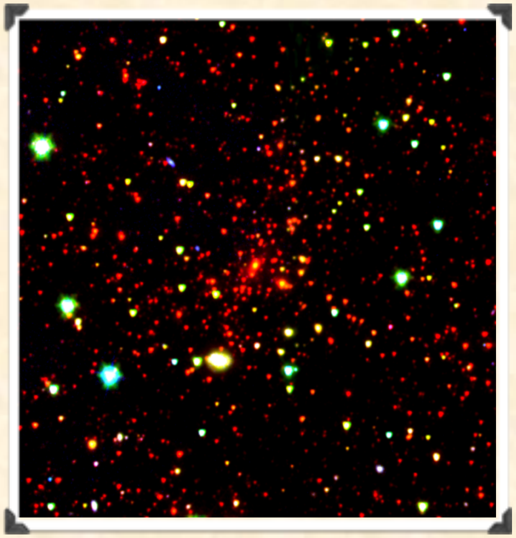
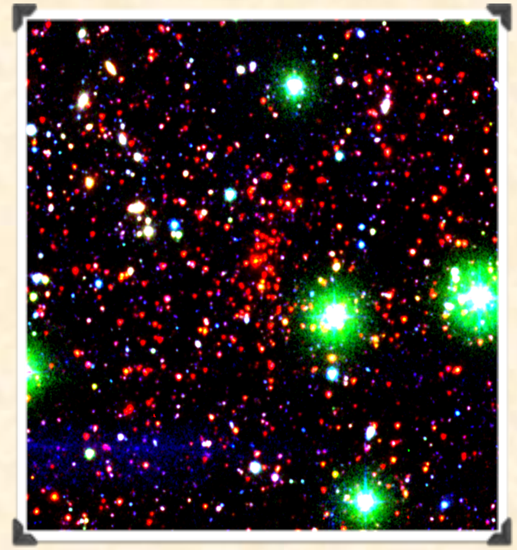
The Role of Environment in Transforming Galaxies across Cosmic Time



Gillian Wilson

UC Riverside



SpARCS Collaboration

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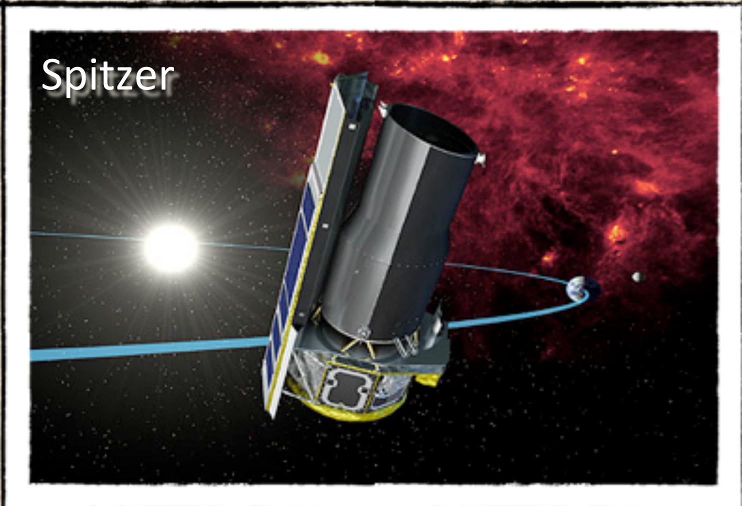
The SpARCS Survey



- Deep-wide z'-band survey combined with Spitzer SWIRE 50 deg^2 survey

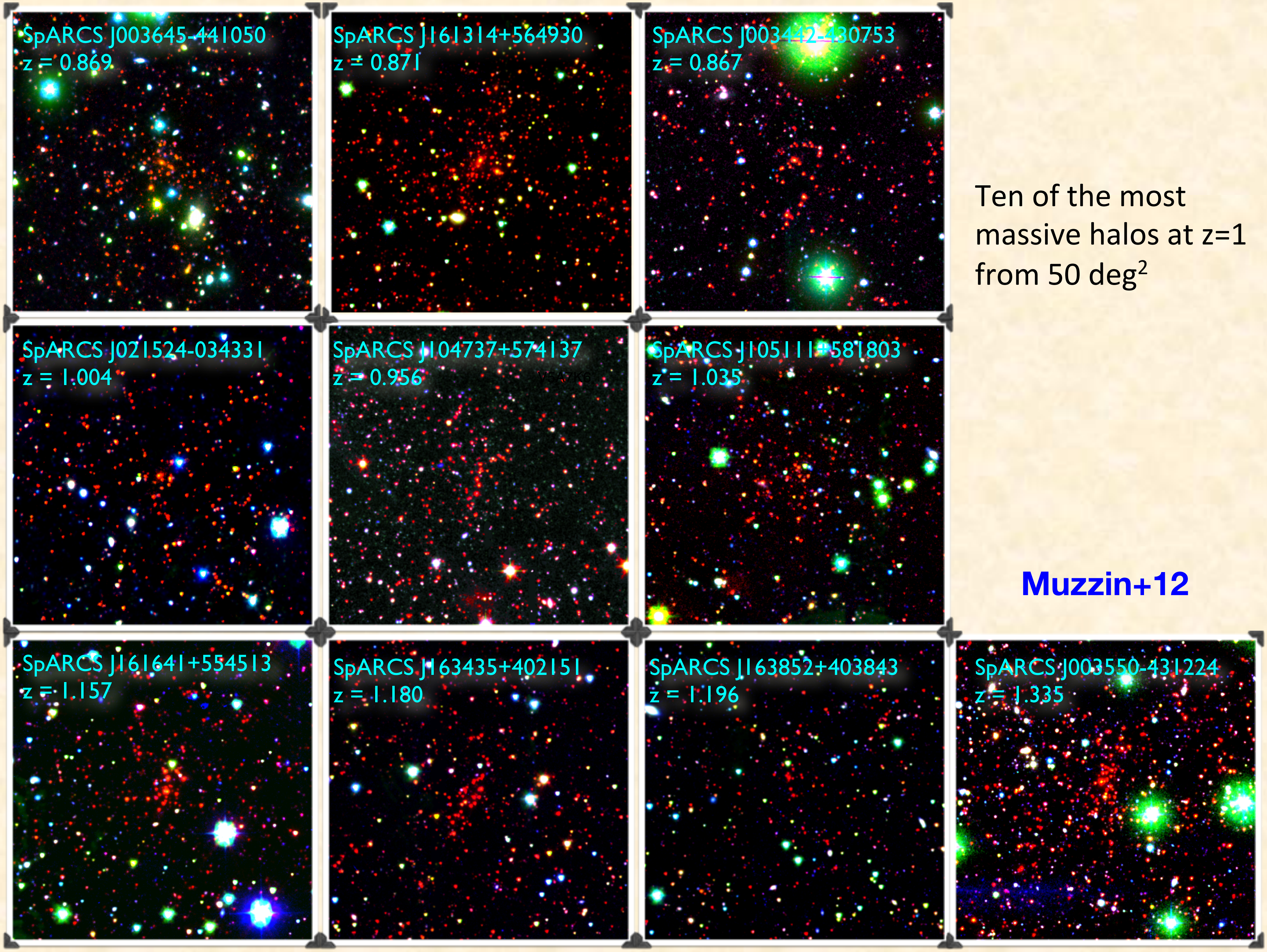
- 200 new cluster candidates z > 1
  (with M > 1 x 10^14 M_{sun})

SAMPLES OF CLUSTERS !!

- > 20 publications so far

Wilson+09, Muzzin+09

$z \sim 1$

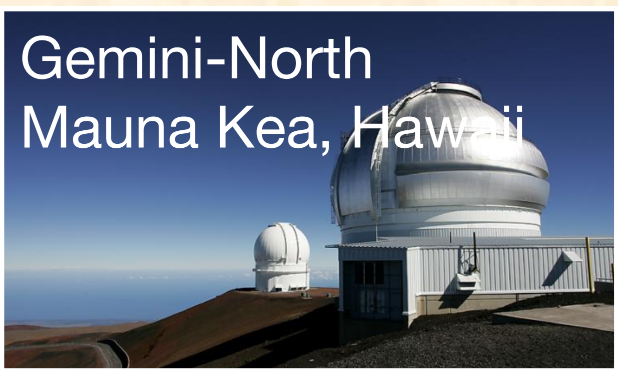


Ten of the most massive halos at z=1 from 50 deg^2

Muzzin+12

The GCLASS Survey (PIs Wilson/Yee)
25 night Gemini spectroscopic program

- 10 SpARCS z~1 clusters
- Total of 500 spectroscopic members

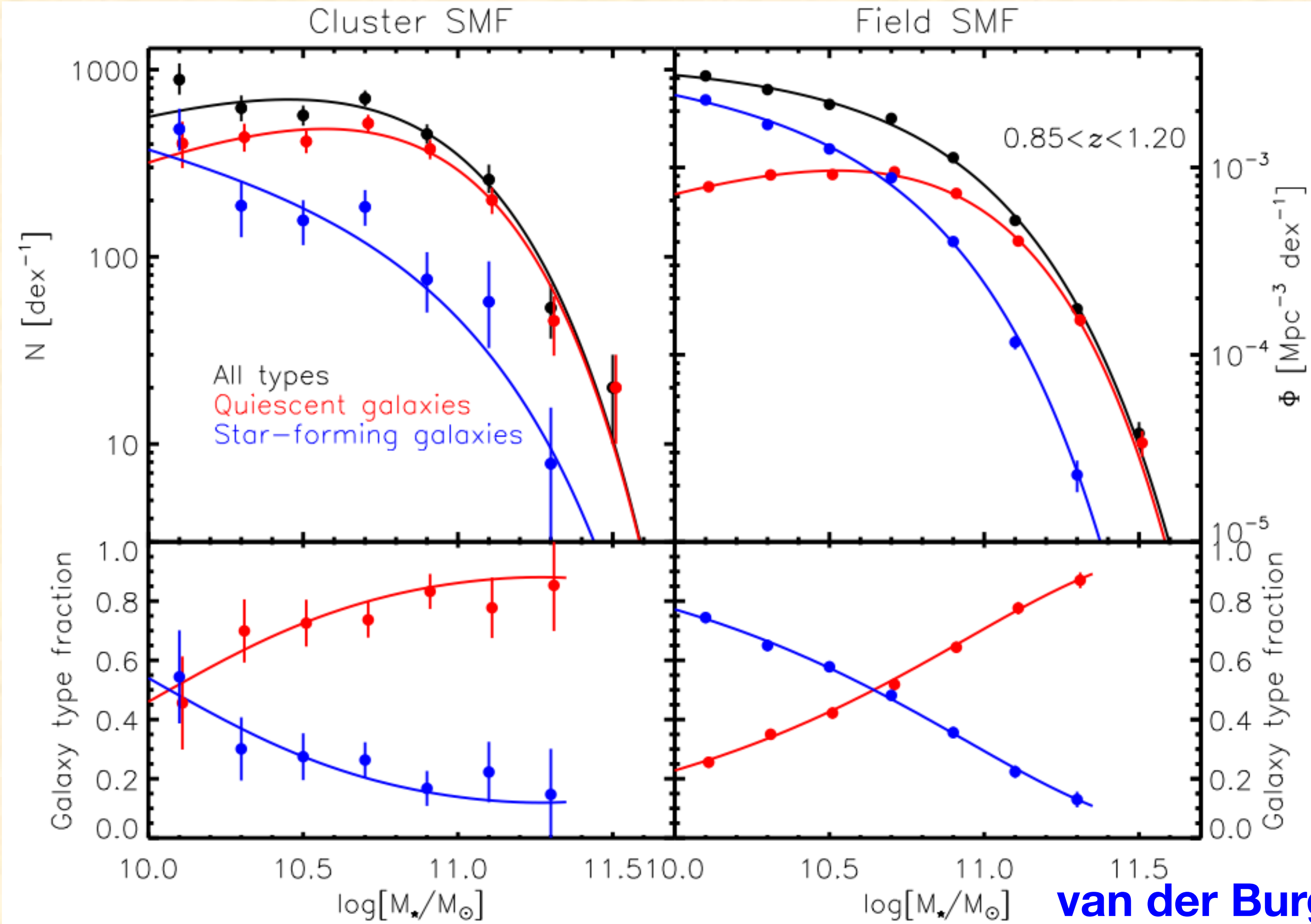


Name[a]	z_{spec}	RA[b] J2000	DEC[b] J2000	σ_v^c [km/s]	M_{200}^d [10^{14} $M_\odot$]	R_{200}^d [Mpc]	Spec-z Members
SpARCS-0034	0.867	00:34:42.06	-43:07:53.41	700^{+90}_{-150}	$2.4^{+1.0}_{-1.2}$	$0.9^{+0.1}_{-0.2}$	45
SpARCS-0035	1.335	00:35:49.70	-43:12:24.20	780^{+80}_{-120}	$2.5^{+0.9}_{-1.0}$	$0.8^{+0.1}_{-0.1}$	20
SpARCS-0036	0.869	00:36:45.03	-44:10:49.91	750^{+80}_{-90}	$2.9^{+1.0}_{-0.9}$	$1.0^{+0.1}_{-0.1}$	47
SpARCS-0215	1.004	02:15:24.00	-03:43:32.15	640^{+120}_{-130}	$1.7^{+1.1}_{-0.8}$	$0.8^{+0.2}_{-0.2}$	48
SpARCS-1047	0.956	10:47:33.43	57:41:13.30	660^{+70}_{-120}	$1.9^{+0.7}_{-0.9}$	$0.8^{+0.1}_{-0.2}$	31
SpARCS-1051	1.035	10:51:11.21	58:18:03.17	500^{+40}_{-100}	$0.8^{+0.2}_{-0.4}$	$0.6^{+0.1}_{-0.1}$	34
SpARCS-1613	0.871	16:13:14.63	56:49:29.95	1350^{+100}_{-100}	$16.9^{+4.0}_{-3.5}$	$1.8^{+0.1}_{-0.1}$	92
SpARCS-1616	1.156	16:16:41.32	55:45:12.44	680^{+80}_{-110}	$1.9^{+0.7}_{-0.8}$	$0.8^{+0.1}_{-0.1}$	46
SpARCS-1634	1.177	16:34:38.22	40:20:58.36	790^{+60}_{-110}	$2.9^{+0.7}_{-1.0}$	$0.9^{+0.1}_{-0.1}$	50
SpARCS-1638	1.196	16:38:51.64	40:38:42.91	480^{+50}_{-100}	$0.6^{+0.2}_{-0.3}$	$0.5^{+0.1}_{-0.1}$	44

van der Burg+14

Also Wilson+09; Muzzin+09,+12; Demarco+10; Lidman+12,13; Noble+13,16; van der Burg+13; Foltz+15; Balogh+16; Biviano+16

z=1 Cluster & Field Stellar Mass Functions

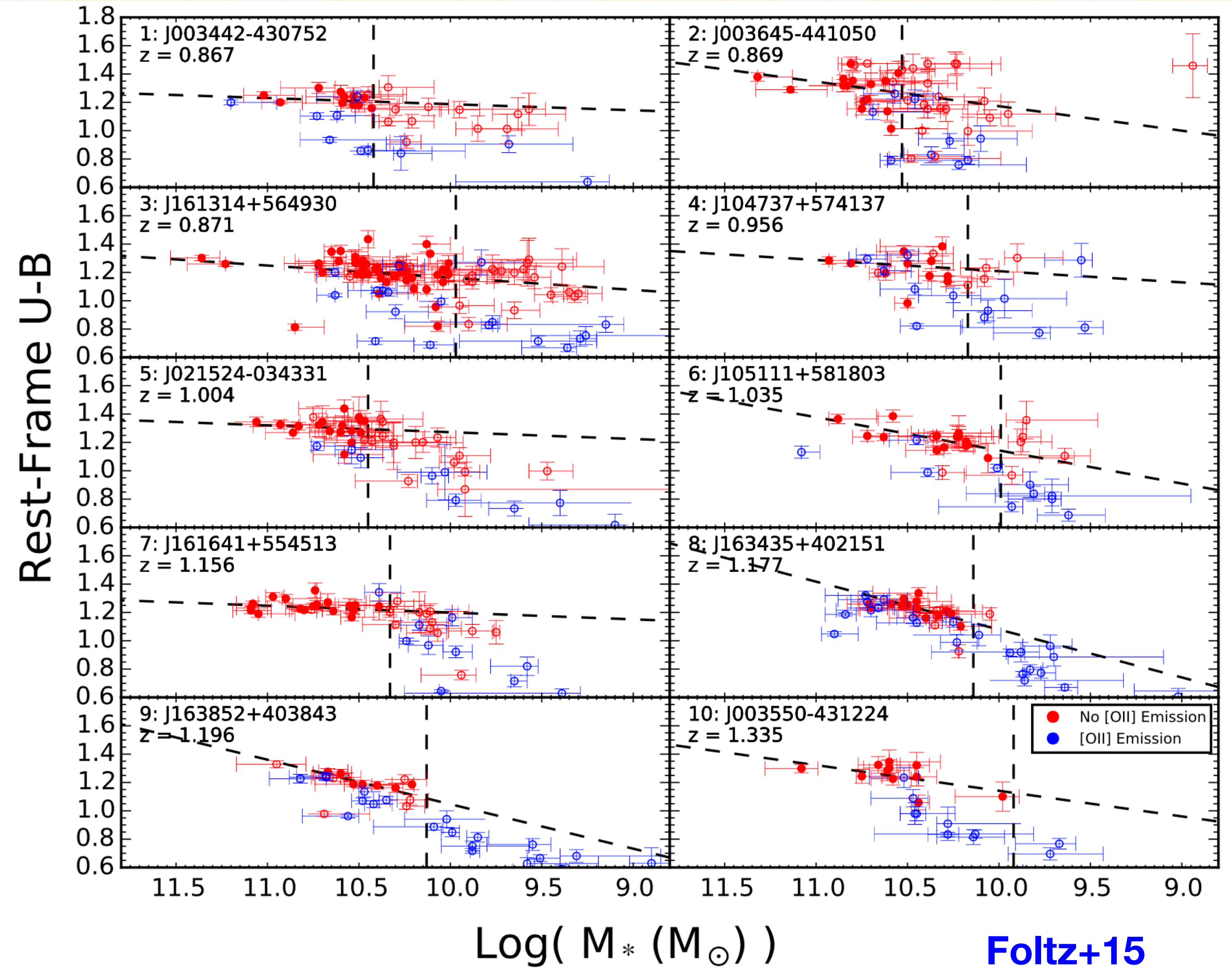


van der Burg+13

Higher fraction of quiescent galaxies in cluster versus field => significant environmental quenching at z = 1

(45% of star-forming galaxies which would normally be forming stars in the field have been quenched by the cluster environment)

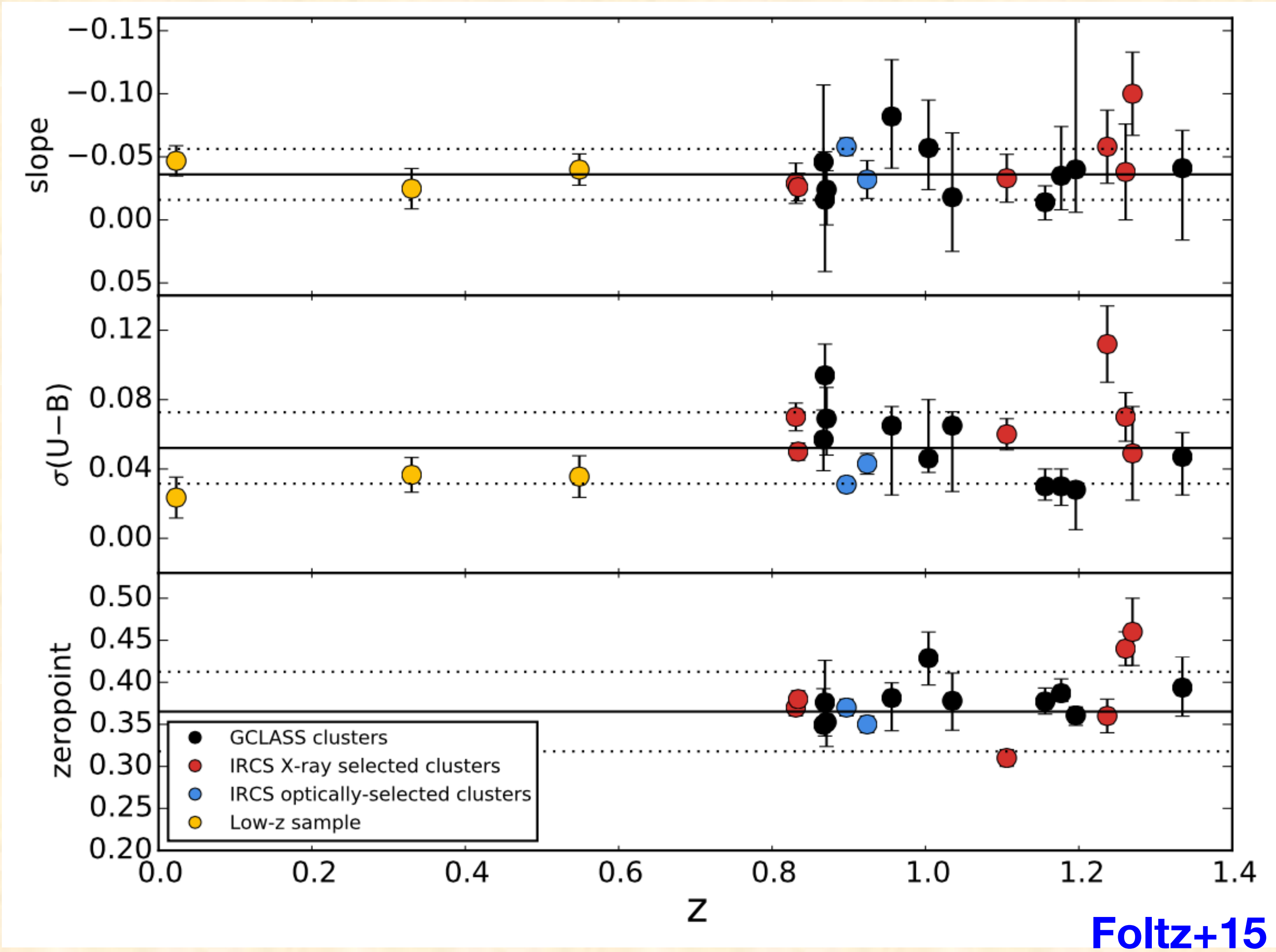
GCLASS: Red Sequence at z = 1



Foltz+15

No difference in Properties of Quiescent Members between Red Sequence (black) and X-ray selected (red) cluster samples

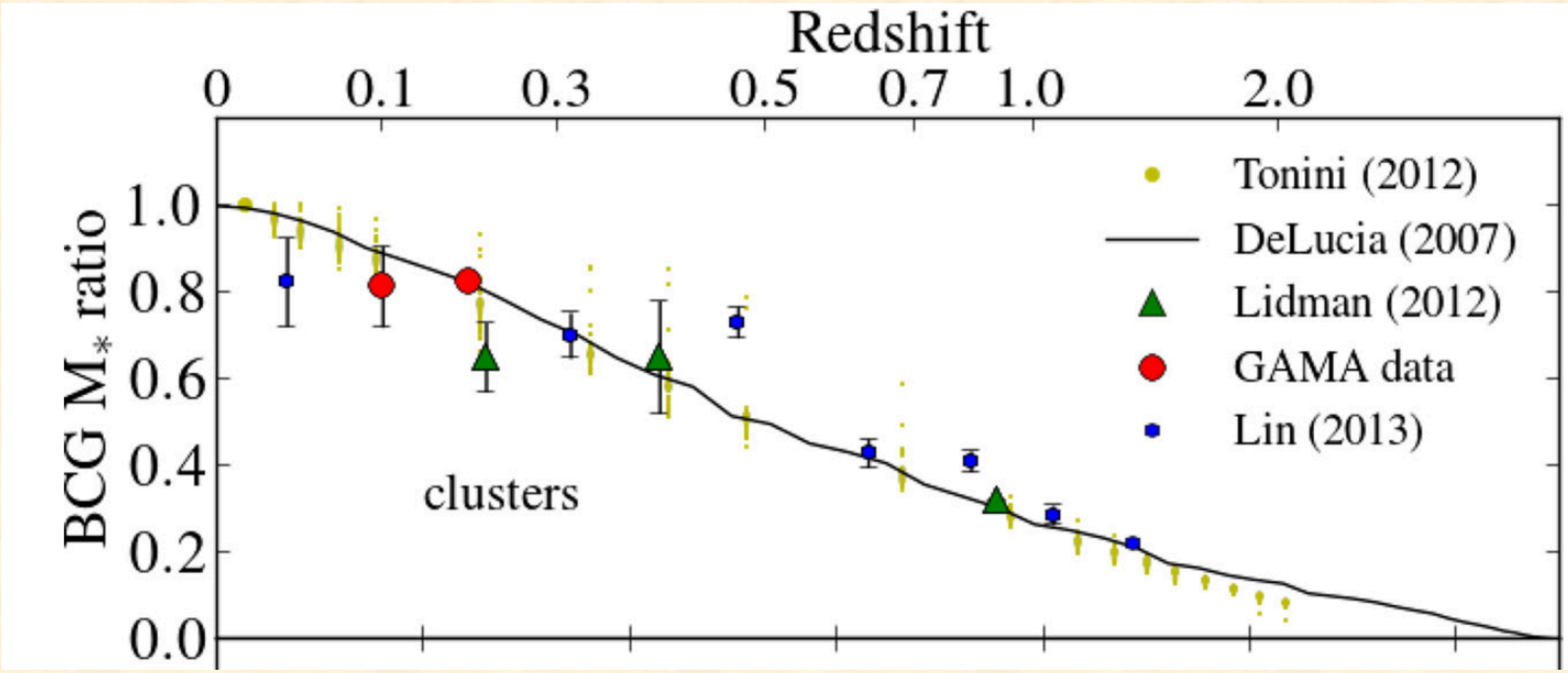
Scatter



=> suggests "pre-processing" or "strangulation" may be responsible for the quenching

Brightest Cluster Galaxies (Centrals)

Good Agreement between Predictions and Observations at z < 1



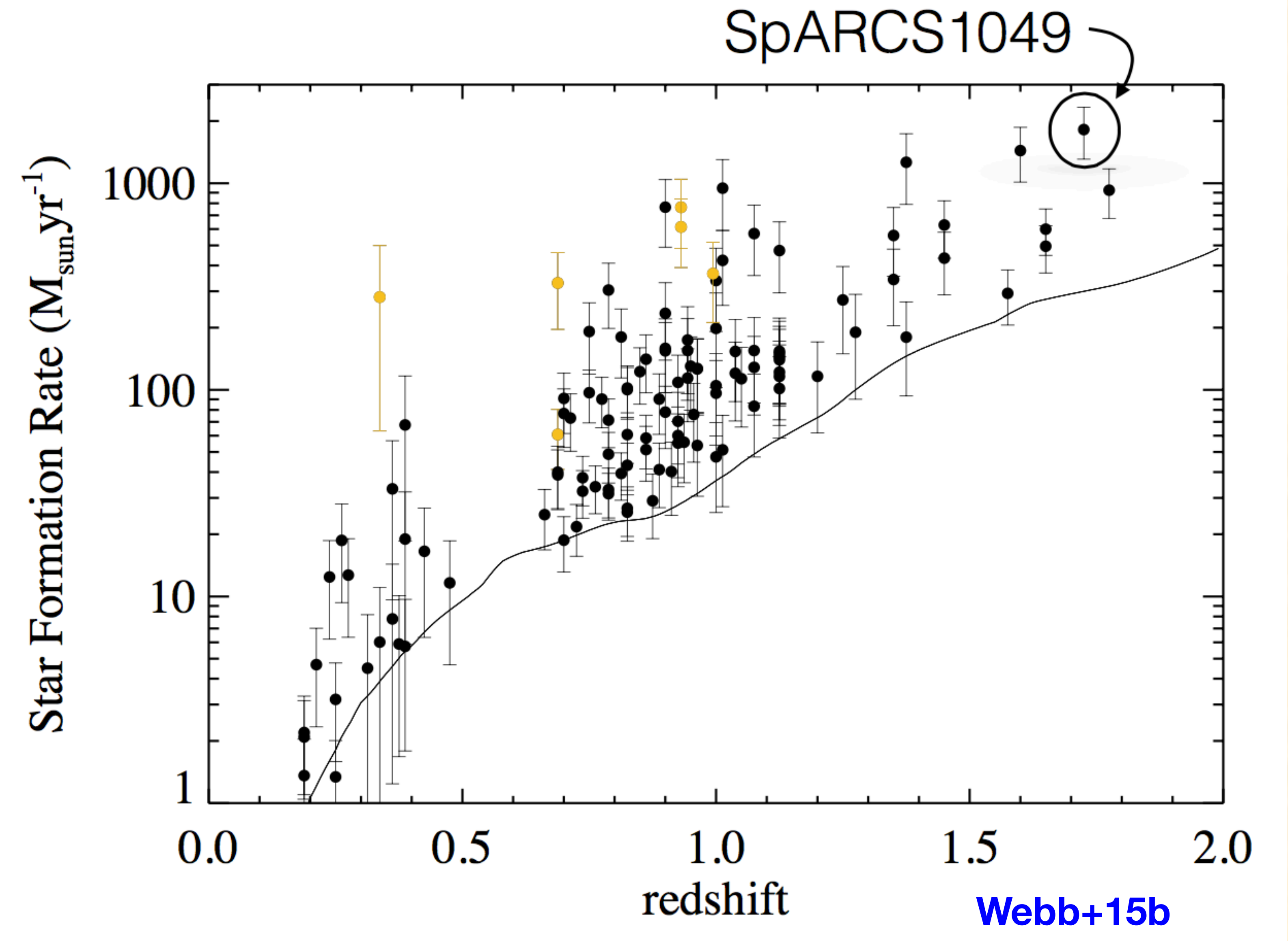
Oliva-Altamirano+14

BCGs grow in stellar mass by a factor of two since z~1

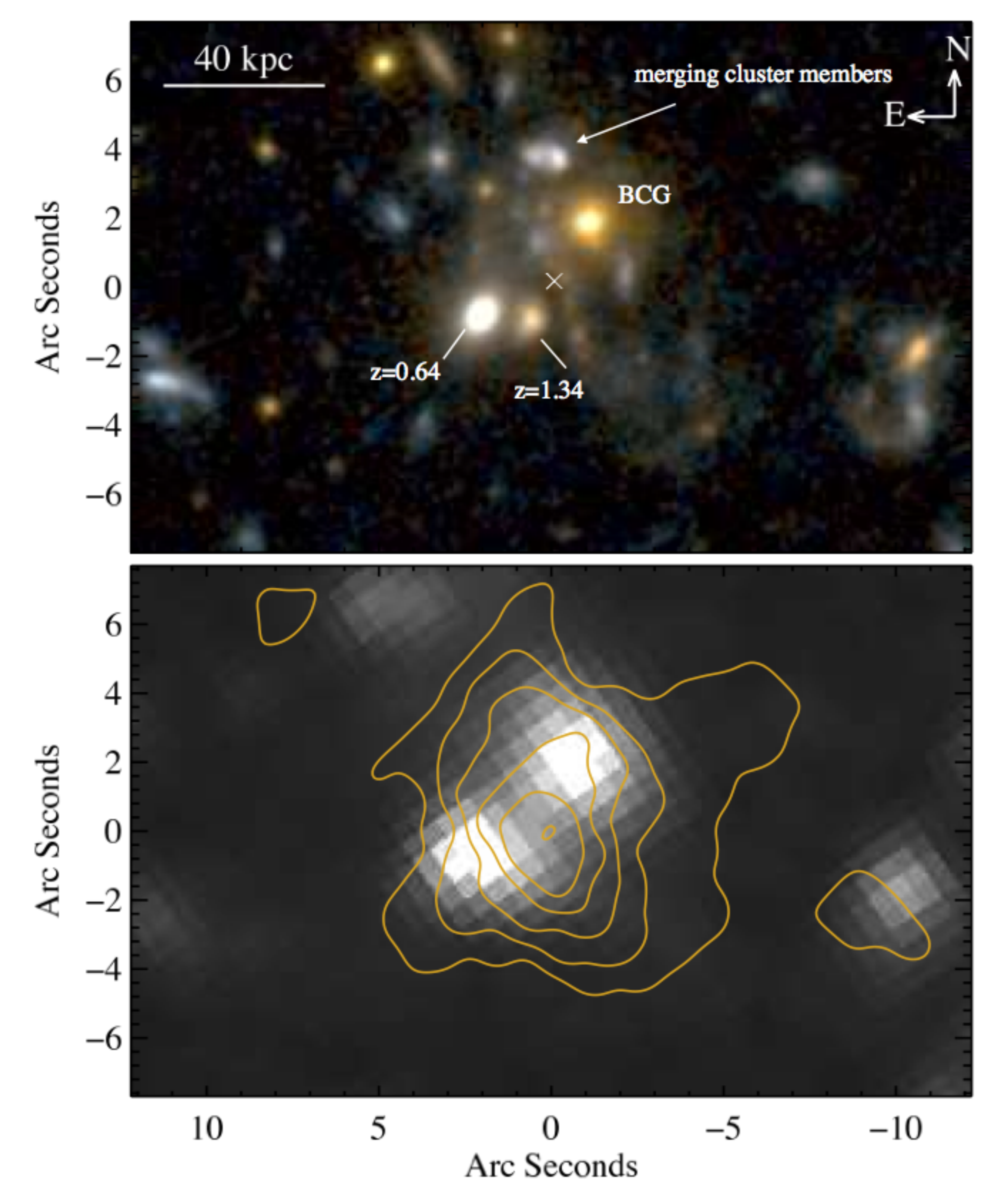
We believe this growth is primarily due to dry (major) mergers

(see Lidman+13)

Evidence for Significant *In Situ* Star Formation at High Redshift



Extreme Starburst in a Cluster Core at z = 1.7

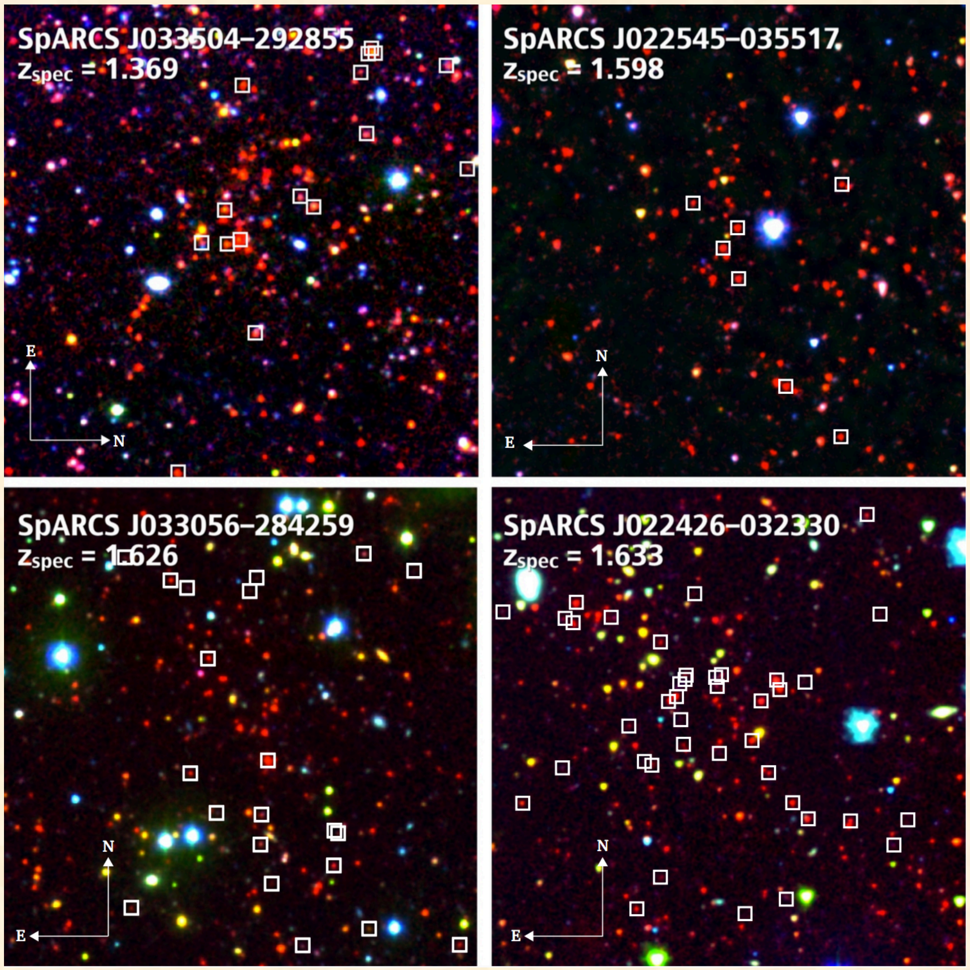


Webb+15a

- 900 solar masses/year !!
- HST imaging reveals chain of 10 individual clumps "beads on a string"
- gas-rich merger has likely triggered the extreme starburst
- "wet" mergers may be an important process in forming the stellar mass of BCGs at early times
- Keck/NASA press releases
- OSIRIS IFU follow-up scheduled for December

$z \sim 1.5$

The SpARCS team has been working hard also to build a z~1.5 Cluster Sample



4 more confirmed clusters

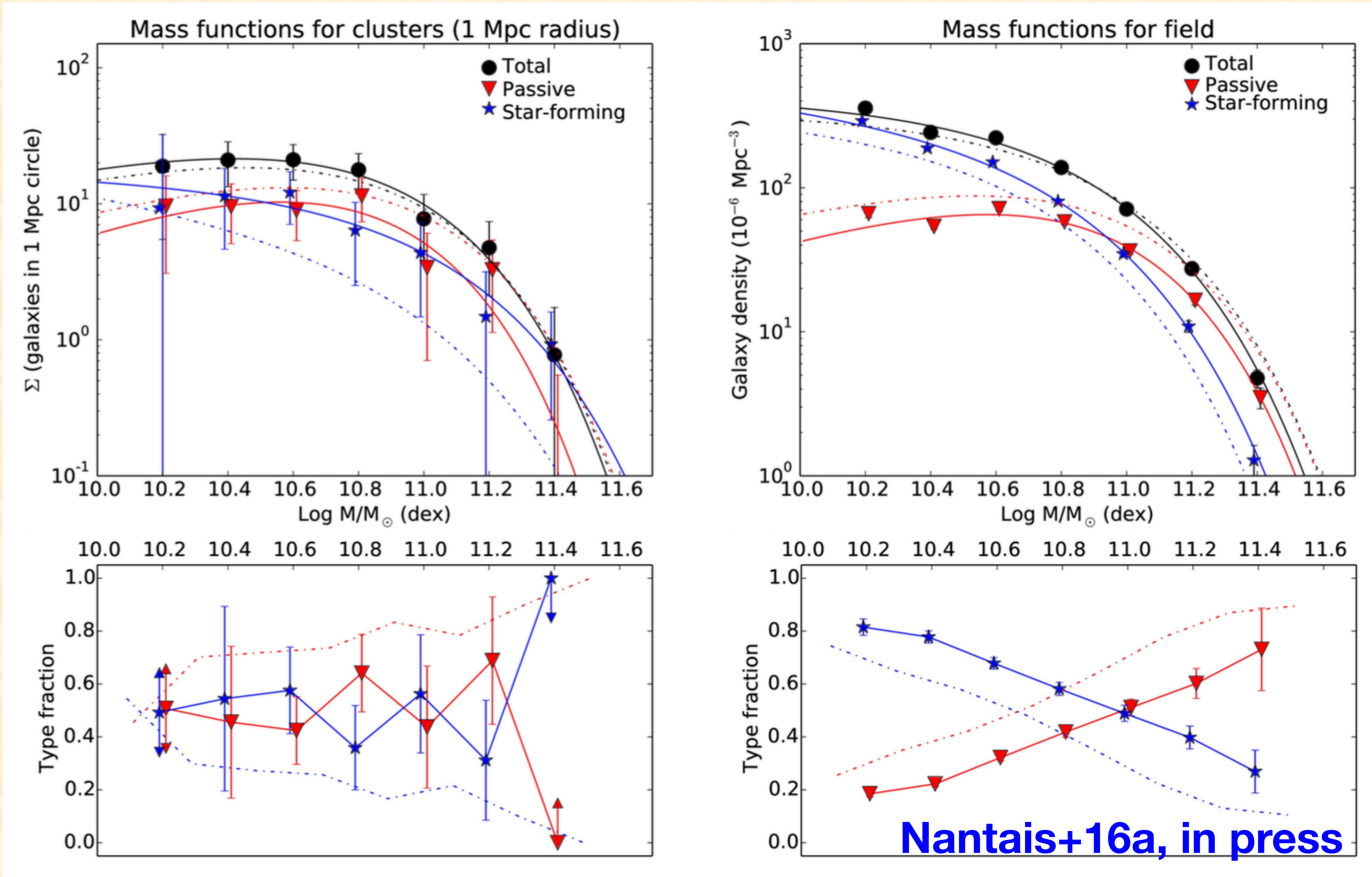
These clusters detected via galaxies but based on their stellar mass not red sequence ("Stellar Bump Sequence" method)

Nantais+16a

see also Muzzin+13; Webb+15a; Nantais+16b DeGroot+16; in prep

Cluster	RA (J2000) h:m:s	Dec (J2000) d:m:s	z	Spectroscopy	Photometry	Spec. Members
SpARCS-J0224	02:24:26.33	-03:23:30.8	1.633	FORS2, MOSFIRE, OzDES	*ugrizYJKs*3.6μm4.5μm5.8μm8.0μm	45
SpARCS-J0330	03:30:55.87	-28:42:59.5	1.626	FORS2, MOSFIRE, OzDES	*ugrizYJKs*3.6μm4.5μm5.8μm8.0μm	38
SpARCS-J0225	02:25:45.55	-03:55:17.1	1.598	FORS2, MOSFIRE, OzDES	*ugrizYKs*3.6μm4.5μm5.8μm8.0μm	8
SpARCS-J0335	03:35:03.58	-29:28:55.6	1.369	FORS2, OzDES	*grizYKs*3.6μm4.5μm5.8μm8.0μm	22

z=1.5 Cluster & Field Stellar Mass Functions



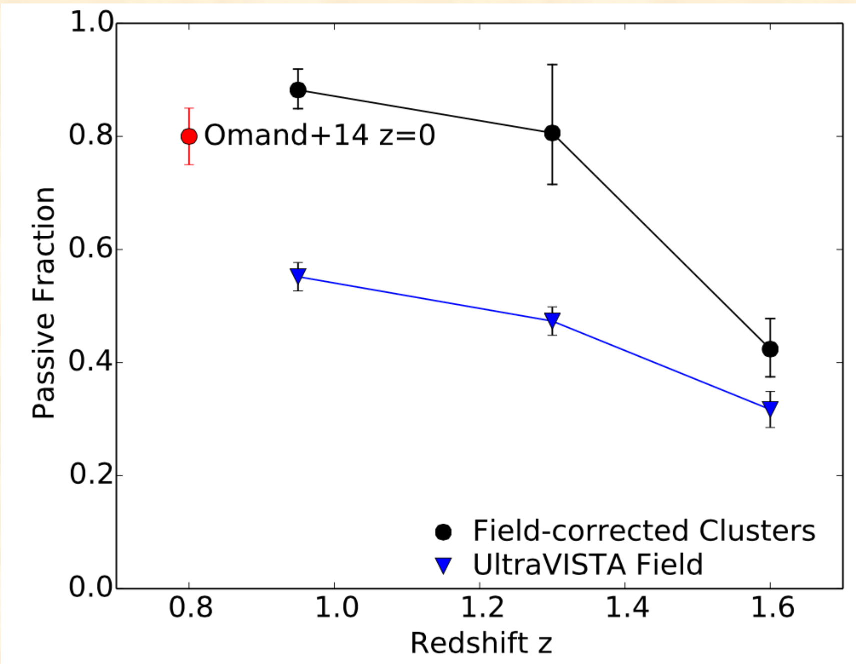
Both clusters and field show quenching evolution between z ~ 1.5 and z ~ 1

However, the quenching is much more dramatic in the clusters

(30% of star-forming galaxies which would normally be forming stars in the field have been quenched by the cluster environment)

Evidence for Different Processes being Primarily Responsible for Environmental Quenching at Different Redshifts

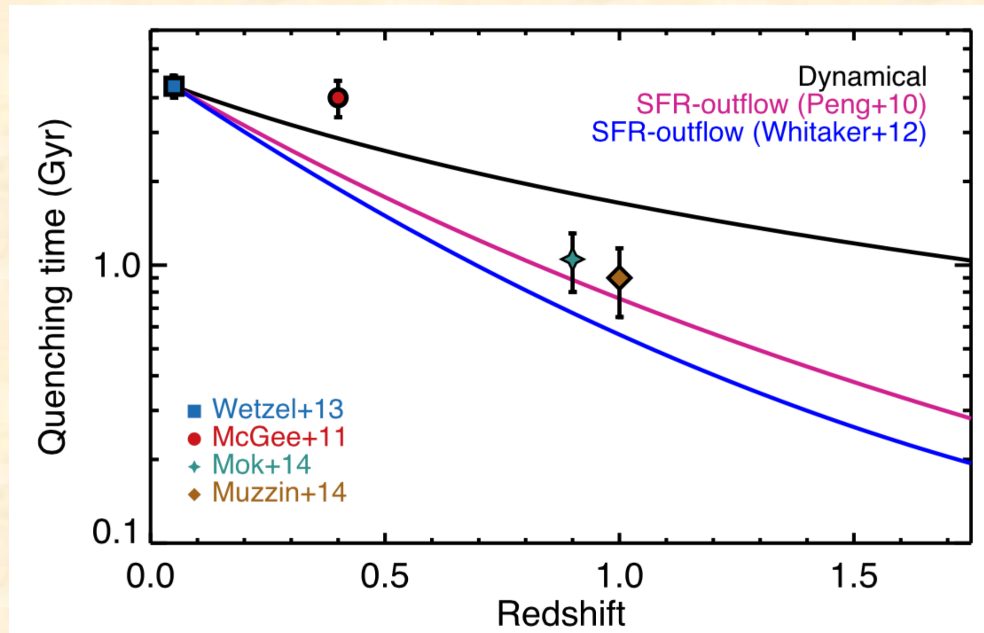
Increase in Passive Fraction



Passive fraction in clusters (black) and field (blue)

Nantais+16b, in prep

Lengthening of Quenching Timescale



Evidence suggests quenching timescales for cluster members at z ~ 1 are much shorter than those at z ~ 0, possibly due to the prevention of fresh fuel accretion rather than gas stripping

McGee+14

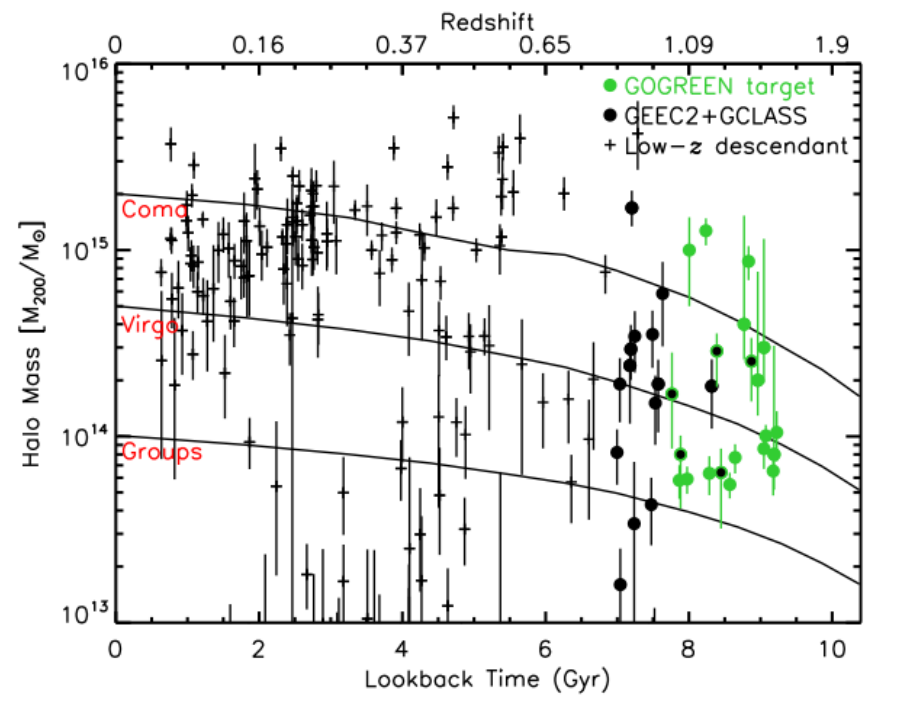
(also Wetzel+13; Muzzin+14; Noble+13,16; Balogh+16)

Ongoing Surveys

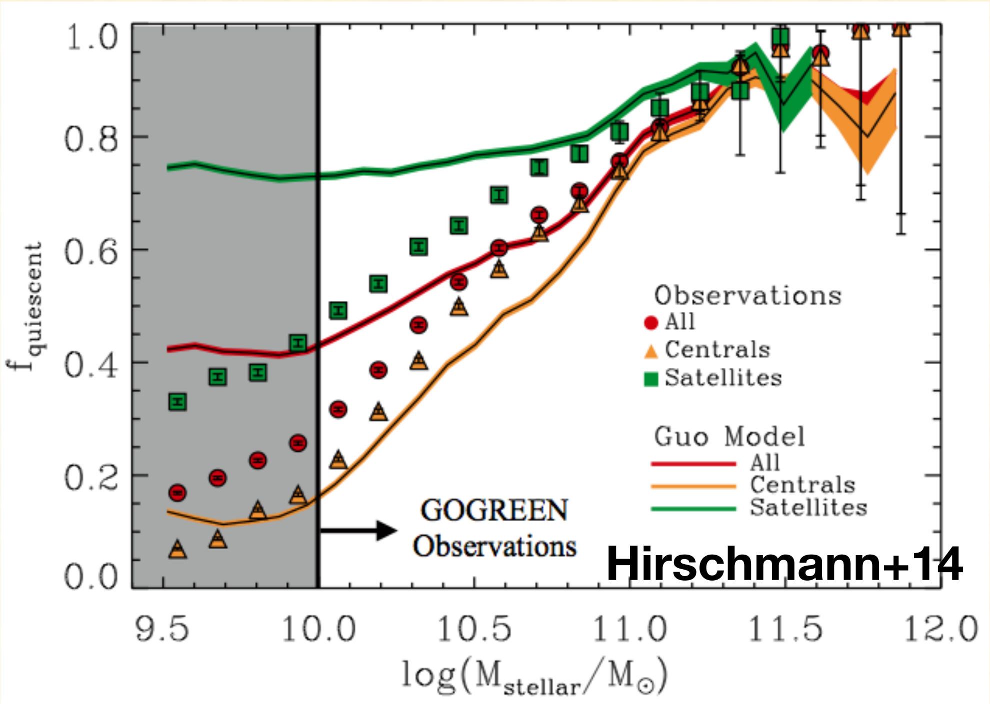
GOGREEN Survey: Low-mass Galaxy Quenching in 21 clusters/groups at 1 < z < 1.5

~50 night (440hr) Gemini/GMOS "Large & Long" Program (PI Balogh)

Lower/Higher Halo Masses than GCLASS



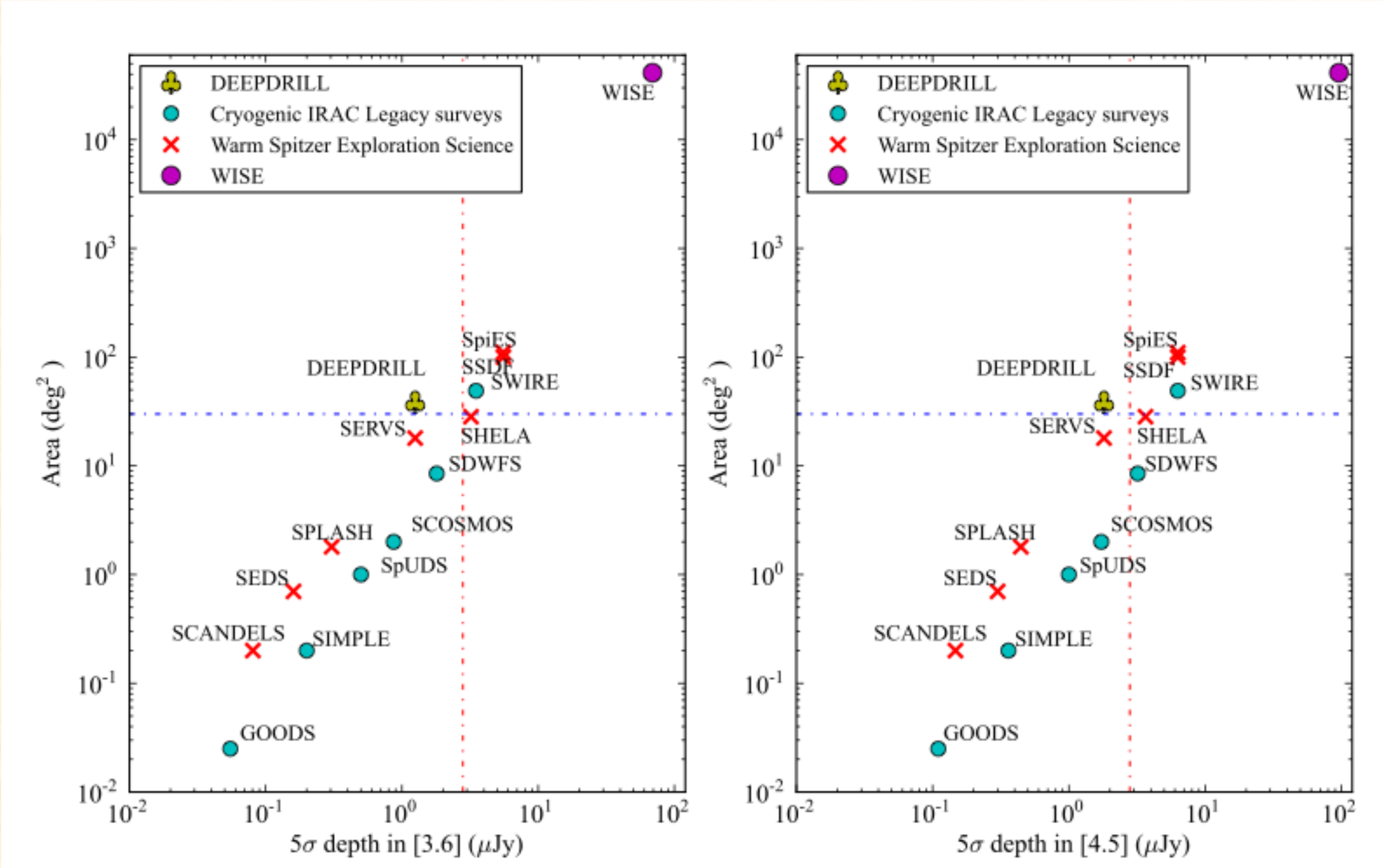
Lower Galaxy Stellar Mass than GCLASS



Simulations greatly overpredict the fraction of quenched satellite galaxies (green), due to shortcomings in our understanding of "environmental" (satellite) quenching

DEEPDRILL Survey: Protoclusters at z > 2

1400 hr Cycle 11 Exploration Science Spitzer/IRAC (PI Lacy)



Area/Depth combination to detect 30 Protoclusters (> 5 x 10^13 Msolar) at z> 2

Also Massive Galaxies (BCG's) at 2 < z < 6

Conclusions

- **Samples of Clusters now available at z > 1 are providing new constraints on Baryon Assembly and Environmental Quenching**
- **The epoch between z=2 and z=1 appears to be when Environmental Quenching really "Kicks In"**
- **Increasing Evidence for Different Processes being Responsible for Environmental Quenching at Different Redshifts**
- **New ongoing surveys e.g., GOGREEN/DeepDrill are pushing down in Galaxy Stellar Mass and out in Redshift**