Dark matter in high-z galaxies

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HI measurements probe dark matter in galaxies

Link it to : galaxy formation problem
detailed structure of our Galaxy

z = 2 ? are galaxies already established ?

z = 1 ? angular resolution problems (~ 8 kpc/arcsec)

z = 0.5 then ? Maybe SKA + ALMA + JWST NIRSpec

z = 0.2 : ought to be possible

z = 0.0 : still a lot to be learned ...

At high z, maybe it can be done, but it won't be easy

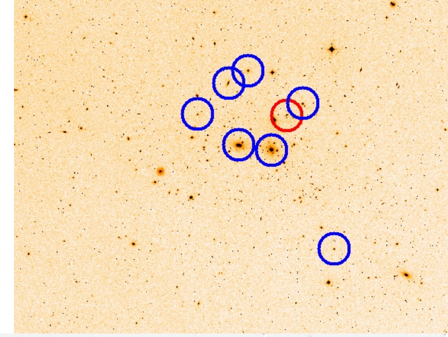
Zwicky 1933 : dunkle Materie

$$\bar{\varepsilon}_k = \overline{v^2}/2 = -\bar{\varepsilon}_p/2 = 32 \times 10^{12}\ \mathrm{cm^2\,sek^{-2}}$$

$$(\overline{v^2})^{1/2} = 80\ \mathrm{km/sek}\ . \qquad (8)$$

Um, wie beobachtet, einen mittleren Dopplereffekt von 1000 km/sek oder mehr zu erhalten, müsste also die mittlere Dichte im Comasystem mindestens 400 mal grösser sein als die auf Grund von Beobachtungen an leuchtender Materie abgeleitete[1]). Falls sich dies bewahrheiten sollte, würde sich also das überraschende Resultat ergeben, dass dunkle Materie in sehr viel grösserer Dichte vorhanden ist als leuchtende Materie.

[1]) Dies wäre grössenordnungsmässig in Übereinstimmung mit der in § 4 besprochenen Auffassung von EINSTEIN und DE SITTER.

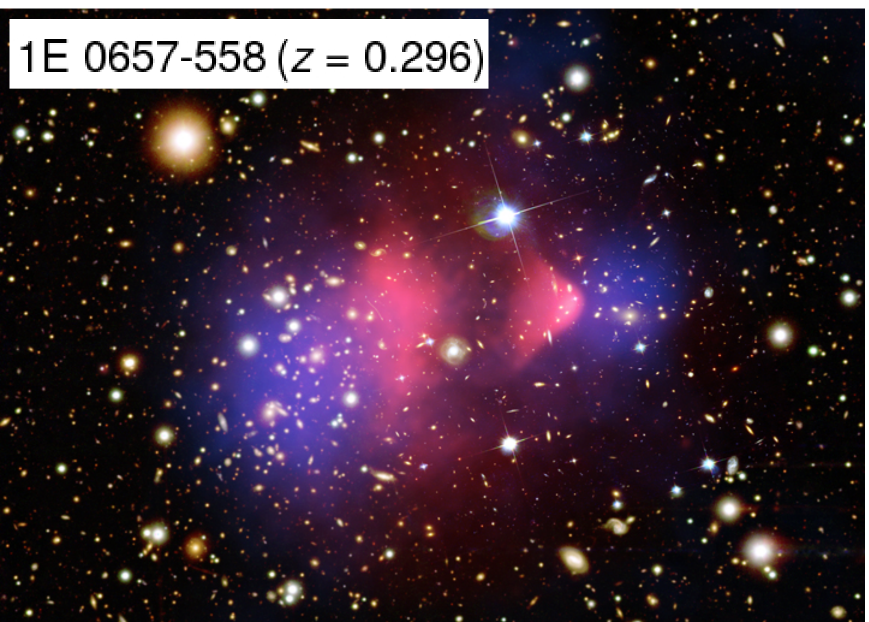


Scheinbare Geschwindigkeiten im Comahaufen.

v = 8500 km/sek	6900 km/sek
7900	6700
7600	6600
7000	5100 (?)

Coma <cz> = 7038 ± 1020

Colless & Dunn 1996 : 6917 ± 1038



DM "proof" Clowe et al. (2006) ApJ 648, L109

Zwicky (1937) suggests lensing can give simple and accurate masses

Schwarschild (1954) finds low values for M/L for M31 and other gas rich galaxies, he also says elsewhere in the paper :

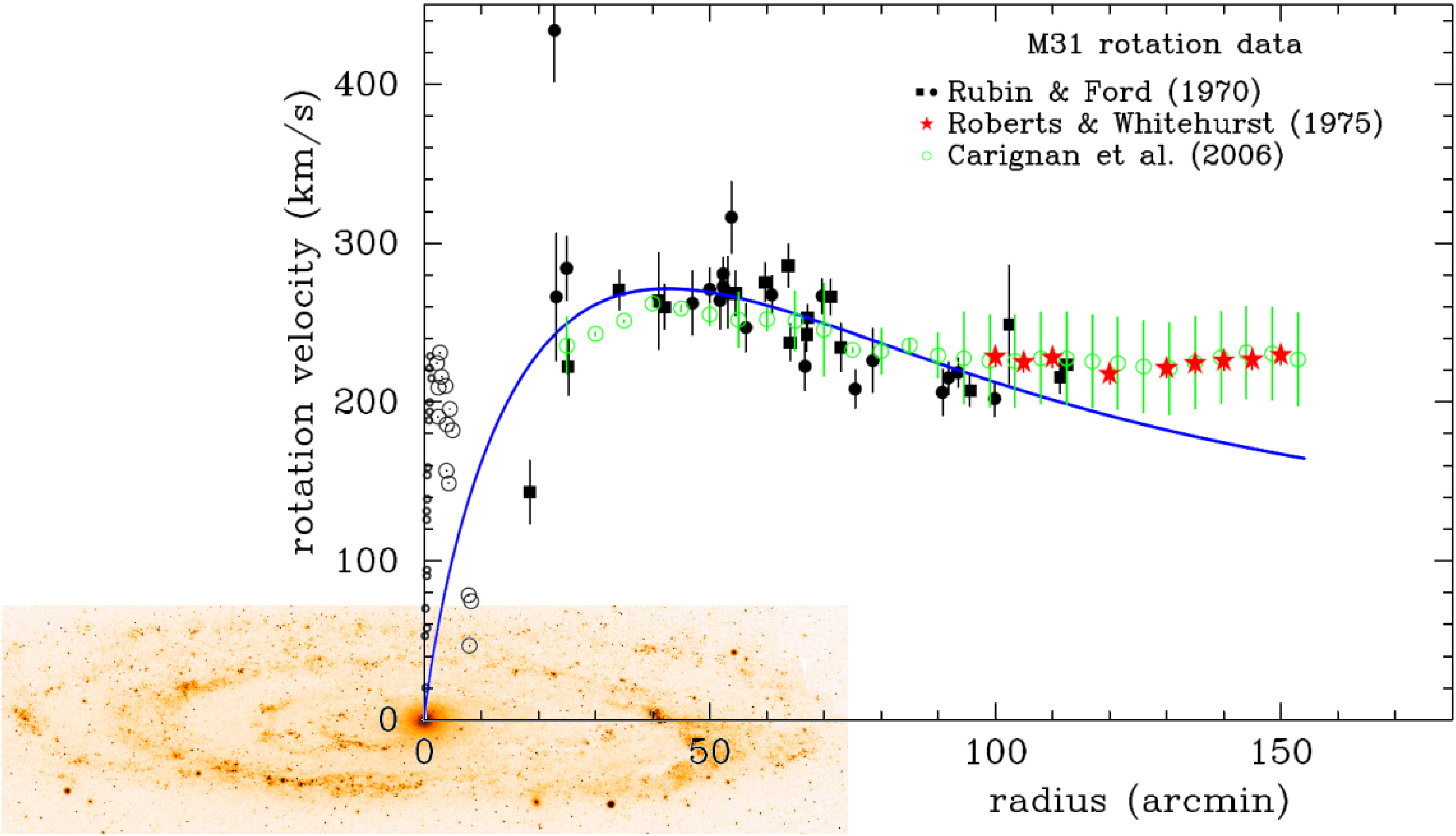
With the above value for the average mass one finally finds for the mass-luminosity ratio in the Coma cluster

$$f = 800.$$

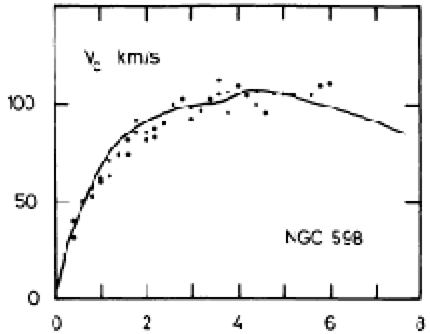
This bewilderingly high value for the mass-luminosity ratio must be considered as very uncertain since the mass and particularly the luminosity of the Coma cluster are still poorly determined.

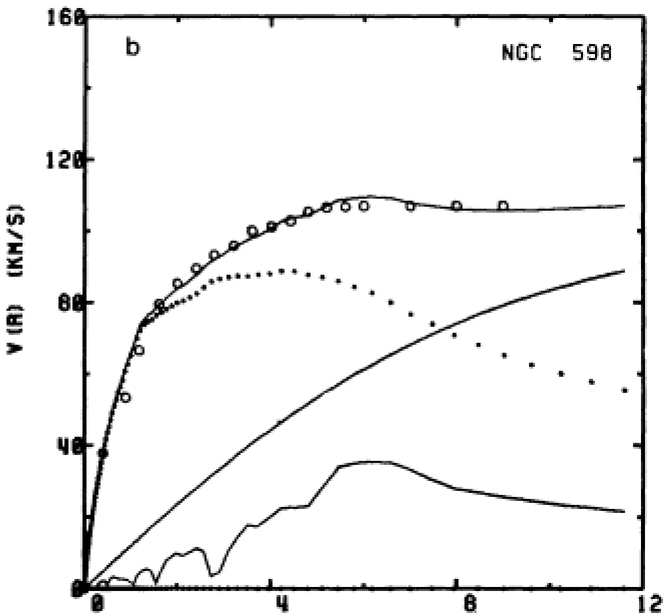
M31 – Rubin-Ford curve can be fitted with exponential disk without need for dark matter (blue curve)

– For the bulge, see Athanassoula & Beaton (2006)



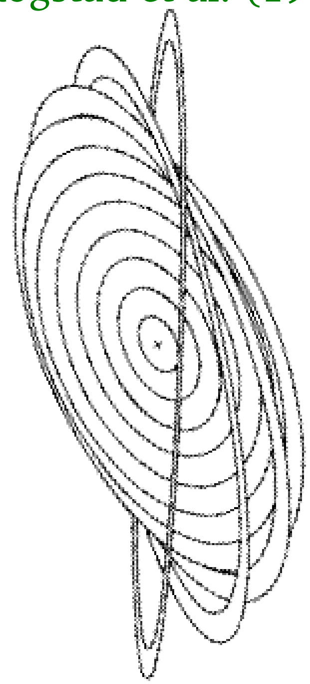
M33 – problem of the warp : again hardly any need for dark matter if one takes data out to the edge of the optical image

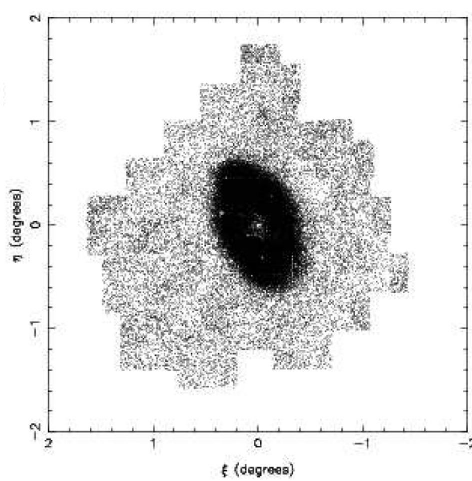




Kalnajs (1983)
Athanassoula et al. (1987)

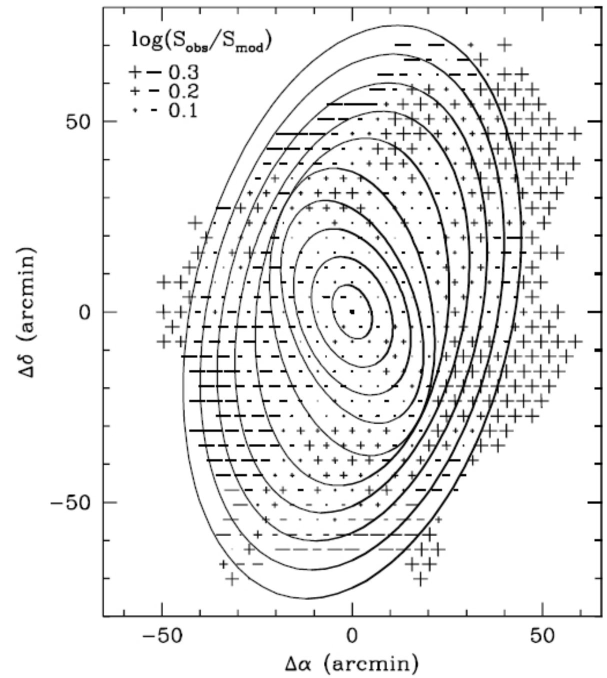
Rogstad et al. (1976)

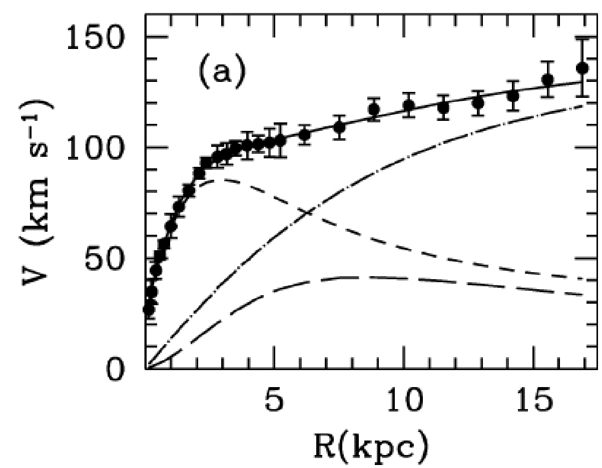




Ferguson et al. (2006)

Corbelli & Salucci 2006+ref





Flat rotation curves beyond the optical image

Bosma, 1978, 1981a,b

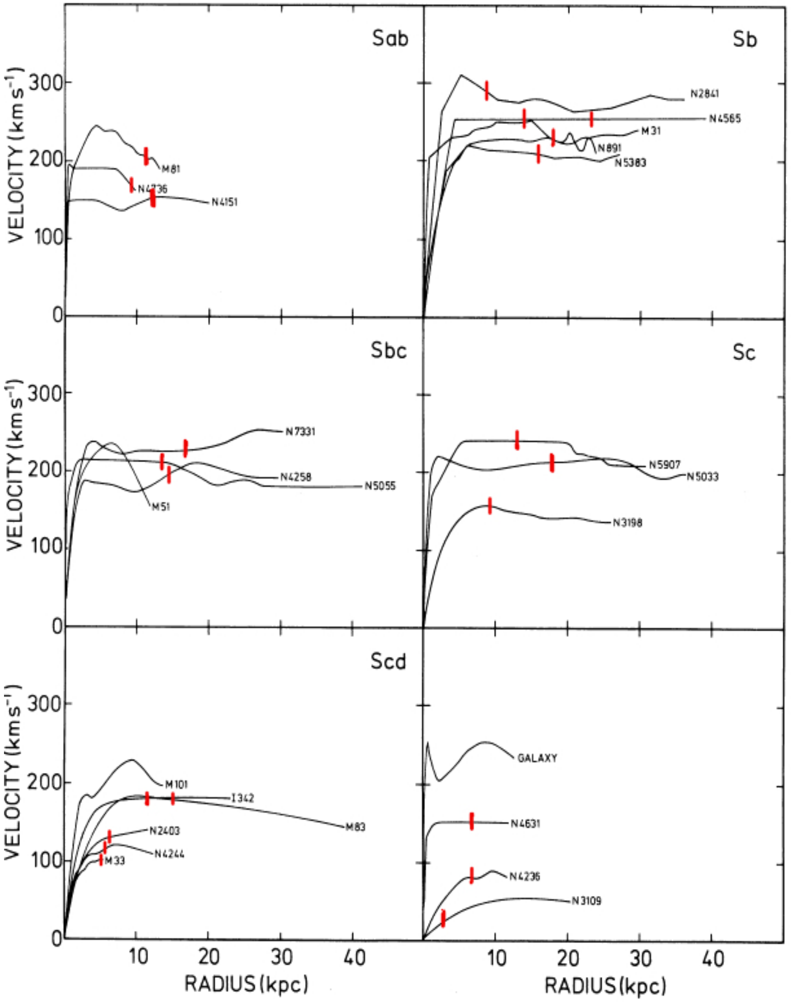
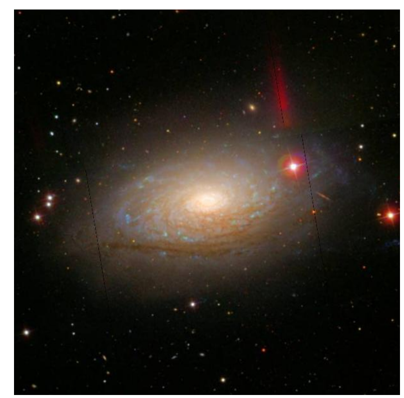
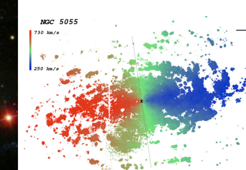


FIG. 3. Rotation curves of 25 galaxies of various Hubble types.





The last point ...matters

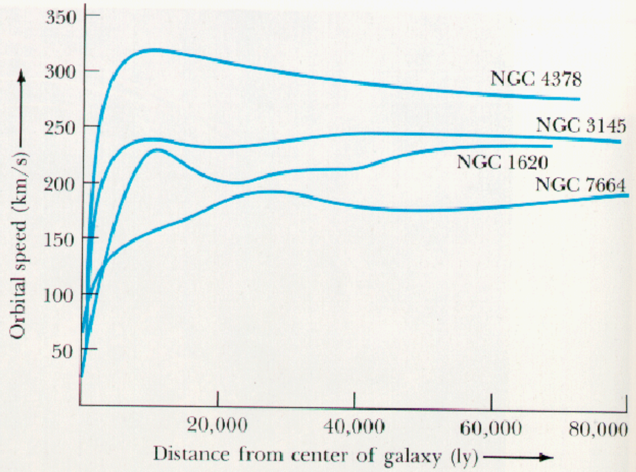
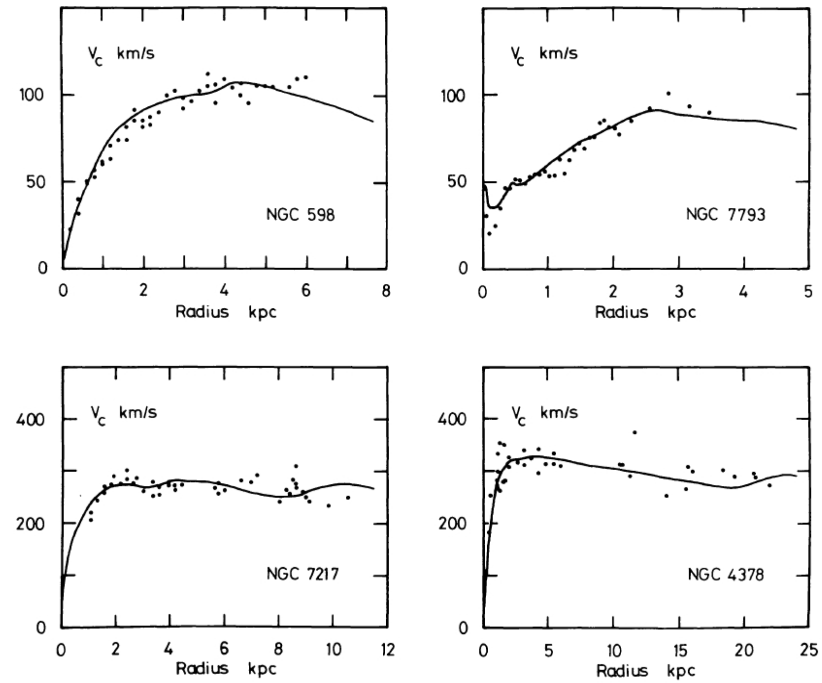
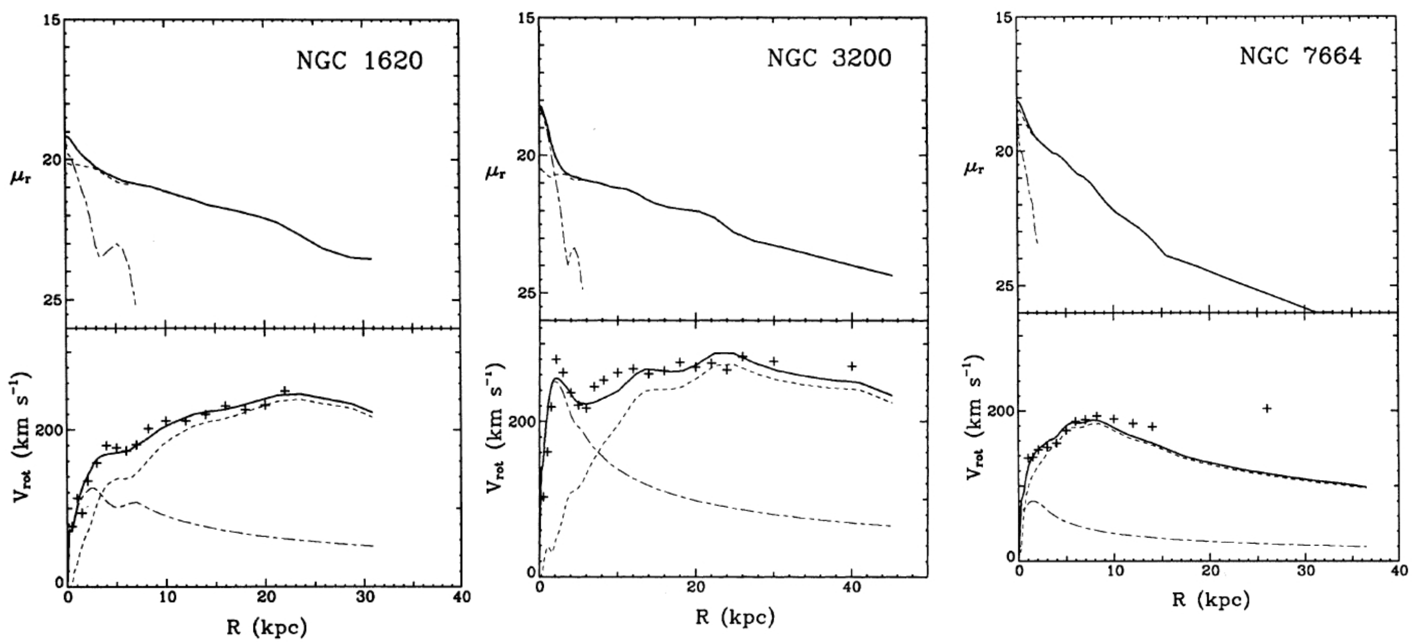


FIGURE 26-25 The Rotation Curves of Four Spiral Galaxies This graph shows the orbital speed of material in the disks of four spiral galaxies. Many galaxies have flat rotation curves, indicating the presence of extended halos of dark matter. (Adapted from V. Rubin and K. Ford)



Rotation curves computed from photometry assuming a constant M/L within each galaxy. The dots are the measured velocities. The values of M/L used are 5.0, 2.9, 4.2 and 6.5.

Kalnajs 1983
Kent 1986/7
Athanassoula et al.1987
Palunas & Williams 2000

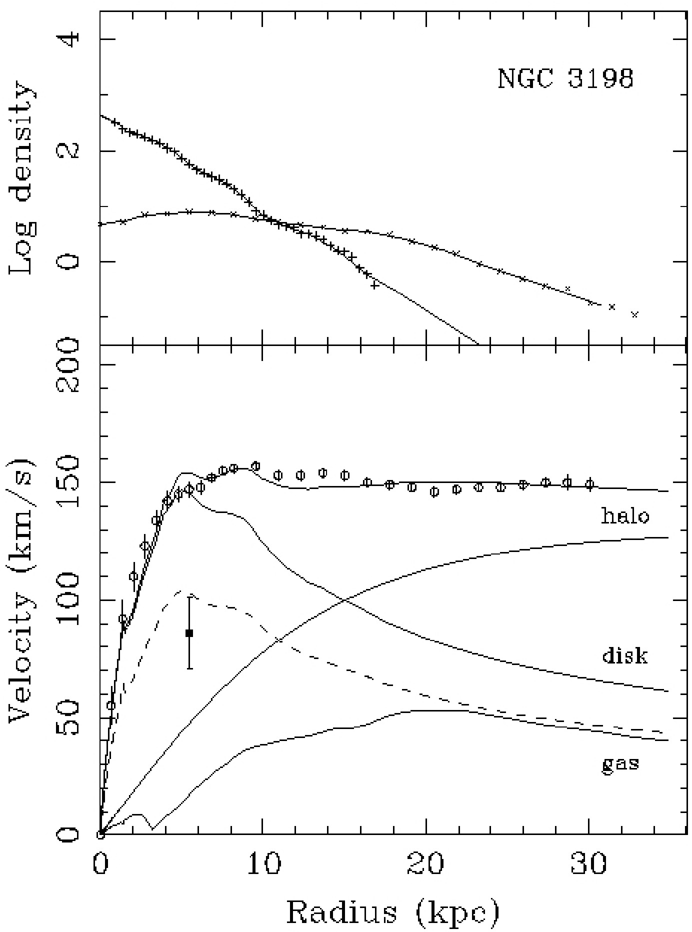


better use HI, since it goes farther out

Open problems concerning galaxy mass distributions at z = 0 (possible conflict with Lambda-CDM) :

- Dominance of baryonic matter in the central parts of bright spirals

- The core/cusp problem in LSB galaxies



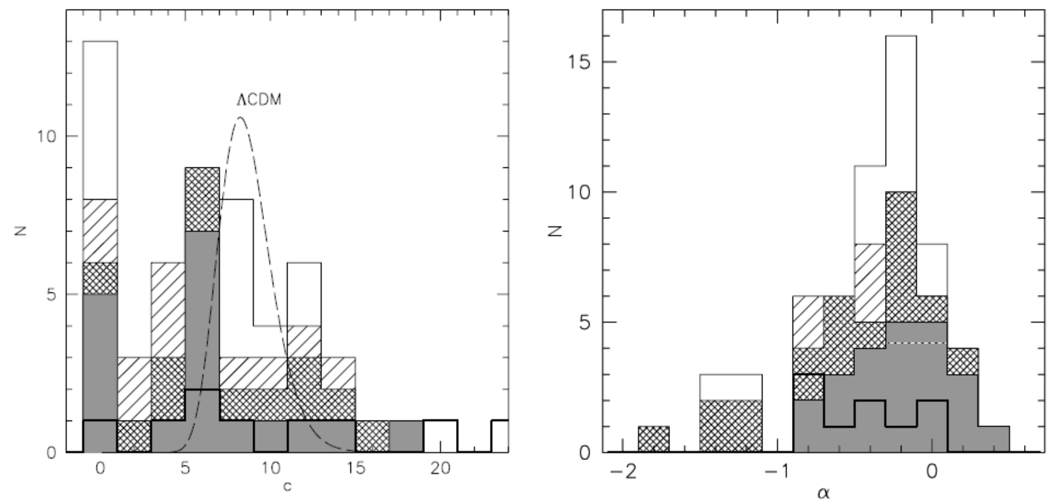


Figure 1: Distribution of the NFW concentration parameter c (left panel) and the inner mass-density slope α (right panel) based on the data from De Blok et al. 2001 and De Blok & Bosma 2002. The various superimposed histograms show the different stages of pruning: open histogram: the full sample; single hatched histogram: galaxies with $i < 30°$ and $> 85°$ have been removed; double hatched histogram: galaxies with low-quality rotation curves, asymmetries etc. have been removed; grey filled histogram: galaxies with less than 2 independent data points in the inner 1 kpc are removed. The thick open histogram in shows a similar restricted sample from Swaters et al. (2003). The dashed curve in the left panel shows the expected distribution of c for a ΛCDM universe.

SKA – 100x more sensitive than the VLA

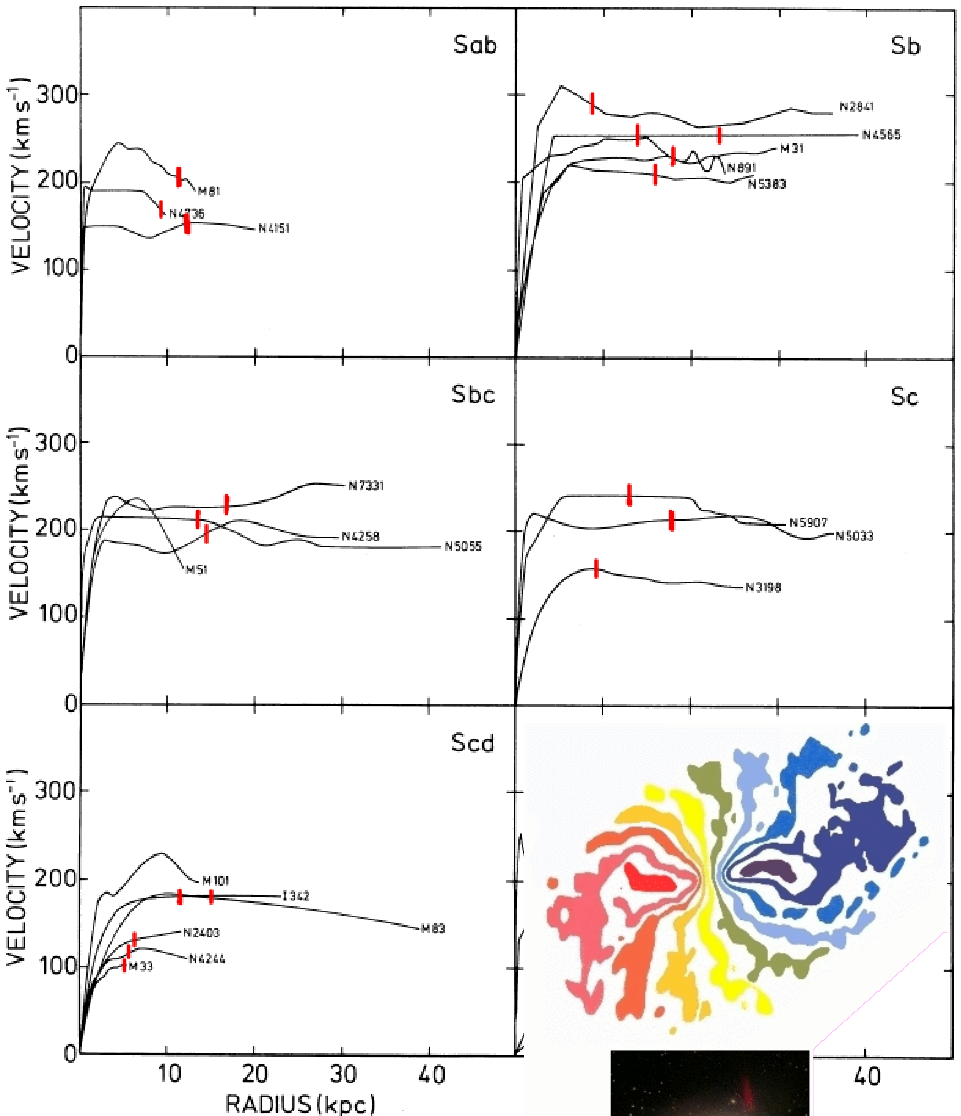
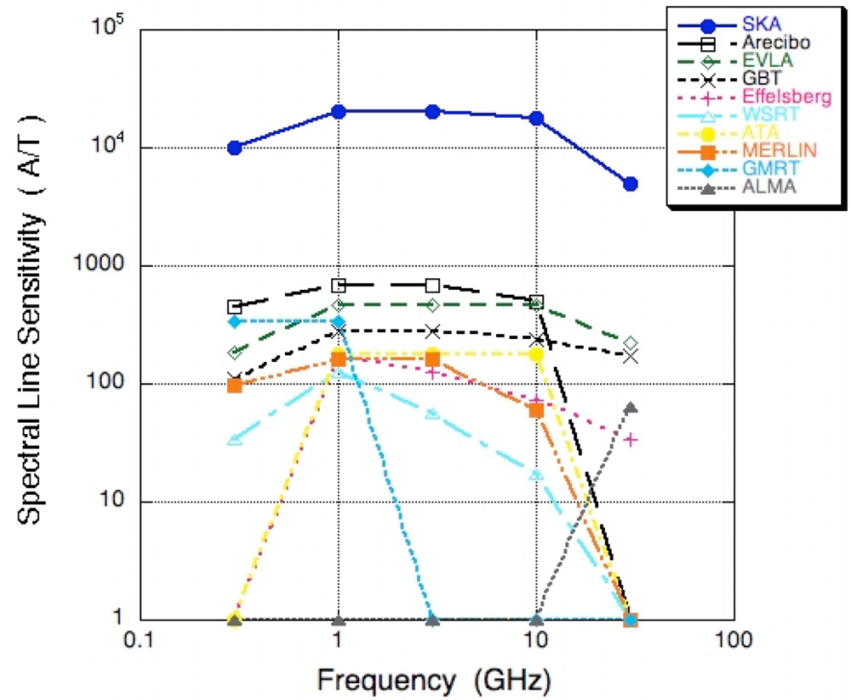
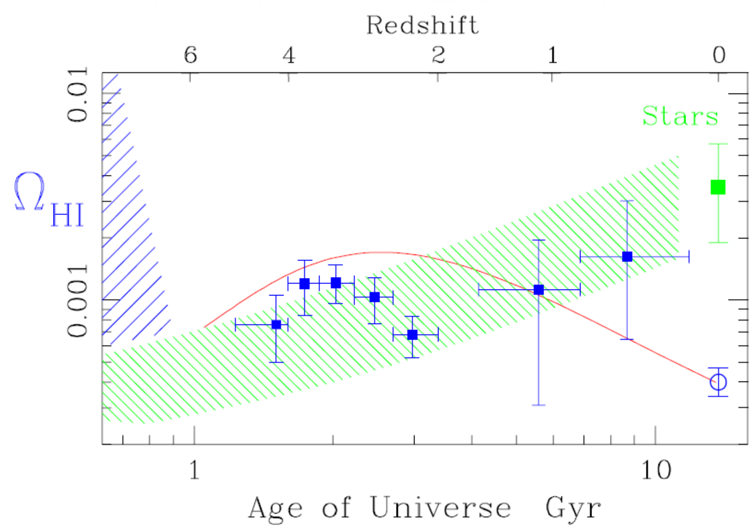


FIG. 3. Rotation curves of 25 galaxies

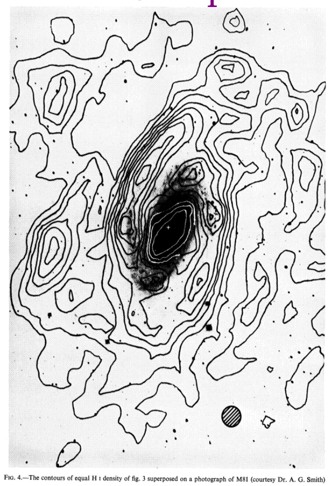




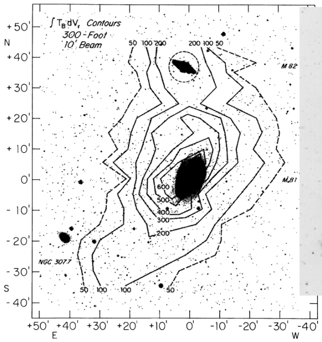
SKA will image galaxies such as M81 and N5055 at z ~ 1

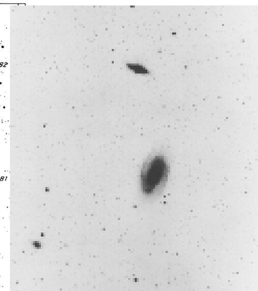
But at a small ratio Radius/Beamsize !

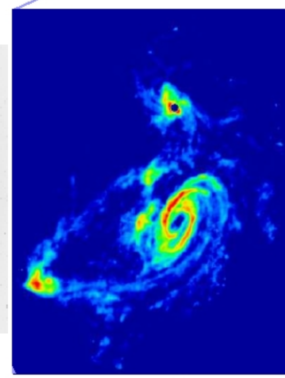
4.0 kpc

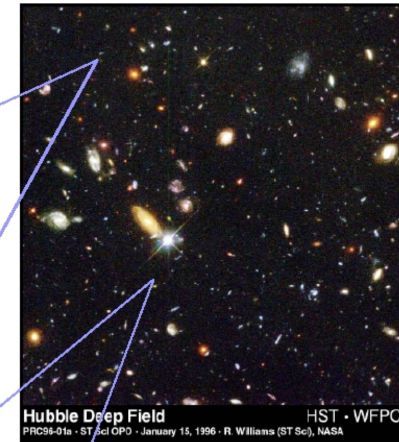


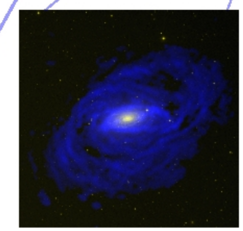
9.0 kpc











Van der Hulst et al. 2004

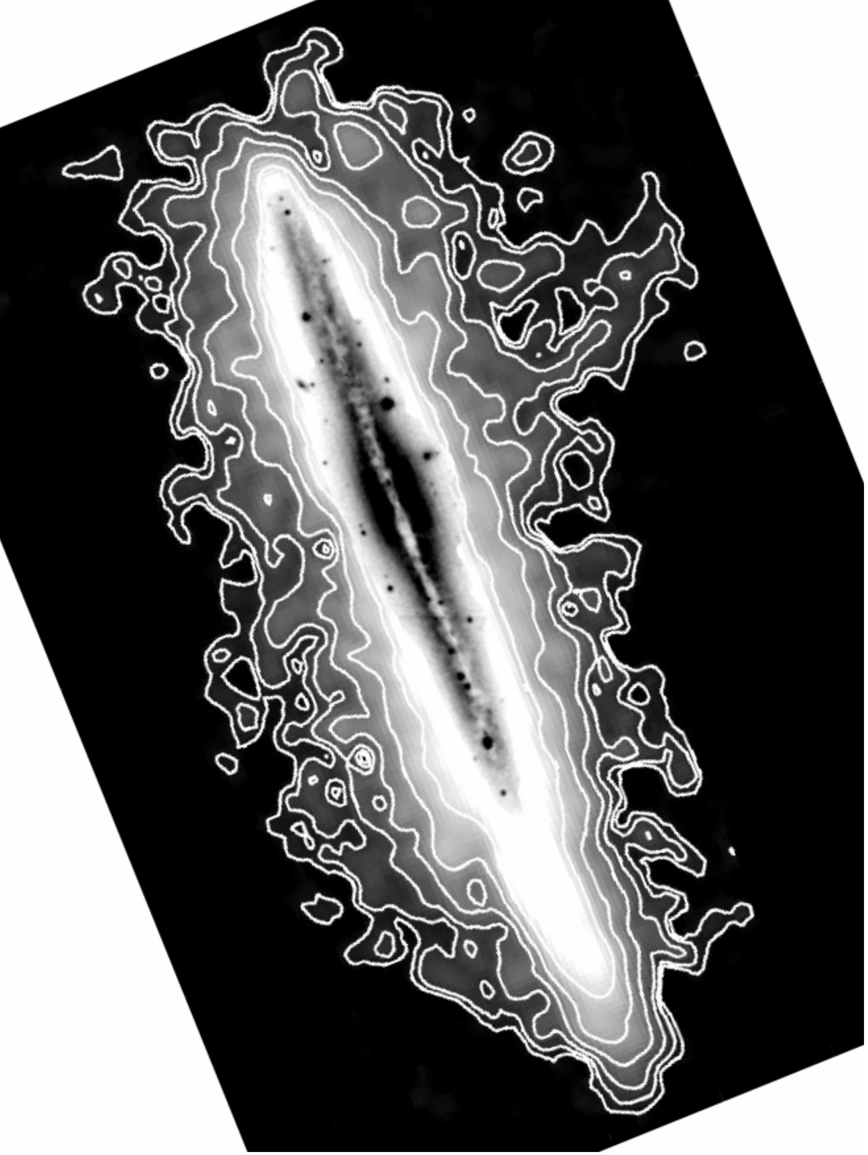
Detection limits for HI emission with SKA[a]

z	Frequency (MHz)	T_{sys}[b] (K)	Angular[c] resolution (arcsec)	Linear resolution (kpc)	SB dimming (mag)	Luminosity distance (Gpc)	Lookback time (Gyr)	HI mass[d] limit ($M_\odot$)
0.2	1183.67	50.4	0.52	1.7	0.796	0.972	2.41	6.1×10^8
0.5	946.94	51.4	0.65	4.0	1.486	2.825	5.02	8.7×10^8
1.0	710.20	53.8	0.87	7.0	3.026	6.640	7.73	2.7×10^9
1.5	568.16	57.5	1.09	9.3	4.000	11.02	9.32	7.2×10^9
2.0	473.47	62.7	1.31	11.1	4.796	15.75	10.32	1.5×10^{10}
2.5	405.83	69.6	1.52	12.5	5.469	20.72	11.00	2.6×10^{10}
3.0	355.10	78.3	1.74	13.6	6.052	25.87	11.48	4.3×10^{10}
3.5	315.64	89.3	1.96	14.6	6.566	31.15	11.83	6.7×10^{10}

[a] Assuming $t = 12$ h, $A_e/T_{sys} = 20000$, 2 polarizations and 70% of A_e within 100 km.
[b] Including a contribution from Galactic foreground emission assuming $T_{Gal}(f_{MHz}) = 20\left(\frac{408}{f_{MHz}}\right)^{2.7}$ K.
[c] Fixed array geometry assumed so that resolution scales with wavelength.
[d] Assuming 5 rms and 100 km s^{-1} profile width. At $z = 0.2$ and $z = 0.5$ the galaxies are assumed resolved so here the flux has been added over 8.5 and 1.5 beams respectively.

HI halo : lagging rotation

Fraternali et al. 2004, 2006



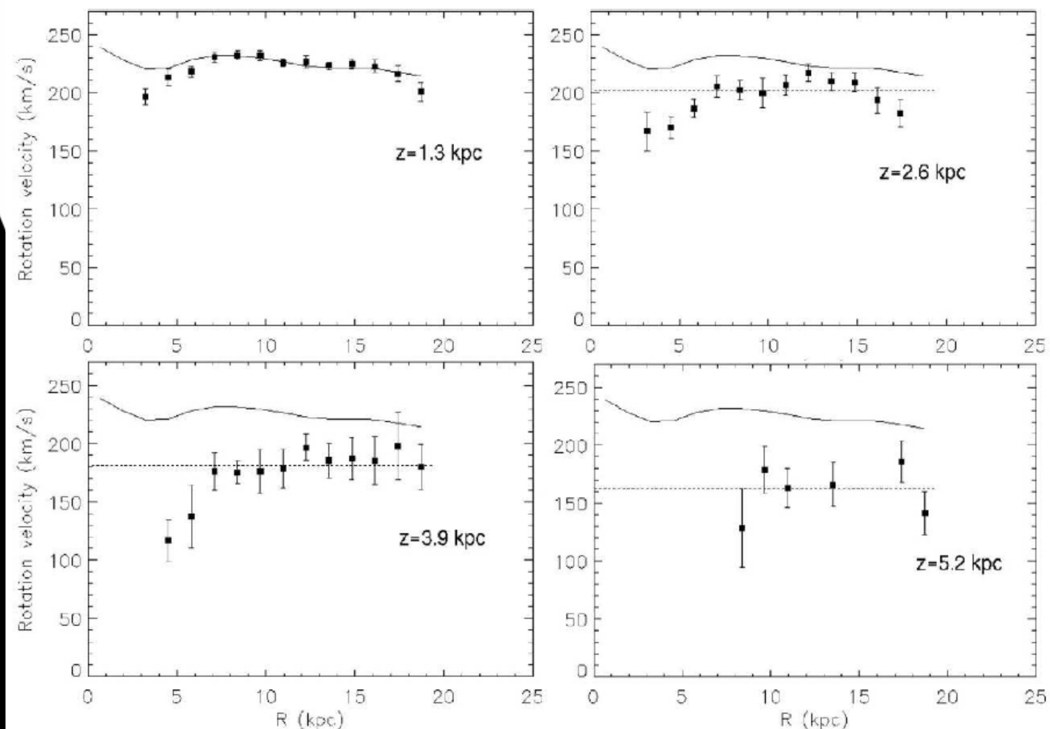
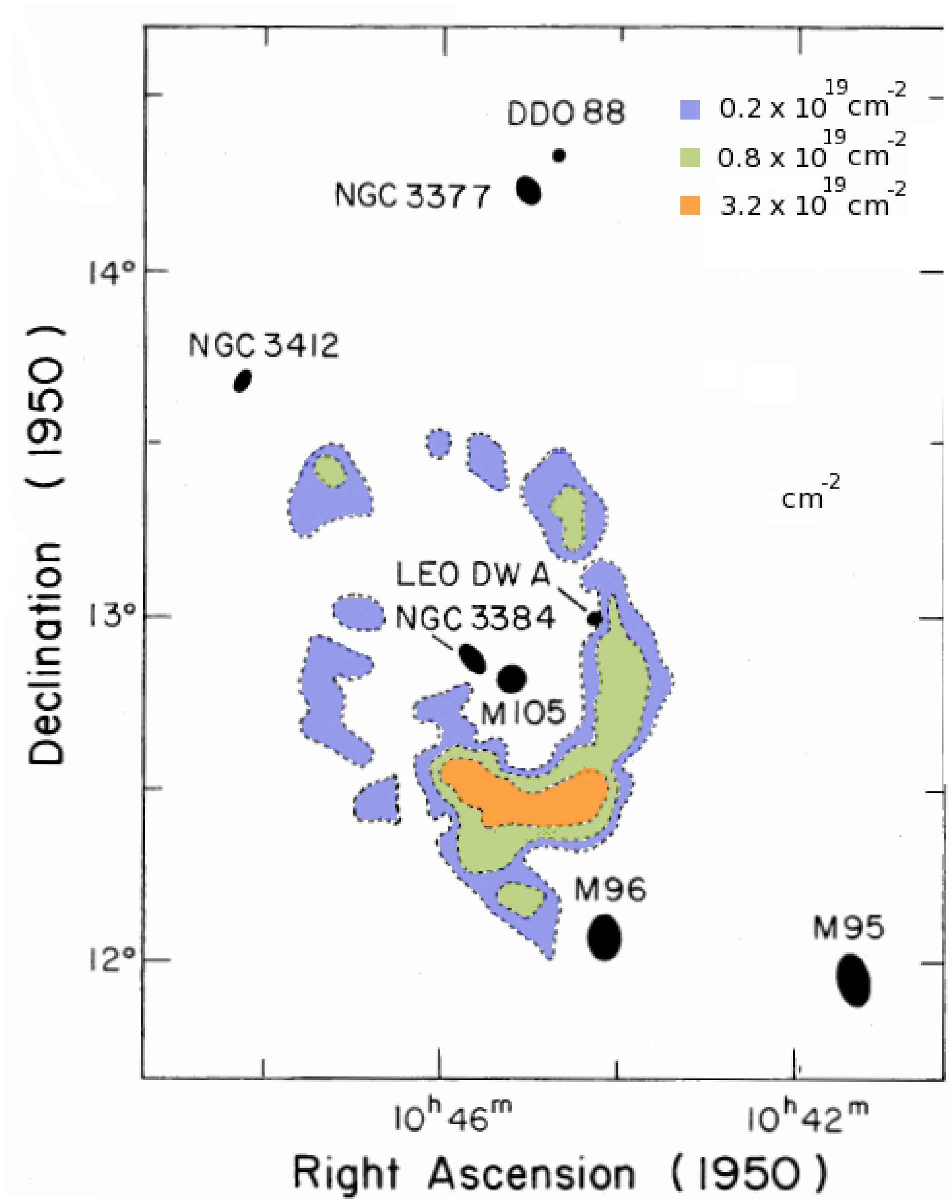


Figure 5. Rotation curves for NGC 891 at various distances from the plane. The solid line shows the rotation curve in the plane and the dashed lines outline the value of the flat part of the rotation curves. Only the N-E side of the galaxy has been used to derive these curves.

Figure 1. Optical DSS image (grey-scale) and total H I map (contours+negative grey-scale) of NGC 891, the latter obtained from the new WSRT observations (Oosterloo, Fraternali & Sancisi 2005). H I contours are: 1.7, 4.5, 9, 18.5, 37, 74, 148, 296.5, 593 × 10^{19} atoms cm^{-2}. The beam size is 28″; 1′ =2.8 kpc.

total integration time about 200 hours

HI around Galaxies and in Cosmic Web



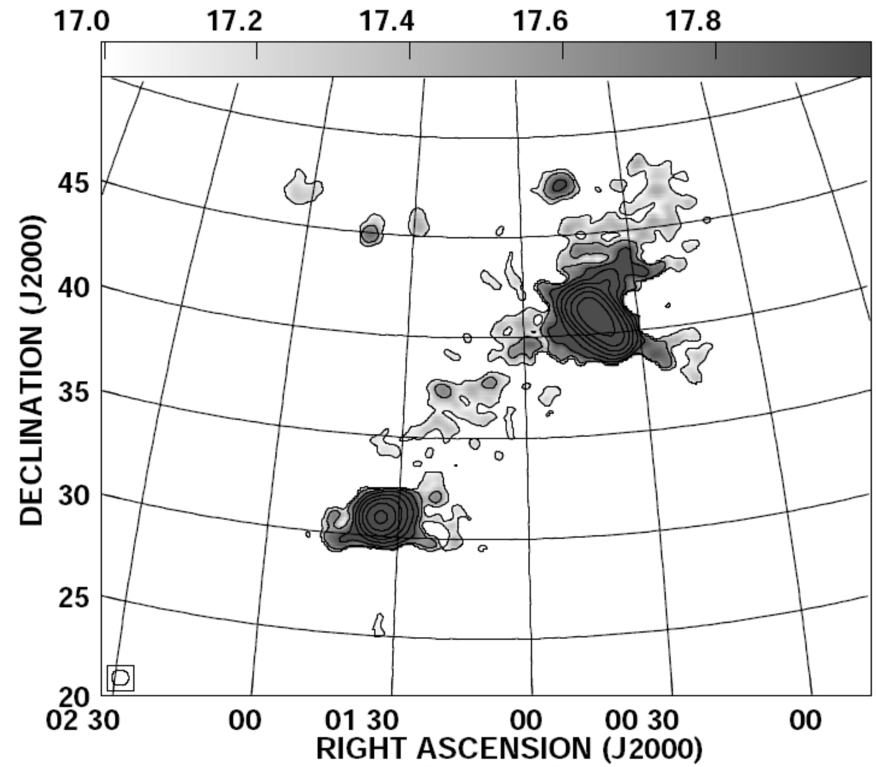


Figure 1. Integrated HI emission from features which are kinematically associated with M31 and M33. The grey-scale varies between $\log(N_{HI}) = 17 - 18$, for N_{HI} in units of cm^{-2}. Contours are drawn at $\log(N_{HI}) = 17, 17.5, 18, \ldots 20.5$. M31 is located at (RA,Dec) = (00:43,+41°) and M33 at (RA,Dec) = (01:34,+30°), The two galaxies are connected by a diffuse filament joining the systemic velocities.

Schneider et al. (1989)

Braun & Thilker (2004)

HI around Galaxies and in Cosmic Web

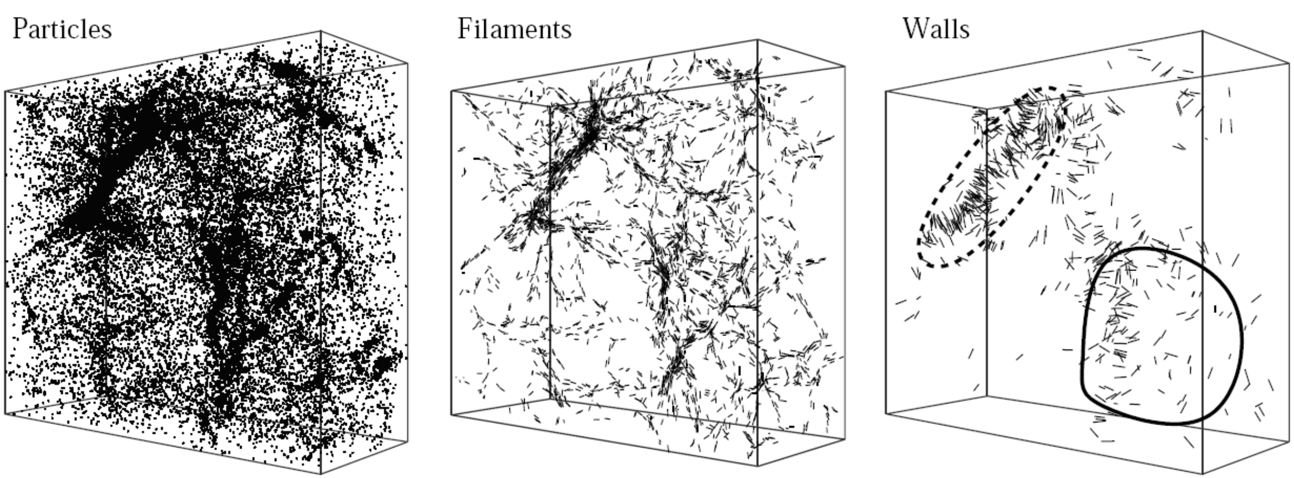
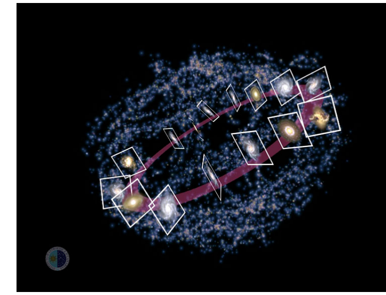
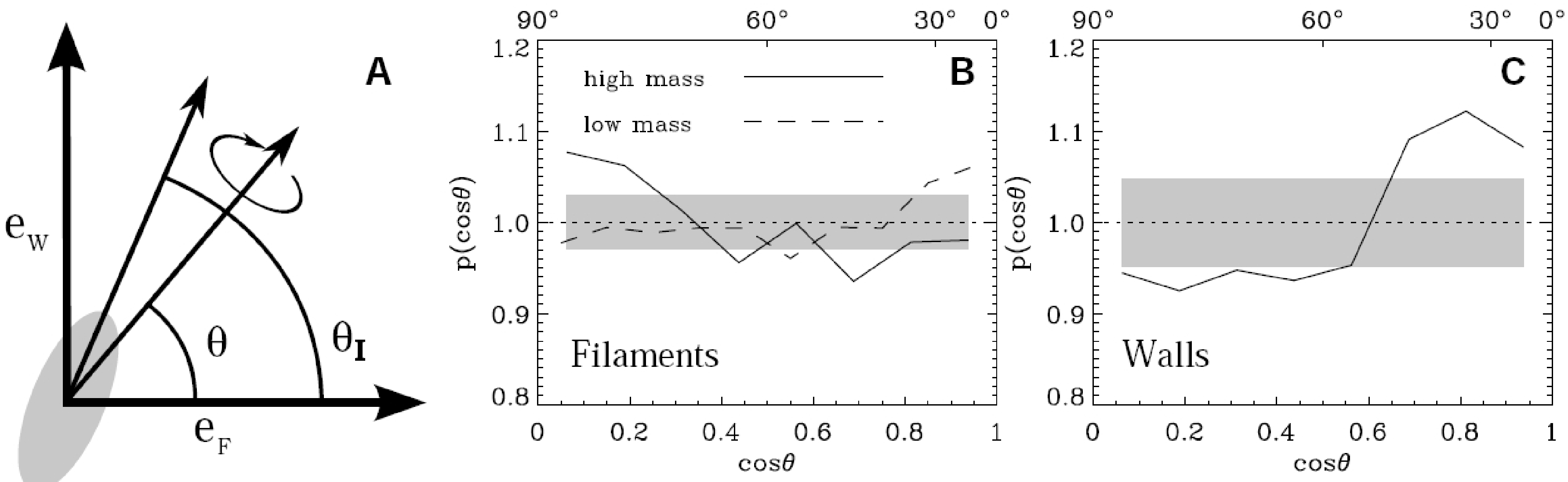


FIG. 1.— Left panel: Particles inside a sub-box of $37.5 \times 75 \times 100\ h^{-1}$ Mpc. For reasons of clarity only a small fraction of the total number of particles is shown. Central panel: filaments delineated by a subsample of the particle distribution. At each particle location we have plotted the filament vector $\mathbf{e_F}$, indicating the direction locally parallel to the filament. Righthand panel: wall particles detected in the same sub-box: at each wall particle we plot the wall vector $\mathbf{e_W}$. Two walls can be clearly delineated: one seen edge-on (dashed outline) and one seen face-on (solid outline).

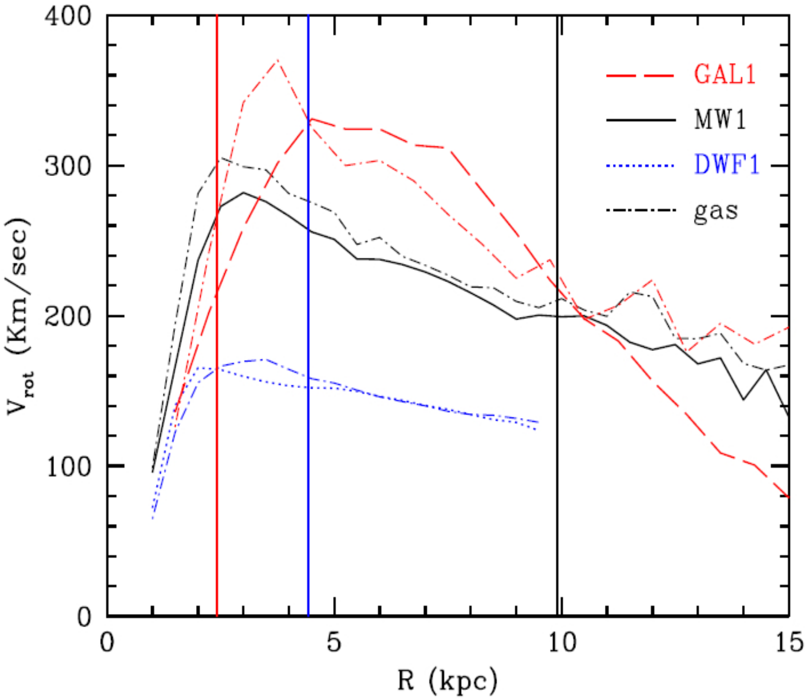


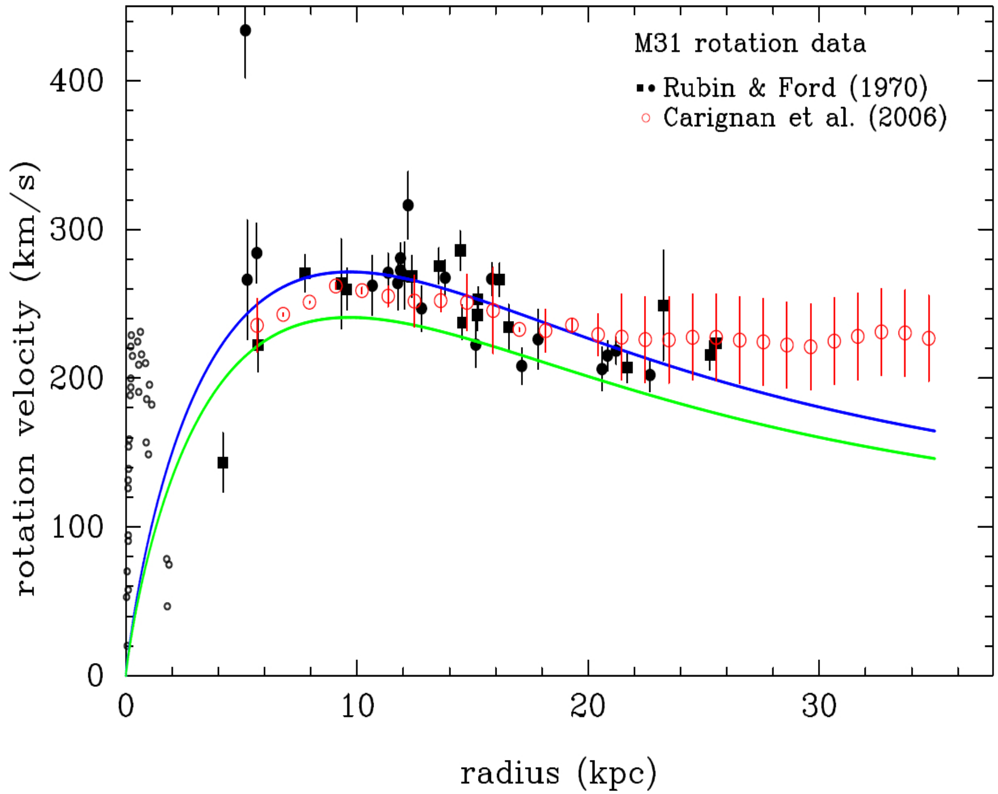
Trujillo et al. (2006)

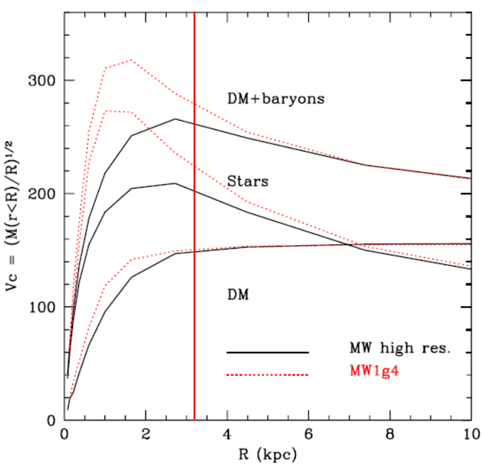


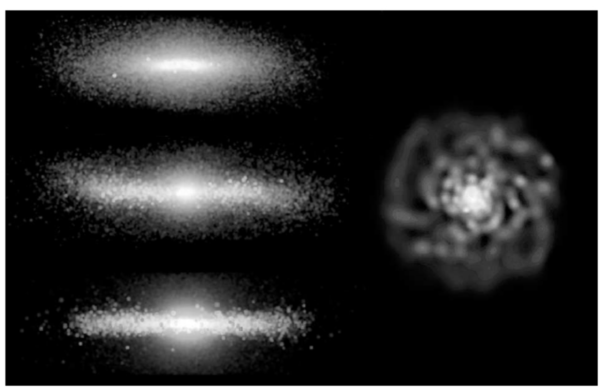
Aragon-Calvo et al. 2006

Galaxy formation in ΛCDM









Feedback helps:

TF-relation zero point OK, but halos still too concentrated...

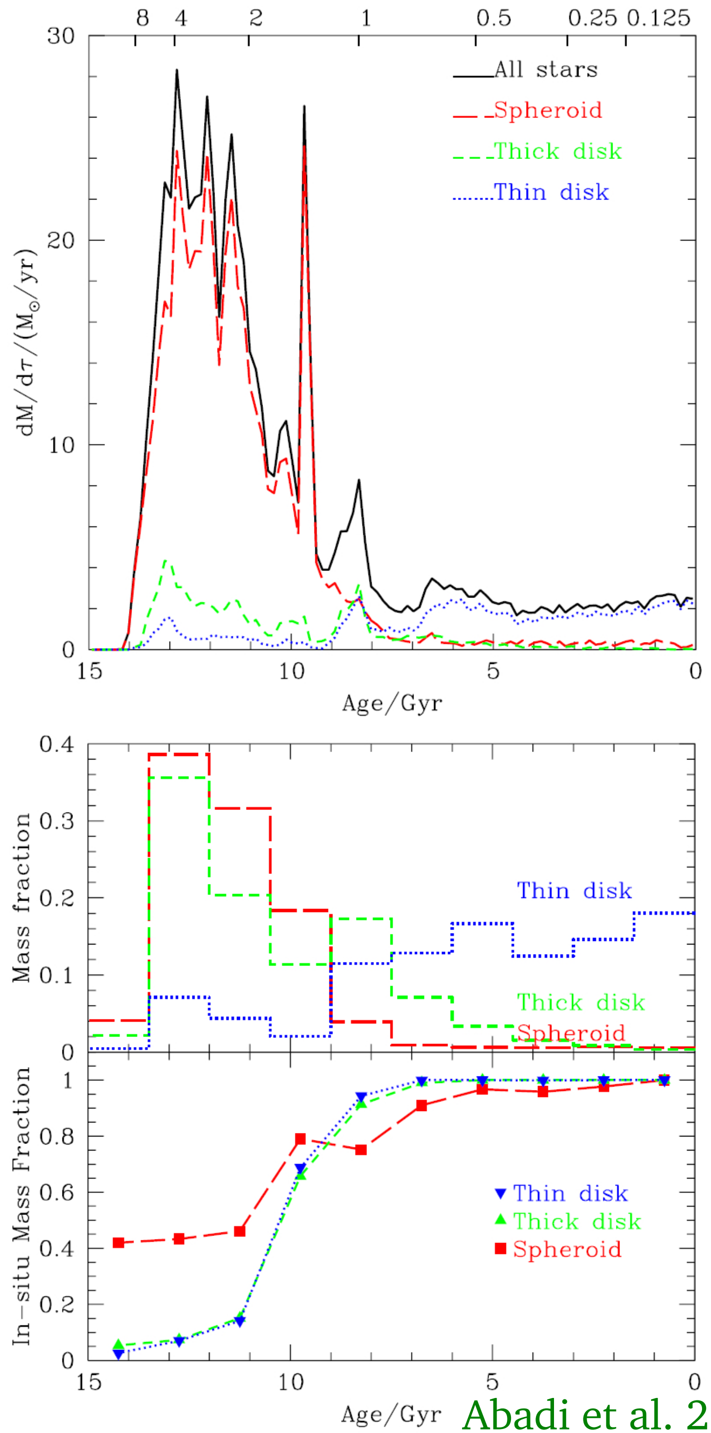
resolution problem ...

Governato et al. (2006)

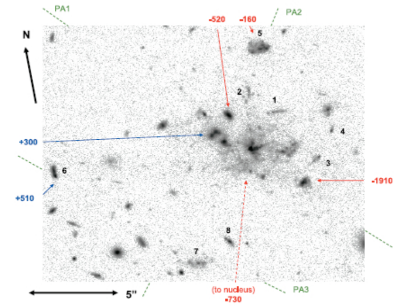
What to expect ?

- rapid evolution with a lot of merging at z > 1.5 – 2

- slow evolution thereafter



Abadi et al. 2003



Miley et al. 2006

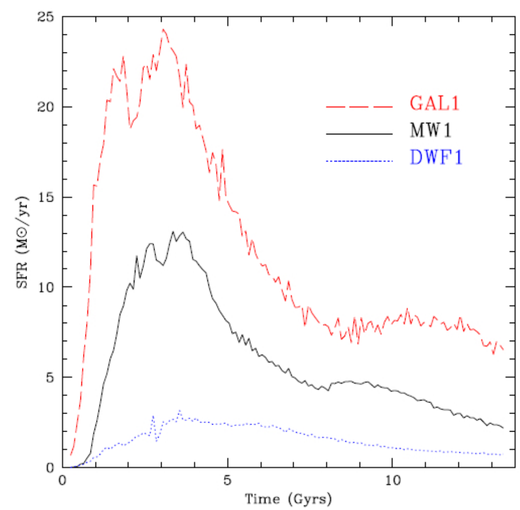


Figure 12. Star formation histories of DWF1, MW1, and GAL1, including all stars within 4 disk radial and vertical scale heights. ϵSN=0.4 and UV field on for all runs. Solid black: MW1, long dashed: GAL1, dotted: DWF1.

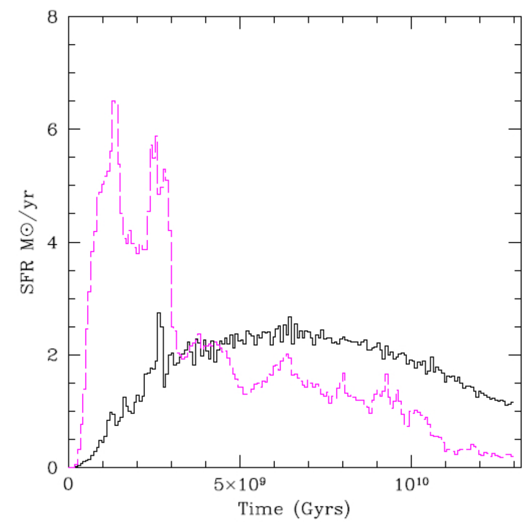


Figure 13. Galaxy DWF1: SFH including all stars within 4 R_z and R_d from the disk plane for two runs. Solid line: ϵSN=0.6, long dashed: no feedback, no UV. The addition of feedback smooths out the SF peaks otherwise present at high redshift and during the last major merger event at z=2.3. Feedback delays the conversion of gas into stars until gas accumulates and cools in the potential well of the main progenitor.

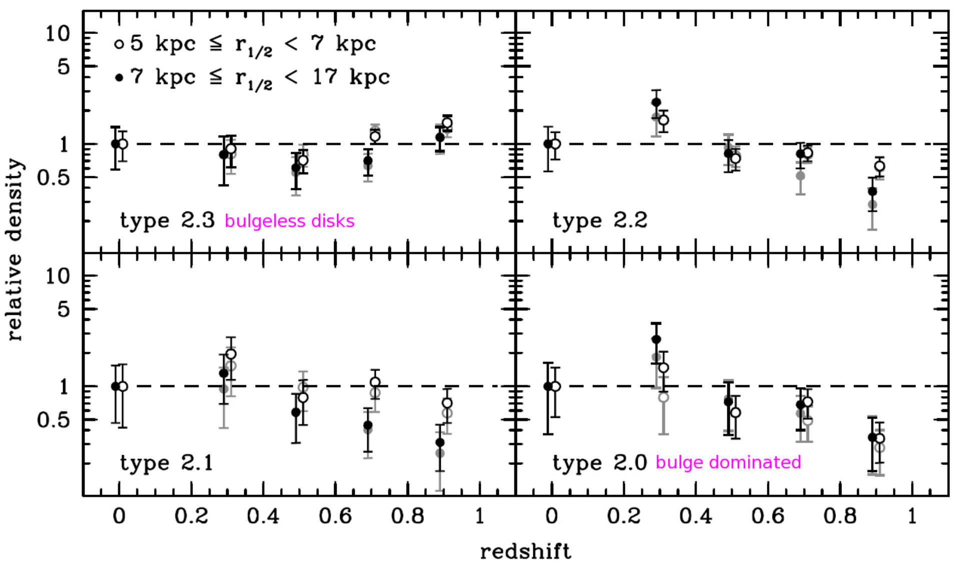
Governato et al. 2006

Bar – Halo interaction

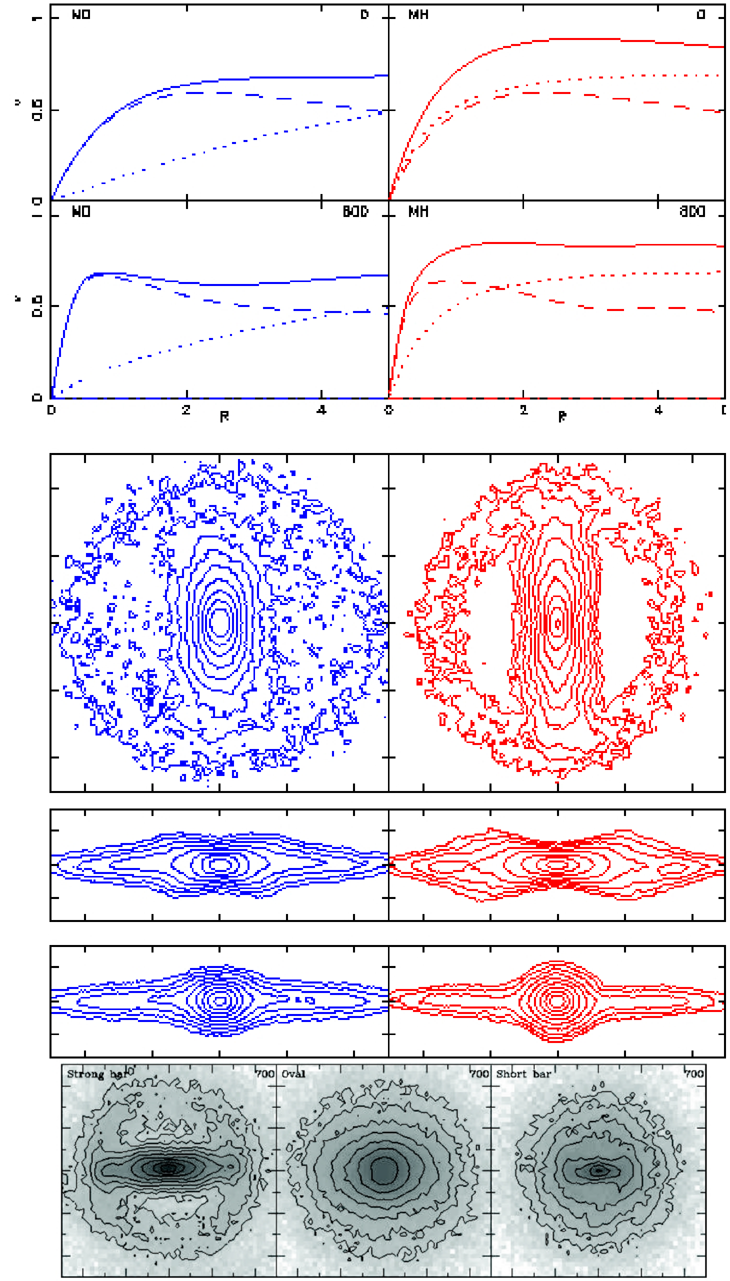
Athanassoula 2002, 2003, 2005, 2006

Mechanism is the exchange of angular momentum via the resonances

As a result, during the slow evolution, the mass concentration of the galaxy increases with time, and a bar/bulge forms from the disk



seen in COSMOS data Sargent et al. (2006)



Considerable amount of angular momentum is exchanged

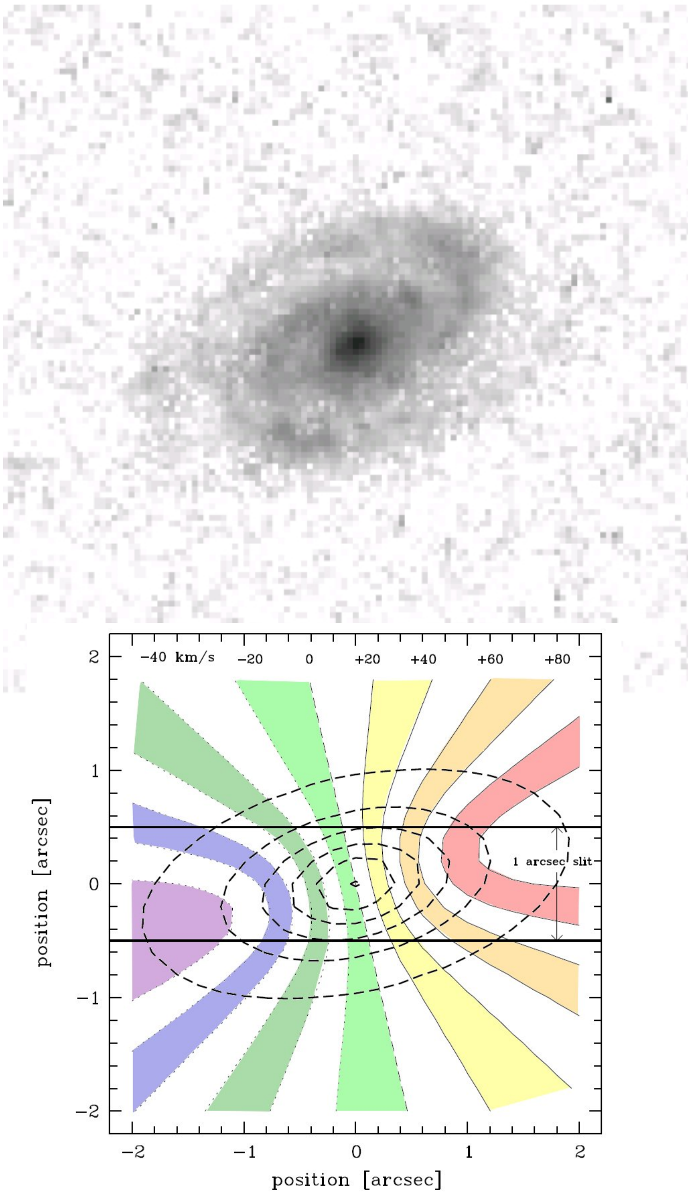
Little angular momentum exchanged

Responsive halo
Hot outer disc

Hot halo

Quantitative interpretation of the rotation curves of spiral galaxies at redshifts $z \sim 0.7$ and $z \sim 1$

Fuchs et al. 2004, use a variation of Athanassoula et al. 1987



Strong spiral => Massive disk

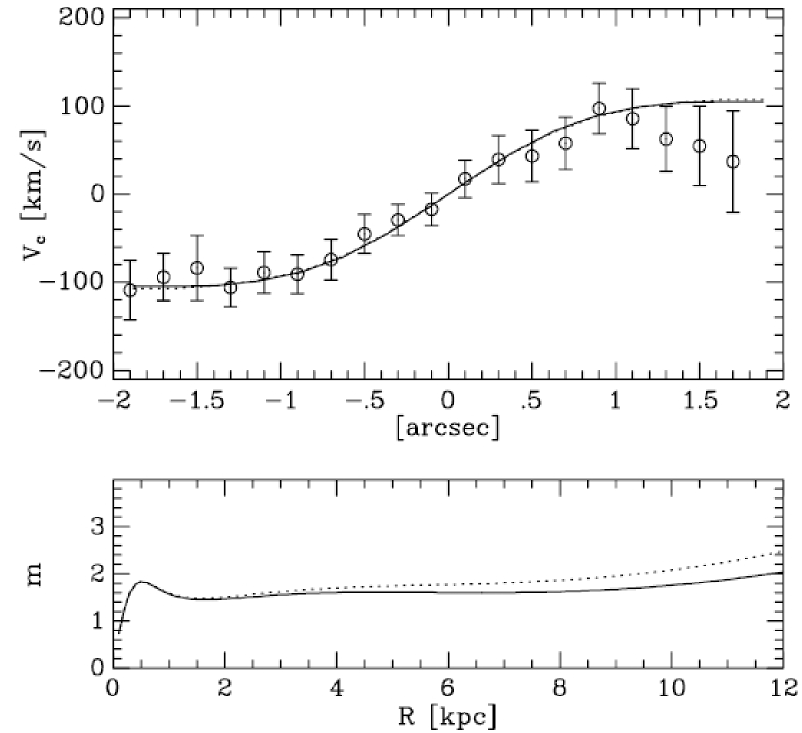
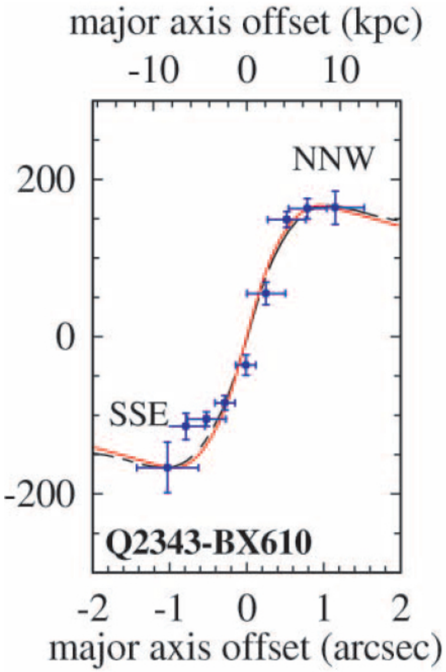
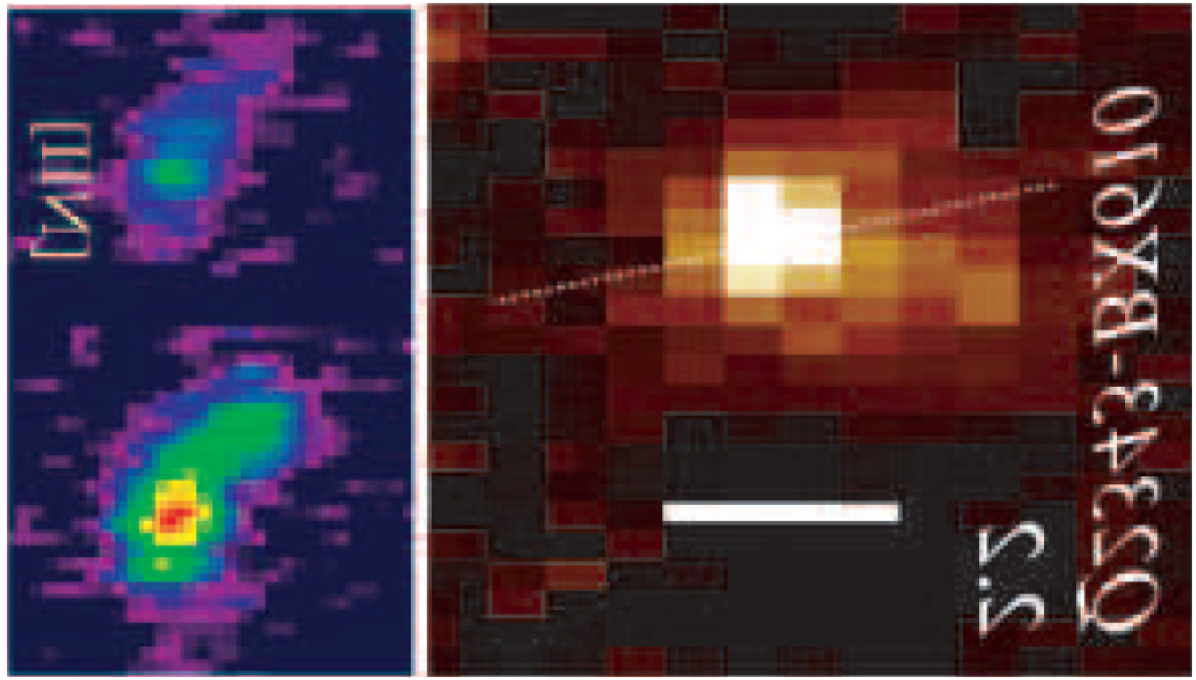


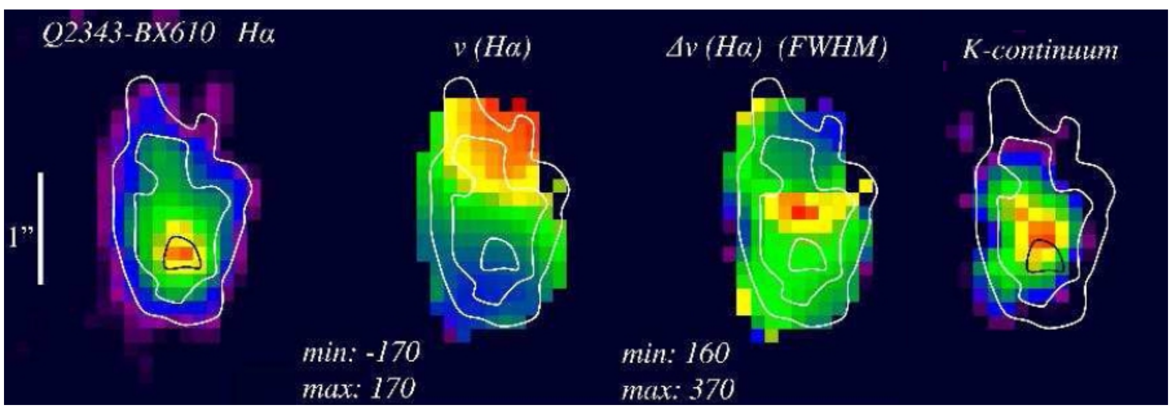
Fig. 3. *Upper panel*: model rotation curves of FDF 2484 fitted to the radial velocity data of Böhm et al. (2004). The solid line is the model without a dark halo, the dotted line shows the corresponding rotation curve when a dark halo component was included. The rotation curves are practically identical. *Lower panel*: expected number of spiral arms in the radial range where spiral structure can be seen. The dotted curve is again for the model with a dark halo included.

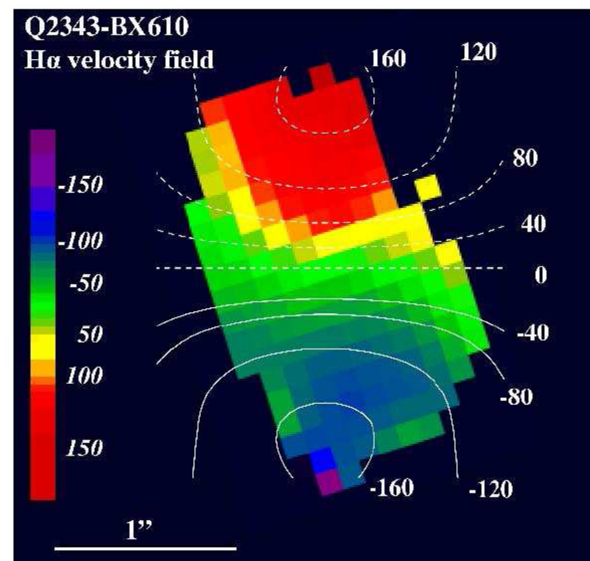
Galaxy at z ~ 2.21

Förster-Schreiber et al. 2006



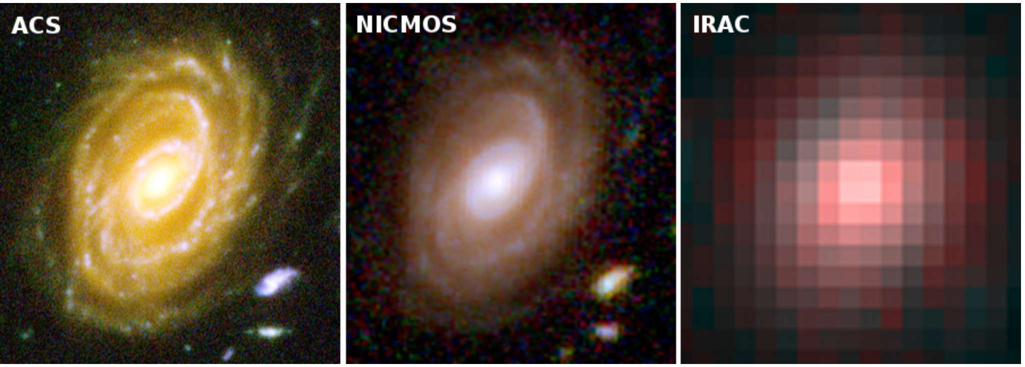


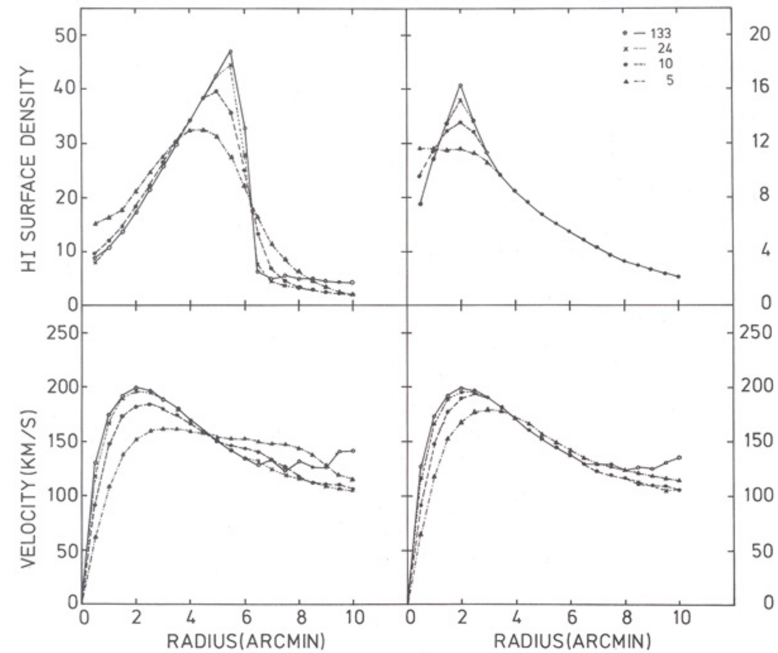




rotating disk, but details are puzzling :
disk seems oval, and pv-diagram is odd

Resolution effect on rotation curves

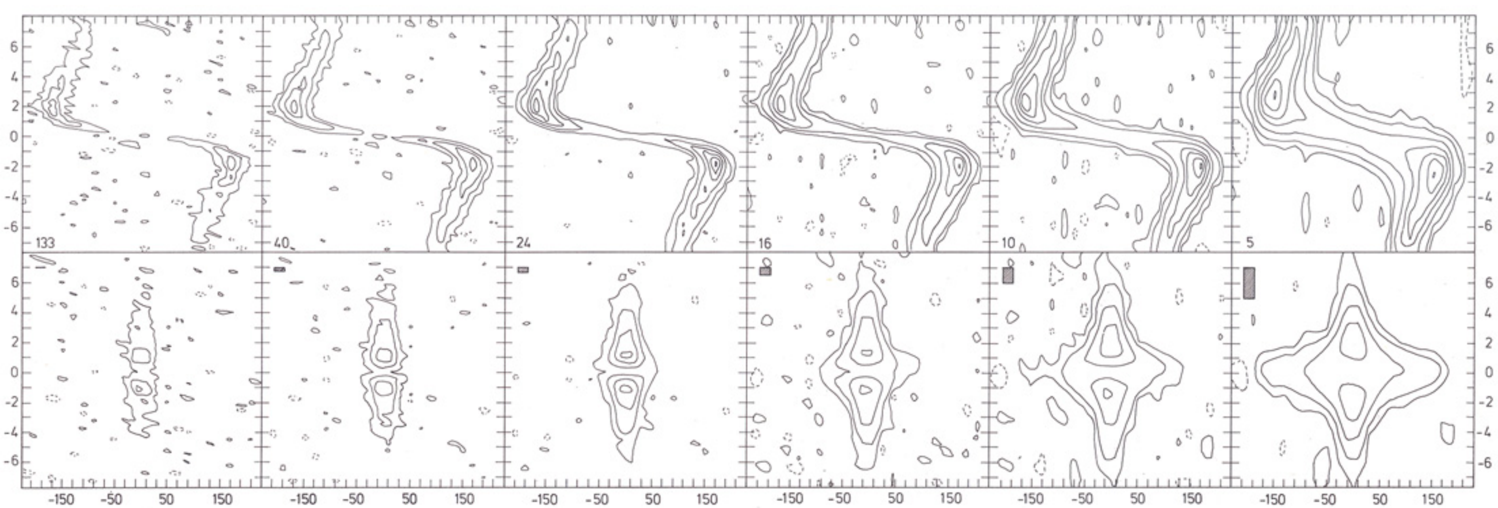


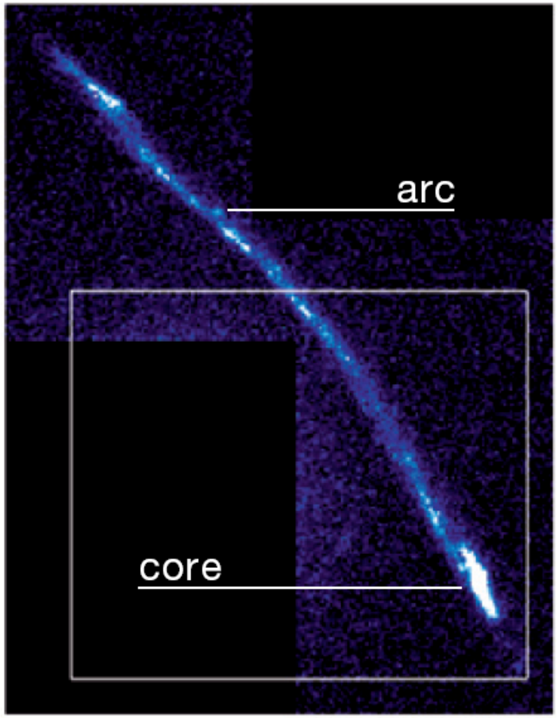


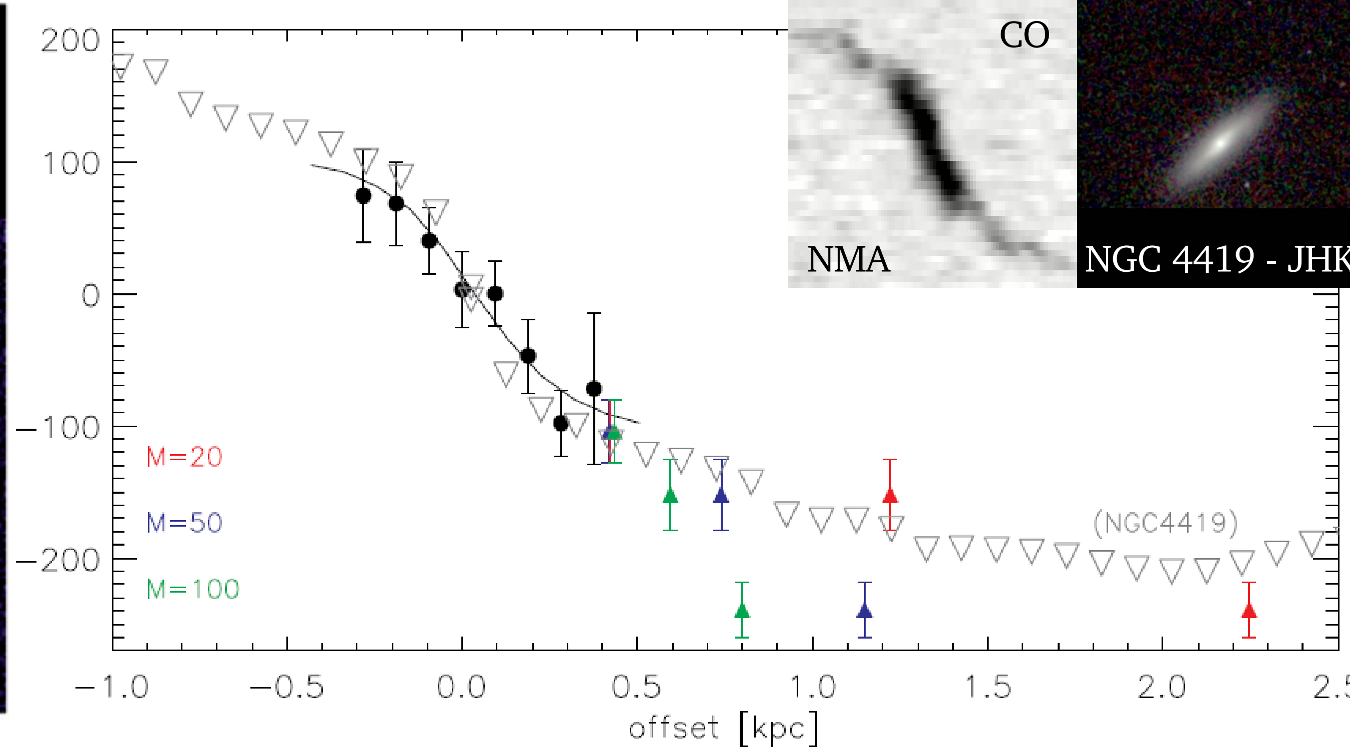
Bosma (1978)

For a good rotation curve one should have radius/beamsize large (>7 at least, better 15)

Note the increase in dispersion at low resolution





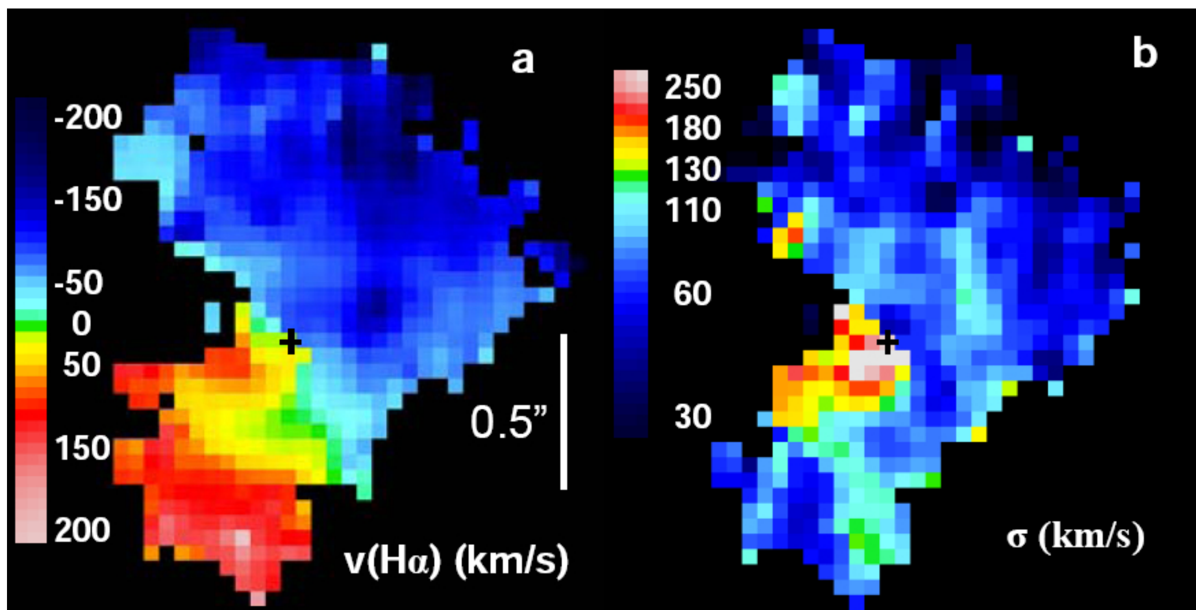


lensed galaxy z=3.2
in 'bullet' cluster

Nesvadba et al. 2006

galaxy at z = 2.38
SINFONI + AO

Genzel et al. 2006



Dark Matter in Galaxies

Resolution problem will not go away :

- for concordance cosmology, at z = 1 – 3, we have ~ 8 kpc/arcsec
- VLT with adaptive optics will done some work (SINFONI, KMOS or MUSE) but the optical data may not go out far enough
- JWST / NIRSpec will have IFU at R ~ 3000
- with ALMA, one can do the CO, which may not go out far enough
- with SKA, one has to integrate a long time on the longer baselines to get adequate sensitivity and resolution for galaxies at z = 1 – 2 in order to get the outer HI properly, and its connection with the Cosmic Web at that redshift