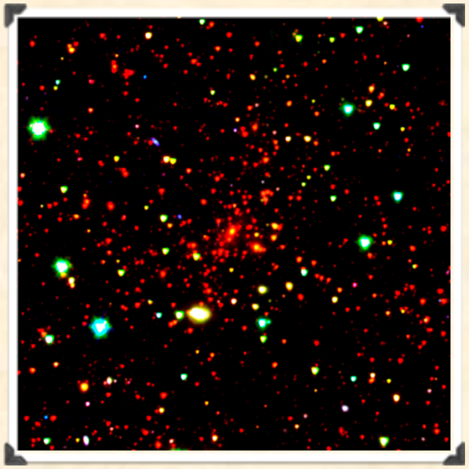
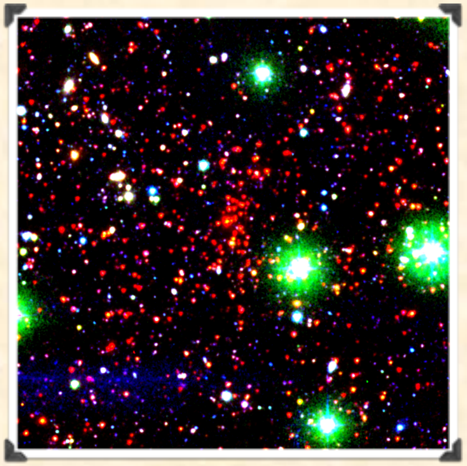
The Spitzer SpARCS z > 1 Cluster Survey



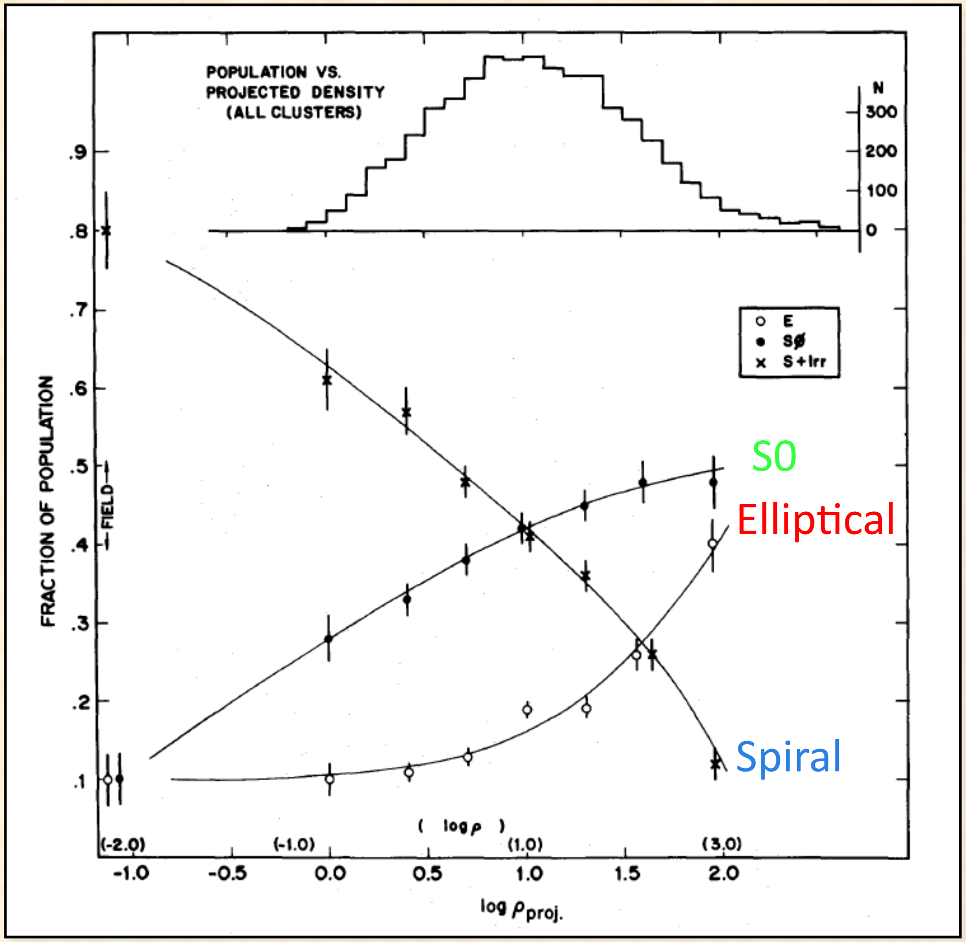
Gillian Wilson

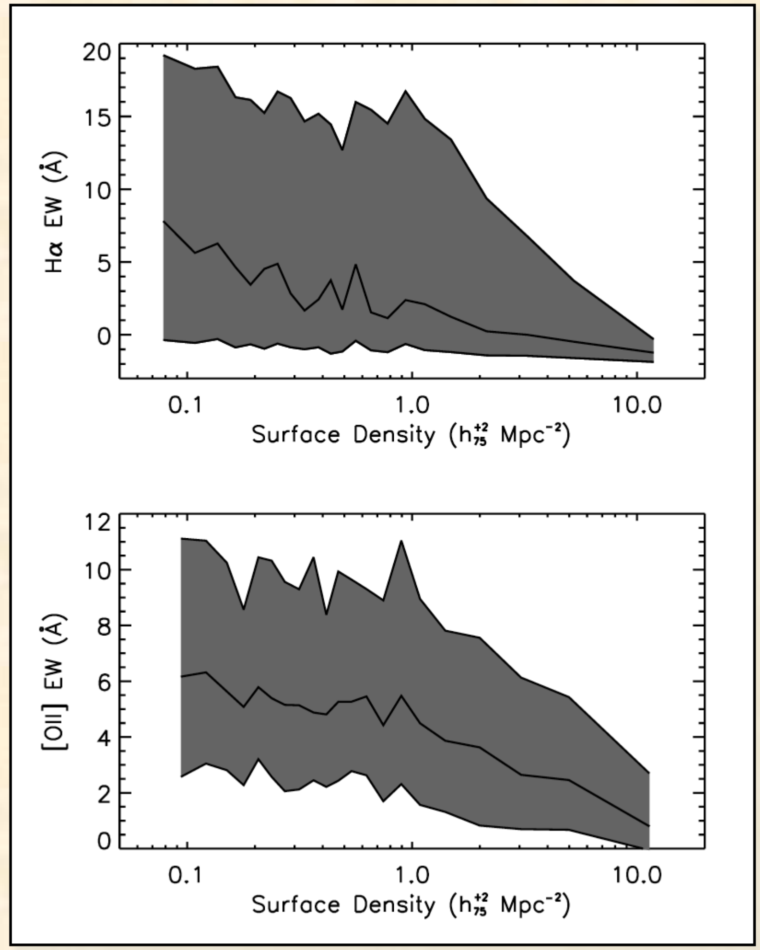
UC Riverside



Adam Muzzin (Leiden), Howard Yee (Toronto), Ricardo Demarco (Concepcion), Chris Lidman (AAO), Alessandro Rettura (UC Riverside), Michael Balogh (Waterloo), Douglas Burke (Chandra/CfA), Erica Ellingson (Colorado), David Gilbank (Waterloo), Hendrik Hildebrandt (UBC), Henk Hoesktra (Leiden), Mark Lacy (NRAO), J.-C. Mauduit (SSC/IPAC), Julie Nantais (Concepcion), Allison Noble (McGill), David Shupe (NHSC/IPAC/Caltech), Jason Surace (SSC/IPAC/Caltech), Eelco van Kampen (ESO), Ludovic van Waerbeke (UBC), Tracy Webb (McGill), Joseph Cox (UC Riverside), Joseph Cox (UCR), Andrew DeGroot (UC Riverside), Alireza Farahmandi (UC Riverside)

Environment Drives Galaxy Evolution





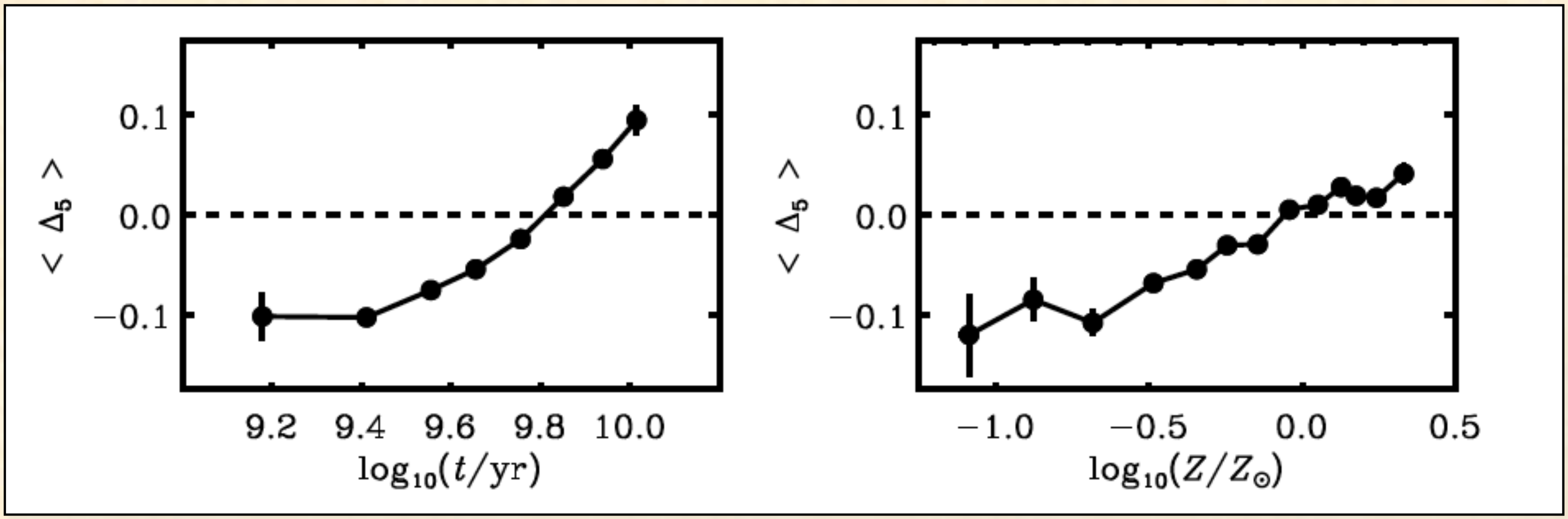
Morphology-Density

Dressler (1980)

Star Formation-Density

Gomez et al. (2003)

Environment Drives Galaxy Evolution

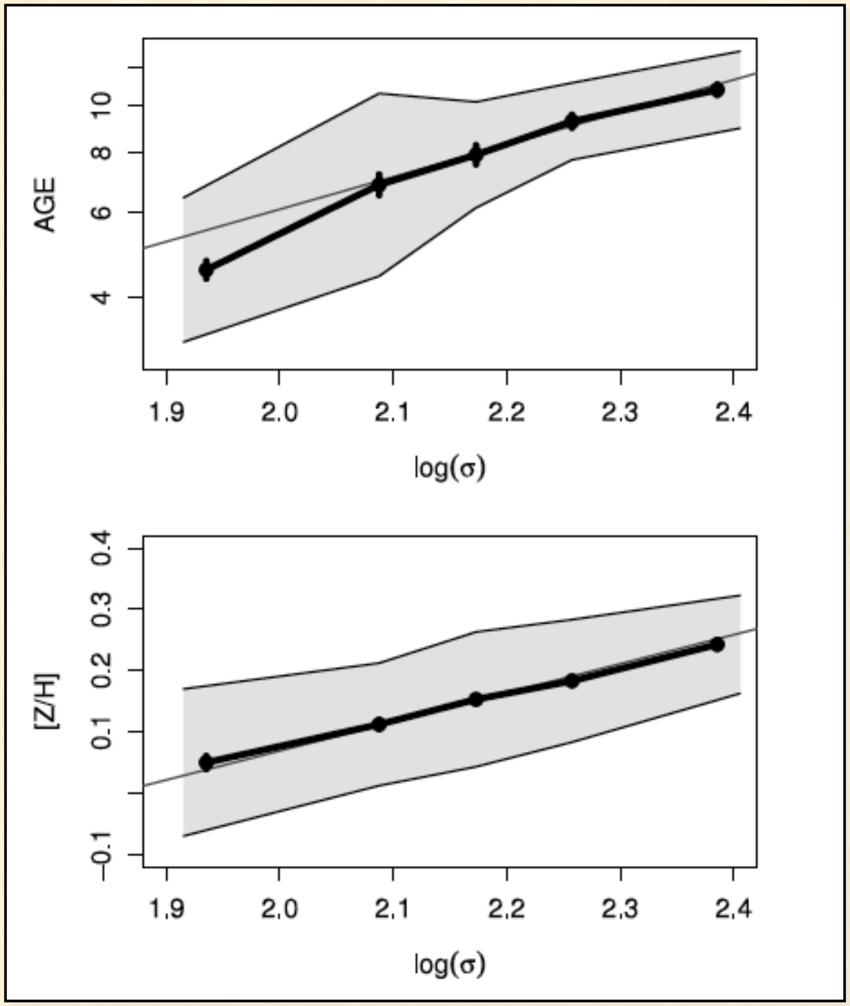


Age-Density

Metallicity-Density

Cooper et al. (2010)

Mass Drives Galaxy Evolution

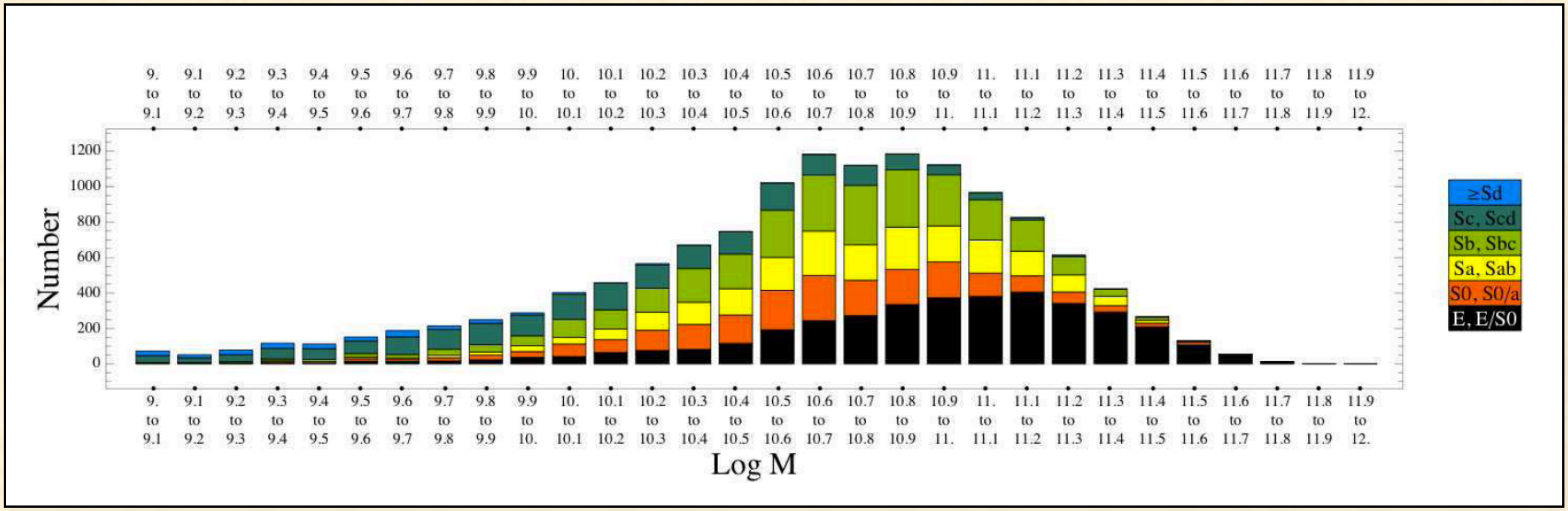


Nelan et al. (2005)

Age-Mass

Metallicity-Mass

Mass Drives Galaxy Evolution



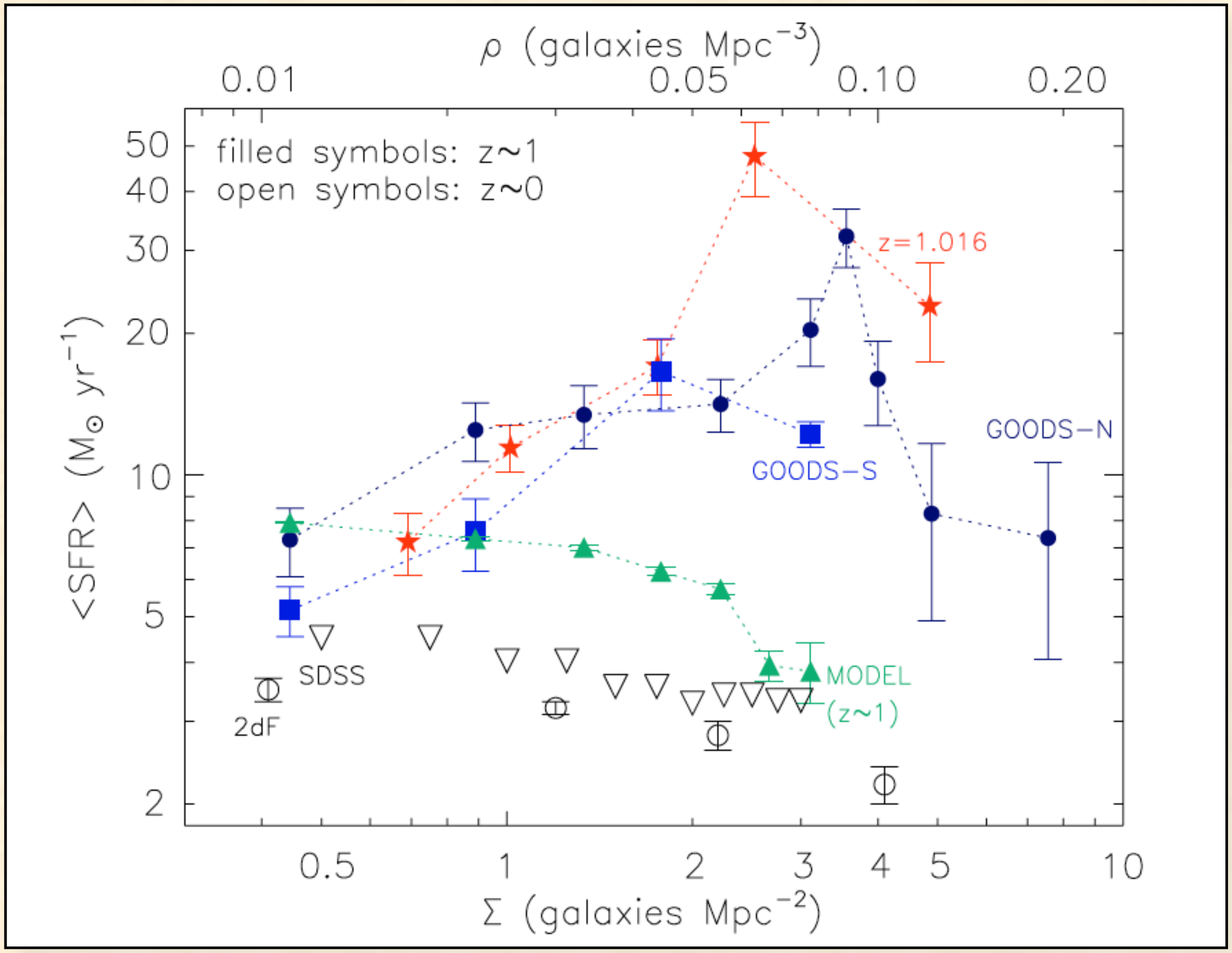
Nair et al. (2010)

Morphology-Mass

Galaxy Evolution

Mass versus environment
("nature" versus "nurture" debate)

The Effect of Environment at z = 1



"Reversal" of SFR-Density relation at z=1

Is the majority of SF at z=1 occurring in high-density regions?

Elbaz et al. (2007) (see also Cooper et al. 2008)

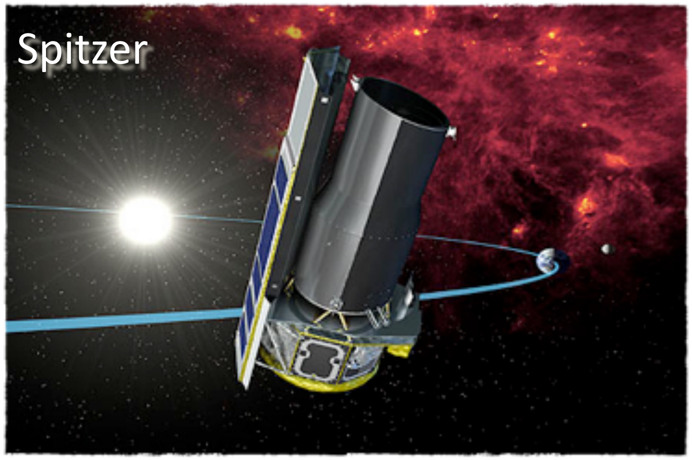
Existing z=1 field galaxy surveys cover only a few deg^2 - too small to sample highest–density environments

Alternative strategy :

Target known clusters

Need widefield surveys to find massive clusters

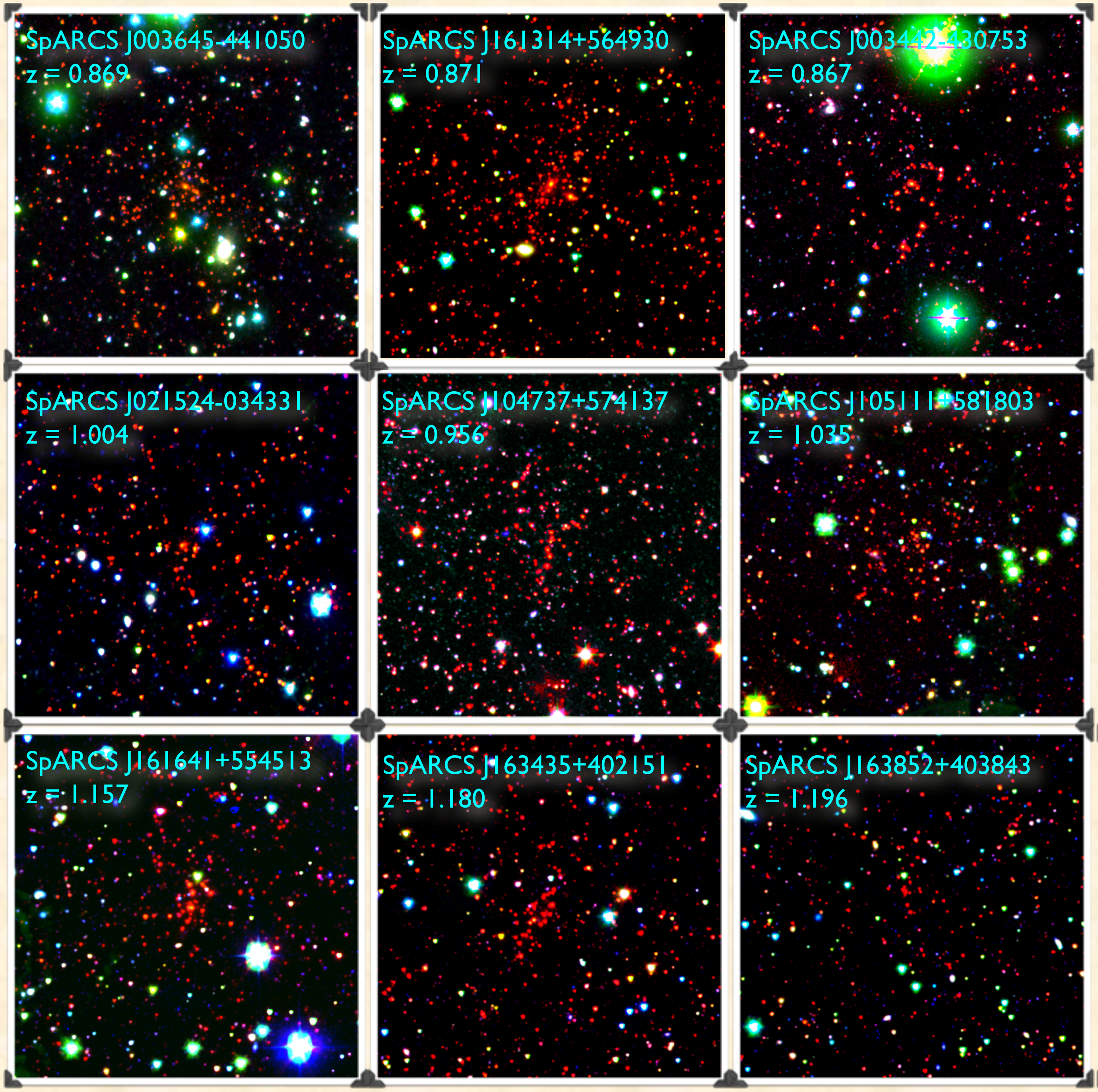
The SpARCS Survey



- Spitzer Adaptation of the Red-sequence Cluster Survey
- Deep-wide z'-band survey combined with SWIRE 50 deg^2 survey
- Clusters are selected based on z'-[3.6] color (gives photo-z)
- 200 new cluster candidates z > 1 with estimated M > 1 x 10^14 M_{Sun}

SAMPLES OF CLUSTERS !!

Wilson et al. (2009), Muzzin et al. (2009), Demarco et al. (2010)



Ten of the most massive halos at z=1 from 50 deg^2

The GCLASS Survey (PIs Wilson/Yee)

- Spectroscopic survey of 10 rich clusters at z ~ 1 (0.87 < z < 1.34) with Gemini/GMOS

- The Gemini Cluster Astrophysics Survey "GCLASS"

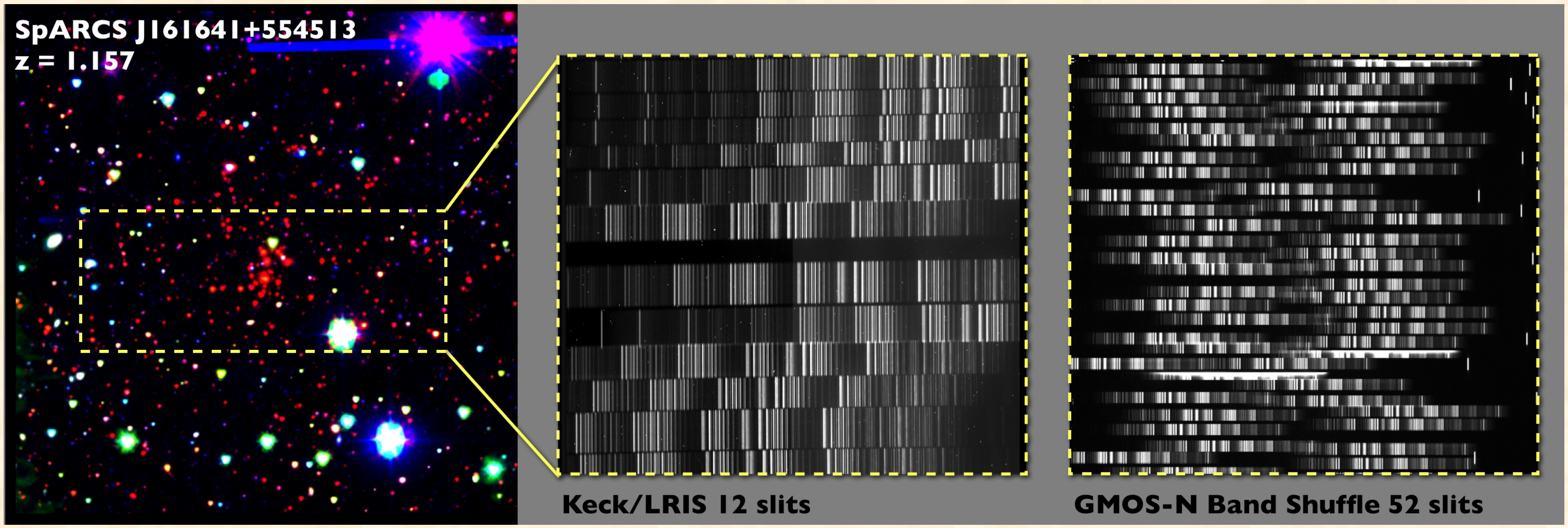
- Low-res: R=450 =17Å = 400km/s
- 4 to 6 masks per cluster (45 total)
- 3.6um selected sample of galaxies

- Nod + Shuffle mode with microslits

- Observational goal: Spectroscopy of **50 members** in each cluster(!)

- 222 hr (25 night) multi-semester project with Gemini/GMOS (completion 2011B)

Gemini/GMOS Nod & Shuffle: An Efficient Redshift Machine



MOS observation of the yellow region from a Keck/LRIS mask using standard length (~10") slits, and a band-shuffle mask on GMOS. More than 4x more slits can be placed within the cluster virial radius using GMOS vs. LRIS, a significant improvement in efficiency.

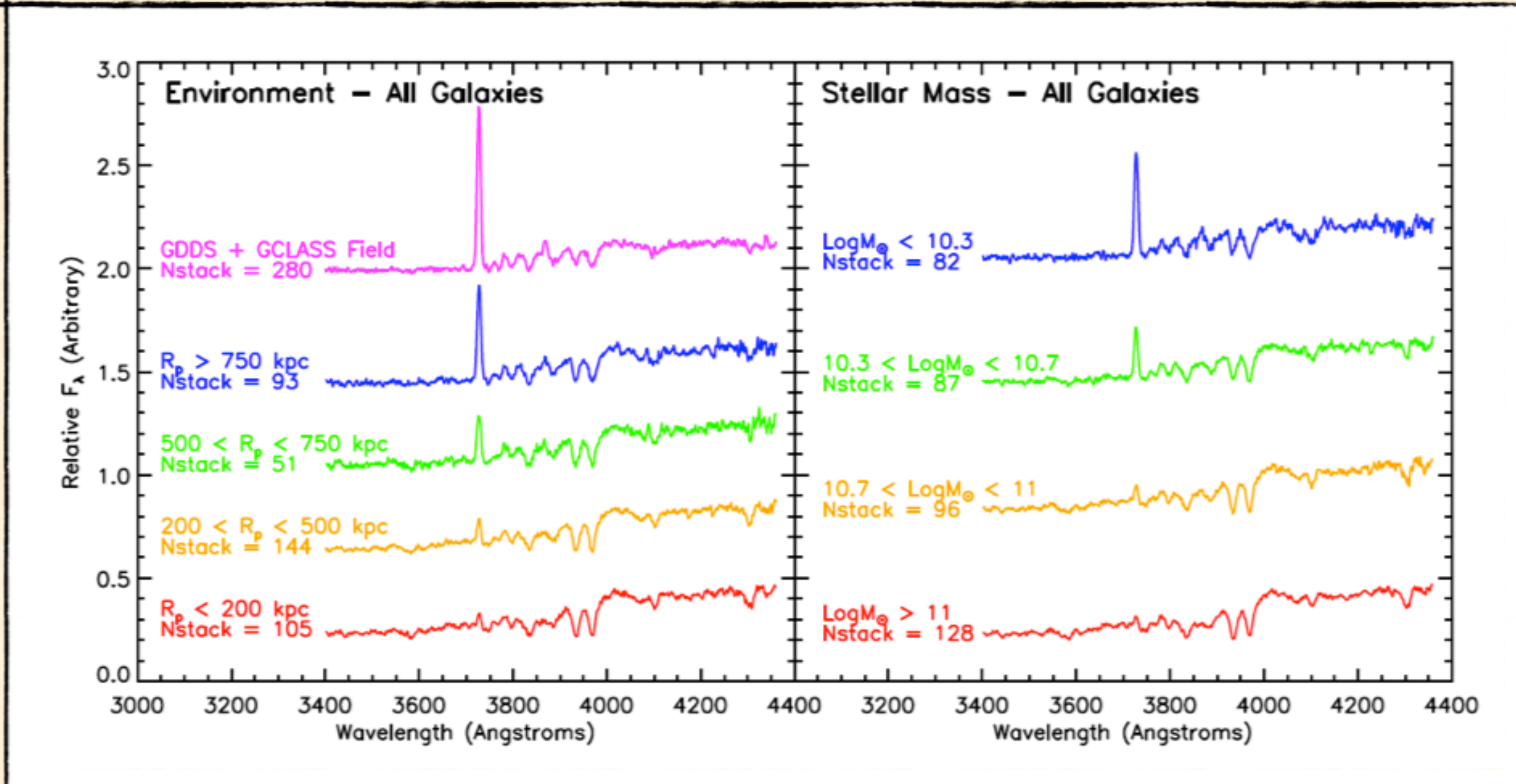
Table 1: The GCLASS sample of clusters

Name	Redshift	σ (km s^{-1})	M_{200}^{σ} ($\times 10^{14} M_{\odot}$)	# members
SpARCS J003645-441050	0.867	780 ± 80	5.1 ± 1.6	**45**
SpARCS J003442-430753	0.869	920 ± 90	8.4 ± 2.6	**47**
SpARCS J161314+564930	0.871	1380 ± 100	28.7 ± 6.3	**92**
SpARCS J104737+574137	0.956	860 ± 170	6.3 ± 3.9	**31**
SpARCS J021524-034331	1.004	560 ± 60	1.7 ± 0.6	**48**
SpARCS J105111+581803	1.035	490 ± 80	1.1 ± 0.6	**34**
SpARCS J161641+554513	1.156	710 ± 80	3.2 ± 1.1	**46**
SpARCS J163435+402151	1.177	800 ± 90	4.5 ± 1.5	**50**
SpARCS J163852+403843	1.196	650 ± 60	2.4 ± 0.7	**44**
SpARCS J003550-431224	1.335	1050 ± 230	9.4 ± 6.2	20

2 masks in 2011B queue

Wilson et al., in prep

No “Reversal of SFR-Density Relation” in z=1 Clusters



Stacked spectra (~500 members), as a fn of clustercentric distance (left) and SM (right).

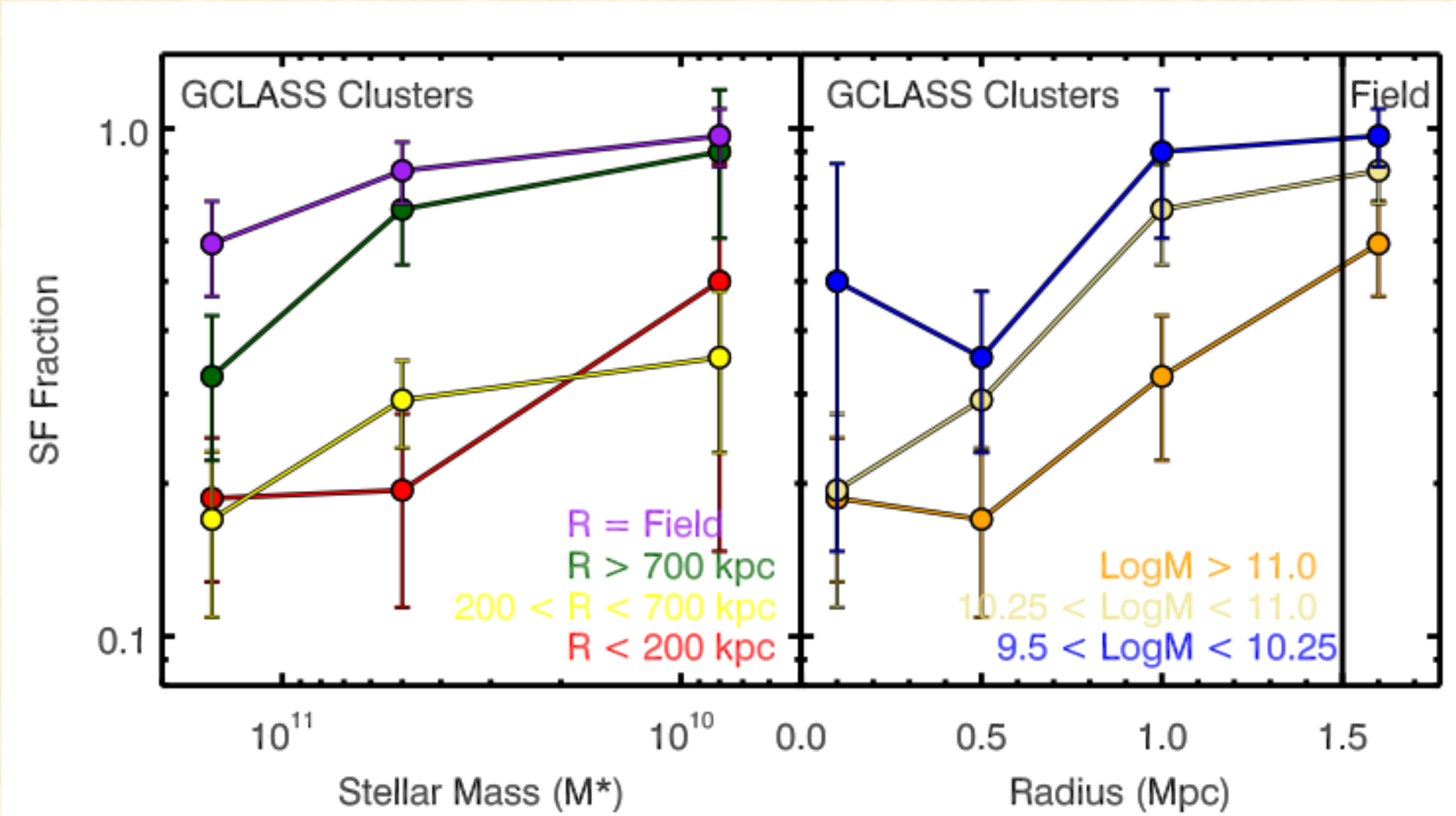
Muzzin et al., in prep

Star formation decreases with increasing density (left) and increasing mass (right)

At z~1, galaxies are strongly influenced both by environment AND stellar mass.

Effect of Environment and SM on SF Fraction:

SF fraction as a function of SM in four environments (left) and as a function of environment for three SMs (right)

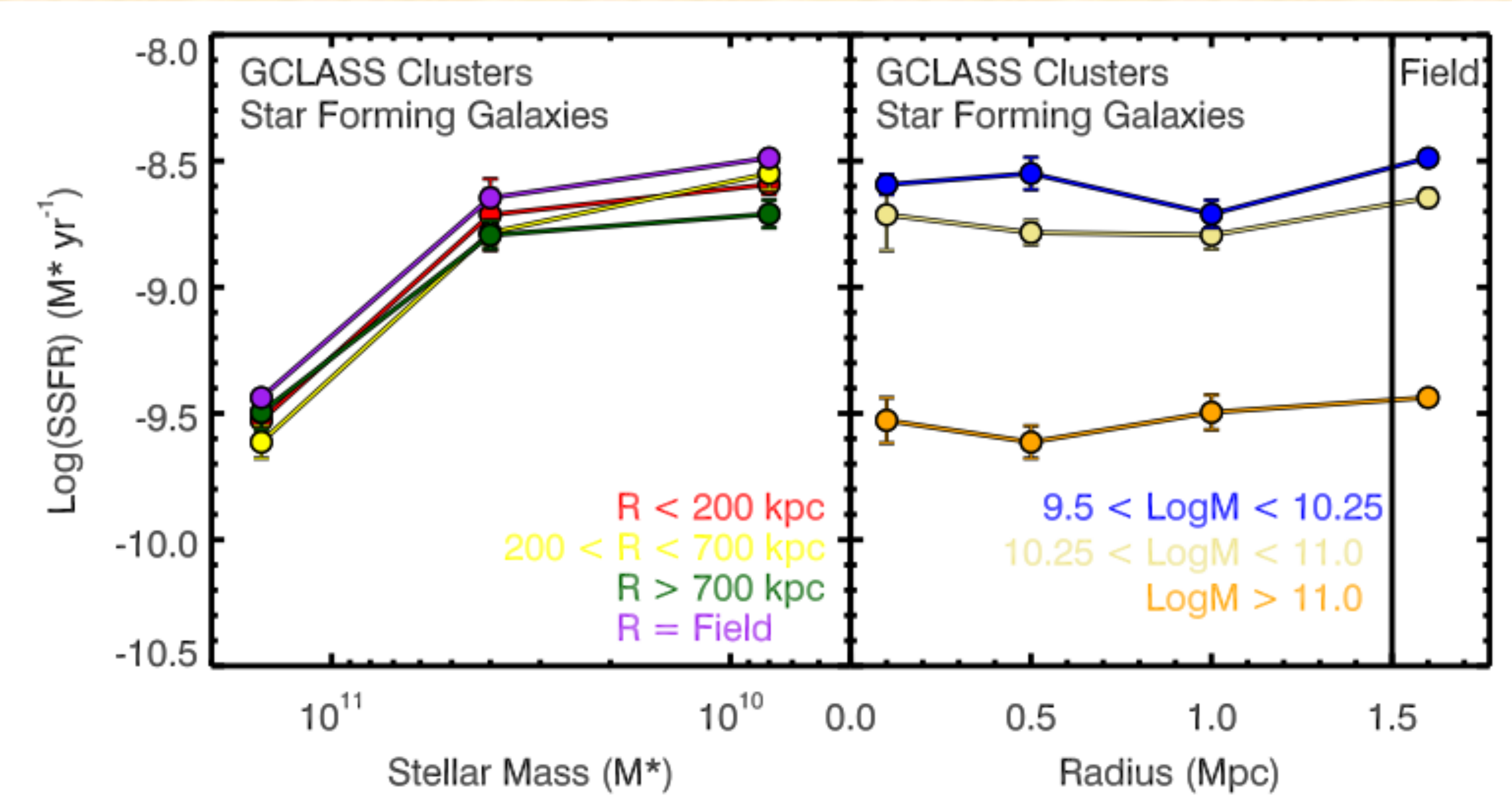


Even at fixed environment (left), the SF fraction is correlated with SM
& at fixed SM (right), the SF fraction is correlated with environment

Both environment and SM play an important and causal role in quenching of galaxies at z=1

Separation of Environmental and SM Evolution:

SSFR of SF galaxies as a function of SM in four environments (left) and as a function of environment for three SMs (right)



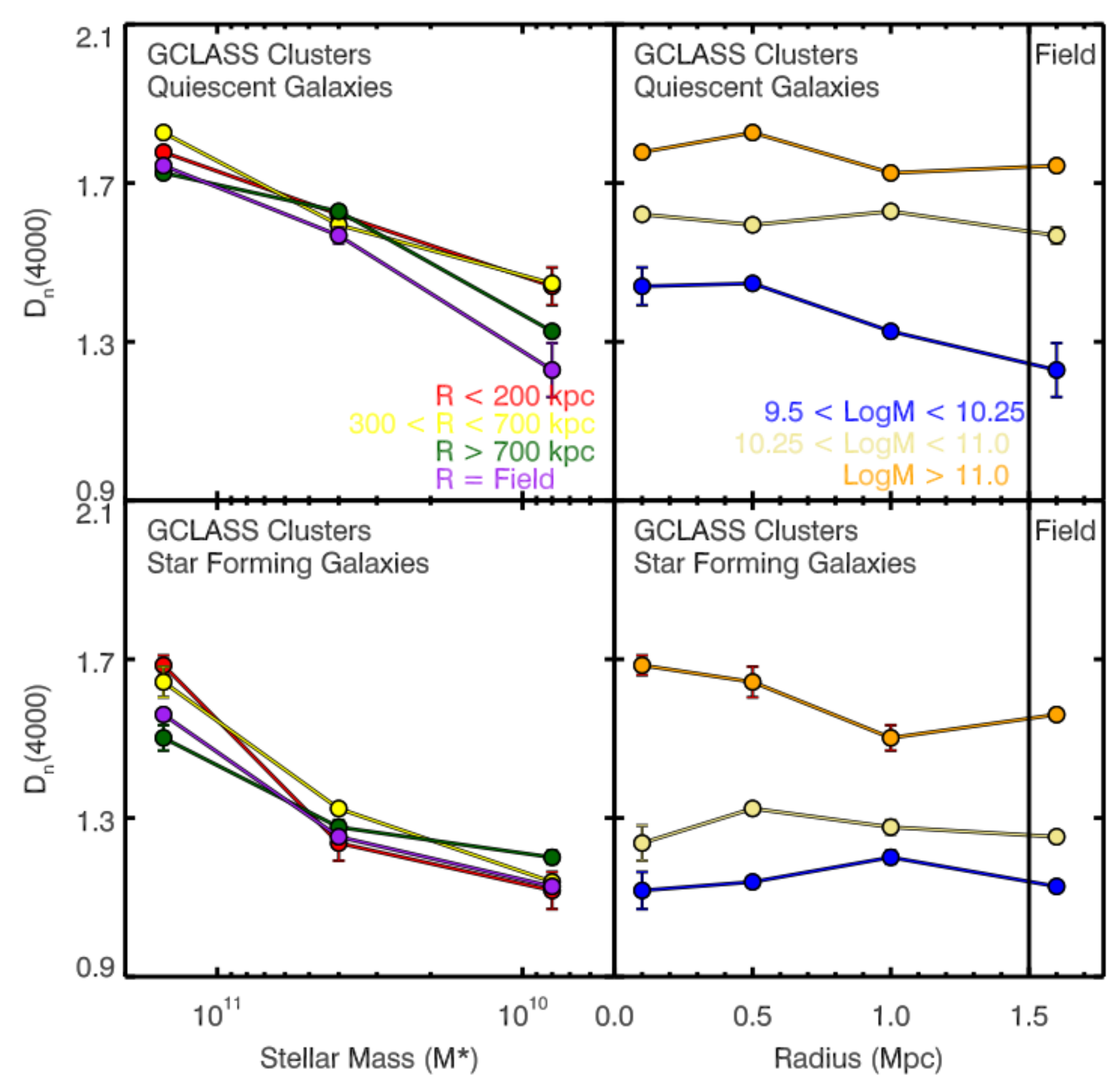
SSFR is correlated with SM in all environments; but is independent of environment for all SMs

Stellar mass is the primary factor determining SSFR of SF galaxies

See also Balogh et al., 2004, Kauffmann et al., 2004, Peng et al., 2010

Separation of Environmental and SM Evolution:

D4000 of quiescent (upper) and SF (lower) galaxies as a function of SM in four environments (left) and as a function of environment for three SMs (right)



D4000 is correlated with SM in all environments; but is independent of environment for all SMs

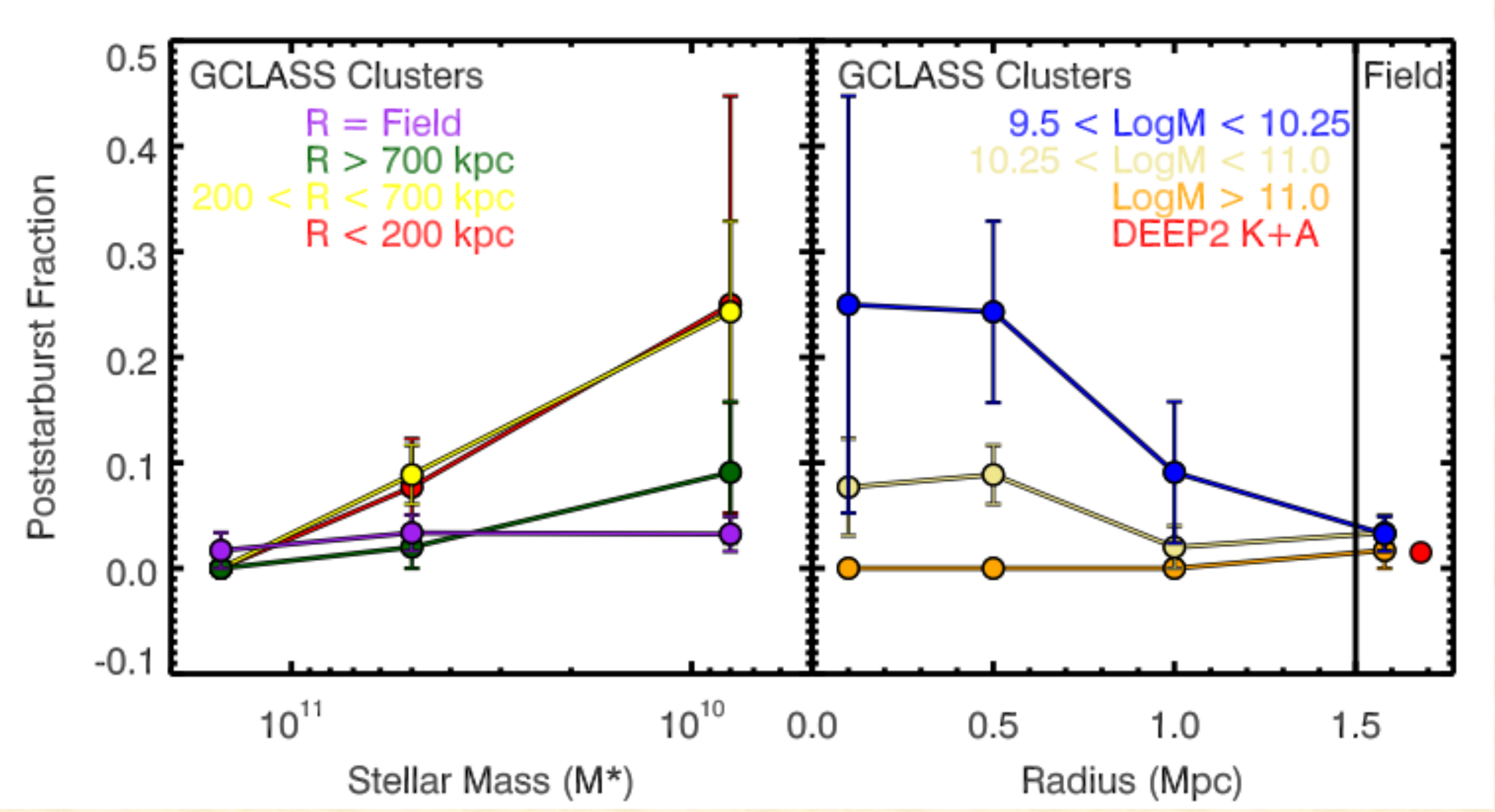
Stellar mass is the primary factor determining age of a galaxy

What does environment do?

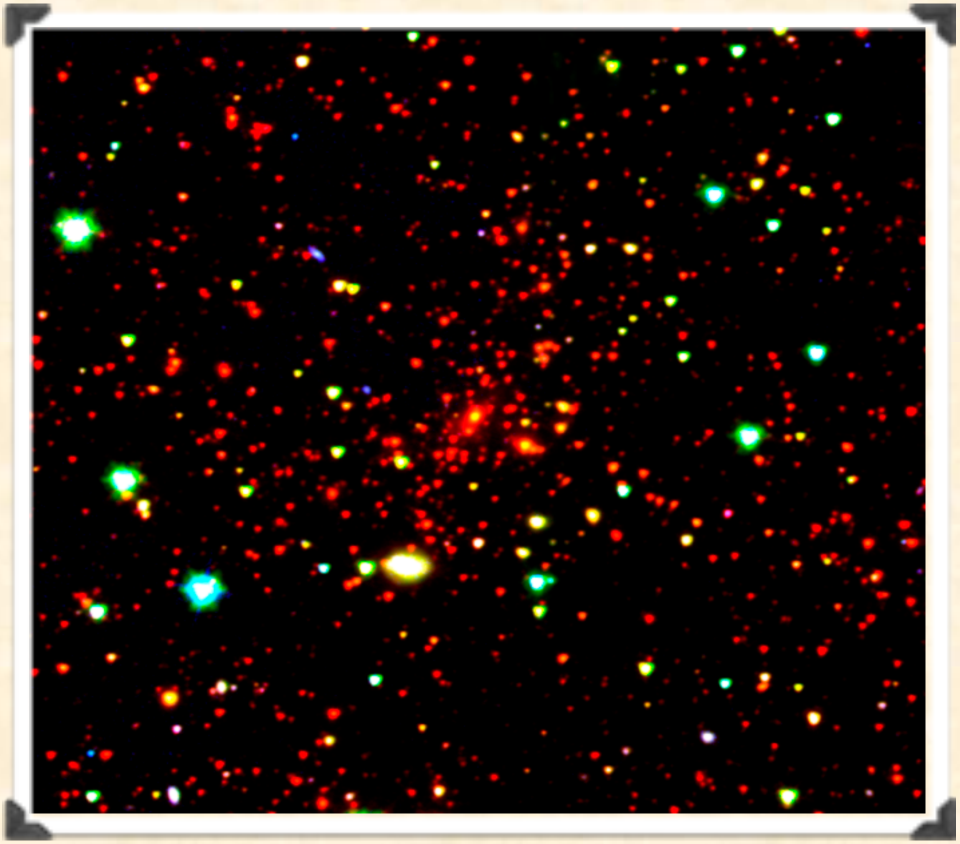
It quickly quenches SF in galaxies, rapidly transforming SF galaxies into quiescent galaxies

It must be a rapid process because no dependence of the SSFR of SF galaxies on environment is seen => environmental quenching moves galaxies out of the SF classification and into the quiescent classification before a drop in their SSFRs is measured

Corroborating Evidence from Poststarburst Population



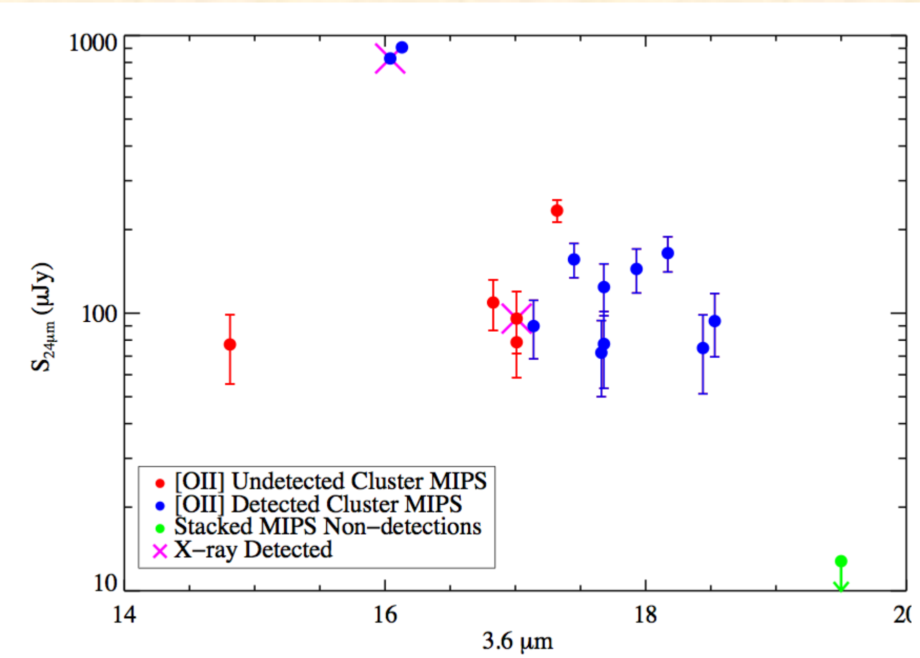
Case Study 1 : 24 micron analysis of massive GCLASS cluster at z=0.871 (SpARCS J161314+564930)



- 92 spectroscopic members
- Deep MIPS imaging (~70 uJy)
- vd ~1400 km/s

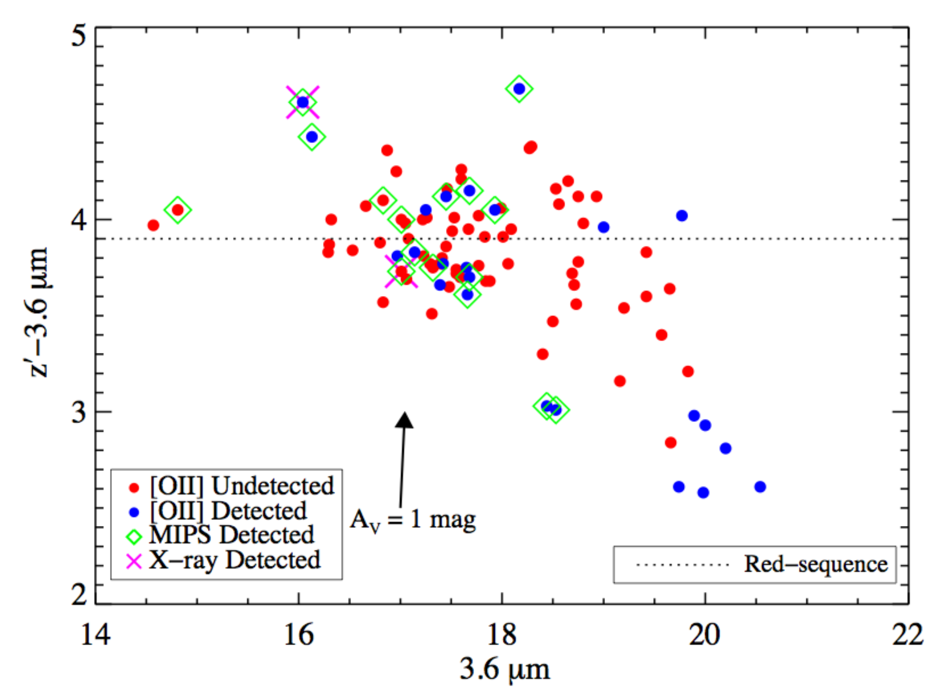
Noble et al., in prep

16 MIPS-detected spectroscopic members

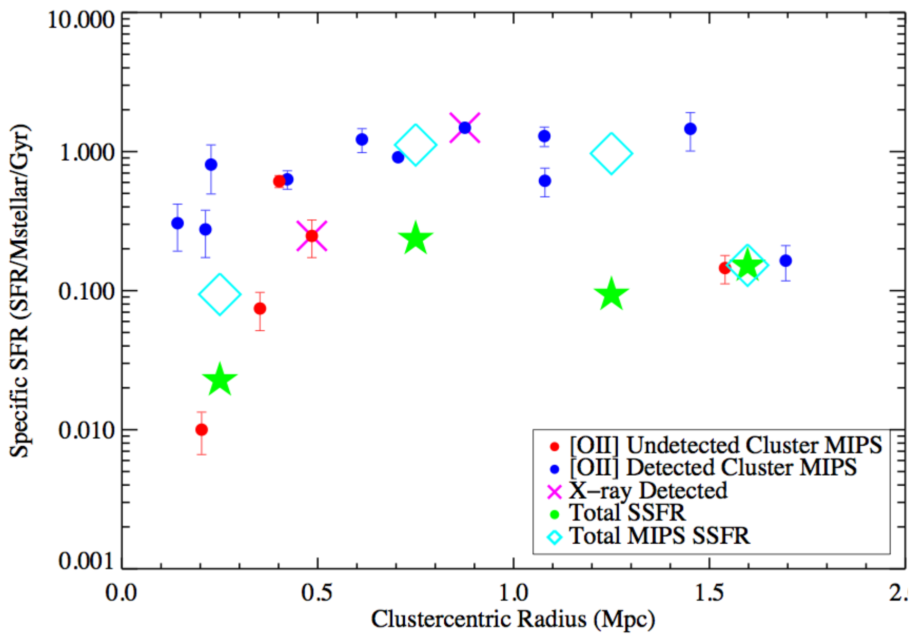


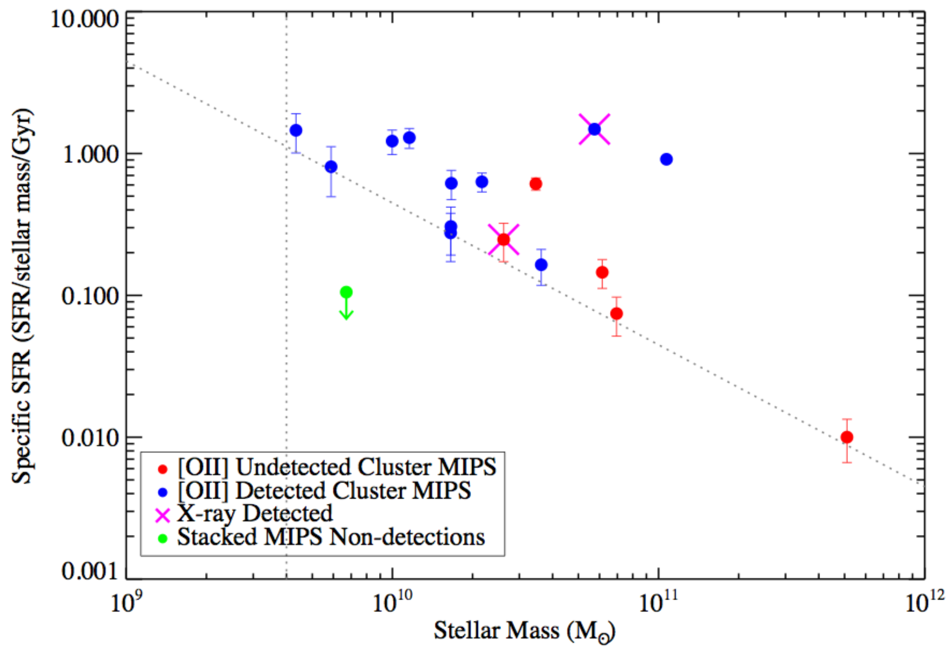
24 micron flux vs. [3.6] mag

z'-[3.6] vs. [3.6] color-mag diagram



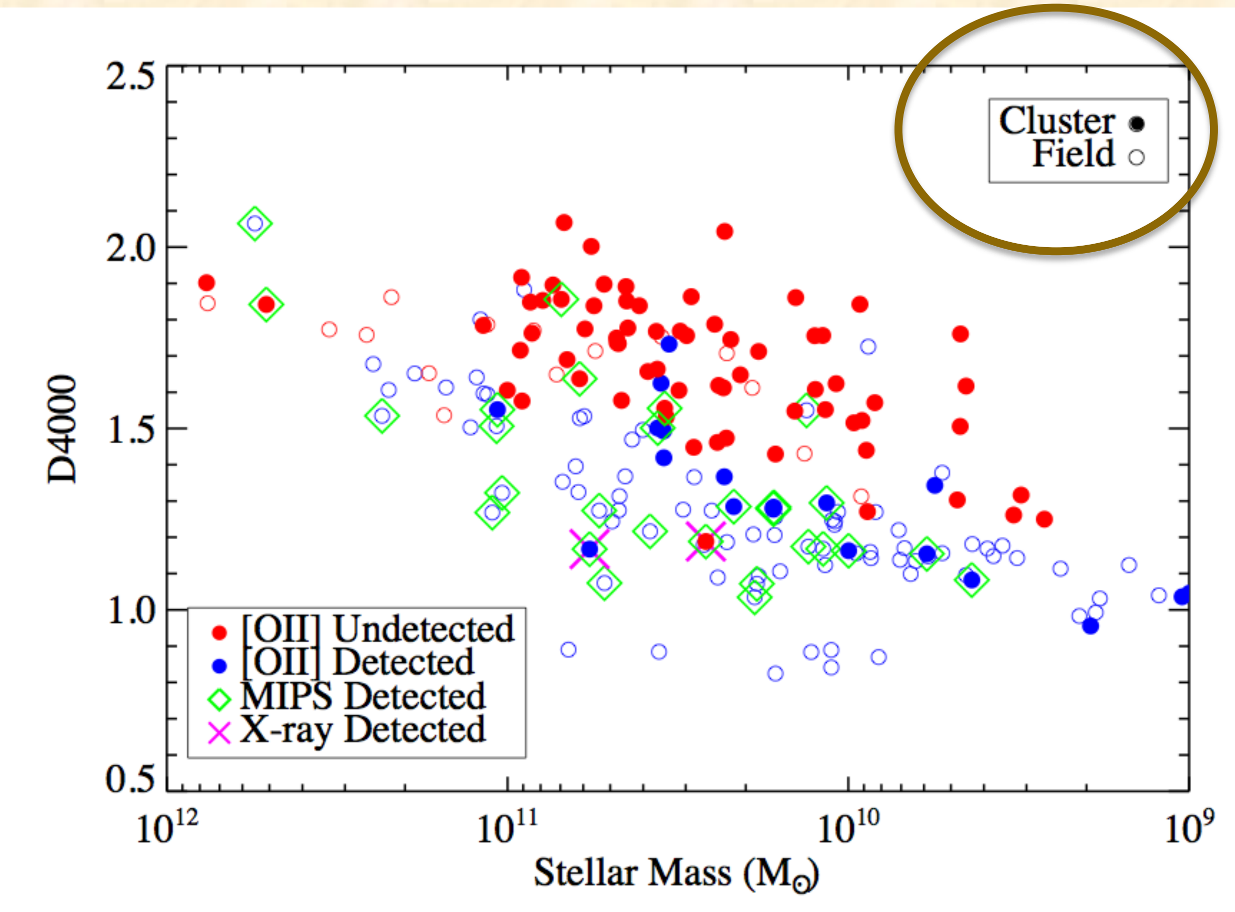
24 micron-inferred SSFR vs Radius/Density and SM





SSFR decreases with increasing density and increasing SM

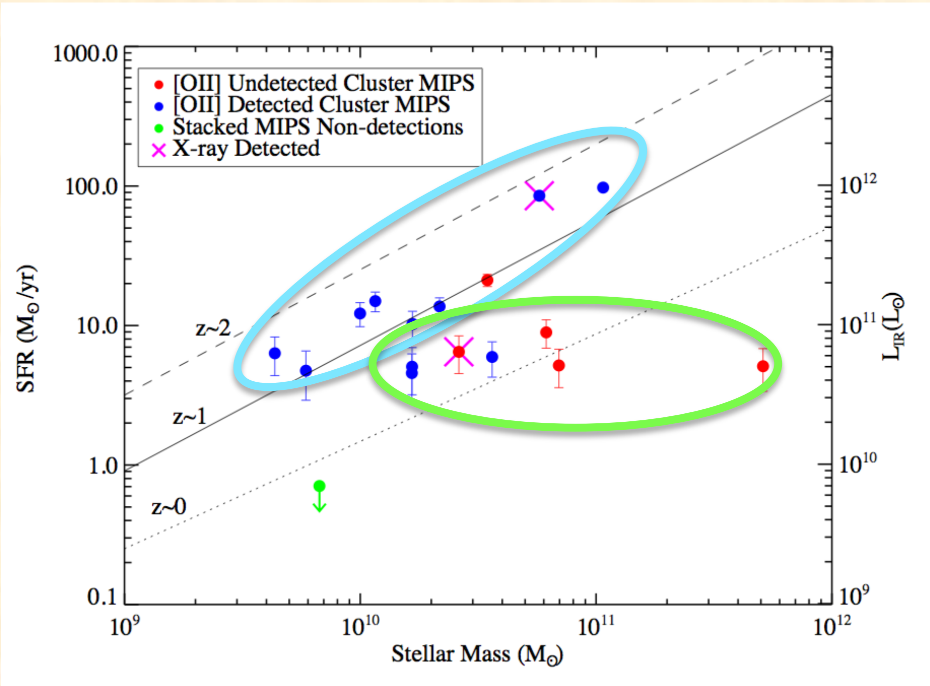
MIPS cluster members with [OII] emission likely recently accreted from field



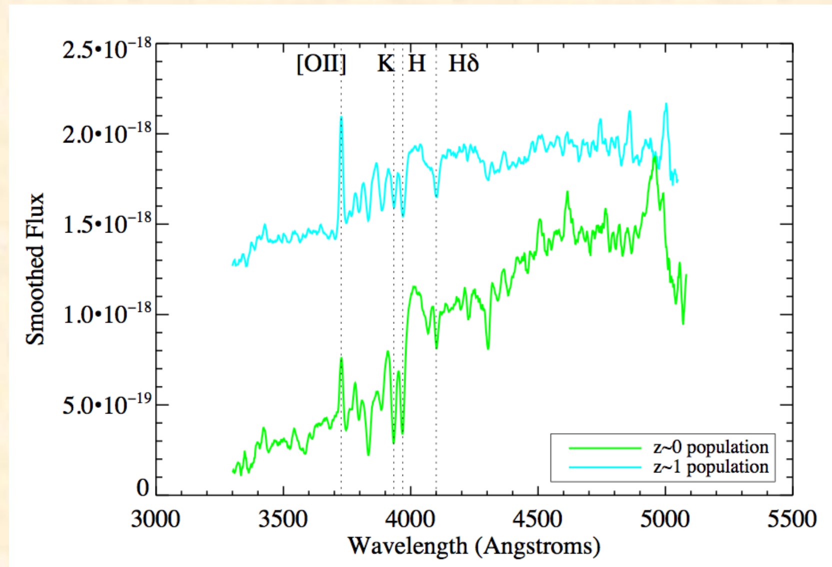
MIPS-detected cluster members with [OII] emission have similar D4000s and SMs as GCLASS z=1 field galaxies

Bimodal Distribution in SFR vs SM

Lower (higher) SM members coincident with z~1 (z~0) FIELD population



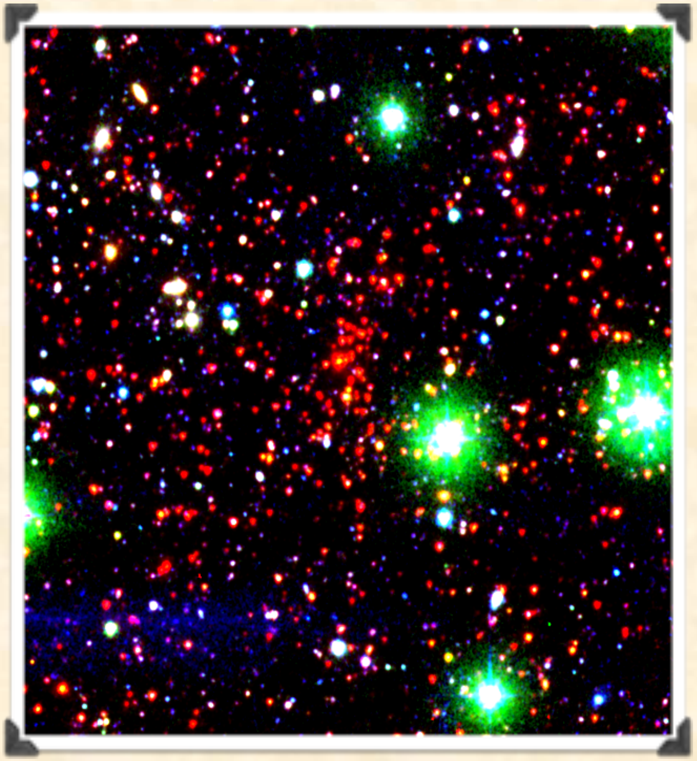
Stacked cluster spectra



Stack of cluster members coincident with z~1 field galaxy population has strong [OII] emission and deep H-delta absorption => infall galaxies recently accreted from field

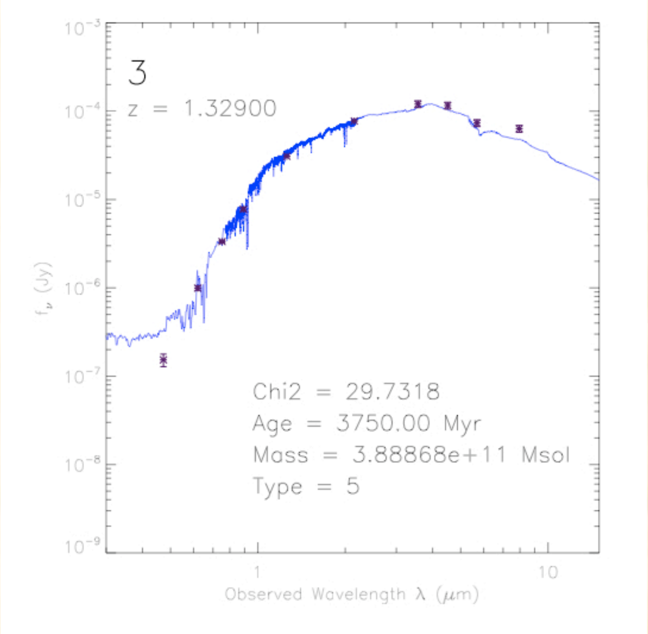
Stack of cluster members coincident with z~0 field galaxy population has weak [OII] emission and shallow H-delta absorption => poststarburst galaxies quenched by cluster environment

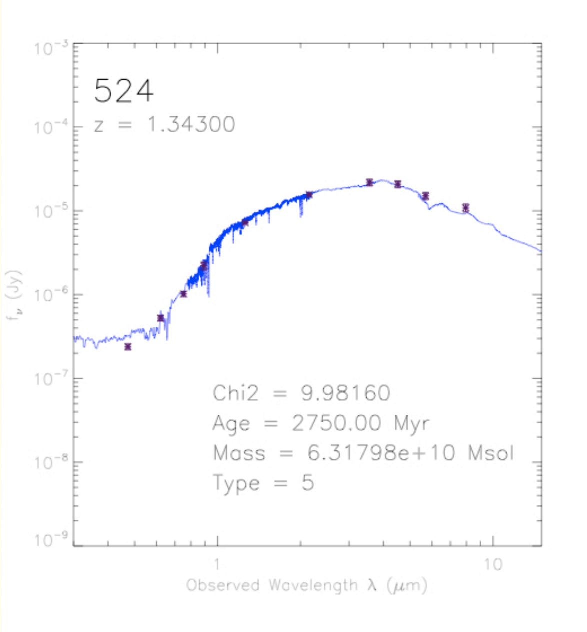
Case Study 2 :Multiwavelength analysis of highest-z GCLASS cluster at z=1.335 (SpARCS J003550-431224)



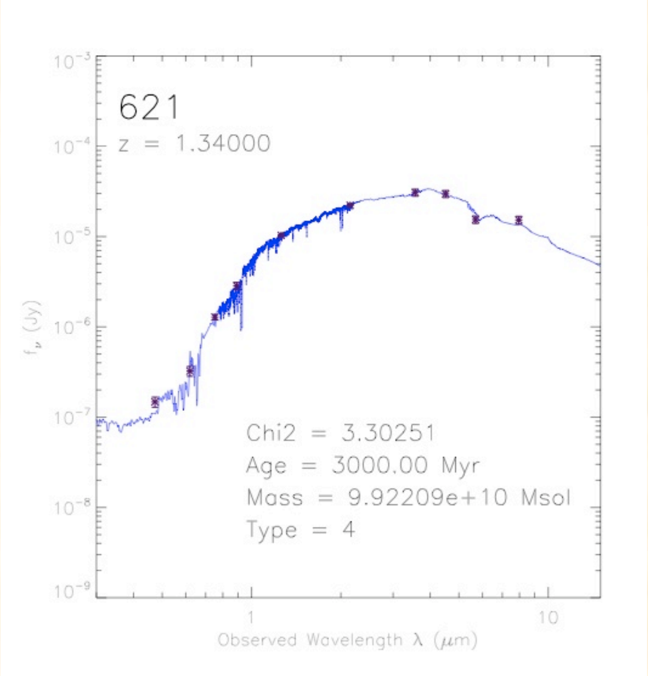
- 20 spectroscopic members
  (2 masks in 2011B Gemini/GMOS queue)
- Magellan/IMACS u’g’r’i’
- CTIO/MOSAICII z’ (Wilson et al. 2009)
- VLT/HAWK-I J, Ks
- Deep Spitzer IRAC/MIPS

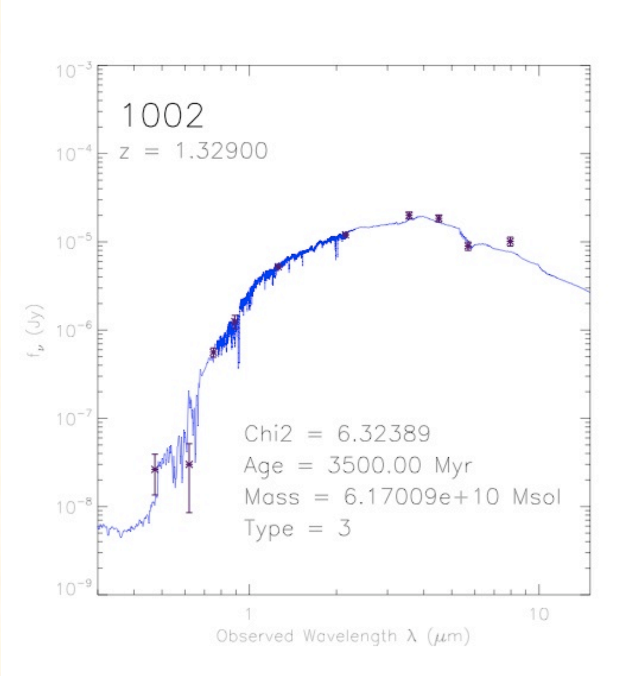
Rettura et al., in prep

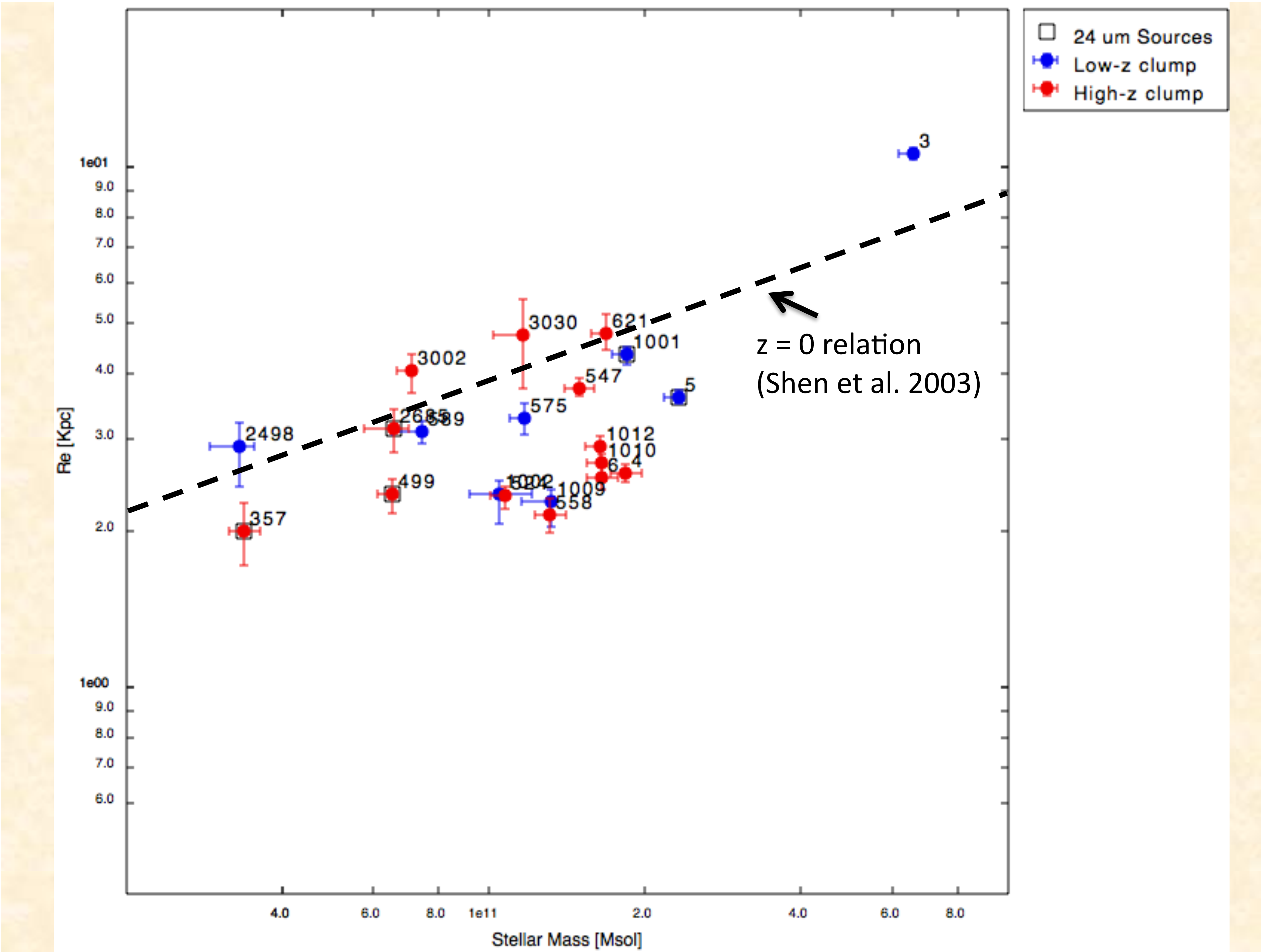




Examples of Stellar Population Fitting

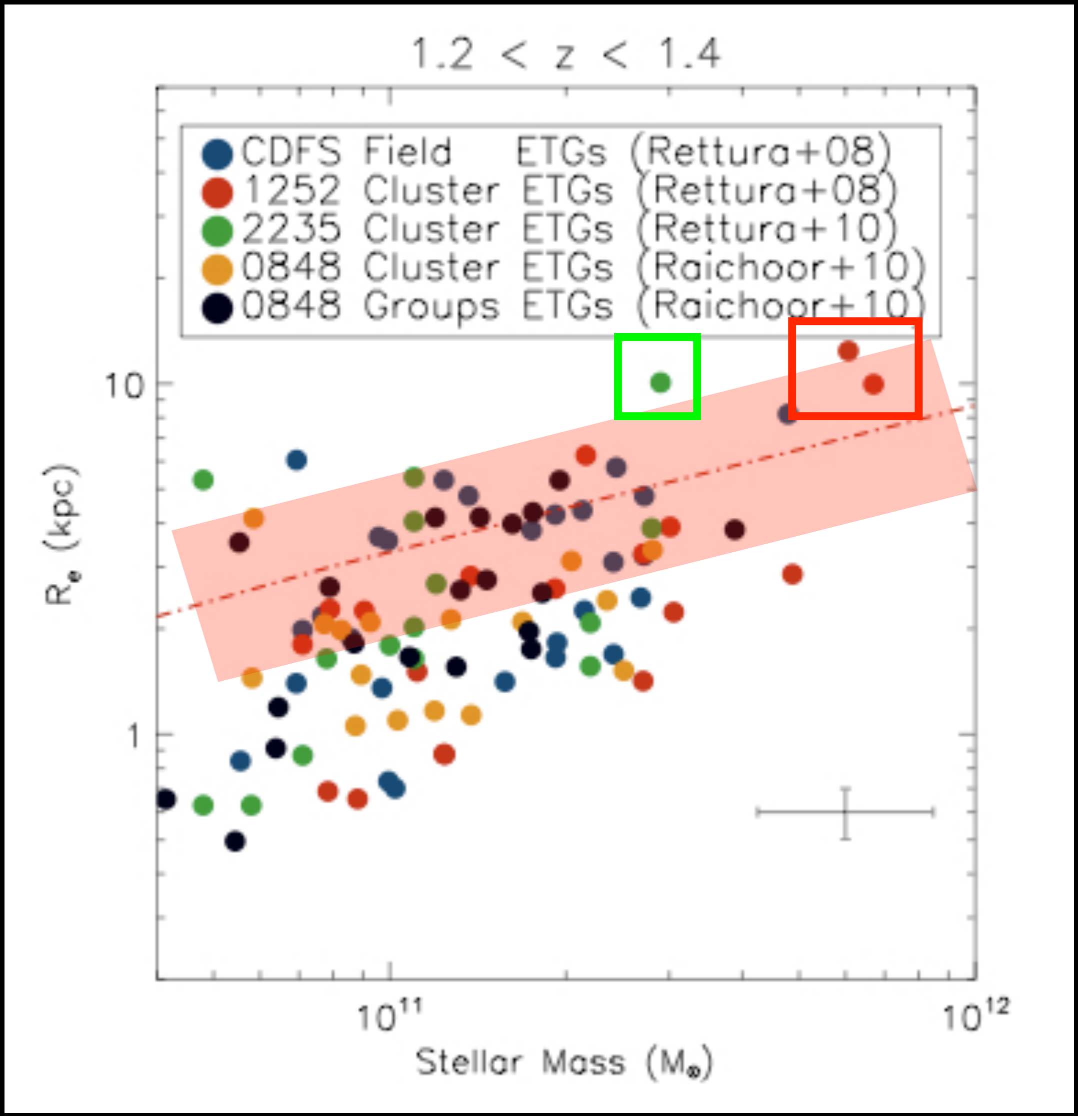






24 um Sources
Low-z clump
High-z clump
Re [Kpc]
Stellar Mass [Msol]
z = 0 relation
(Shen et al. 2003)
3
3030
621
1001
3002
547
5
575
2498
1012
1010
499
1009
558
357

Cluster vs. Groups vs. Field:
Stellar Mass-Size relations of ETGs at 1.2 < z < 1.4



BCGs have their Masses and Sizes already in place at z~1.2-1.4

Posters - #41 & #23

Andrew DeGroot: SpARCS Five-passband Photometric Catalog

Alireza Farahmandi: Dusty Star Formation in Clusters and in the Field at z < 0.5