The Structure of Cold Dark Matter Halos

Navarro, Frenk, & White (1995)

Overview

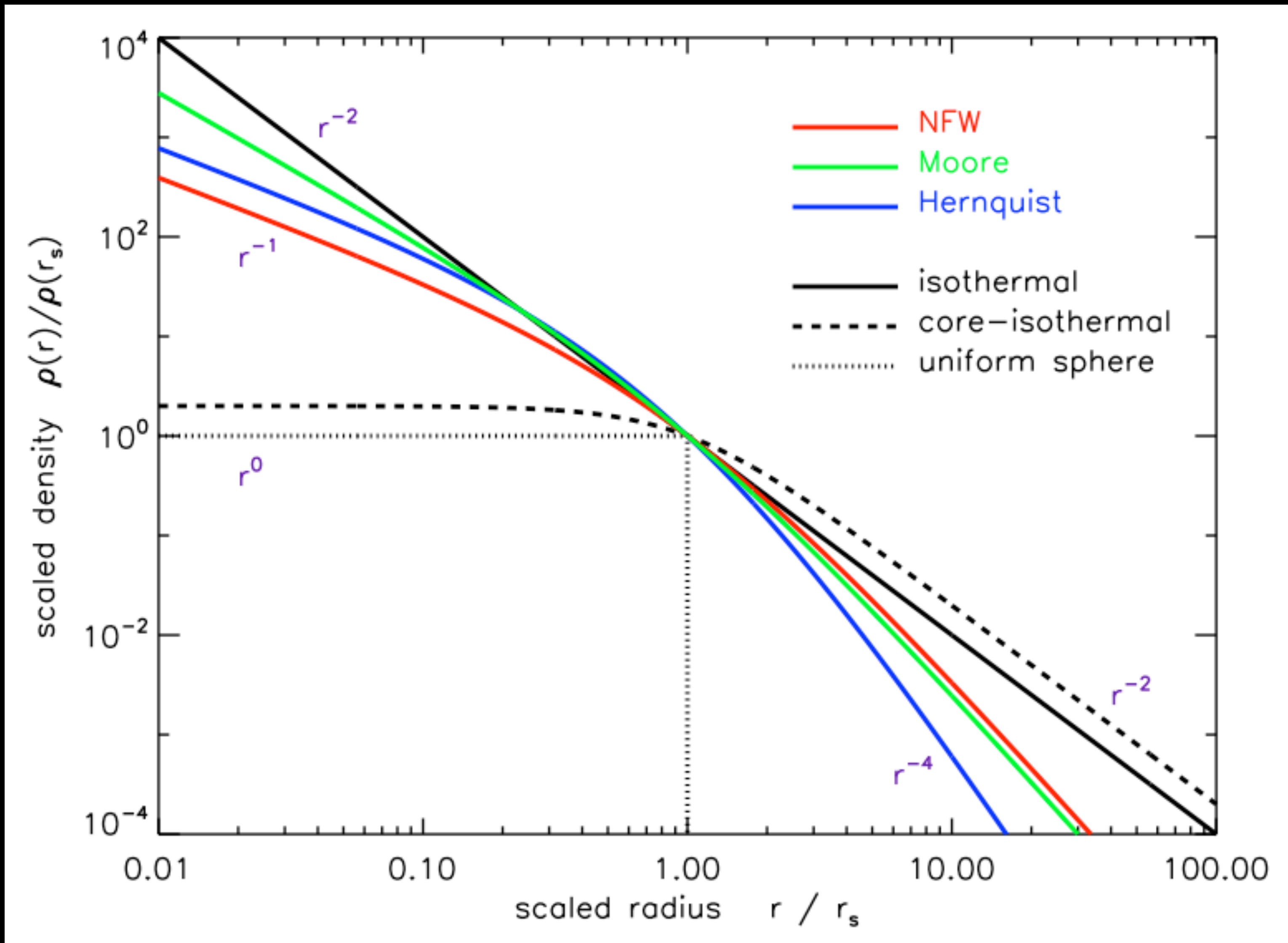
- Navarro, Frenk & White (NFW) Model matches the Dark Matter distribution found in simulations
- NFW Model predicts cusp at center of galaxies
- Observations show core at center of galaxies
    - Core ≡ central region of constant density

Spherical Density Profiles

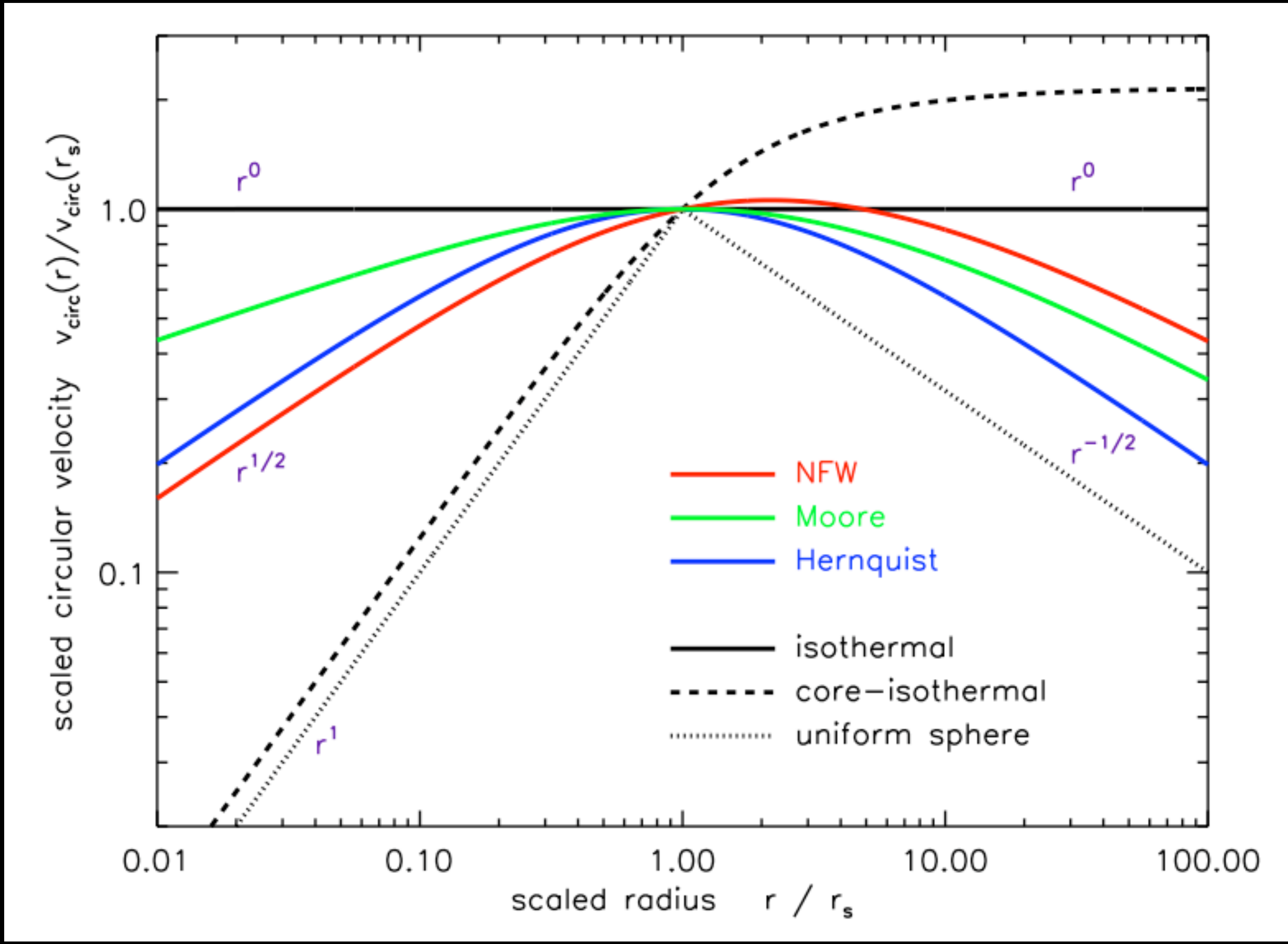
profile	$\rho(r) \propto$	$\rho(r \ll r_s)$	$\rho(r \gg r_s)$	notes
uniform sphere	const ($r \leq r_s$) 0 ($r > r_s$)	const	0	Keplerian ($r > r_s$)
isothermal	$\frac{1}{r^2}$	r^{-2}	r^{-2}	$v_{circular}$ = const cusp, mass diverges
core-isothermal	$\frac{1}{1+(r/r_s)^2}$	const	r^{-2}	central core mass diverges
Hernquist	$\frac{1}{(r/r_s)\,(1+(r/r_s))^3}$	r^{-1}	r^{-4}	central cusp
NFW	$\frac{1}{(r/r_s)\,(1+(r/r_s))^2}$	r^{-1}	r^{-3}	central cusp
Moore	$\frac{1}{(r/r_s)^{3/2}\,(1+(r/r_s))^{3/2}}$	$r^{-3/2}$	r^{-3}	stronger central cusp

$$M(R) = \int_0^R 4\pi r^2 \rho(r)\, dr \qquad v_{\rm circ}(r) = \sqrt{\frac{GM(r)}{r}} \qquad \phi(R) = \int_R^\infty -\frac{GM(r)}{r^2}\, dr$$

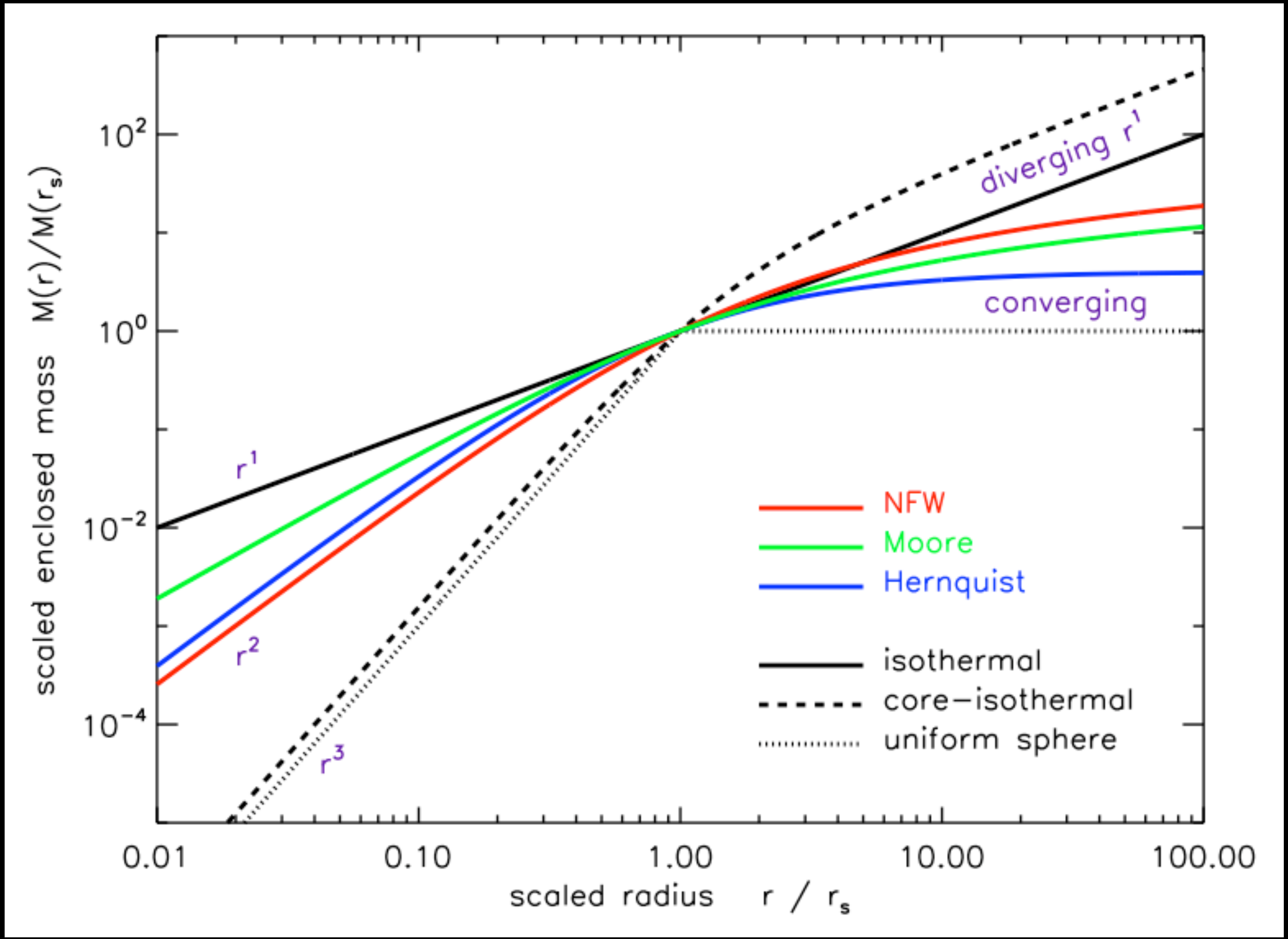
Scaled Density



Scaled Circular Velocity



Scaled Enclosed Mass



NFW Parameters

- 19 systems including individual dwarf galaxies and small and large clusters
- standard $\Omega = 1$ CDM universe
- evolution of 262,144 particles
- virial radius of system, r_{200}
- gravitational softening chosen to be 1% of r_{200}

Density Profiles of CDM Halos

NFW Fit

$$\frac{\rho(r)}{\rho_{crit}} = \frac{\delta_c}{(r/r_s)(1+r/r_s)^2}$$

Concentration (c)

$$\delta_c = \frac{200}{3}\frac{c^3}{(\ln(1+c) - c/(1+c))}$$

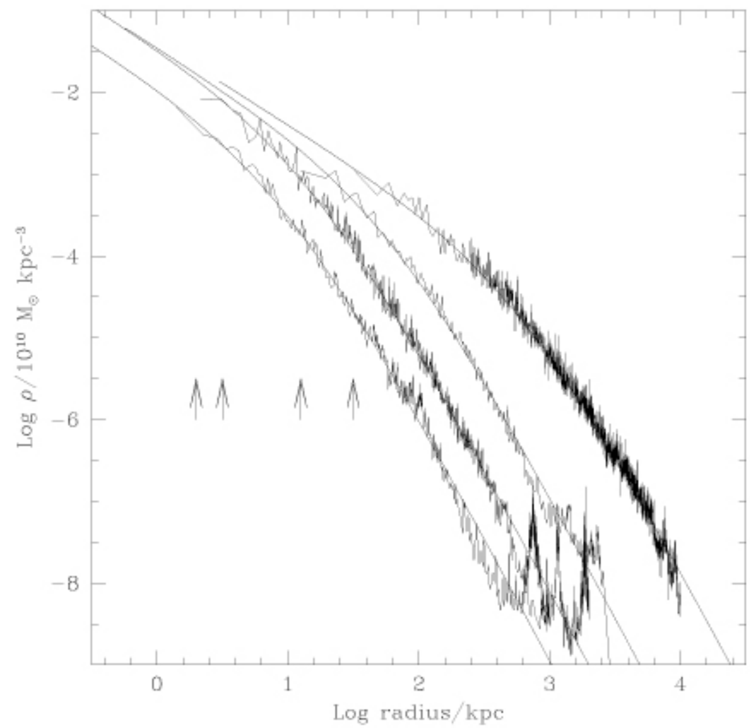


Fig. 3.— Density profiles of four halos spanning four orders of magnitude in mass. The arrows indicate the gravitational softening, h_g, of each simulation. Also shown are fits from eq.3. The fits are good over two decades in radius, approximately from h_g out to the virial radius of each system.

Scaled Density Profiles

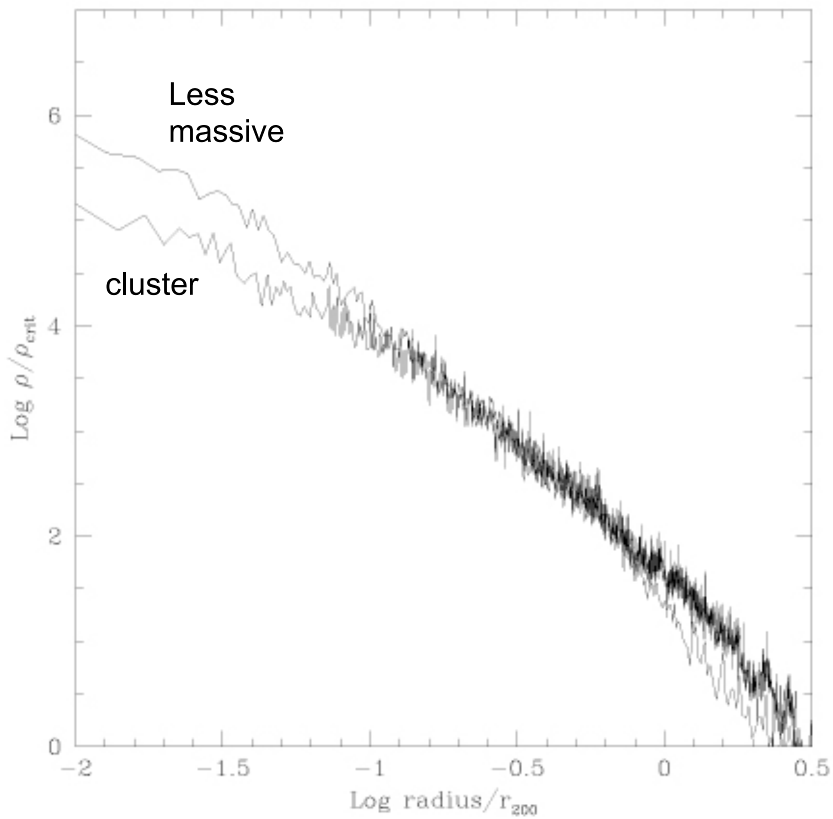


Fig. 4.— Scaled density profiles of the most and least massive halos shown in Figure 3. The large halo is less centrally concentrated than the less massive system.

Circular Velocity Profiles

$$v_{\mathrm{circ}}(r) = \sqrt{\frac{GM(r)}{r}}$$

$$\frac{V_{\max}}{V_{200}}$$

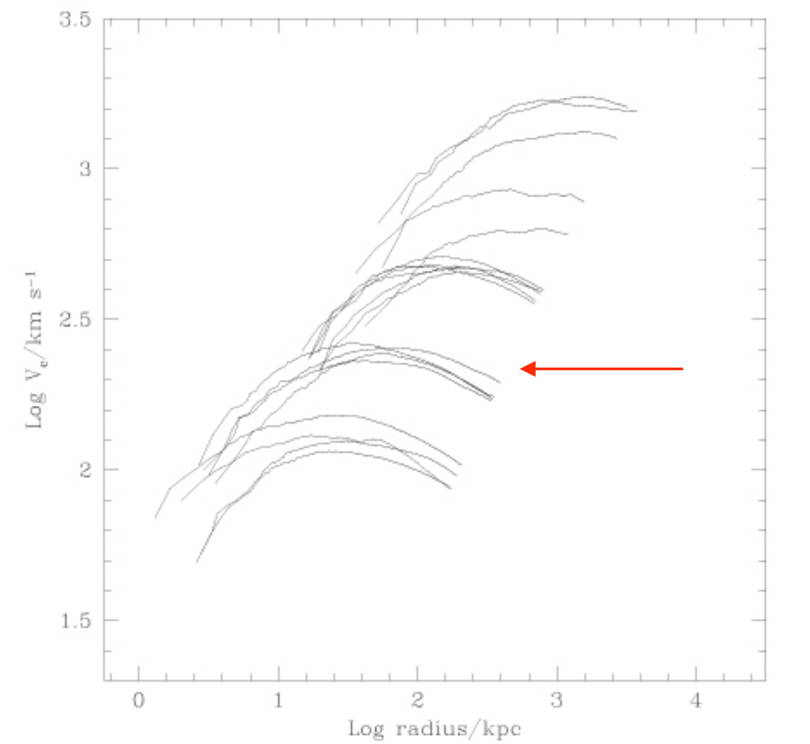


Fig. 5.— Circular velocity profiles of all 19 halos. The profiles are truncated at the virial radius, r_{200}. The gravitational softening is about $10^{-2} \times r_{200}$. Note that all profiles have the same shape.

Circular Velocity Profiles

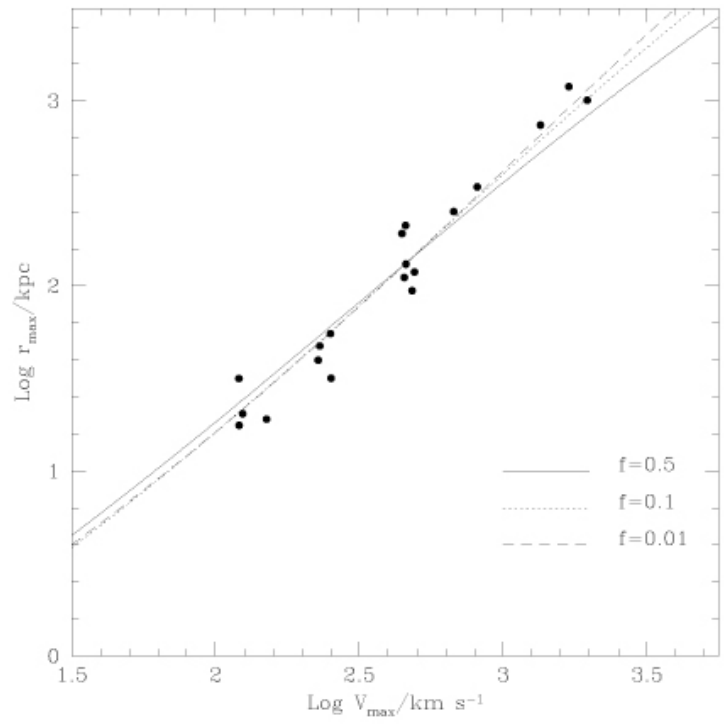


Fig. 10.— The maximum circular velocity as a function of the radius at which it is attained in halos of different mass. Note that a halo with V_{max} = 220 km/s has a rising rotation curve that extends out to about 50 kpc, well beyond the luminous radius of a galaxy like the Milky Way.

Dwarf Galaxy Cores

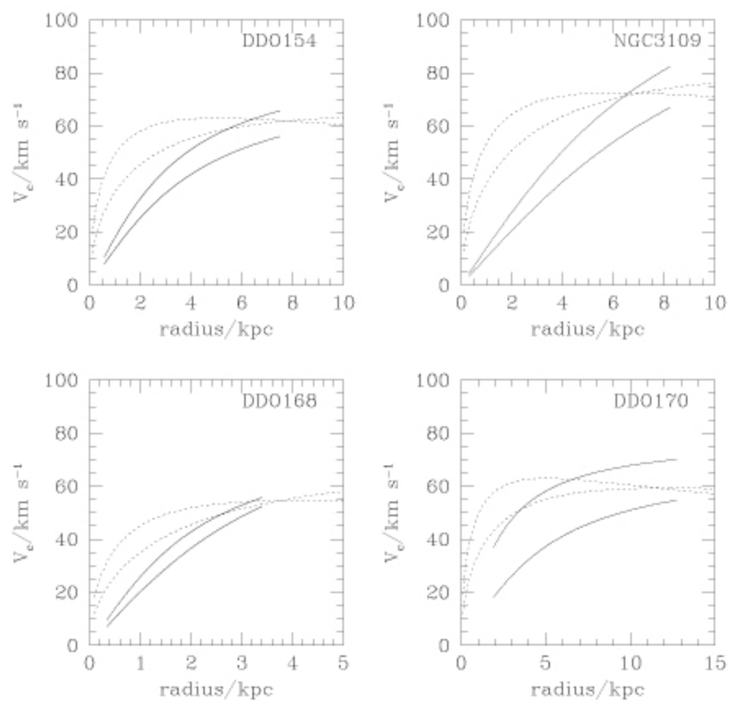


Fig. 12.— The circular velocities of CDM halos (dotted lines) compared with the halo contribution to the rotation curve of four dwarf galaxies (solid lines). The solid lines encompass the likely contribution of the halo, and correspond to the "maximal" and "minimal" disk hypotheses. CDM halos seem to be significantly more concentrated than allowed by observations.

Core Concern?

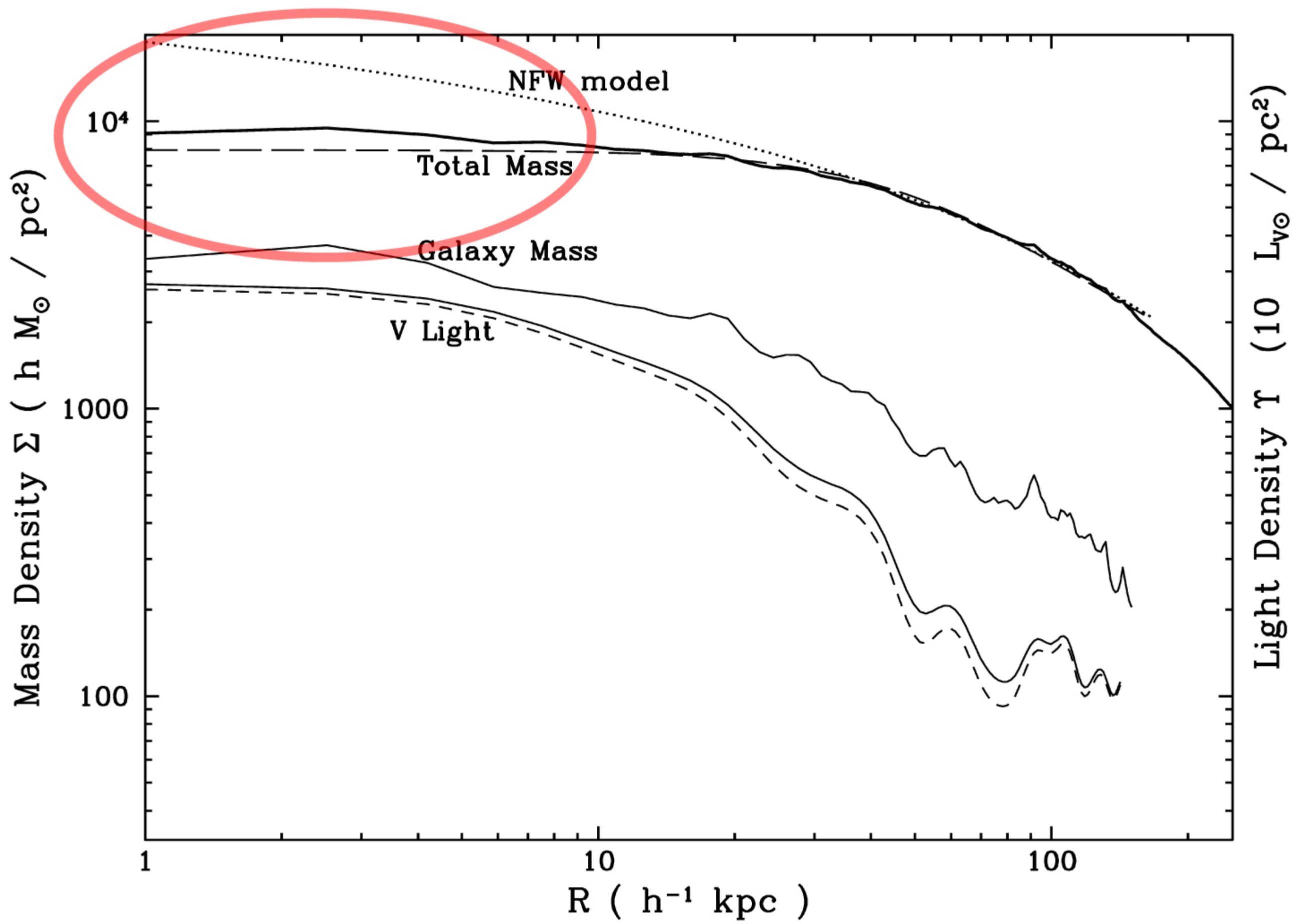


FIG. 4.—A radial plot of the mass density and light density. Total (*thick line*) and galaxy-only (*thin line*) components of the mass are shown. The dotted line is the best NFW fit discussed in the text, and the dashed line is the best-fit single PL model. The 35 h^{-1} kpc soft core in the mass is evident. A singular mass distribution is ruled out. The total rest-frame V light profile (*solid line*) and galaxy V light profile (*dashed line*), smoothed with a 5 h^{-1} kpc Gaussian, are also shown.

Tyson-Kochanski (1998)

Conclusions

- The model predicts a lot of dark matter in the center of the galaxy whereas observations suggest this is not the case. The discrepancy has grown with better simulations

- NFW Model agrees with Observations at higher radii

Dynamical Friction and the Distribution of Dark Matter in Barred Galaxies

Debattista and Sellwood (1997)

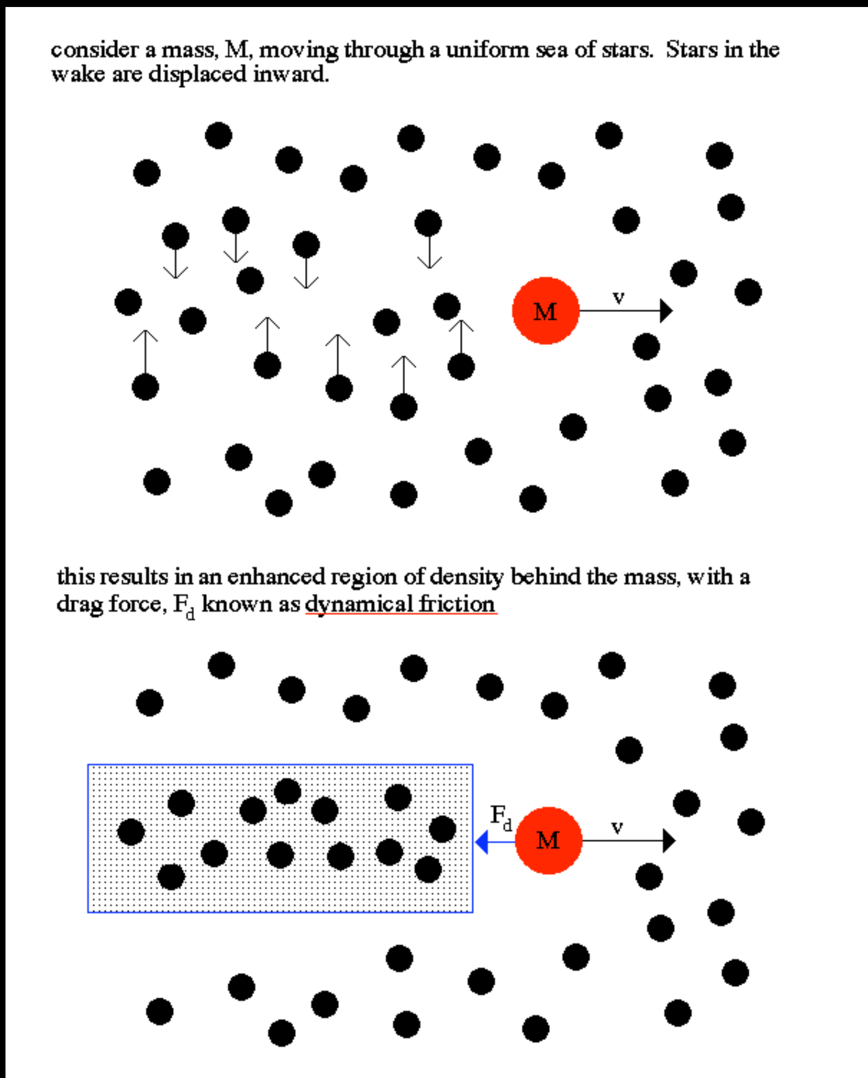
M91- Hubble Telescope

NGC1300- NFO

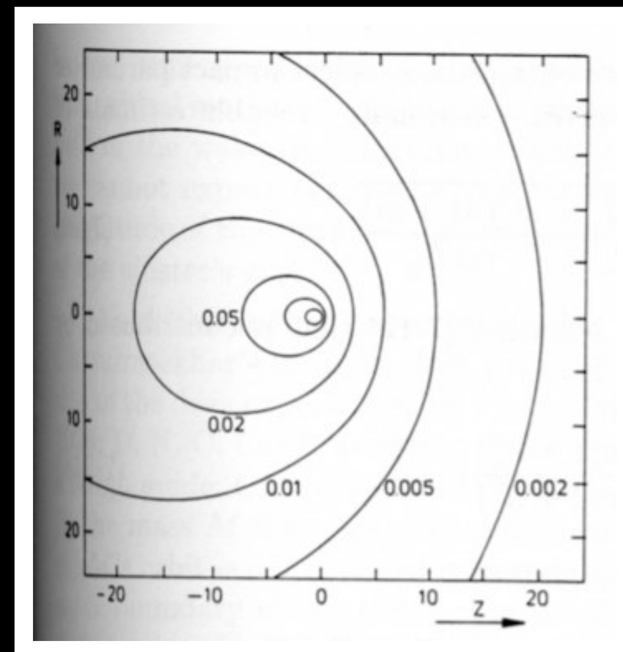
Overview

- Theory predicts massive dark halos should slow down the rotation speed of bars in spiral galaxies
- Observations show:
  - bars are not rotating slowly
  - massive halos are not strongly present in inner regions
  - contrary to NFW and Moore DM profiles

Dynamical Friction



University of Oregon



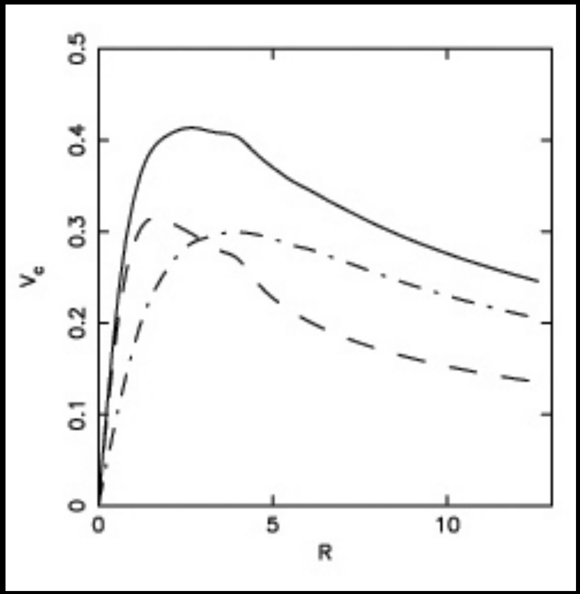
Binney and Tremaine (1987)

$$f_{dyn} \approx C \frac{G^2 M^2 \rho}{v_M^2}$$

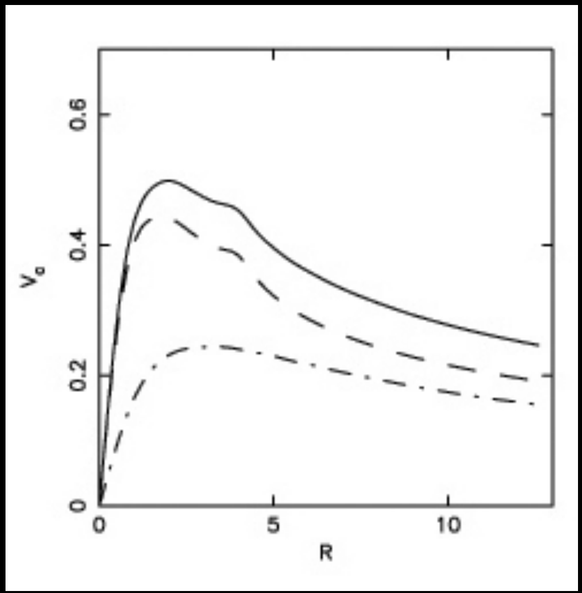
Parameters

- N-body models of disk-halo galaxies used to simulate their evolution
  - Cartesian and polar coordinate grids
  - over 300,000 particles
  - Velocity dispersions set by constant Toomre *Q* parameter and thickness at all radii

Rotation Curves



Most Massive Halo



Least Massive Halo

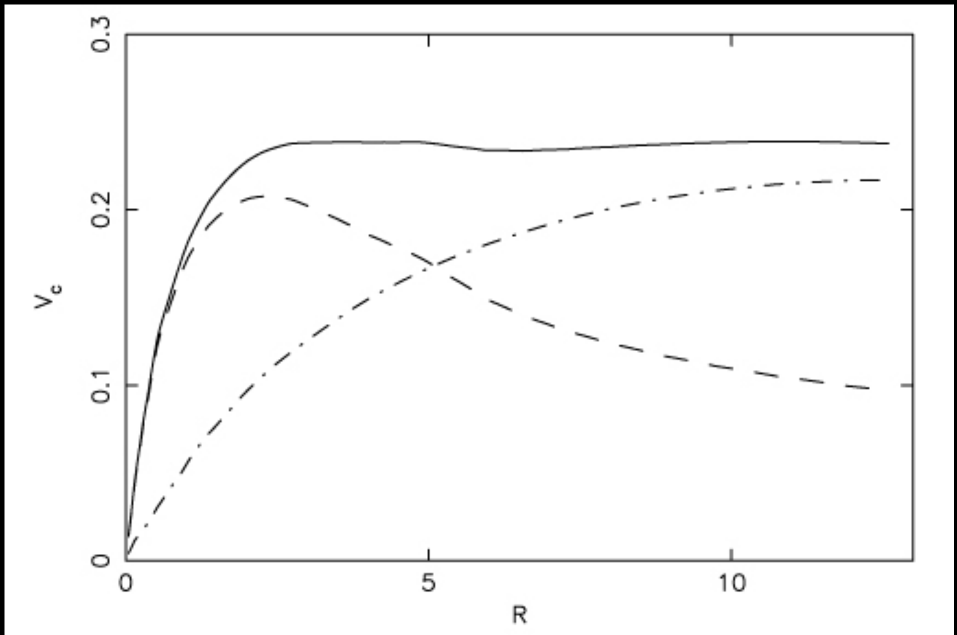
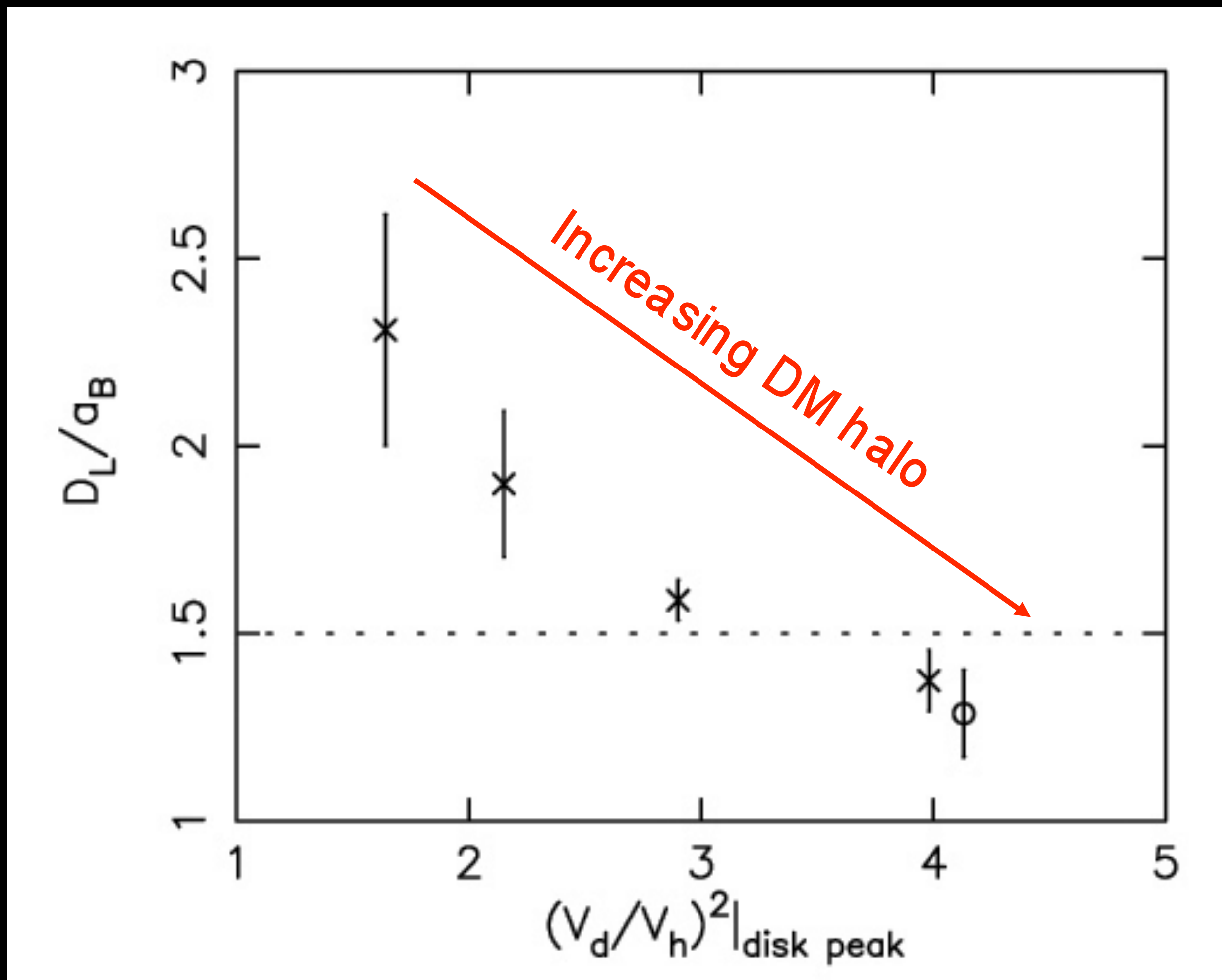


Fig. 3.— The rotation curve for the maximum disk model decomposed into disk (dashed) and halo (dot-dashed) contributions.

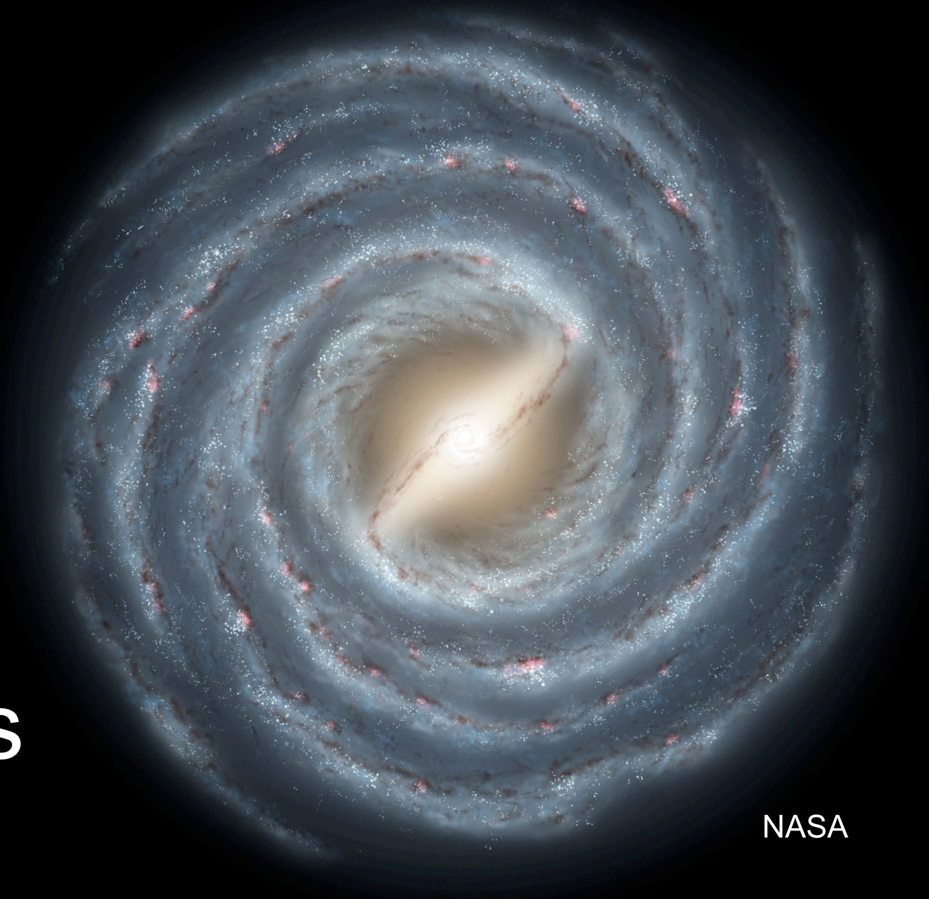
D_L/a_B plotted against $(V_d/V_h)^2$



Milky Way Galaxy

- suggested to be a barred galaxy

- unlikely that D_L/a_B is larger than for other barred galaxies



Slow Bars?

- NFW predicts LSB galaxies should be slowed by dynamical friction
  - Contain larger fractions of DM
- Absence of slow bars may reflect observational bias of HSB galaxies

Conclusions

• Observations favor core over NFW cusp at center of galaxies due to rapid rotation

• absence of slow bars in HSB galaxies indicates that DM should not have high central density