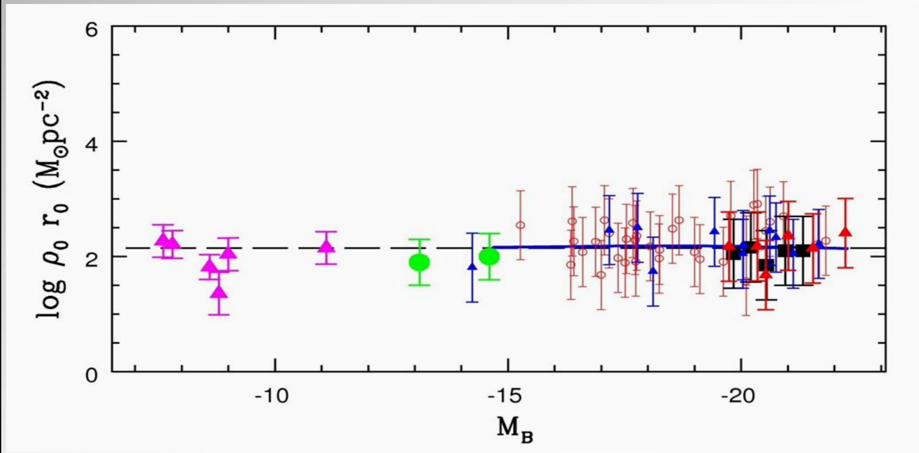
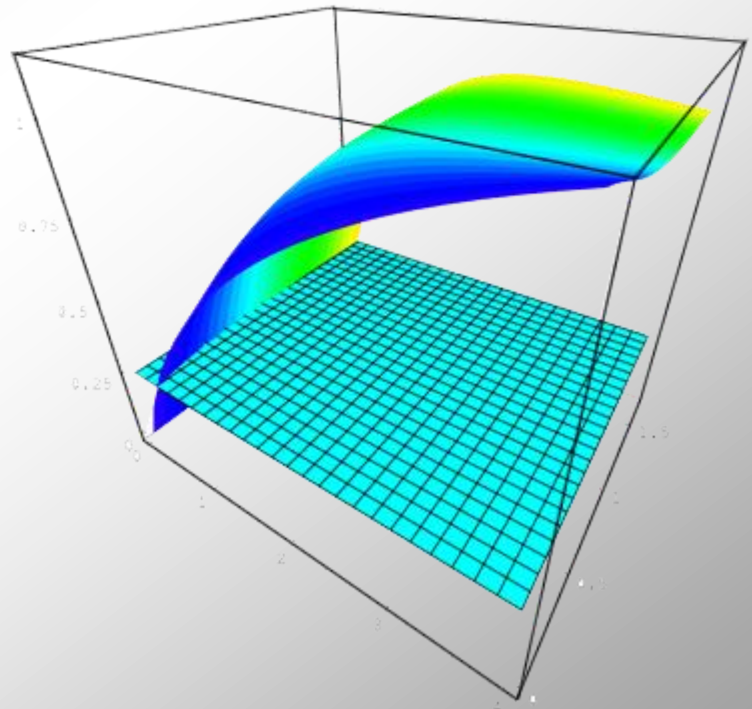
Universality properties in Galaxies and cored profiles

Paolo Salucci (SISSA)





Chalonge School, 2010

OUTLINE

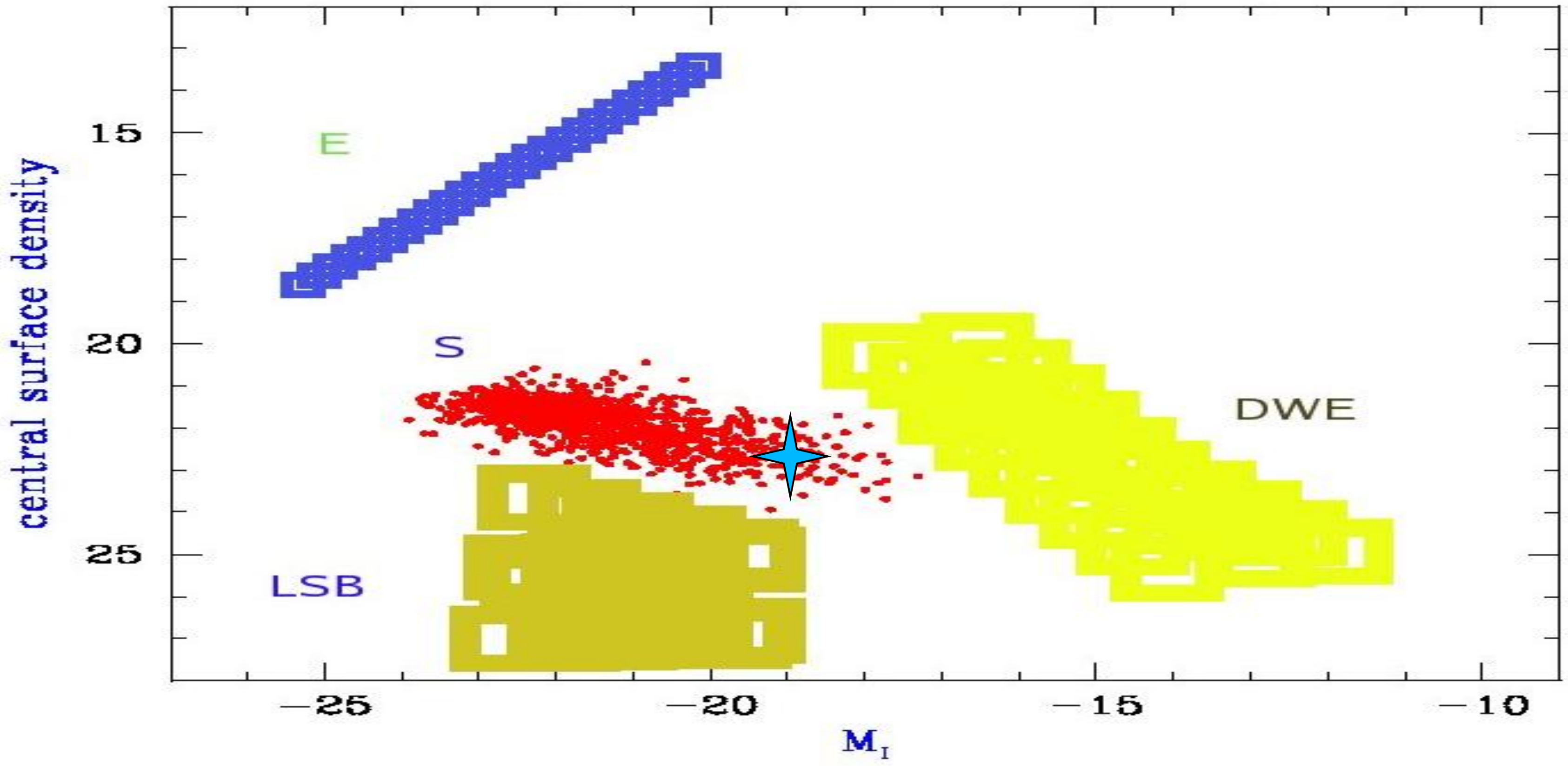
- *DM as explanation of the mass discrepancy in galaxies*
- *Phenomenology of the mass distribution*
- *The amount and distribution of DM in galaxies*
- *Universalities: the radial Tully-Fisher, the URC and central DM surface density*
- *The nature of DM*

Persic, Salucci, Stel 1996 MNRAS, 281, 27
The universal rotation curve of spiral galaxies - I. The dark matter connection
Salucci , Lapi, Gentile, Klein 2007 MNRAS, 37841
The universal rotation curve of spiral galaxies out the virial radius II
Donato, Gentile, Salucci, Frigerio Martins; Wilkinson; Gilmore + 2009 MNRAS 397,1169
A constant dark matter halo surface density in galaxies

The Realm of Galaxies

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

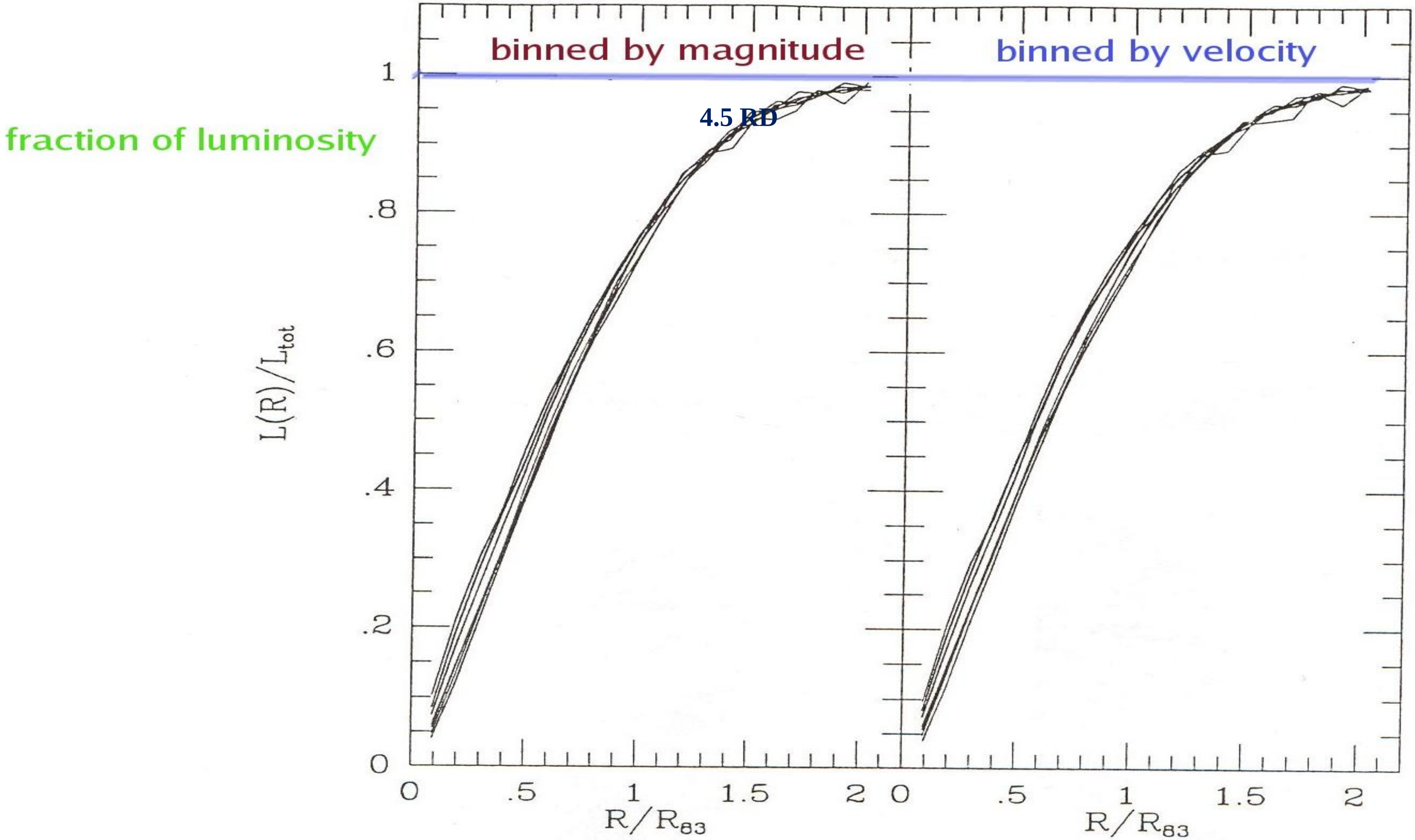
Central surface brightness vs magnitude



Luminosity profile in spirals/galaxies is Universal.

Spirals /galaxies have a luminous lenght-scale

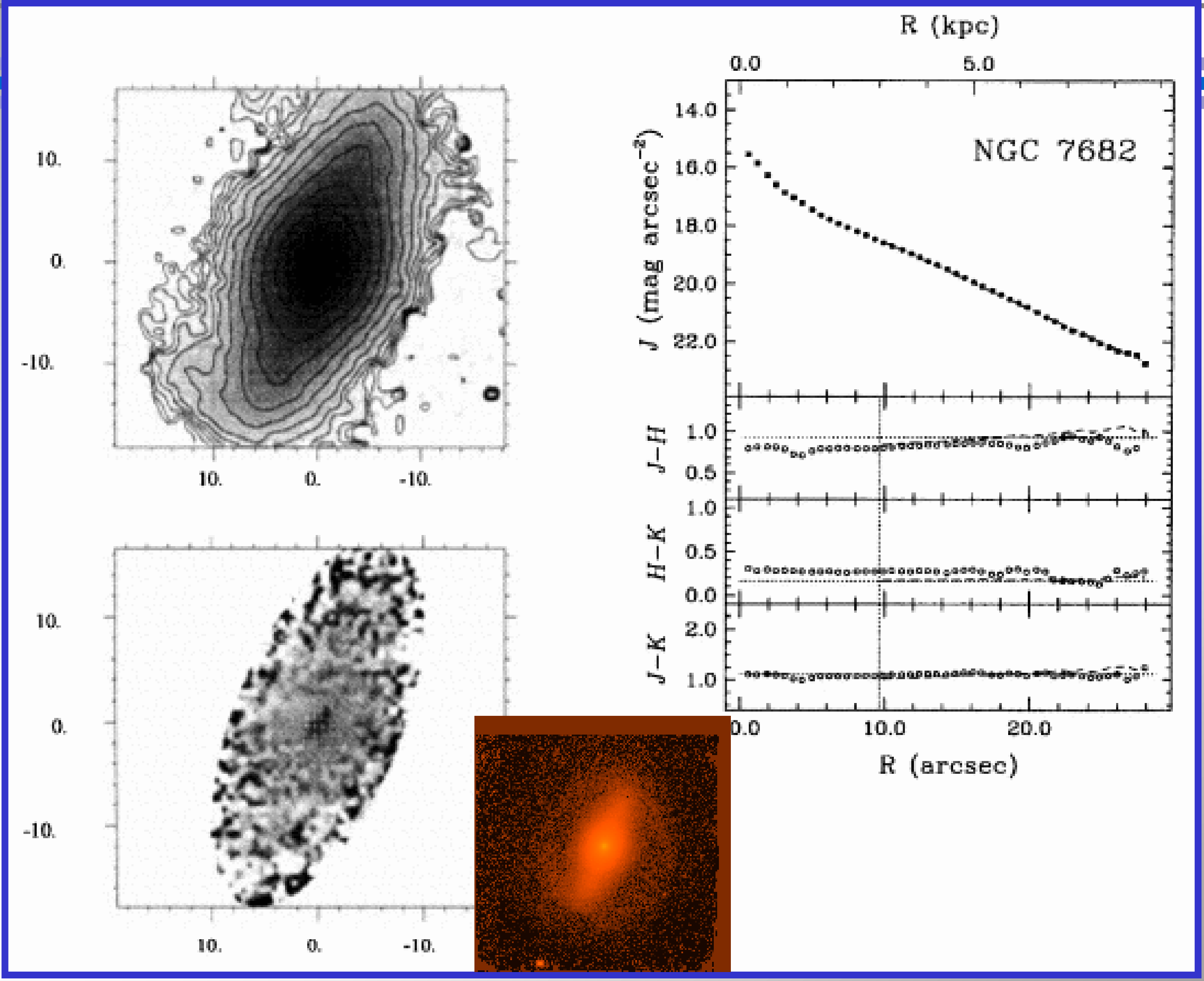
Distribution of stars: $L(R/R_D)/L_T$ independent of Luminosity



The light distribution in spirals is invariant, the luminous surface density:

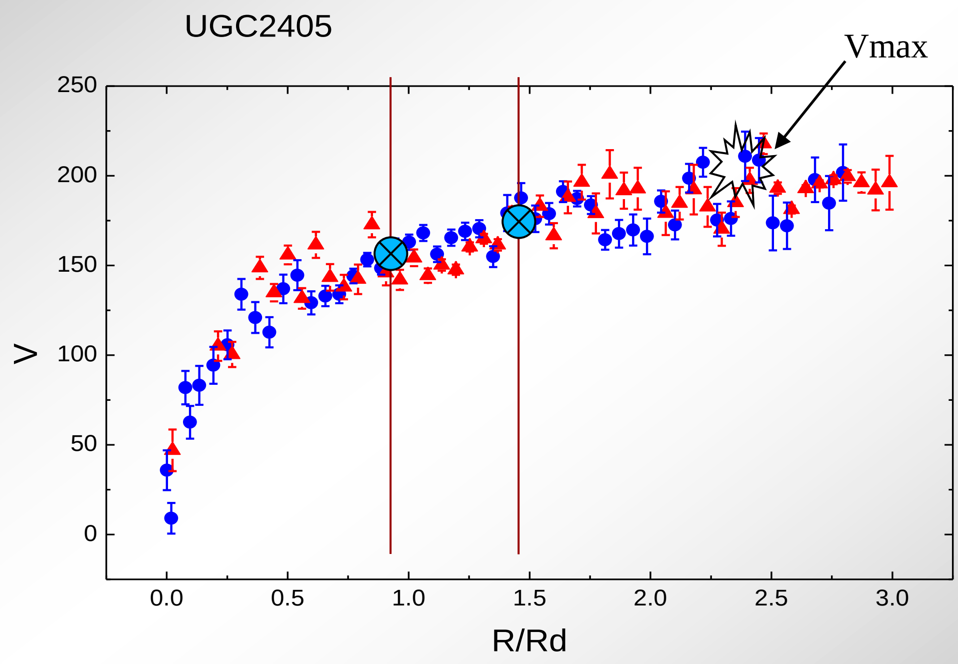
$I(R) = I_0 \exp[-R/R_D]$

Color costant with radius: costant stellar mass to light ratio



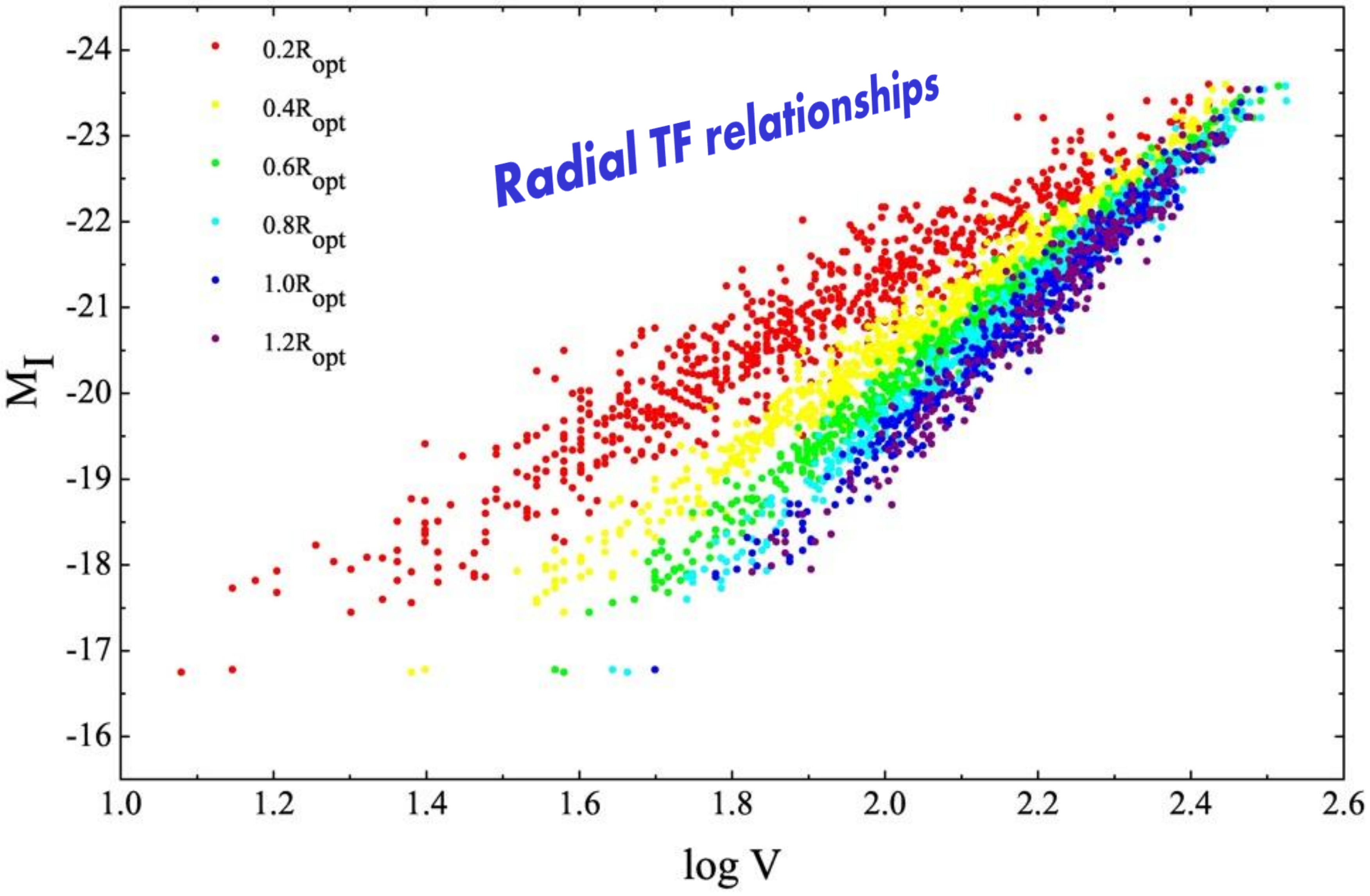
The **mass** **distribution is luminosity dependent. Gravitating matter is related with luminosity**

TF RELASHIOSHIP: link between rotation and luminosity



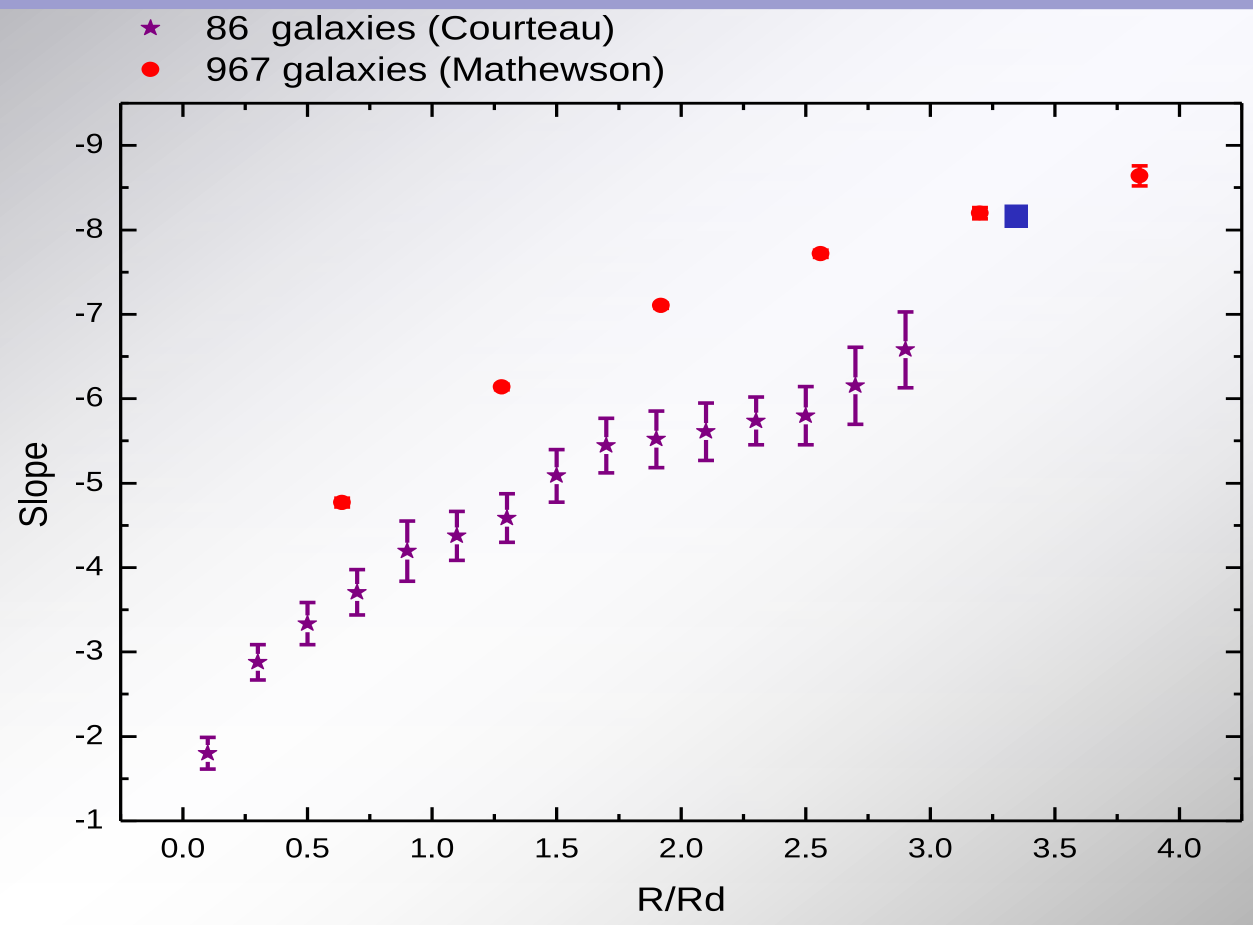
The relation: magnitude vs velocity @ different radii x_i R_D, [x_i=0.5,1,…5]

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



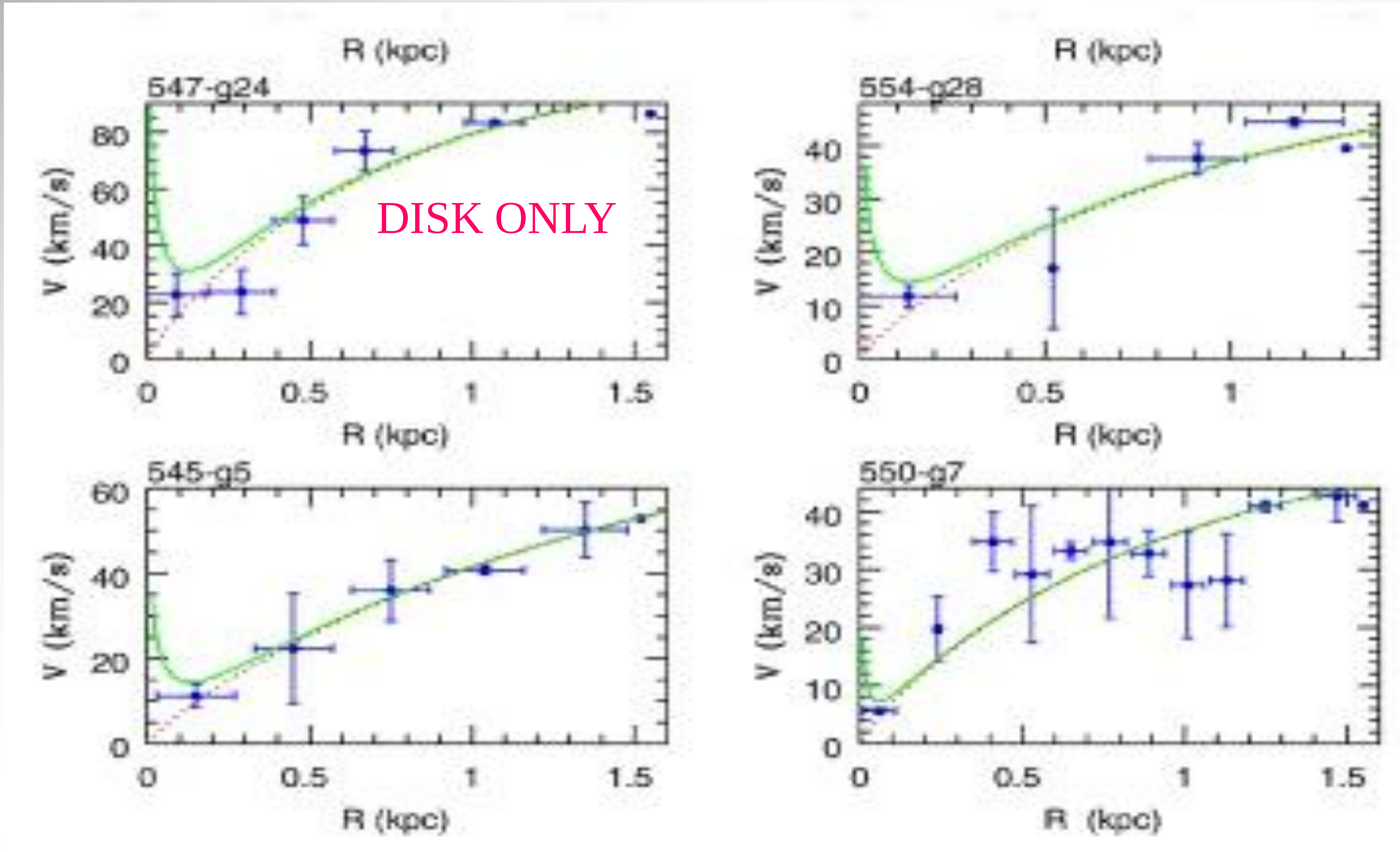
TF exists at local level

The slope of the TFR



very inner circular velocities and dispersion velocities:

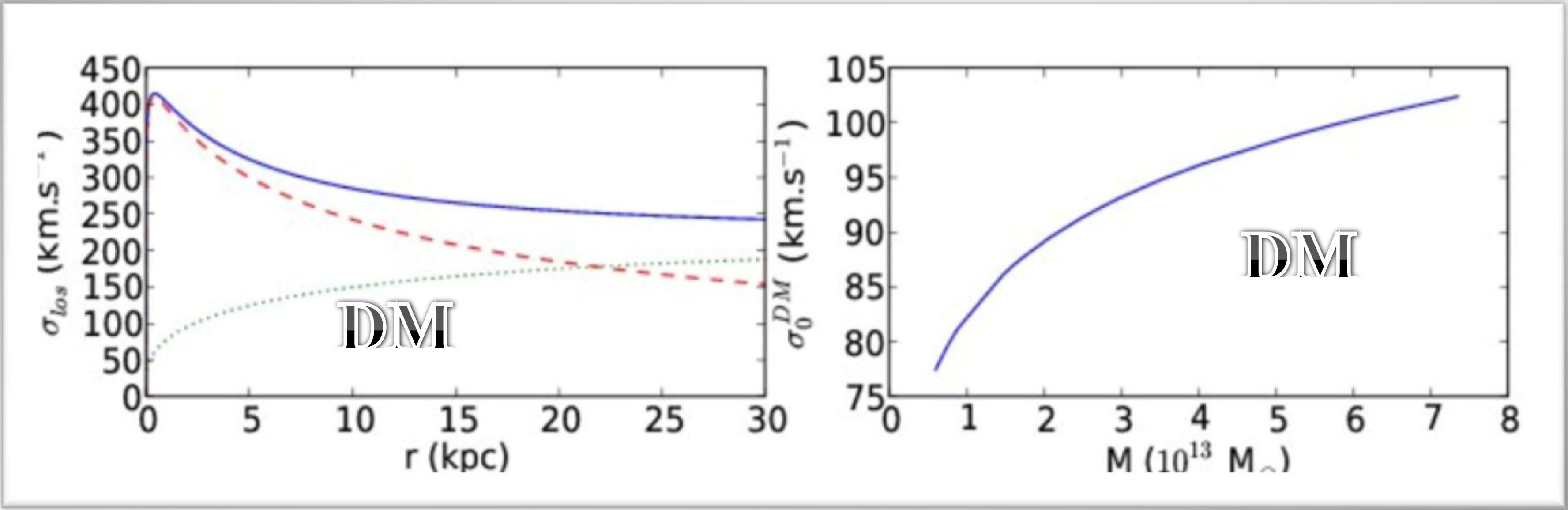
light traces the mass No DM in the innermost regions of galaxies



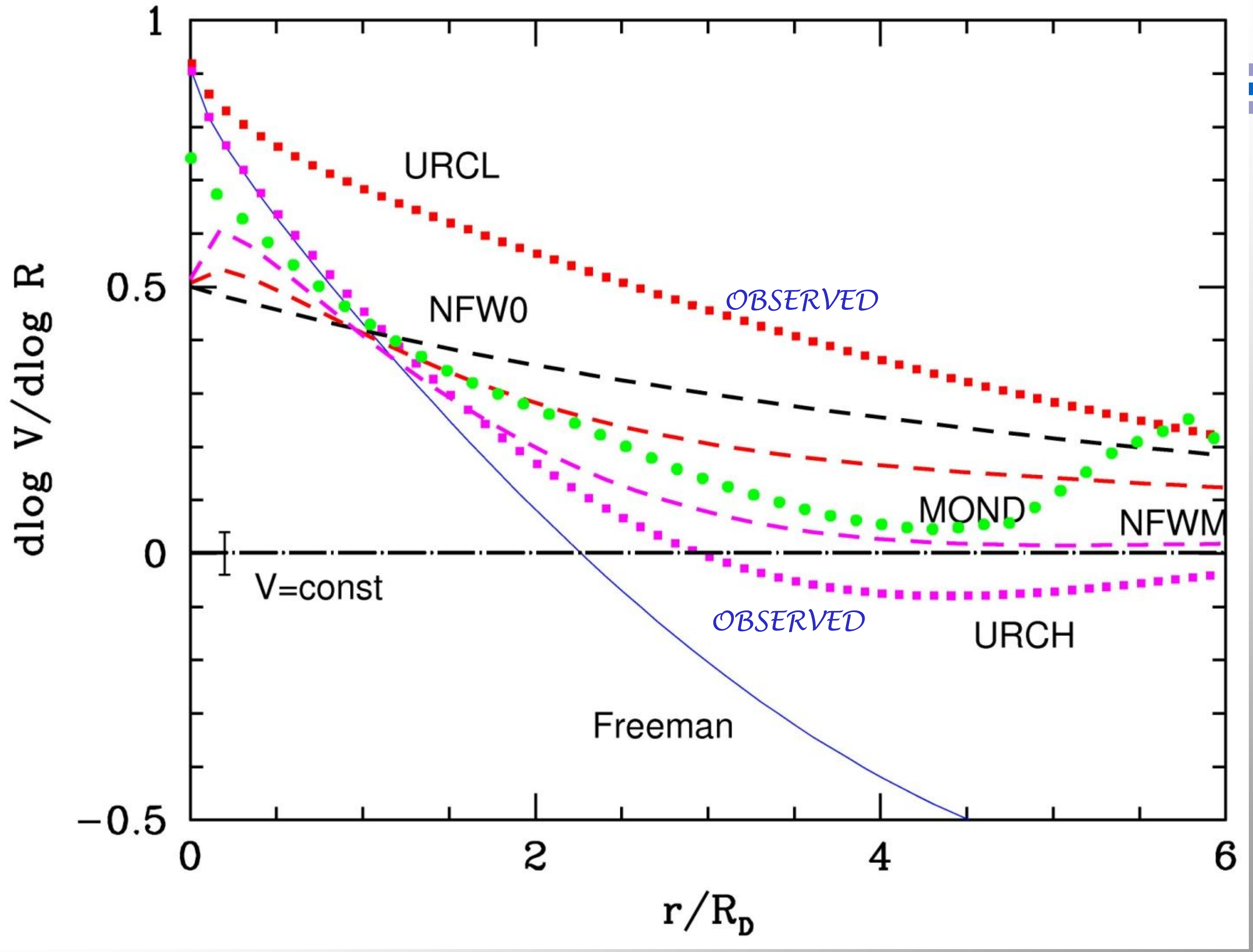
Giant ellipticals: no DM at the center

dispersion velocities not controlled by DM

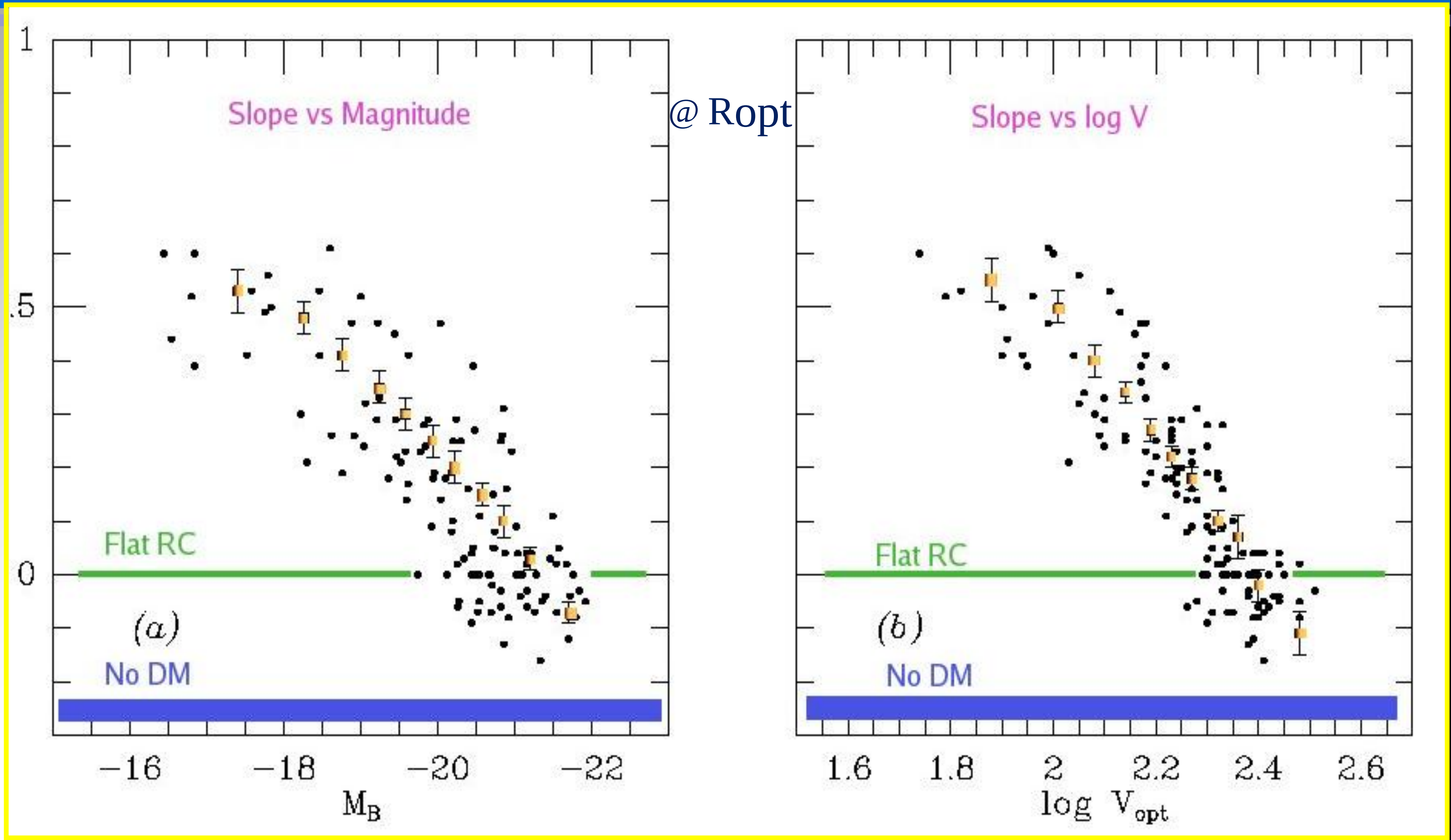
Re=7 kpc, Mstar=10^12 Msun



The slope of the RC/DV/dM(R) is crucial

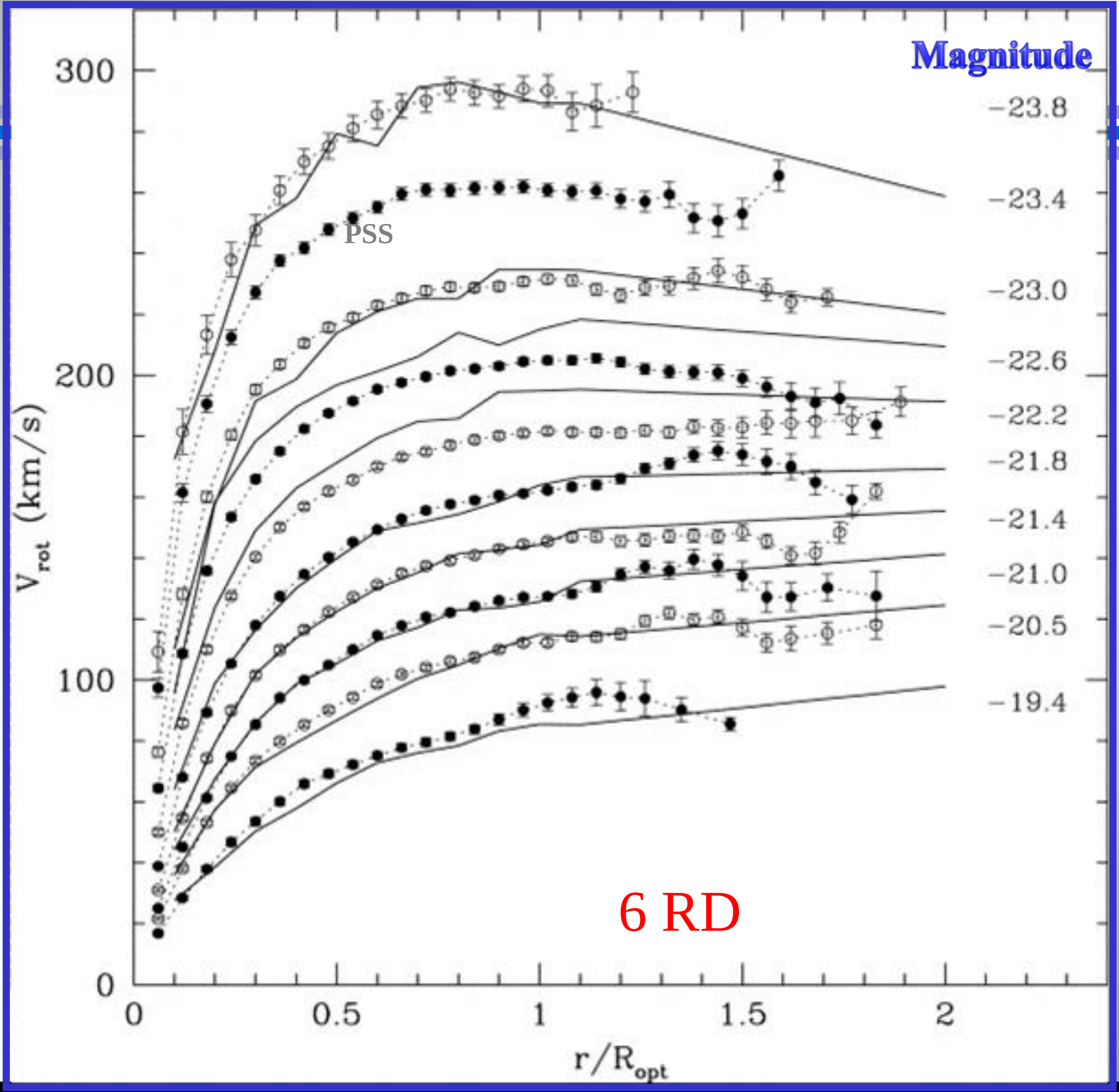


The RC slope indicates the presence and measures the amount of Dark Matter

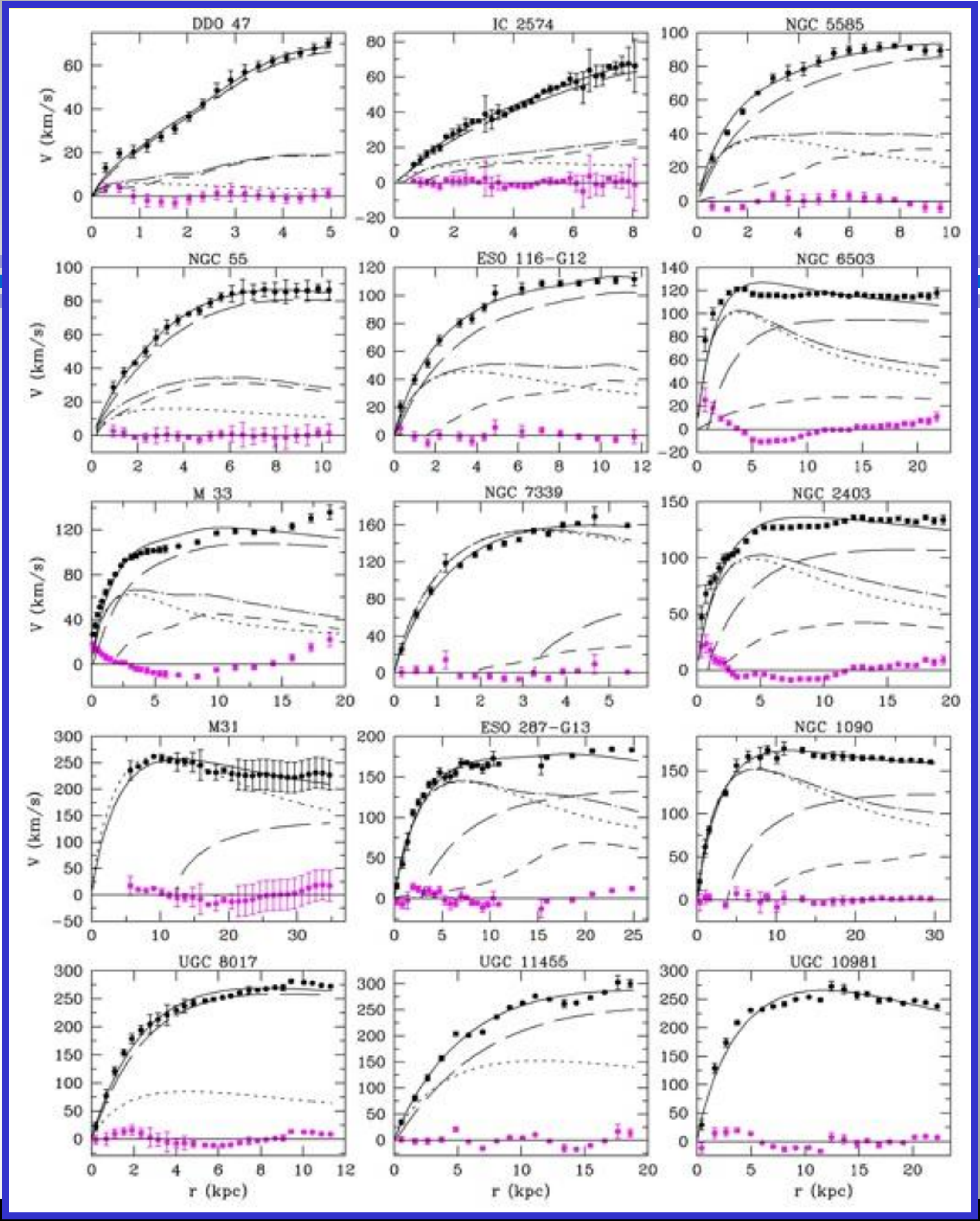


The rotation curves (3200 coadded)

C+06

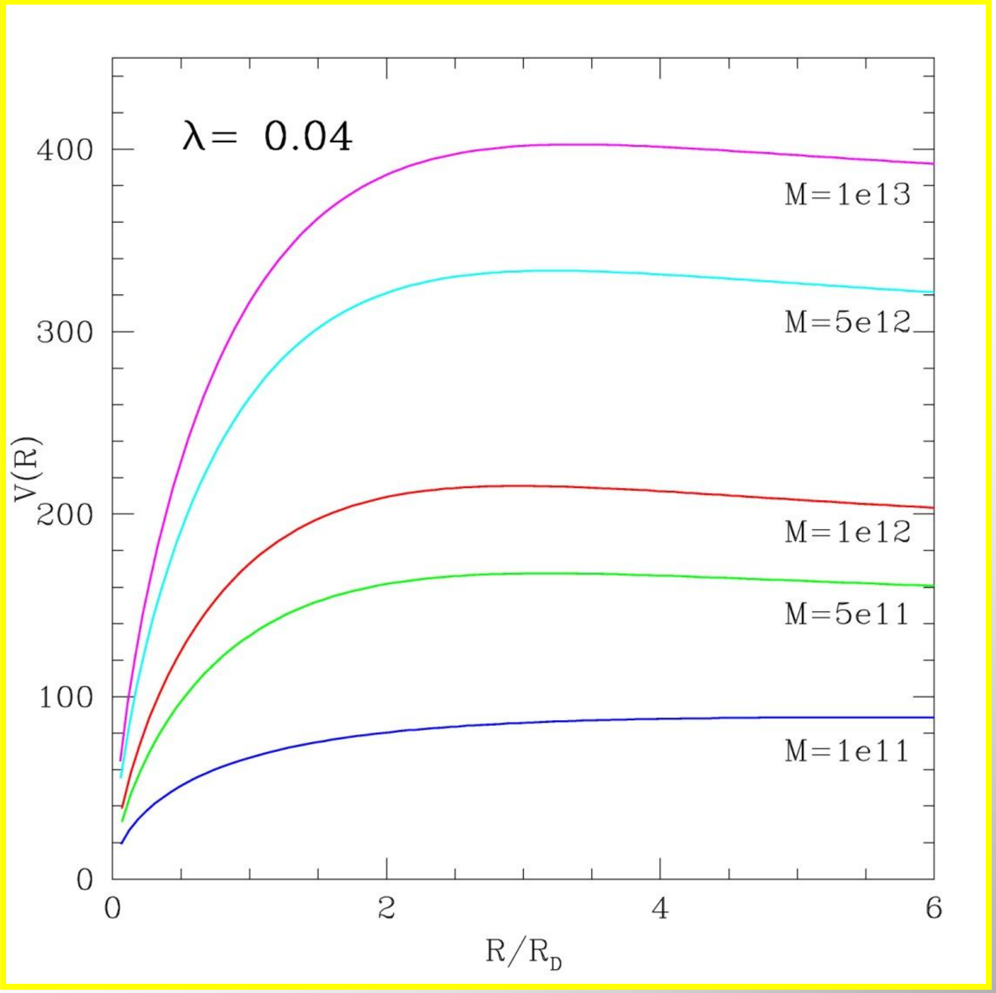


Individual Rotation Curves



An Universal Mass Distribution?

ΛCDM Universal Rotation Curve from NFW profile and MMW theory



The URC Concept

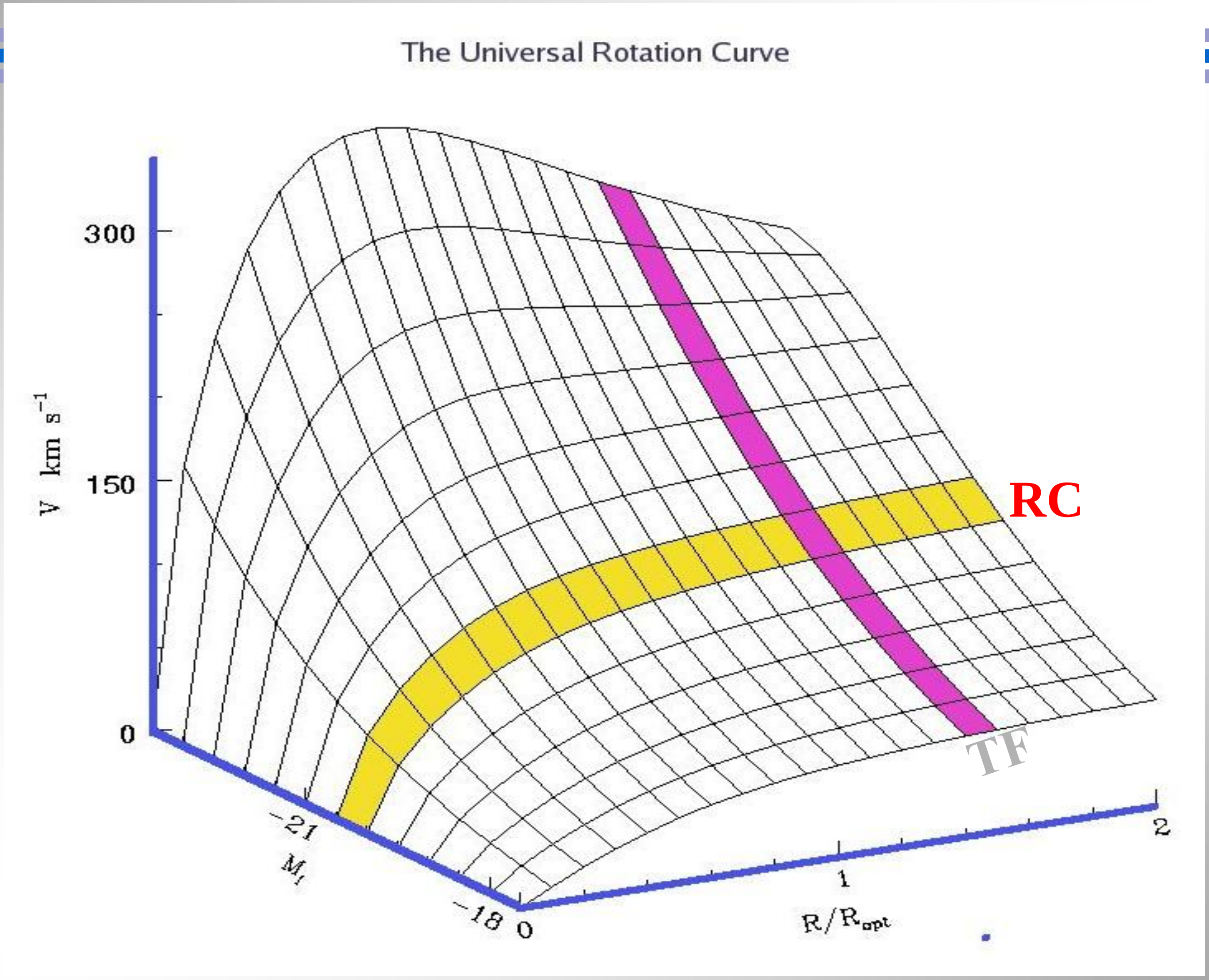
- the Cosmic Variance of the value of V(**X**,**L**) in galaxies of (same) luminosity **L** @ a at (same) radius **X**=R/R_D is negligible with respect to the variations that:

in each galaxy, V(**X**,**L**) has as **X** varies.

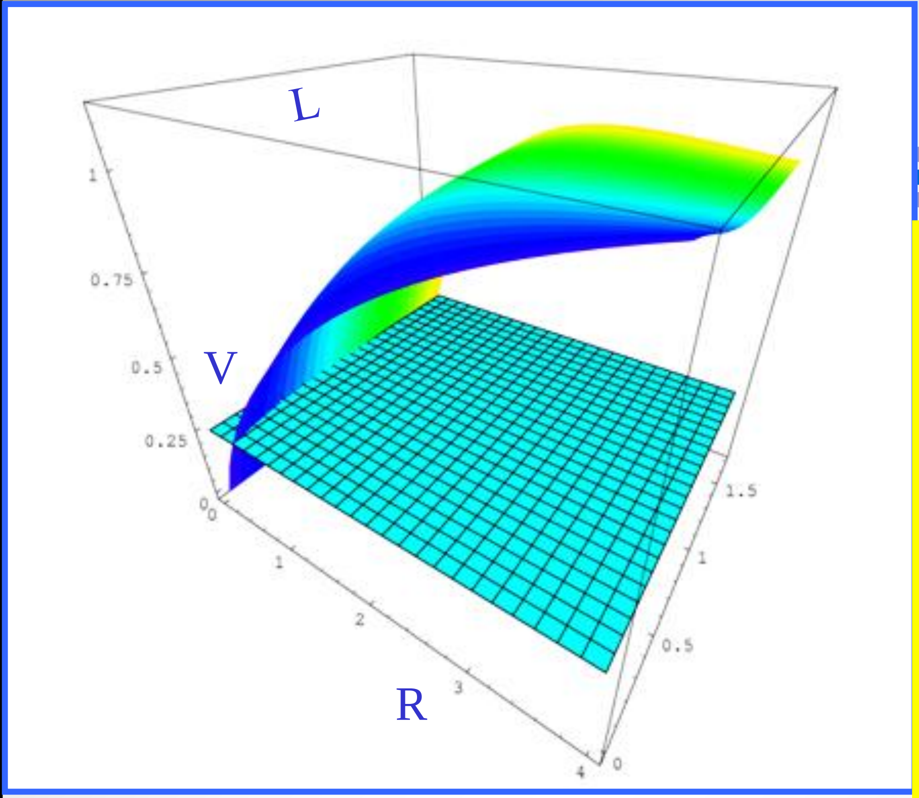
@ each **X**, V(**X**,**L**) has as **L** varies

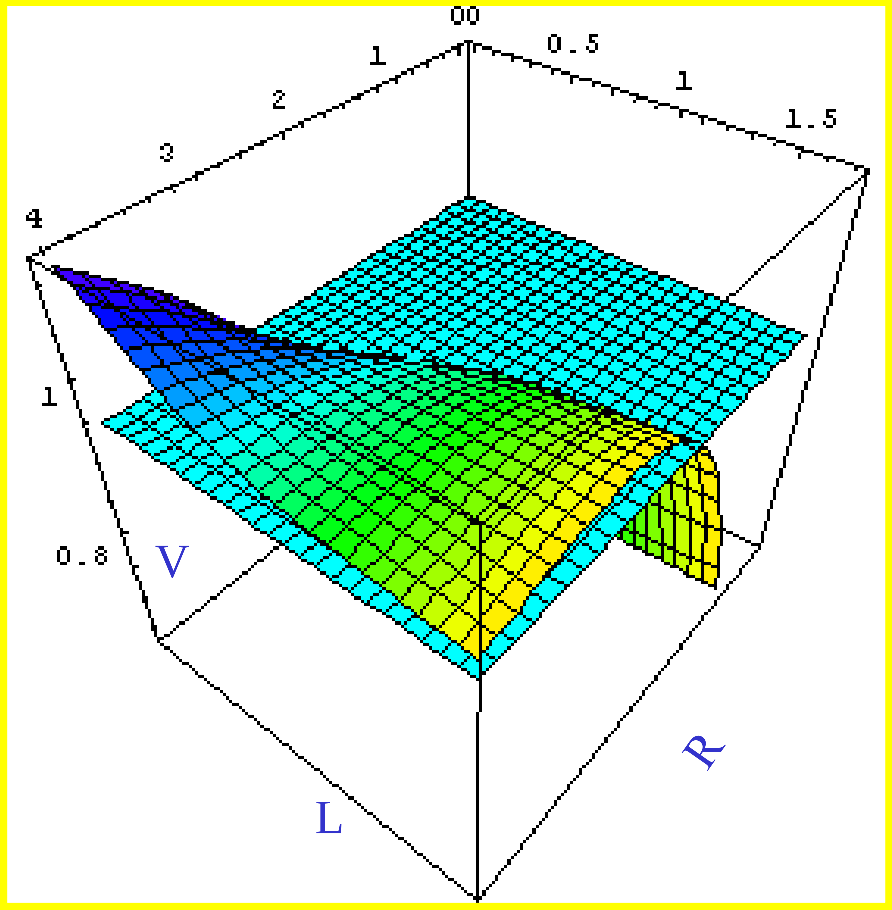
The circular velocity field is luminosity dependent

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

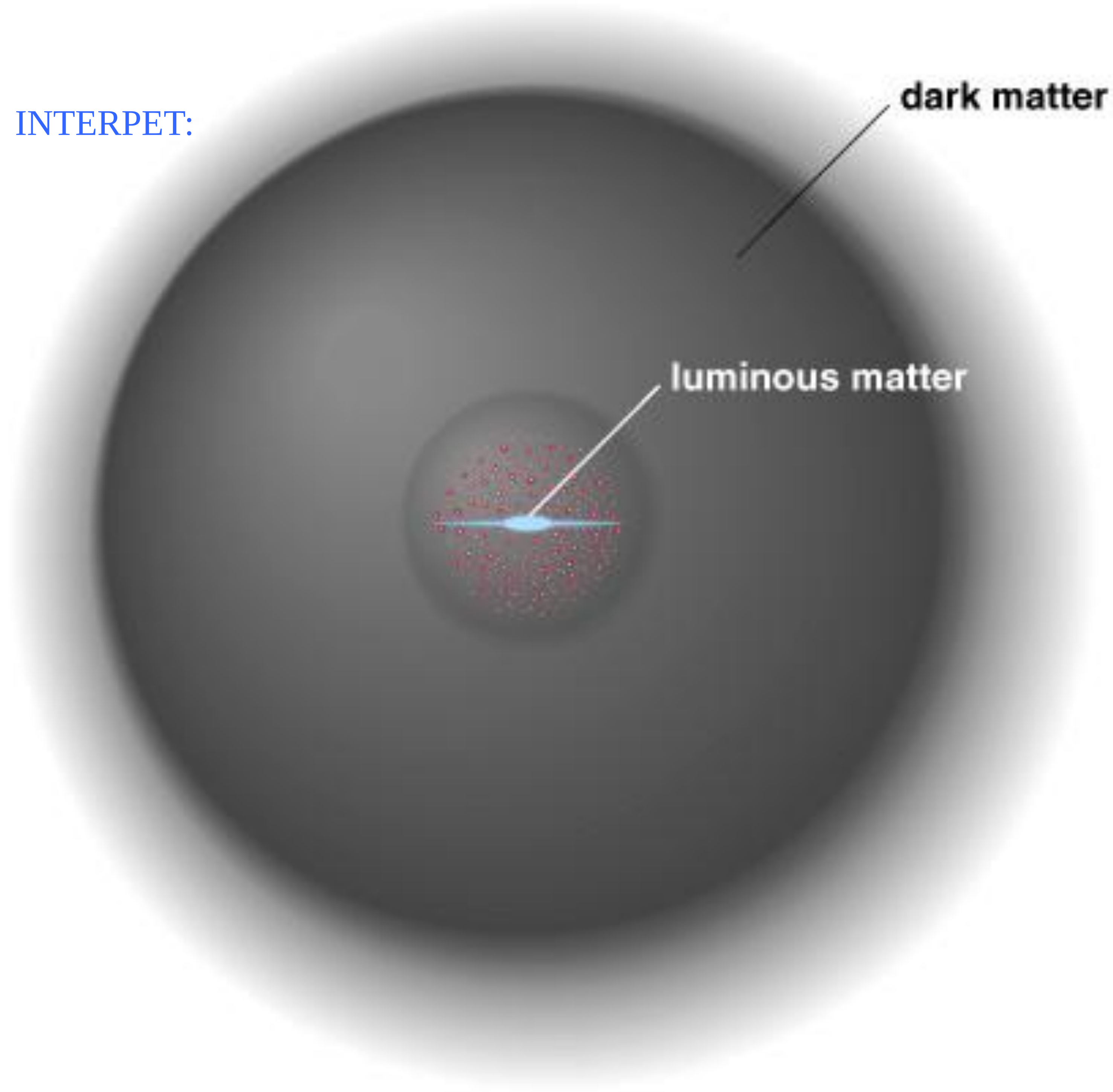


The URC



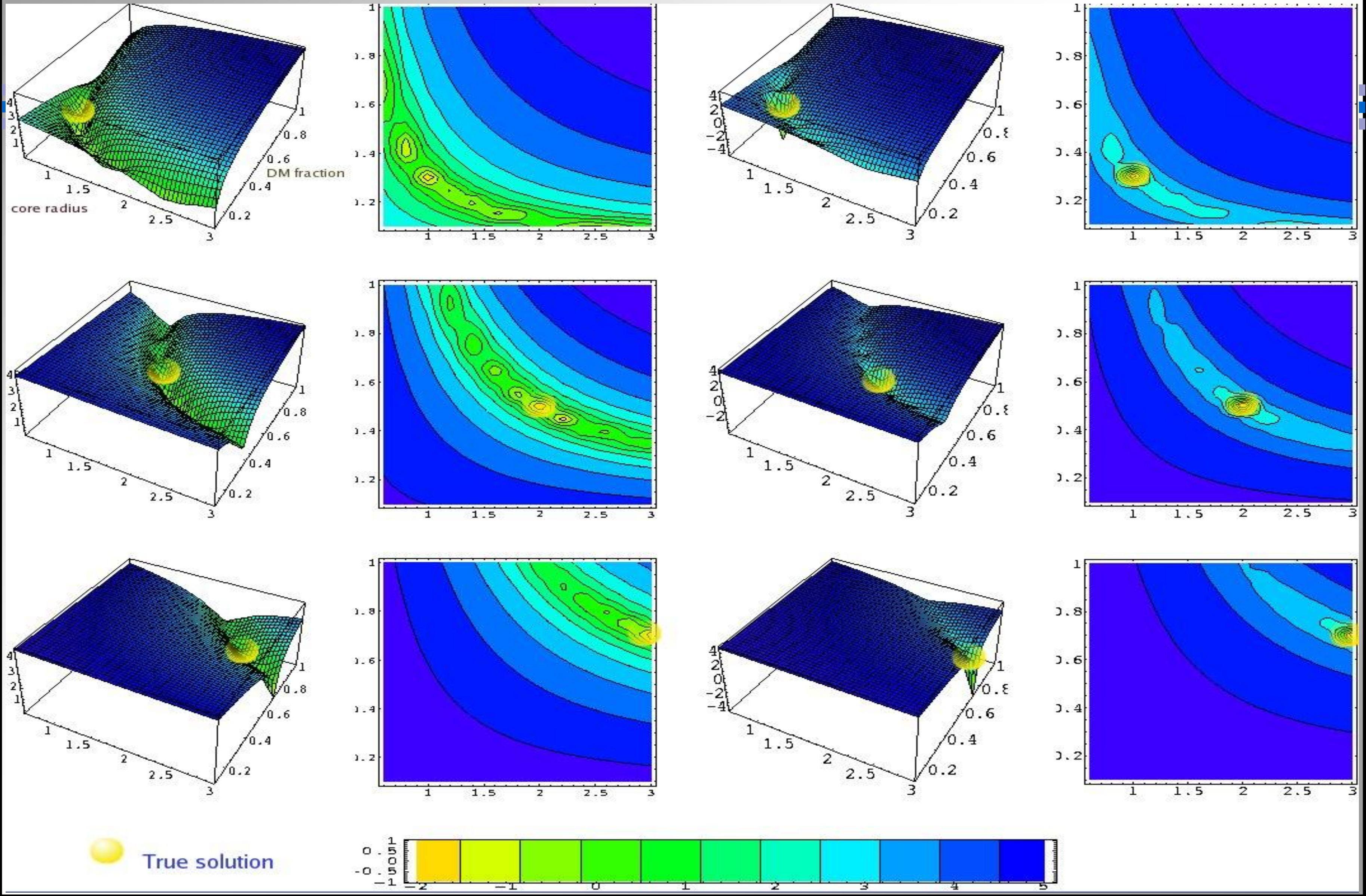


INTERPET:



We can uniquely mass model a RC if :

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



Rotation curve analysis.

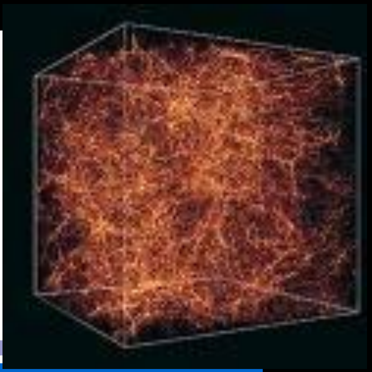
$$V_{tot}^2 = V_{DM}^2 + V_{disk}^2 + V_{gas}^2$$

- $V_{disk}(R)$: **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

2-3 FREE PARAMETERS: MUST INVOLVE THE RC SLOPE

Dark halos profiles from ΛCDM simulations



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

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

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

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

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

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

Navarro, Frenk & White, ApJ 462, 563 (1996)

Bullock et al., MNRAS 321, 559 (2001)

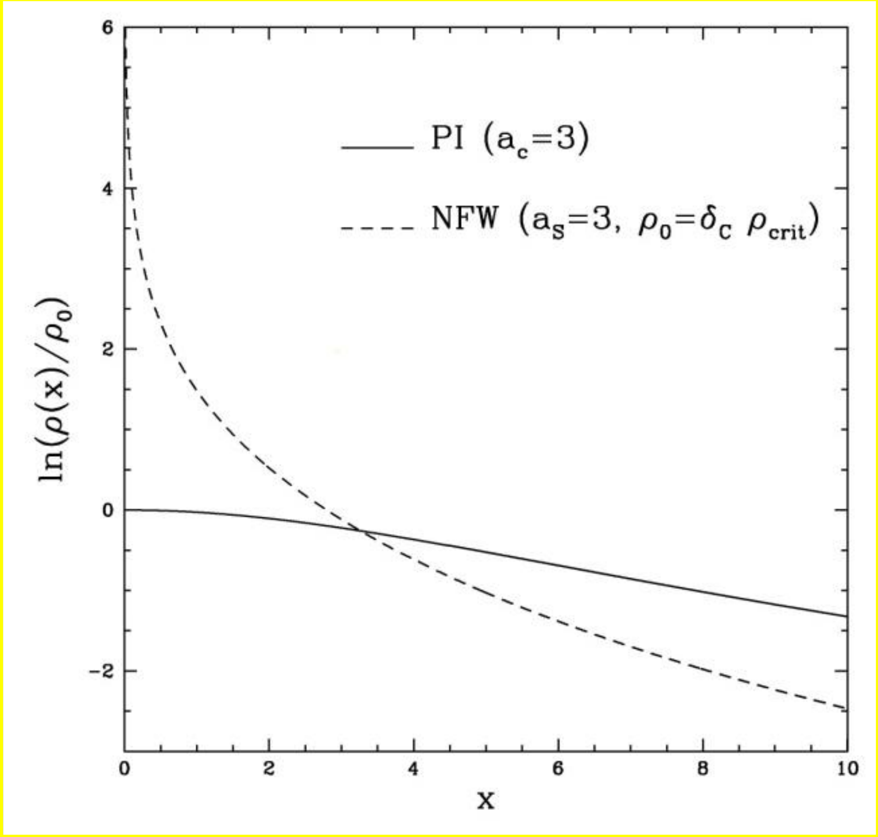
Klypin,2010

EMPIRICAL distribution: Burkert profile

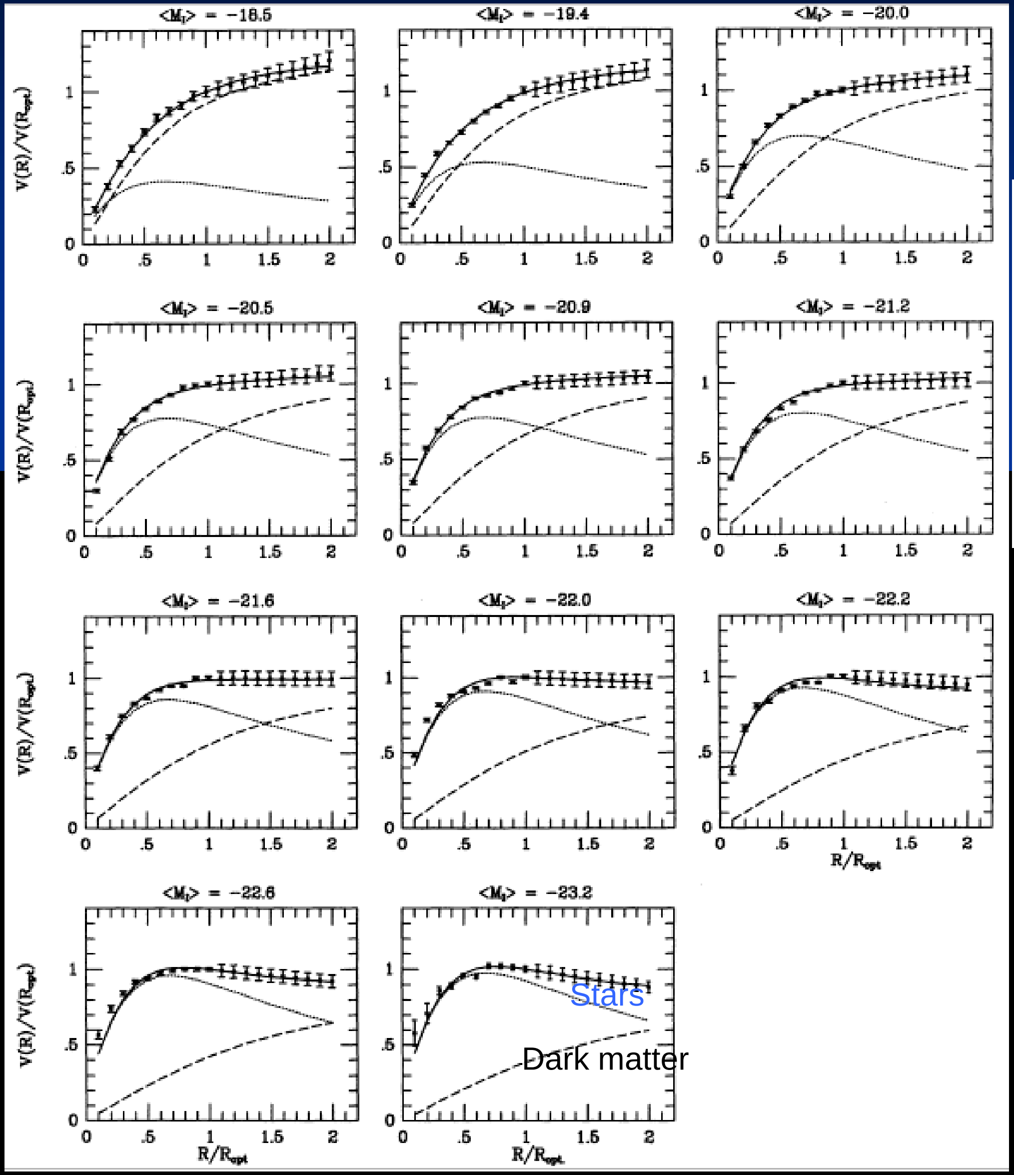
$$\rho_B(r) = \frac{\rho_0}{(1 + r/r_0)[1 + (r/r_0)^2]}$$

$$M_h(r) = M_0 \left\{ \ln\left(1 + \frac{r}{r_0}\right) - \tan^{-1}\left(\frac{r}{r_0}\right) + \frac{1}{2}\ln\left[1 + \left(\frac{r}{r_0}\right)^2\right]\right\},$$

where $M_0 \equiv 6.4\rho_0 r_0^3$.



Modelling the Universal Rotation Curve



Rotation velocity

Stellar contribution

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

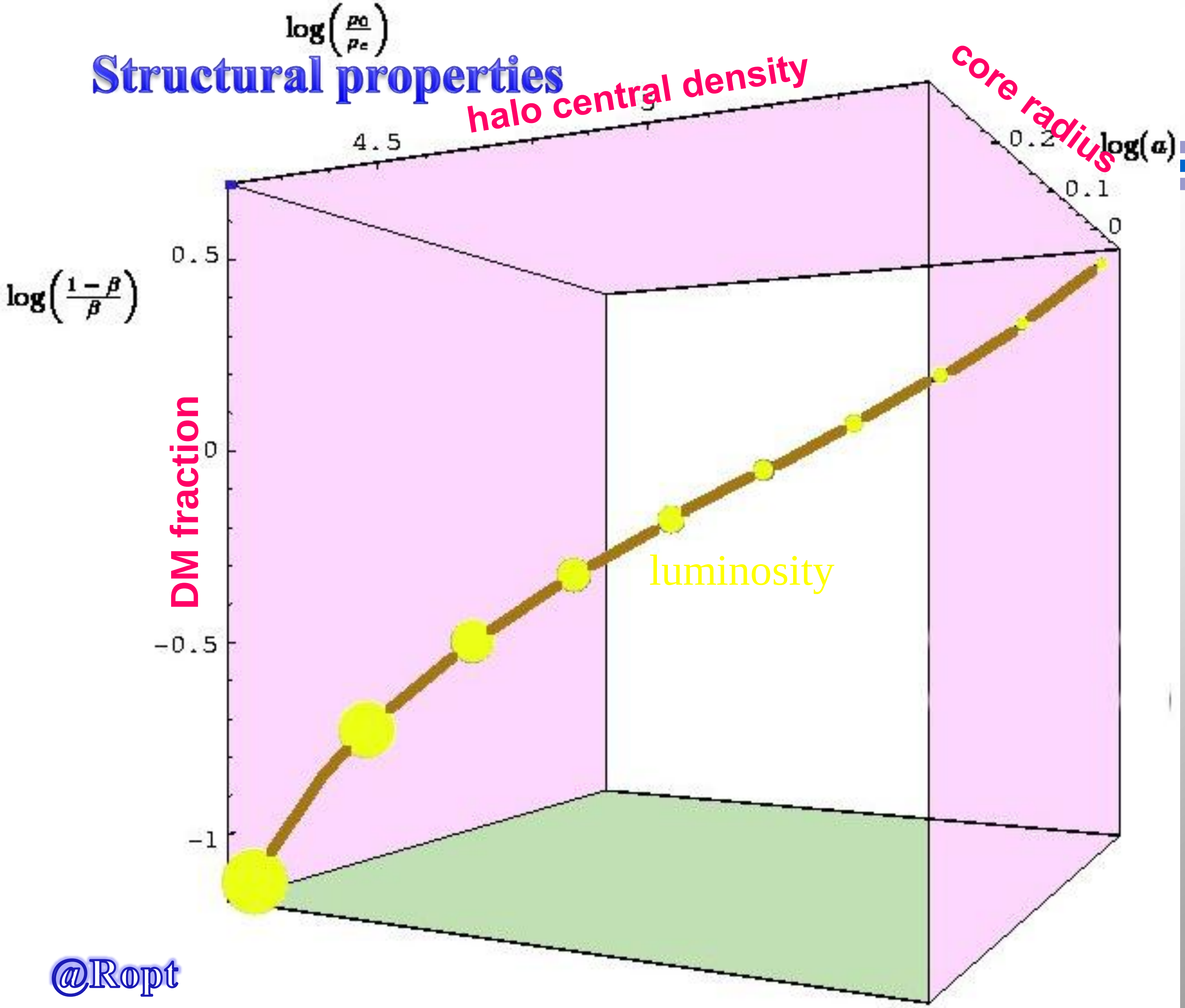
Dark matter halo contribution

Free parameters: disk mass,

DM core radius, central density

A family governed by luminosity

Structural properties



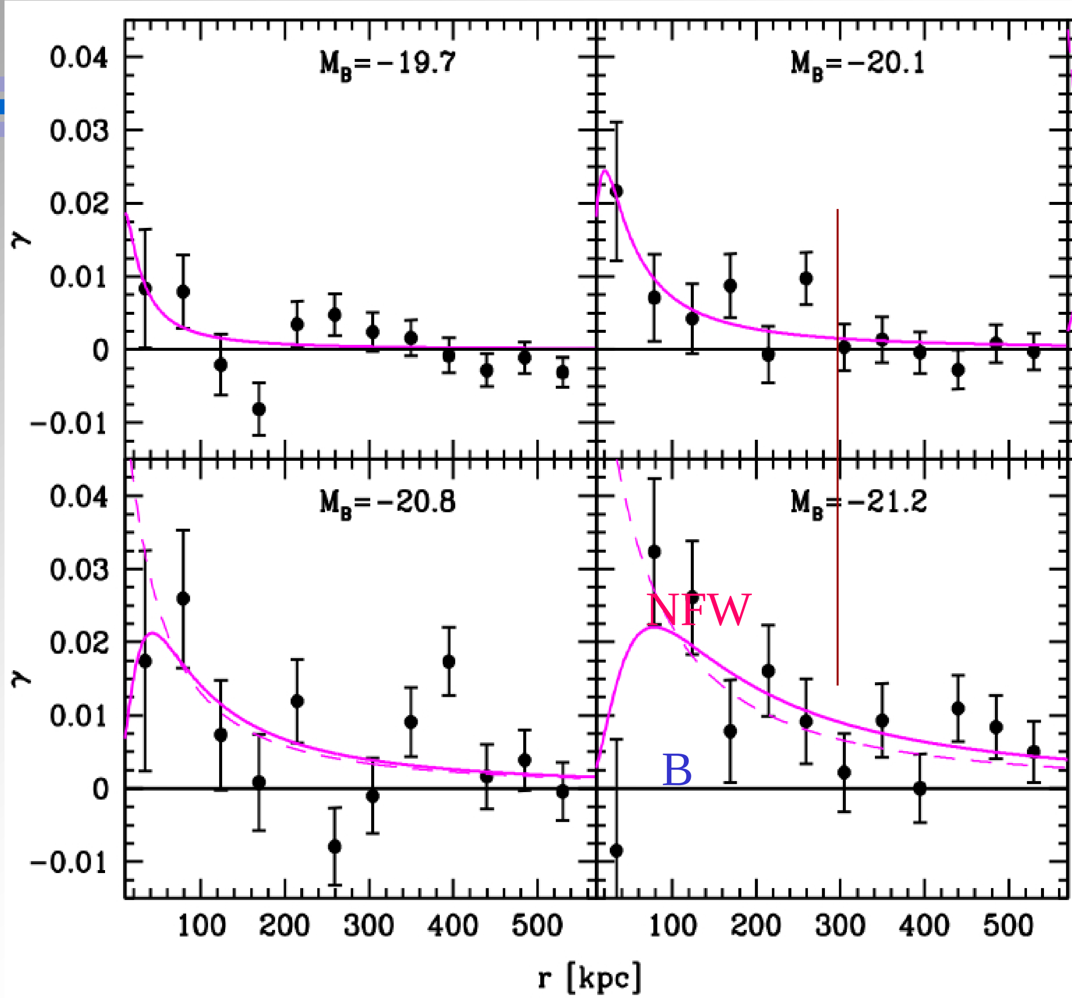
@Ropt

Extrapolating the URC

- Weak lensing
- Mass functions
- Satellite kinematics

Weak lensing

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



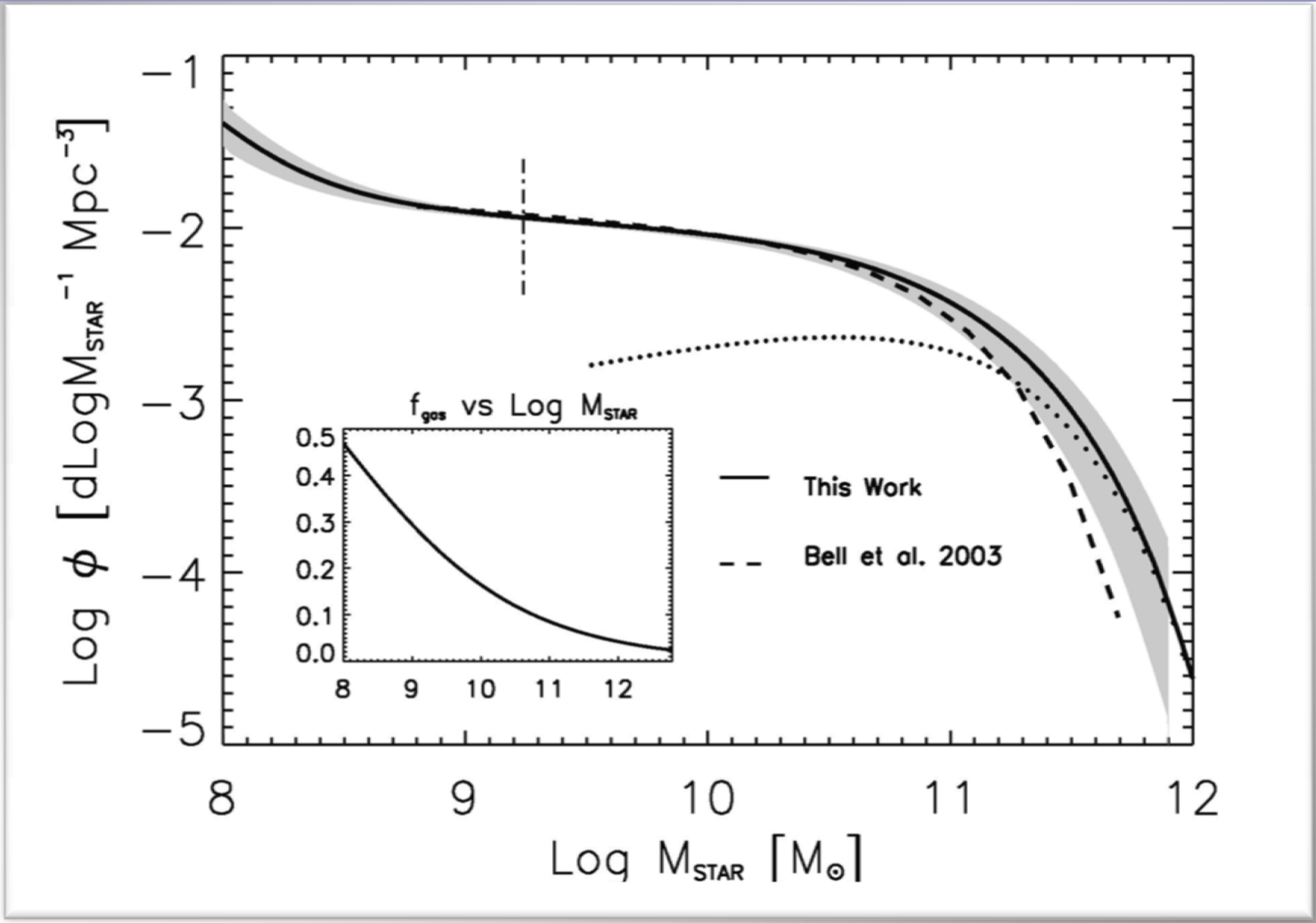
r_0 (kpc)	ρ_0 $(10^6 M_\odot/kpc^3)$
7^{+3}_{-6}	15^{+15}_{-15}
14^{+6}_{-10}	10^{+10}_{-10}
40.4^{+20}_{-20}	$1.7^{+1.5}_{-1.5}$
30^{+10}_{-20}	4.1^{+4}_{-4}
56^{+20}_{-20}	$2.3^{+1.2}_{-1.2}$

Same results as those obtained from RCs.

Burkert profile provides excellent fit, better than NFW.

$$\mathbf{BMF}(M_b)\,dM_b = \left(1.94\times10^{-3}\,\tilde{M}_b^{-1.2}\,e^{-\tilde{M}_b/1.9} + 4\times10^{-7}\;\tilde{M}_b^{-2.6}\right)\frac{dM_b}{10^{11}M_\odot}$$

Stellar mass function



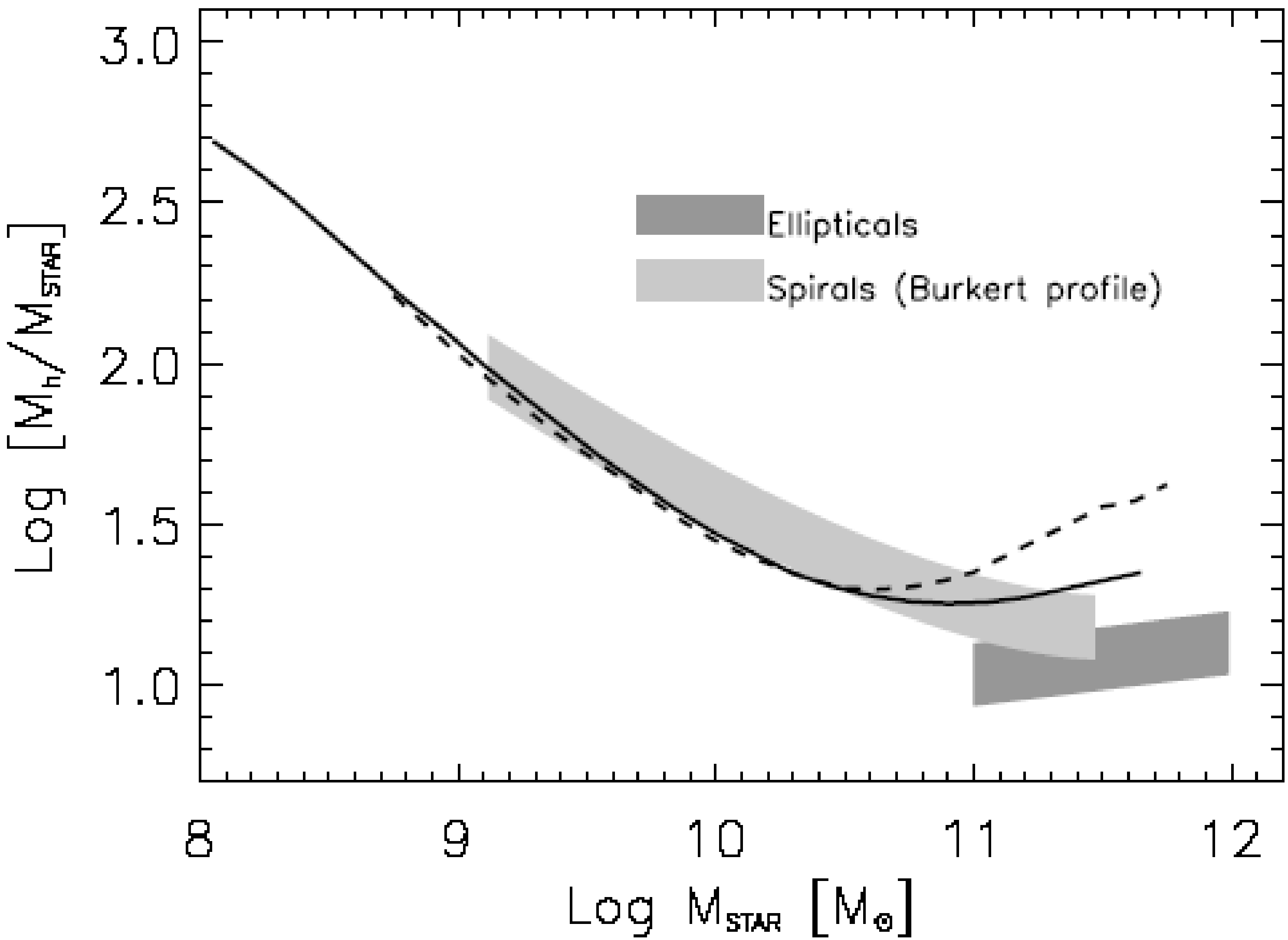
Halo masses from the baryonic and halo mass functions

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

Press Schecter and simulations

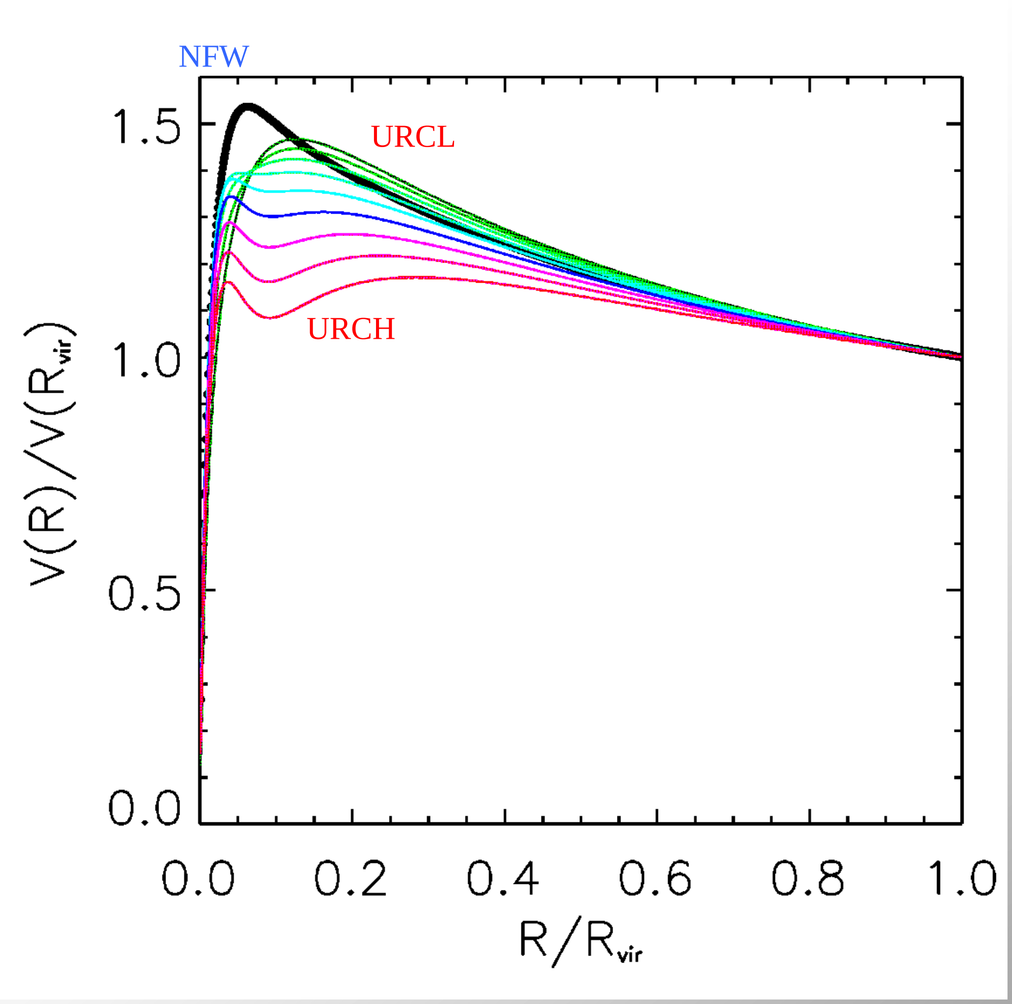
$$HMF(M_h)\,dM_h/dM_b\,dM_b = BMF(M_b)\,dM_b$$

WE OBTAIN THE VIRIAL MASS

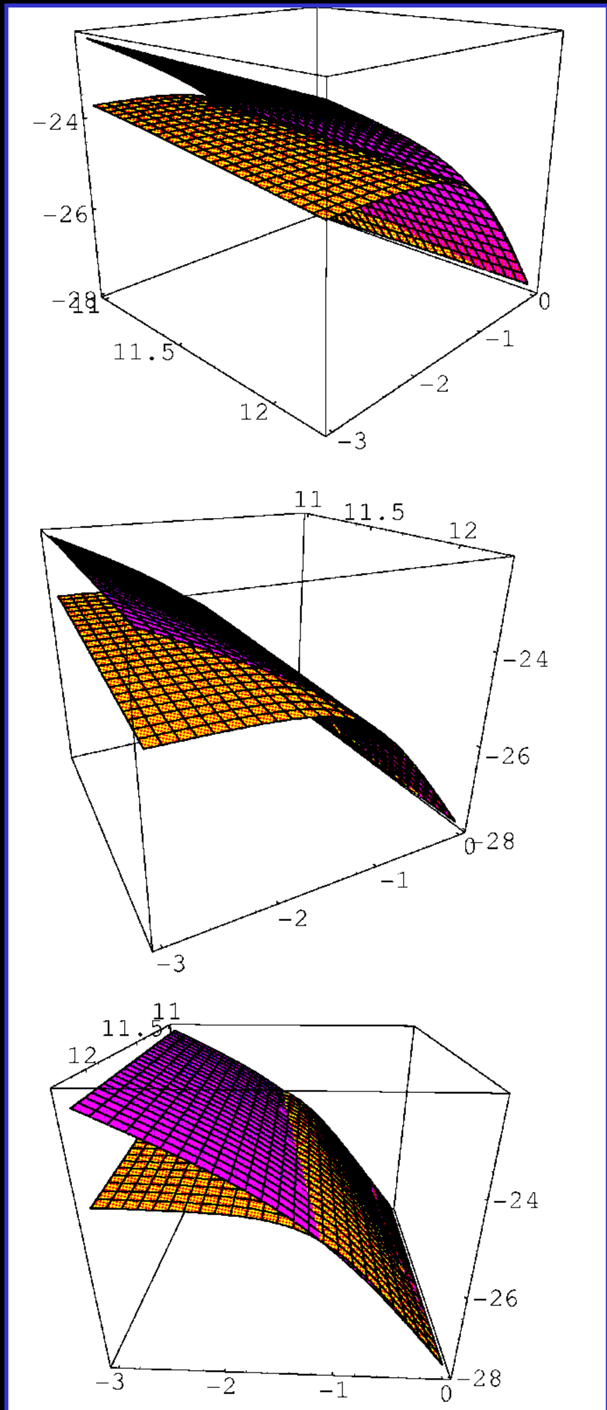


$$M_h = ((|\beta| - 1)/A\ (1.94\ 10^{-3}\Gamma(-0.21, \tilde{M}_b/1.9) + 2.5\ 10^{-7}\tilde{M}_b^{-1.6} + C)^{1/(1-|\beta|)}$$

The Universal Velocity Curve



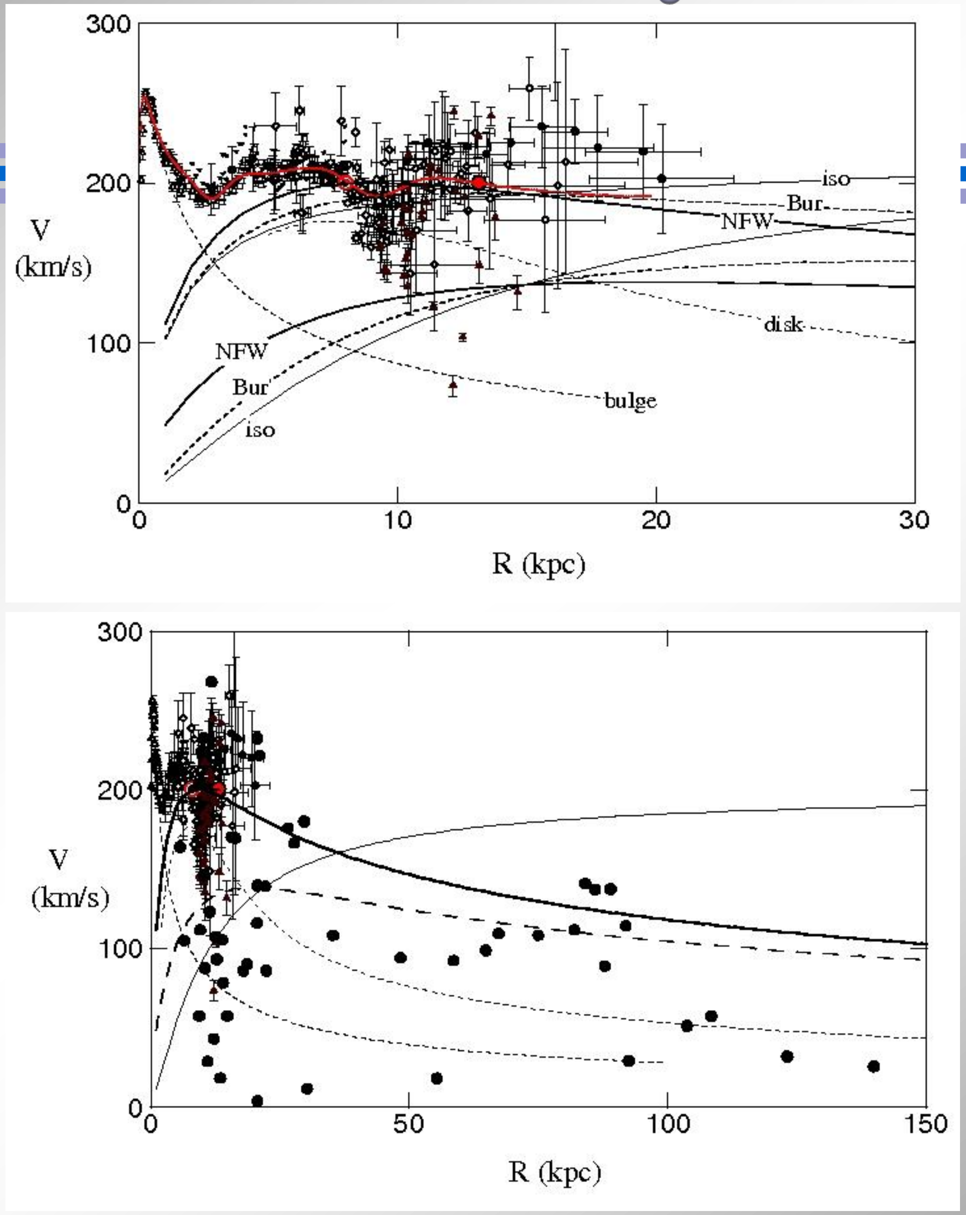
DM halo density: observations vs simulations



Individual objects

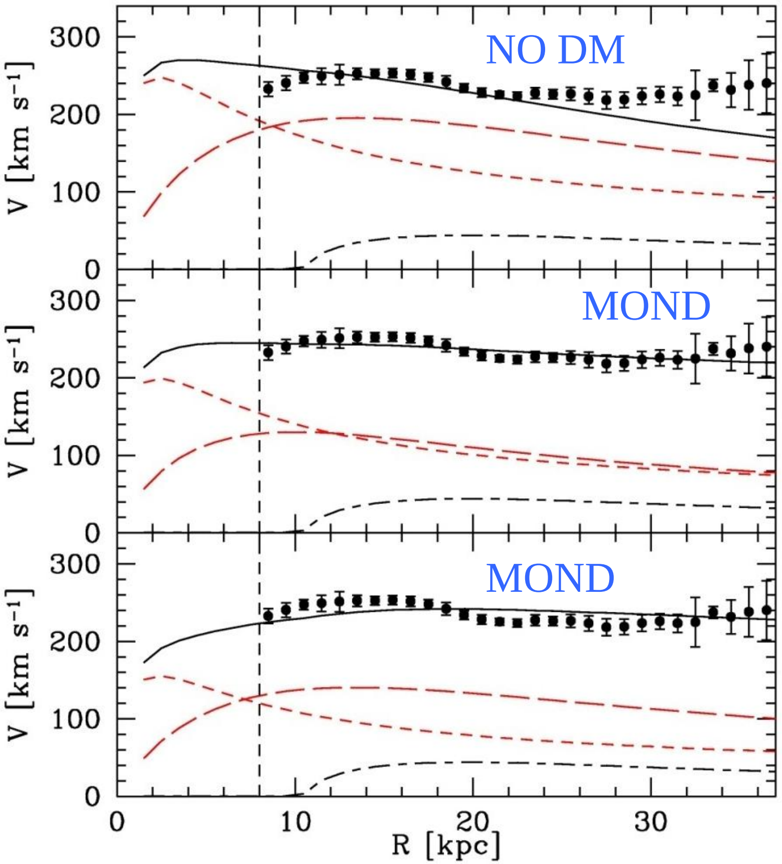
needed to test theories

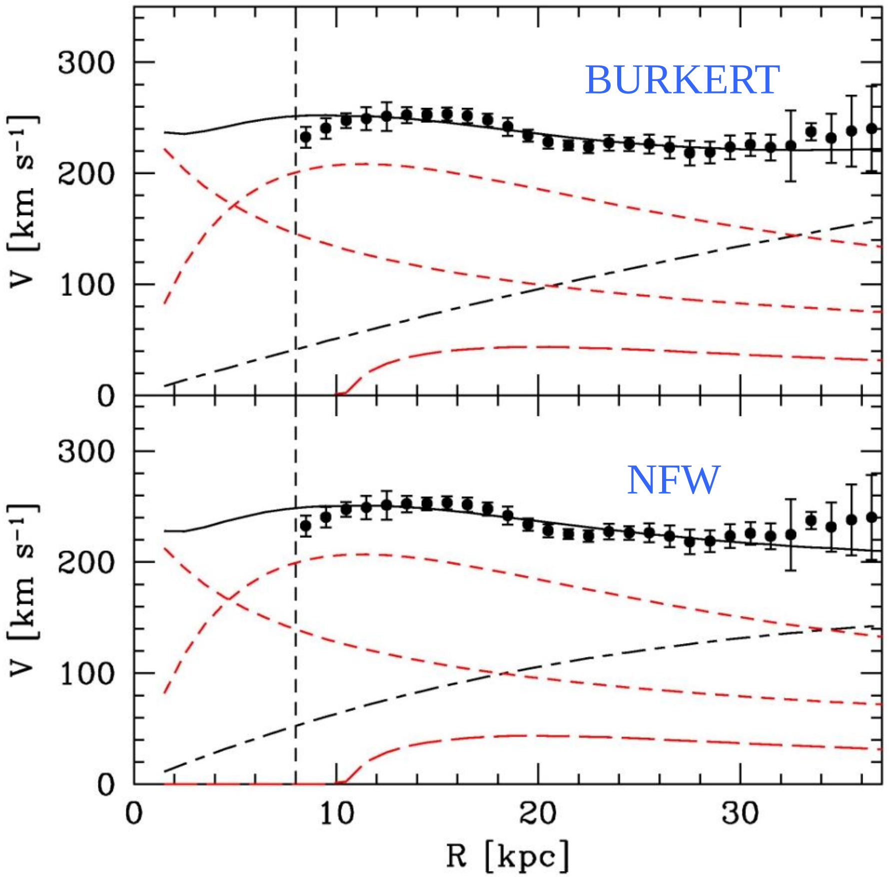
The Galaxy !



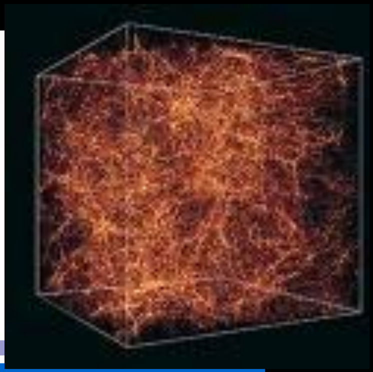
300
200
100
0
V
(km/s)
iso
Bur
NFW
disk
NFW
Bur
iso
bulge
0
10
20
30
R (kpc)
300
200
100
0
V
(km/s)
0
50
100
150
R (kpc)

M31 :THE TWIN GALAXY





Dark halos profiles from ΛCDM simulations



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

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

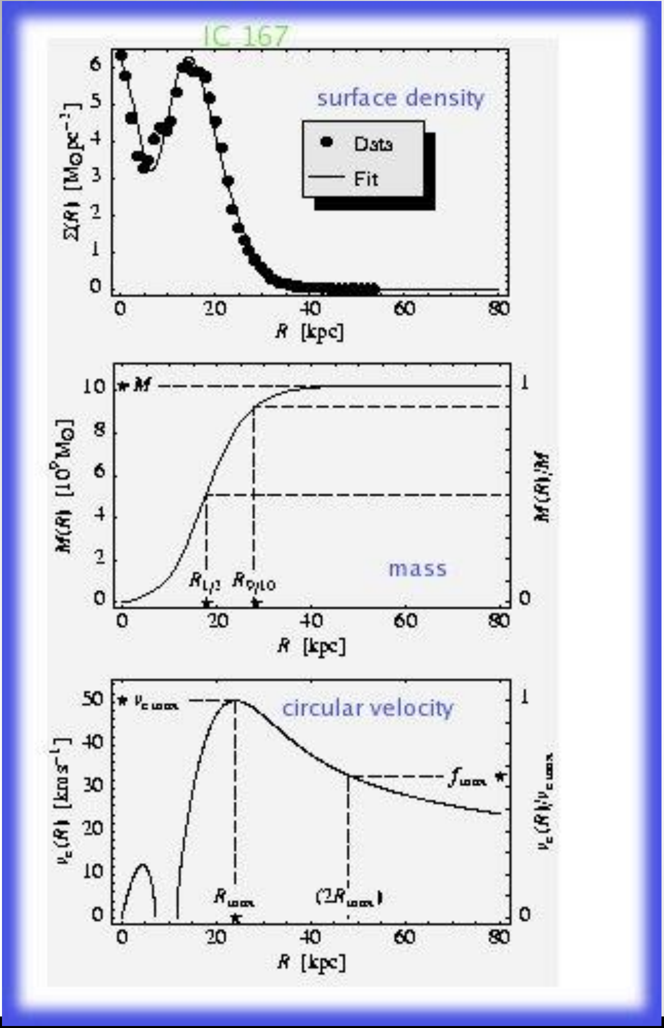
The cusp vs core issue

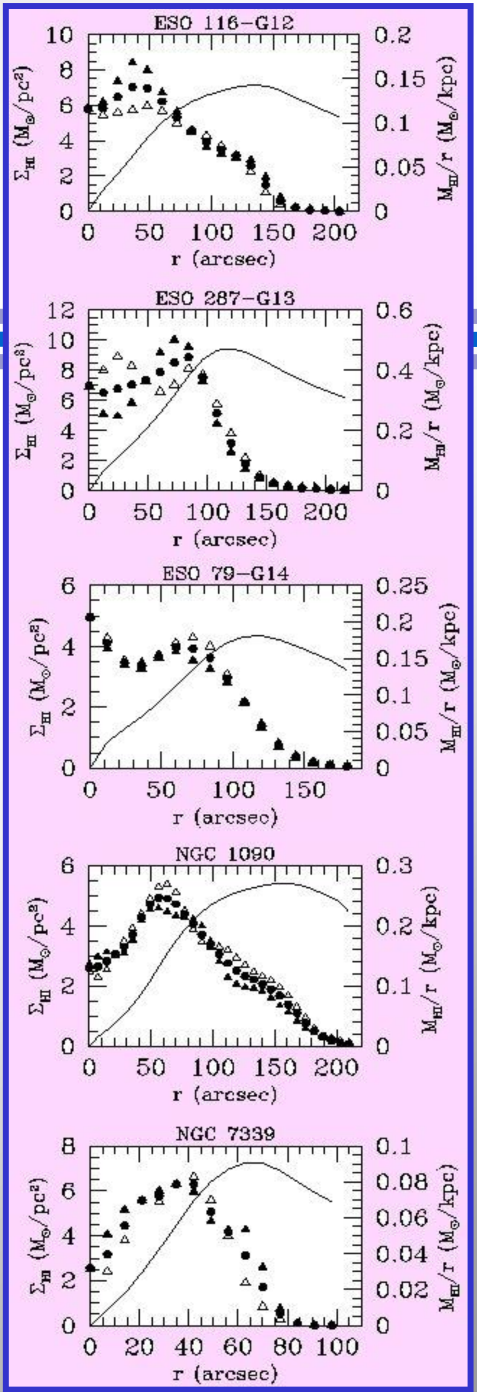
cuspy NFW density profiles disagree with observed kinematics.
comparison galaxy by galaxy and of coadded kinematics highlights a CDM crisis.

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)

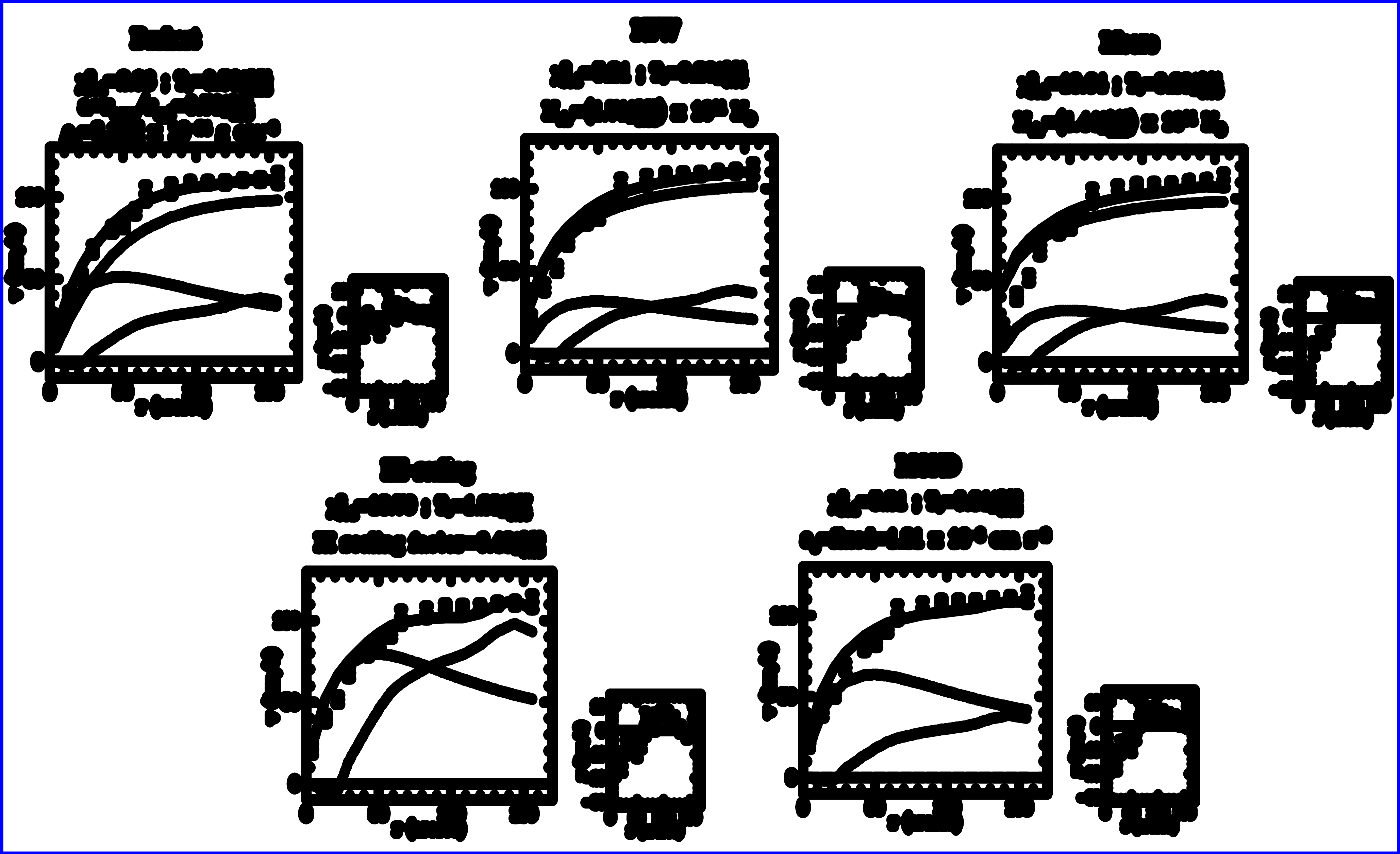
Salucci, Walter & Borriello, A&A 409, 53 (2003)
Gentile et al., MNRAS 351, 903 (2004)
Kuzio de Naray, McGaugh & de Blok, ApJ 676, 920 (2008)

HI disk contribution



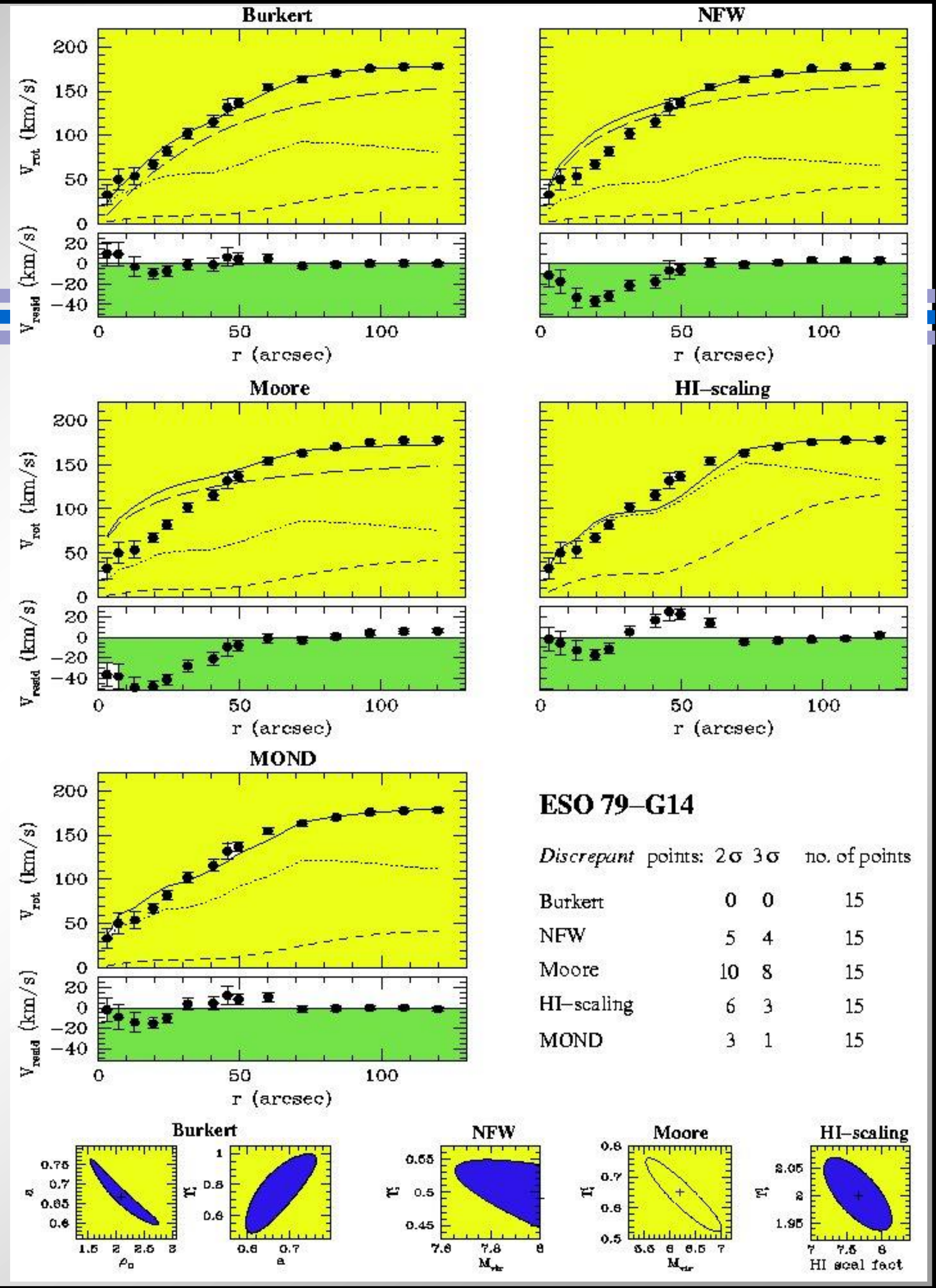


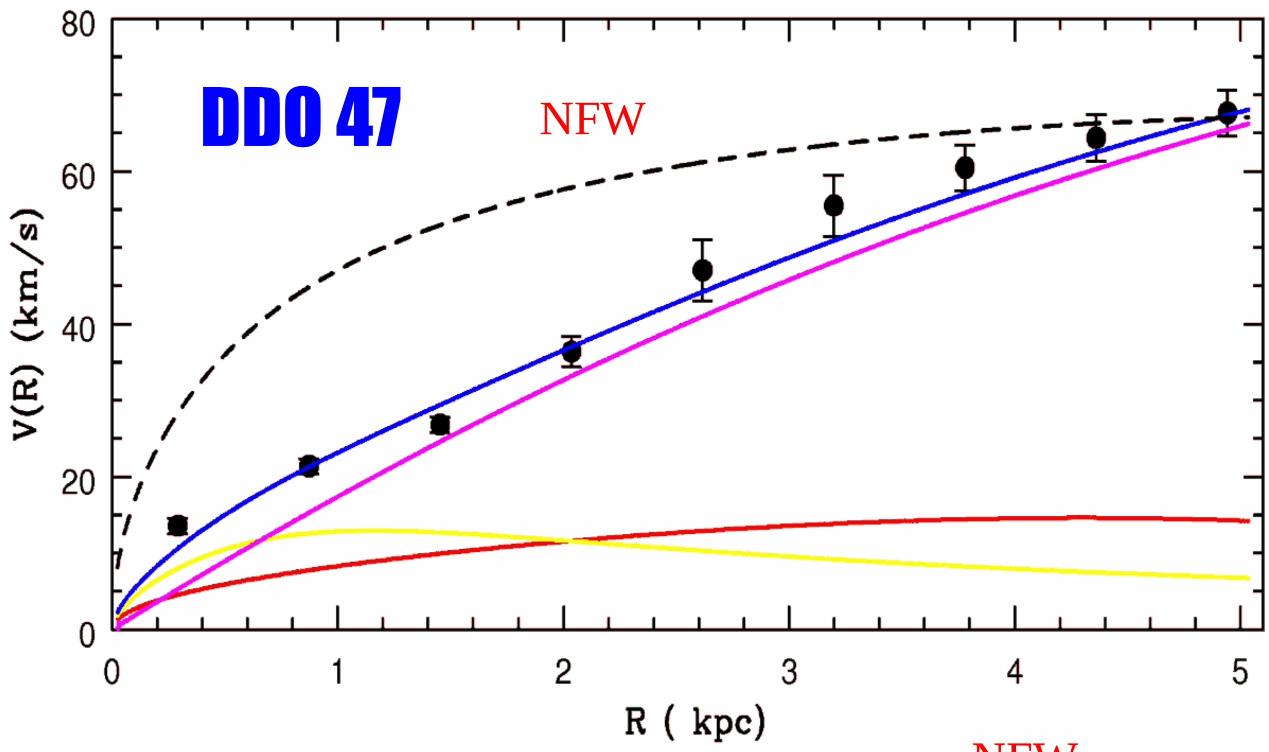
A test case: ESO 116-G12

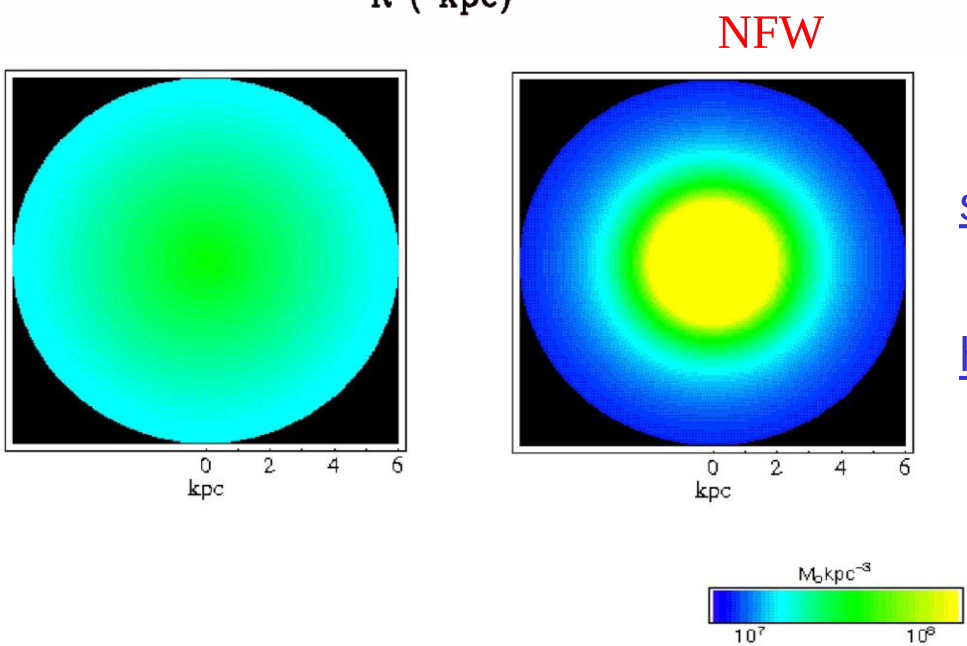


Cored halos fits

50 objects investigated
NFW inconsistent







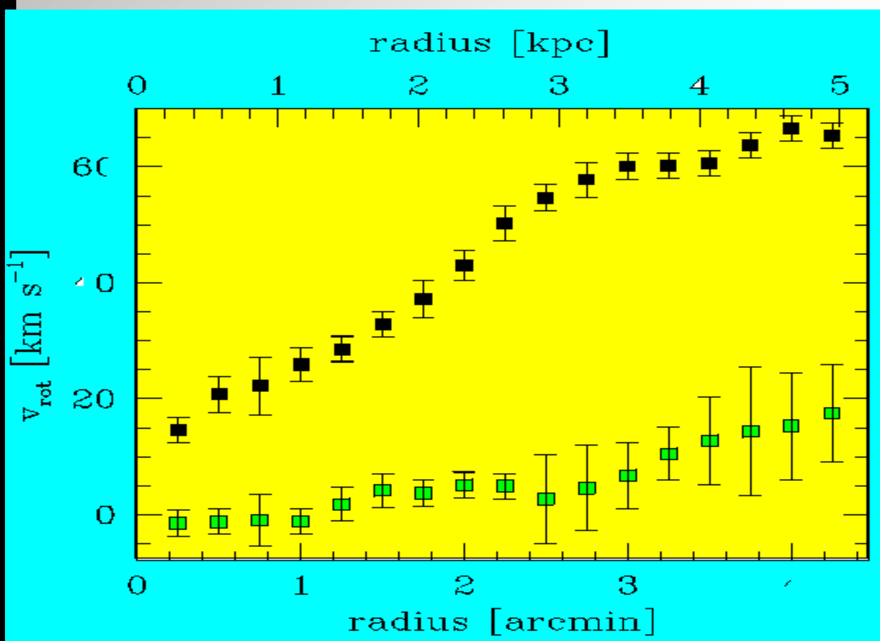
NFW HALOS

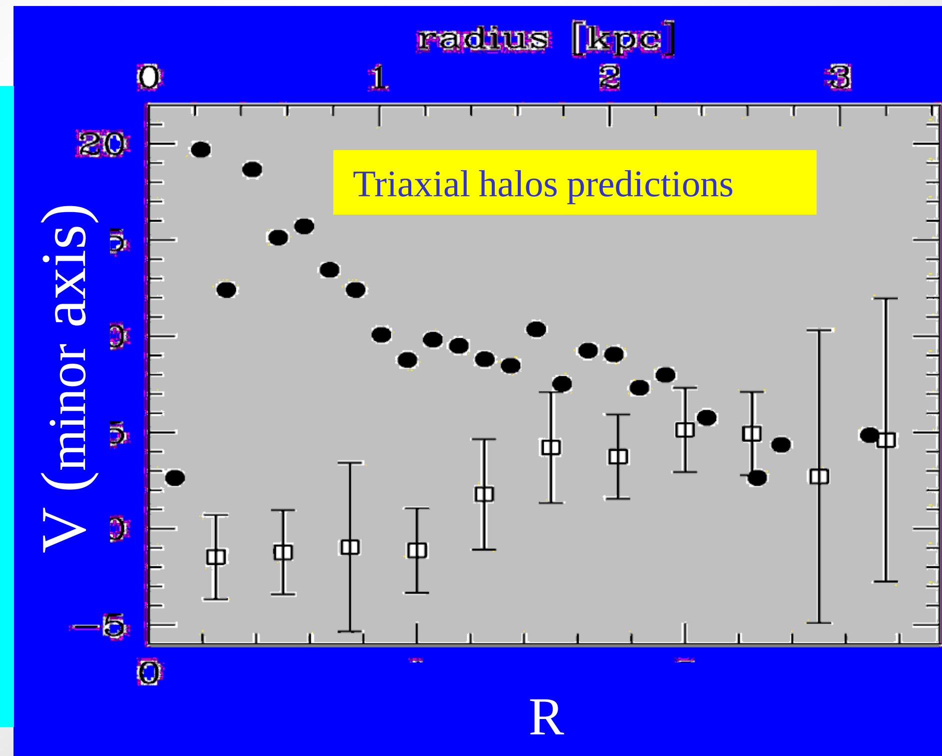
Fit badly the RCs

Unphysically too low stellar mass-to-light ratios

Unphysically too high halo masses

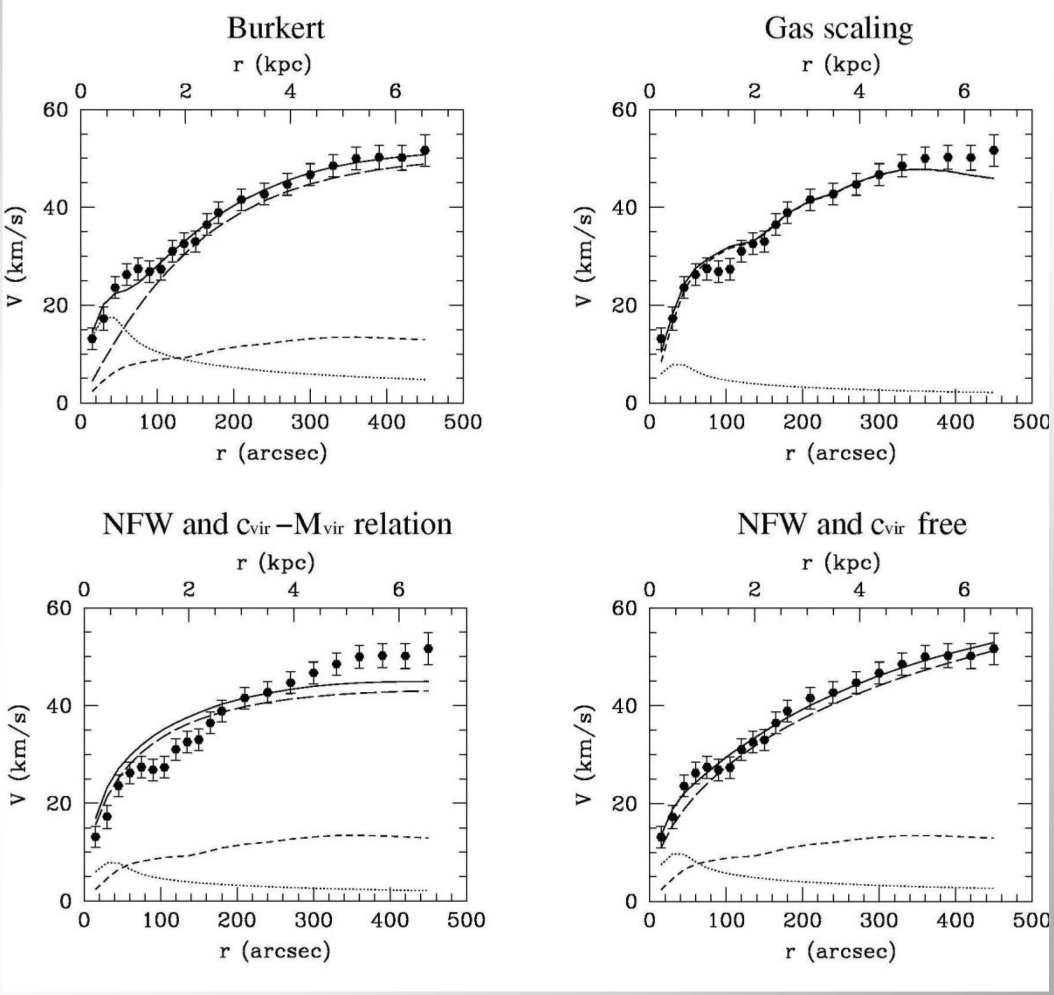
DDO 47: NON CIRCULAR MOTIONS ?





NGC 3741 the most extended RC

Gentile, Salucci + 2007



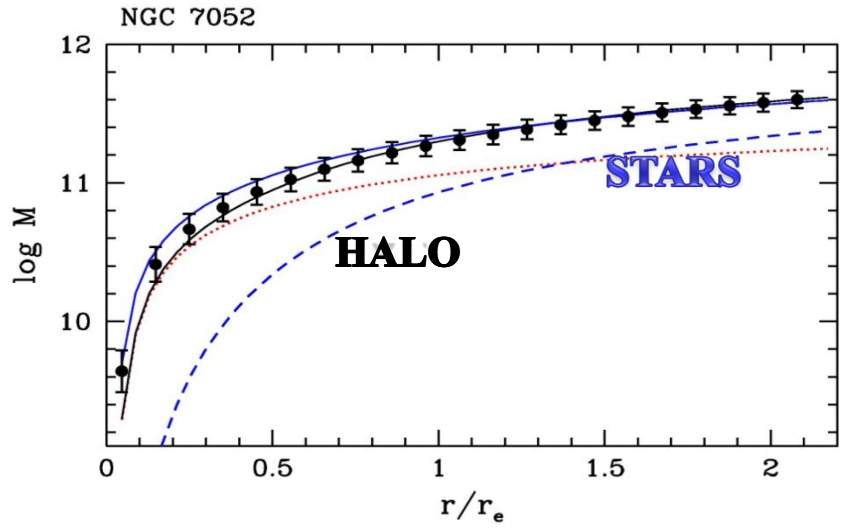
ELLIPTICALS

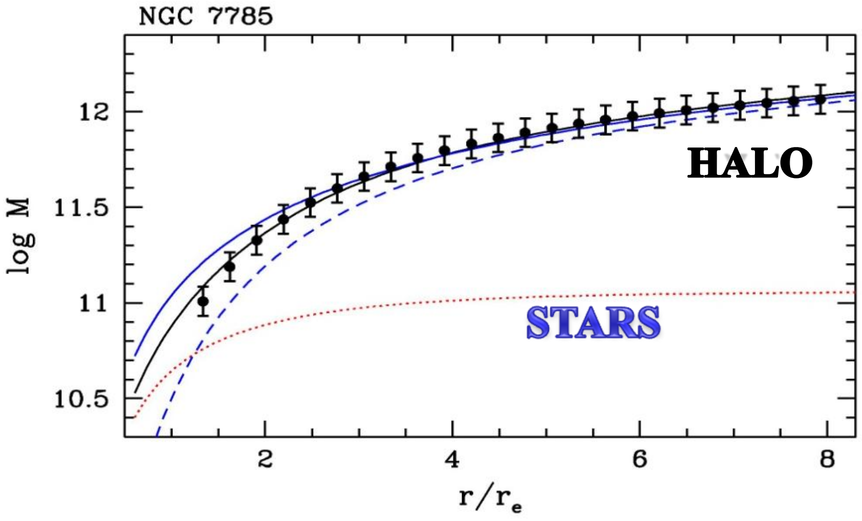
$$M(<r) = \frac{kT_{\mathrm{g}}(r)r}{G\mu m_p}\left(\frac{d\log\ \rho_g}{d\log\ r} + \frac{d\log\ T_{\mathrm{g}}(r)}{d\log\ r}\right),$$

$$\rho_{\mathrm{g}} \propto [1 + (r/r_c)^2]^{-3\beta/2}$$

$$M_h(r) = M_0\left\{\ln\left(1+\frac{r}{r_0}\right) - \tan^{-1}\left(\frac{r}{r_0}\right) + \frac{1}{2}\ln\left[1+\left(\frac{r}{r_0}\right)^2\right]\right\},$$

where $M_0 \equiv 6.4\rho_0 r_0^3$.

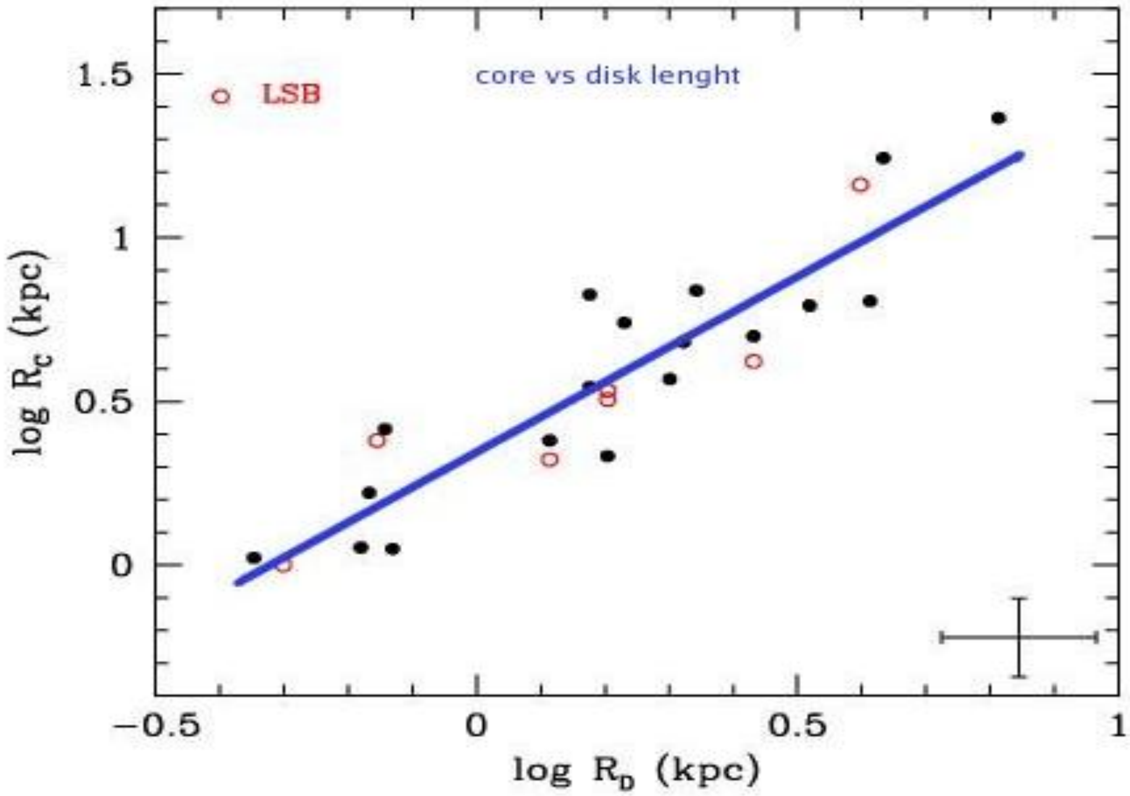

NGC 7052
log M
r/r_e
STARS
HALO


NGC 7785
log M
r/r_e
HALO
STARS

Core radii are sound quantities

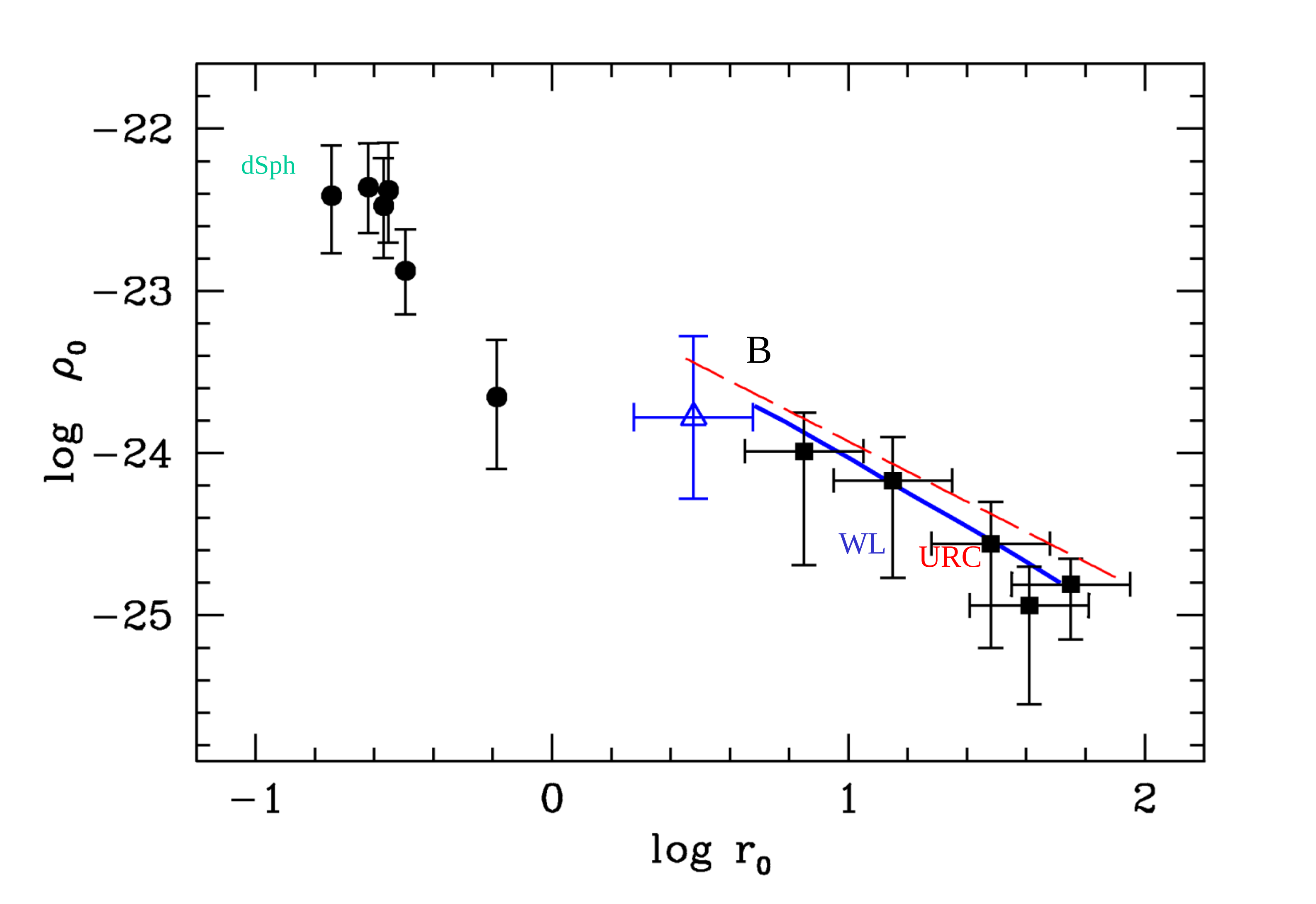
Length-scales correlates with core radii.

Donato et al, 04



Halo central density vs core radius

$\rho_0 = 10^{-23} (r_0/\mathrm{kpc})^{-1}\ \mathrm{g/cm^3}$ (WDM? De Vega et al 2010)



The quantity $\rho_0 r_0 = \Sigma_0$ is constant among galaxies

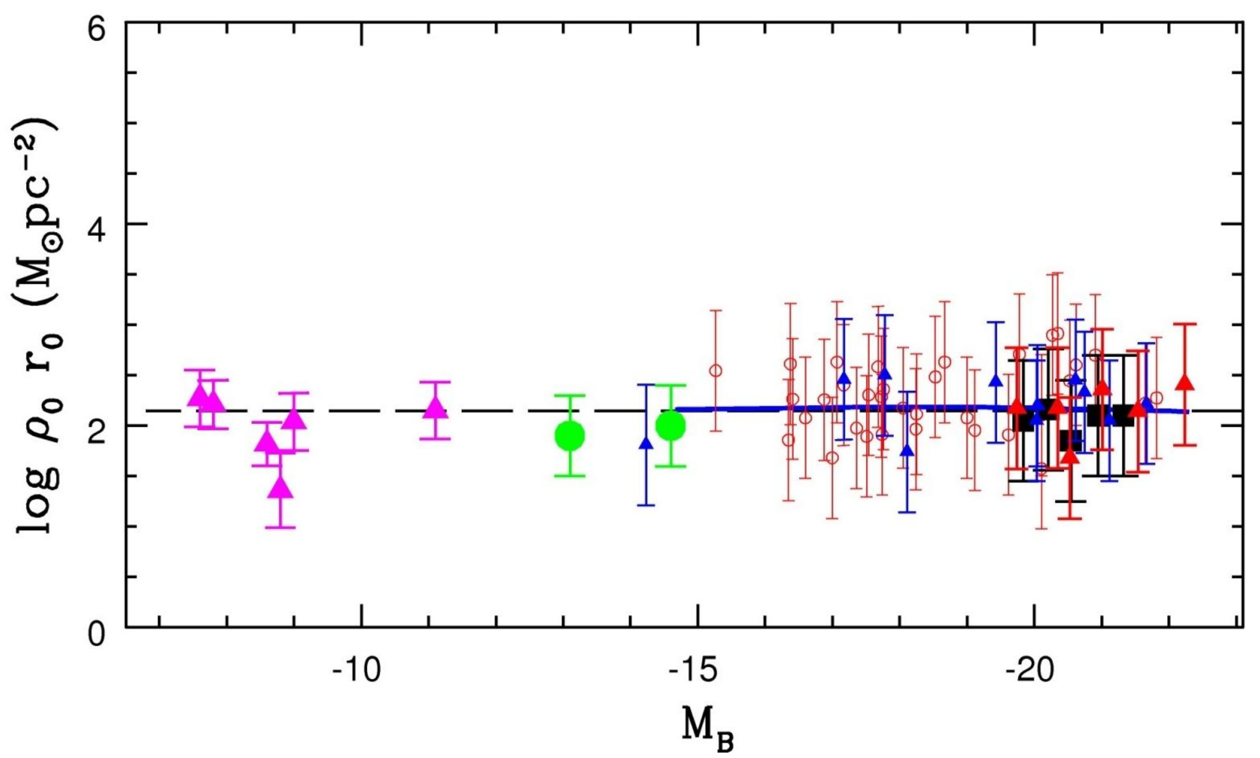
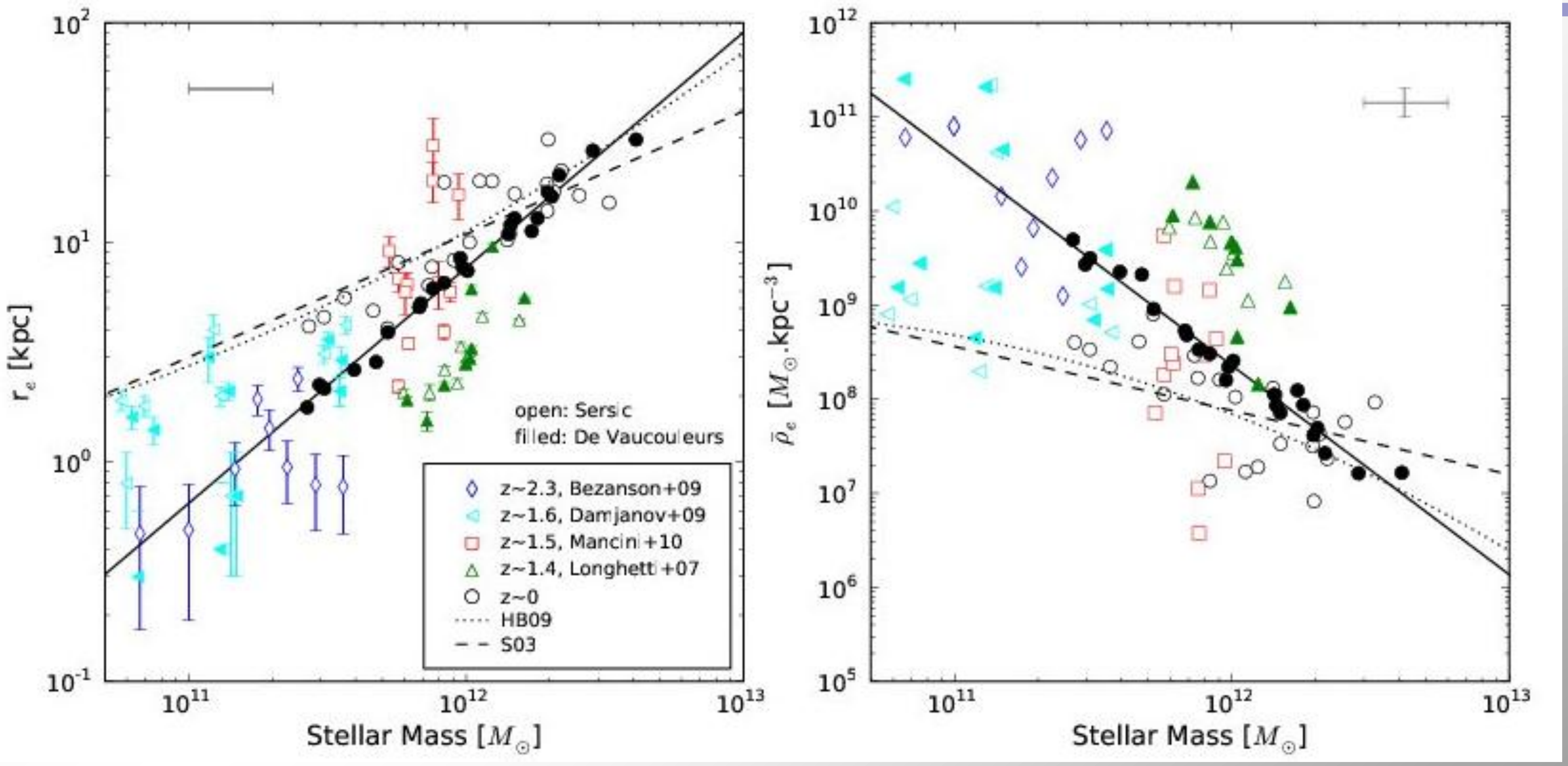
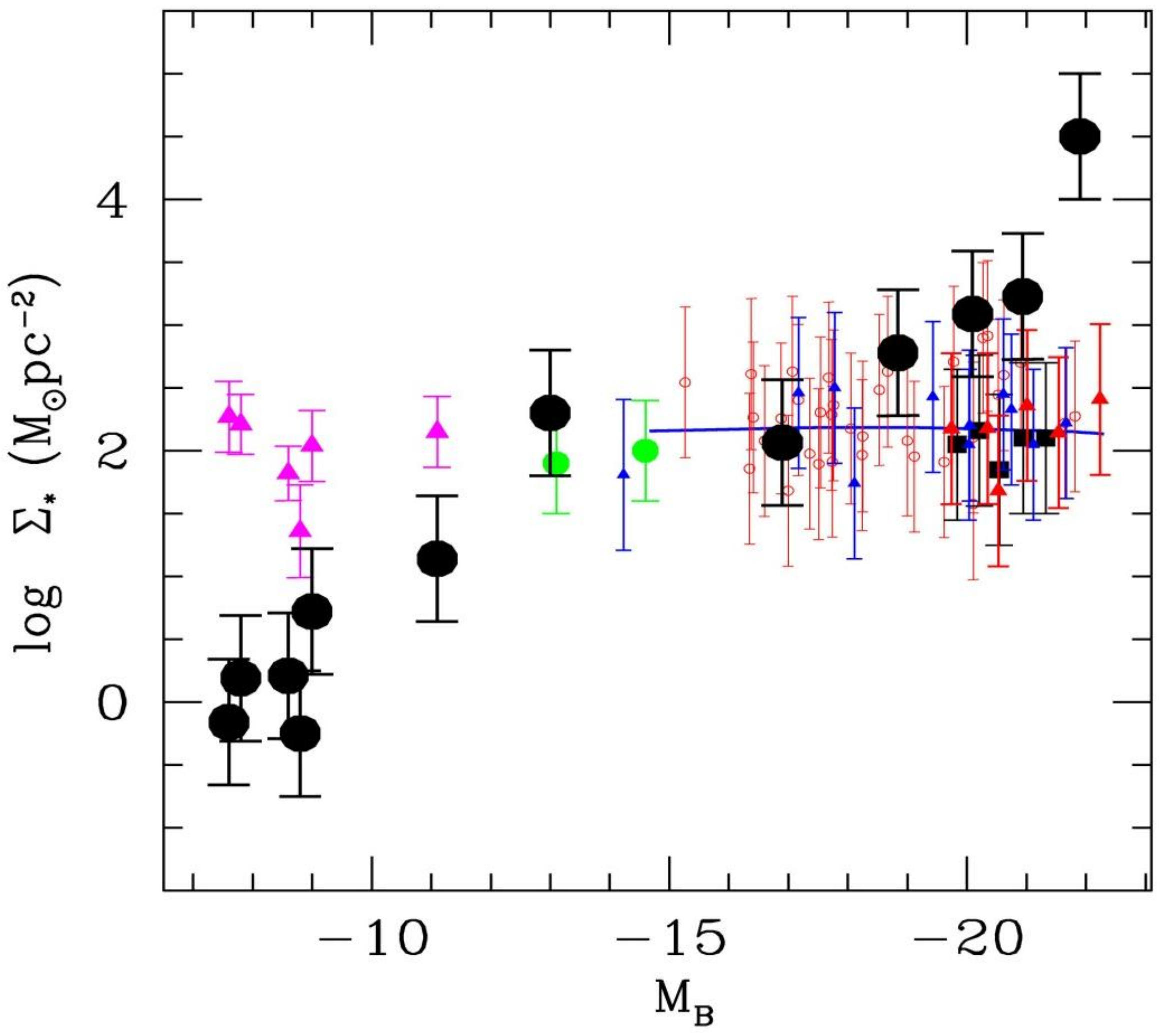


Figure 2. $\rho_0 r_0$ in units of $M_\odot \mathrm{pc}^{-2}$ as a function of galaxy magnitude for different galaxies and Hubble Types. The original Spano et. al. (2008) data (empty small red circles) are shown as a reference of previous work. The new results come from: the URC (solid blue line), the dwarf irregulars (full green circles) N 3741 ($M_B = -13.1$) and DDO 47 ($M_B = -14.6$), Spirals and Ellipticals investigated by weak lensing (black squares), dSphs (pink triangles), nearby spirals in THINGS (small blue triangles), and early-type spirals (full red triangles). The long dashed line is the result of this work.

Densities varies a lot !



A matter enigma




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