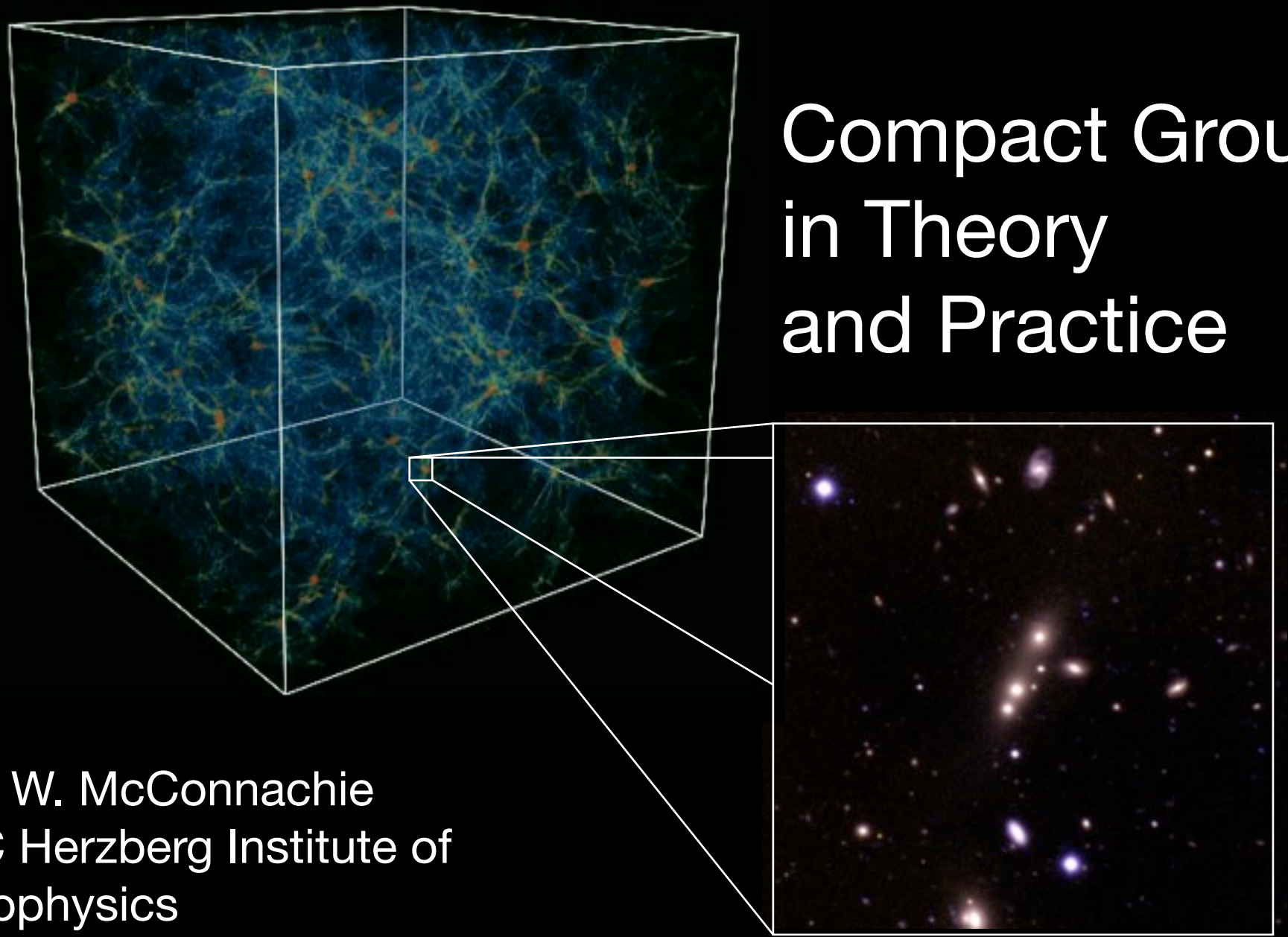


Compact Groups in Theory and Practice

Alan W. McConnachie
NRC Herzberg Institute of Astrophysics

I. McConnachie, Ellison & Patton 2008, MNRAS, 387, 1281
II. Brasseur, McConnachie, Ellison & Patton 2009, MNRAS, 392, 1141
III. McConnachie, Patton, Ellison & Simard 2009, MNRAS, 395, 255
IV. McConnachie, Delahaye, Simard, Ellison & Patton 2009, MNRAS, in prep

Compact Groups: laboratories for galaxy interactions

- Typical intergalactic separations similar to sizes of galaxies, and low velocity dispersions (~200km/s); interactions and merging should be common eg. Barnes 1989, but see Governato et al 1991, Athanassoula et al. 1997)

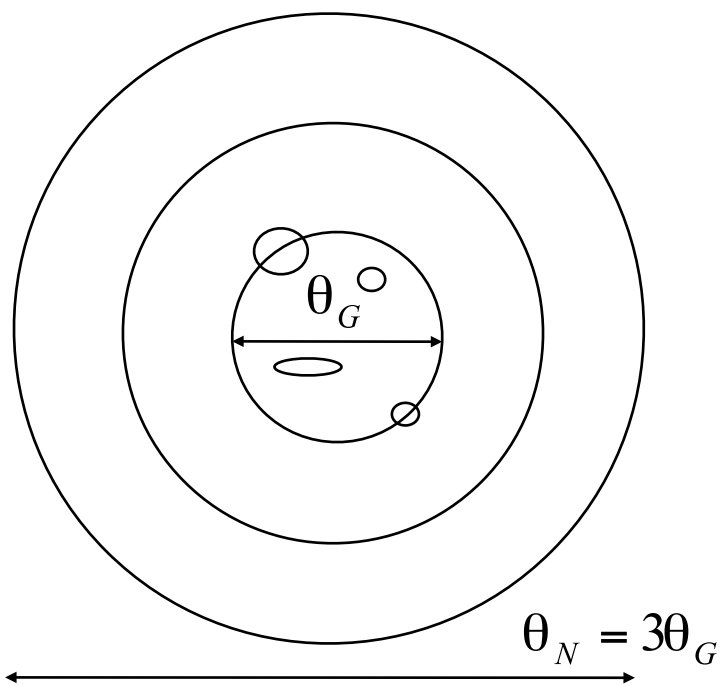
Hickson Compact Groups

- Fundamentally difficult problem: how do you identify compact groups based on only projected information?
- Hickson criteria (1982):

$N \geq 4$ (within dm<=3mags)

$\bar{\mu}_G < 26$ (compactness)

$\theta_N \geq 3\theta_G$ (isolation)

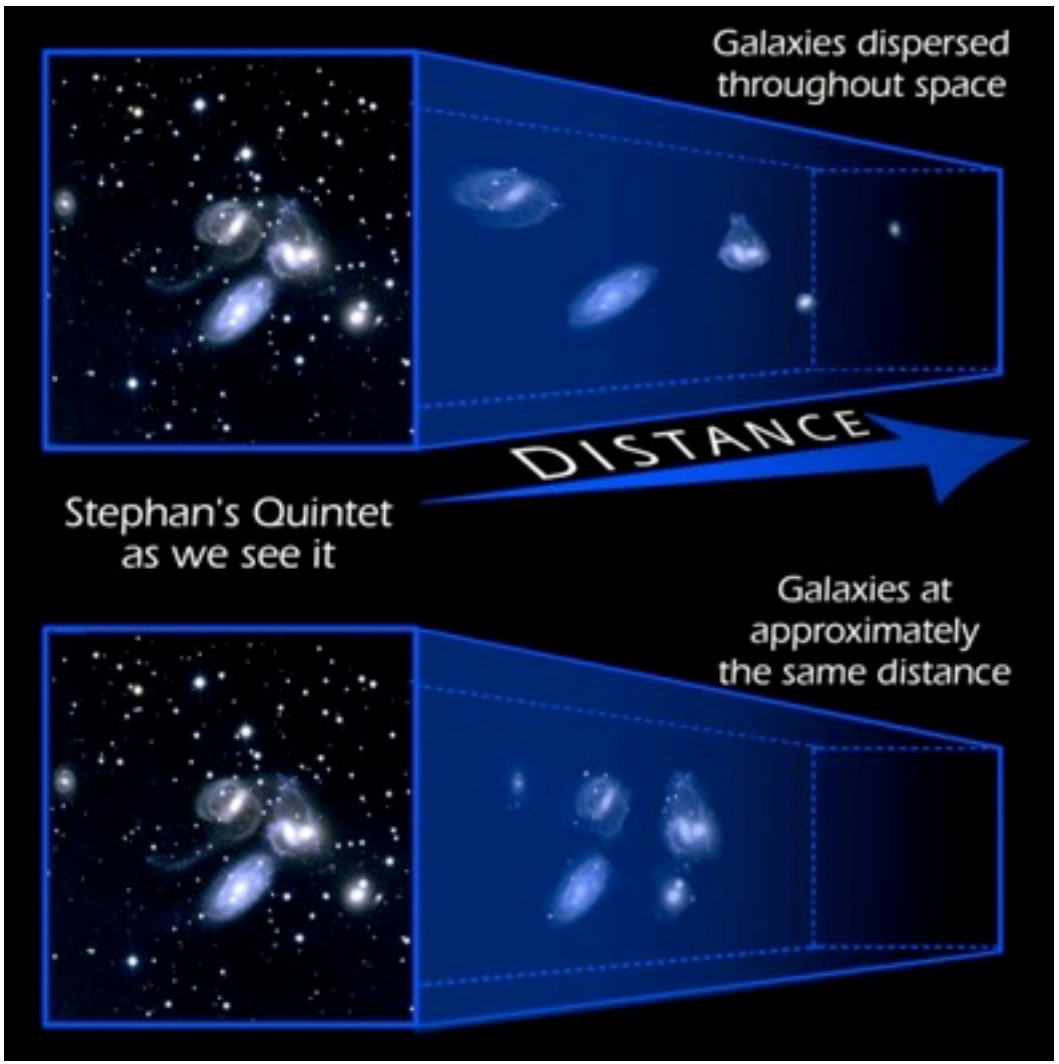


θ_G = angular diameter of smallest circle enclosing all galaxy centres

- Original catalogue contains 451 galaxies in 100 different groups
- Various modified criteria since (eg dm<=2, sb<24) eg. Iovino et al. 2003

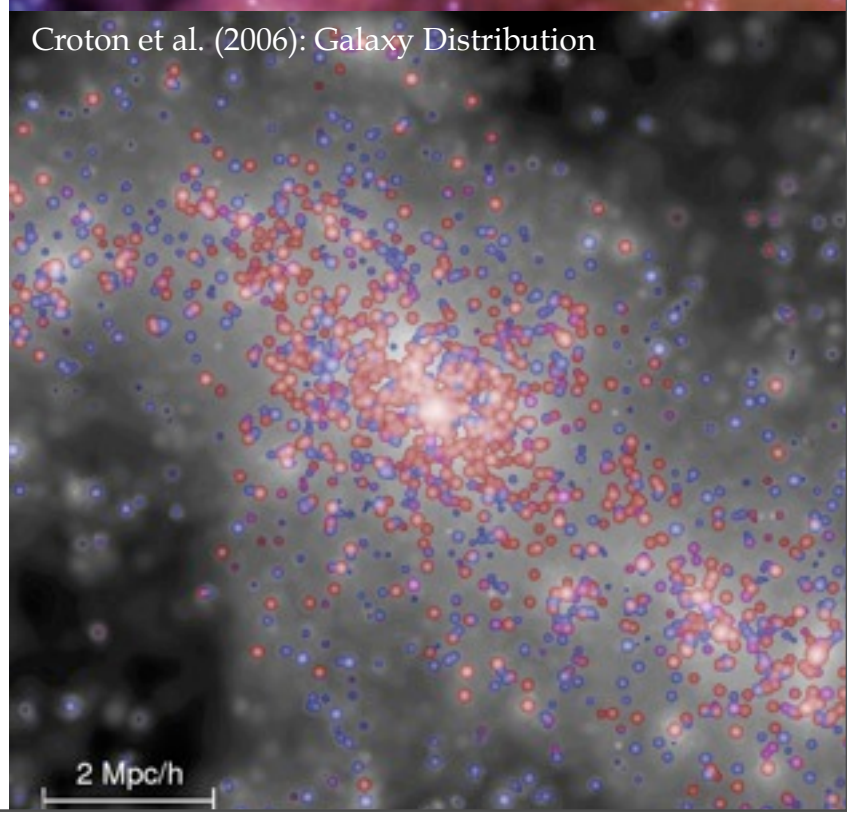
Effect of Interlopers?

- Mamon (1986) argued that roughly 50% are loose groups/ unassociated galaxies
- Hickson (1990) estimated that 17% of HCGs are line-of-sight field galaxies and an additional 13% are projections of loose groups
- Mock catalogues can be used to tackle this long standing question



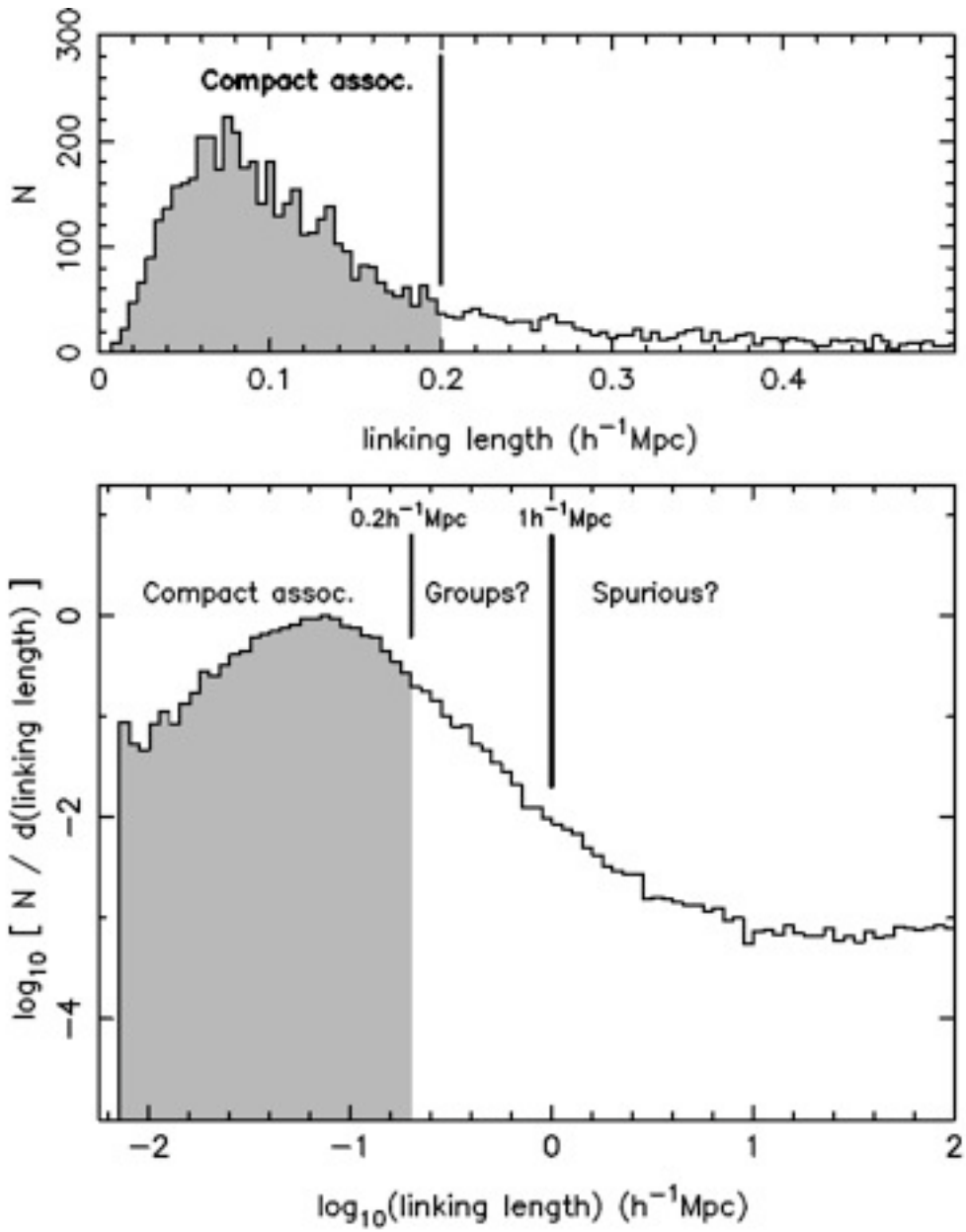
Semi-analytic catalogues

- Use De Lucia & Blaizot (2002) all-sky mock catalogues, based on Millenium Run (Springel et al 2002)
- Magnitude limited to r = 18, ~5.7 million galaxies, down to mass of ~SMC
- Spatial resolution of ~5kpc h^{-1}; can trace haloes down to mass ~$1.7 \times 10^{10}\, h^{-1}$ Ms.
- Typical CG galaxy mass well above this limit.
- Find 15122 CGs using Hickson critera (64525 galaxies)
- (Note groups identified irrespective of magnitude of brightest galaxy)



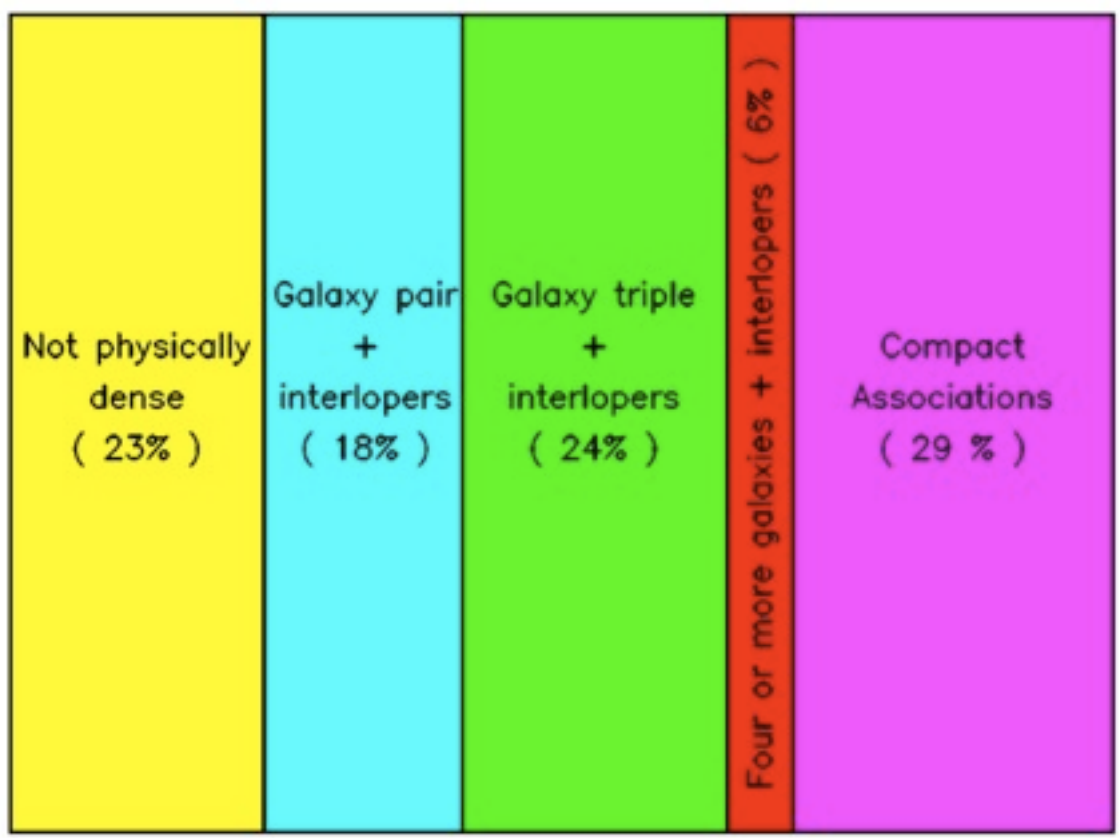
How to define compactness?

- Use well known concept of linking length, l (Huchra & Geller 1982)
- Using 3D positional information, find what is the minimum l required to find each of the systems identified by the Hickson criteria.
- Use l < 200kpc h^{-1}



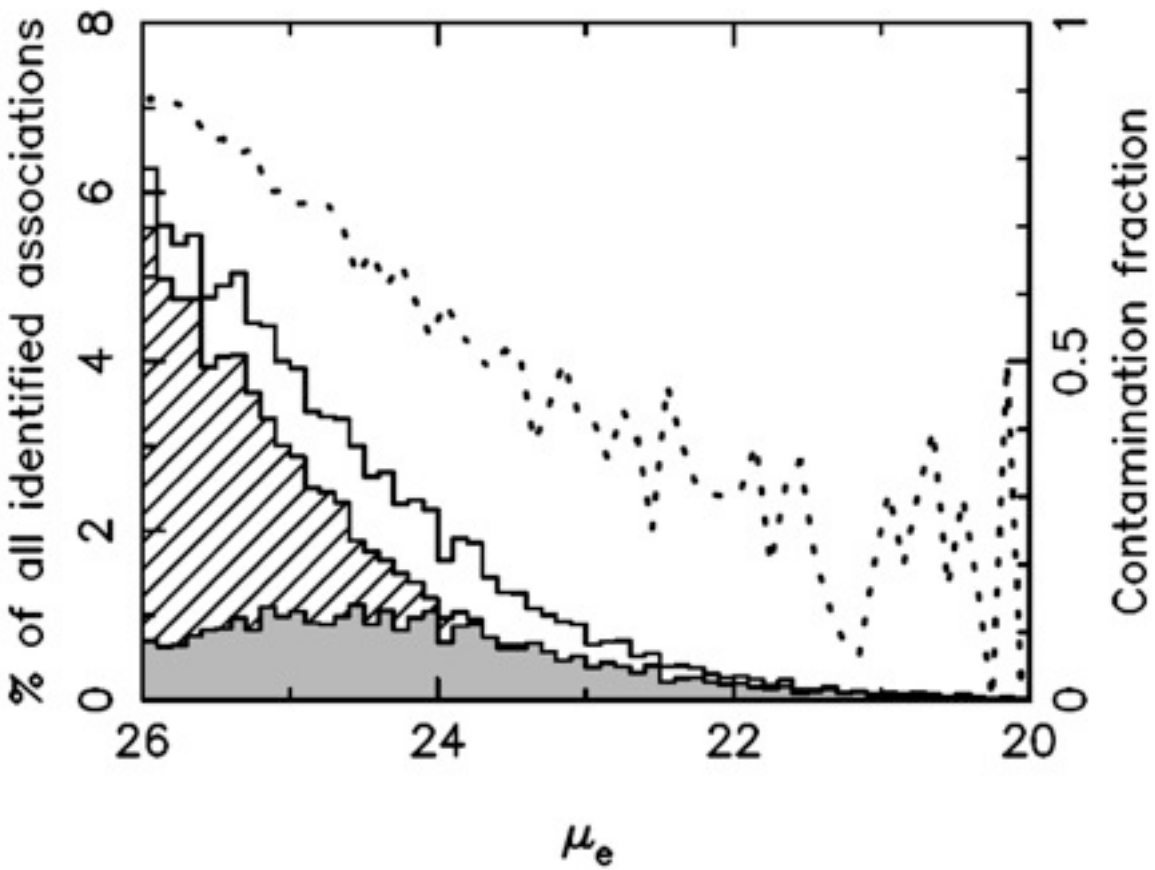
Interloping galaxies/groups

- Are the interloping groups completely spurious, or made up in part of compact pairs, triplets, quadruplets...?
- Interlopers are significant:
  - only 29% of groups have **no** interlopers
  - but 77% of groups consist in part of a compact arrangement of at least 2 galaxies
  - ~**40% of galaxies are not physically close to other galaxies** (>200kpc)
- Can we reduce the contamination to produce a cleaner sample?



Compactness of Hickson associations

Selection and contamination



μ_e	% CAs	% HAs
26	100	29
25	72	43
24	39	56
23	16	67

- Genuine compact groups are brighter (and slightly more isolated) than the contamination
- Selection by surface brightness can dramatically reduce contamination rates

Theory meets reality

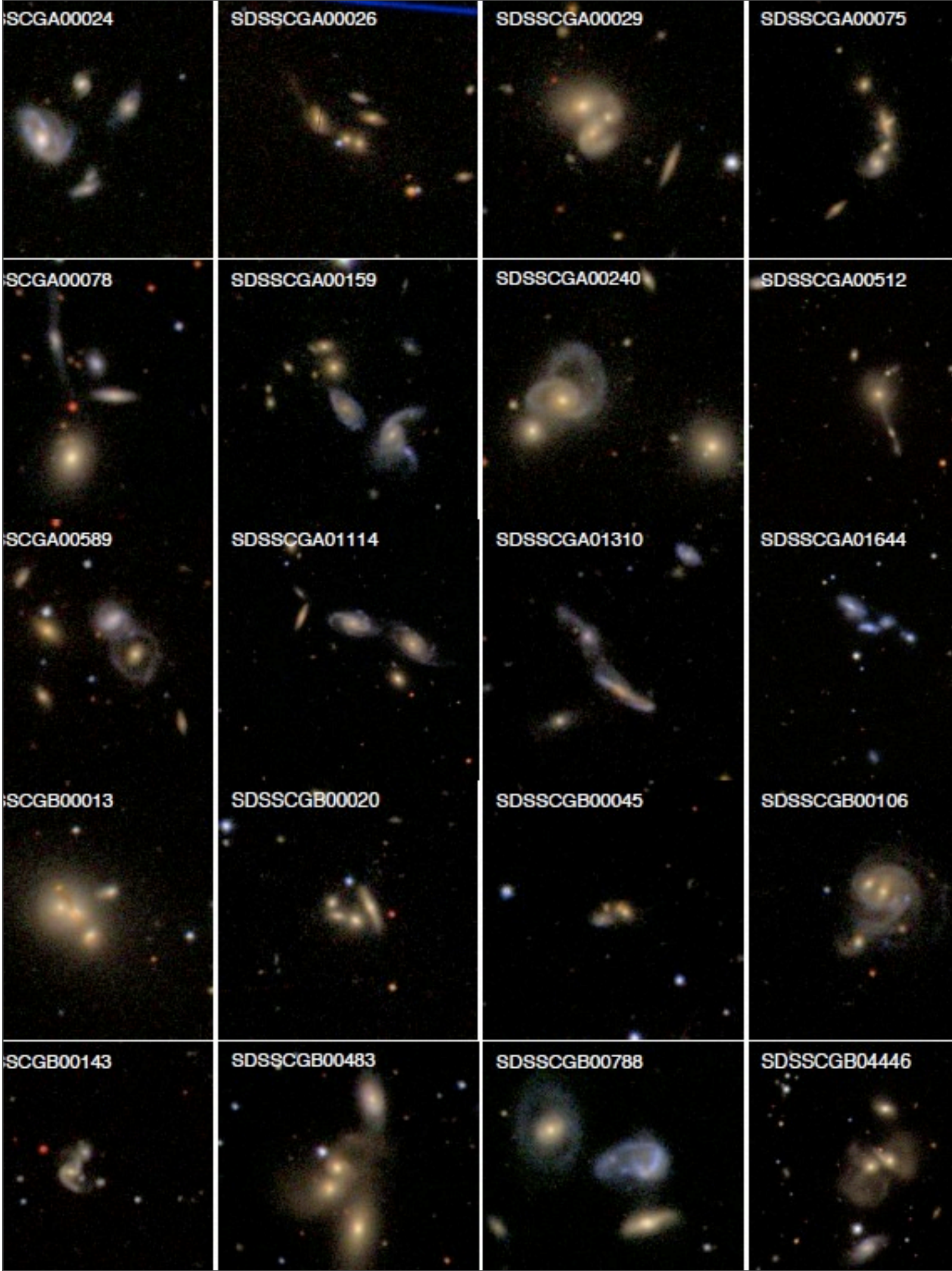
- Apply Hickson criteria to the SDSS DR6 (Adelman-McCarthy et al. 2008)
  - **Catalogue A: ~1.1 million galaxies** brighter than r=18 (same limit as mock catalogue)
  - **Catalogue B: ~29 million galaxies** brighter than r=21 (reliable photometric completeness/star-galaxy separation)
  - Bright-end limit r=14.5
- **2297 CGs to r=18; 74791 CGs to r=21** [~0.9% of all galaxies]
- Can study selected sub-samples of these catalogues as required

Publicly available tables: Group and galaxy properties

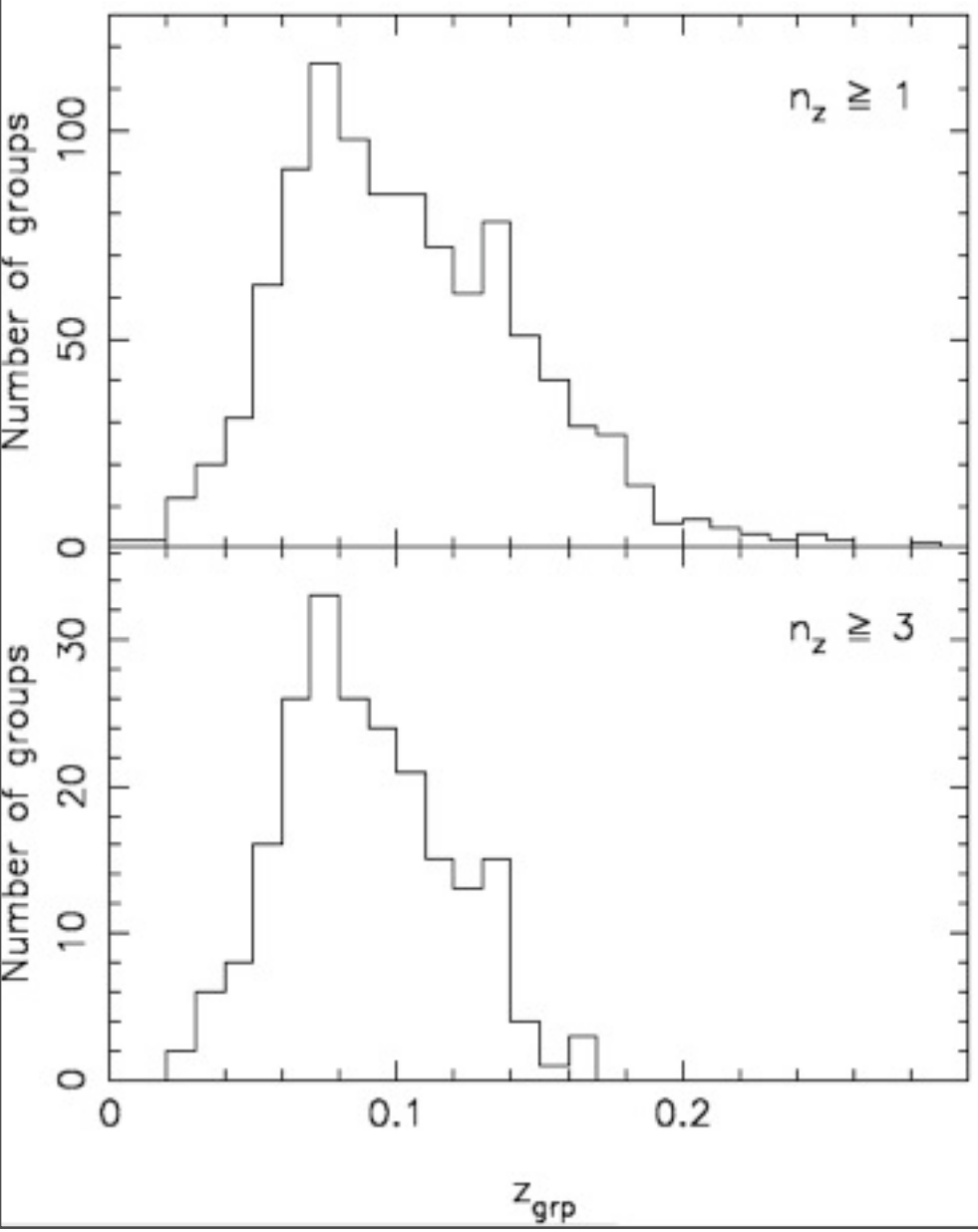
ID	α (J2000)			δ (J2000)			n_{mem}	μ	θ_G	θ_N/θ_G	r_{max}	n_z	z
SDSSCGA00001	14	49	34.3	+11	14	53.4	4	20.991	0.22	4.63	15.01	1	0.055
SDSSCGA00002	2	14	4.5	+13	18	54.3	4	21.238	0.28	3.30	14.81	1	0.060
SDSSCGA00003	23	54	13.5	-10	23	17.2	4	21.279	0.16	5.96	16.42	1	0.079
SDSSCGA00004	15	25	53.7	+5	44	17.8	4	21.501	0.16	18.64	15.82	0	
SDSSCGA00005	23	33	23.6	-1	8	43.8	4	21.519	0.29	5.19	14.53	1	0.091
SDSSCGA00006	21	40	17.4	-8	4	11.7	4	21.566	0.14	4.31	16.84	0	
SDSSCGA00007	8	24	31.6	+20	27	28.5	4	21.585	0.19	9.26	15.77	2	0.109
SDSSCGA00008	16	10	2.6	+5	54	53.5	4	21.747	0.31	3.74	14.89	1	0.065
SDSSCGA00009	12	3	12.9	+57	53	39.2	4	21.755	0.32	7.84	14.95	2	0.034
SDSSCGA00010	16	26	50.4	+25	53	34.7	4	21.913	0.20	7.58	16.01	2	0.111
SDSSCGA00011	16	21	56.5	+25	41	20.1	4	22.054	0.21	5.84	16.48	3	0.100
SDSSCGA00012	7	44	42.7	+16	55	21.6	4	22.130	0.29	3.40	15.36	0	

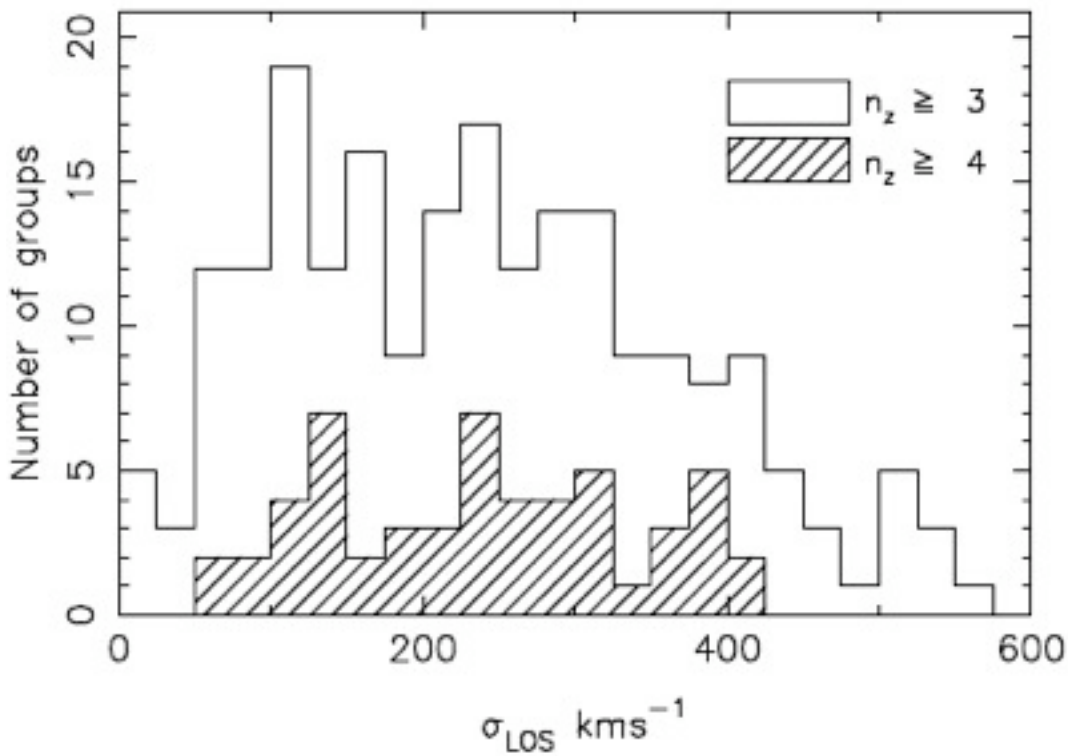
Table 1. Compact groups identified in Catalogue A, ranked in order of decreasing surface brightness. This table has 2297 rows, of which only the first 12 rows are reproduced here. See Section 2.5 for a description of each column.

ID	ObjID (SDSS)	α (J2000)			δ (J2000)			r	$(g-r)$	SpecObjID (SDSS)	z_{conf}	z
SDSSCGA00001.1	587736807771078936	14	49	34.5	+11	14	53.2	15.01	0.86	0		
SDSSCGA00001.2	587736807771078937	14	49	34.9	+11	14	55.2	15.29	0.82	0		
SDSSCGA00001.3	587736807771078935	14	49	34.2	+11	14	44.0	16.23	1.07	482677981936877568	0.999	0.055
SDSSCGA00001.4	587736807771078938	14	49	33.6	+11	15	1.2	17.29	0.97	0		
SDSSCGA00002.1	587724198822412473	2	14	3.9	+13	18	47.2	14.81	1.08	120694126130757632	0.999	0.060
SDSSCGA00002.2	587724198822477903	2	14	5.1	+13	18	39.5	15.07	0.87	0		
SDSSCGA00002.3	587724198822477905	2	14	5.0	+13	19	2.3	15.52	1.12	0		
SDSSCGA00002.4	587724198822412475	2	14	4.2	+13	19	8.1	17.71	0.68	0		
SDSSCGA00003.1	587727225689538694	23	54	13.2	-10	23	11.0	16.42	0.85	182901462030876672	0.999	0.079
SDSSCGA00003.2	587727225689538695	23	54	13.5	-10	23	8.7	16.69	1.03	0		
SDSSCGA00003.3	587727225689538696	23	54	13.5	-10	23	23.6	16.77	0.81	0		
SDSSCGA00003.4	587727225689538697	23	54	13.8	-10	23	25.5	16.86	0.79	0		
SDSSCGA00004.1	587730023333625957	15	25	53.9	+5	44	9.7	15.82	0.99	0		
SDSSCGA00004.2	587730023333625958	15	25	53.7	+5	44	27.7	17.20	1.09	0		
SDSSCGA00004.3	587730023333625960	15	25	53.4	+5	44	10.2	17.57	0.84	0		


SCGA00024
SDSSCGA00026
SDSSCGA00029
SDSSCGA00075
SCGA00078
SDSSCGA00159
SDSSCGA00240
SDSSCGA00512
SCGA00589
SDSSCGA01114
SDSSCGA01310
SDSSCGA01644
SCGB00013
SDSSCGB00020
SDSSCGB00045
SDSSCGB00106
SCGB00143
SDSSCGB00483
SDSSCGB00788
SDSSCGB04446

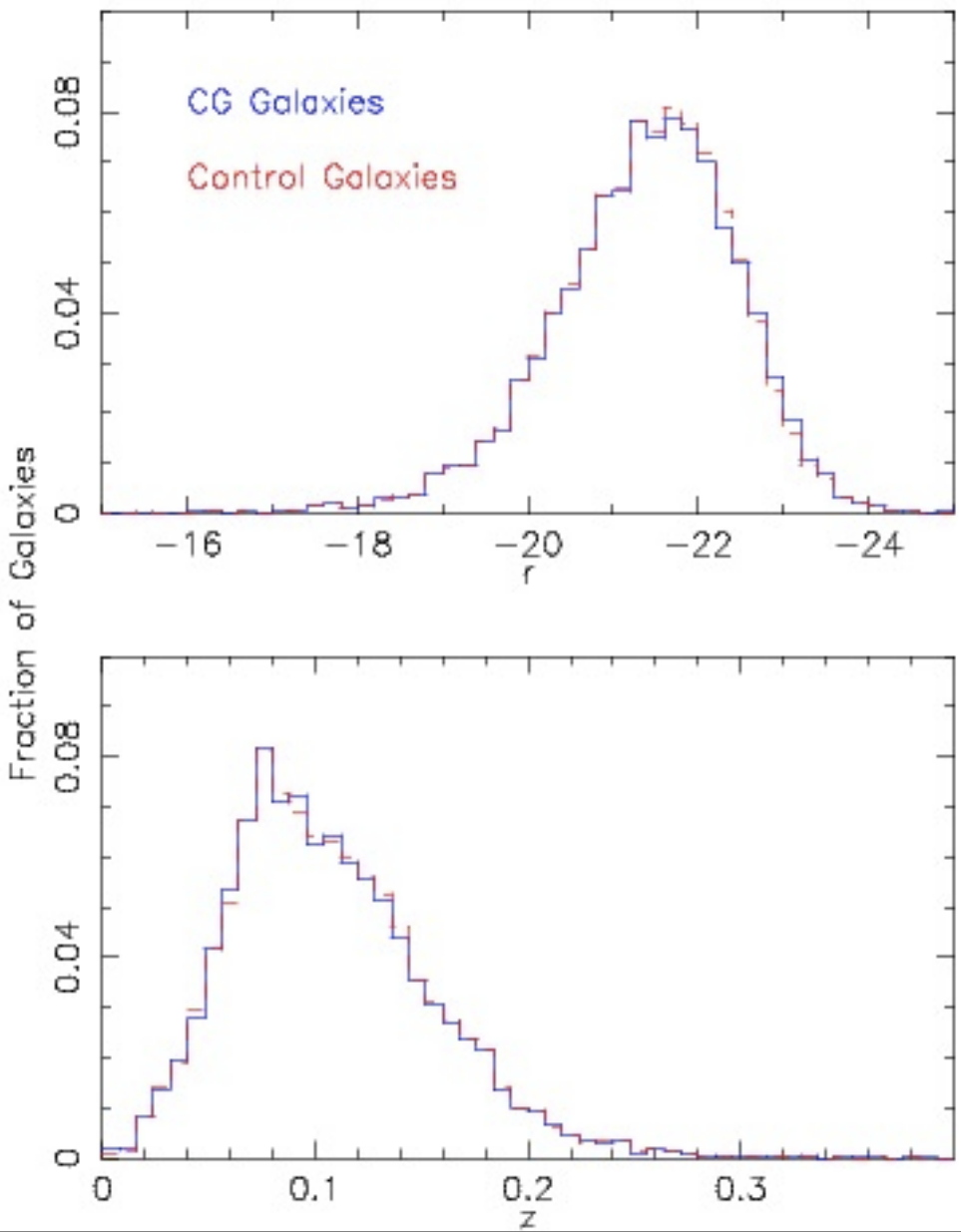
Serendipitous spectroscopic properties





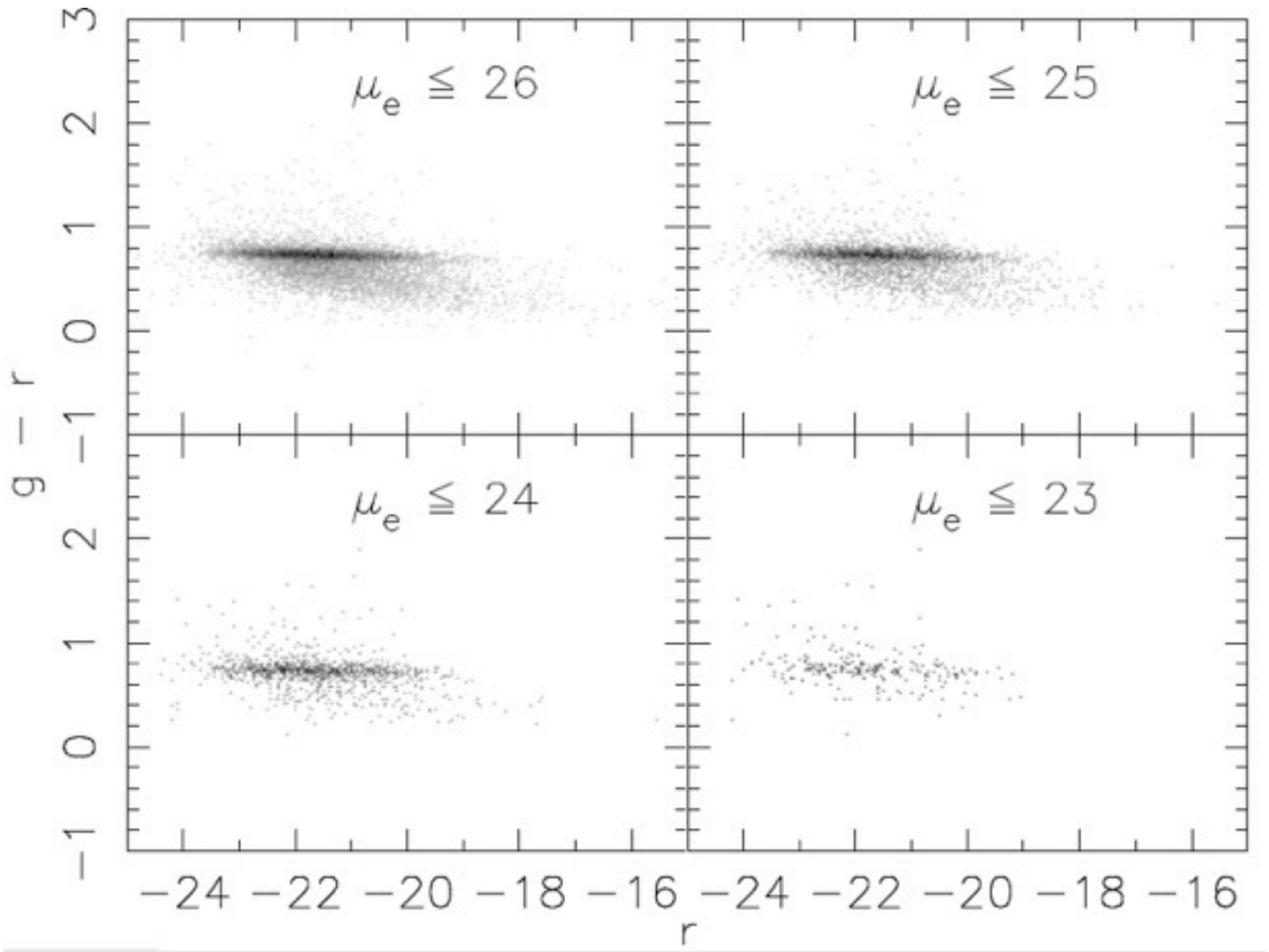
- Median redshift of groups is z=0.09 (cf HCGs)
- Velocity dispersion of groups with 3+ (consistent) redshifts is v_{disp} =~230km/s
- Groups with multiple redshifts can provide independent handle on interloper fractions

Galaxy luminosity, redshift, and the control

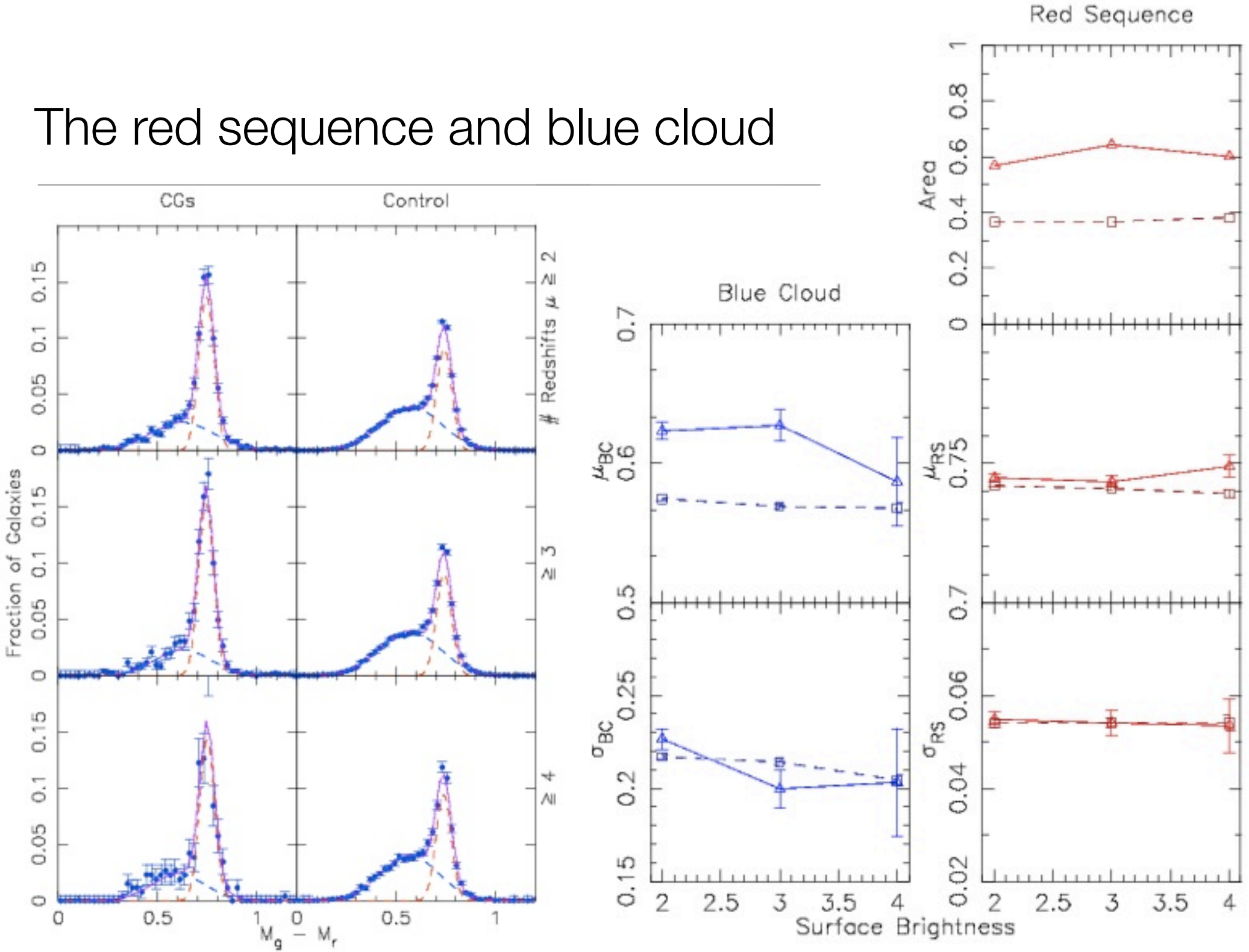


- 15 control galaxies per CG galaxy
- Matched in rest-frame r and z
- Used photo-z info when required
- Control constructed from all SDSS DR6 galaxies that are not compact group galaxies

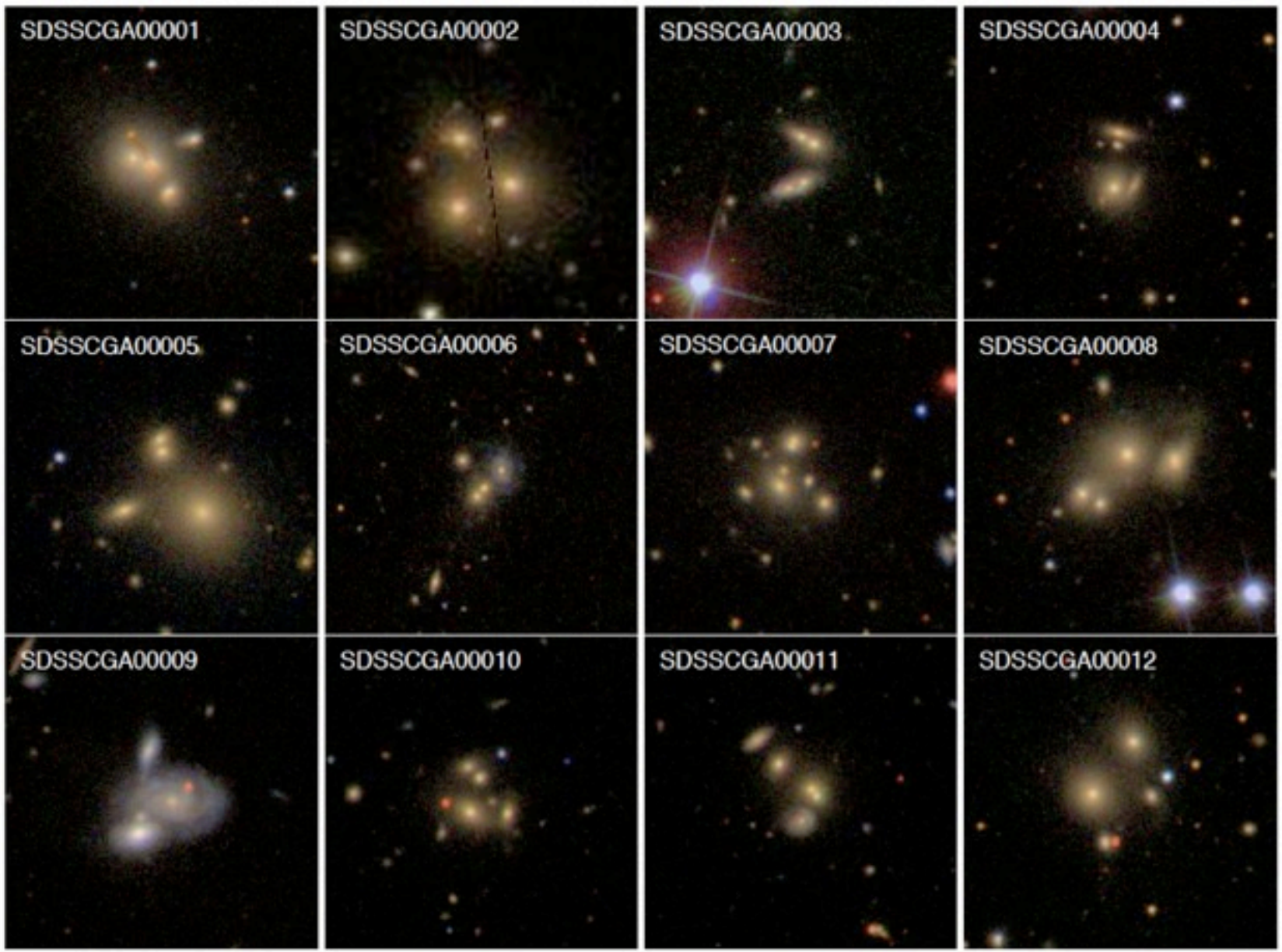
Colour-magnitude diagram for CG galaxies



The red sequence and blue cloud



These groups sure do look red...



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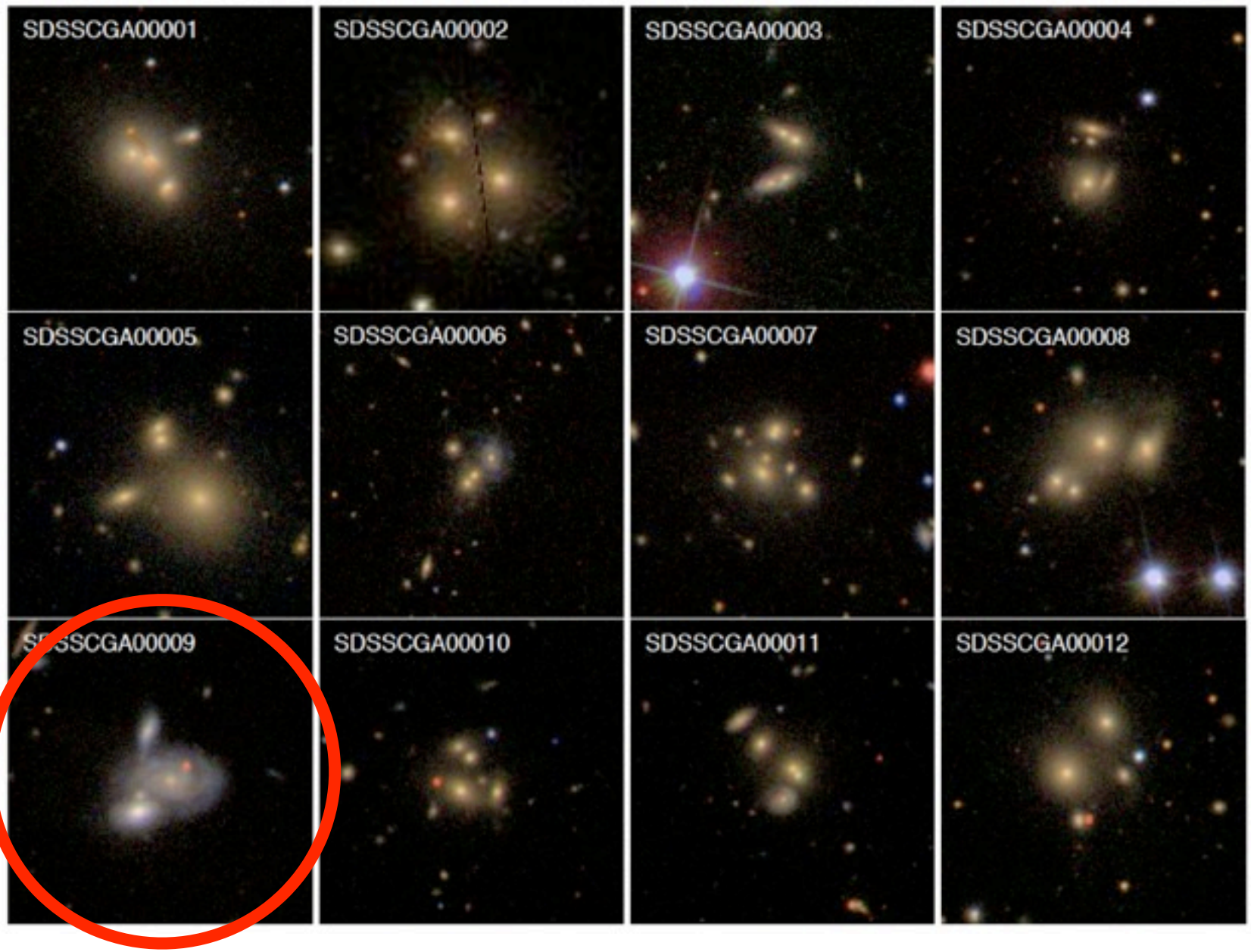
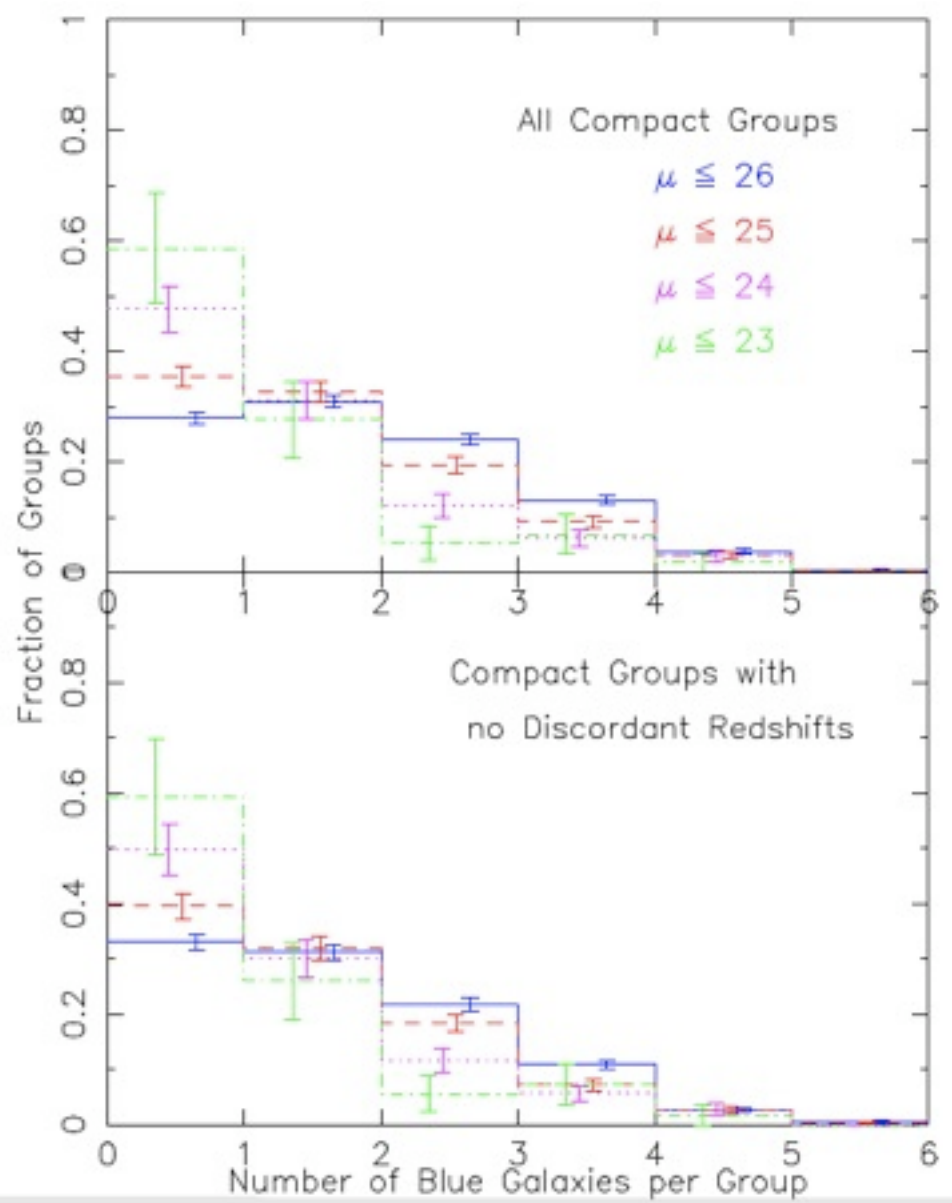


Blue groups?

- Are there any “blue” groups, or are the blue galaxies the ‘odd one out’ (interlopers?) in otherwise red groups?
- Look at number of blue (g-r < 0.65) galaxies per group
- Around 80-90% of groups have no blue galaxies or only 1 blue galaxy
- BUT there is definitely a population of “blue groups” (2 or more blue galaxies), at the 5-15% level.



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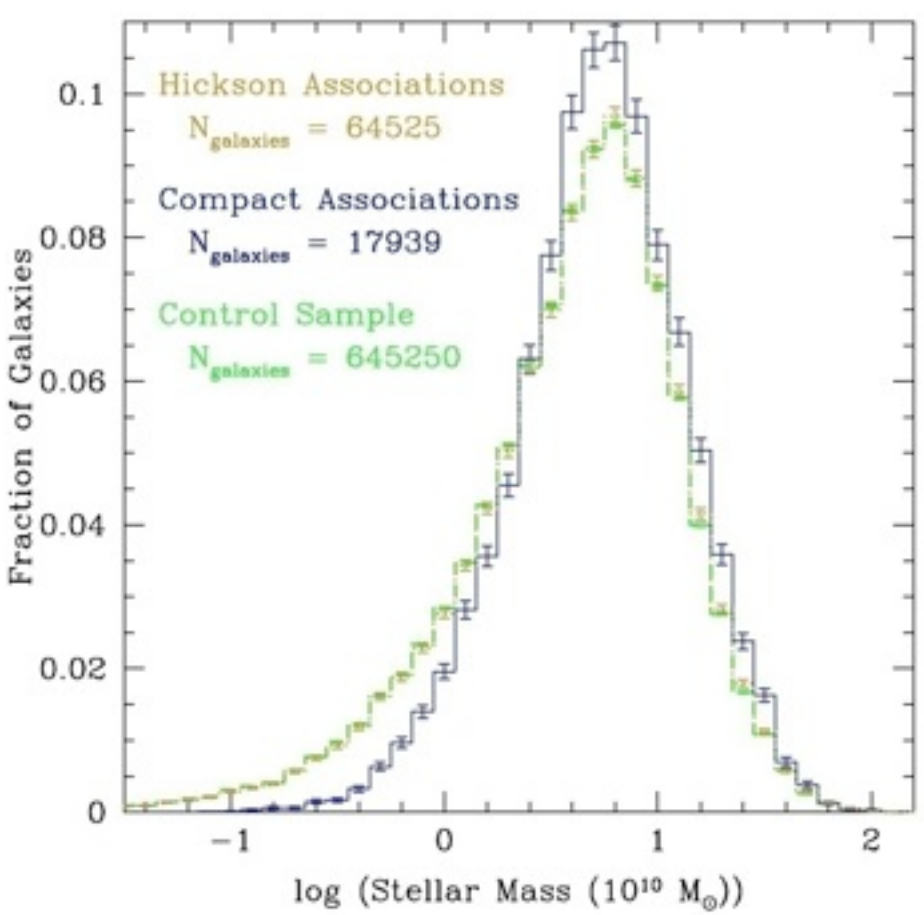
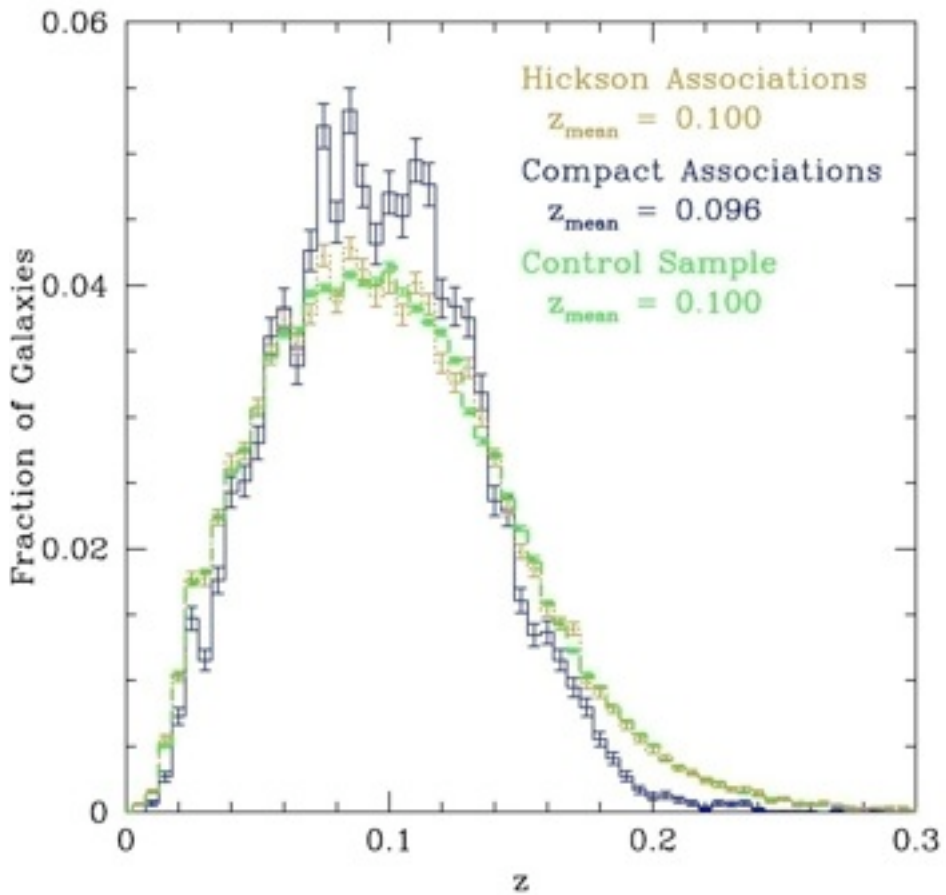
  - ***Are these "newly-formed" groups?***

Fin

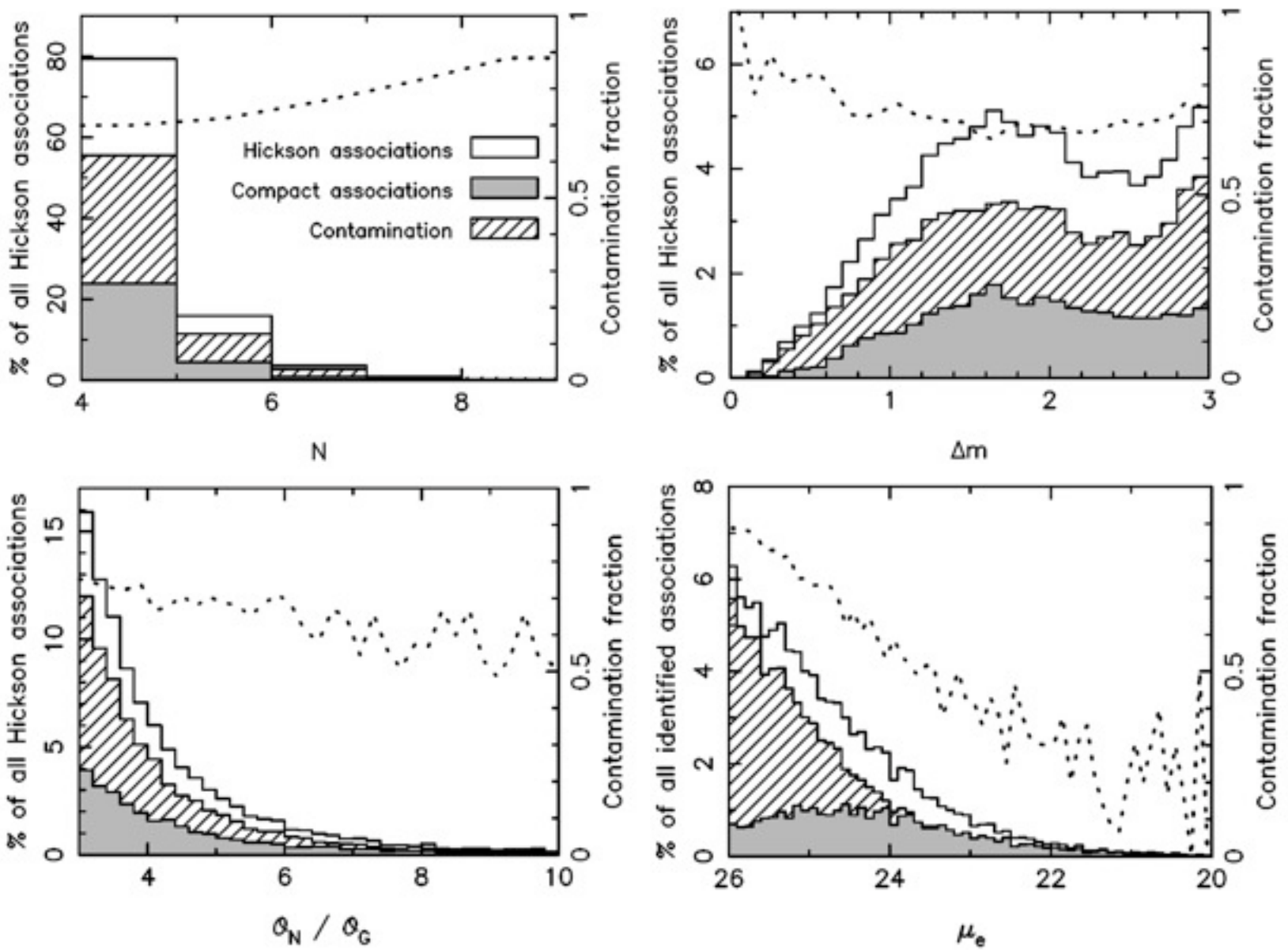
Mass, redshift of the semi-analytic sample





- (Note that the mean redshift of the original Hickson compact groups is z~0.03, considerably less than the sample used here)

Selection and contamination I.



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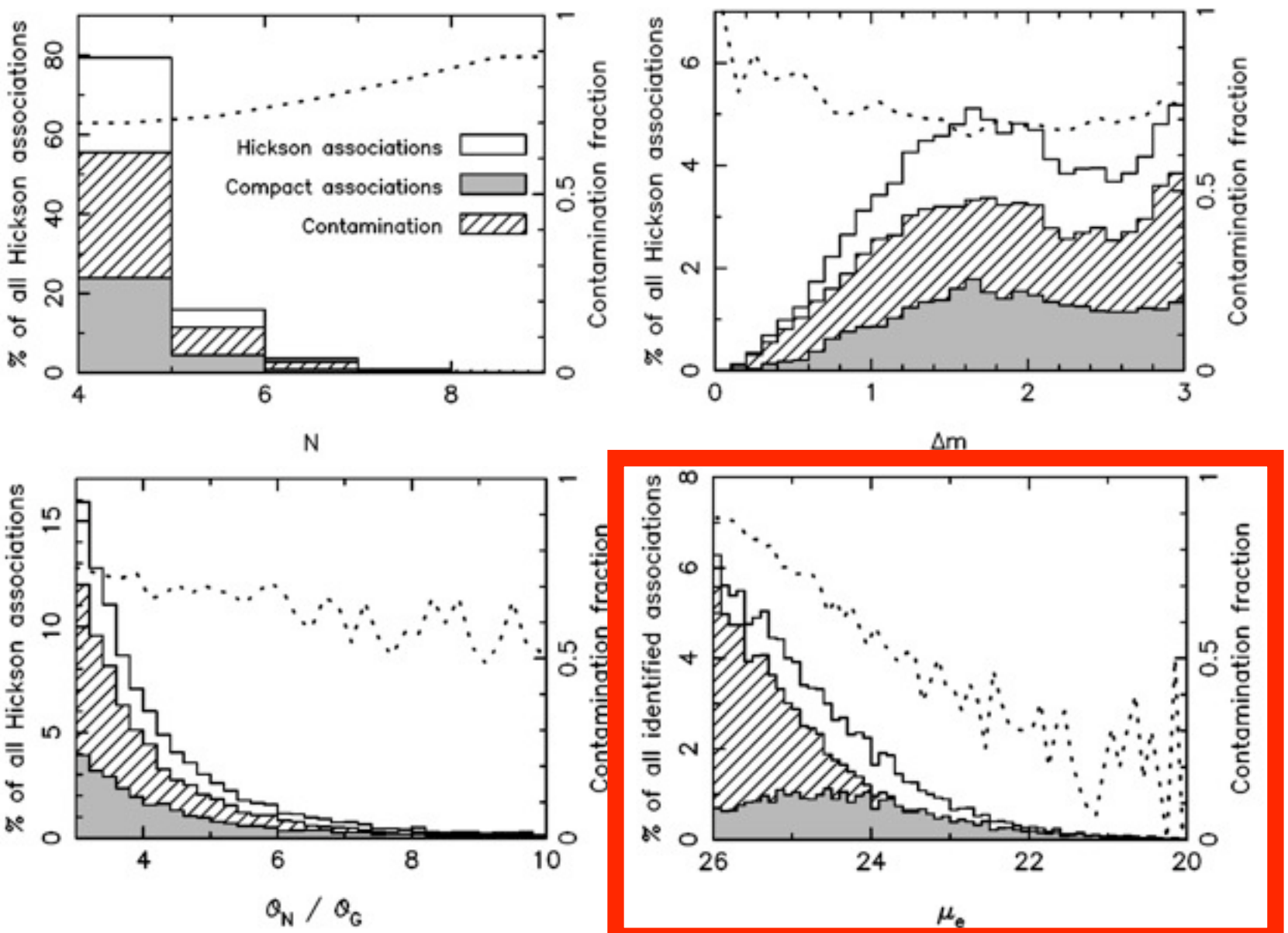

Selection and contamination II.

N	% CAs	% HAs	Δm	% CAs	% HAs
4	100	29	3.0	100	29
5	19	27	2.5	79	30
6	4	22	2.0	57	29
7	1	17	1.5	31	27
θ_N/θ_G	% CAs	% HAs	μ_e	% CAs	% HAs
3	100	29	26	100	29
4	51	34	25	72	43
5	29	37	24	39	56
6	19	41	23	16	67

- Genuine compact groups are brighter and more isolated than the contamination
- Selection by surface brightness can dramatically reduce contamination rates

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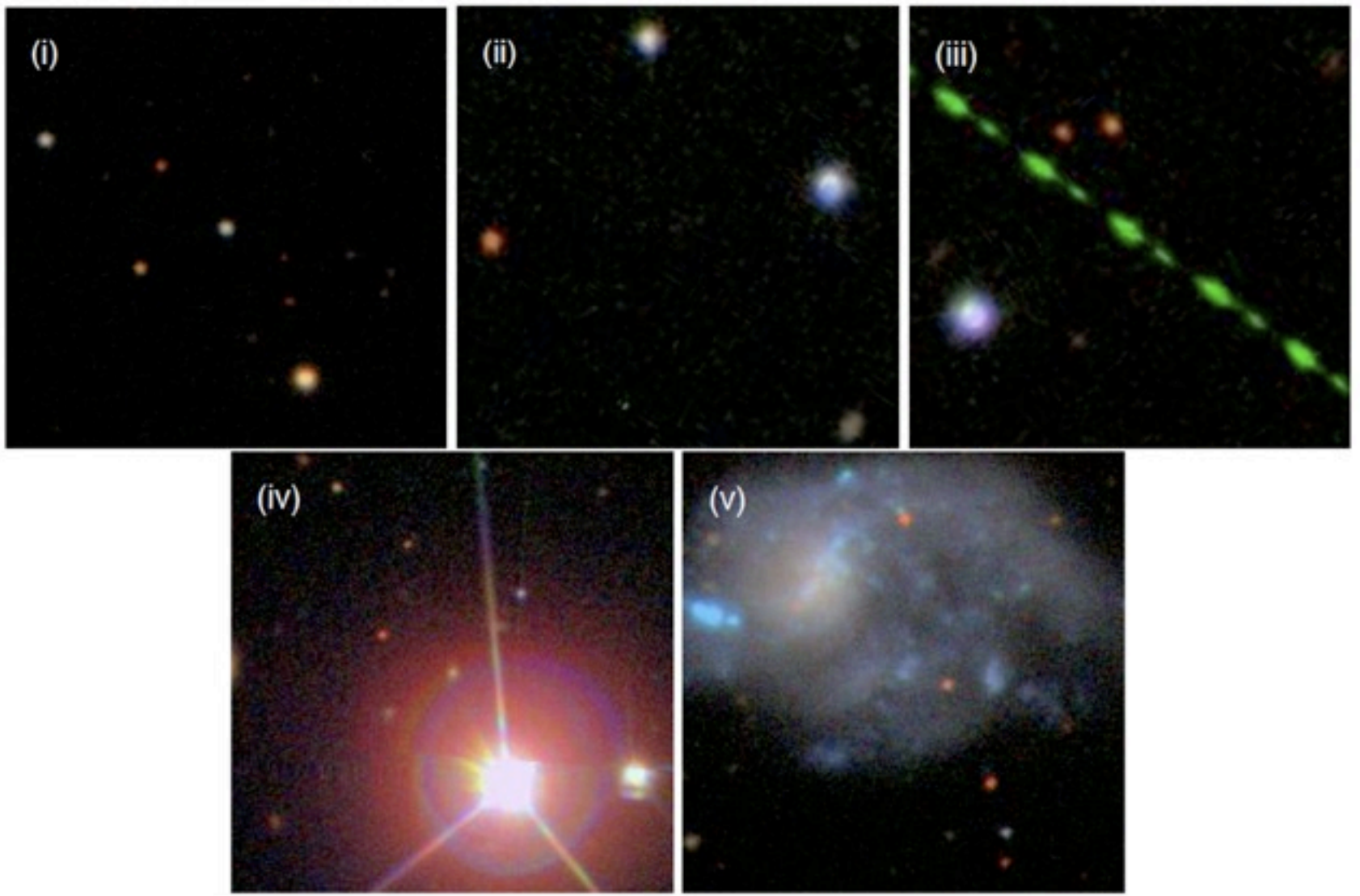
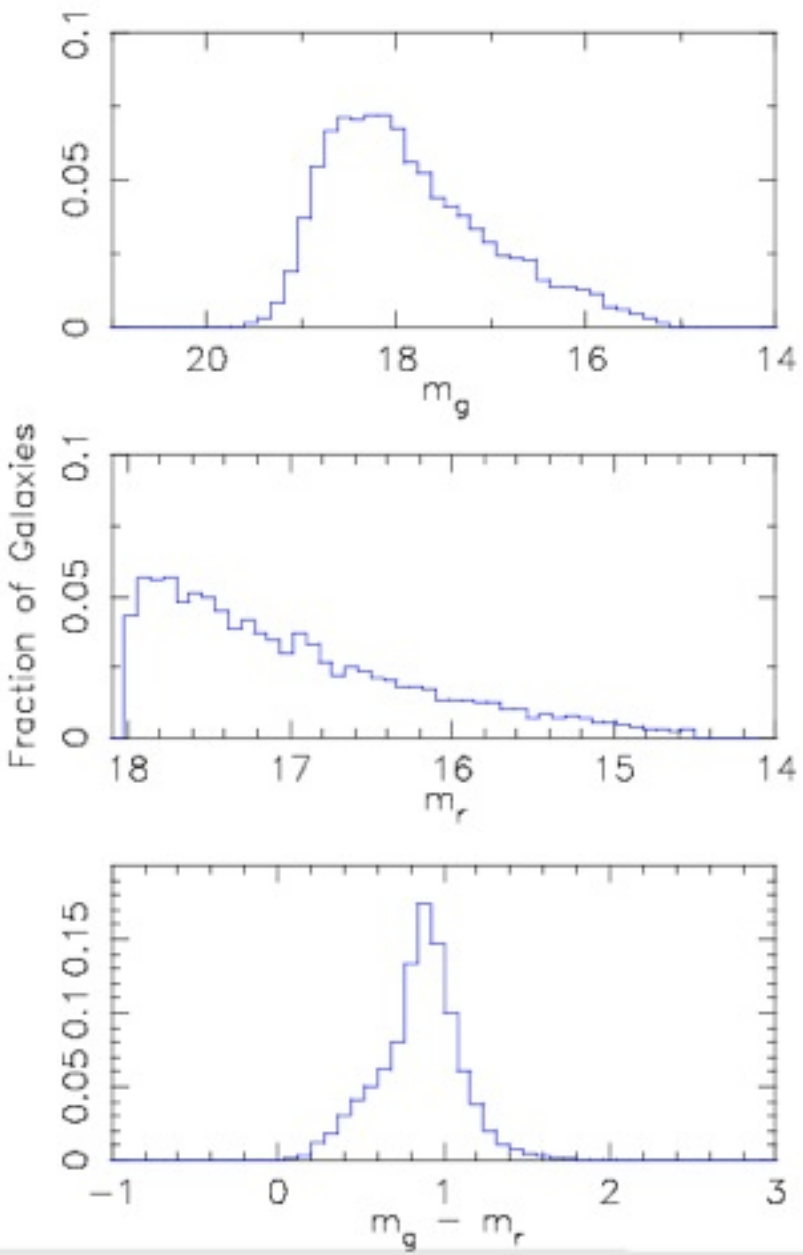
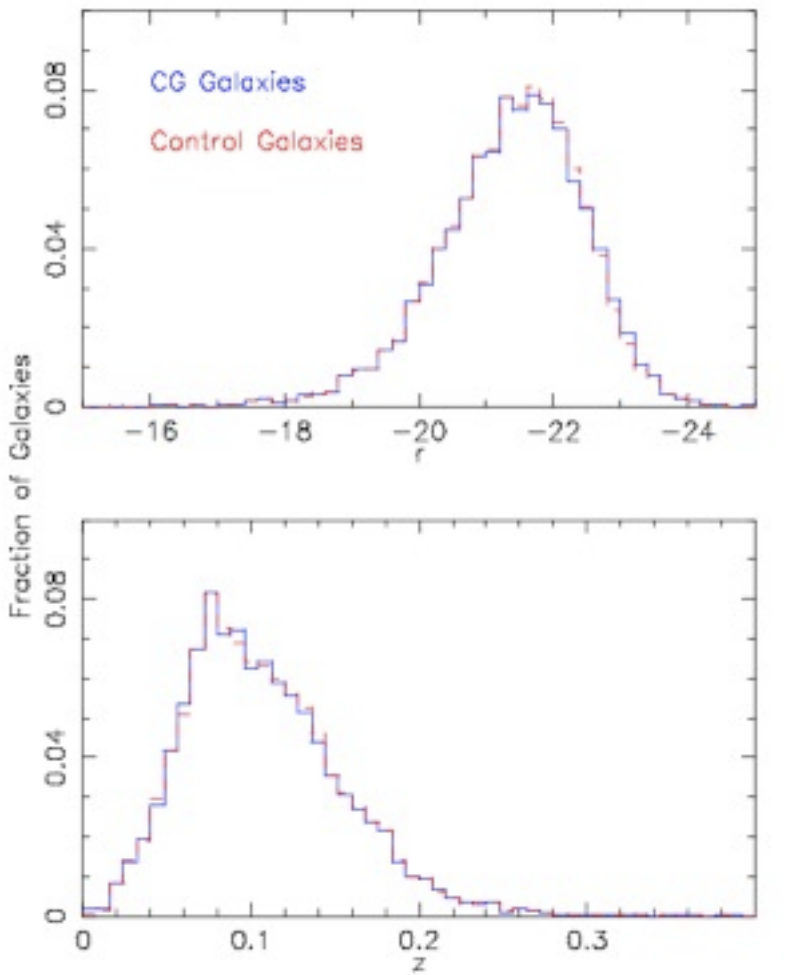
Health warning: these are **not** compact groups



Galaxy luminosity, colour and redshift

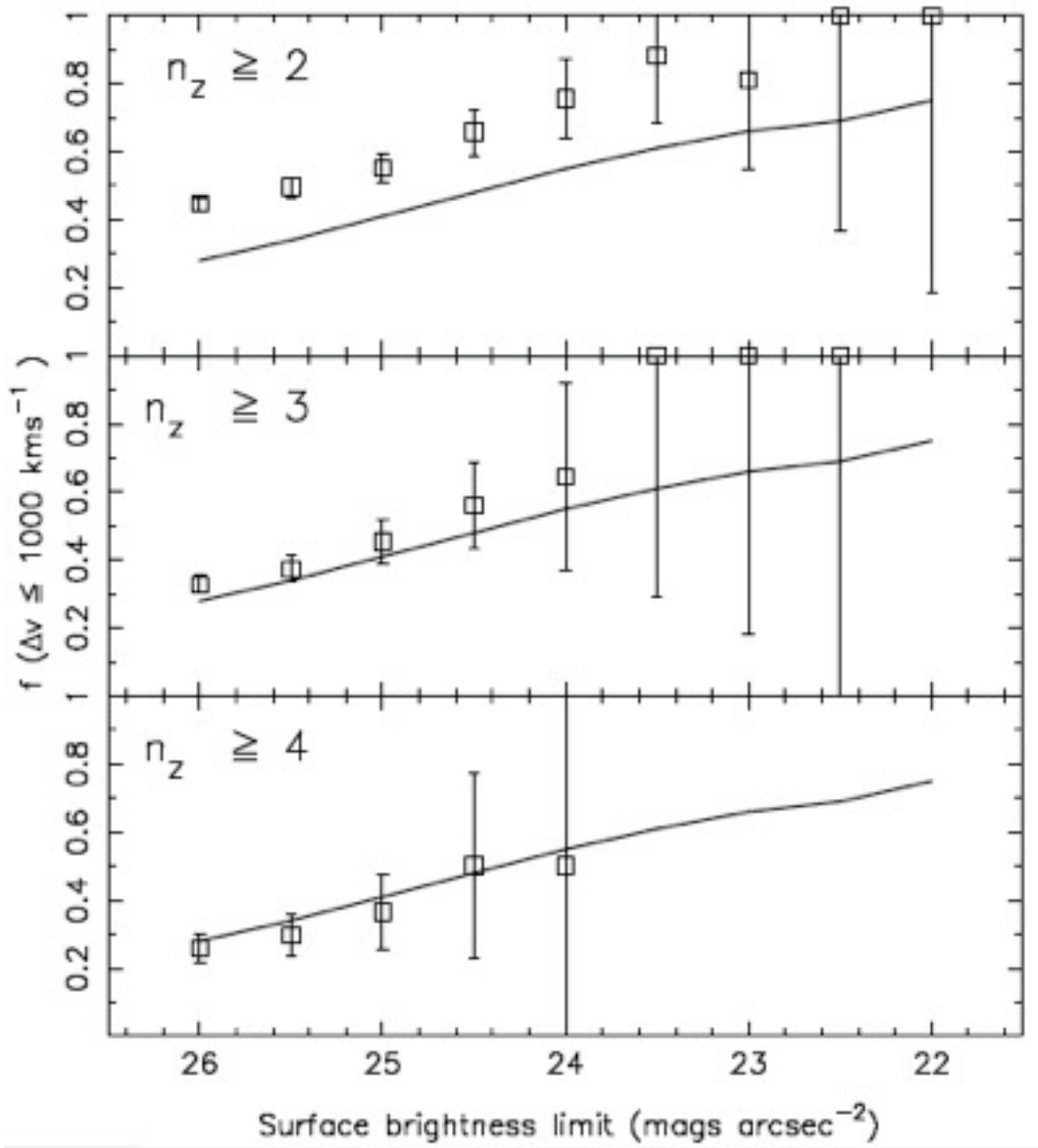




- 15 control galaxies per CG galaxy
- Matched in rest-frame r and z
- Used photo-z info when required

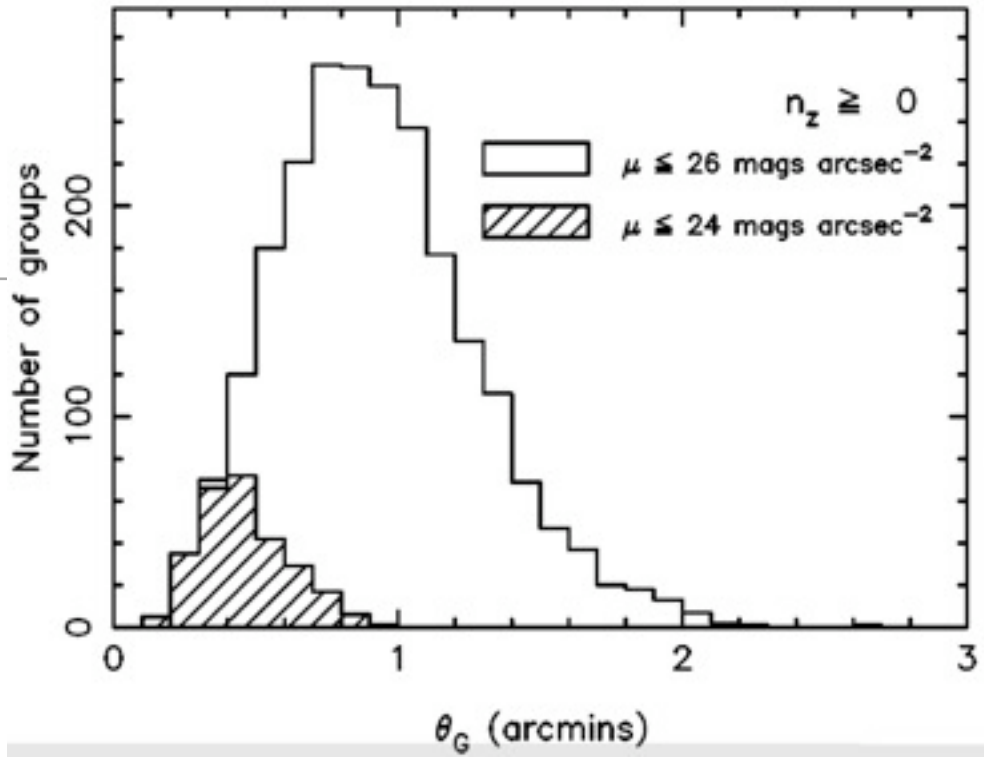
Serendipitous redshift information

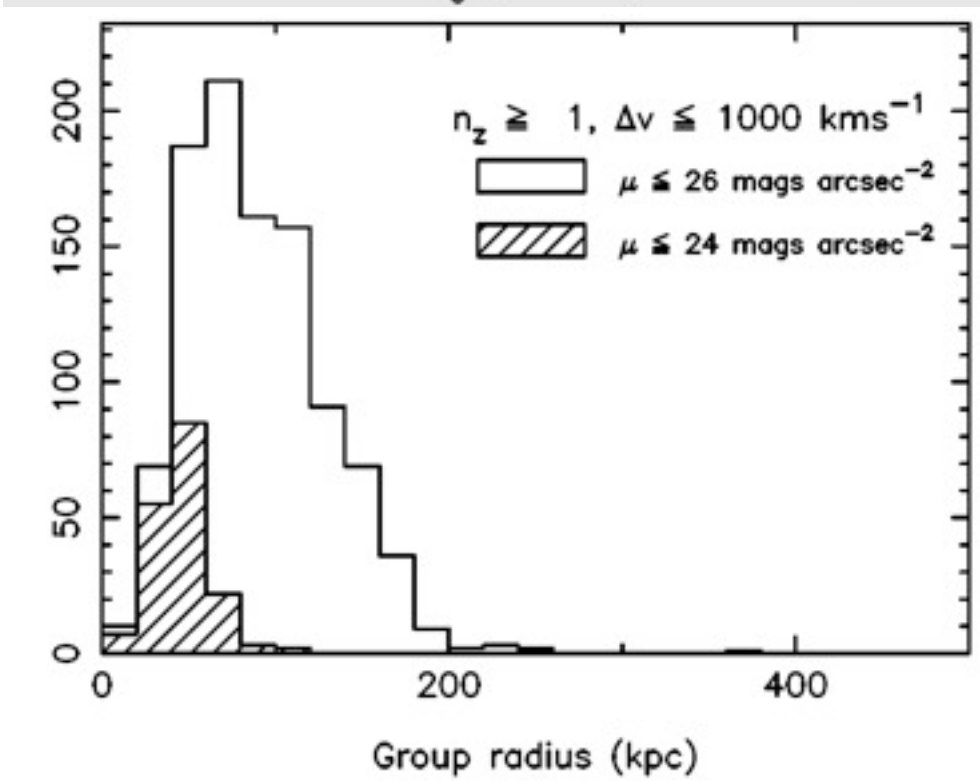
- Redshift information was **not** used to identify groups
- 42% (5%) CG galaxies have redshift information in Cat A (B) [4131 / 16566]
- 78% (19%) CGs have redshift information in Catalogue A (B) [1797 / 14275]
- Groups with multiple redshifts can provide independent handle on interloper fractions



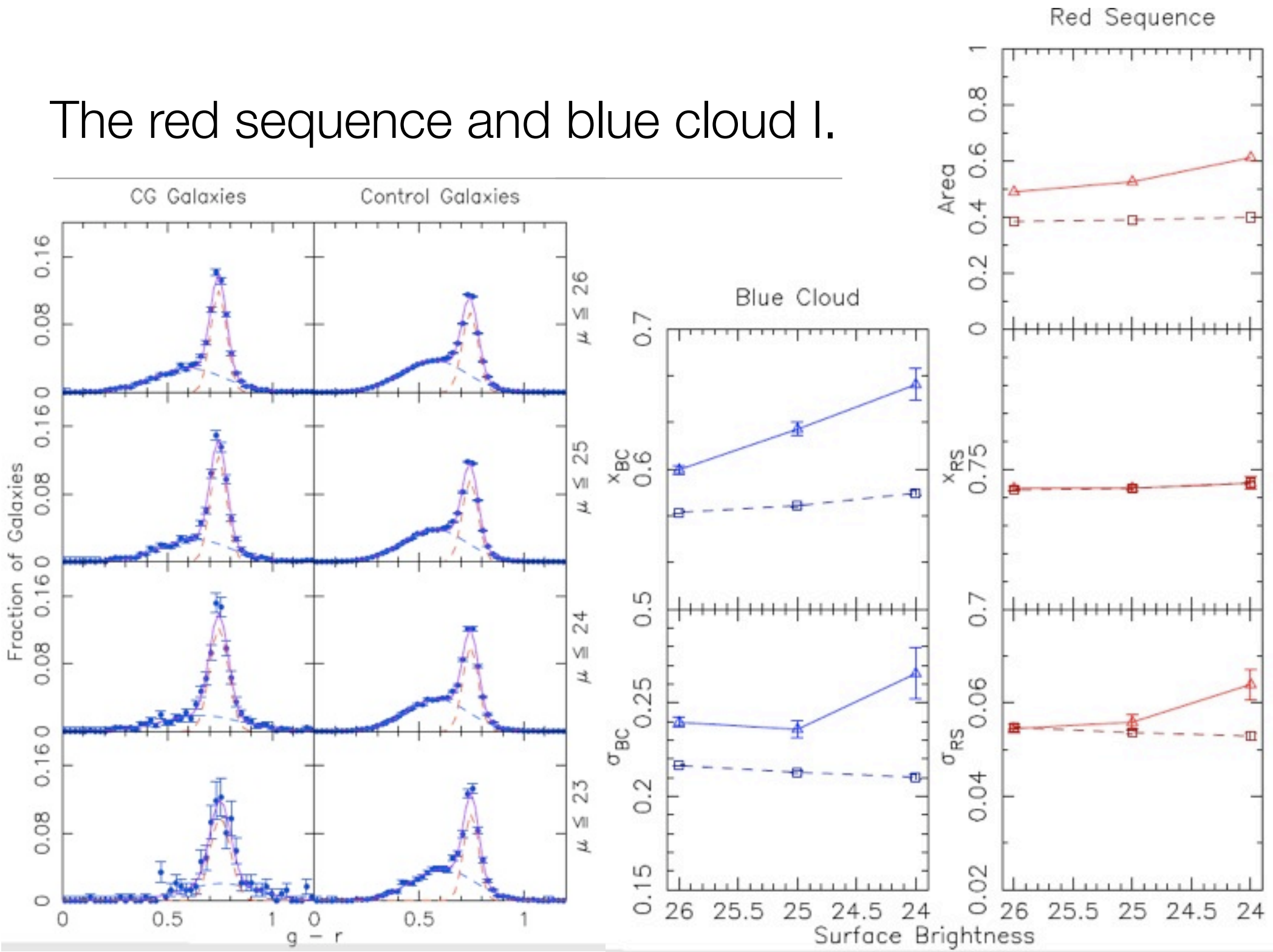
Group sizes

- Angular radius of groups is typically 1 arcmin, although brightest subset (fewest interlopers) are typically 0.5 arcmins
- For groups with (consistent) redshift information, this converts to a typical projected radius of 90kpc (50kpc for the brightest subset)
- Very small inter-galactic separations (~50kpc)

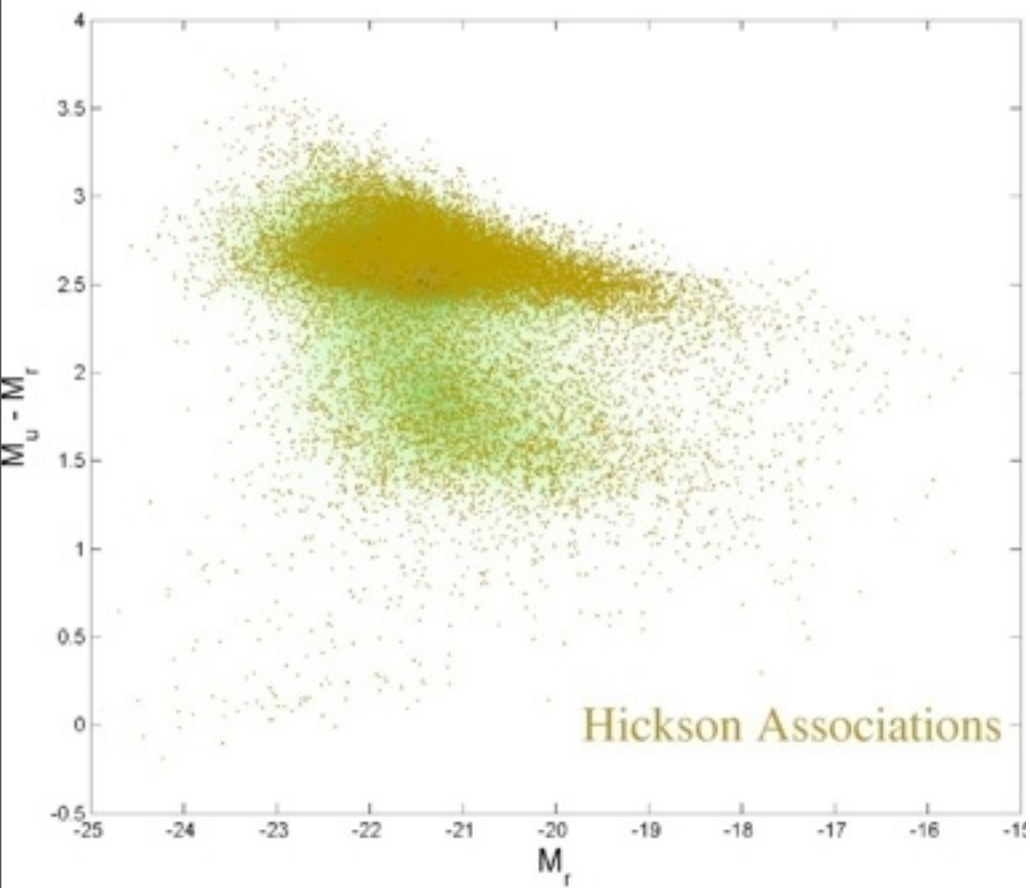


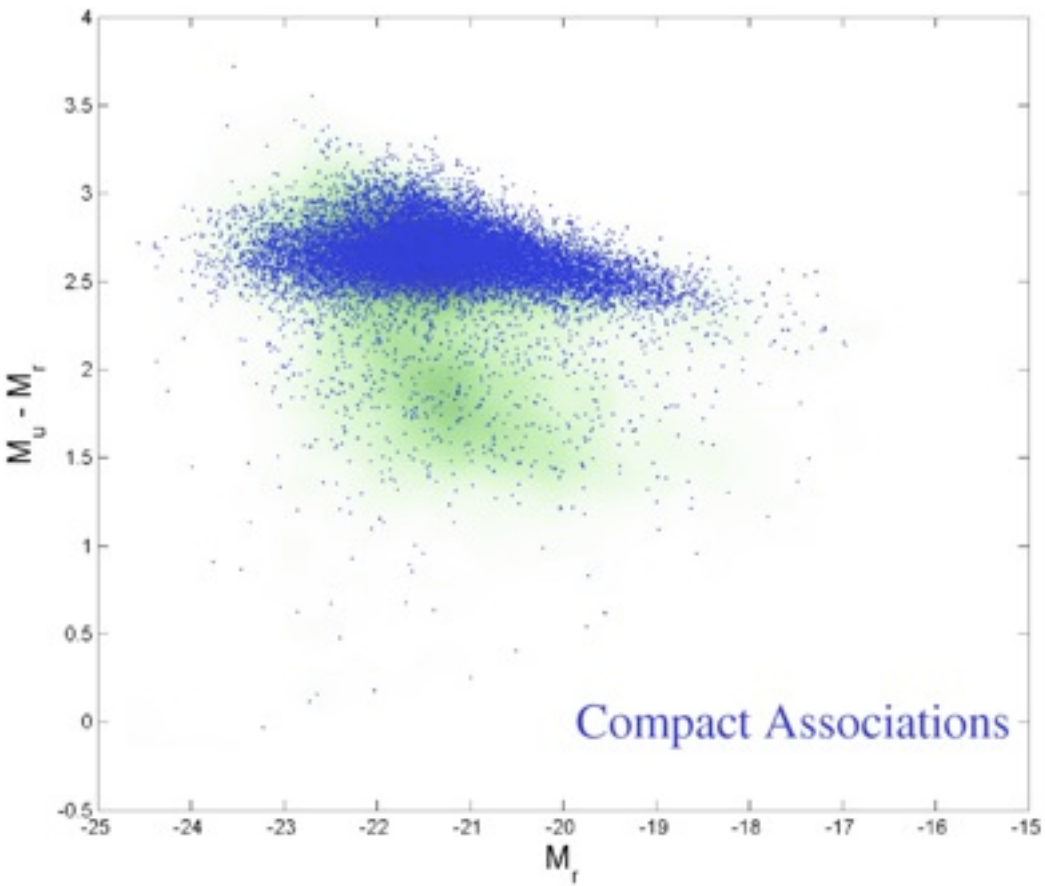


The red sequence and blue cloud I.



“Predicted” galaxy colours





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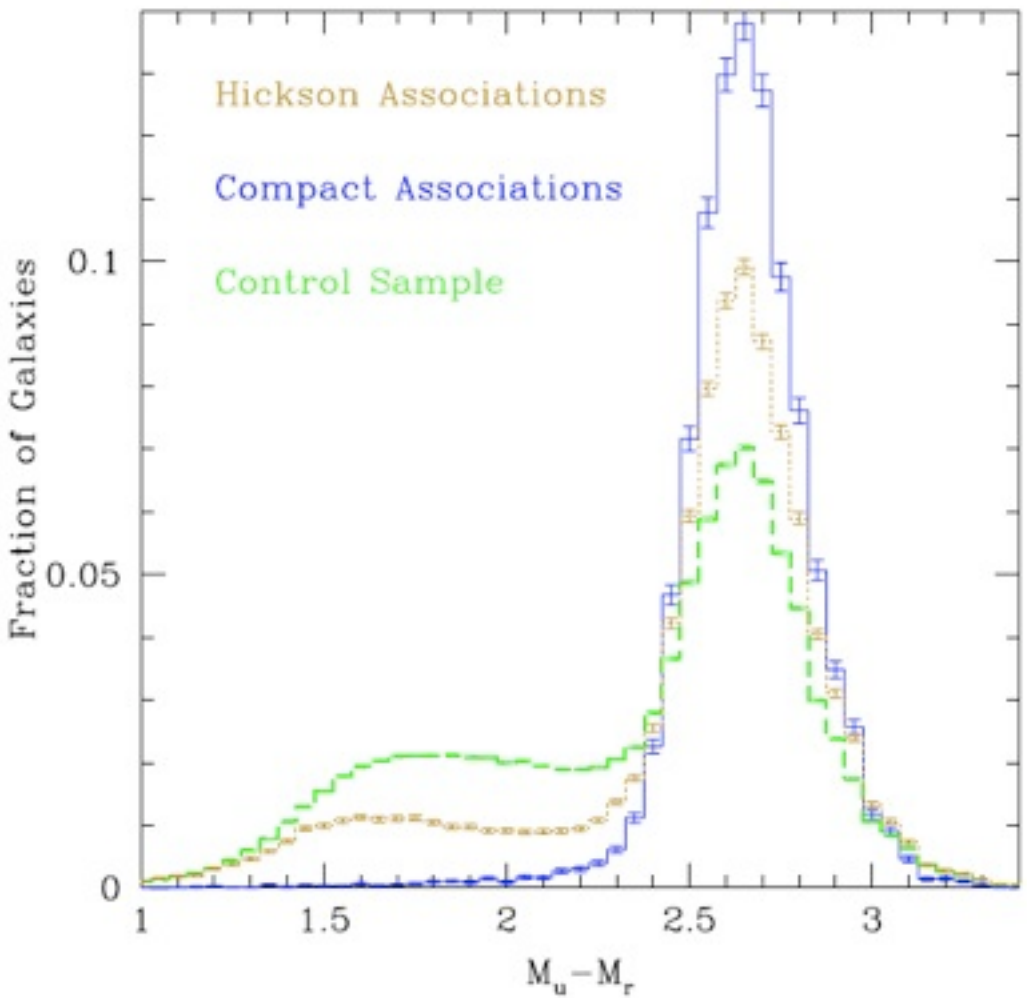

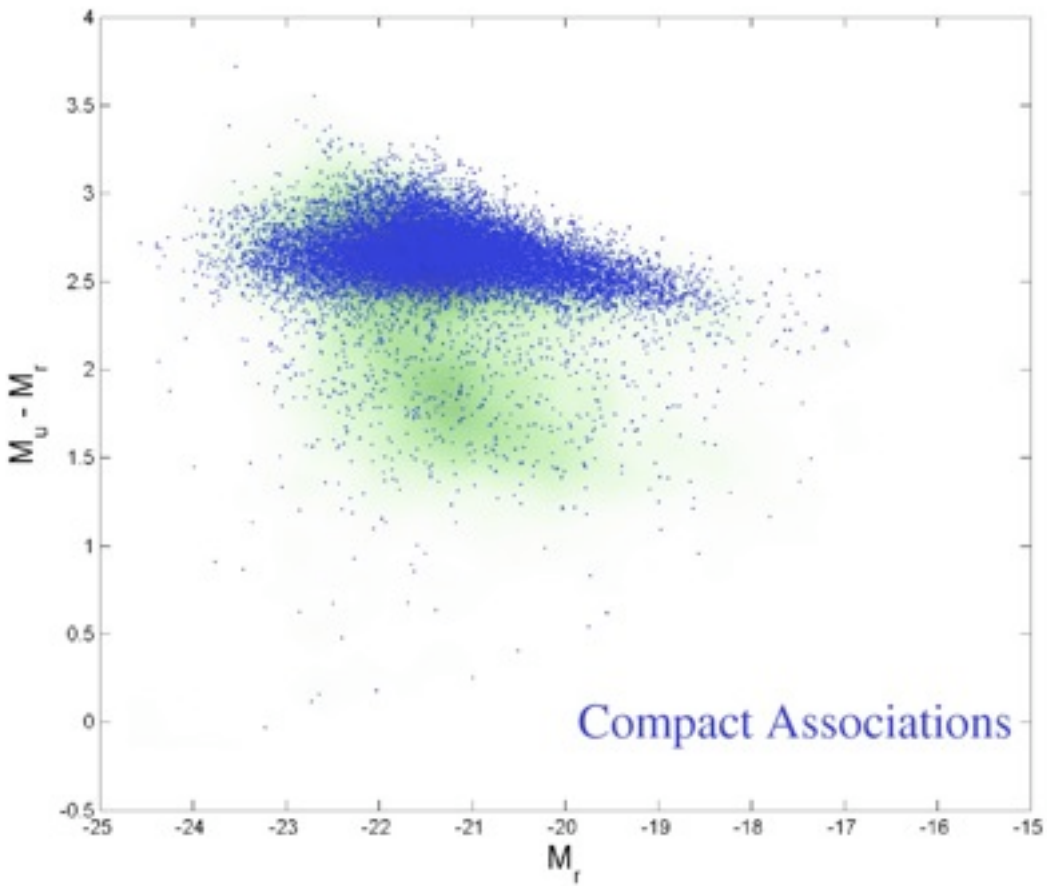

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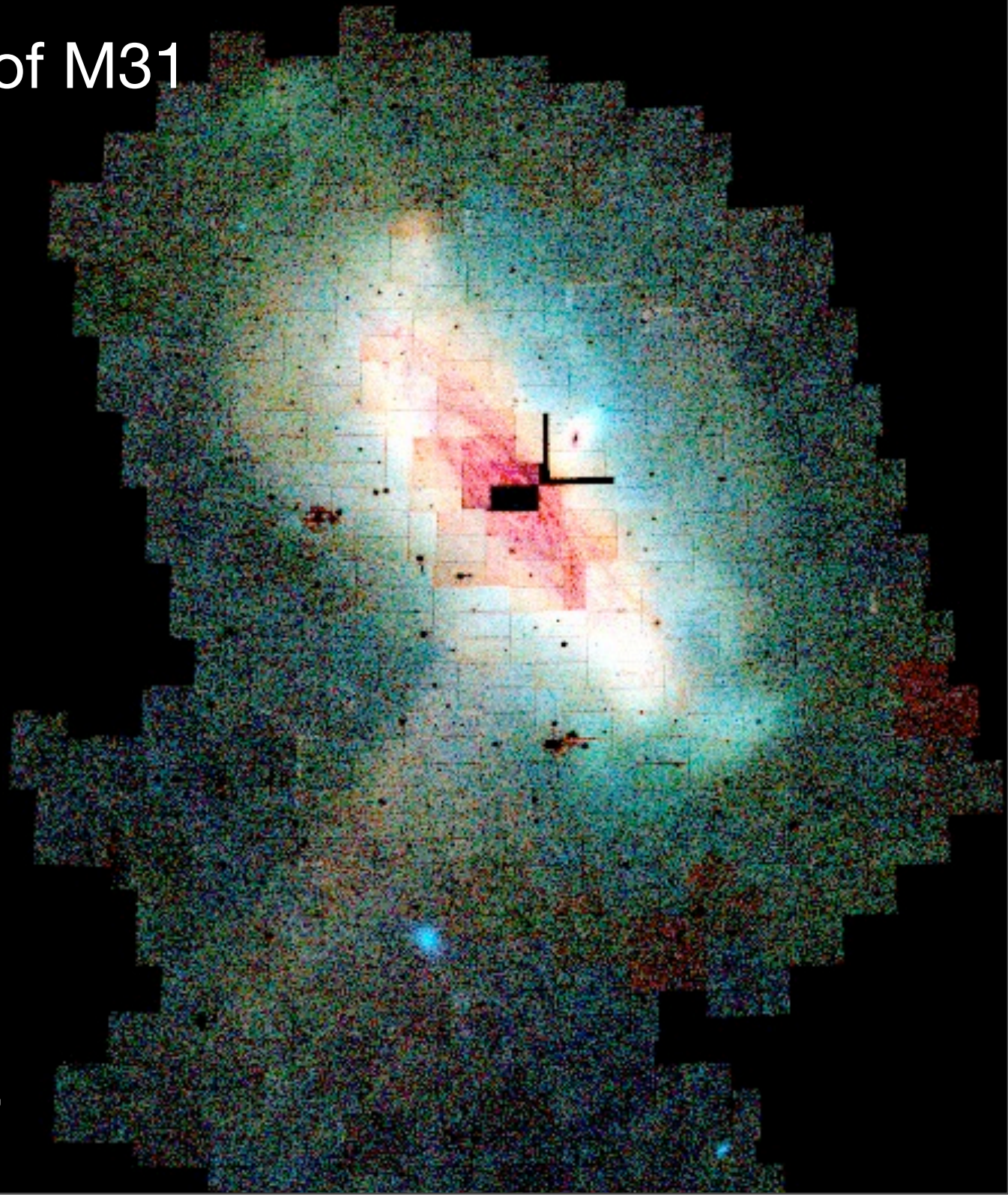
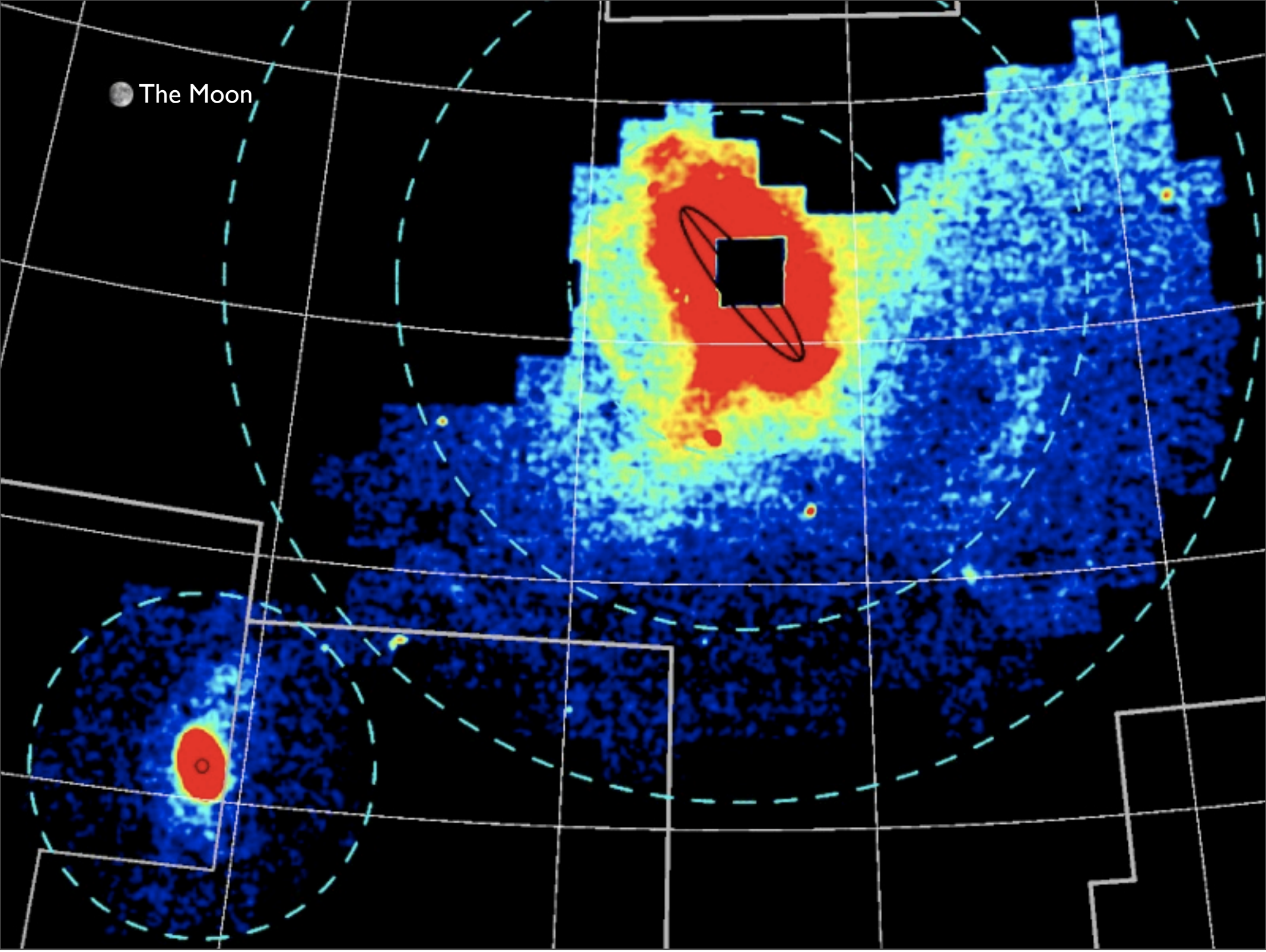
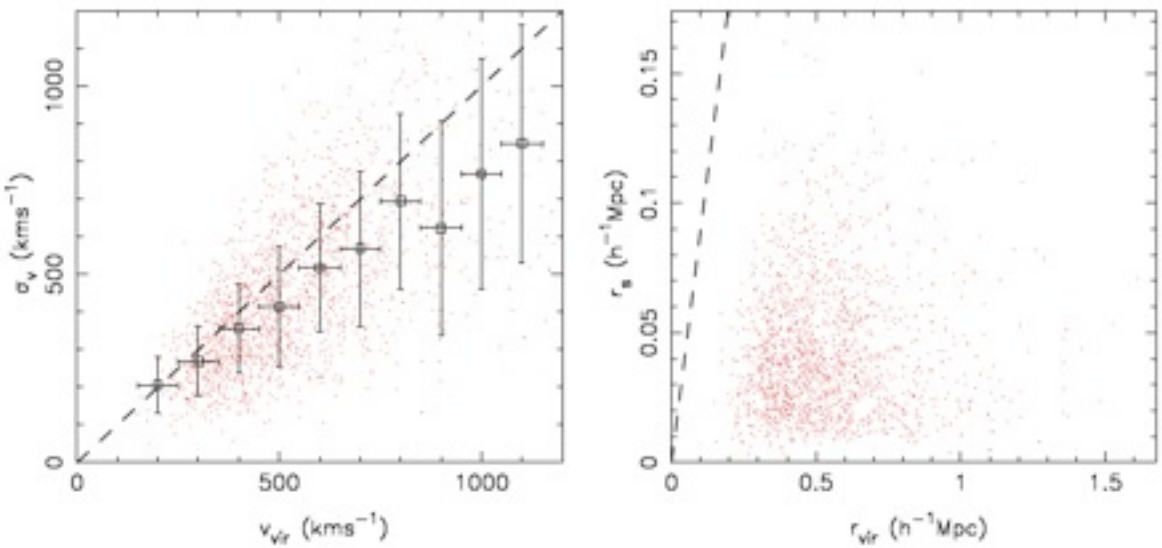


Ibata et al. 2001,
Ferguson et al. 2002,
McConnachie et al. 2005a,b,
Irwin et al. 2005, 2007

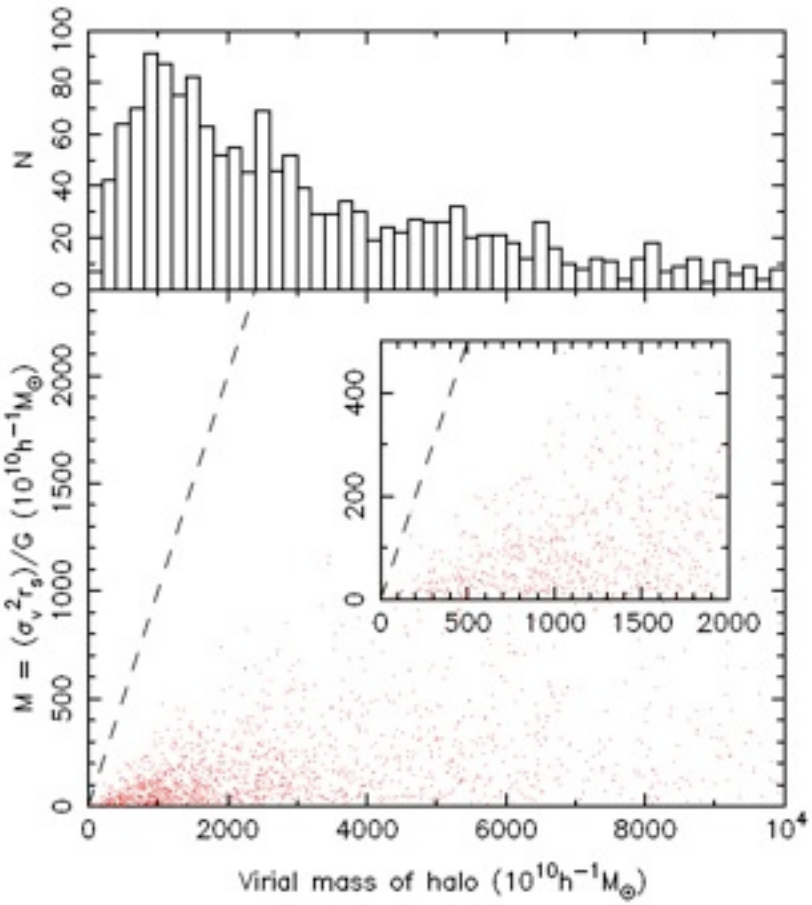
The Pan-Andromeda Archaeological Survey (PAndAS)


The Moon

Aside: size and velocity ≠ mass ?



- Group velocity dispersion correlates broadly with halo virial velocity
- But scale radius of the group is completely uncorrelated with halo scale radius



- Simple estimates of group mass based on these quantities do not correlate with, let alone estimate, the halo virial mass

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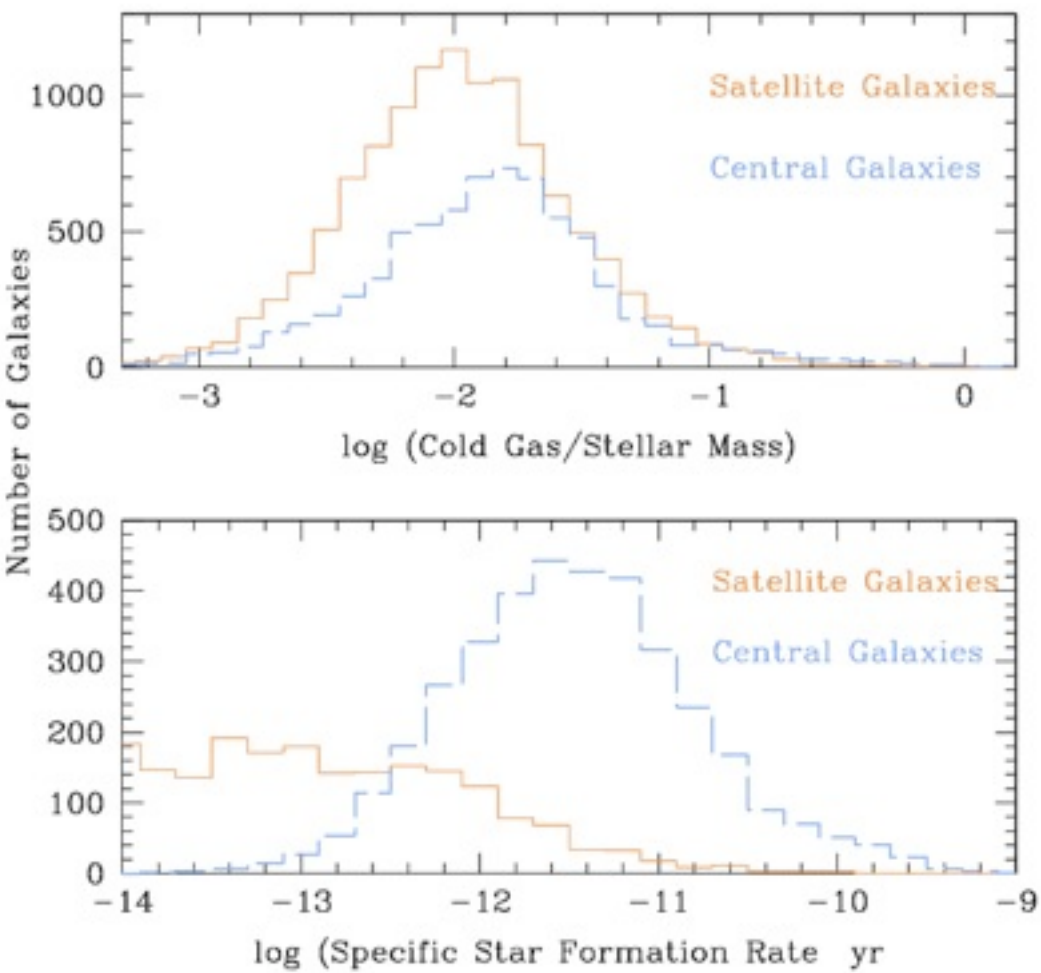
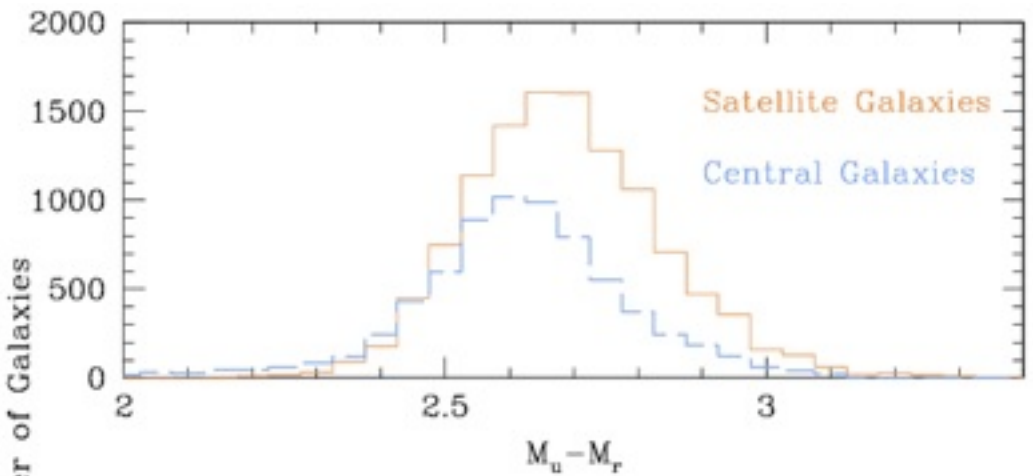
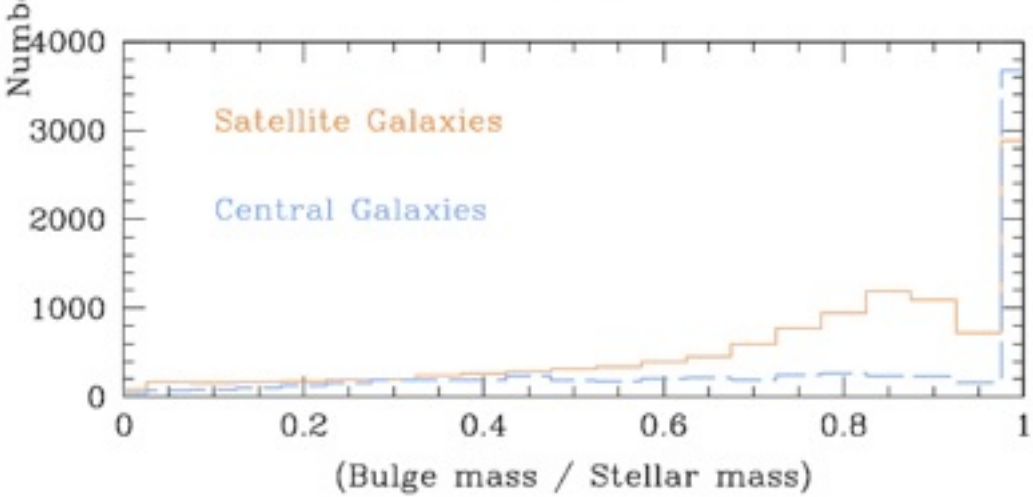
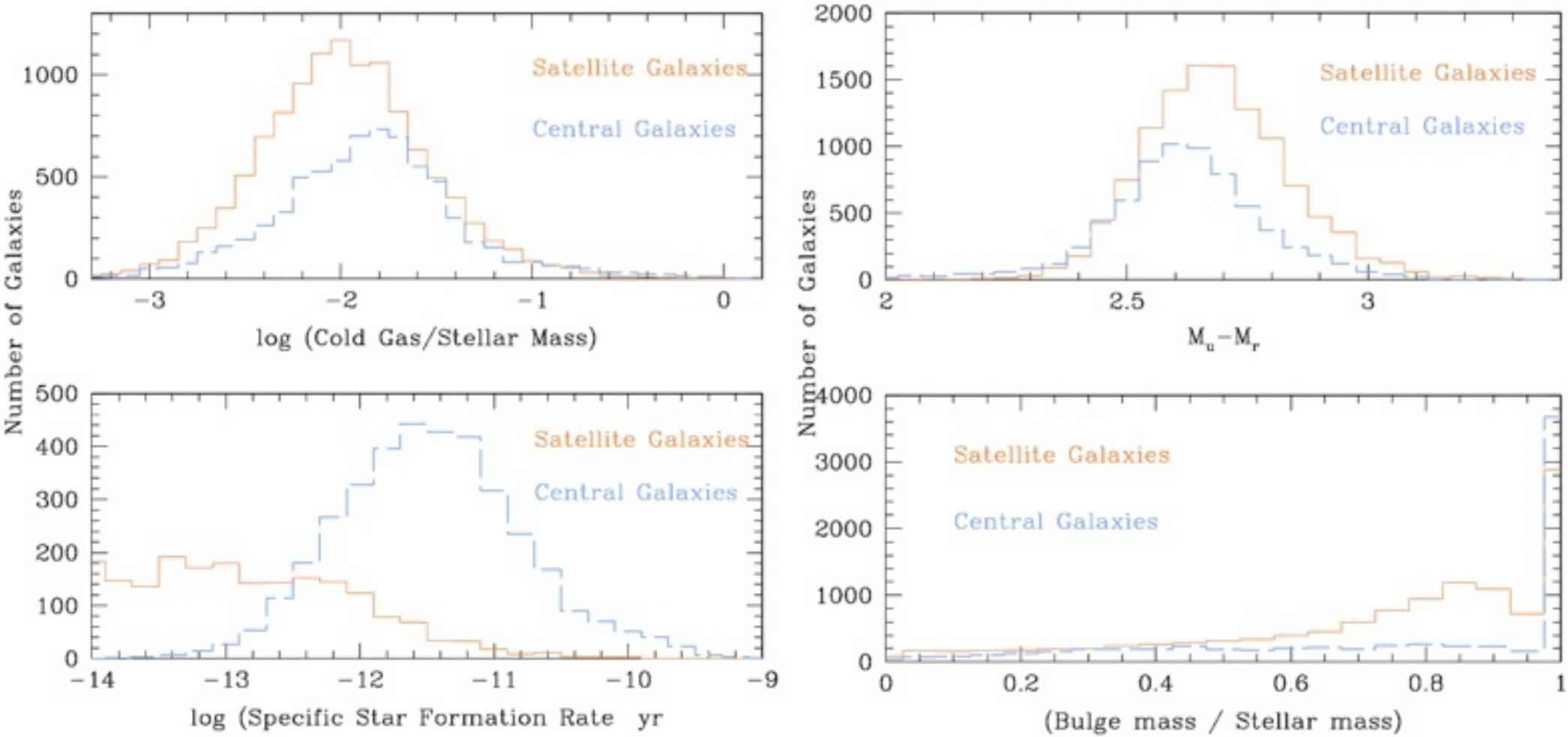
  - Broadly similar SFRs compared to field (Moles et al. 1994, Iglesias-Paramo & Vichez 1999)

Central versus satellite galaxies



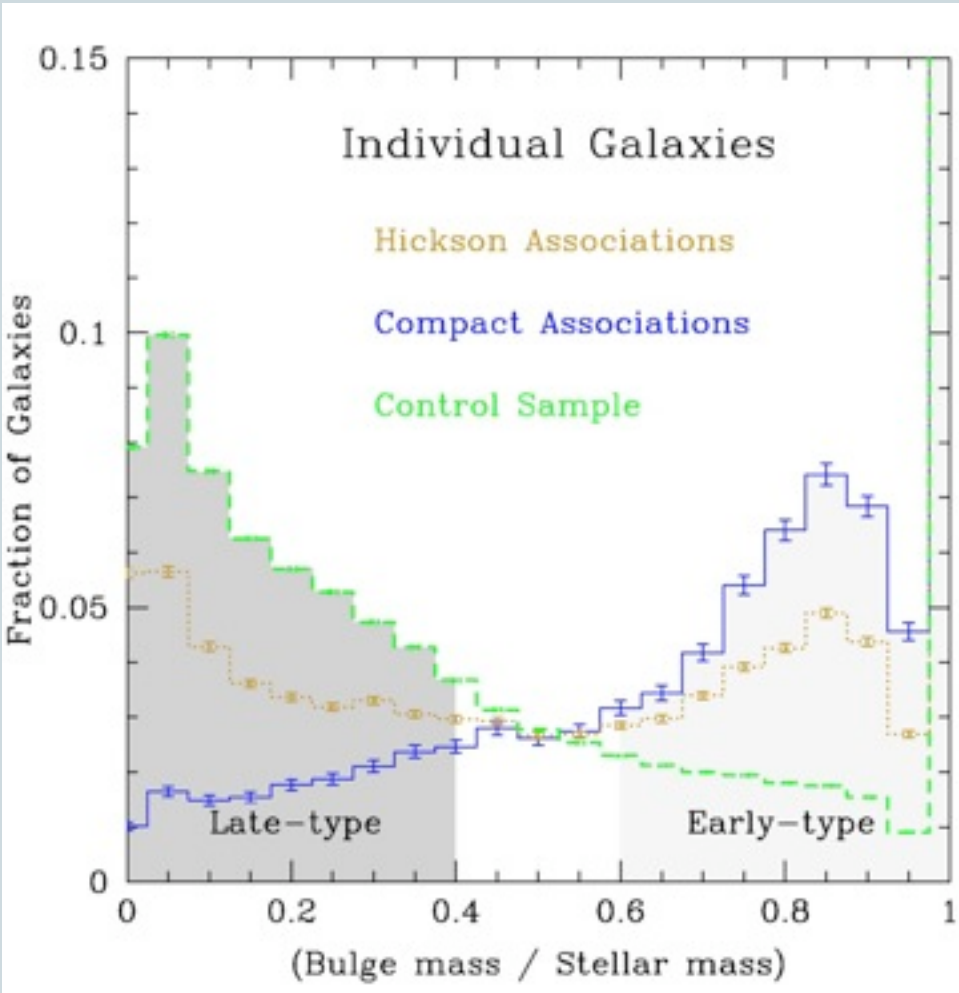


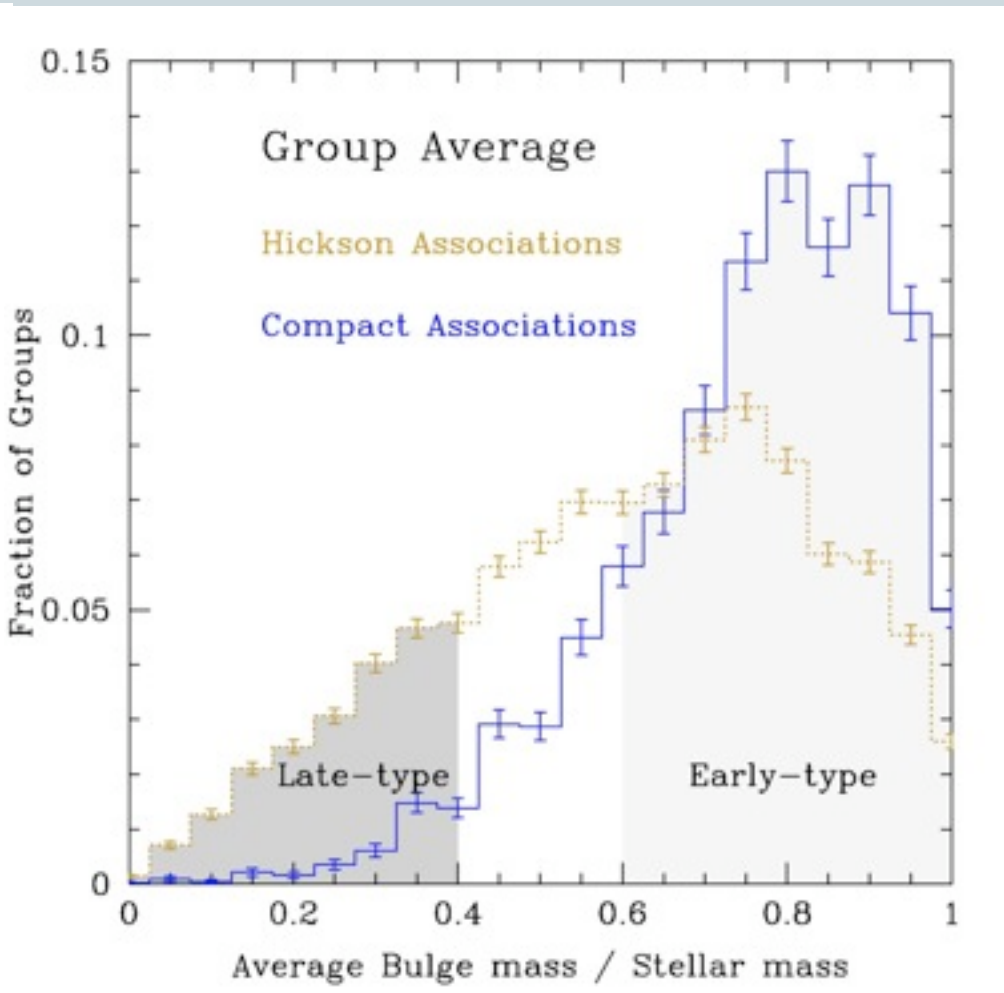



Number of Galaxies
1000
500
0
−3
−2
−1
0
log (Cold Gas/Stellar Mass)
Satellite Galaxies
Central Galaxies
2000
1500
1000
500
0
2
2.5
3
$M_u - M_r$
Satellite Galaxies
Central Galaxies
500
400
300
200
100
0
−14
−13
−12
−11
−10
−9
log (Specific Star Formation Rate yr
Satellite Galaxies
Central Galaxies
4000
3000
2000
1000
0
0
0.2
0.4
0.6
0.8
1
(Bulge mass / Stellar mass)
Satellite Galaxies
Central Galaxies

Group morphology

- Contain higher fraction of early-type galaxies than the field (roughly half are early type cf ~20% for field; Hickson et al. 1988, Palumbo et al. 1995)

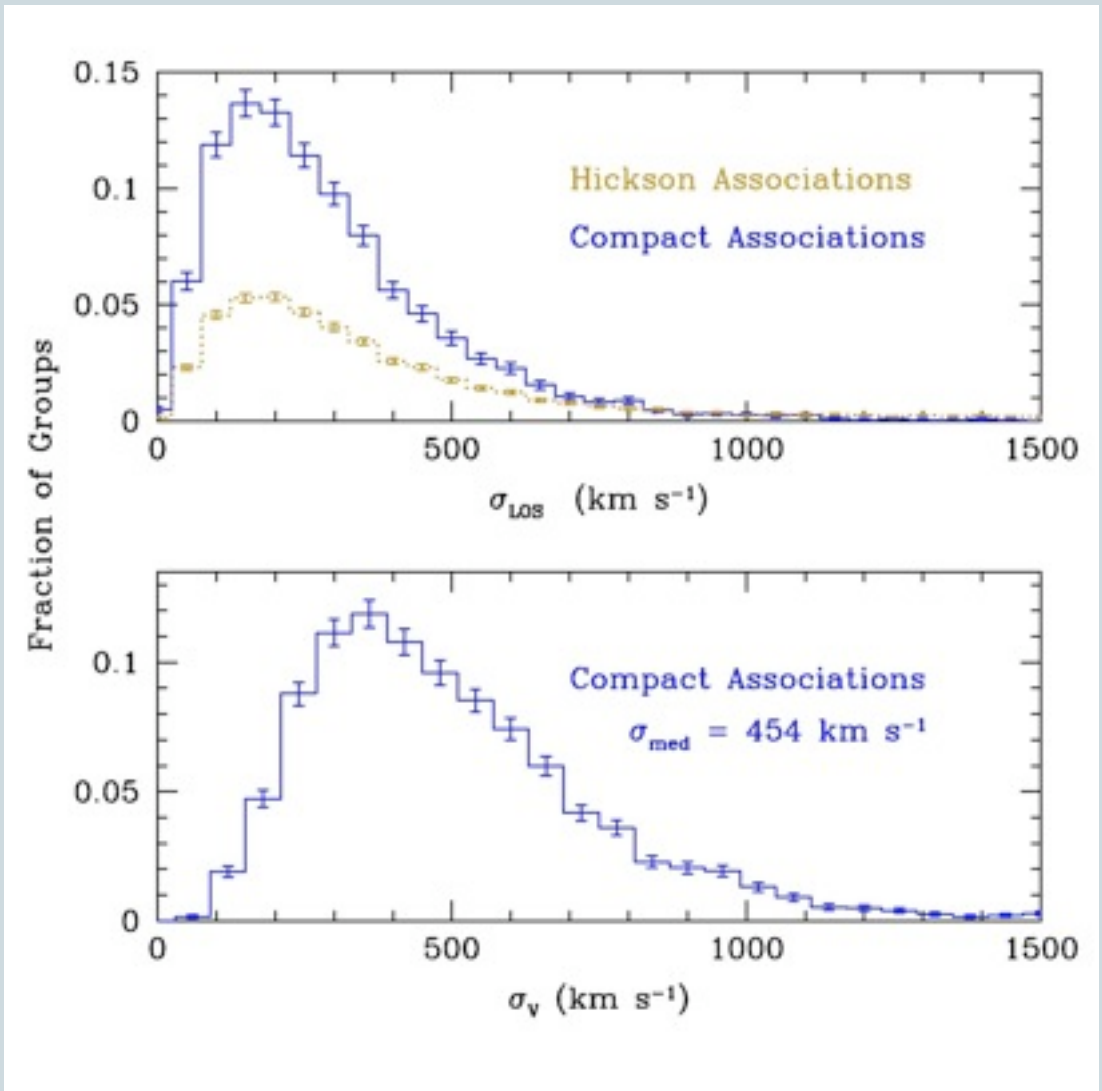




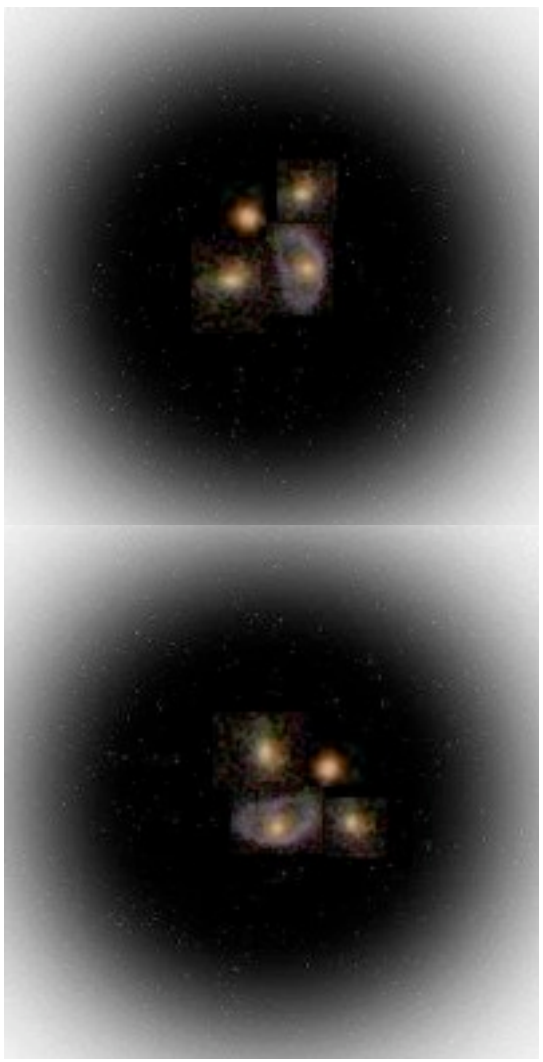
CA Galaxies	Control Sample	HA Galaxies	CA group average	HA group average
• B/T > 0.6 74%	• B/T > 0.6 35%	• B/T > 0.6 55%	• B/T > 0.6 84%	• B/T > 0.6 54%

Dynamics and dark matter I

- HCGs have generally low l.o.s. velocity dispersion (~250km/s)
- Groups with large velocity dispersions (>1000km/s) generally discarded
- but even then 1/3 of groups appear to consist of interlopers



Dynamics and dark matter II



- Over half the CAs, all members were found to be within the same DMH
- Only ~4% of CAs are made up of galaxies in their own individual halos
- Interpret this as :

separate halos→dynamically young (have not had time to merge) ???

single halo→dynamically older ???

Group membership