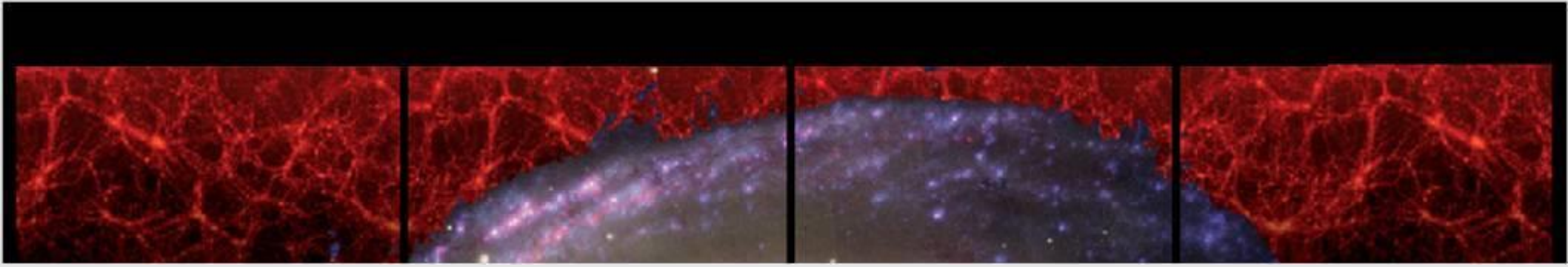
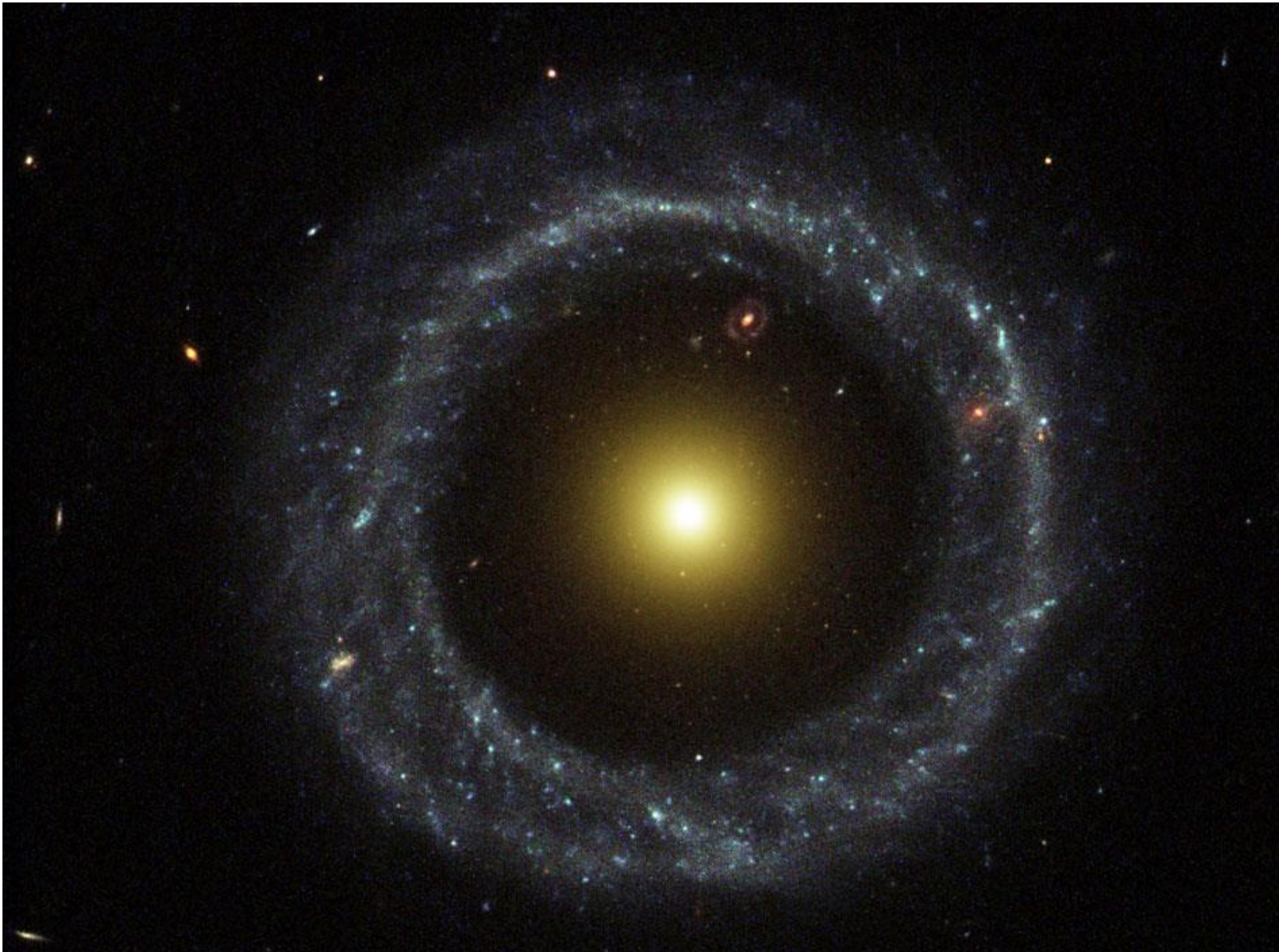


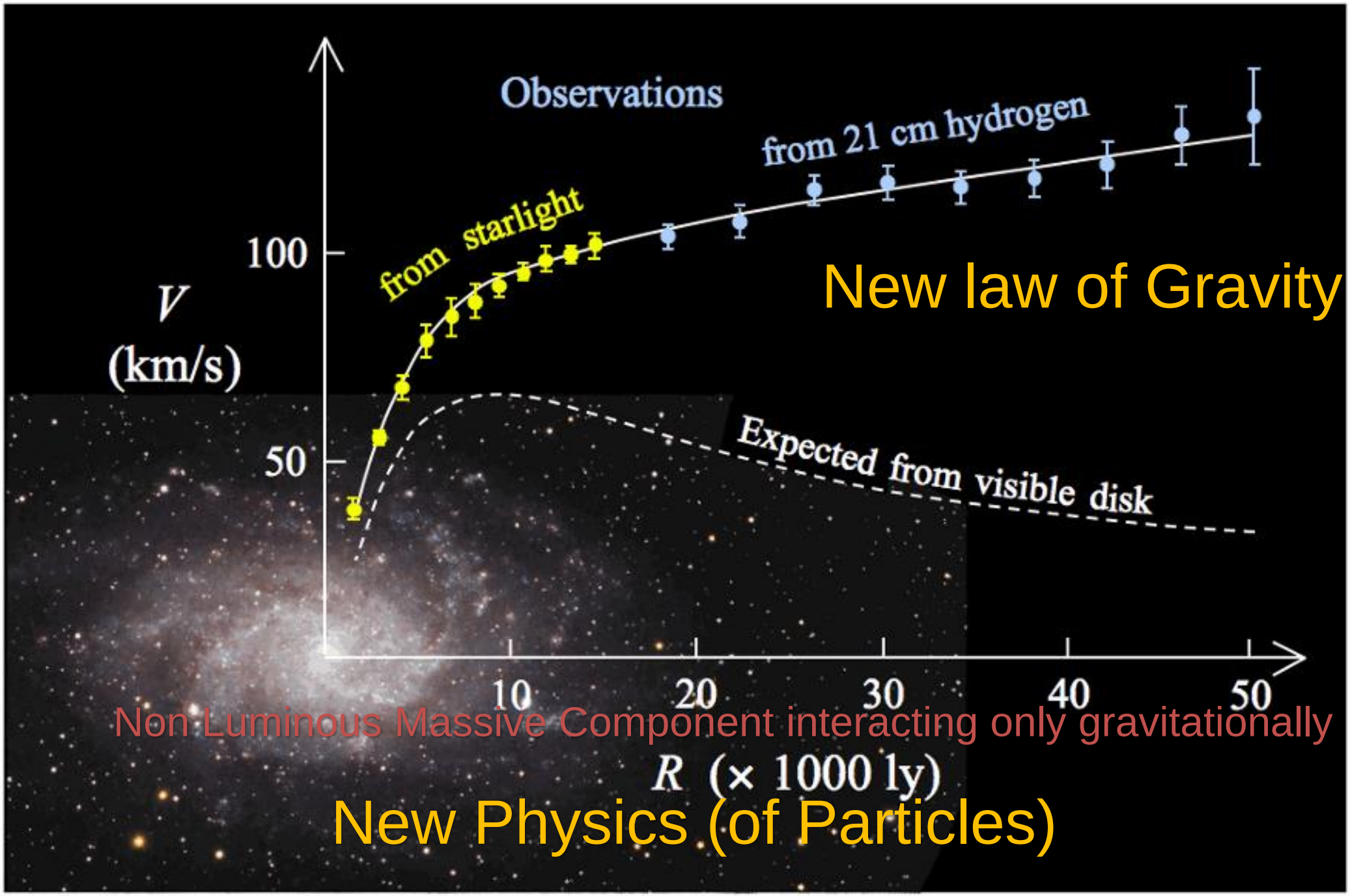
Dark Matter and Exotic Dark Matter

PAOLO SALUCCI

SISSA, INFN

Corfu Summer Institute 2018, Beyond Standard Model





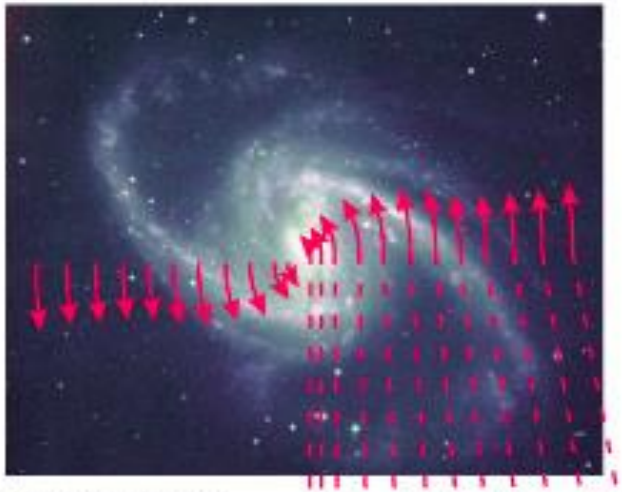
New law of Gravity

Non Luminous Massive Component interacting only gravitationally

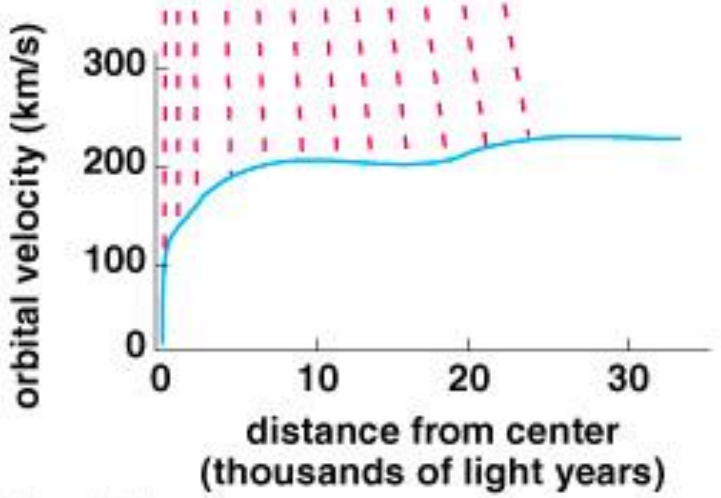
New Physics (of Particles)

ROTATION CURVES

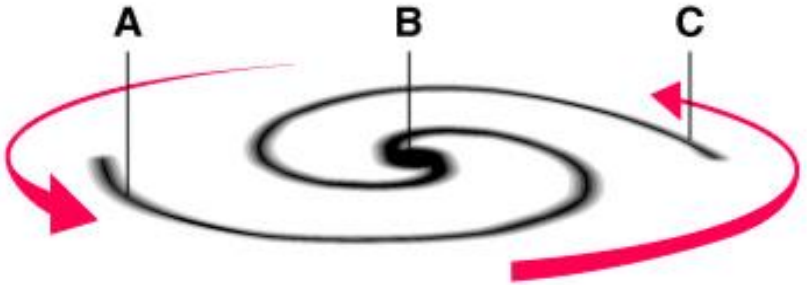
artist impression

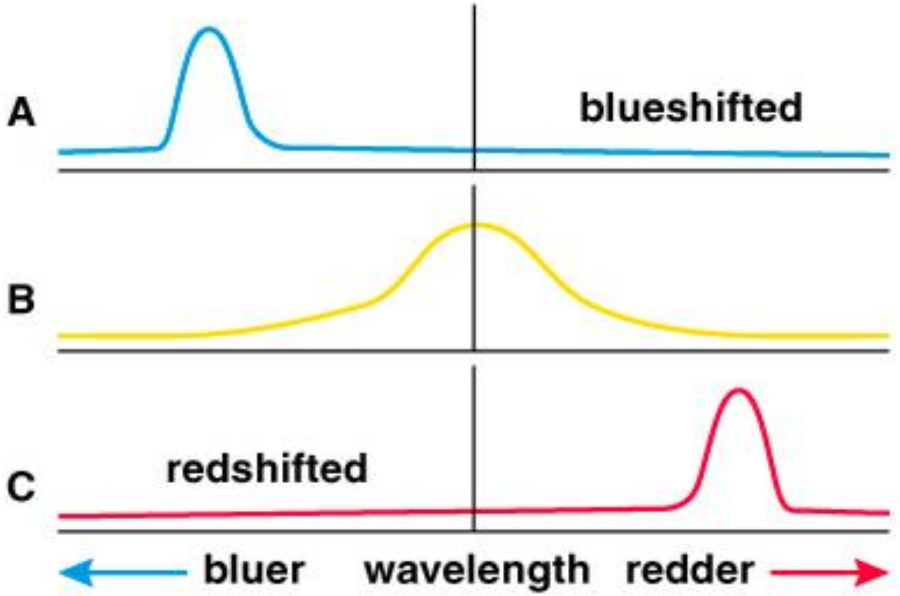


Longer arrows represent larger orbital velocities.



artist impression



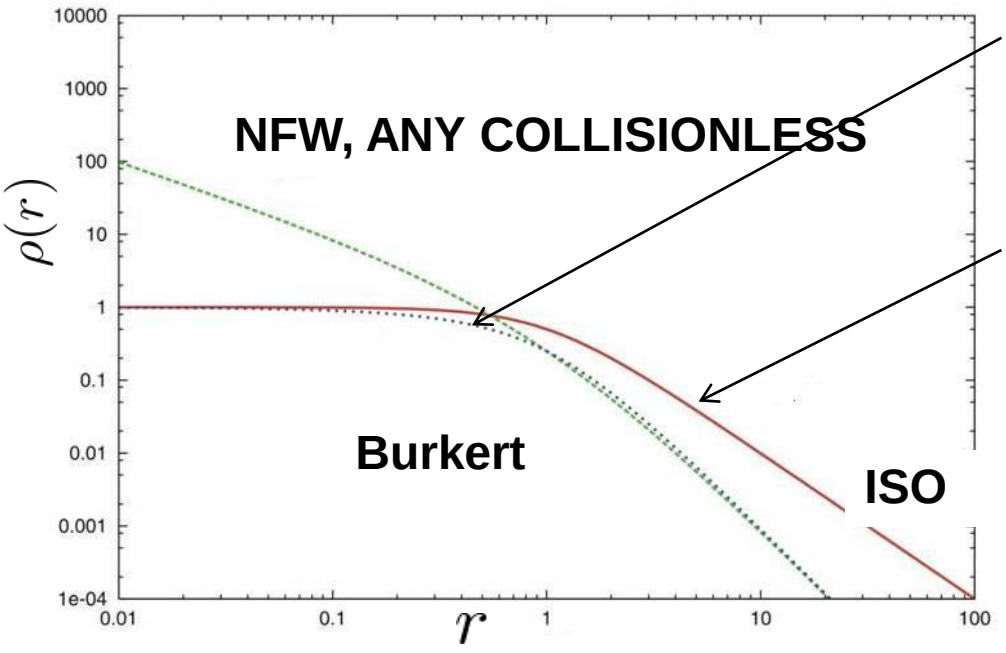


Rotation curve analysis

$$V^2(R) = V^2_{halo}(R) + V^2_{HI}(R) + V^2_{disk}(R) \text{ + dP/dR}$$

observations = model

- V^2_{disk} **from I-band photometry**
- V^2_{HI} **from HI observations**
- V^2_{halo} **1) collisionless dark matter 2) empirical 3) exotic dark matter**



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

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

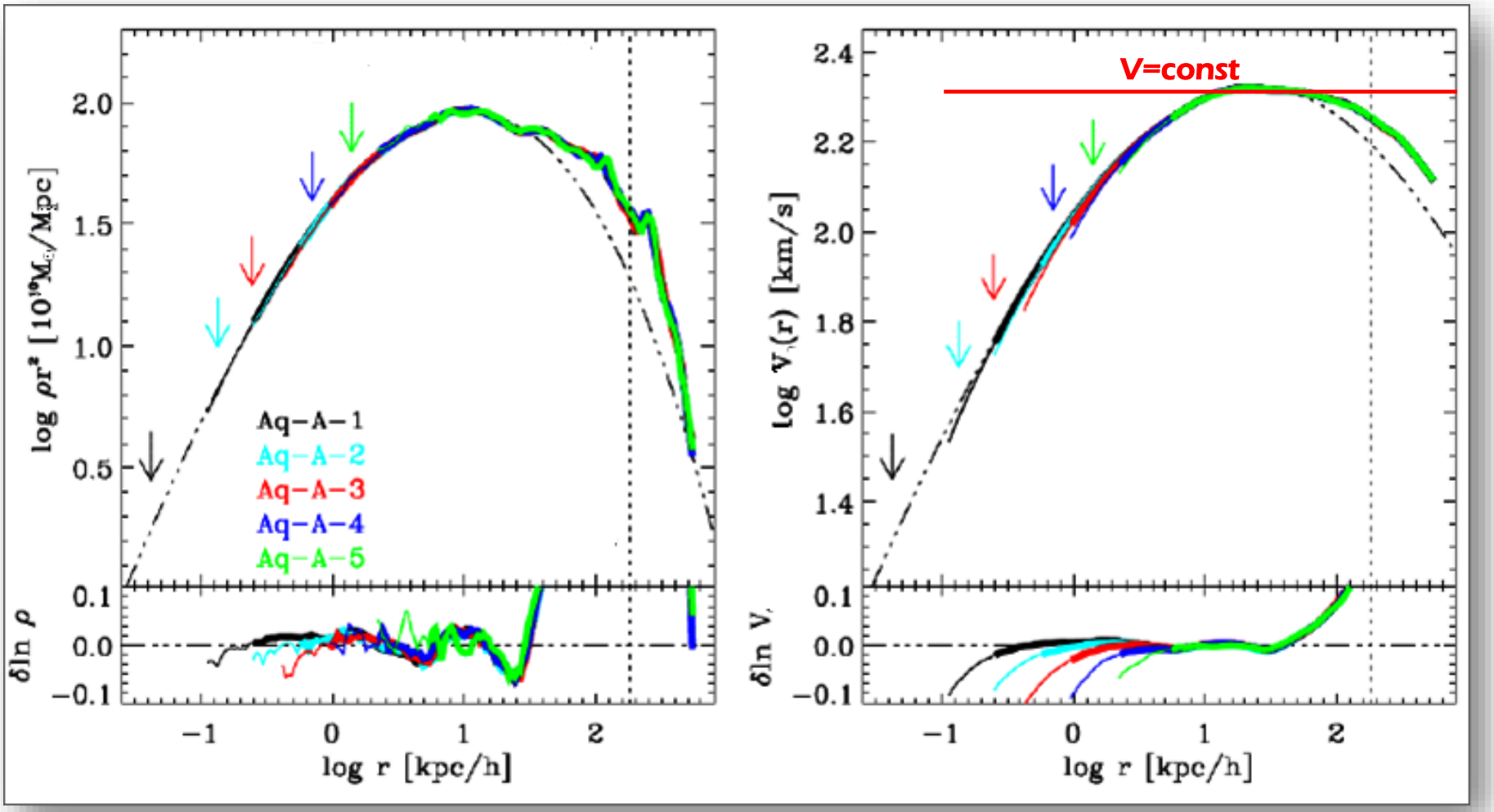
The mass model has 3 free parameters:
disk mass
halo central density
Halo core radius (length-scale)

LCDM

Navarro et al +10

density

circular velocity



Density Profiles (N-body simulations almost 10^10 particles)

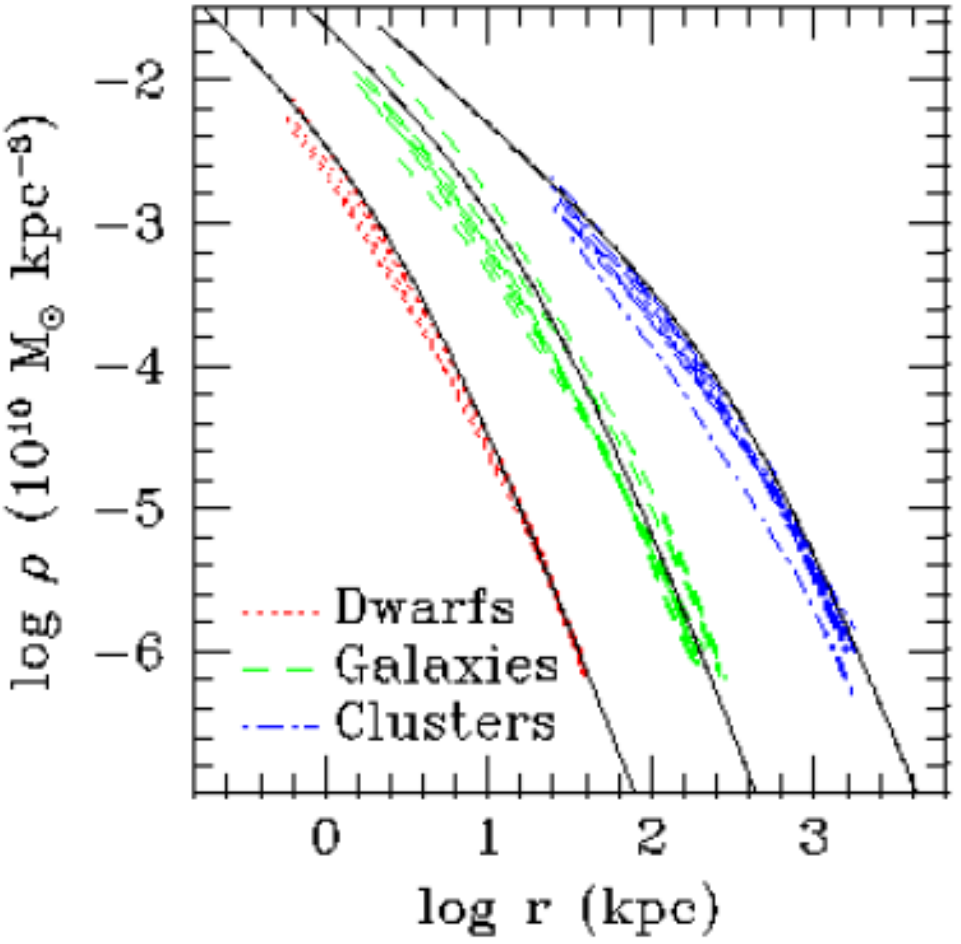
$$\rho_{NFW}(r) = \delta\rho_c \frac{r_s}{r} \frac{1}{(1 + r/r_s)^2}$$

$$c = \frac{R_{vir}}{r_s}$$

$$R_{vir} = 260 \left(\frac{M_{vir}}{10^{12}\ M_\odot}\right)^{1/3} kpc$$

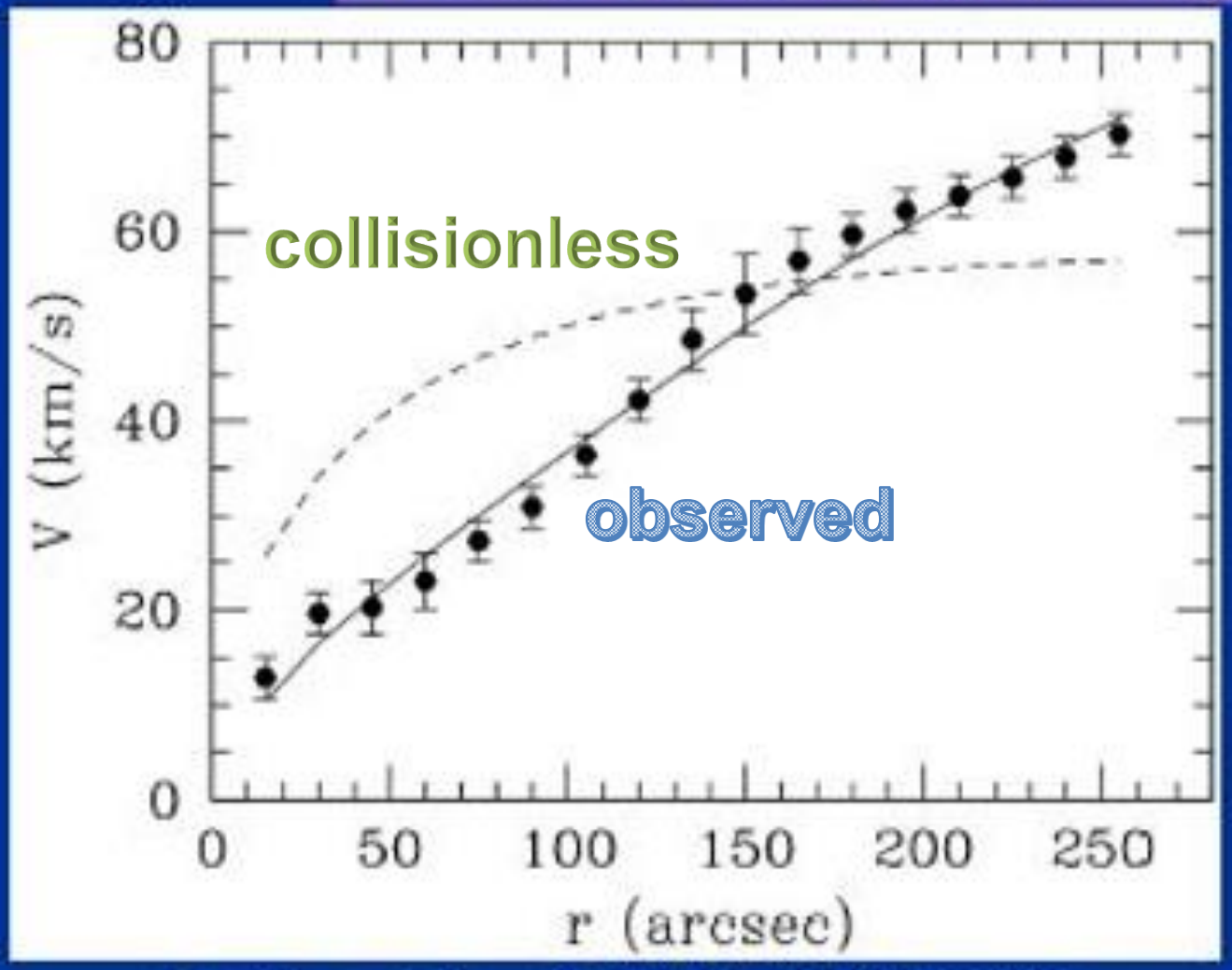
$$c(M_{vir}) = 9.35 \left(\frac{M_{vir}}{10^{12}\ M_\odot}\right)^{-0.09}$$

Klypin, 2010



Borriello & Salucci, MNRAS 323, 285

DDO 47



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

PHYSICALLY DIFFERENT DM HALOS

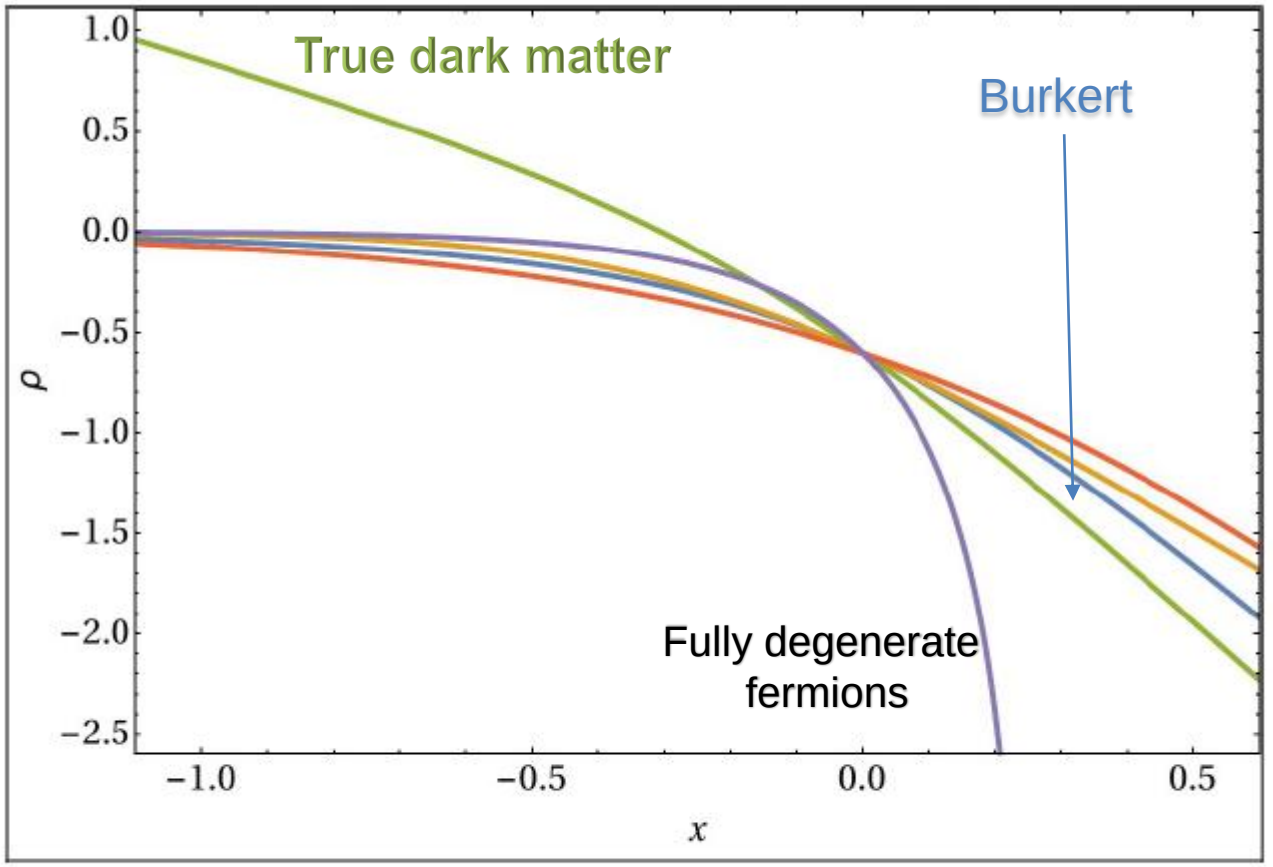
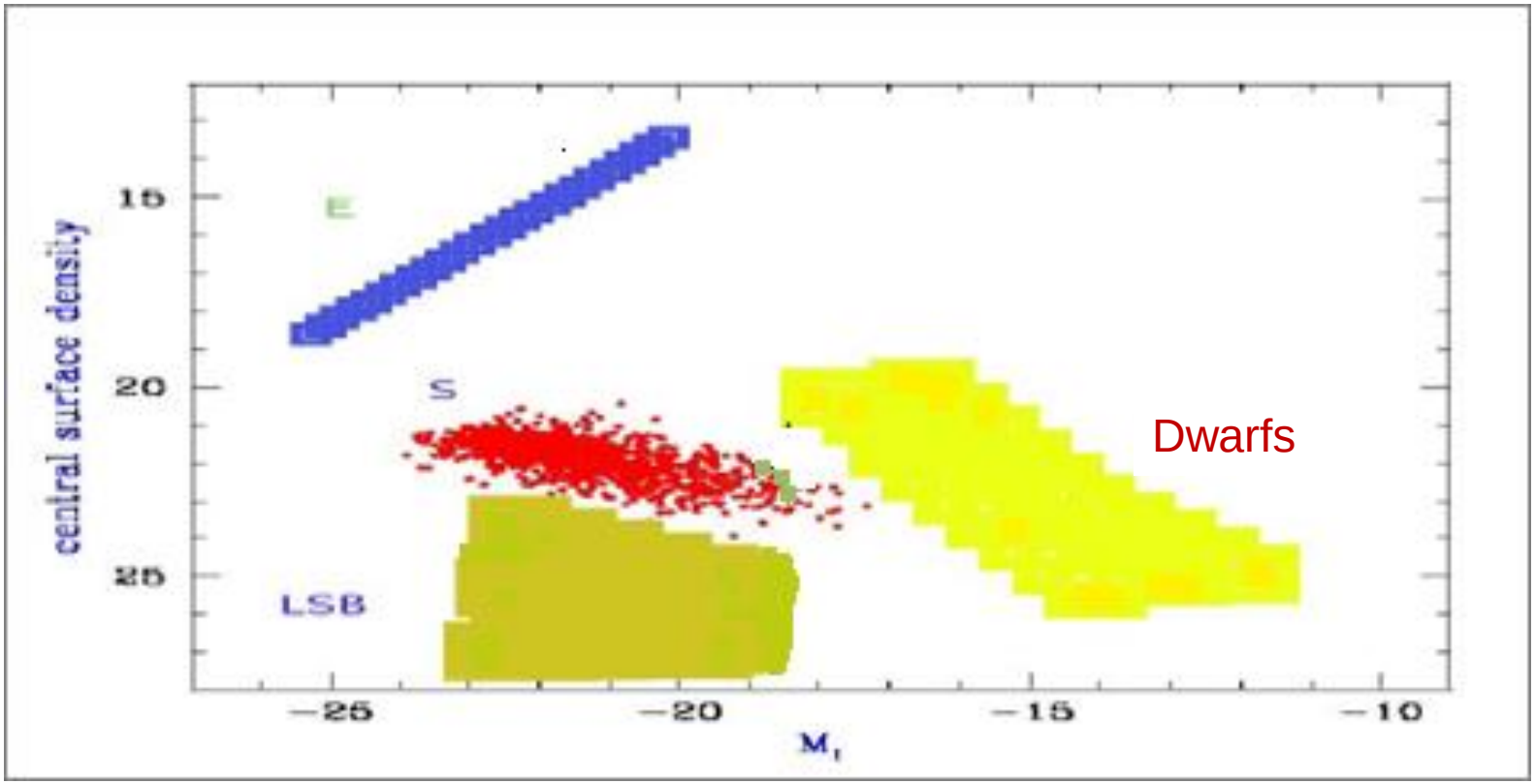


Fig. 7 Density profiles. NFW (red line), Burkert (blu line), fermionic degenerate (violet line), pseudo isothermal: $\rho_{PI}(r) \propto (r^2 + a^2)^{-1}$ with a the core radius (green line).

The Realm of Galaxies

The range of galaxies in magnitudes, types and central surface densities : 15 mag, 4 types, 16 mag arsec^{-2}

Central surface brightness vs galaxy magnitude



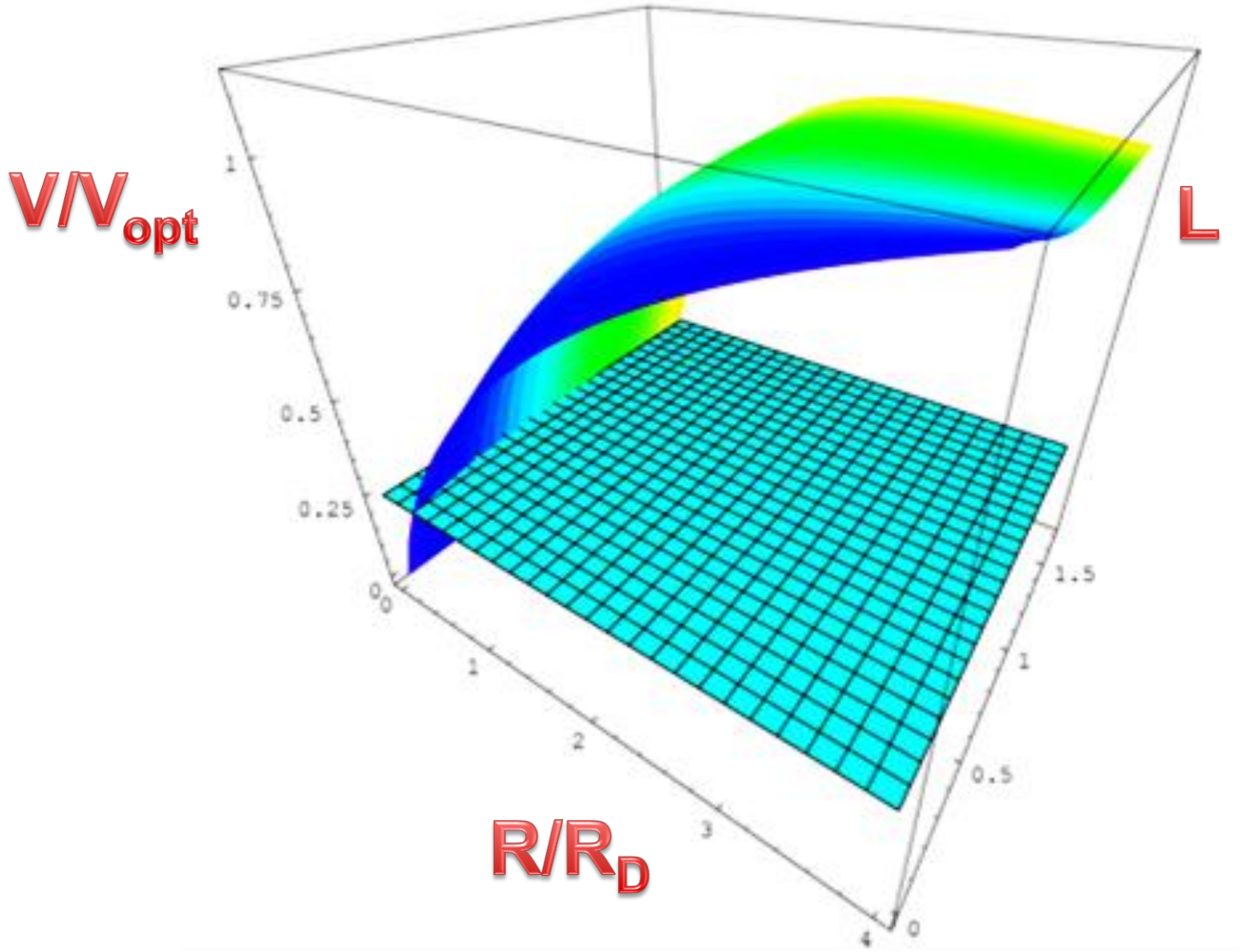
The distribution of luminous matter :

Spirals : stellar disk +bulge +HI disk

Ellipticals & dwarfs E: stellar spheroid

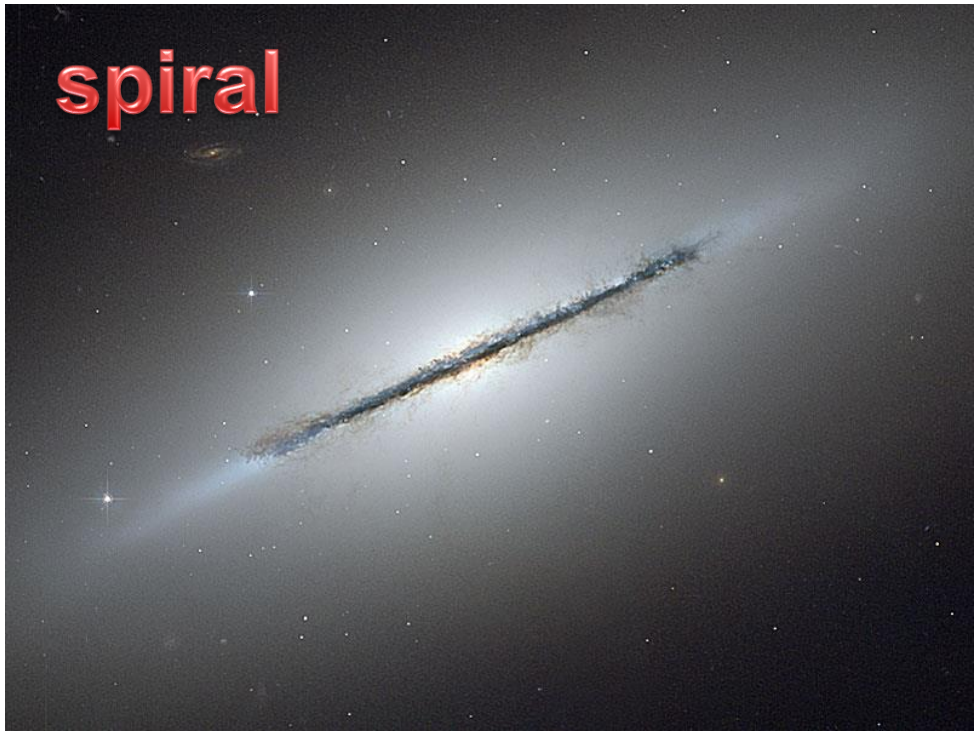
The Concept of the Universal Rotation Curve (URC)

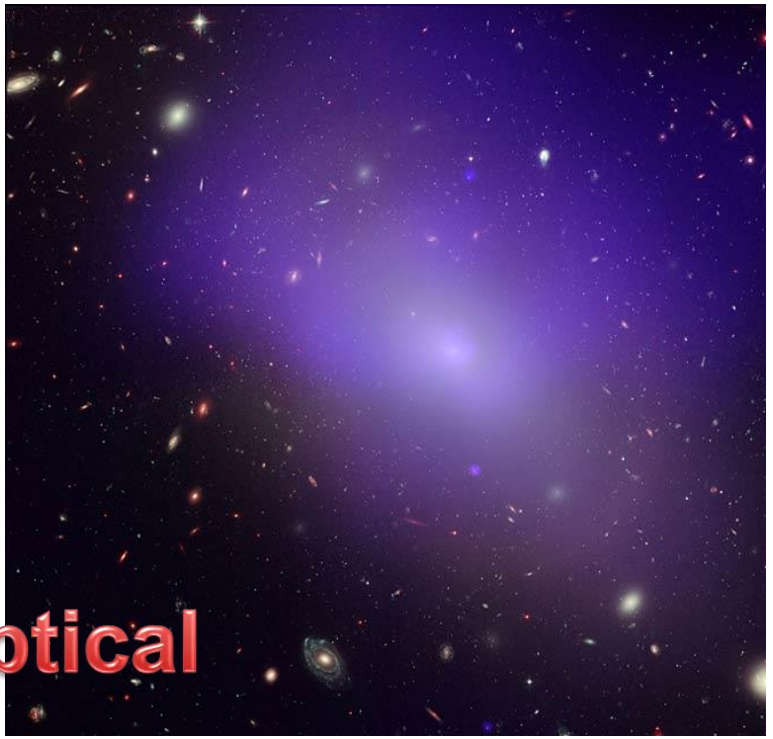
Every RC can be represented by: V(x,L) x=R/R_D



The URC out to 6 R_D is derived directly from observations
Extrapolation of URC out to virial radius by using V(R_{vir})

-> Movie 2

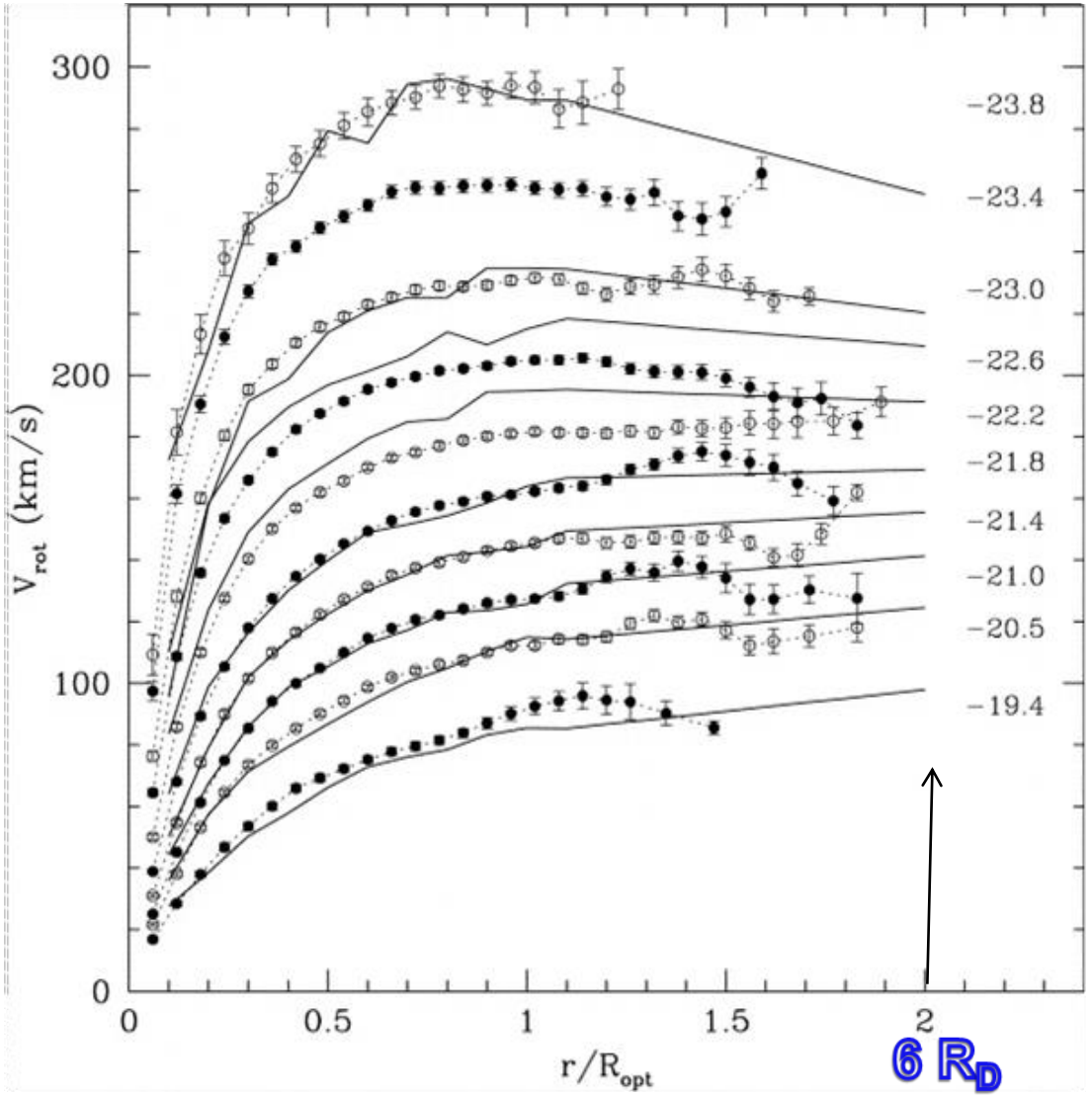




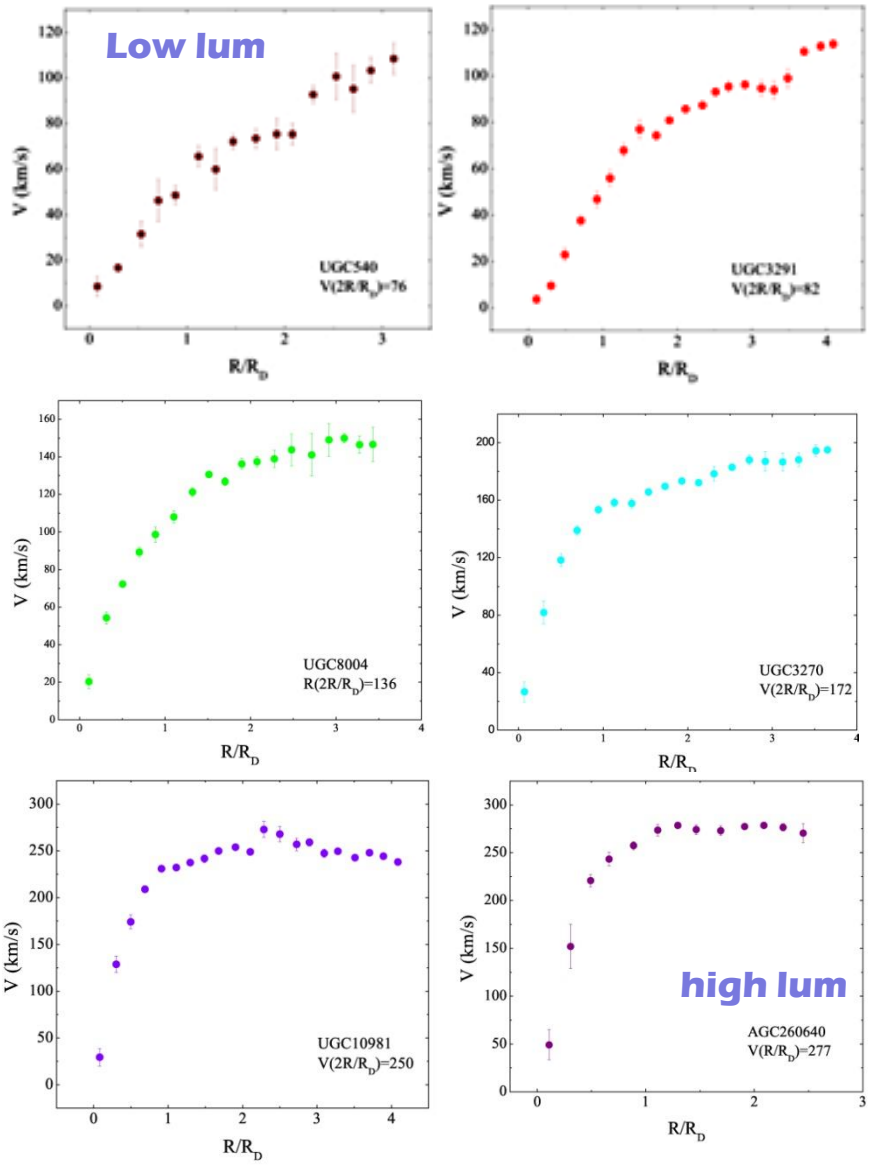
3 MAJOR TYPES OF GALAXIES

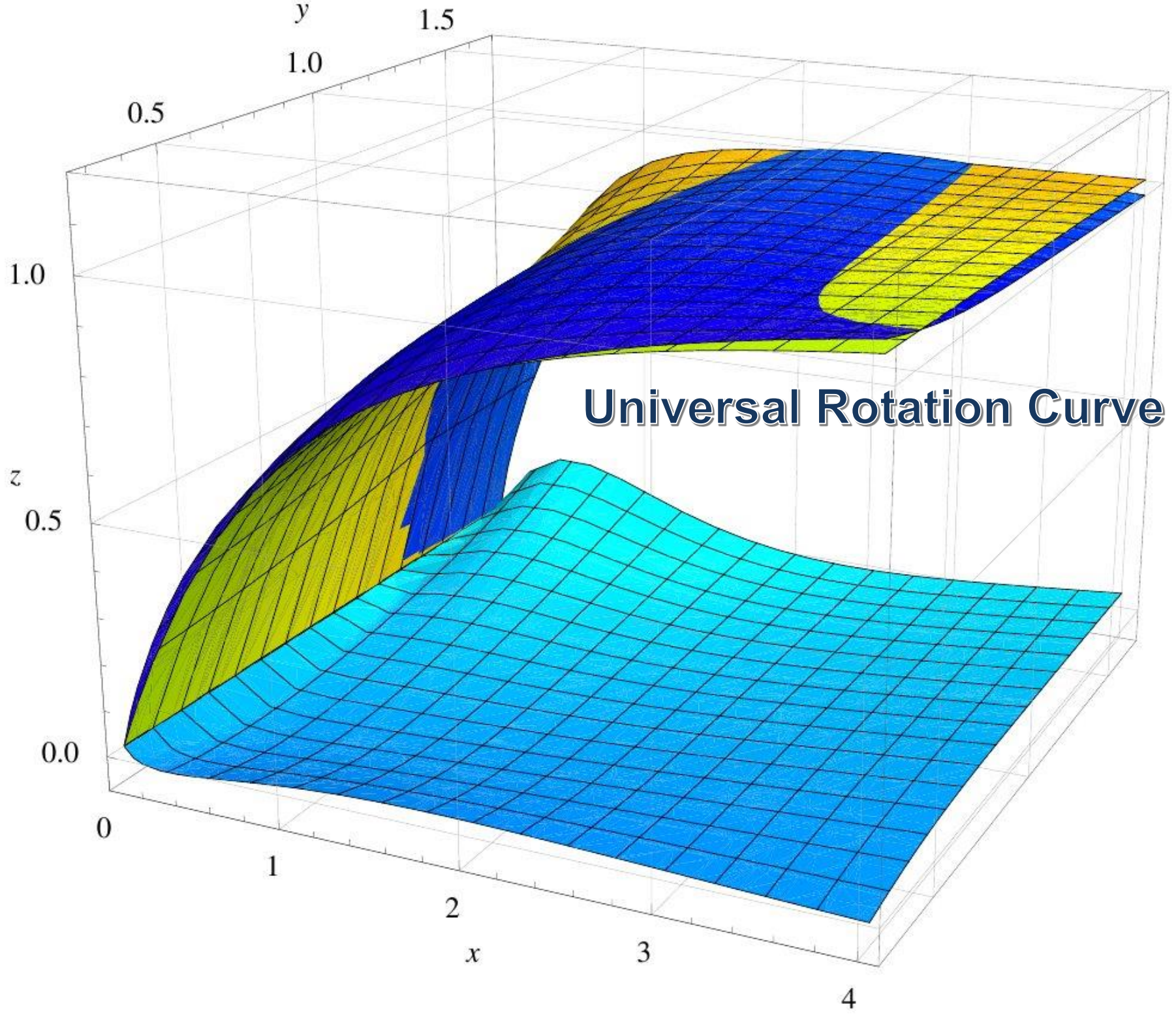
SPIRALS Rotation Curves

Coadded from 3200 individual RCs

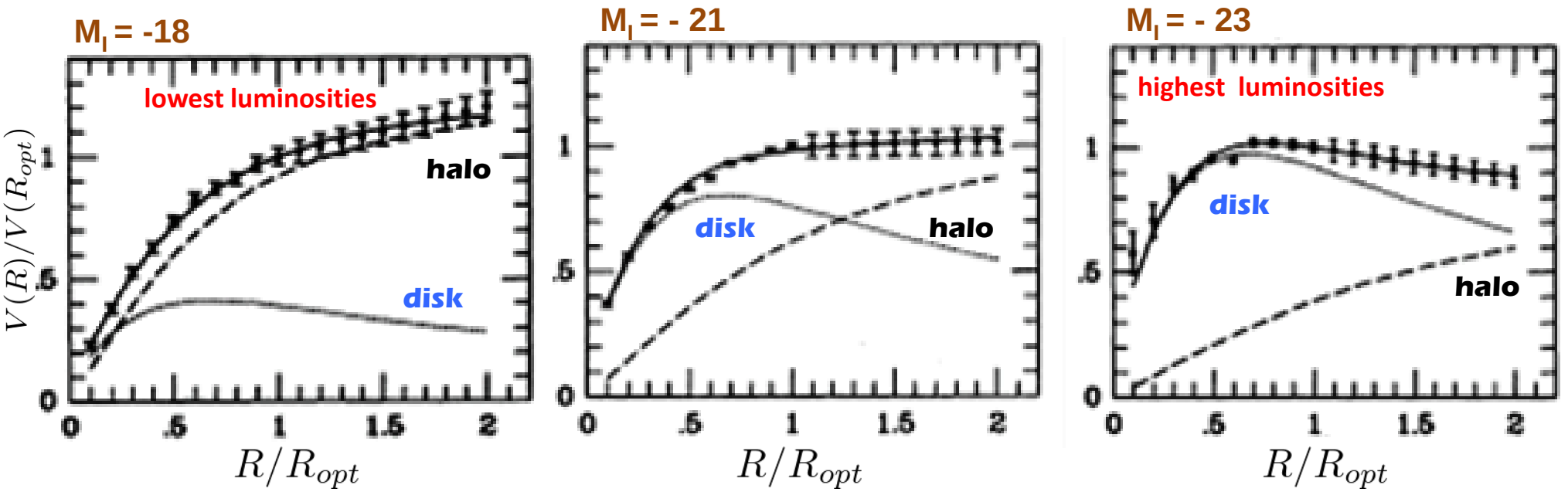


TYPICAL INDIVIDUAL RCs OF INCREASING LUMINOSITY



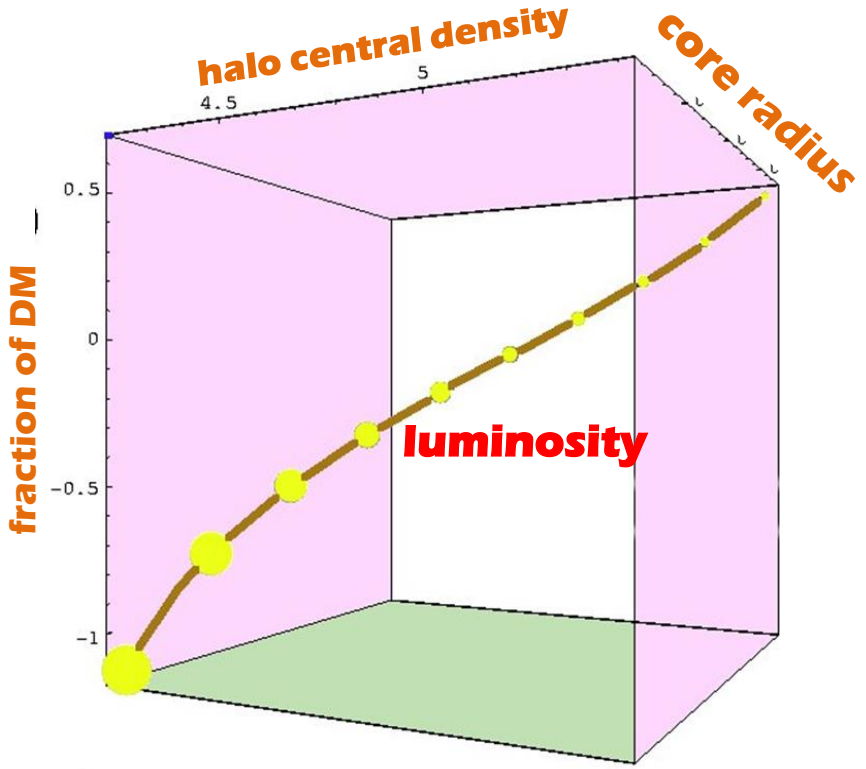

y
0.5
1.0
1.5
1.0
z
0.5
0.0
0
1
2
3
4
x
Universal Rotation Curve

MASS MODELLING RESULTS

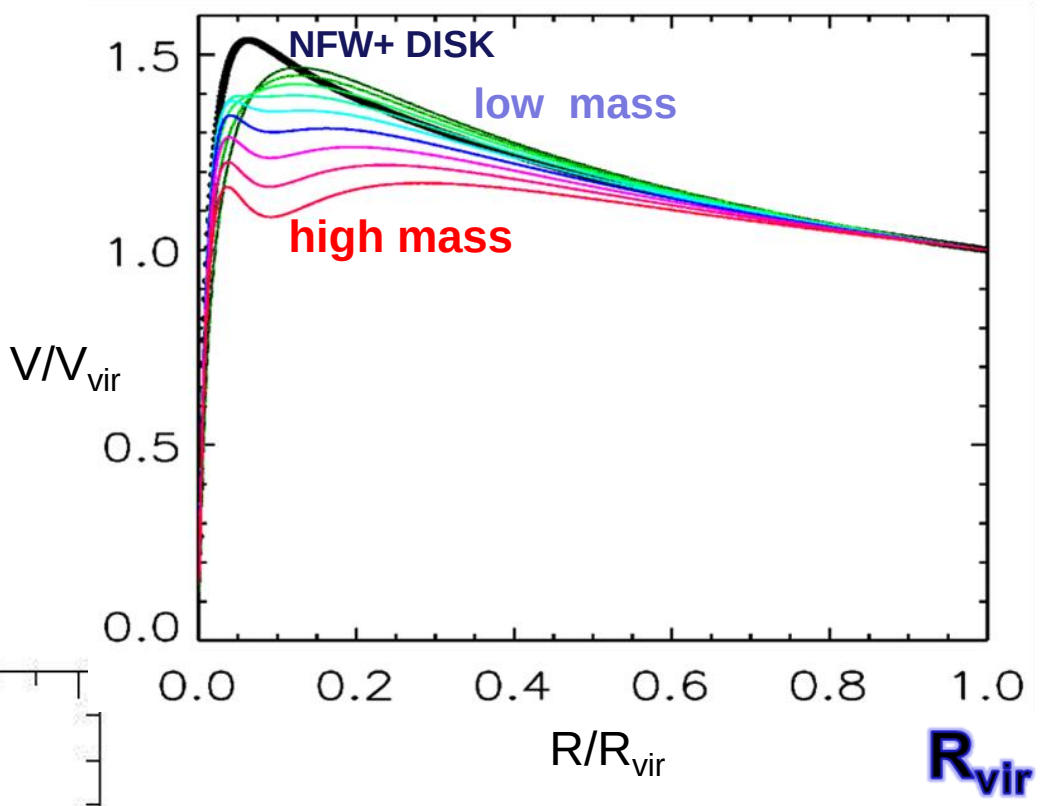


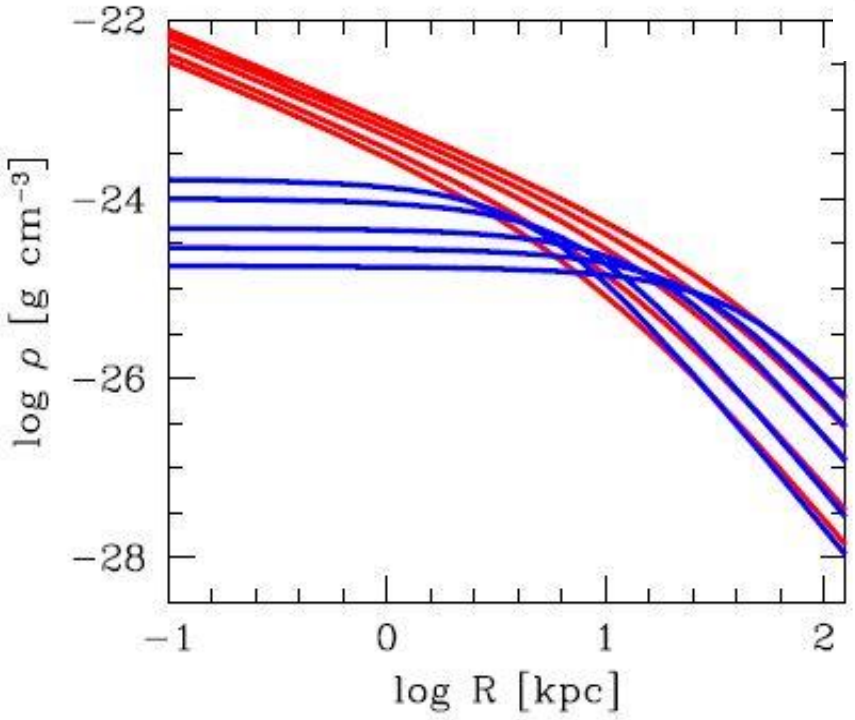
All structural DM and LM parameters are related with luminosity.g

Smaller galaxies are denser and have a higher proportion of dark matter.



U R C

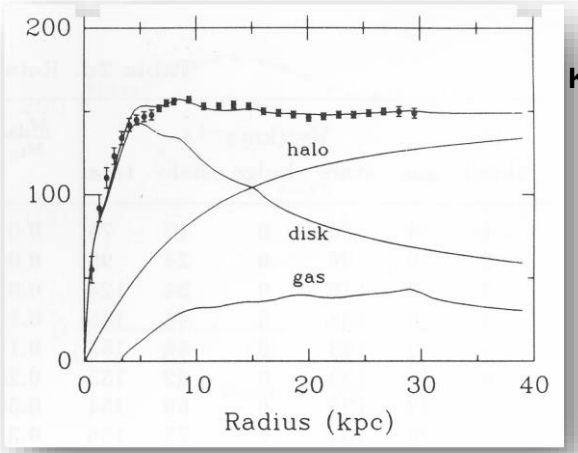

NFW+ DISK
low mass
high mass
1.5
1.0
0.5
0.0
V/V_vir
0.0
0.2
0.4
0.6
0.8
1.0
R/R_vir
R_vir


−22
−24
−26
−28
log ρ [g cm^-3]
−1
0
1
2
log R [kpc]

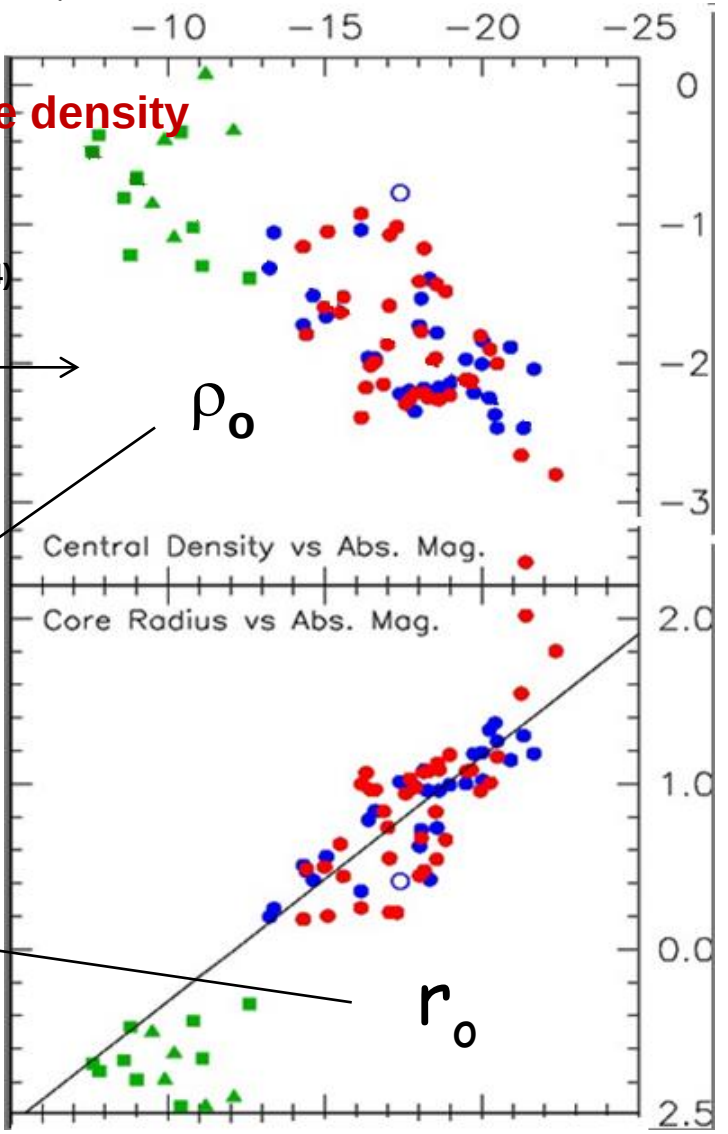
Dark Halo Scaling Laws in Spirals

Careful investigation of relationships between halo structural parameters and luminosity.
via mass modelling of individual galaxies (ρ_0, r_0)

- Assumption: Maximun Disk, 30 objects
- the central slope of the halo rotation curve gives the halo core density
- extended RCs provide an estimate of halo core radius r_0



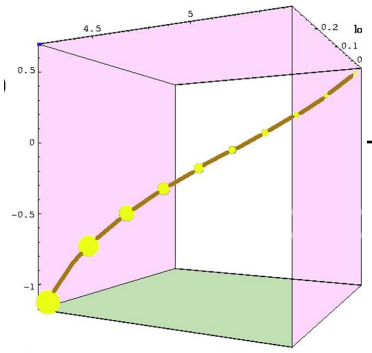
Kormendy & Freeman (2004)



ρ_o

r_o

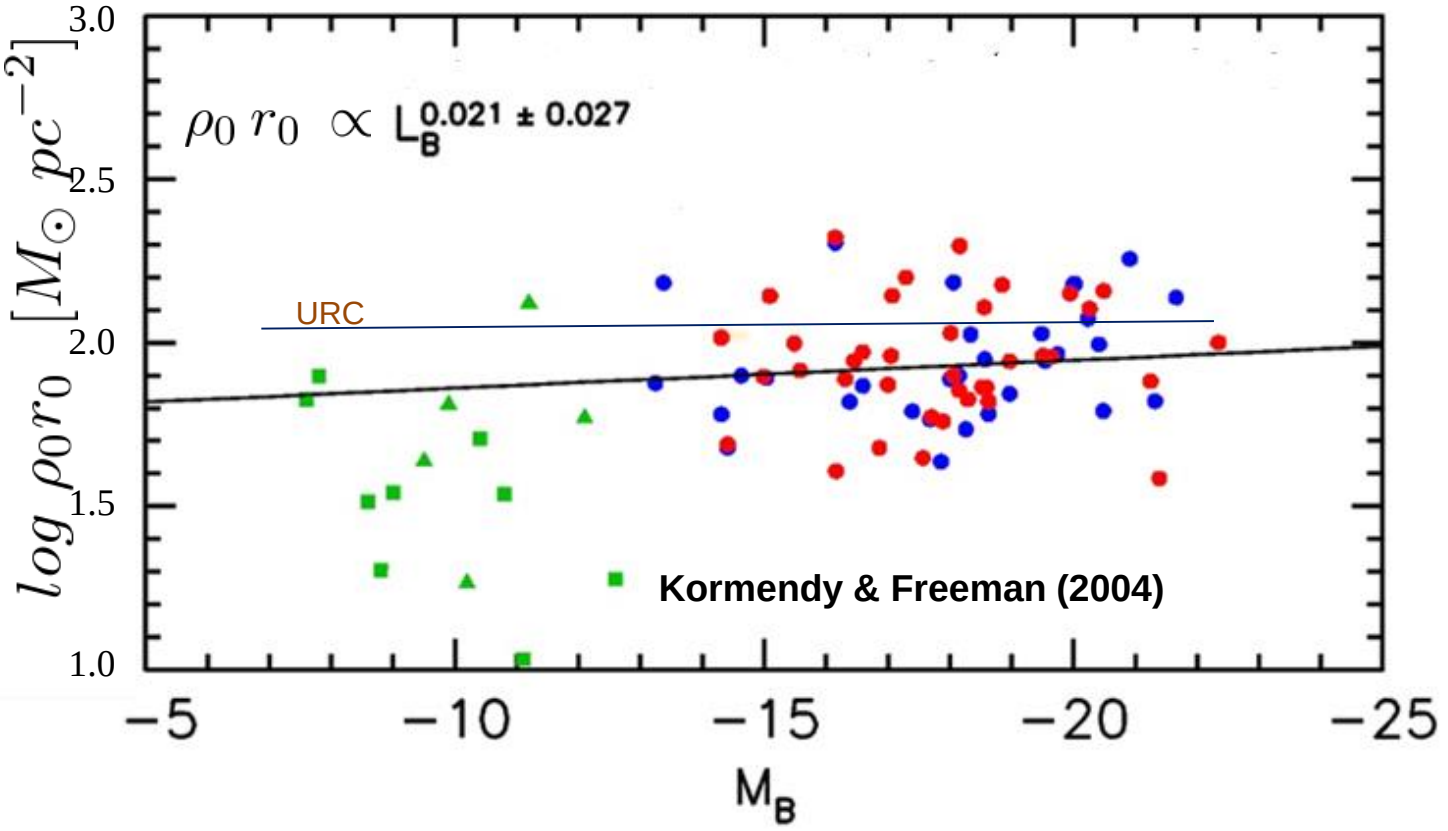
URC



$\rho_o \sim L_I^{-0.7}$ $\quad r_o \sim L_I^{0.7}$

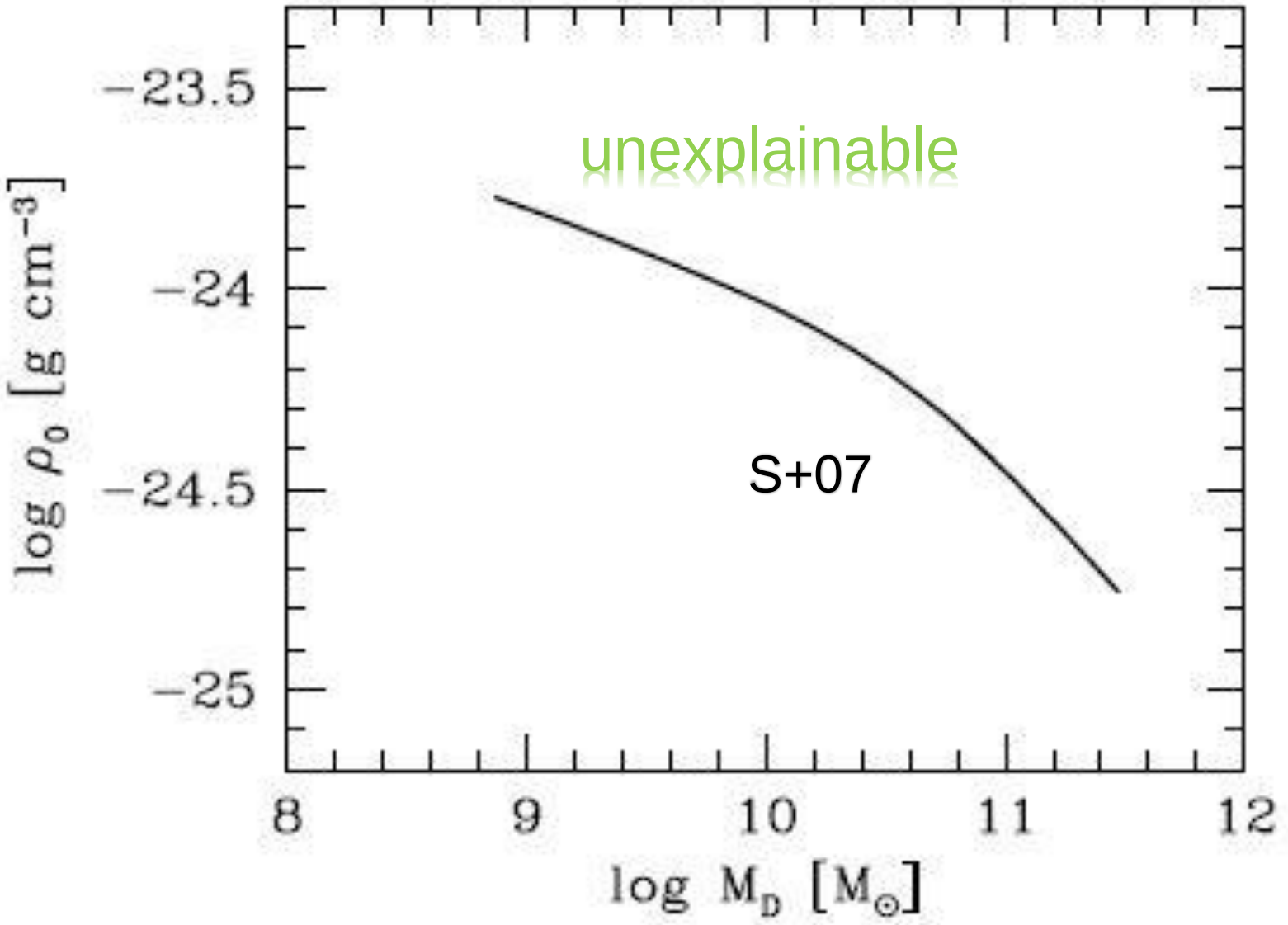
$\rho_o \sim L_B^{-0.6}$ $\quad r_o \sim L_B^{0.6}$

The halo central surface density $\rho_0 r_0$: constant in Spirals



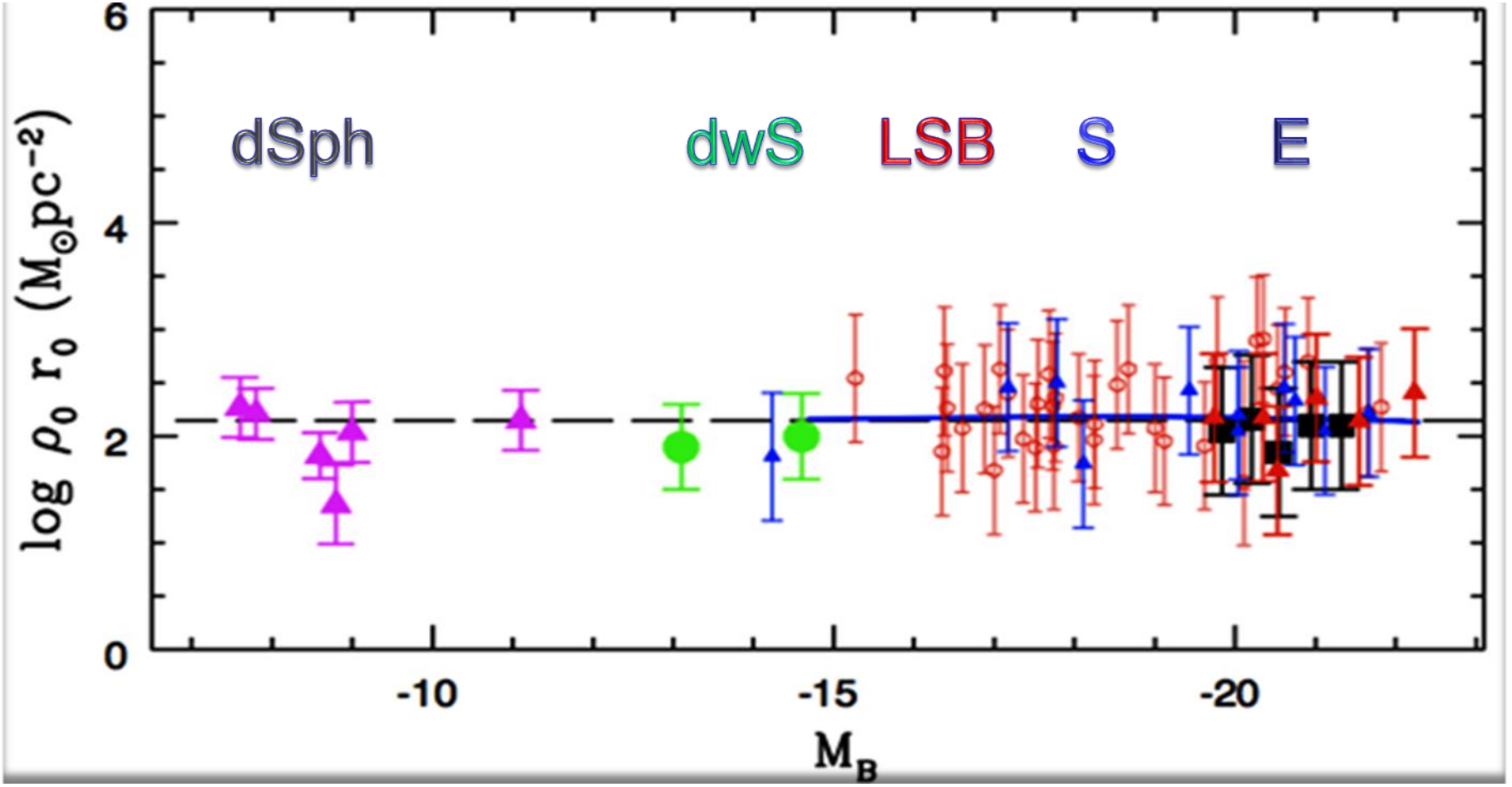
Kormendy & Freeman (2004)

Spirals


unexplainable
S+07
−23.5
−24
−24.5
−25
log ρ_0 [g cm^{-3}]
8
9
10
11
12
log M_D [$M_\odot$]

GALAXY HALOS STRUCTURAL PARAMETRES

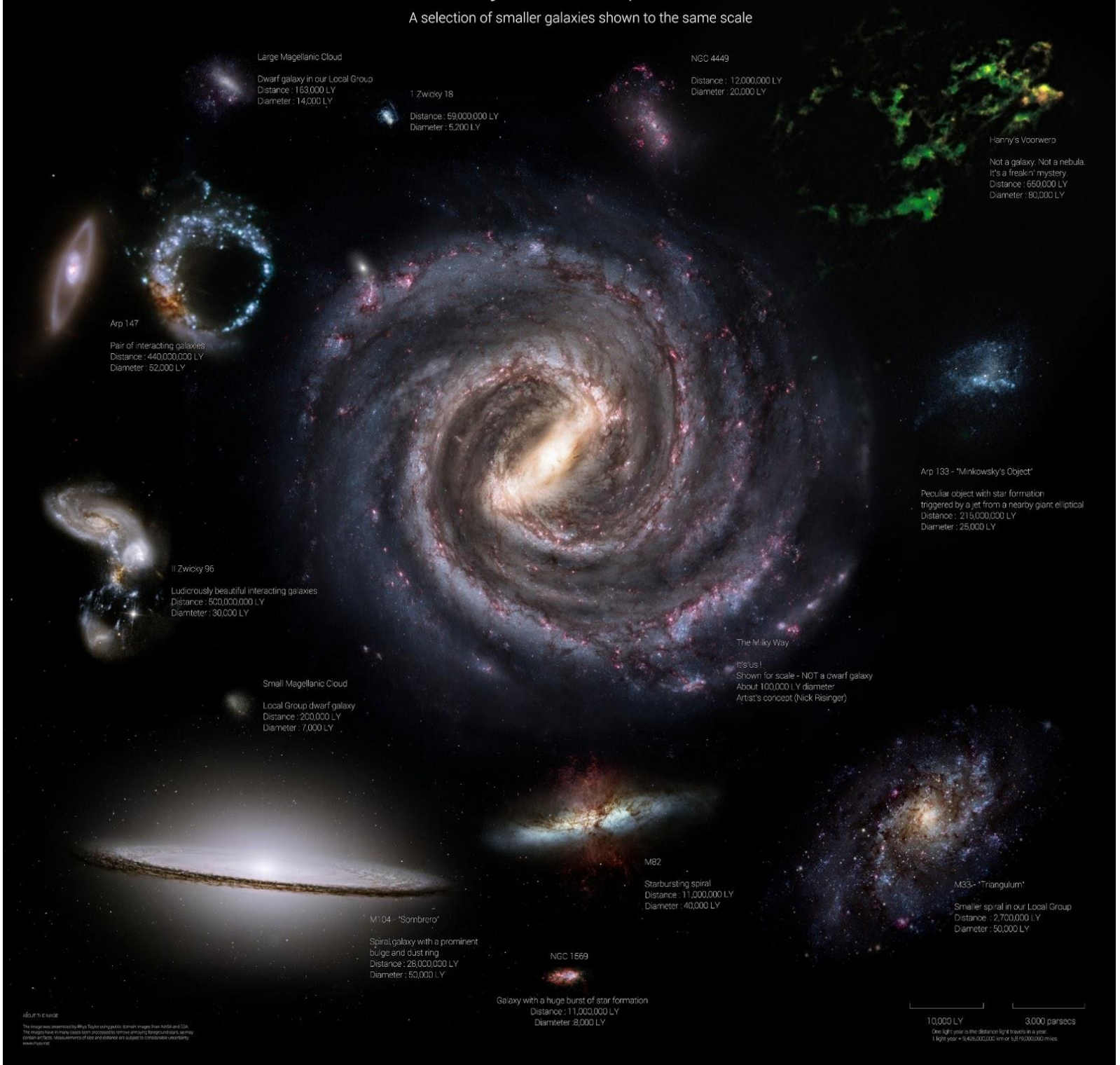
M87



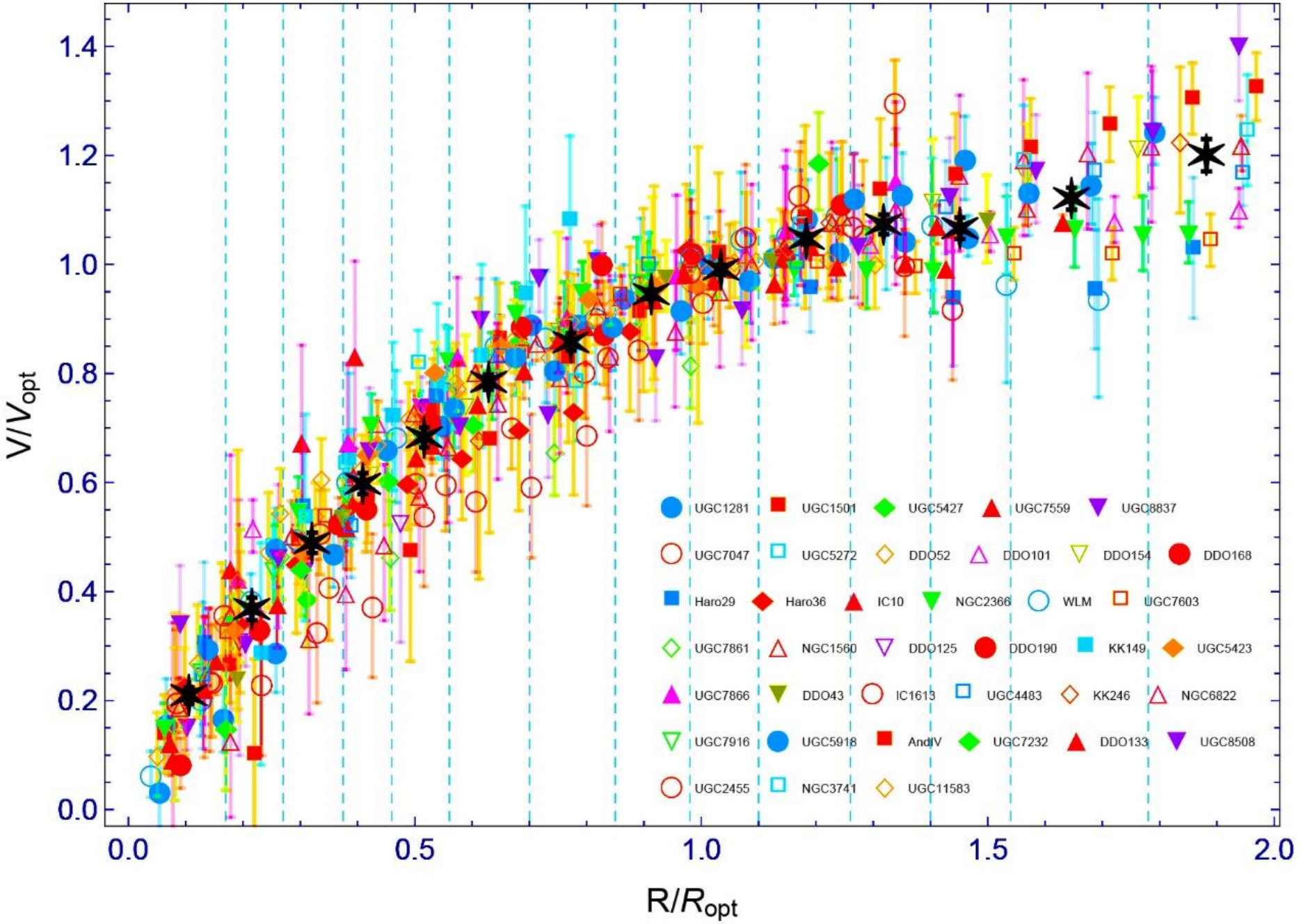
Core radii between 0.1 kpc to 100 kpc

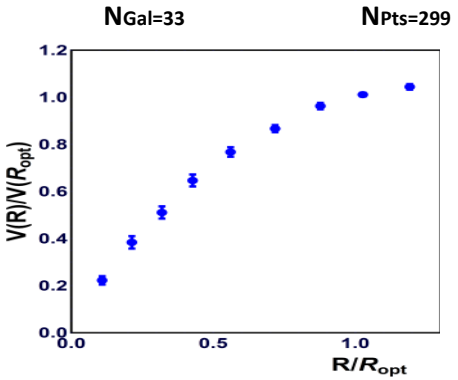
Dwarf Galaxy Size Comparison Chart

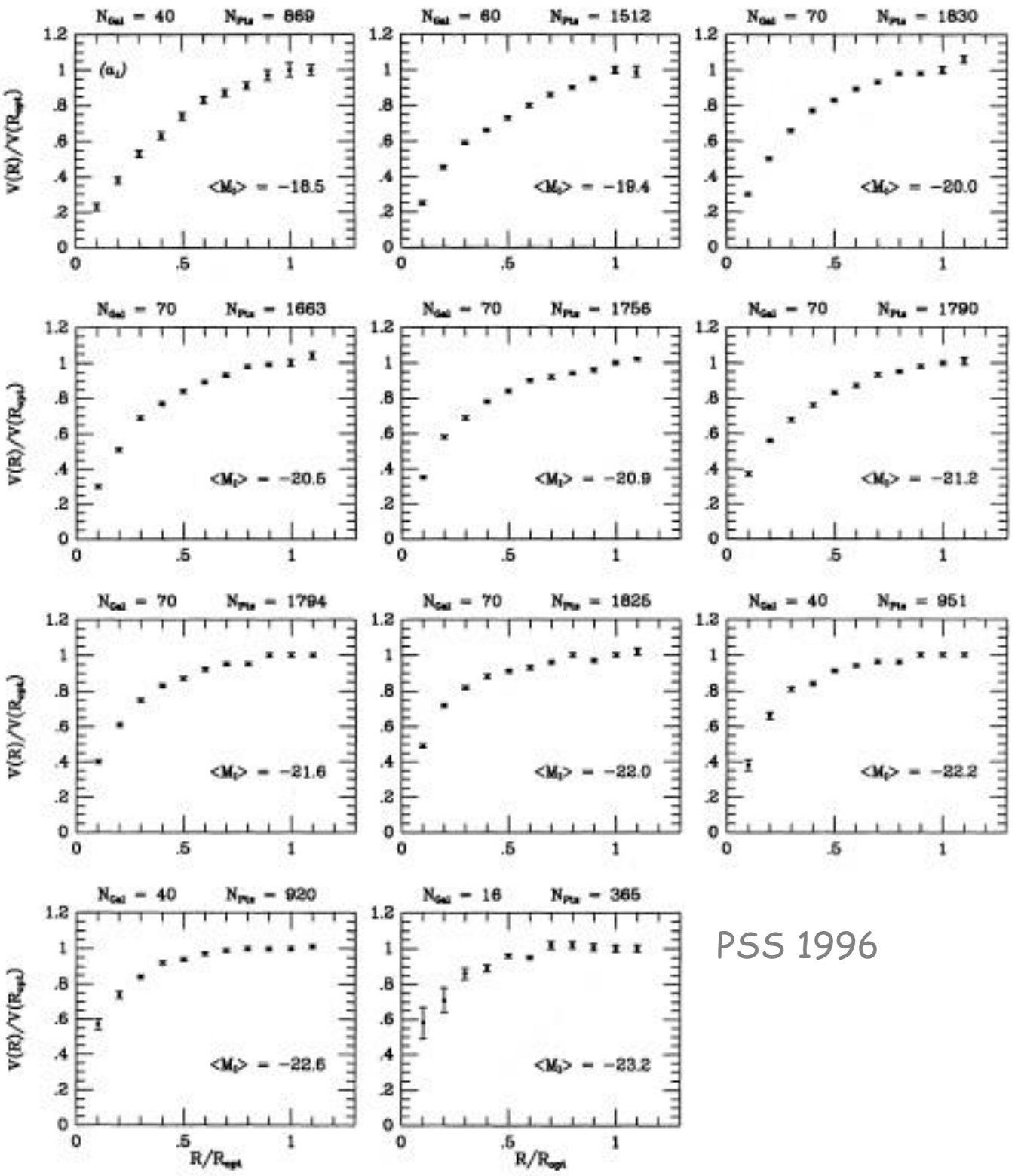
A selection of smaller galaxies shown to the same scale



Universal Rotation Curve of Dwarfs



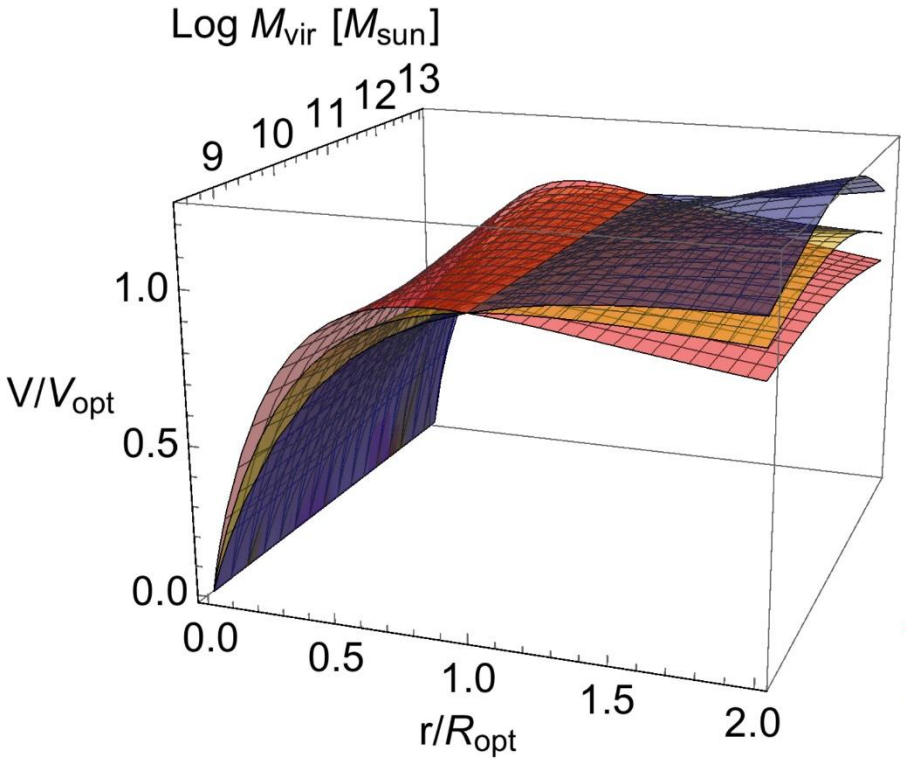


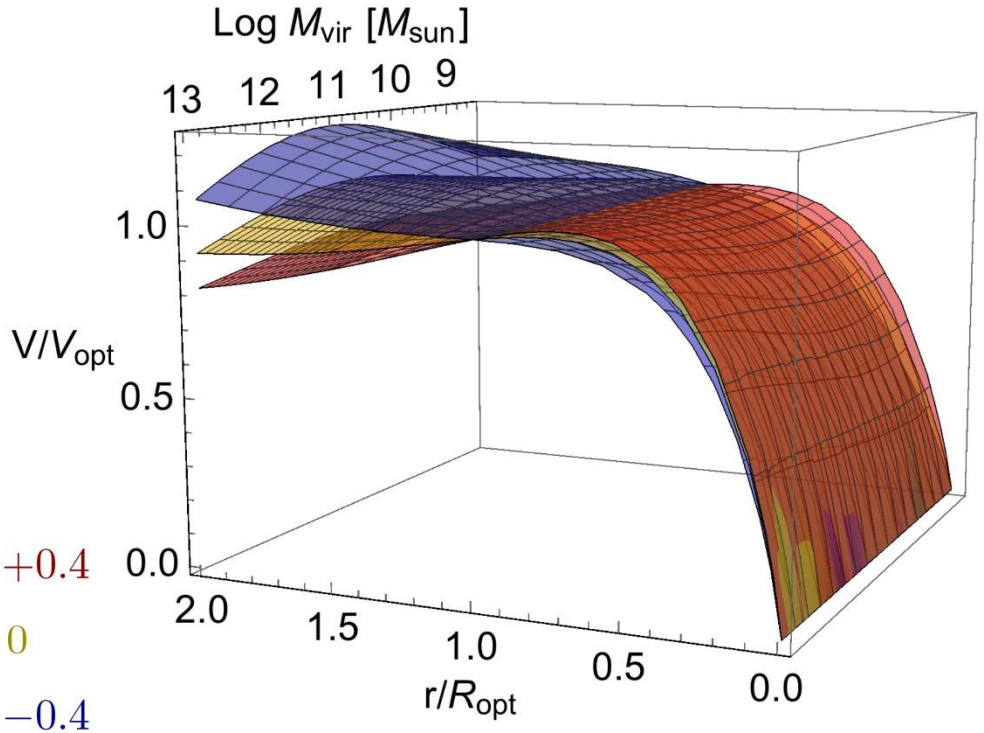


PSS 1996

Disk Dwarf Galaxies

URC LSB



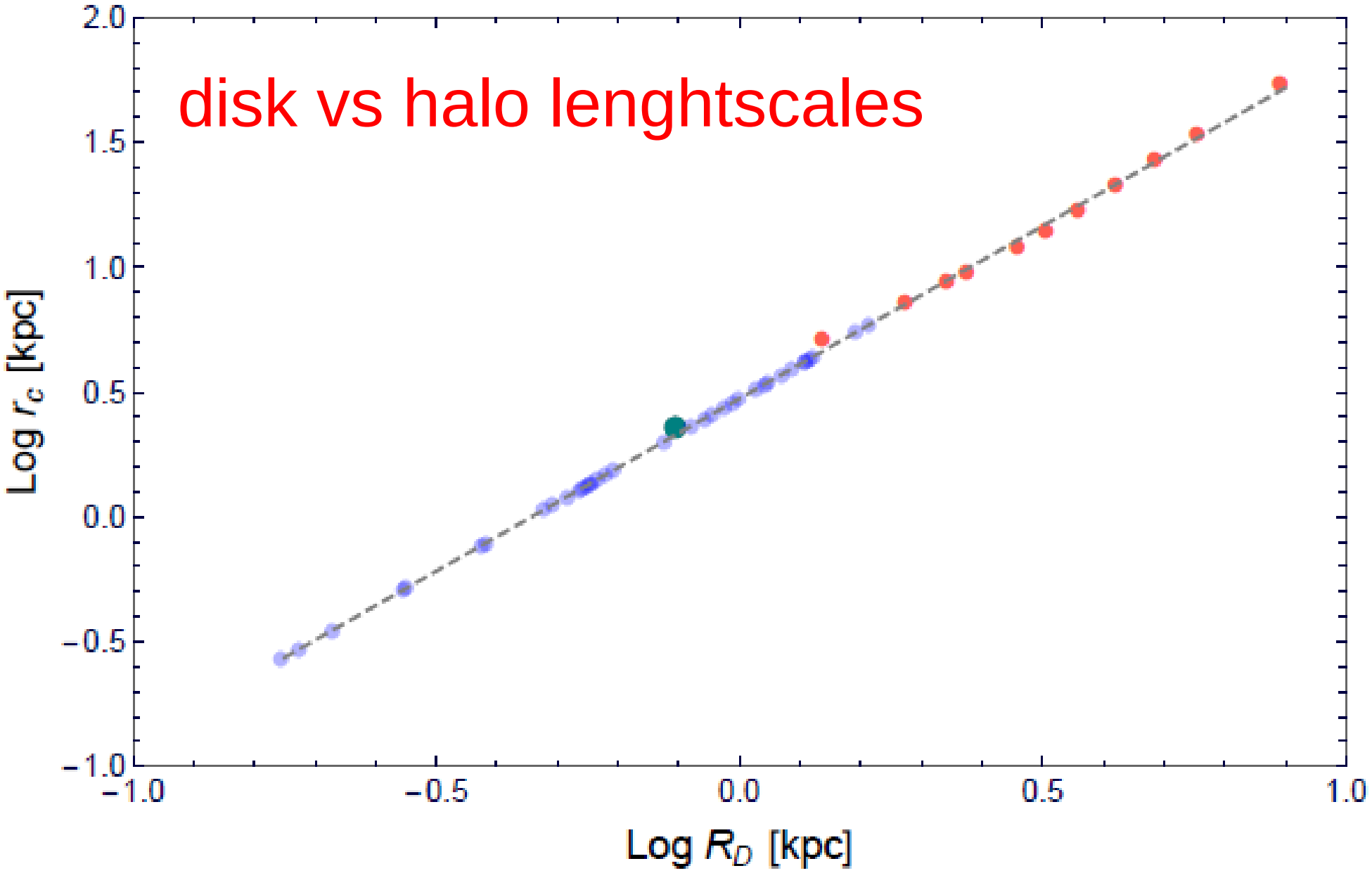


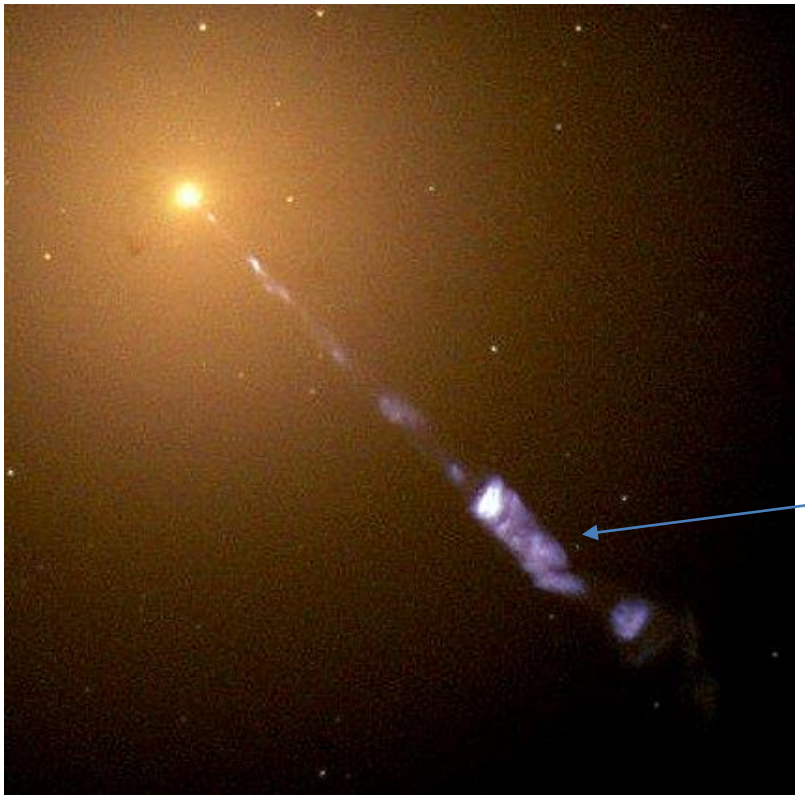
$Log\, C_* = +0.4$

$Log\, C_* = 0$

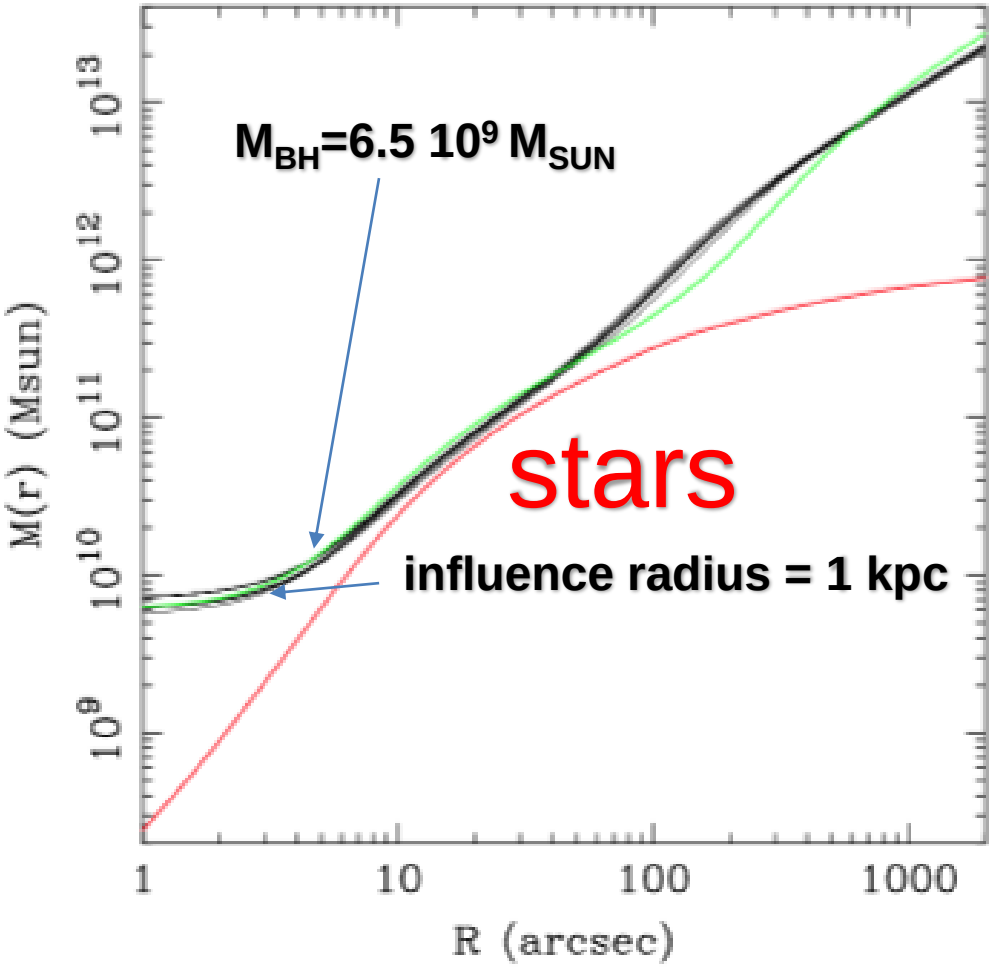
$Log\, C_* = -0.4$

MISTERY

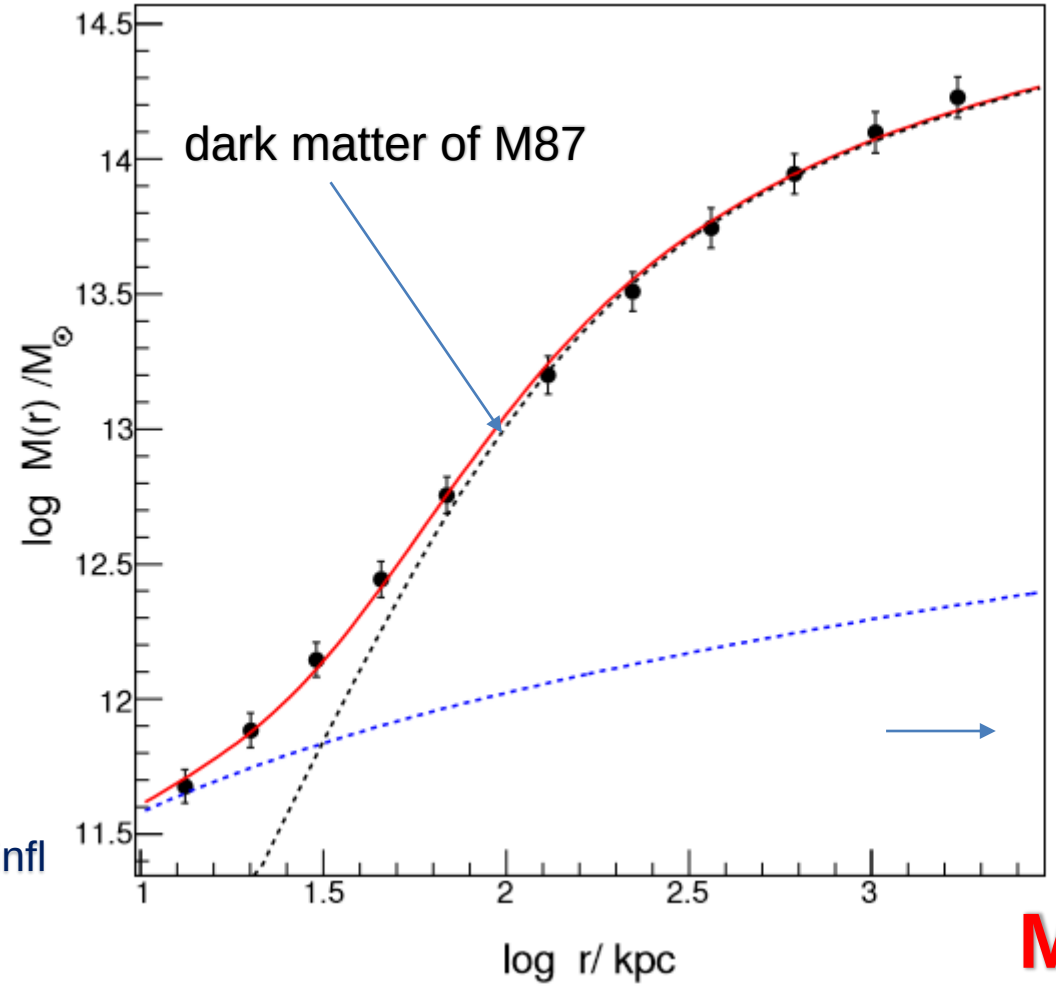

disk vs halo lenghtscales
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0
Log r_c [kpc]
Log R_D [kpc]



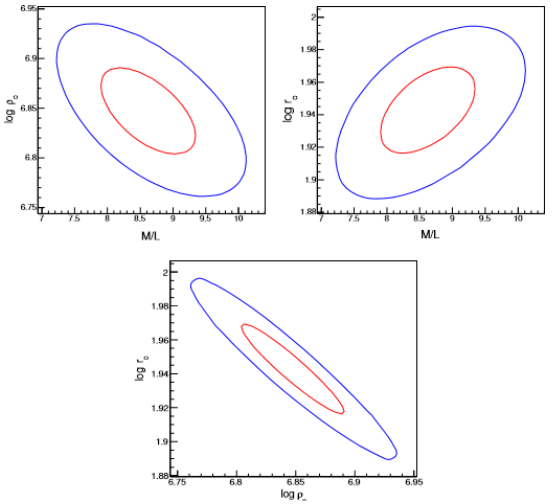
$$\rho = \gamma_v + M_{BH}\delta(r)$$



The Mass Model of M87



r_{infl}



r0 $= (91.2 \pm 9.0)$ kpc

M_{sph} $= (1.3 \pm 0.1) \times 10^{12} M_\odot$

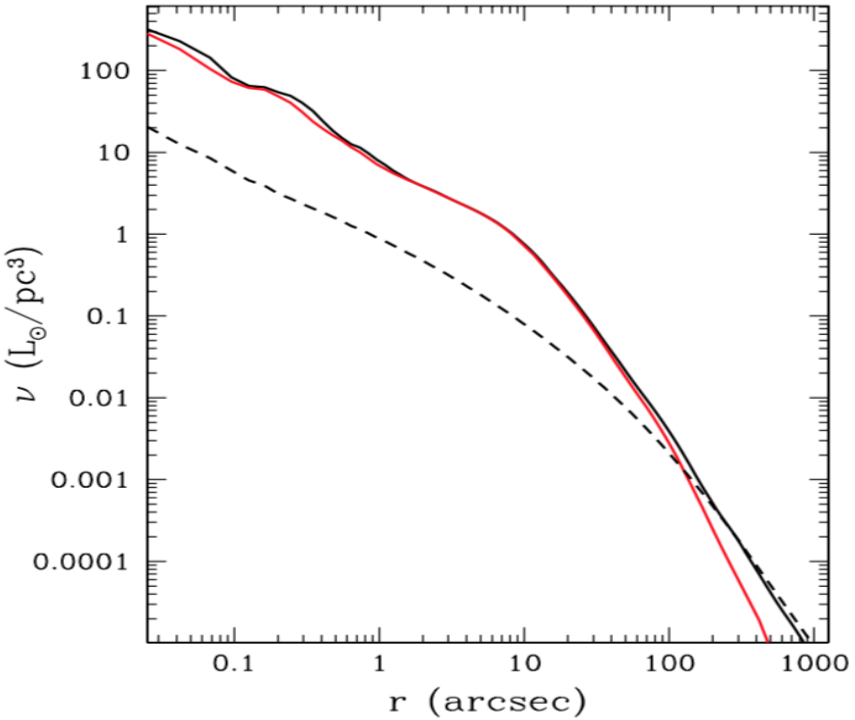
$M/L_V = (8.6 \pm 1.2) M_\odot L_\odot^{-1}$.

log Mvir/Msun=14.0

rho_0 $= (6.9 \pm 1.4) \times 10^6 M_\odot / kpc^3$

$$M_\star(r) = -M/L \int_0^r r^2 \left(\int_r^\infty \left(\frac{dI(R)}{dR} \right) \frac{dR}{\sqrt{R^2 - r^2}} \right) \qquad I(R) = I_0 \left(\frac{R}{R_b} \right)^{-\zeta} \left(1 + \left[\frac{R}{R_b} \right]^\alpha \right)^{\frac{\zeta - \eta}{\alpha}}$$

Where, $I_0 = 3.5 \times 10^9 L_\odot kpc^{-2}$, $\zeta = 0.186$ the inner slope, $\eta = 1.88$ the outer slope and $r_b = 1.05 kpc$ the break radius, $\alpha = 1.27$ the break softening and adopted from (Oldham &



from Mass distribution to Density distribution

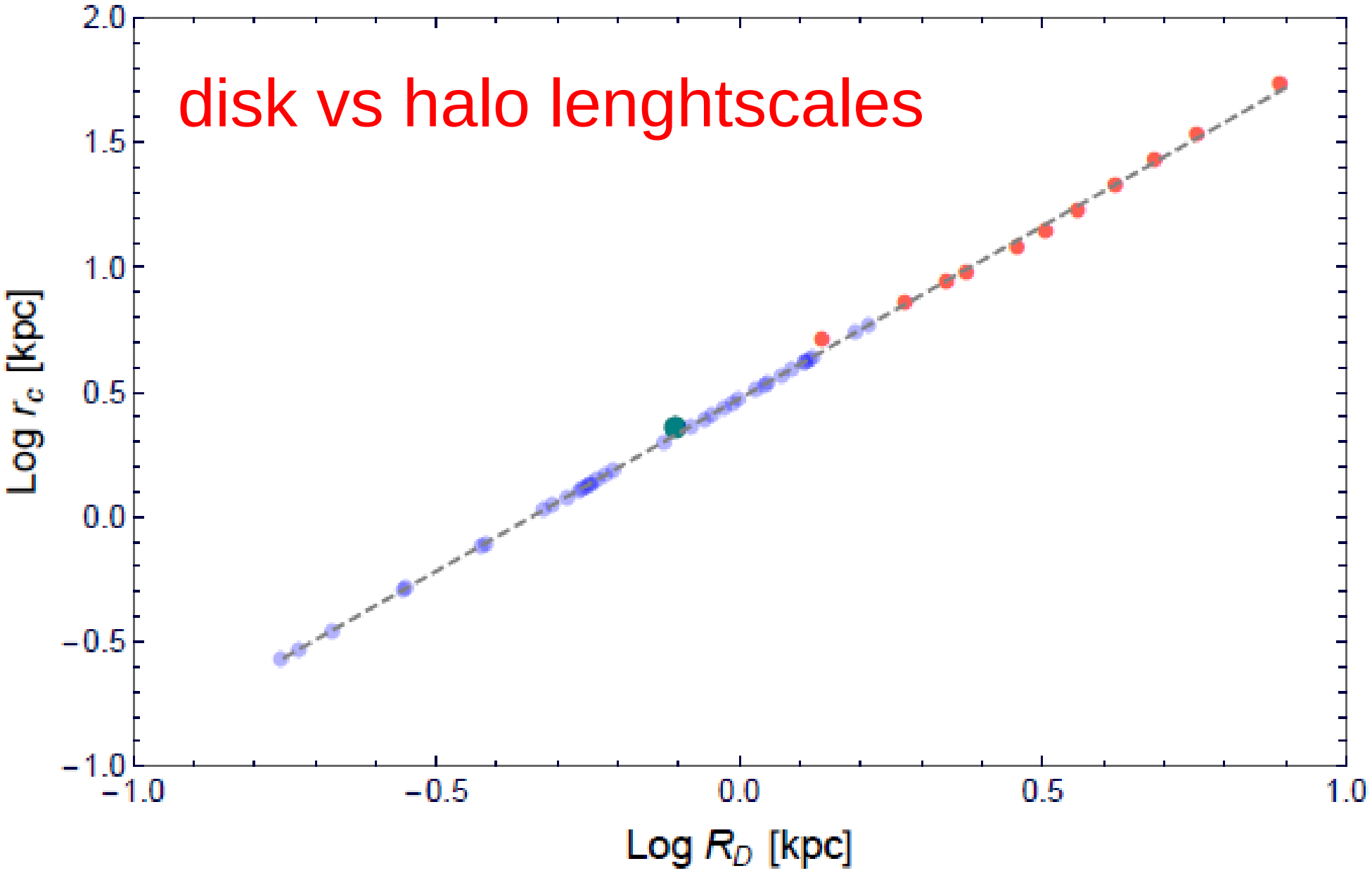
Modelling the giant galaxy

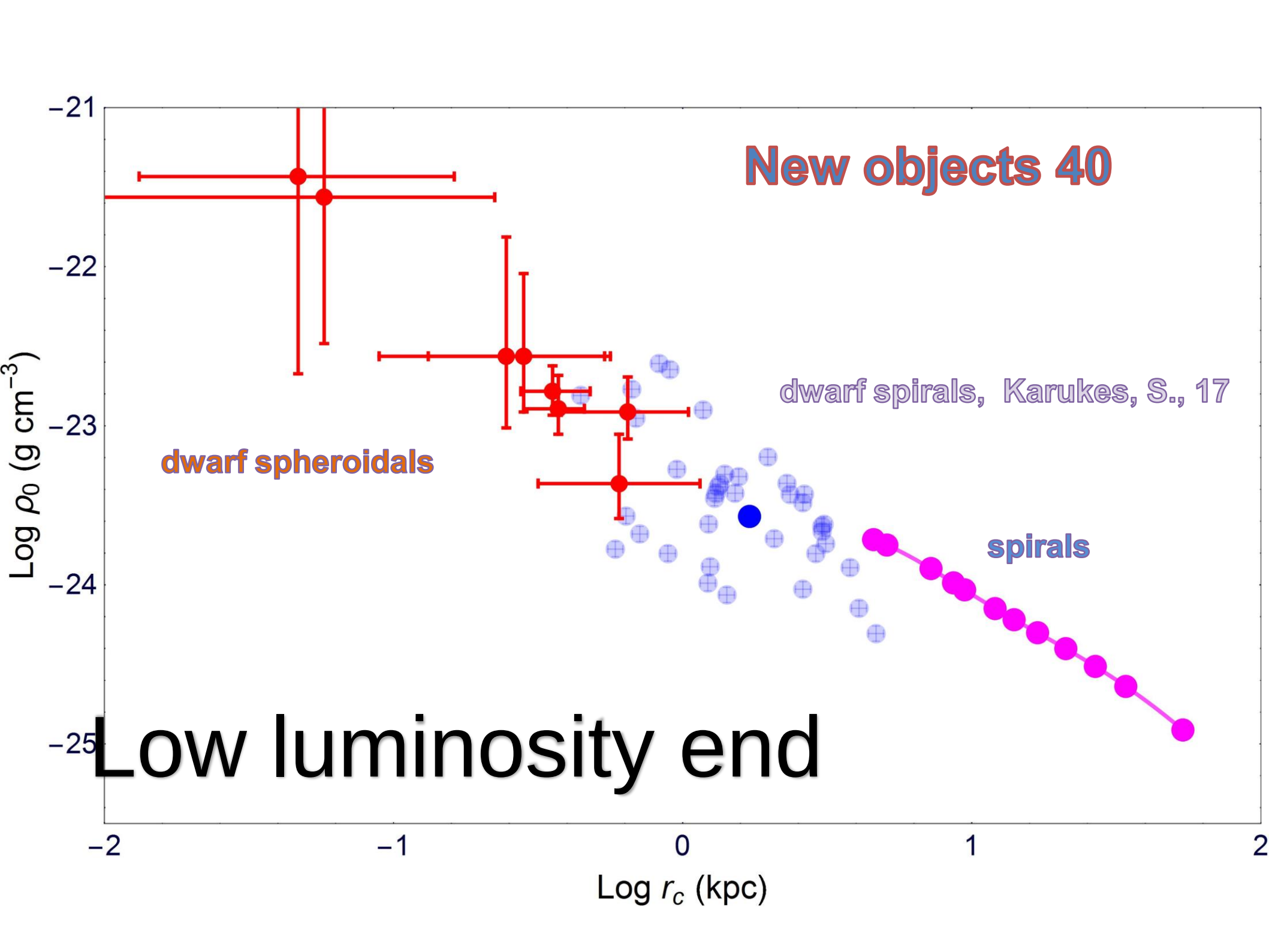
$$M(r) = M_\star(r) + M_h(r)$$

$$\frac{d}{dr}\nu(r)\sigma_r^2(r) + \frac{2\beta}{r}\nu(r)\sigma_r^2(r) = \nu(r)\frac{GM(r)}{r^2}$$

Jeans Equation

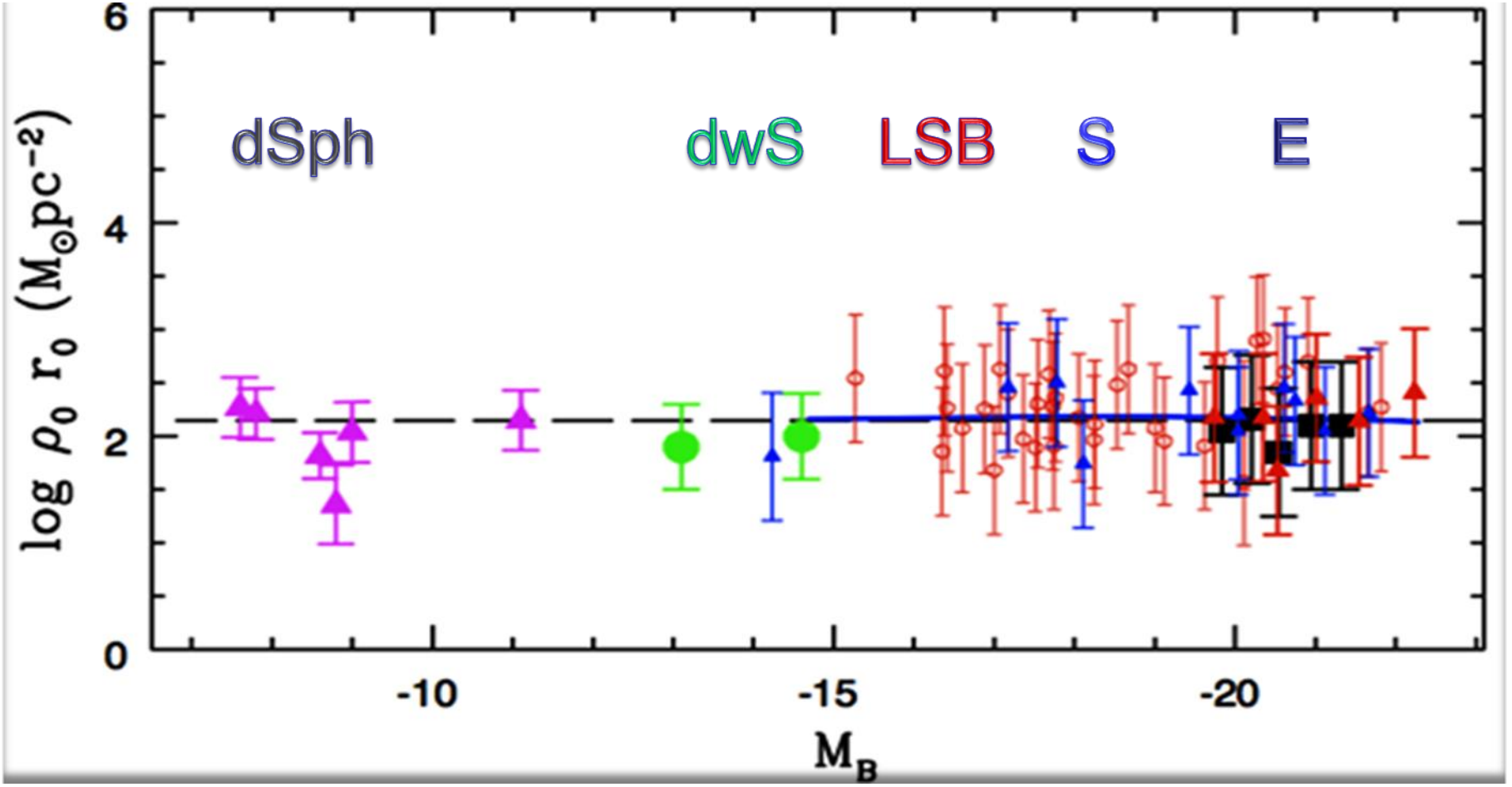
MISTERY


disk vs halo lenghtscales
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0
Log r_c [kpc]
Log R_D [kpc]


New objects 40
dwarf spirals, Karukes, S., 17
dwarf spheroidals
spirals
Low luminosity end
−21
−22
−23
−24
−25
−2
−1
0
1
2
Log ρ_0 (g cm^{-3})
Log r_c (kpc)

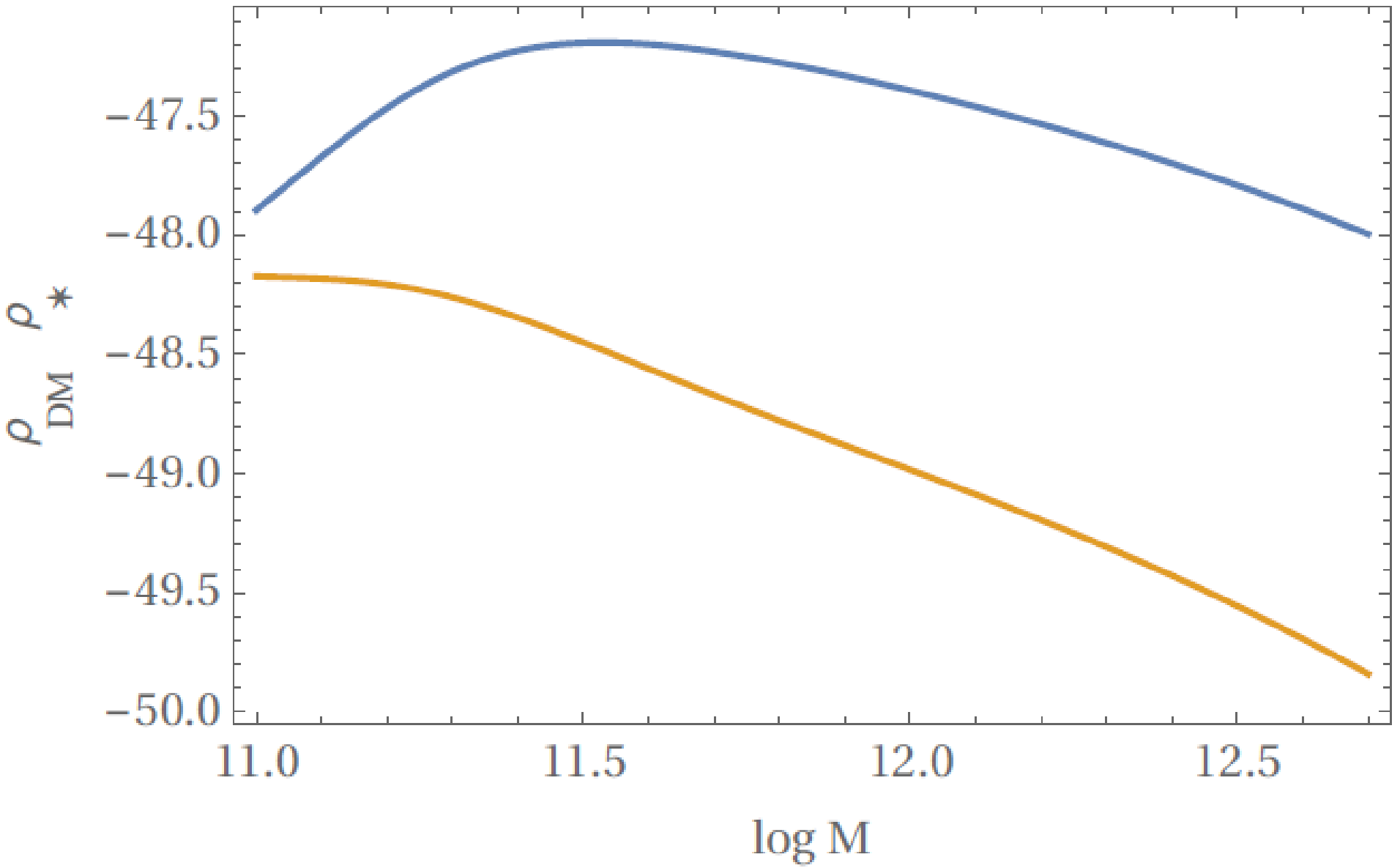
GALAXY HALOS STRUCTURAL PARAMETRES

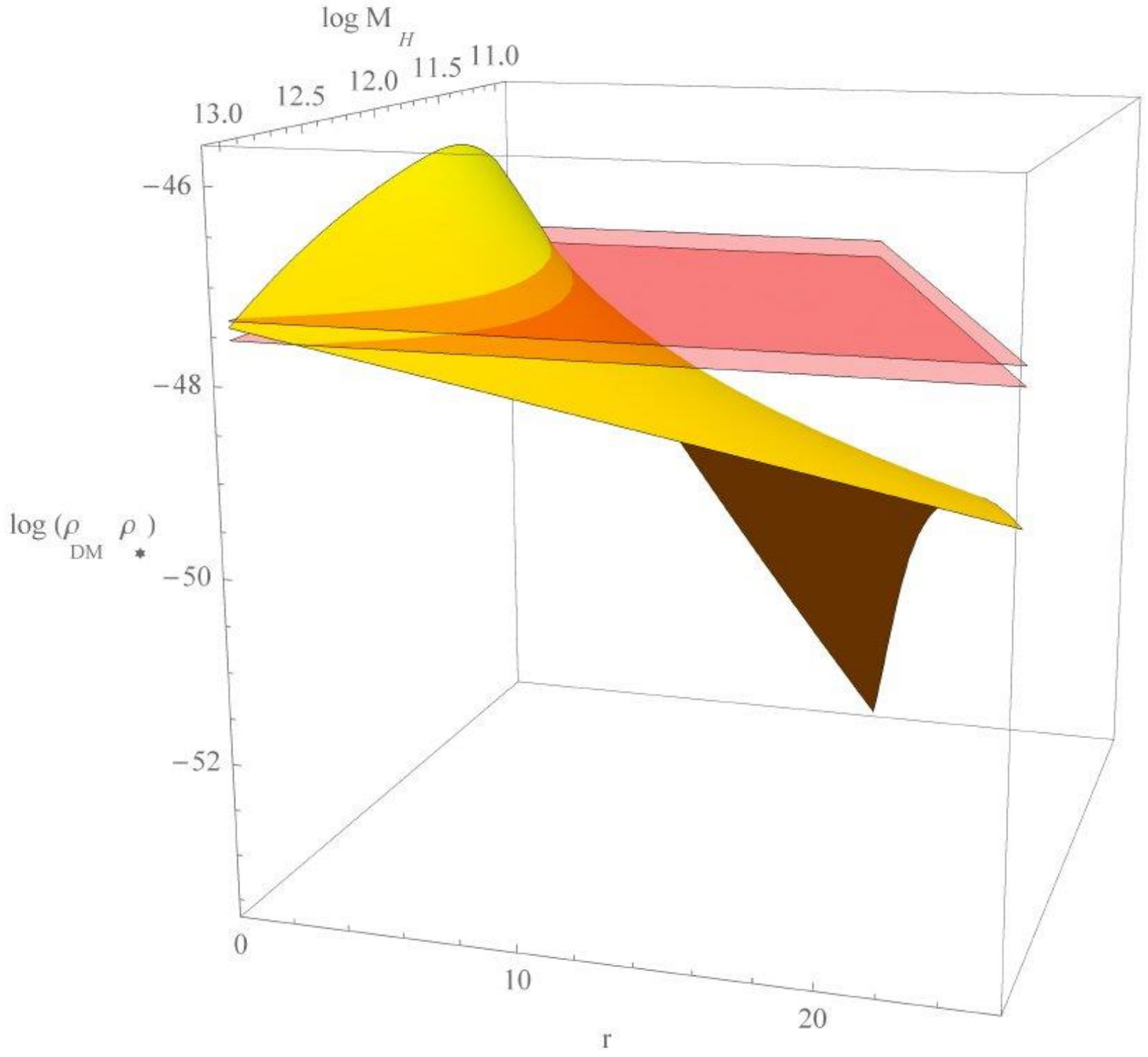
M87



Core radii between 0.1 kpc to 100 kpc

Product of DM and LM densities at core radius




log M H
13.0
12.5
12.0
11.5
11.0
−46
−48
−50
−52
log (ρ DM ρ *)
0
10
20
r

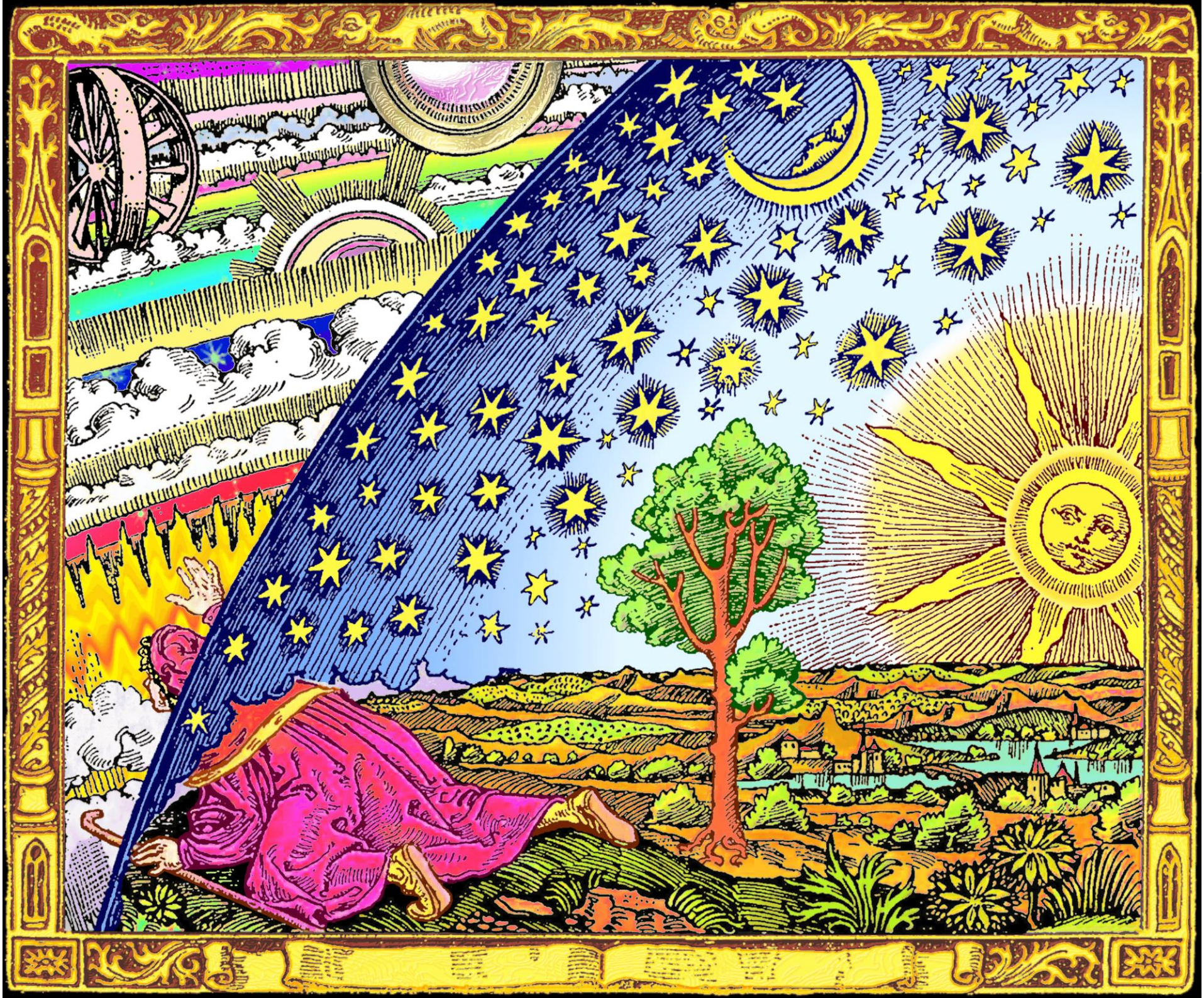
New Paradigm

MOTIVATION
In galaxies, physical quantities, deep rooted in the Dark World, correlate with the most important quantities of the Luminous World. This colllides paradigm according to which dark and luminous matter interact only through the gravitational force.

We propose that in halos dark particles, over the Hubble time, exchange a fraction of their kinetic energy with the ordinary matter.

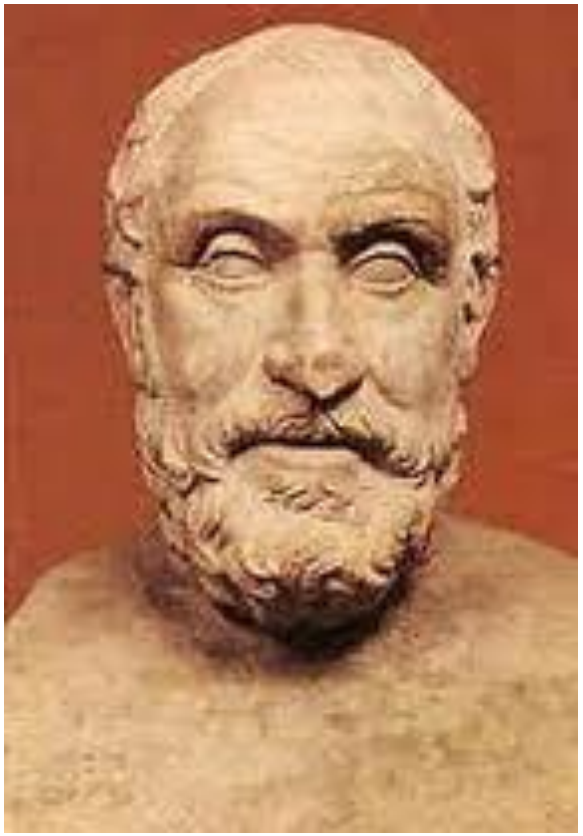
This opens a talking line between dark and luminous matter so that h the above relations are a straight dynamical outcome of the above new interactions.

We postulate then existence of a *collisional* Dark Matter Particle acting in an astrophysically relevant way. Crucially in this paradigm we work in a reverse engereeing model / The foundations of the new theory rests in galaxy properties but any other cosmological observation also helps in selecting the correct theory from a plethora of possibilities



Conclusions

The Nature of the Dark matter



Pirrone: We do not know.