UNIVERSAL PROPERTIES IN GALAXIES AND CORED DM PROFILES

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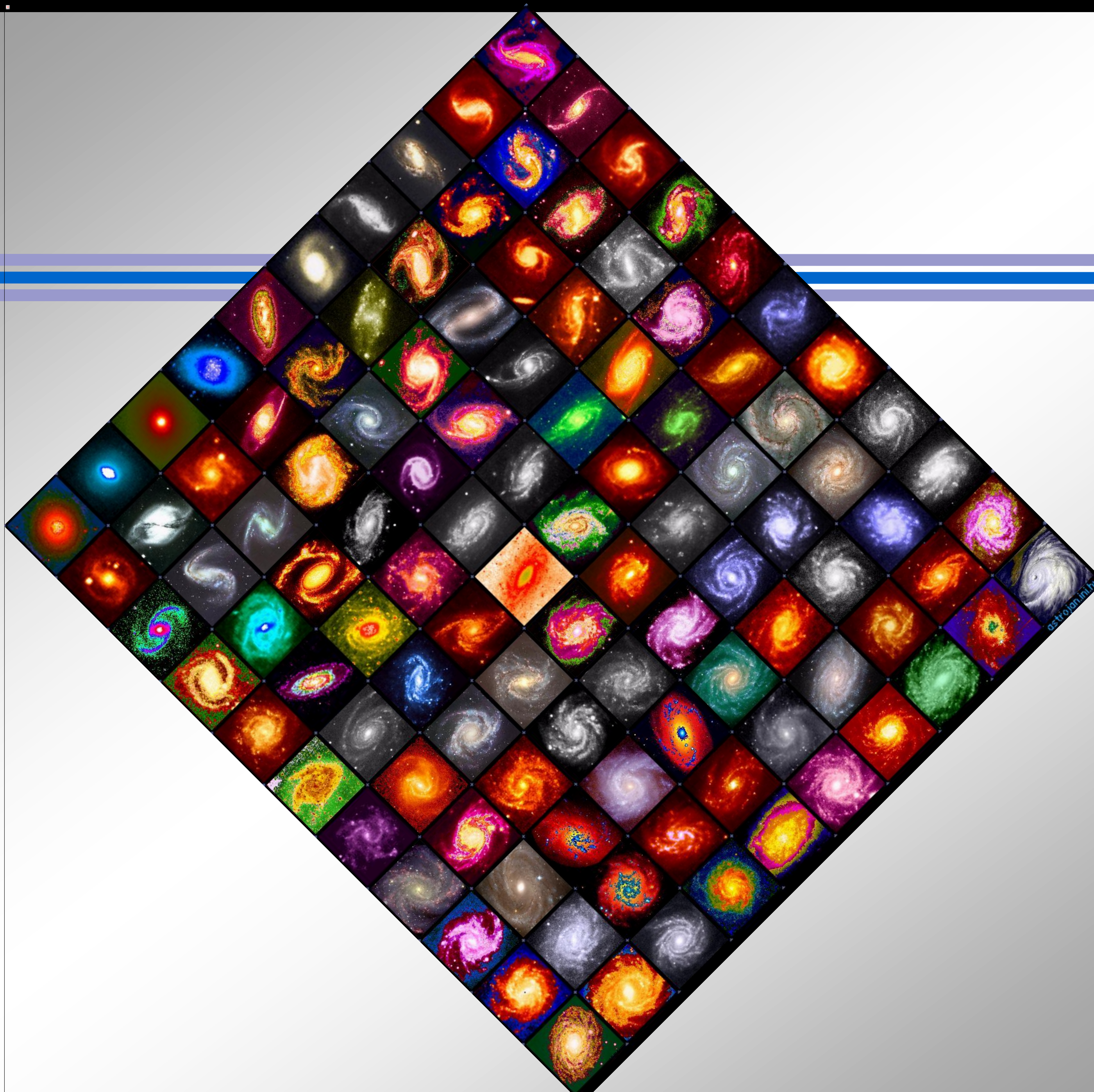
ECOLE INTERNATIONALE D. CHALONGE
CIAS Workshop 2010, Meudon

OUTLINE

- ***The kinematics of galaxies***
- ***Universal Properties of DM halos: relation to LM***
- ***The amount and distribution of DM around Spirals***
- ***The nature of DM***

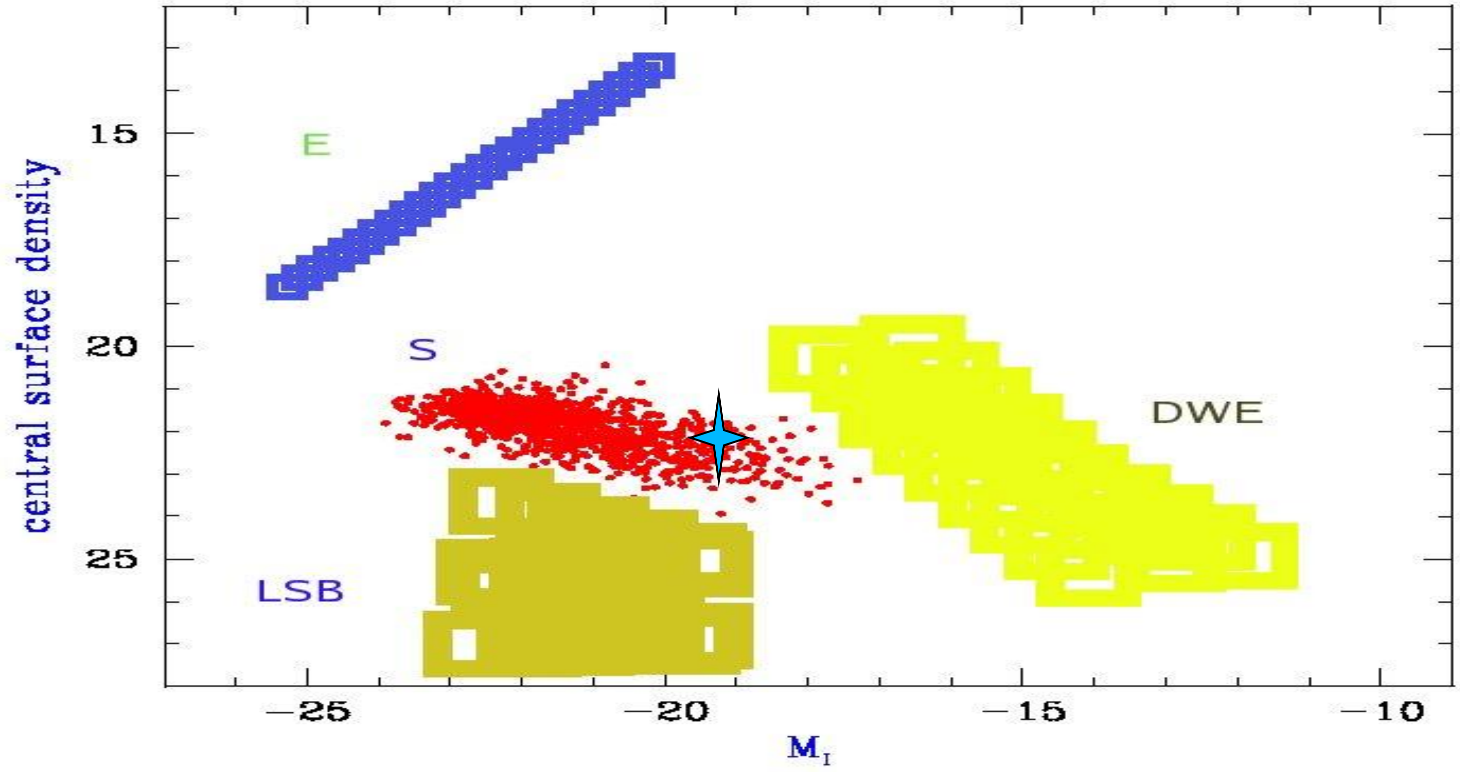
1996 MNRAS, 281, 27 Persic, M.; Salucci, P.; Stel, F.
The universal rotation curve of spiral galaxies - I. The dark matter connection
2007 MNRAS, Salucci , Lapi, Gentile, Klein
The universal rotation curve of spiral galaxies out the virial radius II


astrojan.ini.hu

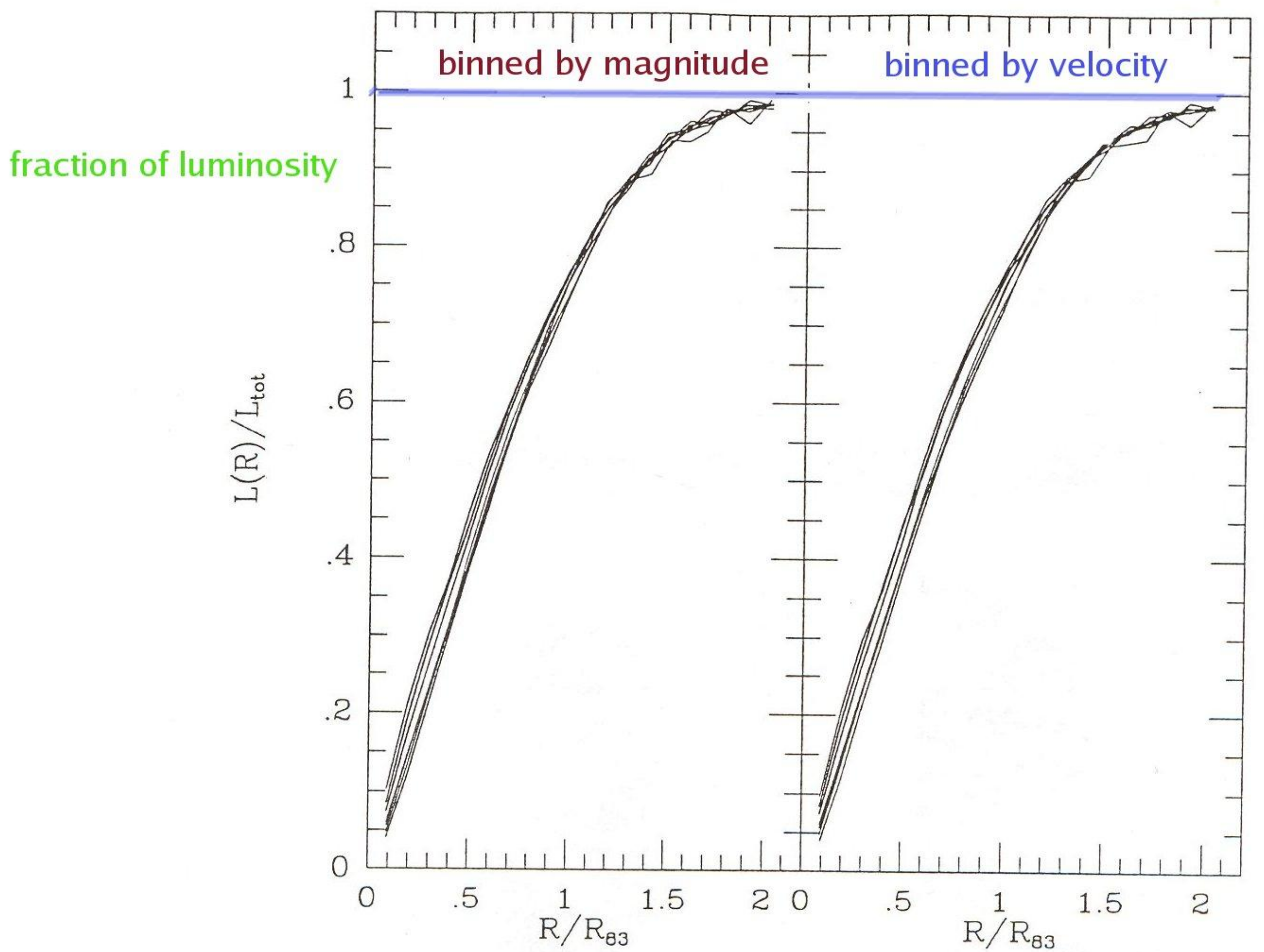
The Realm of Galaxies

15 mag range, 4 types, 16 mag arsec^{-2}.range

Central surface brightness vs magnitude



Luminosity profile is Universal.
Spirals have a lenght-scale
Distribution of stars: L(R/RD)/LT independent of Luminosity

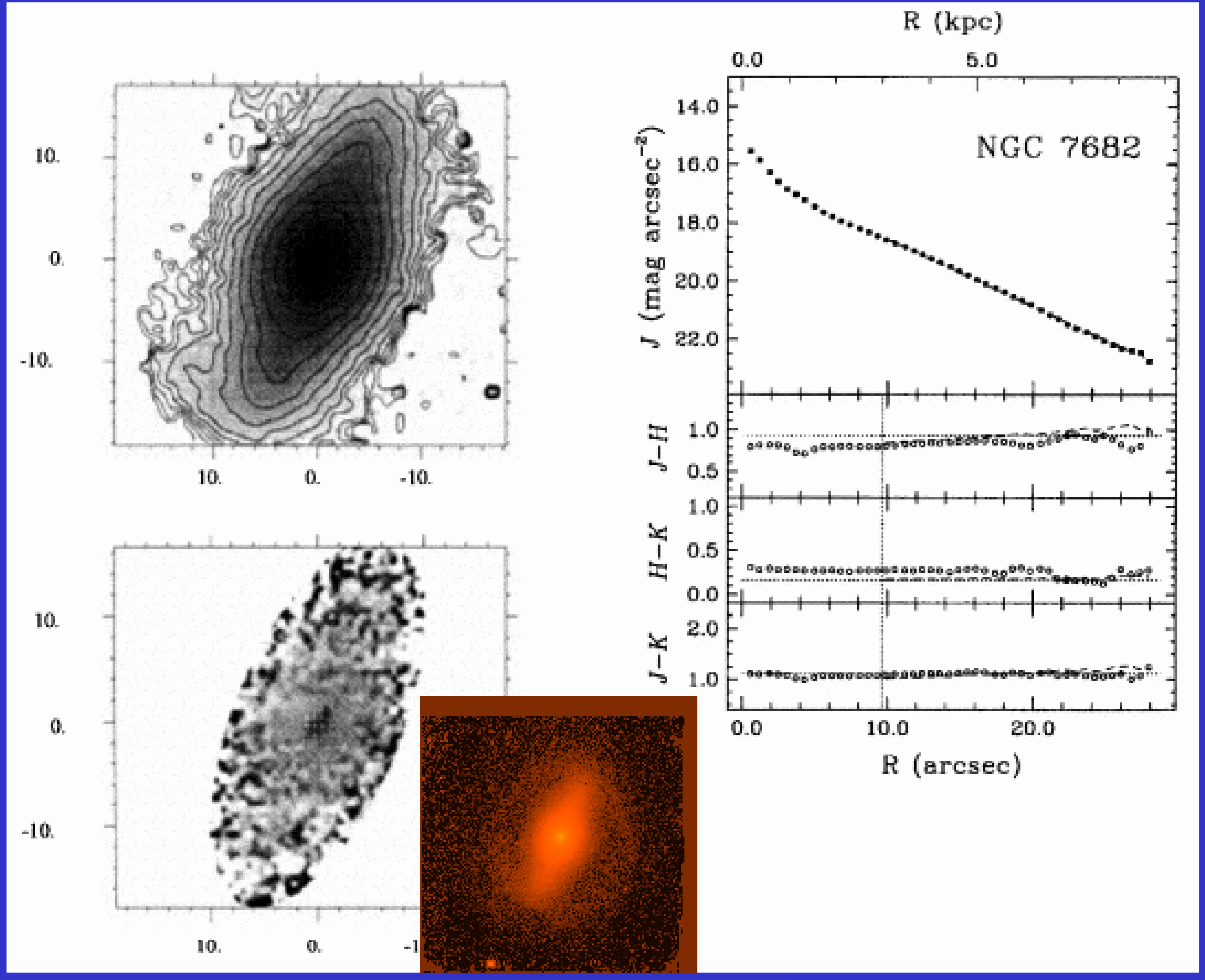


The light distribution in spirals is invariant $I(r) = I_0 \exp[-R/R_D]$

The mass distribution is luminosity dependent:

-TF at different radii

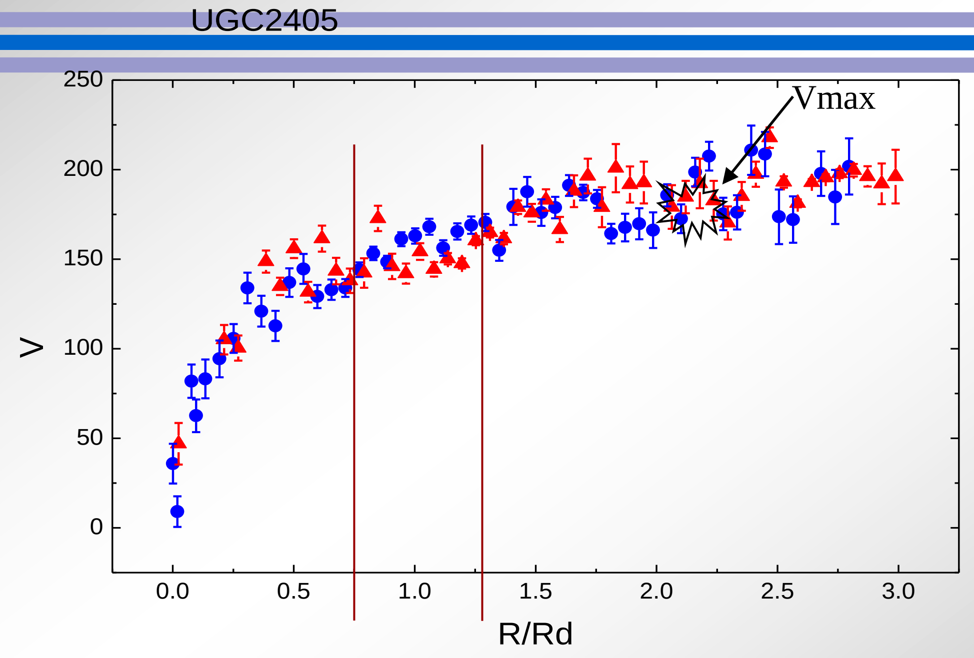
-The Universal profile of the RC's



Do the RC's probe the mass distribution of galaxies ?
What is the zeroth order of their mass profiles

- **Radial Tully Fisher**
- **Inner mass distribution**

TF at different radii



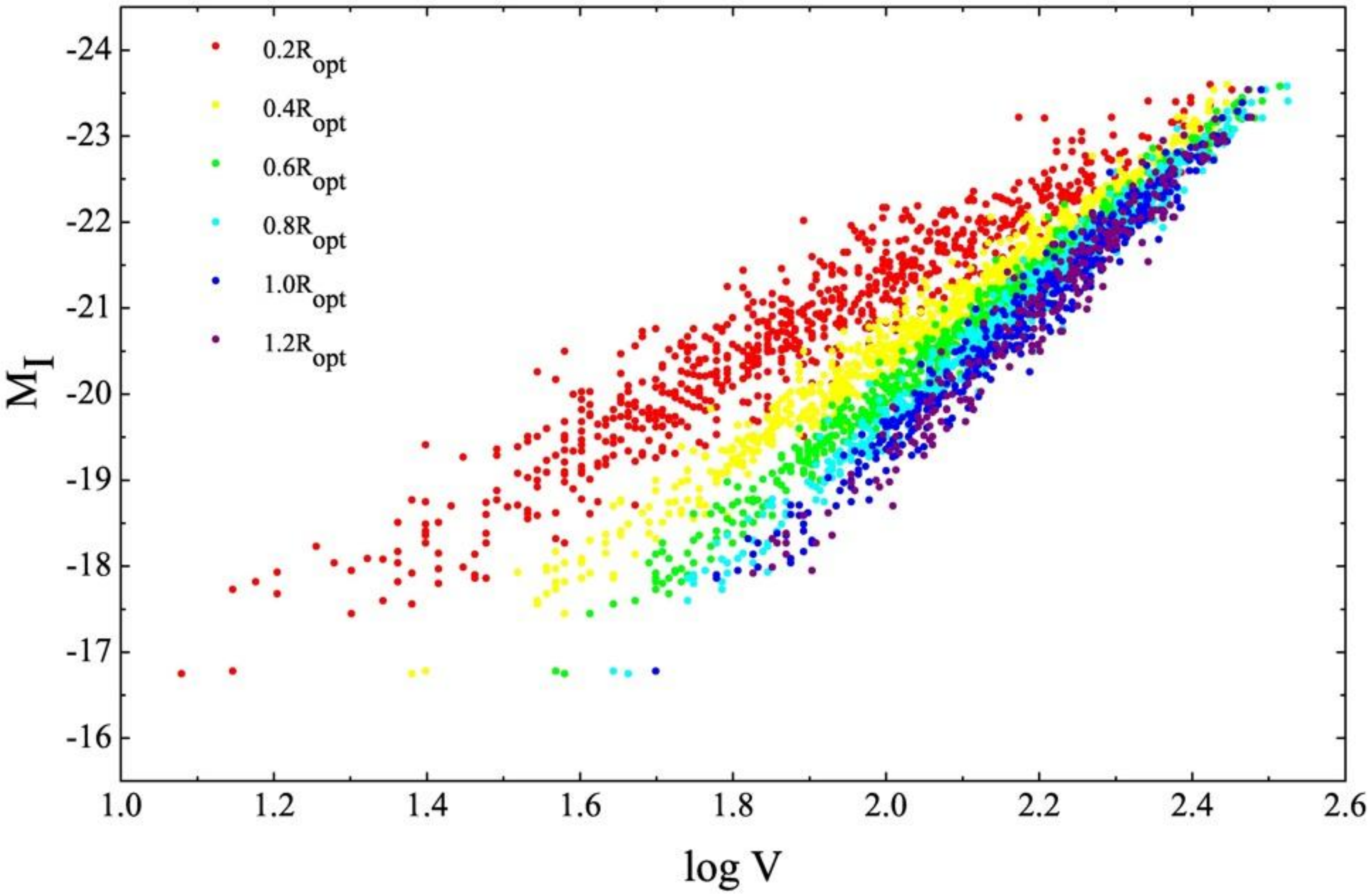
The relation: magnitude vs velocity @ different radii $x_i R_D$, [x_i=0.5,1,…5]

3 samples (600, 89, 78) $M = a_i + b_i \log V(x_i)$

No change in slope implies: i) no DM or ìi) constant fraction of DM

No relationship if V does not trace the mass

Radial TF relationships

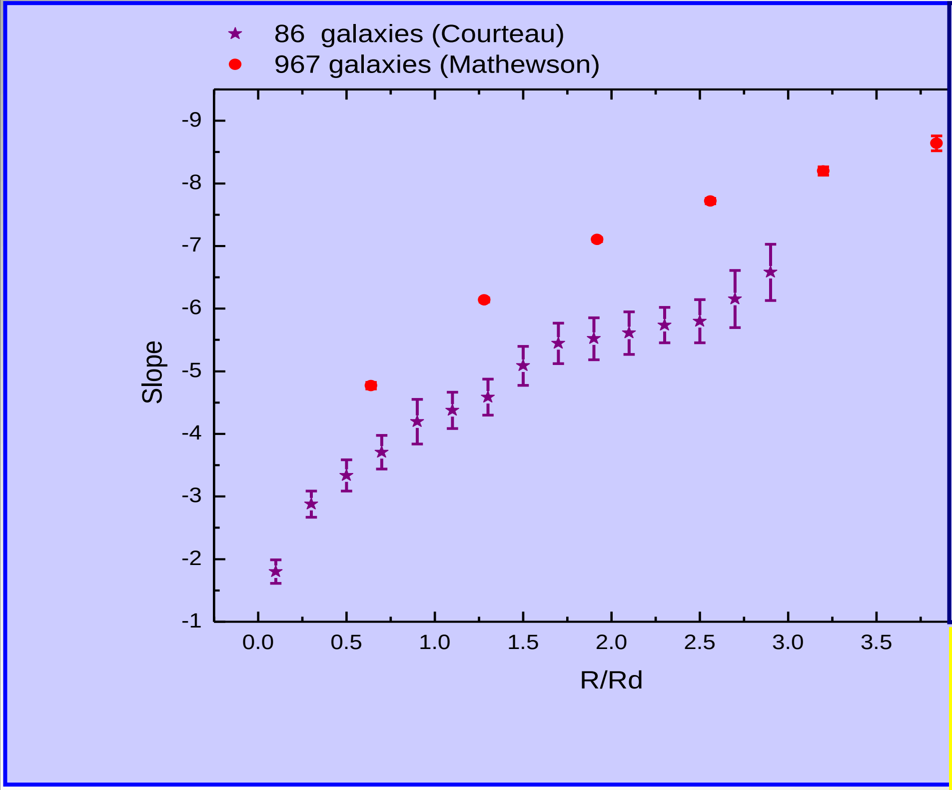


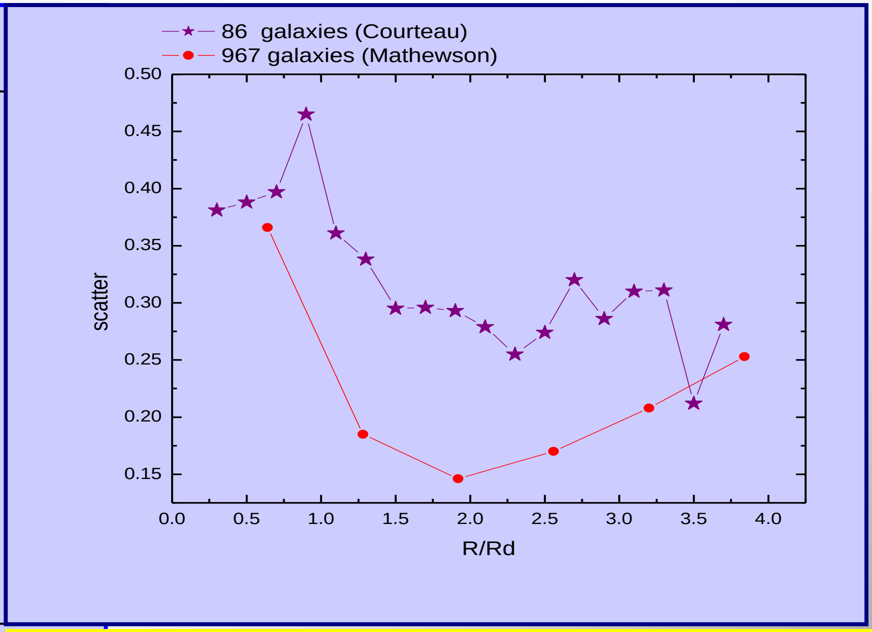
Results: Slope and scatter of the TF-relations:

$$M_B = a_i + b_i \log V(x_i)$$

The slope increases from -4 to -8

The minimum scatter 0.2 mag at 2.2 R_D





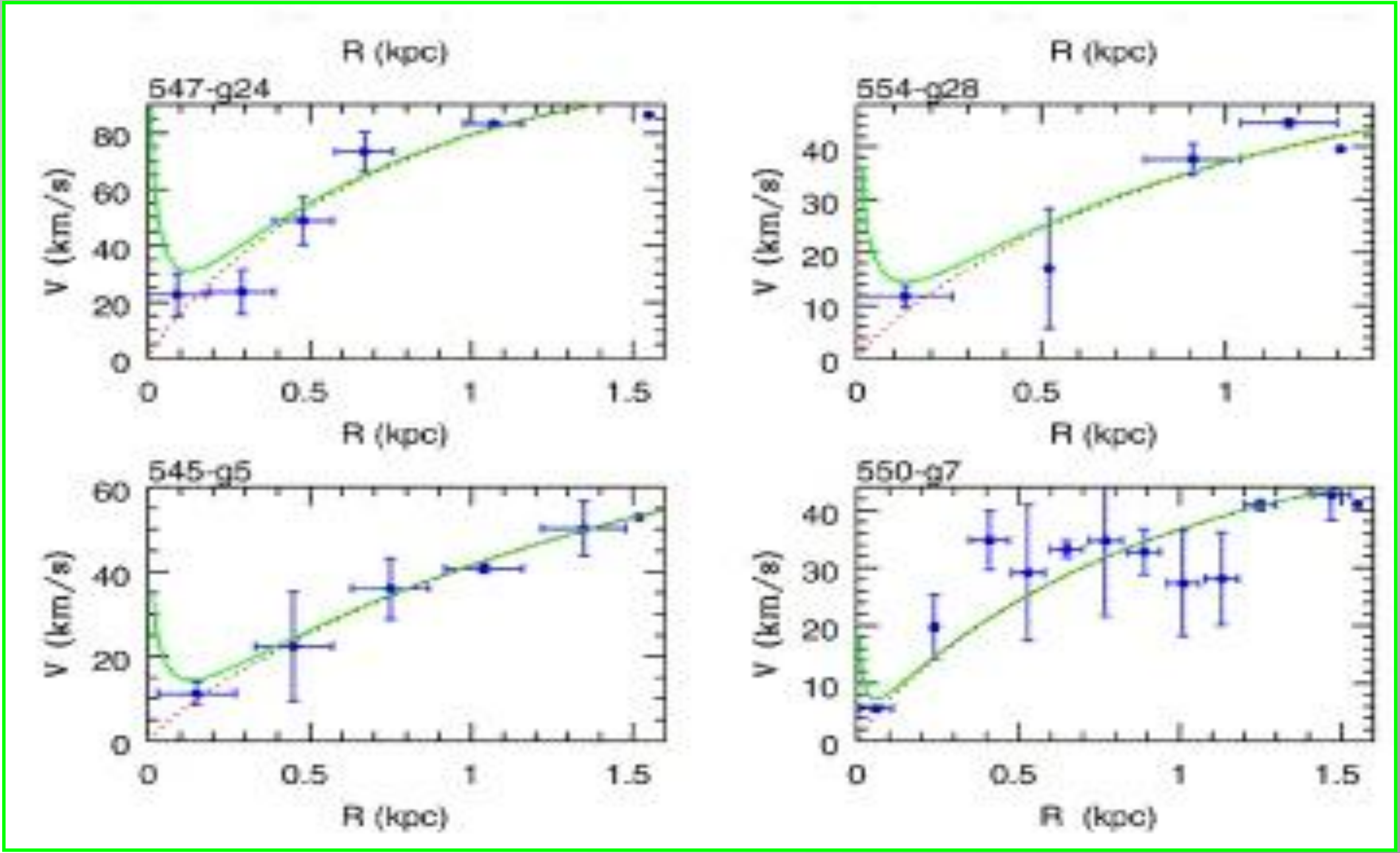
Implications:

V traces the potential

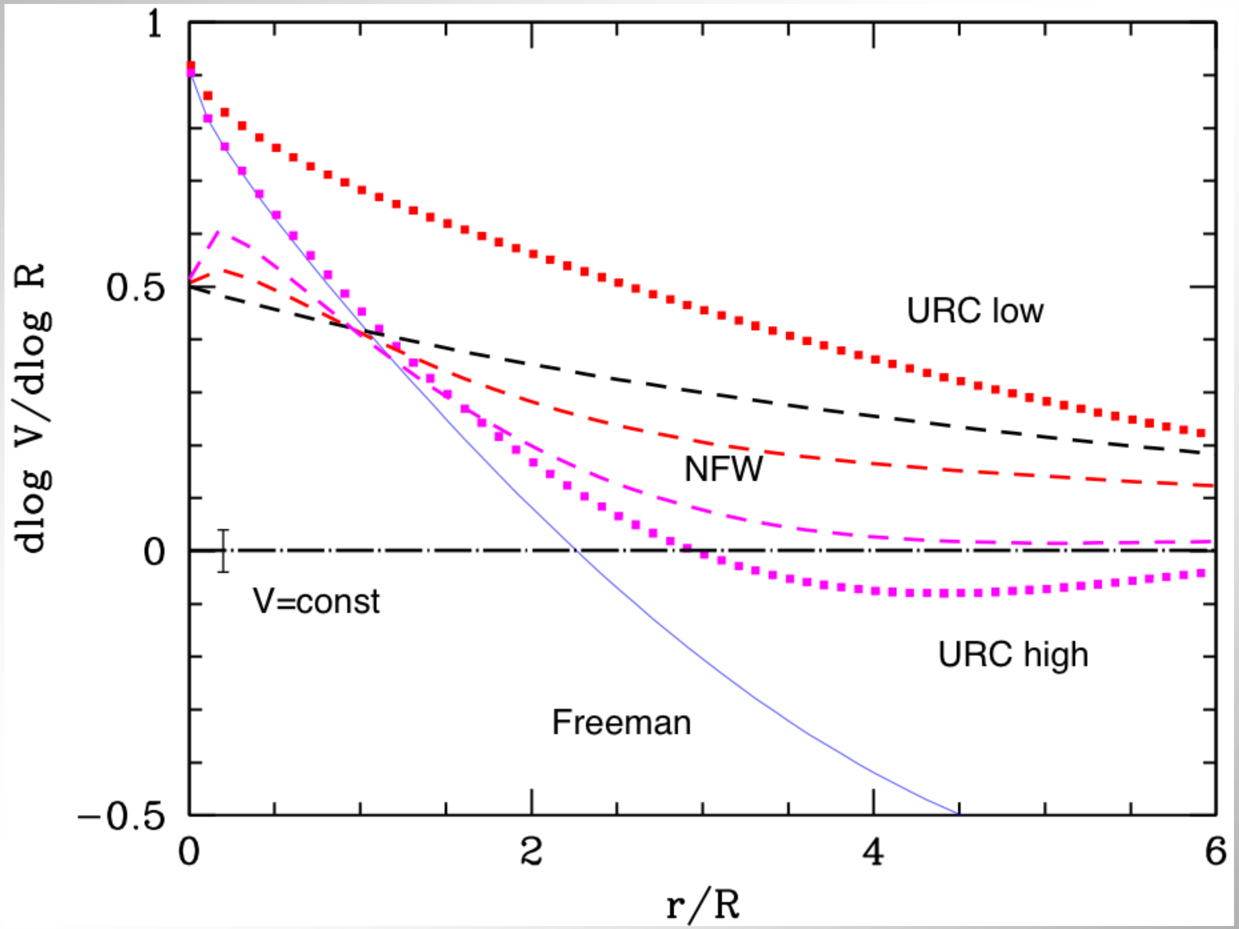
DM emerges at large radii

Modelling the very inner circular velocities:

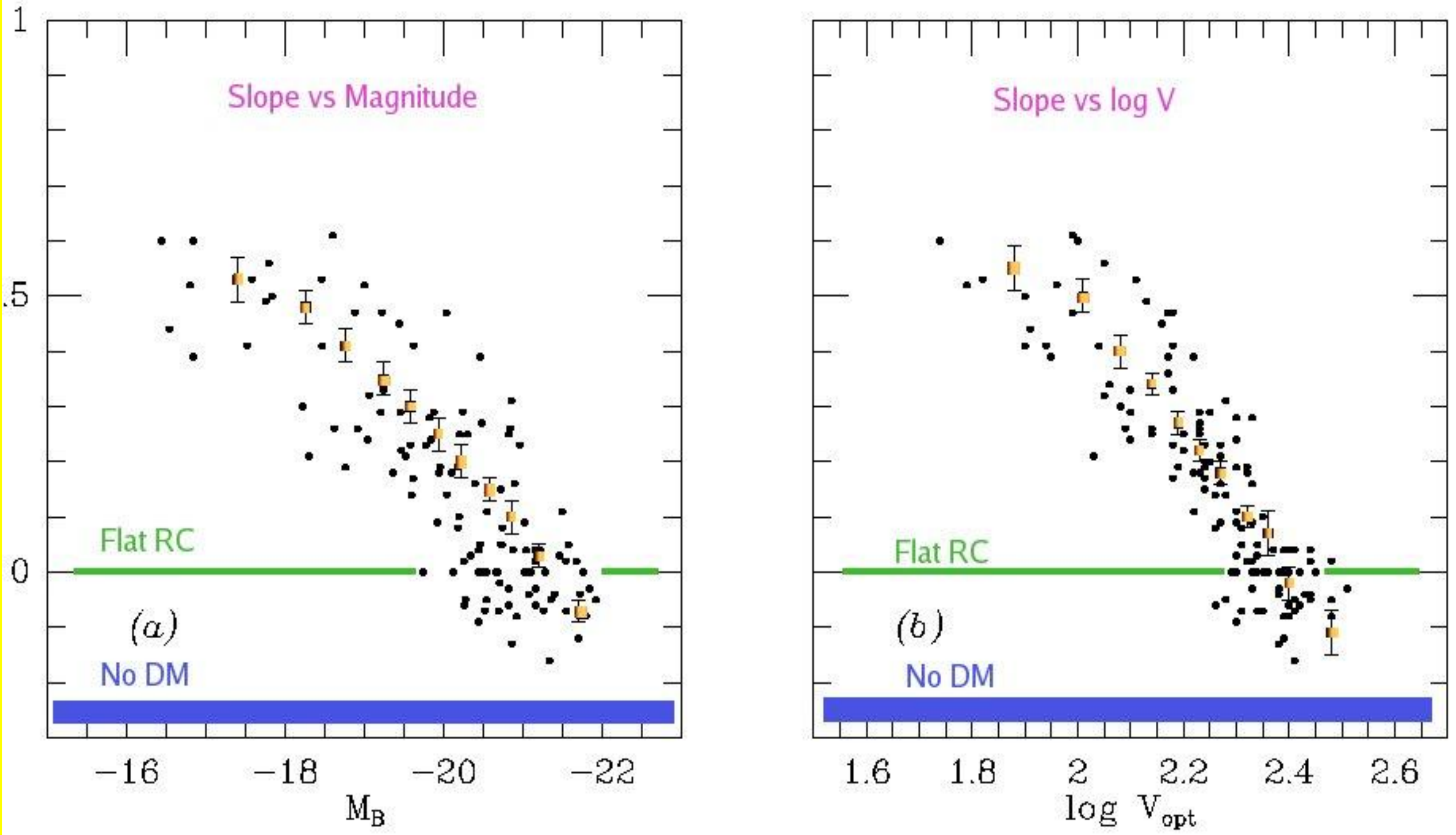
light traces the mass



The slope of the RC

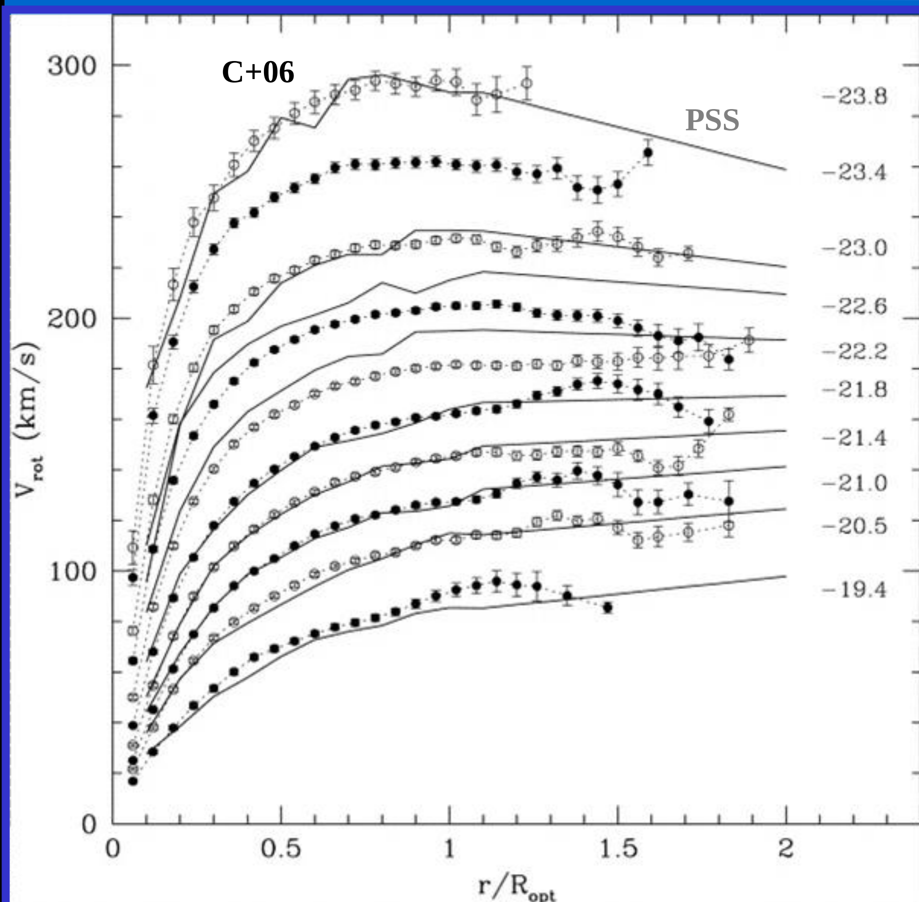


The RC Slopes indicate the presence and the amount of Dark Matter

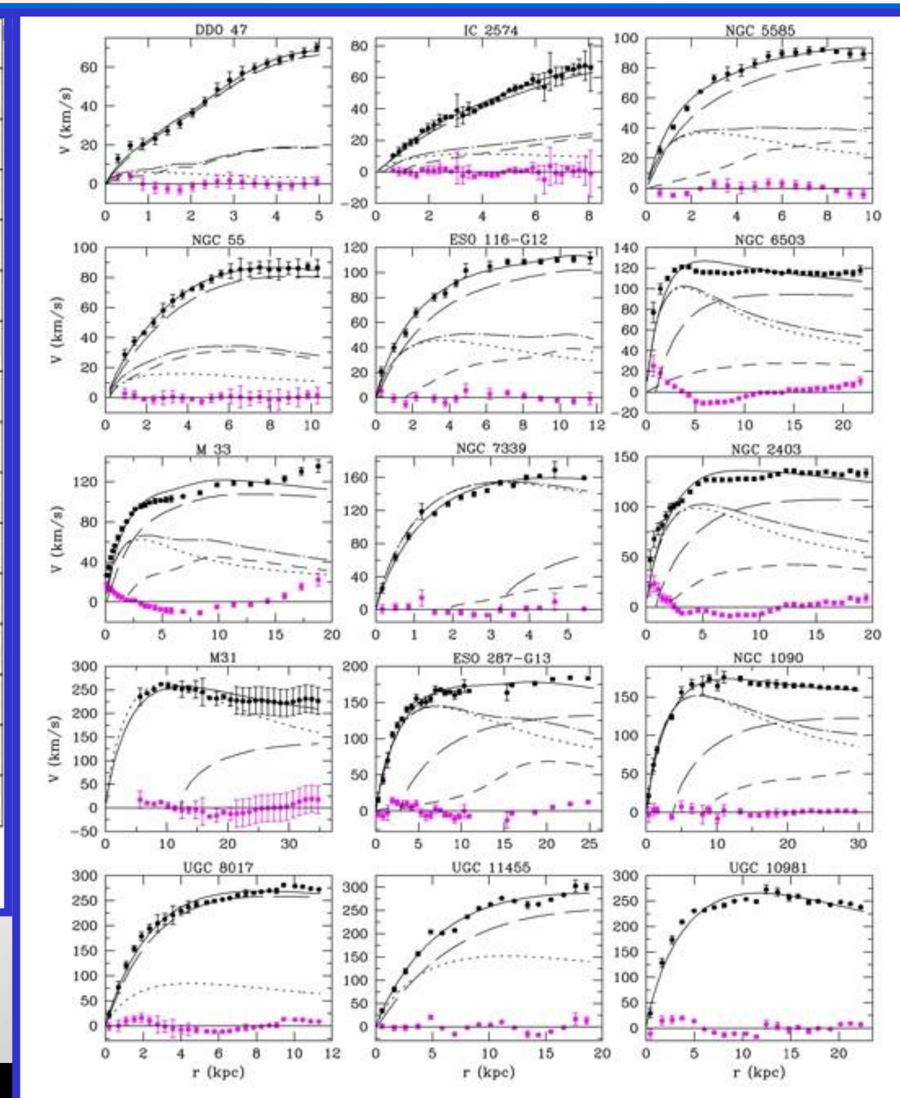


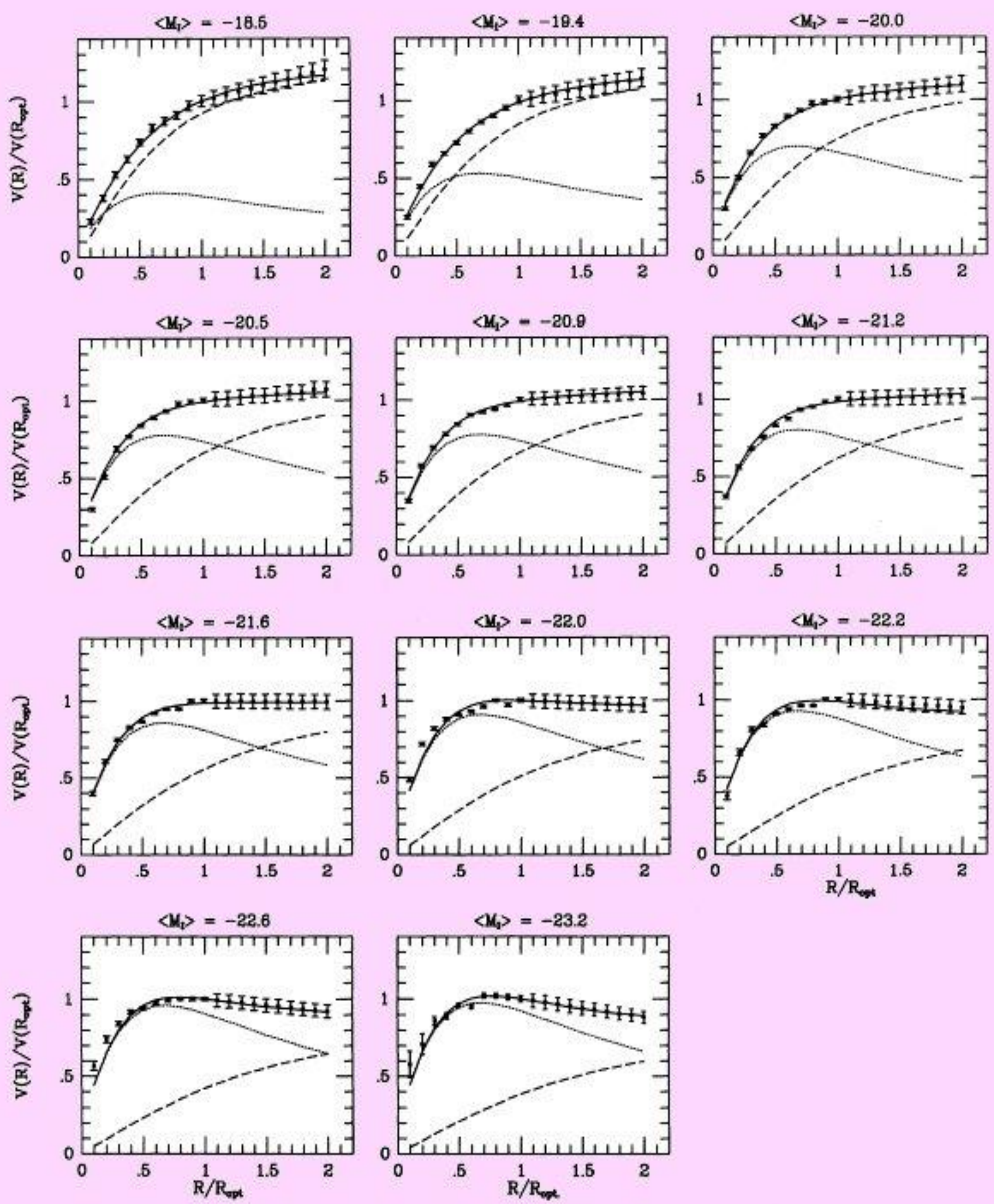
The rotation curves

3200 coadded

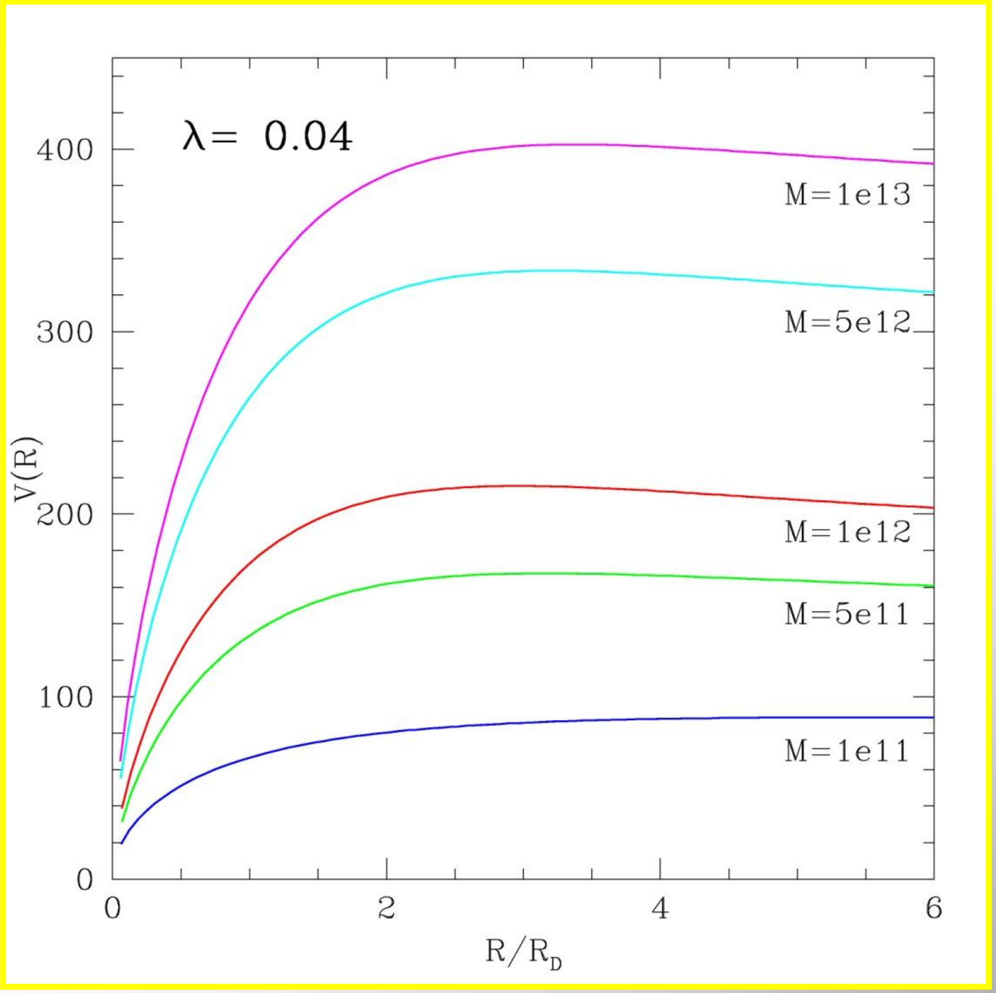


Individual




<M_I> = −18.5
<M_I> = −19.4
<M_I> = −20.0
<M_I> = −20.5
<M_I> = −20.9
<M_I> = −21.2
<M_I> = −21.6
<M_I> = −22.0
<M_I> = −22.2
<M_I> = −22.6
<M_I> = −23.2
V(R)/V(R_opt)
R/R_opt

ΛCDM Universal Rotation Curve from NFW profile and MMW theory



The URC Concept

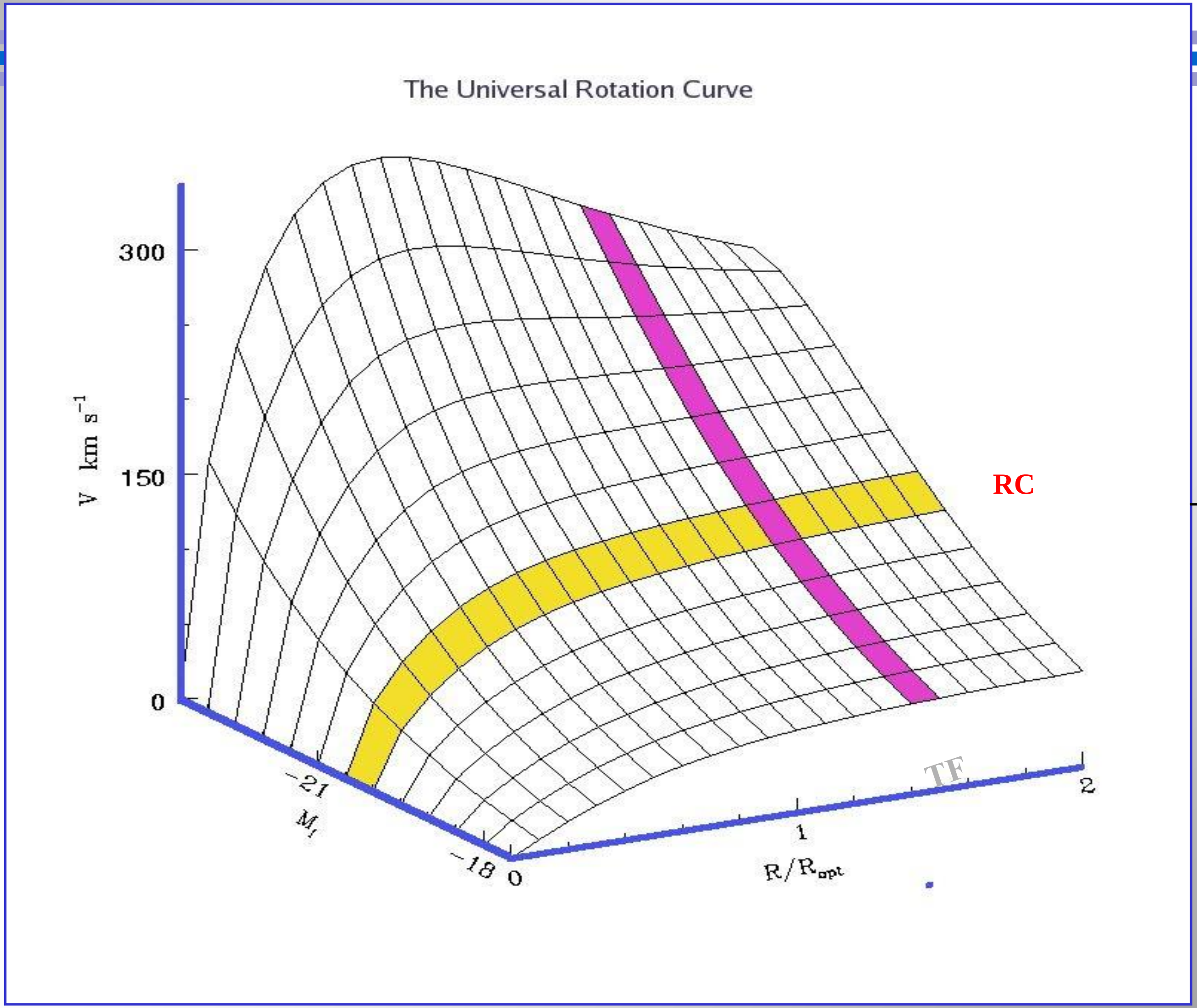
- @ fixed **L** and **X**=R/R_D, the Cosmic Variance of V(**X**,**L**) is one order of magnitude smaller than:

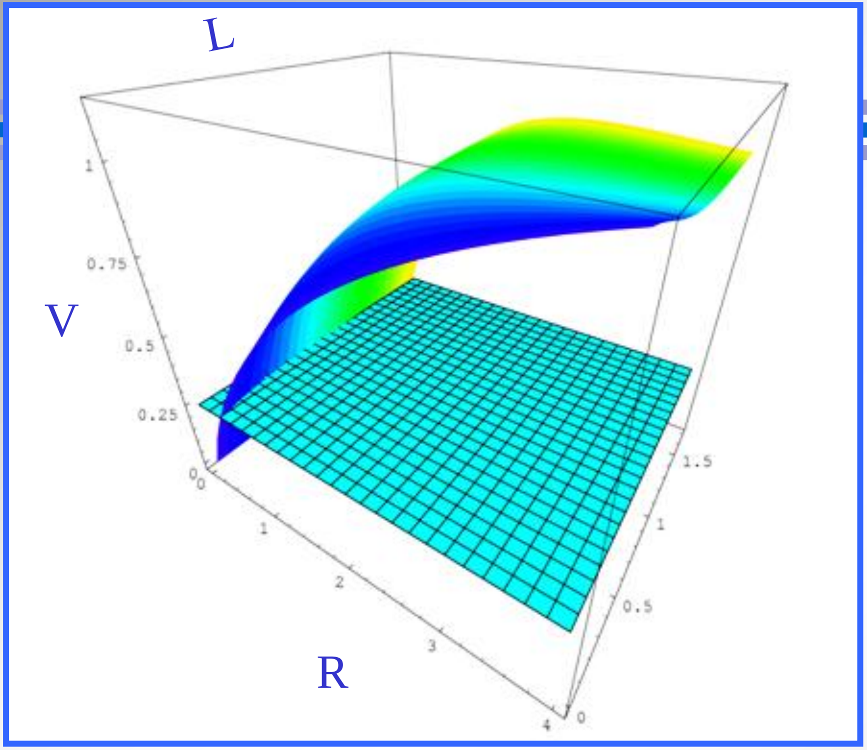
The variations that, in each galaxy, V(**X**) shows as **X** varies.

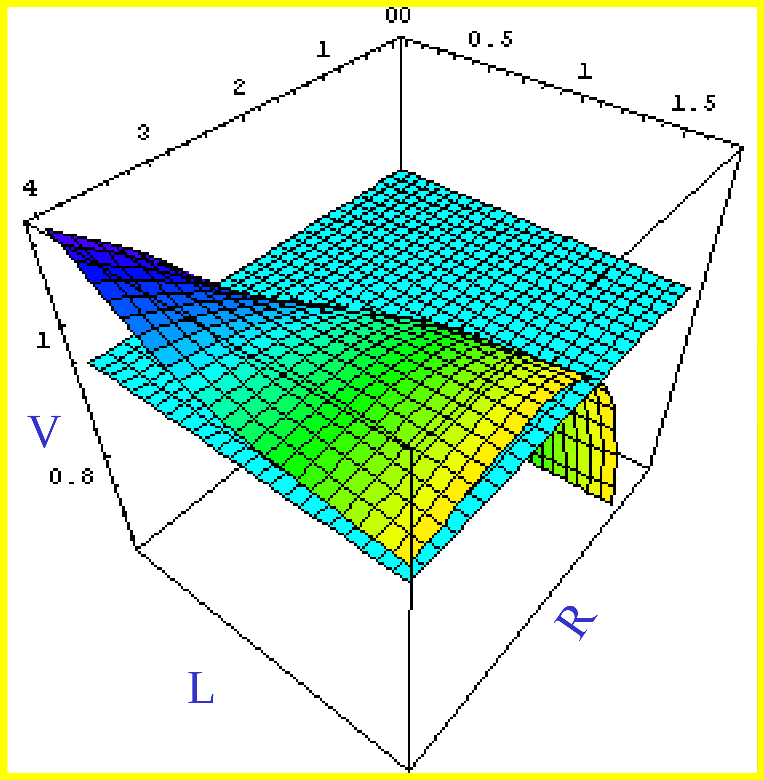
The variations that, @ fixed **X**,V(**X**) shows in galaxies of different **L**

The circular velocity is luminosity dependent

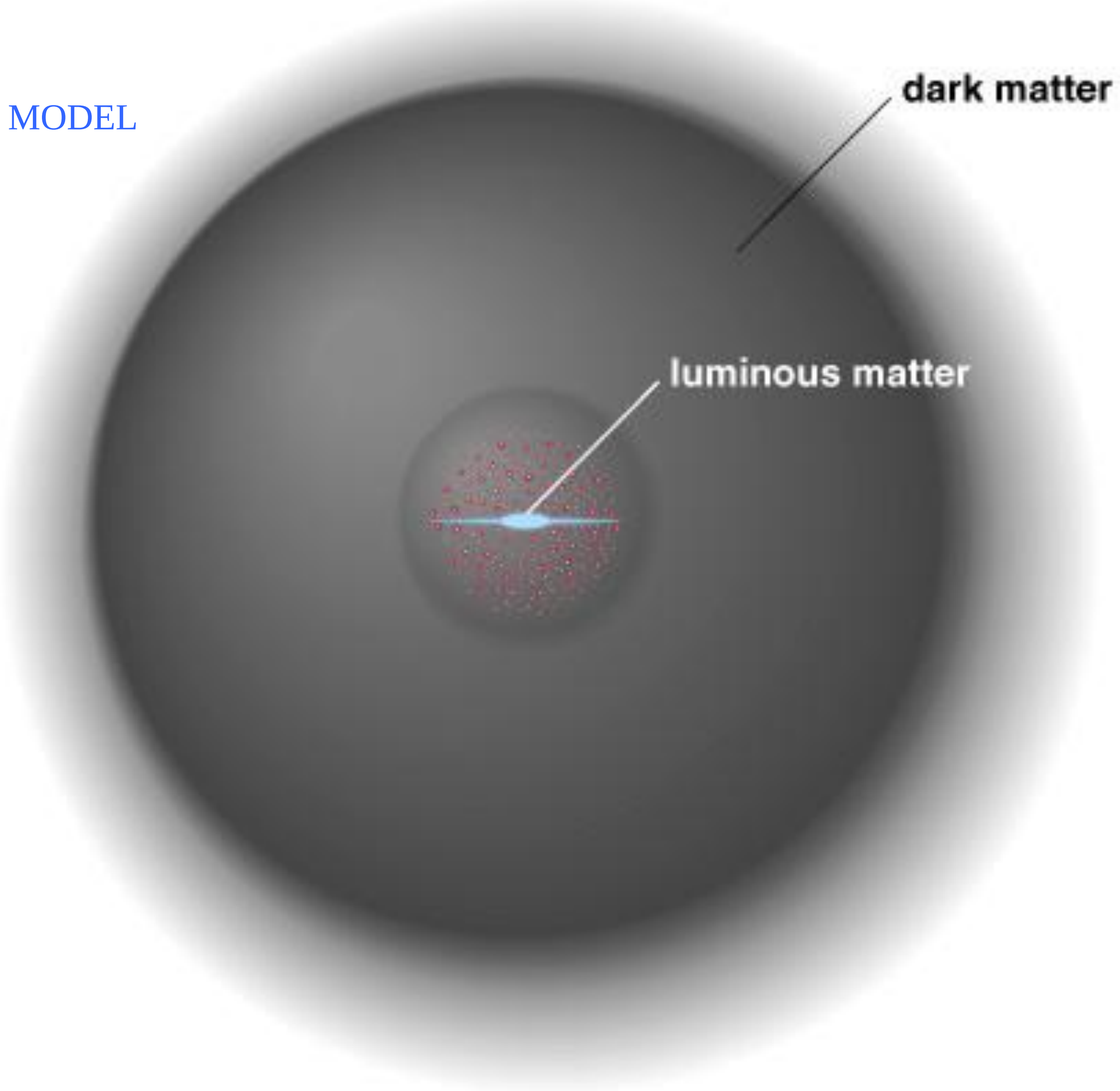
$V(R/R_D)=F(L,R/R_D)$




L
1
0.75
V
0.5
0.25
0
0
1
2
3
R
4
0
0.5
1
1.5


00
0.5
1
1.5
1
2
3
4
1
V
0.8
L
R

MODEL



Rotation curve decomposition.

$$V_{tot}^2 = V_{DM}^2 + V_{disk}^2 + V_{gas}^2$$

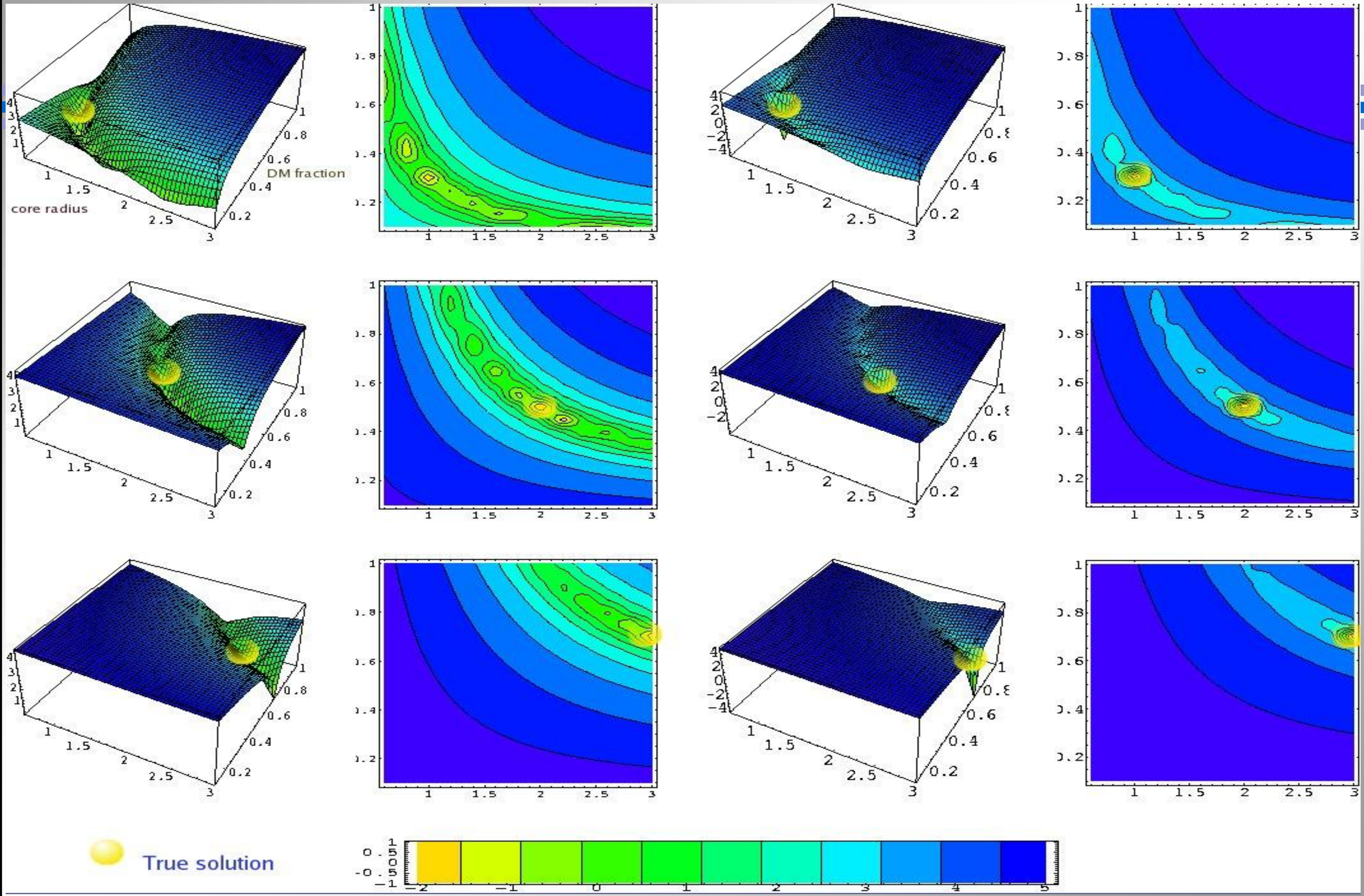
- $V_{disk}(R)$: **from I-band photometry**
- $V_{gas}(R)$: **from HI observations**
- $V_{halo}(R)$

  - dark halos with constant density cores
  - dark halos with "cusps" (NFW, Moore)

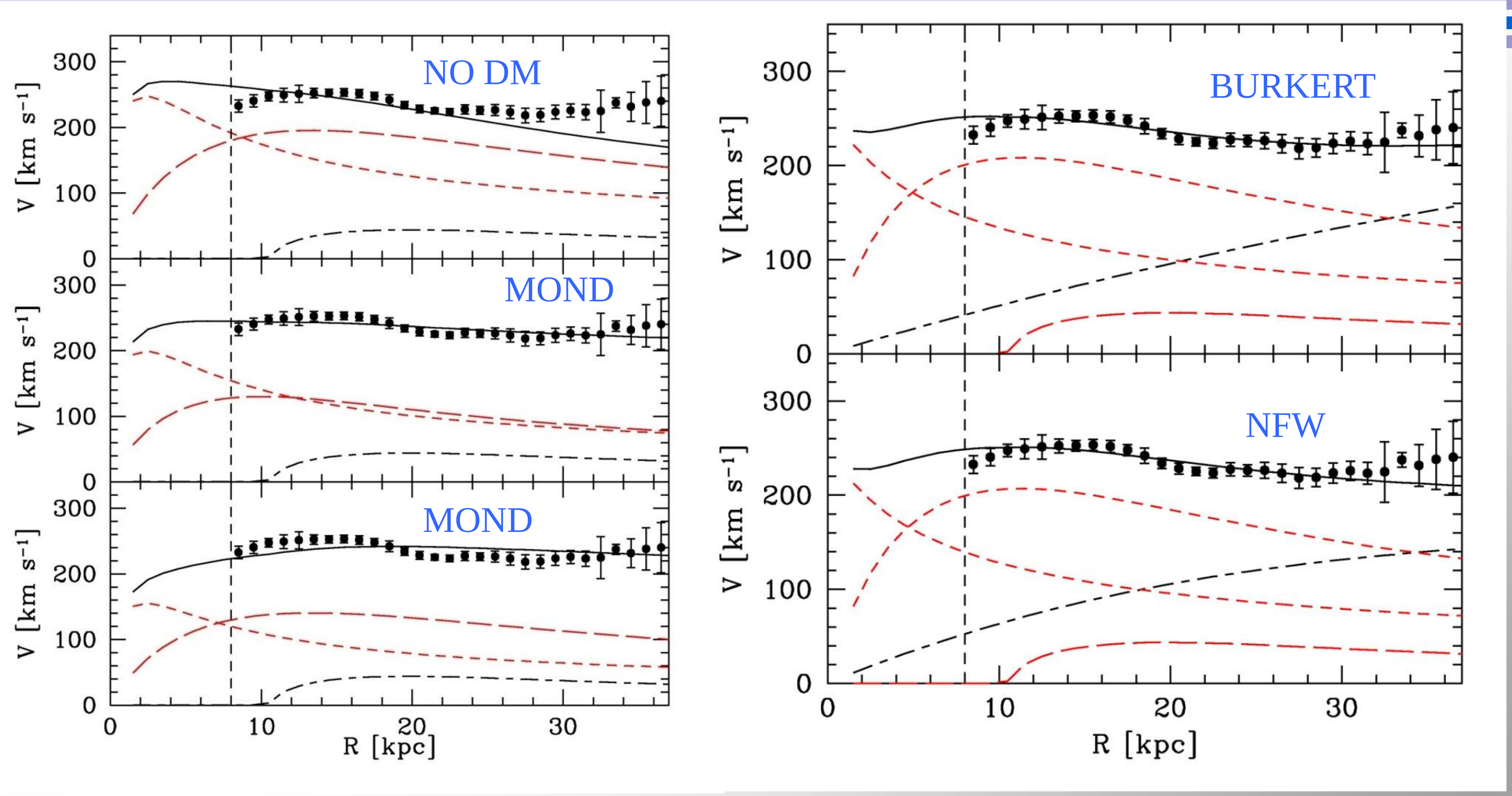
- **HI-scaling**
- MOdified Newtonian Dynamics

We can uniquely mass model a RC

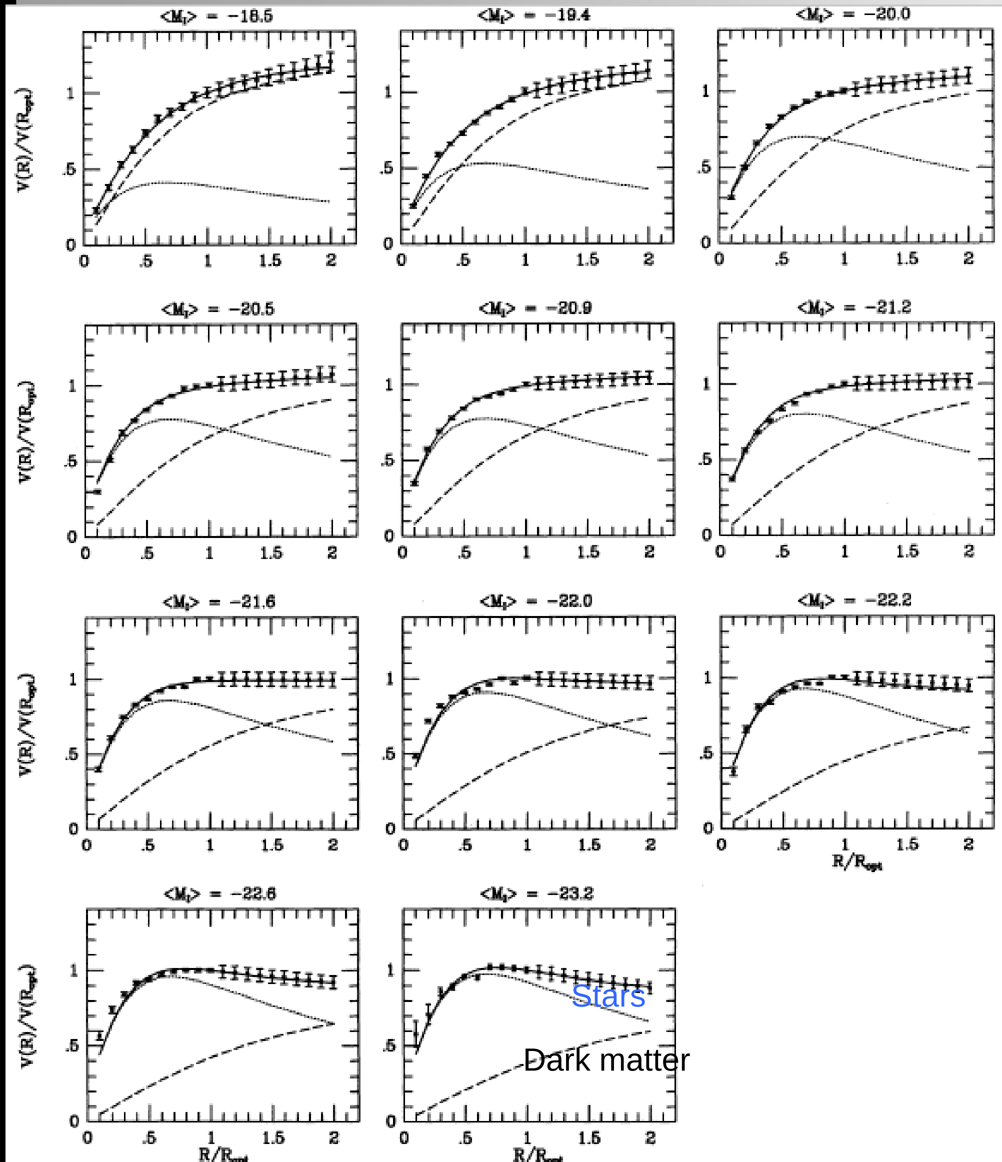
disk-halo components, known surf phot, reliable V(R) and dV/dR, resolution ~ 0.3 R_D



M 31



Modelling the Universal Rotation Curve

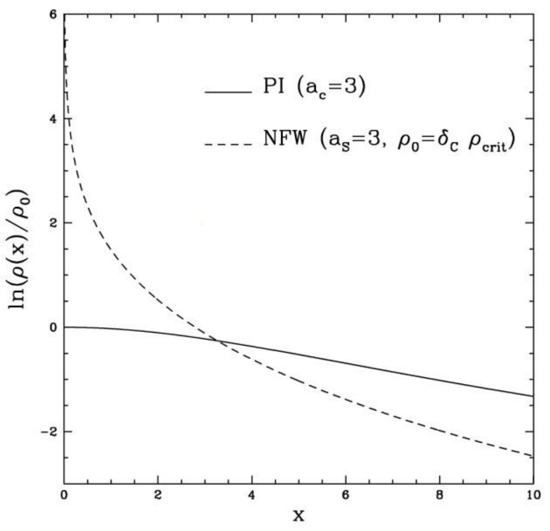


Rotation velocity

Stellar contribution

$$V_{\mathrm{URC}}\left(\frac{R}{R_{\mathrm{opt}}}\right) = V(R_{\mathrm{opt}})\left\{\left(0.72 + 0.44\log\frac{L}{L_*}\right)\frac{1.97x^{1.22}}{(x^2+0.78^2)^{1.43}} + 1.6\exp\left[-0.4(L/L_*)\right]\frac{x^2}{x^2+1.5^2\left(\frac{L}{L_*}\right)^{0.4}}\right\}^{1/2}\ \mathrm{km\ s^{-1}}$$

Dark matter halo contribution



NFW Halos

$$\rho_{NFW}(r) = \frac{\rho_s}{(r/r_s)(1+r/r_s)^2}$$

$$c_{vir} \equiv r_{vir}/r_s$$

$$M_{NFW}(r) = M_{vir}\,\frac{A(r, r_s)}{A(c_{vir}, r_s/r_s)}$$

$$A(x_1, x_2) \equiv \ln(1 + x_1/x_2) - (1 + x_2/x_1)^{-1}$$

Burkert-URCH-PI Halos

$$\rho_B(r) = \frac{\rho_0}{(1+r/r_0)[1+(r/r_0)^2]}$$

The profile is characterized by a density–core of extension r_0 and value ρ_0, while it resembles the NFW profile at large radii.

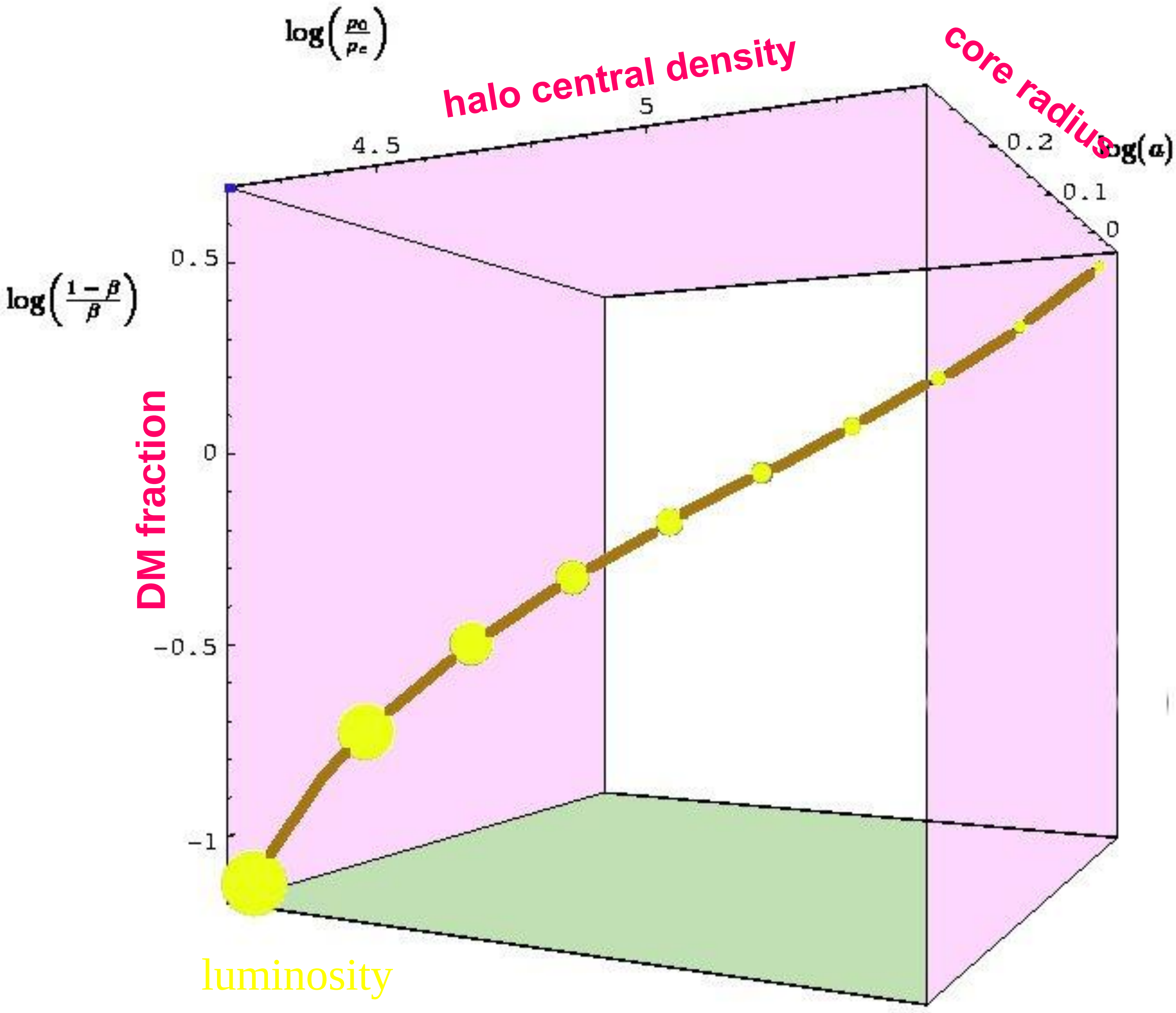
$$M_B(r) = M_e\,\frac{B(r, r_0)}{B(1, r_0/r_e)}$$

s= r/r0 ; B(s)= 2 ln(1+s)+ln(1+s^2)-2 arctg(s)

@ L* , VB ~ VNFW (R)

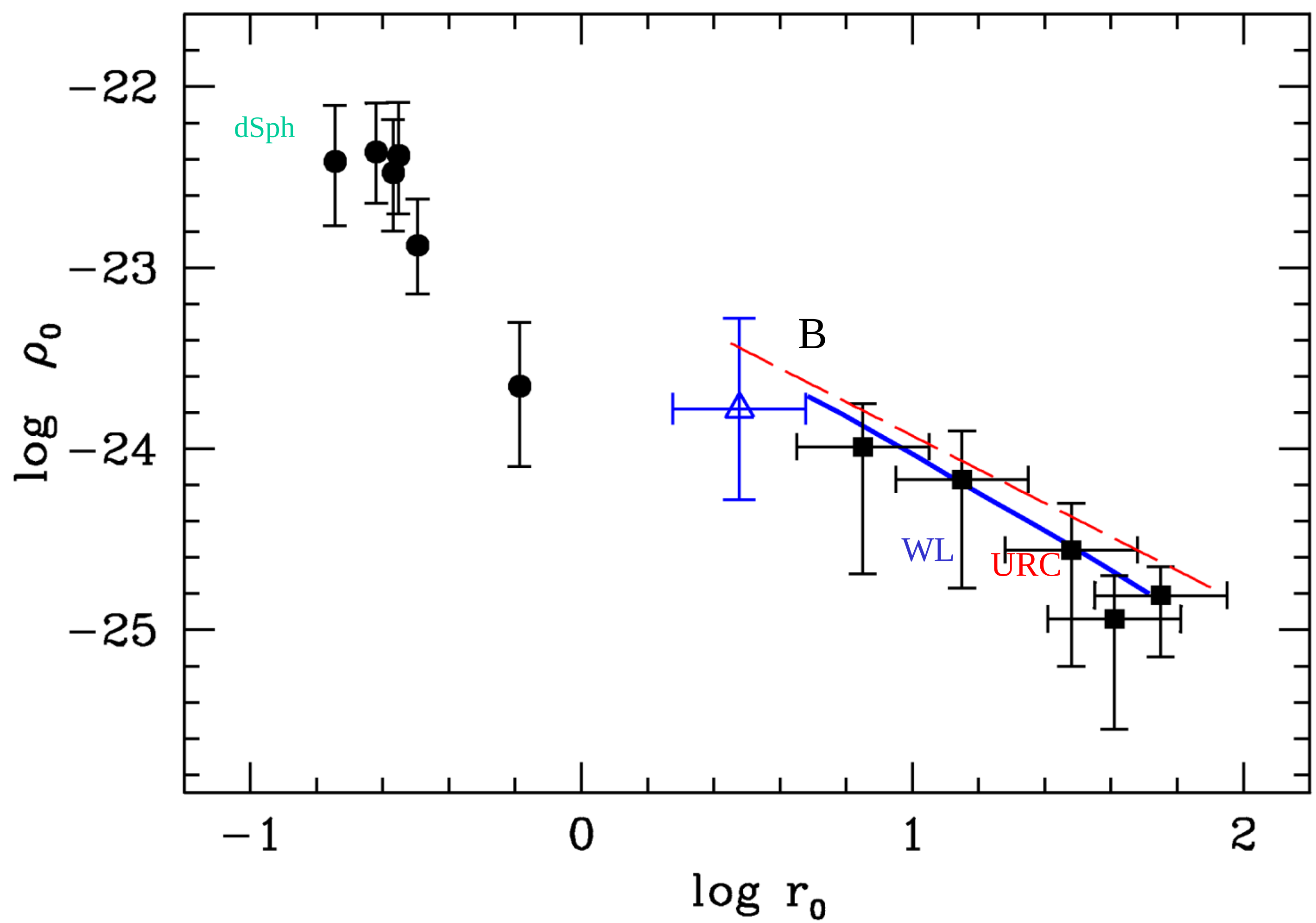
VNFW easier to fit uniquely

A family governed by luminosity



Halo central density vs core radius scaling

$\rho_0 = 10^{-23} (r_0/\mathrm{kpc})^{-1}\ \mathrm{g/cm^3}$



Halo masses

$$\mathbf{BMF}(M_b)\,dM_b = \left(1.94 \times 10^{-3} \tilde{M}_b^{-1.2} e^{-\tilde{M}_b/1.9} + 4 \times 10^{-7}\ \tilde{M}_b^{-2.6}\right) \frac{dM_b}{10^{11} M_\odot}$$

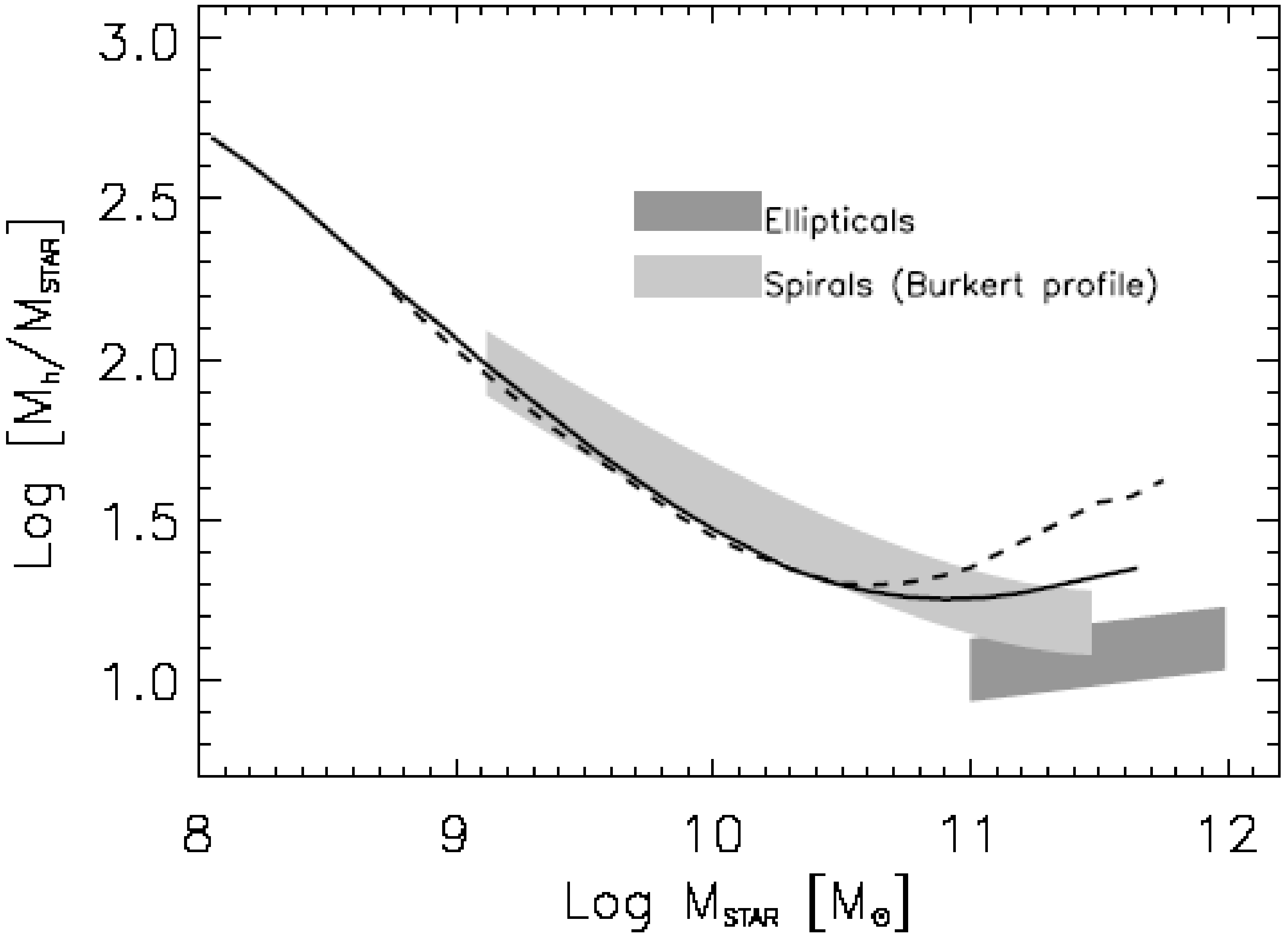
$$HMF(M_h)\,dM_h = A\,M_h^{-1.84}\,dM_h$$

and

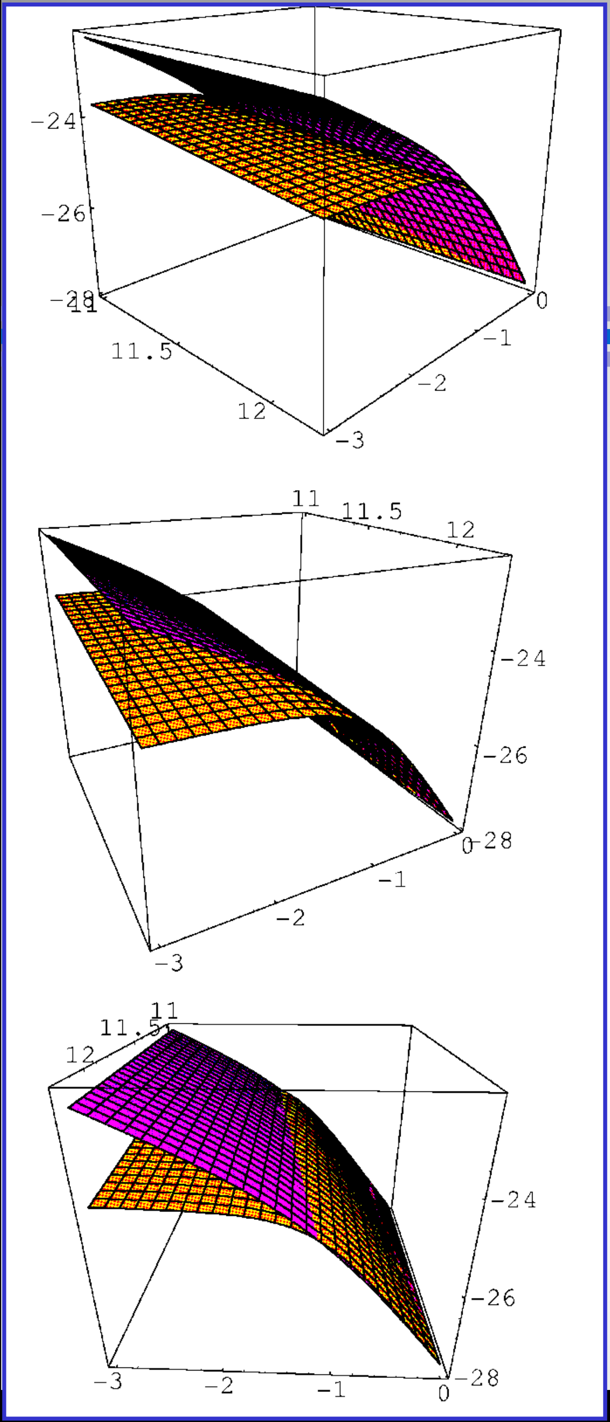
$$HMF(M_h)\,dM_h/dM_b\,dM_b = BMF(M_b)\,dM_b$$

$$M_h = \left((|\beta| - 1)/A\ \left(1.94\ 10^{-3}\Gamma(-0.21, \tilde{M}_b/1.9) + 2.5\ 10^{-7}\tilde{M}_b^{-1.6} + C\right)\right)^{1/(1-|\beta|)}$$

RESULTS



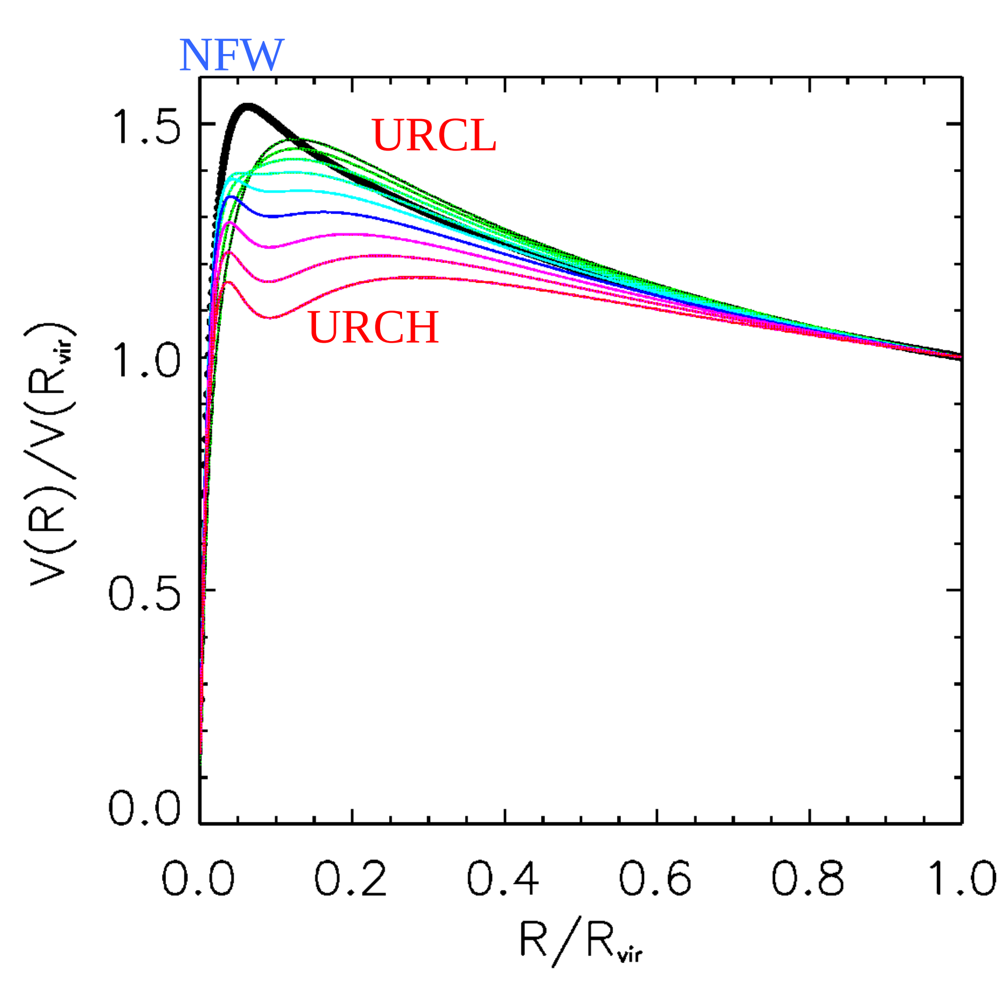
3.0
2.5
2.0
1.5
1.0
Log [Mh/MSTAR]
Ellipticals
Spirals (Burkert profile)
8
9
10
11
12
Log MSTAR [M⊙]



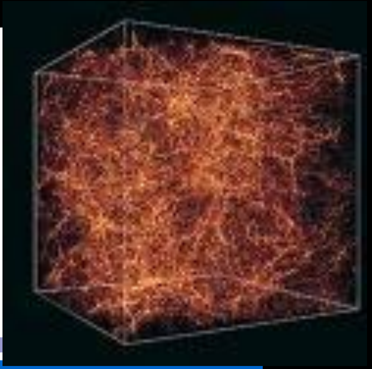
RESULTS

DM halo density: observations vs simulations

The Universal Velocity Curve



Dark halos from simulations



Halos form hierarchically bottom-up via gravit. amplification of initial density flucts. Most evident property: CENTRAL CUSP

$$M_{vir} \equiv \frac{4\pi}{3} \Delta_{vir} \rho_u R_{vir}^3 \qquad V_{vir}^2 \equiv G M_{vir} / R_{vir} \qquad c_{vir} \equiv R_{vir}/r_s \simeq 9.7 (M_{vir}/10^{12} M_{un})^{-0.09}$$

$$\rho_{NFW}(r) = \frac{\rho_s}{(r/r_s)(1+r/r_s)^2}$$

Navarro, Frenk & White, ApJ 462, 563 (1996)
Bullock et al., MNRAS 321, 559 (2001)
Klypin,2010

The cusp vs core issue

cuspy NFW density profiles disagree with observed kinematics.
comparison galaxy by galaxy and of coadded kinematics highlights a CDM crisis.

NFW HALOS

- Fit badly the RCs
- Unphysically too low stellar mass-to-light ratios
- Unphysically too high halo masses

Moore, Nature 370, 629 (1994)
Kravtsov et al., ApJ 502, 48 (1998)
Salucci & Burkert, ApJ 537, L9 (2000)
de Blok, McGaugh & Rubin, AJ 122, 2396 (2000)

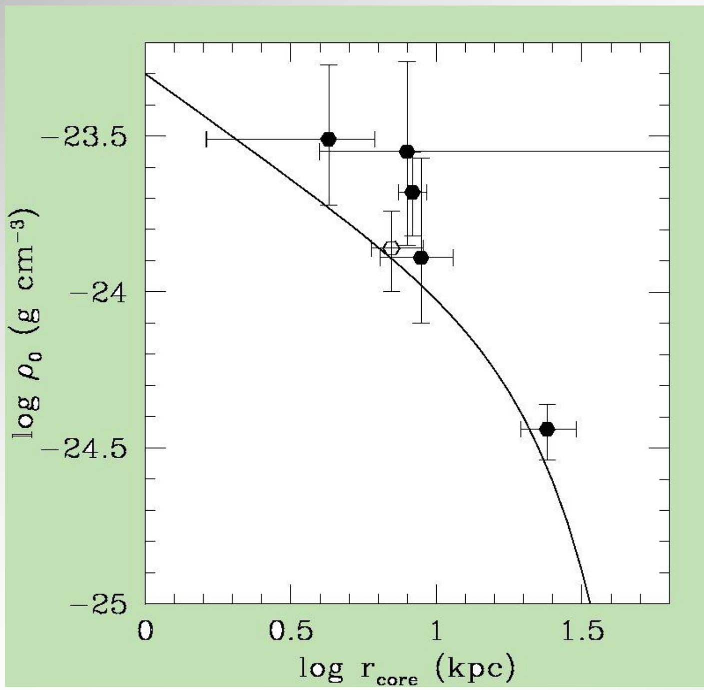
Salucci, Walter & Borriello, A&A 409, 53 (2003)
Gentile et al., MNRAS 351, 903 (2004)
Kuzio de Naray, McGaugh & de Blok, ApJ 676, 920 (2008)

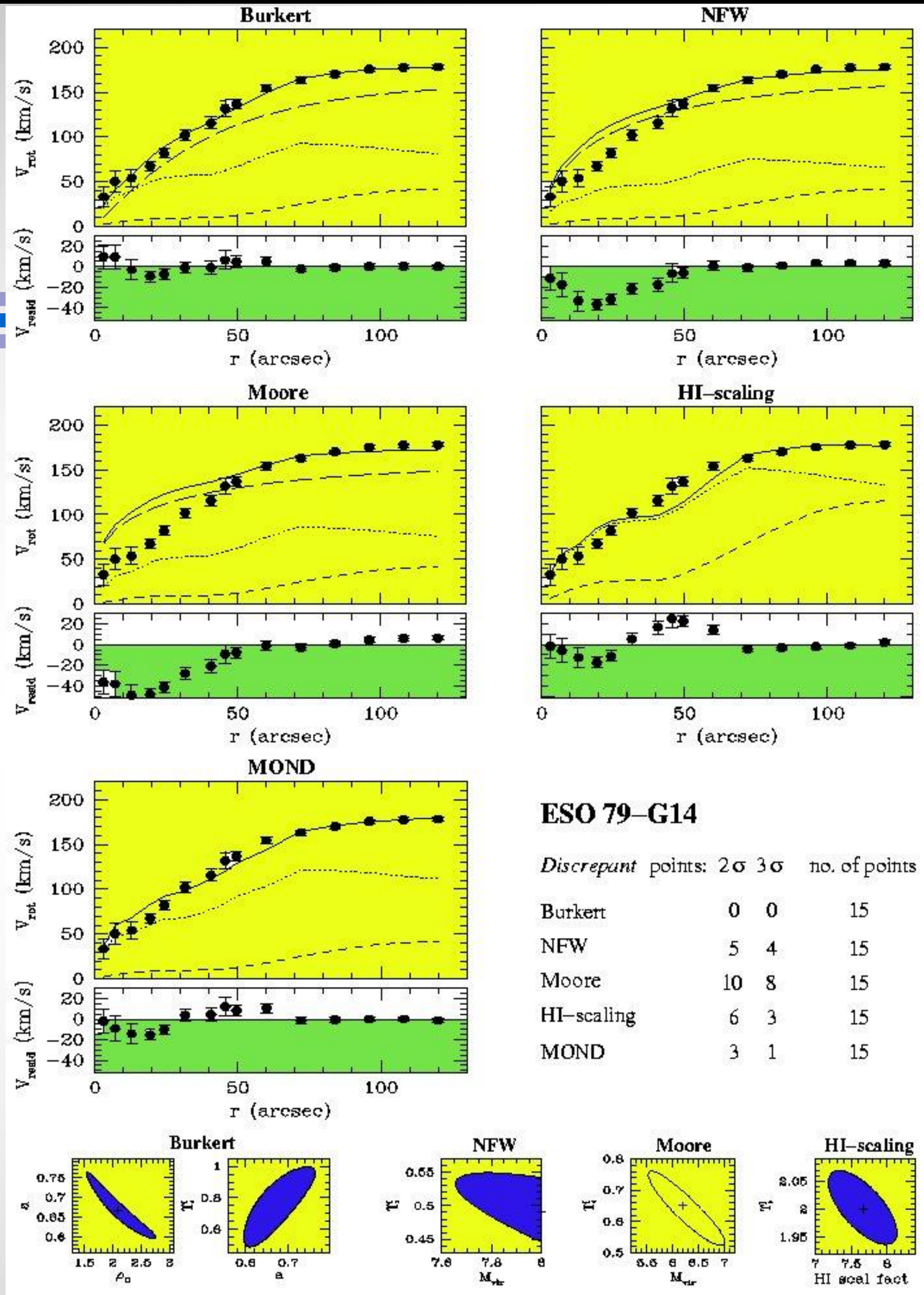
A test case: ESO 116-G12

Cored halos the best fits

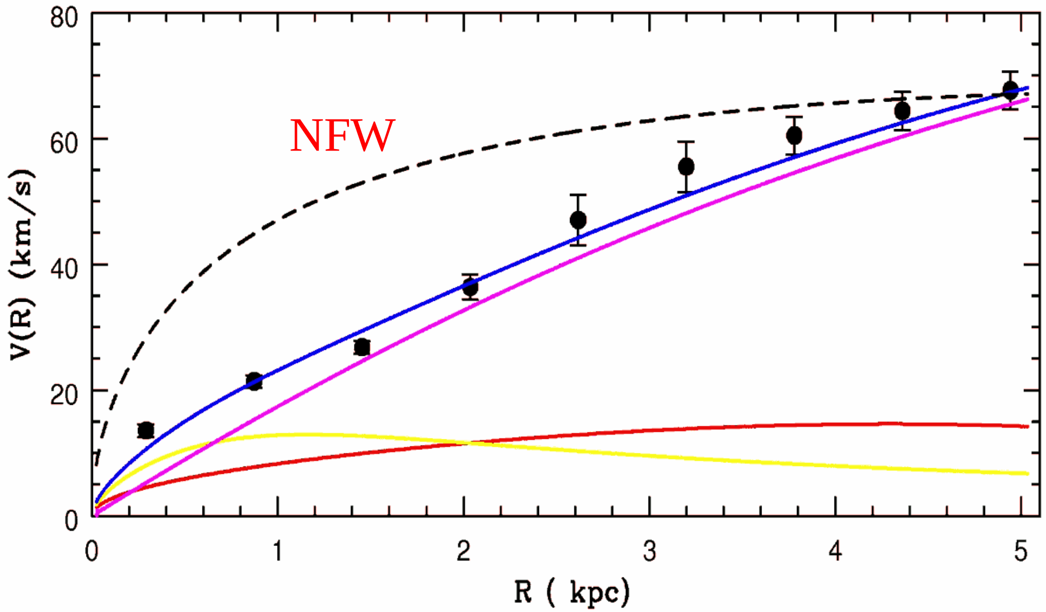
50 objects investigated
NFW inconsistent

Density vs core radius



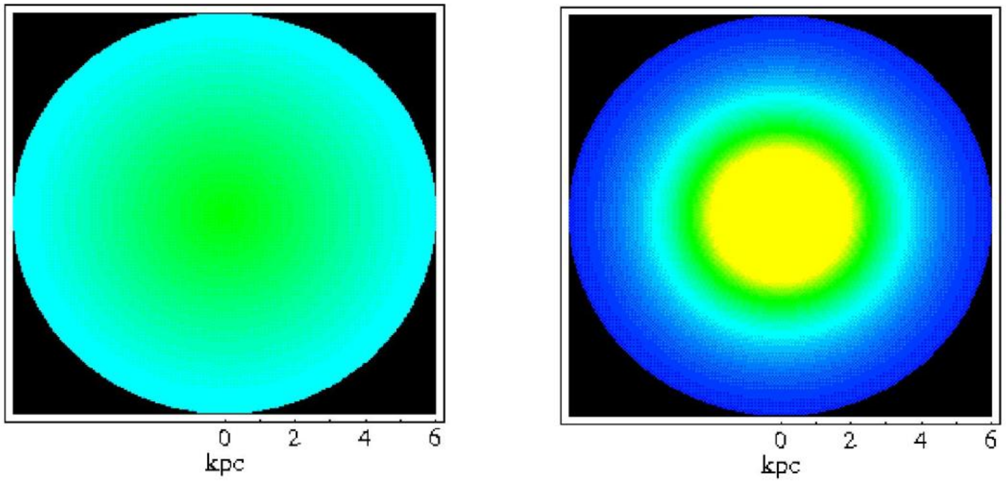


DDO 47

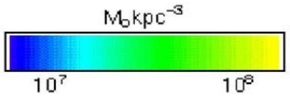


NFW
V(R) (km/s)
R (kpc)
0
20
40
60
80
1
2
3
4
5

NFW

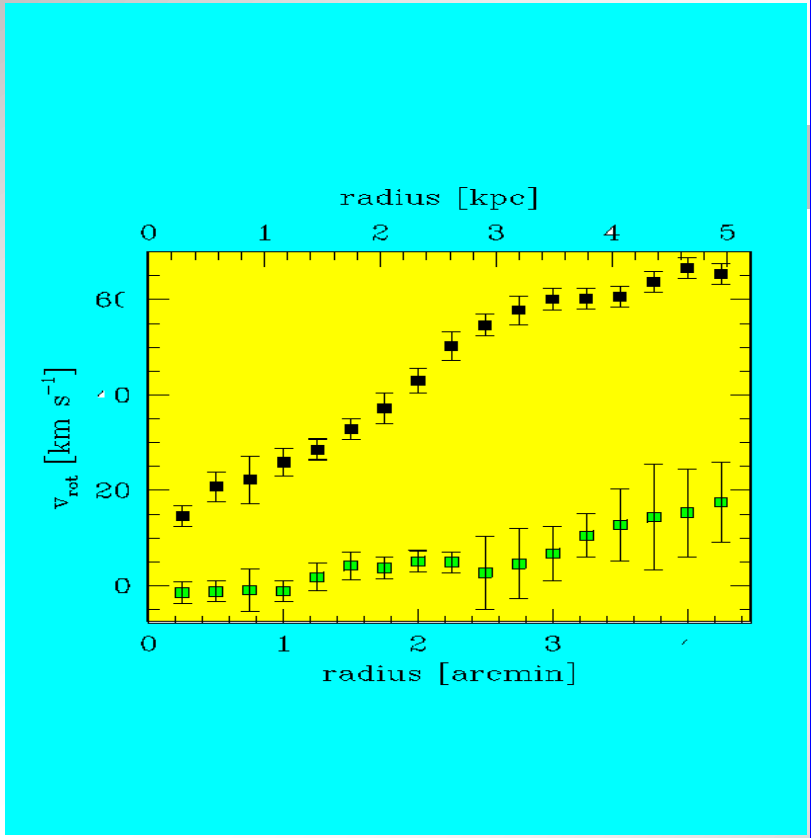


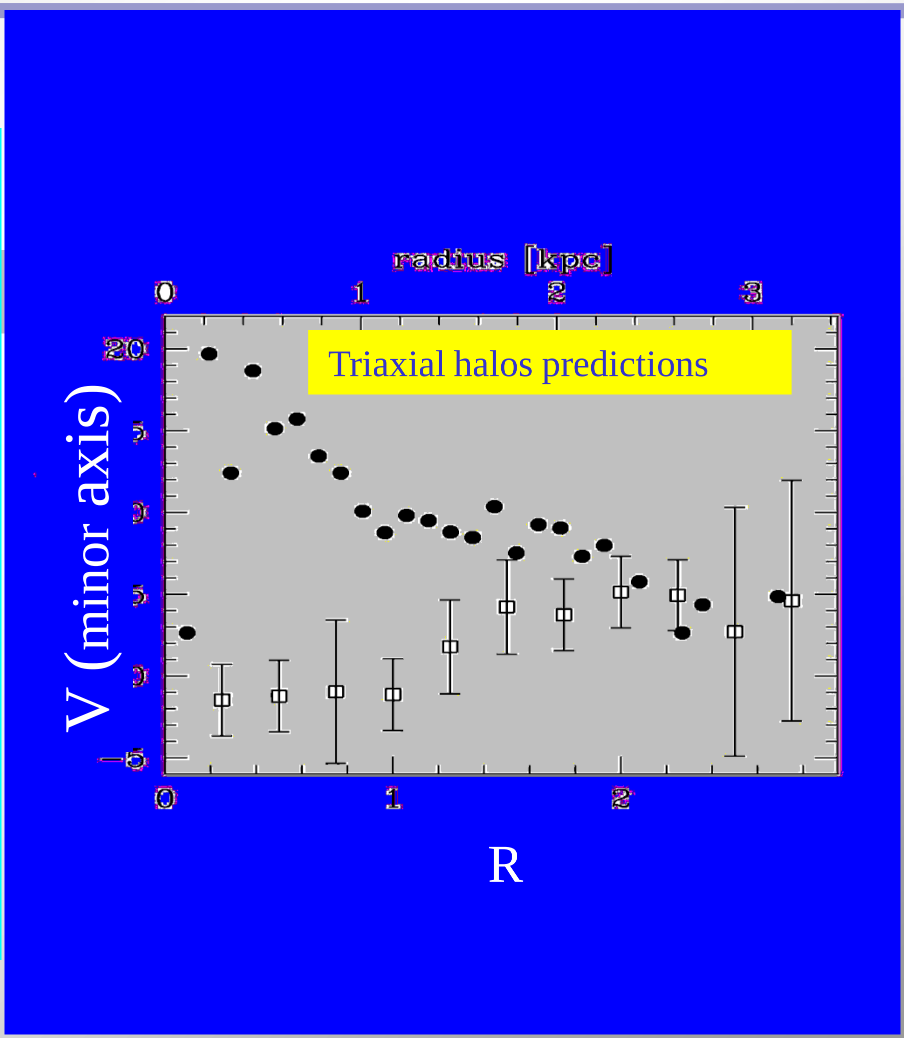
0 2 4 6
kpc
0 2 4 6
kpc



$M_{\odot} kpc^{-3}$
10^7
10^8

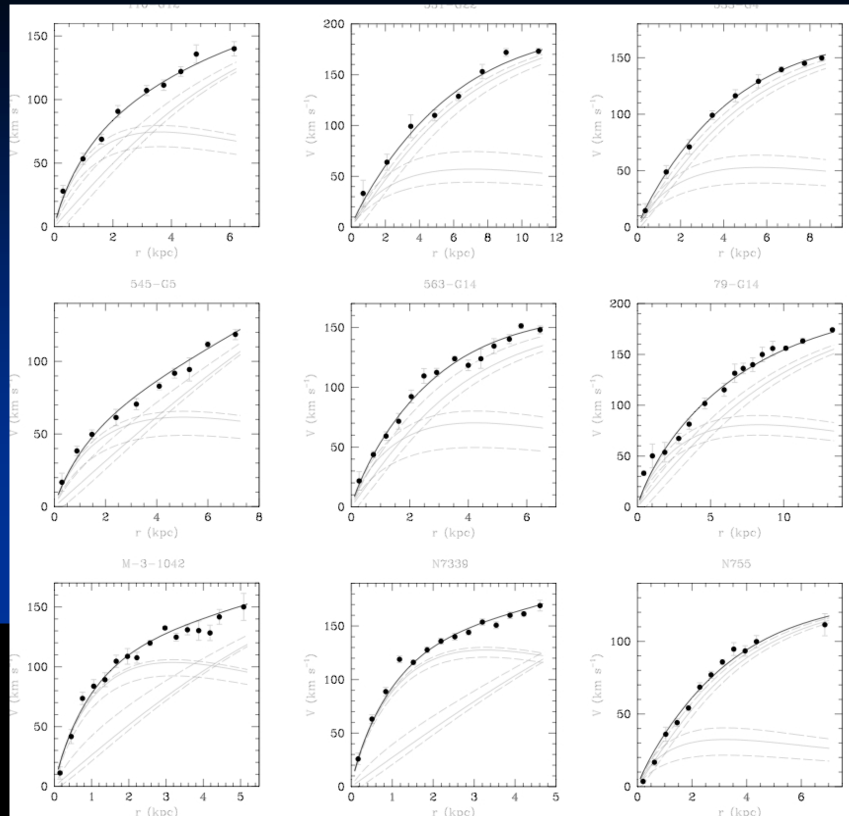
DDO 47: NON CIRCULAR MOTIONS ?

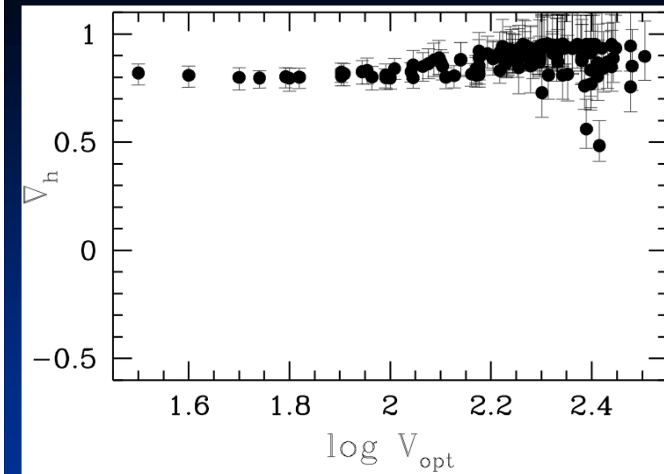


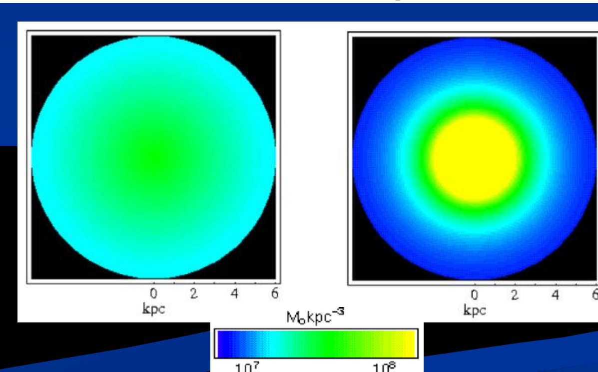


Results from Trieste: analysis of high quality RCs

URC fits to RCs

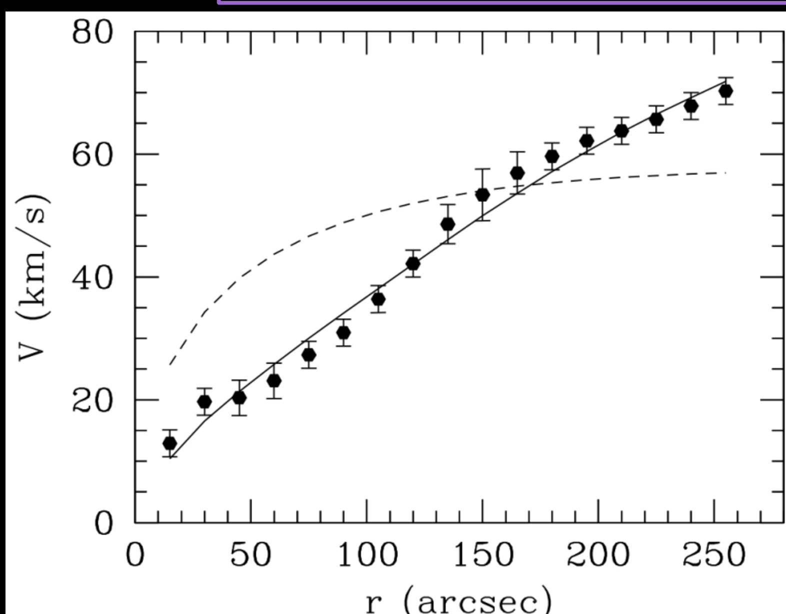




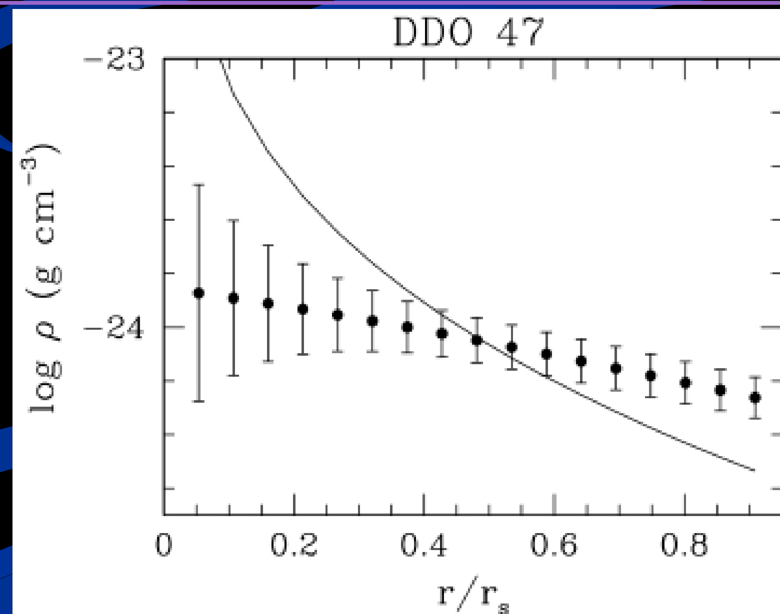


Borriello & Salucci, MNRAS 323, 285 (2001)

DDO 47



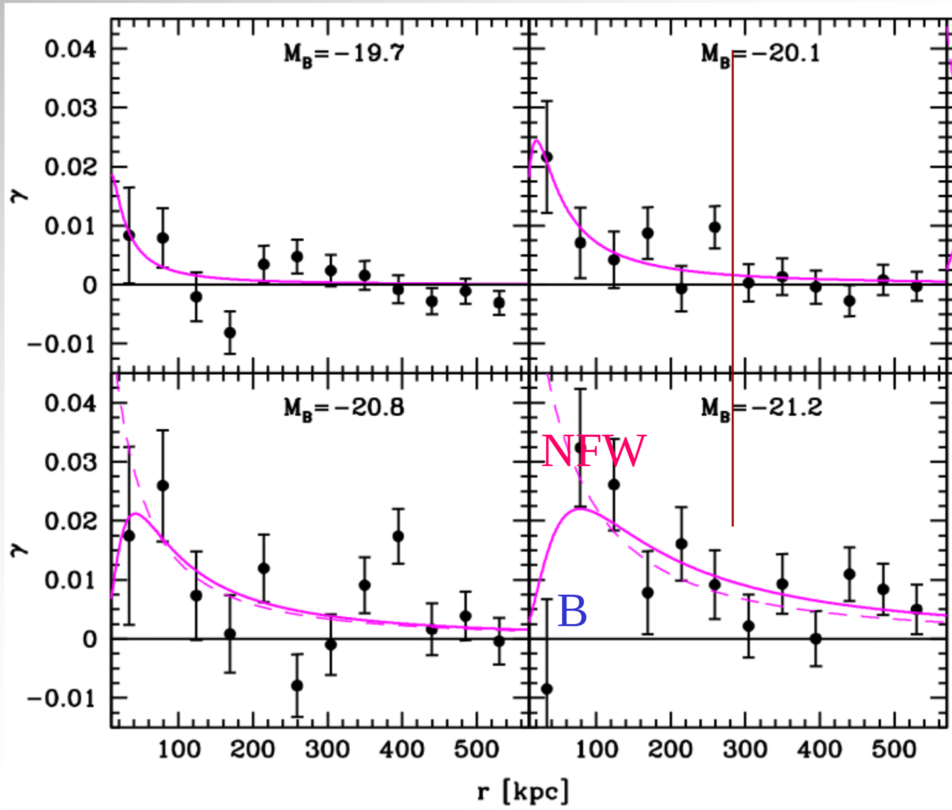
Gentile et al., ApJ 634, L145 (2005)



Gentile, Tonini & Salucci, A&A 467, 925 (2007)

Weak lensing

With a density profile we model the tangential shear
Obtain the structural free parameters.



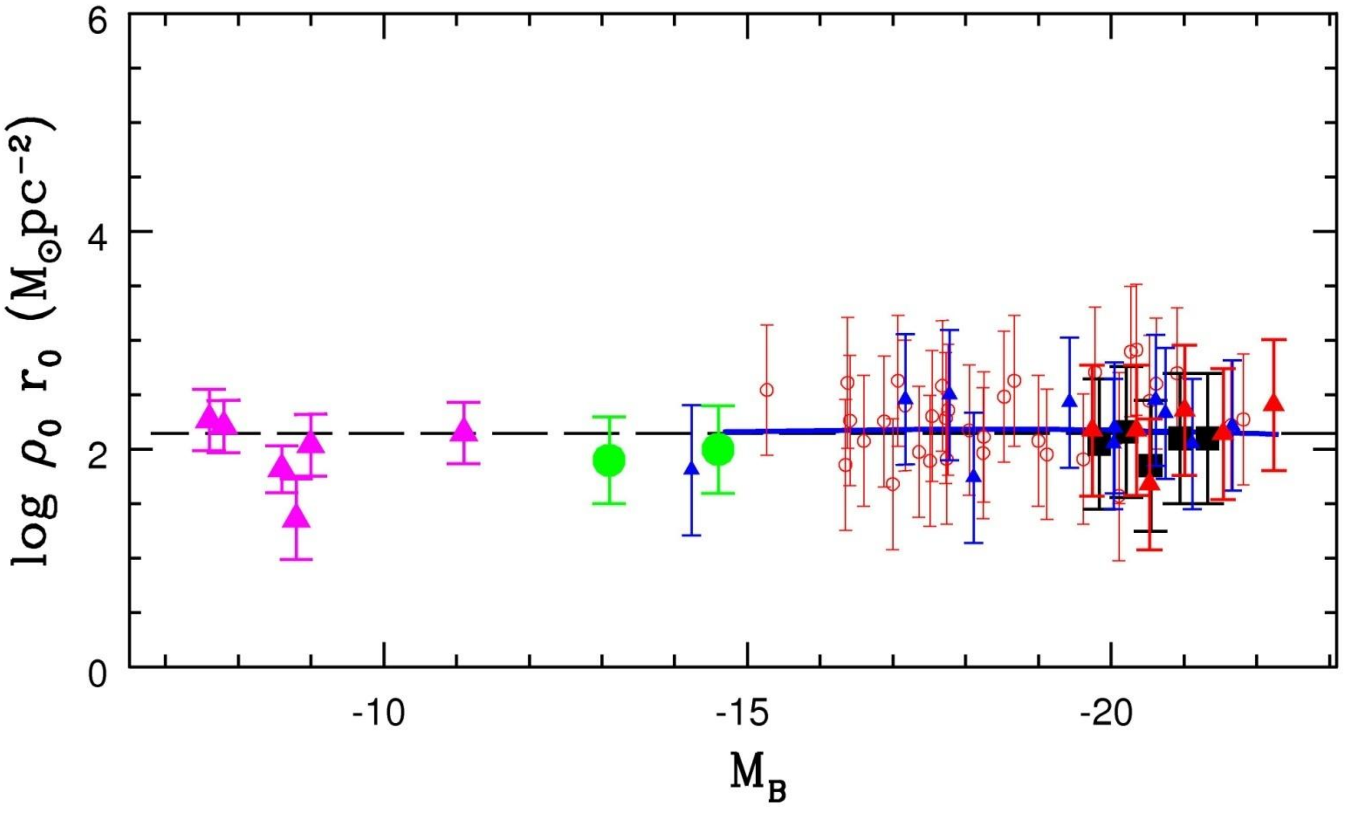
r_0 (kpc)	ρ_0 ($10^6 M_\odot/kpc^3$)
7^{+3}_{-6}	15^{+15}_{-15}
14^{+6}_{-10}	10^{+10}_{-10}
40.4^{+20}_{-20}	$1.7^{+1.5}_{-1.5}$
30^{+10}_{-20}	4.1^{+4}_{-4}
56^{+20}_{-20}	$2.3^{+1.2}_{-1.2}$

Same results as those obtained from RCs.
Burkert profile provides excellent fit, better than NFW.

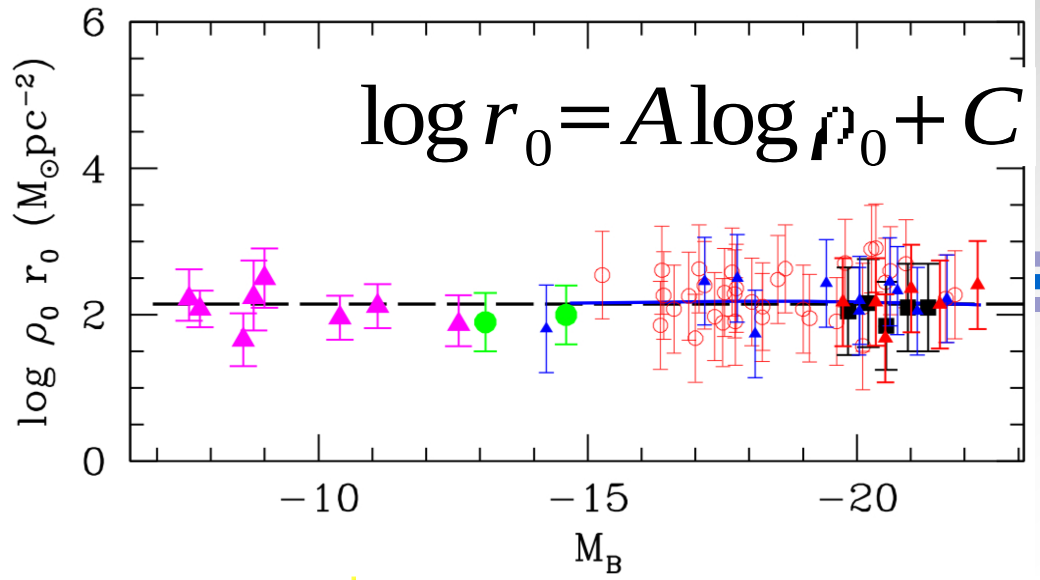
Dwarf spheroidal galaxy kinematics and spiral scaling laws: preliminary results

Attempt to investigate whether
properties of DM halos around dSphs obey to well known scaling laws found for the mass distribution of Spirals

➲ AN INTRIGUING PROPERTY

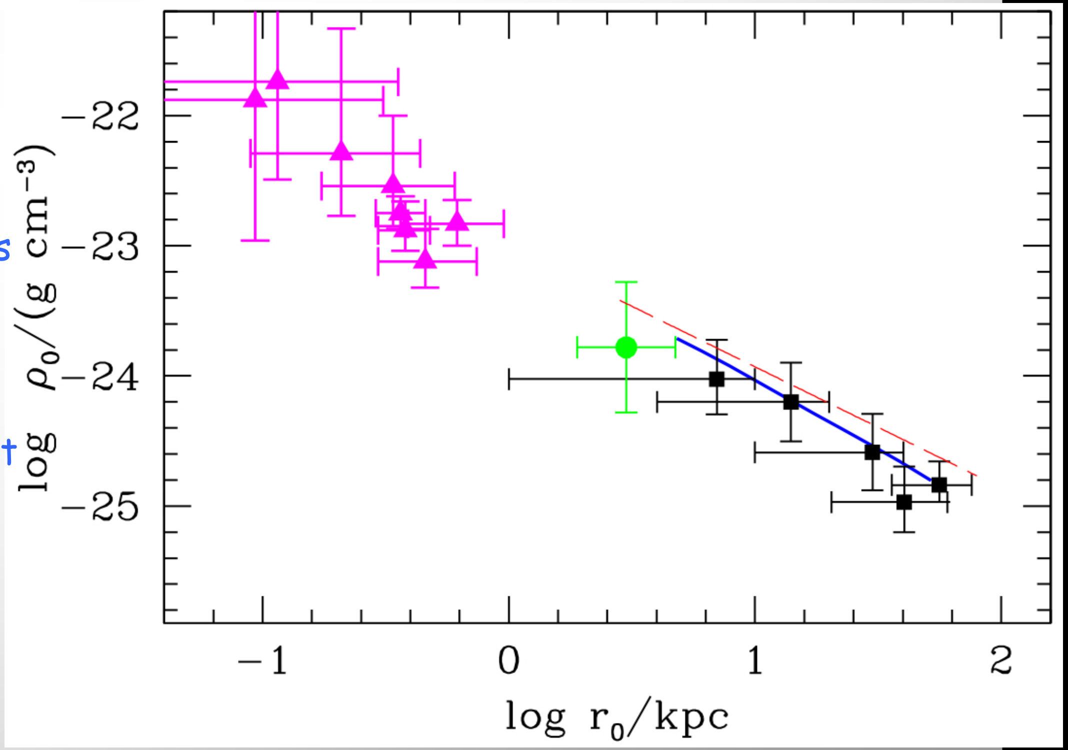


Preliminary results



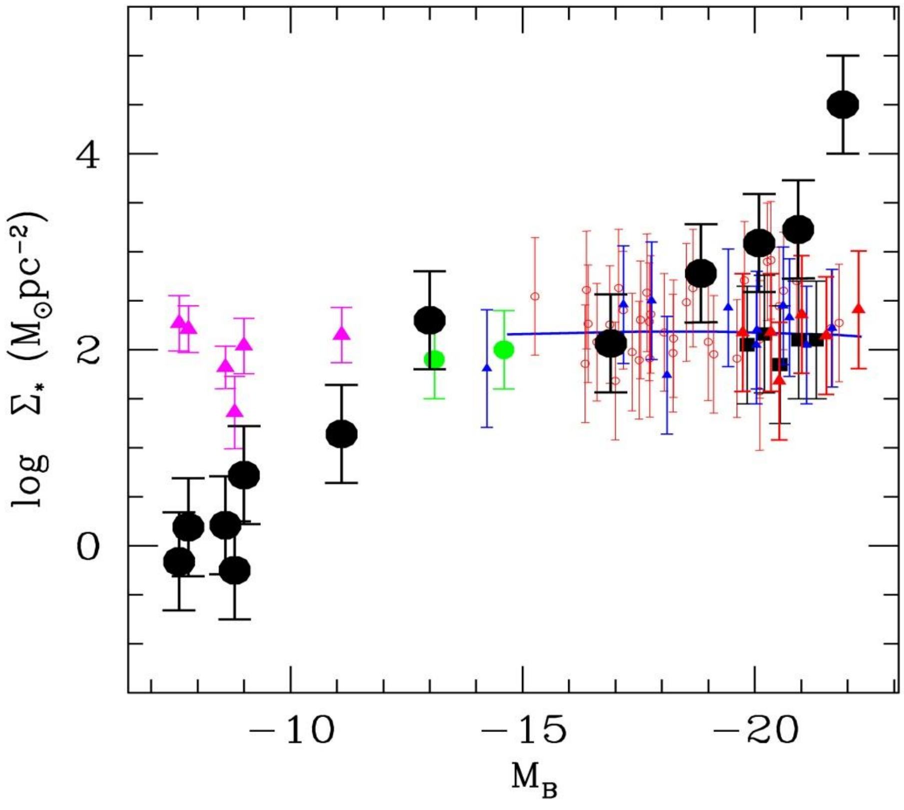
- we find similar ρ_0 and r_0 relationships independently whether the mass profiles are obtained from RCs or lensing data or from analysis of individual or coadded objects
- dSph halos are much denser, lie on the Spiral relationship
- data can be reproduced by
- existence of scaling relations between ρ_0 and r_0 over three orders of magnitude can rule out WDM
- DM relations cannot arise due to self-annihilation which would predict narrow range in ρ_0

Gilmore et al., ApJ 663, 948 (2007)



Salucci, CFM, Walker, Wilkinson, Gilmore, Koch (in prep)

A matter enigma




DARK MATTER IS PRESENT IN GALAXIES
IT IS STRONGLY RELATED TO THE LUMINOUS MATTER
THERE IS A SOLID EMPIRICAL SCENARIO