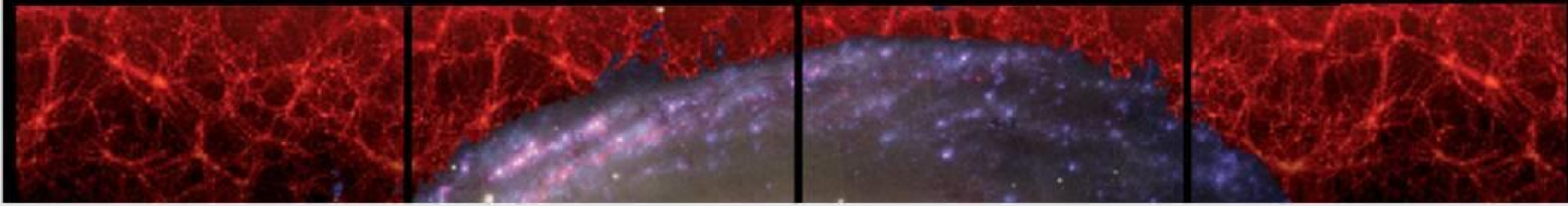


Warm is the new Cold: the case of Dwarf Disks

PAOLO SALUCCI

SISSA, GSSI

XII DSU, Bergen, Norway, July 2016

Brief outline

Properties of DM around Dwarf Spirals
Implications

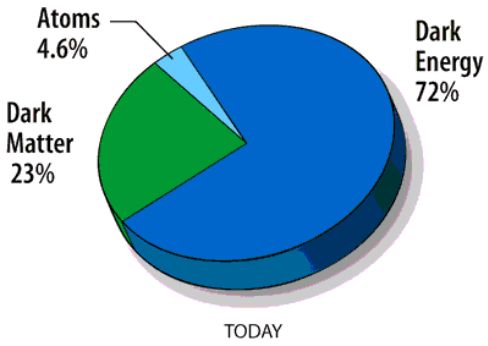
Kate Karukes,

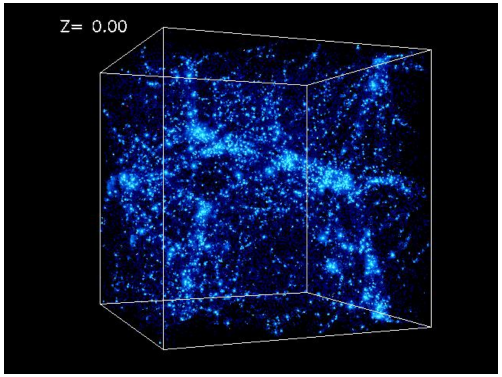
JP. Fontaine, S.Harisadu, A. Subranaiman, E.Lopez Fune, C. Di Paolo
A. Lapi, F. Nesti, MF de Laurentis
Hector dV and Norma Sancez

de Vega, H. J.; Salucci, P.; Sanchez, N. G. 014MNRAS.442.2717D
Observational rotation curves and density profiles versus the Thomas-Fermi galaxy structure theory
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 `
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

Outline

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





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

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

Spirals best place to investigate DM

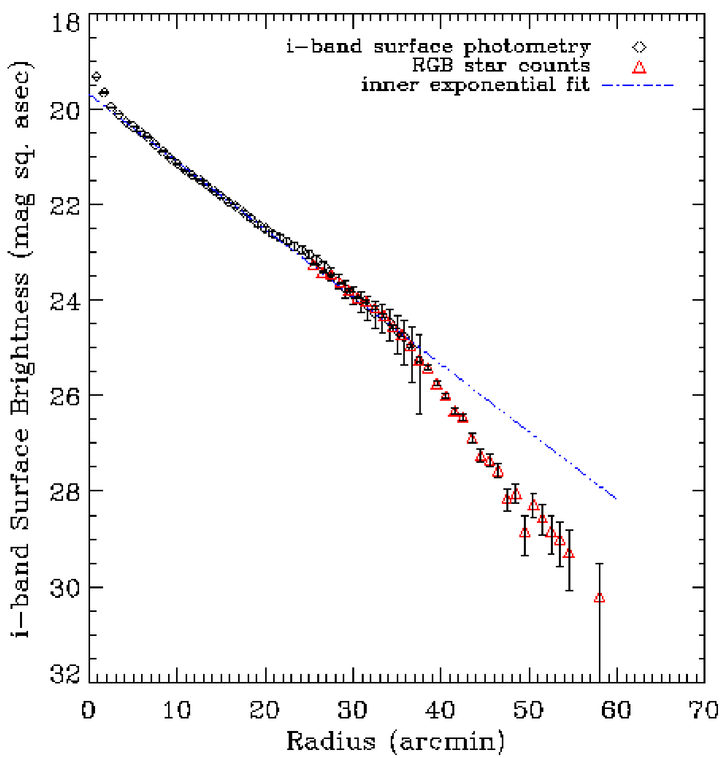
M33 disk very smooth,
truncated at 4 scale-lengths

NGC 300 exponential disk
for at least 10 scale-lengths

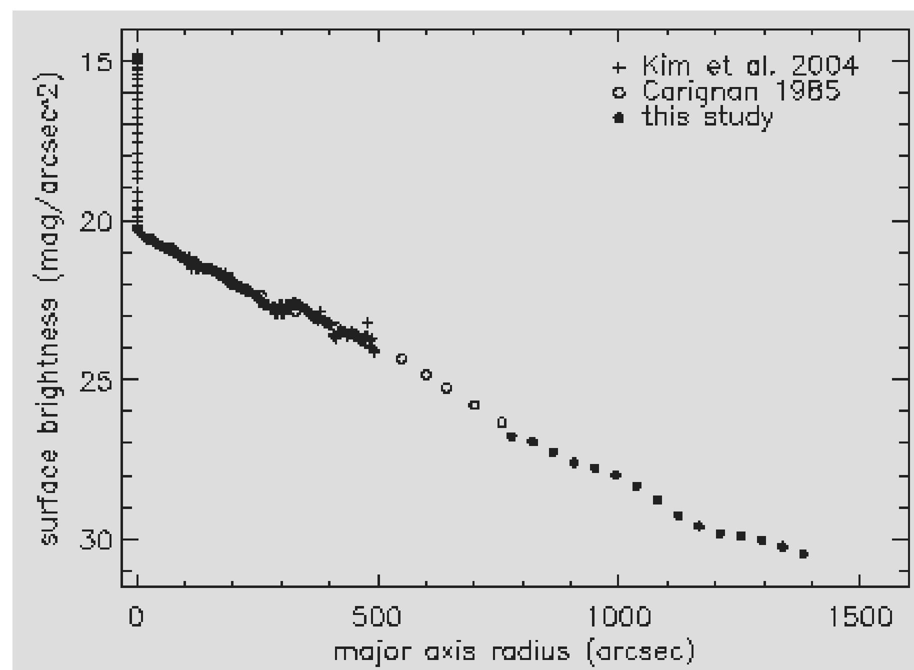
$$I(r) = I_0 e^{-r/R_D}$$

R_D lenght scale of the disk

Freeman, 1970



Ferguson et al 2003



Bland-Hawthorn et al 2005

Rotation curve analysis

From data to mass models

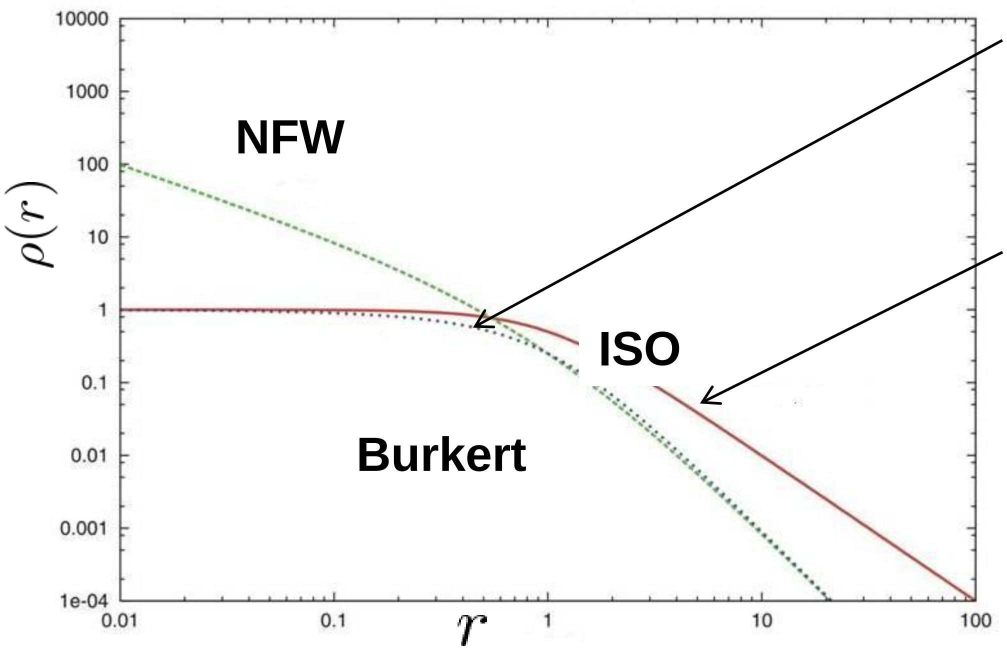
$$V^2(R) = V^2_{halo}(R) + V^2_{HI}(R) + V^2_{disk}(R)$$

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)



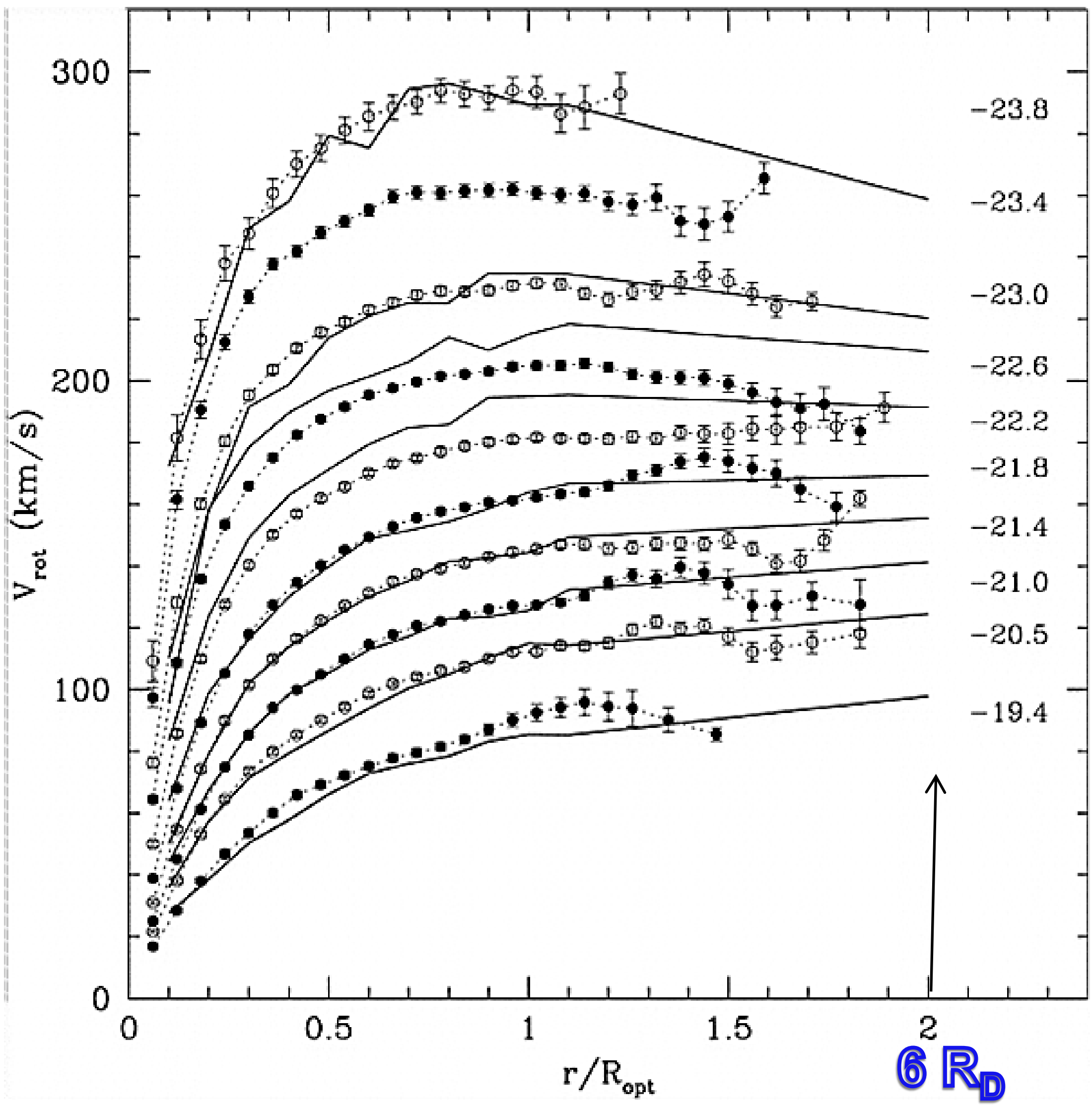
$$\rho(r) = \frac{\rho_0}{(1 + r/r_0)(1 + (r/r_0)^2)}$$

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

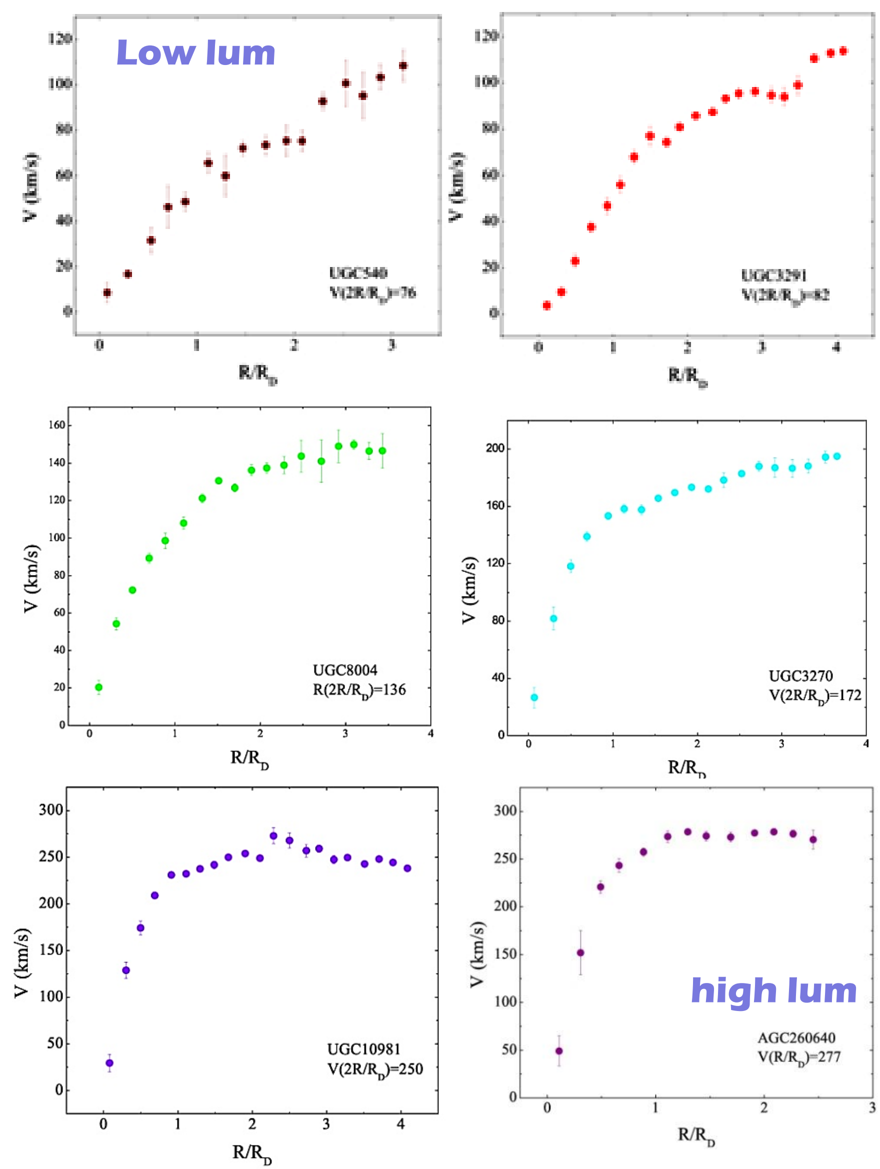
The mass model has 3 free parameters:
disk mass
halo central density
Halo core radius (length-scale)
Obtained by MCMC methods

Radio + Optical Rotation Curves of Spirals

Coadded from 3200 individual RCs

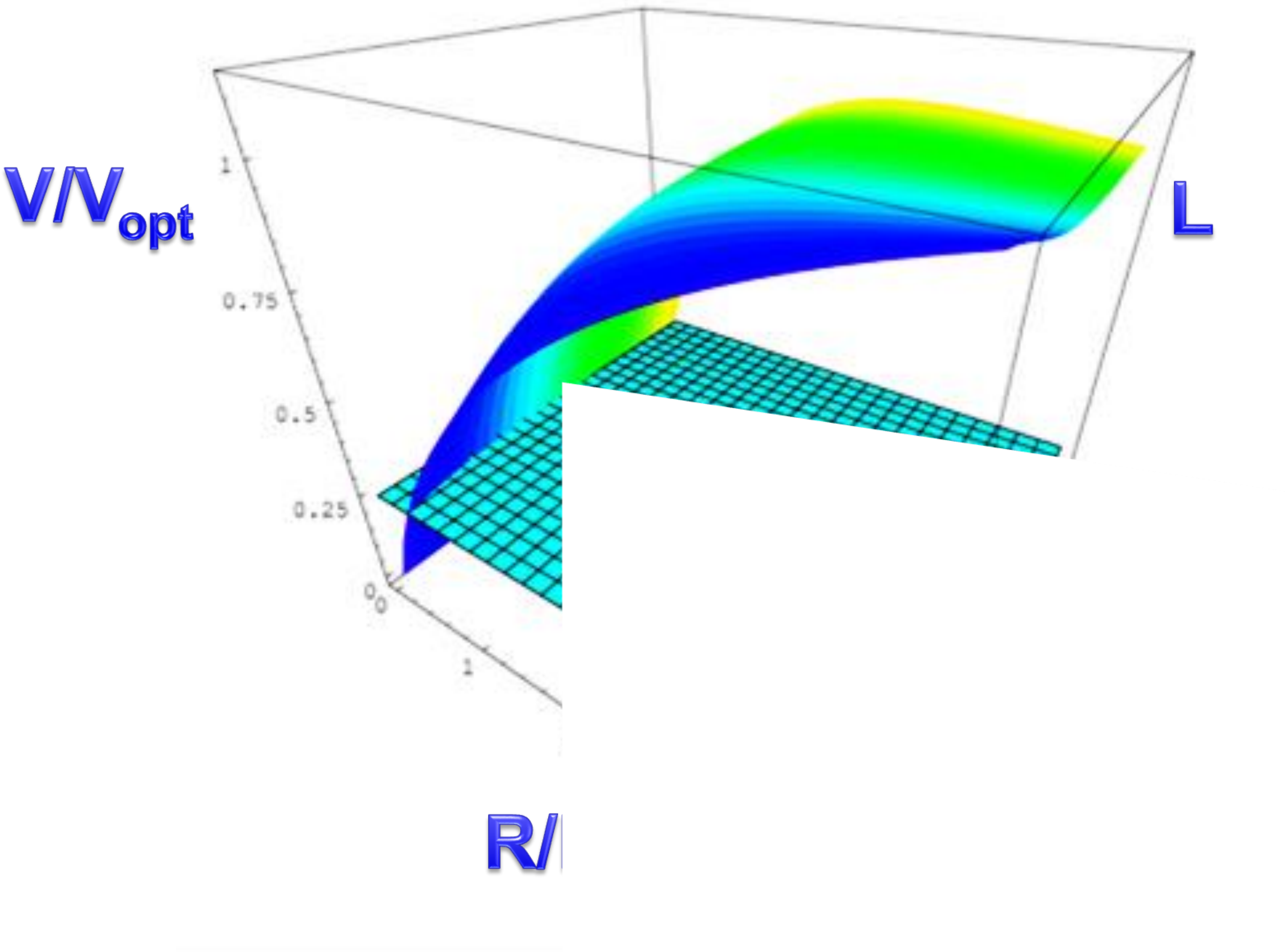


TYPICAL INDIVIDUAL



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).

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

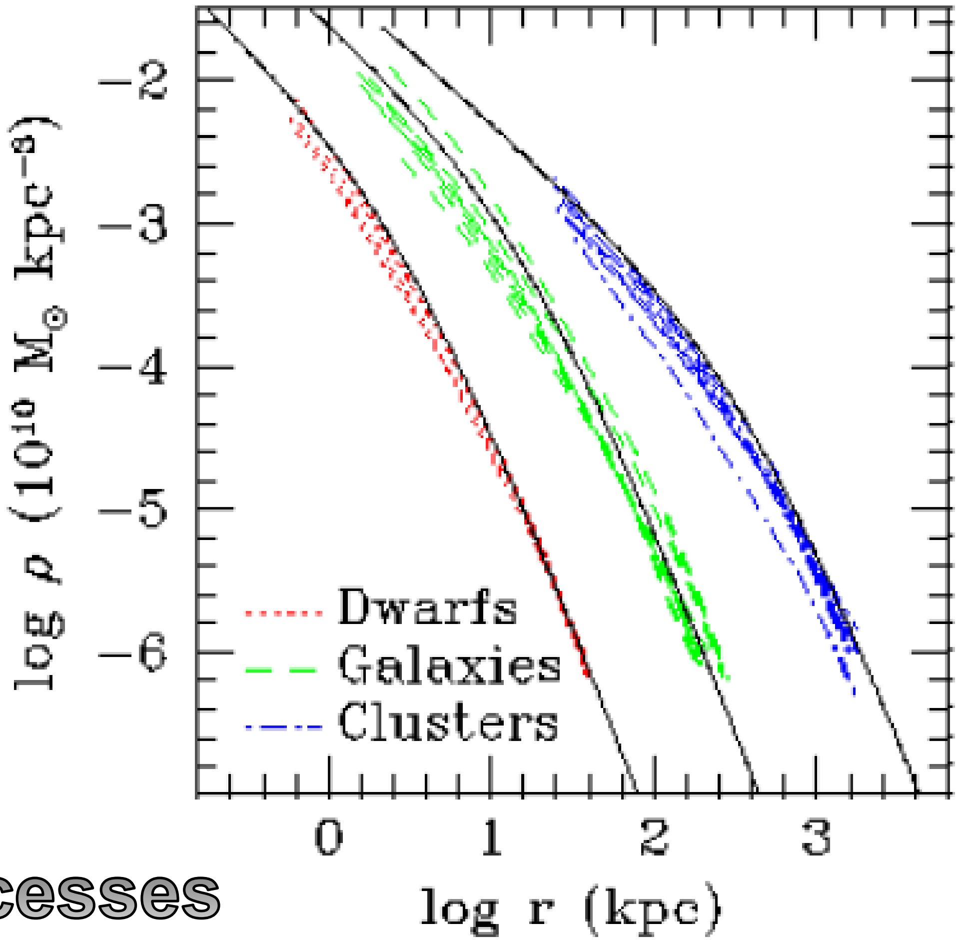
small cosmic variance

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

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

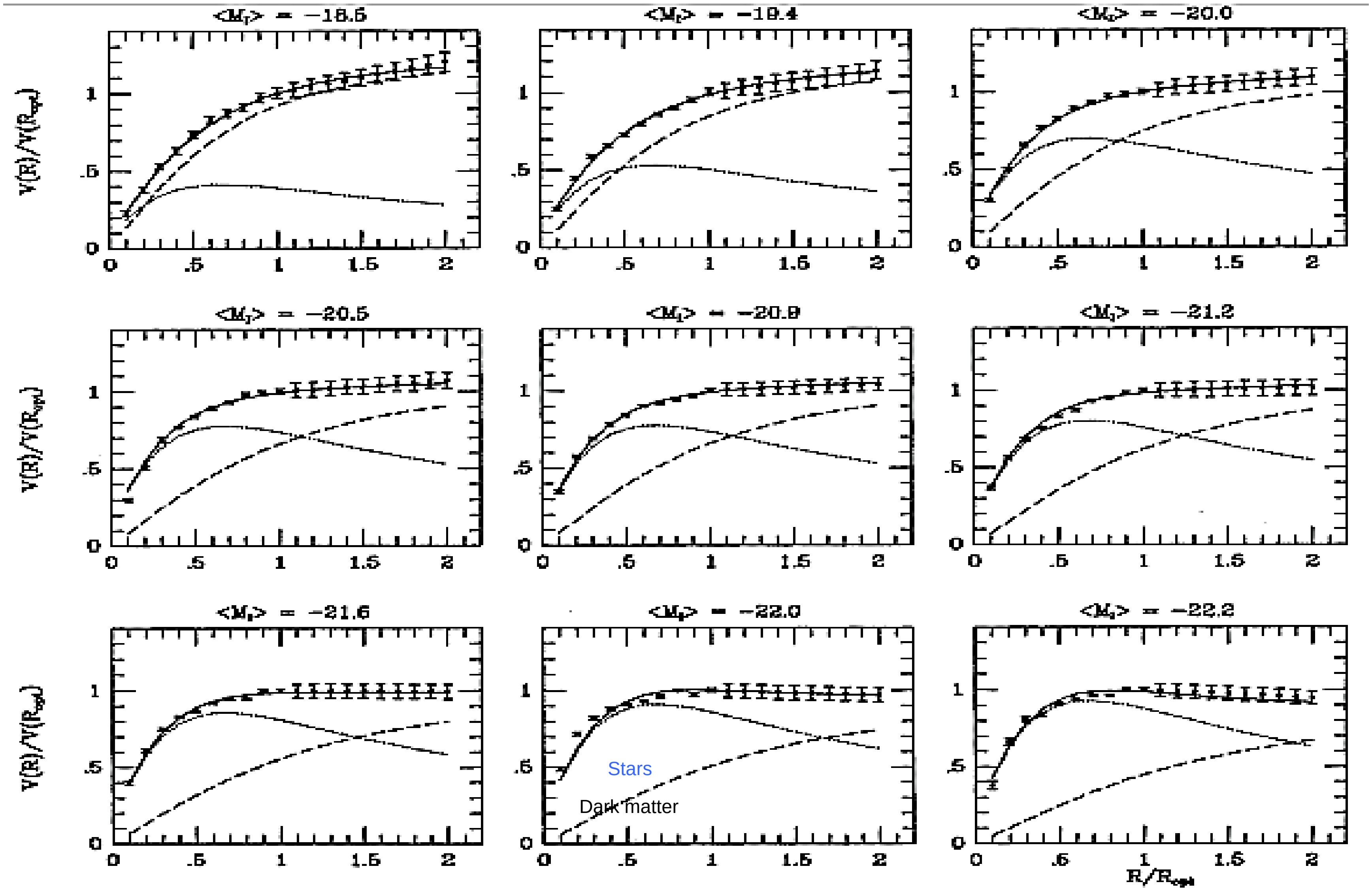
$$c(M_{vir}) = 9.35 \left(\frac{M_{vir}}{10^{12}\ M_\odot}\right)^{-0.09}$$

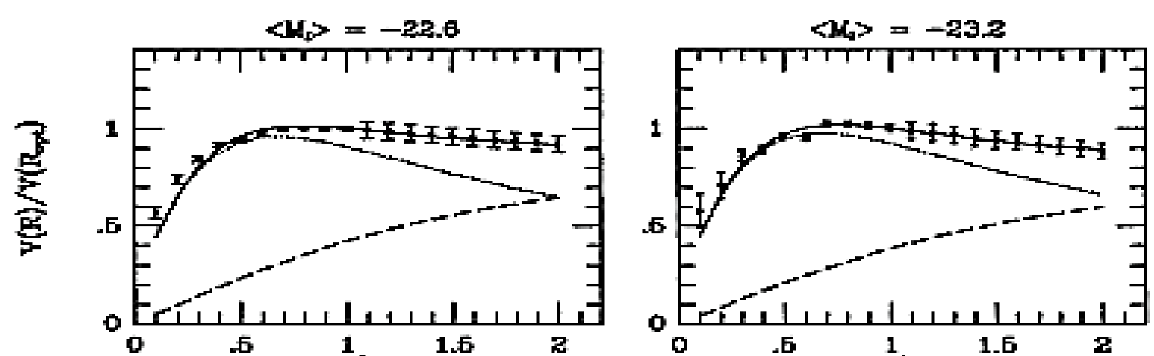
Klypin, 2010



Instrumental for ΛCDM successes

URC Modelling the Coadded Rotation Curves





150000 vel measures
11 L x 11 R bins
11 coadded RCs
URC their analytical fit

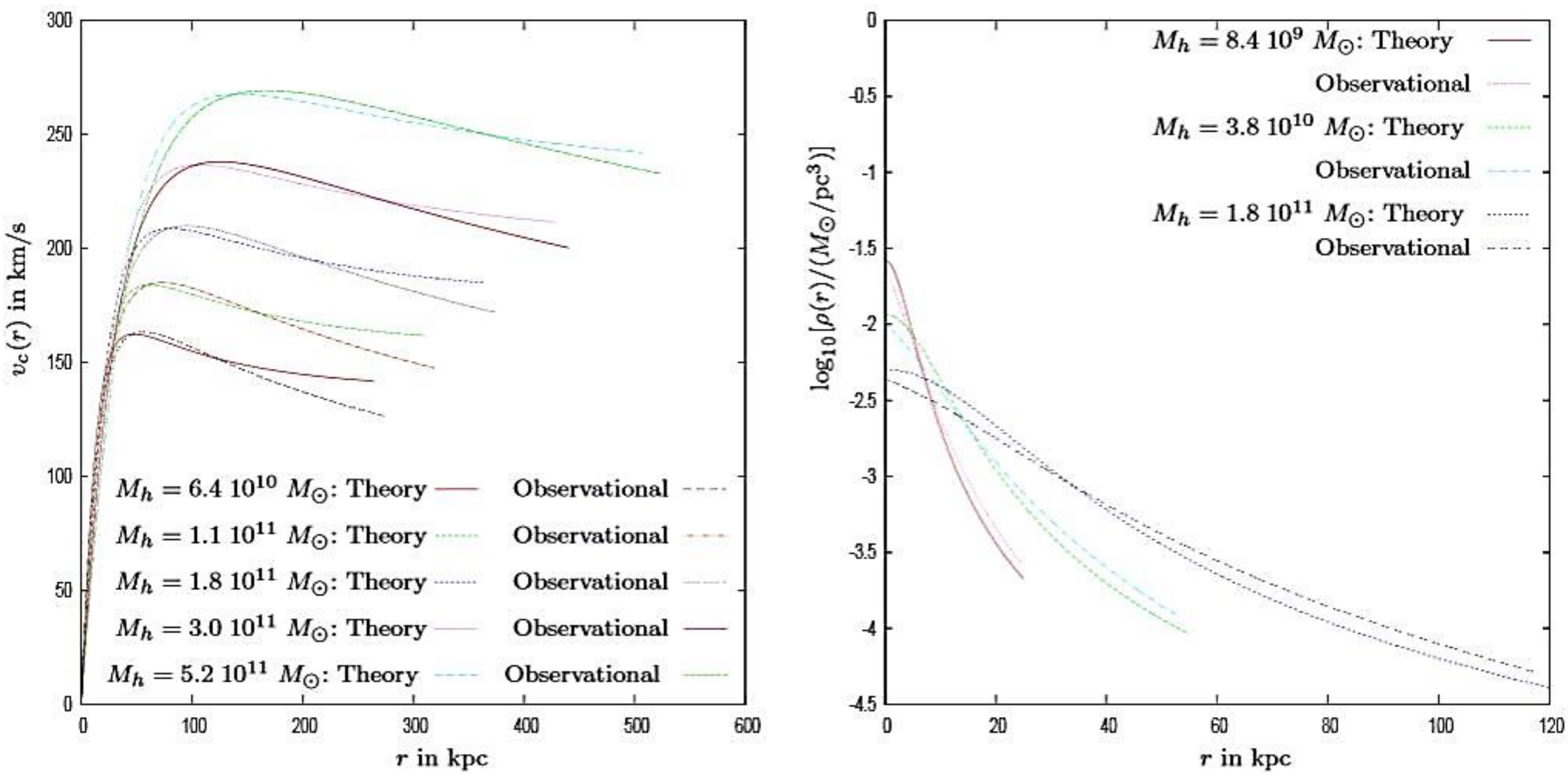
Observational rotation curves and density profiles versus the Thomas–Fermi galaxy structure theory

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

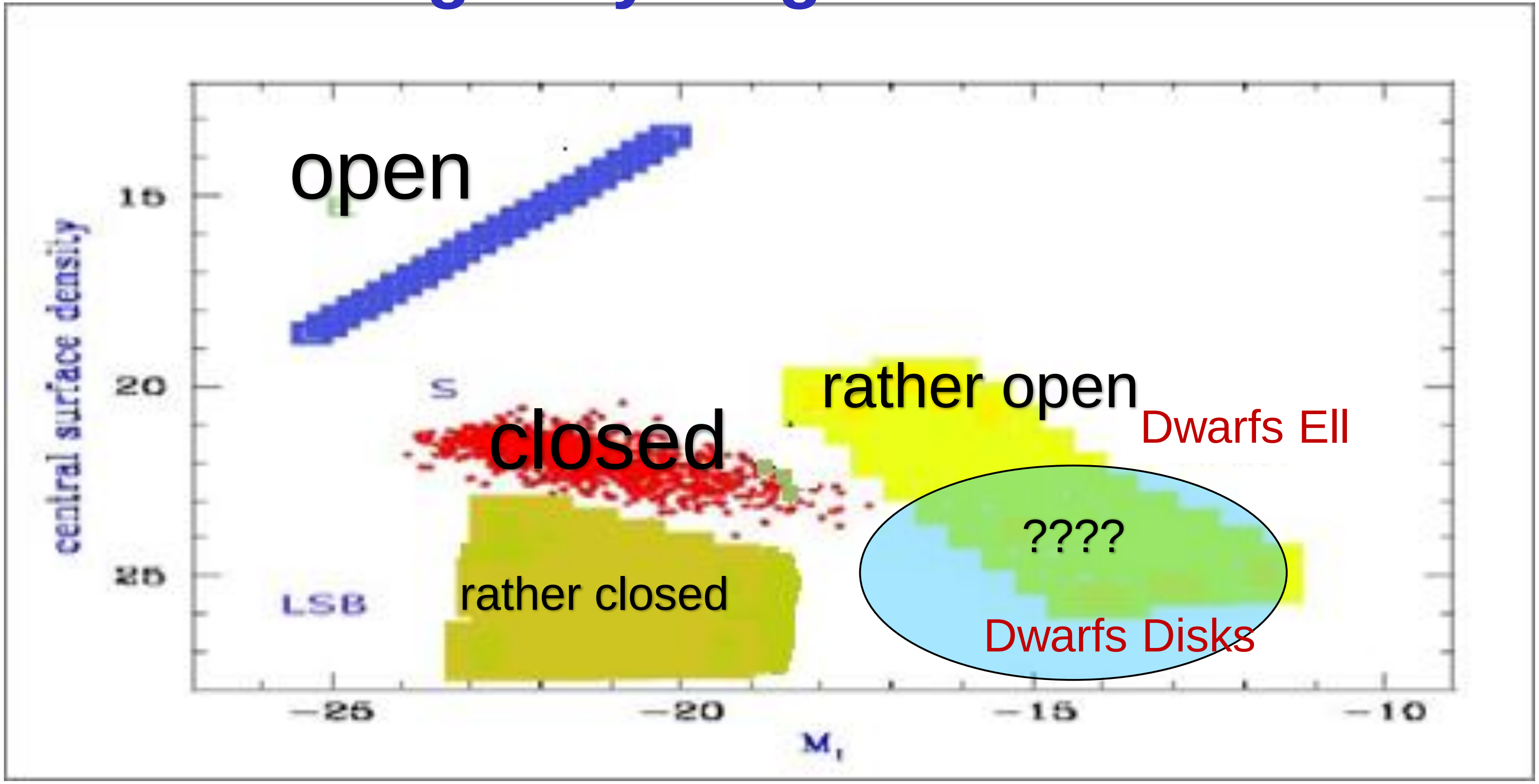
[3] SISSA/ISAS and INFN, Trieste, Iniziativa Specifica QSKY, via Bonomea 265, I-34136 Trieste, Italy



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



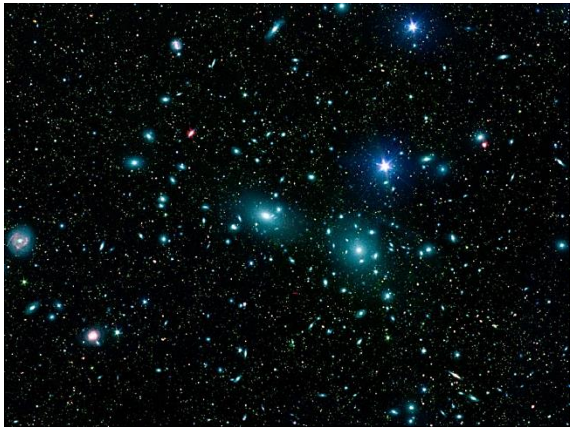
The distribution of luminous matter :

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 ?



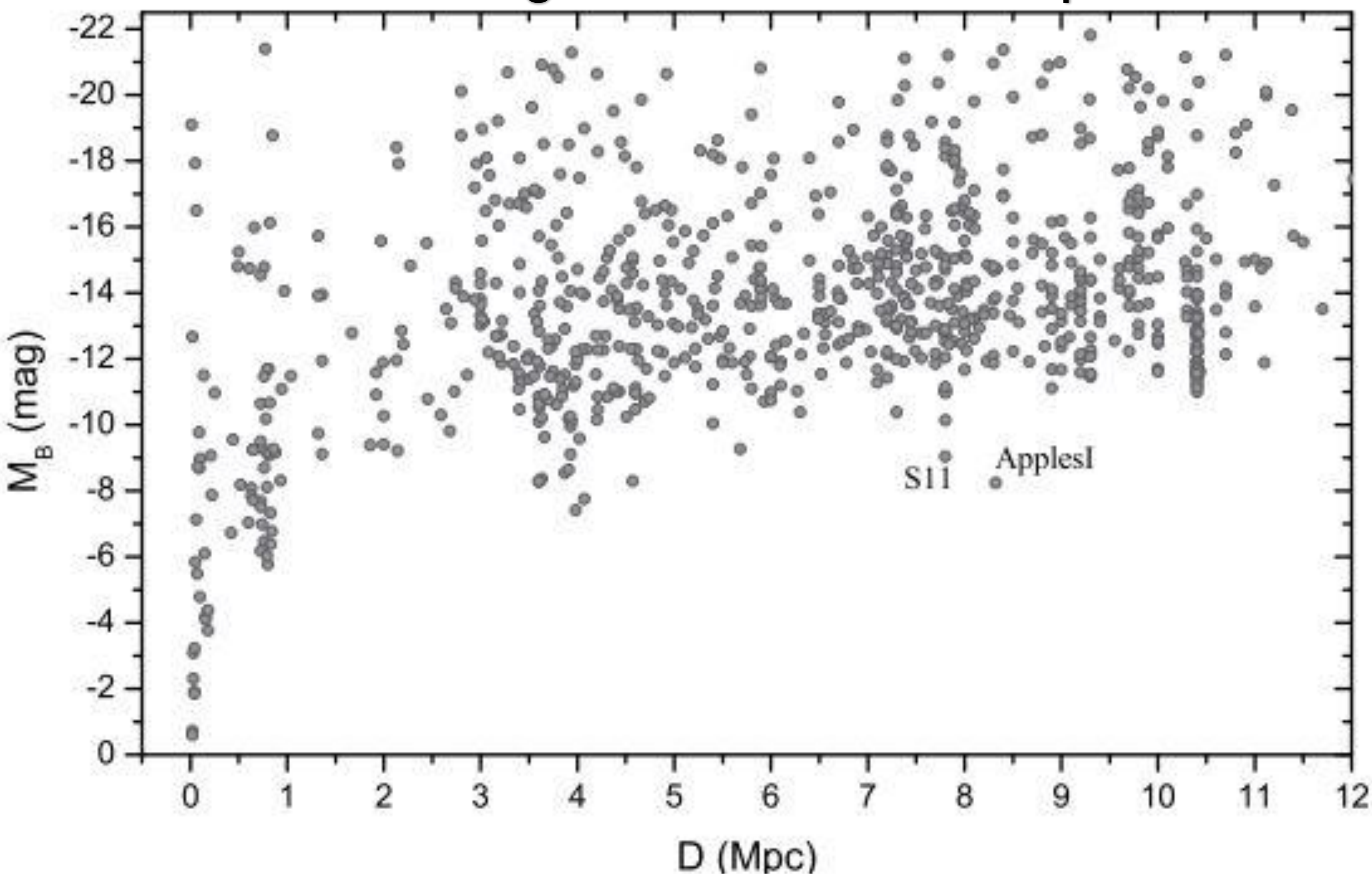
dSph (Gilmore+)

DD
simple dynamics

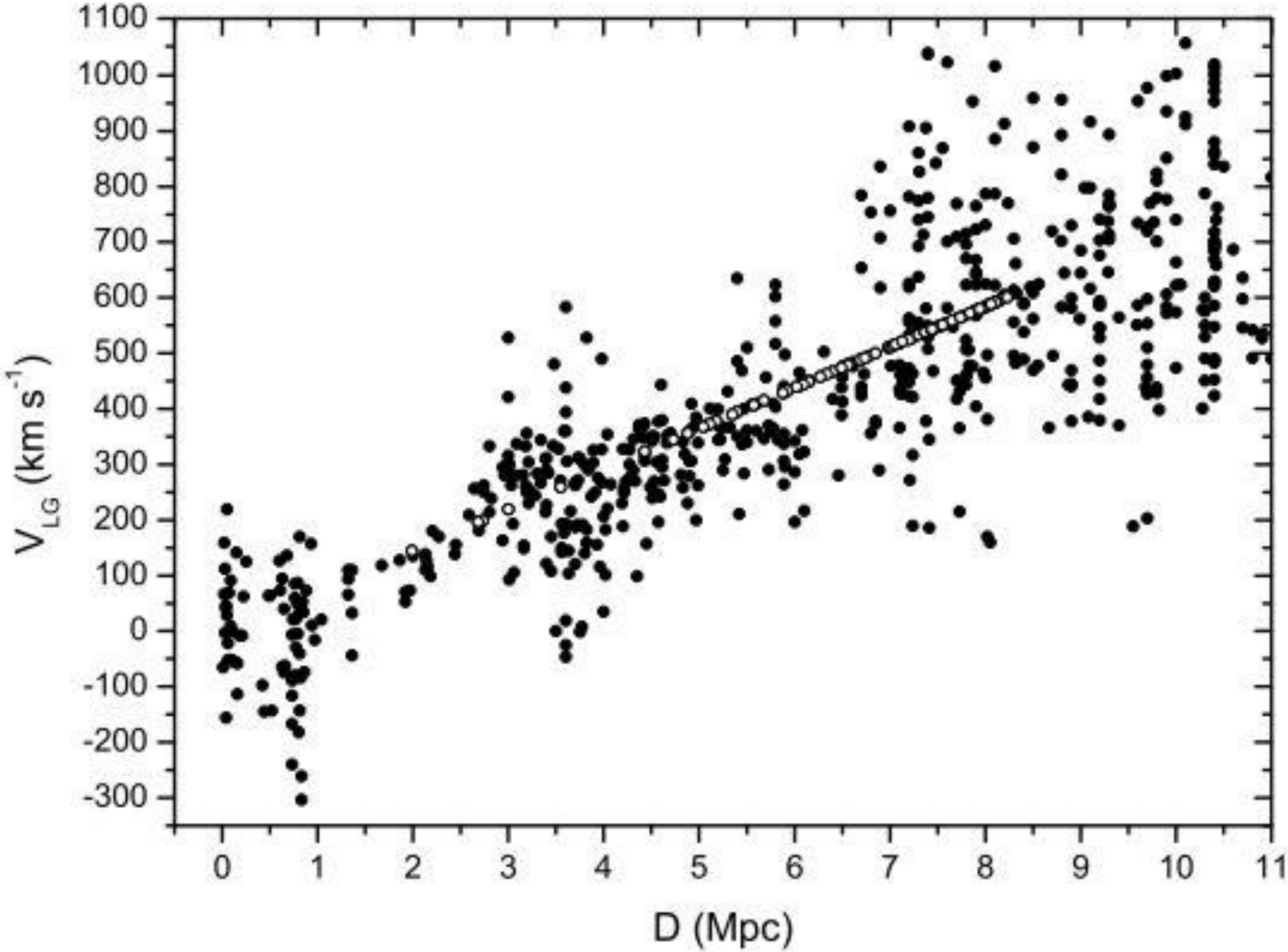
Updated Nearby Galaxy Catalog.

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

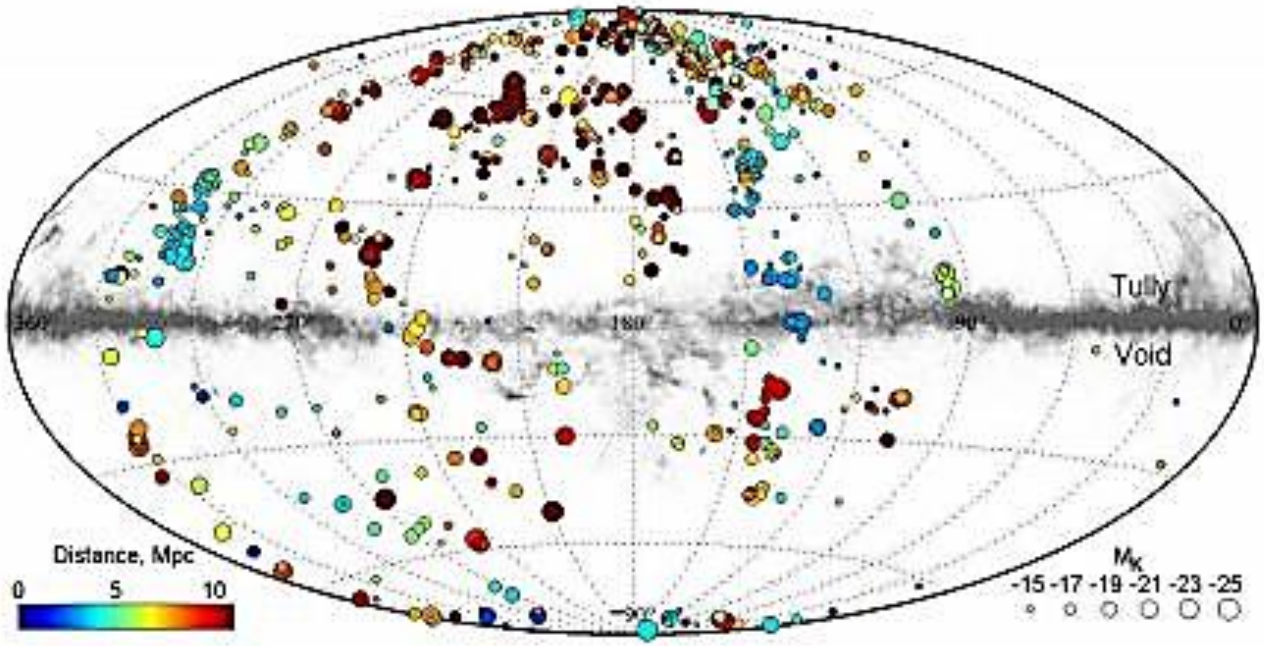
1000 galaxies inside 11 Mpc

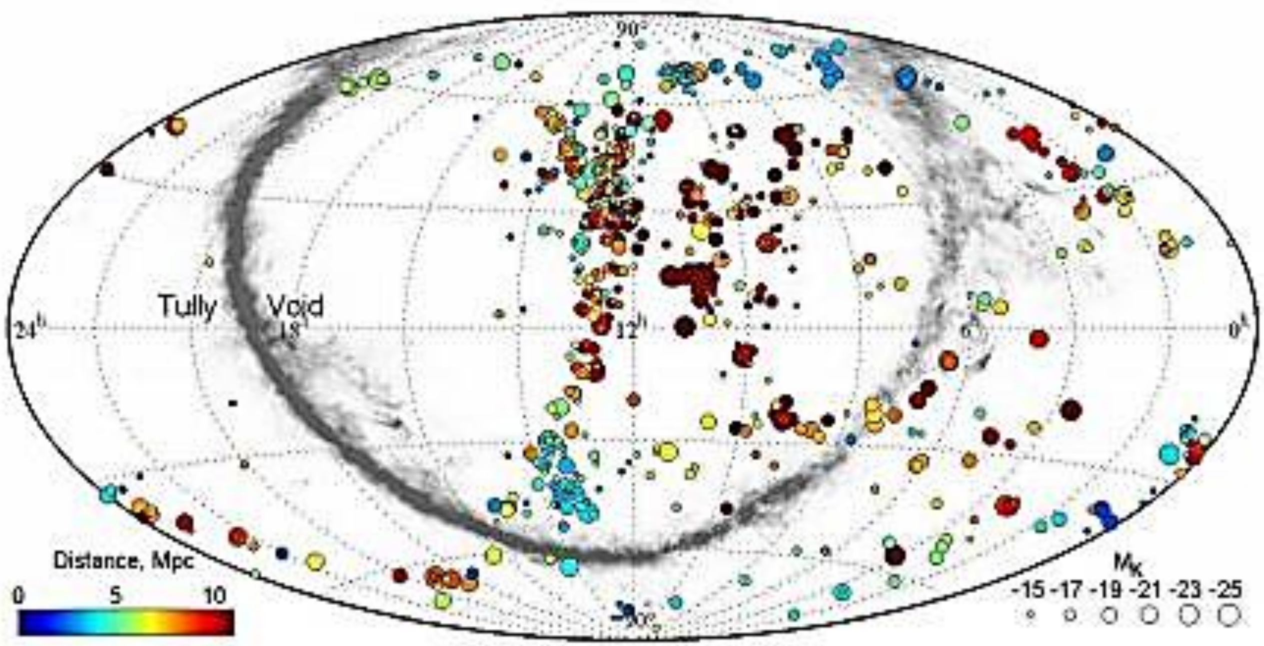


Hubble Flow



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
24^h
18
12^h
6
0^h
-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)

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
	Red	**Mixed**	**Blue**

SB

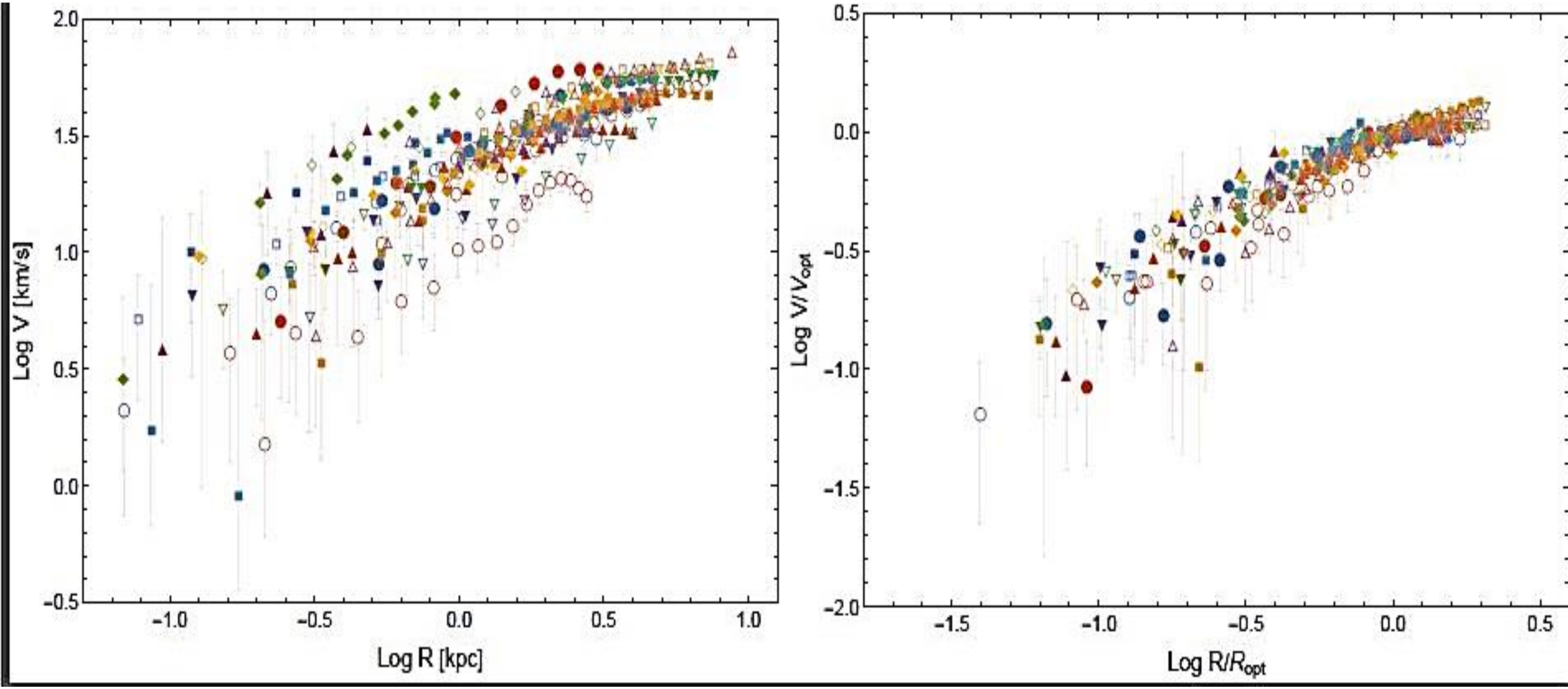
Gas content **Color Index**

Name	M_D	$M_D(K_S)$	M_{HI}	$M_{HI}(K13)$	r_c	$log(\rho_0)$	M_h	c
—	$\times 10^7$	$\times 10^7$	$\times 10^7$	$\times 10^7$	—	—	$\times 10^9$	—
—	$M_\odot$	$M_\odot$	$M_\odot$	$M_\odot$	kpc	g/cm^3	$M_\odot$	—
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(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

DD Sample
36 objects
V_{opt}<60 km/s
High quality RCs
20 new RCs

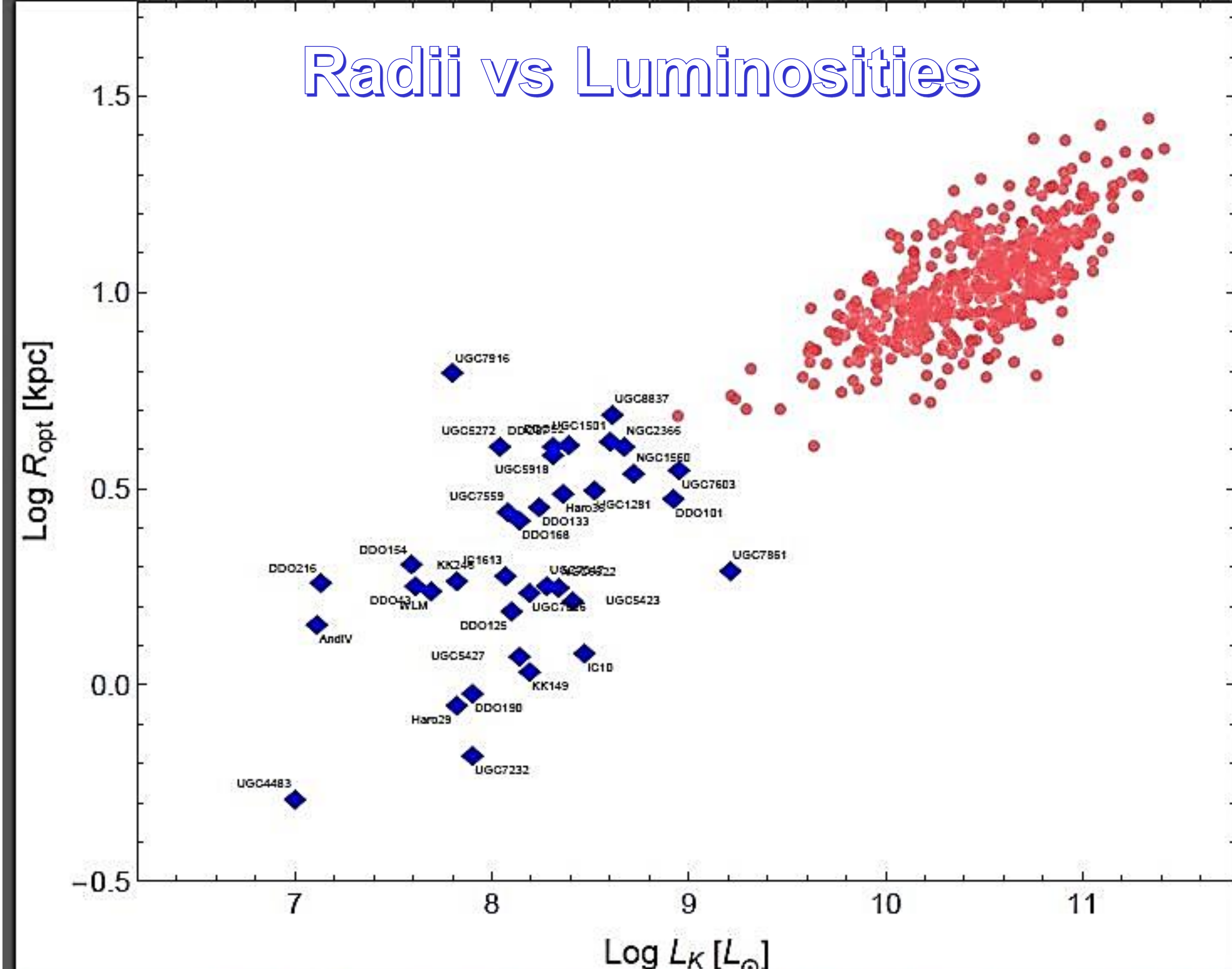
36 Individual RCs

Double Normalized

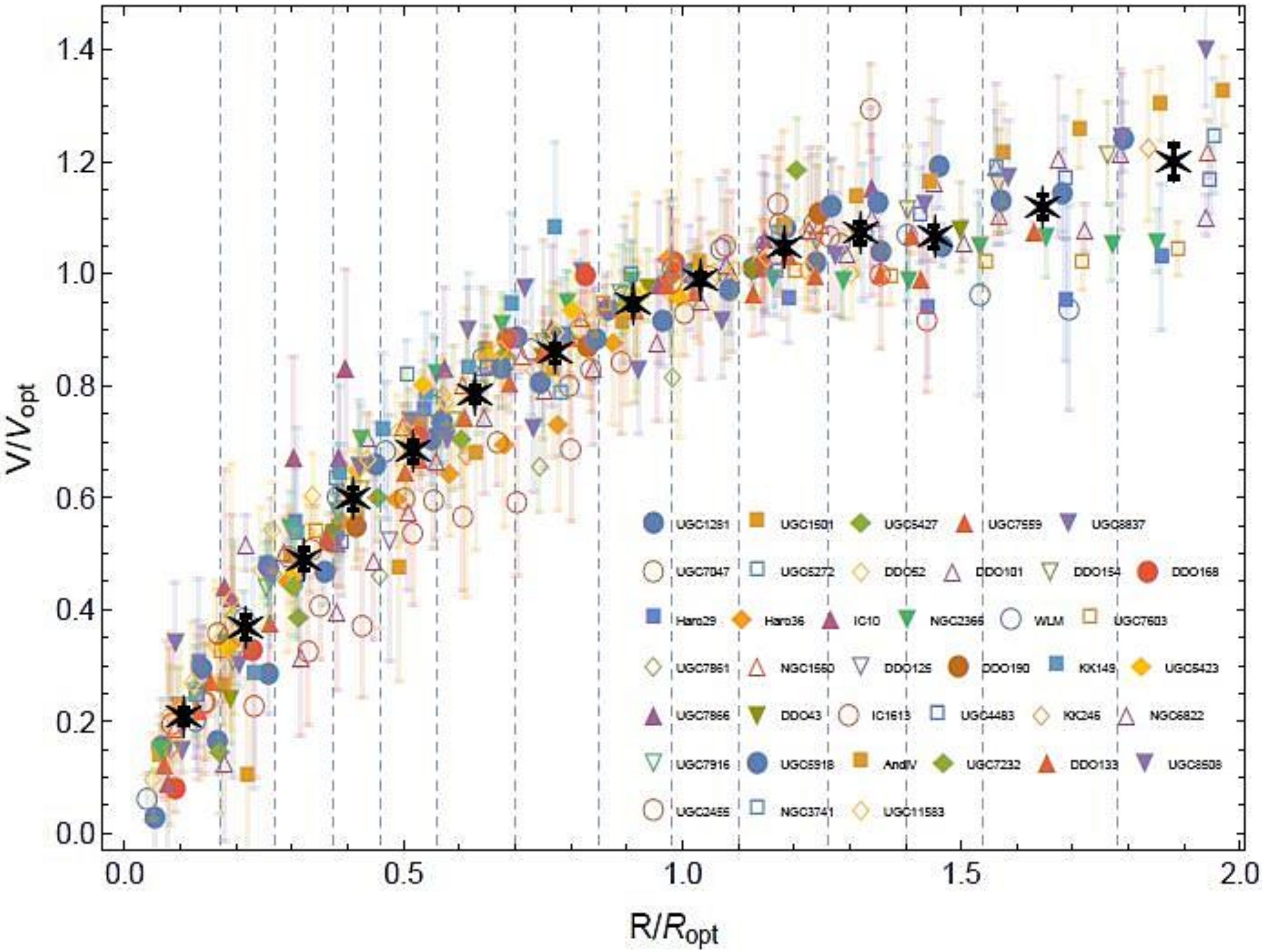


$R_{opt} = 3\ R_D$, $V_{DN} = V(R/R_{opt})/V_{opt}$

Radii vs Luminosities



Coadded curve

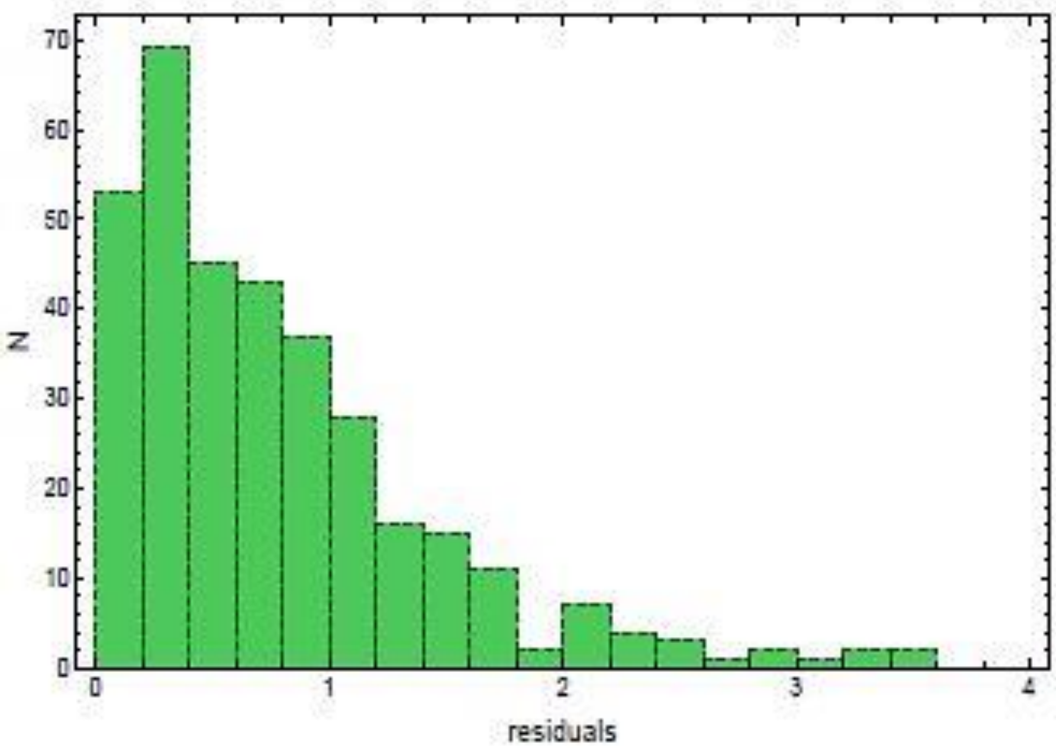


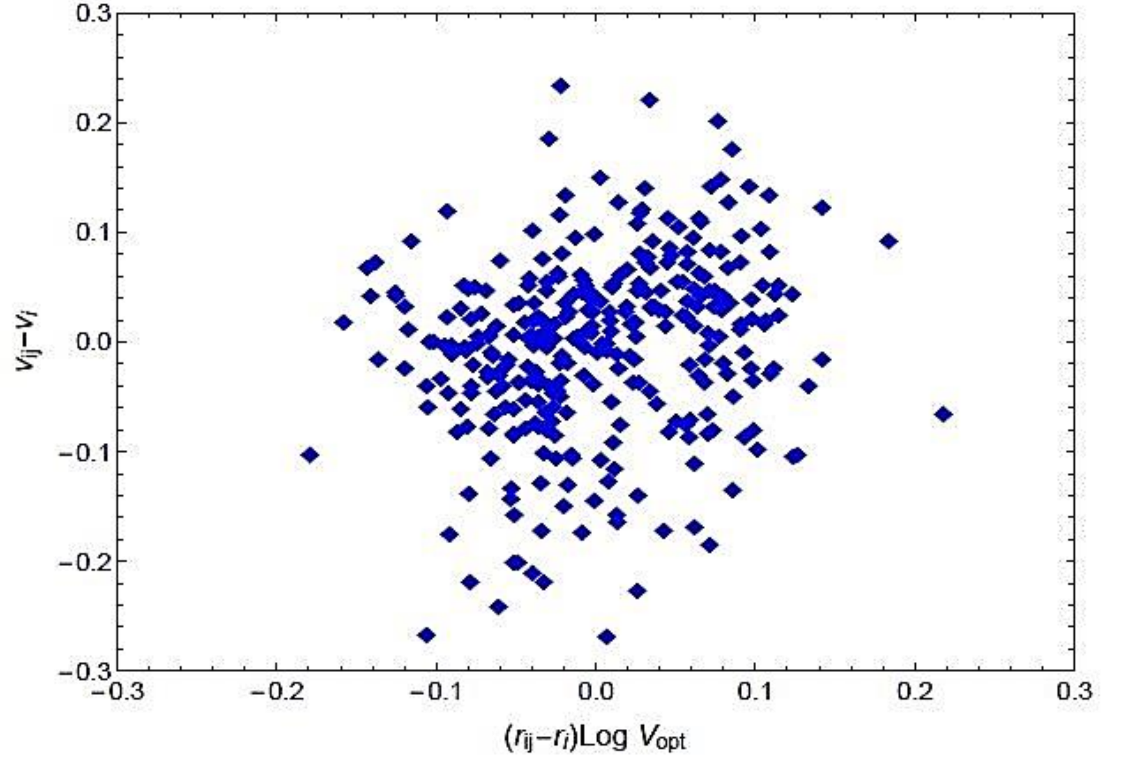
The DD Coadded Curve - DDURC

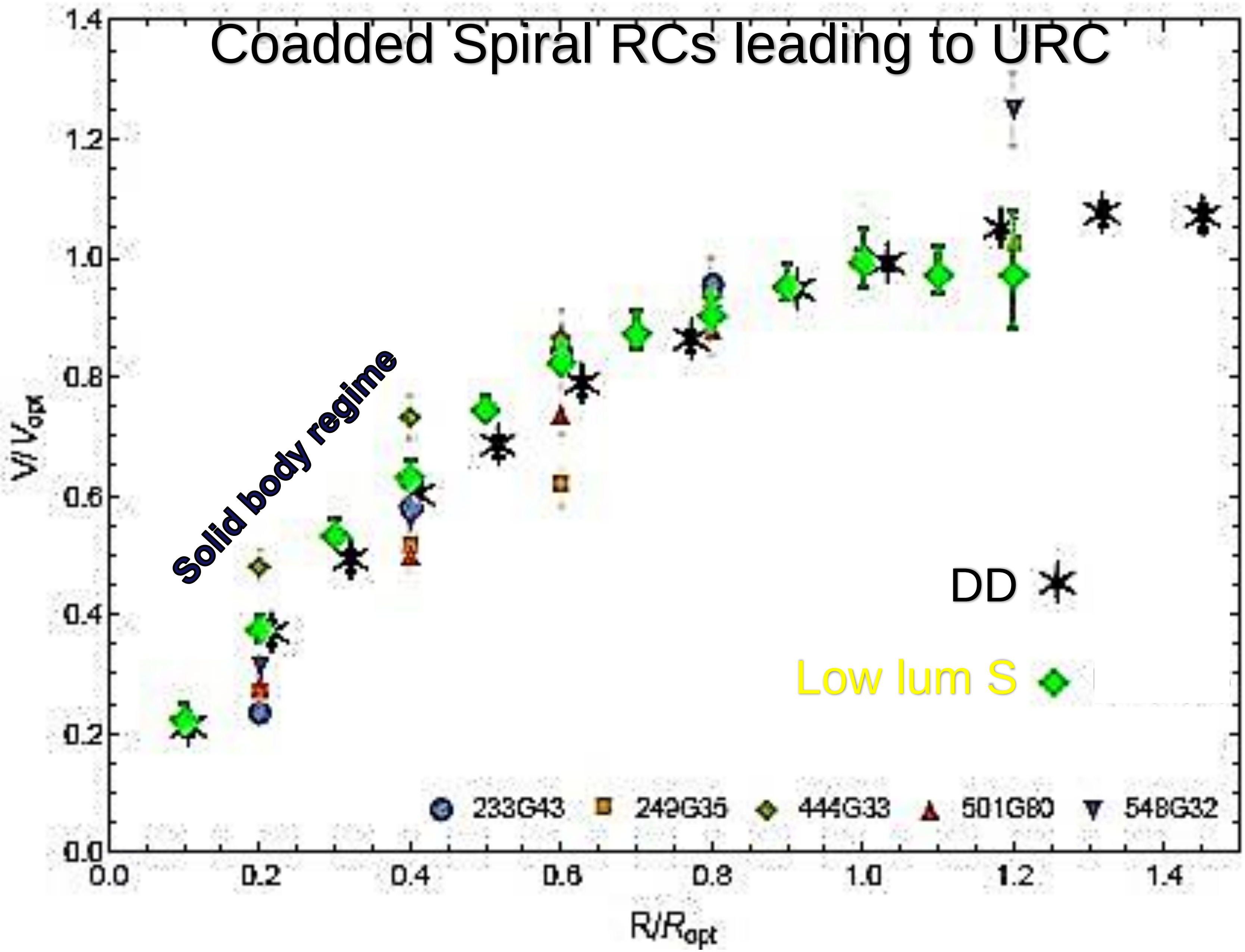
$V(R/R_{opt})/V_{opt}$

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

Velocity residuals: just observational errors and no biases

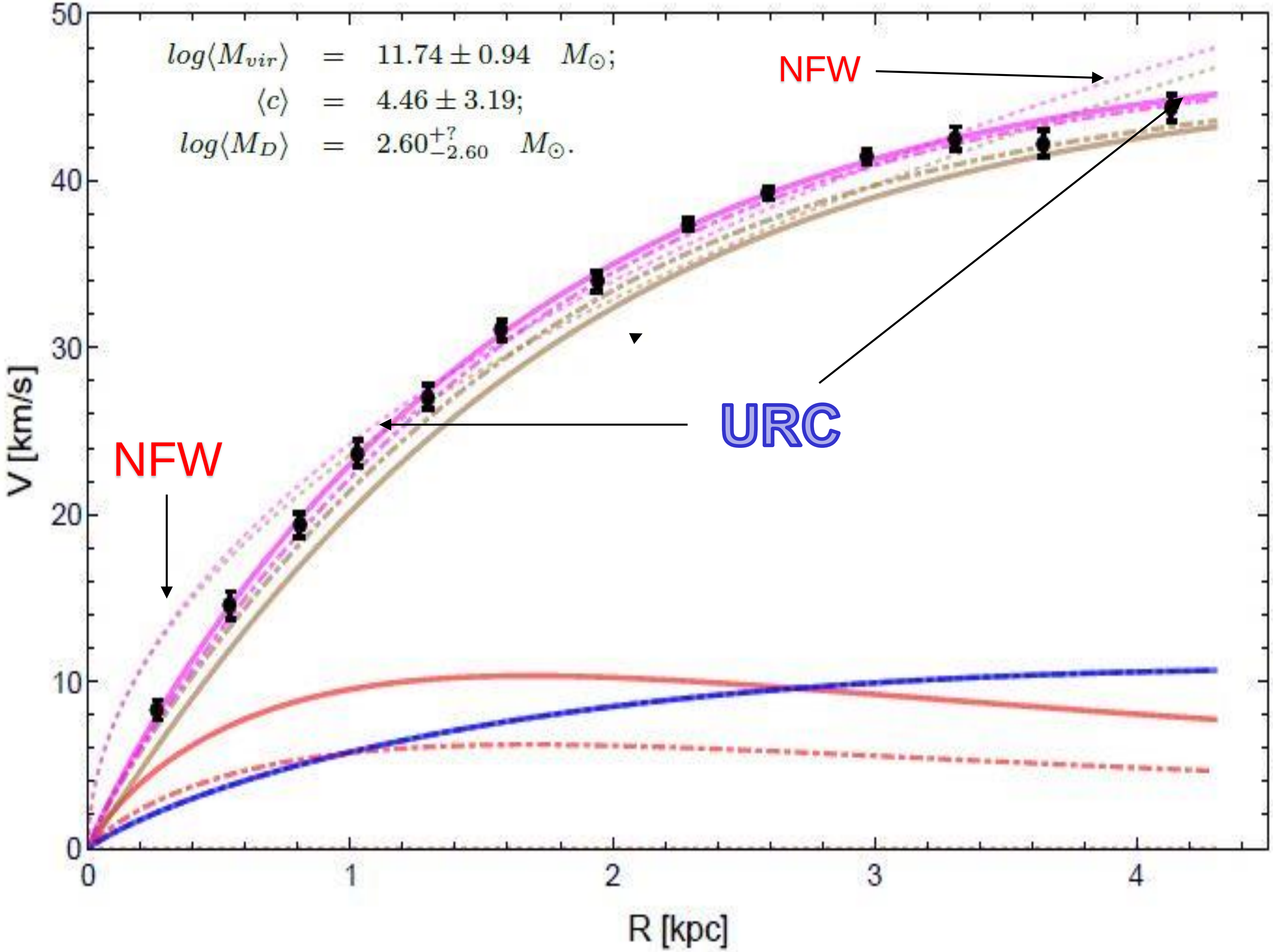




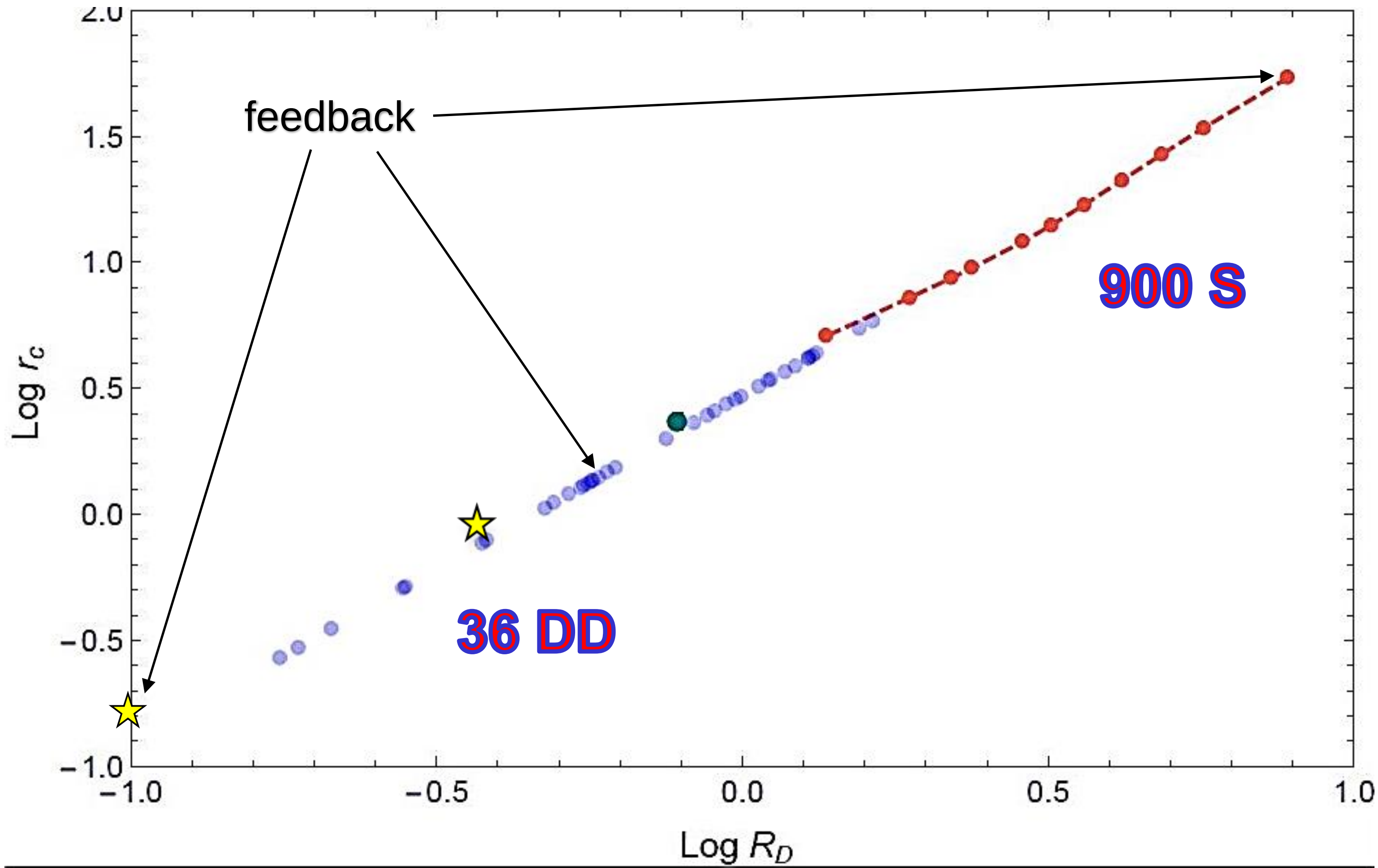


Coadded Spiral RCs leading to URC
Solid body regime
DD
Low lum S
233G43
249G35
444G33
501G80
548G32
V/V_opt
R/R_opt
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

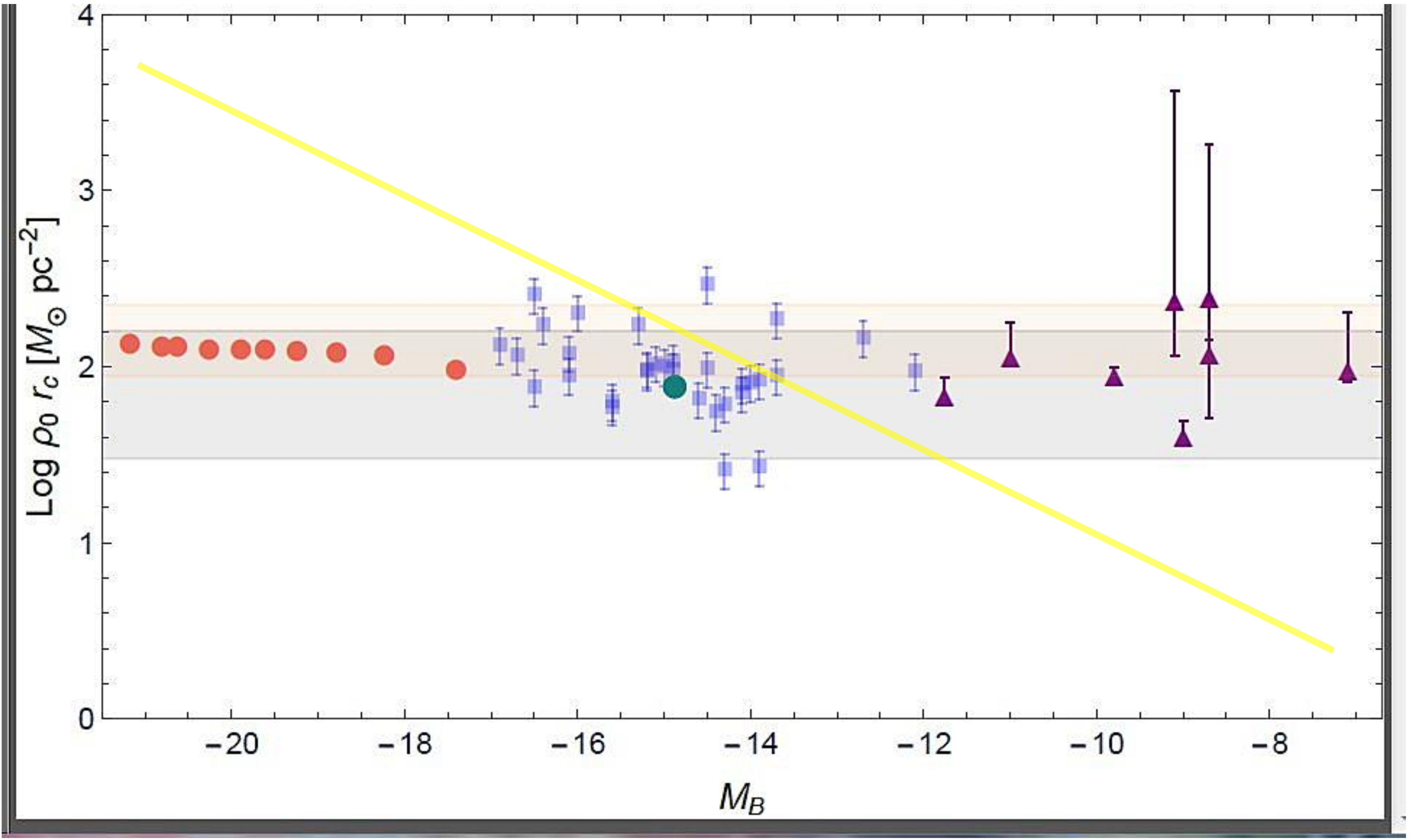
DDURC: modelling the coadded curve



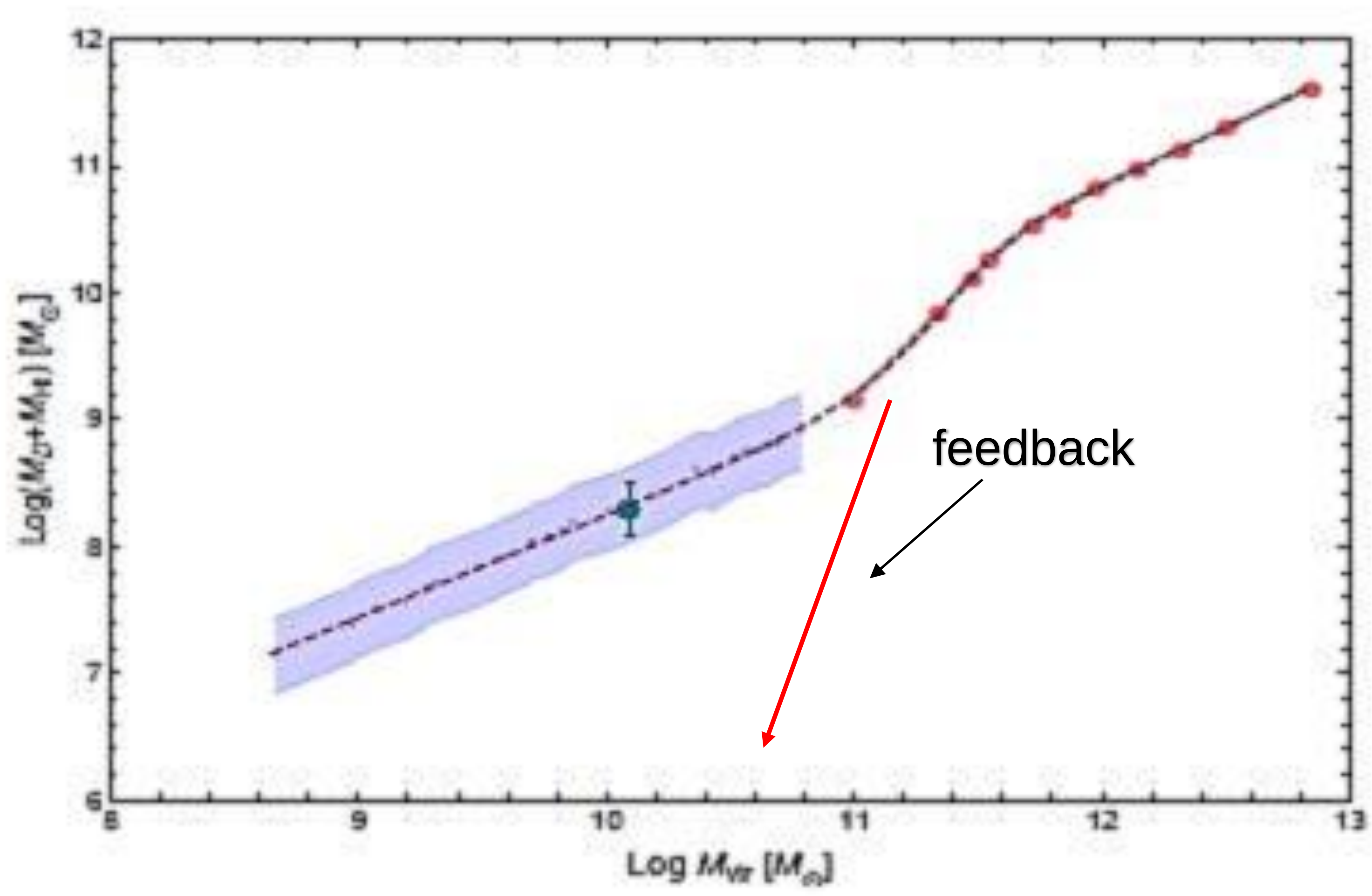
tight correlation core radius-half light radius



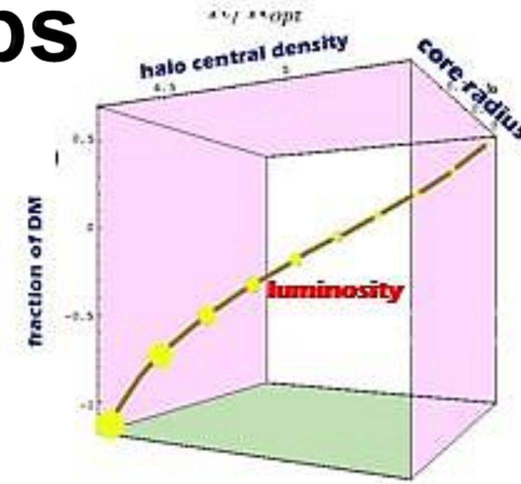
Central DM surface density

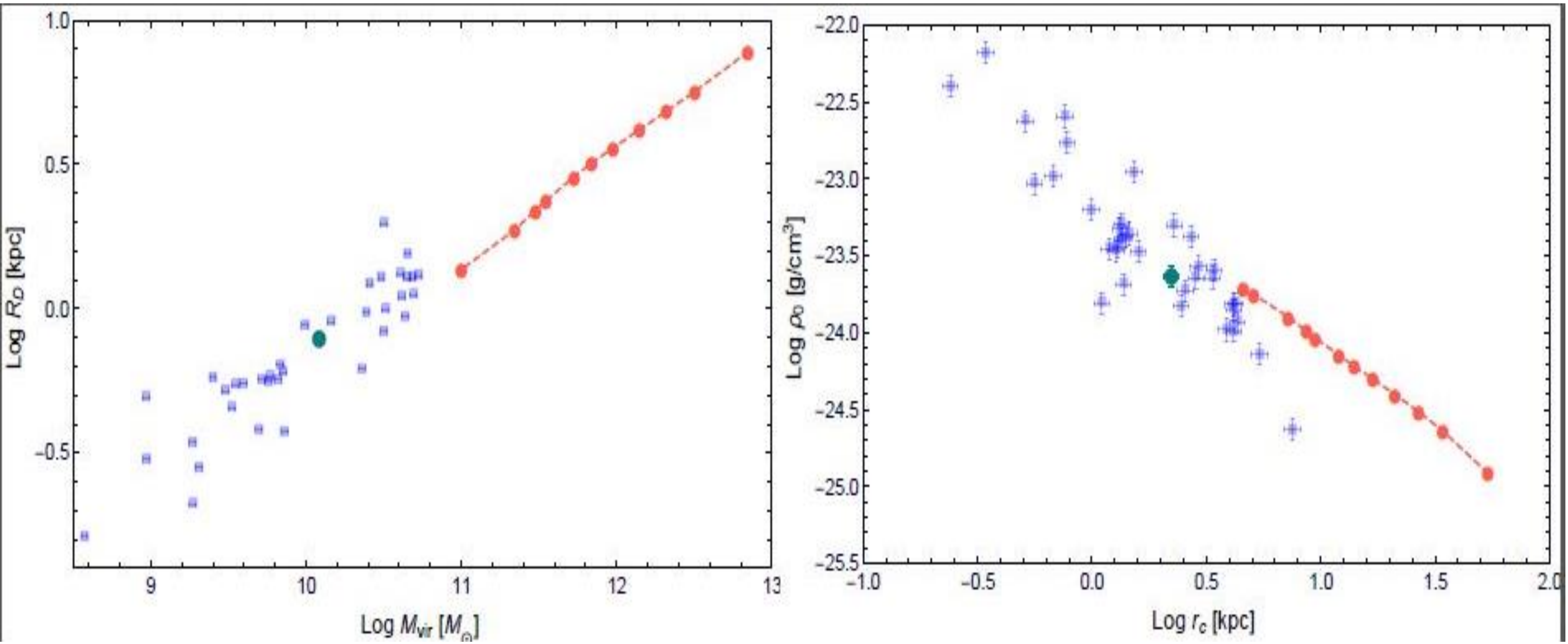


Baryonic – halo masses relationship



Dwarf Disks structural relationships

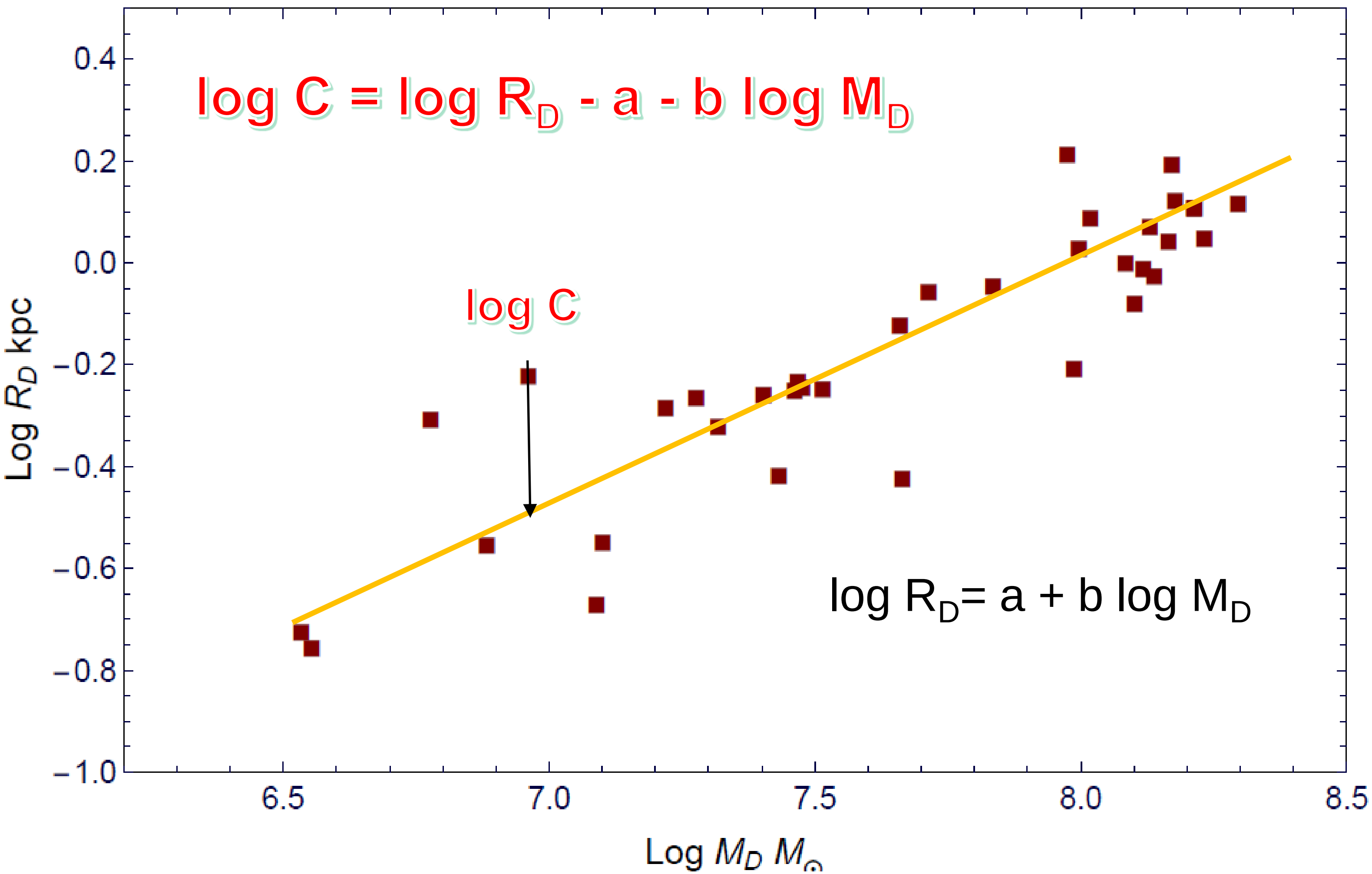




not 1 parameter Universal Curve

The C parameter

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



ΛCDM PARADIGM

-we know the dark particle, ab initio

Large scales observations are in agreement .

Observations of dark matter in galaxies are bound to agree with the ΛCDM scenario via cosmo astrophysics , but very likely this will not even necessary, as decive evidences for the scenario are about to come up at any moment.

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

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

CONCLUSIONS

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 may already indicate for a Warm Dark Particle

NEW PARADIGM
Cores from DM structure from DM nature.

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