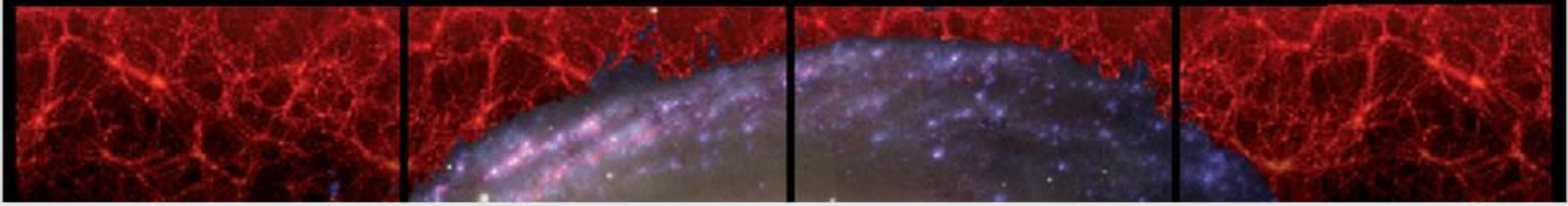


Structural properties of Galaxies lead to WDM: The case of Dwarf Disks

PAOLO SALUCCI

SISSA, GSSI

XX Chalonge School, Paris, July 2016

Brief outline

Properties of DM around Spirals

Properties of DM around Dwarf Spirals

Implications

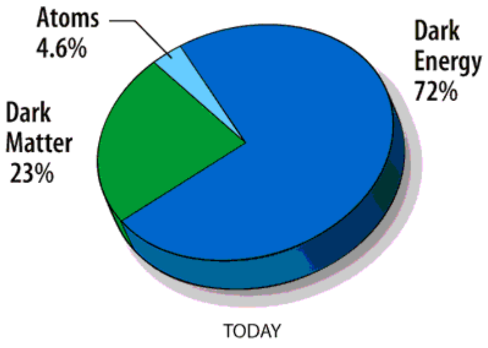
K. Karukes, JP. Fontaine, S.Harisadu, A. Subranaiman, E.Lopez Fune, C. Di Paolo
A.   Lapi, F. Nesti, MF de Laurentis
Hector dV and Norma S,

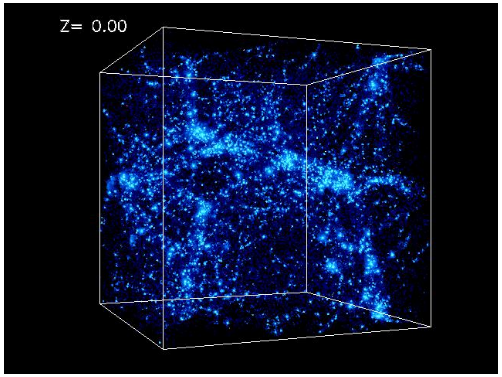
le Vega, H. J.; Salucci, P.; Sanchez, N. G.   014MNRAS.442.2717D
Observational rotation curves and density profiles versus the Thomas-Fermi galaxy structure theory
Salucci et al .   2012, MNRAS, 420, 2034
Dwarf spheroidal galaxy kinematics and spiral galaxy scaling laws
de Vega, H. J.; Salucci, P.; Sanchez, N. G.
The mass of the dark matter particle: Theory and galaxy observations 2012NewA...17..653D,2011
Salucci, P.; Nesti, F.; Gentile, G.; Martins, C. F 2010 A&A 523,   83   `
The dark matter density at the Sun's location
Donato, F.; Gentile, G.; Salucci, P.; Frigerio Martins, C.; Wilkinson, M. I.; Gilmore, G.; Grebel, E. K.; Koch, A.; Wyse, R. 2009 MNRAS, 397, 1169
A constant dark matter halo surface density in galaxies
Salucci, P. Lapi, A. Tonini, C. Gentile, G. Yegorova, I. Klein, U.   2007, MNRAS, 378, 41
The universal rotation curve of spiral galaxies - II. The dark matter distribution out to the virial radius

Donato, F . Gentile, G,. Salucci, P., 2004 MNRAS, 353, 17
Cores of dark matter haloes correlate with stellar scalelengths
Persic, M. Salucci, P. Stel, F. 1996, MNRAS, 281, 27
The universal rotation curve of spiral galaxies - I. The dark matter connection

Outline

Dark Matter is a main **protagonist** in the Universe





In the mass distribution of the structures of the Universe we detect a dark massive component Atoms cannot develop these structures neither be responsable of this component

Standard Model of Elementary particles has not this

Details of the In the mass distribution in galaxies play today a totally new role

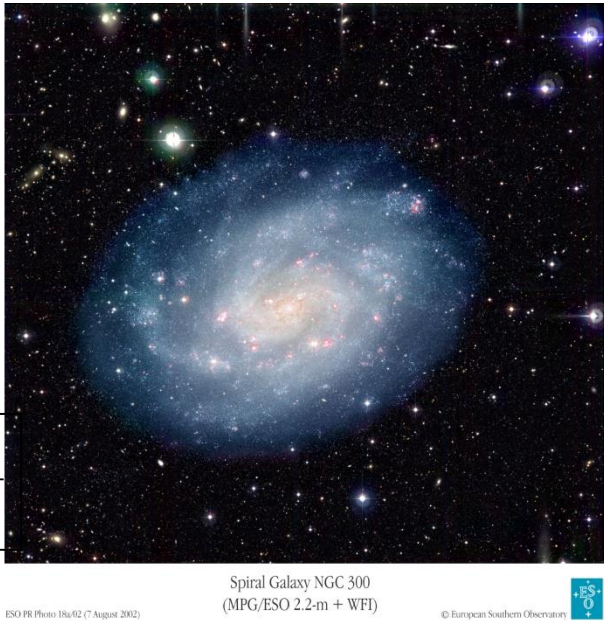
R


Wimp
HIGGSINO
DARK PHOTONS
GRAVITINO
DARK MATTER
PROTON
PHOTON
e-
NEUTRINO
NEUTRALINO
AXION
AXION
e
e
DARK ELECTRONS
NEUTRON
MUON
QUARK
VISIBLE MATTER
Wimp
DARK NEUTRON

Spirals best place to investigate DM

M33 disk very smooth, truncated at 4 scale-lengths

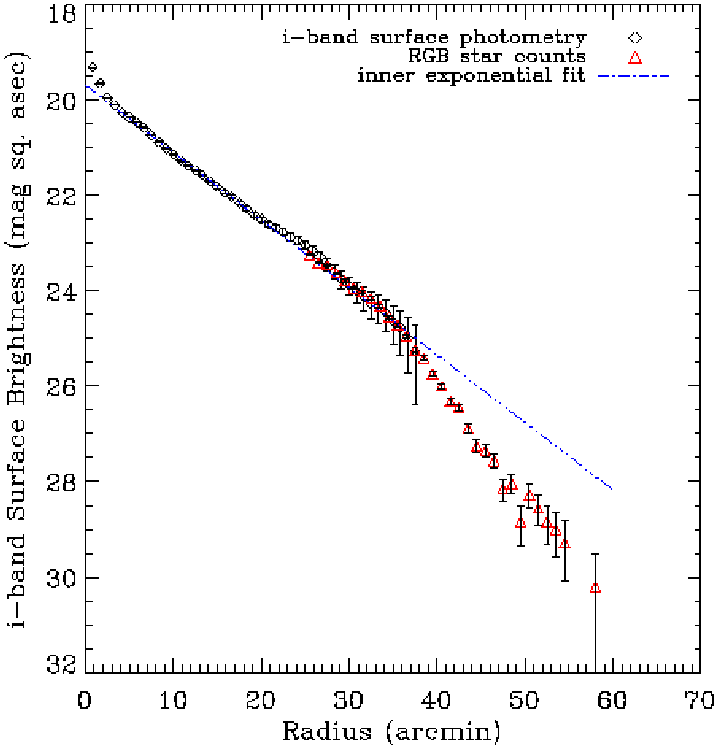
NGC 300 exponential disk for at least 10 scale-lengths



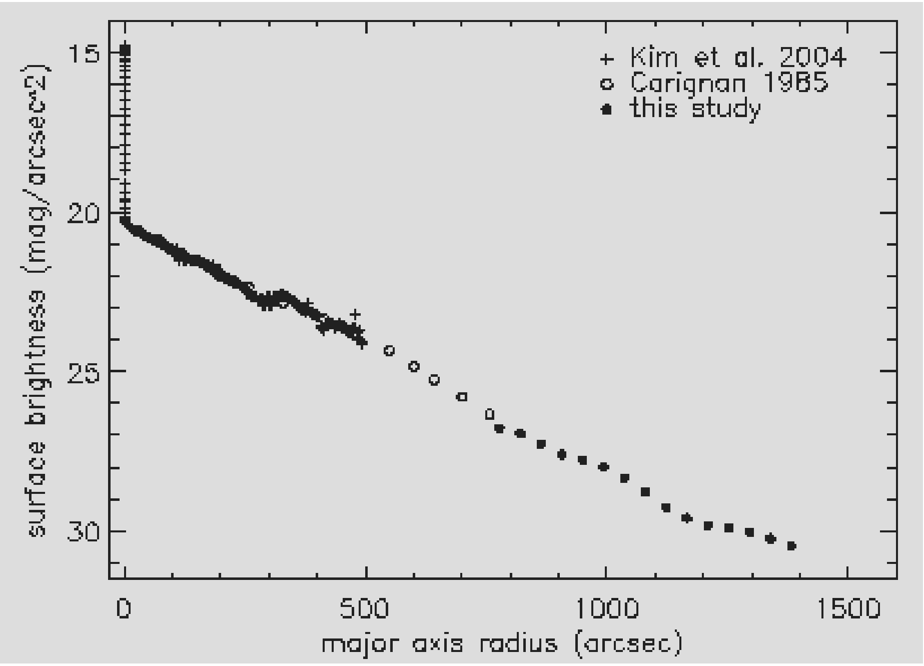
$$I(r) = I_0 e^{-r/R_D}$$

R_D lenght scale of the disk

Freeman, 1970



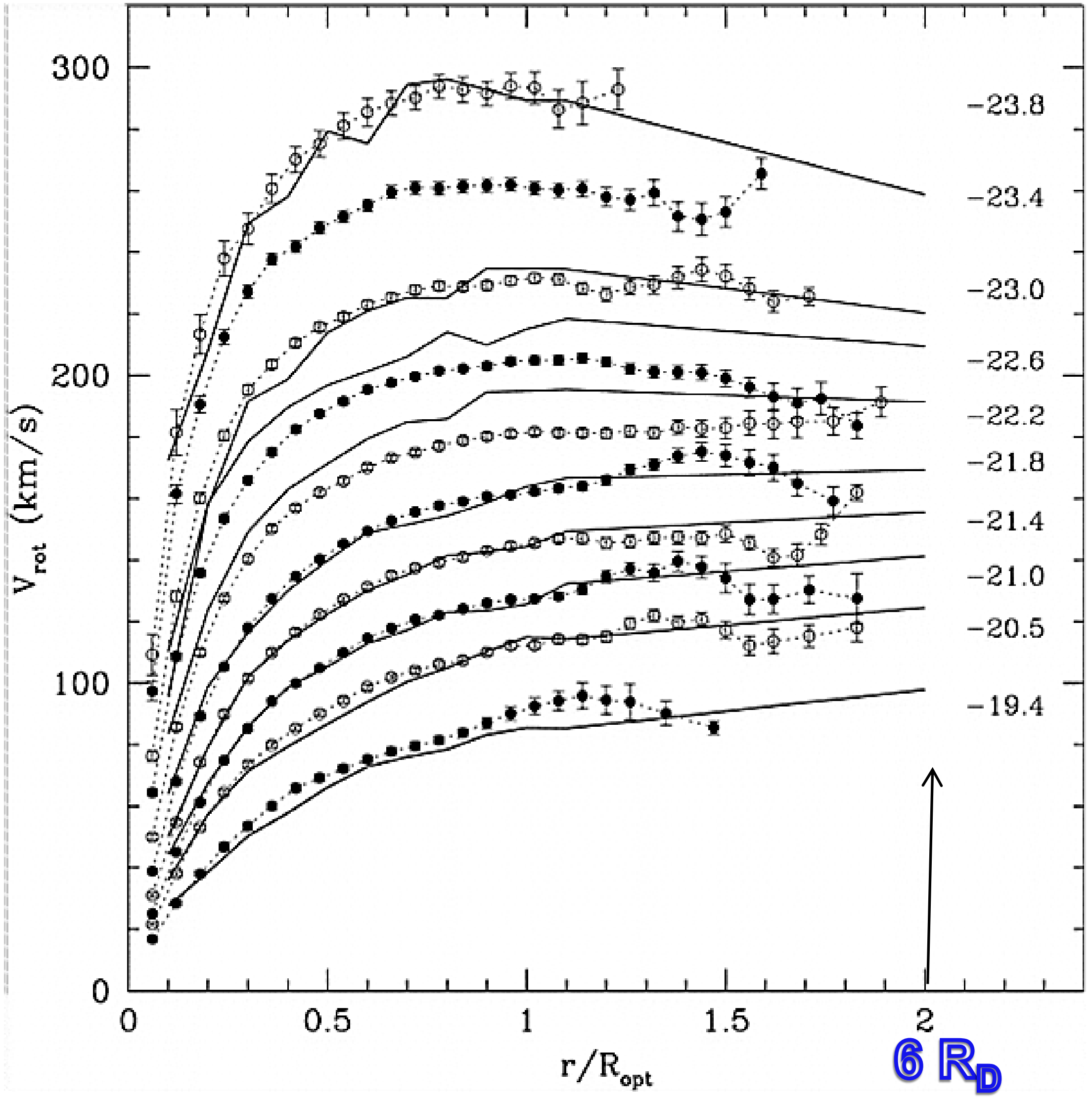
Ferguson et al 2003



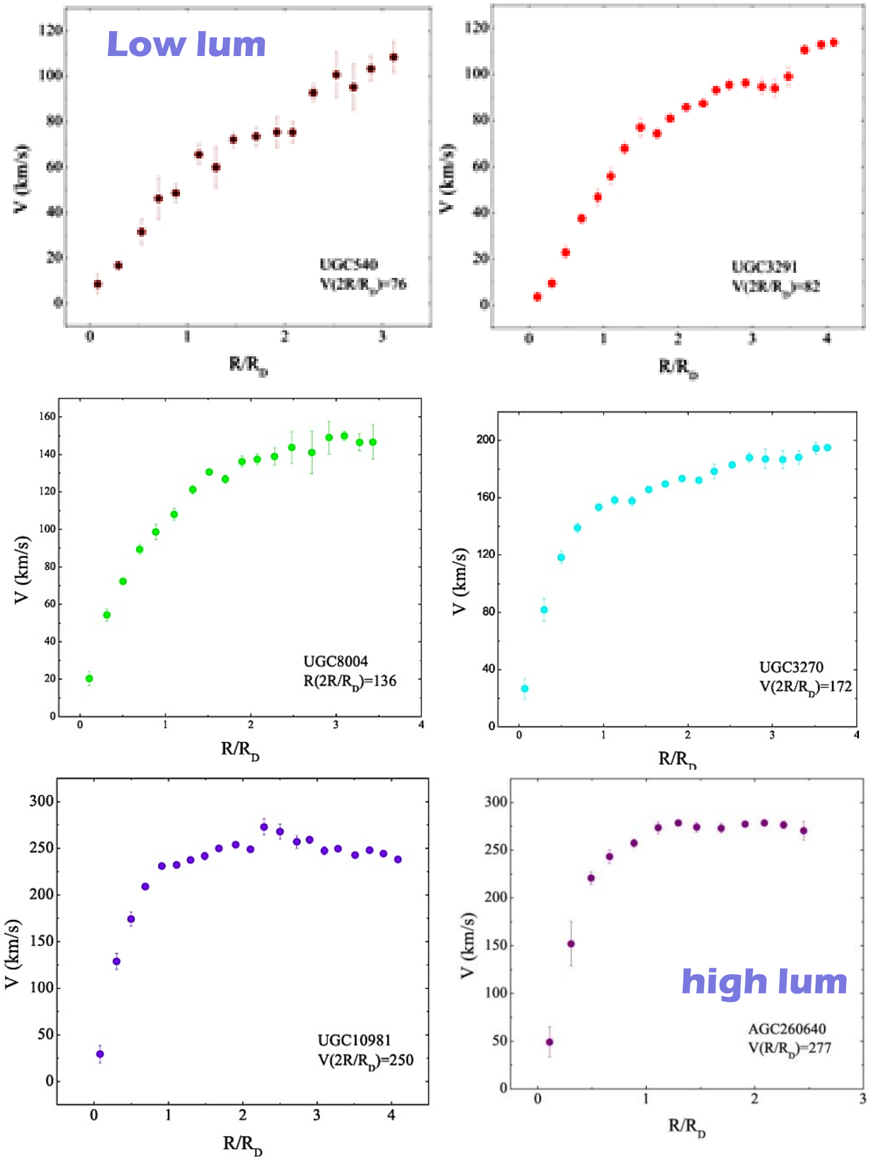
Bland-Hawthorn et al 2005

Radio + Optical Rotation Curves of Spirals

Coadded from 3200 individual RCs

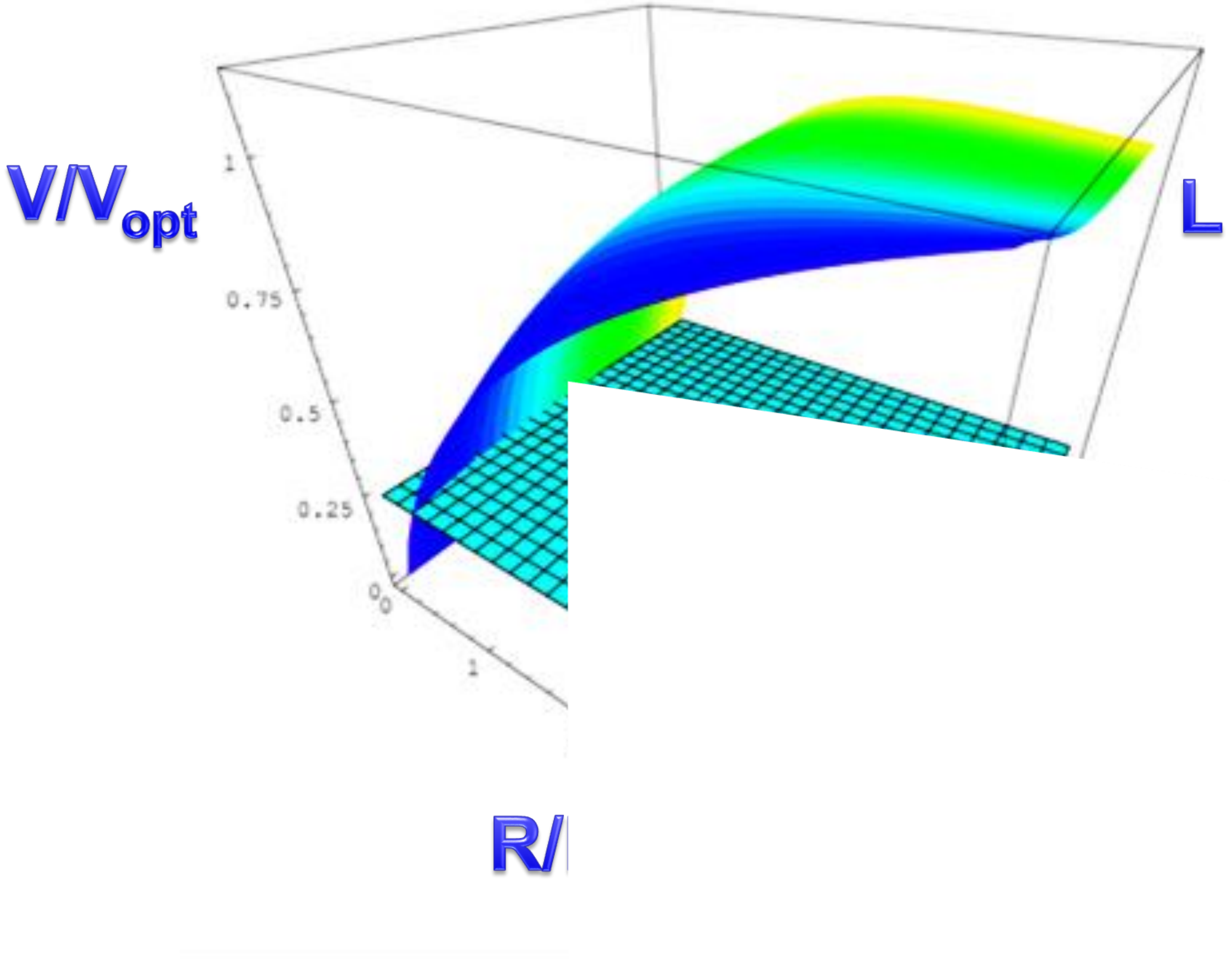


TYPICAL INDIVIDUAL



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

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).

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

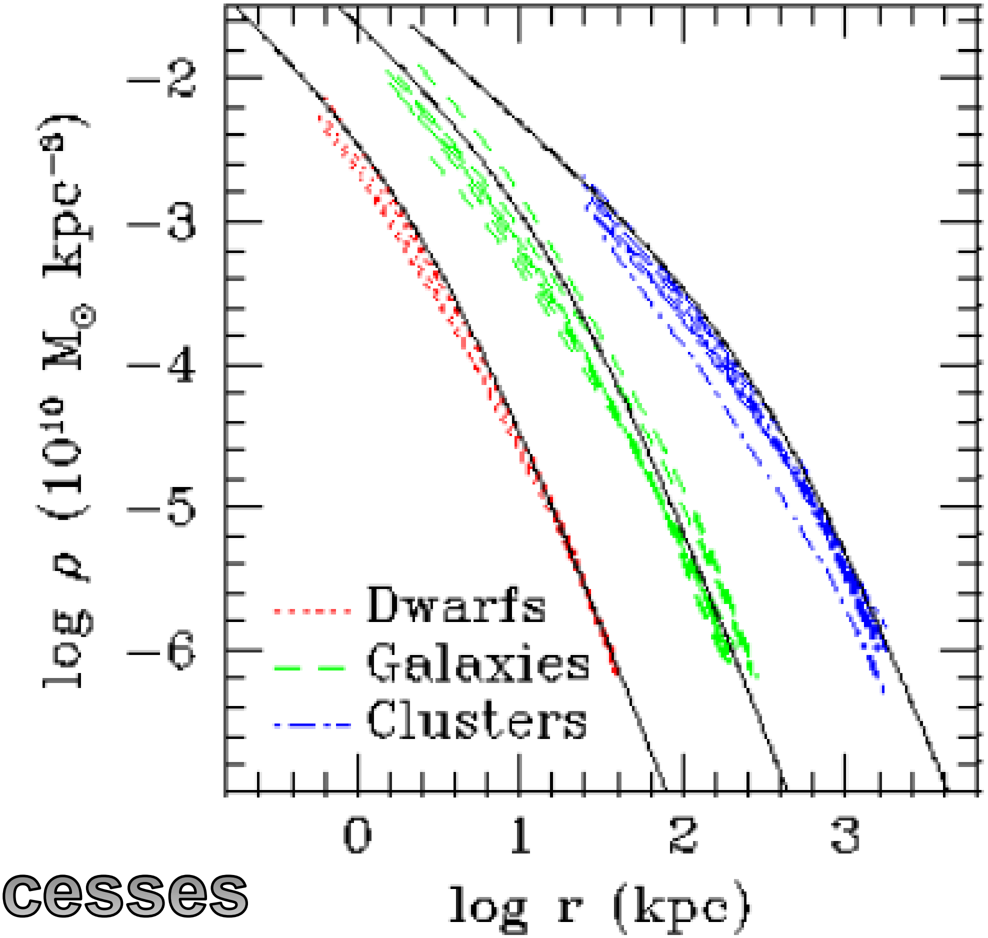
$$c = \frac{R_{vir}}{r_s}$$

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

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

small cosmic variance

Klypin, 2010



Instrumental for LCDM successes

Rotation curve analysis

From data to mass models

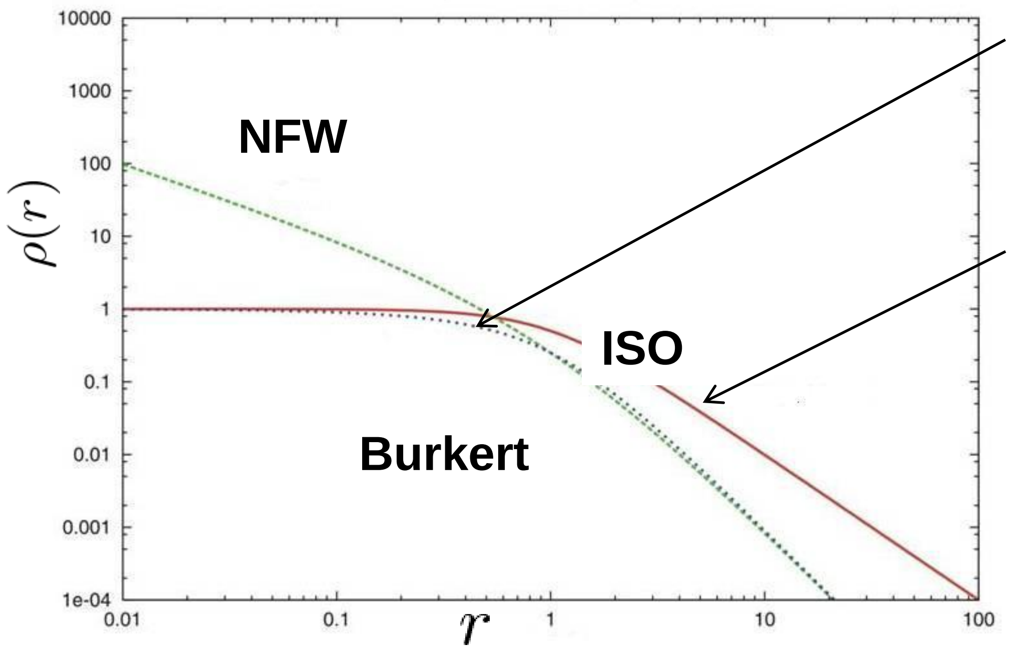
$$V^2(R) = V^2_{halo}(R) + V^2_{HI}(R) + V^2_{disk}(R)$$

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)

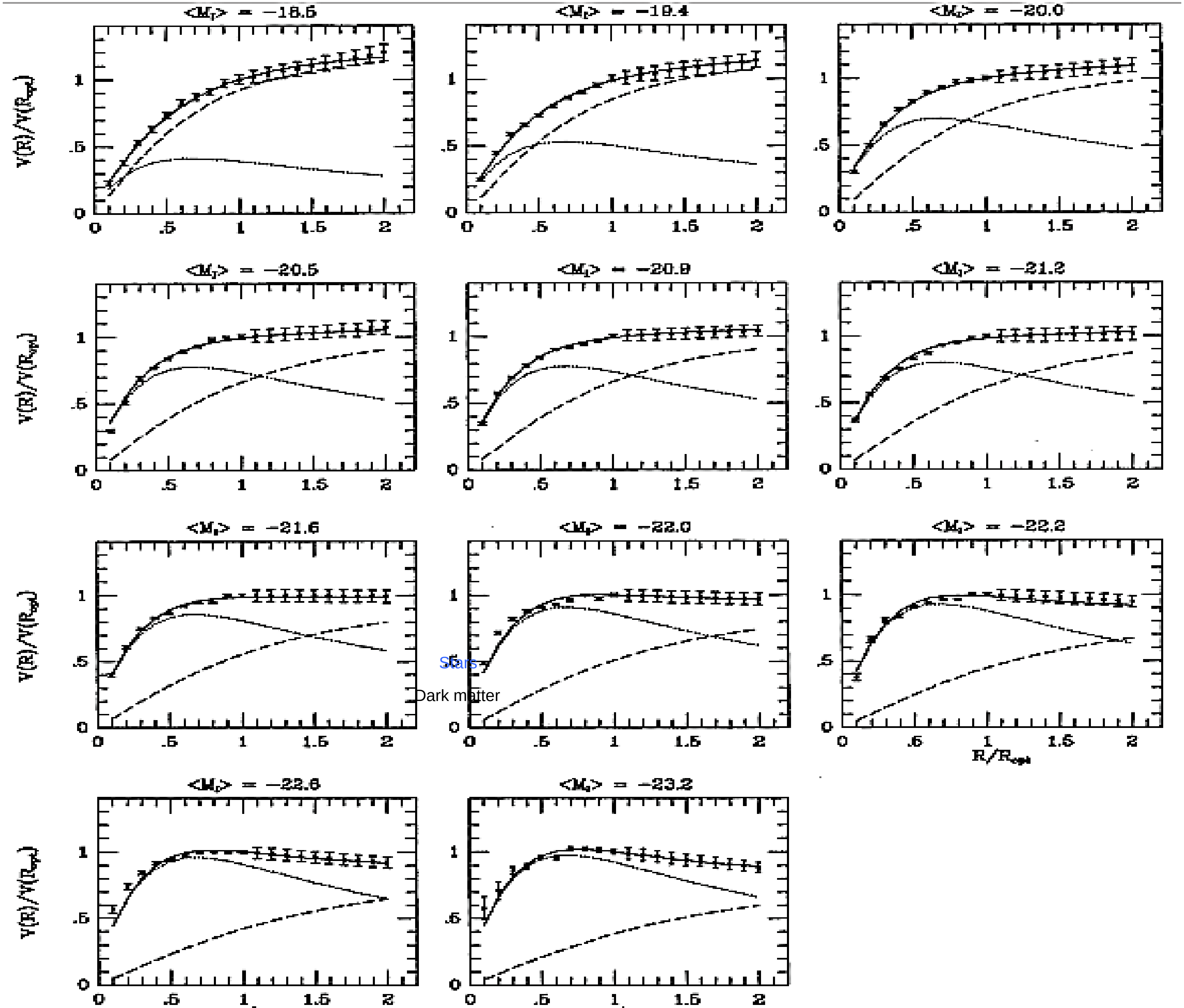


$$\rho(r) = \frac{\rho_0}{(1 + r/r_0)(1 + (r/r_0)^2)}$$

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

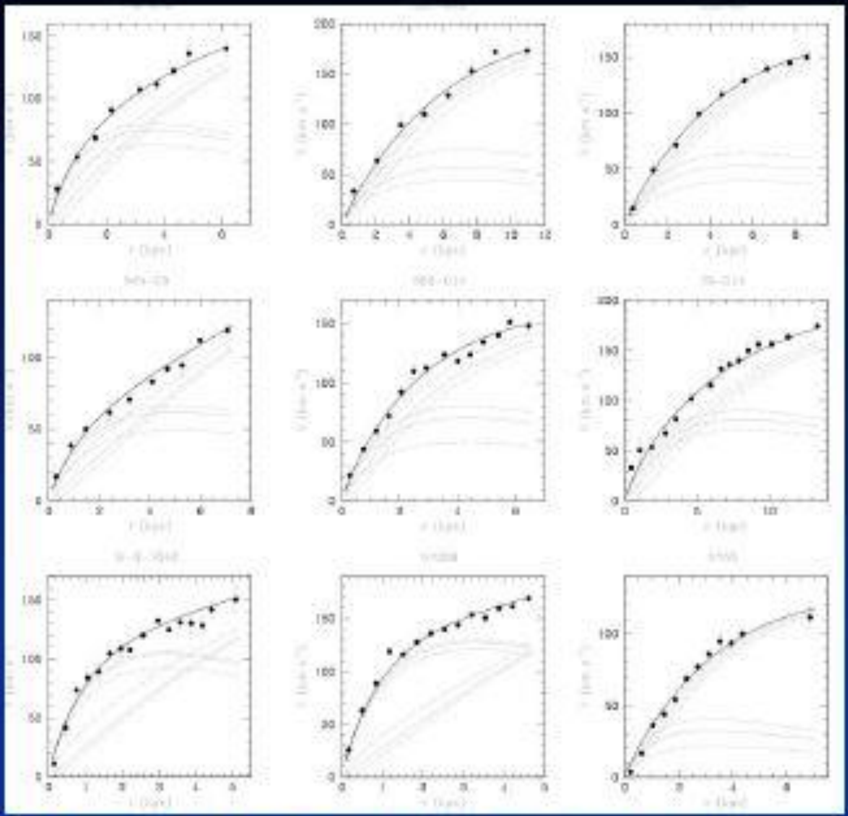
The mass model has 3 free parameters:
disk mass
halo central density
Halo core radius (length-scale)
Obtained by best fitting method

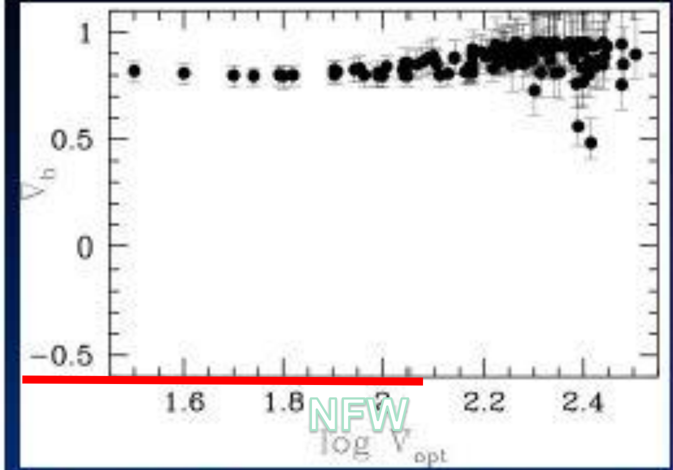
URC Modelling the Coadded Rotation Curves

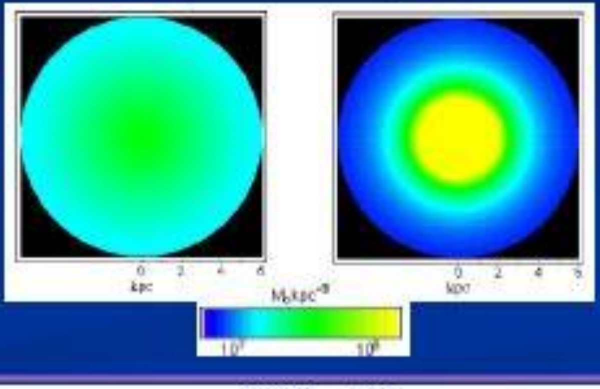


Results from Trieste: analysis of high quality RCs

URC fits to RCs

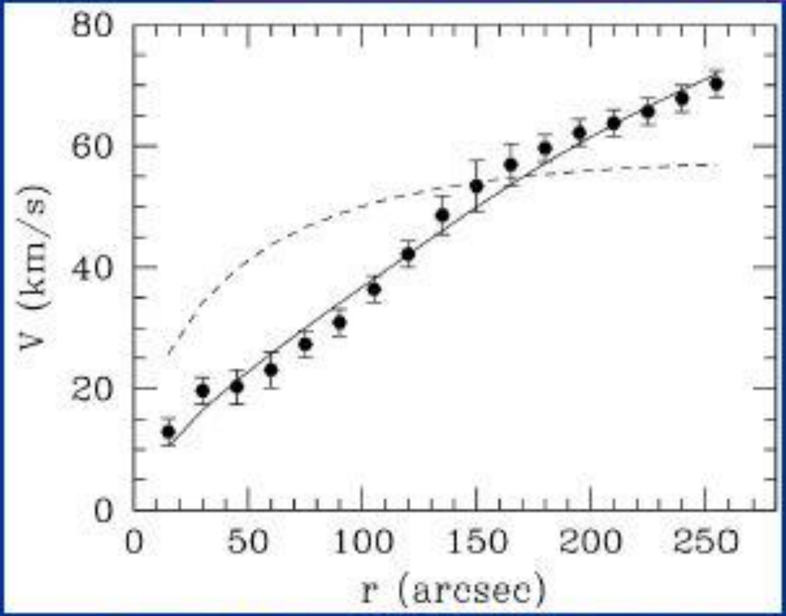




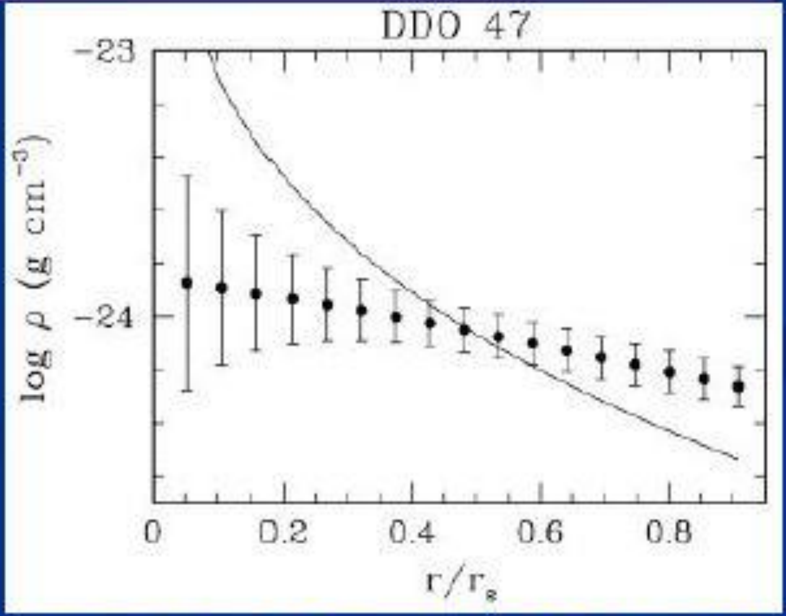


Borriello & Salucci, MNRAS 323, 285 (2001)

DDO 47

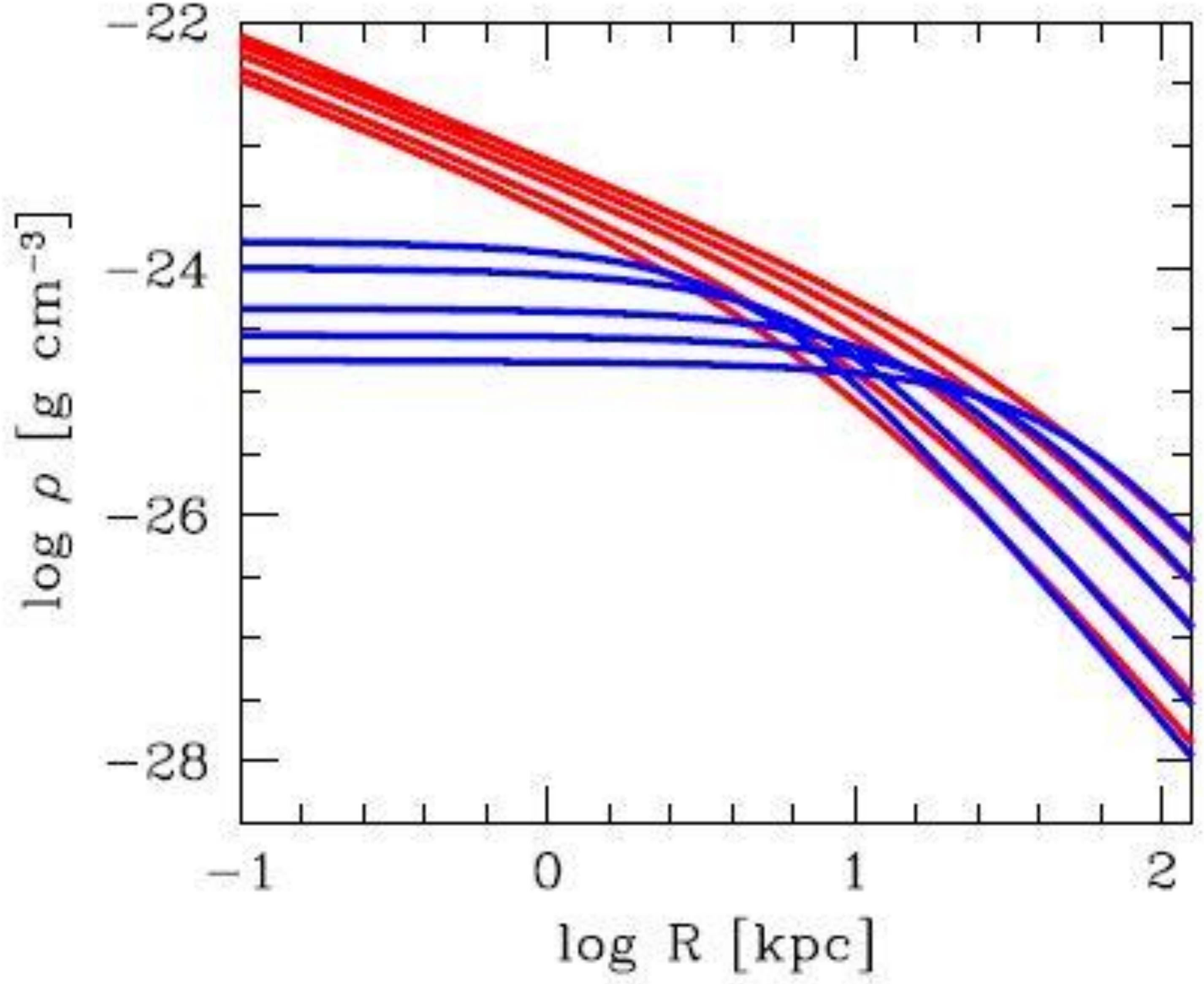


Gentile et al., ApJ 634, L145 (2005)

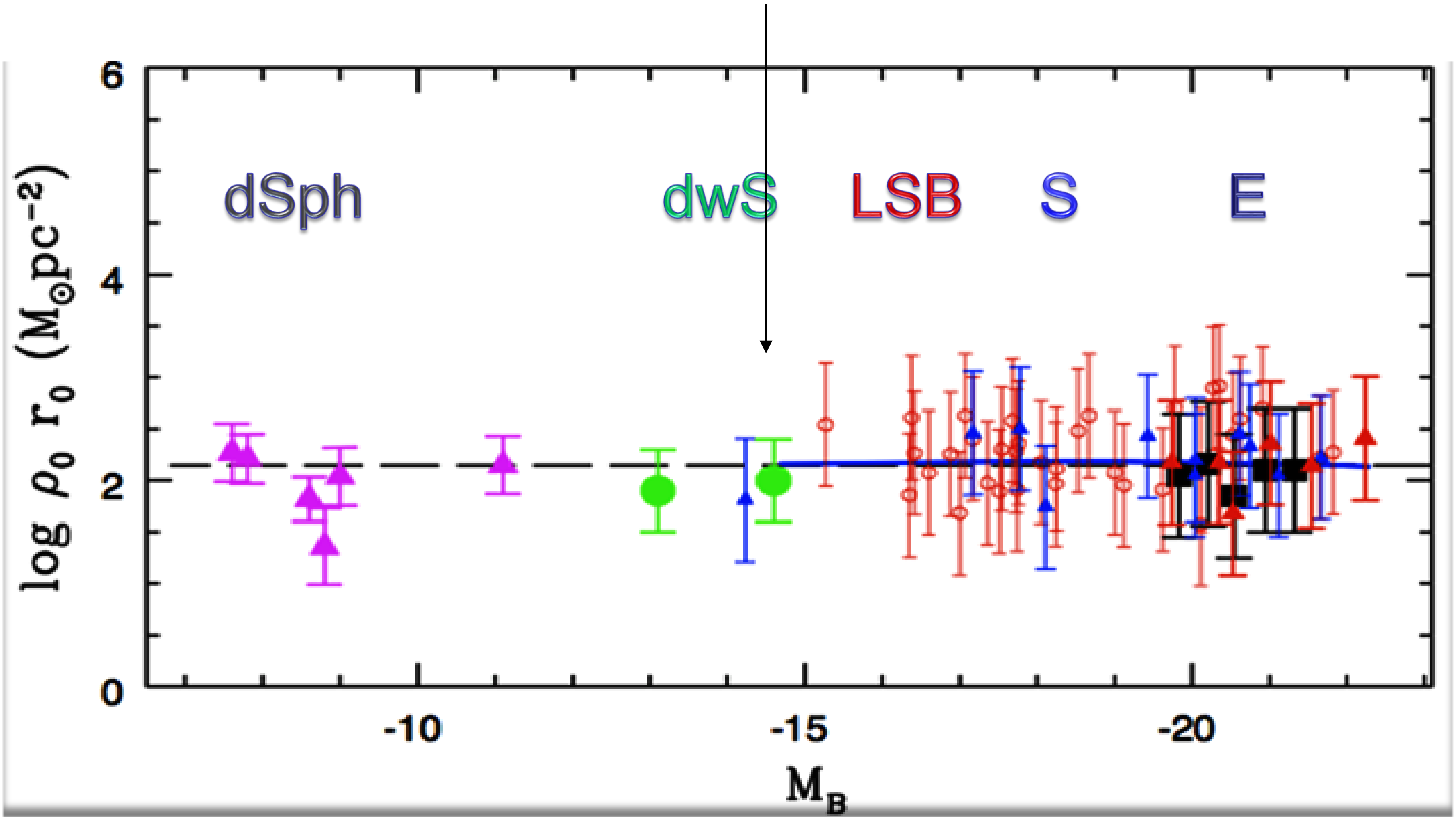


Gentile, Tonini & Salucci, A&A 467, 925 (2007)

Dark Matter density



GALAXY HALOS STRUCTURAL PARAMETRES

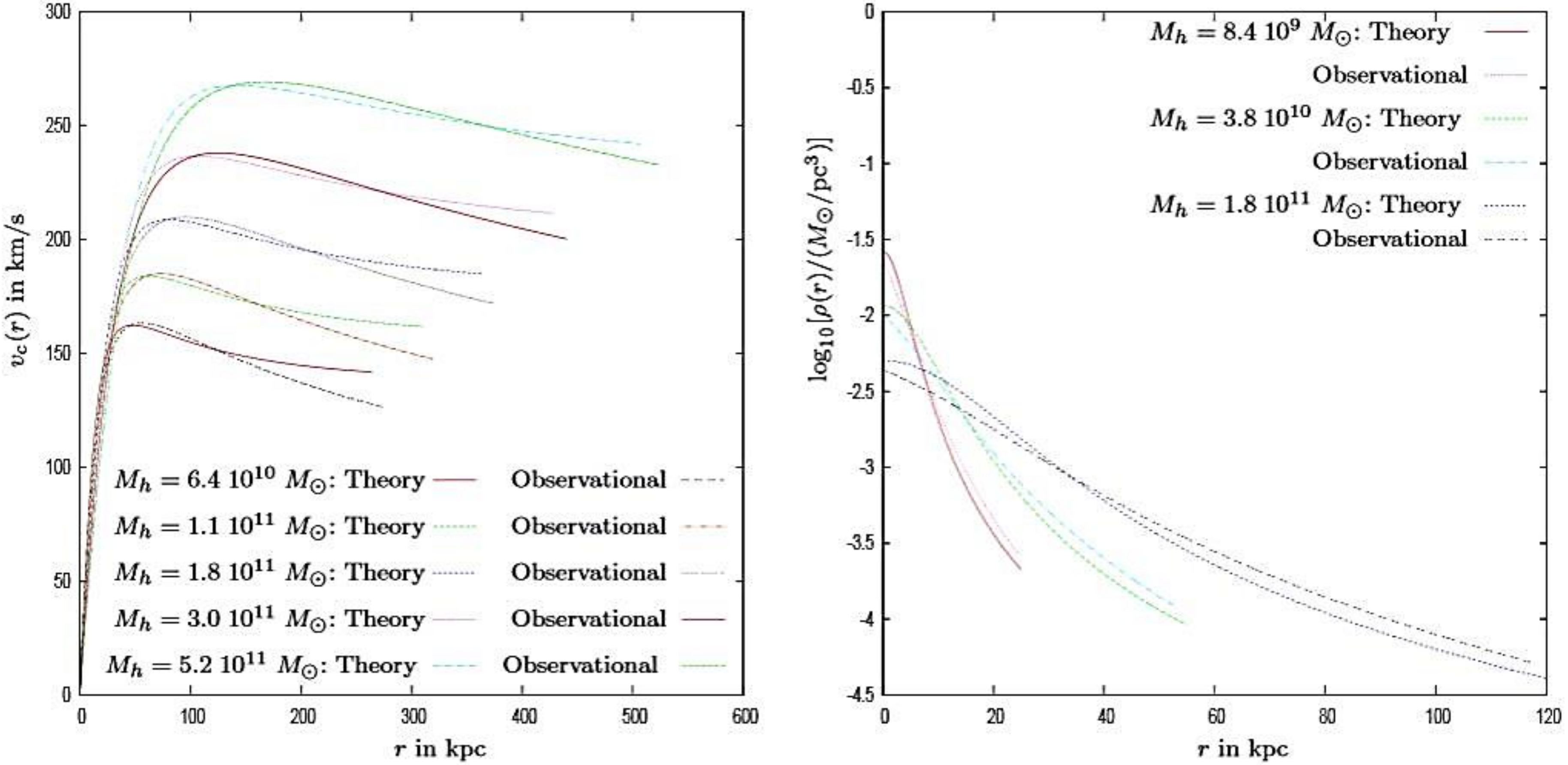


Core radii between 0.1 kpc to 100 kpc

Observational rotation curves and density profiles versus the Thomas–Fermi galaxy structure theory

H. J. de Vega,[1,2]★ P. Salucci[3] and N. G. Sanchez[2]

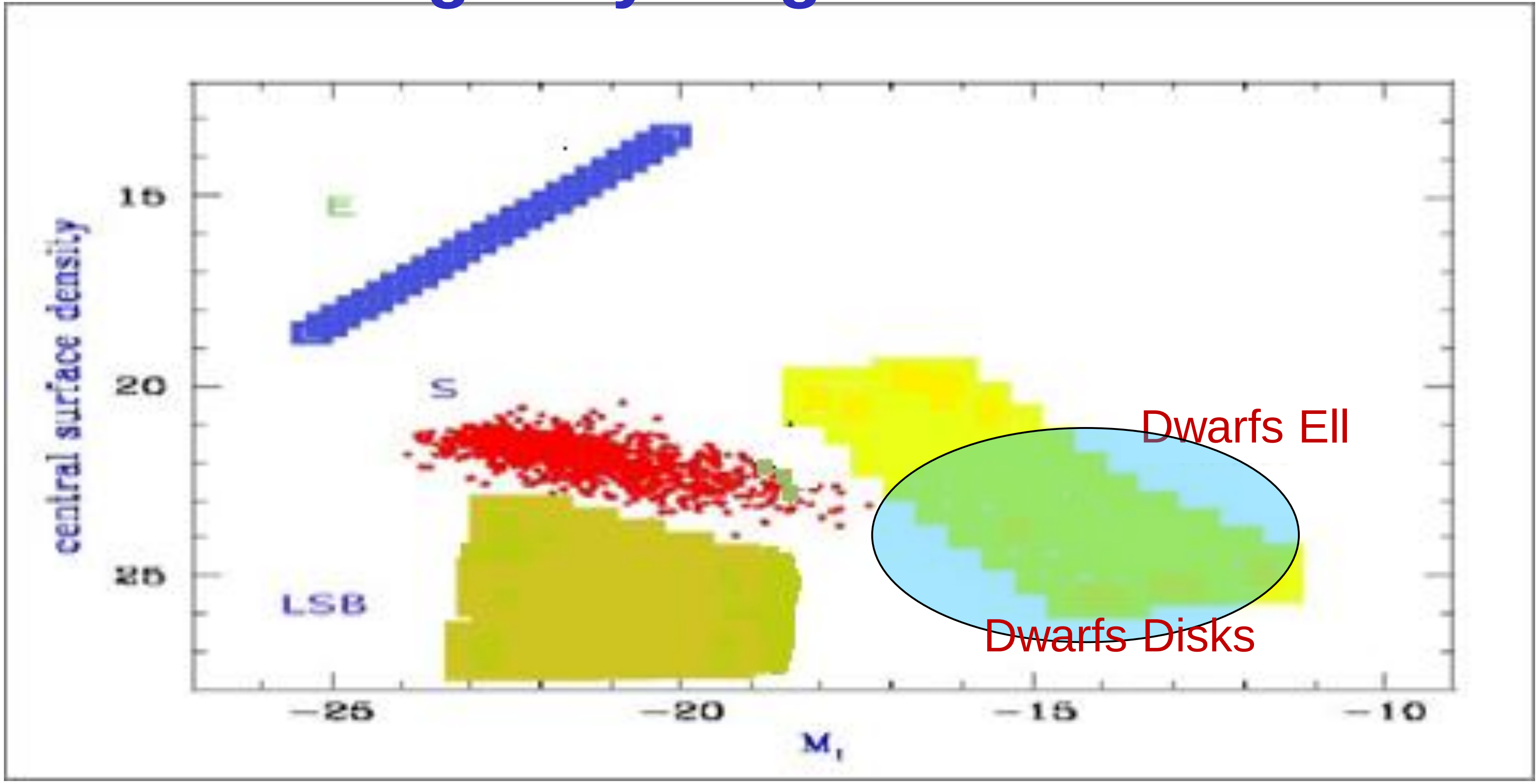
[1] *Sorbonne Universités, UPMC (Univ. Paris VI), CNRS, Laboratoire Associé au CNRS UMR 7589, Tour 13-14, 4ème. et 5ème. étage, Boîte 126, 4, Place Jussieu, F-75252 Paris, France*
[2] *Observatoire de Paris, LERMA, Laboratoire Associé au CNRS UMR 8112, 61, Avenue de l'Observatoire, F-75014 Paris, France*
[3] *SISSA/ISAS and INFN, Trieste, Iniziativa Specifica QSKY, via Bonomea 265, I-34136 Trieste, Italy*



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 :

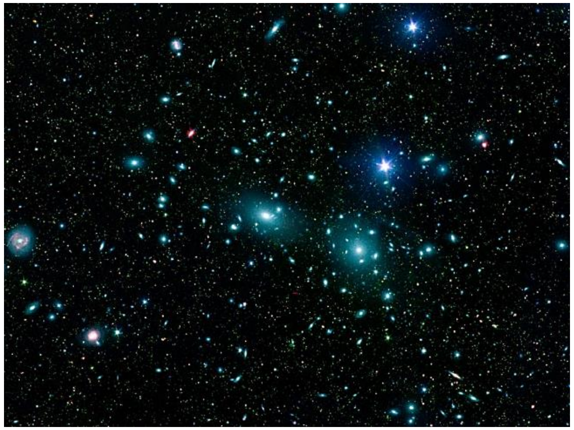
Spirals : stellar disk +bulge +HI disk

Ellipticals & dwarfs E: stellar spheroid

SMALLEST GALAXIES:
DWARF DISKS

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

dSph (Gilmore+)

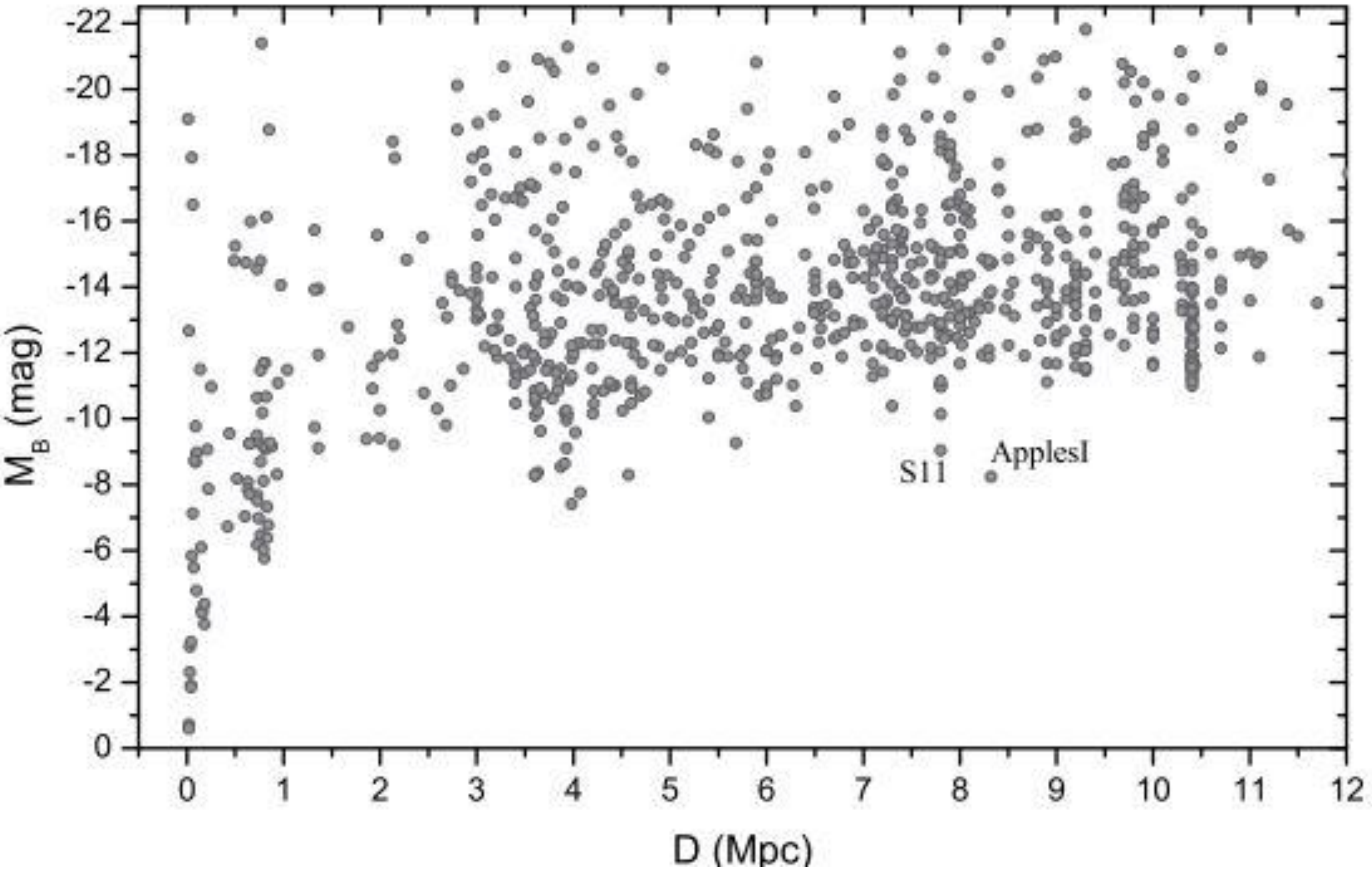


DD
simple dynamics

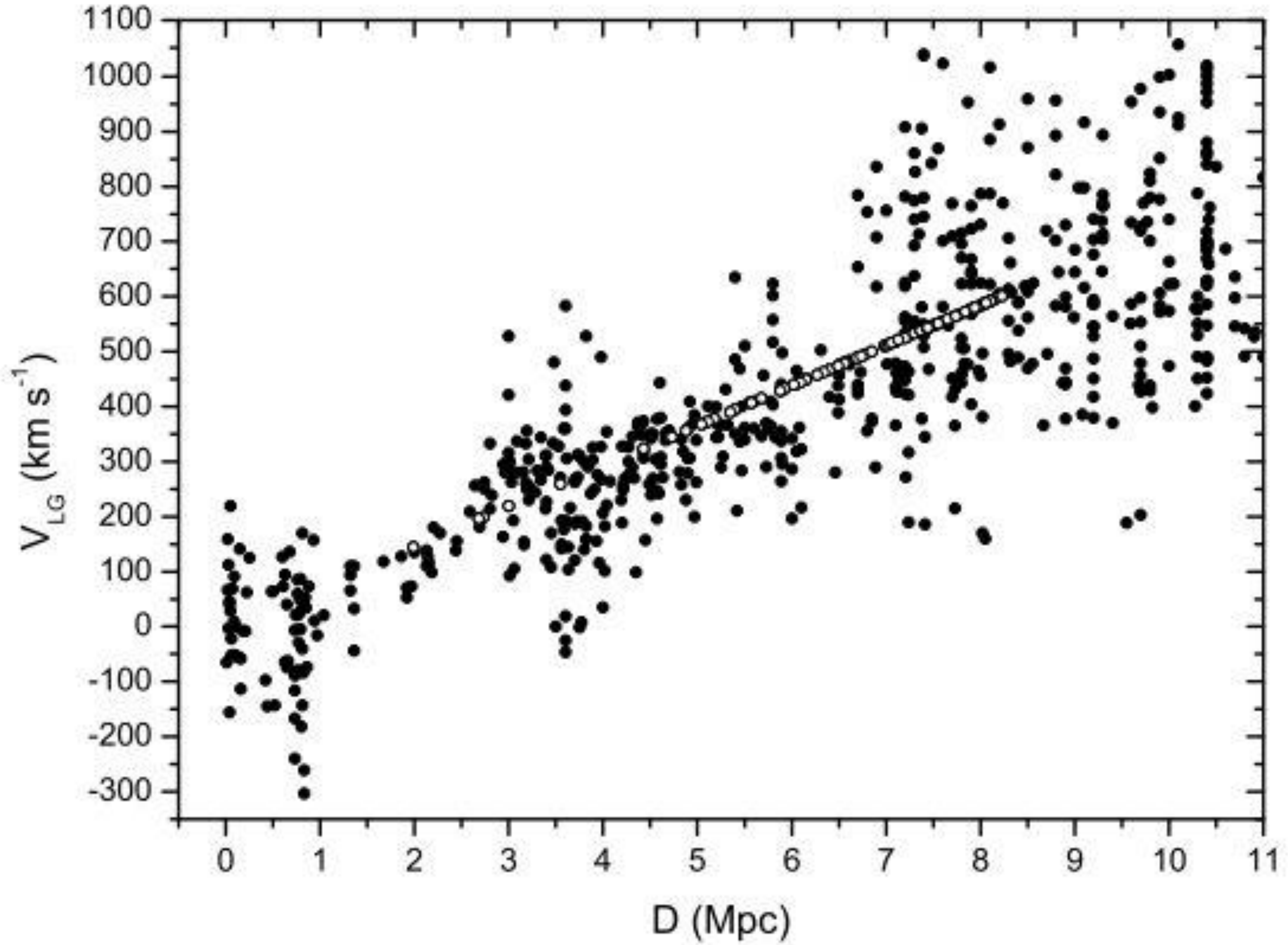
Updated Nearby Galaxy Catalog.

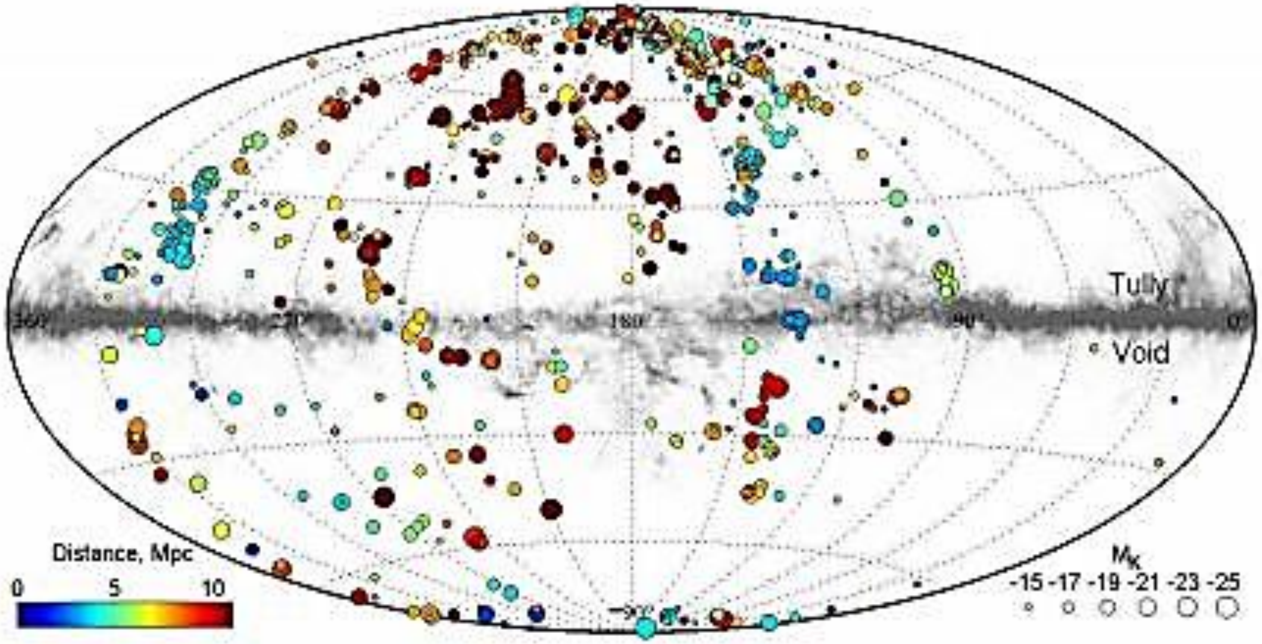
Igor D. Karachentsev, Dmitry I. Makarov and Elena I. Kaisina

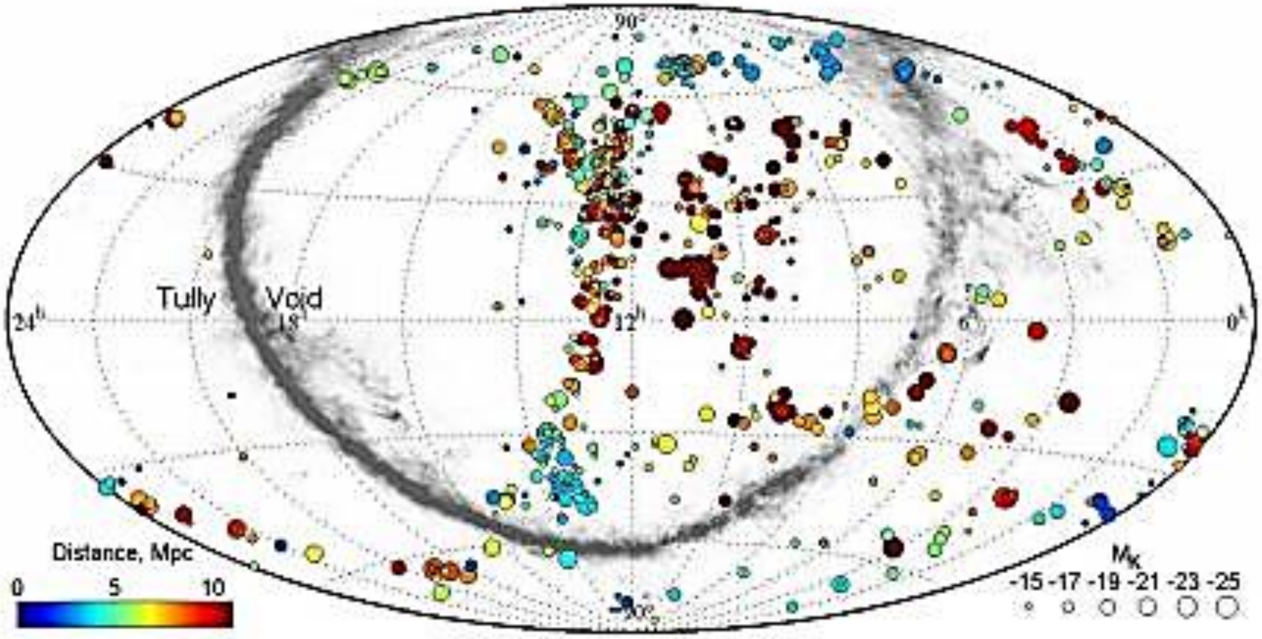
1000 galaxies inside 11 Mpc



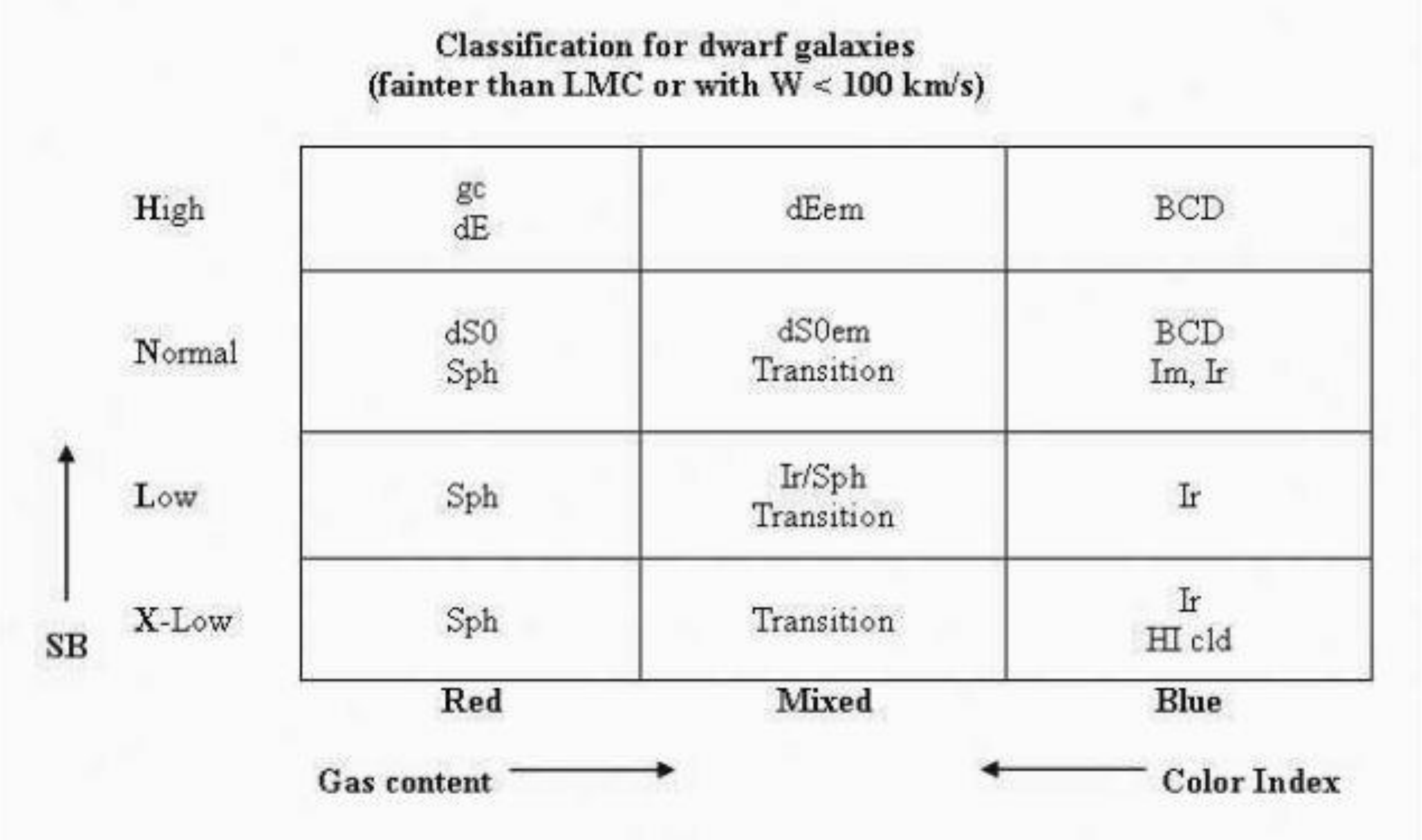
Hubble Flow


1100
1000
900
800
700
600
500
400
300
200
100
0
-100
-200
-300
V_{LG} (km s^{-1})
0
1
2
3
4
5
6
7
8
9
10
11
D (Mpc)


Tully
Void
360°
270°
180°
90°
0°
-90°
Distance, Mpc
0
5
10
M_K
-15 -17 -19 -21 -23 -25


90°
Tully
Void
24h
18h
12h
6h
0h
-90°
Distance, Mpc
0
5
10
M_K
-15 -17 -19 -21 -23 -25

Classification of Dwarfs



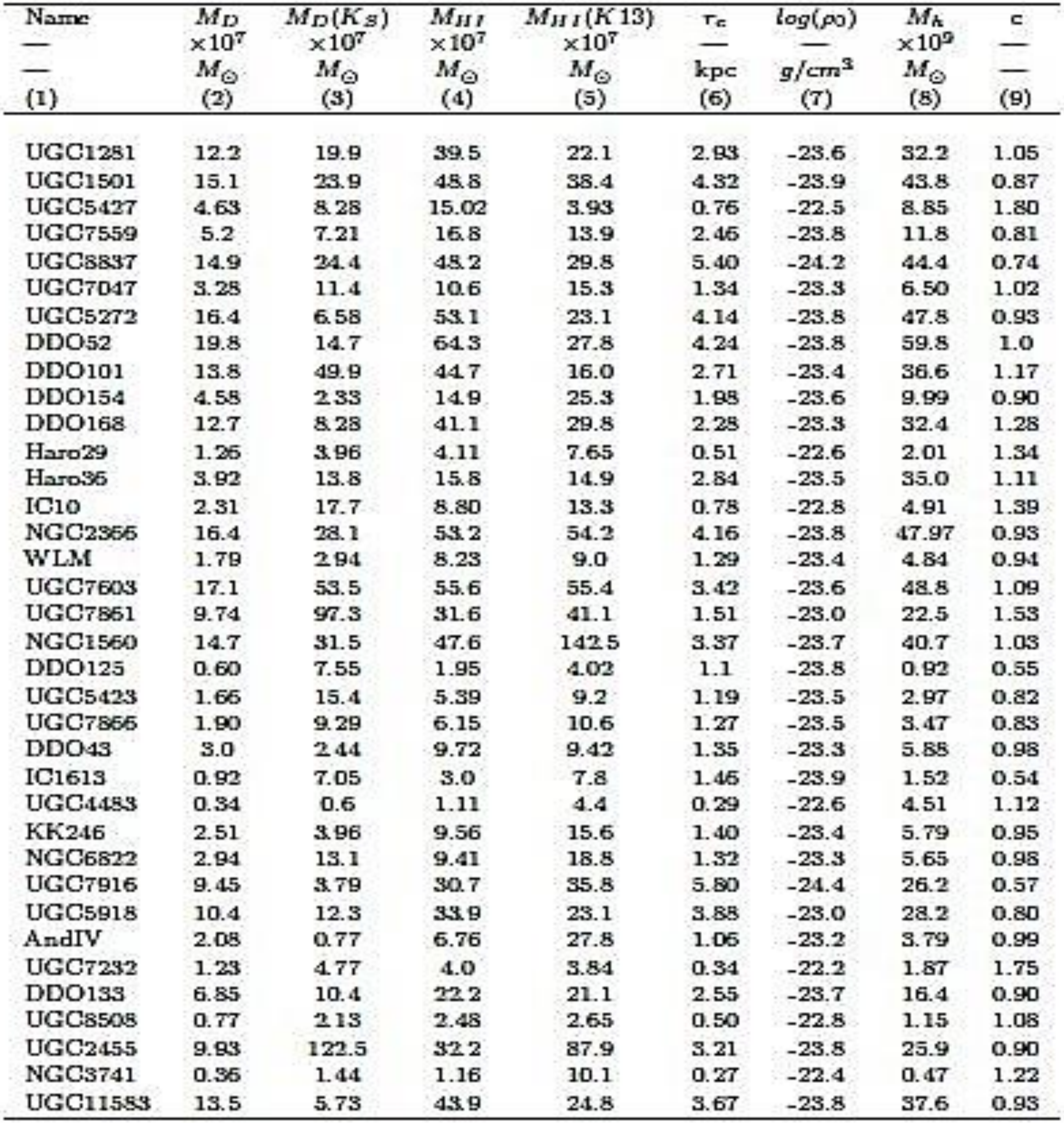
Classification for dwarf galaxies
(fainter than LMC or with W < 100 km/s)

SB	Red	Mixed	Blue
High	gc dE	dEem	BCD
Normal	dS0 Sph	dS0em Transition	BCD Im, Ir
Low	Sph	Ir/Sph Transition	Ir
X-Low	Sph	Transition	Ir HI cld

Gas content →

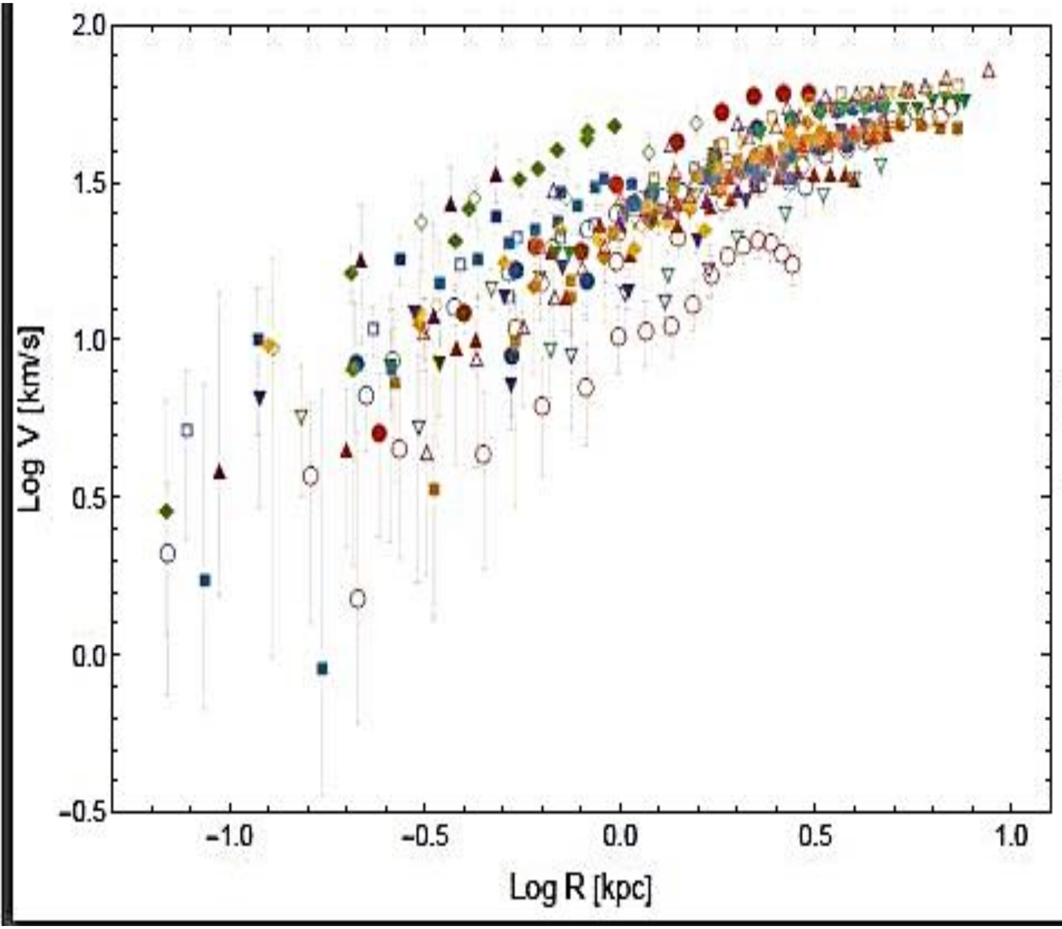
← **Color Index**

The DD Sample

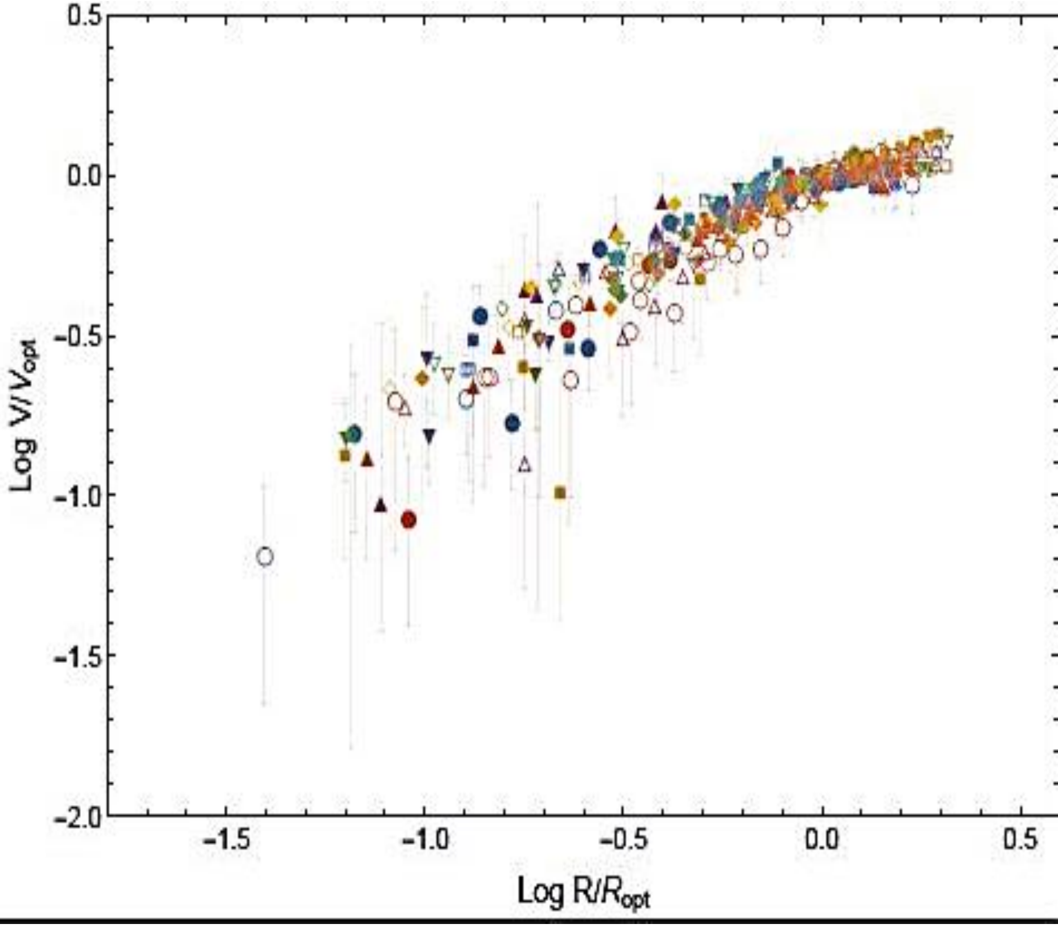


Name — — (1)	M_D $\times 10^7$ $M_\odot$ (2)	$M_D(K_S)$ $\times 10^7$ $M_\odot$ (3)	M_{HI} $\times 10^7$ $M_\odot$ (4)	$M_{HI}(K13)$ $\times 10^7$ $M_\odot$ (5)	r_c — kpc (6)	$log(\rho_0)$ — g/cm^3 (7)	M_h $\times 10^9$ $M_\odot$ (8)	c — — (9)
UGC1281	12.2	19.9	39.5	22.1	2.93	-23.6	32.2	1.05
UGC1501	15.1	23.9	48.8	38.4	4.32	-23.9	43.8	0.87
UGC5427	4.63	8.28	15.02	3.93	0.76	-22.5	8.85	1.80
UGC7559	5.2	7.21	16.8	13.9	2.46	-23.8	11.8	0.81
UGC8837	14.9	24.4	48.2	29.8	5.40	-24.2	44.4	0.74
UGC7047	3.28	11.4	10.6	15.3	1.34	-23.3	6.50	1.02
UGC5272	16.4	6.58	53.1	23.1	4.14	-23.8	47.8	0.93
DDO52	19.8	14.7	64.3	27.8	4.24	-23.8	59.8	1.0
DDO101	13.8	49.9	44.7	16.0	2.71	-23.4	36.6	1.17
DDO154	4.58	2.33	14.9	25.3	1.98	-23.6	9.99	0.90
DDO168	12.7	8.28	41.1	29.8	2.28	-23.3	32.4	1.28
Haro29	1.26	3.96	4.11	7.65	0.51	-22.6	2.01	1.34
Haro36	3.92	13.8	15.8	14.9	2.84	-23.5	35.0	1.11
IC10	2.31	17.7	8.80	13.3	0.78	-22.8	4.91	1.39
NGC2366	16.4	28.1	53.2	54.2	4.16	-23.8	47.97	0.93
WLM	1.79	2.94	8.23	9.0	1.29	-23.4	4.84	0.94
UGC7603	17.1	53.5	55.6	55.4	3.42	-23.6	48.8	1.09
UGC7861	9.74	97.3	31.6	41.1	1.51	-23.0	22.5	1.53
NGC1560	14.7	31.5	47.6	142.5	3.37	-23.7	40.7	1.03
DDO125	0.60	7.55	1.95	4.02	1.1	-23.8	0.92	0.55
UGC5423	1.66	15.4	5.39	9.2	1.19	-23.5	2.97	0.82
UGC7866	1.90	9.29	6.15	10.6	1.27	-23.5	3.47	0.83
DDO43	3.0	2.44	9.72	9.42	1.35	-23.3	5.88	0.98
IC1613	0.92	7.05	3.0	7.8	1.46	-23.9	1.52	0.54
UGC4483	0.34	0.6	1.11	4.4	0.29	-22.6	4.51	1.12
KK246	2.51	3.96	9.56	15.6	1.40	-23.4	5.79	0.95
NGC6822	2.94	13.1	9.41	18.8	1.32	-23.3	5.65	0.98
UGC7916	9.45	3.79	30.7	35.8	5.80	-24.4	26.2	0.57
UGC5918	10.4	12.3	33.9	23.1	3.88	-23.0	28.2	0.80
AndIV	2.08	0.77	6.76	27.8	1.06	-23.2	3.79	0.99
UGC7232	1.23	4.77	4.0	3.84	0.34	-22.2	1.87	1.75
DDO133	6.85	10.4	22.2	21.1	2.55	-23.7	16.4	0.90
UGC8508	0.77	2.13	2.48	2.65	0.50	-22.8	1.15	1.08
UGC2455	9.93	122.5	32.2	87.9	3.21	-23.8	25.9	0.90
NGC3741	0.36	1.44	1.16	10.1	0.27	-22.4	0.47	1.22
UGC11583	13.5	5.73	43.9	24.8	3.67	-23.8	37.6	0.93

36 Individual RCs

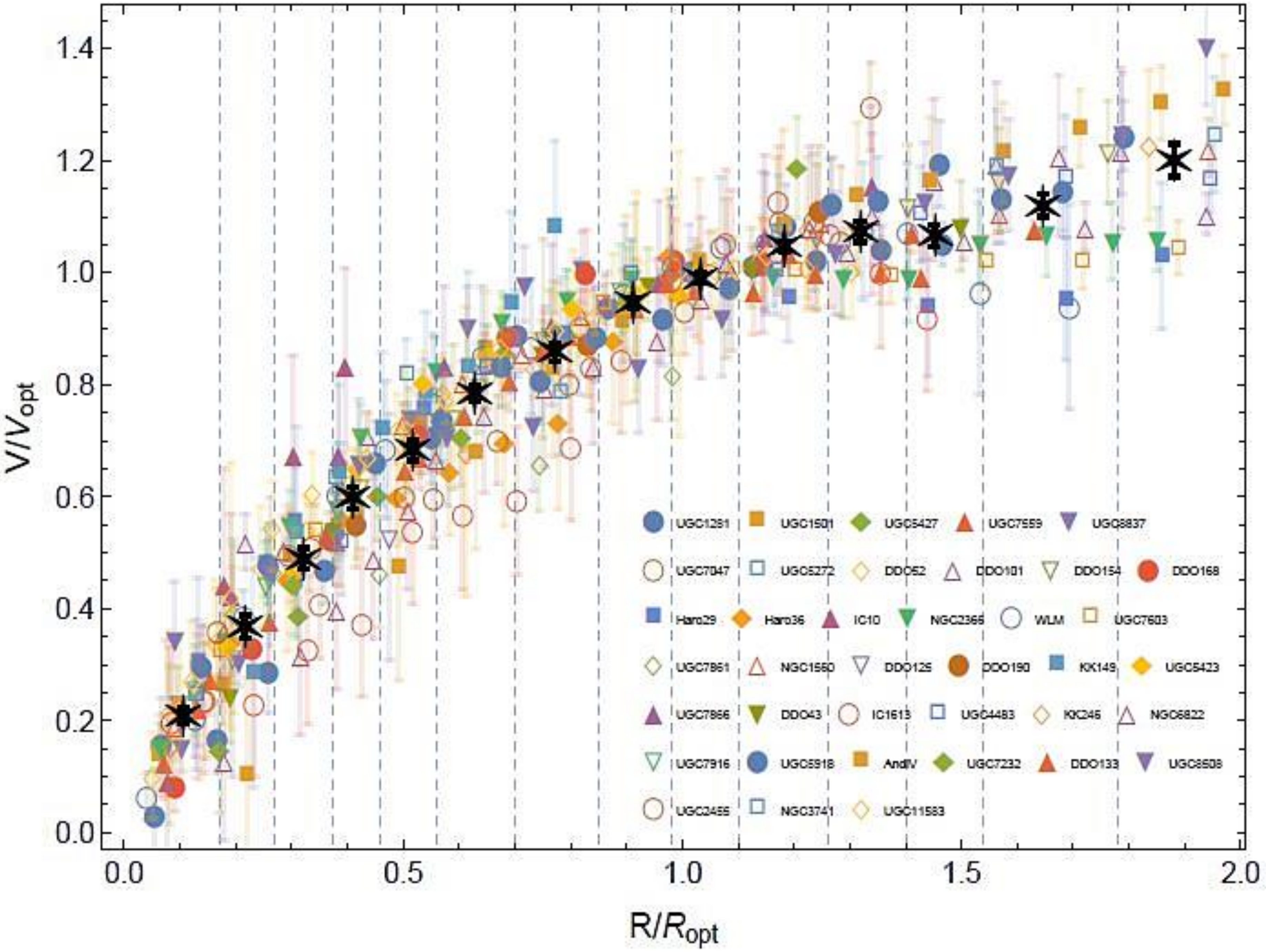


Double Normalized



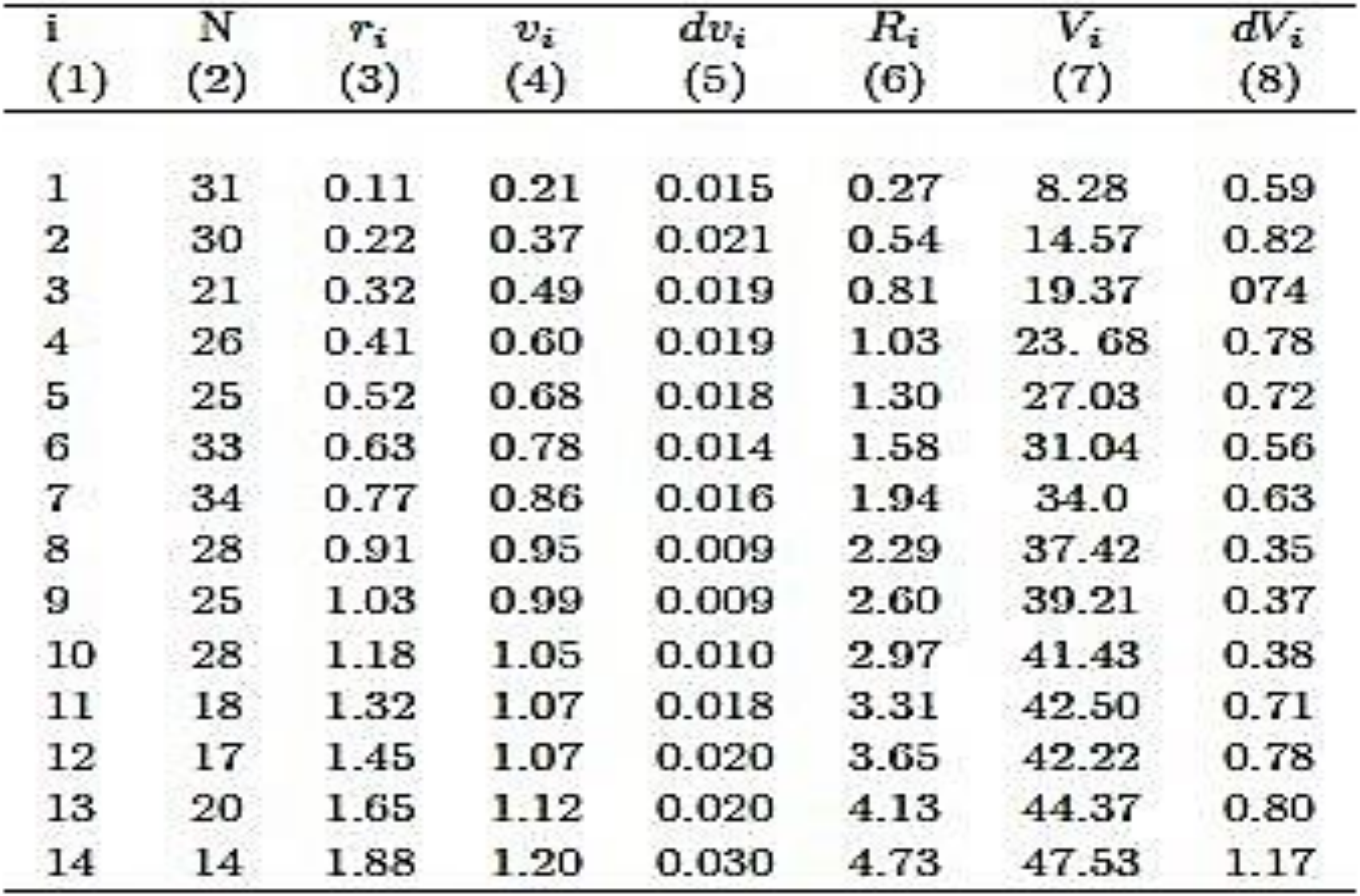
$$V_{DN} = V(R/R_{opt})/V_{opt}$$

Coadded curve



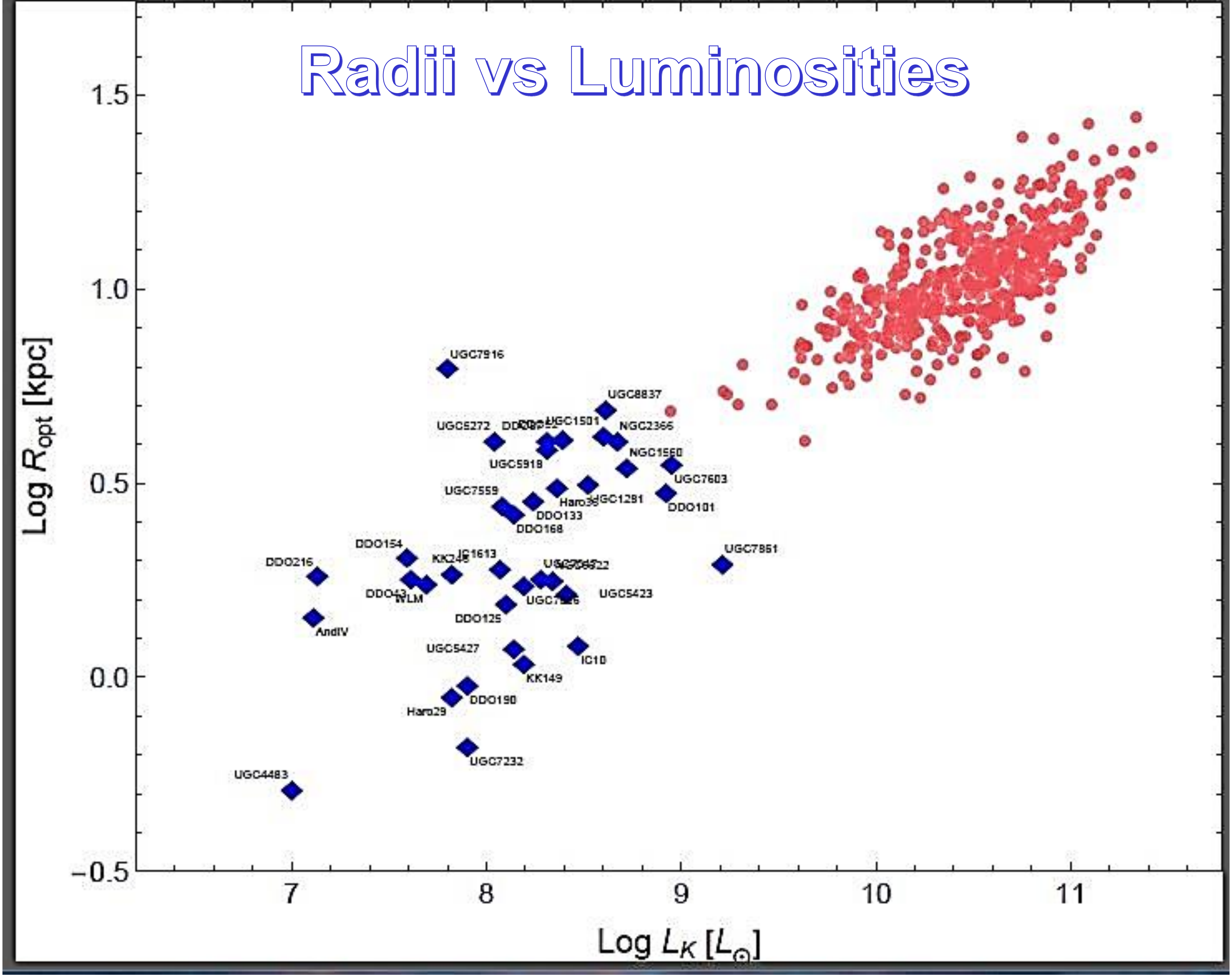
The DD Coadded Curve - DDURC

$V(R/R_{opt})/V_{opt}$

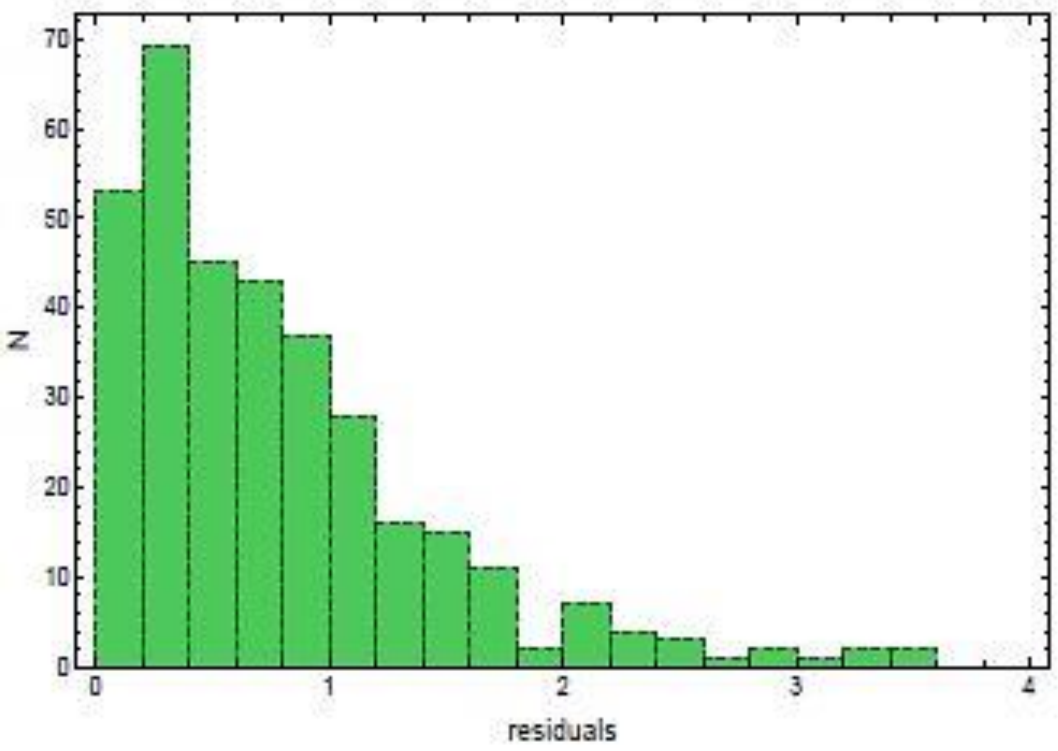


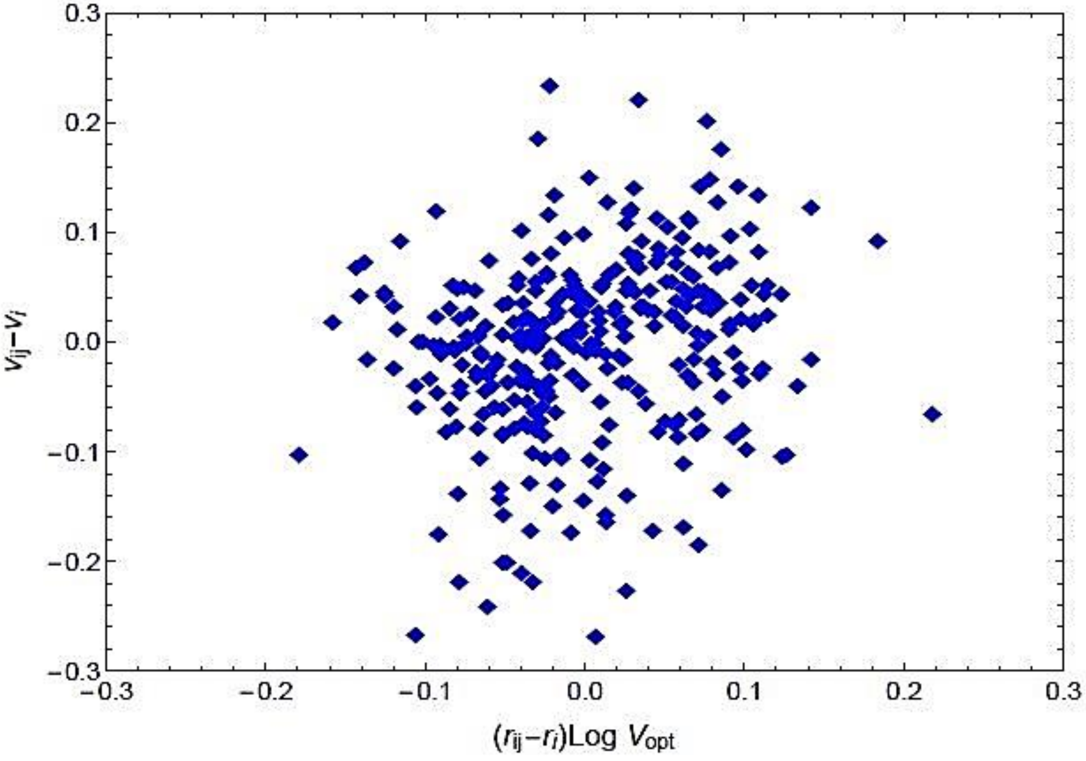
i (1)	N (2)	r_i (3)	v_i (4)	dv_i (5)	R_i (6)	V_i (7)	dV_i (8)
1	31	0.11	0.21	0.015	0.27	8.28	0.59
2	30	0.22	0.37	0.021	0.54	14.57	0.82
3	21	0.32	0.49	0.019	0.81	19.37	074
4	26	0.41	0.60	0.019	1.03	23. 68	0.78
5	25	0.52	0.68	0.018	1.30	27.03	0.72
6	33	0.63	0.78	0.014	1.58	31.04	0.56
7	34	0.77	0.86	0.016	1.94	34.0	0.63
8	28	0.91	0.95	0.009	2.29	37.42	0.35
9	25	1.03	0.99	0.009	2.60	39.21	0.37
10	28	1.18	1.05	0.010	2.97	41.43	0.38
11	18	1.32	1.07	0.018	3.31	42.50	0.71
12	17	1.45	1.07	0.020	3.65	42.22	0.78
13	20	1.65	1.12	0.020	4.13	44.37	0.80
14	14	1.88	1.20	0.030	4.73	47.53	1.17

Radii vs Luminosities

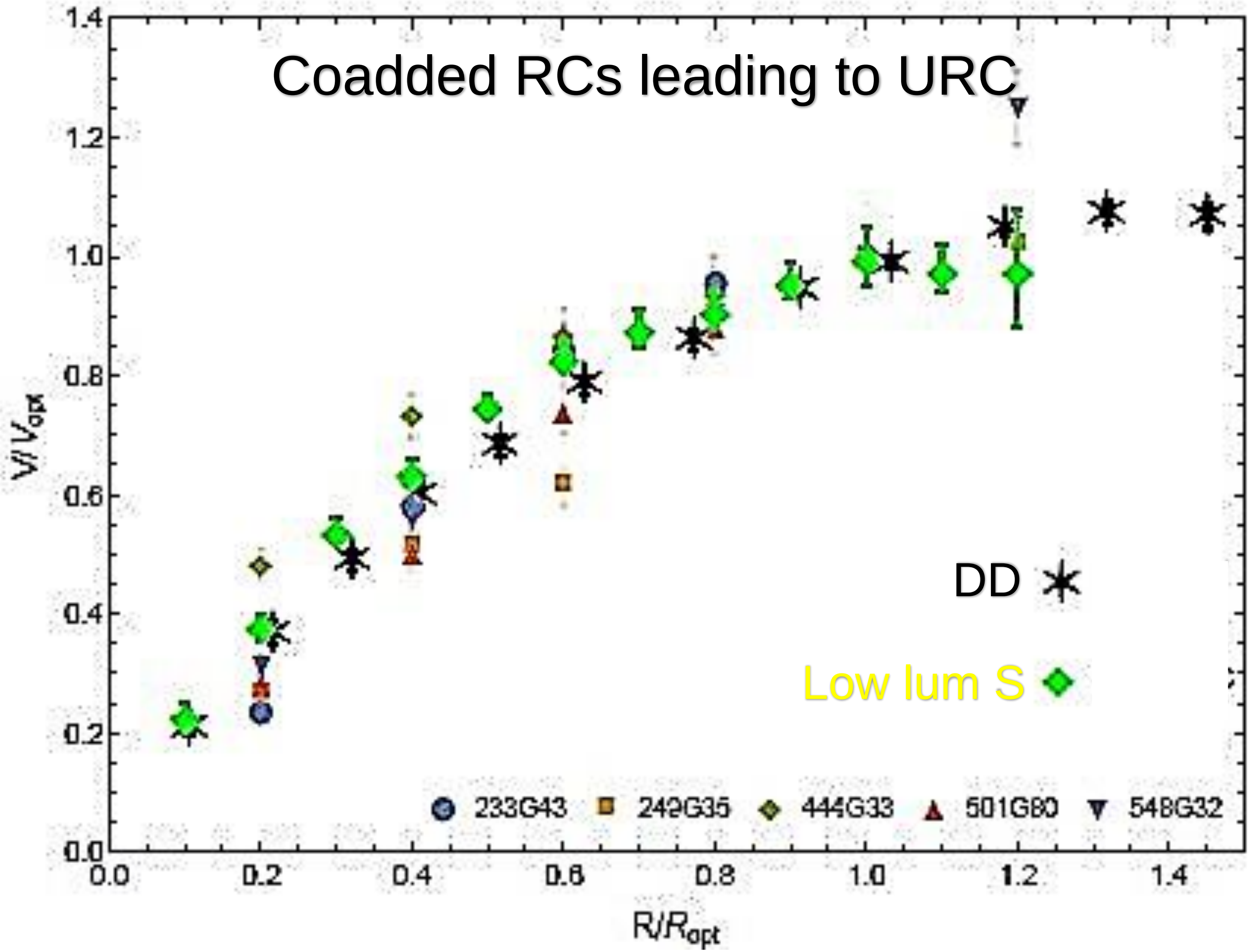


Velocity residuals: just observational errors and no biases

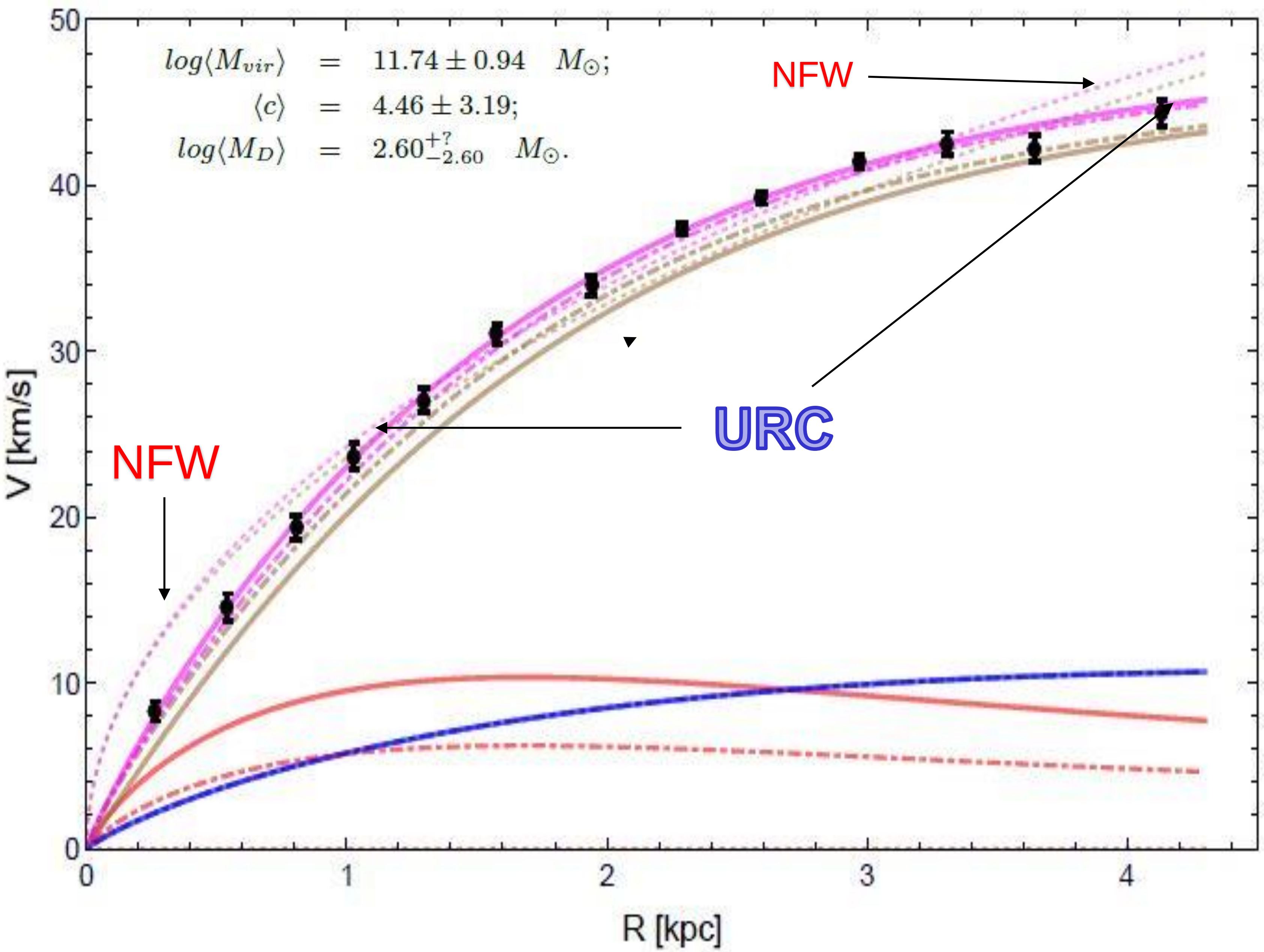




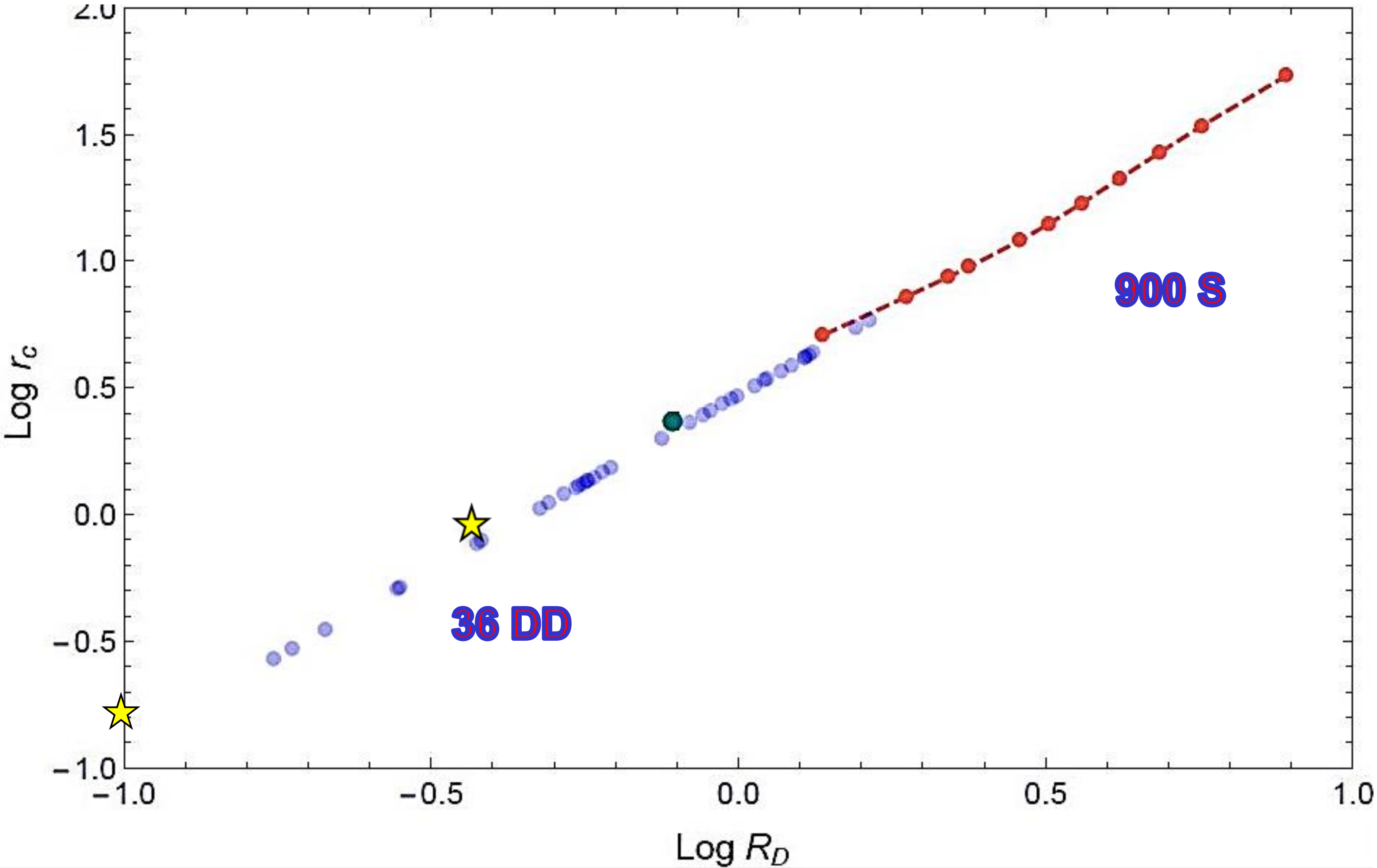
Coadded RCs leading to URC



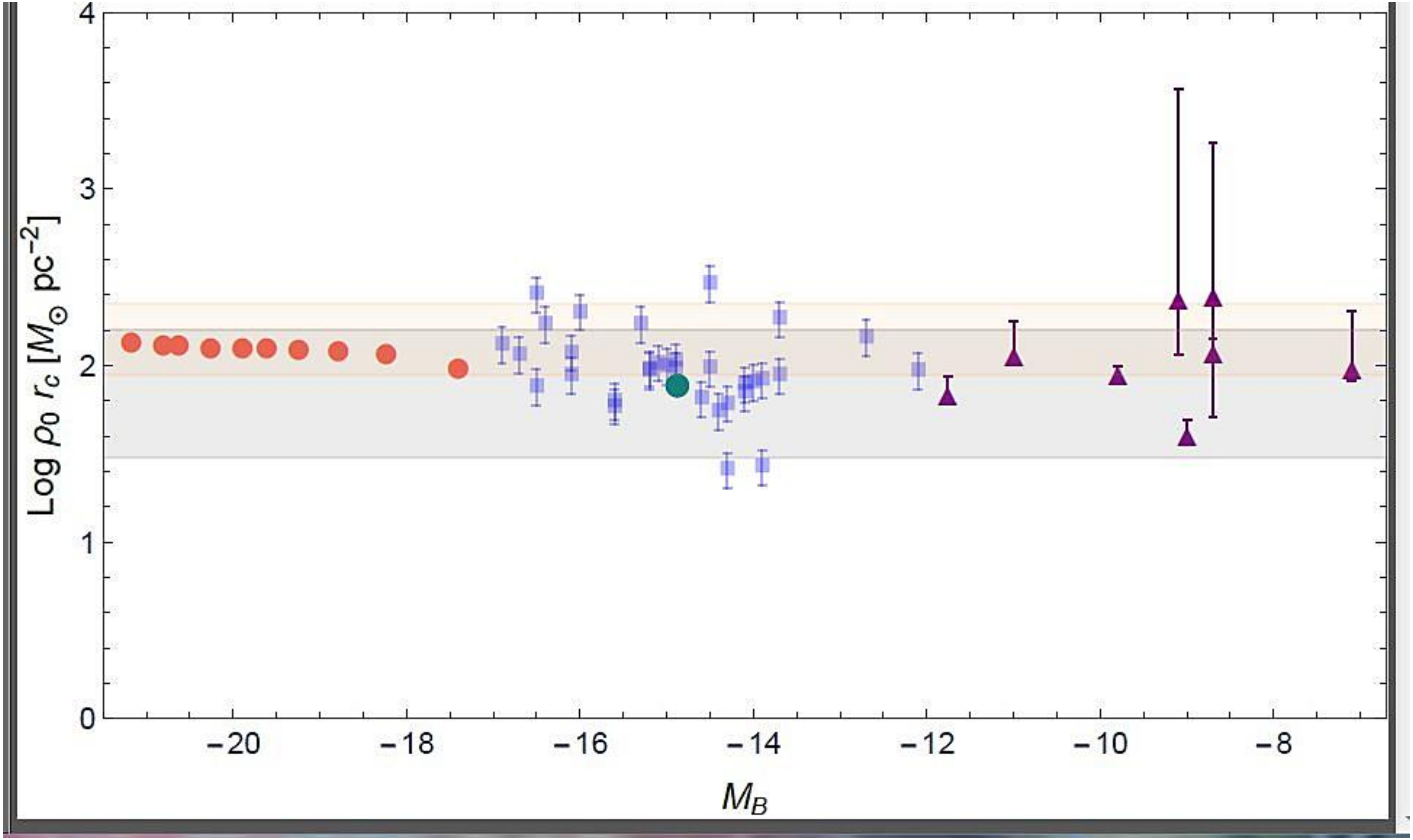
DDURC: modelling the coadded curve



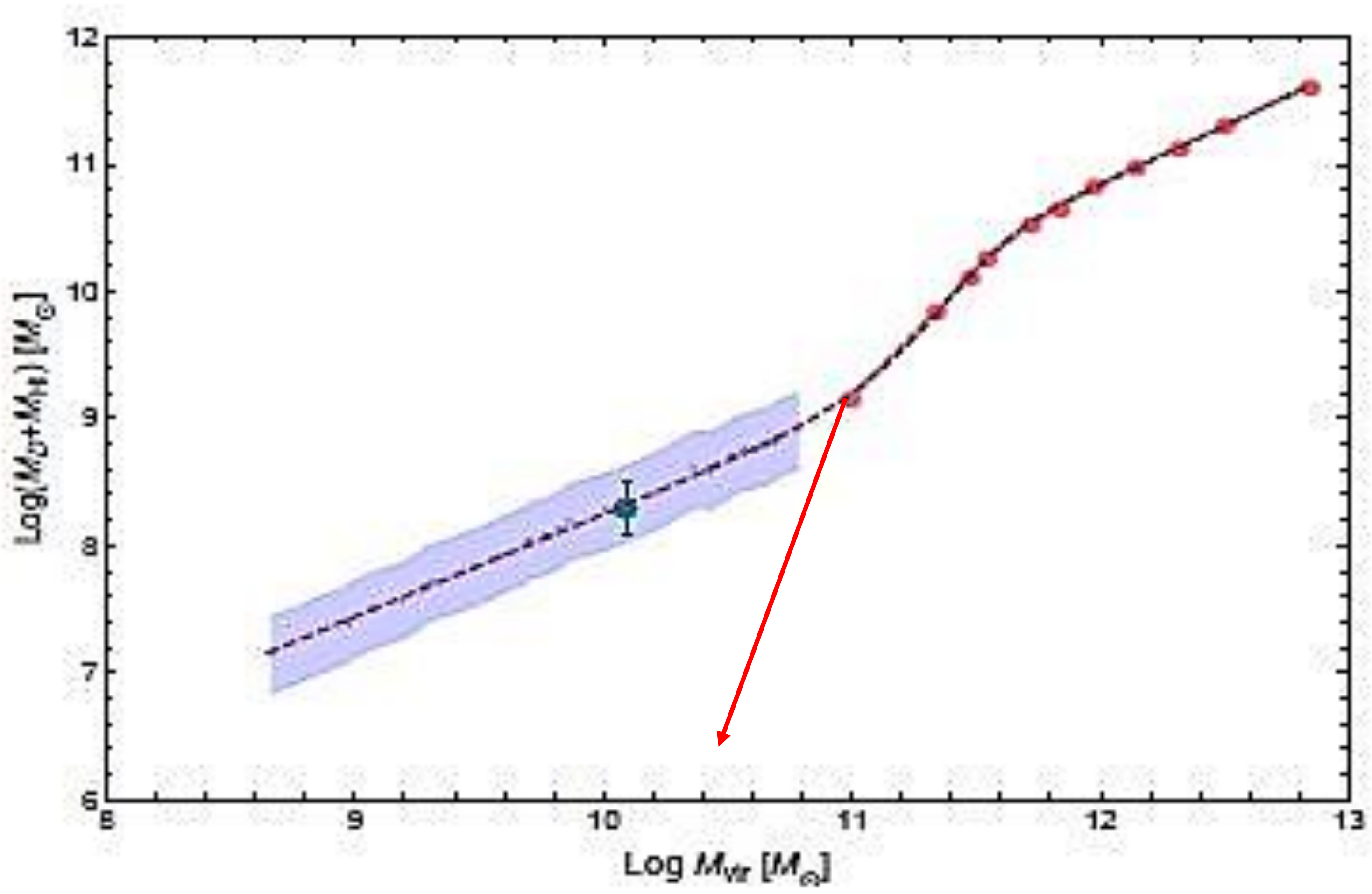
tight correlation core radius-half light radius



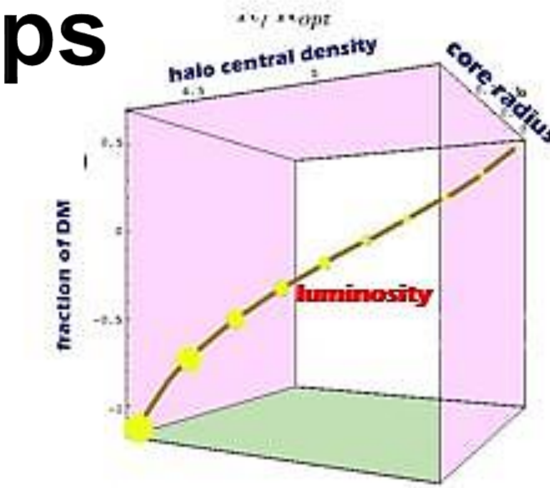
Central DM surface density

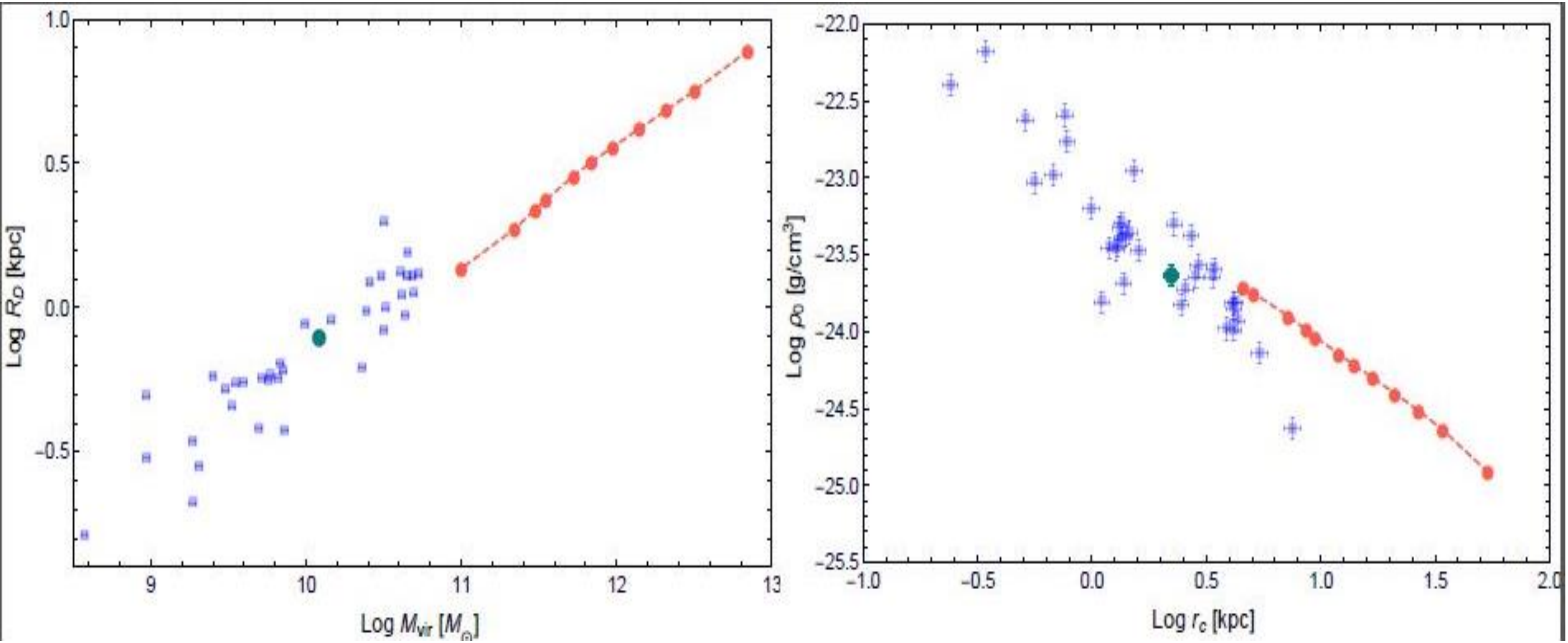


Baryonic – halo masses relationship



Dwarf Disks structural relationships

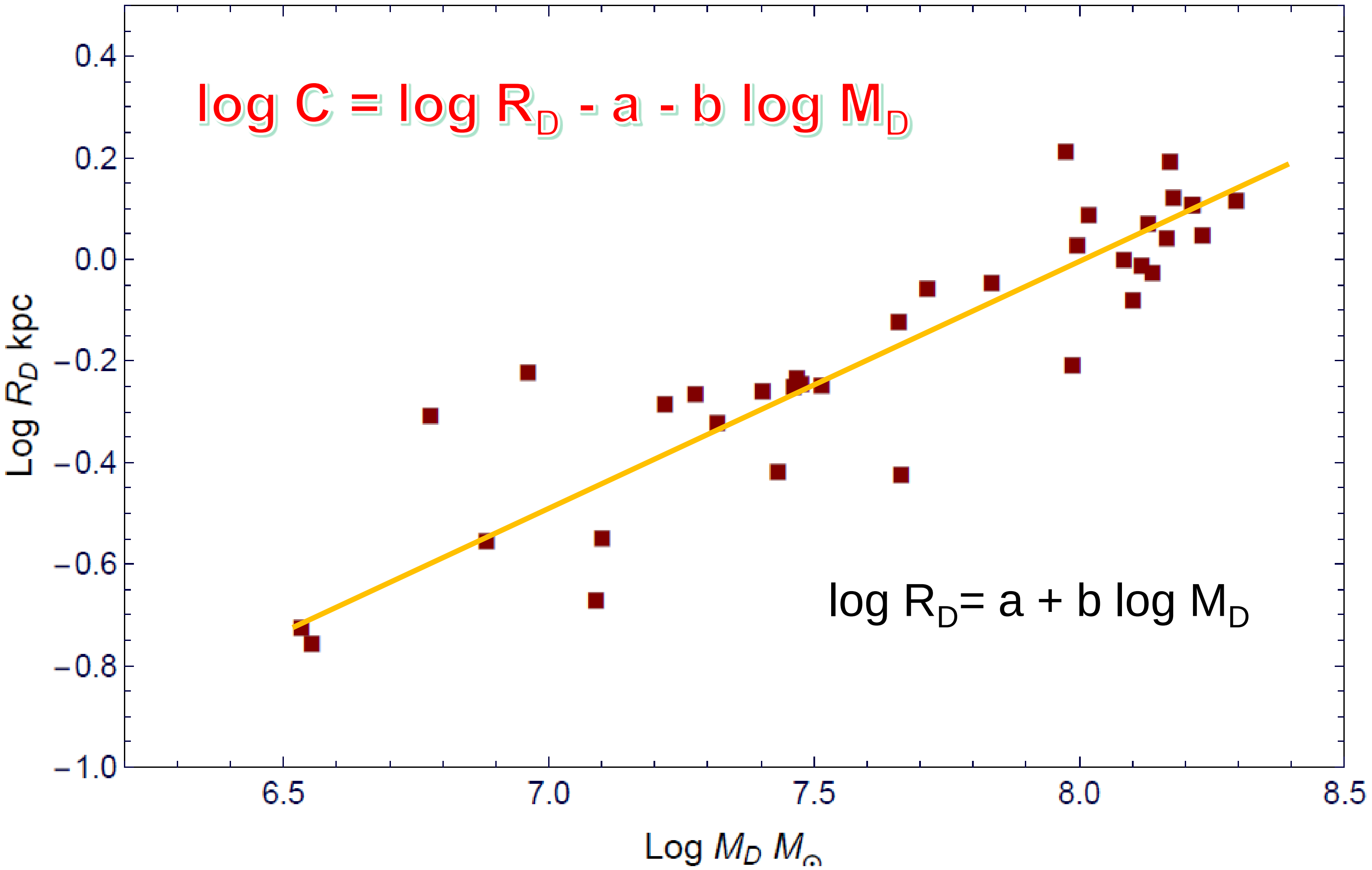




not anymore a Universal Curve

The C parameter

$$\log R_D = a + b \log M_D$$



$$\log C = \log R_D - a - b \log M_D$$

$$\log R_D = a + b \log M_D$$

ΛCDM + feedback ?

Good Luck!

CDM PARADIGM

-we know the dark particle ab initio

-we will detect it through LHC experiments, by capturing it or by detectitd its annihilation or decay product

Large scales observations in agreement

Observations of dark matter in galaxies must fit the LCDM scenario once their cosmo astrophysics is correctly considered

Inferred properties of Dark Matter halos give no new information on the particle

After 30 years CDM

Progresses in detecting the particle have been very few, if any.

No dark particle has been "produced" or "seen" at LHC (also in run 2)

no dark particle has been detected in the many underground dark matter experiments

no dark particle has exposed itself by emitting radiation while annihilating with its antiparticle in the centers of Earth, Sun and Galaxy.

the number of dark halos and their density profiles are very different with respect to those that are predicted within the CDM paradigm.

very serious lack of the "shooting gun" that a collisionless COLD elementary particle runs the Universe.

CONCLUSIONS

Cosmo-astrophysical Observations are an Unique Portal to the nature of DM & galaxies Formation and Evolution

The amazing properties of the mass distribution of Dark Matter in very different types of galaxies clearly indicates for a Warm Dark Particle

Other possibilties are too much fine tuned and or ineffective to explain the observational scenario.