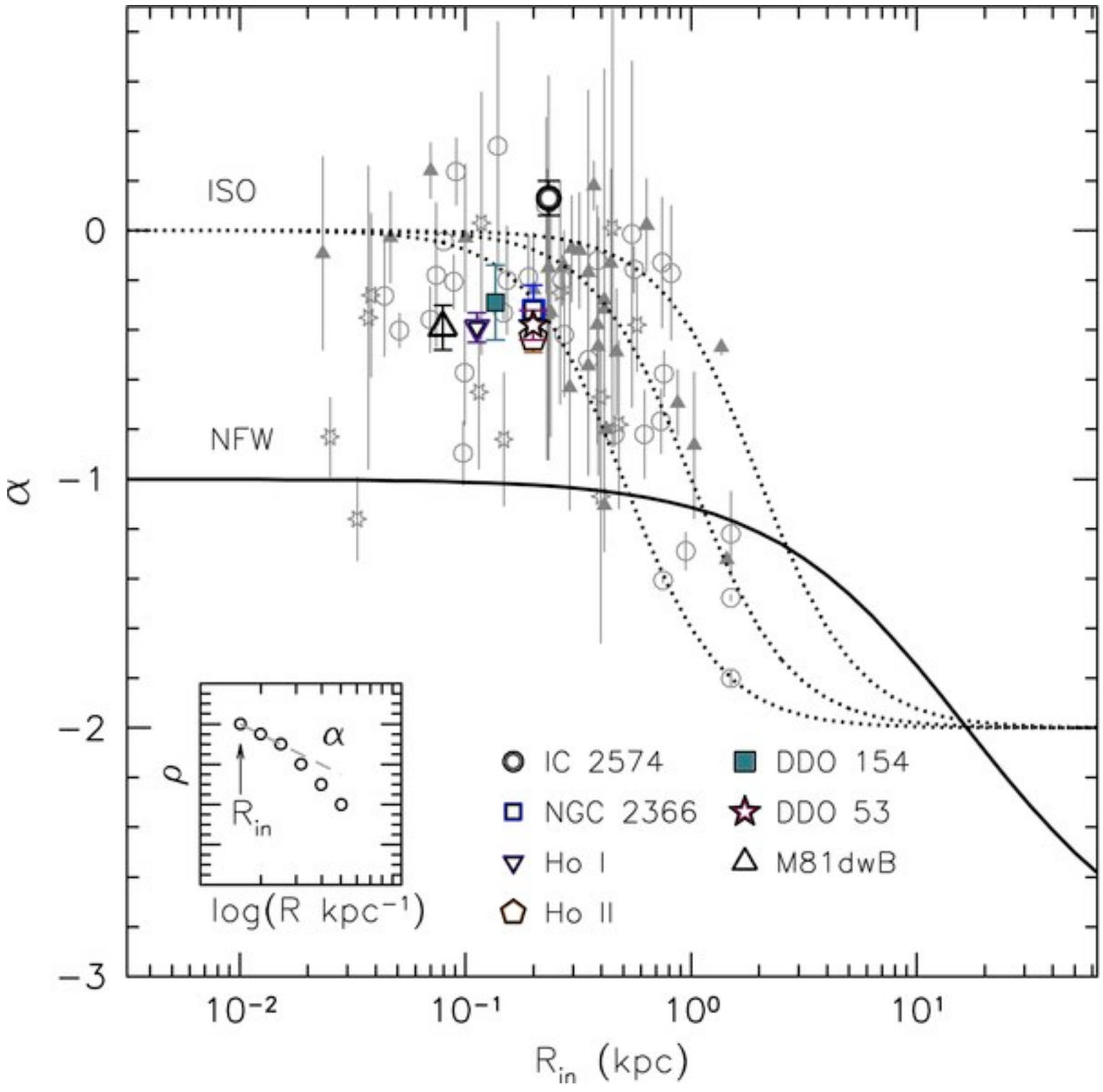
the cusp-core problem



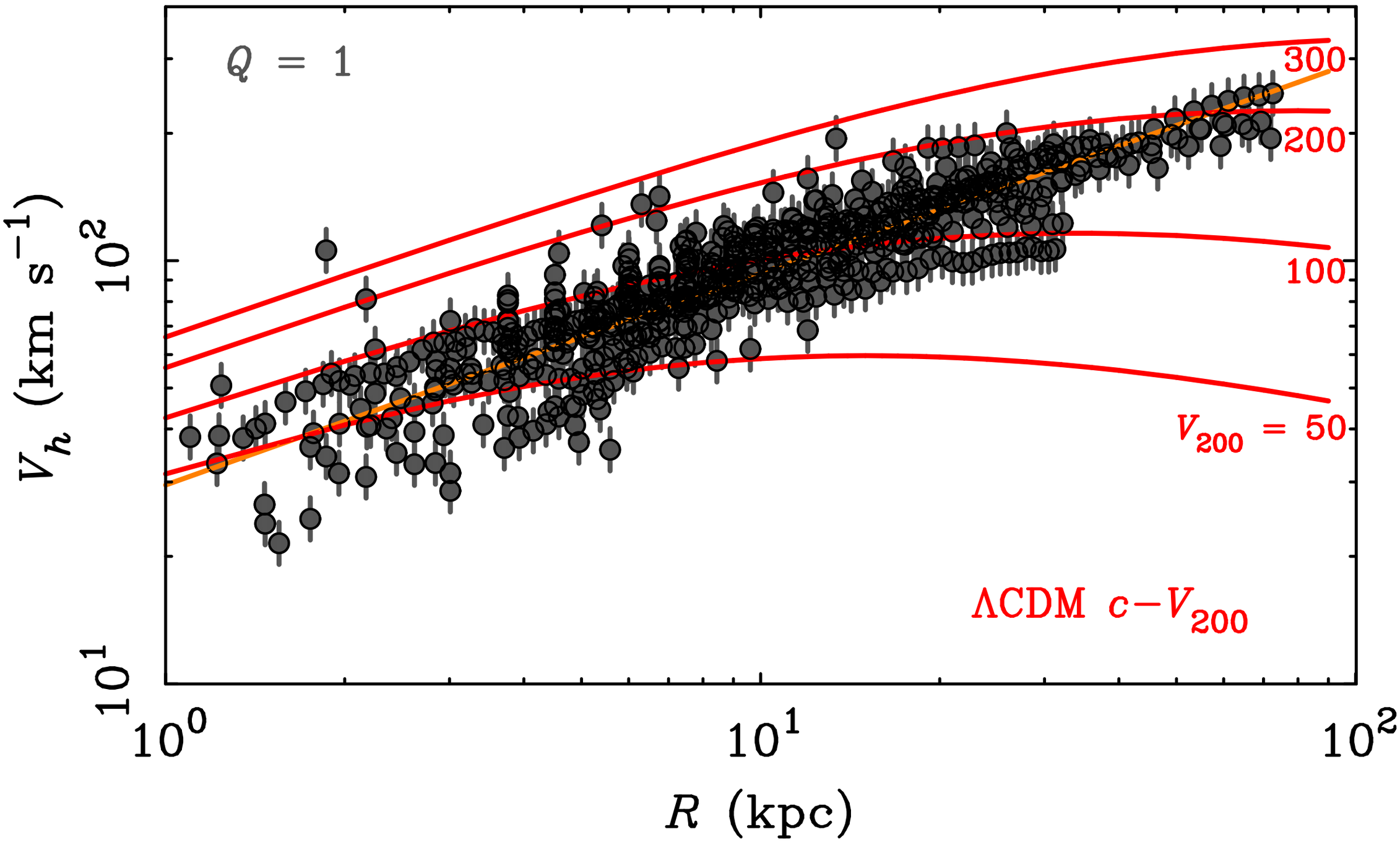
Kuzio de Naray et al. (2008)

Inner density profiles of dark matter halos

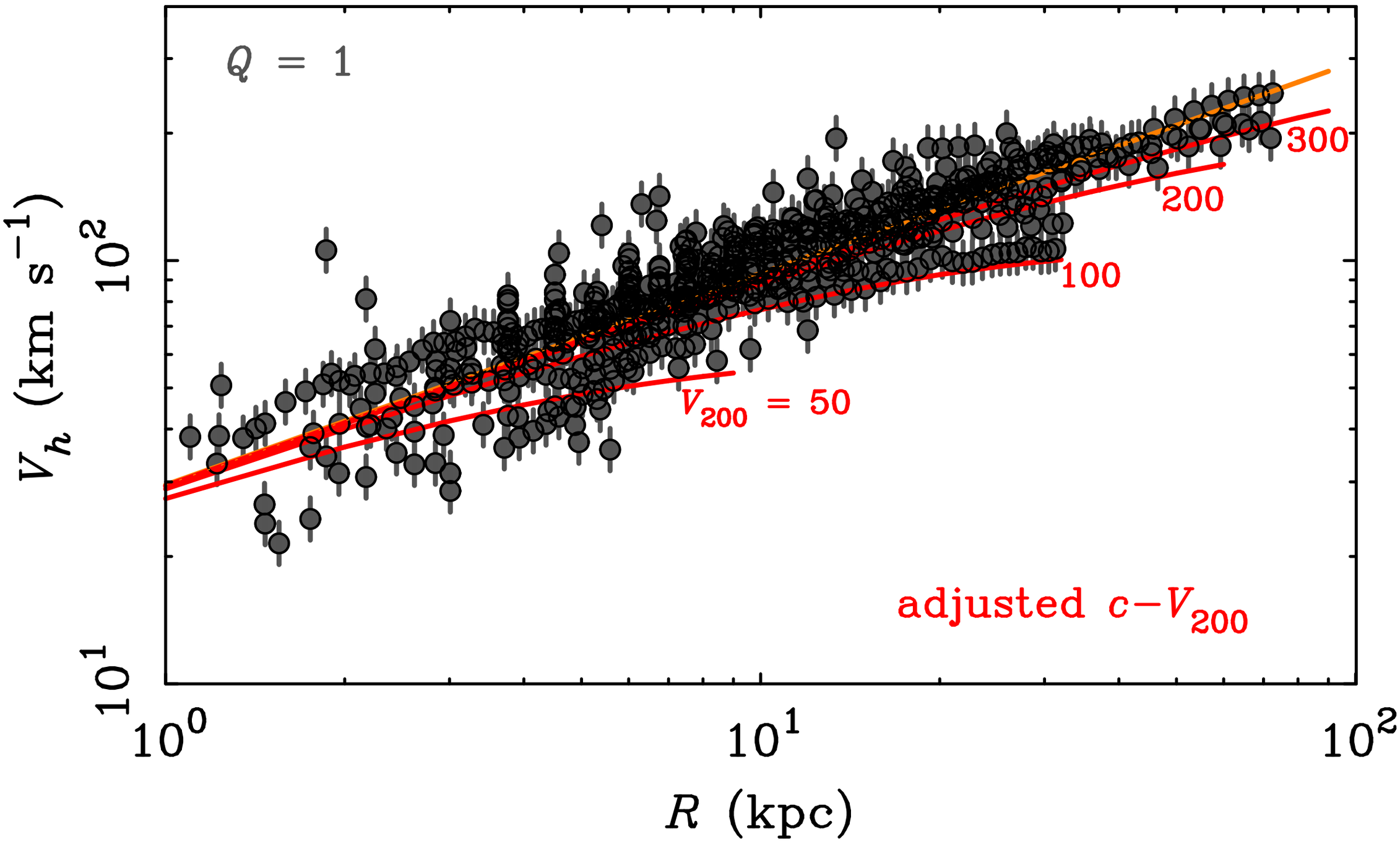
$$\rho \sim r^{\alpha}$$



Oh et al (2011) AJ, 141, 193

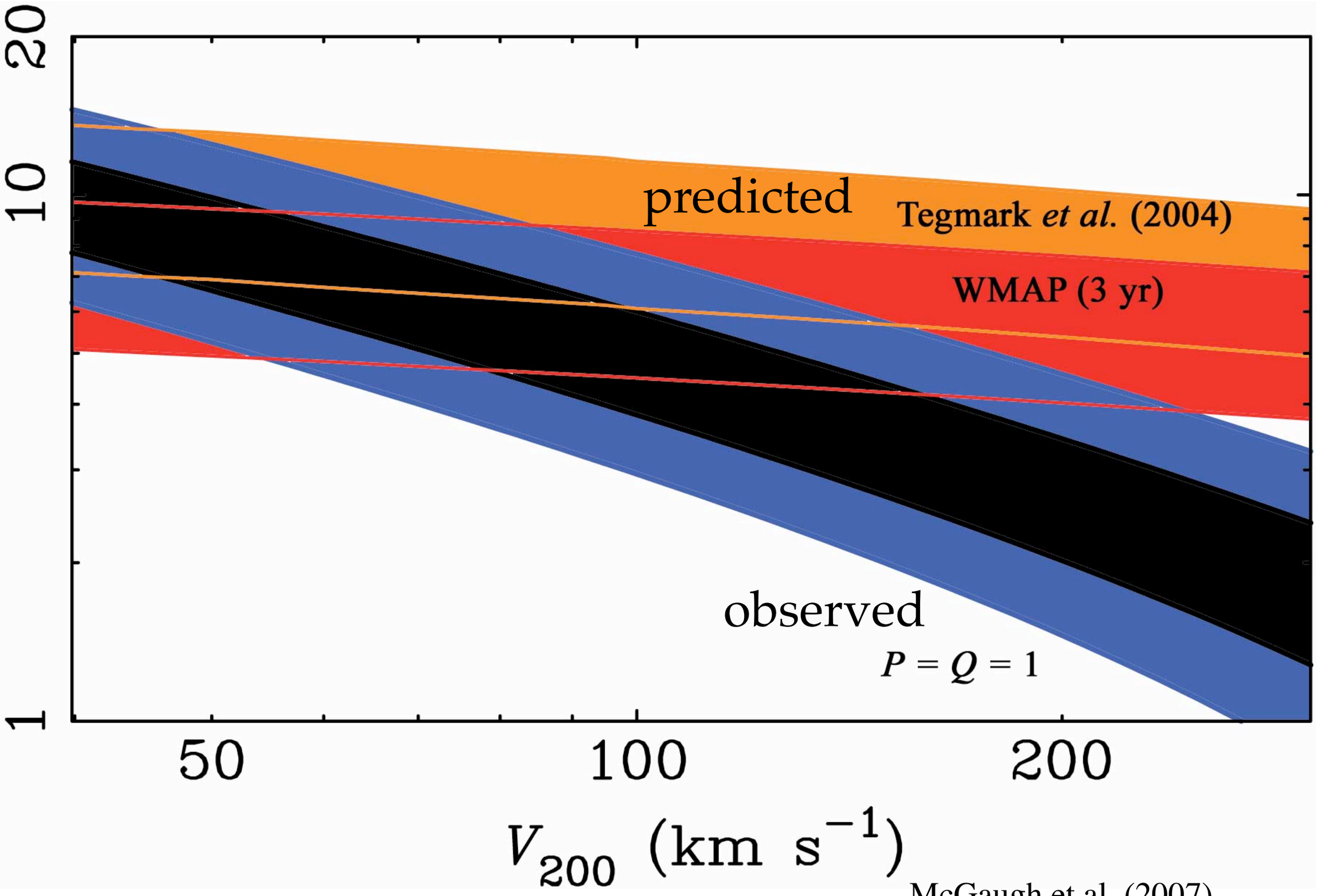


McGaugh et al. (2007)



McGaugh et al. (2007)

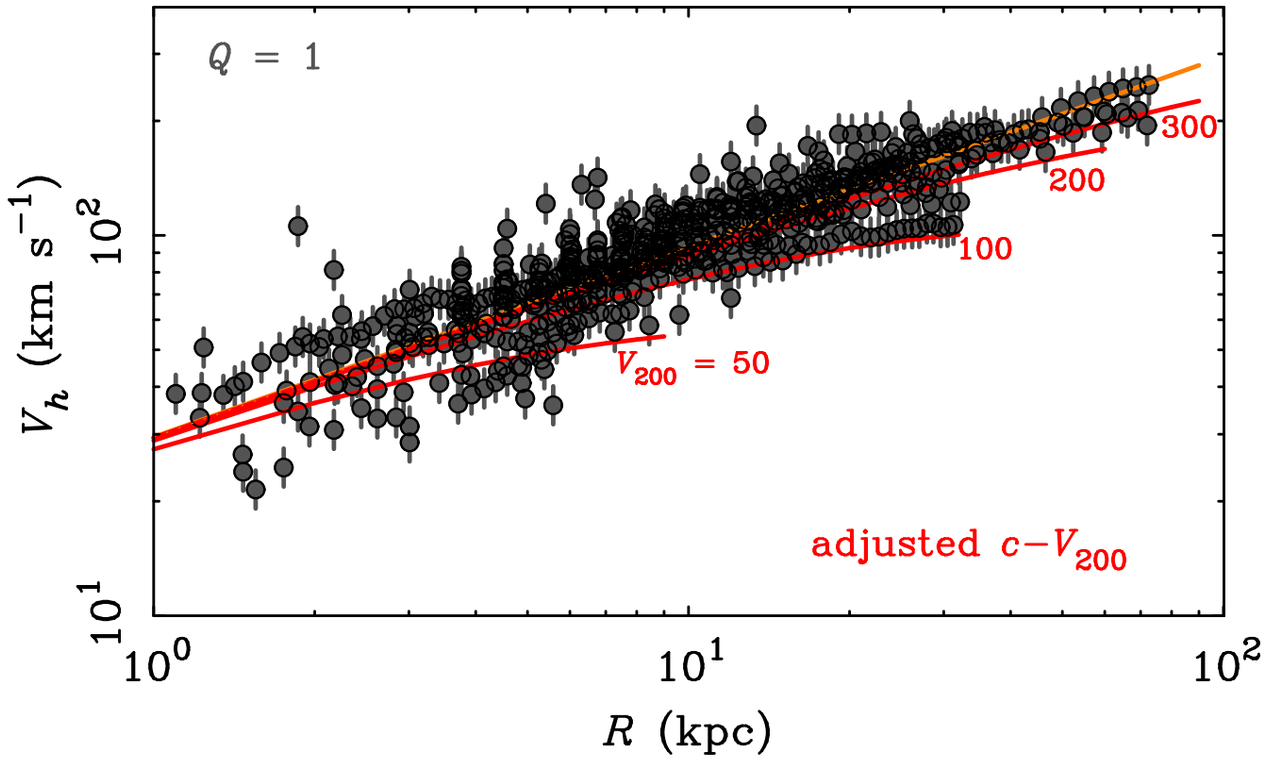
NFW c-V200 relation



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