Mass models of disc galaxies

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Outline

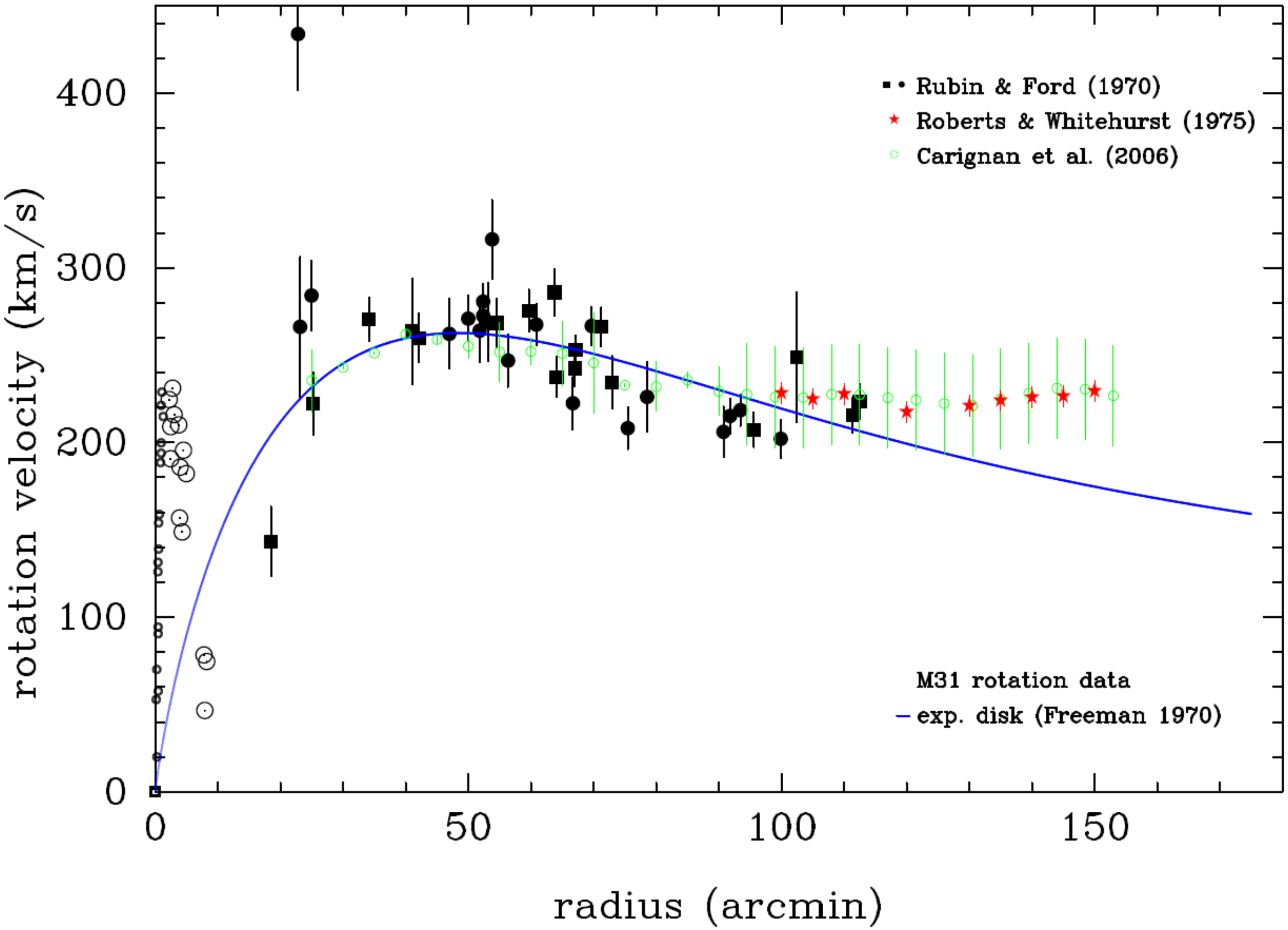
Are discs maximum?
Do haloes have cores or cusps?

Halo-Disc decomposition. Degeneracy and how to constrain it.

- Rotation curves best fits
- Colour – M/L relation
- Dyn : Spiral structure and swing amplification
- Dyn : Response simulations of gas flow in discs with spirals or bars
- Dyn : Velocity dispersions
- Dyn : Bars formation
- Dyn : Bar slowdown
- Deviations from the TF relationship
- Lensing
- Our own Galaxy

Cusps versus cores controversy.
The simulation and the observational points of view
How can we get rid of cusps? (Bars, Mergings, ...)
Preventing cusp formation (or getting rid of cusps very early on)

Optical versus HI rotation curves



Most optical rotation curves can be fitted without any halo.

Extended HI rotation curves can not.

Kalnajs 1983, Kent 1986,87, Athanassoula, Bosma & Papaioanou 1987, Palunas & Williams 2000

Halo-Disc decomposition : Degeneracy!

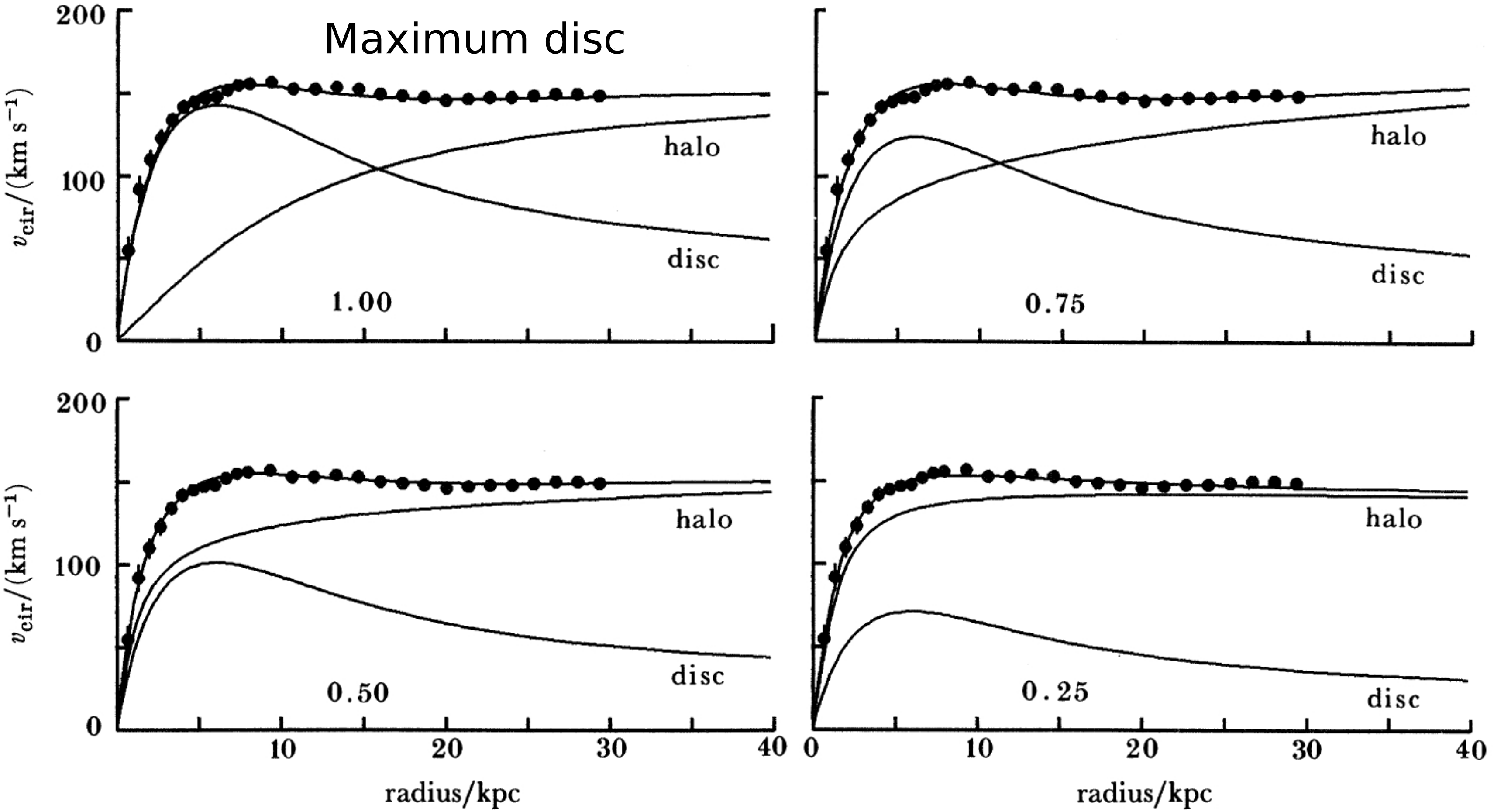
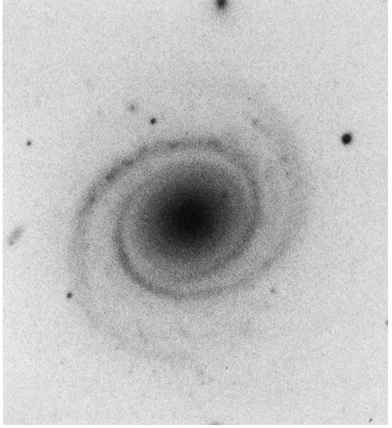


FIGURE 5. Fits of exponential disc and halo to the observed rotation curve (dots) for NGC 3198 (see van Albada *et al.* 1985). Disc models with maximum mass (upper left) and also with masses 0.75, 0.50 and 0.25 times the maximum mass are shown. Constraints on the amount of luminous matter discussed in §3 indicate that the halo contribution in the lower two panels is too large.

NGC 3198 Van Albada & Sancisi 1986



Rotation curves and swing amplification

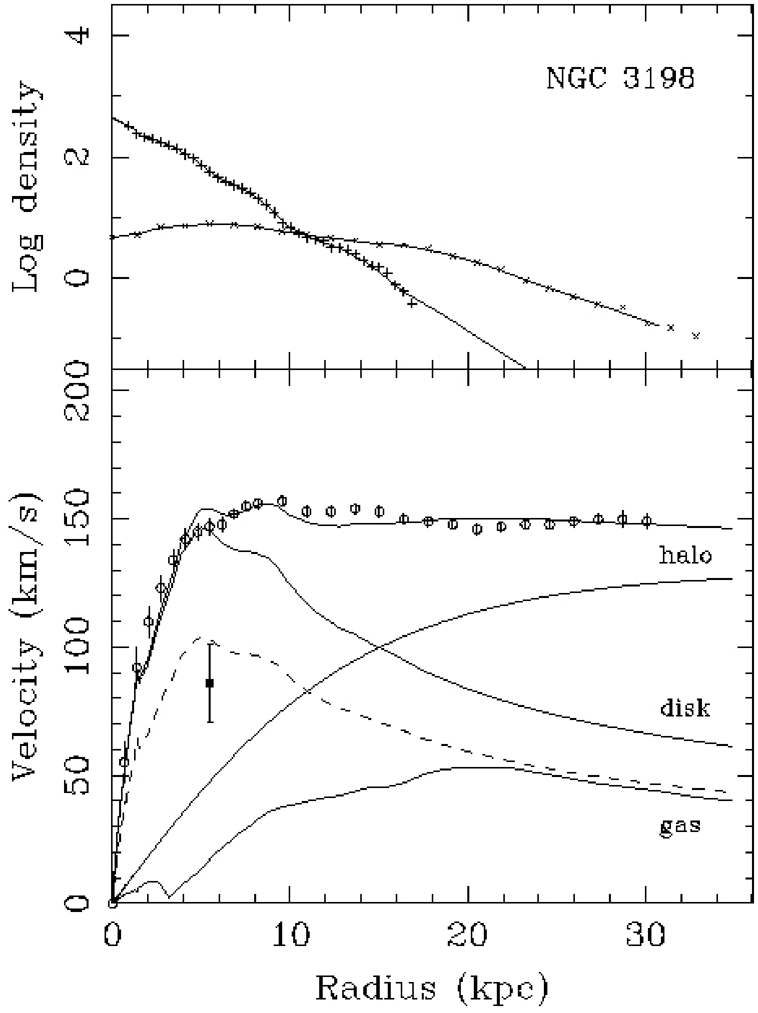
Athanassoula, Bosma & Papaioannou 1987 = ABP

Disc stability theory:
M_H/M_D limits the number of arms a spiral can have (Toomre 1981). Therefore, simply by counting the number of arms, one can set limits on M_H/M_D

No m=1 (model near maximum disc)
No m=2

Advantages
-give good fits to the data
-consistent with the number of arms observed (e.g. m=4 in the outer parts)
-predict the right radial extent for the spirals
-result in reasonable gas fractions, M/L, etc

But: Are all spirals due to swing amplification?

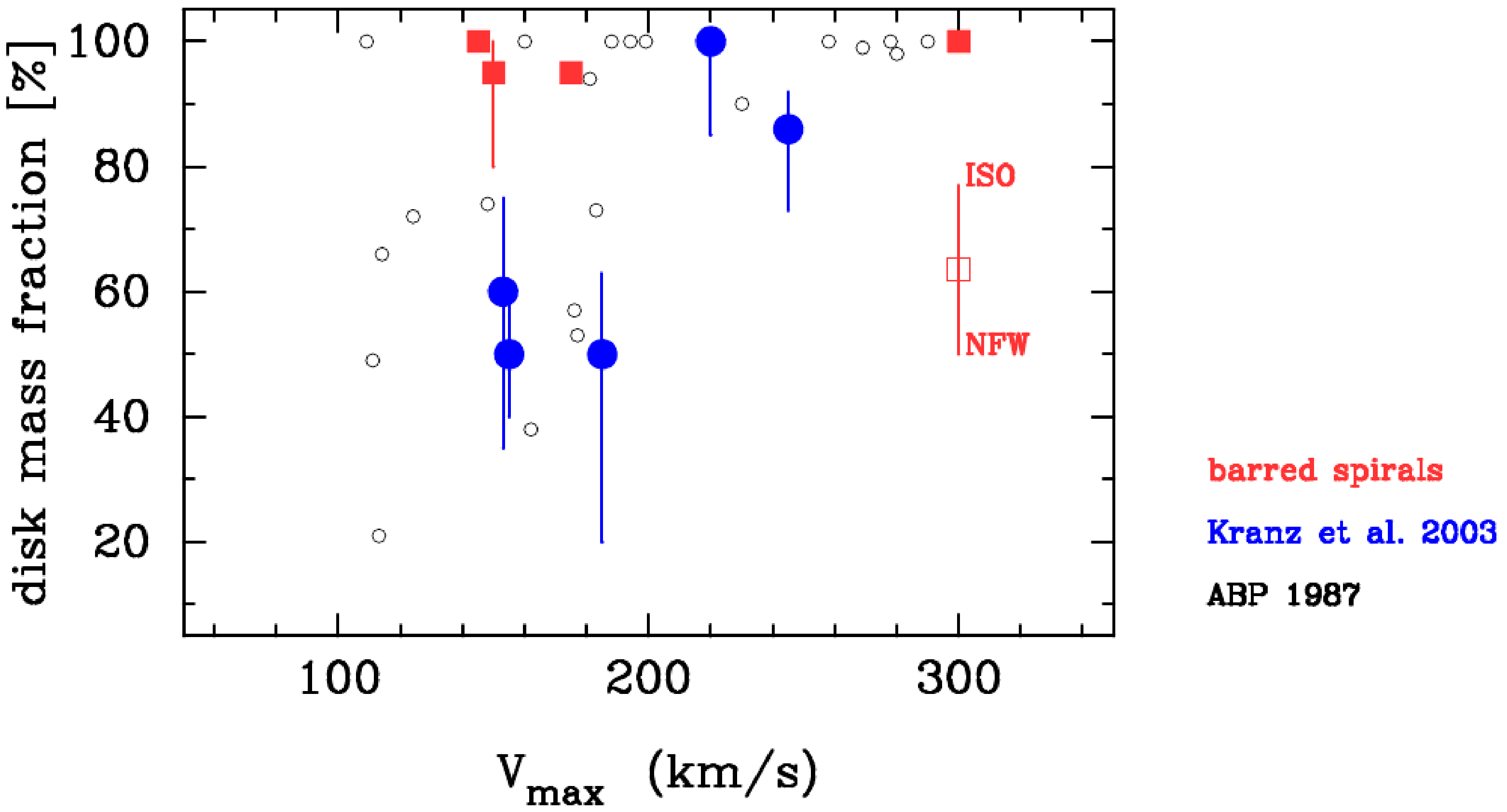


Gas flows in discs with non-axisymmetric components

Spirals : Kranz, Slyz, Rix 01, 03 (NGC 3810, 3893, 4254, 5676, 6643)

Bars : Lindblad, Lindblad, Athanassoula 96 and Zanmar-Sanchez et al. 08 (NGC 1365); Weiner, Sellwood, Williams 01 (NGC 4123); Weiner 04 (NGC 3095); Perez, Fux, Freeman 04 (IC 5186)

Different hydro codes
Different ways of calculating the potential from the photometry



Haloes necessary for disc stability ????

Ostriker & Peebles (1973):

Cold disks cannot 'survive': they are prone to a bar instability

If a spherical halo is added, the model is more stable

For our Galaxy this implies a halo mass interior to the disk which is about equal to the disk mass

Thus the halo mass exterior to the disk may be extremely large

(this was based on simulations with 500 mass points, as well as some analytic calculations)

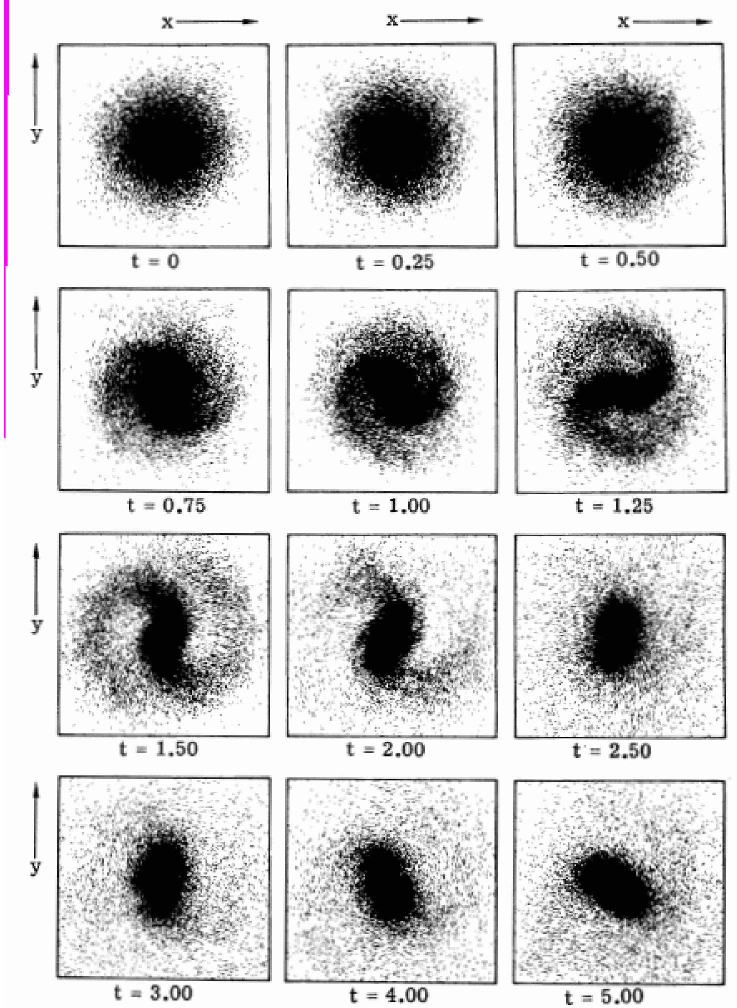


Fig. 9. Evolution of a disk of stars with an initially exponential mass distribution.

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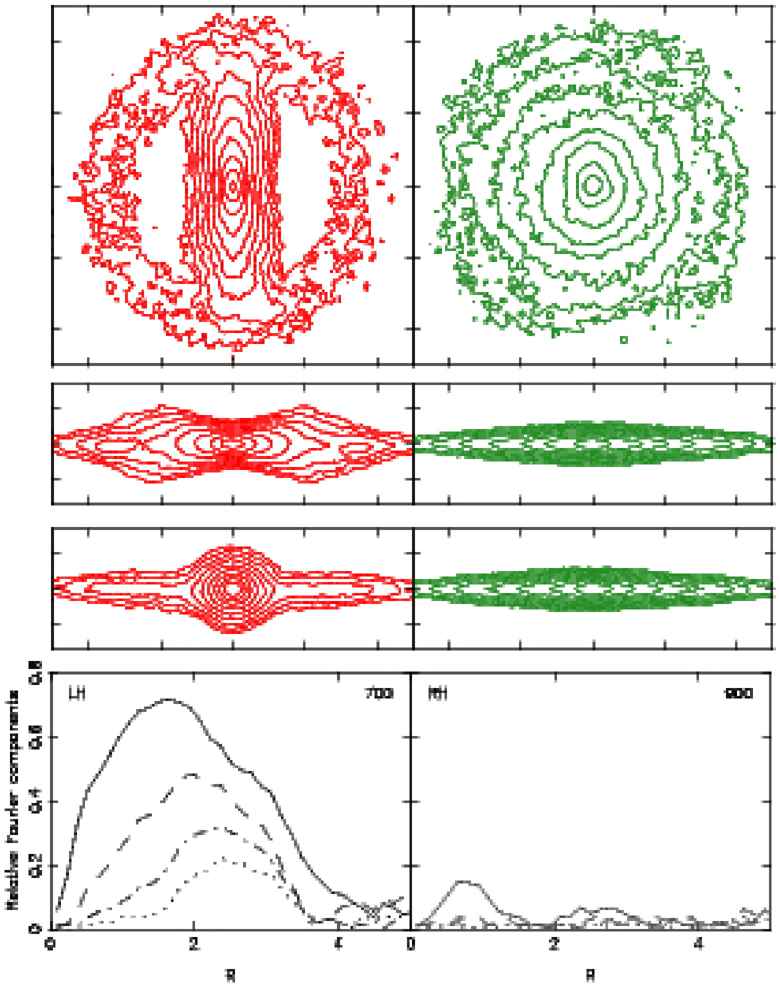
Hohl (1971)

Haloes should be adequately modelled

Live halo

Halo can receive angular momentum

Strong bar develops



Rigid halo

Halo can not receive angular momentum

No bar develops

Athanassoula 2002

The slowing-down of the bar due the halo (1)

$$1 < R_{CR}/a_B < 1.5$$

Corotation radius RCR: the radius at which a star on a circular orbit will corotate with the bar

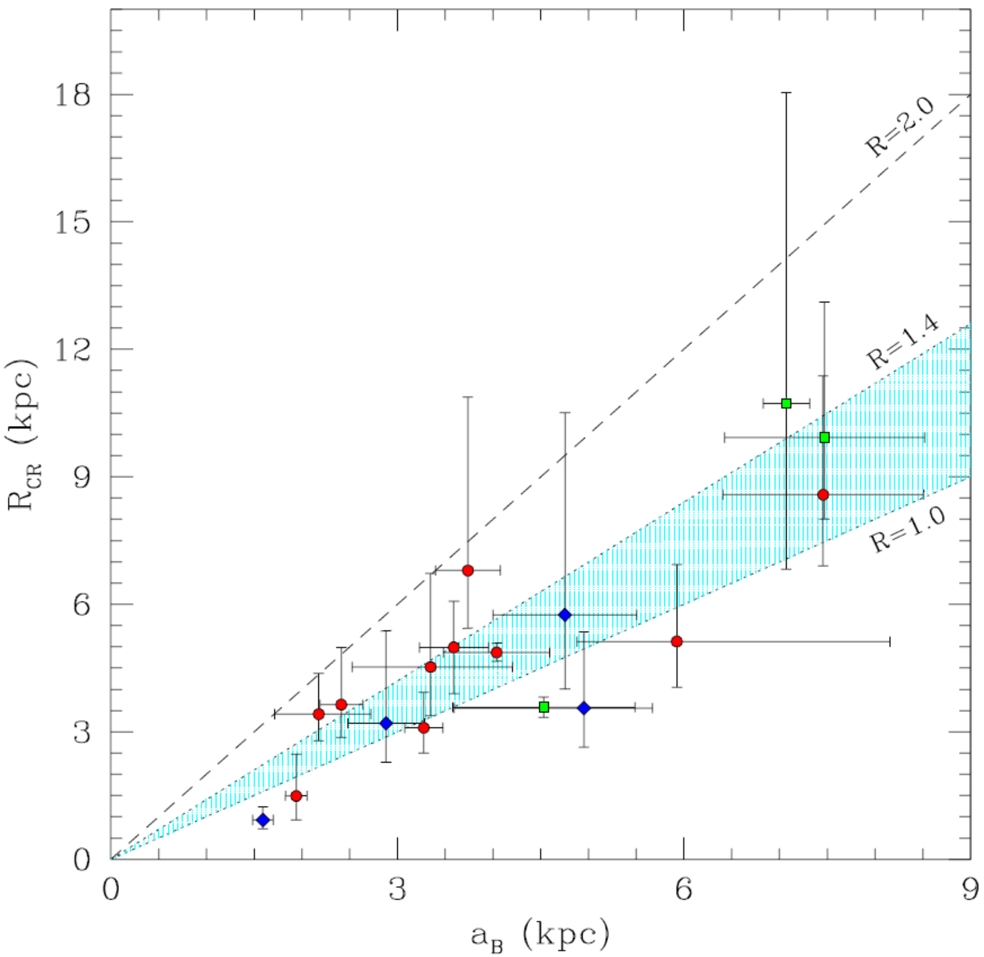
Ratio = R_{CR}/a_B

Constraints on this value:

Tremaine-Weinberg (1984) method on galaxies (Corsini 2008)

Shape of dust lanes from gas flow simulations (Athanassoula 1992)
1. < Ratio < 1.4

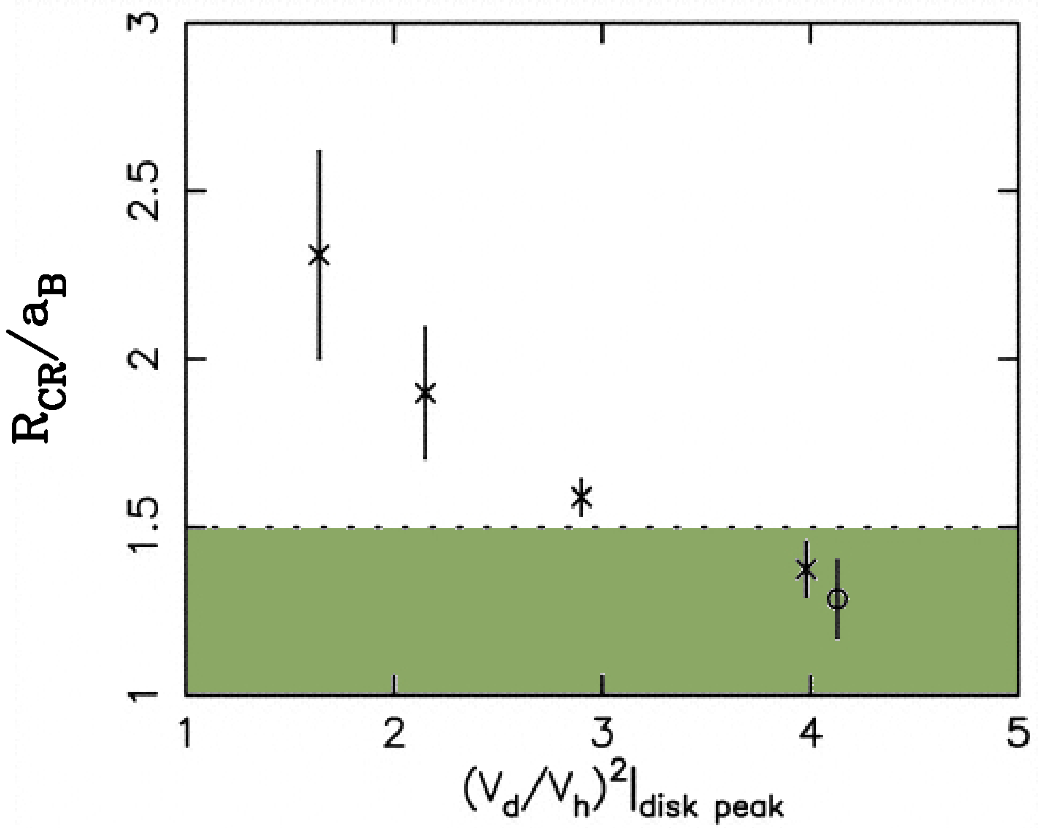
Other observational methods



Corsini 2008)

The braking of the bar by the halo

Debattista and Sellwood (1998, 2000)



Evolution

Athanassoula 2002, 2003

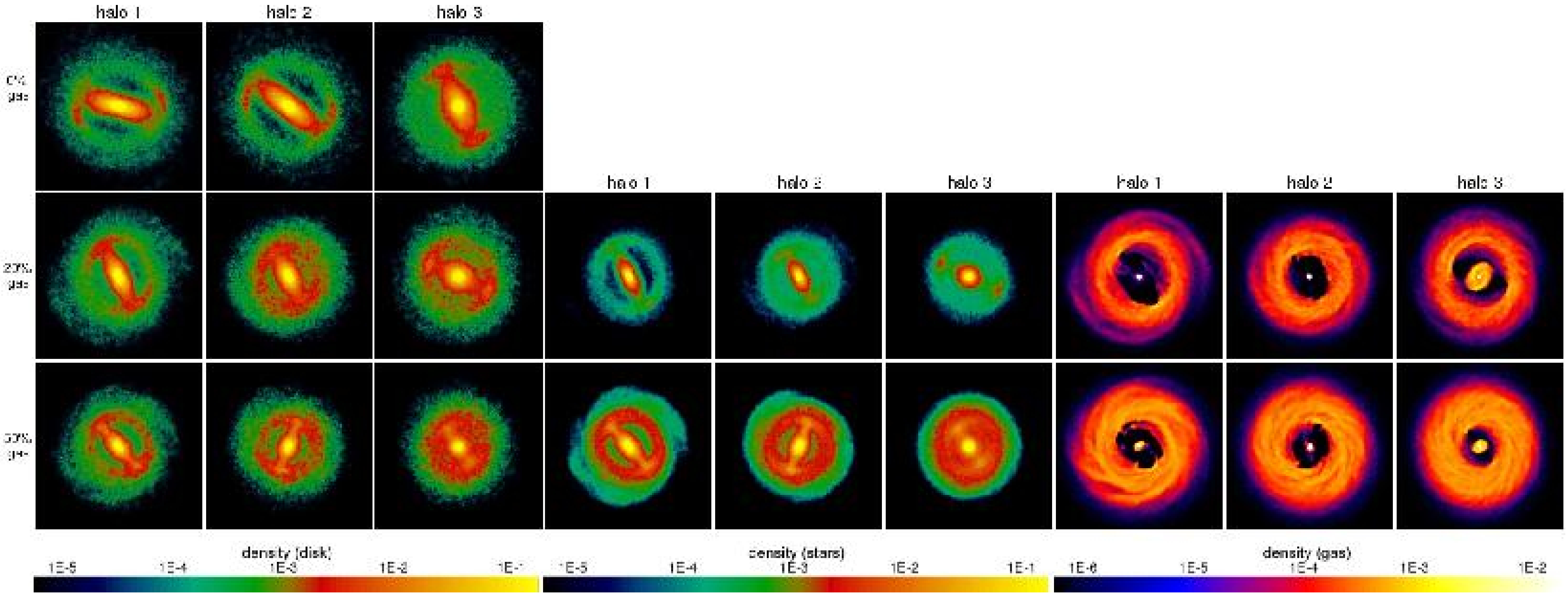
R_{CR} and a_B (and their ratio) depend on:

- the amount of halo and disc material that can emit/absorb angular momentum (i.e. the halo density).
- how hot/cold this material (disc/halo) is (i.e. the halo and disc DF)
- what the shape of the halo is, or was (spherical or triaxial)
- whether there is (or was) gas in the disc
- whether the bar was generated by an interaction

Old stars

Young stars

Gas



Athanassoula, Machado & Rodionov 2010a

Vertical motions

$$\langle v_z^2\rangle^{1/2}_{R=0} = \sqrt{\pi G \mu_0 \left(\frac{M}{L}\right) z_0}$$

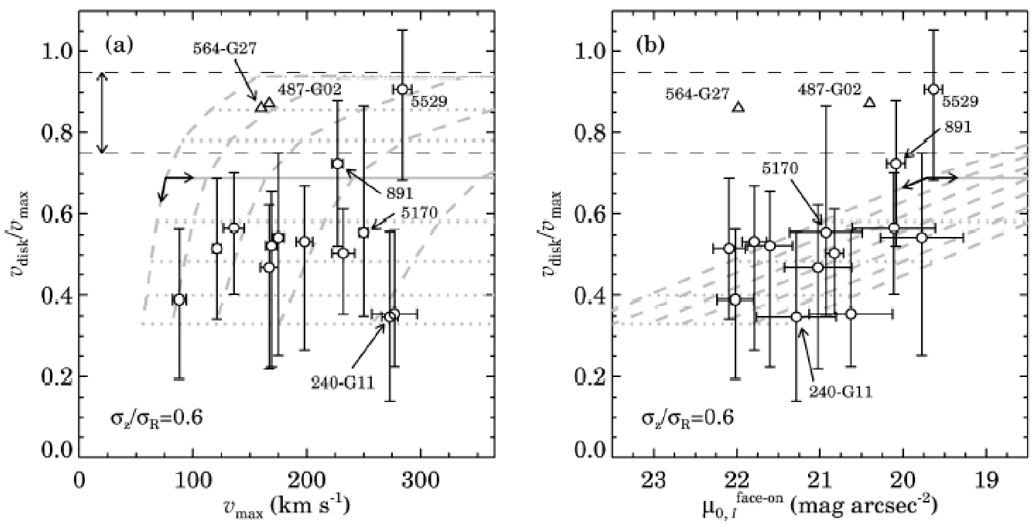


Figure 7.10: Contribution of the disk to the observed maximum rotation for $\sigma_z/\sigma_R = 0.6$. (a) – as a function of maximum rotational velocity (circles). The black dashed lines bracket the range for maximal disks (Sackett 1997). (b) – as function of face-on central surface brightness. In both panels several galaxies are highlighted, and the triangles indicate the outliers in Fig. 7.9, ESO 487-G02 and ESO 564-G27. The gray lines show the prediction of the collapse model (Dalcanton et al. 1997); dashed lines connect models of the same total mass ($\log_{10}(M_{tot}) = 10$–13 in steps of 0.5) and dotted lines connect models of with same spin parameter (logarithmically spaced, separated by factors of 0.2 dex, with the solid line at $\lambda = 0.06$). The arrows indicate the direction of increasing M_{tot} and λ.

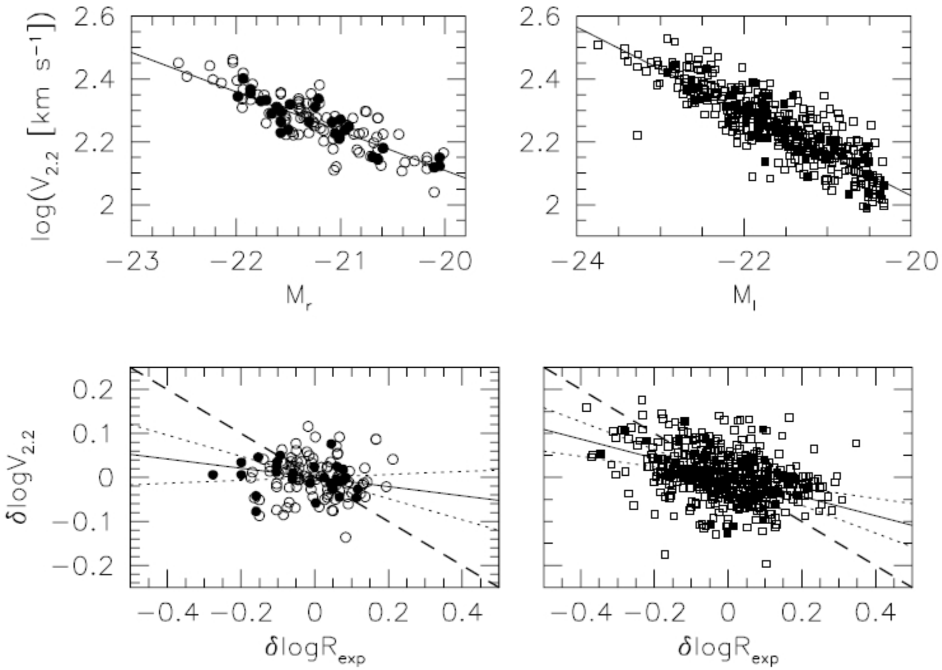
Bottema (1993)
Kregel et al (2003)
Hermann & Ciardullo 2009
O'Brien et al. (2010)
Bershady et al. 2010;
Westfall et al. 2009

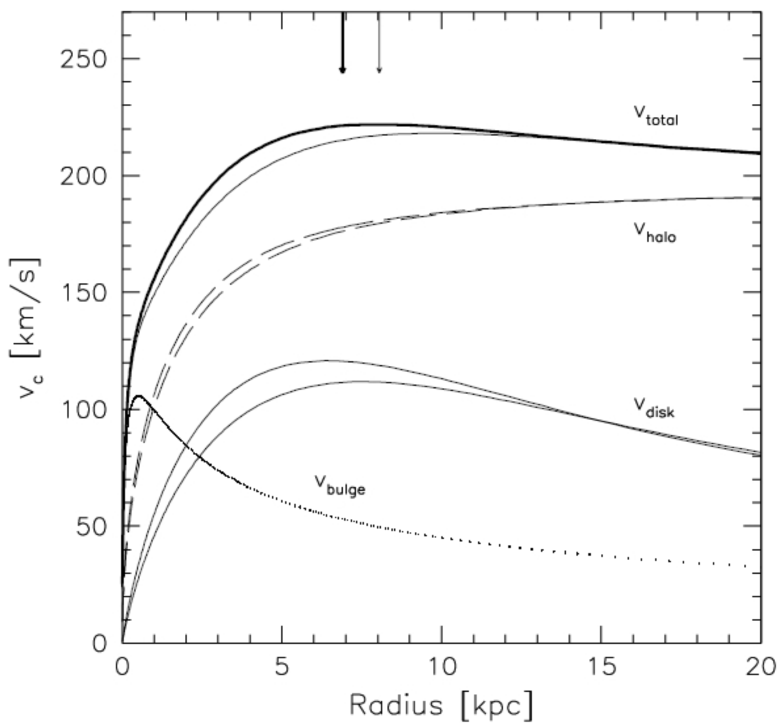
zo and the vertical light distribution can be obtained for galaxies observed edge-on

The dispersion of the z velocity component can be obtained for galaxies observed face-on

Barred galaxies seen edge-on?

TF residuals





$$v_c^2(R) = 4\pi G \Sigma_0 R_{\rm exp}\, y^2[I_0(y)K_0(y) - I_1(y)K_1(y)]$$

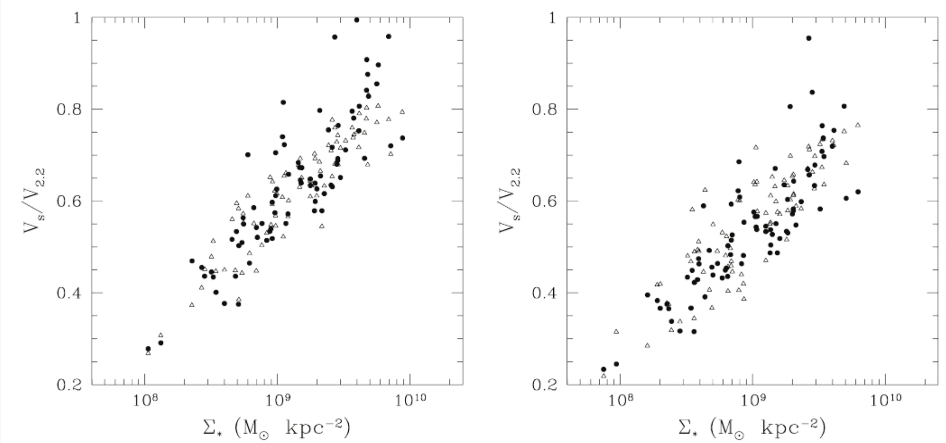


Fig. 10.—Contribution of stars to the circular velocity at $2.2R_d$ vs. stellar surface density. Filled circles are the data, using the SED-based estimates of the stellar mass; triangles are a realization of our best-fit model with $\bar{m}_d \propto \Sigma_*^{p_2}$, including the AC effect. *Left*: Kroupa IMF; *right*: light IMF.

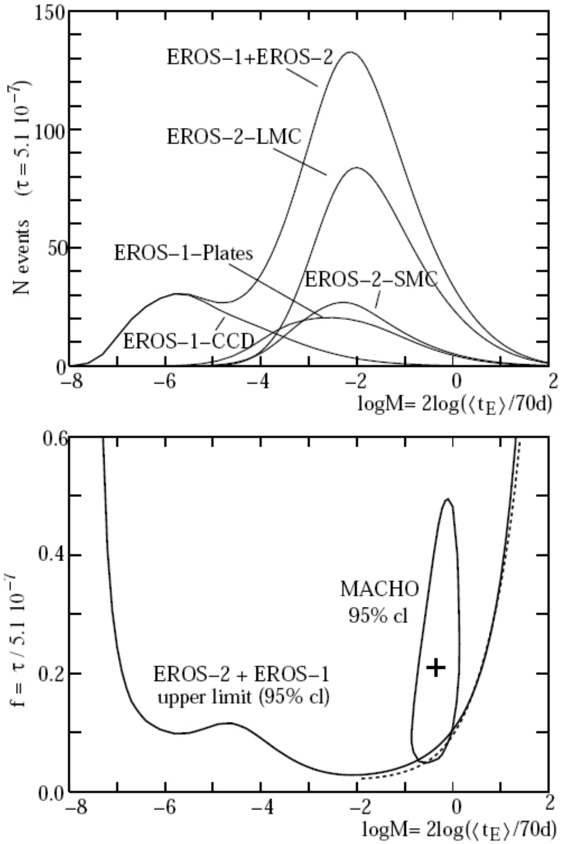
$$\partial \log V_{2.2} / \partial \log R_{\rm exp} = -0.5$$

Courteau & Rix, 1999
Gnedin et al, 2007

Our Galaxy : microlensing and gas dynamics

Microlensing towards LMC/SMC :
- no evidence for much baryonic DM

Microlensing towards bulge :
- not much room for NFW-like profile



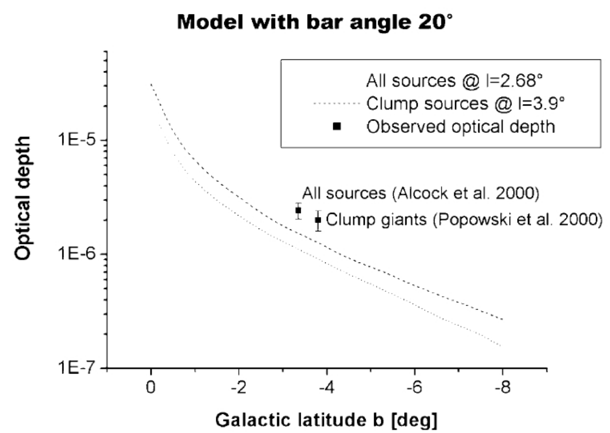
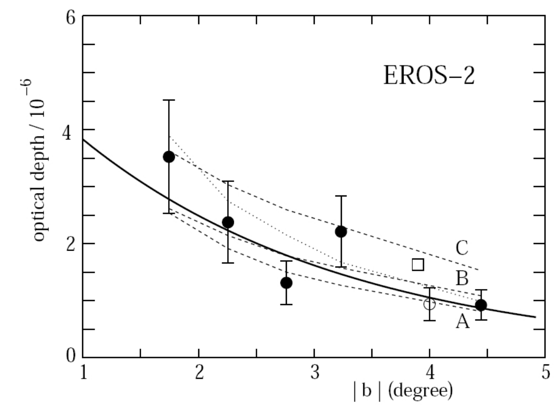


Figure 17. Microlensing optical depth of our reference model at the longitudes of the newly published *MACHO* results, plotted as function of galactic latitude. The observations are indicated in the figure. The upper curve shows the optical depth for clump giant sources, the lower curve for all sources. Both curves are for the galactic longitude of the published observations for the respective group of sources.



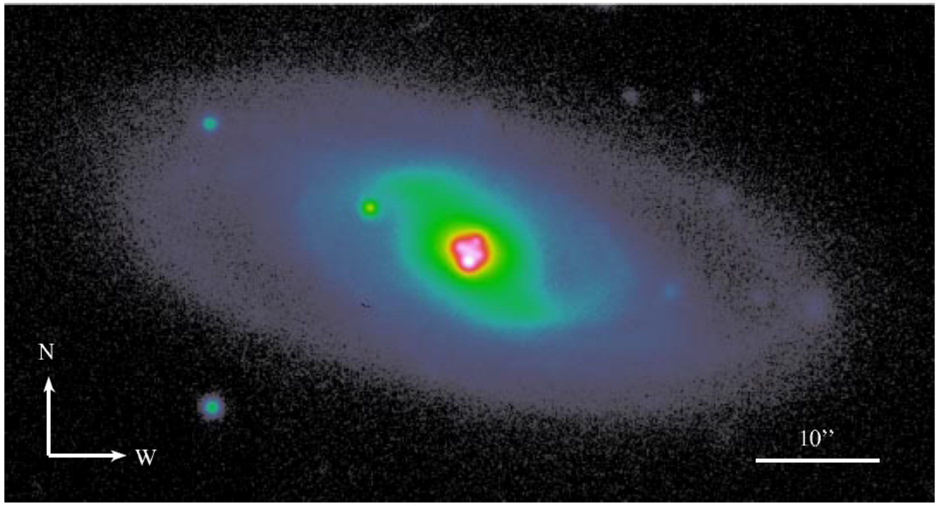
Tisserand et al. (2006)

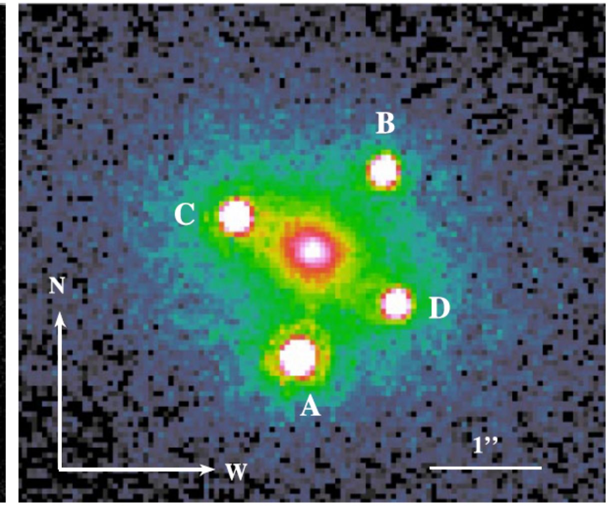
Bissantz & Gerhard (2002)
Bissantz et al. (2003)

Hamadache et al. (2006)

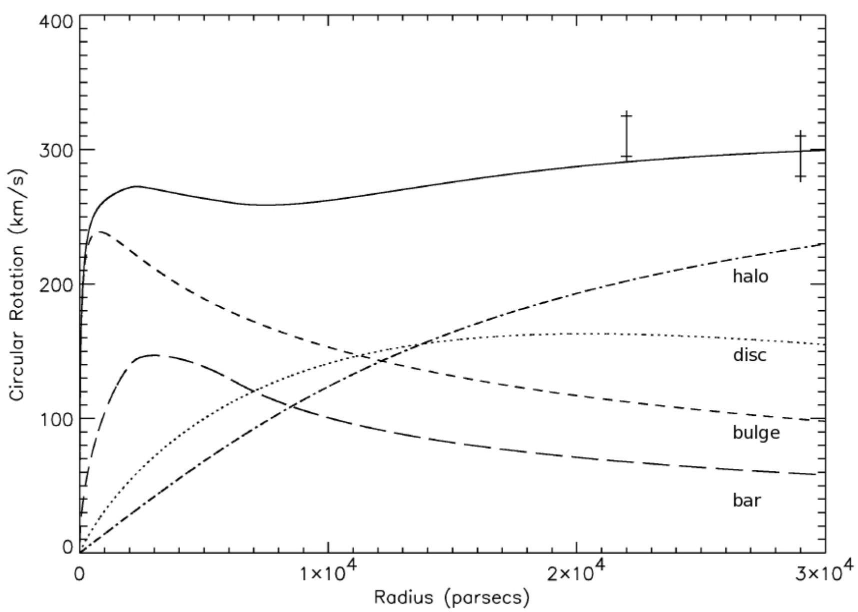
Lensing – QSO 2237+0305

Eigenbrod 2008

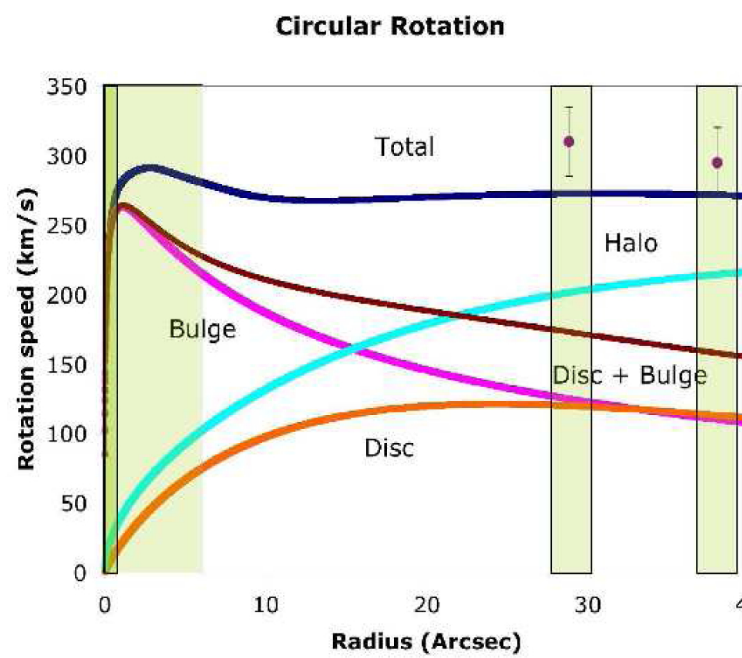




Trott et al. 2002



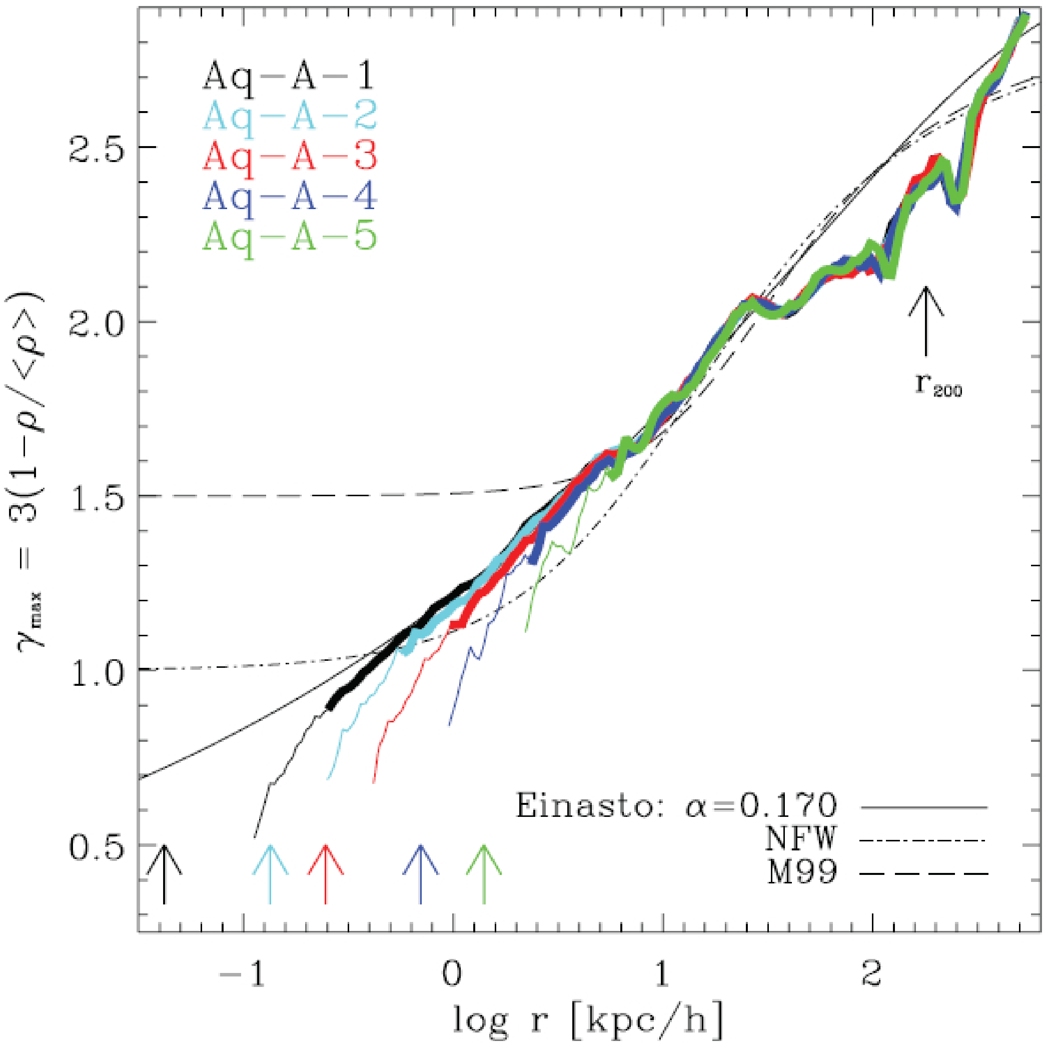
Trott et al. 2010



Cusp versus core controversy

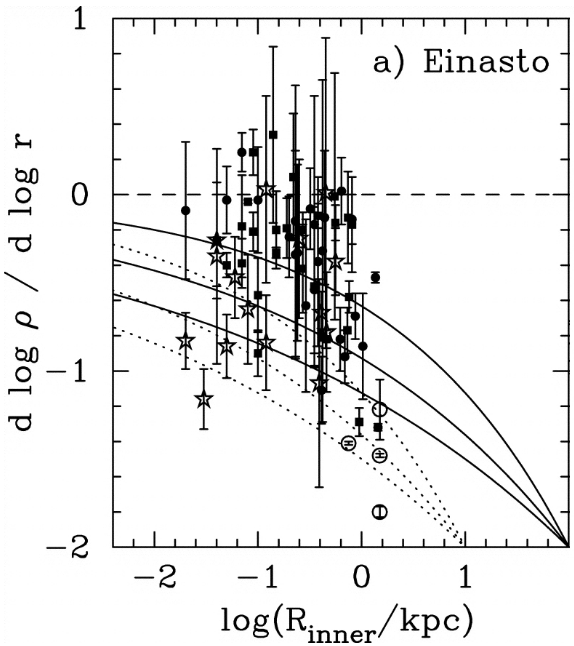
DM only, VERY high resolution cosmological simulations

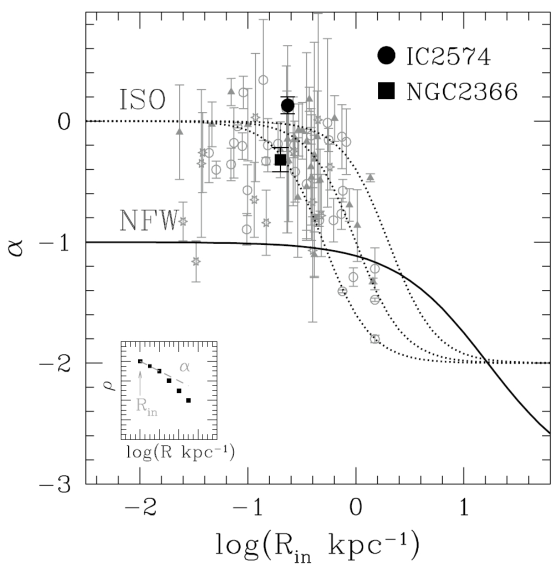
Navarro, Frenk, White 1996, Navarro et al 2004, 2010



Observations of dwarf and LSB galaxies

Graham et al. 2006





De Blok et al 2003

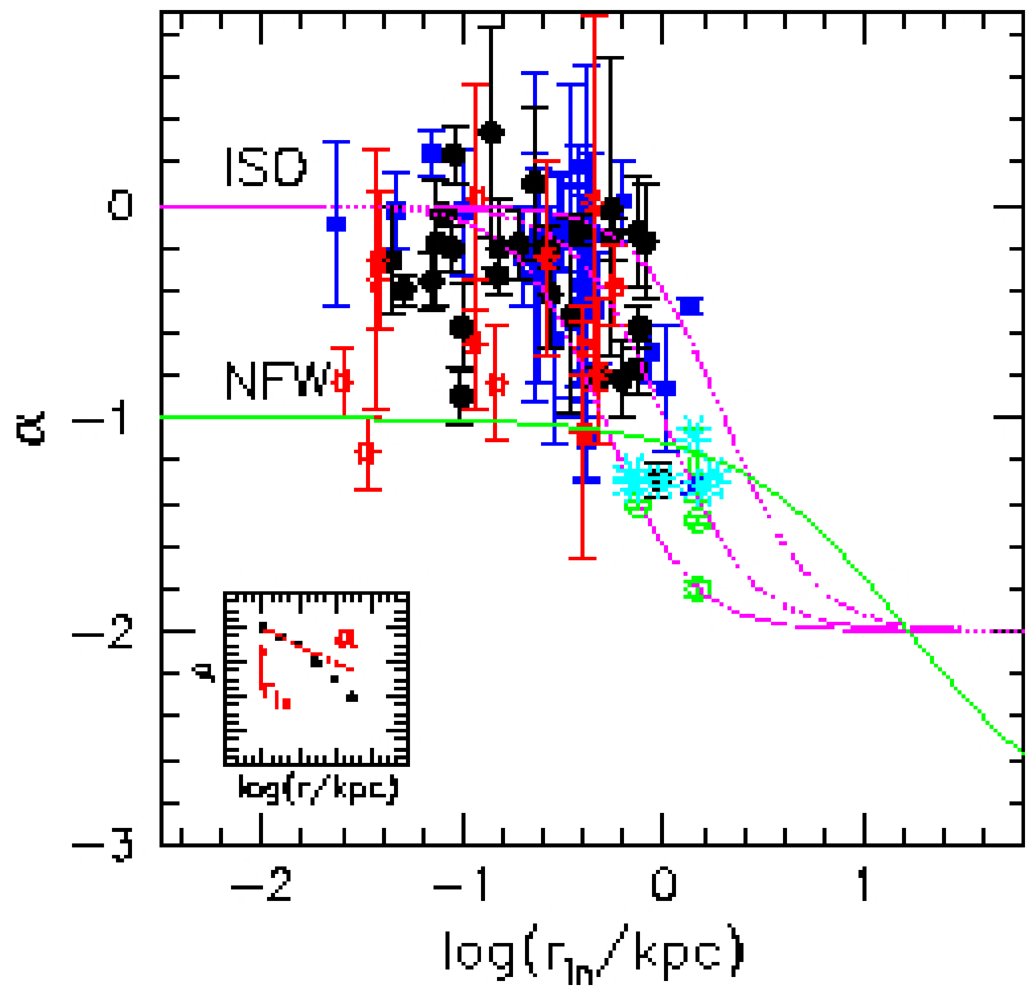
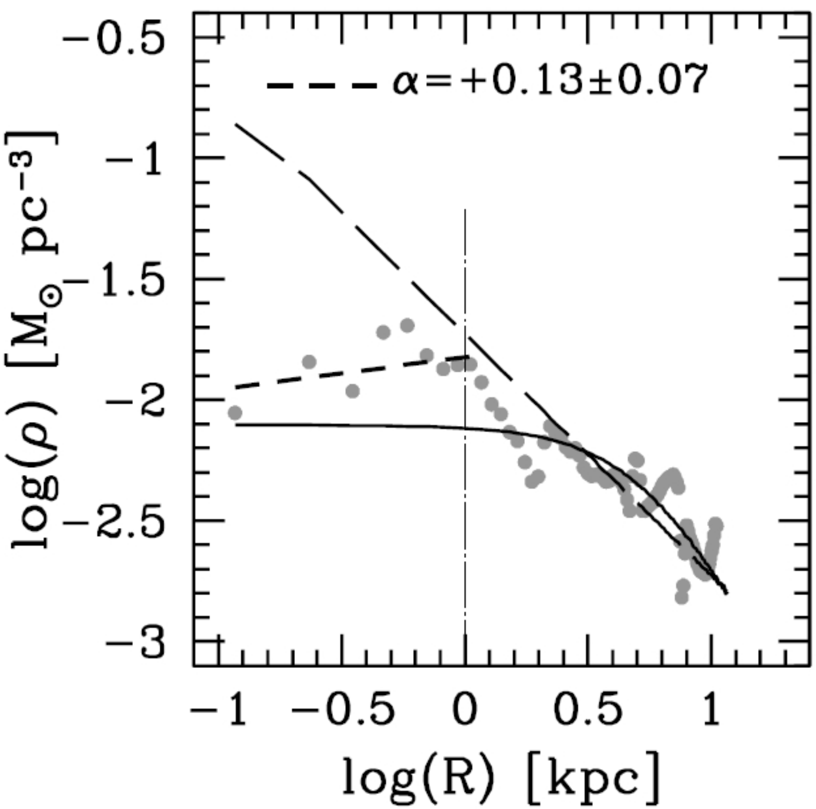


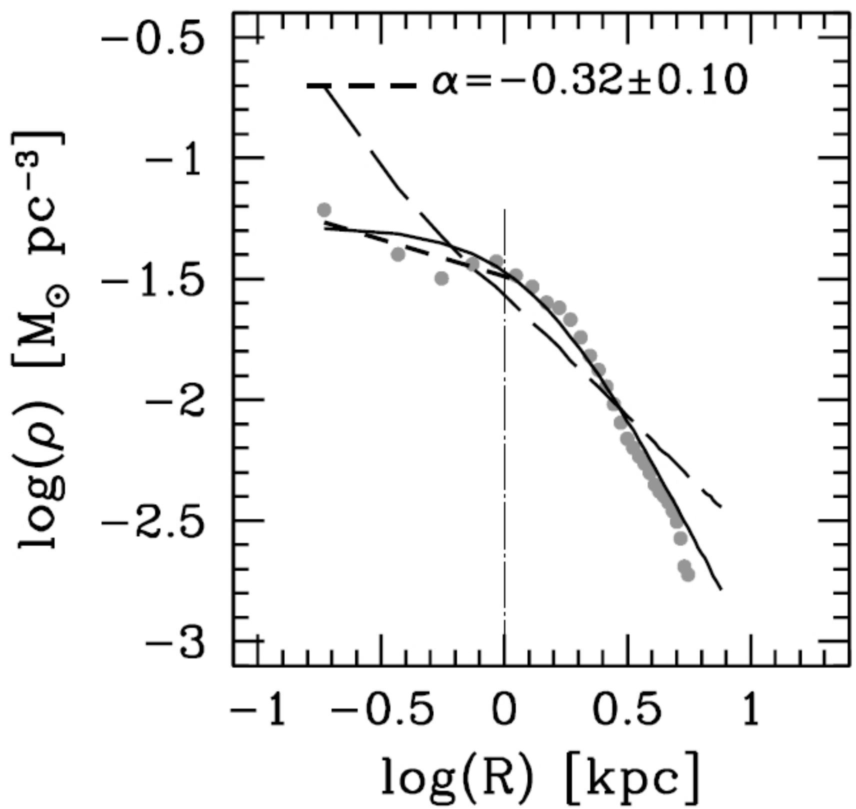
Figure 3. Inner mass-density slope α versus resolution r_{in} of the LSB rotation curves. Symbols with error bars are observational data. Circles: de Blok et al. (2001a); squares: de Blok & Bosma (2002); open stars: Swaters et al. (2003). The large asterisks near $\alpha \sim -1$, $r_{in} \sim 0$ are the simulations by Hayashi et al. (2003). Curves indicate predicted slopes for various core models (dots) and a NFW model (full line). See

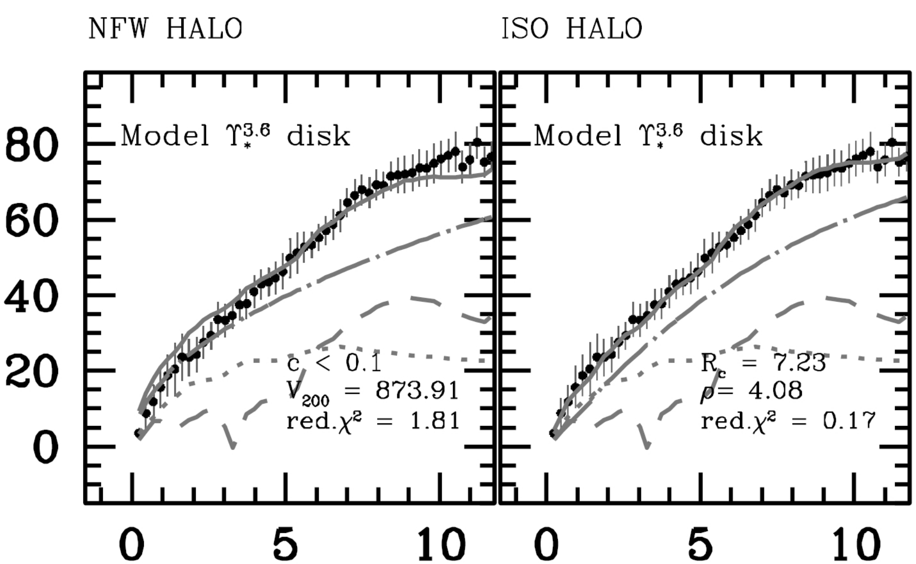
THINGS survey, Oh et al. 2008

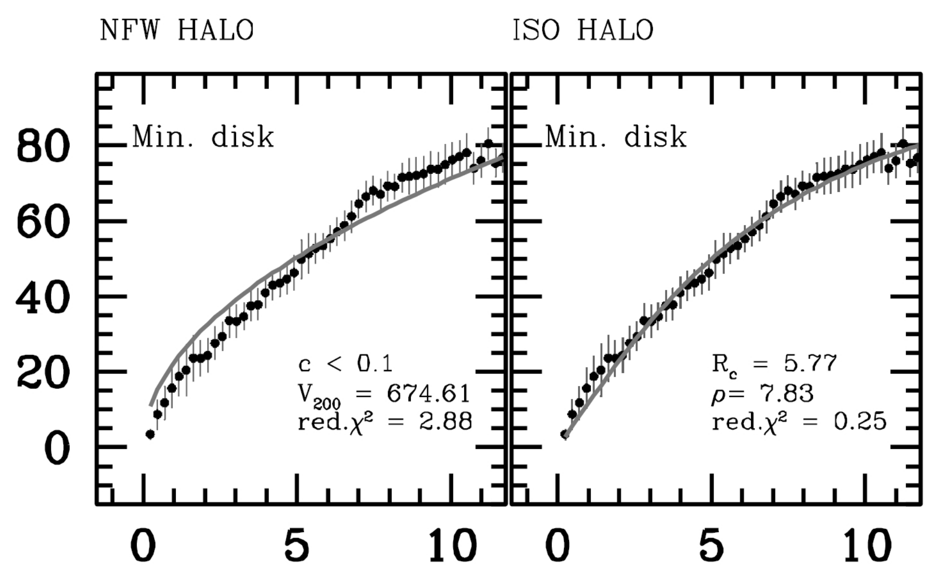
IC 2574



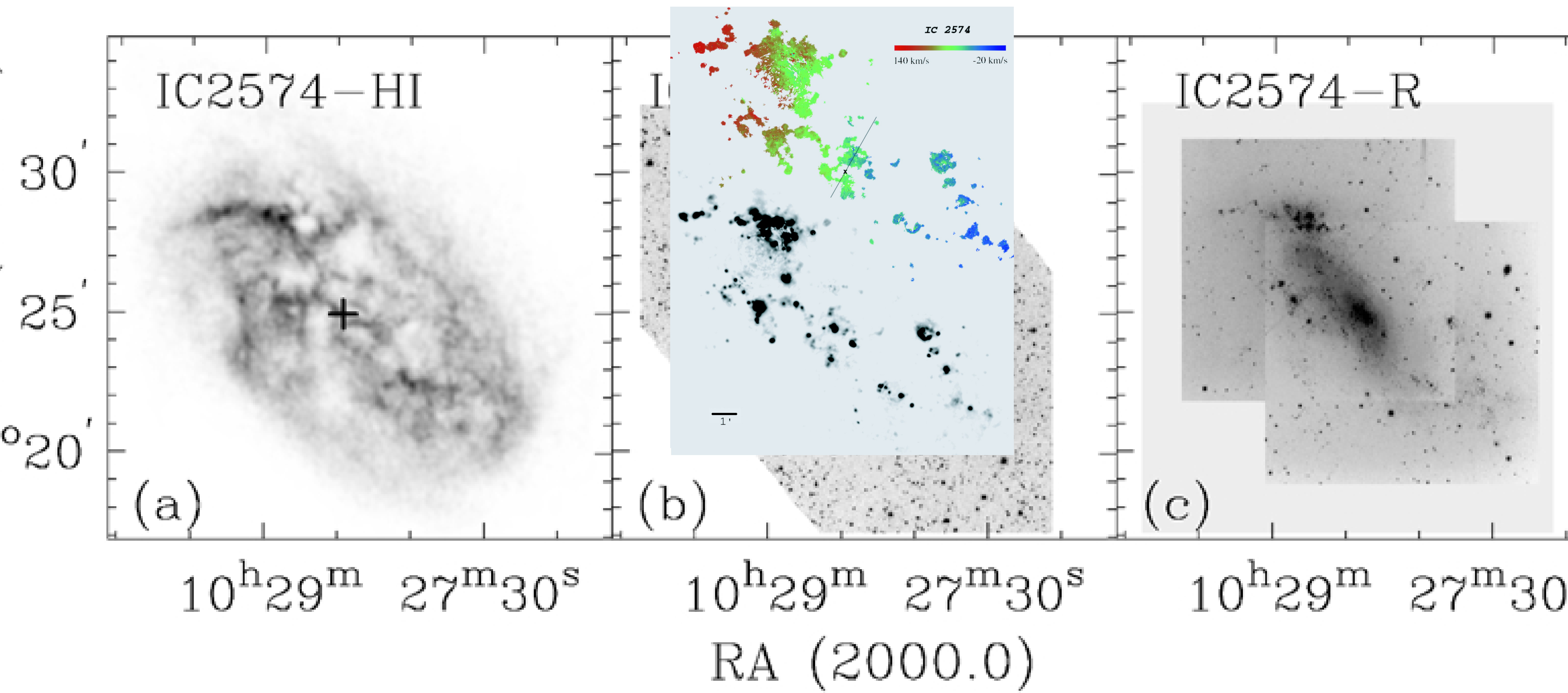
NGC 2366





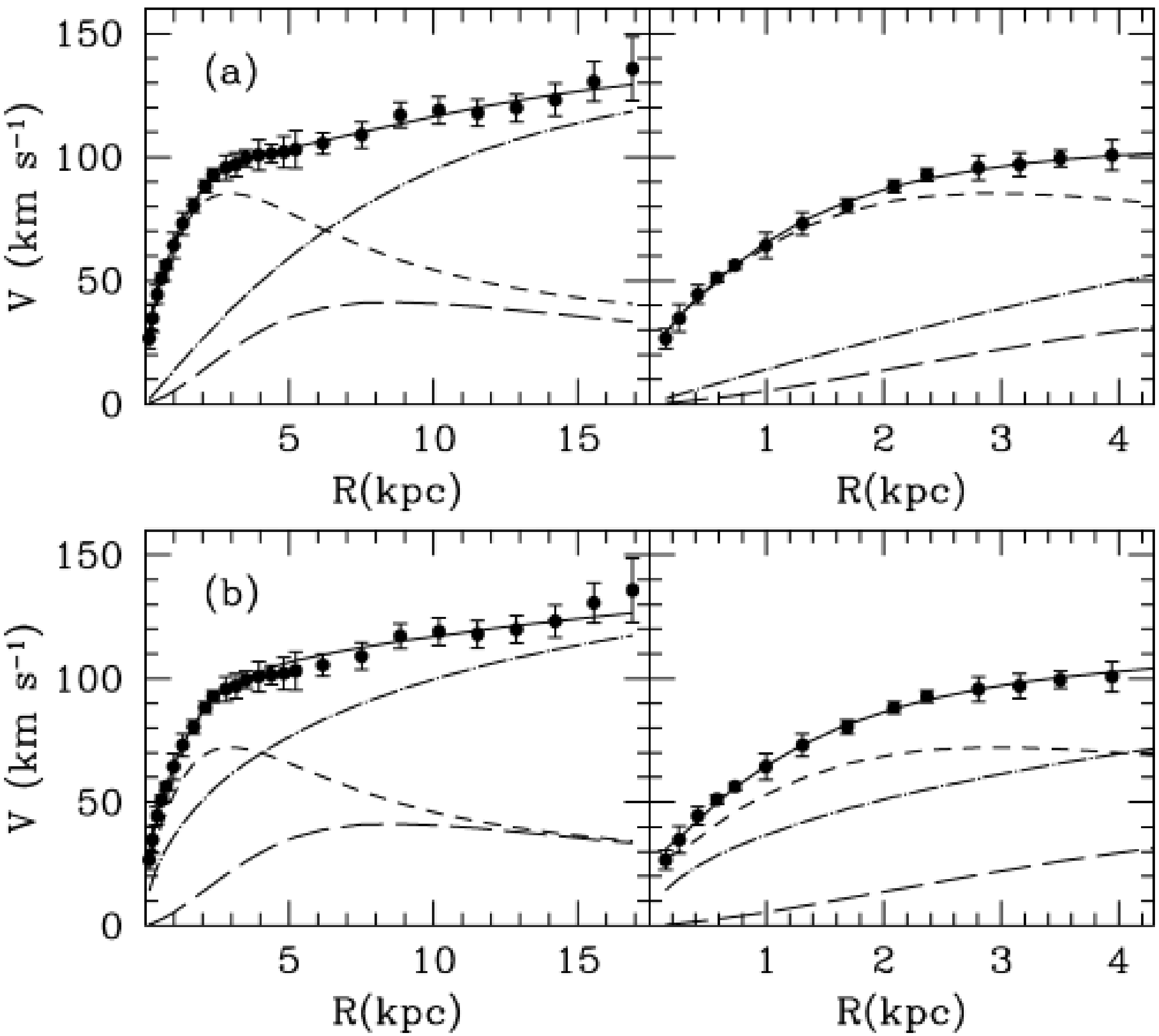


Hα Blais-Ouellette et al. 2001
HI Oh et al. 2008

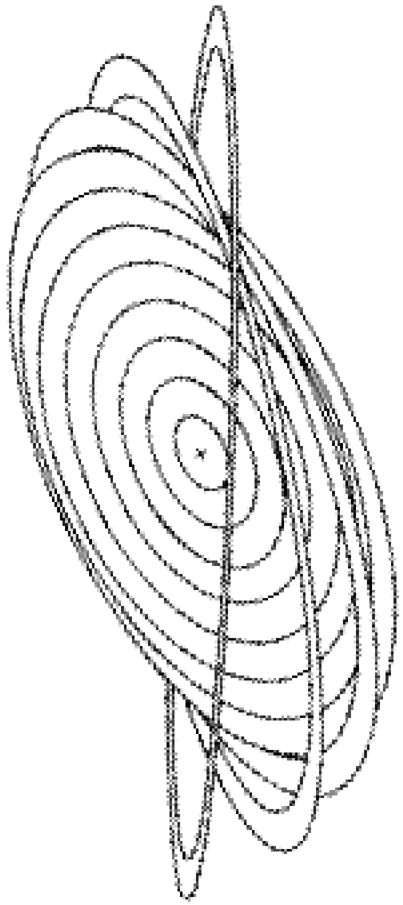


M33

Corbelli 2003



Rogstad et al. 1974



Back to degeneracy!

Infall of heavy baryonic clumps

El-Zant, Shlosman, Hoffman 01
Ma & Boylan-Kolchin 04
Nipoti et al 04
Arena & Bertin 07
Jadrel & Sellwood 09

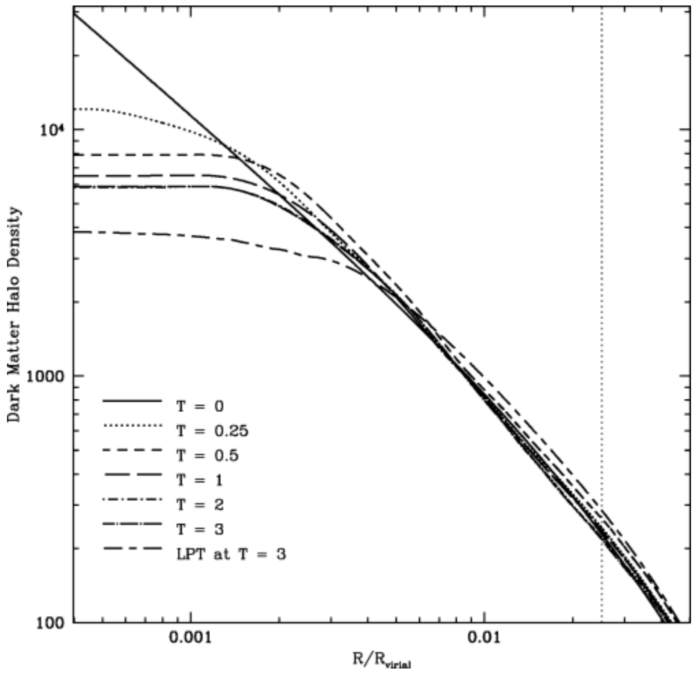
Clumps are can be described as baryonic bullets (heavy mass particles)

- not tidally disrupted
- have no internal physical processes (no SF, feedback etc)
- small enough so as not to collide
- are largely baryonic (very small DM/baryon mass ratio)
- must be massive to have some effect on the density profile and to reach the centre in a sufficiently short time (> 1% of the halo mass). How can so massive clumps be baryonic? If satellite, i.e. baryons + DM, the DM from the cusp is simply replaced by the DM from the satellite. So no change in density profile

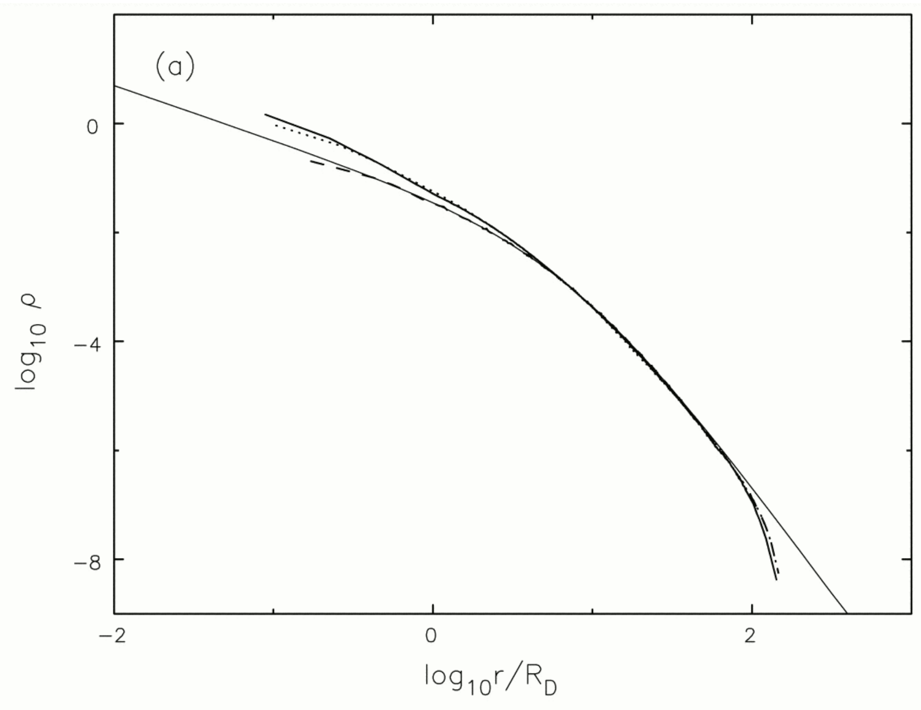
Decrease of the halo central density due to a bar (1)

Weinberg and Katz 2002, 2005

Near-resonant material in the inner halo takes angular momentum from the bar and moves to larger radii



Holley-Bockelmann, Weinberg and Katz 2005



Sellwood 2003
Also Colin, Valenzuela, Klypin 06

Decrease of the halo central density due to a bar (2)

Dynamically sound … but …

1) Bar formation and evolution concentrates the disc material inwards. This will pull the halo inwards. How much depends on the bar strength

2) inner part of the halo emits angular momentum in disc geometry, but absorbs it in halo geometry. So a dark disc will emit, not absorb (Athanassoula 2002)

The outcome depends on the balancing of these counter-acting effects and therefore on many parameters of the halo and disc DF

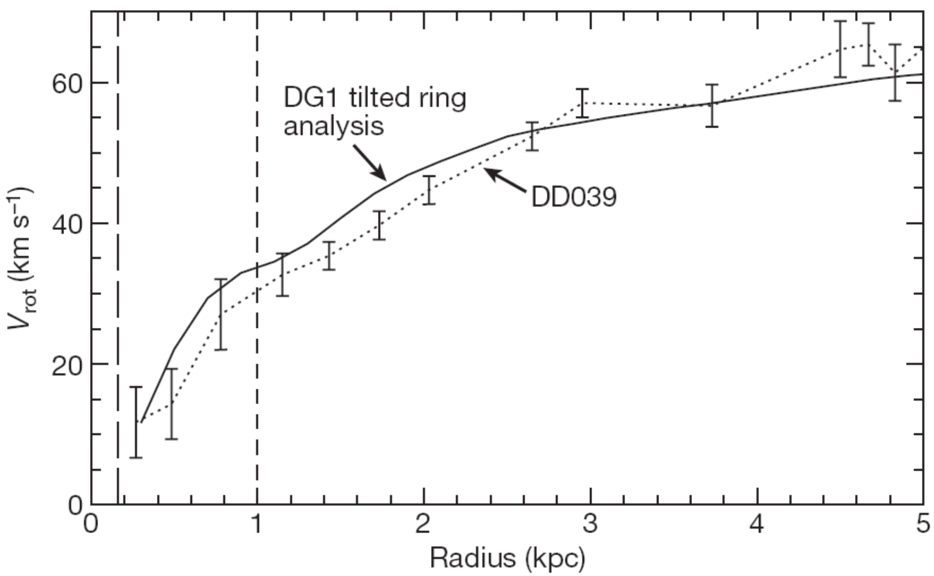
Dark matter cores due to supernova-driven outflows

Binney, Gerhard & Silk 2002, Mashchenko, Couchman & Wadsley 2006, 2008

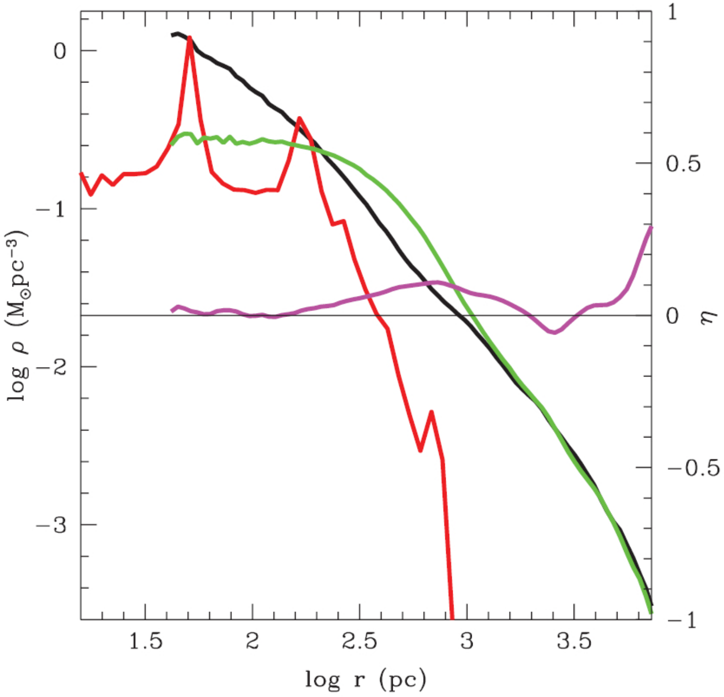
Winds from SN removing selectively low angular momentum material

Governato, Brook, Mayer et al 2010, Mashchenko et al 2008,
Navarro, Eke, Frenk 1996

High resolution LCDM cosmological simulation of a dwarf galaxy with 'resolved' ISM
Feedback drives large-scale, bulk motions of the gas, leading to substantial potential fluctuations and a sizeable decrease of the central density



Governato et al 2010



Mashchenko et al 2008

Stellar feedback in high redshift galaxies

This could solve the core-cusp controversy in dwarfs, but not in MW size galaxies (e.g. MacLow & Ferrara 1999, Gnedin & Zhao 2002 etc)

But when these dwarfs merge, they will form merger remnants also with a core
(Merger remnants radial density profiles: Saitoh & Wada 2003, Dehnen 2005, Kazantzidis et al 2006, McMillan, Athanassoula & Dehnen 2007, etc ..)

Dwarfs with a core are more easy to disrupt than dwarfs with a cusp. So this may solve also the problem of over-abundance of satellite in MW type galaxies

LCDM would be in good agreement with observations at all scales

Conclusions

Are discs maximum?

No definite answer.

Maximum discs are not in good agreement with NFW-like profiles

Cusps or cores?

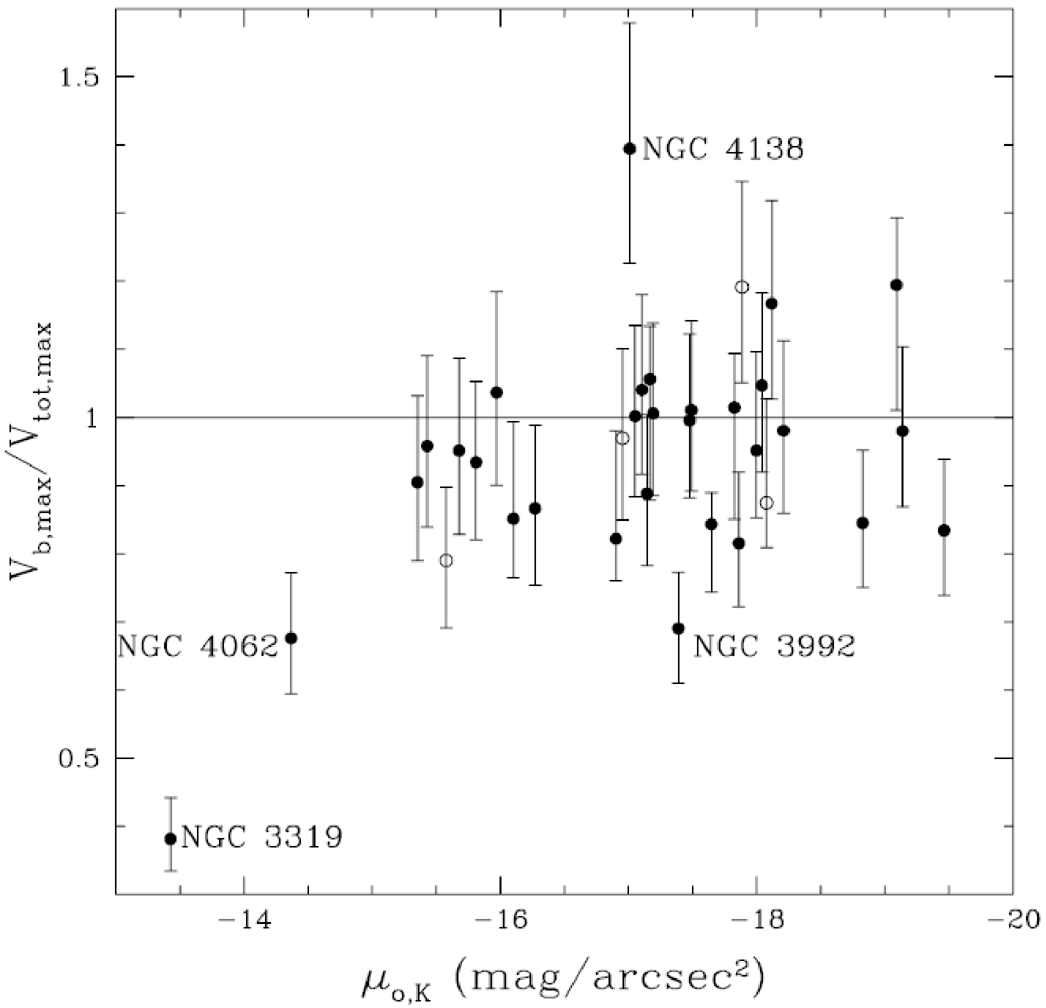
DM-only , very high resolution simulations argue for NFW-like profiles (cusps)

Observations argue mainly for cores

Feedback from the baryons around z~1 may flatten the cusps in dwarf galaxies. Then mergings would produce large spirals with cores. This could perhaps also solve the problem of satellite over-abundance το τέλος

Colour – M/L relation

Kassin et al (2006a, 2006b)



Colour – M/L relation by Bell & de Jong (2001) from spectrophotometric evolution models. They give an upper limit to the baryonic mass.

Halo fits by NFW are poor and worse if adiabatic compression is included