GOGREEN: Gemini Observations of Galaxies in Rich Early Environments – A deep spectroscopic survey of galaxies in 1.0<z<1.5 clusters

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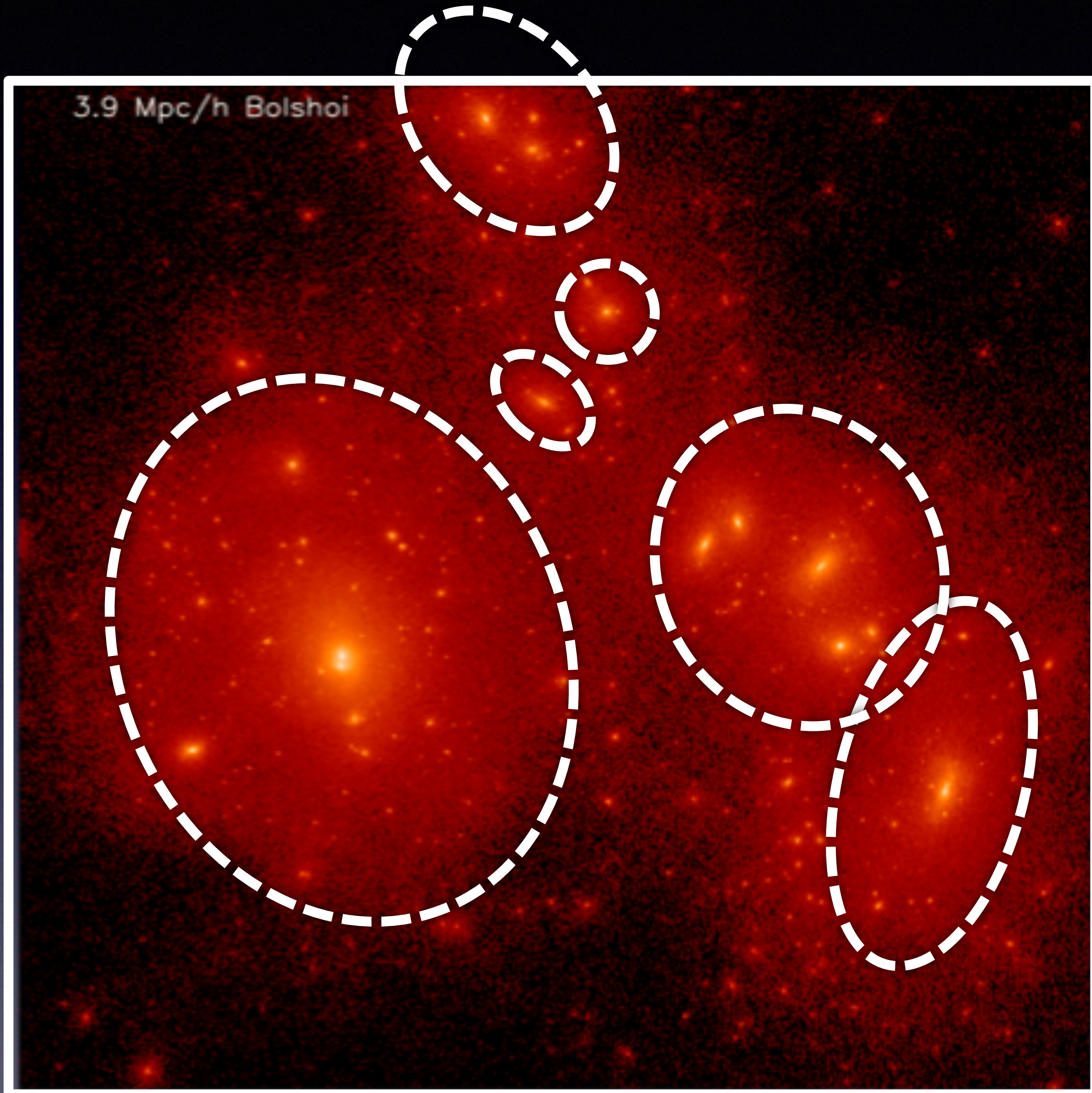
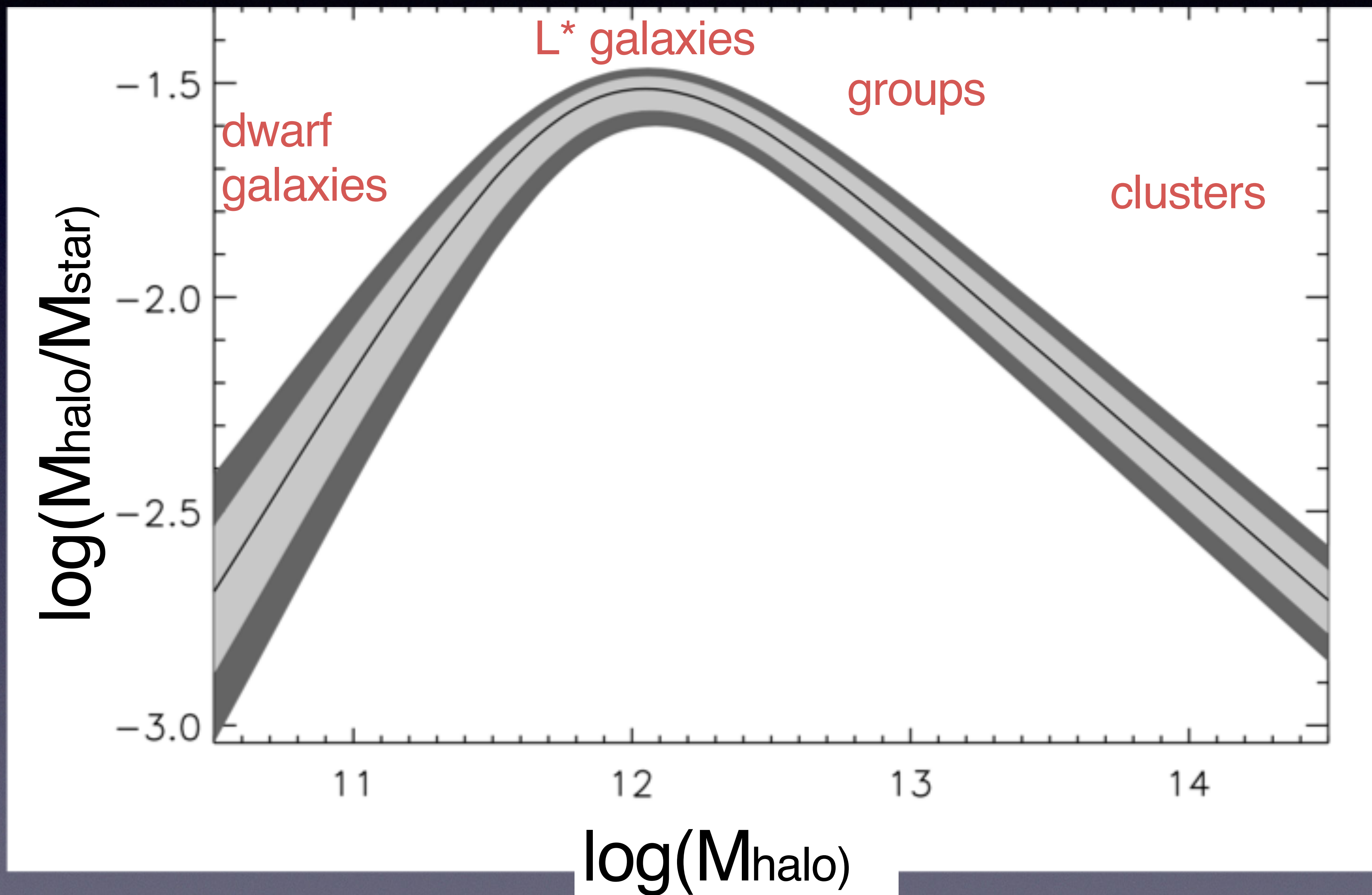
Galaxies and the halo model



Virialized dark matter haloes with a dominant central object and many satellites

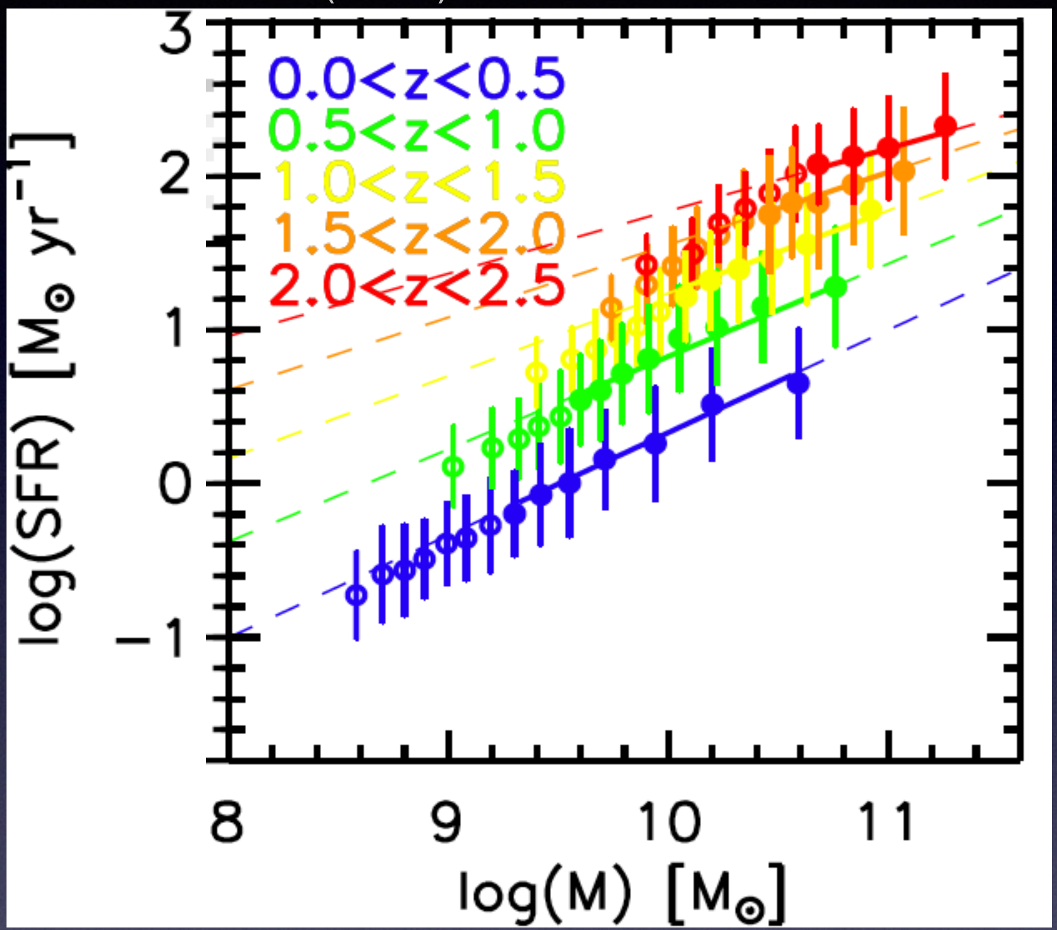
Galaxy formation efficiency is very dependent on halo mass



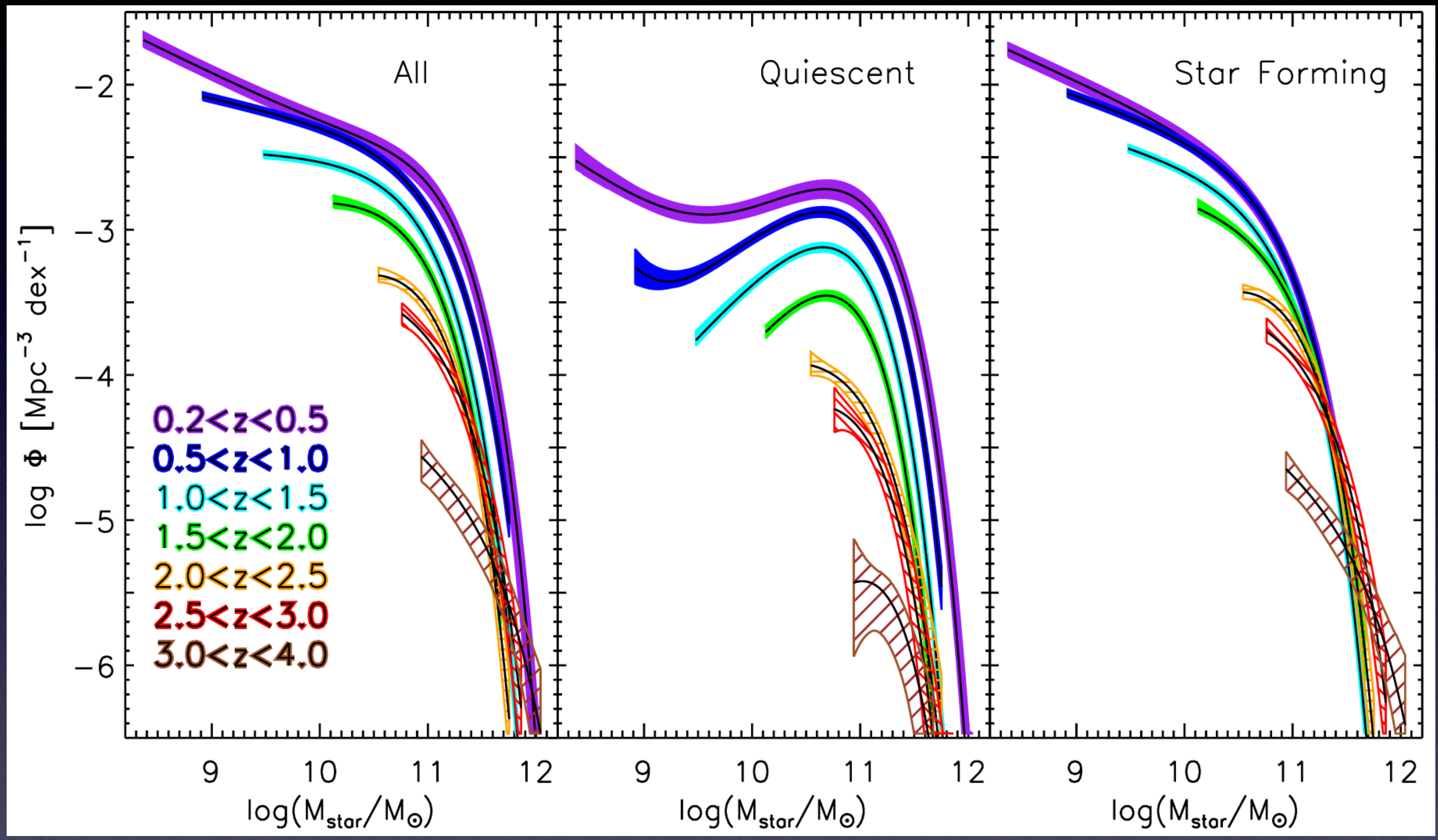
Moster et al. 2010

Galaxy properties evolve over time

Whitaker et al. (2012)



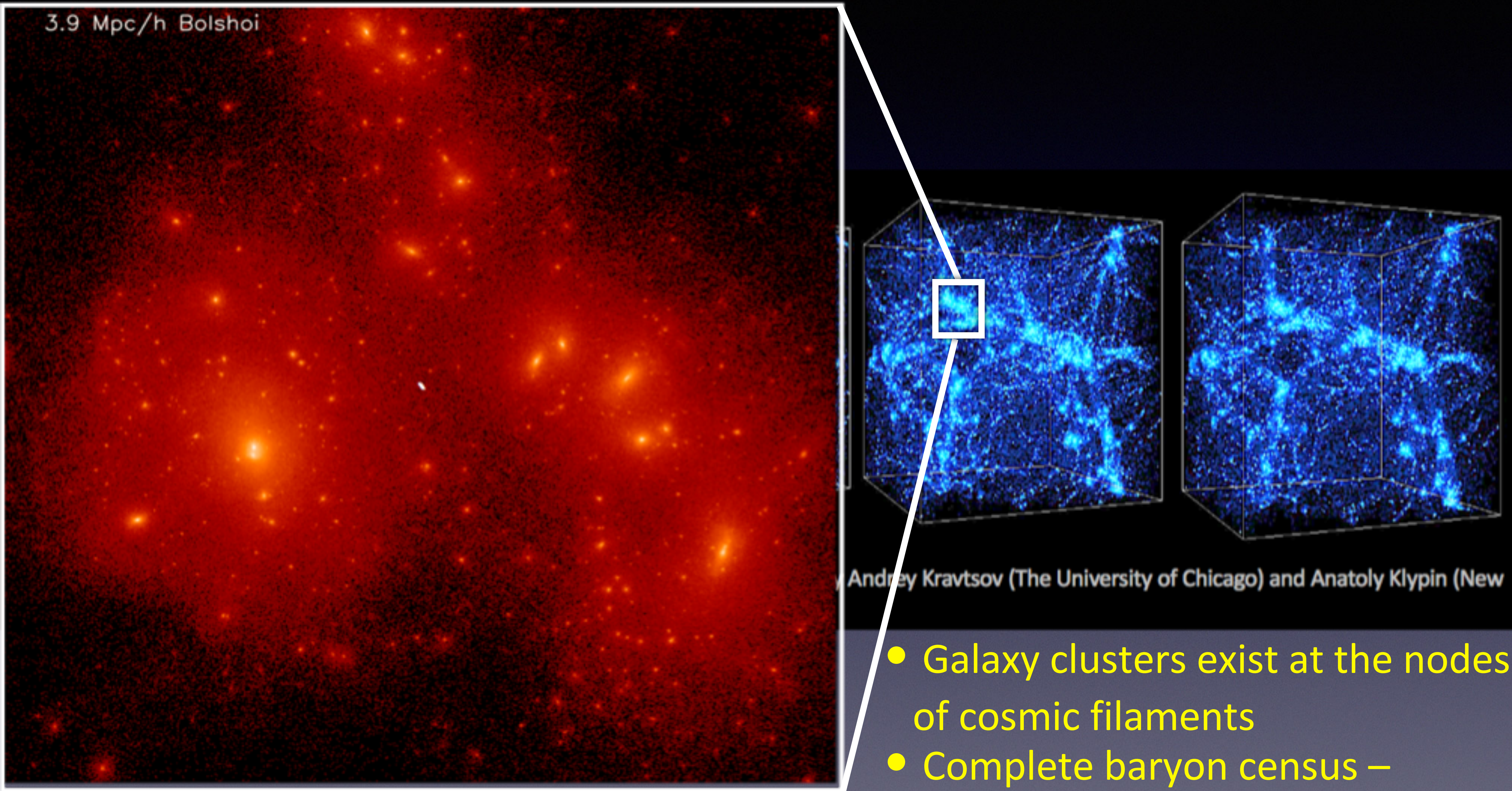
Muzzin et al. (2014)



Requires two types of evolution:

1. Steady evolution of SFR with time
2. Possibly sudden transition from SF to Quiescent

Galaxy clusters as laboratories for understanding galaxy evolution



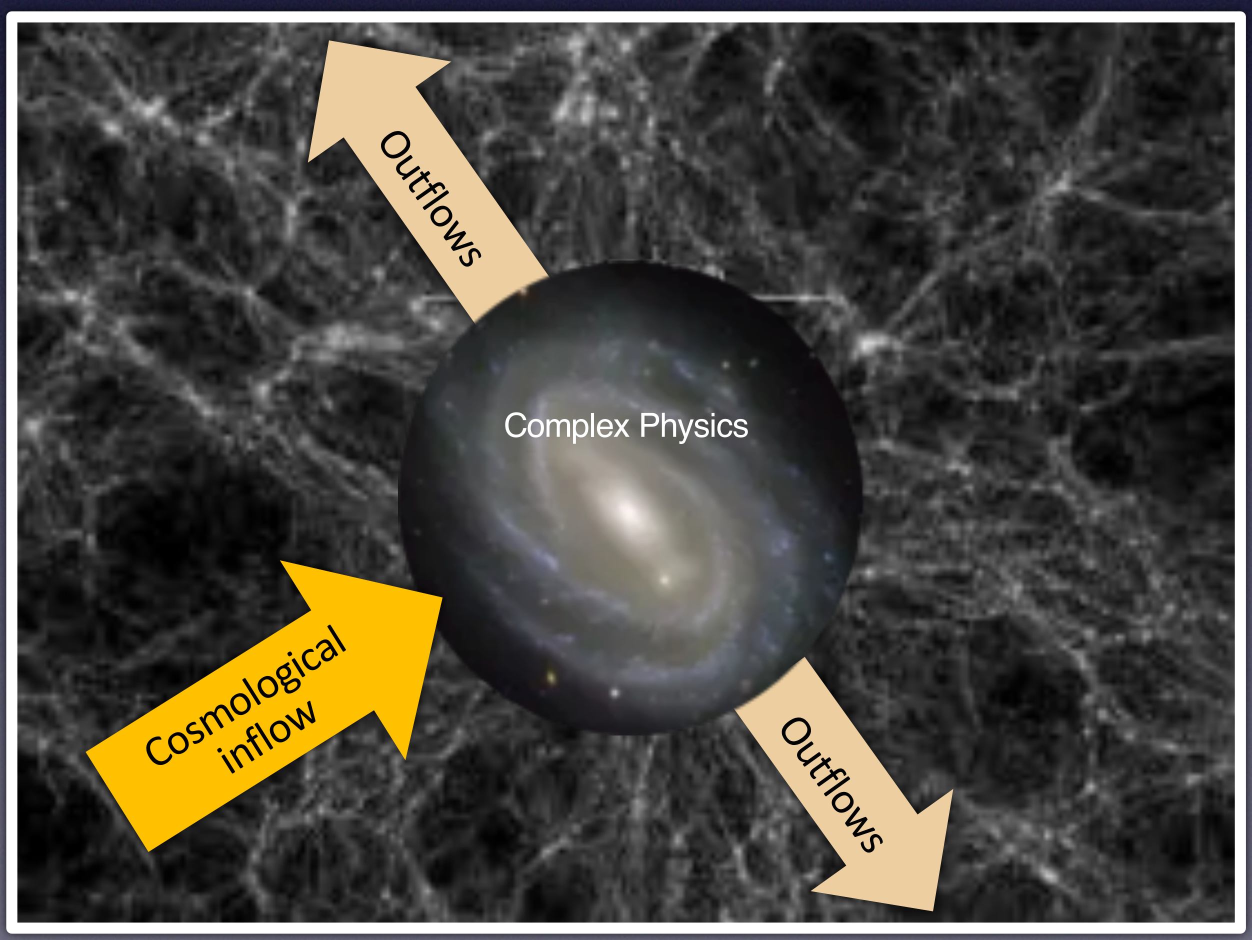
- Galaxy clusters exist at the nodes of cosmic filaments
- Complete baryon census – cosmic calorimeters
- Galaxies falling into clusters pass through a range of environments.

Central galaxies

Star formation rates are determined by a variety of processes occurring over a wide range of time and spatial scales.

Interpretations rely on sophisticated, parameterized models that have little predictive power.

Central galaxy



The physics is simpler on the largest scales, and inflow rates from the cosmic web may be more predictable

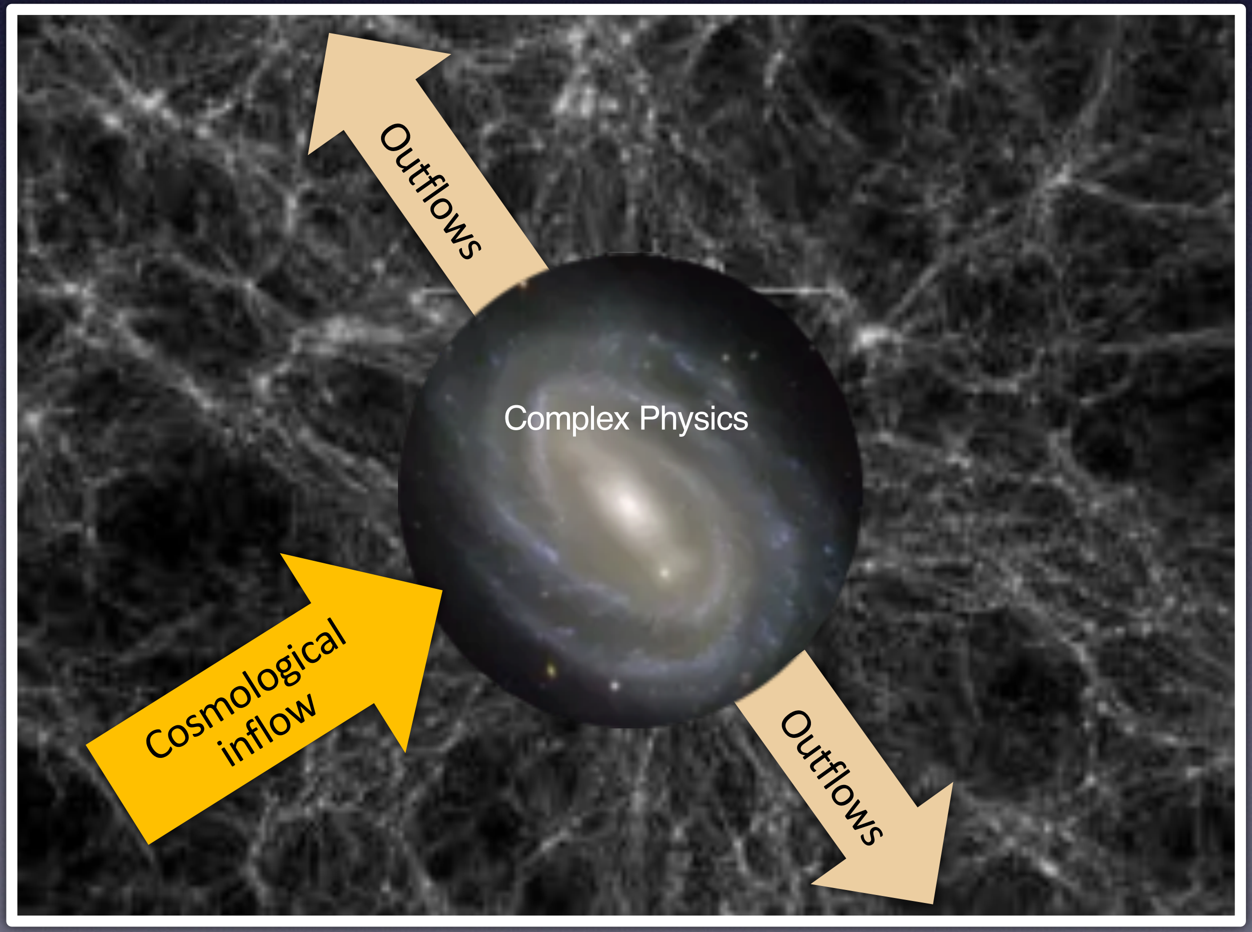
Satellite galaxies

A satellite galaxy loses its source of fresh gas from cosmological accretion.

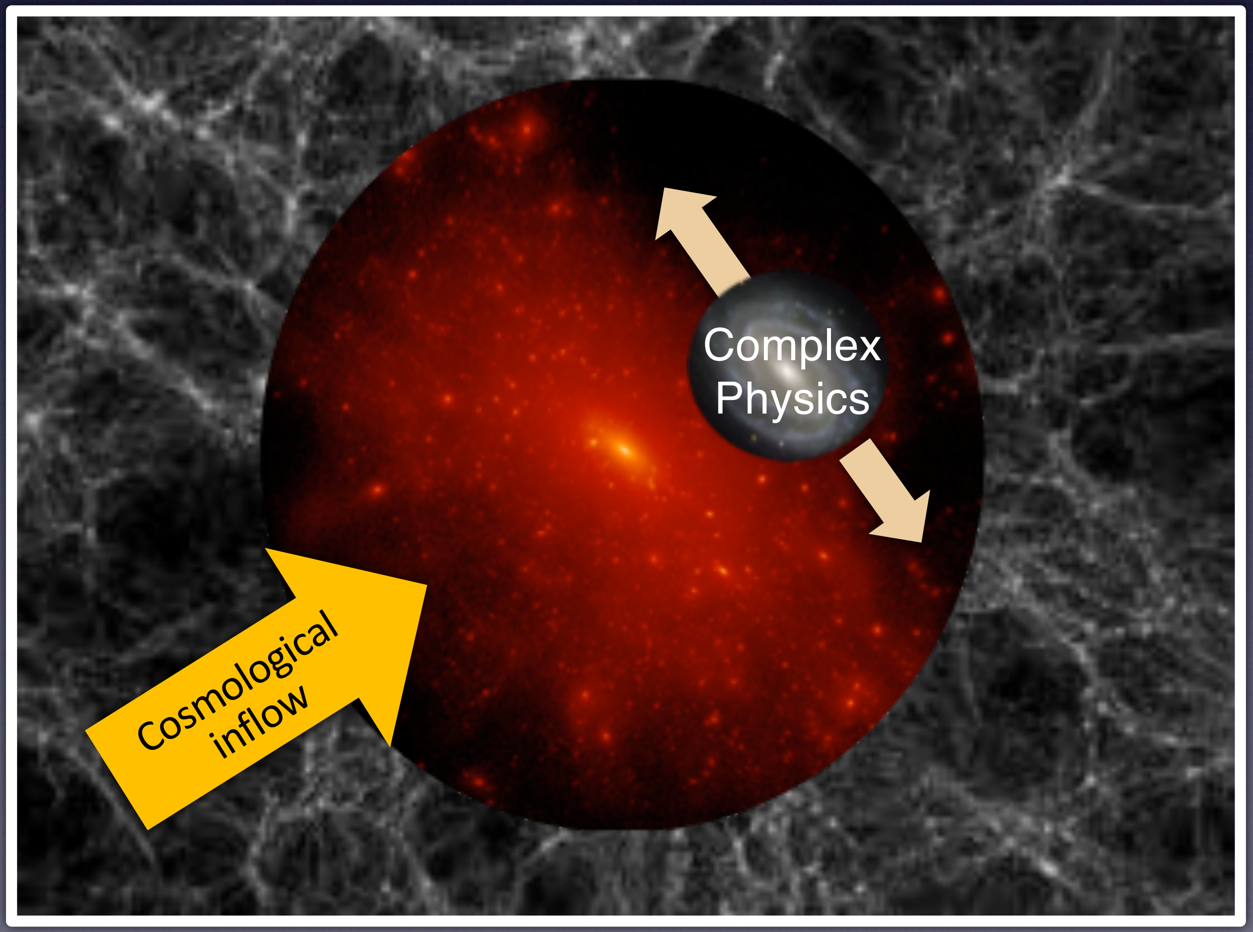
– For most satellites, everything else may be largely unaffected.

– We can test predictions of the "complex physics"

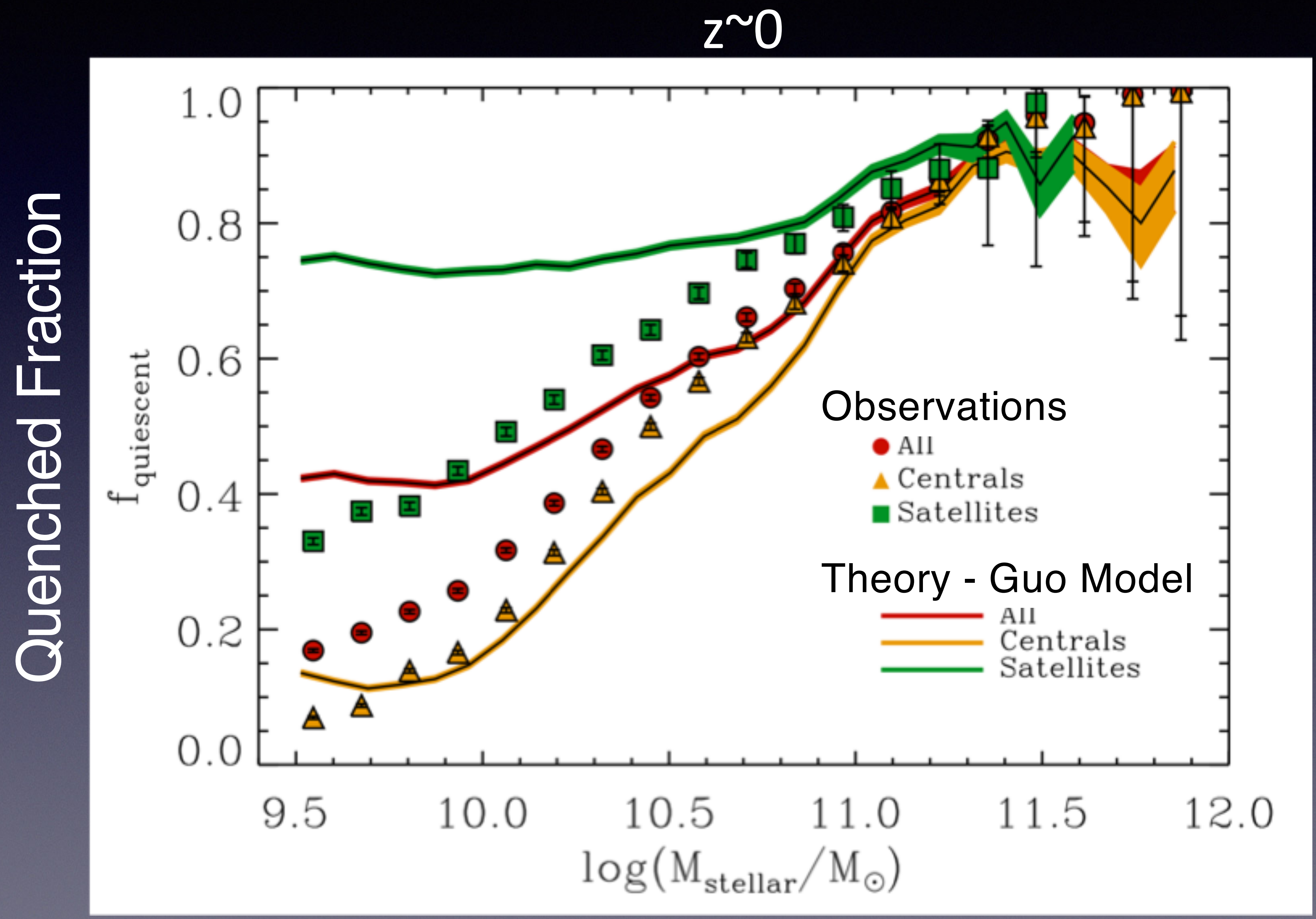
Central galaxy



Satellite galaxy



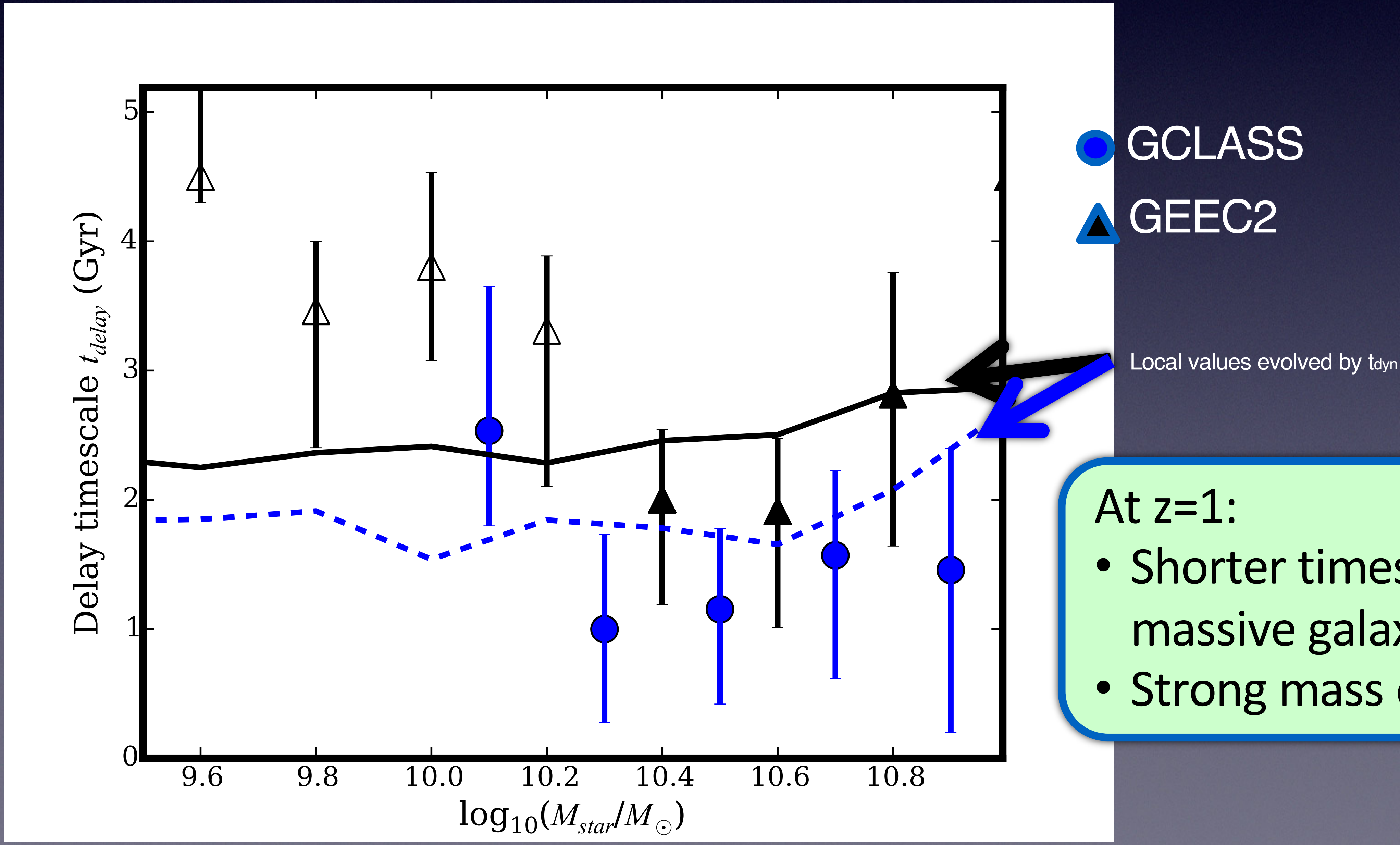
Theoretical models quench satellite galaxies too efficiently.



Hirschmann et al. 2014

Satellite quenching mechanisms evolve qualitatively

Quenching may be directly related to feedback processes, rather than dynamical processes like ram pressure stripping (McGee et al. 2014)



At z=1:

- Shorter timescales for massive galaxies
- Strong mass dependence

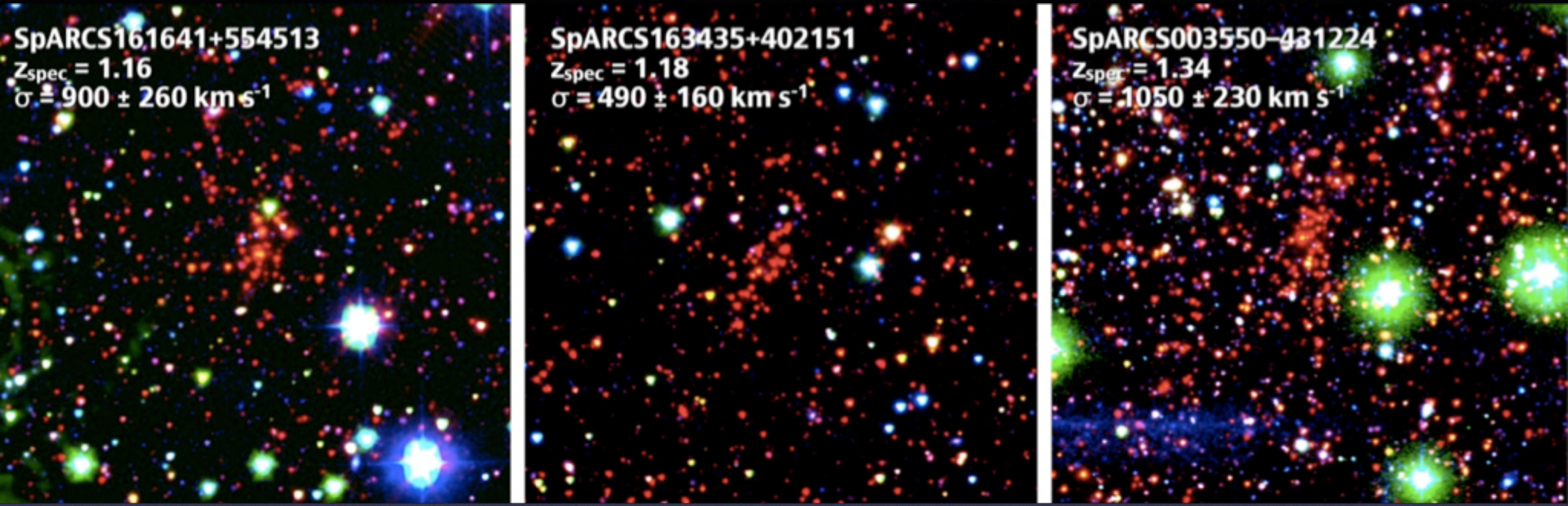
Balogh et al. (2016)

What is needed?

- Measurements of stellar contents of halos over a large range in redshift and halo mass.
- star formation histories of galaxies as a function of redshift, stellar mass and halo mass.
- Growth history of halos

- Spectroscopy for precise redshifts, halo masses, stellar populations
- Multiwavelength imaging for photo-redshifts, stellar populations, stellar masses

galaxy clusters and groups at z>1 can provide these elements



- Comparison to field gives a range in halo mass
- linking progenitor and descendant clusters is easier than for galaxies
- galaxy kinematics give insight to accretion history
- observationally efficient to obtain spectroscopy

GOGREEN

Gemini Observations of Galaxies in Rich Early ENvironments

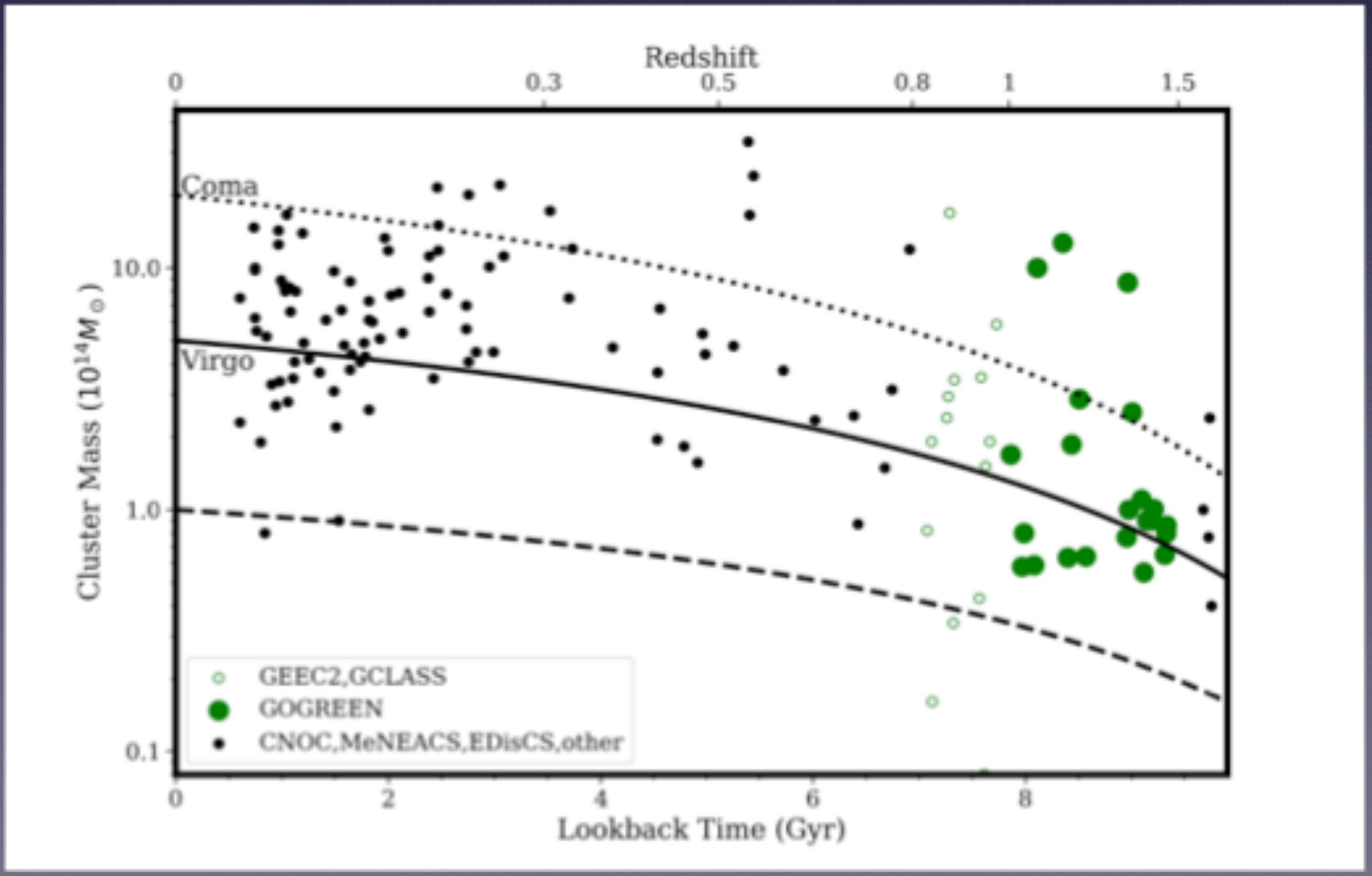
440h Gemini Large and Long Program

Unique features of GOGREEN:

1. Very deep, unbiased spectroscopy for all galaxy types, probing stellar masses below 10^{10} MSun at $1 < z < 1.5$
2. Wide range of halo masses, ranging from groups (10^{13} MSun) to massive clusters (10^{15} MSun)

GOGREEN Science goals:

- Environmental-Quenching of Low Mass Galaxies
- Hierarchical Assembly of Baryons
- Cluster Dynamics and Masses

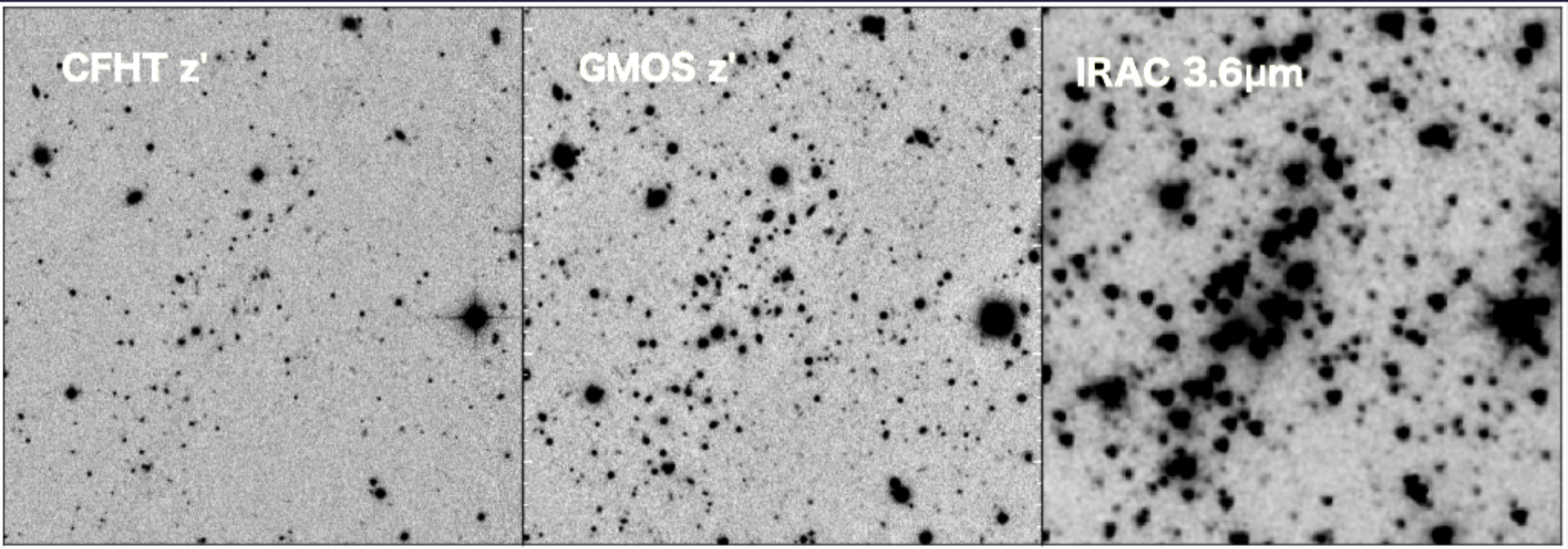


http://gogreensurvey.ca/

Sample Properties

Stellar mass limited to $M_{star} = 10^{10} M_{sun}$

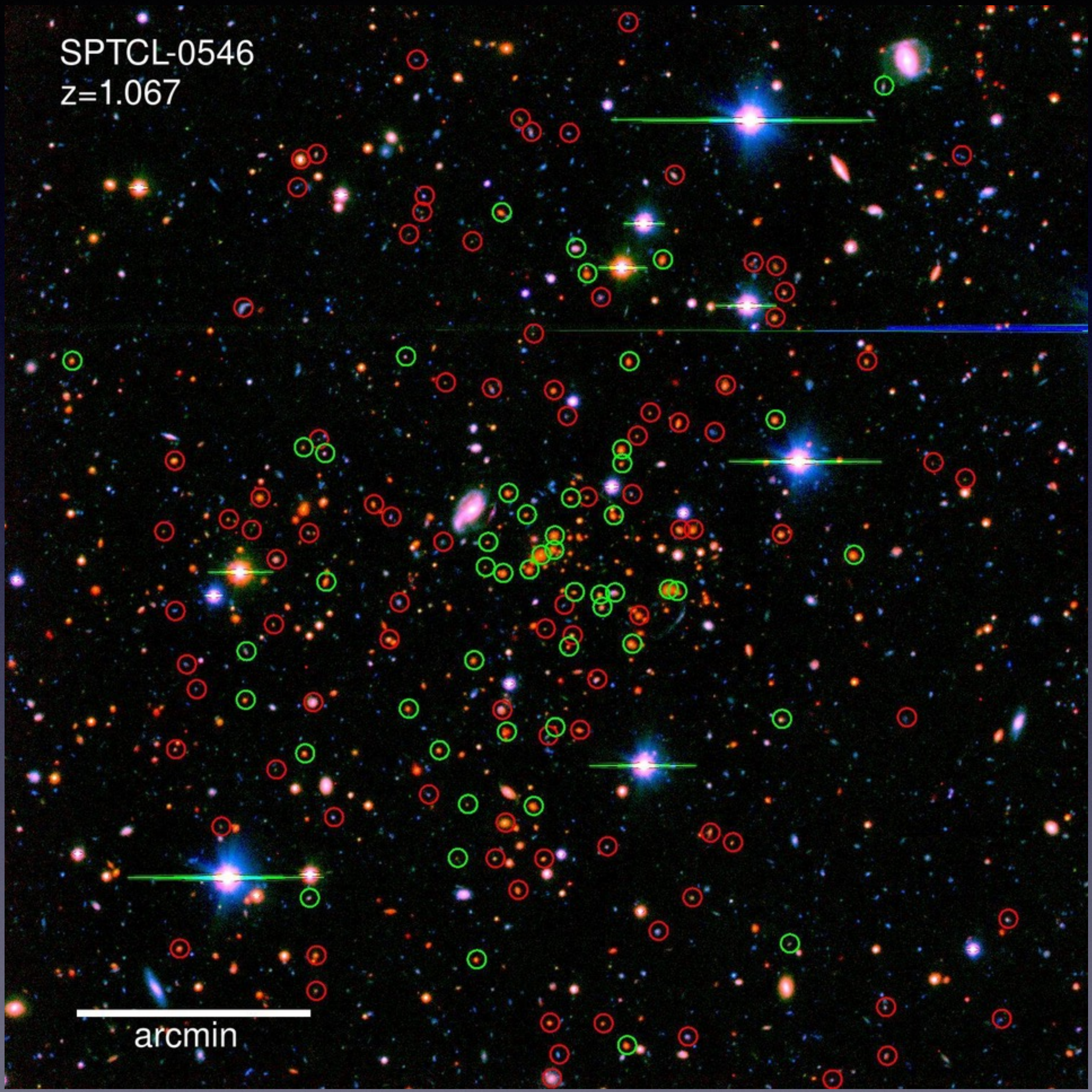
- Use deep GMOS z-band and 3.6μm imaging to select galaxies



z=1.177

Sample Properties

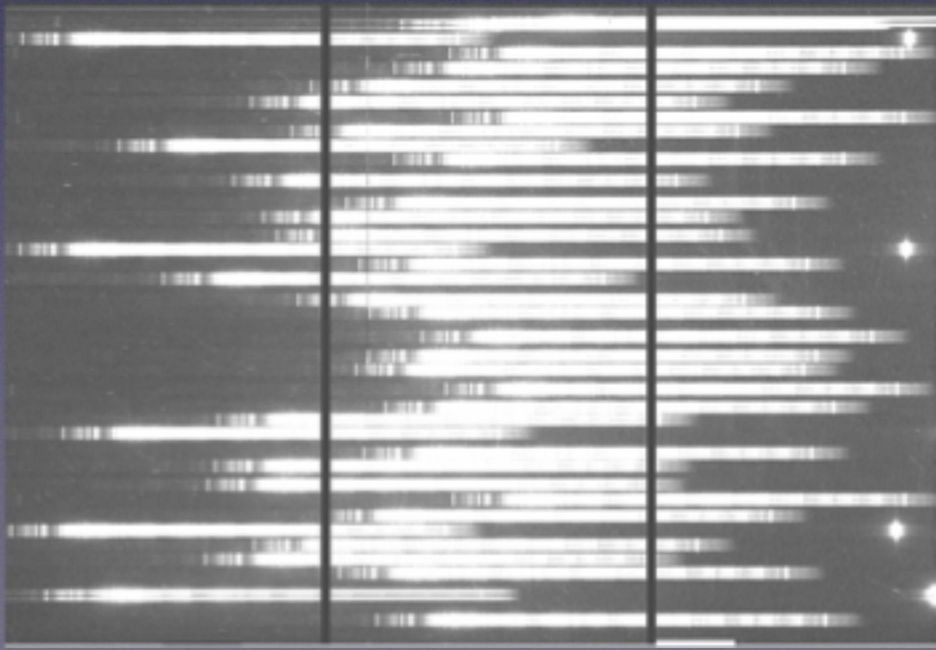
High spectroscopic completeness



member

field galaxy

- High spectroscopic completeness enabled by nod and shuffle with Gemini/GMOS
- >1000 members and >600 field galaxies with z_{spec} at $1<z<1.5$
- 15 hour/mask on faintest targets



Deep (i ~ 26 AB) multiwavelength (u-band through 3.6 μm) imaging for all systems

Northern clusters	z	u	g	r	i	z	Y	J	K	
Target depth			26.5	26.5	26	25	24.5	24	23.5	
SpARCS 1033+5753	1.46		Subaru	Subaru	Subaru	Subaru	Subaru	MMT	MMT	
SpARCS 1034+5818	1.40		Subaru	Subaru	Subaru	Subaru	Subaru	CFHT	CFHT	
SpARCS 1051+5818	1.04	GCLASS	Subaru	Subaru	Subaru	Subaru	Subaru	CFHT	CFHT	
SpARCS 1616+5545	1.16	GCLASS	Subaru	Subaru	Subaru	HSC	HSC	CFHT	CFHT	
SpARCS 1634+4021	1.18	GCLASS	Subaru	Subaru	Subaru	Subaru	Subaru	CFHT	CFHT	
SpARCS 1638+4038	1.20	GCLASS	Subaru	Subaru	Subaru	Subaru	Subaru	CFHT	CFHT	
Southern clusters	**z**	**U**	**B**	**V**	**R**	**I**	**z**	**J1**	**J**	**K**
Target depth		26	26.8	26.2	26.2	25.9	25	24.5	24	23.5
SpARCS 0219-0531	1.30	VIMOS	VIMOS	VIMOS	VIMOS	VIMOS	VIMOS	Magellan	Magellan	Magellan
SpARCS 0035-4312	1.34	VIMOS	VIMOS	VIMOS	VIMOS	VIMOS	VIMOS	Magellan	HAWK- I	HAWK- I
SPT-CL J0205-5829	1.32	VIMOS	VIMOS	VIMOS	VIMOS	VIMOS	VIMOS	Magellan	Magellan	Magellan
SpARCS 0335-2929	1.37	VIMOS	VIMOS	VIMOS	VIMOS	VIMOS	VIMOS	HAWK-I	Magellan	Magellan
SPT-CL J0546-5345	1.07	VIMOS	VIMOS	VIMOS	VIMOS	VIMOS	VIMOS	Magellan	Magellan	Magellan
SPT-CL J2106-5844	1.13	VIMOS	VIMOS	VIMOS	VIMOS	VIMOS	VIMOS	Magellan	Magellan	Magellan

Approved/18A

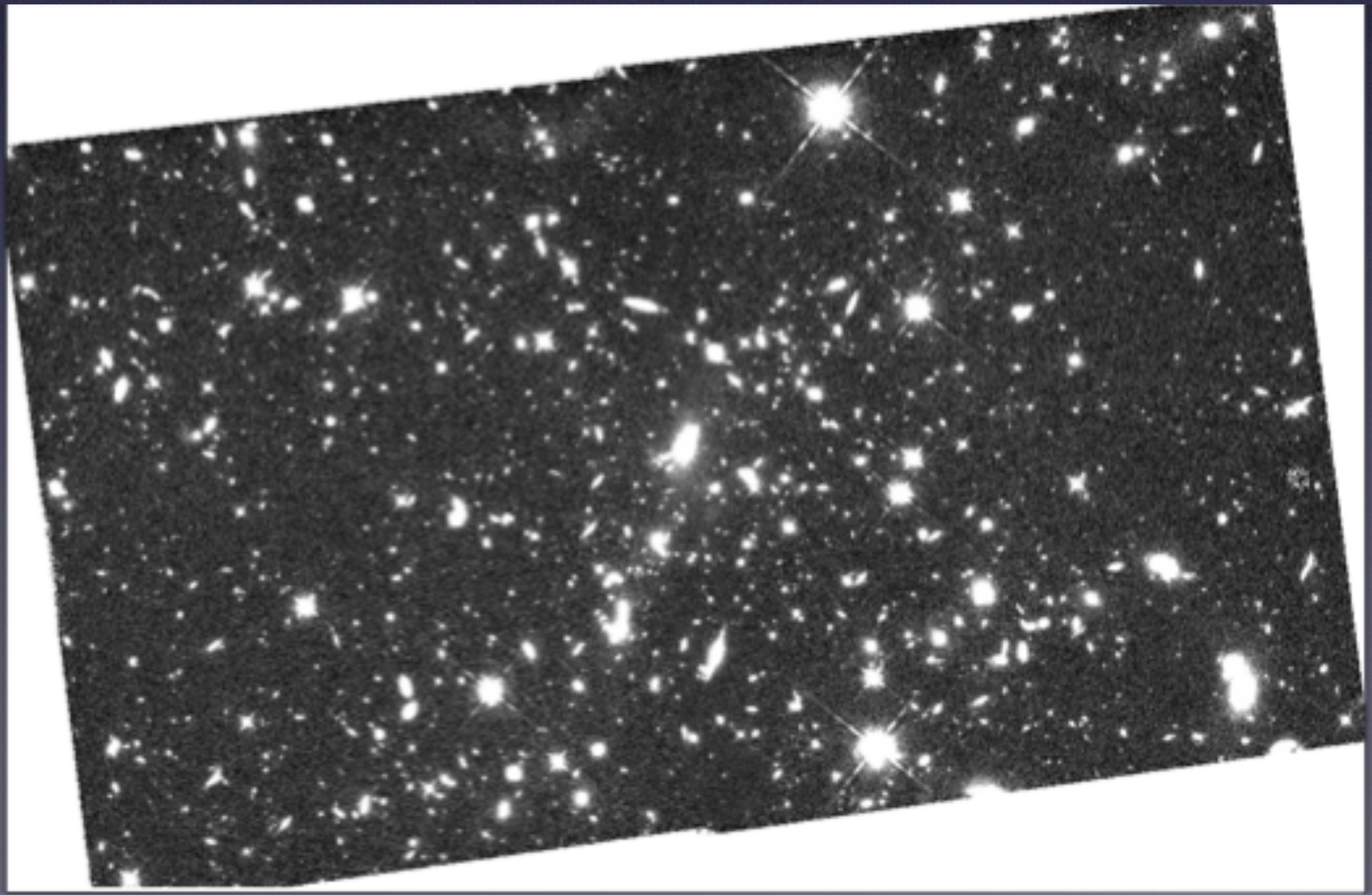
Successfully executed

Proposed (18B)

Gregory Rudnick (Imaging acquisition team lead)

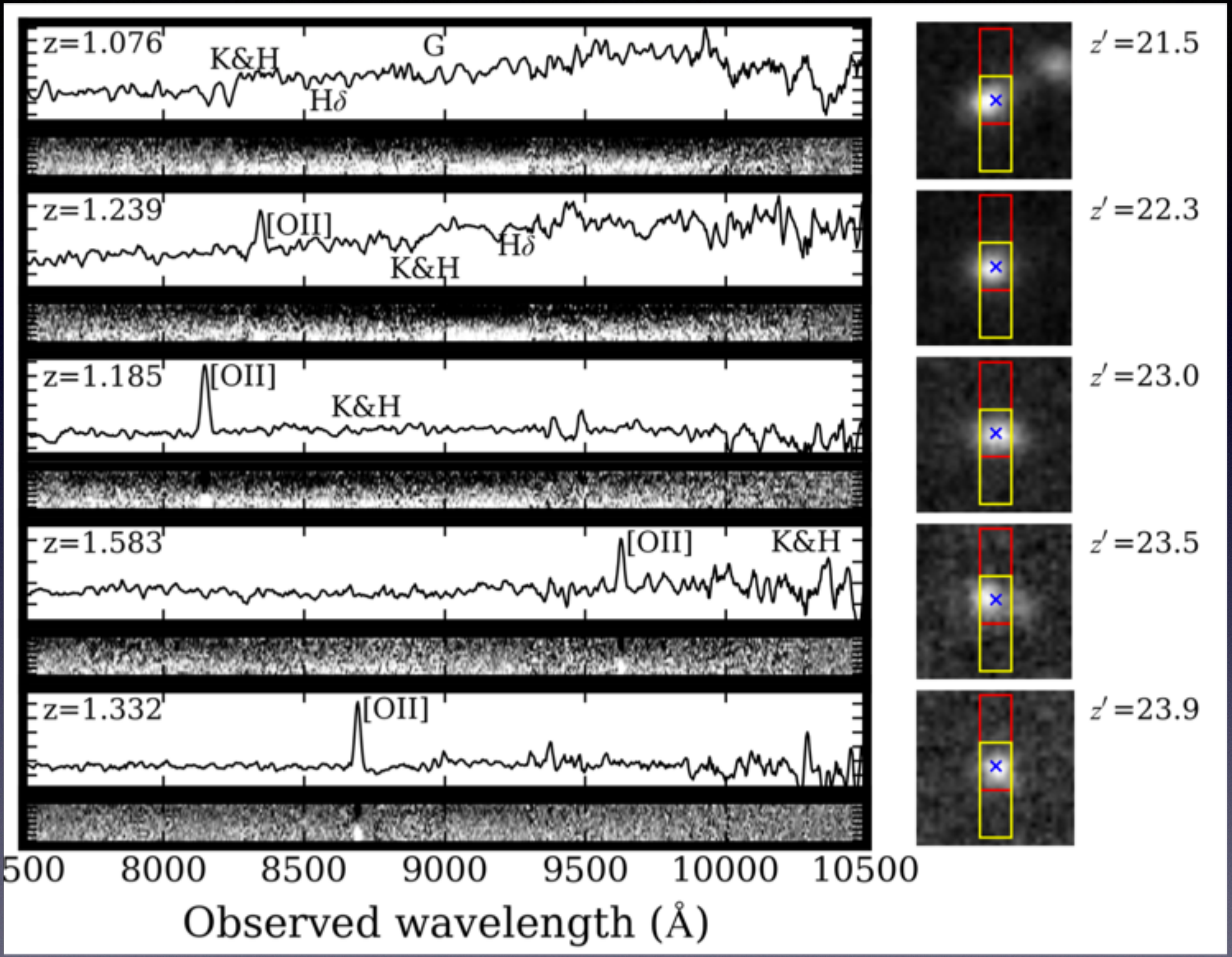
Remco van der Burg (photometry team lead)

HST F160W

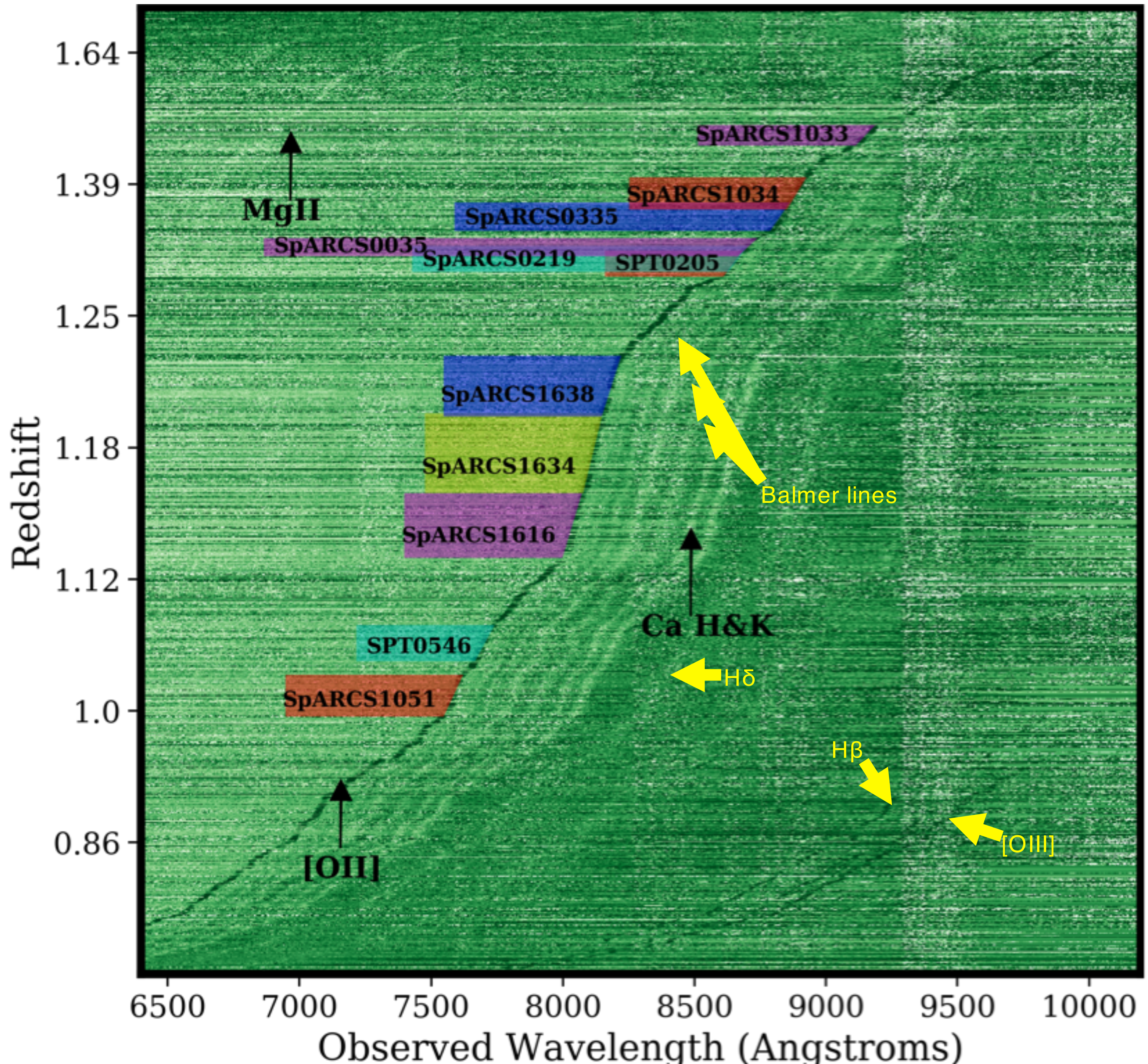


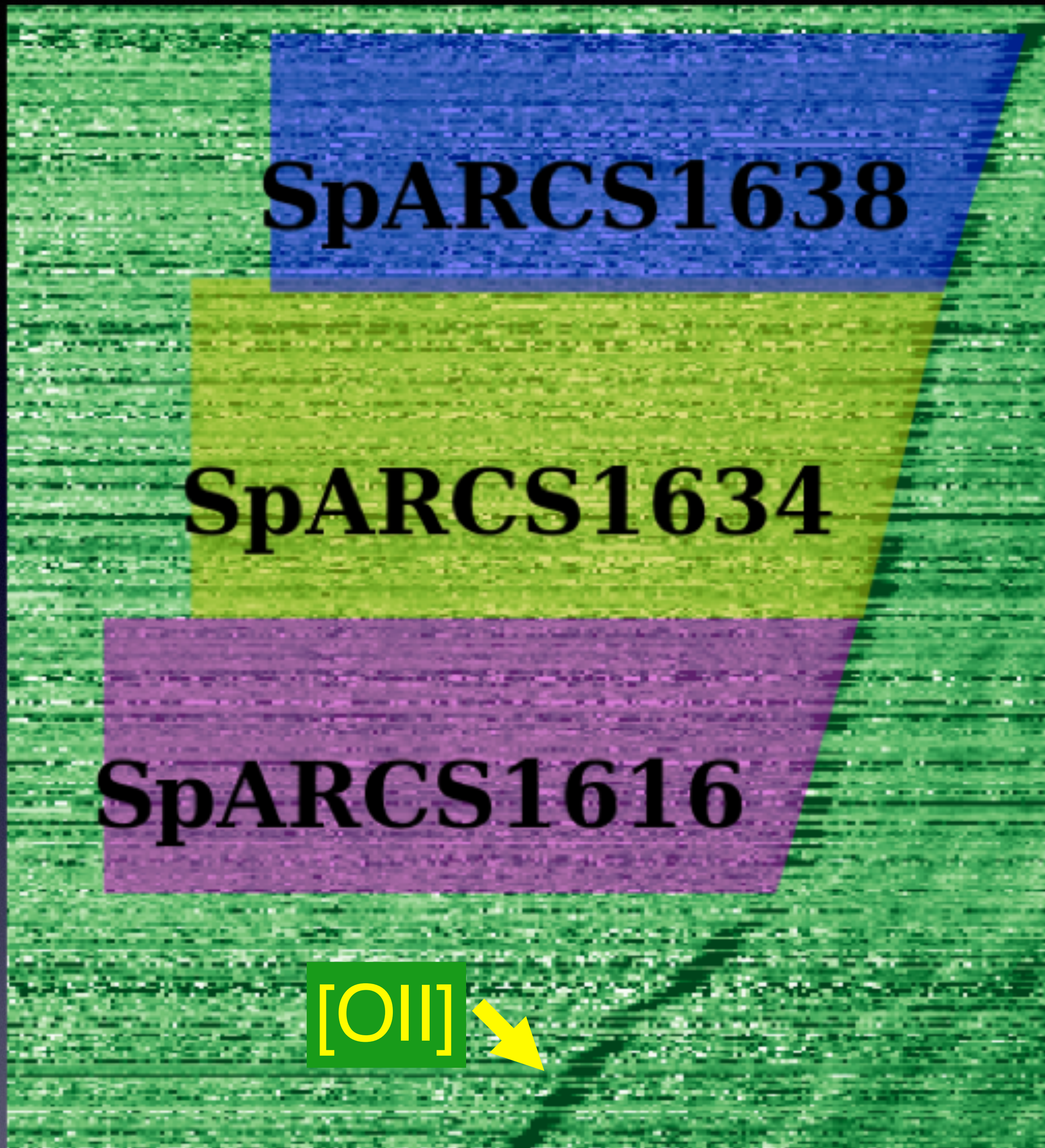
Sizes and morphology, stellar masses, select red sequence ...

Example Spectra



Balogh et al. 2017


1.64
1.39
1.25
1.18
1.12
1.0
0.86
Redshift
6500
7000
7500
8000
8500
9000
9500
10000
Observed Wavelength (Angstroms)
MgII
SpARCS1033
SpARCS1034
SpARCS0335
SpARCS0035
SpARCS0219
SPT0205
SpARCS1638
SpARCS1634
SpARCS1616
SPT0546
SpARCS1051
Balmer lines
Ca H&K
Hδ
Hβ
[OIII]
[OII]

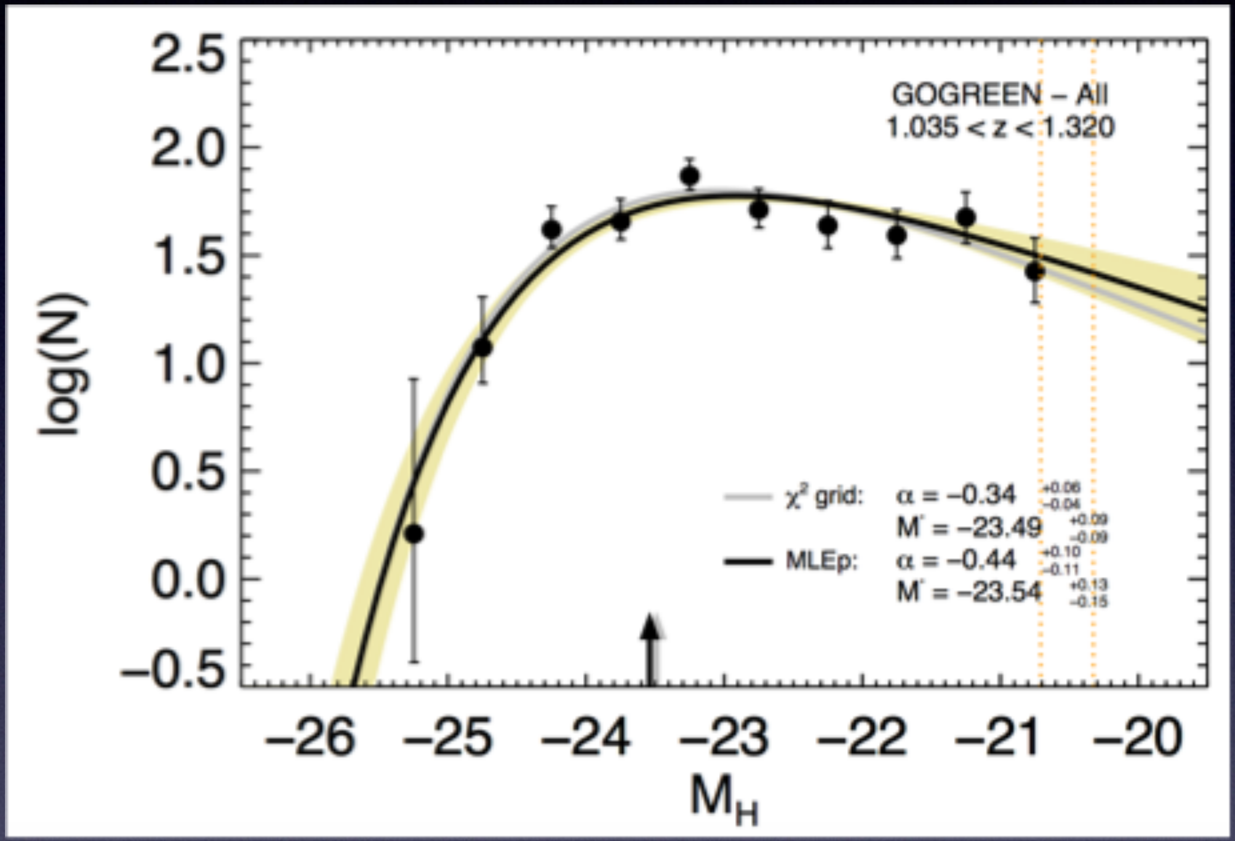


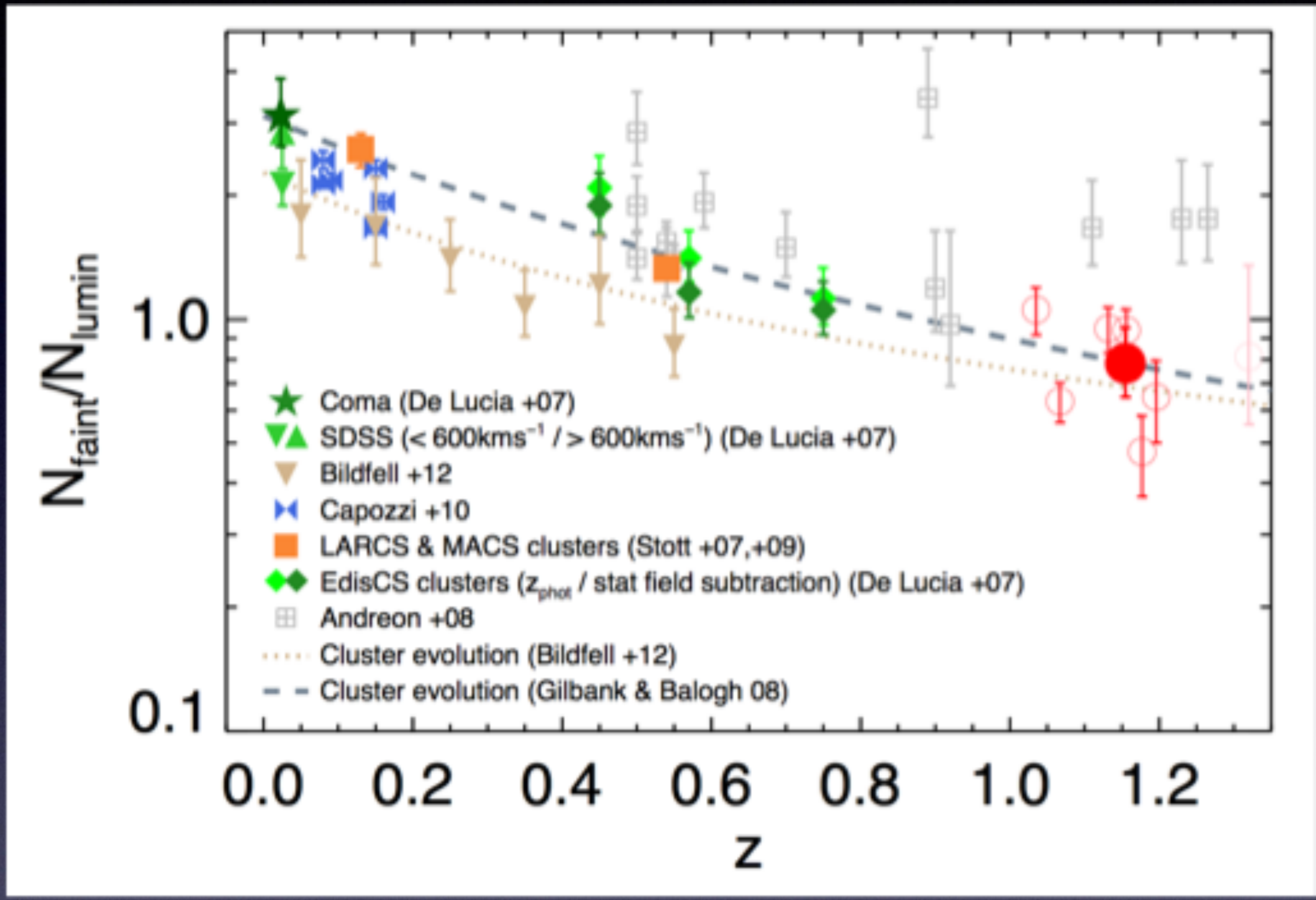
increased quenched fraction
in clusters

Growth of the red sequence

Jeffrey Chan, UC Riverside

PRELIMINARY





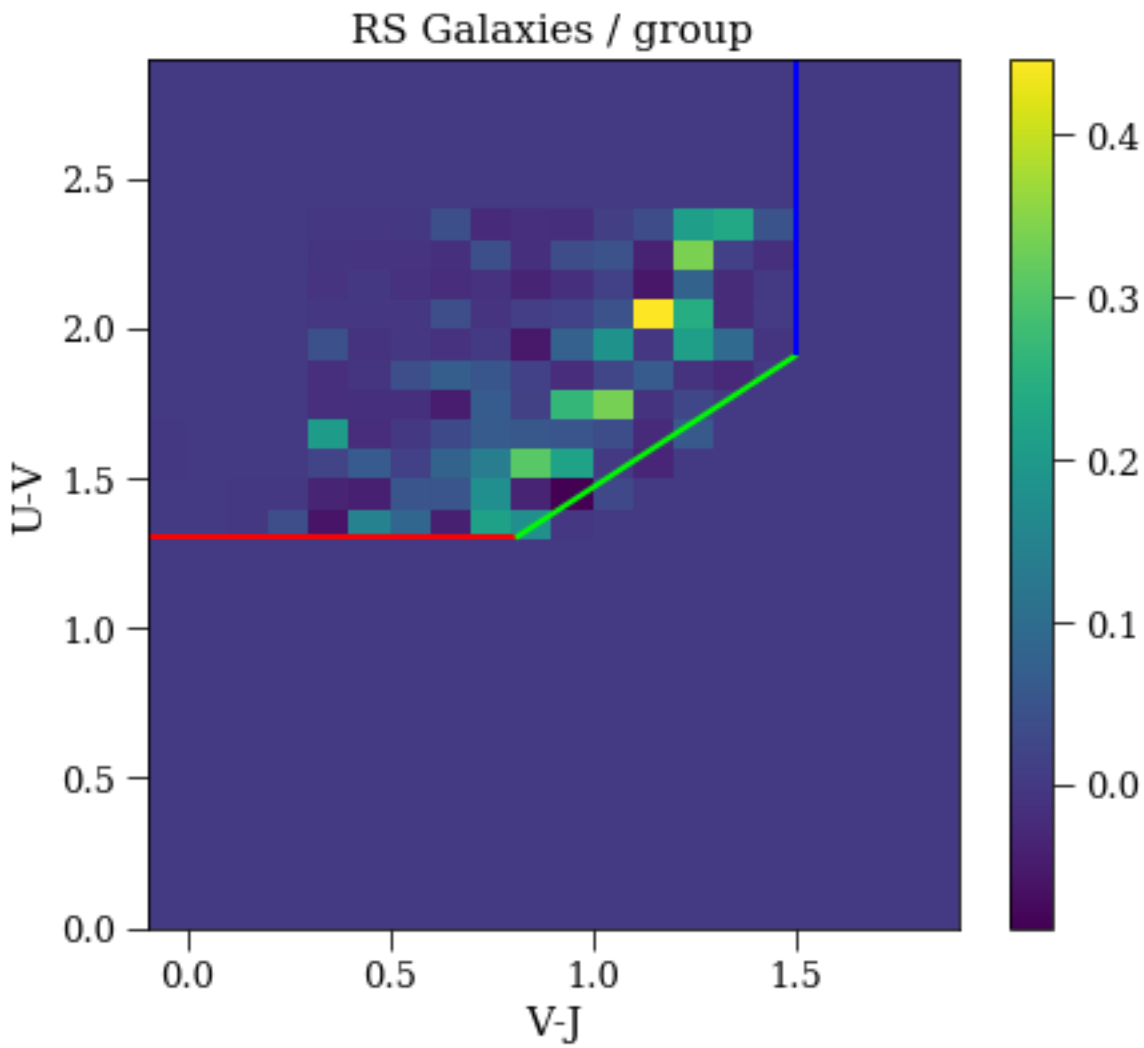
Fewer low-mass quiescent galaxies than counterparts at z=0.7

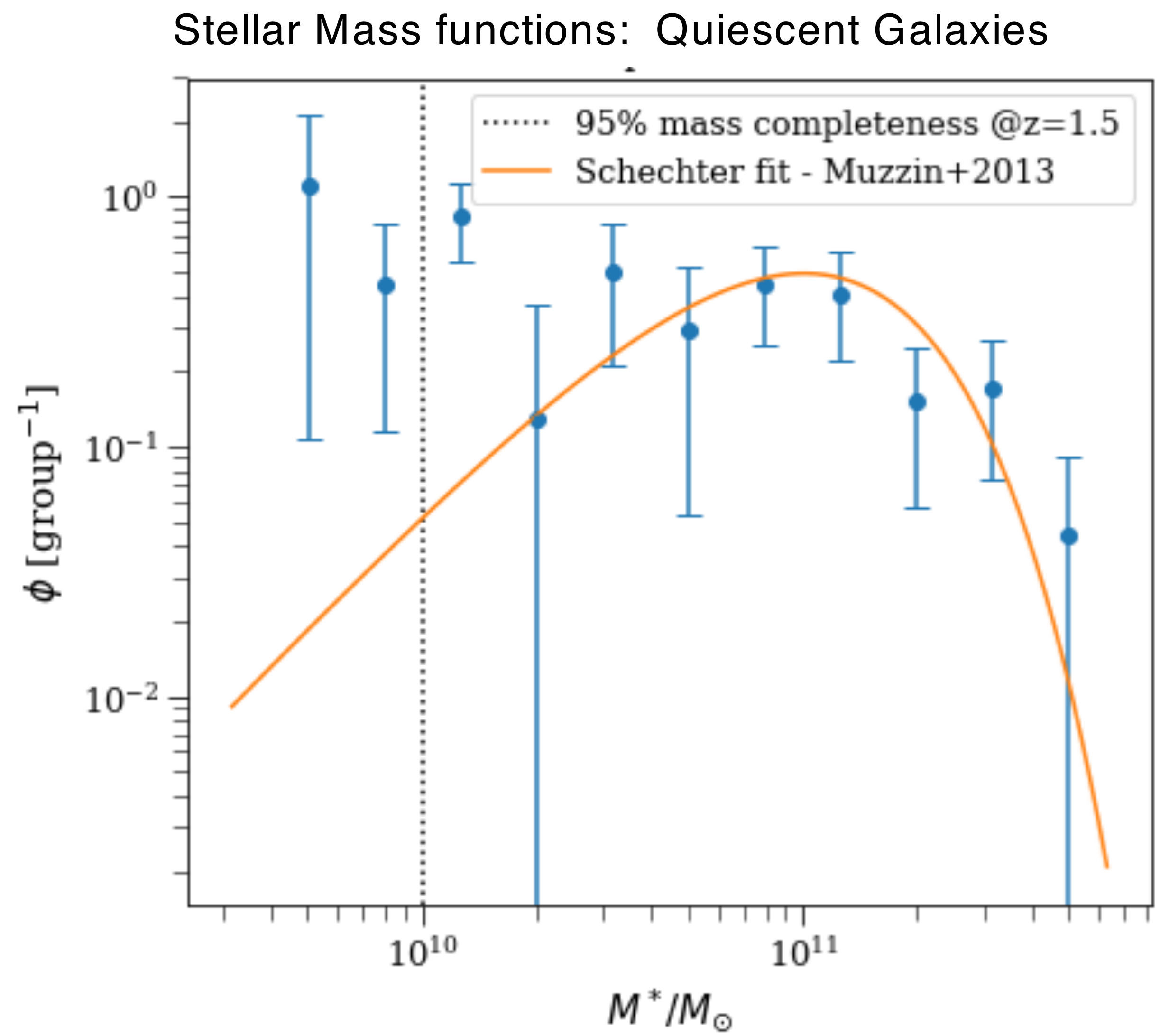
Chan et al. in prep.

Stellar mass functions in galaxy groups

Andrew Reeves, U Waterloo

PRELIMINARY





Stellar mass functions require full photometry.
Available for the group sample

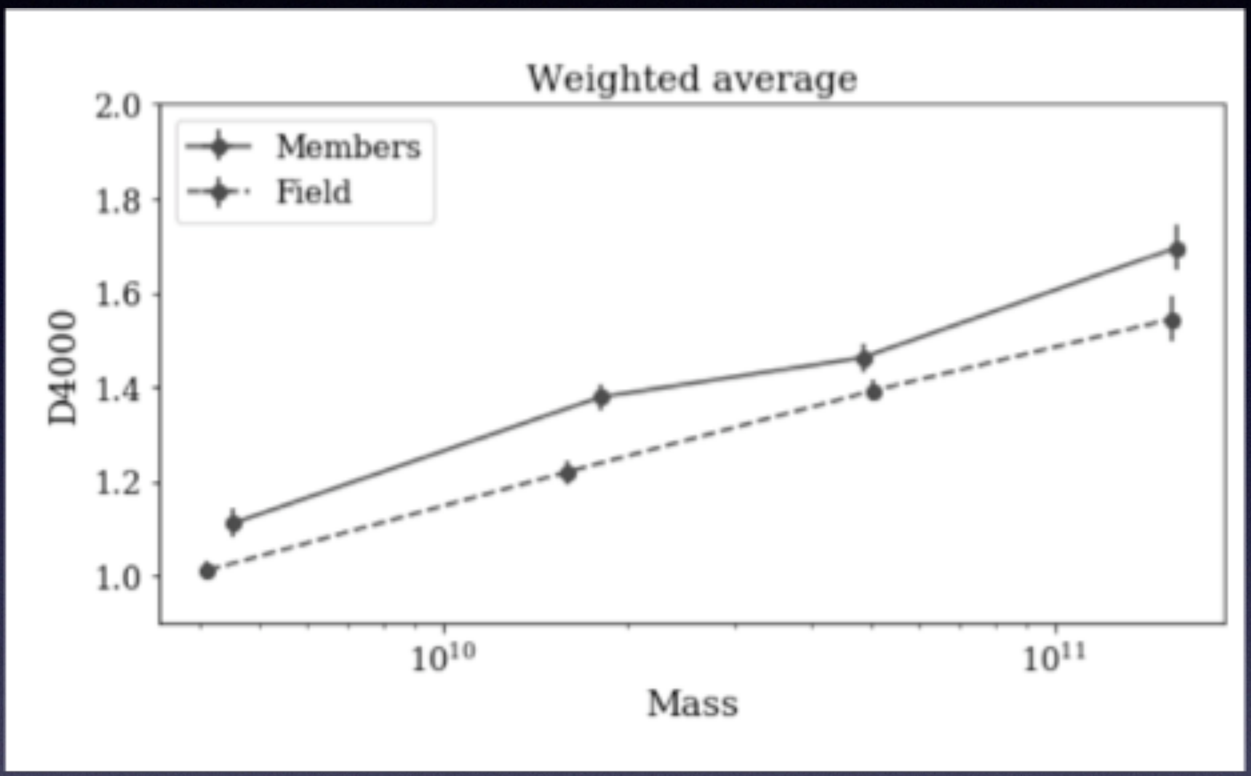
GOGREEN groups have evidence for environmentally quenched, low mass galaxies

Reeves et al. in prep.

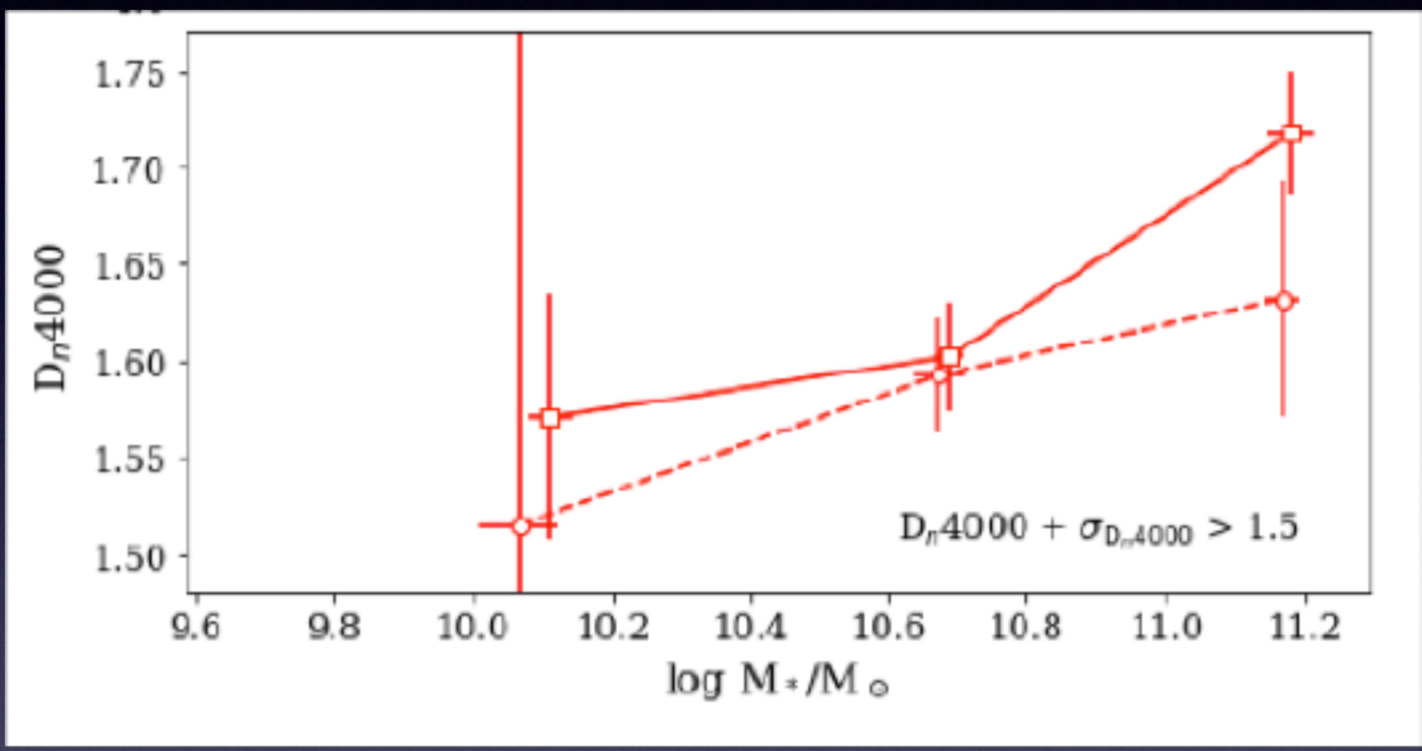
Spectral diagnostics

Kristi Webb, U Waterloo

All Galaxies



Passive Galaxies



Trend of D4000 with mass reflects passive fraction

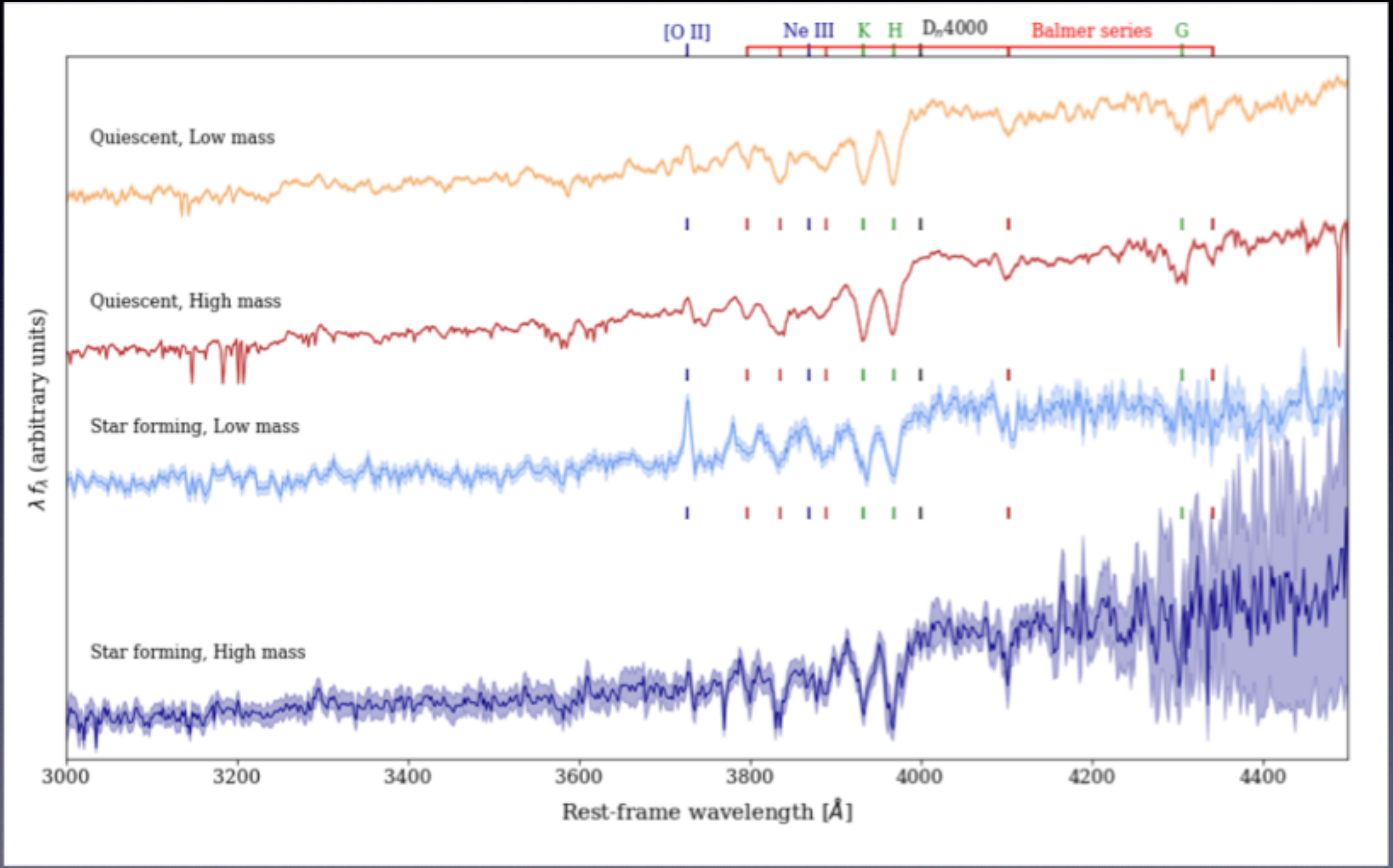
Among passive galaxies there is a weak trend of D4000 with mass.

PRELIMINARY

Webb et al. in prep.

Stacked Spectra

Kristi Webb, U Waterloo



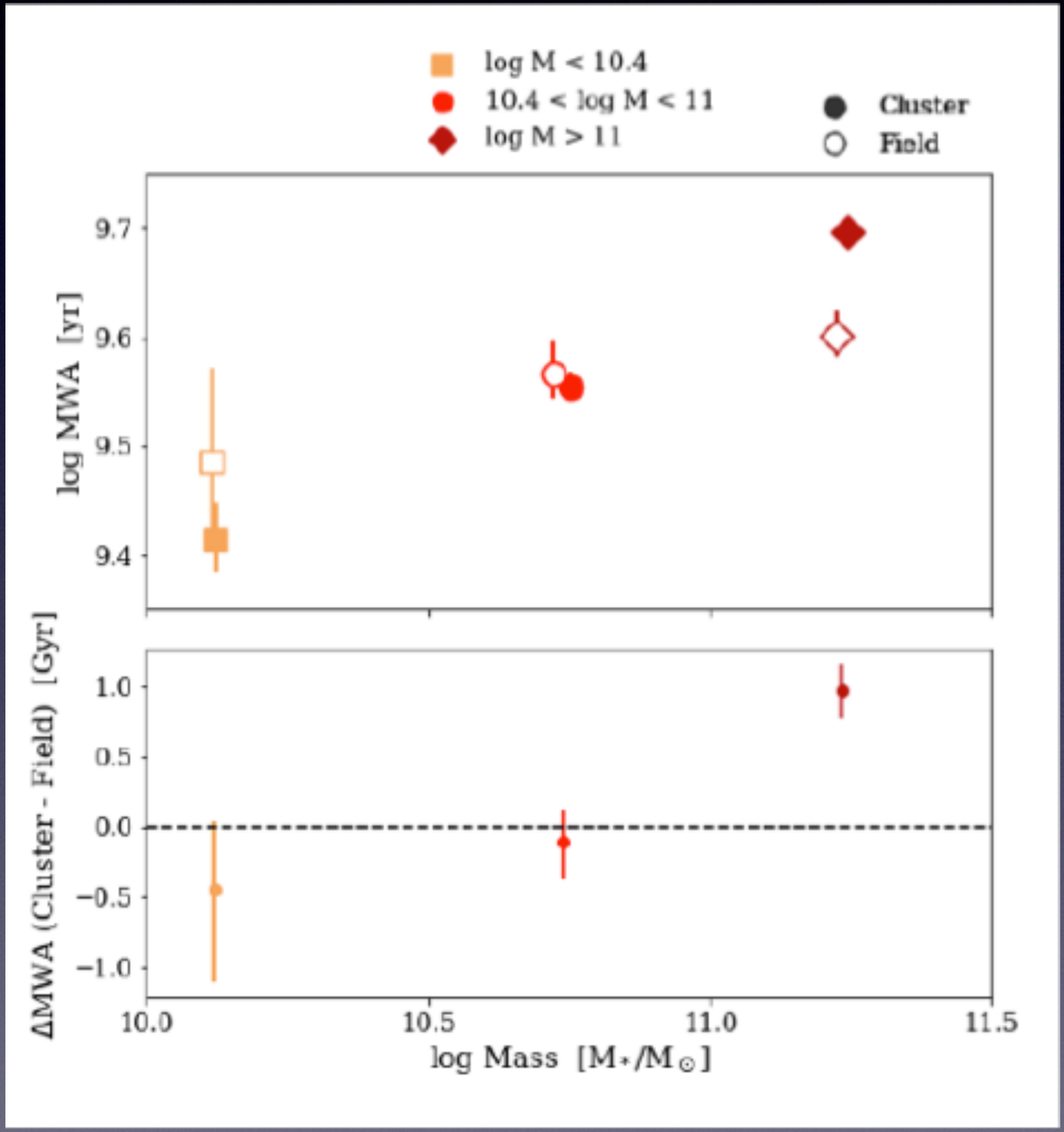
Balogh et al. 2017
Webb et al. in prep.

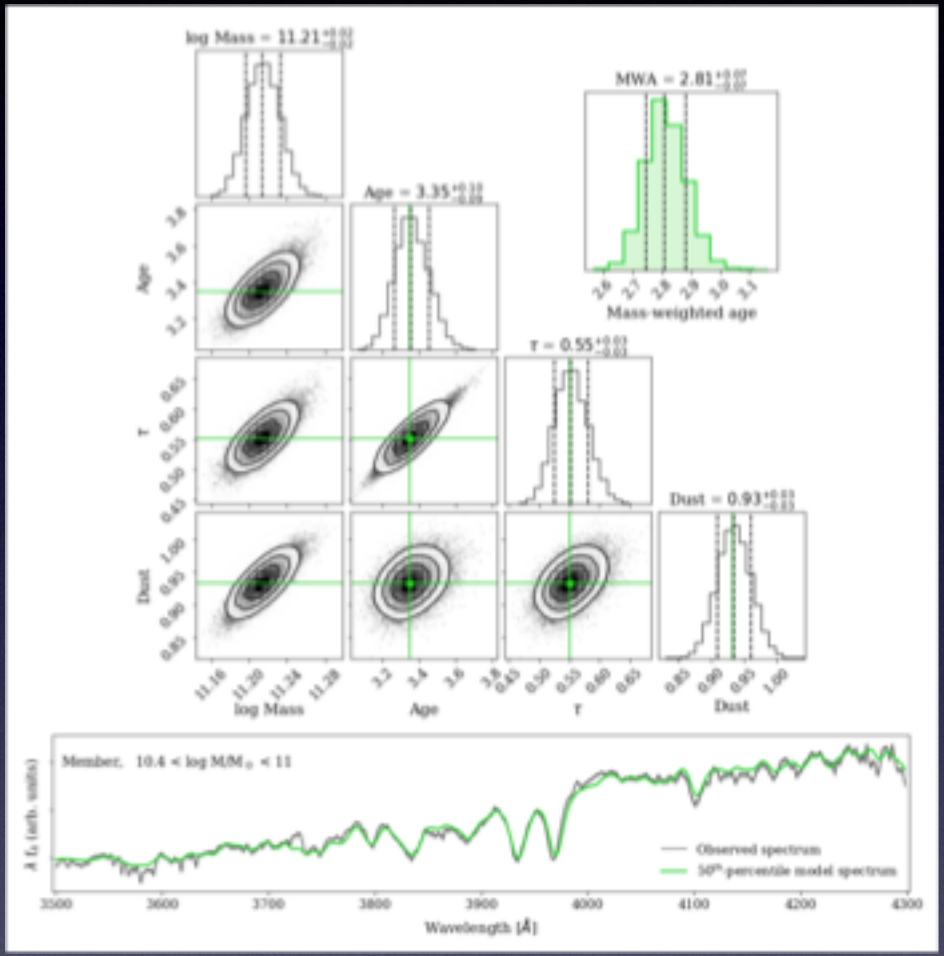
Fitting of individual spectra

Kristi Webb, U Waterloo

PRELIMINARY

Passive Galaxies



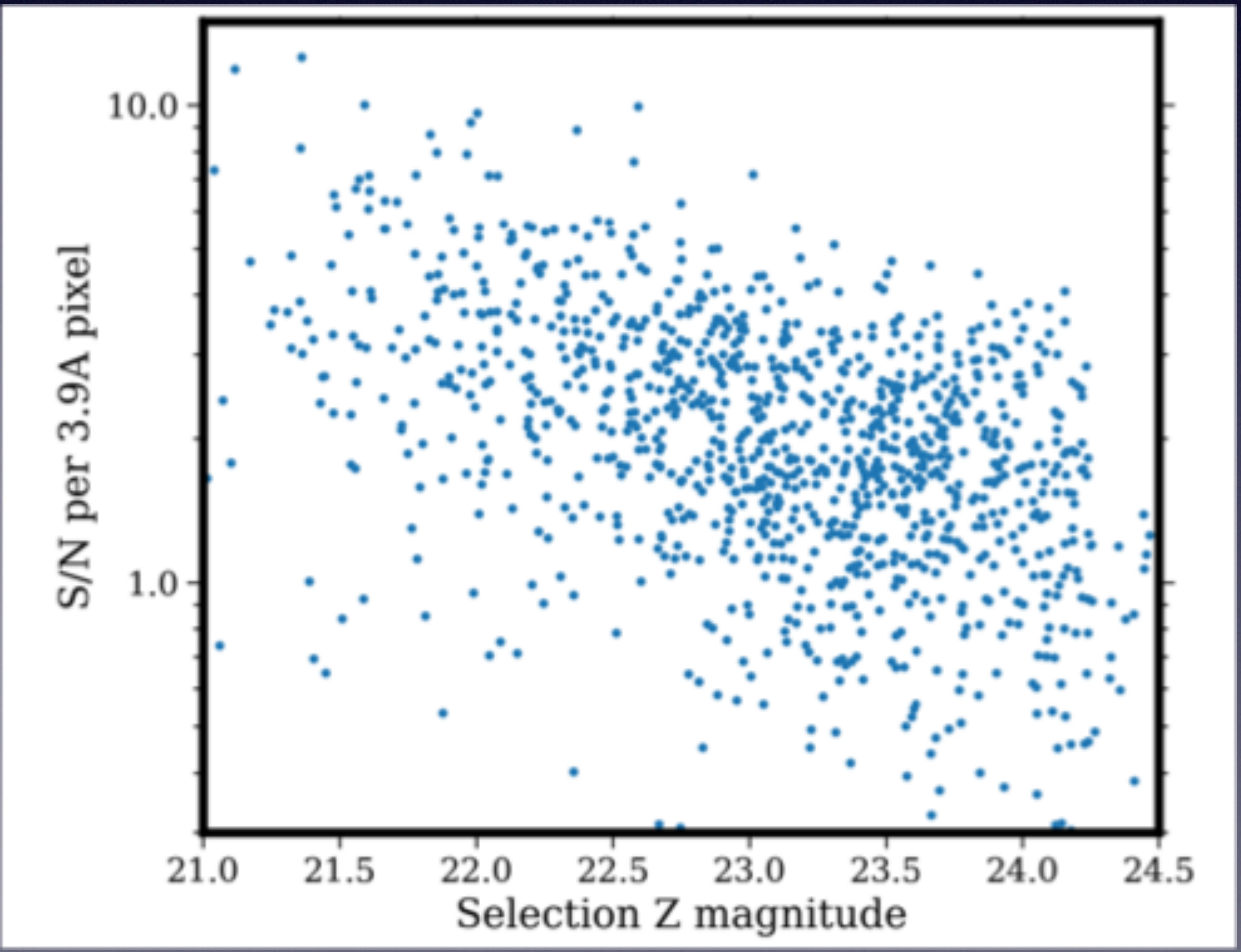


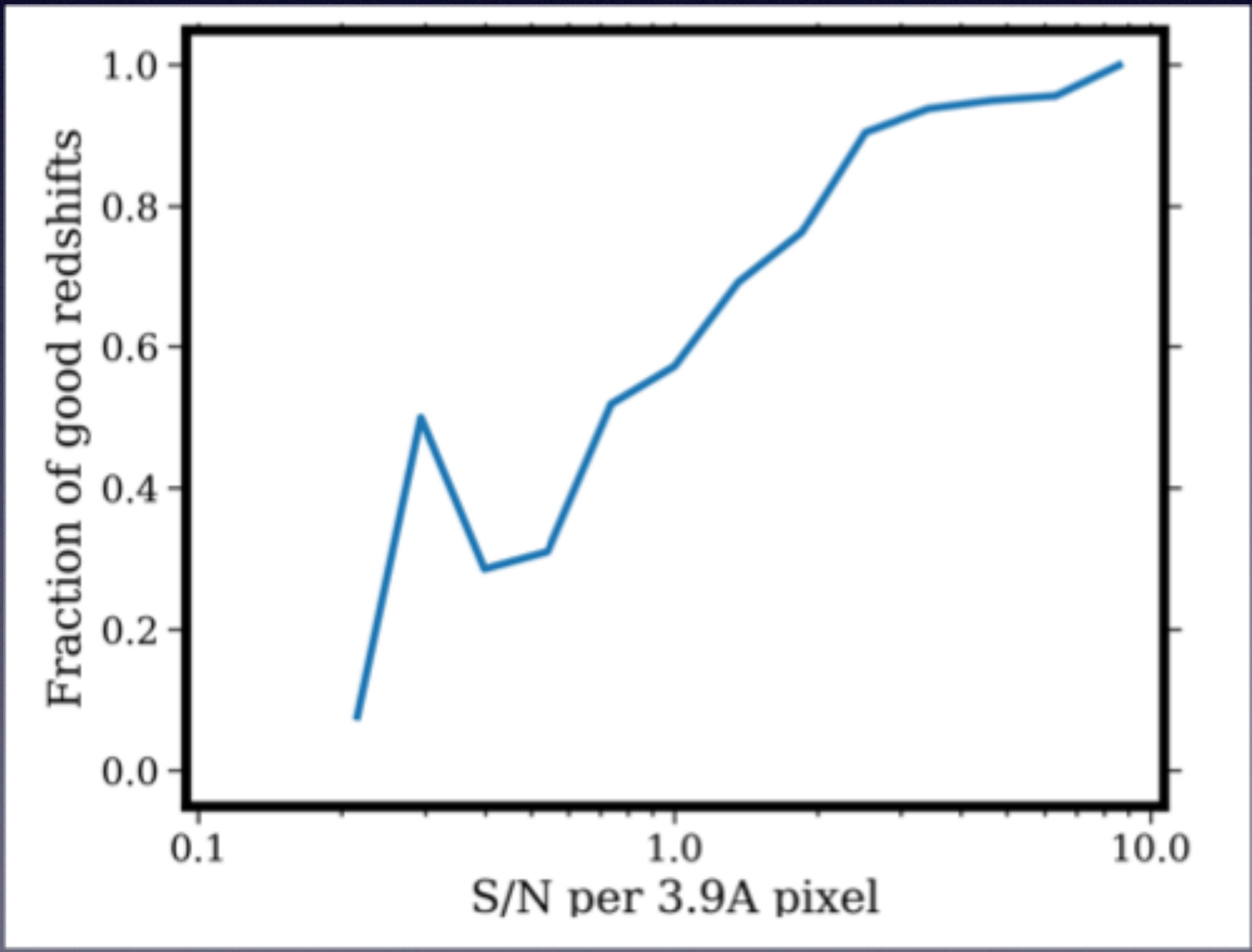
Most massive quiescent cluster galaxies may be older than those in the field. At lower masses, ages are indistinguishable

Webb et al. in prep.

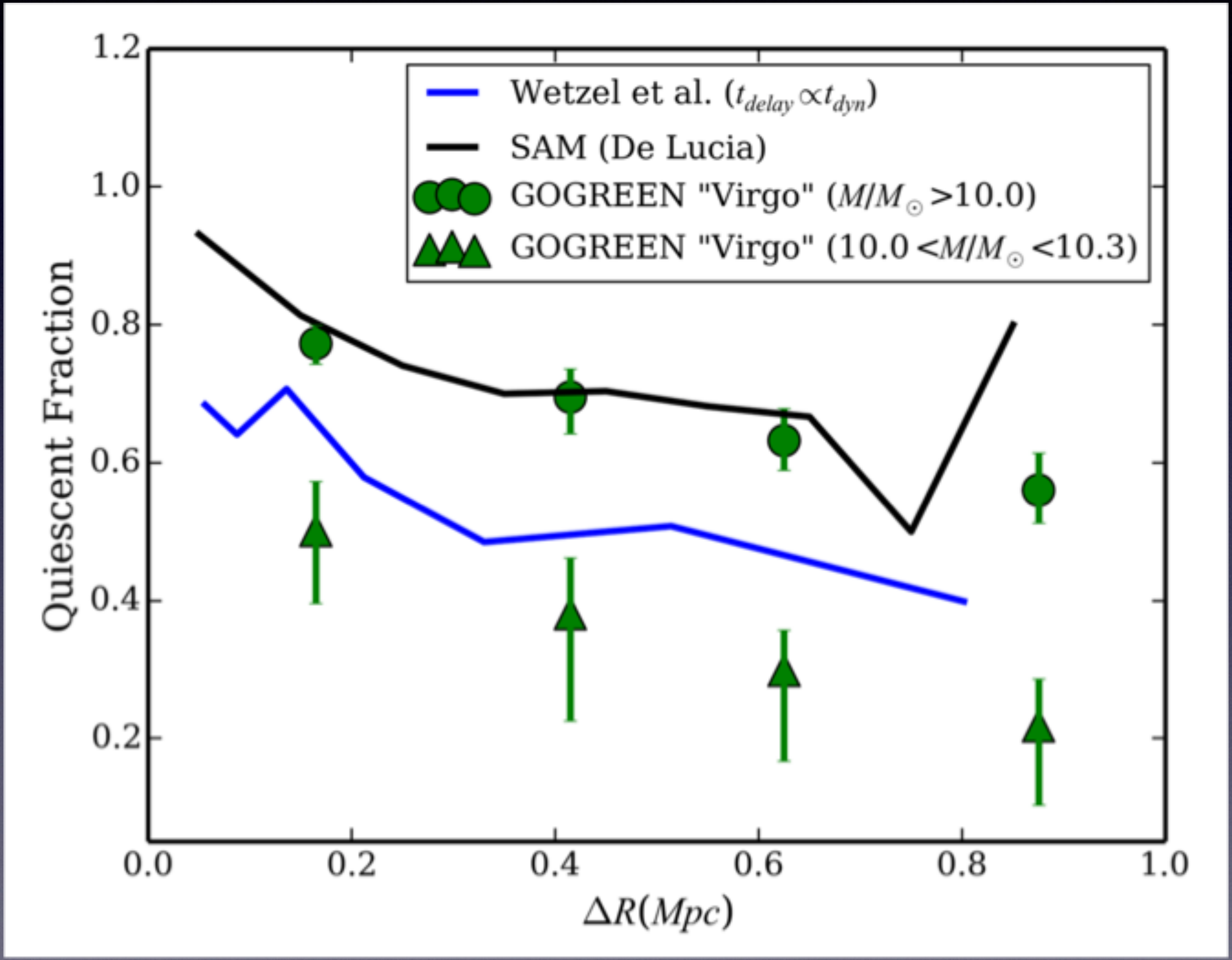
Survey progress

- Spectroscopy is 70% finished. Survey extended to 2019A
- Reaching 50% redshift completeness at z(AB)=24.25 — **On Target**
- >100 hours of imaging now 80% complete





Expected final quenching constraints



Take away points

GOGREEN is the premier spectroscopic study of faint galaxies in dense environments at z>1

Ultra-deep stellar mass-limited spectroscopy is yielding unique constraints on quenching down to $10^{10}M_{sun}$ in 21 groups and clusters

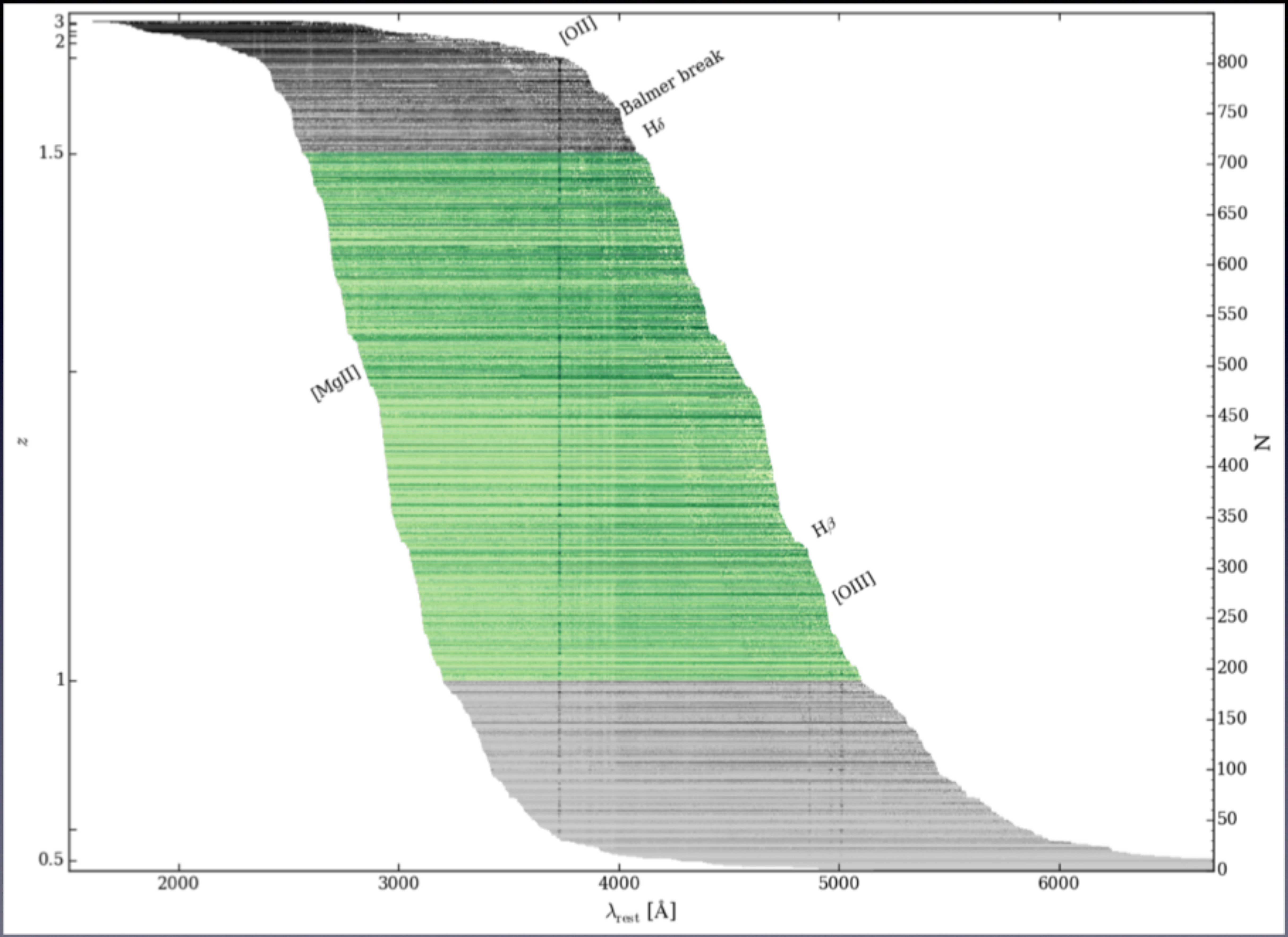
Public release to come following completion of survey.

http://gogreensurvey.ca/

GOGREEN

Gemini Observations of Galaxies in Rich Early ENvironments

Example Spectra



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