The Progenitors of Dwarf Galaxies in Galaxy Clusters

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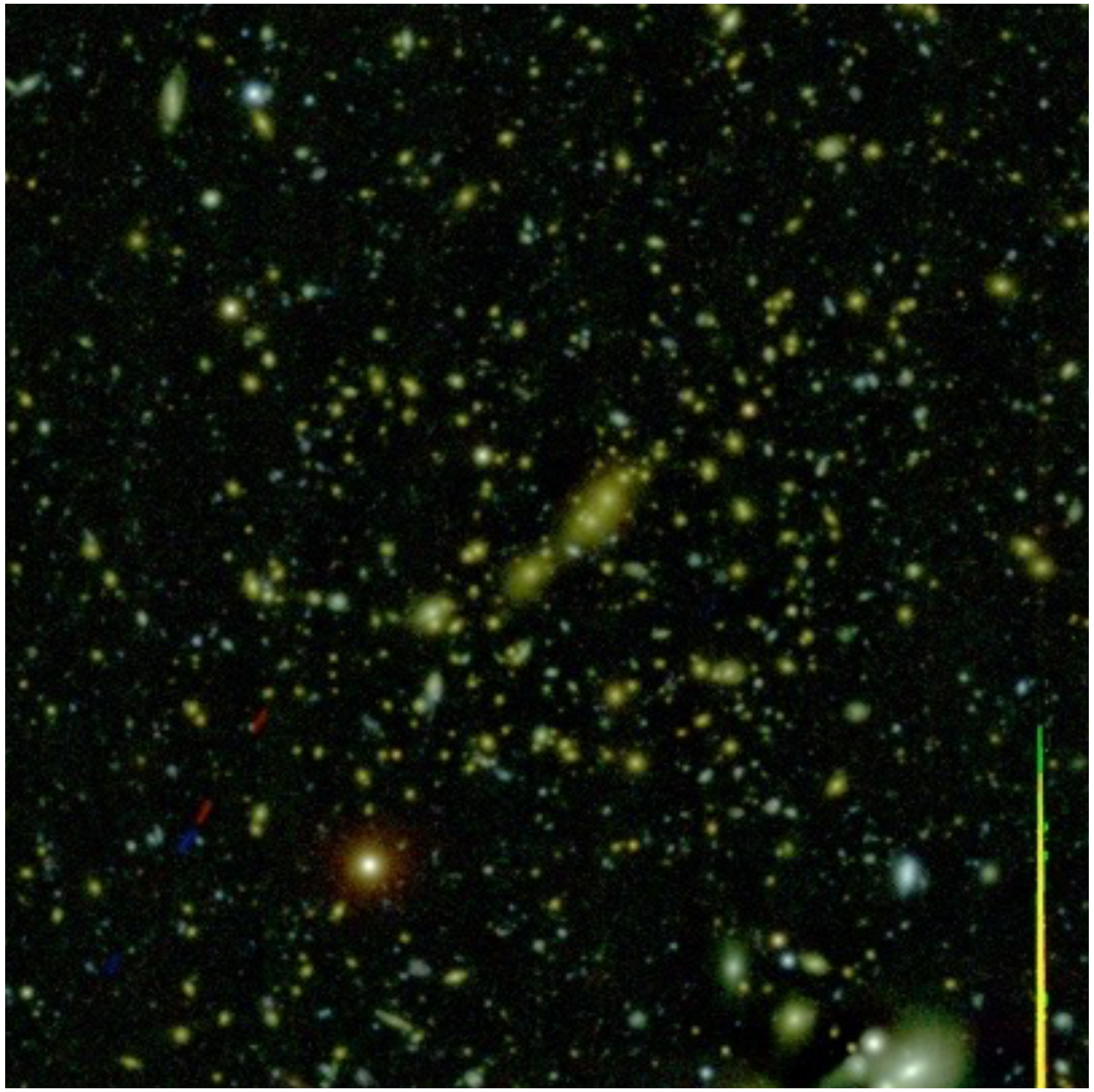
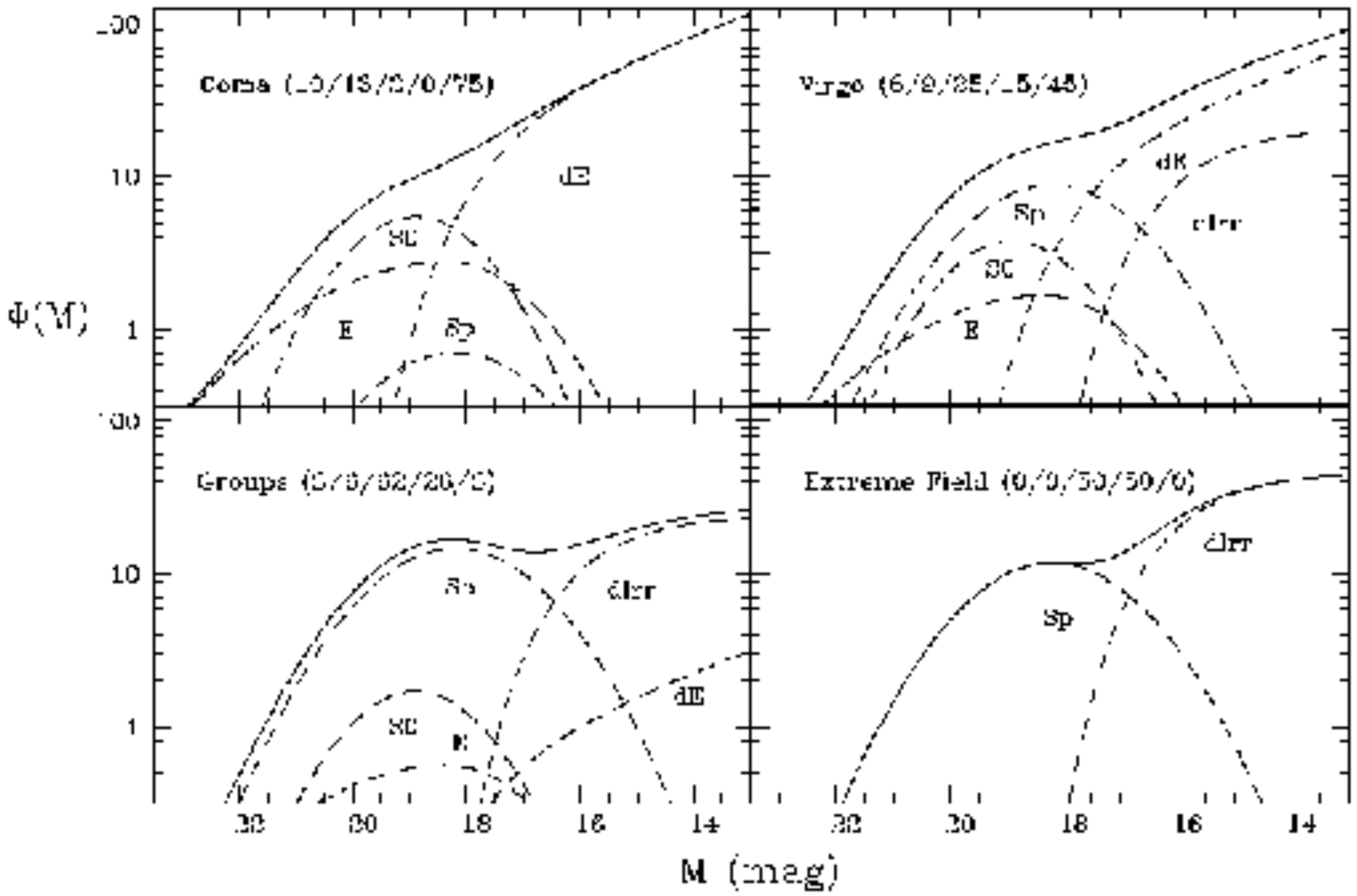
Overview

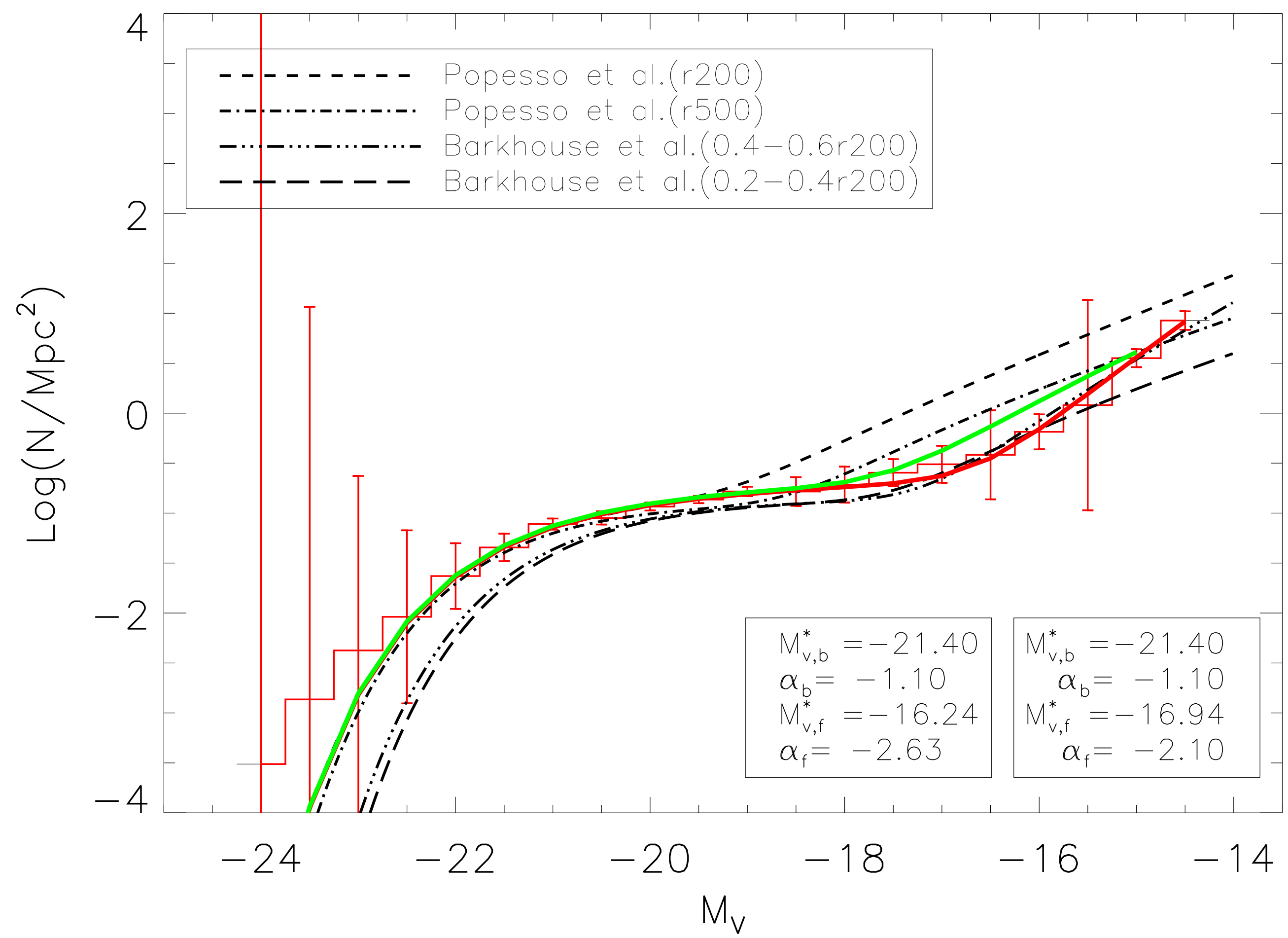
- Connecting populations
- Luminous Compact Blue Galaxies are triggered in galaxy clusters
- LCBGs have similar properties as dE
- Fate of LCBGs



Dwarf Ellipticals in clusters



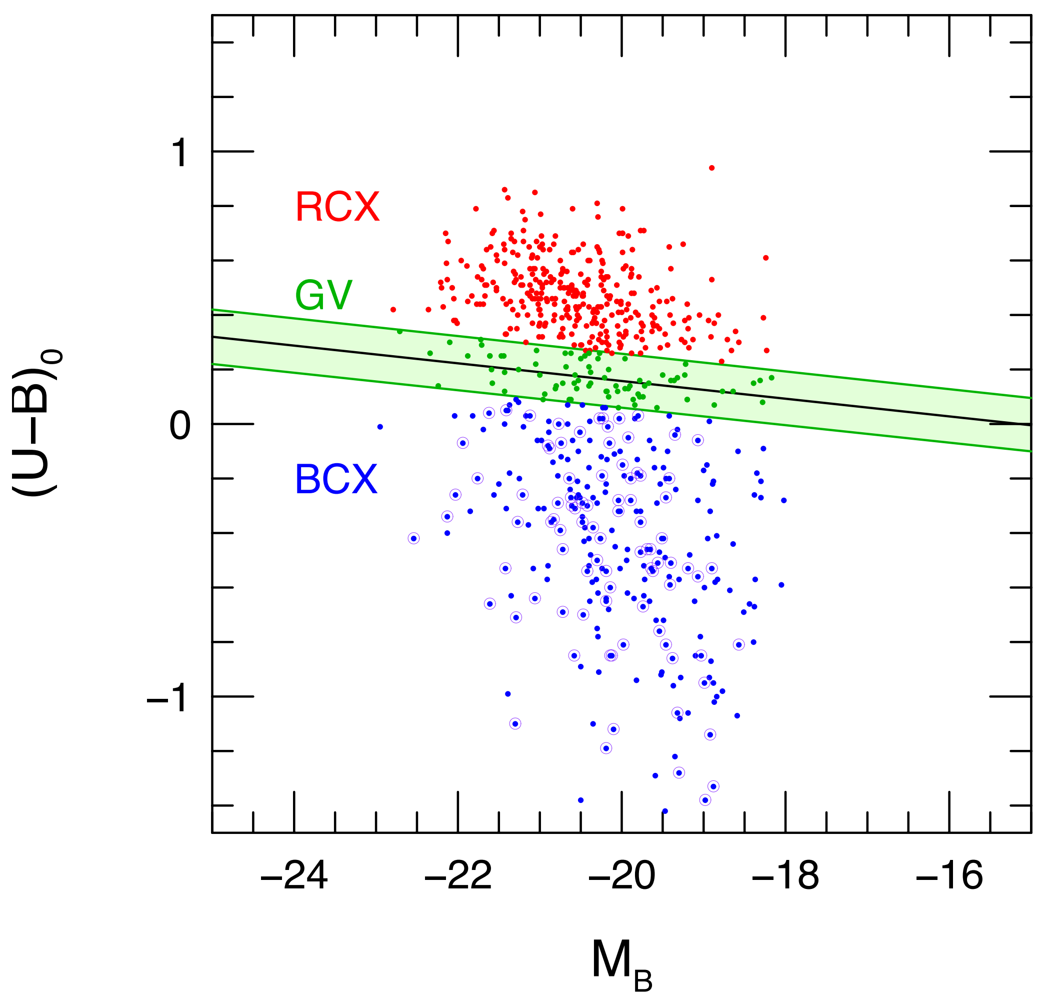
Jerjen



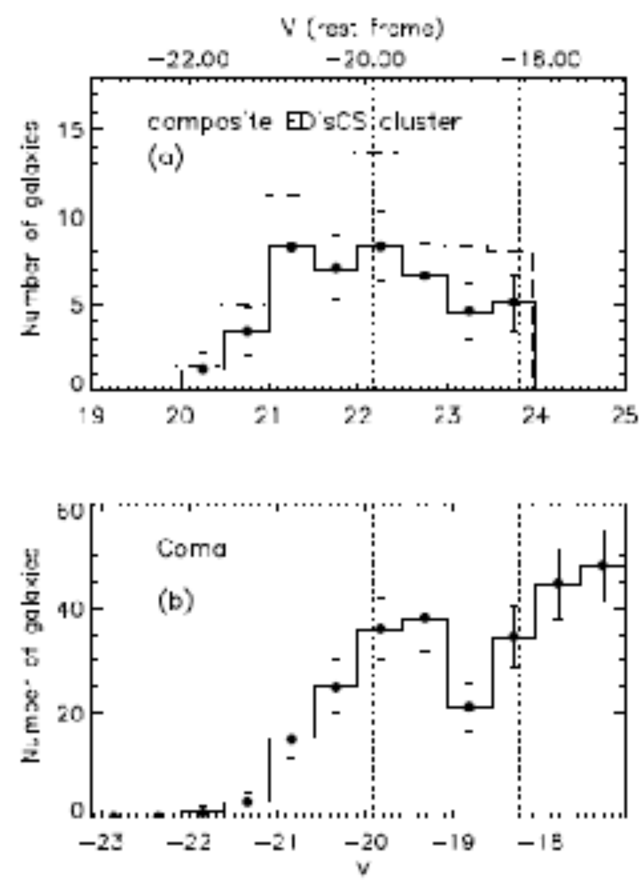
Moretti et al. 2015

Dwarf Ellipticals are heterogeneous class that is the most numerous in clusters

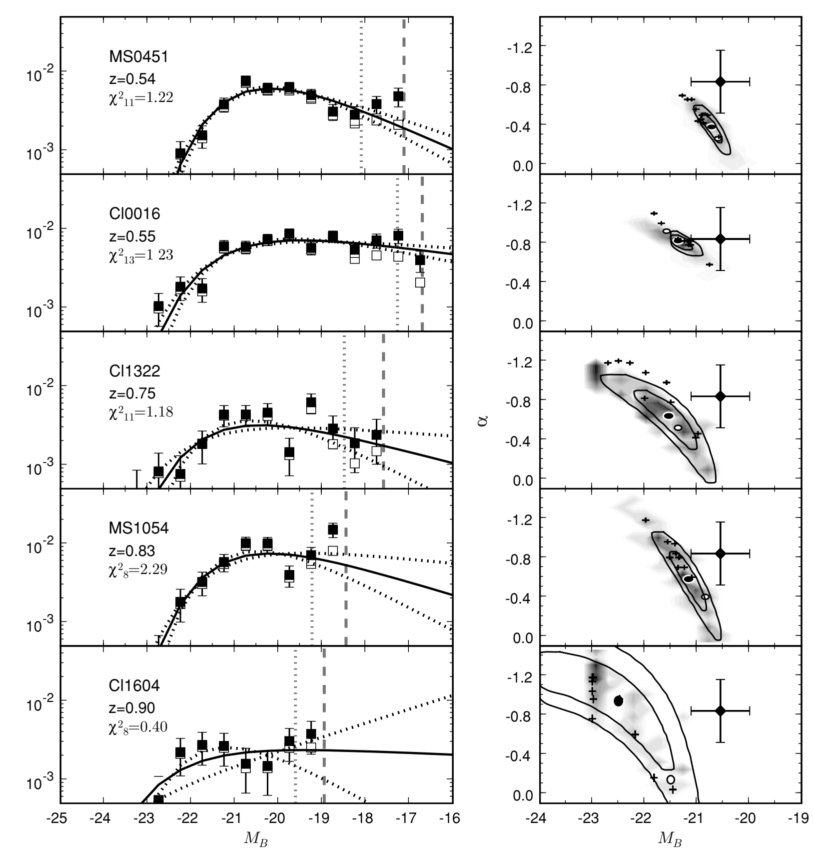
But how did they get there?



Build up of the faint end of the red sequence?



de Lucia et al. 2004

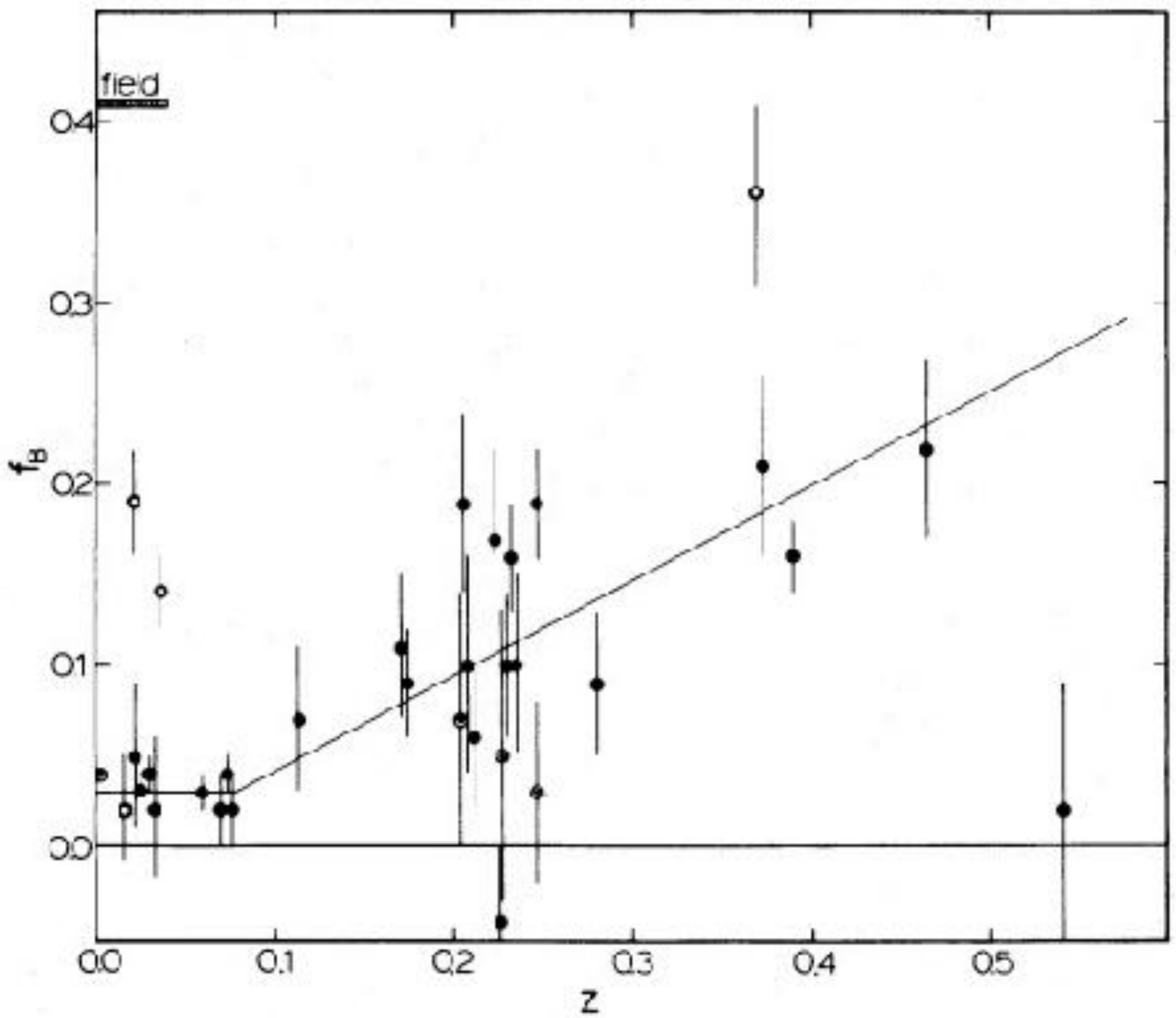


Crawford, Bershady, & Hoessel 2009

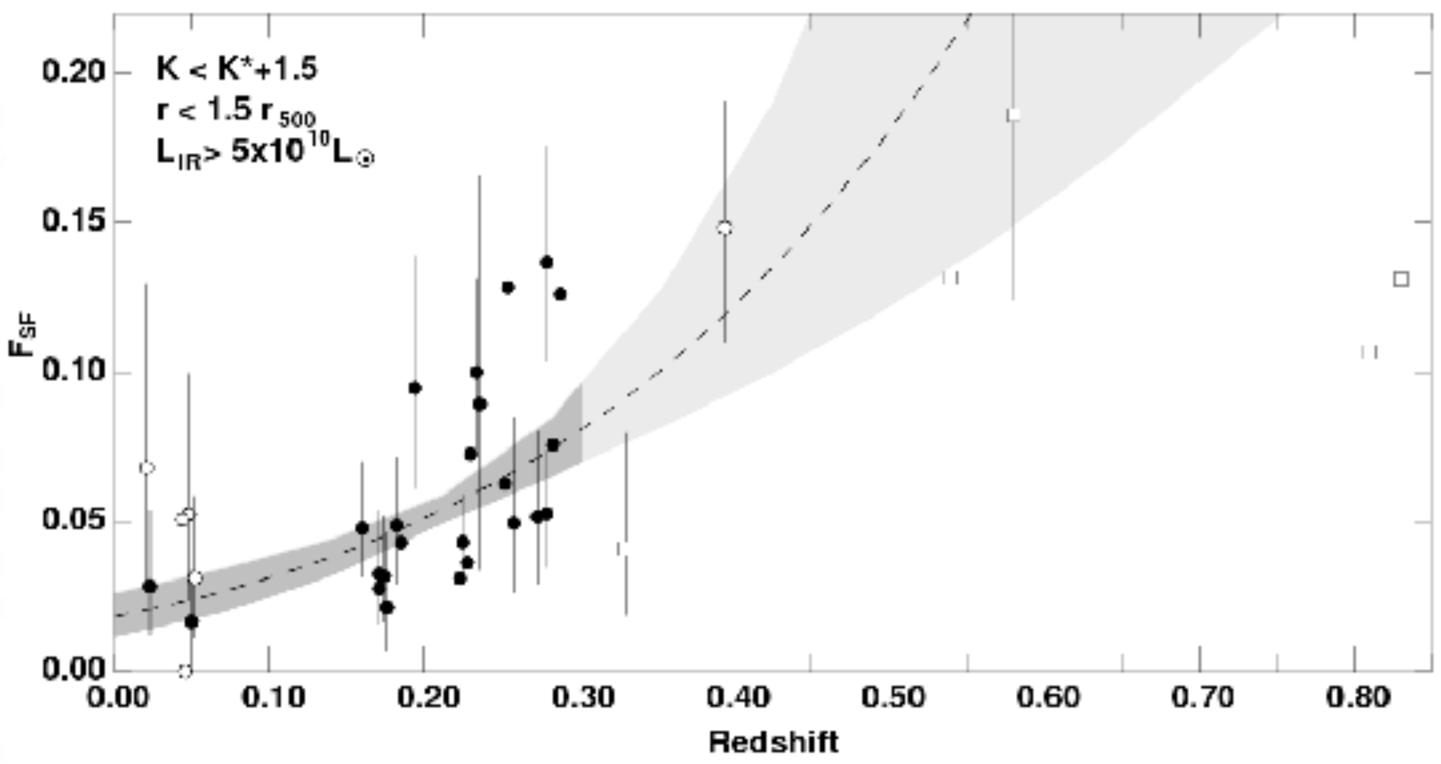
See also Capozzi, Collins & Stott 2010, Bildfell et al. 2012, De Lucia et al. 2007, Gilbank & Balogh 2008, Huertas-Company et al. 2009, Lemaux et al. 2012, Rudnick et al. 2012, Fassbender et al. 2014)

Also see Andreon (2008), Andreon et al. (2014), Lidman et al. (2008), and De Propris, Phillipps & Bremer (2013), Cerulo et al. (2017)

Blue fraction

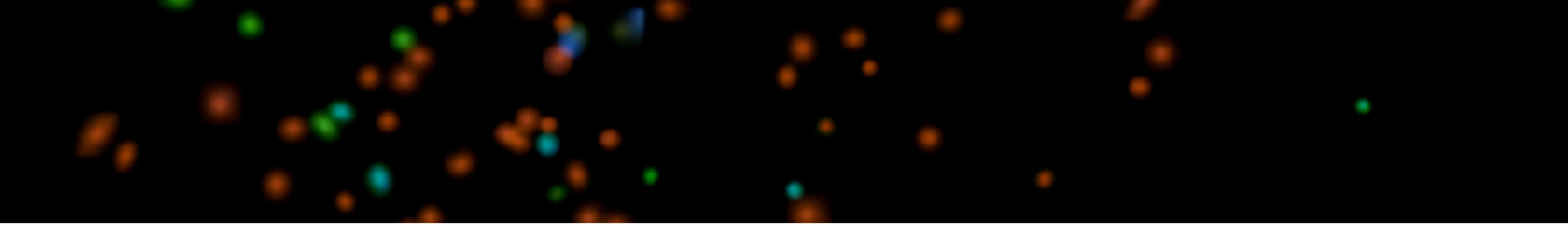


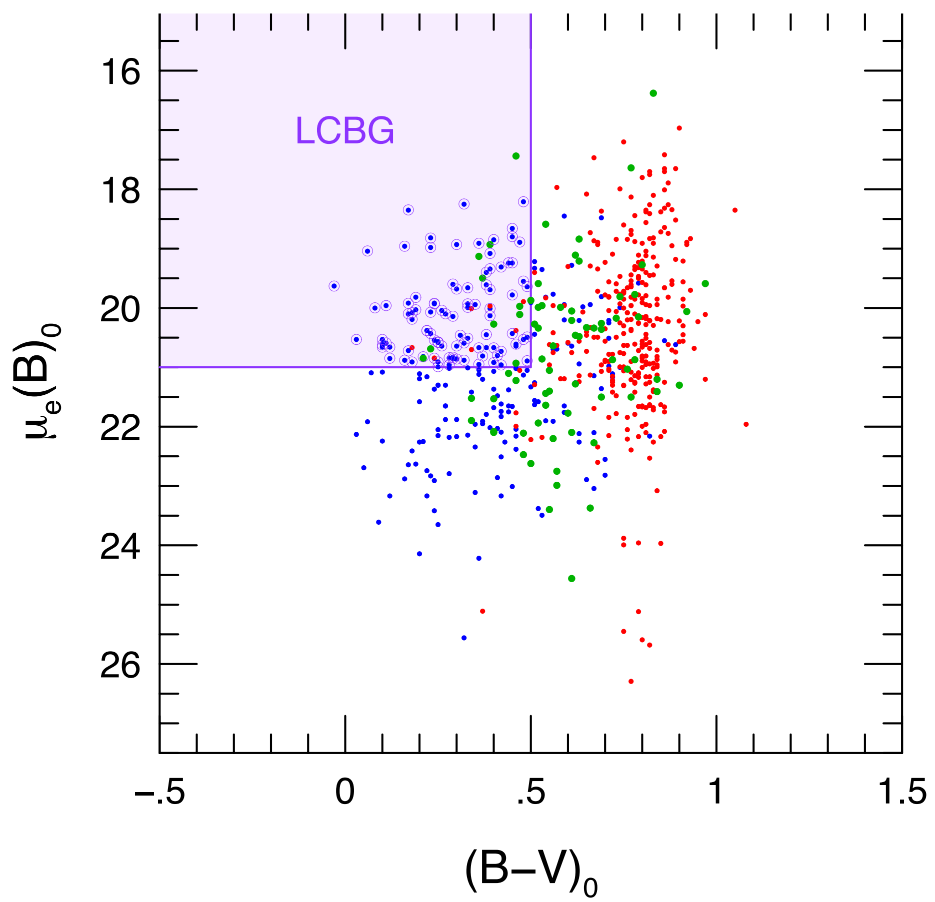
Butchler & Oemler 1984



Haines et al. 2009

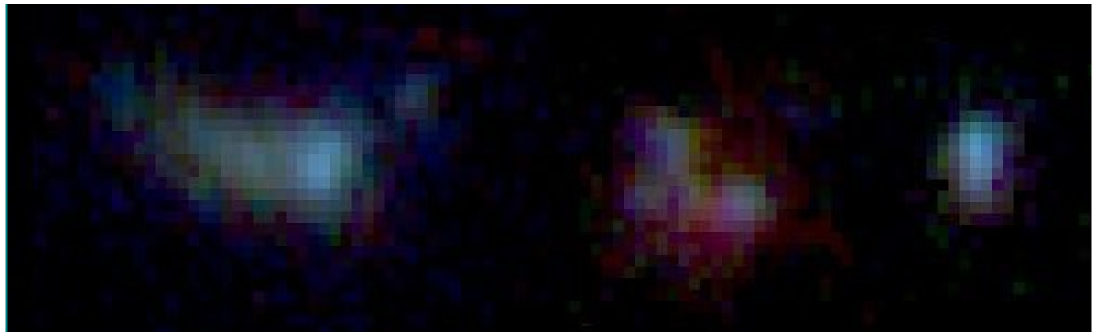
LCBGs





Luminous Compact Blue Galaxies

- Original discovered by Koo & Kron in 80s as an observational class: unresolved blue galaxies
- Rapidly evolution *heterogeneous* population of galaxies (factor of ~10 drop since z~1, Guzman et al. 1997)
- Luminous (M_B ~ -20), small (r_e ~2 kpc), and intense star formation rates



HST/WFPC2/NICMOS

Ref: Koo et al. 1994, Koo et al. 1997, Guzman et al. 1996; Phillips et al. 1997; Kobulnicky & Zaritsky 1999; Guzma´n et al. 2003; Garland et al. 2004; Werk et al. 2004; Barton et al. 2006; Noeske et al. 2006; Rawat et al. 2007; Hoyos et al. 2007; Tollerud et al. 2010

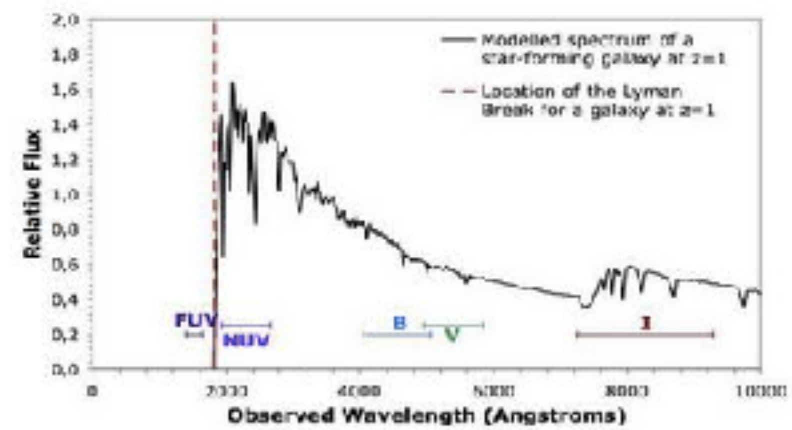
LCBG are like ...

	Low-z	Int-z	High-z
	<3.5 Gyrs ago z < 0.3	Up to 3.5-9 Gyrs ago 0.3 < z < 1	>9 Gyrs ago z>1

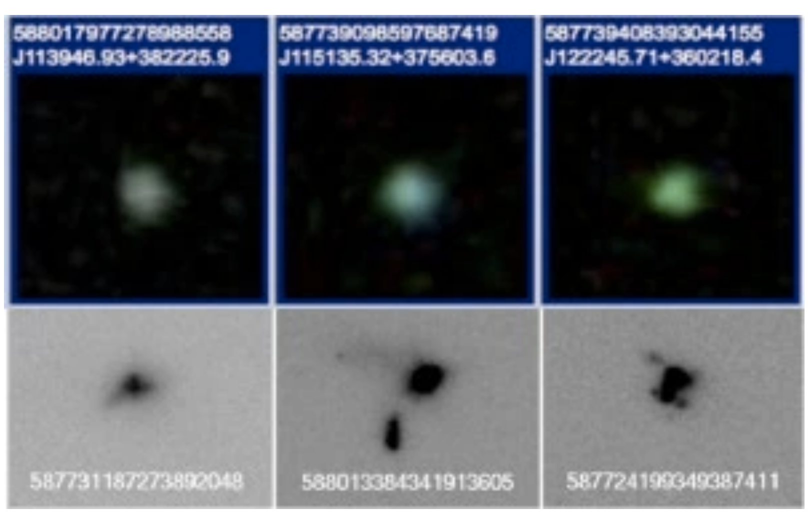
Blue Compact Dwarfs, HII galaxies

Extreme Emission Line Galaxies

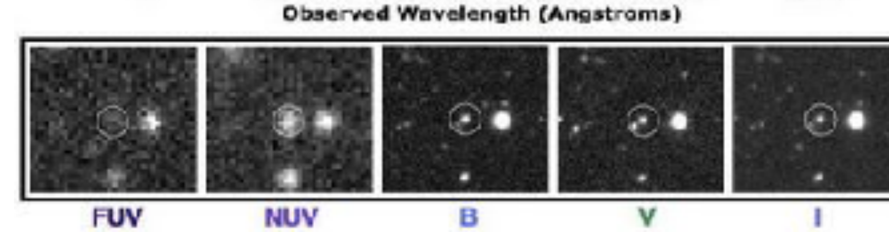
Lyman Break Galaxies



green peas



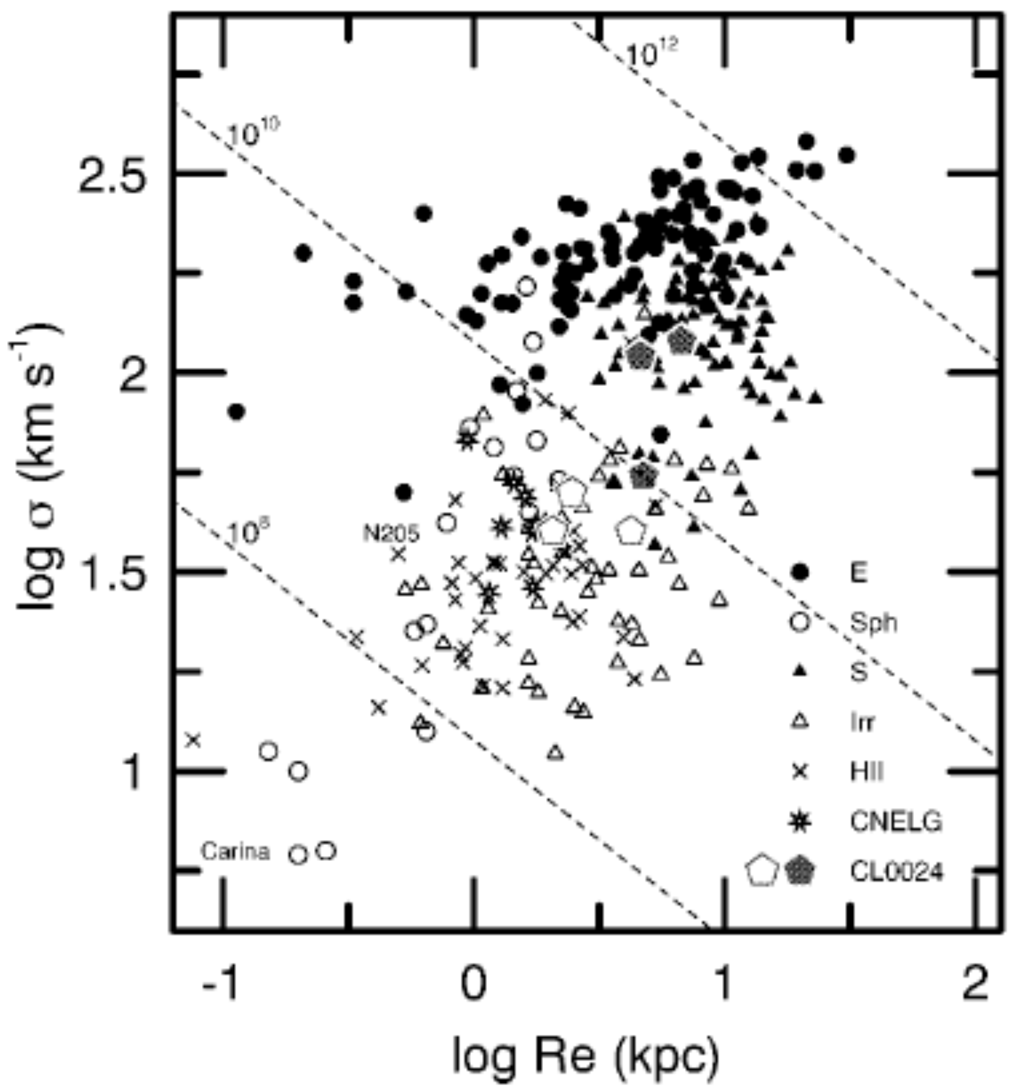
CNELGs



Cardamone et al. 2009

Burgarella et al. 2009

LCBGs in Clusters



Handful of LCBGs in CL0024 seem to have similar properties to low redshift dwarf galaxies

Koo original proposed LCBGs as the progenitors of dE

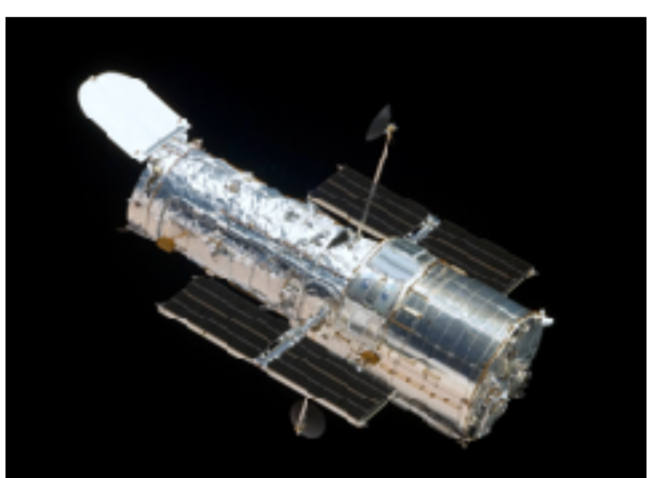
Koo et al. 1994

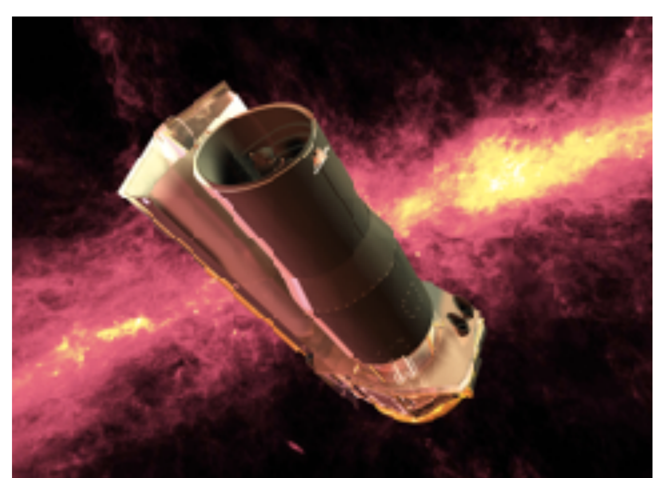
Observations

Table 1. Summary of Fields

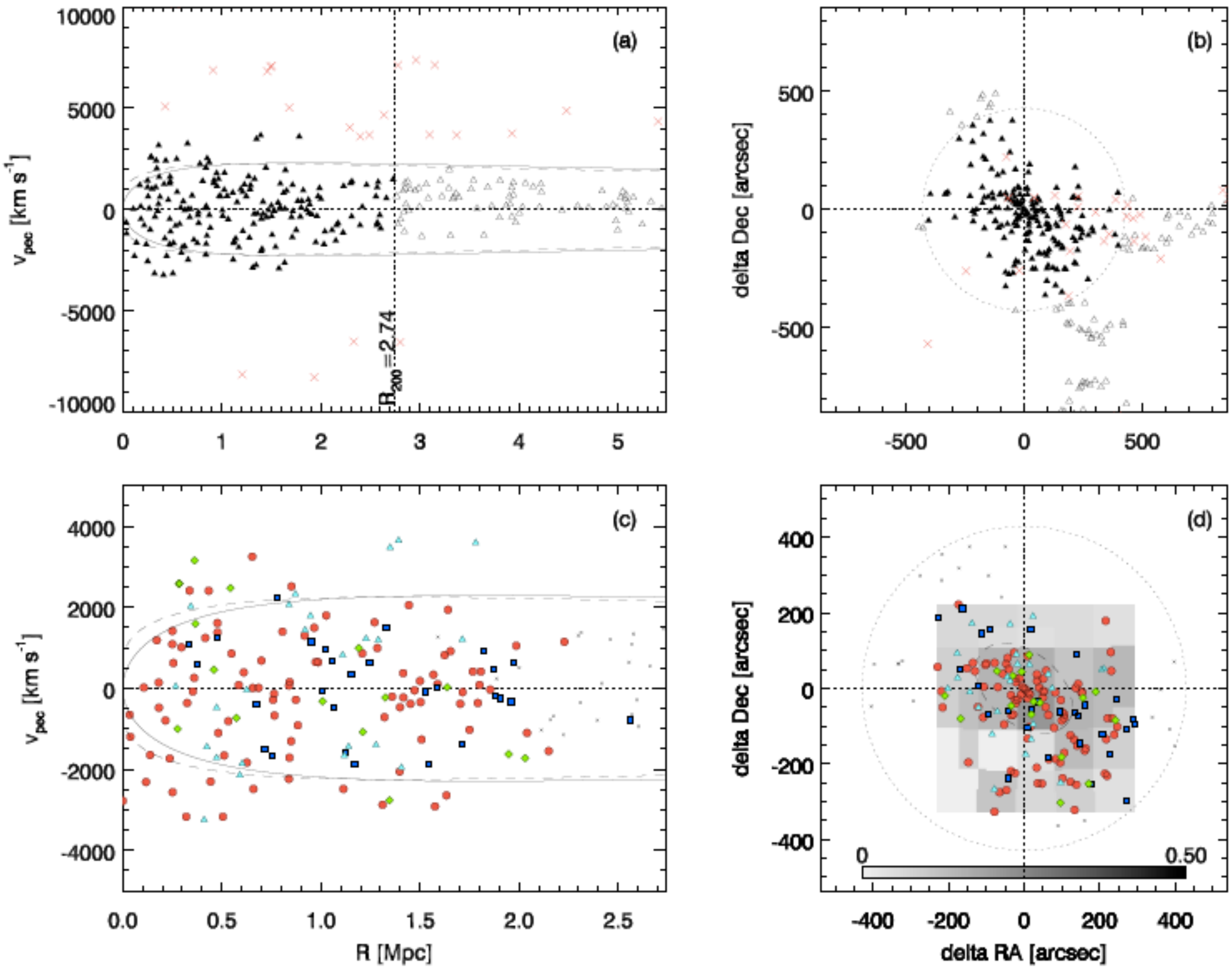
Field (1)	WLTV ID (2)	α (J2000) (3)	δ (J2000) (4)	z (5)	σ_p (km s^{-1}) (6)	R_{200} (Mpc) (7)	R_{200} ($''$) (8)
MS 0451-03	w05	04:54:10.8	−03:00:51	0.5389	1328	2.45	386
Cl 0016+16	w01	00:18:33.6	+16:26:16	0.5467	1490	2.74	428
Cl J1324+3011	w08	13:24:48.8	+30:11:39	0.7549	806	1.31	178
MS 1054-03	w07	10:56:60.0	−03:37:36	0.8307	1105	1.72	225
Cl J1604+4304	w10	16:04:24.0	+43:04:39	0.9005	1106	1.65	211

Deep WIYN narrow band imaging combined with DEIMOS spectra, Archive HST, Spitzer, and VLA observations





Identifying Cluster LCBGs

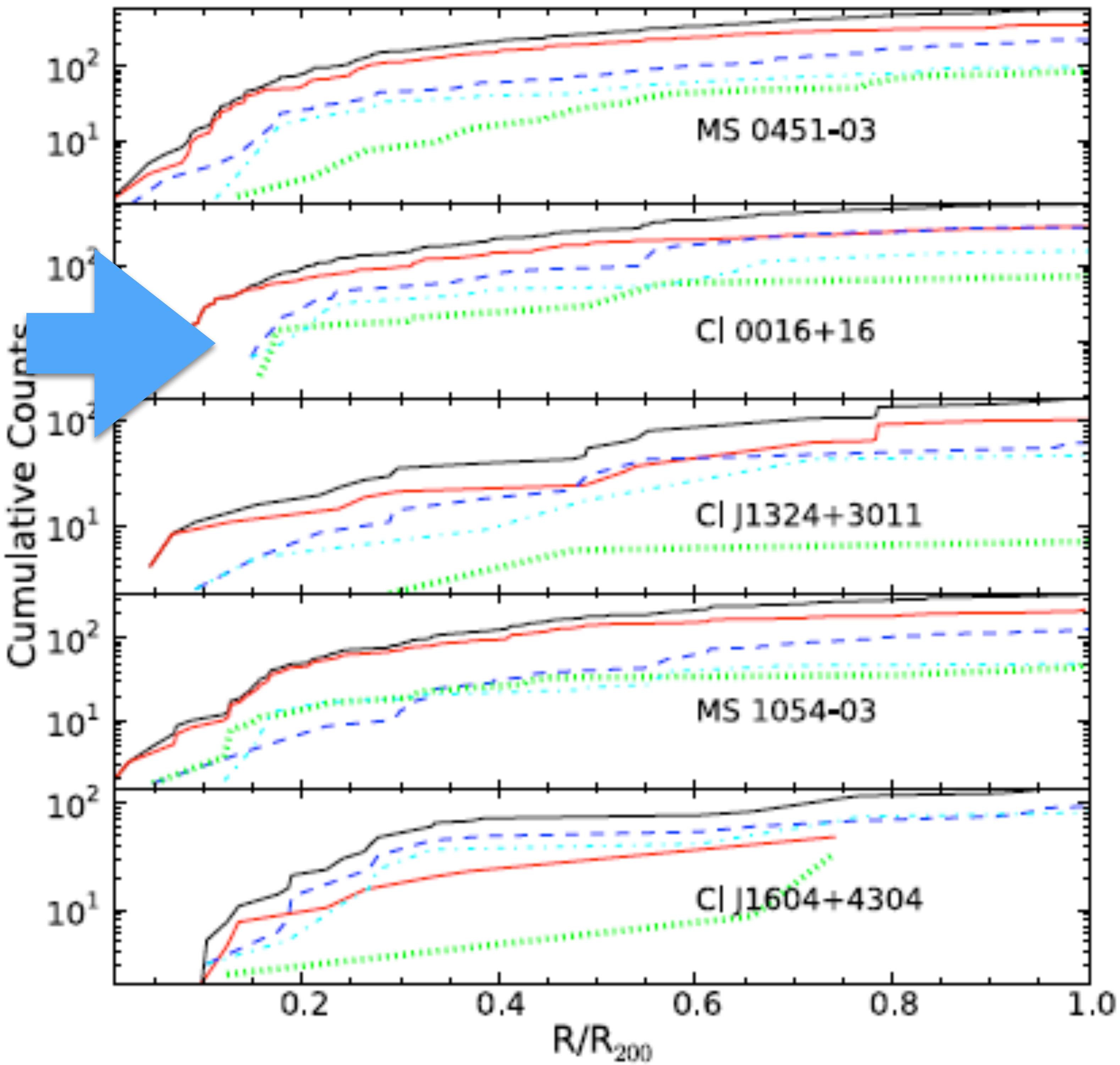


~15-35% of z=0.5-0.9 cluster galaxies are LCBGs

Color key:
Red Sequence Galaxies
Green Valley Galaxies
Blue Cloud Galaxies
Luminous Compact Blue Galaxies

Crawford et al. 2011, 2014

“Shell-like” LCBG Radial Distribution

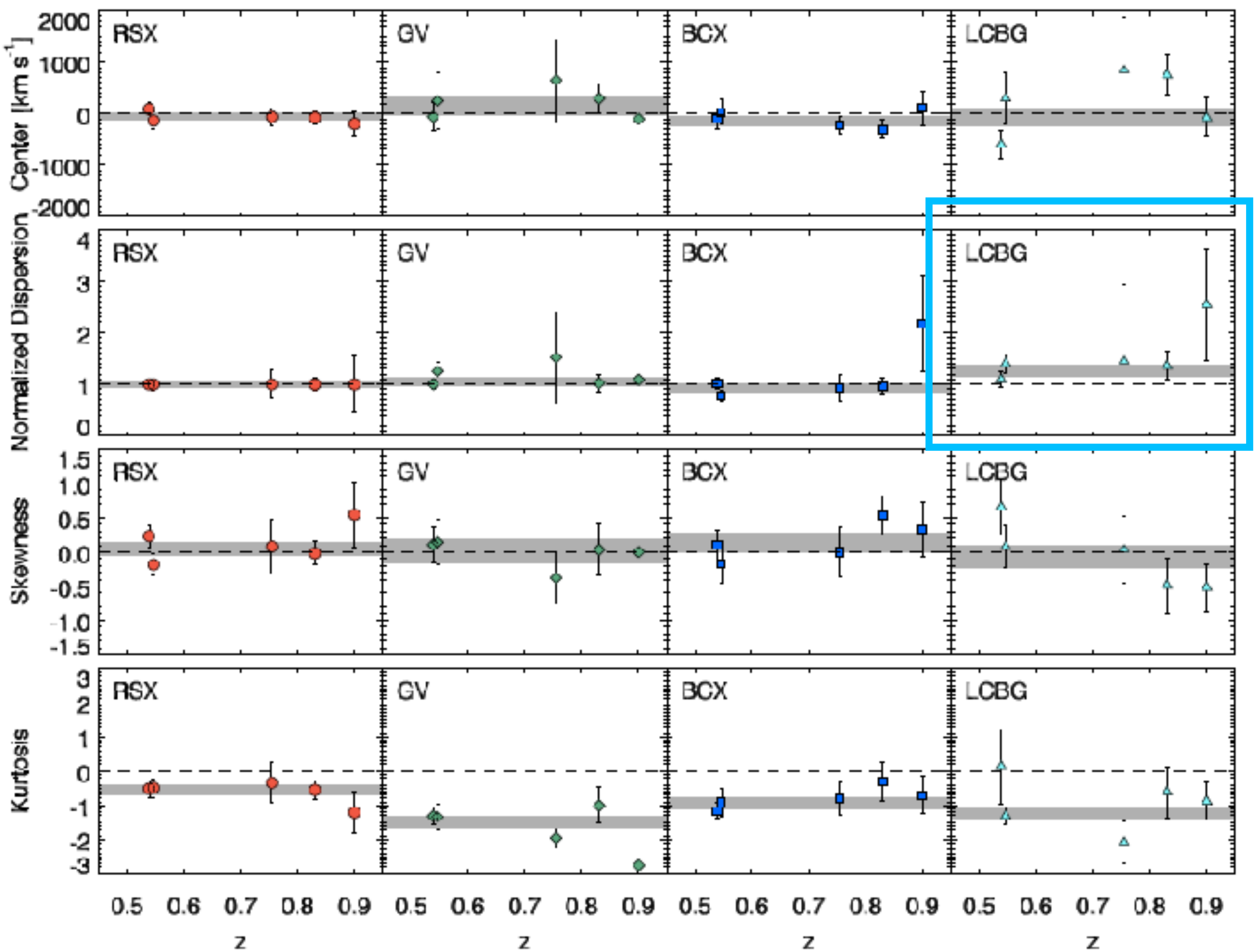


Similar to results for low-z SF galaxies

e.g. Thompson 1986; Ellingson et al. 2001; Mahajan et al. 2010

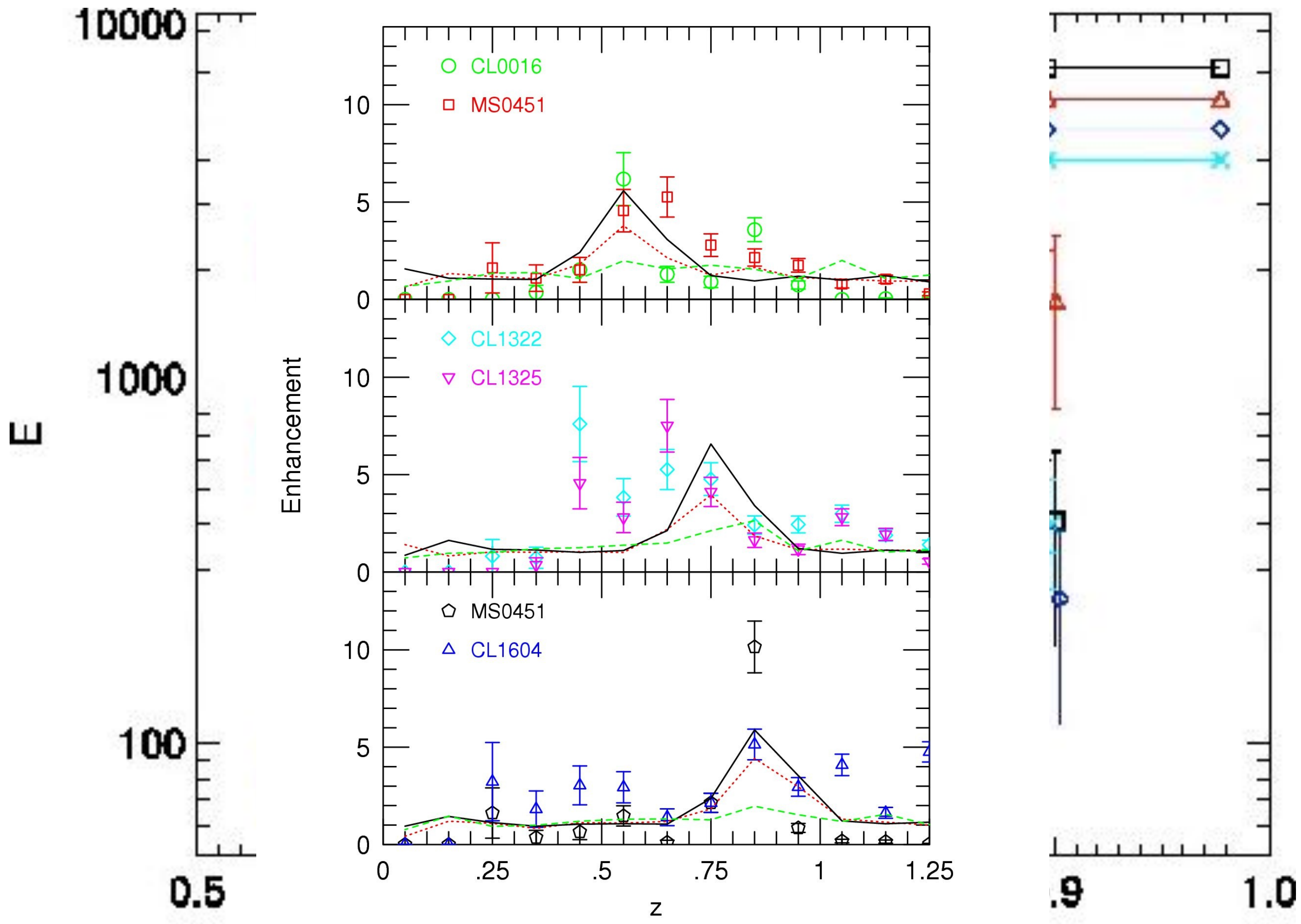
Crawford et al. 2011, 2014

LCBGs are falling into the cluster



Crawford et al. 2014

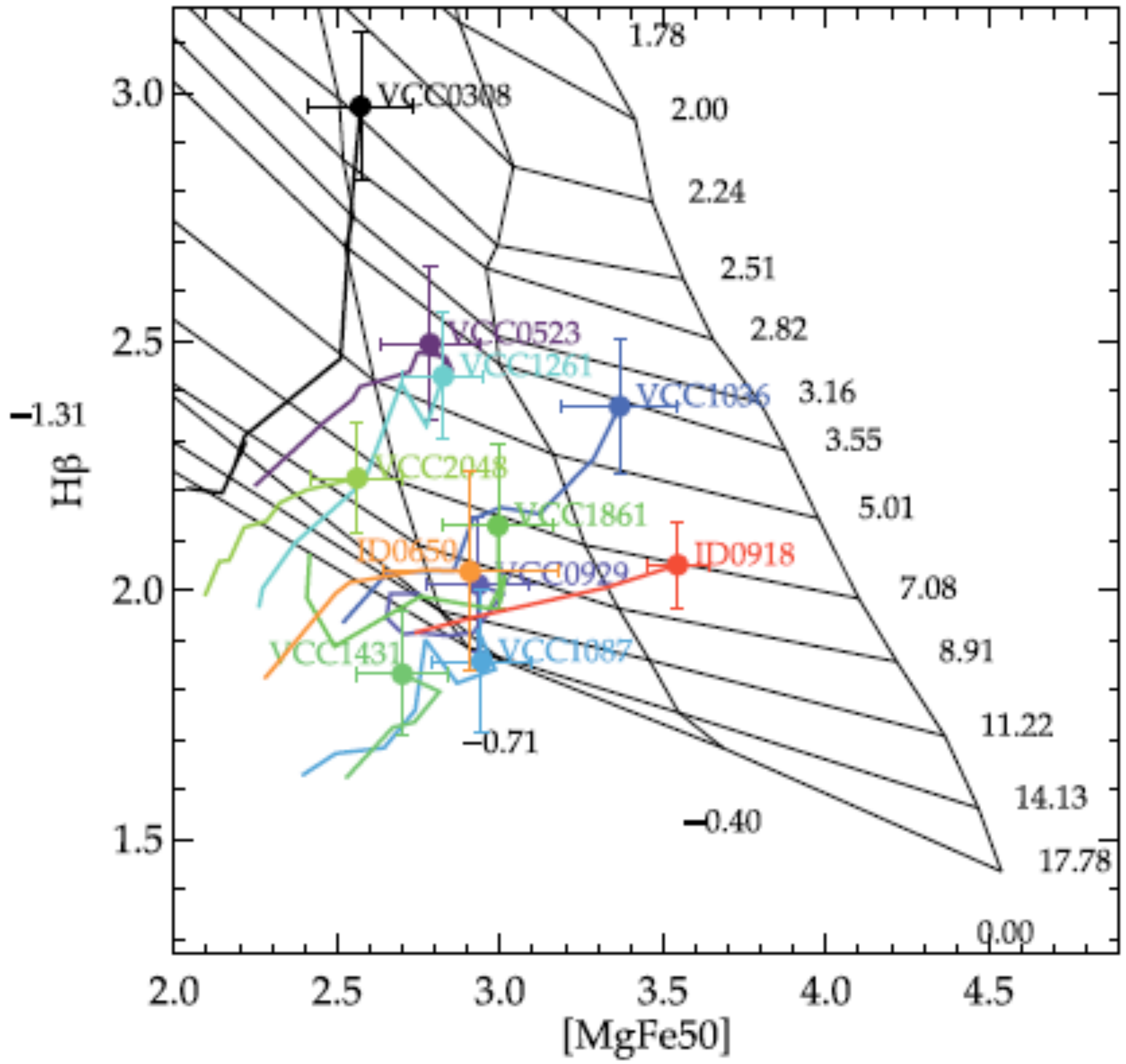
Clusters Triggering LCBGs



Enhancement = $\frac{\text{Density of Cluster Galaxies}}{\text{Density of field galaxies}}$

Crawford et al. 2006, 2011

Young burst in dE



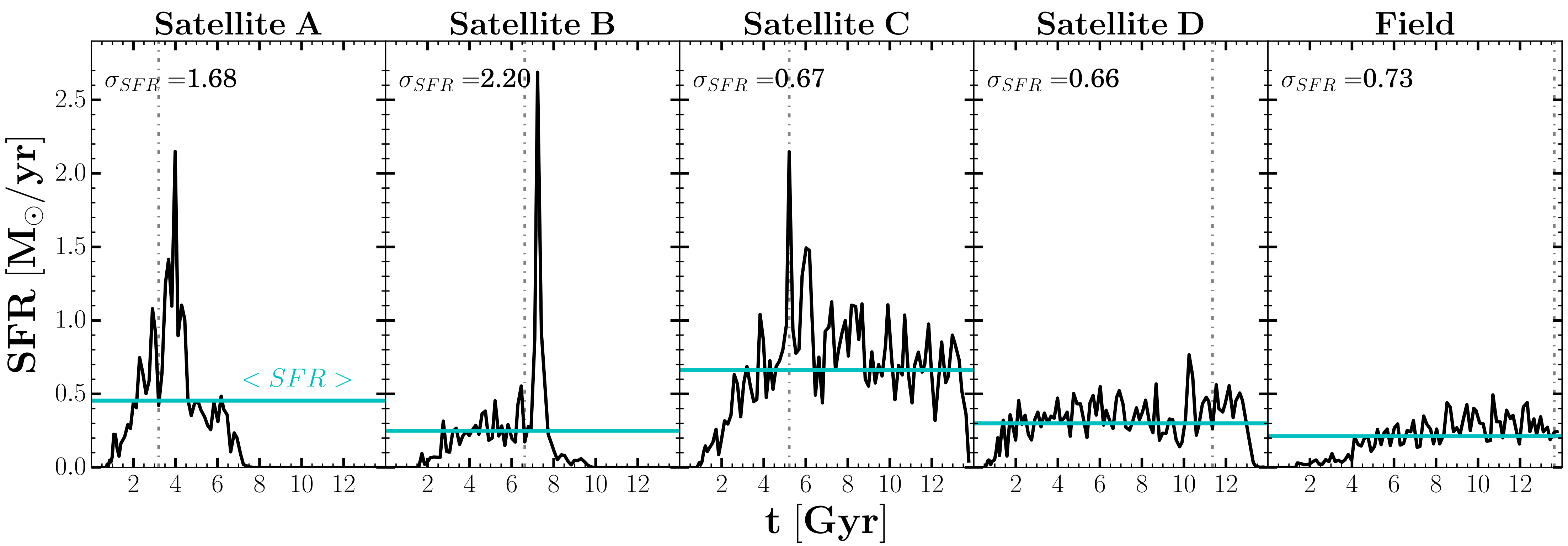
Rys et al. 2015

Rys et al. showed that the typical dE had a burst of star formation ~5 Gyrs ago

Also see Michielson et al 08, Lelli et al. 2014, Toloba et al. 2014, Mentz et al 2016

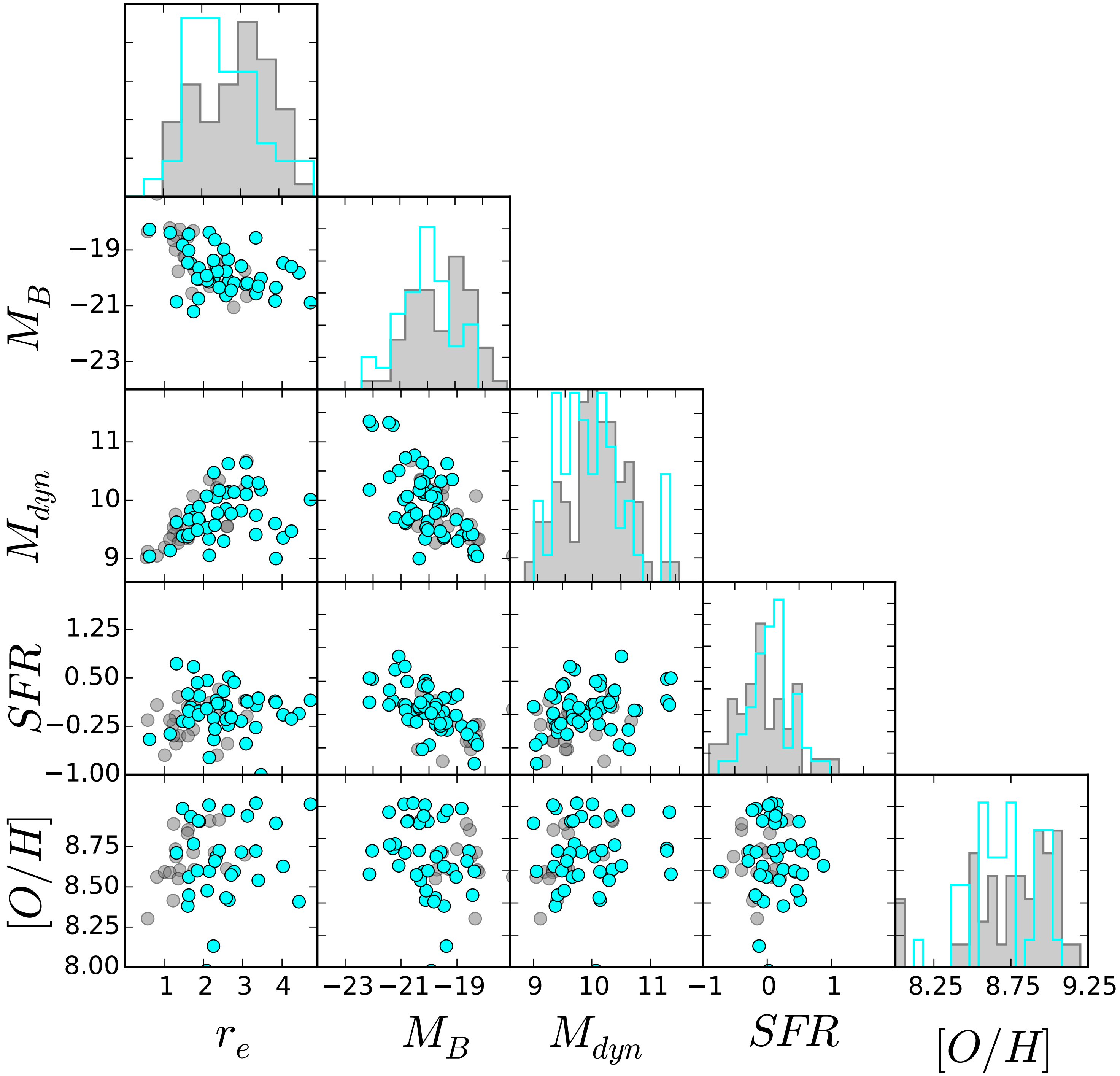
Bursts in Illustris Simulations

Dwarfs galaxies undergo a burst
when entering the cluster



Mistani et al. 2015

Spectroscopic Properties

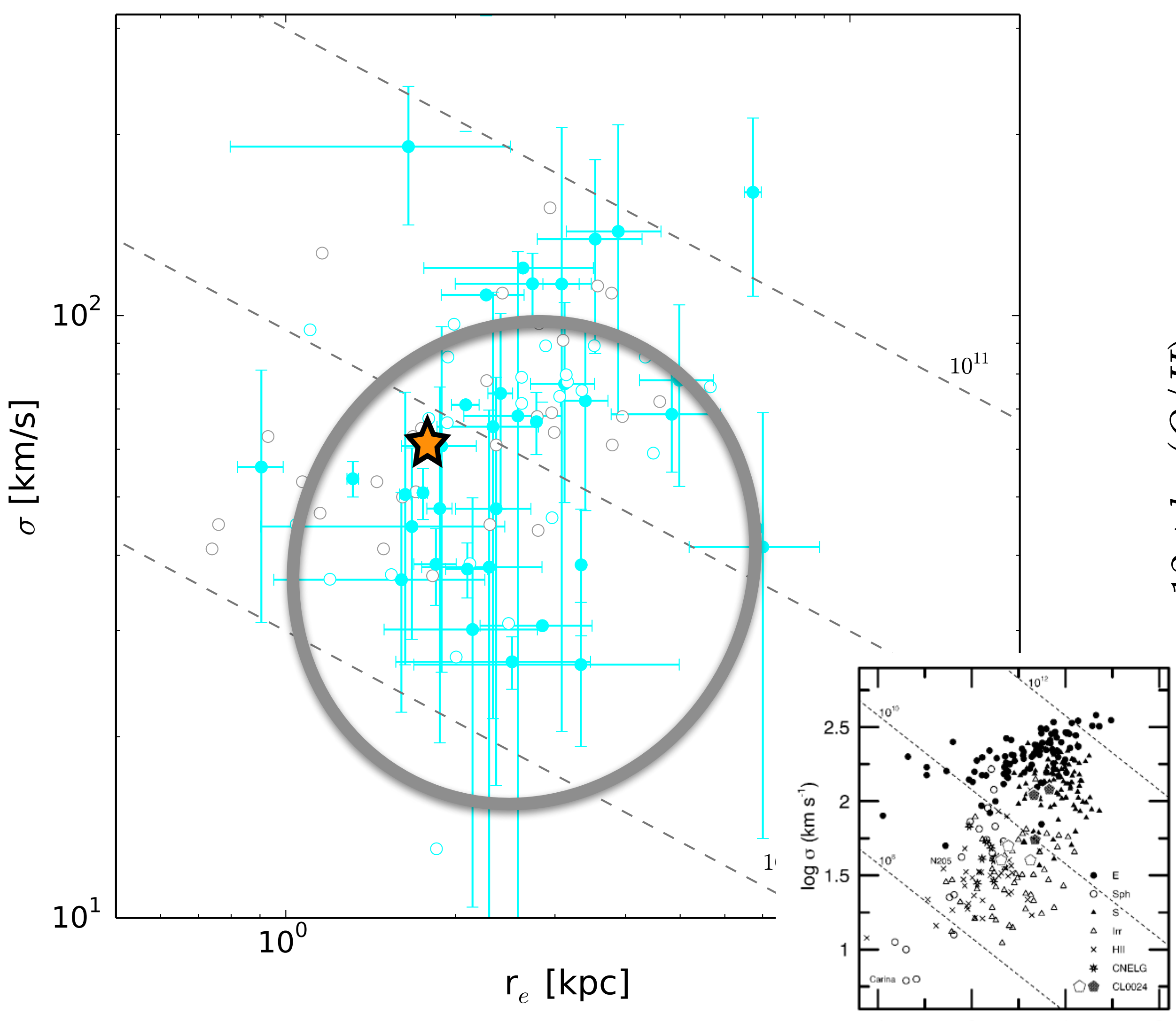


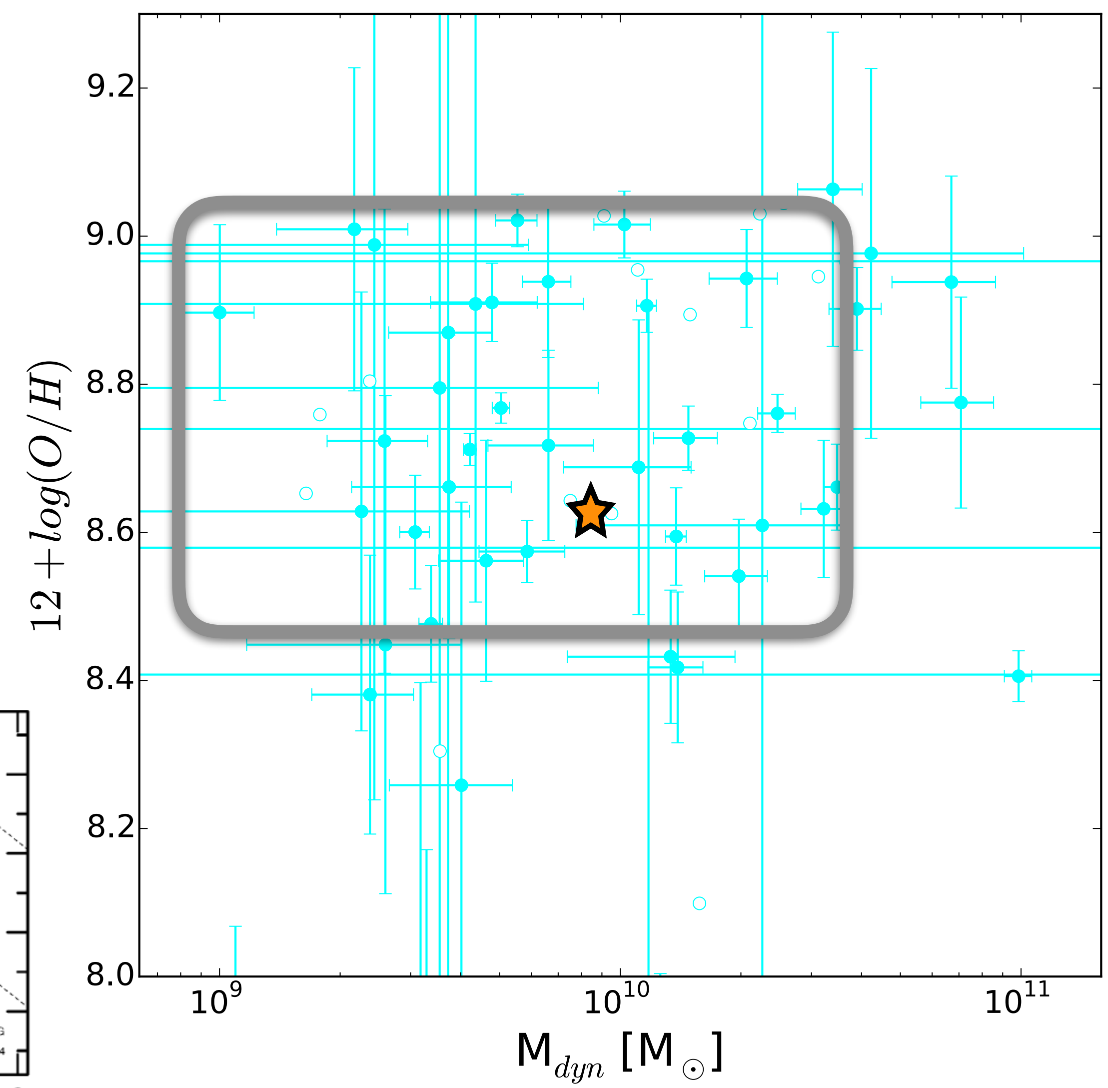
Cluster and field LCBGs nearly indistinguishable in terms of dynamical mass, SFR, abundance, or size.

Typical properties:
σ~56 km/s,
$r_{1/2}$~1.8 kpc
M_{dyn}~5x10^9 M$_\odot$
12 + log(O/H) = 8.6.

Crawford et al. 2016

Spectroscopic Properties



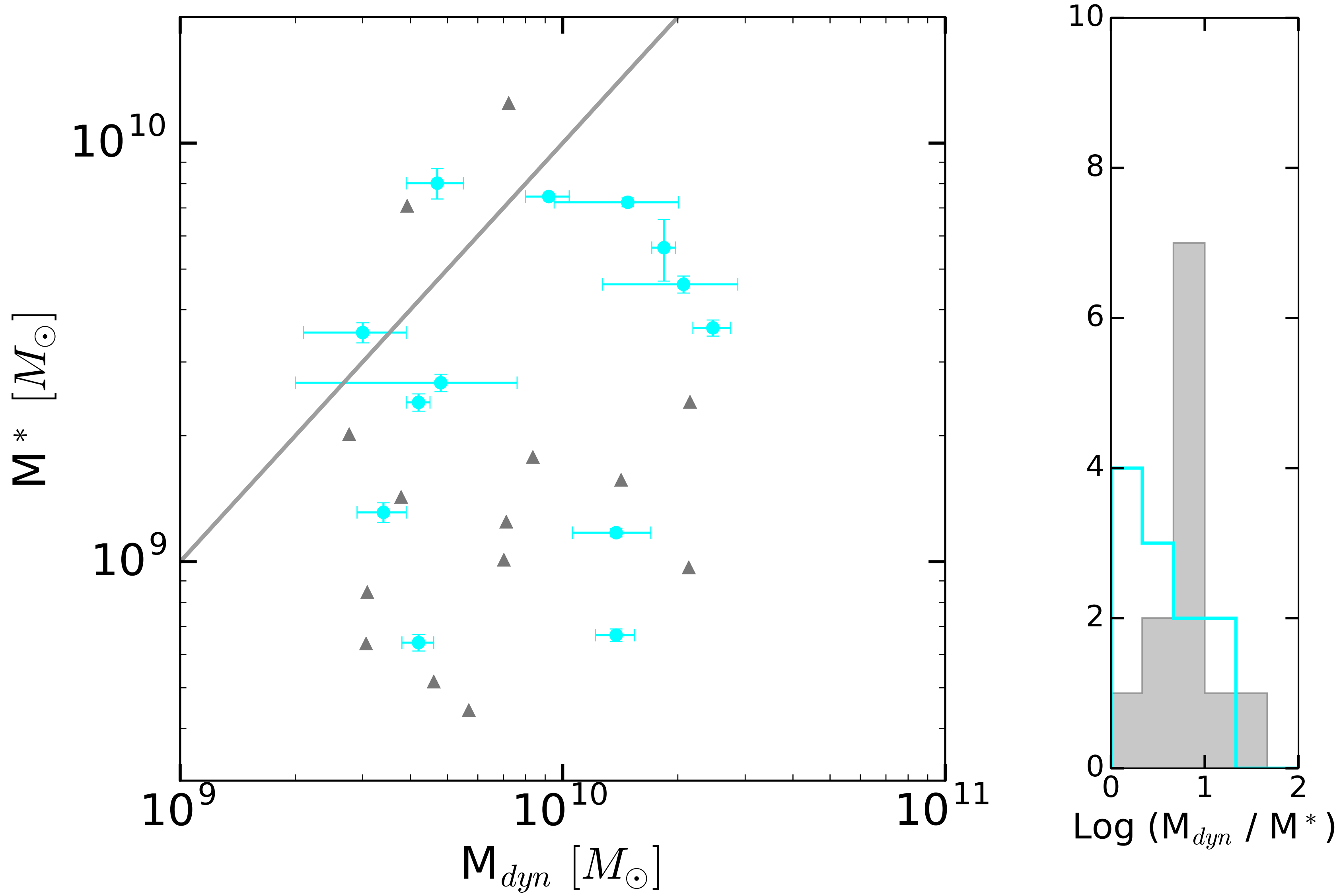


★ NGC 205 — local dwarf Elliptical

◯ Distribution of cluster dE

Crawford et al. 2016

Dynamical to Stellar Mass



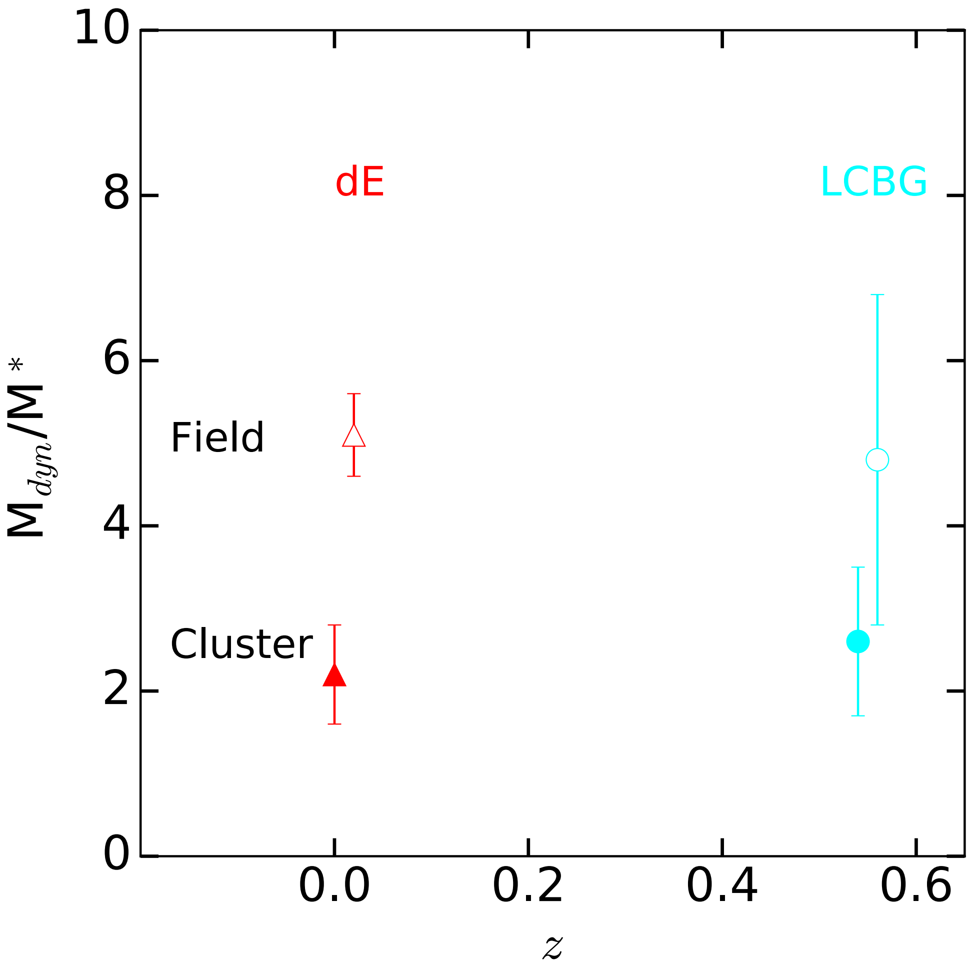
LCBG M_{dyn}/M^*
Cluster~ 2.6
Field ~ 4.8

dE M_{dyn}/M^*
Cluster~ 2.2
Field ~ 5.1
Penny et al. 2015

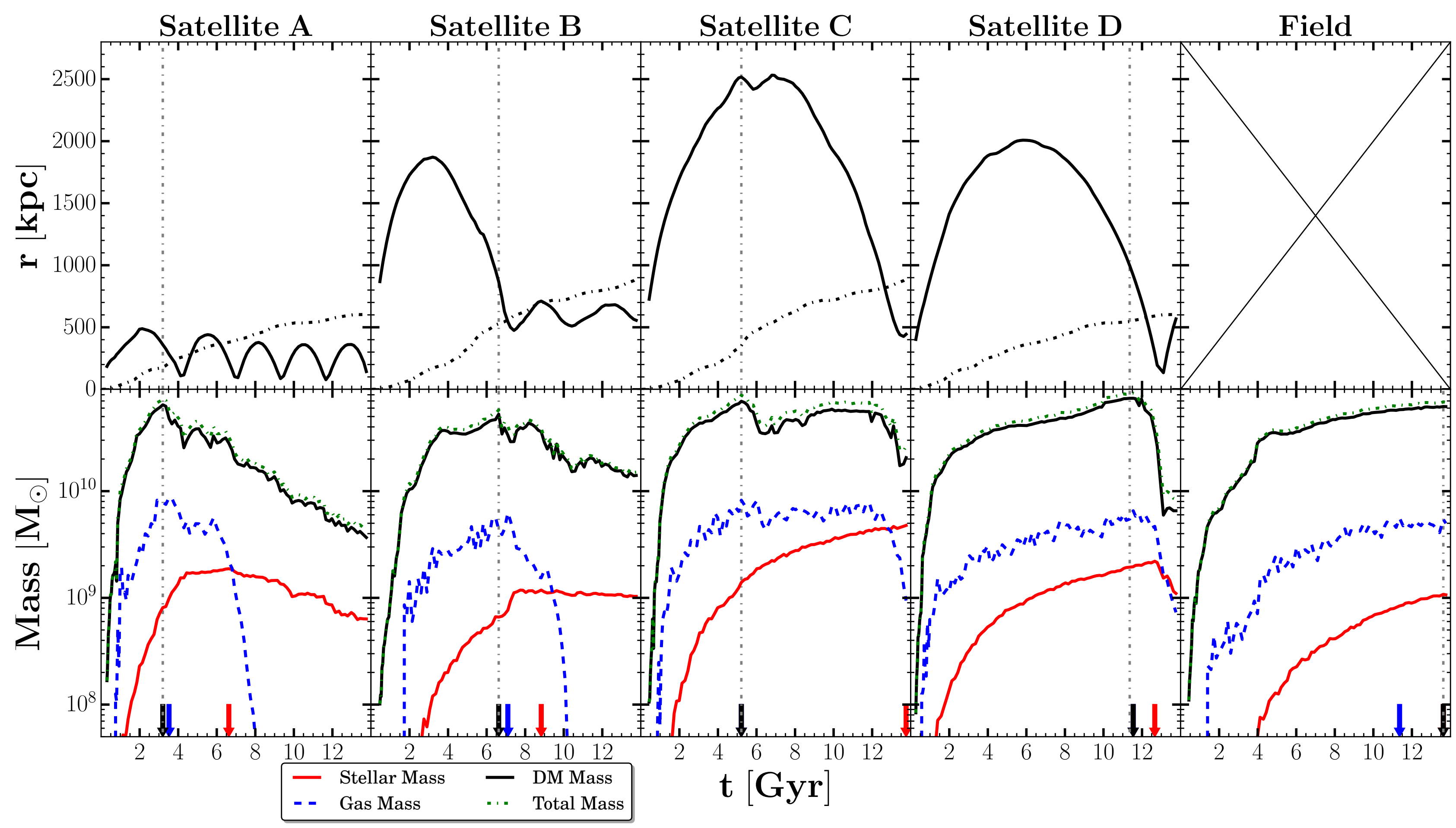
Randriamapandry et al. 2017
https://arxiv.org/abs/1706.04534

“Longitudinal Study”

Observed



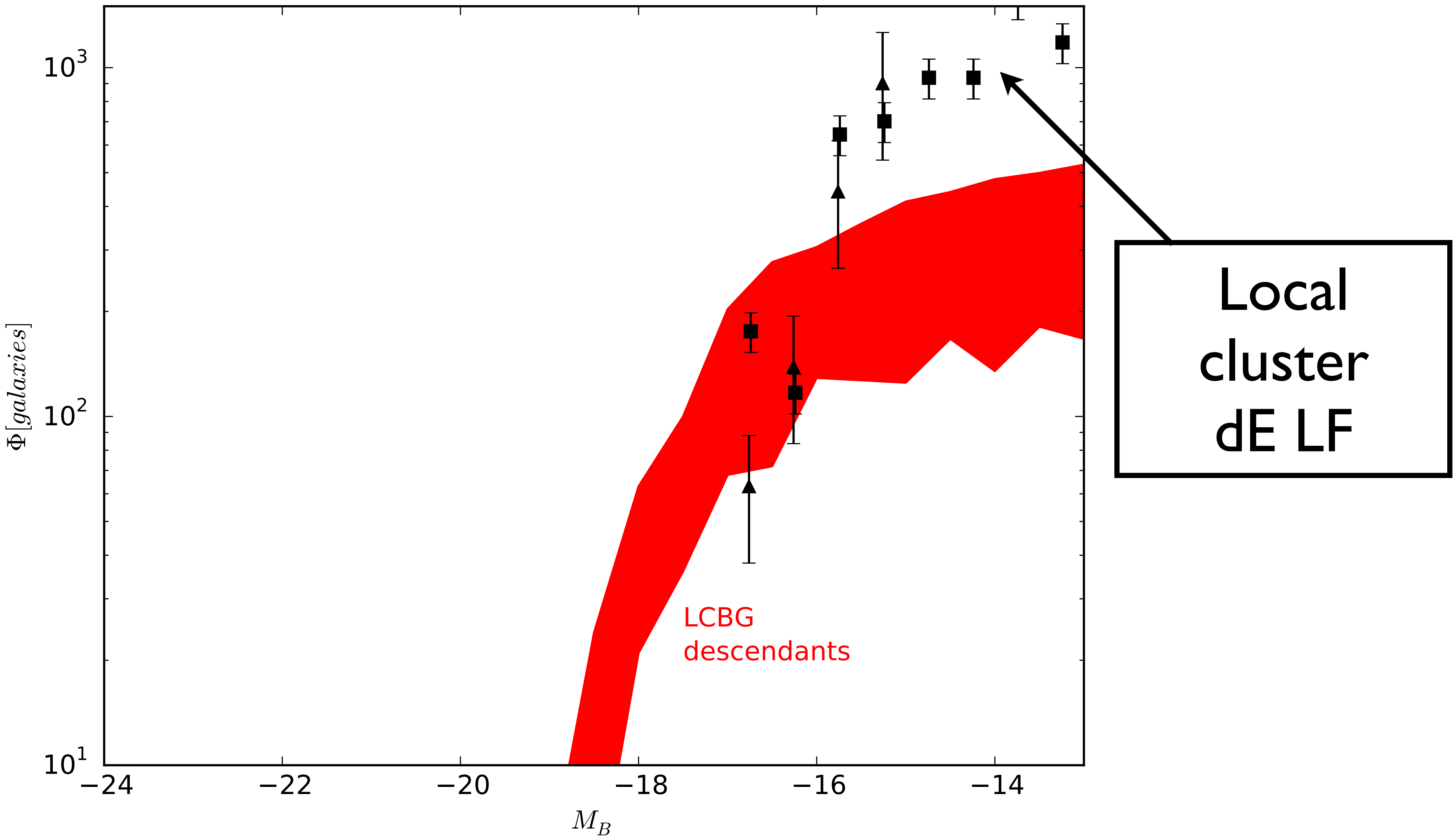
Simulated



Mistani et al. 2015

Fate of LCBGs

30-75% of dE went through an LCBG phase between z=0.3-1

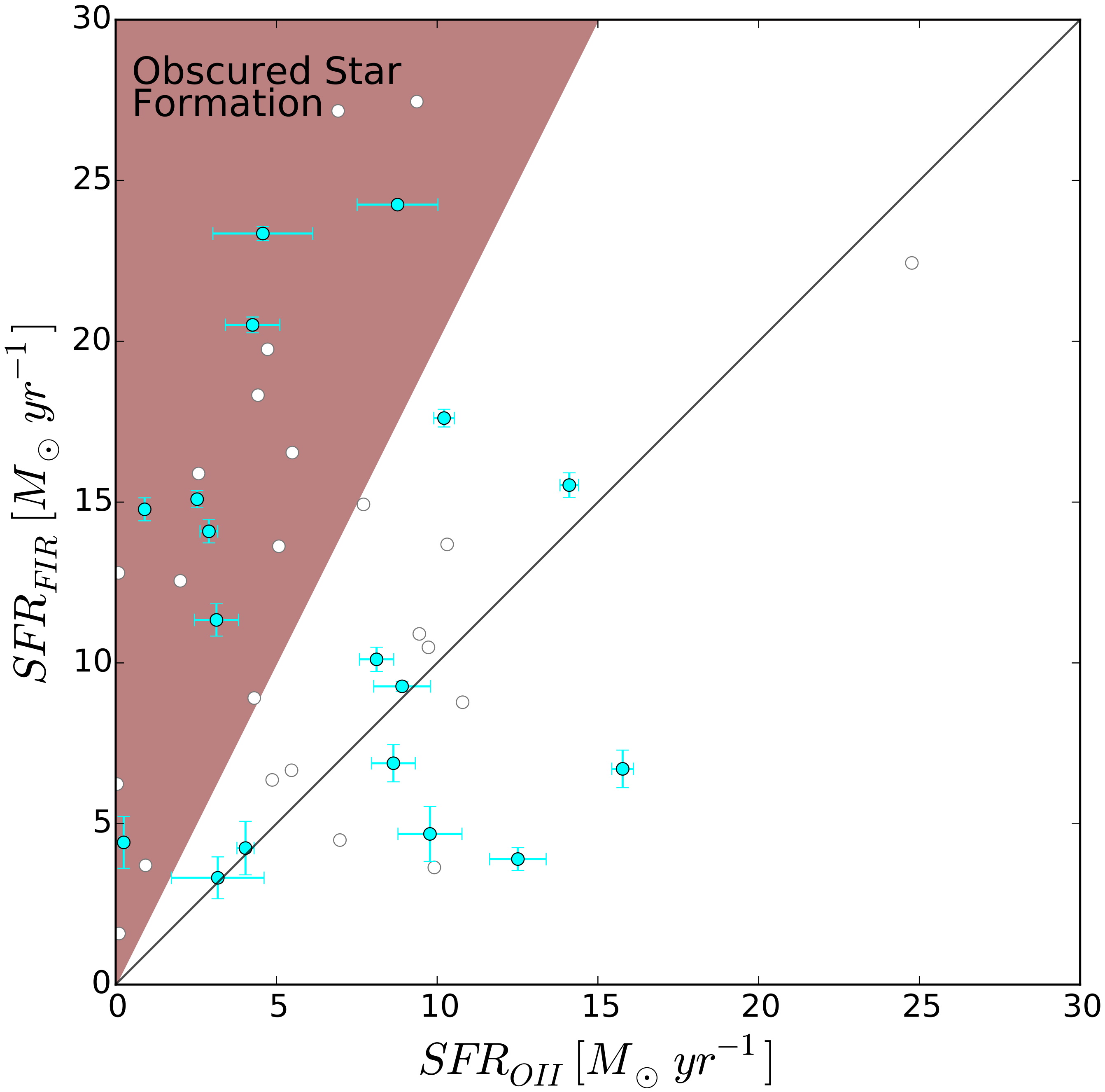


Crawford et al. 2016

Summary

- Galaxy Clusters trigger the star burst phase in inflating dwarf galaxies at intermediate redshifts
- Spectral properties of LCBGs are very similar to local, cluster dE
- Likely between 30-75% of dE experienced a LCBG phase in the last 7.5 Gyrs
- Further work needed to study the evolution in dynamical to stellar mass, morphology/size, and complex star bursts

Complex Star formation in LCBGs



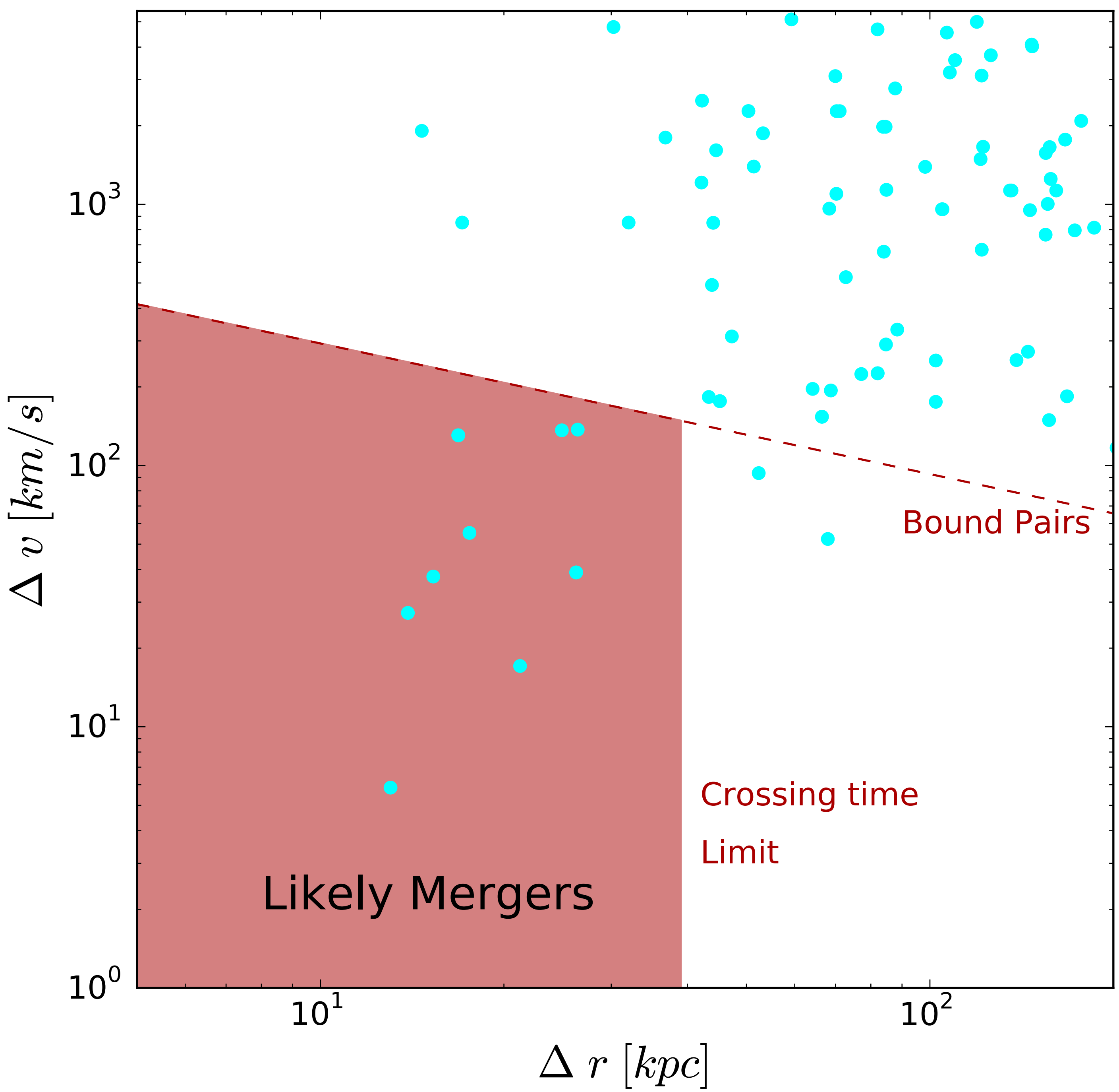
Range of star formation in different metrics

Starbursting galaxies need better modeling

Crawford et al. 2016

Merging Together

velocity difference with neighbor

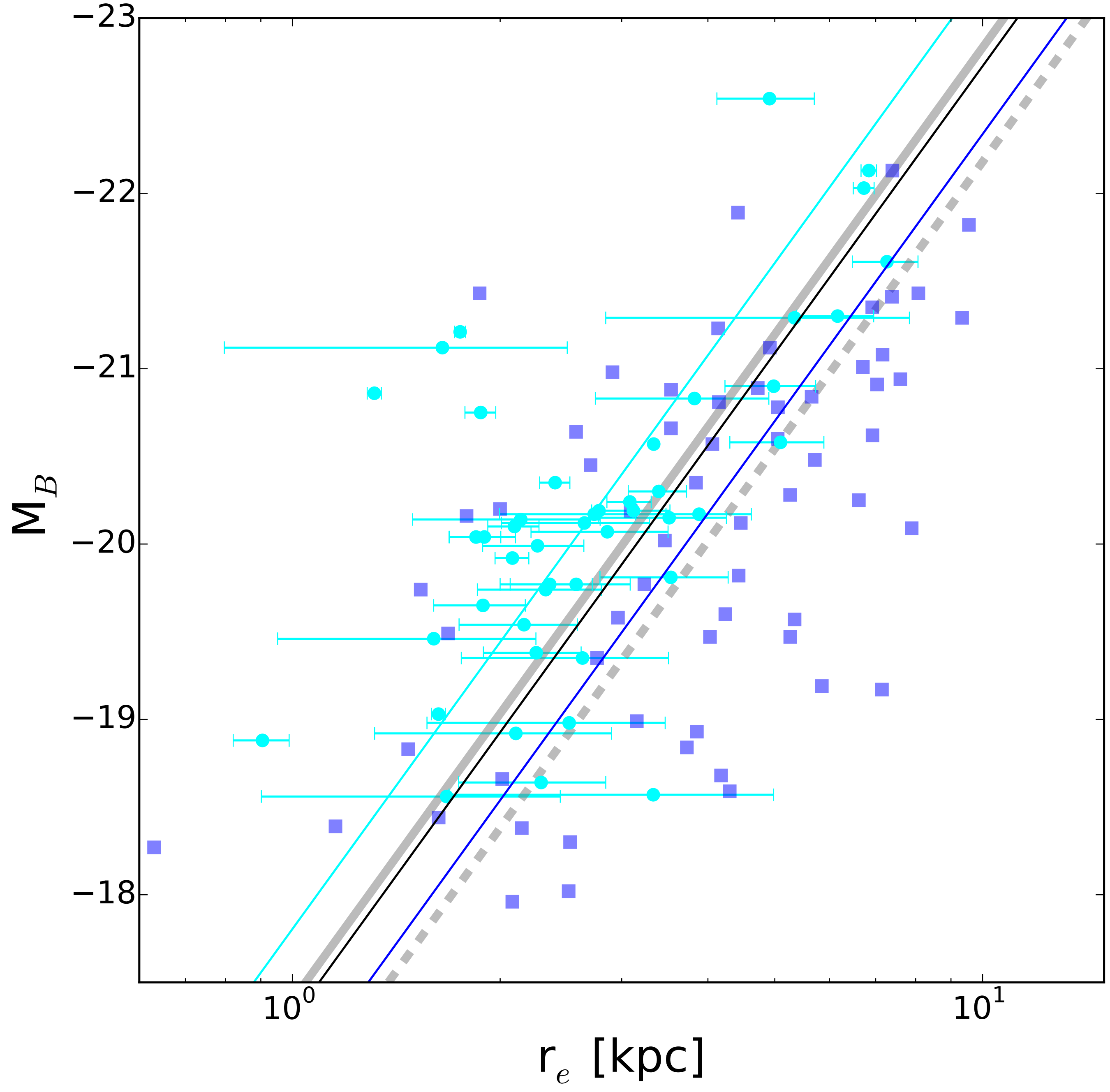


Distance to neighbor

~10% of cluster LCBGs will merge with another galaxy

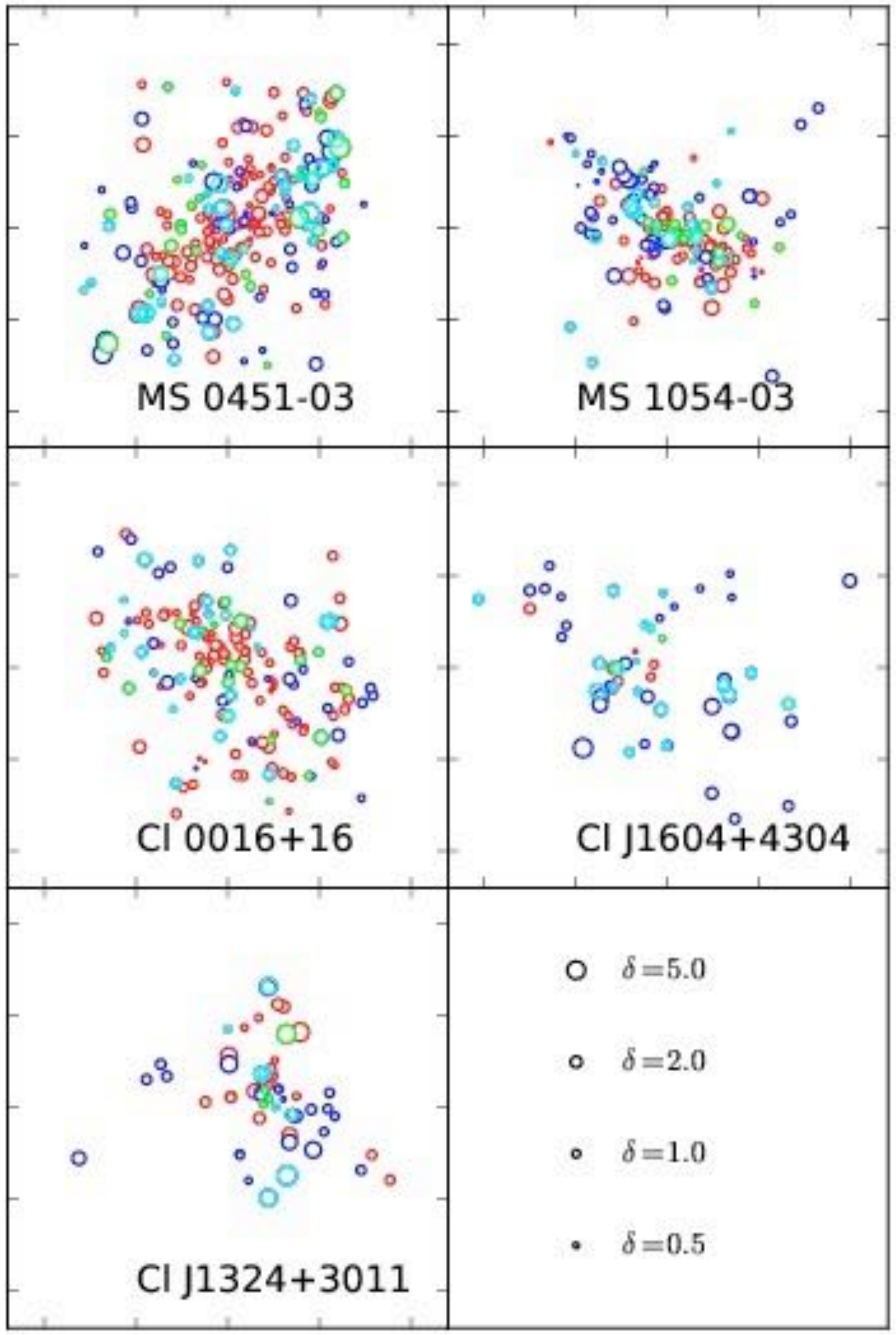
Crawford et al. 2016

Magnitude-size



Crawford et al. 2016

Substructure

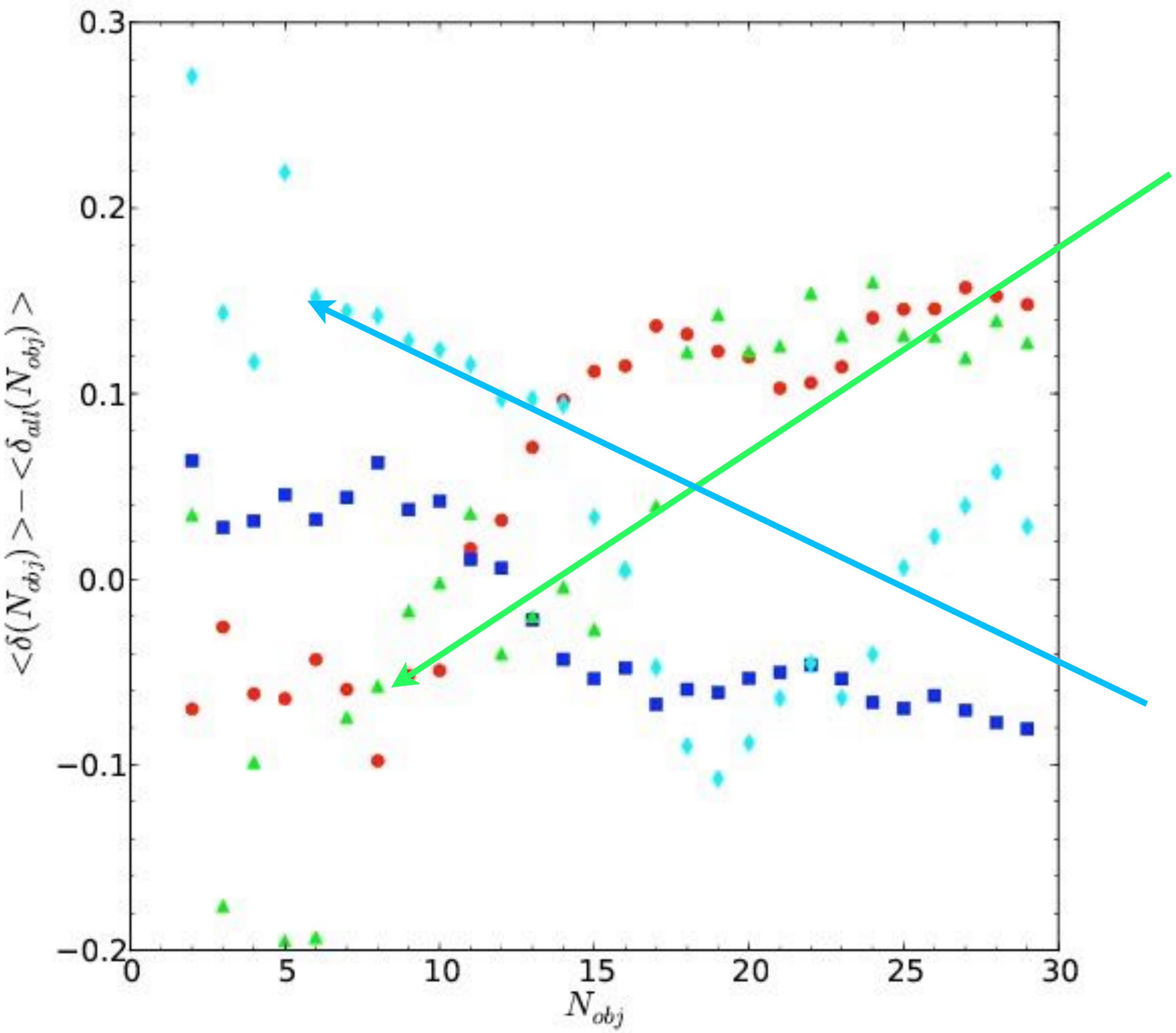


Dressler-Shectman statistic is the classic test for substructure:

$$\delta^2 = \frac{N_{obj}}{\sigma^2}[(\bar{v}_{local} - \bar{v})^2 + ((\sigma_{local} - \sigma)^2].$$

Calculated as the offset from the cluster mean for the 10 nearest neighbors

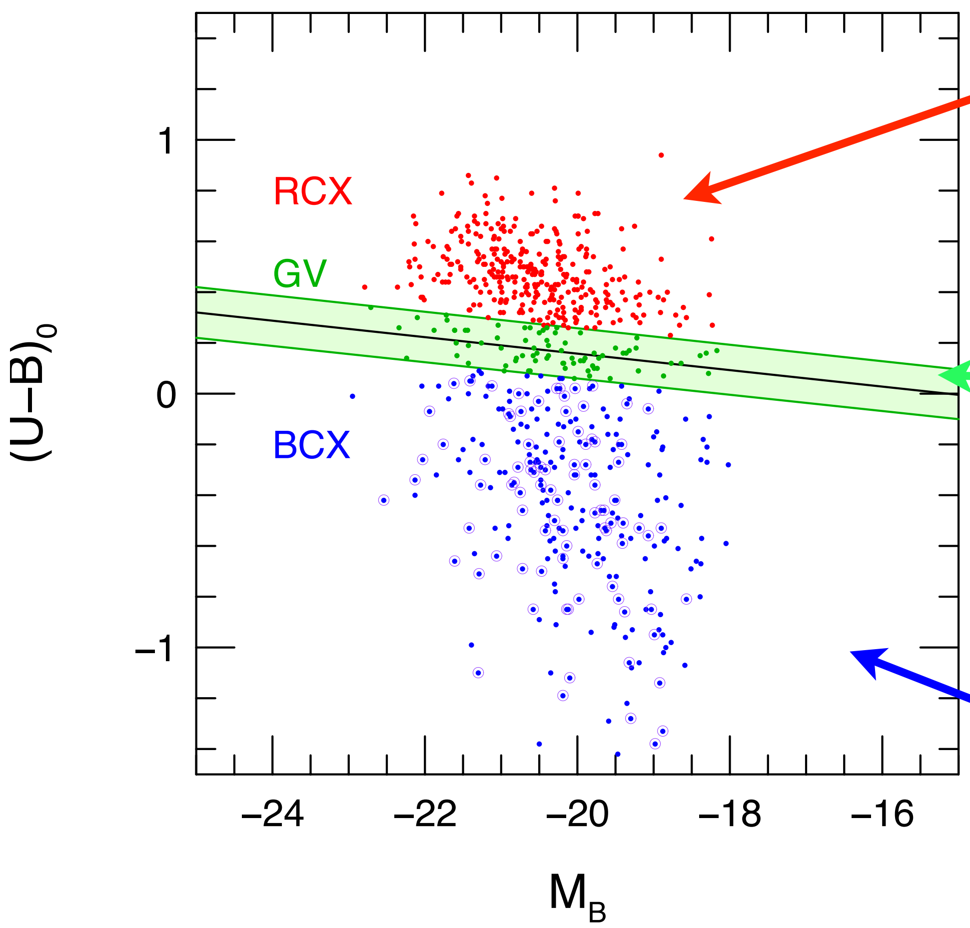
Different Scales



Green valley galaxies show a similar substructure as red sequence galaxies, but LCBGs show a strong peak at small numbers

Crawford et al. 2016

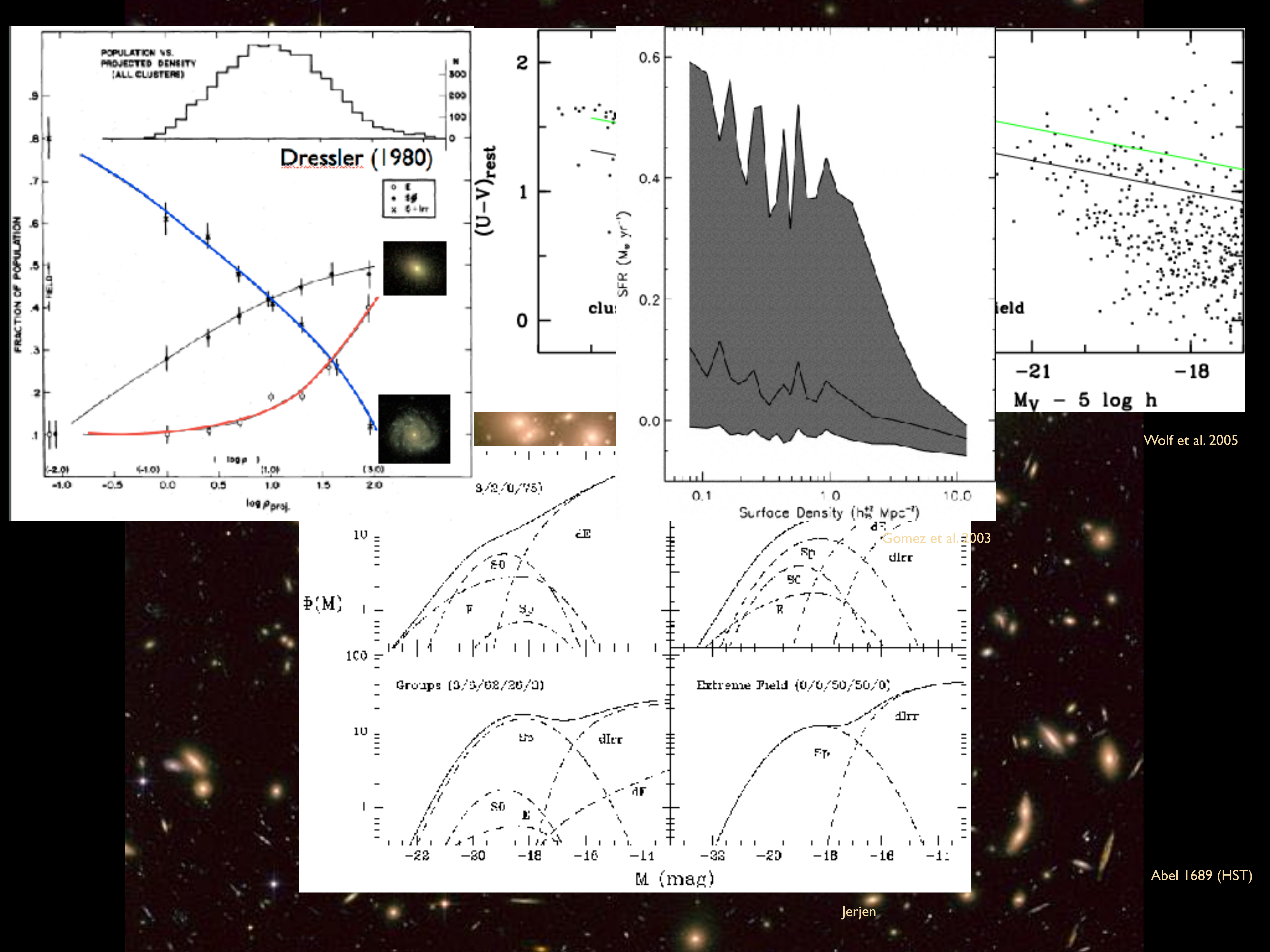
Other Populations



Red Sequence Galaxies

Green Valley Galaxies

Blue Cloud Galaxies



POPULATION VS.
PROJECTED DENSITY
(ALL CLUSTERS)
Dressler (1980)
FRACTION OF POPULATION
FIELD
log ρproj.
(U−V)rest
SFR (M☉ yr⁻¹)
Surface Density
Gomez et al. 2003
M_V − 5 log h
ield
Wolf et al. 2005
Φ(M)
Groups (3/5/62/20/0)
Extreme Field (0/0/50/50/0)
dE
S0
E
Sp
dIrr
M (mag)
Abel 1689 (HST)
Jerjen