Galaxy populations in the first massive clusters

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(INAF)

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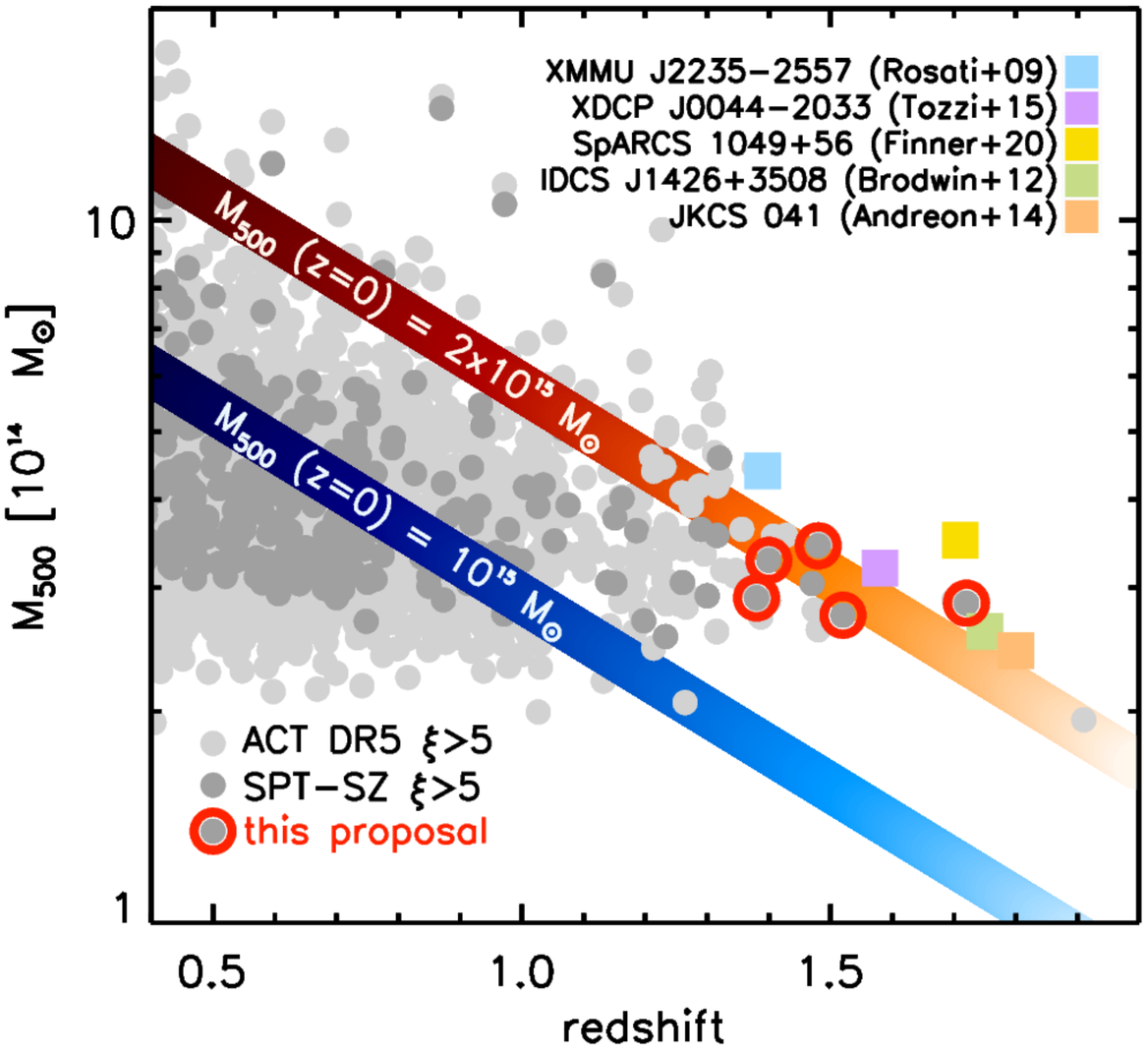
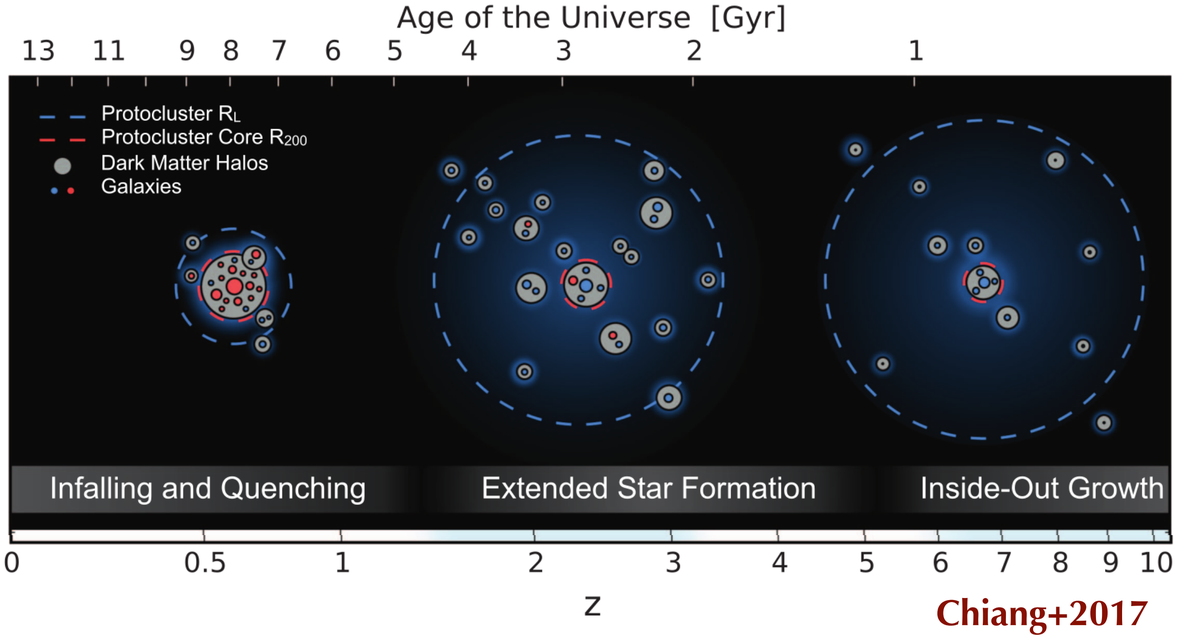
L. Di Mascolo, M. Nonino, G. De Lucia, P. Lustig, I. Marini

GAEA focus week at IFPU, June 2023

What “first clusters”… ?



the first massive clusters emerging from the proto-cluster to cluster transition



Chiang+2017

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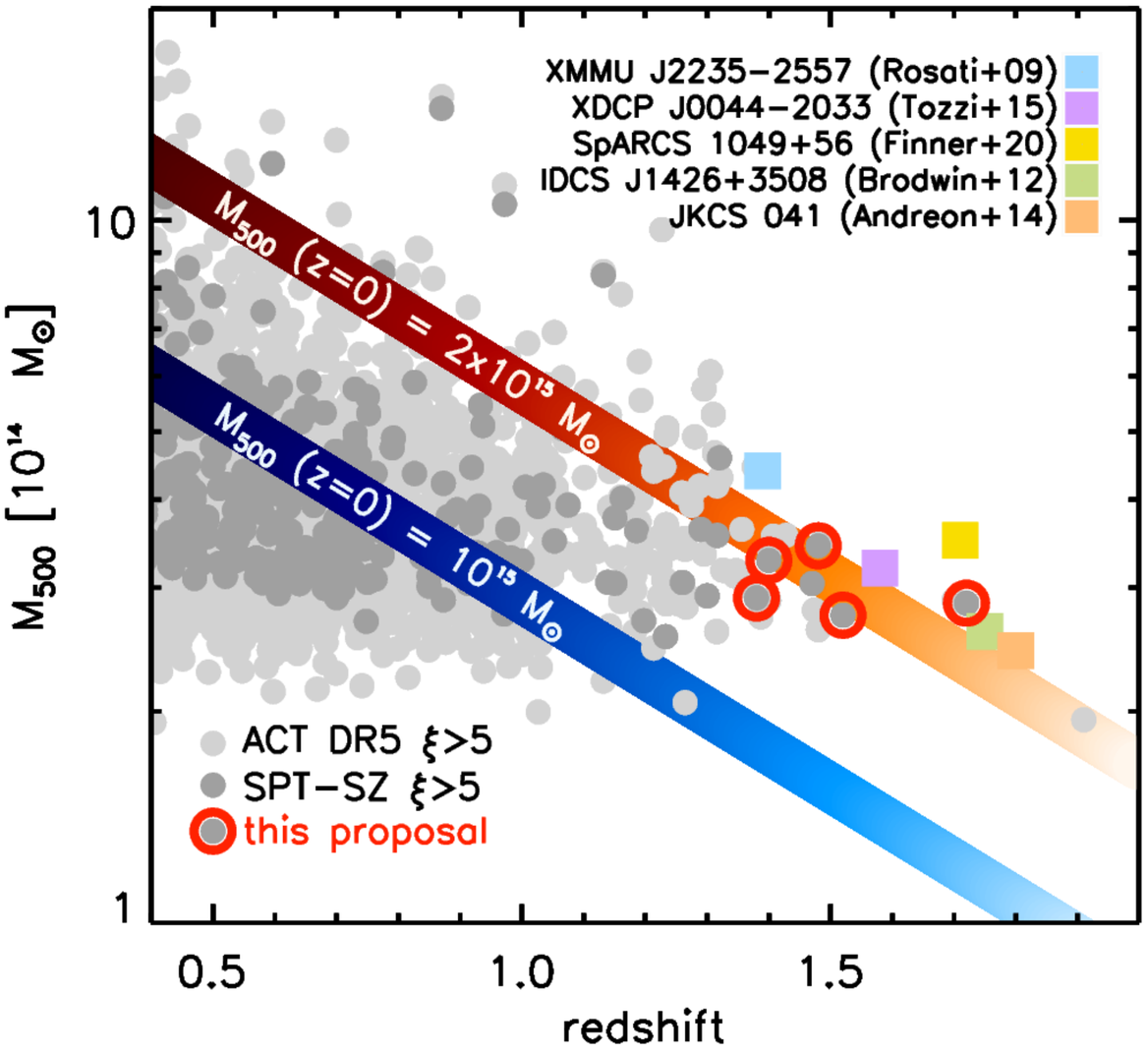
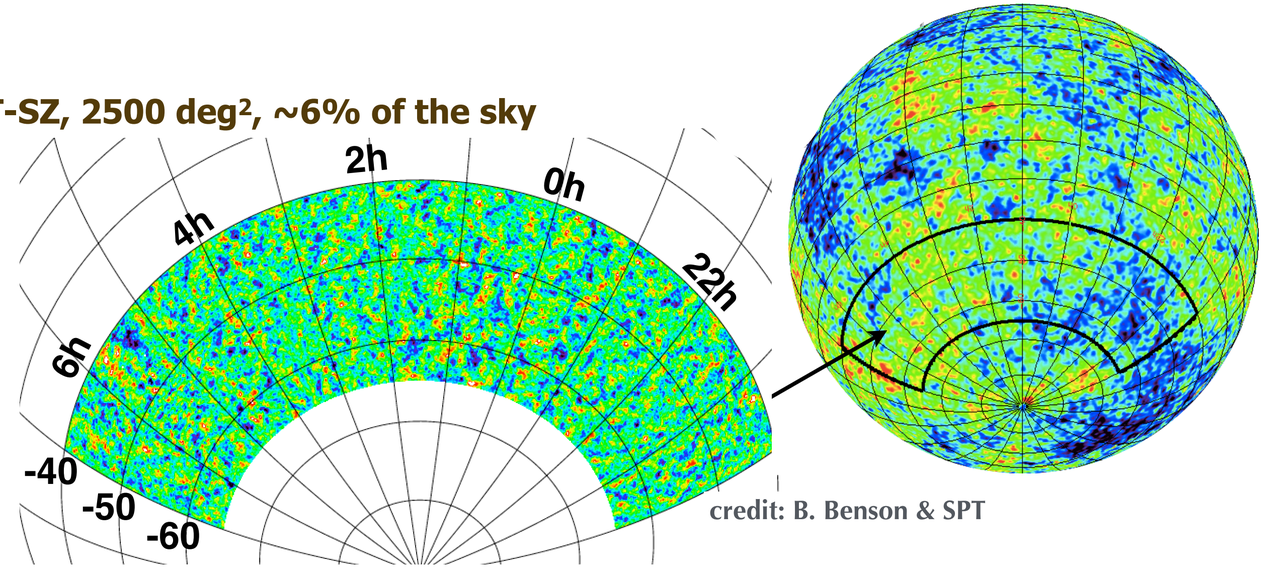


- 5 massive clusters at z~1.4-1.7 from SPT-SZ

SPT-SZ, 2500 deg², ~6% of the sky



>500 clusters, ~40 clusters at z>1, 5 ξ>5 clusters at z>1.4 (as of Bleem+15)

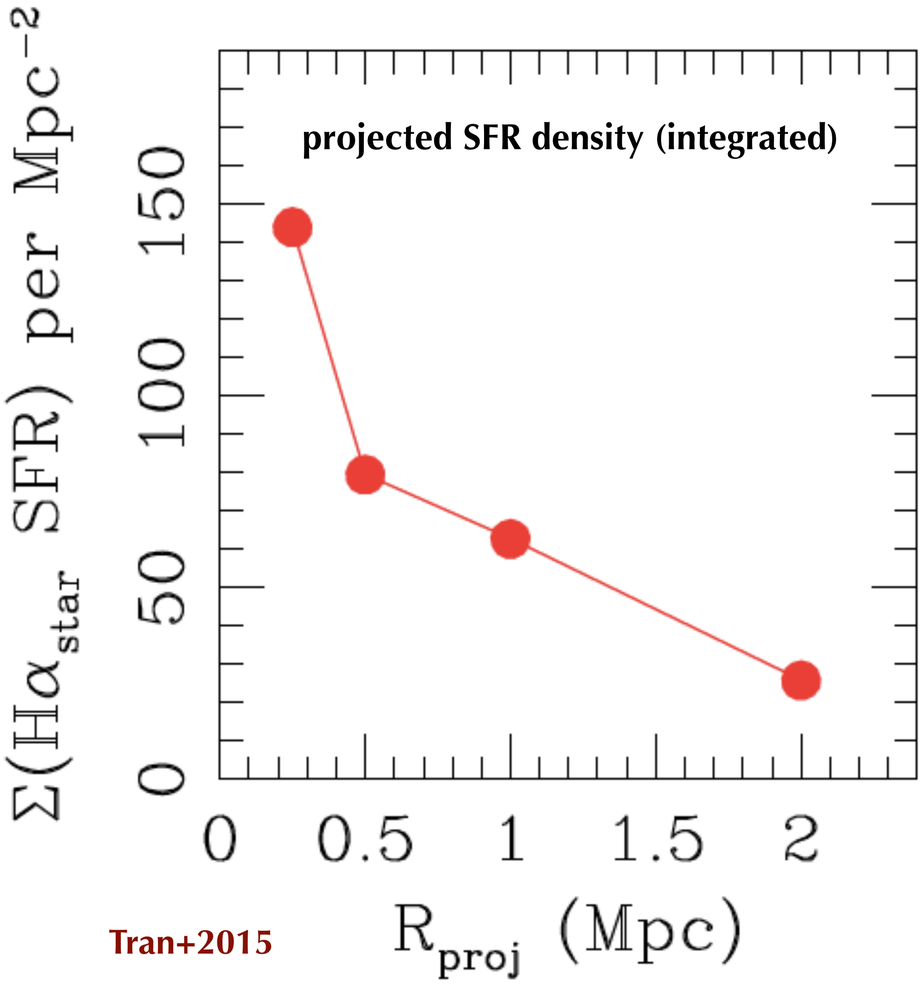
clean sample with roughly redshift independent mass threshold $M_{500} \gtrsim 3 \cdot 10^{14}\ M_\odot$

clean selection probing the first very massive clusters

SZE-based cluster mass determinations

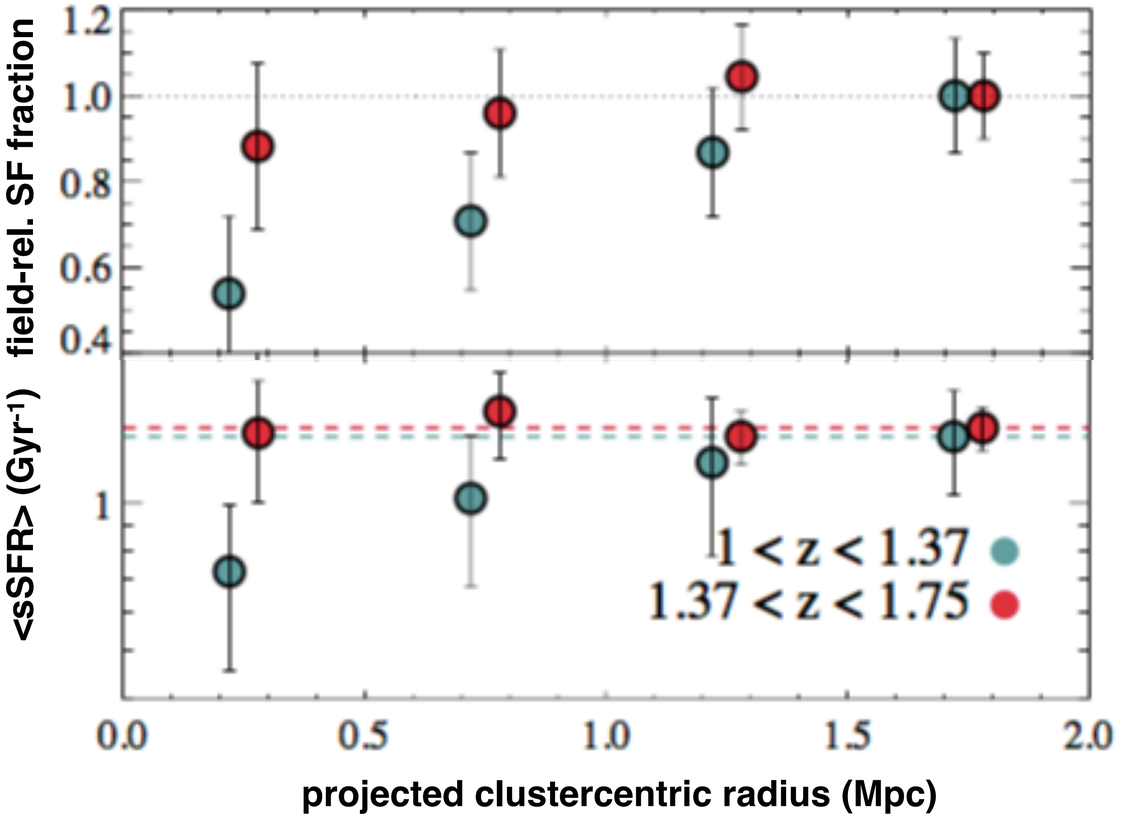
- among the rarest, most massive clusters known at these redshifts
- (after a bit of time…) homogeneous dedicated follow-up for galaxy evolution studies

Main science drivers — star formation vs. quenching in massive clusters at high redshift



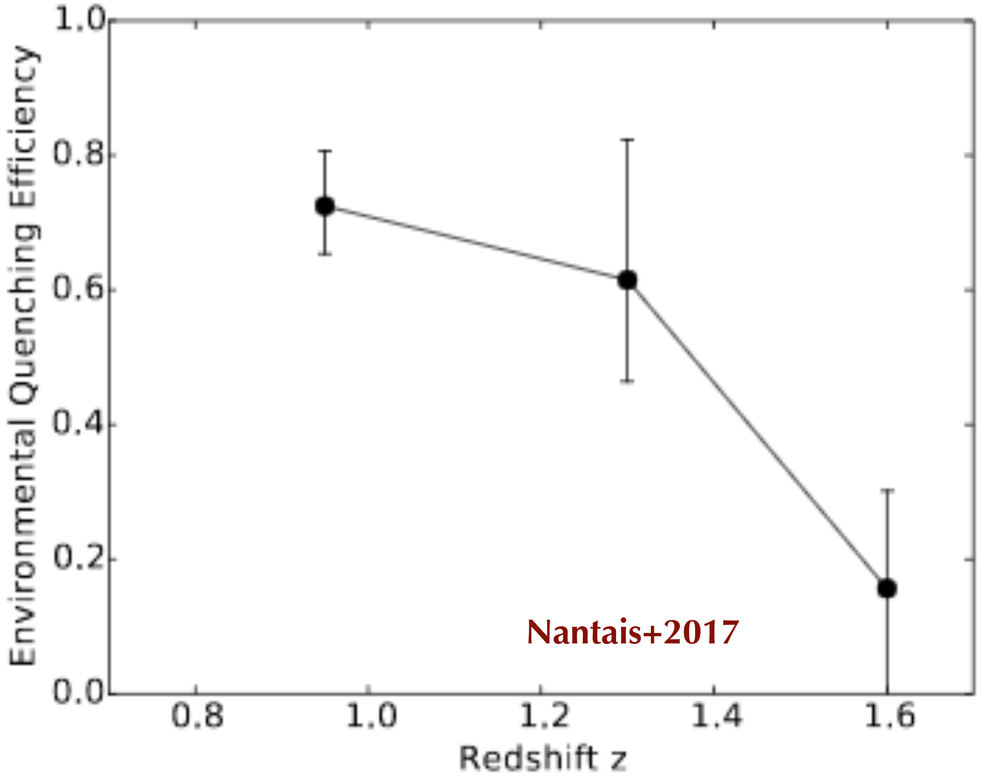
Tran+2015

Alberts+2016



the flattening (or in some cases "reversal"…) of the SFR-density relation

Main science drivers — star formation vs. quenching in massive clusters at high redshift



how significant is environmental quenching

in high-redshift clusters ?

(also note: in which clusters, where within cluster, at what stellar mass, … ?)

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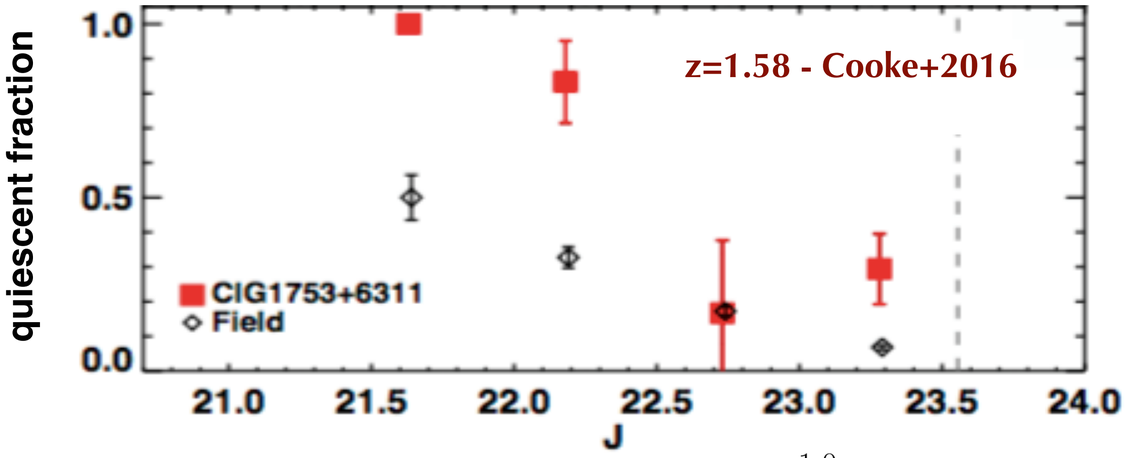

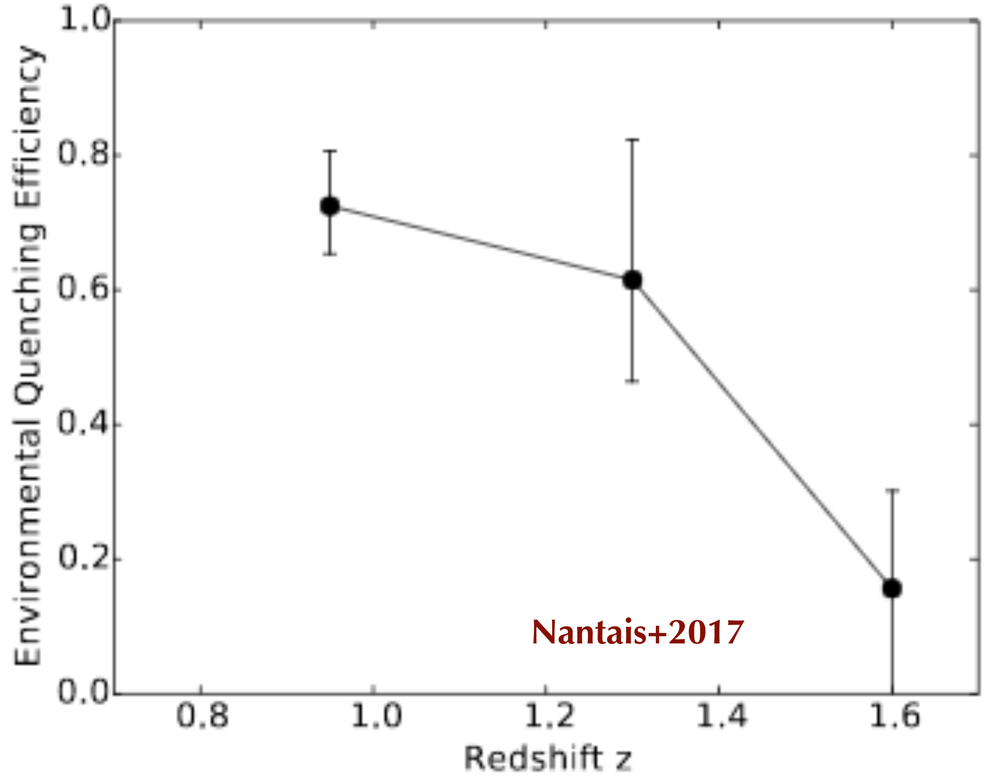

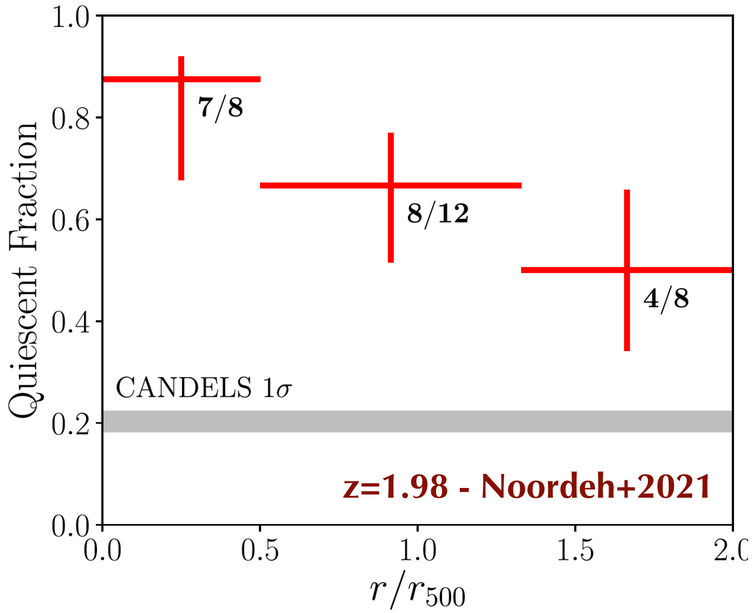

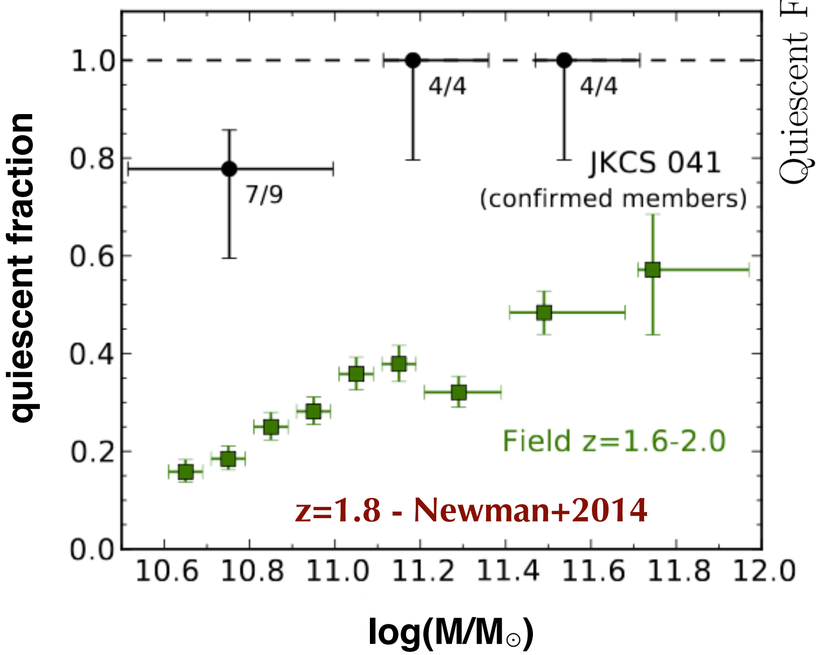

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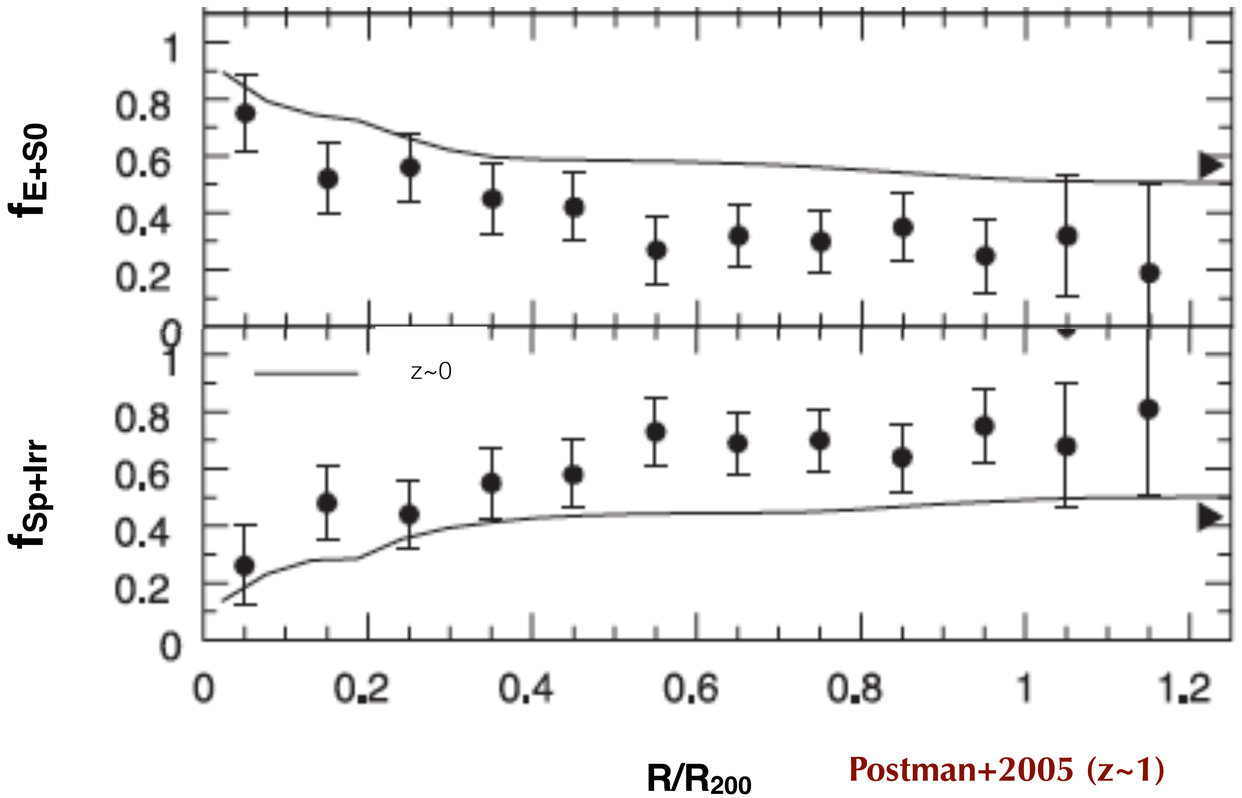
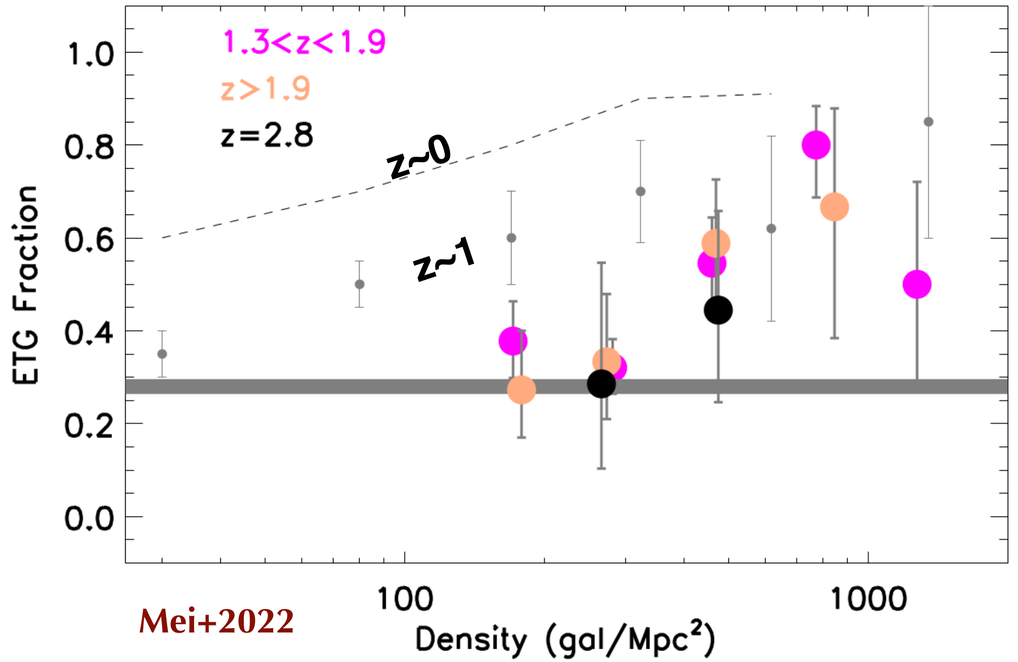
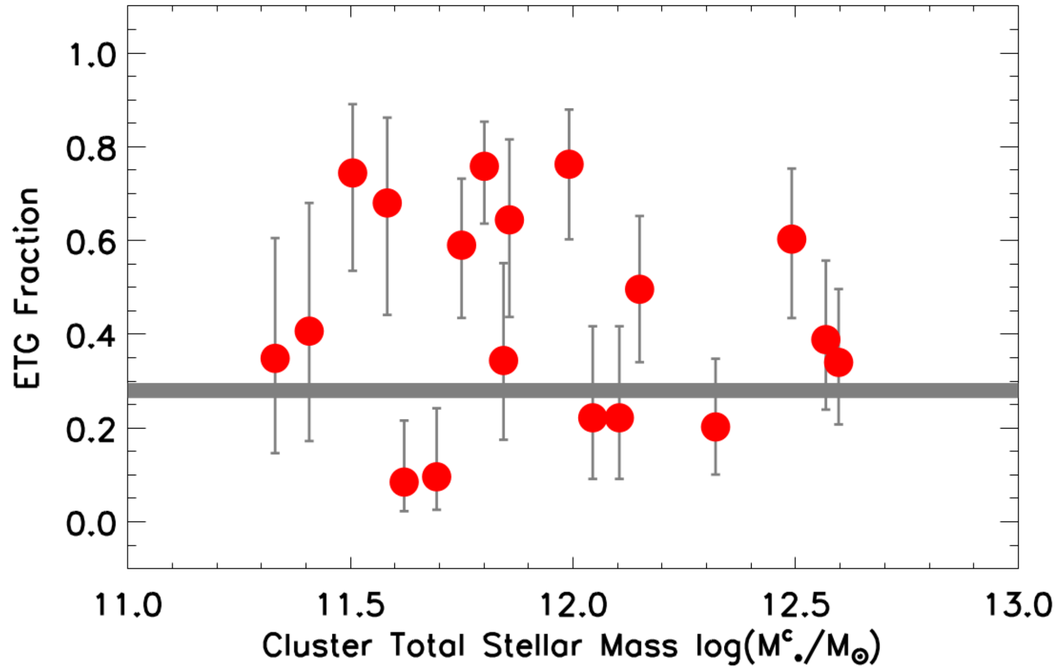
Main science drivers — structural properties of high-redshift cluster galaxies



Postman+2005 (z~1)



Mei+2022

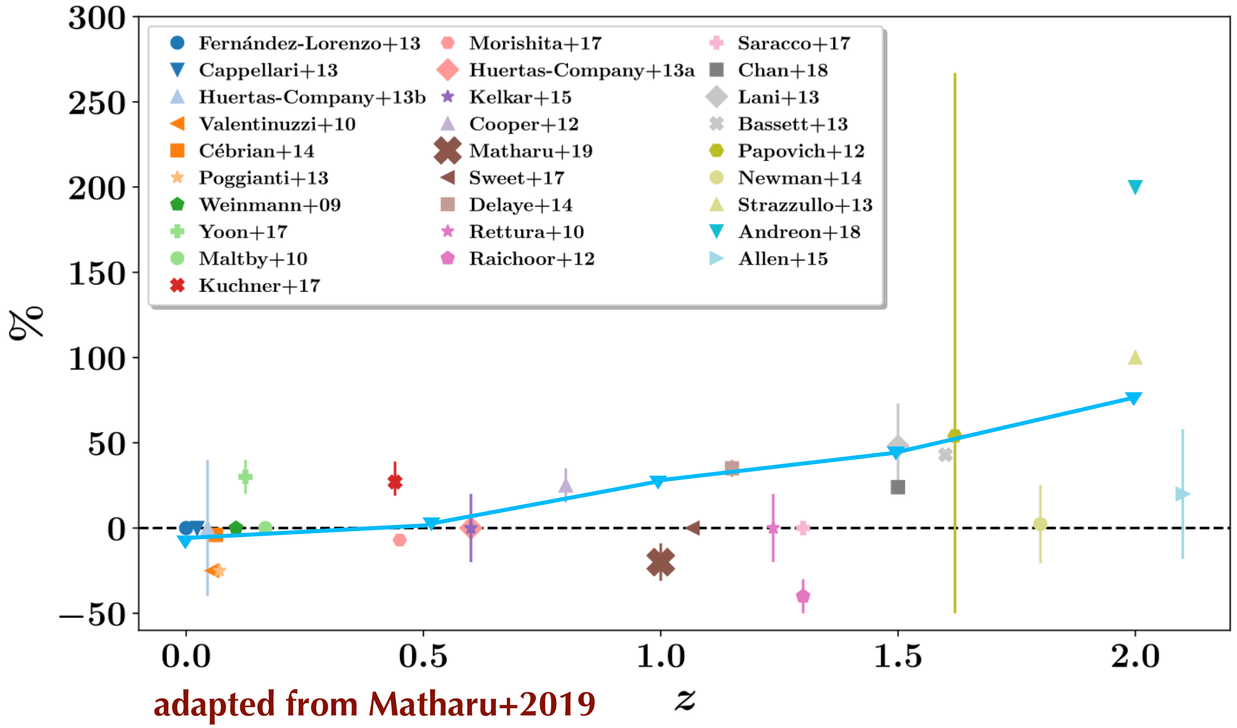


the morphology-density relation evolves,

but it is observed at least in some clusters even up to z~2

Main science drivers — structural properties of high-redshift cluster galaxies

size difference (cluster - field)



adapted from Matharu+2019

varied results on environmental dependence of galaxy sizes …

Main science drivers — structural properties of high-redshift cluster galaxies

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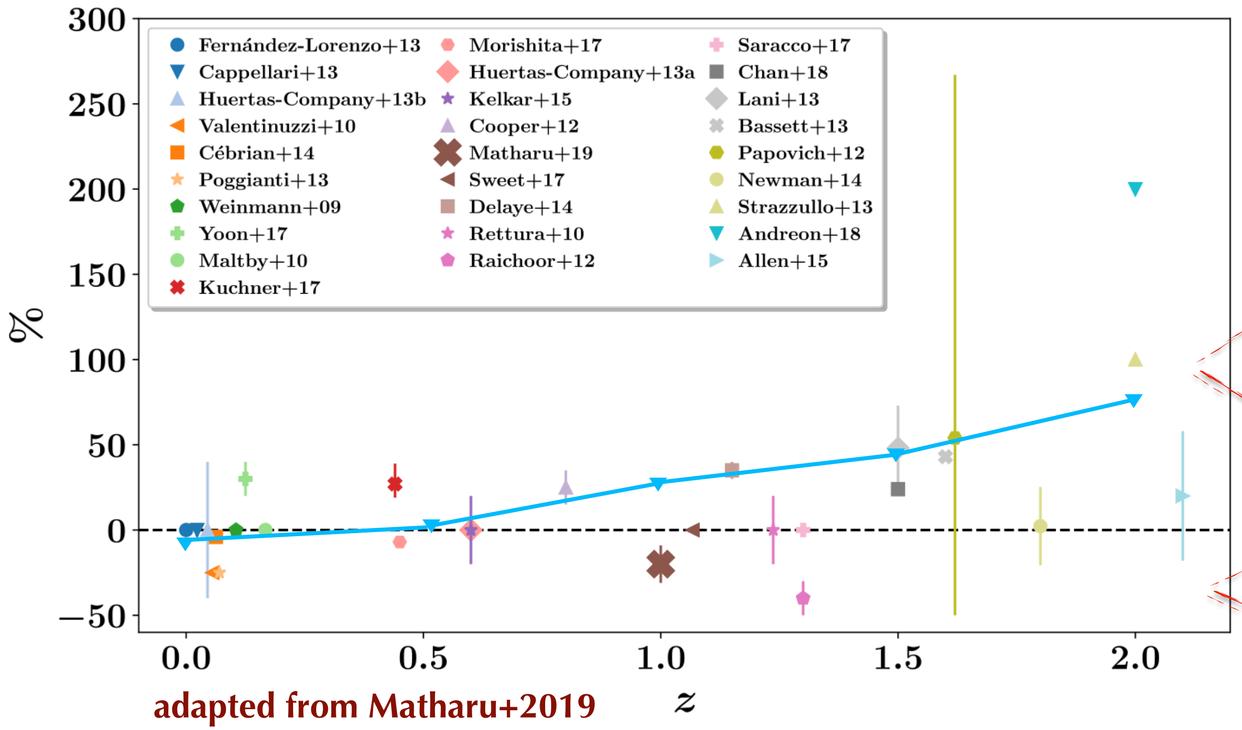
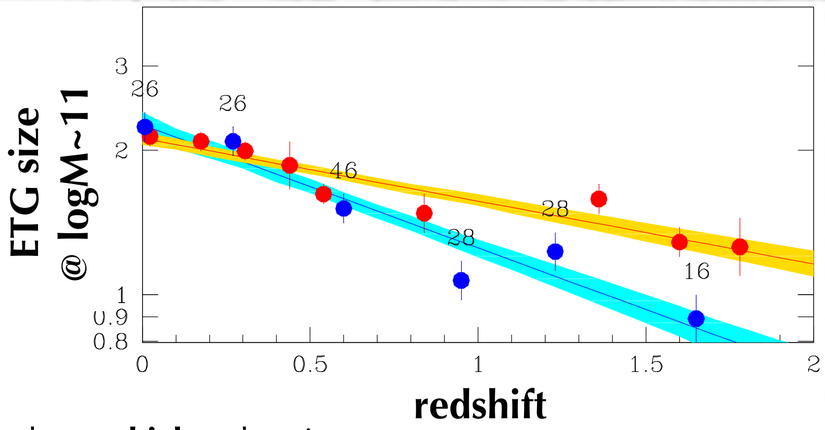


adapted from Matharu+2019

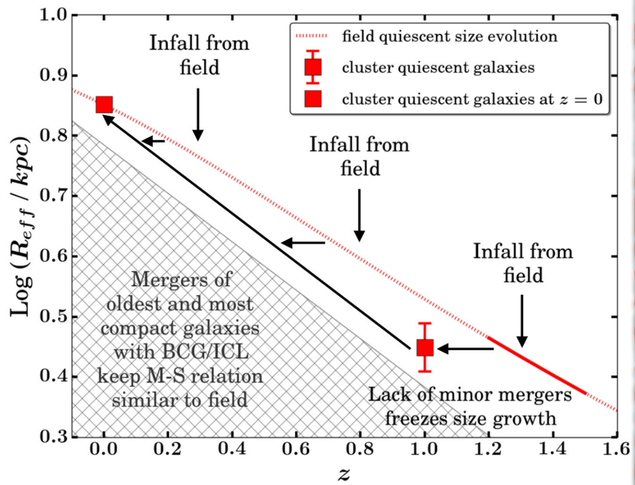
varied results on environmental dependence of galaxy sizes

imply different scenarios for evolutionary paths



mass-size relation in z≥0.6 clusters **higher** than in tne field because of accelerated evolution at early times

Andreon+2018



mass-size relation in z~1 clusters **lower** than in the field because of lack of growth through minor mergers

Matharu+2019

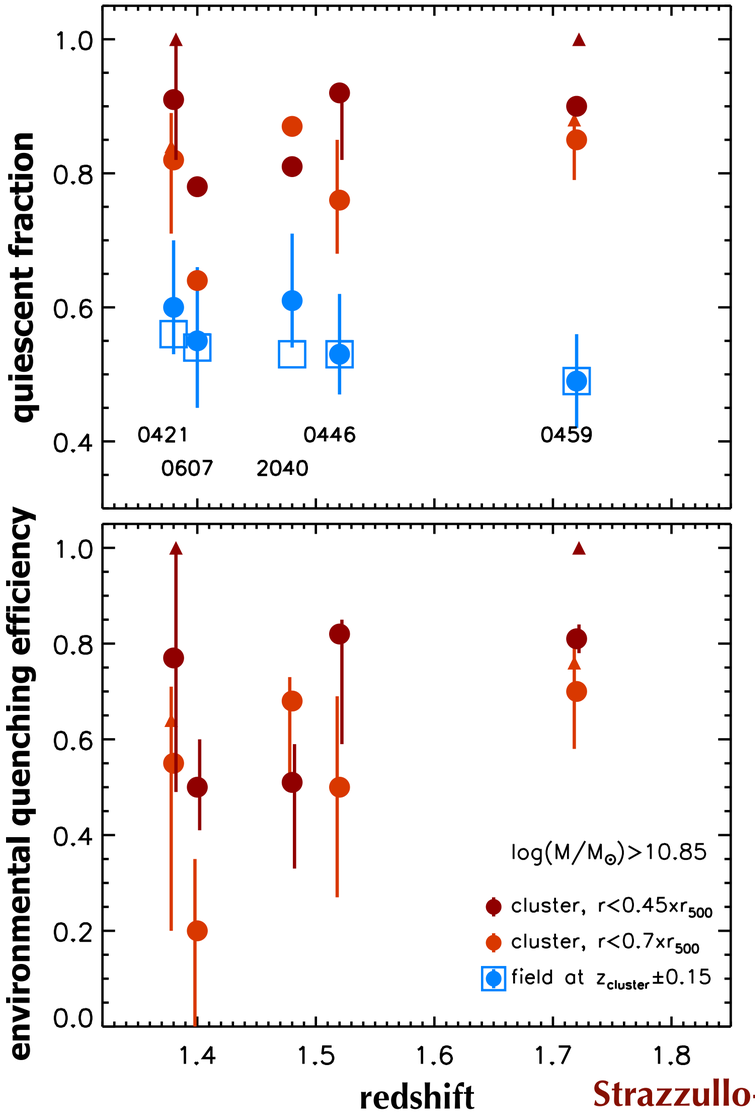
This project — galaxy population properties and environmental signatures in the first massive clusters

- largely unbiased cluster selection wrt galaxy properties
- high mass -> high richness
- most extreme environments

    -> more evident environmental signatures (on star formation / gas / structural properties, AGN activity)
- the first established massive clusters, at a redshift bridging proto-cluster and cluster regimes
- **until recently, largely based on 4-band optical/NIR imaging in cluster core (HST & Spitzer)**

This project — galaxy population properties and environmental signatures in the first massive clusters

environmental signatures on star-formation/quenching



Strazzullo+2019

log(M/M$_\odot$)>10.85

- **cluster (r<0.45 r_{500})**
- **cluster (r<0.7 r_{500})**
- **field (at the cluster redshift)**

The environmental quenching efficiency at high stellar masses in the central cluster regions is typically ≳50% over the probed redshift range.

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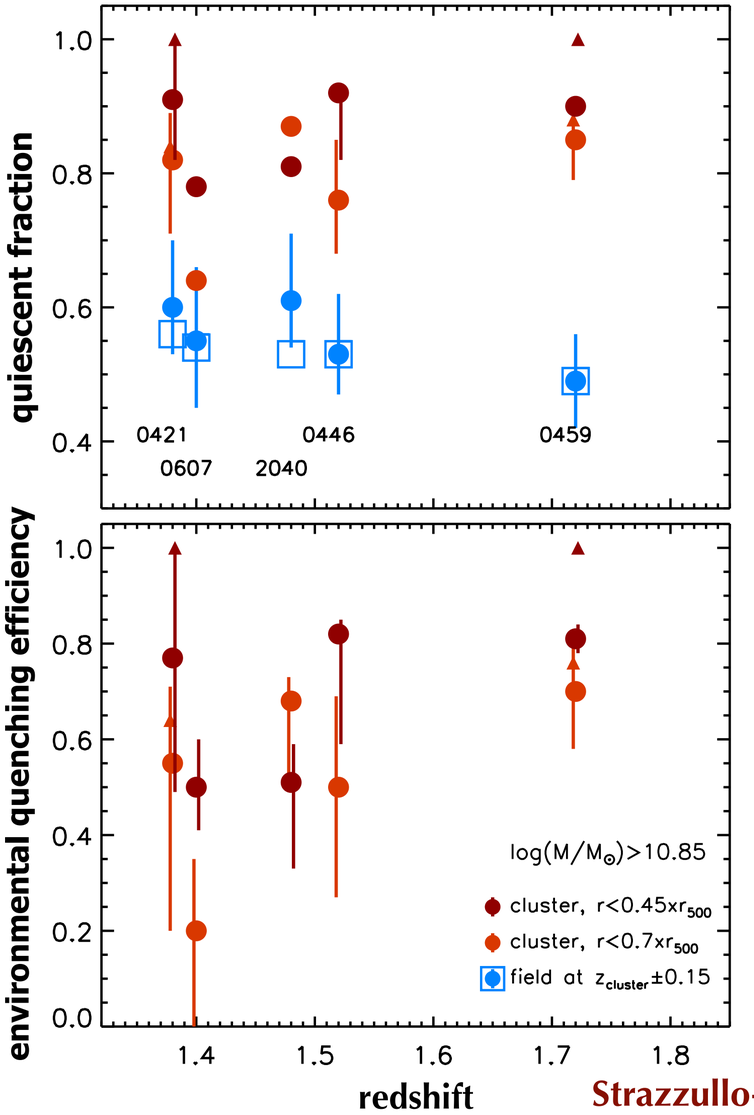

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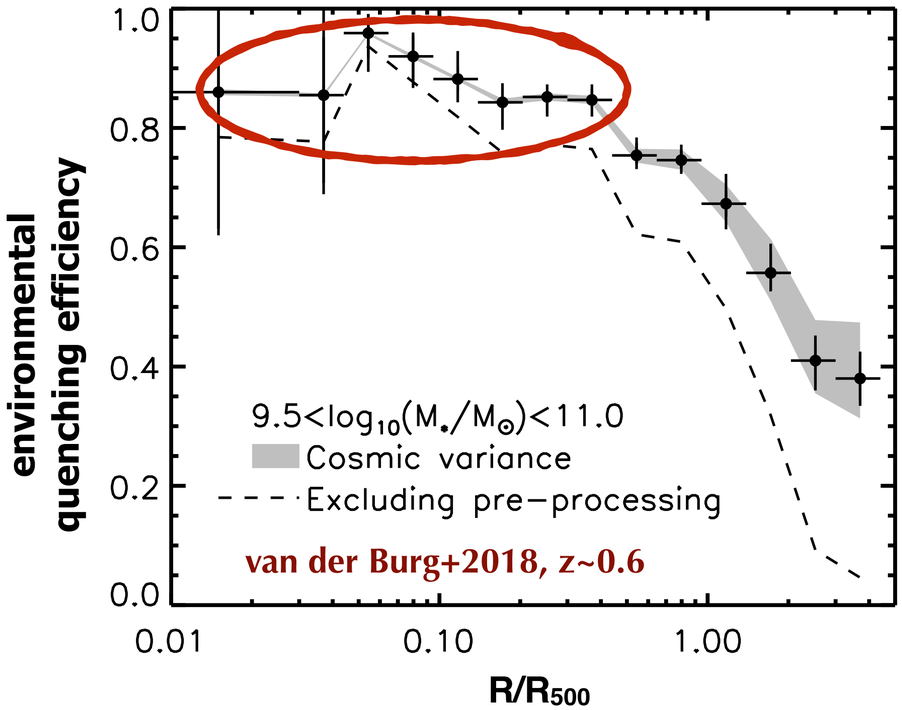

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Strazzullo+2019

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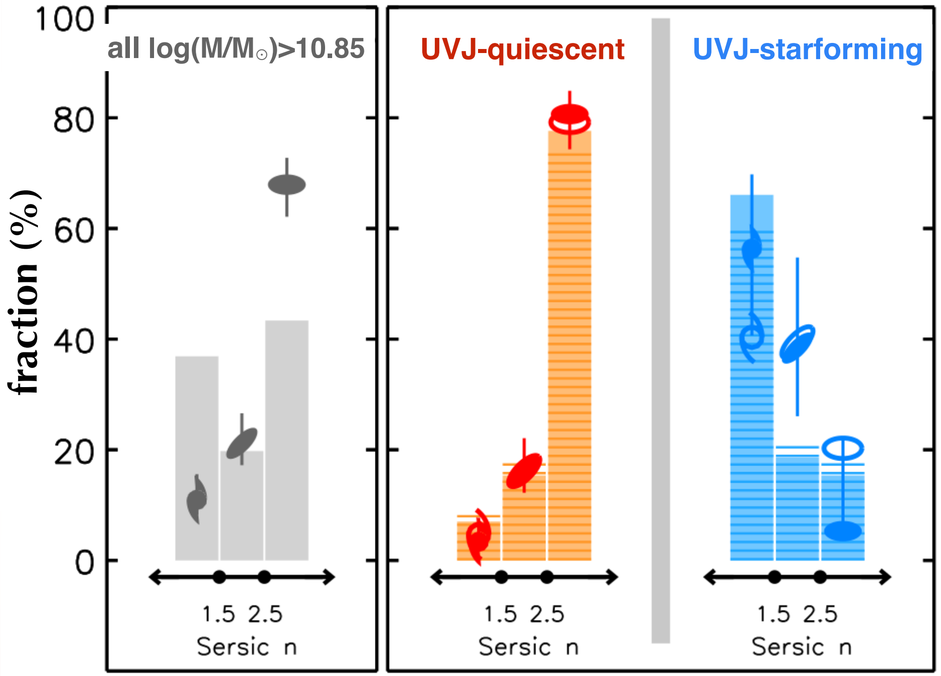
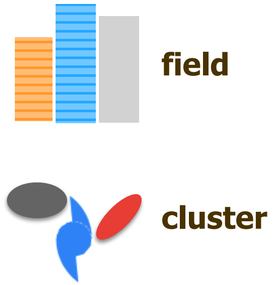
environmental signatures on structural properties





morphology-density relation

largely connected to high quiescent fraction

Strazzullo+2023

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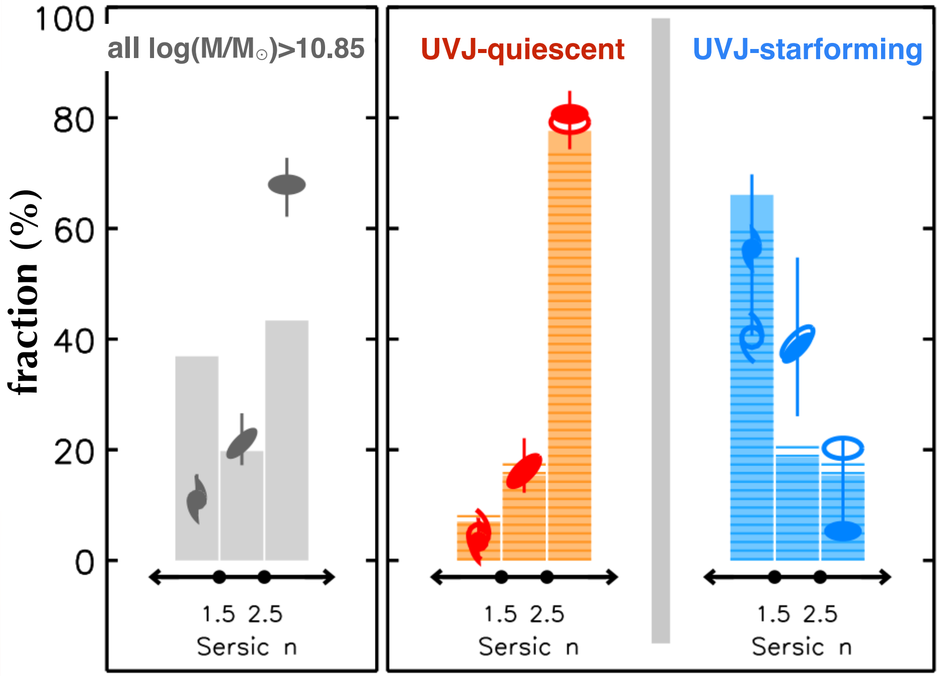

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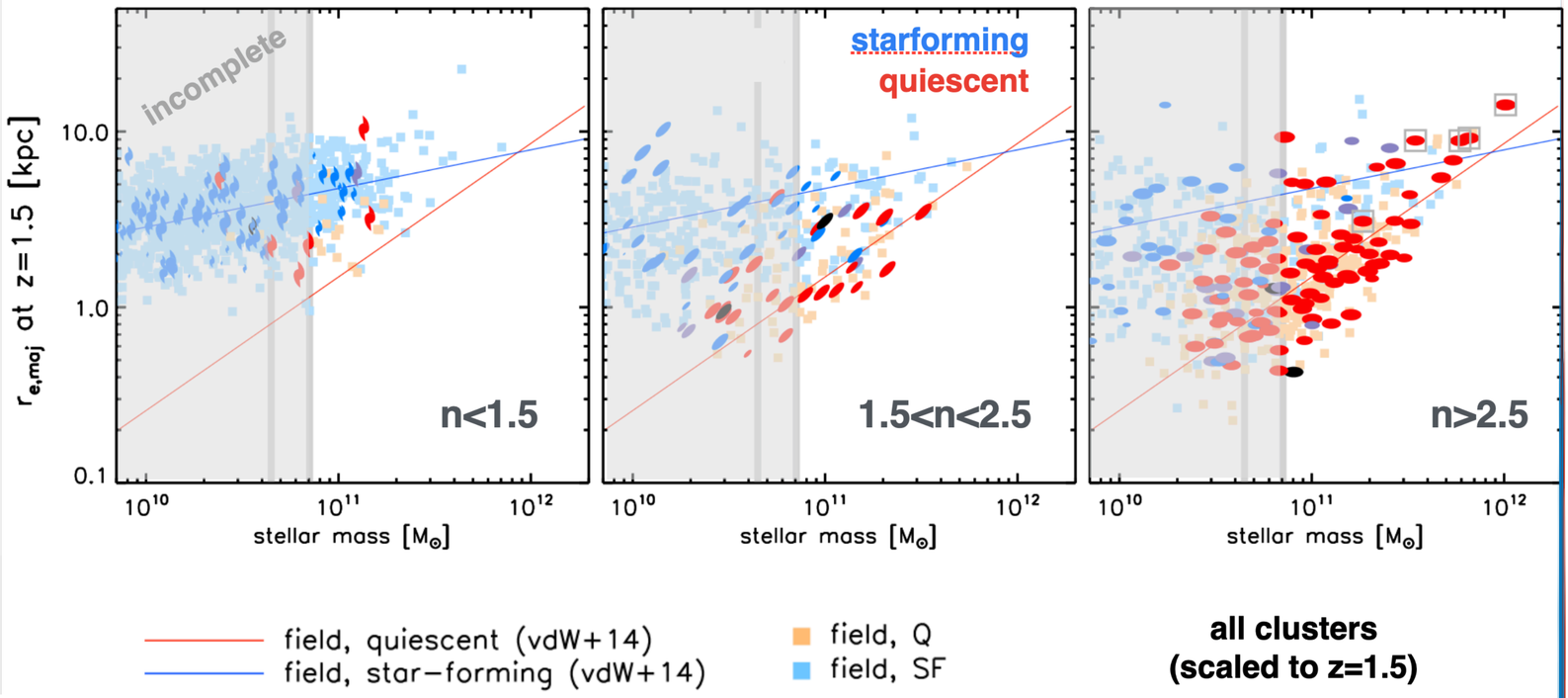

all clusters (scaled to z=1.5)

Strazzullo+2023

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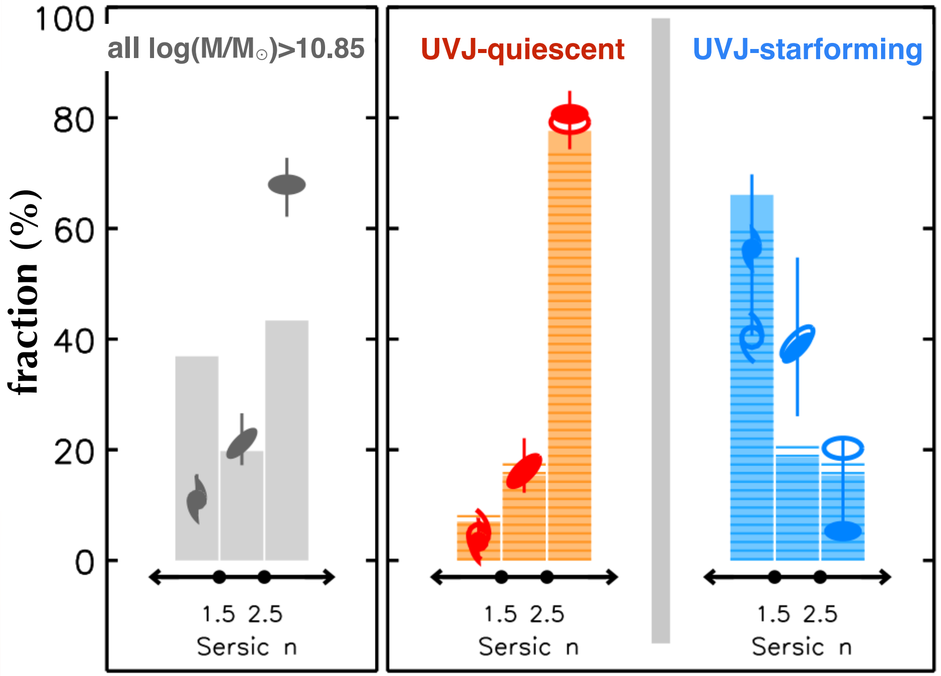

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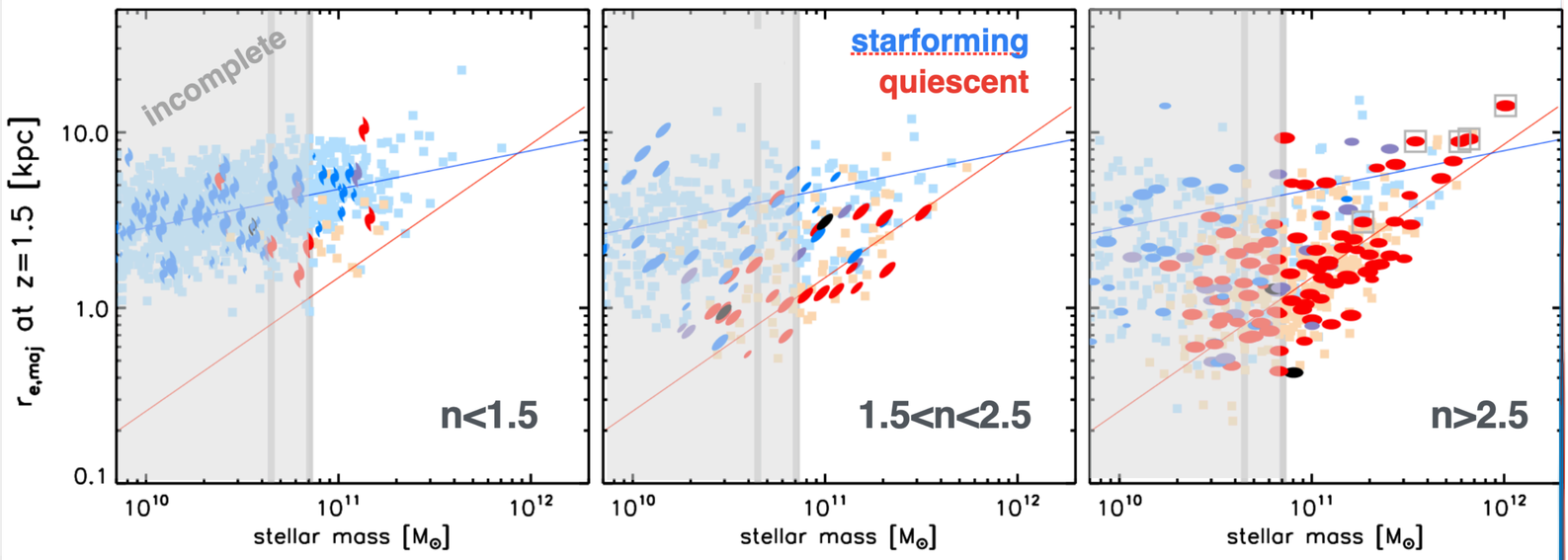

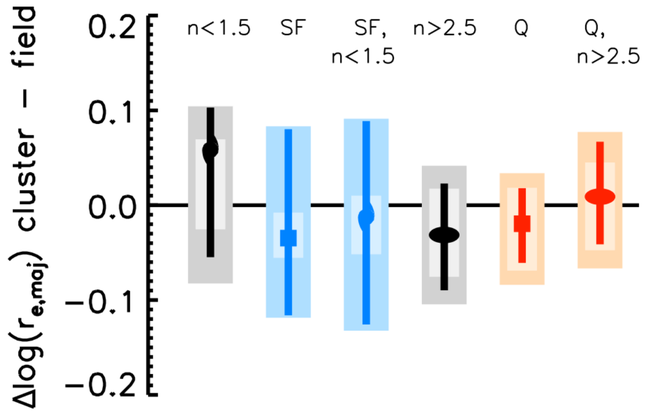

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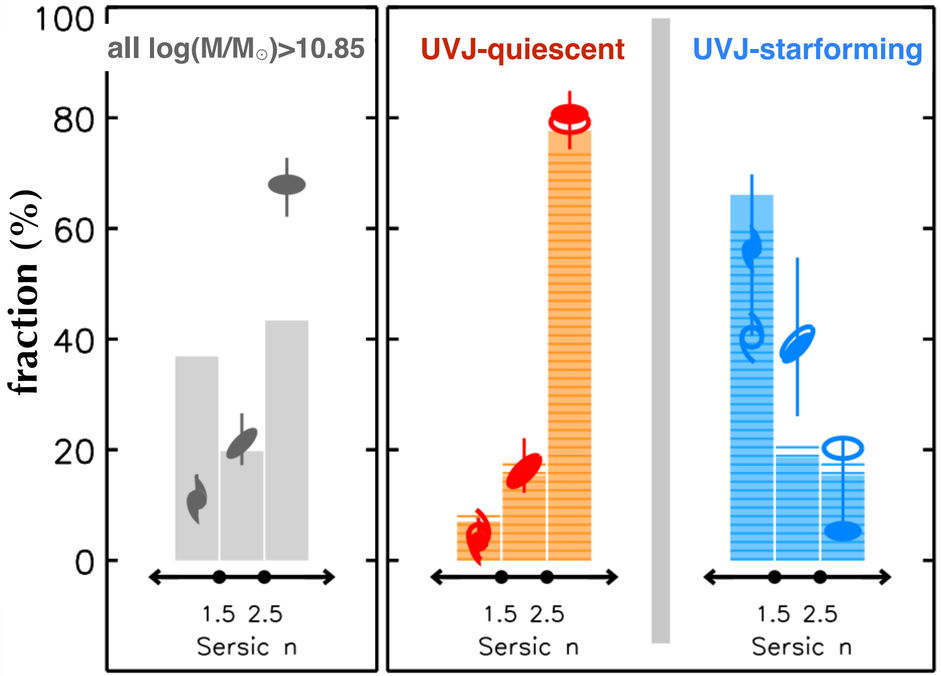

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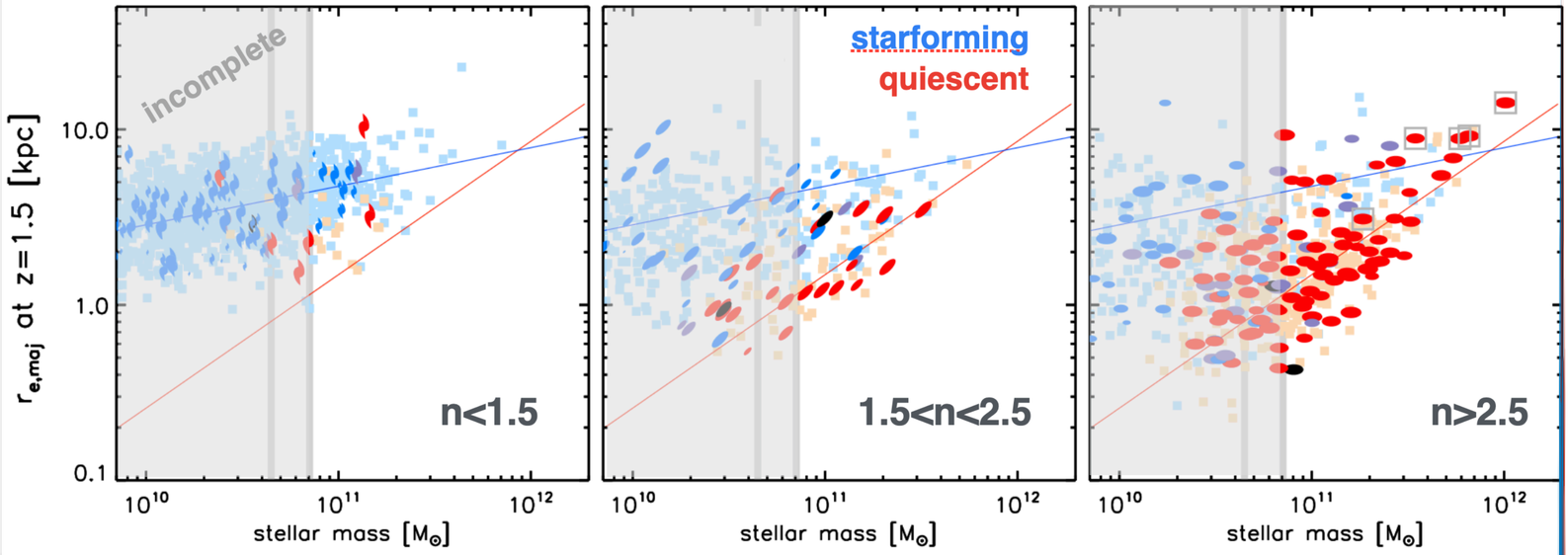
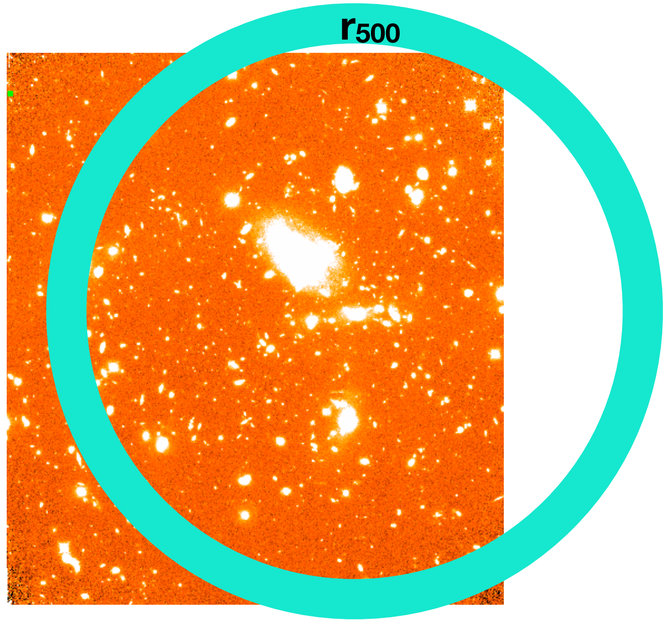


- structural properties of quiescent and star-forming galaxies, <u>separately</u>, in cluster and field environments are similar
- a morphology-density relation is in place, reflecting the higher quiescent galaxy fraction in clusters wrt field

Strazzullo+2023

This project — galaxy population properties and environmental signatures in the first massive clusters

currently… — quenching efficiency across the virial volume



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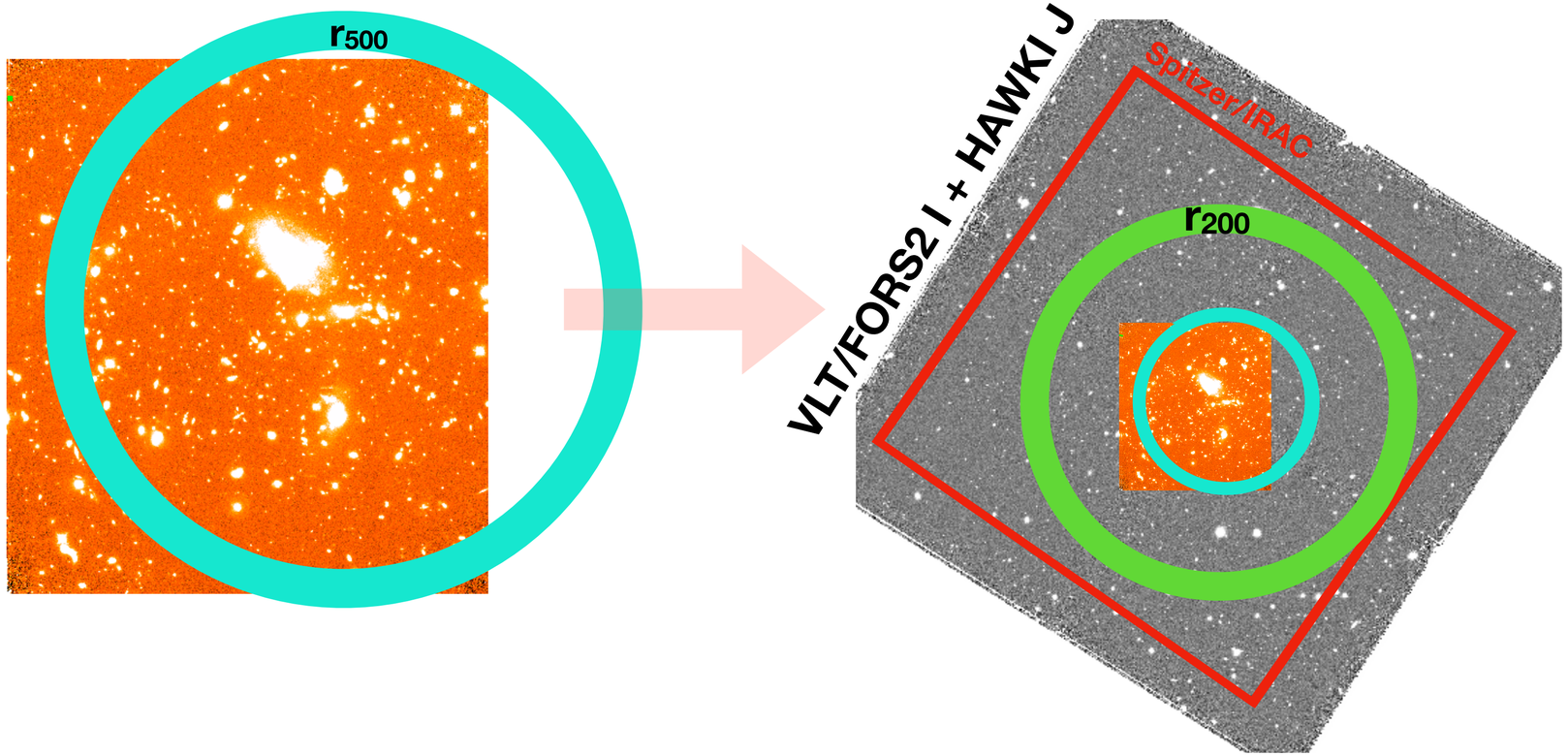
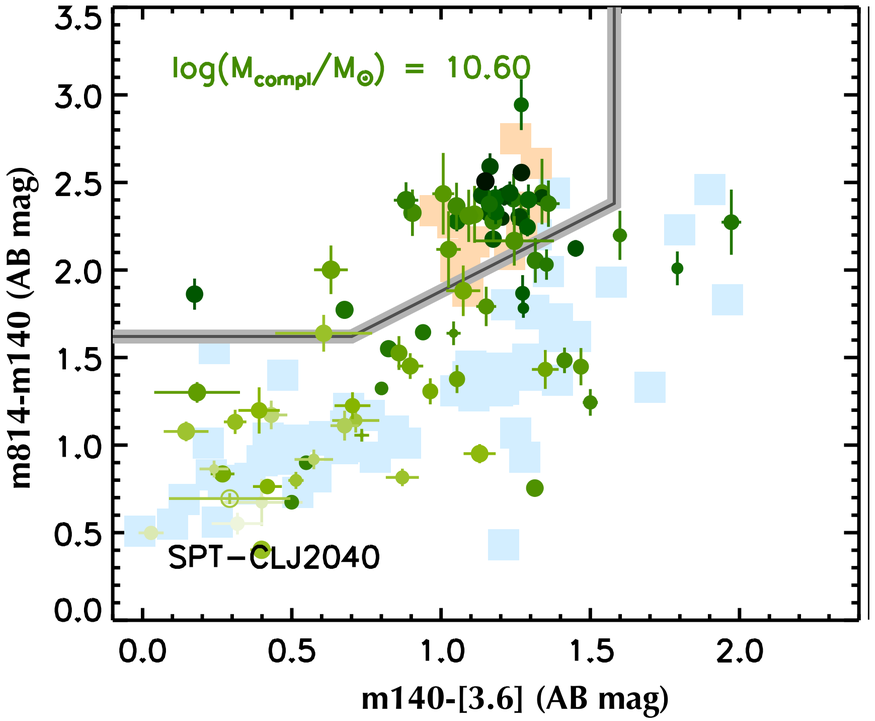




Added VLT imaging complements IRAC data out to r_{200} and beyond

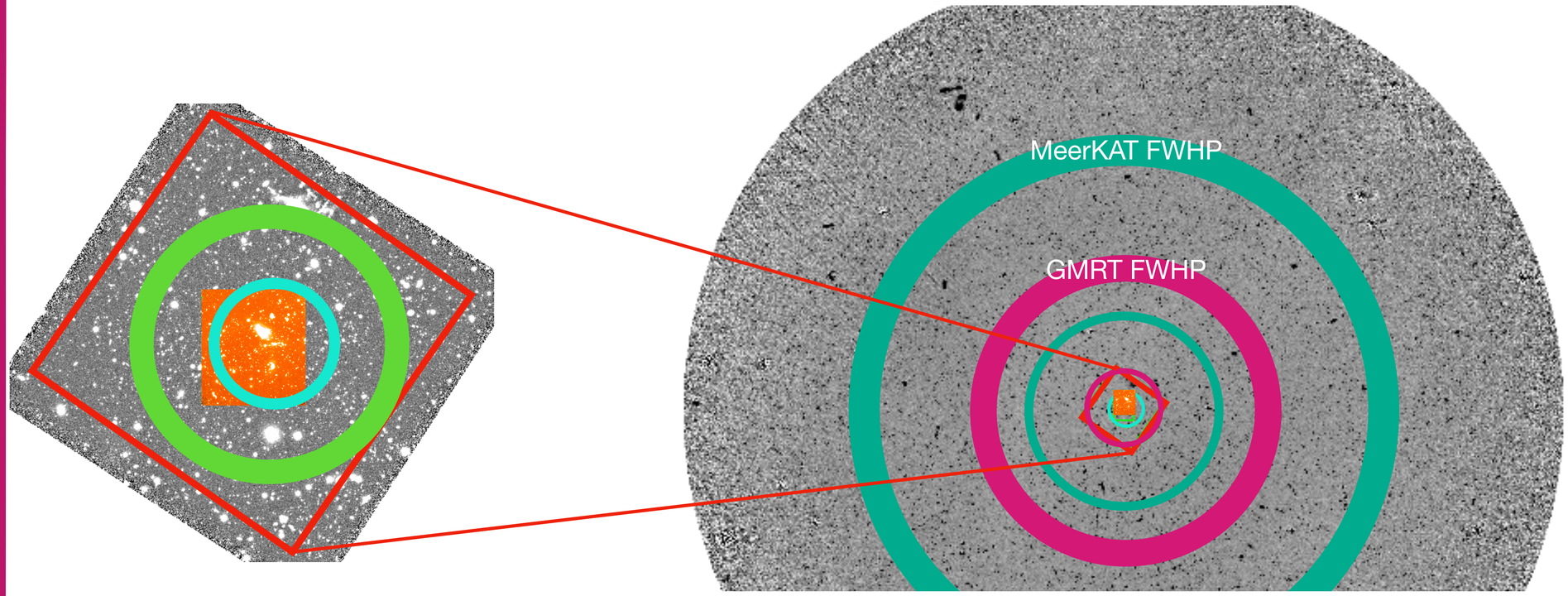
- **stellar mass assembly over full virial volume**
- photometric classification of quiescent vs star-forming galaxies out to ~1.5 r_{200}

-> environmental quenching efficiency profile out to the infall region, pre-processing, …

This project — galaxy population properties and environmental signatures in the first massive clusters

currently… — star formation across the virial volume

New MeerKAT and GMRT L band data (PI M. Pannella) probe radio continuum emission over the full virial region (and well beyond)



- **dust attenuation unbiased star formation rates for massive galaxy samples matching previous analyses** (thus also potential MS offset of cluster vs. field SF galaxies, identification of very massive sources (>$10^{11}M_{\odot}$) undergoing quenching, cluster SFR density profile, SFR density per halo mass, …)
- **nuclear activity - to be disentangled…** lacking IR data based on optical/NIR information, and/or also in combination with X-ray where available

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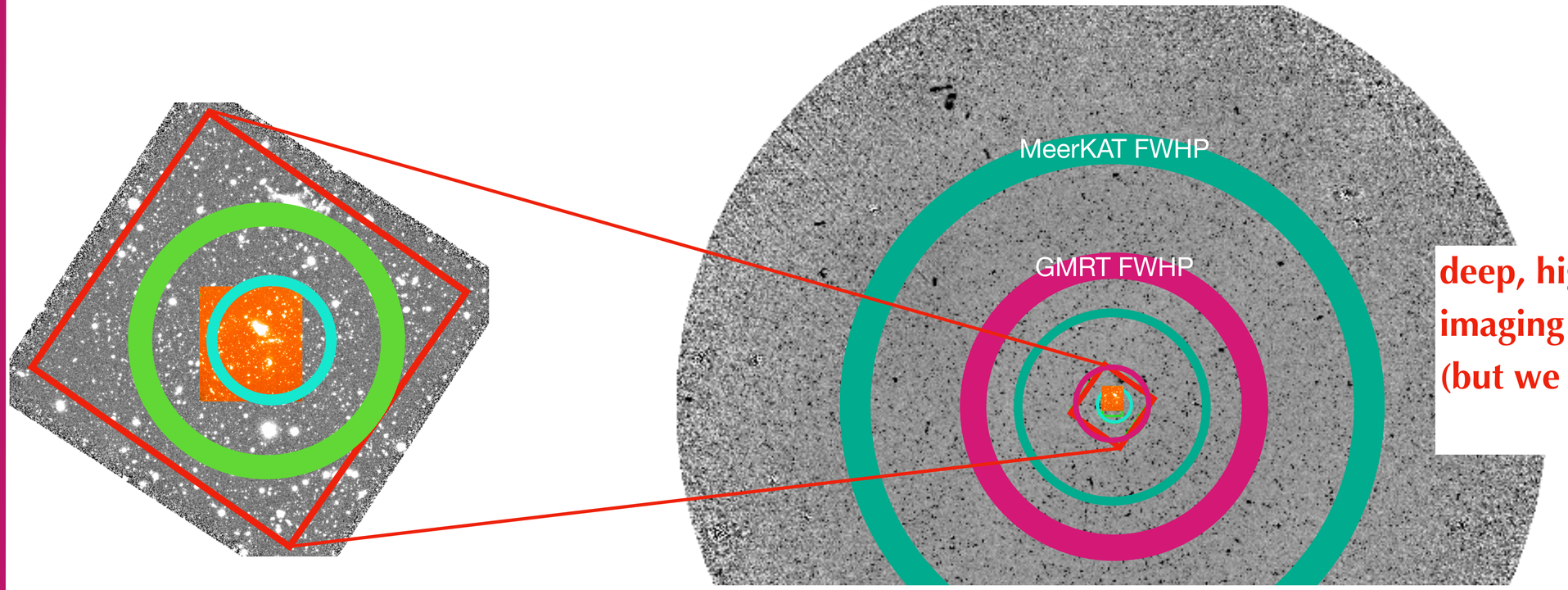

deep, high-resolution mid-IR JWST imaging is a critical complement to this (but we keep failing…)

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From passive fractions to … ?

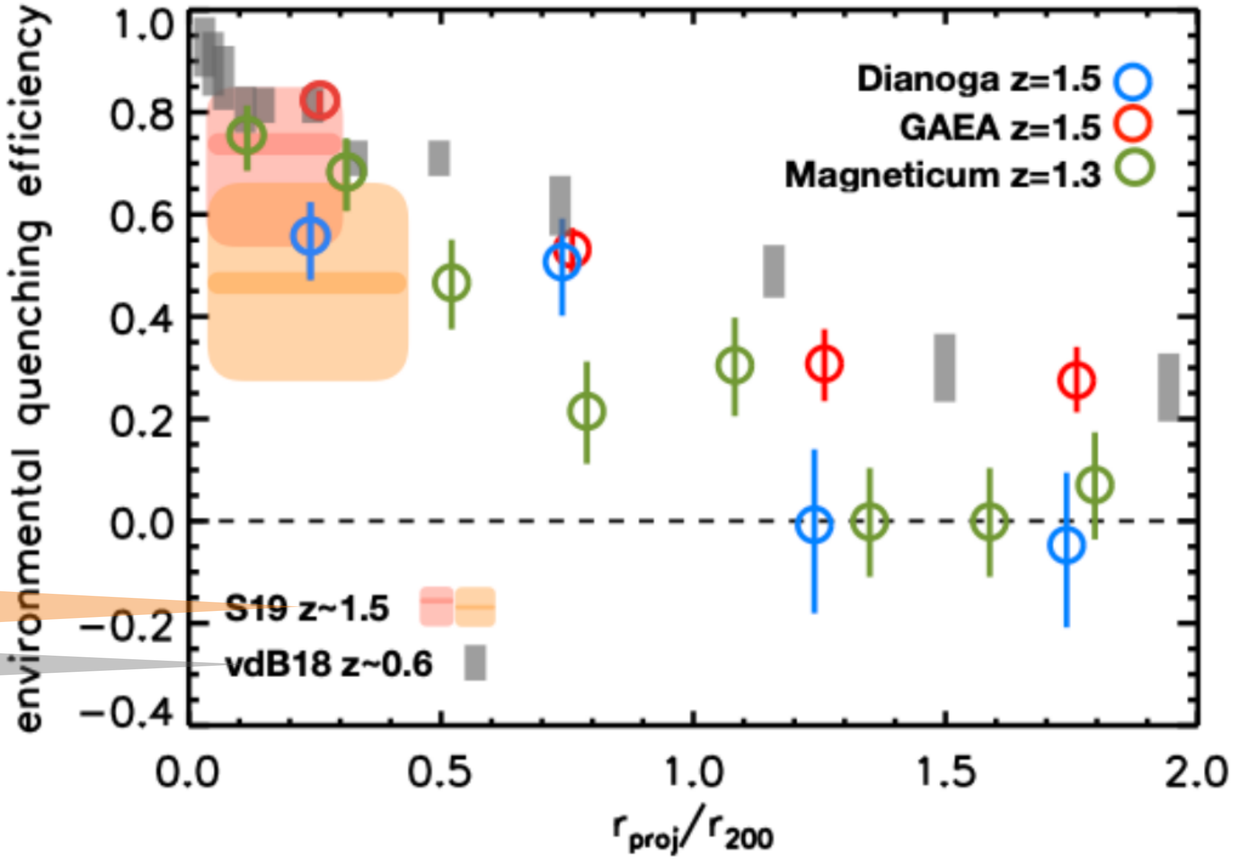
From observations to physical processes…

Comparison with simulations far from trivial… but interaction with "theoretical counterparts" is needed to extend the reach of observations a bit closer to constraints on physical processes, within a proper cosmological context

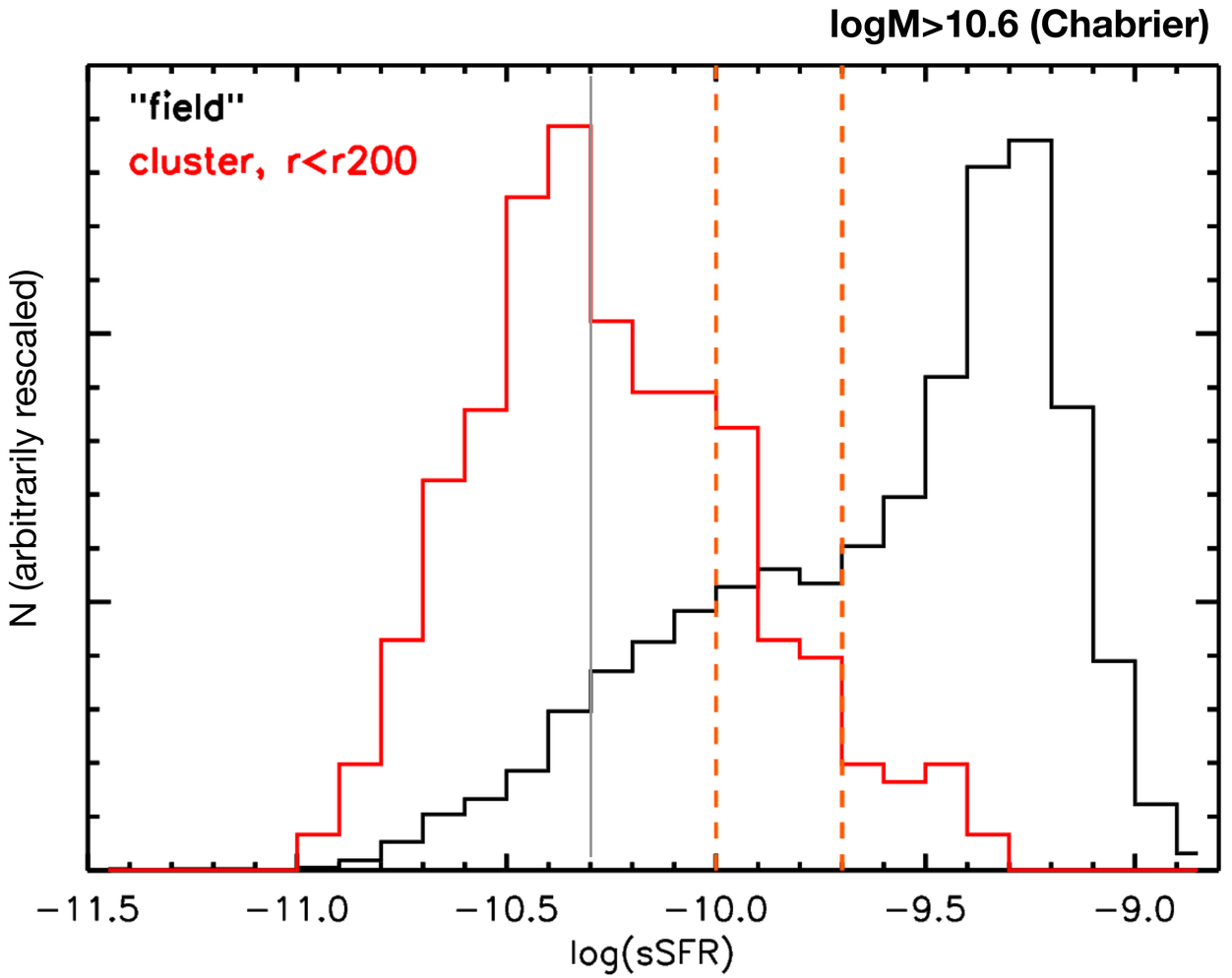
PRELIMINARY AND OUTDATED!

Our work on this cluster sample (central regions), to be extended to 1.5-2 r_{200} (upcoming)

Quenching efficiency profile in likely low-z descendants, massive Planck clusters at z~0.6 (van der Burg et al. 2018)



Star-forming and quiescent populations in GAEA clusters and “field” at z~1.5

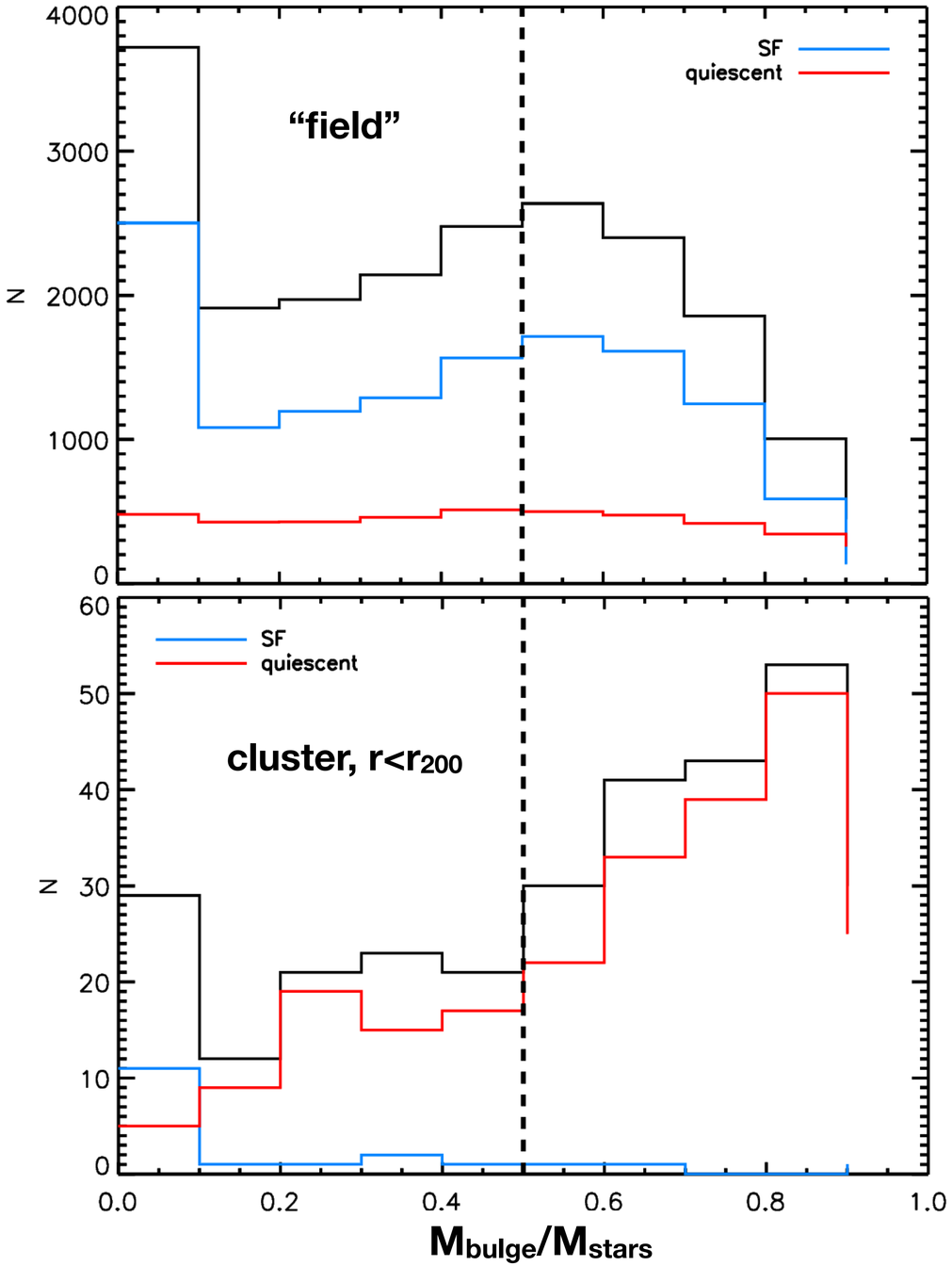


Not current model !

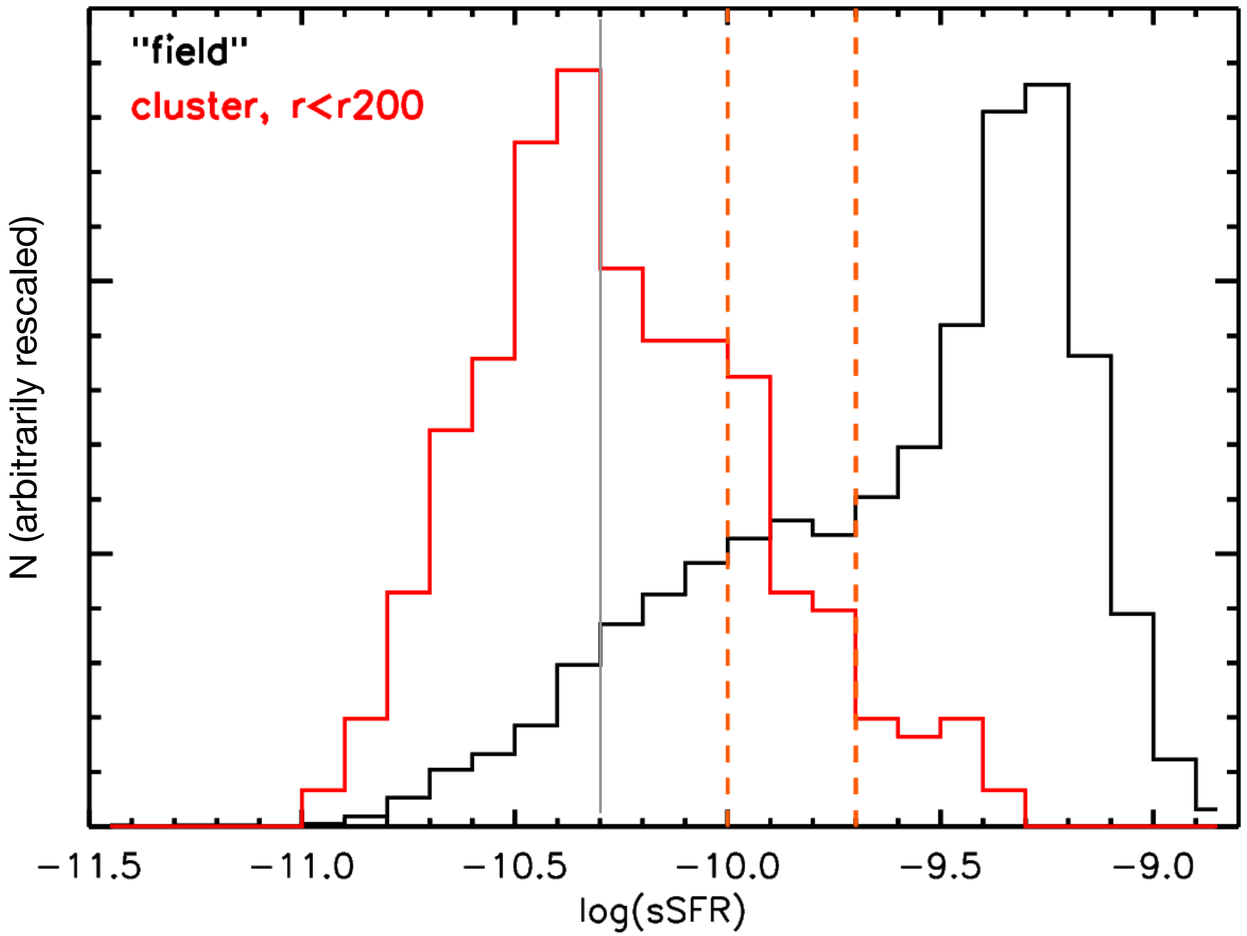
23 haloes with $M_{200}>2\cdot10^{14}\,M_\odot$

(only 6 have $M_{200}>3\cdot10^{14}\,M_\odot$)

Stellar population vs structural properties



logM>10.6 (Chabrier)



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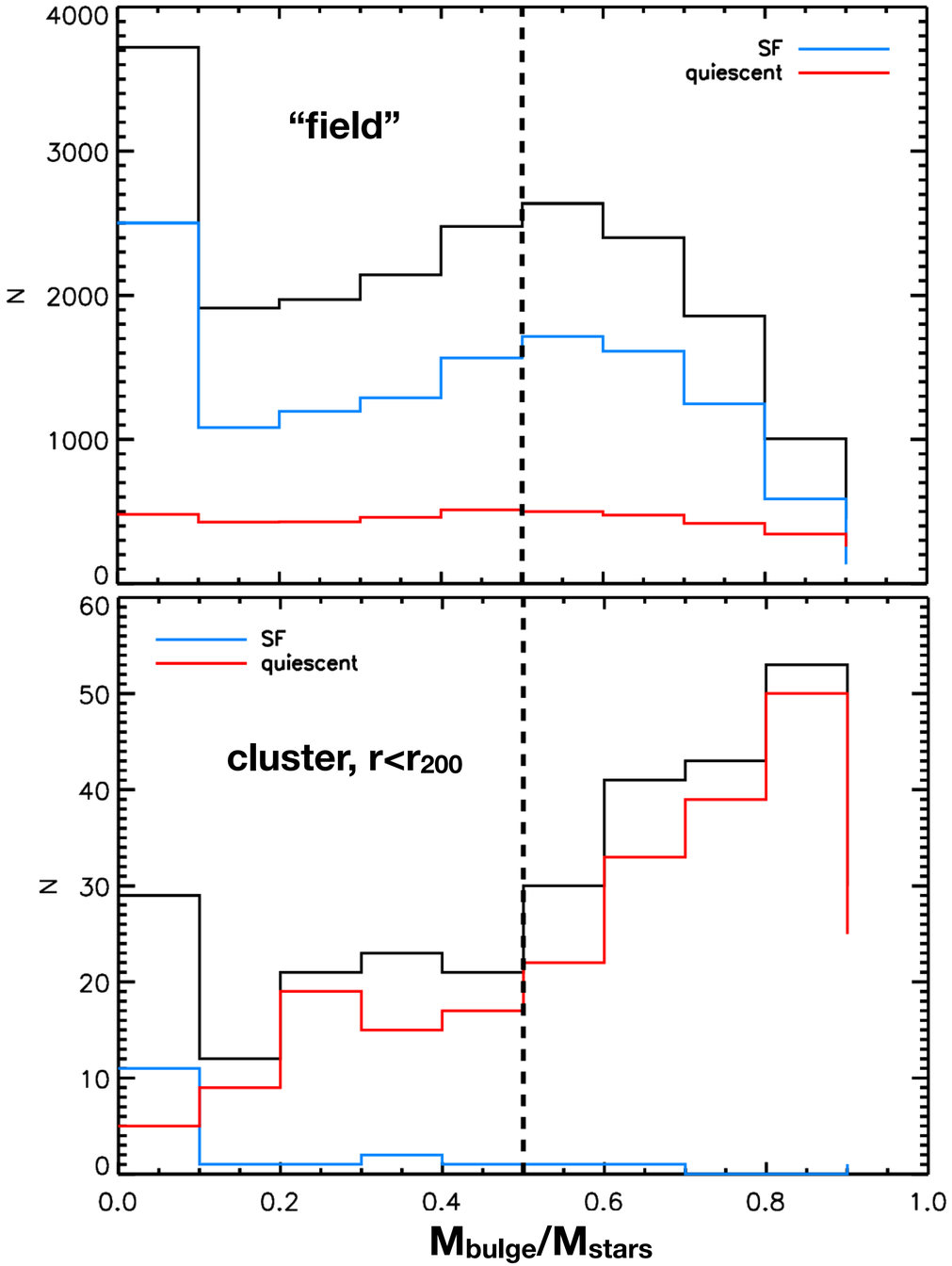
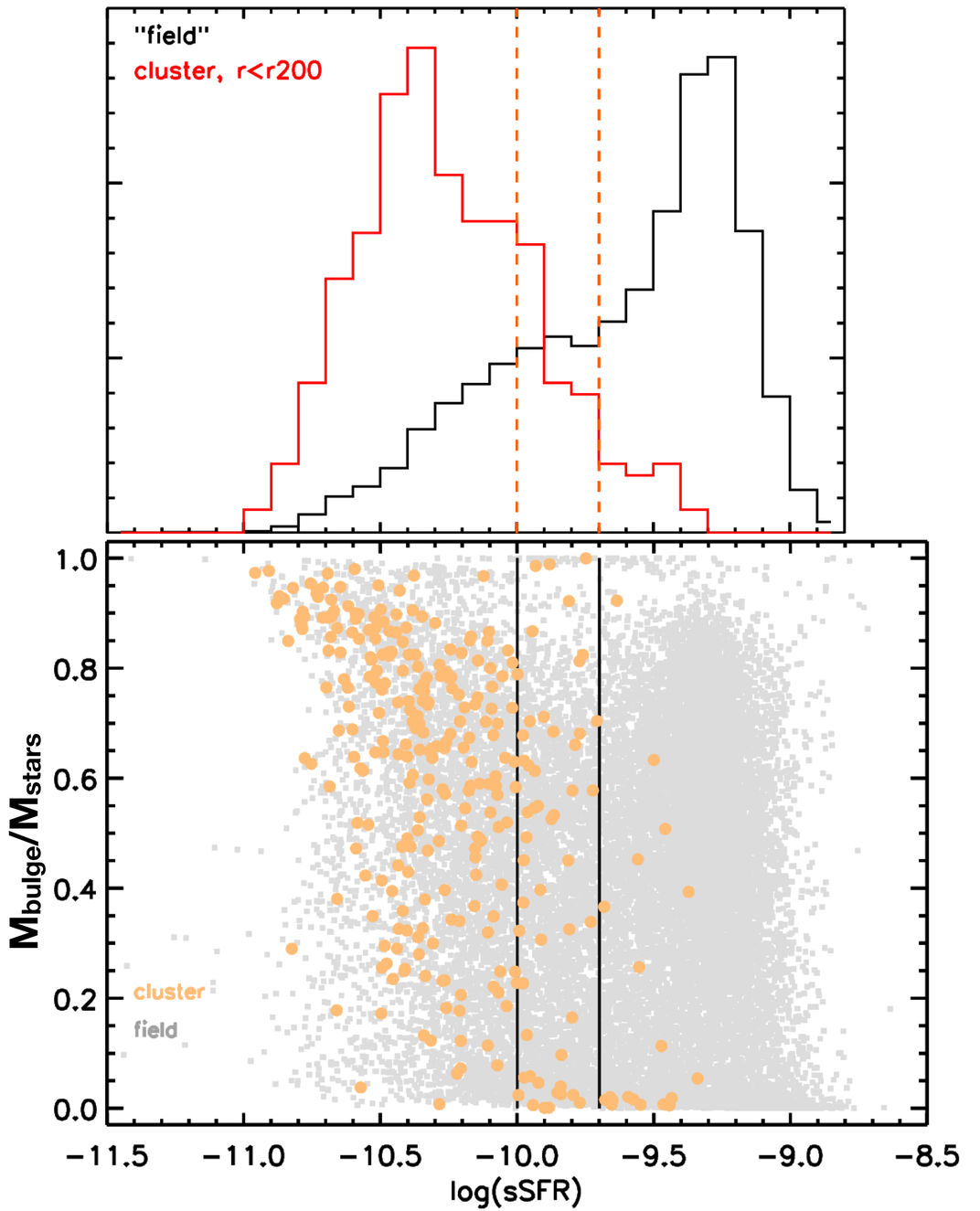
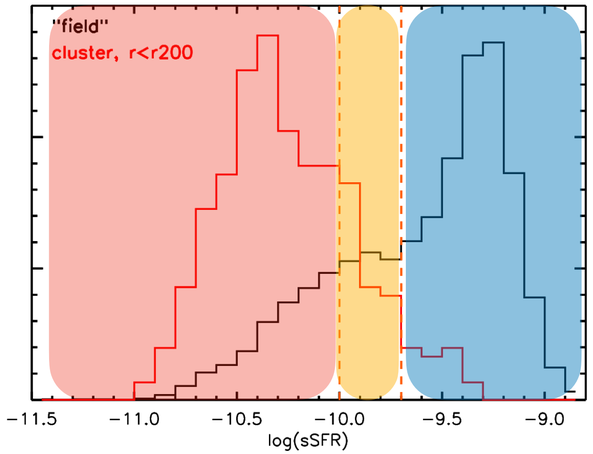
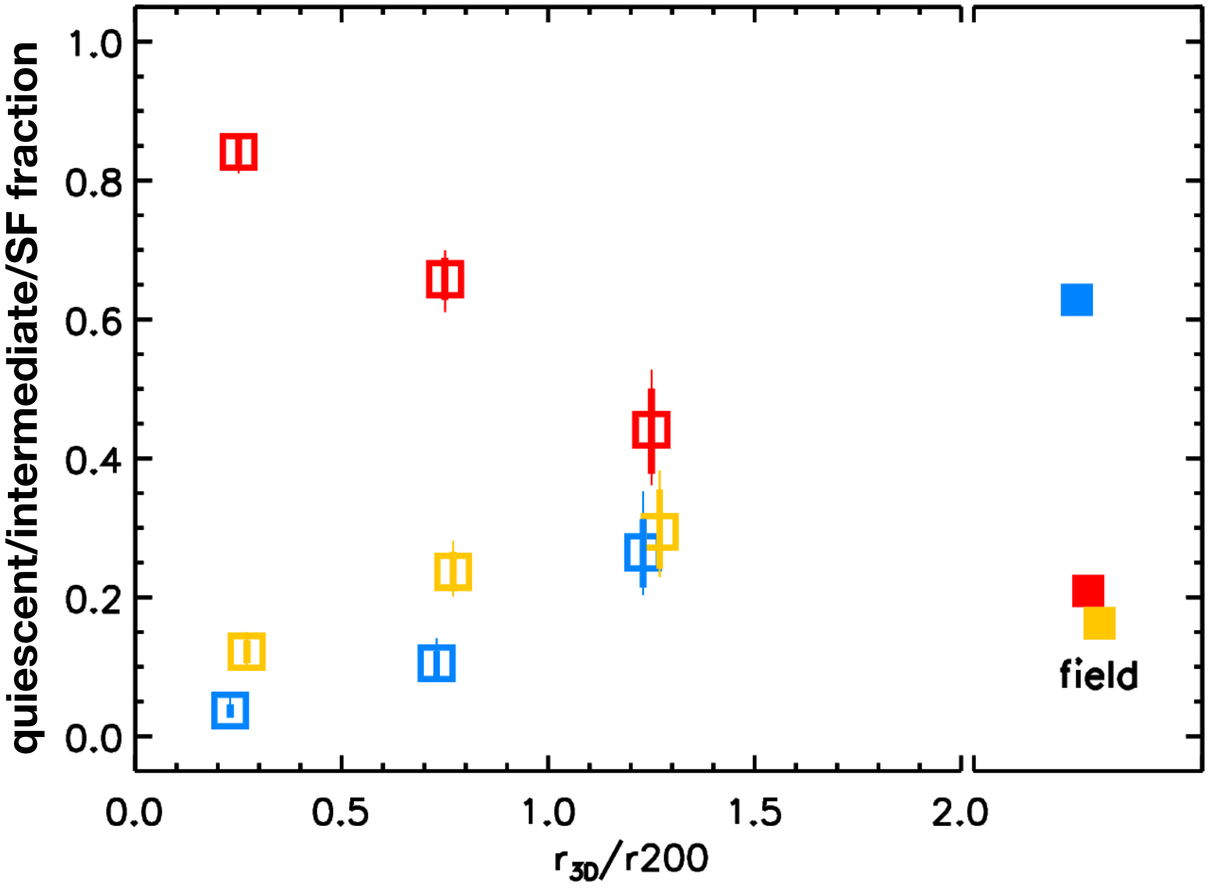
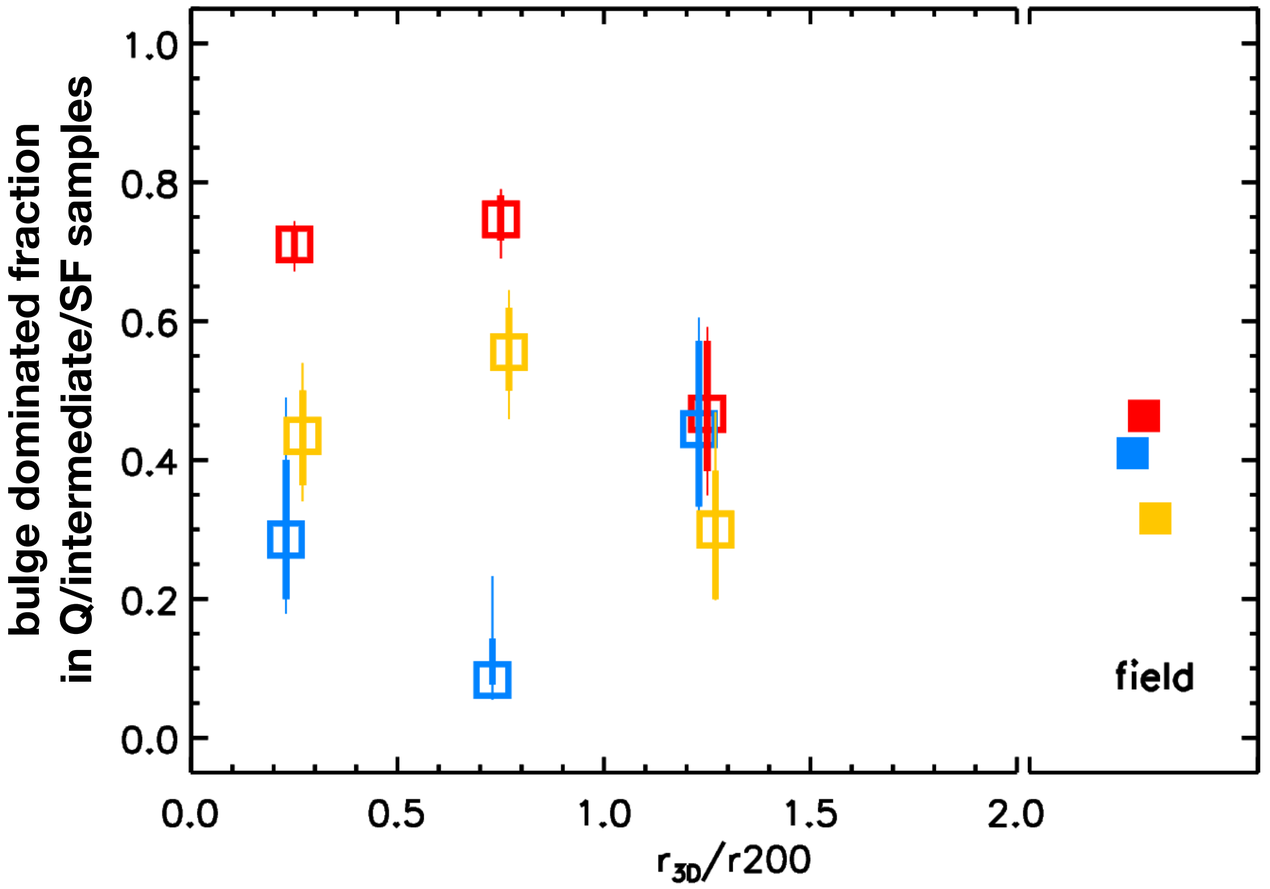




Environmental quenching - or “environmental signatures”…



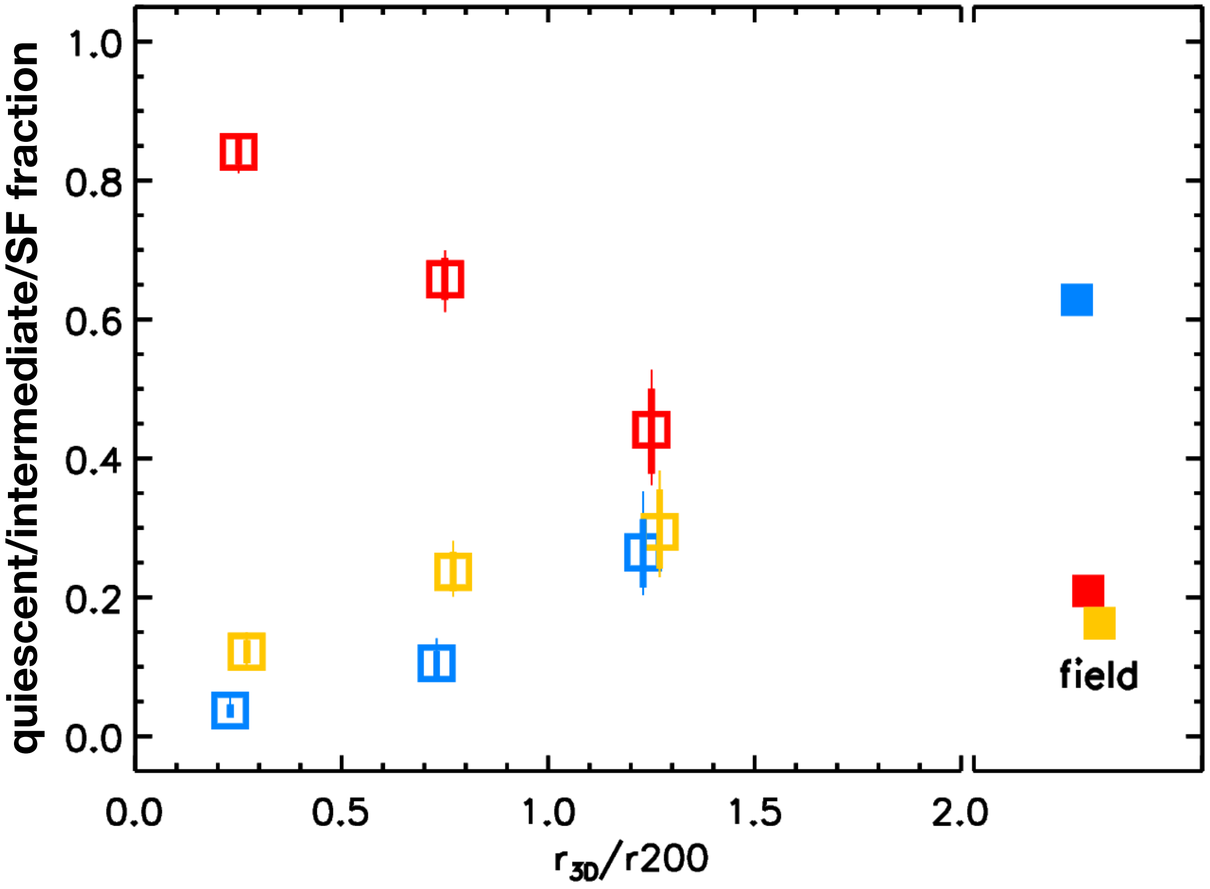


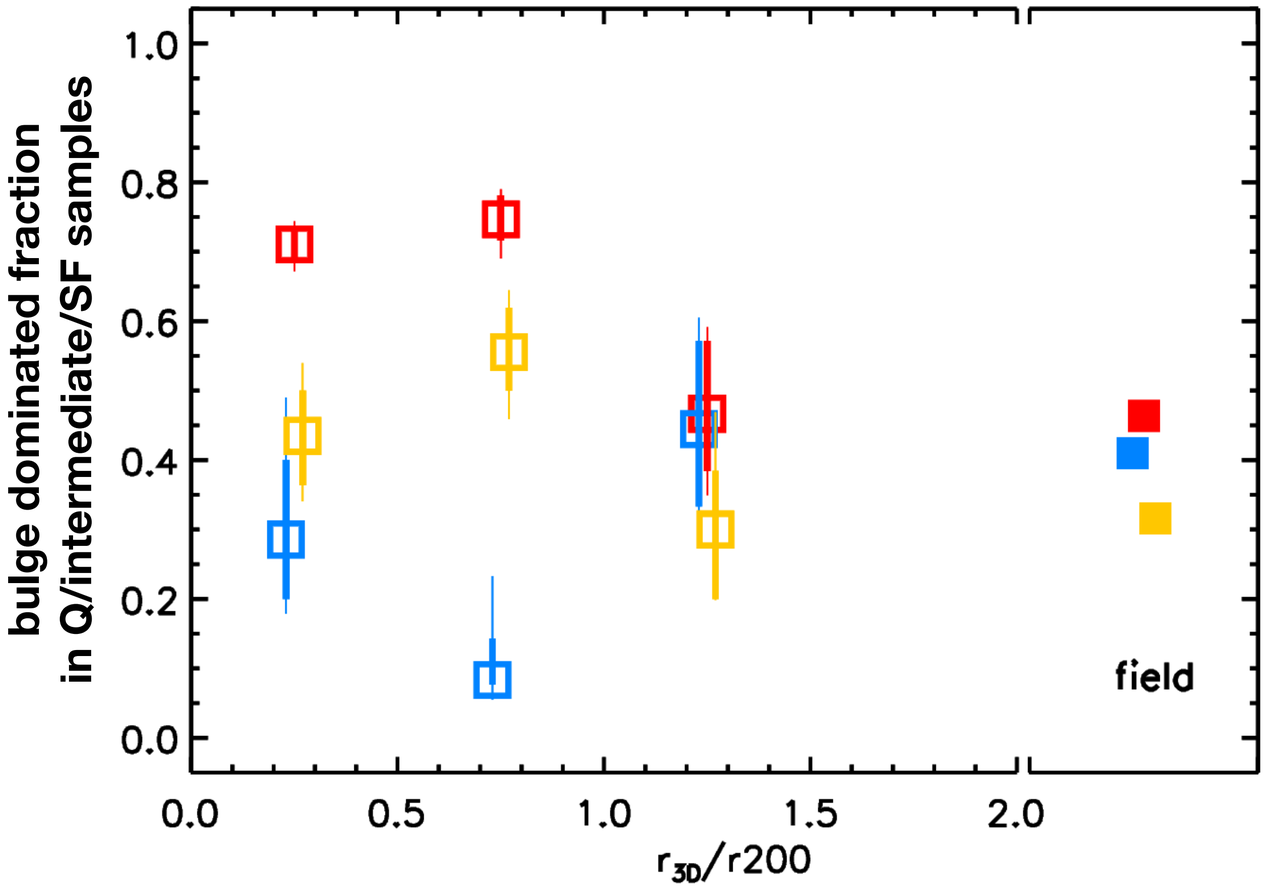


Environmental quenching - or "environmental signatures"…

… and then:

- environmental signatures on stellar mass vs "size" relation for different populations
- sSFR offset of SF galaxies in cluster vs field environments
- SFR vs stellar continuum radii…
- environmental dependence of stellar ages…
- …





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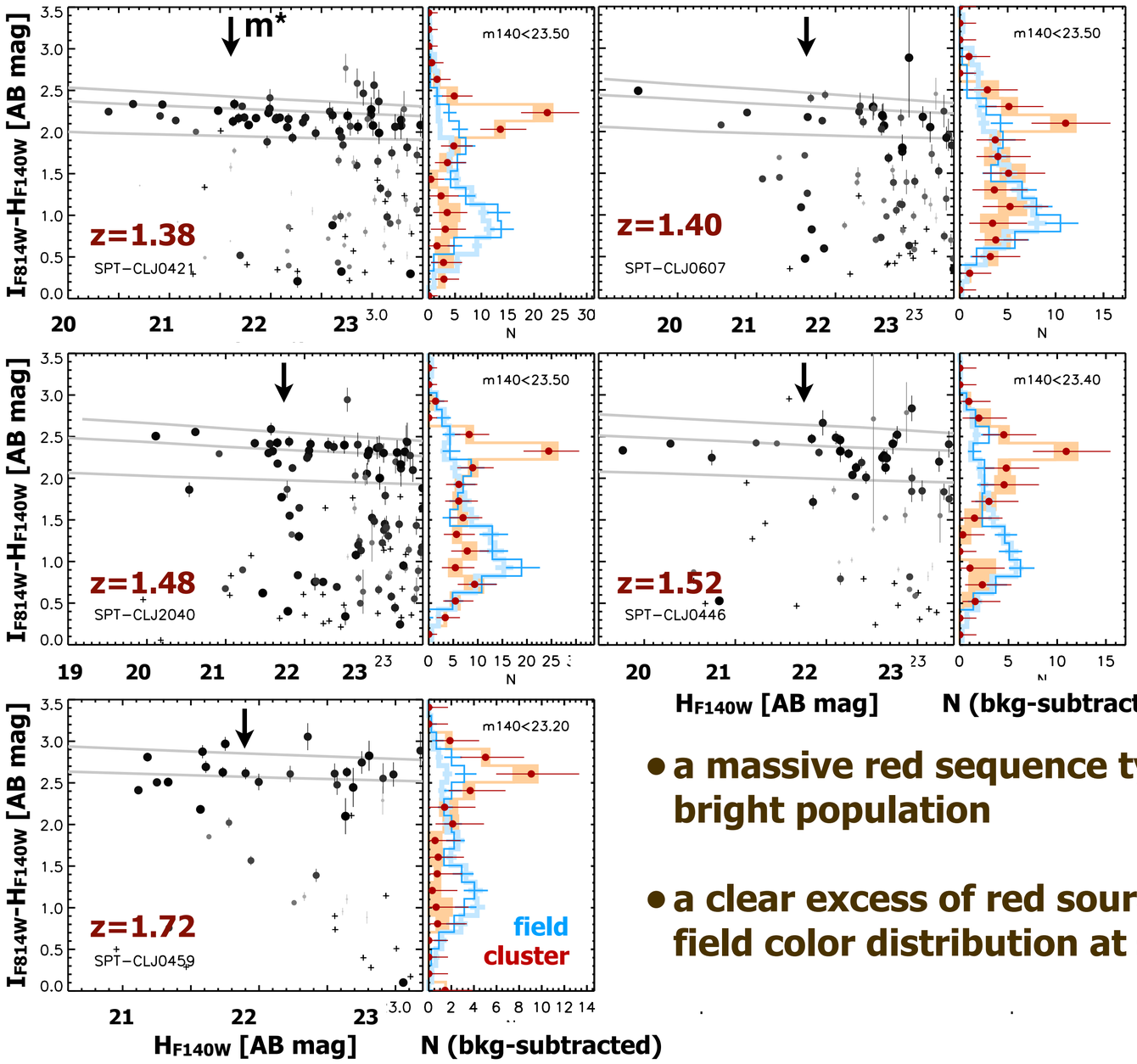
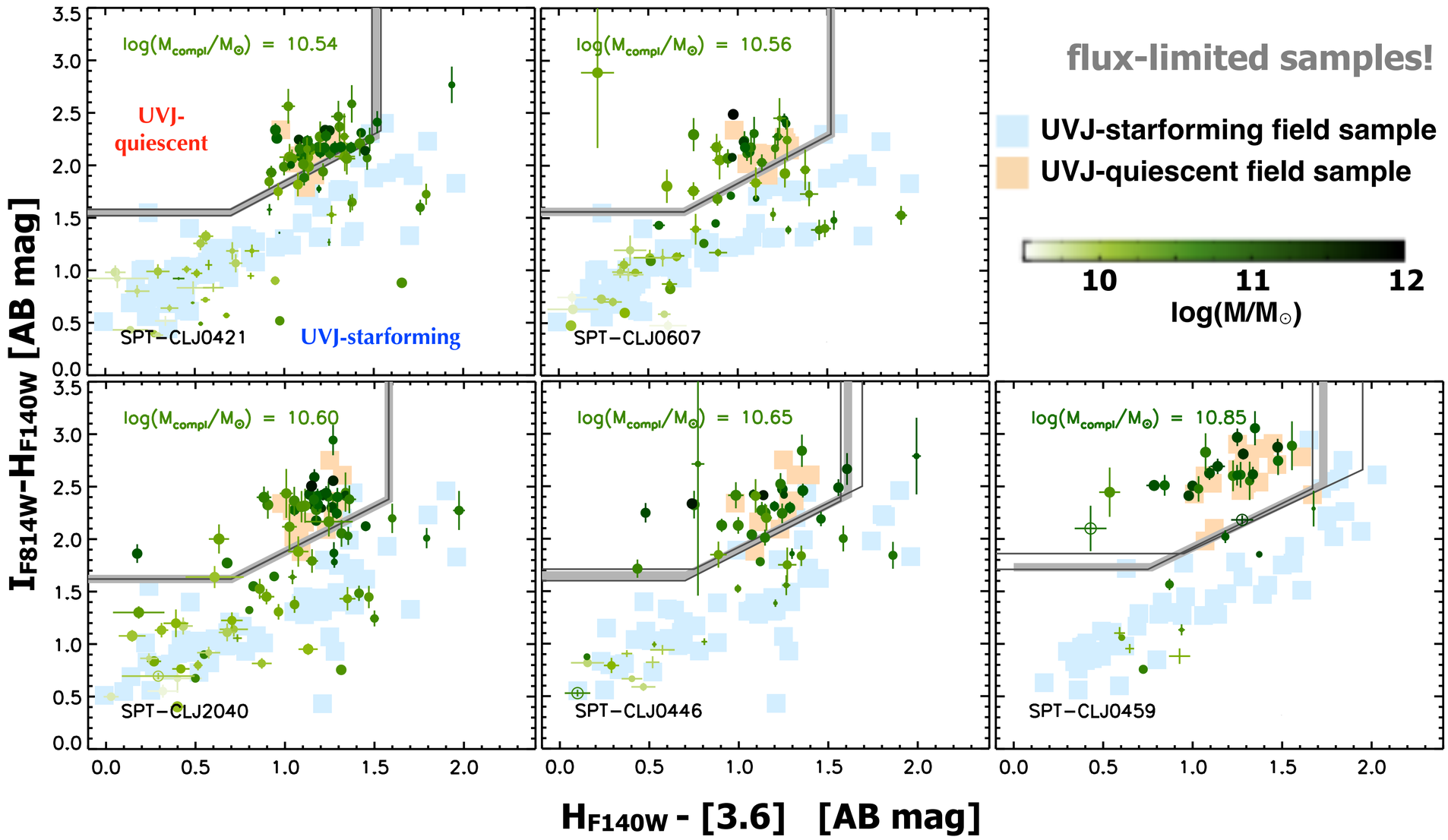


r<0.7 r_{500}

- a massive red sequence typically dominates the bright population
- a clear excess of red sources compared to the field color distribution at same redshift

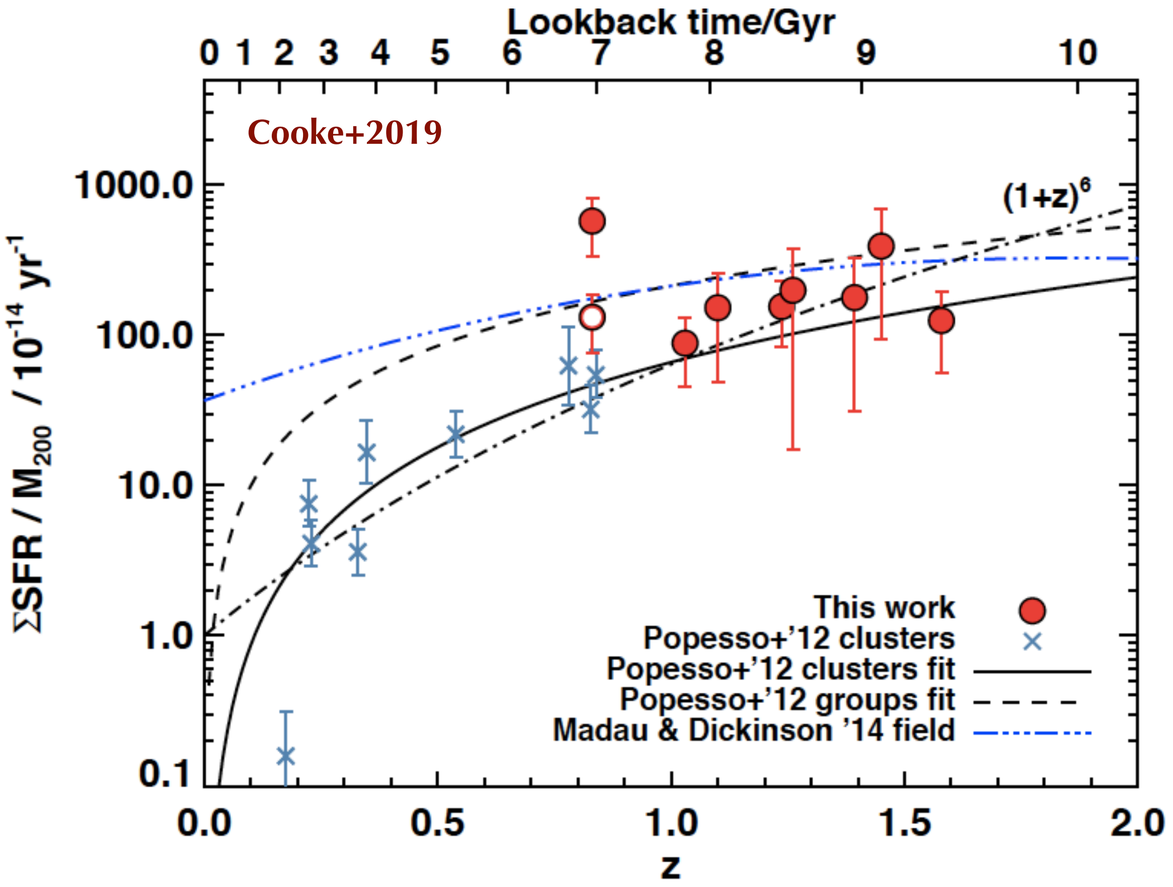
Strazzullo+2019

Quiescent and star-forming populations

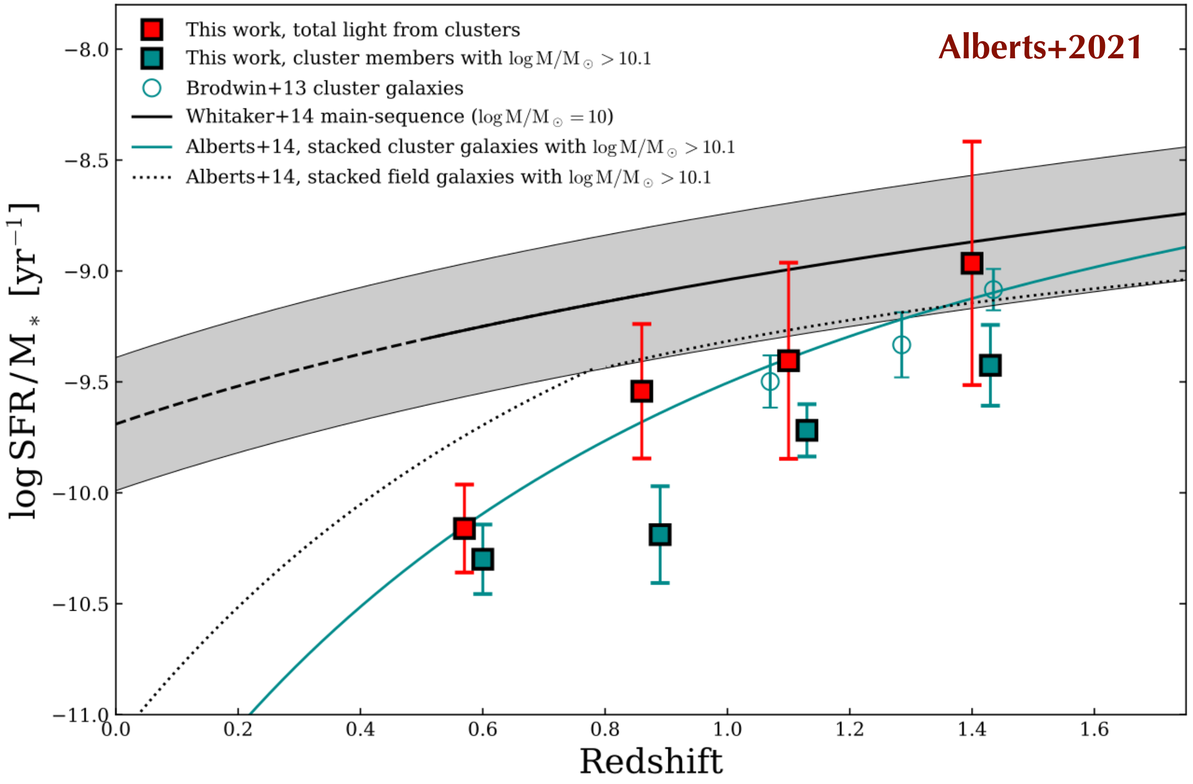


Strazzullo+2019

Main science drivers — star formation vs. quenching in massive clusters at high redshift



SFR density per halo mass



"total light" sSFR

star formation catching up with field levels at z~1.5? or still lower...?