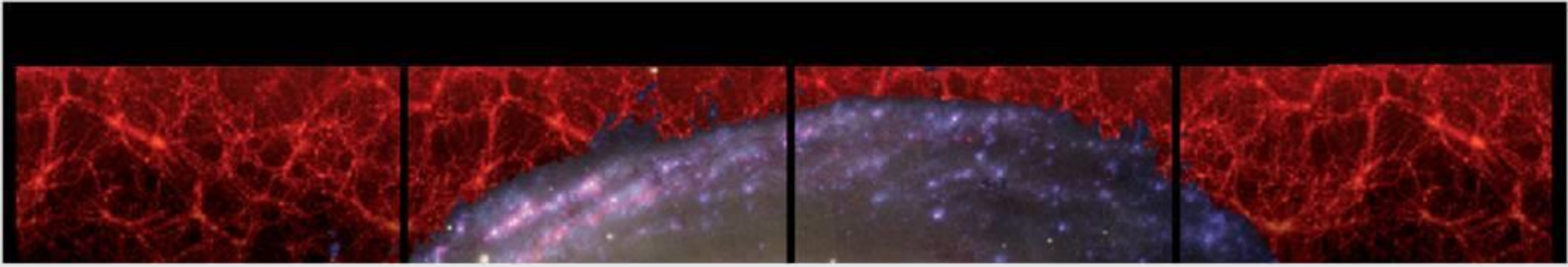


The nature of Dark Matter: observations and experiments

Nicola Turini
Paolo Salucci

CERN, TeVPA,12-16 Sept 2016

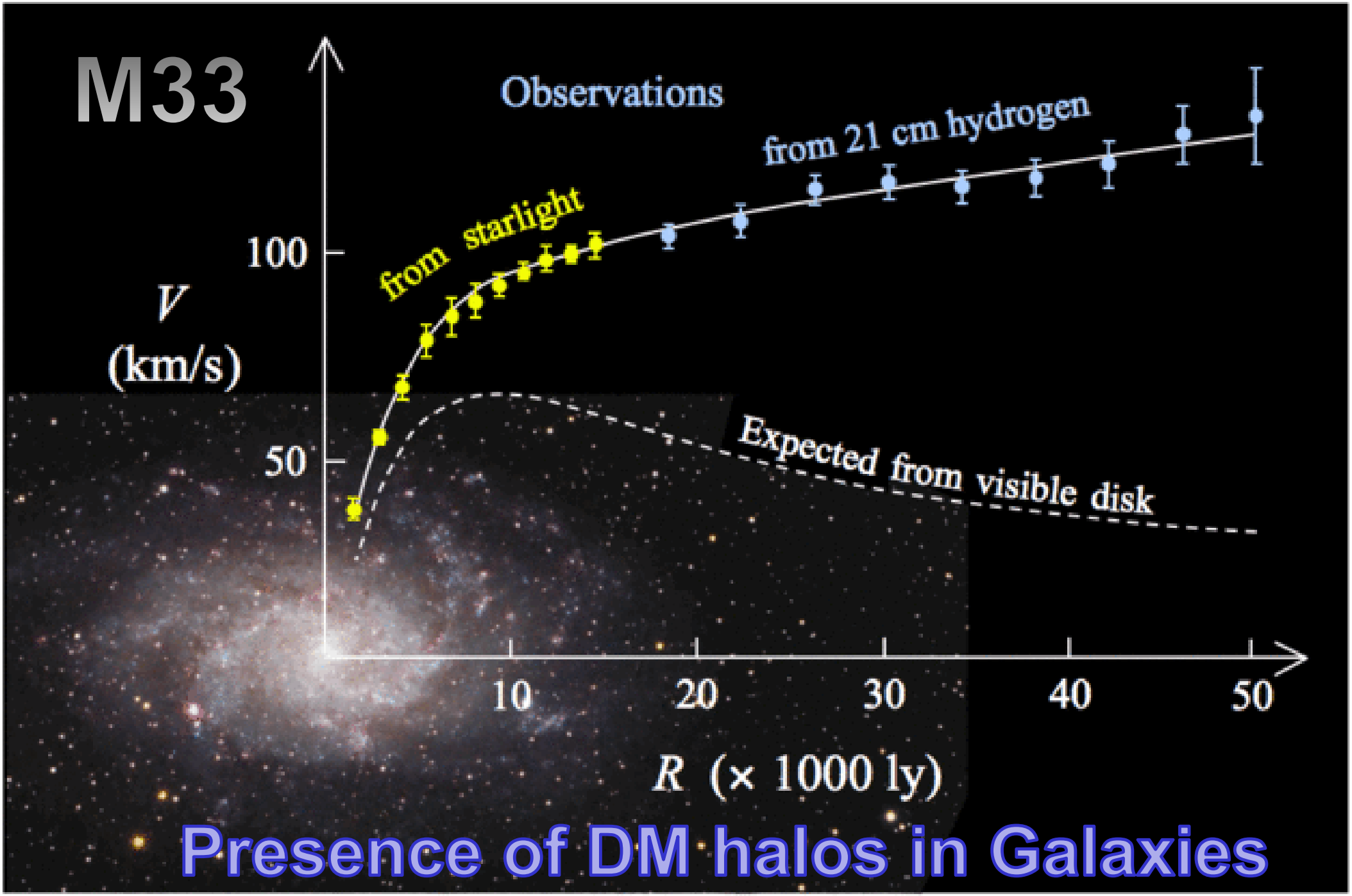
Outline

A set of phenomenal properties of dark halos in and around Galaxies are unexplained by the currently agreed scenario of dark matter physics

And seem to point towards a collisional nature for the DM properties

Salucci and Turini (in prep)

Salucci, P. Lapi, A. Tonini, C. Gentile, G. Yegorova, I. Klein,
U. 2007, MNRAS, 378, 41

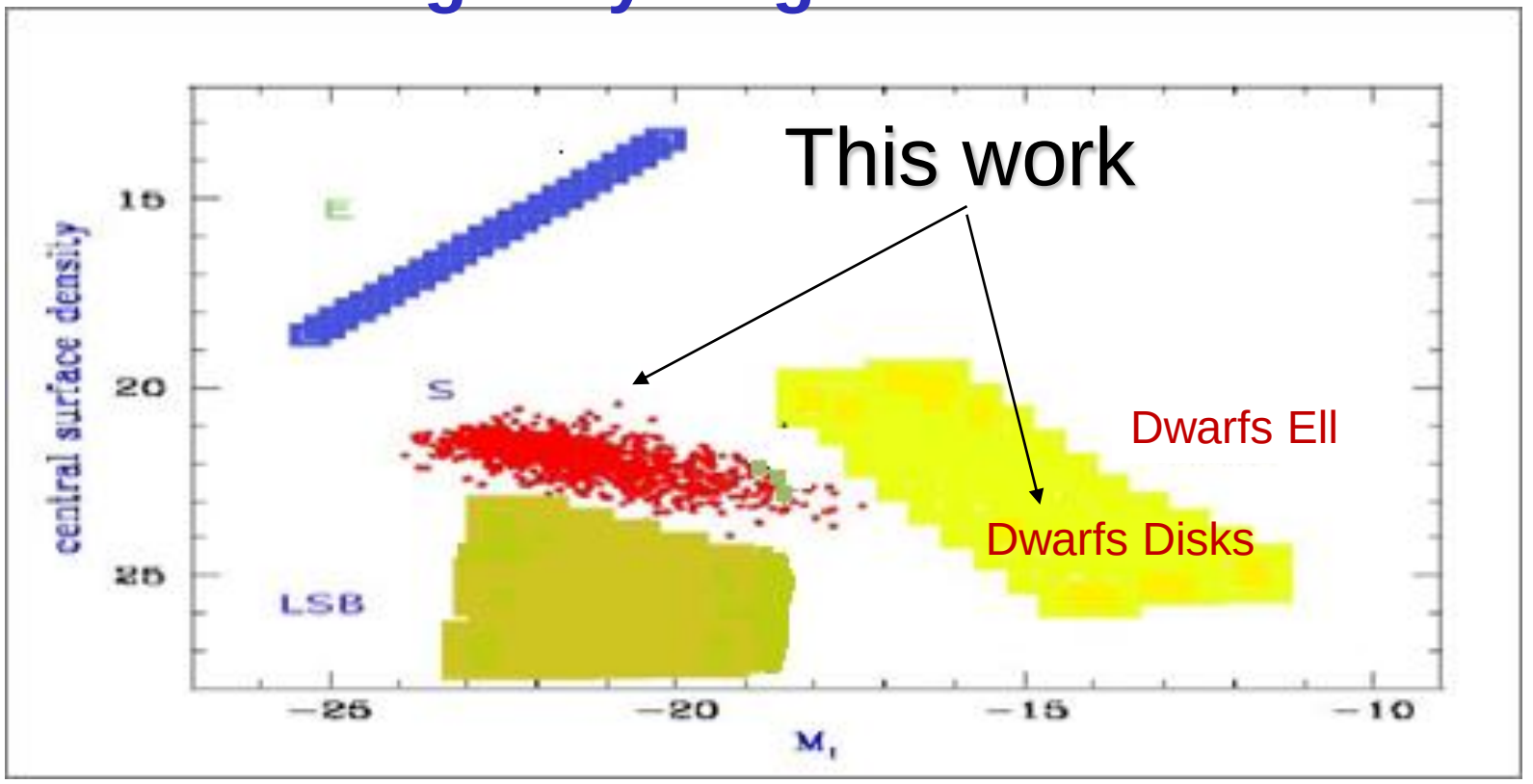


Presence of DM halos in Galaxies

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
Dwarf Disks : stellar disk +HI disk

Rotation curve analysis

From data to mass models

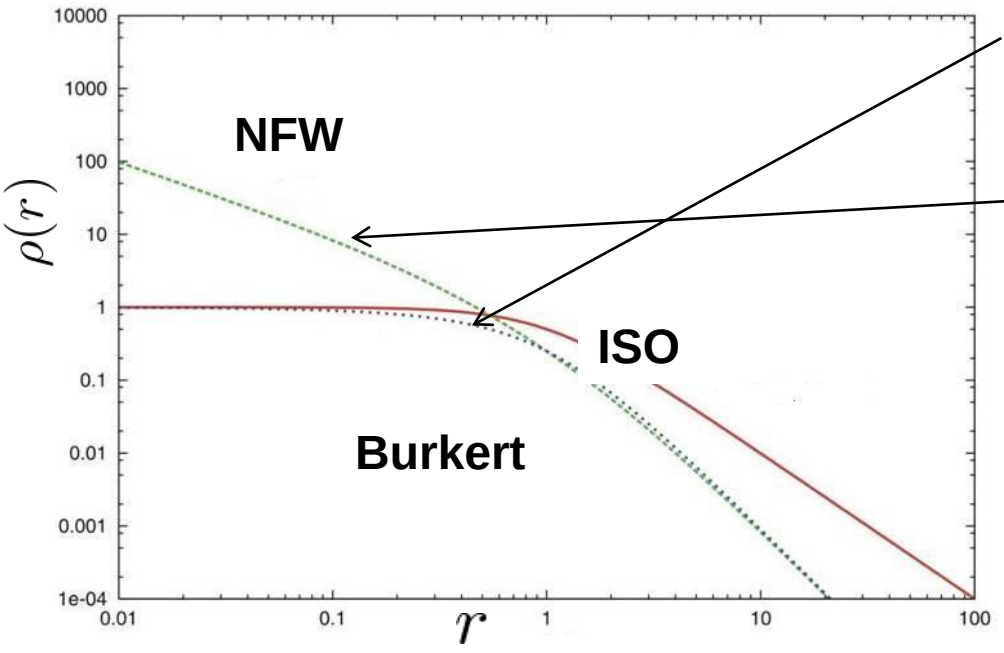
$$V^2(R) = V^2_{halo}(R) + V^2_{HI}(R) + V^2_{disk}(R)$$

observations = model

- V^2_{disk} **from I-band photometry**
- V^2_{HI} **from HI observations**
- V^2_{halo} **different choices for the DM halo density**

Dark halos with central constant density (Burkert, Isothermal)

Dark halos with central cusps (NFW, Einasto)



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

from simulations

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

ΛCDM Halo Density Profiles from N-body simulations

The density of virialized DM halos of any mass is empirically described at all times by an Universal profile (Navarro+96, 97, NFW).

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

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

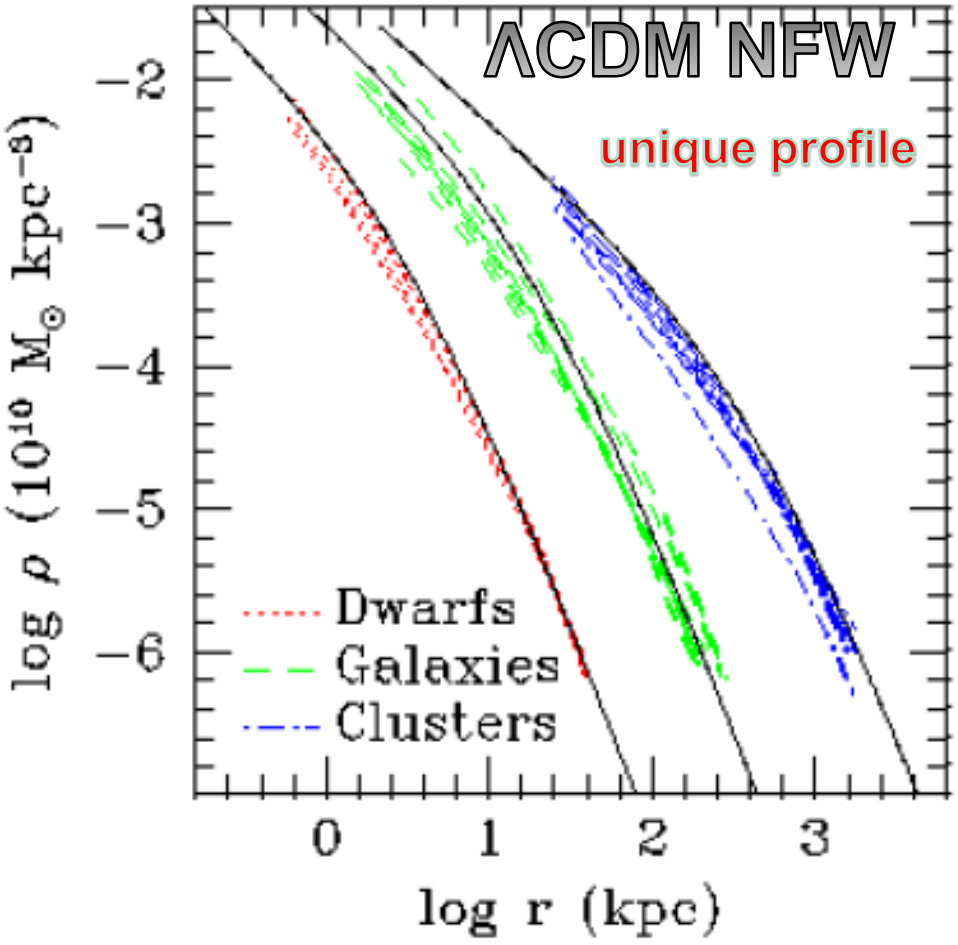
cusp

small cosmic variance

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

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

Klypin, 2010

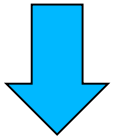


The distribution of Dark Matter in Spirals and Dwarfs

-poses strong evidences against a CDM halo
-gives information for the actual nature of the Dark particle trough two revealing relationships

at the core radius, the product (DM density x Baryon density) is constant in all galaxies

disk lenghtscales correlate perfectly with the halo core radii



Collisional dark matter ?

Spirals

Spirals disks are best place to investigate DM

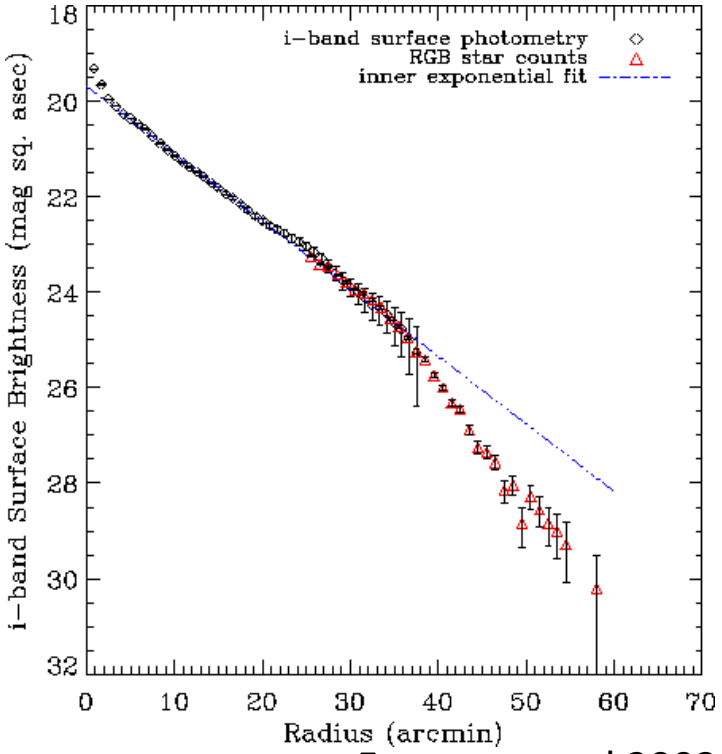
gaseus component not important

Stellar distribution:

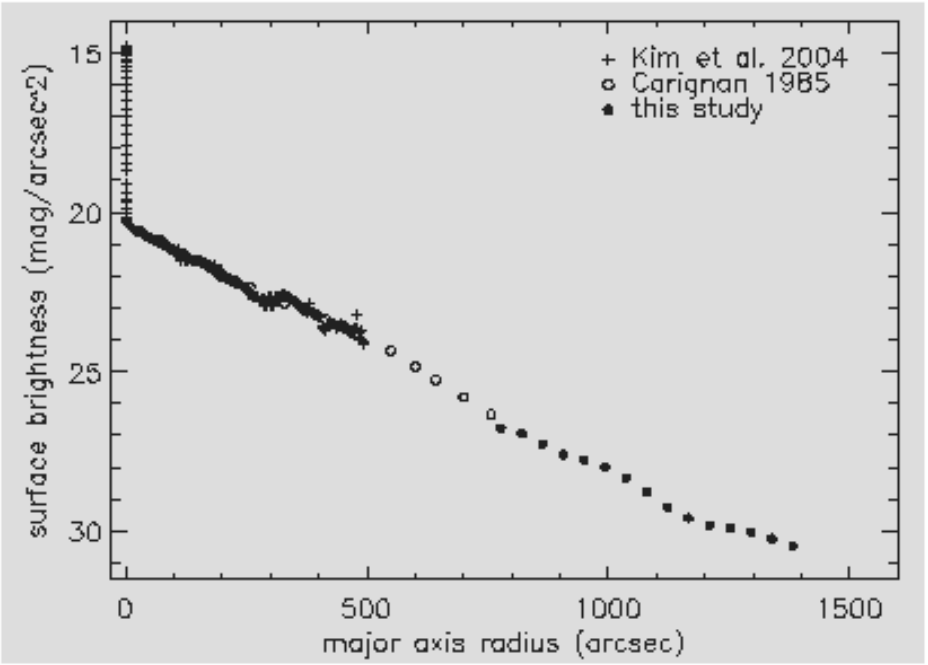
$$I(r) = I_0 e^{-r/R_D}$$

R_D lenght scale of the disk

Freeman, 1970



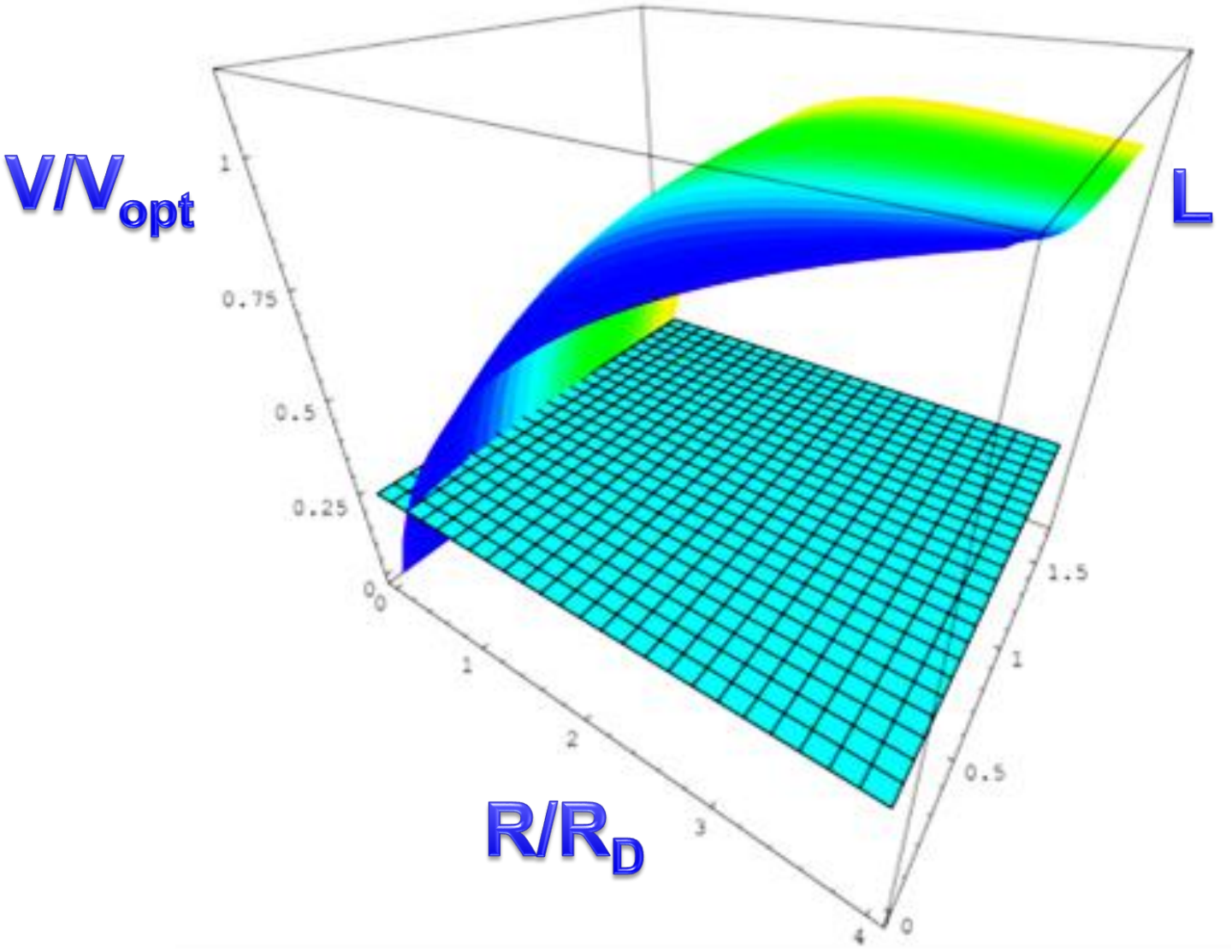
Ferguson et al 2003



Bland-Hawthorn et al 2005

The Concept of the Universal Rotation Curve (URC)

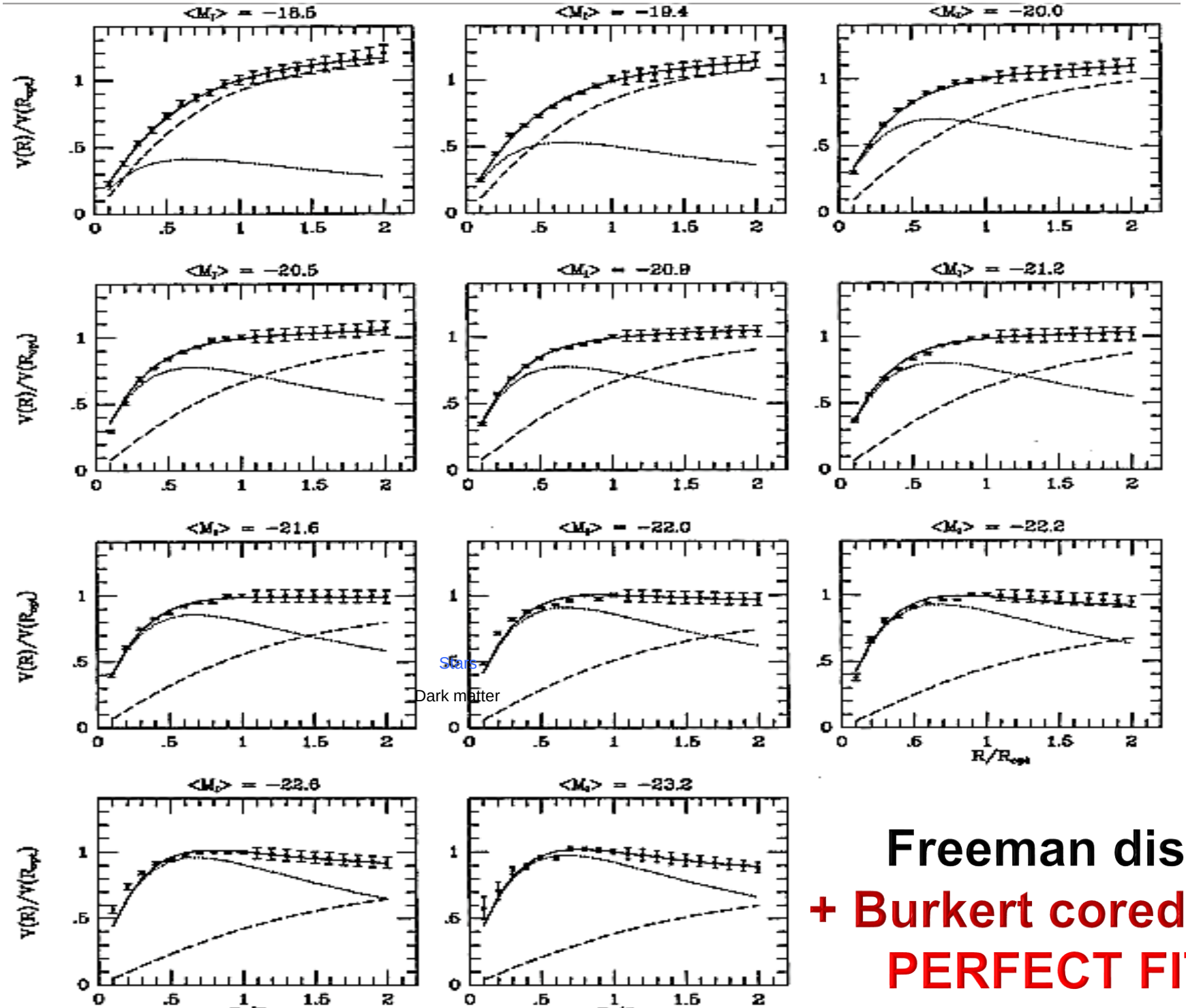
Every RC can be represented by: V(x,L) x=R/R_D



The URC out to 6 R_D is derived directly from observations

The URC as the individual RCs imply a cored distribution very different from the original NFW density profile

URC Modelling the Coadded Rotation Curves



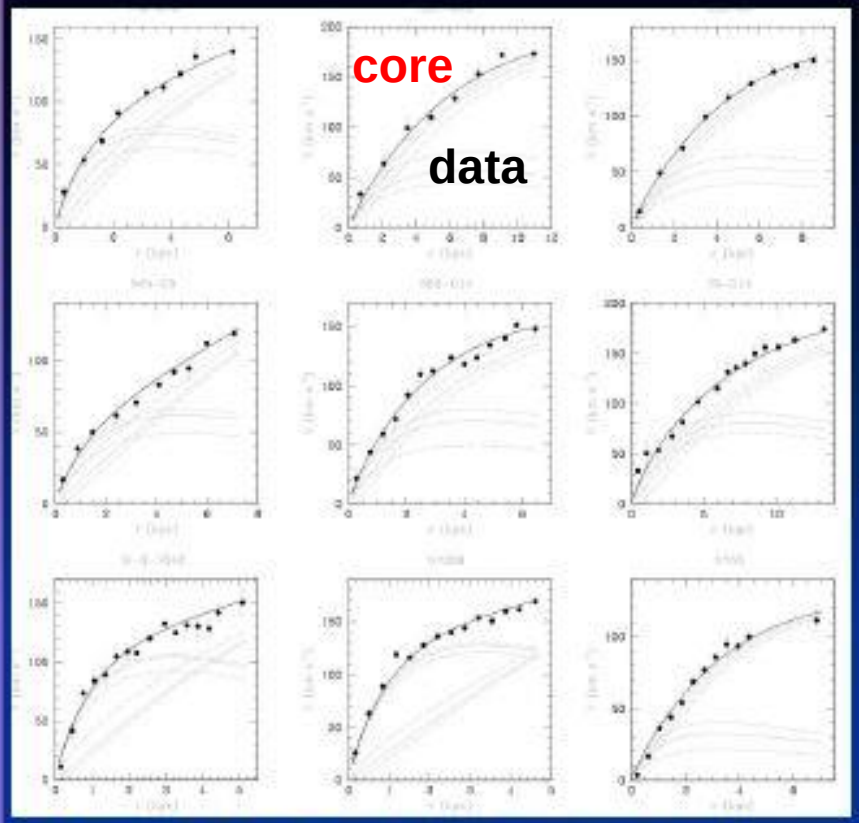
Freeman disk

+ Burkert cored halo

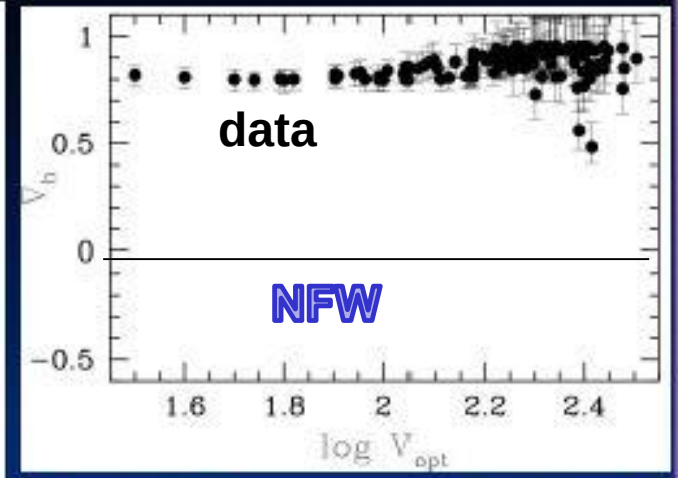
PERFECT FIT

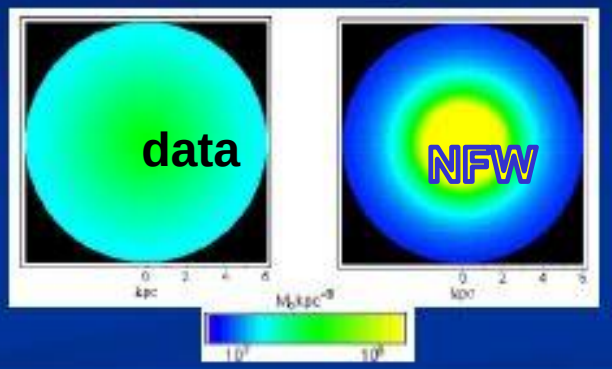
Results from Trieste: analysis of high quality RCs

URC fits to RCs

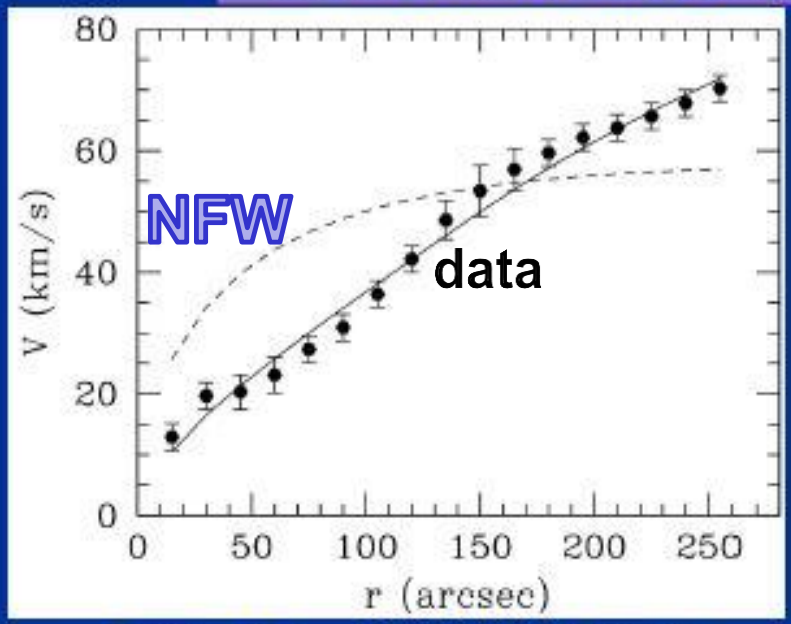


Borriello & Salucci, MNRAS 323, 285 (2001)

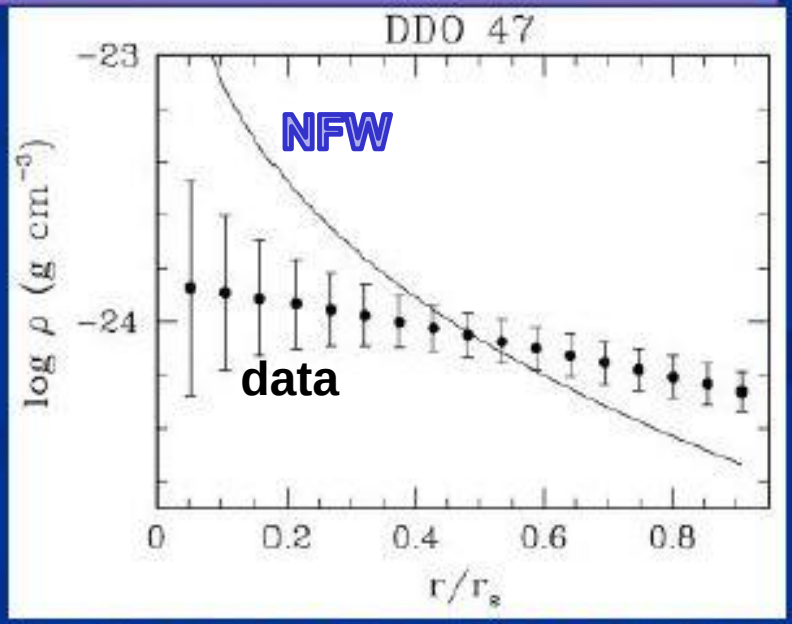




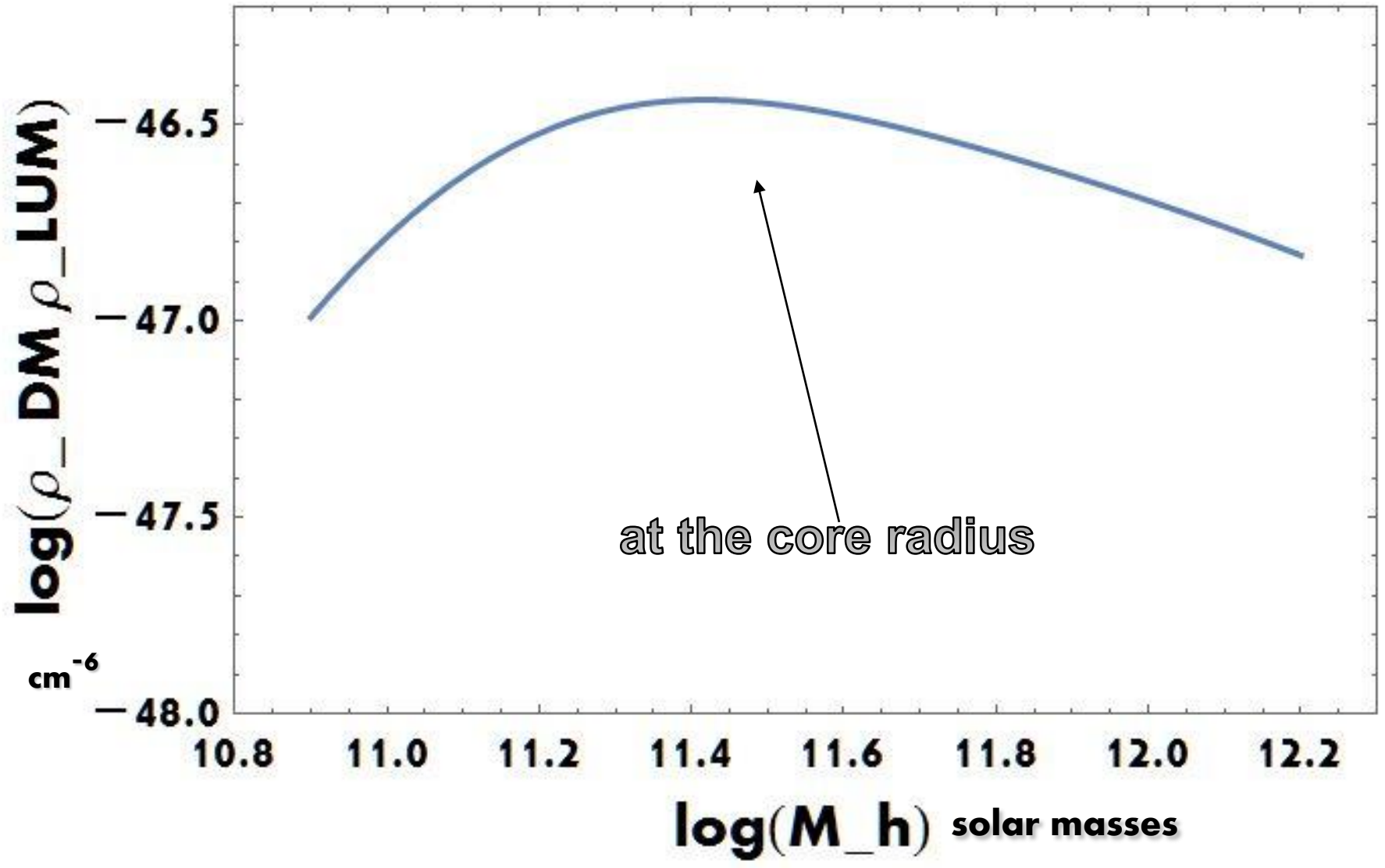
DDO 47



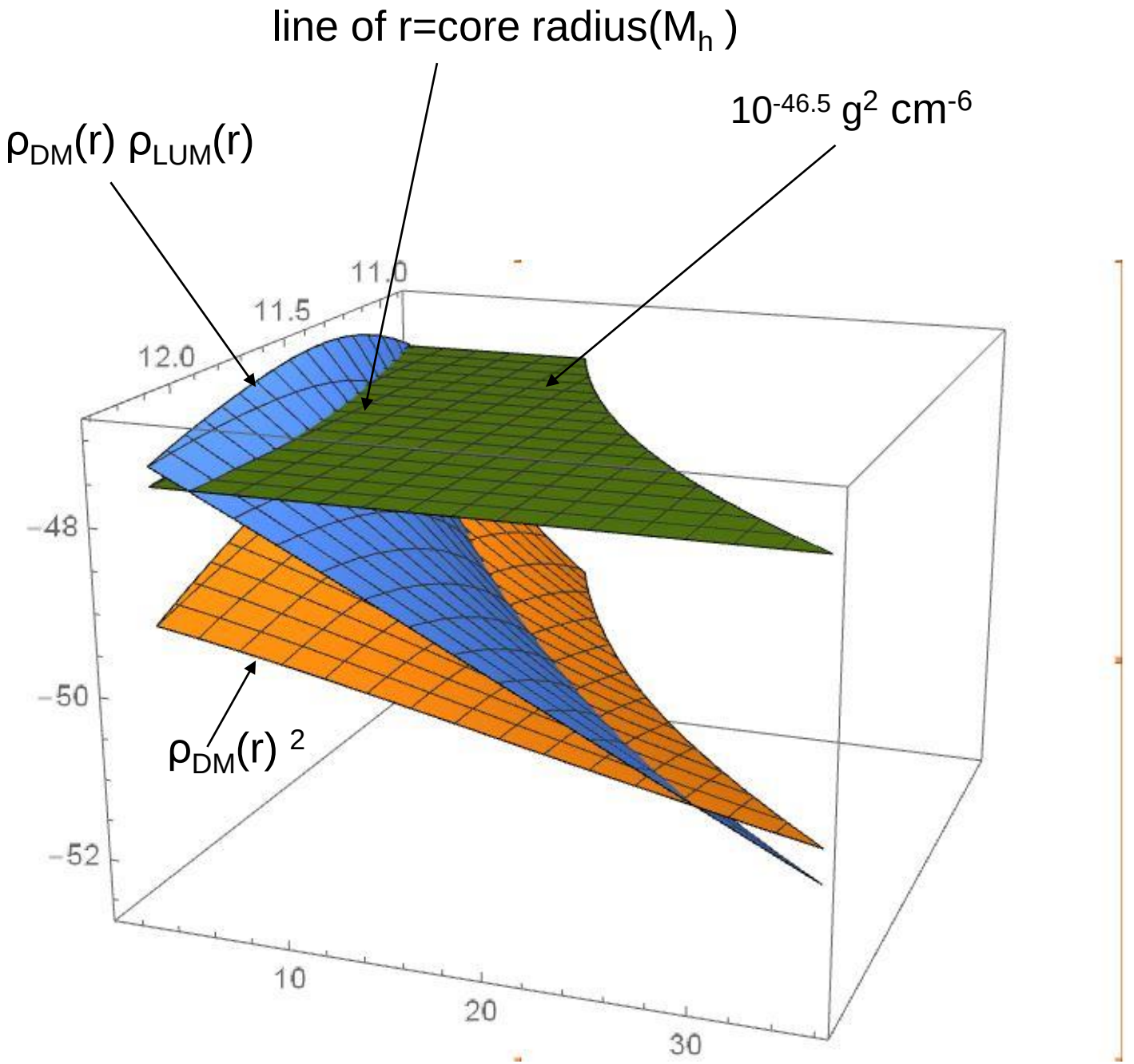
Gentile et al., ApJ 634, L145 (2005)



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



Similar relationship in Dwarf disk



DM LM interaction has much larger astrophysical factor than DM annihilation

Dwarf Disks
(mini spirals)

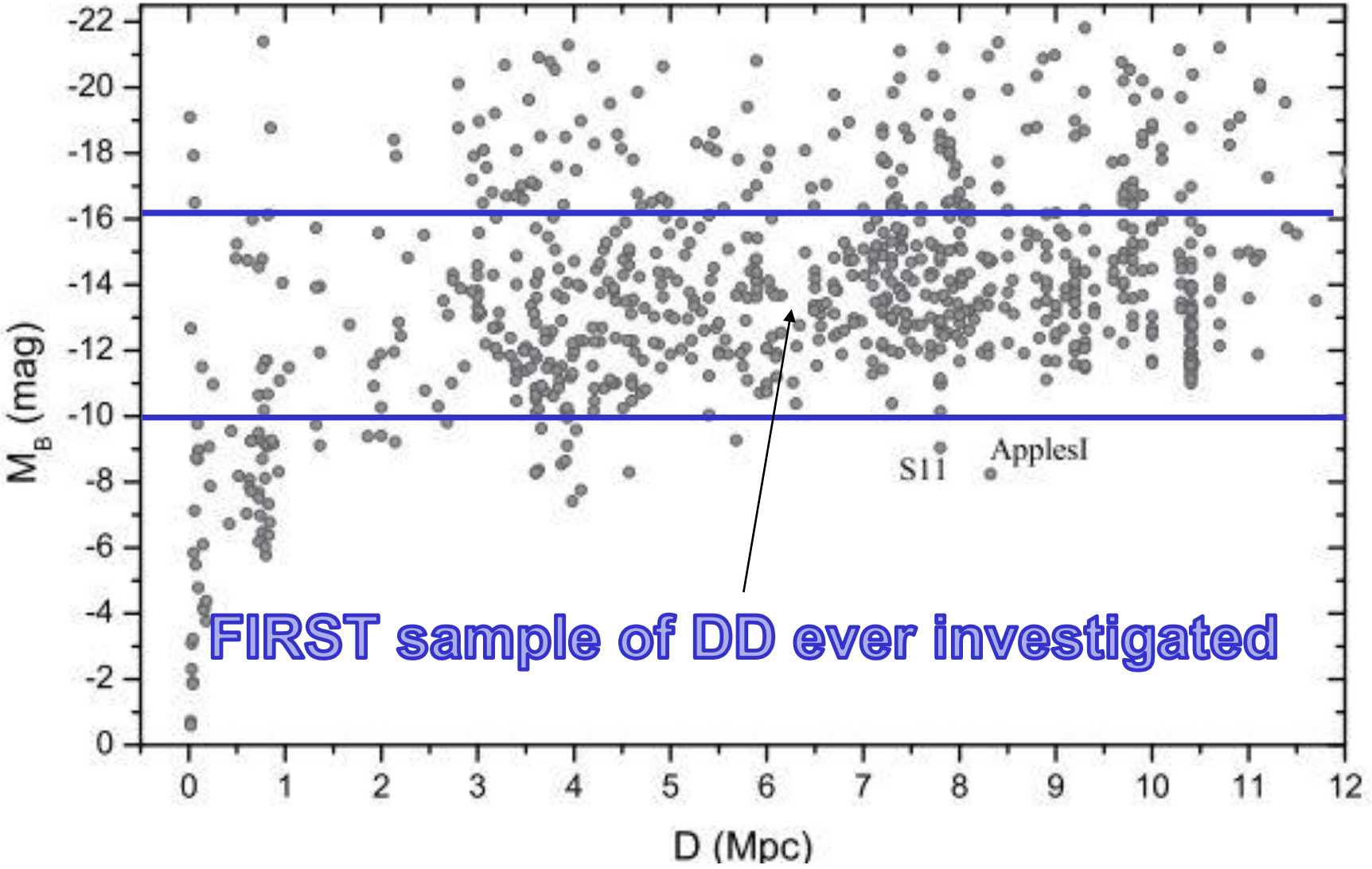
THE SMALLEST GALAXIES: DWARF DISKS

the most numerous ones
the more DM dominated
the densest objects
the first born
immune by feedback ?
simple dynamics

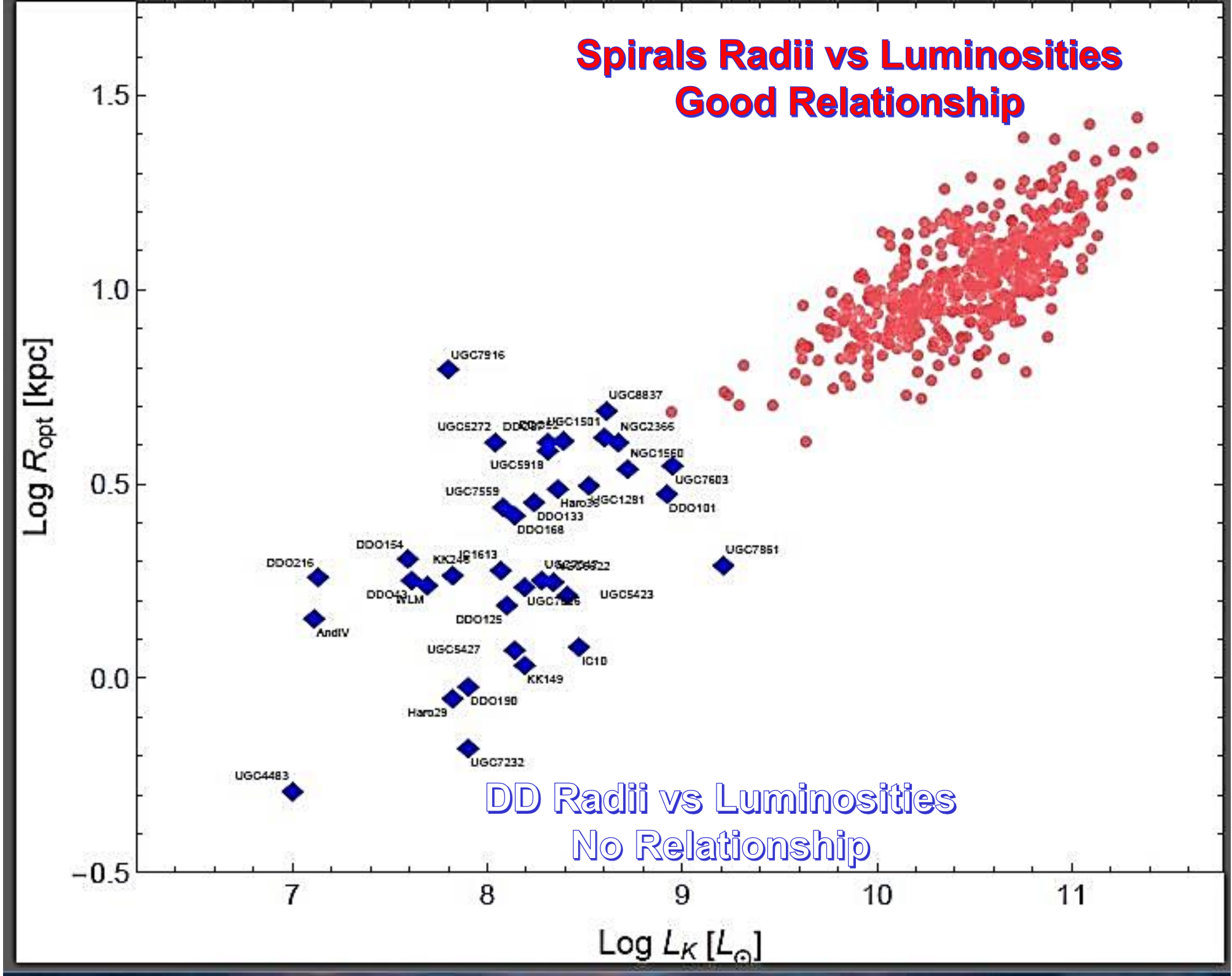
Updated Nearby Galaxy Catalog.

Igor D. Karachentsev, Dmitry I. Makarov and Elena I. Kaisina

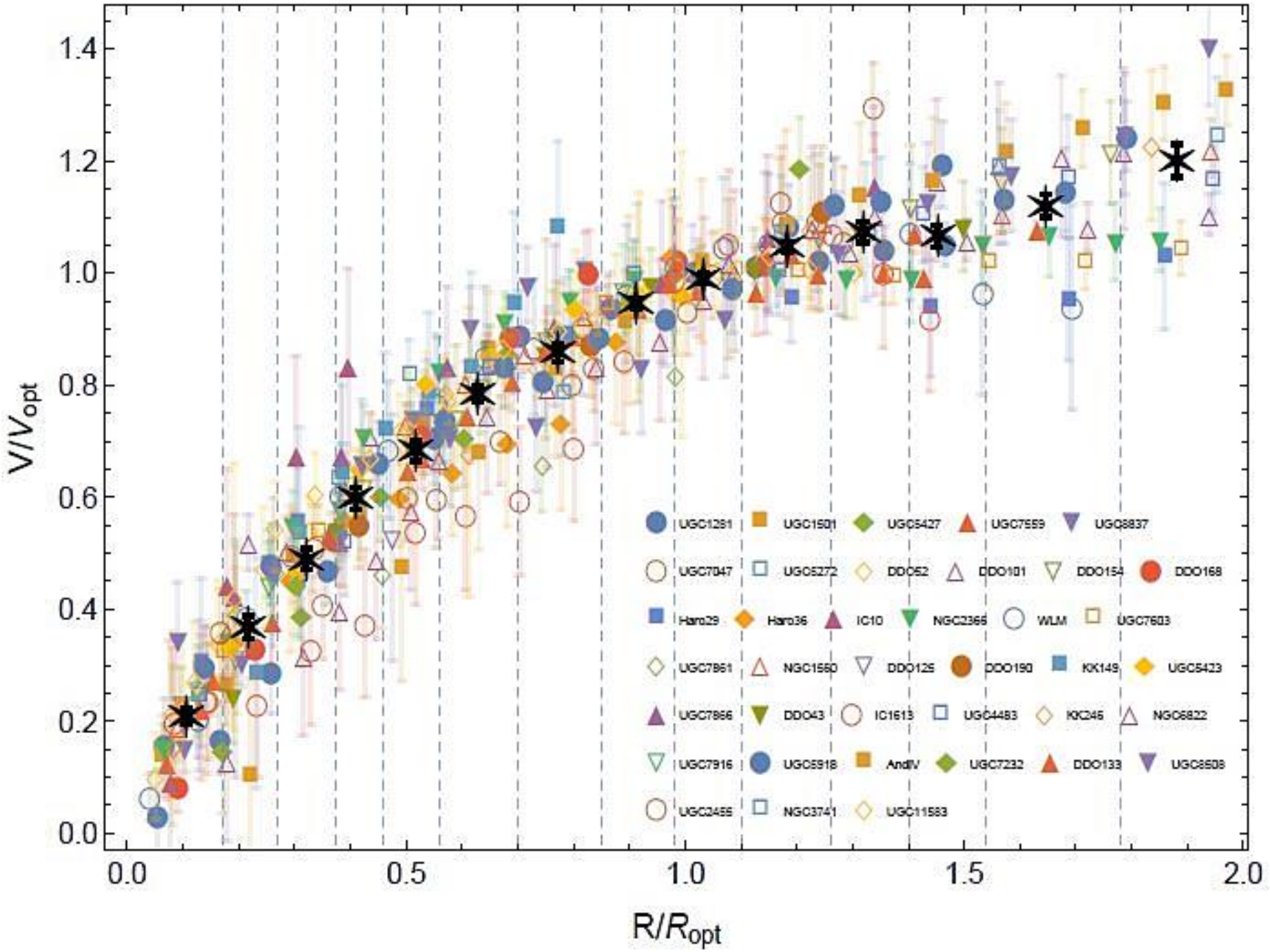
1000 galaxies inside 11 Mpc



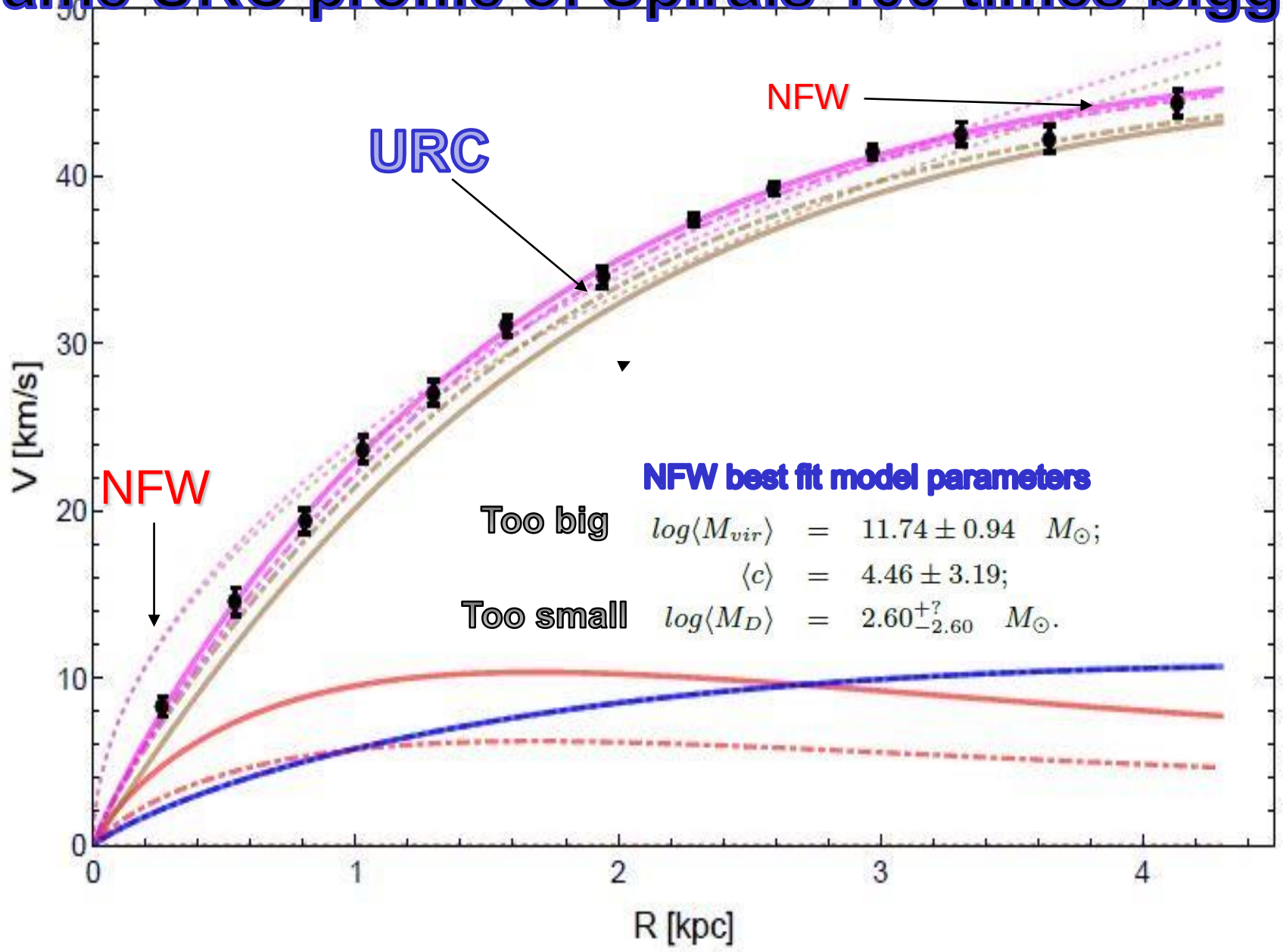
FIRST sample of DD ever investigated


Spirals Radii vs Luminosities
Good Relationship
DD Radii vs Luminosities
No Relationship
Log R_{opt} [kpc]
Log L_K [$L_\odot$]
1.5
1.0
0.5
0.0
−0.5
7
8
9
10
11
UGC7916
UGC8837
UGC5272
UGC1501
NGC2366
UGC5918
NGC1560
UGC7603
UGC7559
UGC1281
DDO101
DDO133
DDO168
DDO154
UGC7861
DDO216
IC1613
KK246
DDO43
WLM
UGC5423
DDO125
AndIV
UGC5427
IC10
KK149
DDO190
Haro29
UGC7232
UGC4483

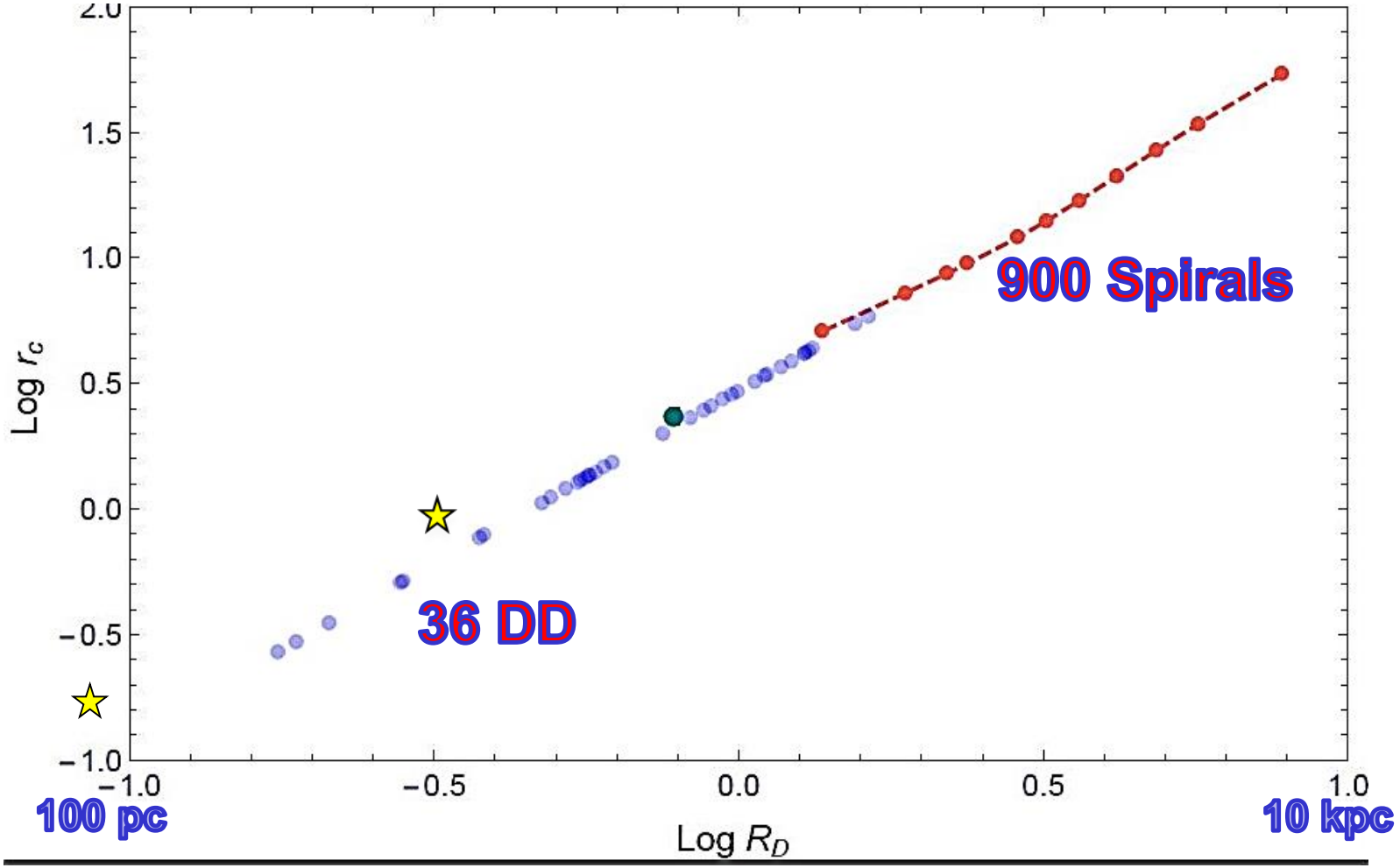
Coadded rotation curve



modelling the coadded curve: NO Cusp
Same URC profile of Spirals 100 times bigger



tight correlation between the dark matter core lenght and the scalelenght of the stellar disk



Strict power law relation among quantities defining the shape of the two different mass distributions

Dark-luminous particles interaction?

collisional cross section

$$d\rho_{DM}(r,t) = - A \rho_{DM}(r,t) \rho_{LUM}(r,t)$$

$$d\log \rho_{DM}(r,t)/d\log r = B\, d\log \rho_{LUM}(r,t) /d\log r$$

From our relationships

To forhm DM cores as observed

ΛCDM PARADIGM

- We know the dark particle, ab initio. Both from cosmological and from elementary physics sides.

- *DM halos the protagonist. Large scales observations are in agreement .*

- *Observations of dark matter in galaxies are bound to agree with the ΛCDM scenario prediction via cosmo astrophysics , but this is not even strictly necessary, as the shooting gun for this scenario comes up, at this point, from the detection of particle.*

- progresses in detecting the WIMP particle have been very few, if any.

- the number of dark halos and their density profiles are very different with respect to those predicted from raw ΛCDM cosmology.

CONCLUSIONS towards a new paradigm

Cosmo-astrophysical Observations are an Unique Guide to the nature of DM

The amazing properties of the mass distribution of Dark Matter in very different types of galaxies will guide as
NEW PARADIGM

in which dark and luminous matter interact
about 0.01 interaction for Dark particle for Gyr

Other possibilities are too much fine tuned and or ineffective to explain the observational scenario that strongly links DM and LM .