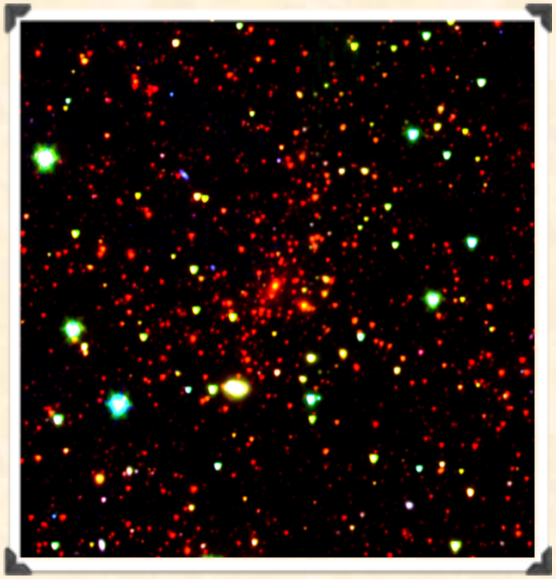
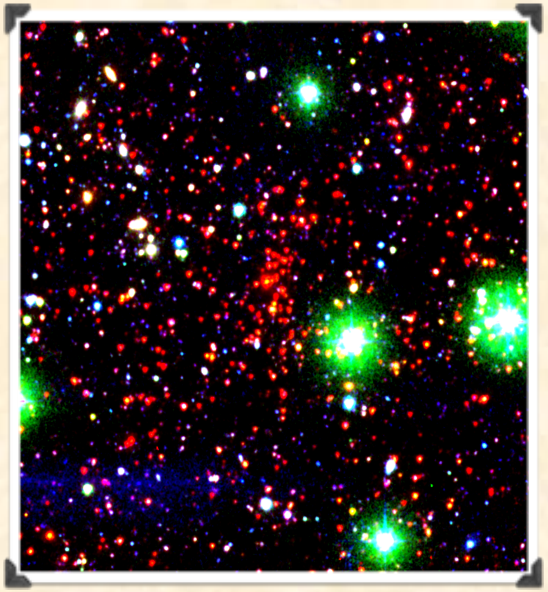
Galaxy Quenching in Clusters and Growth of BCGs



Gillian Wilson
UC Riverside

SpARCS Collaboration



Adam Muzzin (York), Remco van der Burg (CEA Saclay), Ryan Foltz (UCR), Julie Nantais (Andres Bello), Tracy Webb (McGill), Nina Bonaventura (McGill), Chris Lidman (AAO), Michael Cooper (UCI), Allison Noble (Toronto), Anna Delahaye (McGill), Howard Yee (Toronto), Michael Balogh (Waterloo), Jason Surace (SSC/IPAC), Julie Hlavacek-Larrondo (Montreal), Ricardo Demarco (Concepcion), Eelco van Kampen (ESO), Mark Lacy (NRAO), Greg Rudnick (Kansas), Lyndsay Old (Toronto), Mohamed Elhashash (UCR), Ian McConachie (UCR)

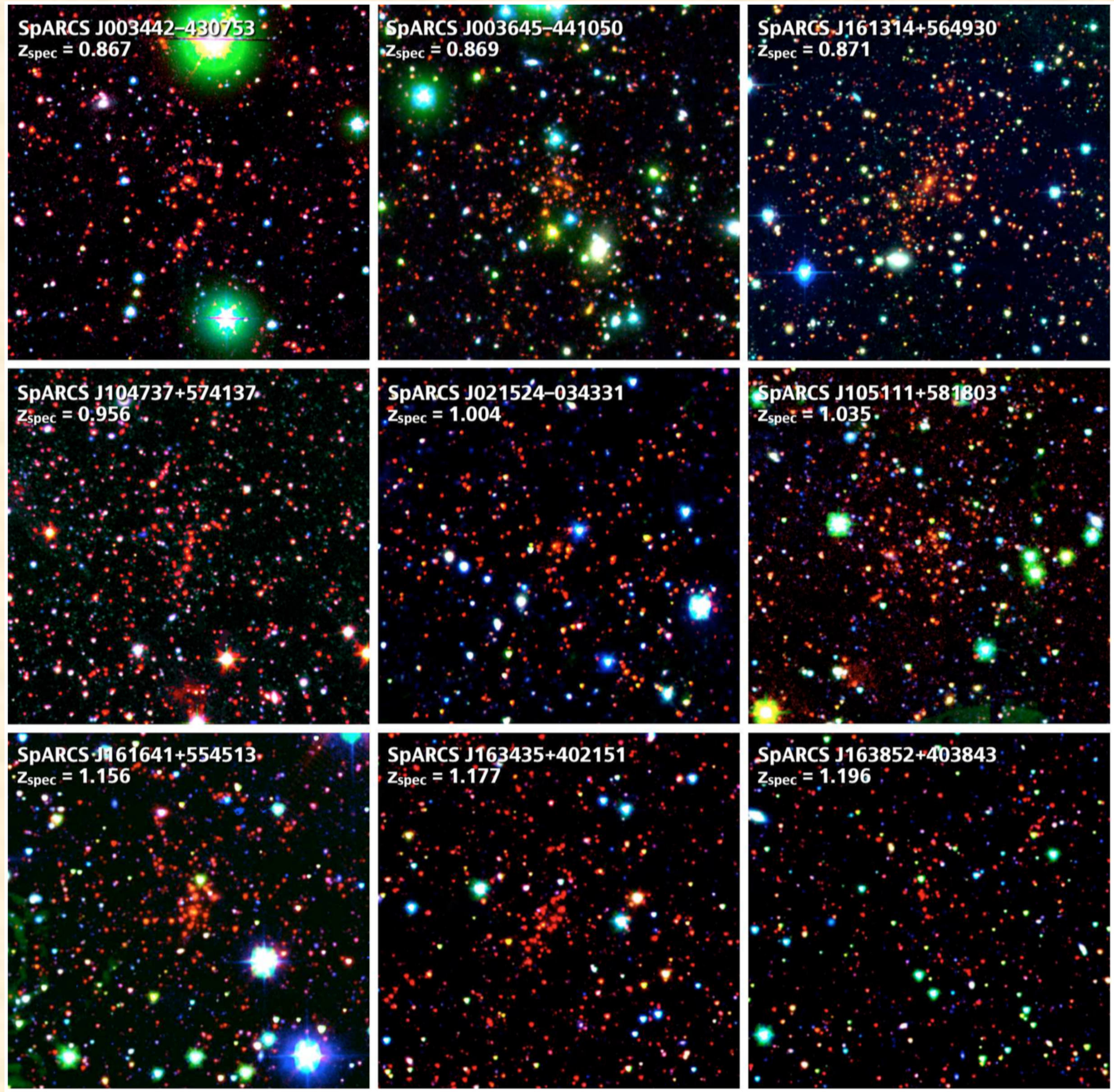
z~1.0 Cluster Sample

<u>SpARCS "GCLASS" sample</u>

10 galaxy-selected clusters (red-sequence method)

0.87 < z < 1.35

~500 spectroscopic members + multi-passband photometry



Muzzin+12

Also Wilson+09; Muzzin+09,+12; Demarco+10; Lidman+12,13; Noble+13,16; van der Burg+13, 14; Foltz+15; Balogh+16; Biviano+16; Nantais+17

z~1.6 Cluster Sample

<u>SpARCS "high redshift" sample</u>

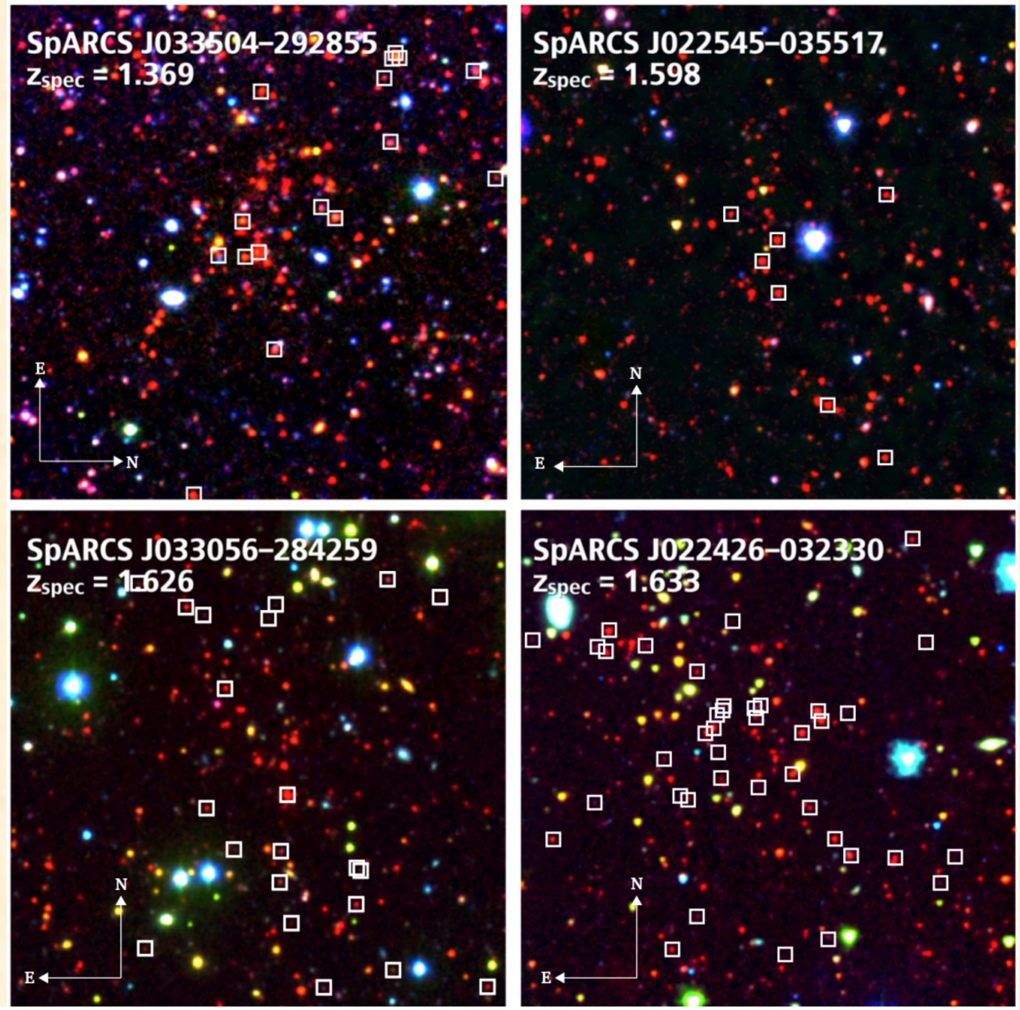
4 galaxy-selected clusters (stellar mass overdensity method)

1.37 < z < 1.63

Extensive spec + phot

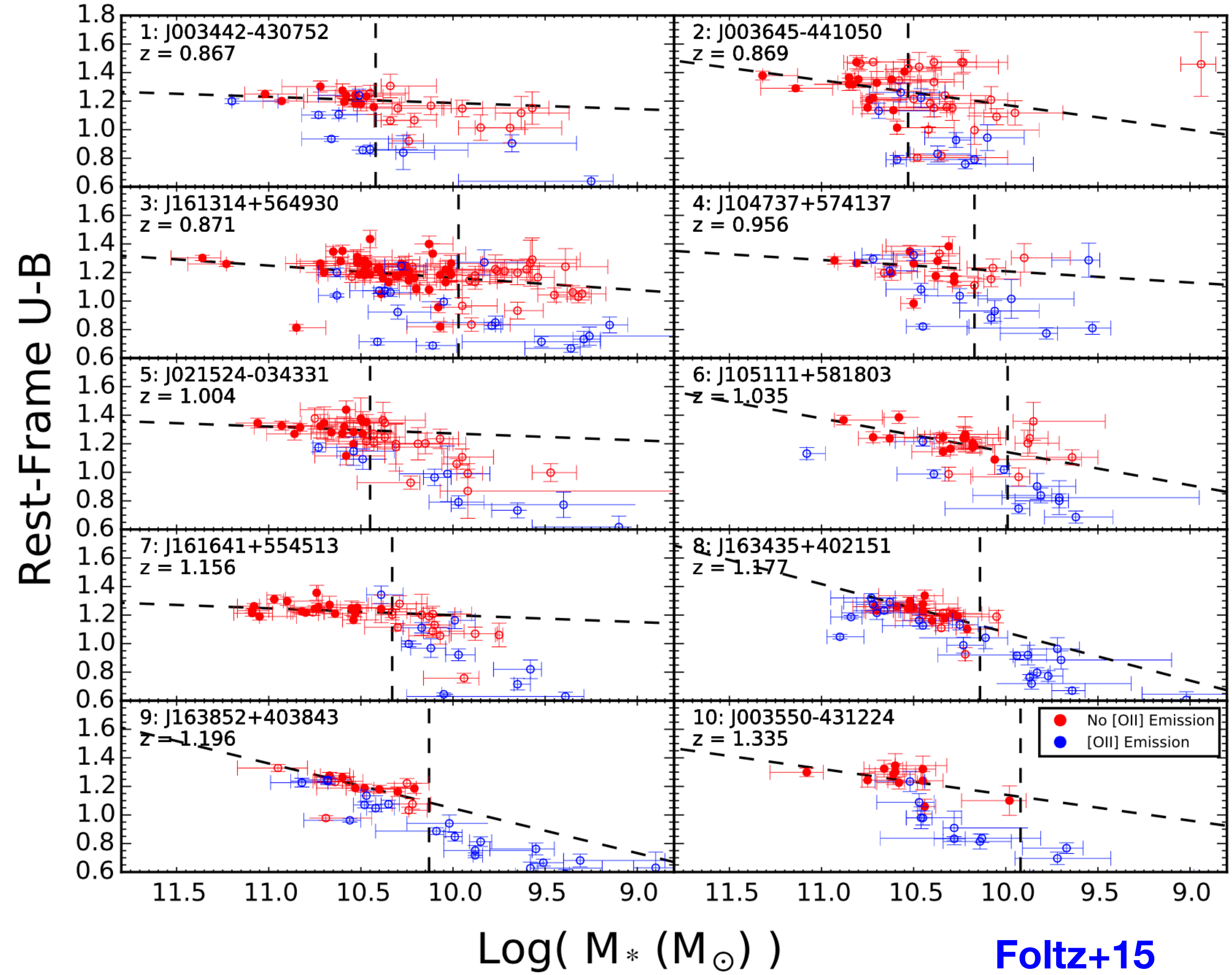
Nantais+16

See also Muzzin+13; Webb+15a; Bonaventura+17; Delahaye+17; Nantais+17; Foltz+17, in prep



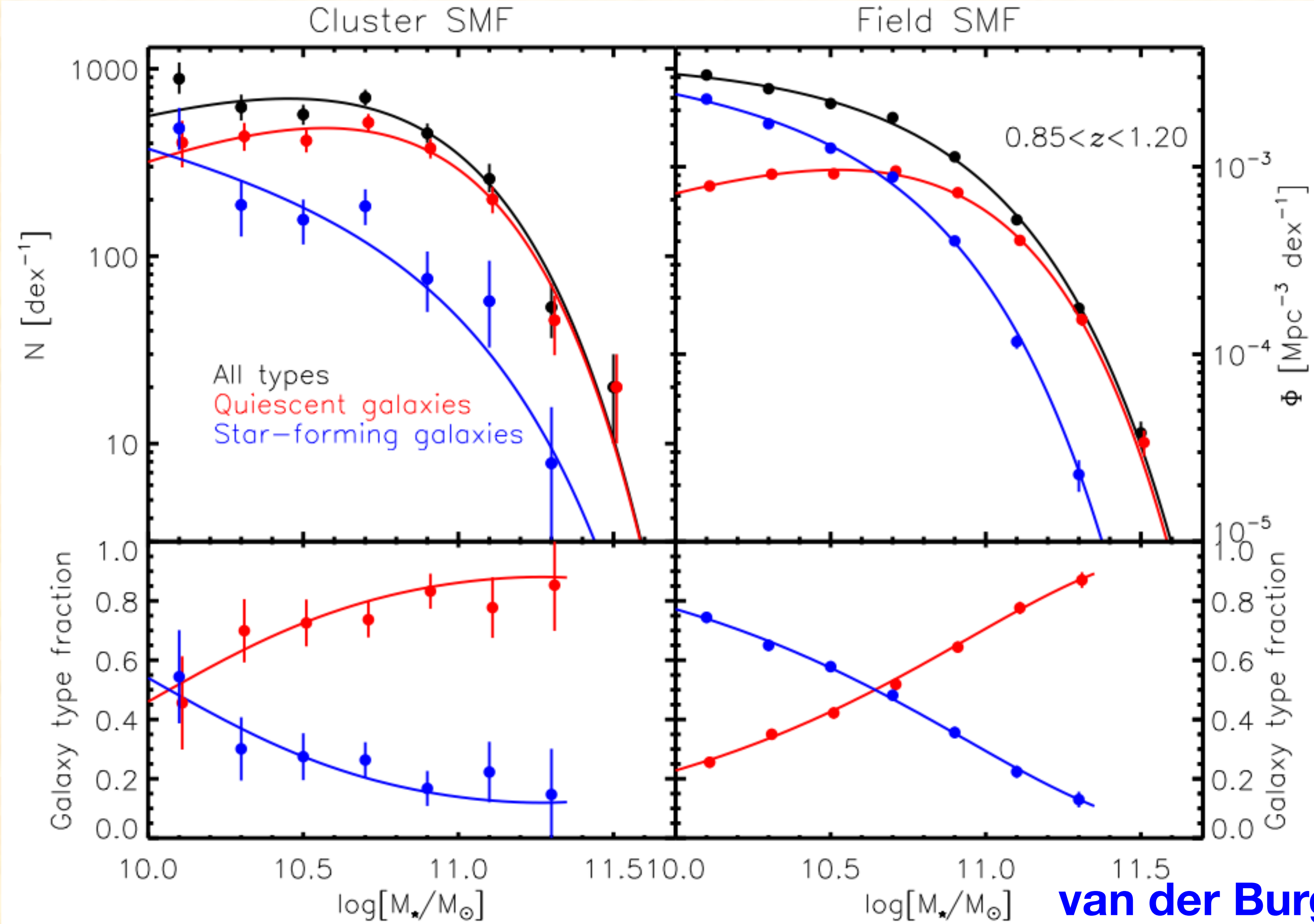
Cluster	R.A.	Decl.	z	Spectroscopy	Photometry	Spectra[a]	N^{b}_{spec}
SpARCS-J0224	02:24:26.33	-03:23:30.8	1.633	MOSFIRE, FORS2, OzDES	*ugrizYJKs* [3.6] [4.5] [5.8] [8.0]	187	52
SpARCS-J0330	03:30:55.87	-28:42:59.5	1.626	MOSFIRE, FORS2, OzDES	*ugrizYJKs* [3.6] [4.5] [5.8] [8.0]	535	40
SpARCS-J0225	02:25:45.55	-03:55:17.1	1.598	MOSFIRE, FORS2, OzDES	*ugrizYKs* [3.6] [4.5] [5.8] [8.0]	126	22
SpARCS-J0335	03:35:03.58	-29:28:55.6	1.369	FORS2, OzDES	*grizYKs* [3.6] [4.5] [5.8] [8.0]	81	22

GCLASS: Red Sequence at z = 1



Foltz+15

z=1 Cluster & Field Stellar Mass Functions

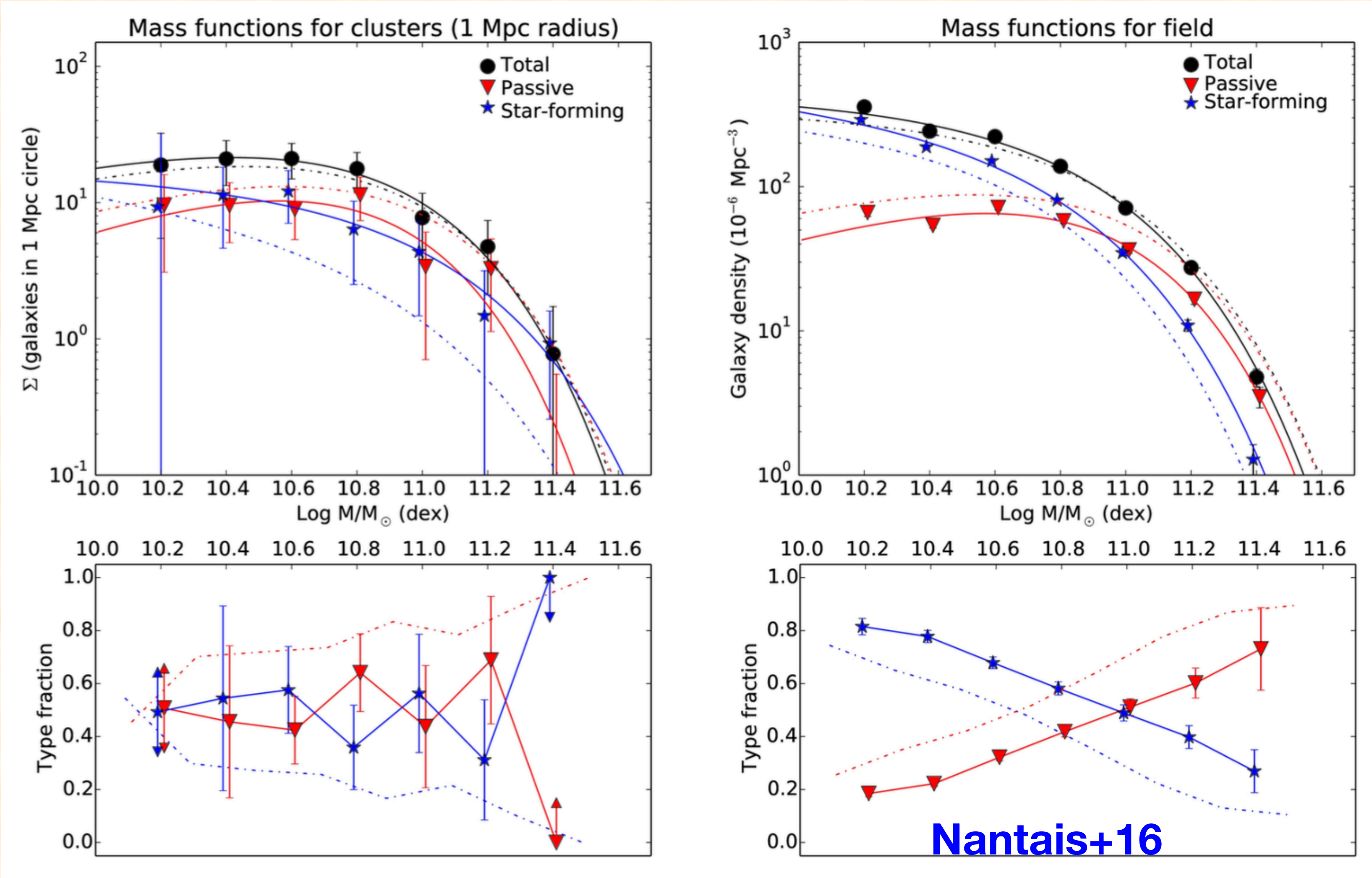


van der Burg+13

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

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

z=1.6 Cluster & Field Stellar Mass Functions



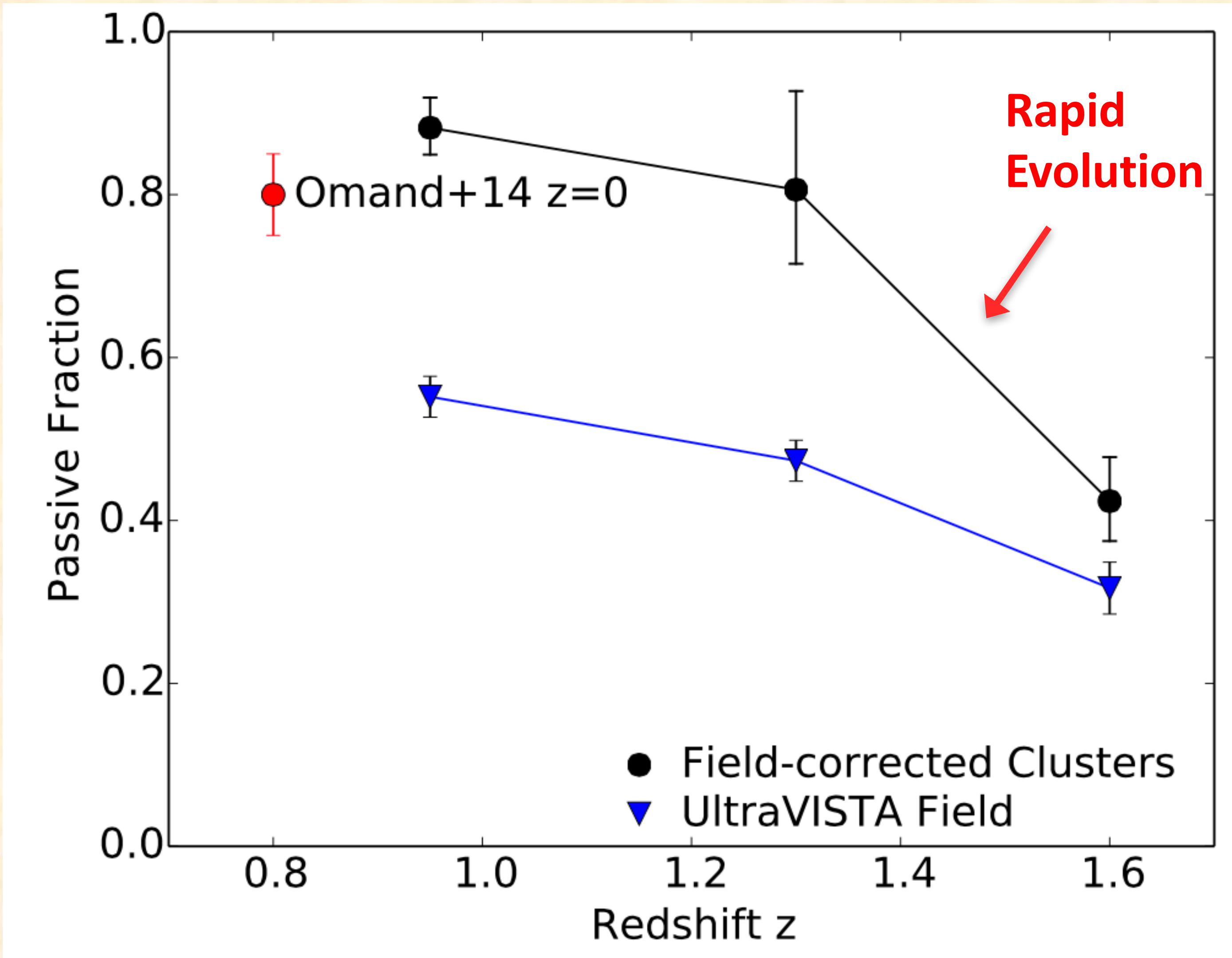
Both clusters and field show quenching evolution between z ~ 1.6 and z ~ 1

However, the quenching is much more dramatic in the clusters

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

Environmental Quenching "Kicks In" at 1 < z < 2

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

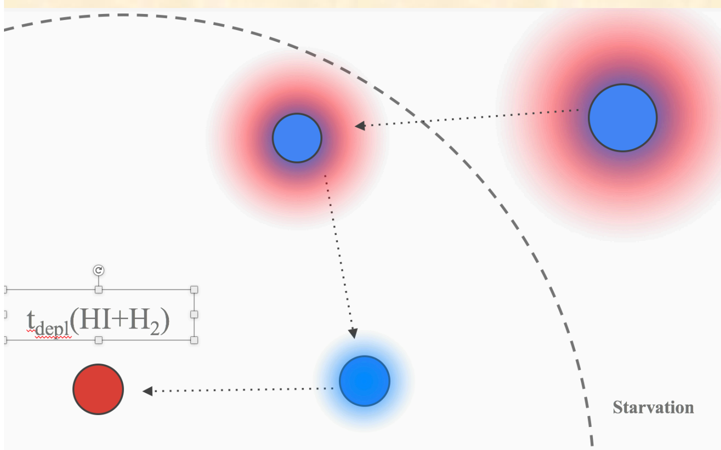


Nantais+17

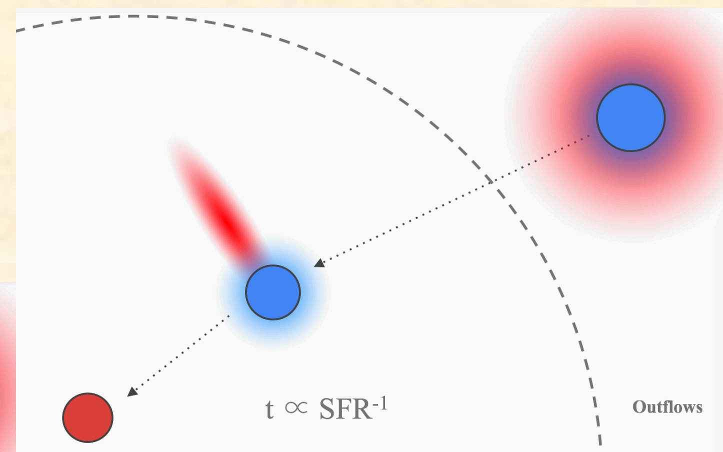
What Causes Environmental Quenching?

Constraints from the Evolution of Environmental Quenching Timescales to z~1.6

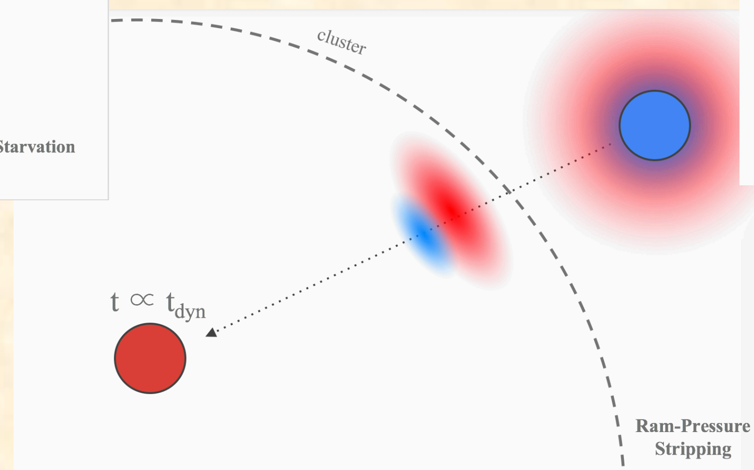
Starvation?



Outflows?



Dynamical process?

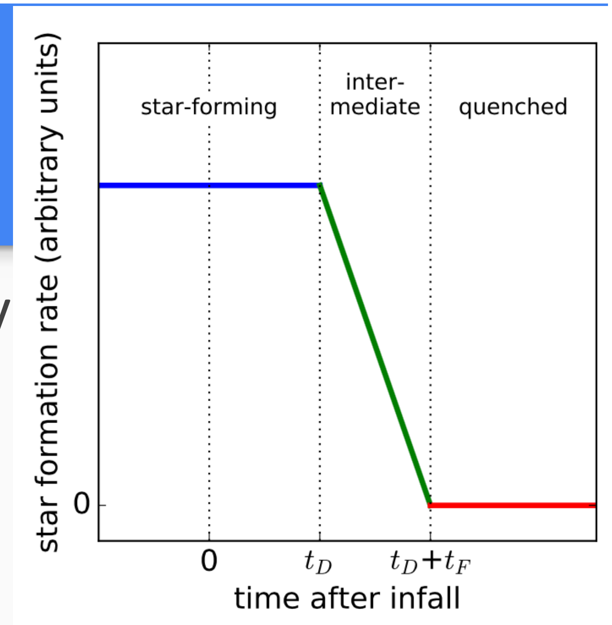


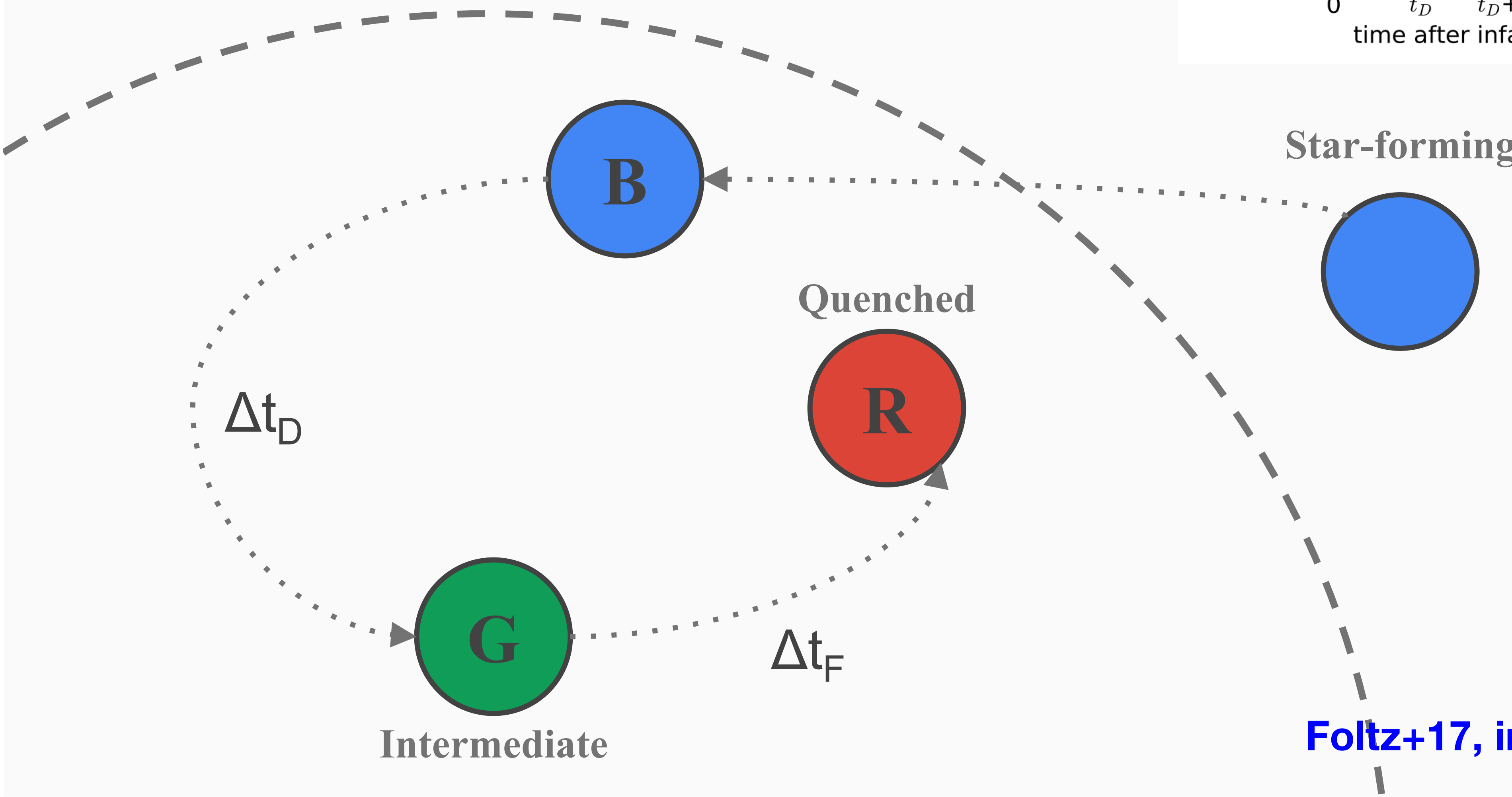
Foltz+17, in prep

Environmental Quenching Timescale

We assume that galaxies remain unaffected for a “delay time” t_D, then rapidly quench over a “fade time” t_F

(correct for galaxies quenched in field before infalling)



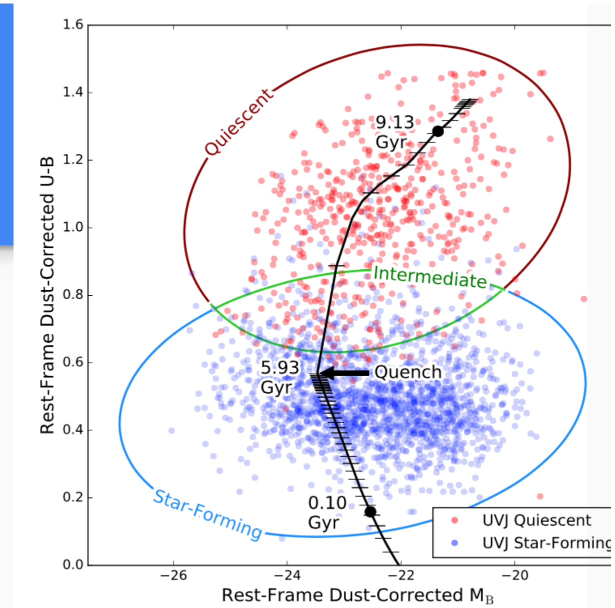


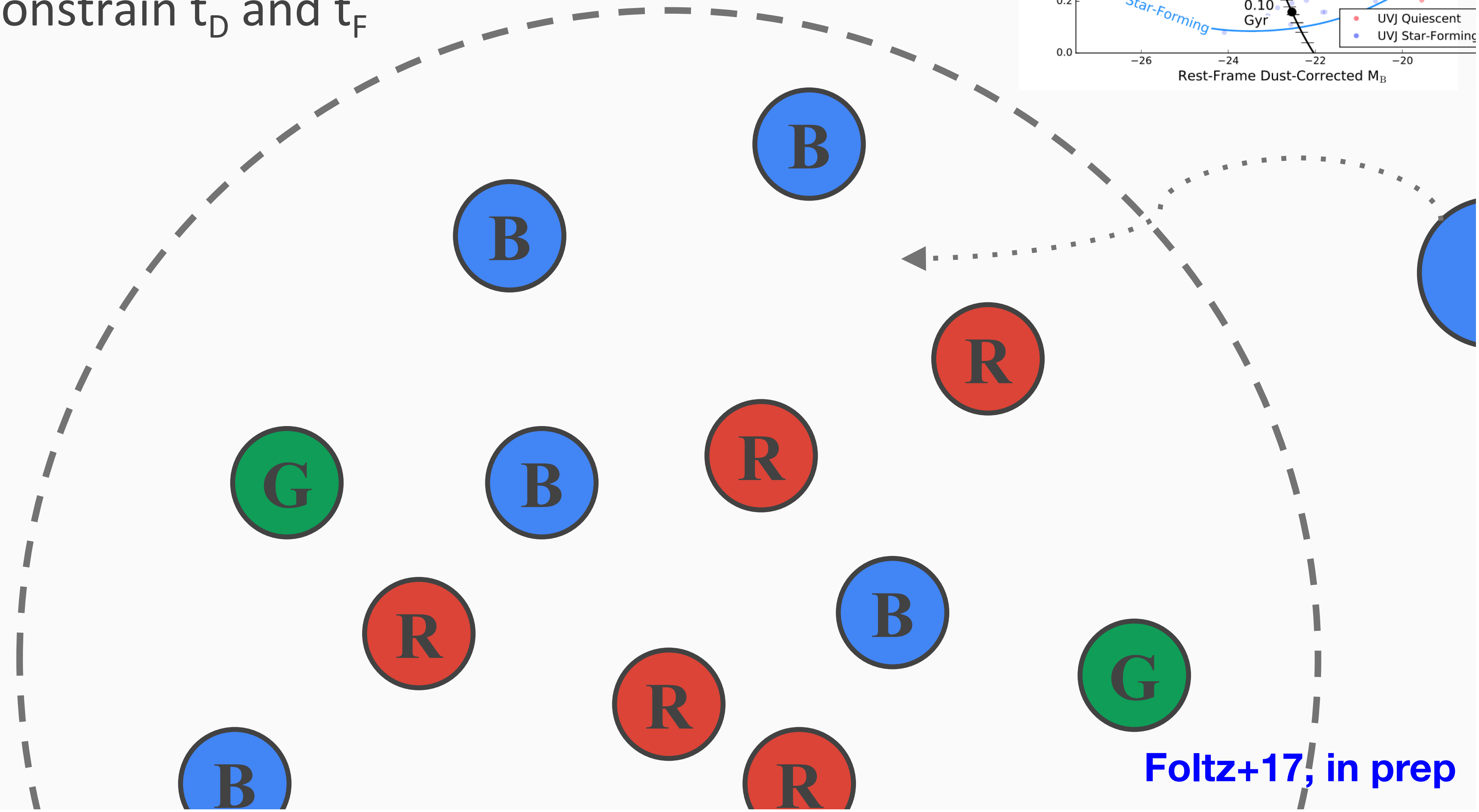
Foltz+17, in prep

Environmental Quenching Timescale

We use the observed numbers of R, G, B galaxies to constrain t_D and t_F

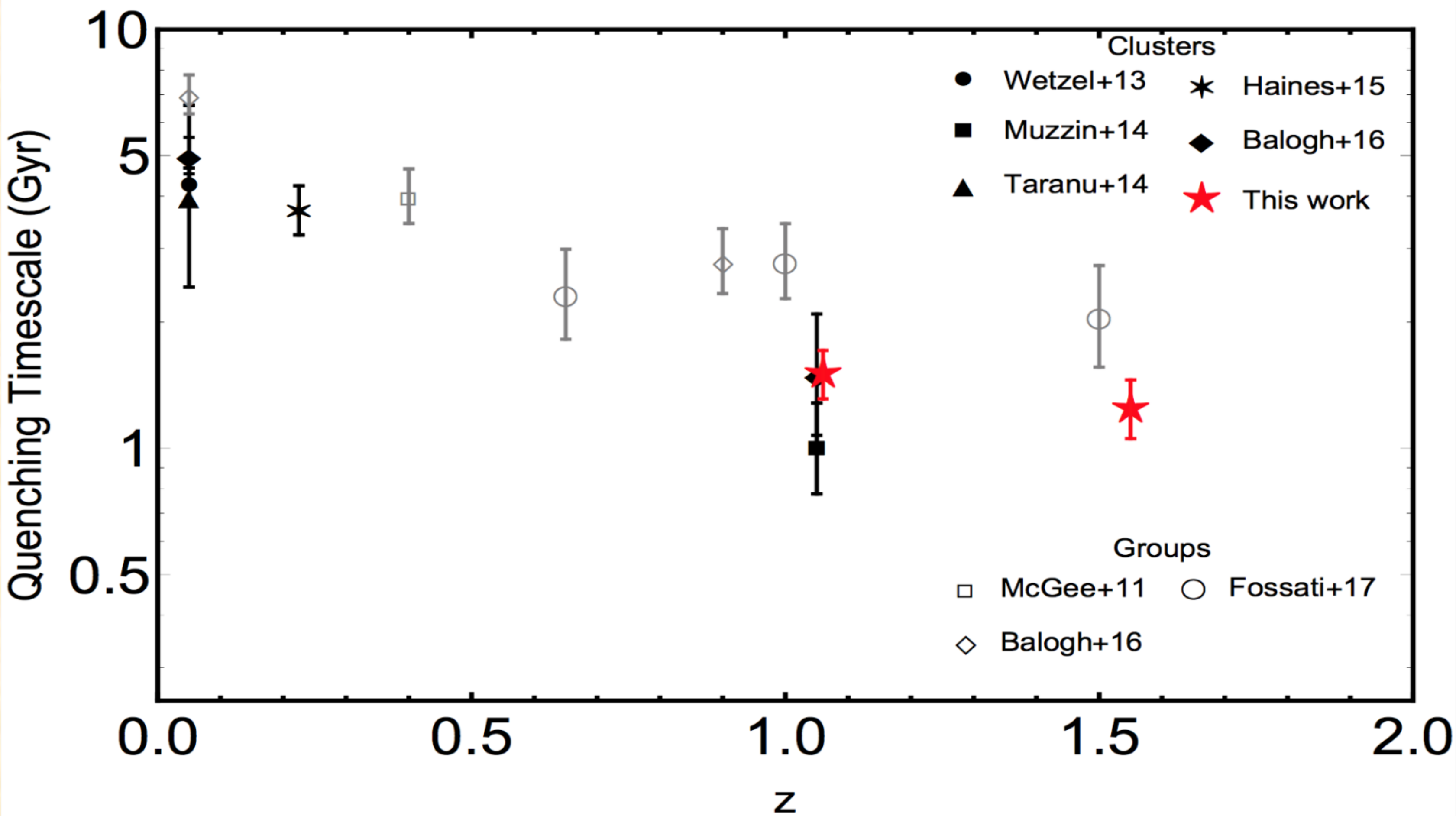
$$M_* \geq 10^{10.5}\ M_\odot$$





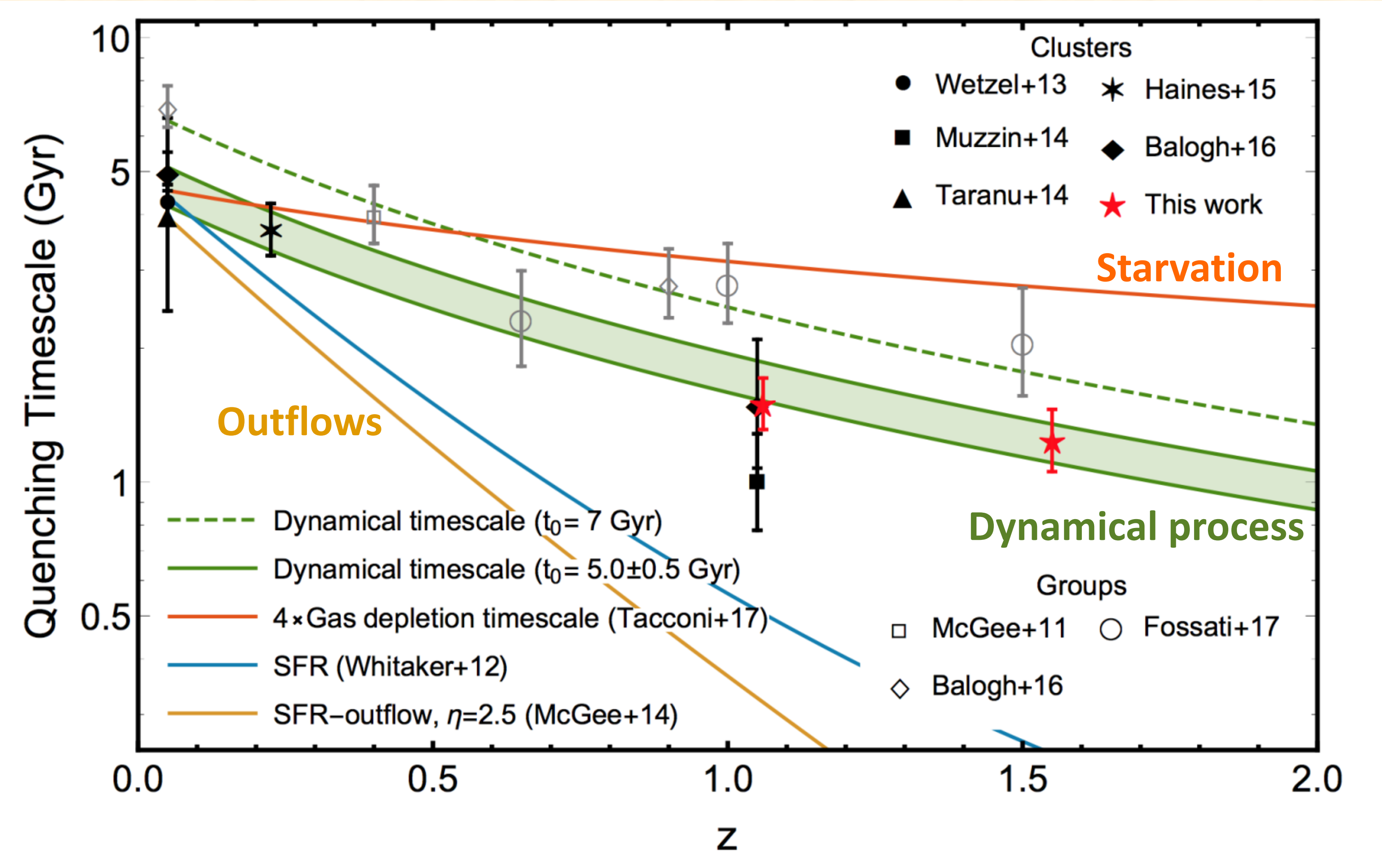
Foltz+17, in prep

Redshift Evolution of Quenching Timescales



Cluster Sample	N[a]	$\bar{z}$	R[b]	G[b]	B[b]	t_D (Gyr)	t_F (Gyr)	t_Q (Gyr)
GCLASS	10	1.04	160	42	38	$0.69^{+0.13}_{-0.13}$	$0.80^{+0.15}_{-0.18}$	$1.50^{+0.19}_{-0.18}$
SpARCS high-redshift	4	1.55	79	17	63	$0.94^{+0.20}_{-0.18}$	$0.29^{+0.14}_{-0.15}$	$1.24^{+0.23}_{-0.20}$

Comparison with Models

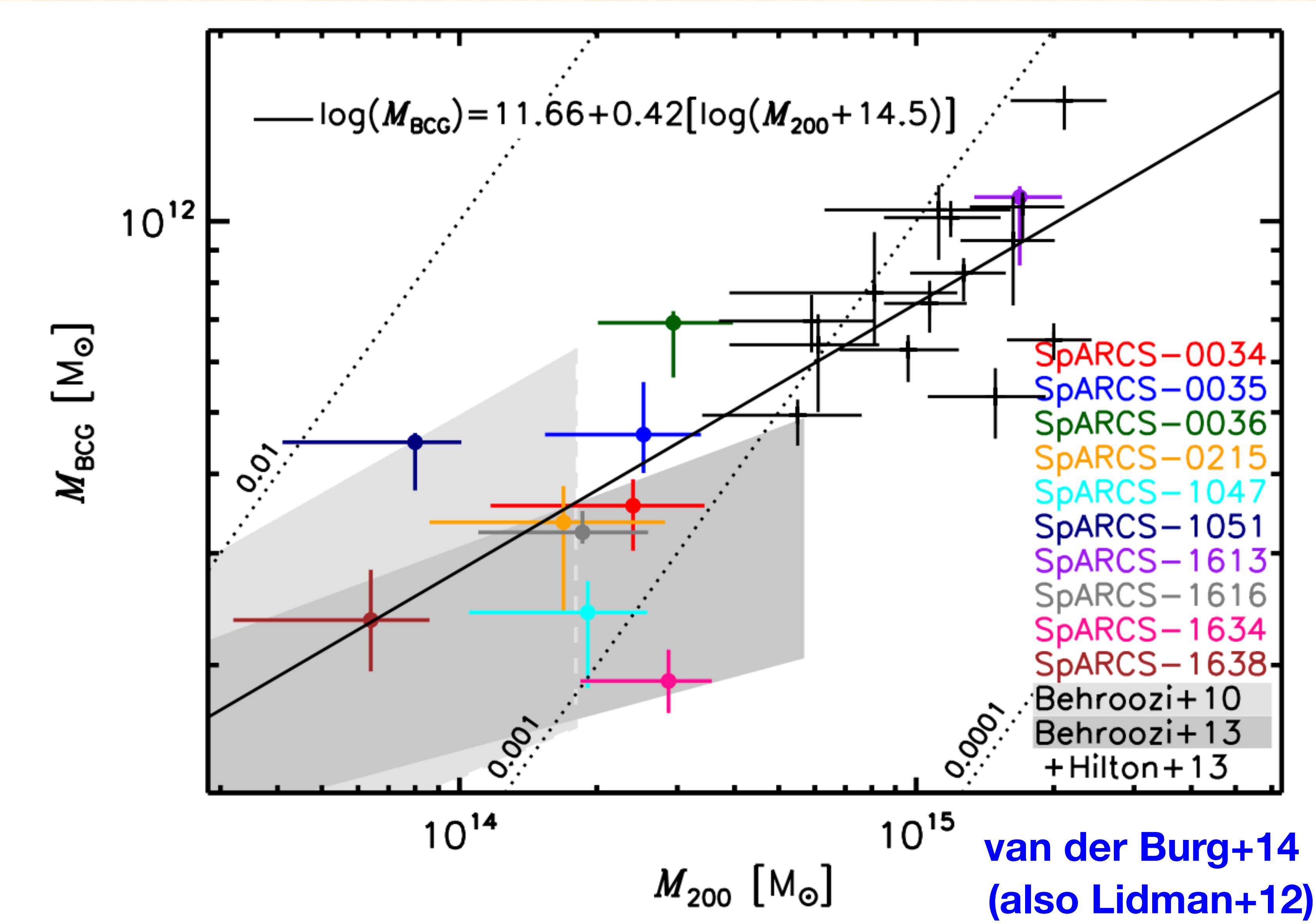


$M_* \geq 10^{10.5}\ \mathrm{M}_\odot$

Foltz+17, in prep

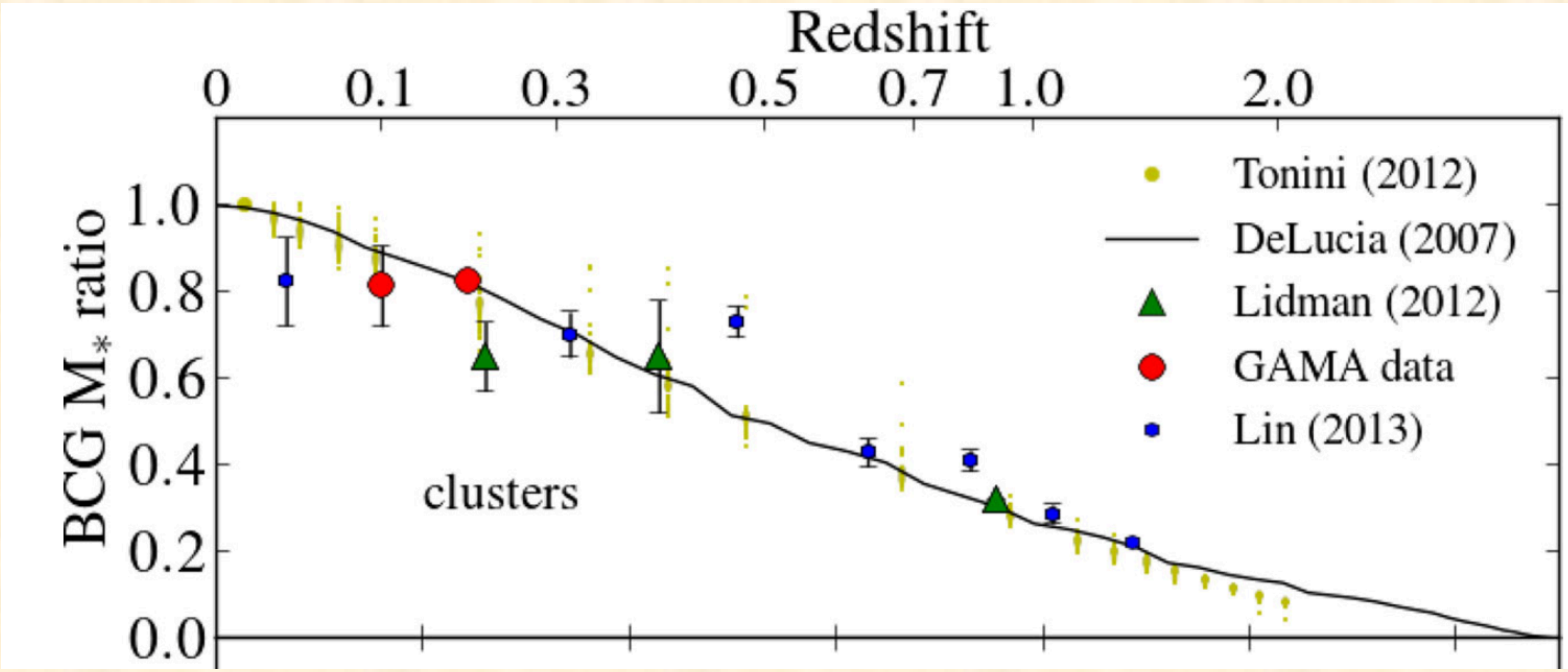
Brightest Cluster Galaxies (Centrals)

BCG Stellar Mass – Total Halo Mass Relation



ICL not included in SpARCS/GCLASS analysis

Good Agreement between BCG Stellar Mass Predictions and Observations at z < 1



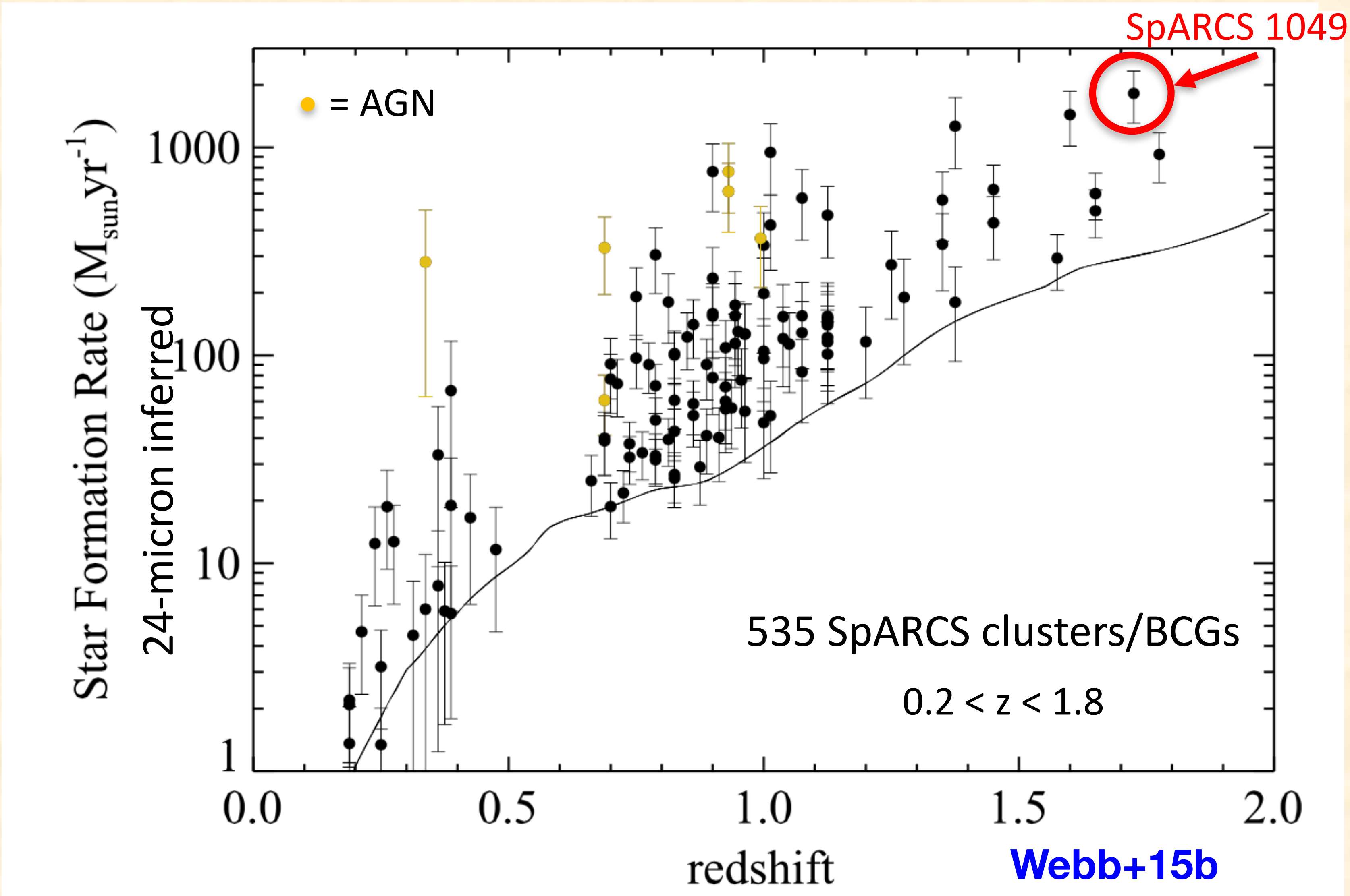
Oliva-Altamirano+14

BCGs grow by a factor of two in stellar mass between z=1 and z=0

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

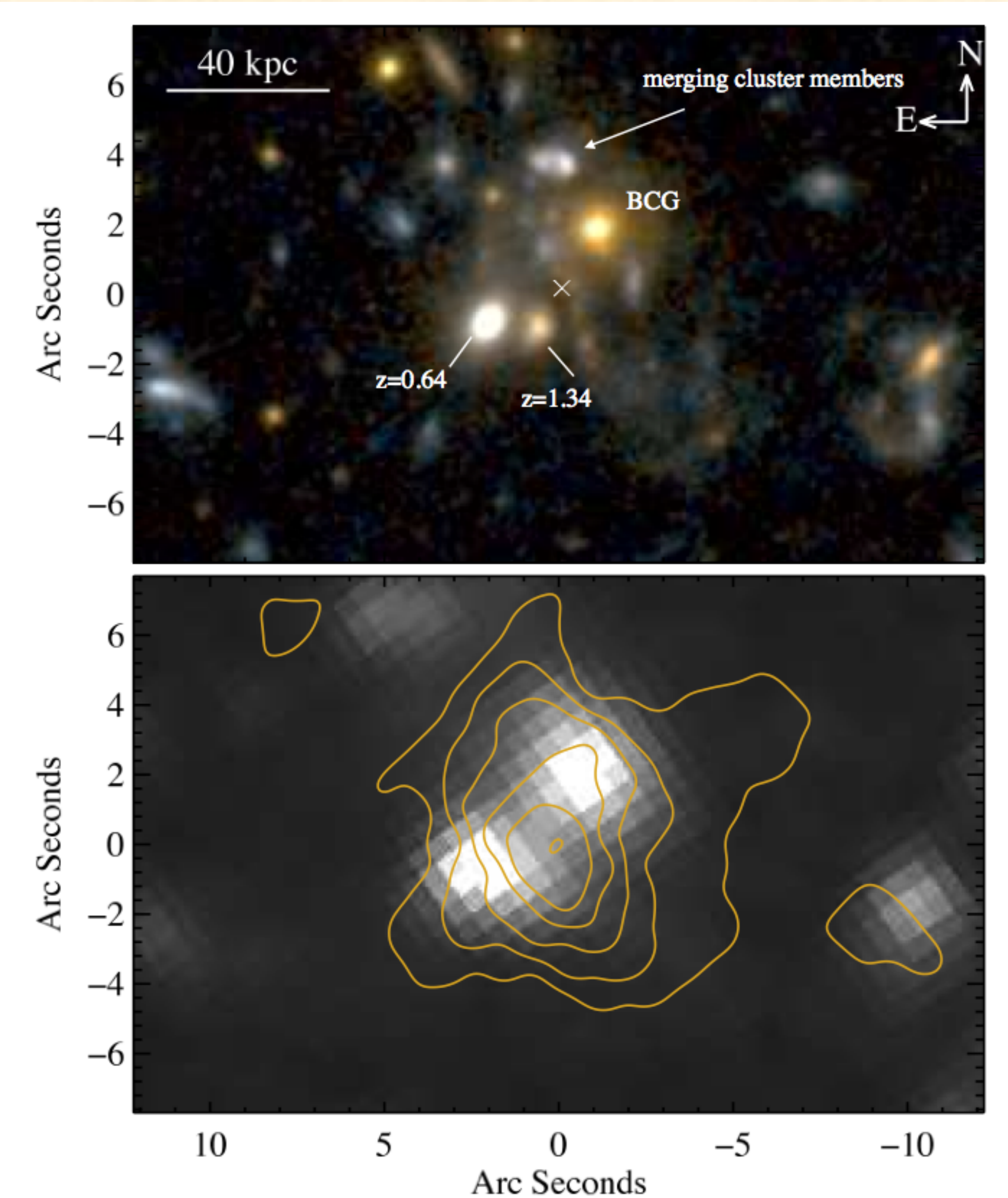
see Lidman+12,13

BCG Star Formation Rate as a Function of Redshift: Significant *In Situ* Star Formation at High Redshift



At z > 1 *in situ* star formation may be the dominant mode of BCG stellar mass growth

Extreme Starburst in a Cluster Core at z = 1.71



Webb+15a, 17

- 900 solar masses/year !!
- HST imaging reveals chain of 14 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
- Strong LMT CO signal
- Keck/MOSFIRE spectra of 31 members
- Keck/OSIRIS run Dec 2017

Conclusions

- **Samples of Clusters now available are providing new constraints on SMF, Baryon Assembly and Environmental Quenching out to z~2**
- **The epoch between z=2 and z=1 appears to be when Environmental Quenching really "Kicks In"**
- **Quenching Timescale Analysis suggests that Environmental Quenching in Clusters may be due to a Dynamical Process or Starvation**
- **New ongoing surveys e.g., GOGREEN (Balogh et al 2017) and SERVS/DeepDrill (Nyland et al 2017) are pushing down in Galaxy Stellar Mass and out in Redshift**

University of California Riverside Postdoc Position
High-z Massive Galaxies & Protoclusters

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