Associations of Dwarf Galaxies

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Introduction

- Groups vs Clusters
- Groups vs Associations

Defined by the luminosity density threshold

The *group* threshold captures familiar loose groups like the Local Group

The *association* threshold set an order of magnitude lower in luminosity density

Associations of dwarf galaxies

↓

Derived from linkages between galaxies that have such insignificant luminosities that the luminosity density fails to reach the threshold to be called a group

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ASSOCIATIONS OF DWARF GALAXIES

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ABSTRACT

The *Hubble Space Telescope* Advanced Camera for Surveys has been used to determine accurate distances for 20 galaxies from measurements of the luminosity of the brightest red giant branch stars. Five associations of dwarf galaxies that had originally been identified based on strong correlations on the plane of the sky and in velocity are shown to be equally well correlated in distance. Two more associations with similar properties have been discovered. Another association is identified that is suggested to be unbound through tidal disruption. The associations have the spatial and kinematic properties expected of bound structures with $(1-10) \times 10^{11}\ M_{\odot}$. However, these entities have little light, with the consequence that the mass-to-light ratios are in the range 100–1000 $M_{\odot}\ L_{\odot}^{-1}$. Within a well-surveyed volume extending to a 3 Mpc radius, all but one known galaxy lie within one of the groups or associations that have been identified.

Key words: dark matter — galaxies: clusters: general — galaxies: distances and redshifts

Online material: color figures

TABLE 1

Candidate Association Members or Galaxies with 1.1 Mpc $< d <$ 3.2 Mpc at $|b| > 30°$

Group	Names	R.A. (J2000.0)	Decl. (J2000.0)	SGL (deg)	SGB (deg)	B_T	Morph. Type	V_{LG}	*HST*	I_{tip}	A_I	$m - M$	d (Mpc)	ΔV	R (kpc)	M_B
14+12	NGC 3109, DDO 236	10 03 06.6	−26 09 32	262.0981	−45.1065	10.10	9	110	8601	21.71 ± 0.03	0.13	25.63	1.34	15	307	−15.53
	U5373, Sex B, D70	09 59 59.8	+05 19 57	233.1991	−39.6203	11.75	10	111	8601	21.80 ± 0.02	0.06	25.79	1.44	16	450	−14.03
	Sex A, DDO 75	10 11 01.3	−04 42 48	246.1704	−40.6659	11.94	10	94	7496	21.82 ± 0.06	0.09	25.78	1.43	−1	212	−13.84
	Antlia	10 04 03.9	−27 20 01	263.0984	−44.8031	16.19	10	66	10210	21.60 ± 0.13	0.15	25.49	1.25	−29	346	−9.30
14+13	NGC 55	00 15 08.4	−39 13 13	332.6740	−2.4102	8.78	9	111	8697	22.66 ± 0.03	0.03	26.68	2.17	−5	186	−17.90
	NGC 300	00 54 52.6	−37 40 57	299.2306	−9.4984	8.89	7	114	9492	22.52 ± 0.03	0.03	26.54	2.04	−2	322	−17.65
	UGCA 438, E407-18	23 26 22.2	−32 23 29	11.8694	9.2990	13.80	10	99	8192	22.72 ± 0.06	0.03	26.74	2.22	−17	404	−12.94
	ESO 410-005	00 15 31.5	−32 10 47	357.8469	−0.2573	14.85	−5	176	8192	22.42 ± 0.05	0.03	26.44	1.94	60	196	−11.59
	ESO 294-010	00 26 33.3	−41 51 19	320.4159	−5.2699	15.51	10	81	8601	22.42 ± 0.08	0.01	26.46	1.96	−35	195	−10.95
	IC 5152	22 02 41.2	−51 17 47	343.9191	11.5285	10.95	10	75	8192	22.47 ± 0.08	0.05	26.47	1.97	−41	817	−15.52
	UGC 7577, DDO 125	12 27 40.9	+43 29 44	137.7581	5.9272	12.86	10	240	8601	23.18 ± 0.03	0.04	27.19	2.74	−9	381	−14.33
	NGC 4163	12 12 09.1	+36 10 09	163.2040	0.8761	13.54	10	164	9771	23.33 ± 0.02	0.04	27.34	2.94	−85	227	−13.81
	UGC 6817, DDO 99	11 50 53.0	+38 52 49	166.1978	−2.1220	13.59	10	248	8601	23.11 ± 0.04	0.05	27.11	2.64	−1	294	−13.52
	NGC 3741	11 36 06.2	+45 17 01	157.5712	−2.0769	14.28	10	264	8601	23.52 ± 0.06	0.05	27.52	3.19	15	510	−13.24
	UGCA 276, DDO 113	12 14 57.9	+36 13 08	161.1018	1.4295	15.61	10	283	8601	23.51 ± 0.06	0.04	27.51	3.18	34	182	−11.91
	UGC 8508	13 30 44.4	+54 54 36	111.1410	17.9057	14.06	10	186	8601	23.13 ± 0.04	0.03	27.15	2.69	−63	896	−13.09
14+08	UGC 9240, DDO 190	14 24 43.4	+44 31 33	82.0084	26.8518	13.05	10	263	8601	23.21 ± 0.04	0.02	27.24	2.80	−6	463	−14.19
	UGC 8760, DDO 183	13 50 50.6	+38 01 09	77.7919	20.4675	14.35	10	257	10210	23.54 ± 0.06	0.03	27.55	3.24	−12	213	−13.20
	UGC 8651, DDO 181	13 39 53.8	+40 44 21	89.7337	18.5795	14.46	10	272	10210	23.36 ± 0.05	0.01	27.40	3.02	3	184	−12.94
	UGC 8833	13 54 48.7	+35 50 15	69.7137	21.0897	15.09	10	285	10210	23.50 ± 0.07	0.02	27.53	3.20	16	258	−12.43
17+06	NGC 784	02 01 17.0	+28 50 15	140.9029	−6.3056	11.98	8	386	10210	24.64 ± 0.05	0.11	28.58	5.19	8	114	−16.59
	UGC 1281	01 49 31.5	+32 35 17	136.8680	−2.5928	12.67	8	367	10210	24.59 ± 0.03	0.09	28.55	5.13	−11	310	−15.88
	KK 16	01 55 20.3	+27 57 14	139.7495	−5.4137	16.	10	400	10210	24.78 ± 0.05	0.14	28.69	5.47	22	330	−12.7
	KK 17	02 00 10.2	+28 49 53	140.6333	−6.0816	17.	10	360	10210	24.51 ± 0.07	0.11	28.45	4.91	−18	282	−11.4
	UGC 685	01 07 22.4	+16 41 02	128.4313	1.6065	14.51	10	349	10210	24.42 ± 0.03	0.11	28.36	4.70	−29	1257	−13.84
14−14	NGC 1313	03 18 15.4	−66 29 51	283.3598	−28.2223	9.19	6	270	10210	24.25 ± 0.03	0.21	28.09	4.15	...	...	−18.90
	ESO 115-021	02 37 48.1	−61 20 18	282.7904	−25.9622	13.23	6	337	10210	24.49 ± 0.03	0.05	28.49	4.99	...	...	−15.26
	KK 27	03 21 02.4	−66 19 09	282.9130	−28.5528	16.17	−3	...	10210	24.19 ± 0.07	0.15	28.09	4.15	...	...	−11.92
14+14	ESO 154-023	02 56 51.2	−54 34 23	271.8077	−30.2306	12.62	7	412	10210	24.79 ± 0.03	0.03	28.80	5.76	−13	373	−16.18
	IC 1959	03 33 09.0	−50 24 42	261.2838	−36.8068	13.21	8	464	10210	24.88 ± 0.05	0.02	28.91	6.06	39	443	−15.70
	NGC 1311	03 20 06.7	−52 11 13	265.2951	−34.2690	13.09	9	398	10210	24.67 ± 0.03	0.04	28.68	5.45	−27	311	−15.46
14+19	UGC 3974, DDO 47	07 41 52.0	+16 47 54	203.0986	−55.5005	13.51	10	160	10210	25.54 ± 0.04	0.06	29.53	8.04	−19	245	−16.02
	UGC 4115	07 57 02.4	+14 23 12	207.0078	−56.2273	14.21	10	210	10210	25.44 ± 0.05	0.05	29.44	7.72	31	443	−15.23
	KK 65, CGCG 87-33	07 42 32.0	+16 33 39	203.3957	−55.6679	15.42	10	168	10210	25.53 ± 0.07	0.06	29.52	8.01	−11	199	−14.10
	UGC 3755	07 13 51.6	+10 31 19	206.0134	−63.3576	14.71	10	190	10210	25.47 ± 0.06	0.17	29.35	7.41	11	1067	−14.64
Dregs	UGC 9128, DDO 187	14 15 56.5	+23 03 19	25.5731	24.3518	14.27	10	172	10210	22.75 ± 0.05	0.05	26.75	2.24	11	301	−12.48
	U8091, D155, GR 8	12 58 40.4	+14 13 03	310.7381	4.6684	14.57	10	136	5915	22.64 ± 0.05	0.05	26.64	2.13	−25	490	−12.07
	KKH 86	13 54 33.6	+04 14 35	339.0439	15.4650	16.68	10	209	8601	23.07 ± 0.13	0.05	27.07	2.60	48	673	−10.39
	KK 230	14 07 10.5	+35 03 37	63.7099	23.5498	17.84	10	126	9771	22.63 ± 0.08	0.03	26.65	2.14	−35	697	−8.81
Isol.....	KKR 25	16 13 47.9	+54 22 16	83.8790	40.3703	17.	−5	...	8601	22.62 ± 0.15	0.02	26.65	2.14	...	...	−9.7

Note.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

Tully's dwarf associations

TABLE 2

PROPERTIES OF GROUPS OF DWARF GALAXIES

Group	Principal Galaxy	No.	Distance (Mpc)	R_I^{3D} (Mpc)	V_r (km s^{-1})	L_B ($10^8\ L_\odot$)	M_{pm} ($10^{11}\ M_\odot$)	M_{vir} ($10^{11}\ M_\odot$)	M_{pm}/L ($M_\odot\ L_\odot^{-1}$)	M_{vir}/L ($M_\odot\ L_\odot^{-1}$)	$(M/L)^{old}$ ($M_\odot\ L_\odot^{-1}$)	t_xH_0
14+12	NGC 3109	4	1.37	0.35	20	3.7	2.1	1.7	580	460	1220/300	0.74
14+13	NGC 55	5	2.07	0.28	36	40.7	3.8	6.5	90	160	13/17	0.33
		6[a]	...	0.45	36	43.2	6.7	8.4	160	190	...	0.54
14 +7.....	NGC 4214	6	2.94	0.32	42	13.7	5.5	8:[b]	400	590[b]	...	0.30
14 +8.....	UGC 9240	4	3.06	0.30	11	1.4	0.4	0.5	300	380	250/945	1.2
17 +6.....	NGC 784	4	5.2	0.26	17	10.5	1.3	1.7	120	160	330/1110	0.68
14+14	ESO 154-23	3	5.8	0.38	35	10.0	7.3	10.4	730	1040	...	0.48
14+19	UGC 3974	3	7.9	0.31	26	6.6	4.0	2:[b]	600	300[b]	...	0.52
		4[c]	...	0.67	22	7.7	3.5	2:[b]	450	300[b]	1060/2040	1.3
Dregs	DDO 155	4	2.28	0.57	37	0.3	13.	16.	44000	56000	...	0.66

[a] Including IC 5152 in group.
[b] Virial mass estimate biased low: close pair.
[c] Including UGC 3755 in group.

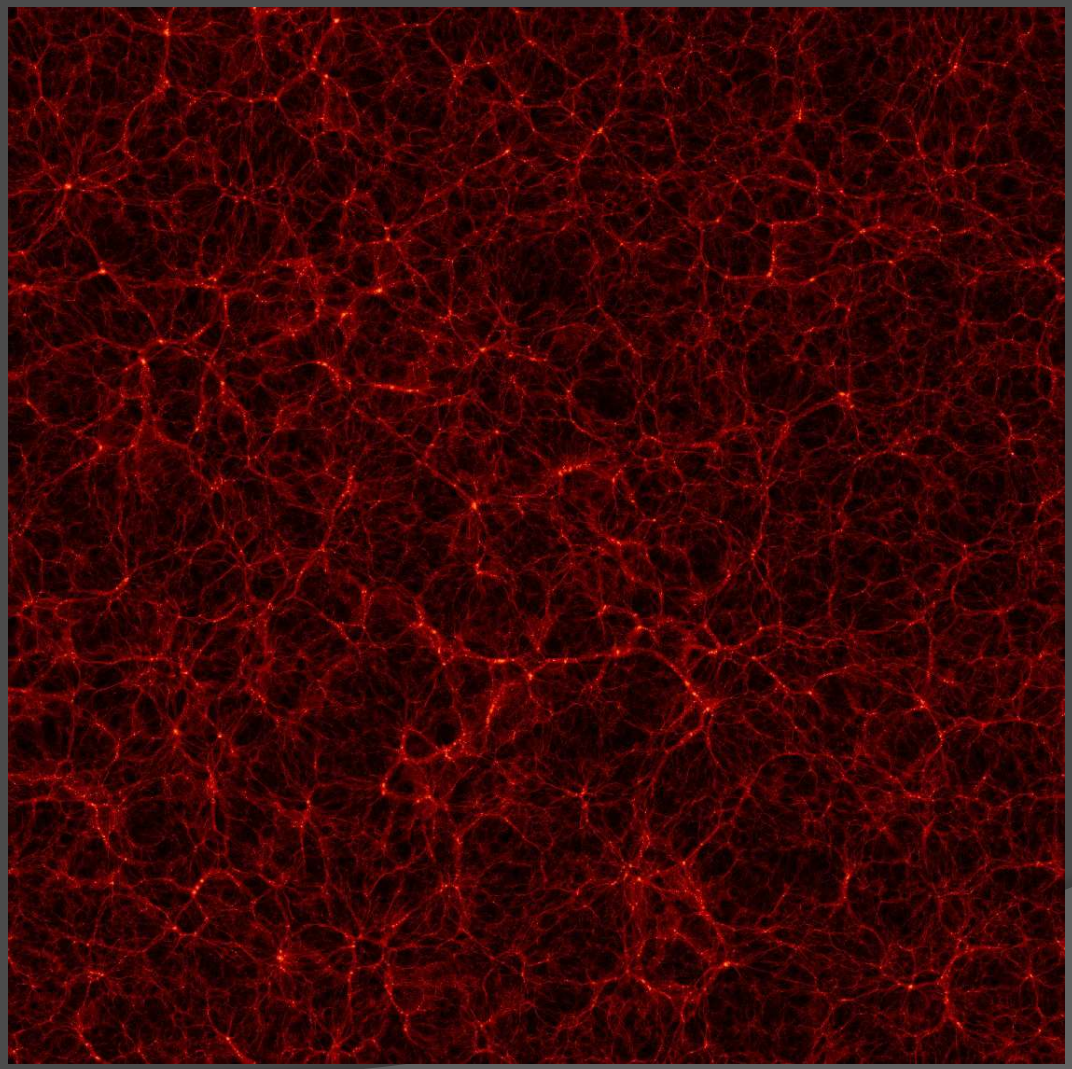
Tully et al. (2006)

Motivation

Can we find these kind of systems in the ΛCDM cosmological model?

Are the cosmological simulations reliable to trace the hierarchical processes that are expected to influence the evolution of dwarf galaxies?

Small MultiDark Planck Simulation (SMDPL)



Small MultiDark Planck Simulation (SMDPL)

Box size	400 Mpc/h
Number of particles	3840^3
Mass resolution	$9.63 \times 10^7\ M_\odot/h$
h	0.6777
Ω_λ	0.692885
Ω_m	0.307115
Ω_b	0.048206
n	0.96
σ_8	0.8228

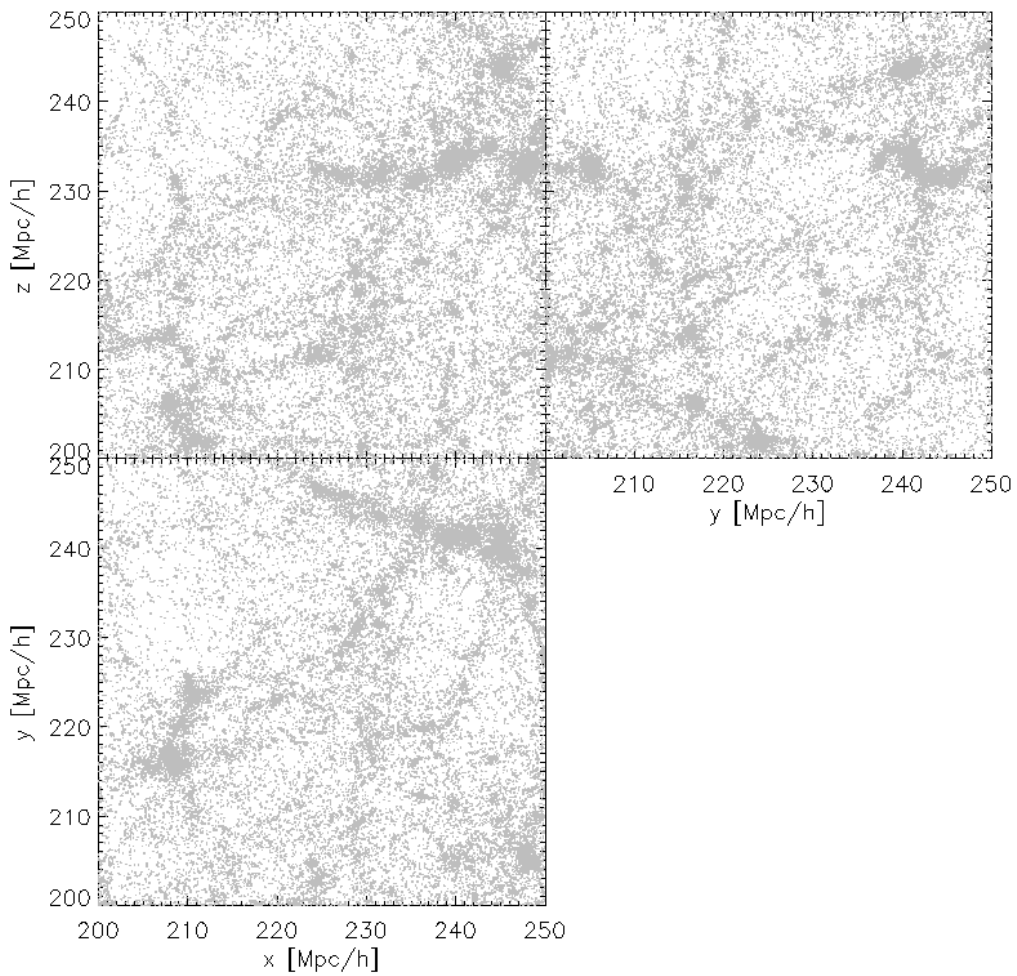
Klypin et al. (2014)

Semi-analytic model SAG

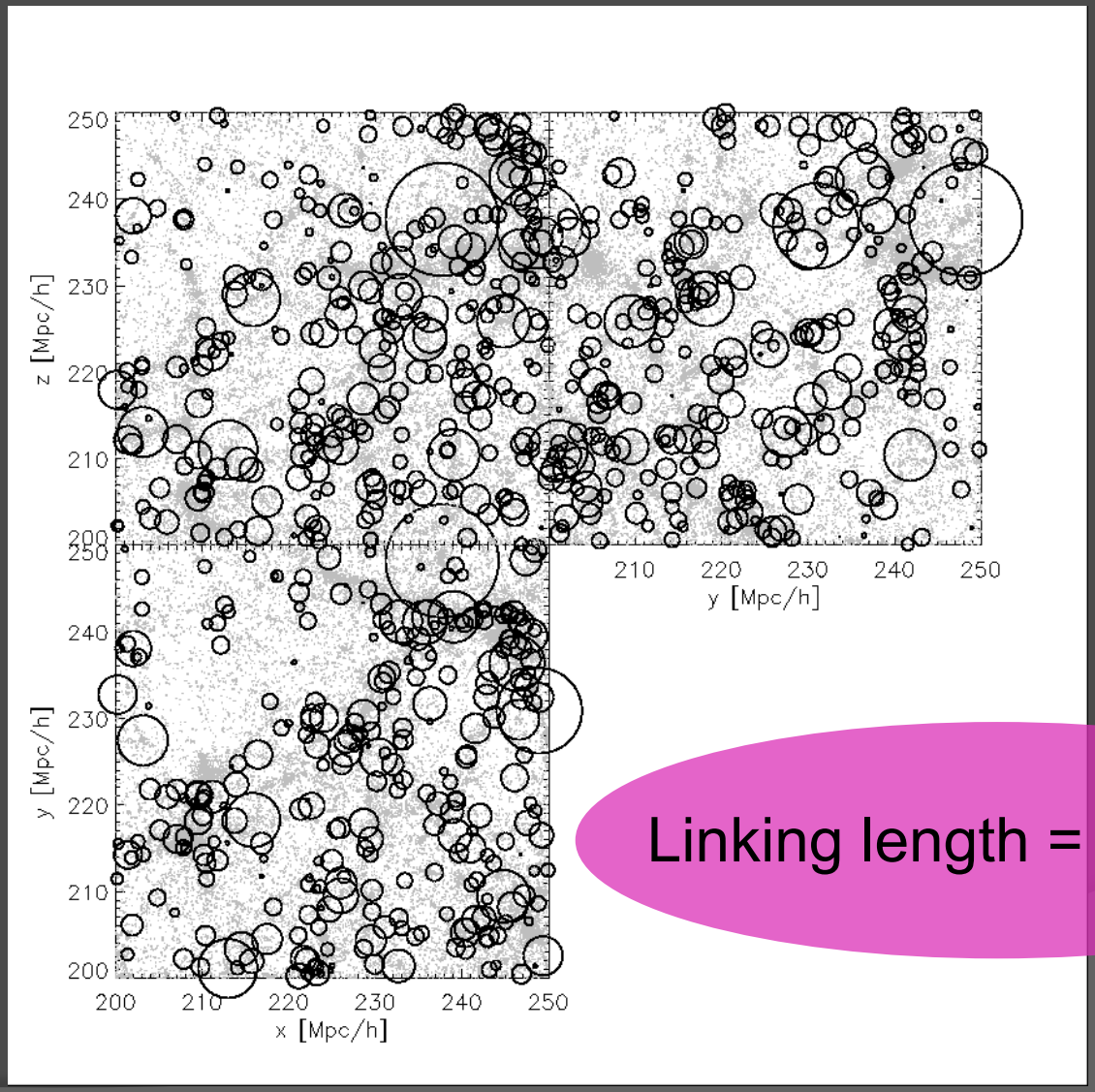
- Radiative cooling of hot gas
- Star formation
- Feedback from SN explosions
- Chemical enrichment
- Growth of supermassive black holes in galaxy centers
- AGN feedback
- Starbursts triggered by disc instabilities or galaxy mergers
- Strangulation
- Gradual starvation

Cora et al. (2018)

Spatial distribution of galaxies



Spatial distribution of galaxy groups

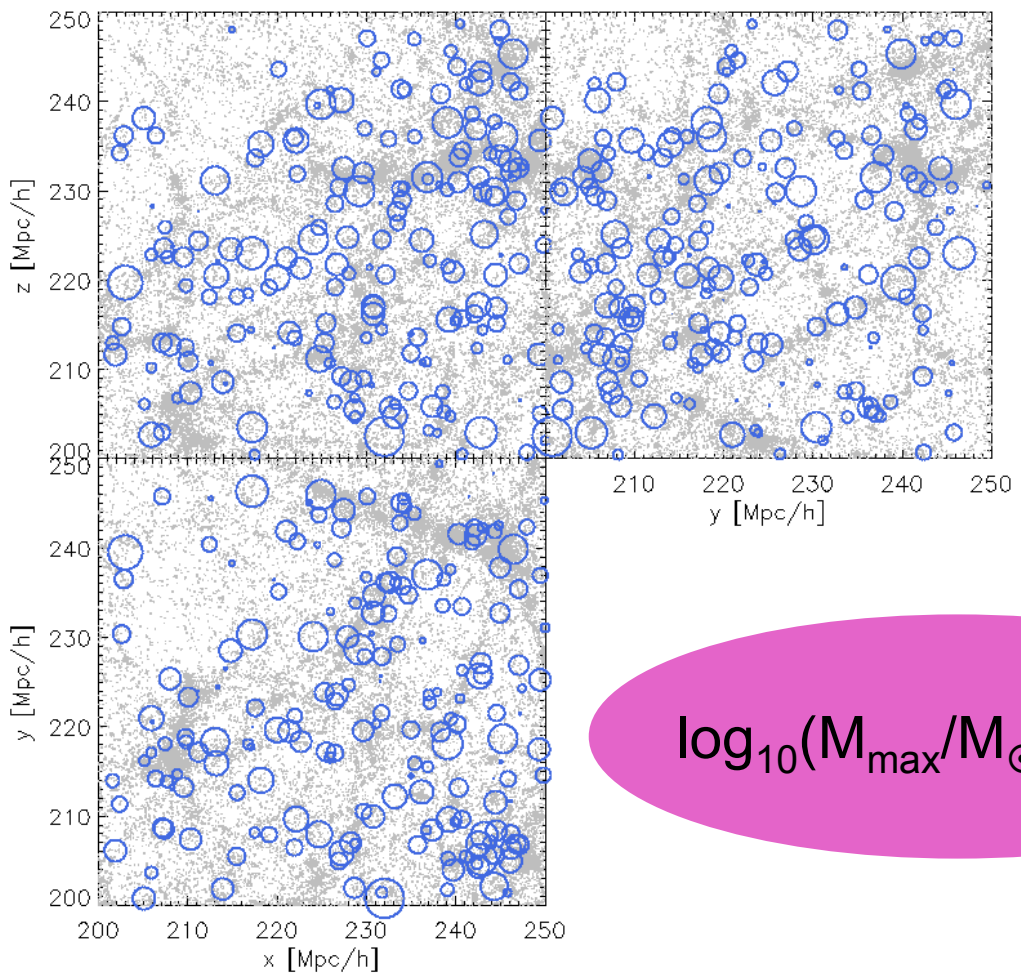


Linking length = 0.4 Mpc/h

Stellar mass thresholds

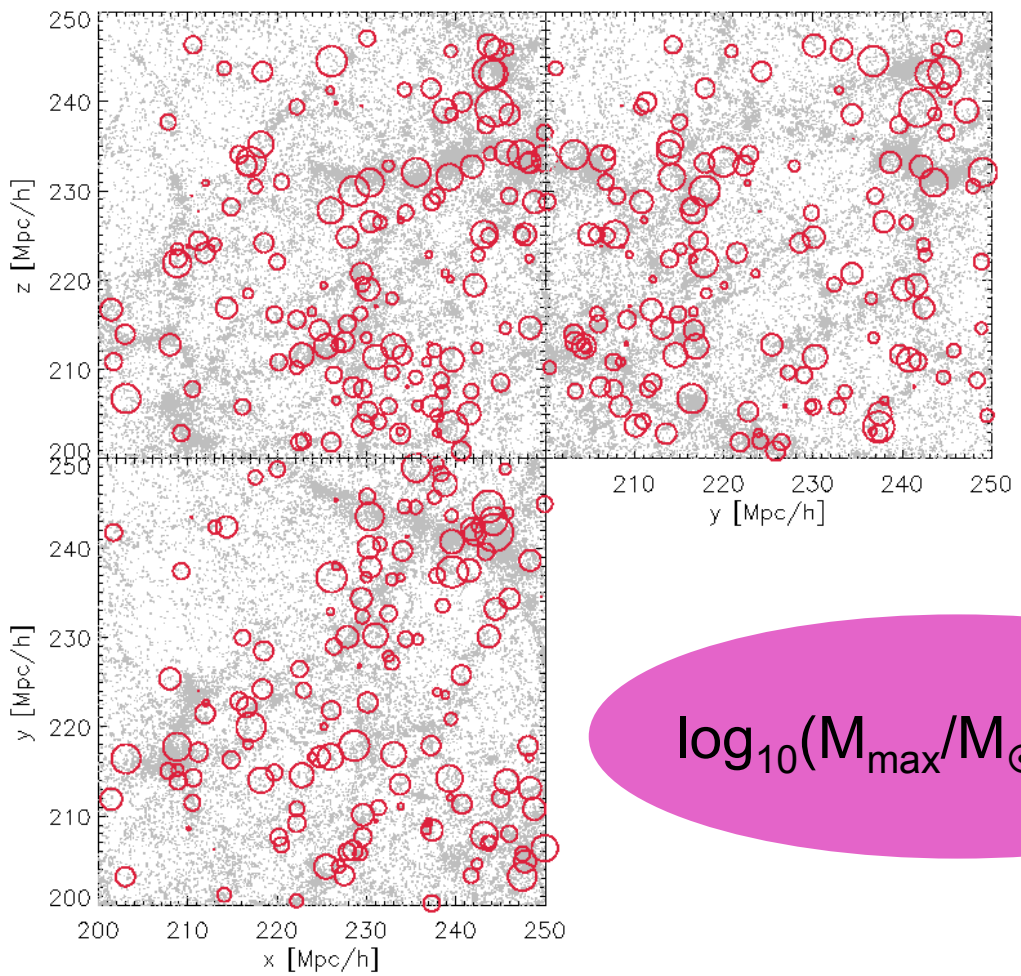
- $\log_{10}(M_{max}/M_{\odot}/h) = 9.5$
- $\log_{10}(M_{max}/M_{\odot}/h) = 9.0$
- $\log_{10}(M_{max}/M_{\odot}/h) = 8.5$

Spatial distribution of dwarf associations



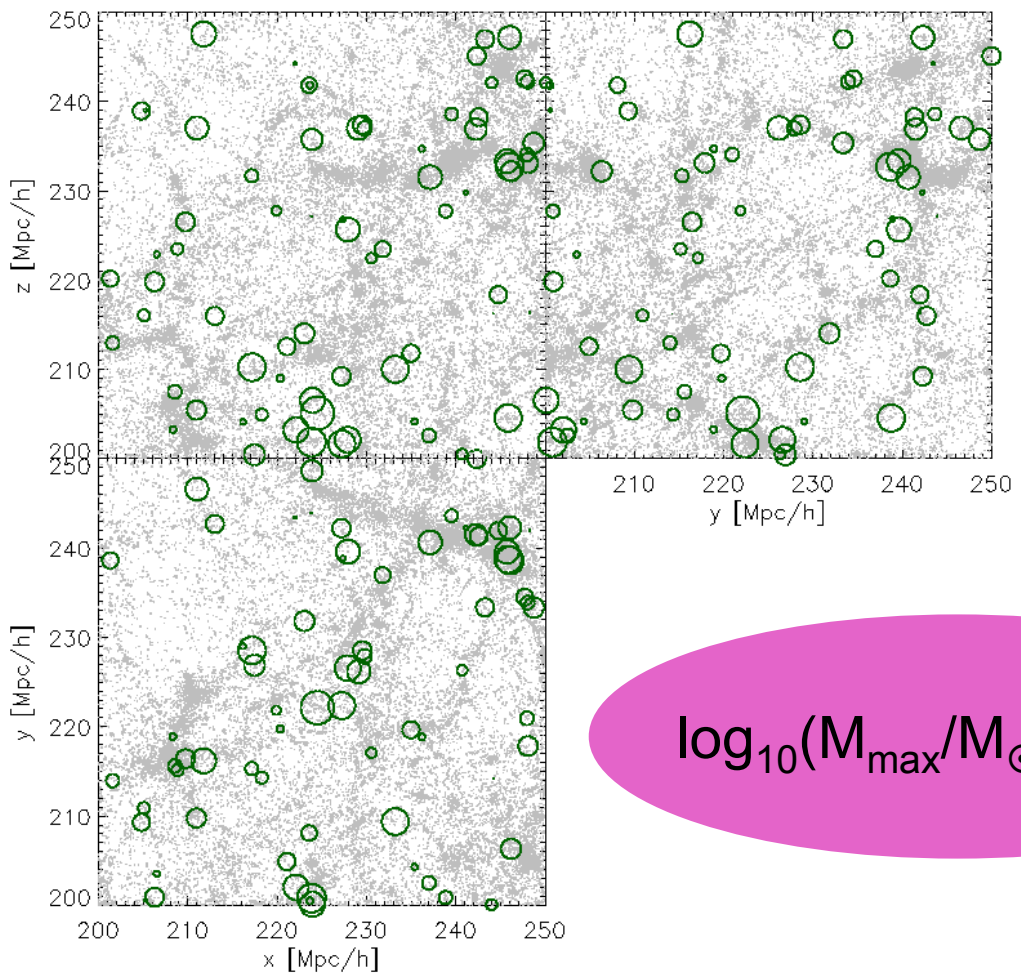
$\log_{10}(M_{max}/M_{\odot}/h)=9.5$

Spatial distribution of dwarf associations



$\log_{10}(M_{max}/M_{\odot}/h)=9.0$

Spatial distribution of dwarf associations

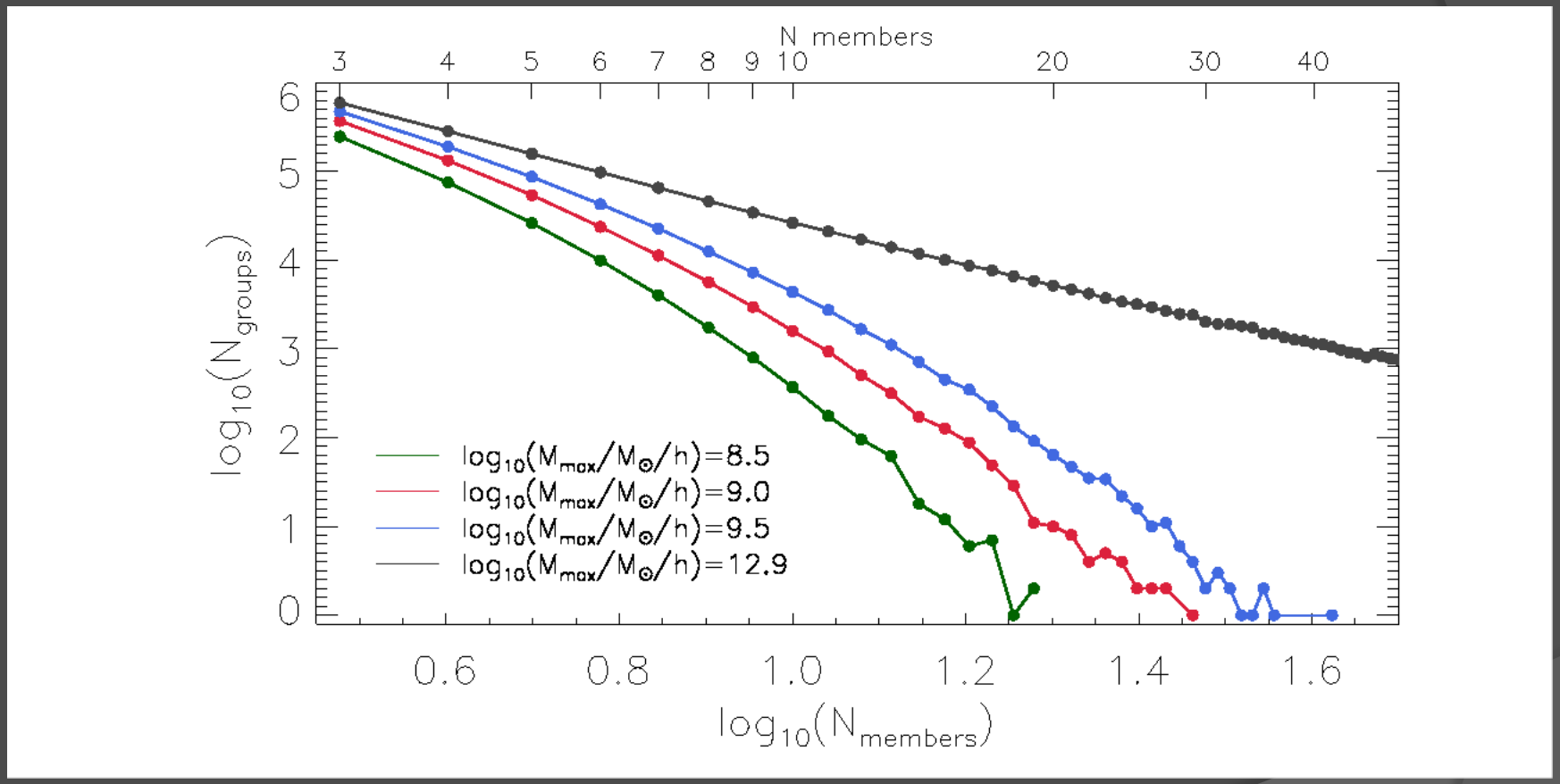


$\log_{10}(M_{max}/M_{\odot}/h)=8.5$

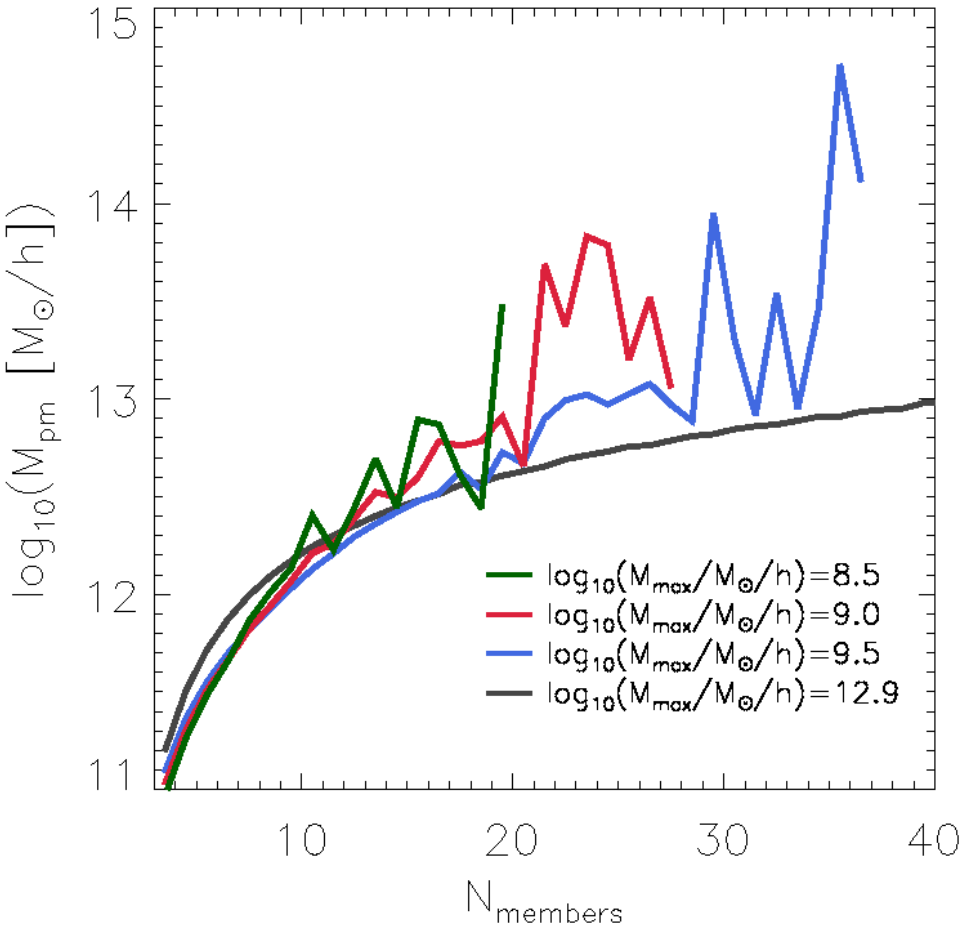
Dwarf associations

$\log_{10}(M_{max})$ $[M_\odot/h]$	Number of groups N_{groups}	Minimum number of members per group	Maximum number of members per group
12.9	1,508,530	3	16,380
9.5	850,856	3	42
9.0	606,320	3	29
8.5	366,713	3	19

Dwarf association properties



Dwarf association properties



Projected Mass

$$M_{pm} = \frac{f_{pm}}{G(N-\alpha)} \sum_{i}^{N} r_i v_i^2$$

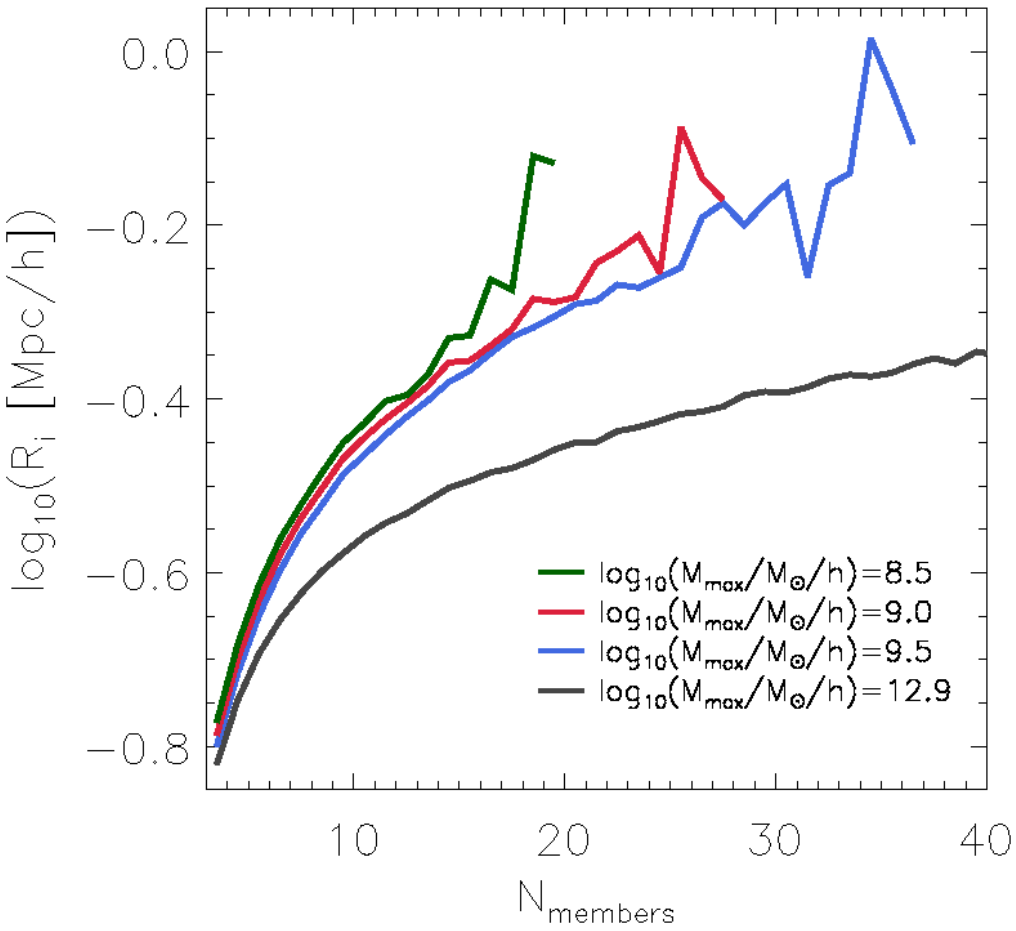
$f_{pm} = 5$

$\alpha = 1.5$

r_i : three-dimensional distance of a galaxy from the group centroid

v_i : radial velocity difference between a galaxy and the group mean

Dwarf association properties

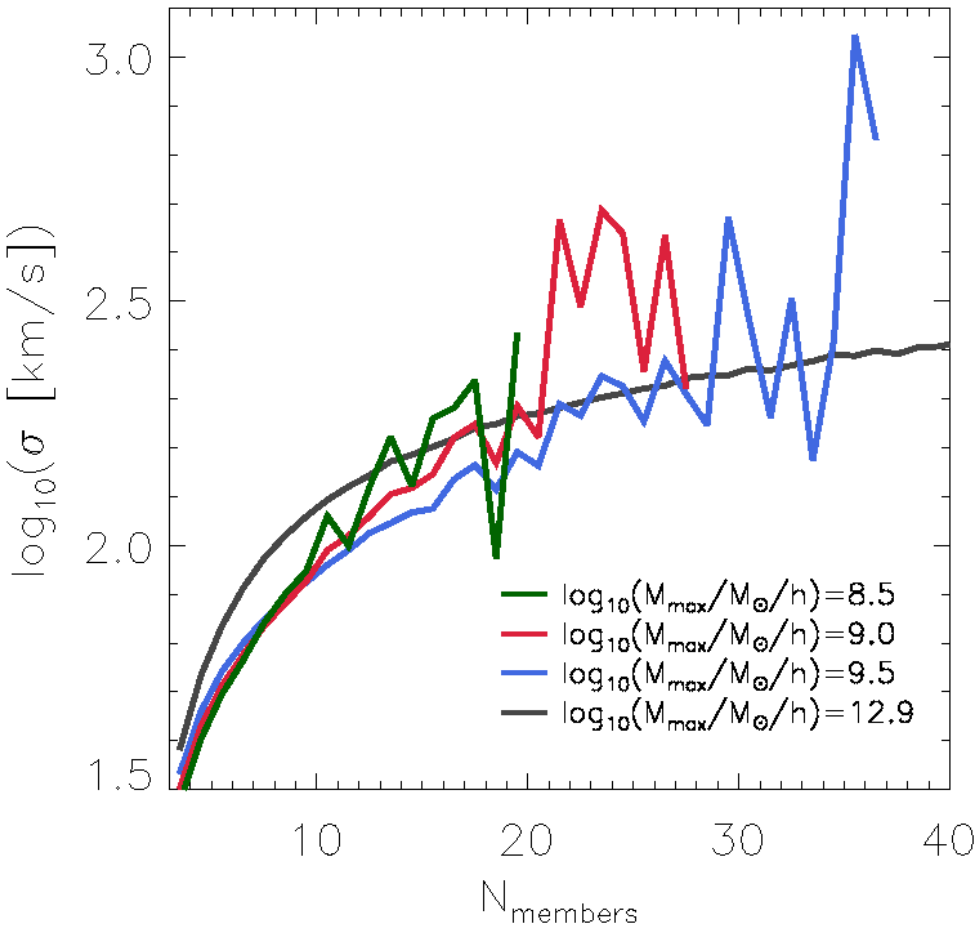


Inertial Radius

$$R_i = \left(\sum_i^N r_i^2 / N\right)^{1/2}$$

r_i : three-dimensional distance of a galaxy from the group centroid

Dwarf association properties

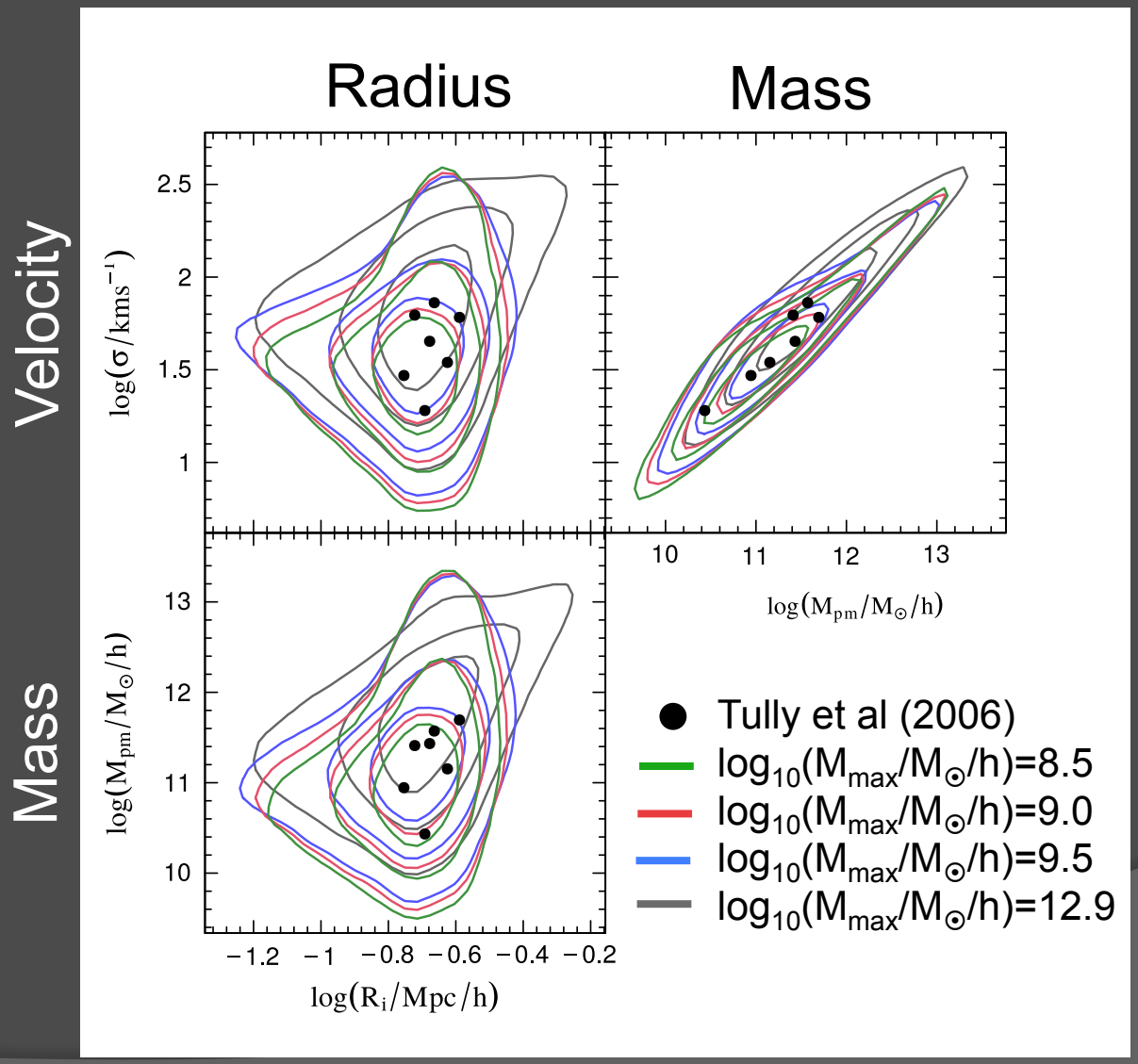


Velocity dispersion

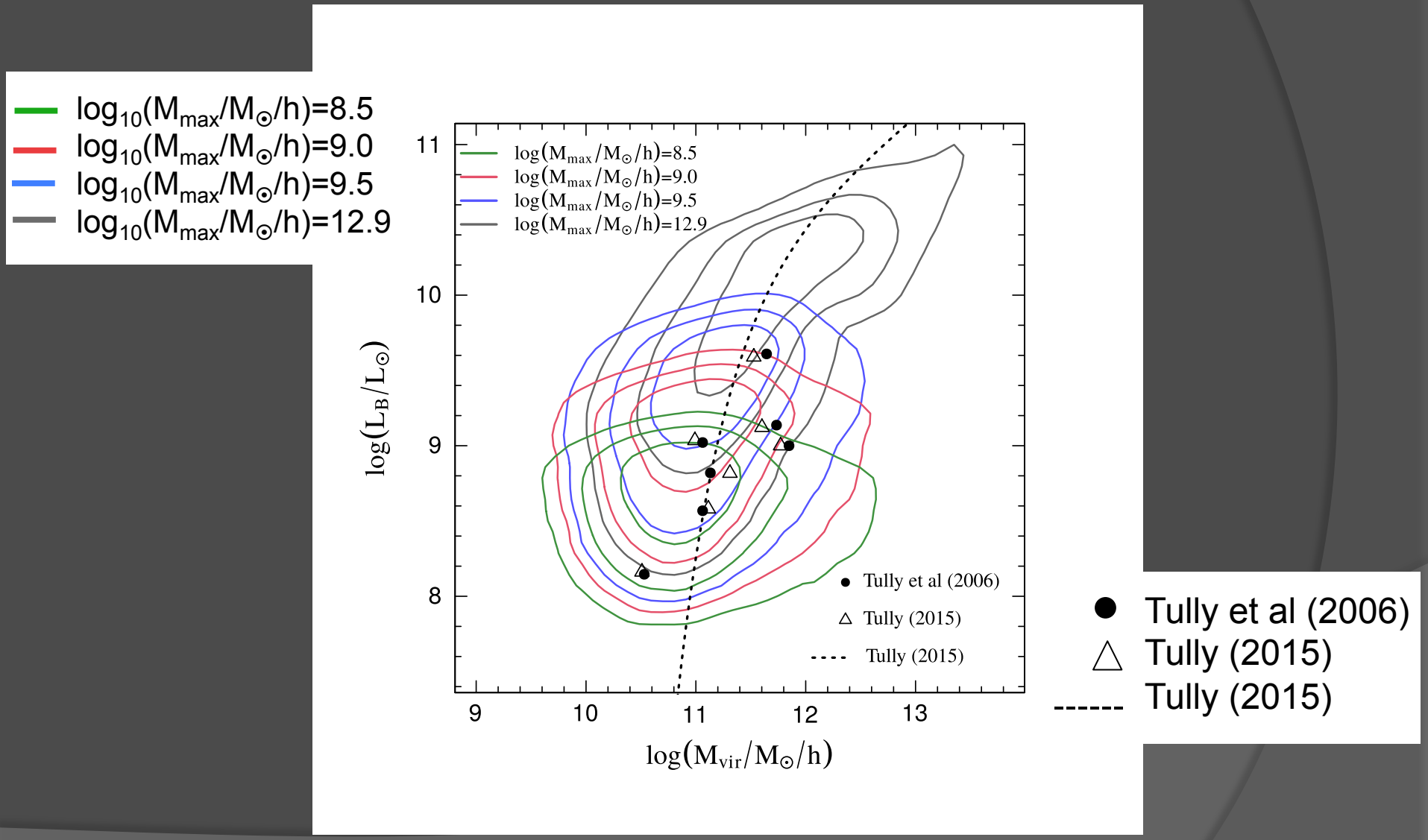
$$\sigma = \sqrt{3}\sigma_{los}$$

σ_{los} : one-dimensional line of sight velocity dispersion (taken as the z-coordinate)

Dwarf association properties



Dwarf association properties



Conclusion and future work

- We find associations of dwarf galaxies in the ΛCDM model.
- We reproduce the dynamical properties of associations of dwarf galaxies presented by observational results.

Future work

- Continue with the analysis of the properties dwarf associations.
- Analyze temporal evolution of dwarf associations.
- Study the properties of the members of the dwarf associations and the relationship between them.

- Study the dwarf galaxies groups to compare with observational results.

Muchas gracias!