Leiden
eas 2020
Virtual

European Astronomical Society Annual Meeting
EWASS

The cluster vs. field stellar mass-size relation at z ~ 1

implications for galaxy size growth and quenching

by

Jasleen Matharu

Adam Muzzin, Gabriel Brammer, **Remco van der Burg**, Matt Auger, Paul Hewett, Arjen van der Wel, Pieter van Dokkum, Michael Balogh, **Jeffrey Chan**, Ricardo Demarco, Danilo Marchesini, Erica Nelson, Allison Noble, Gillian Wilson & Howard Yee

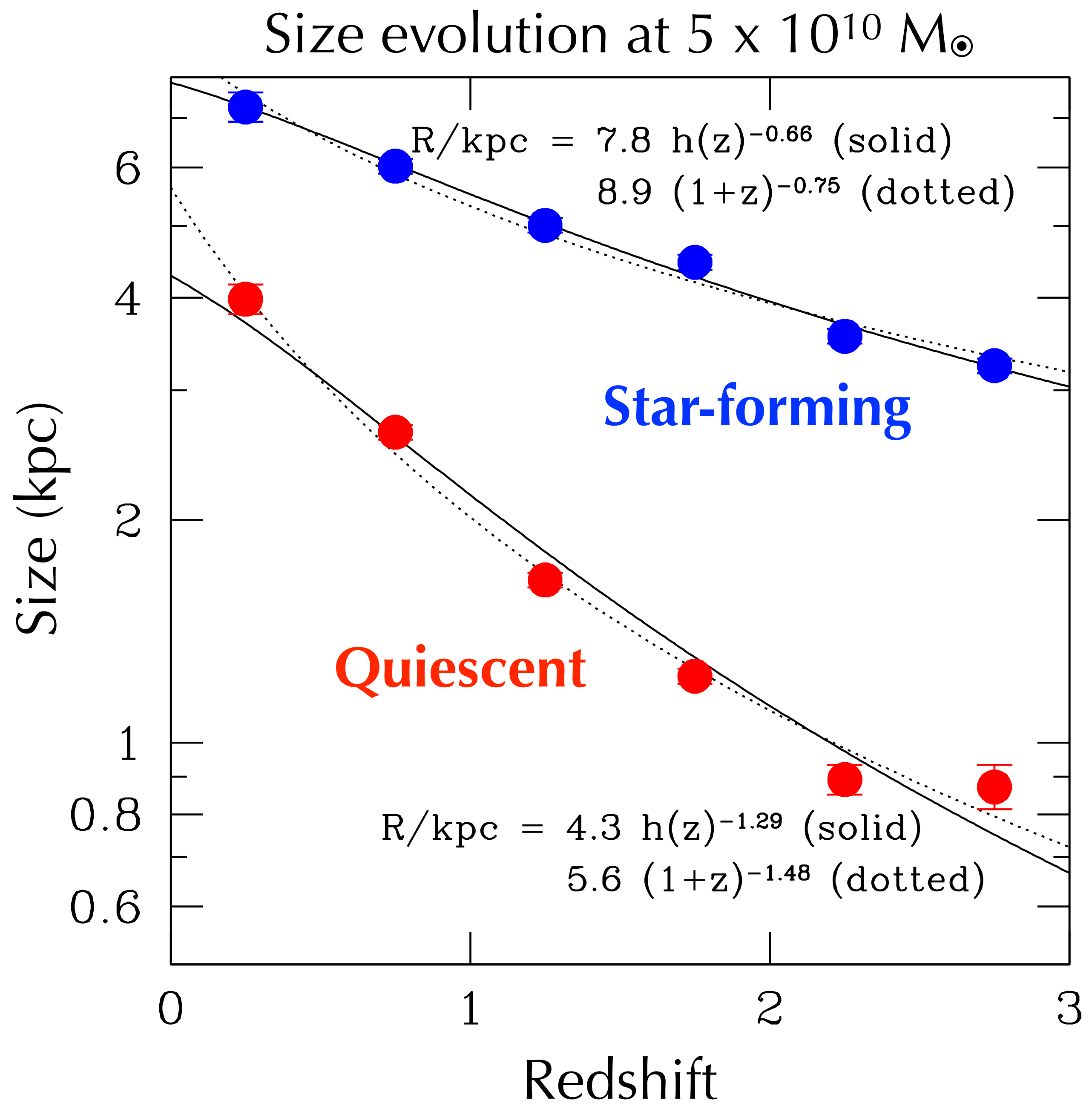
Science & Technology Facilities Council

ioa

UNIVERSITY OF CAMBRIDGE

TEXAS A&M UNIVERSITY

Quiescent galaxies **grow more in size than stellar mass** with decreasing redshift



van der Wel et al., (2014)

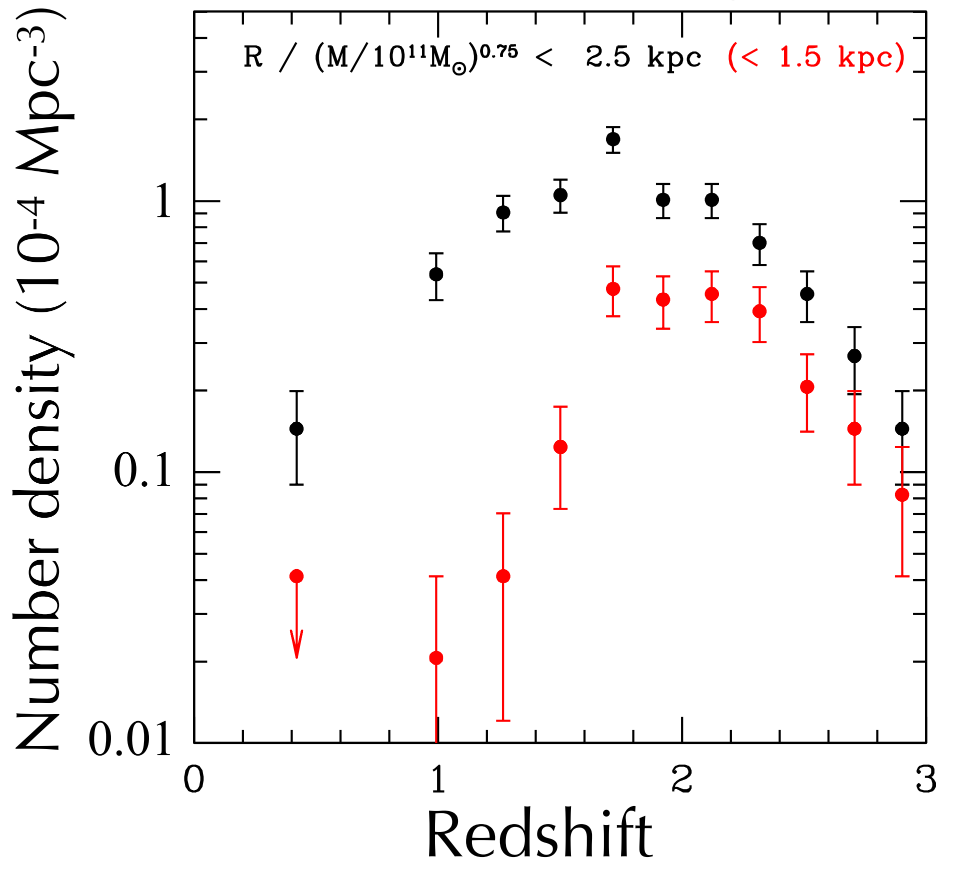
See also Daddi et al., (2005); Trujillo et al., (2006); van Dokkum et al., (2008); Buitrago et al., (2008); van der Wel et al., (2008); Damjanov et al., (2011); Raichoor et al., (2012); Cimatti et al., (2012); Mei et al., (2012) and Huertas-Company et al., (2013a)

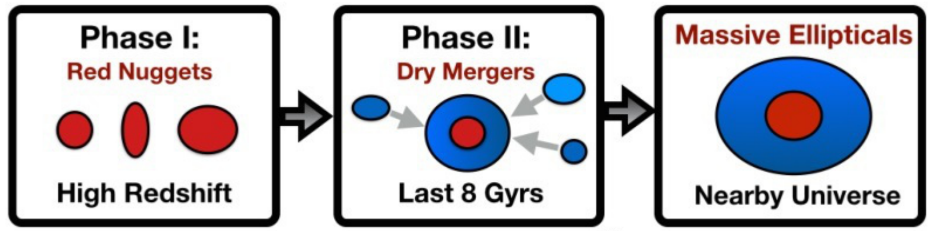
Explanations for this size growth

eas 2020 Leiden Virtual

Minor mergers

Compact quiescent galaxies





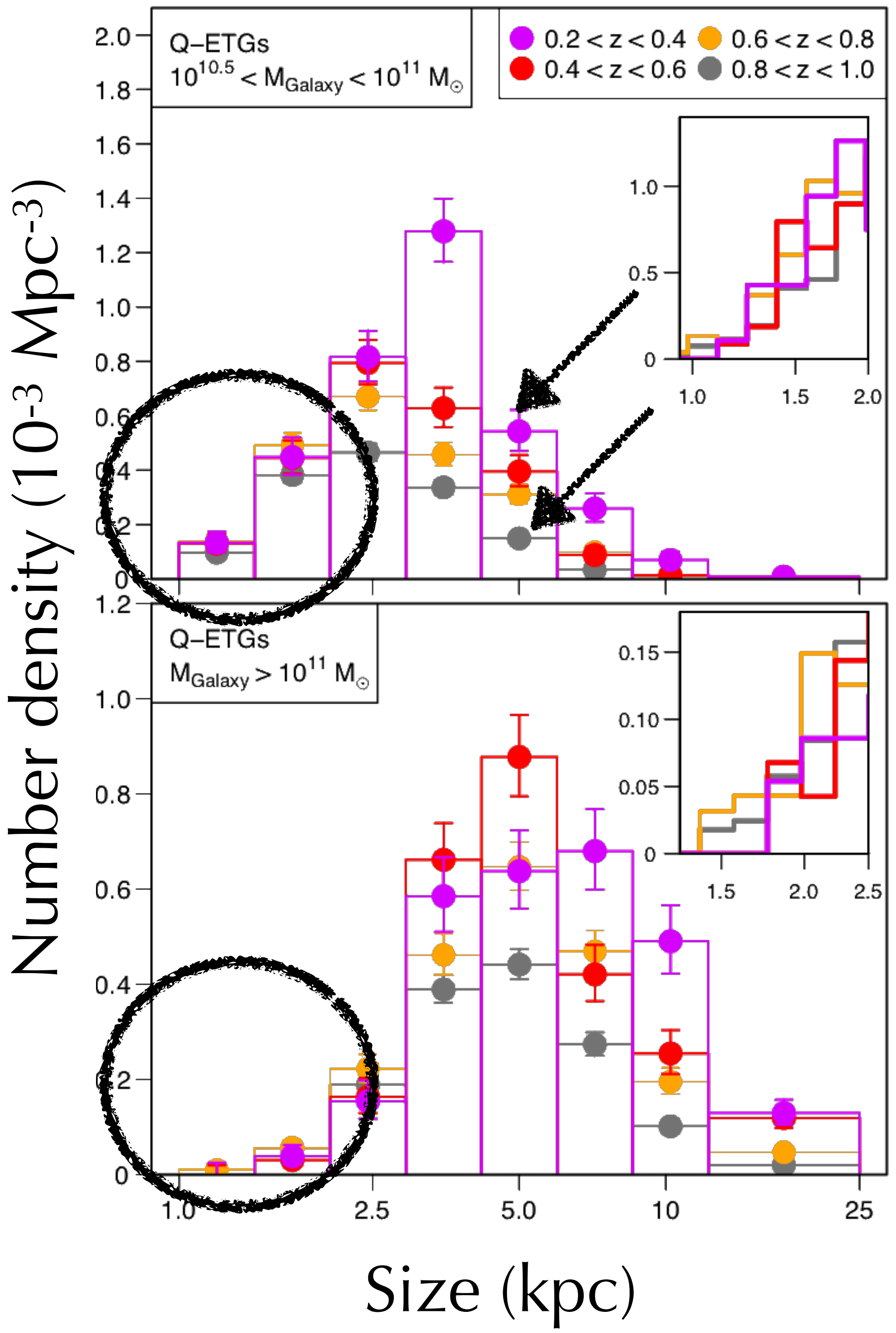
Size α (Stellar mass)^2

van der Wel et al., (2014), Bezanson et al., (2009) and Huang et al., (2016)

See also Hopkins et al., (2009); Naab et al., (2009); van Dokkum et al., (2010); Trujillo et al., (2011); Hilz et al., (2012) and Oser et al., (2012)

Recently quenched galaxies

Quiescent galaxies

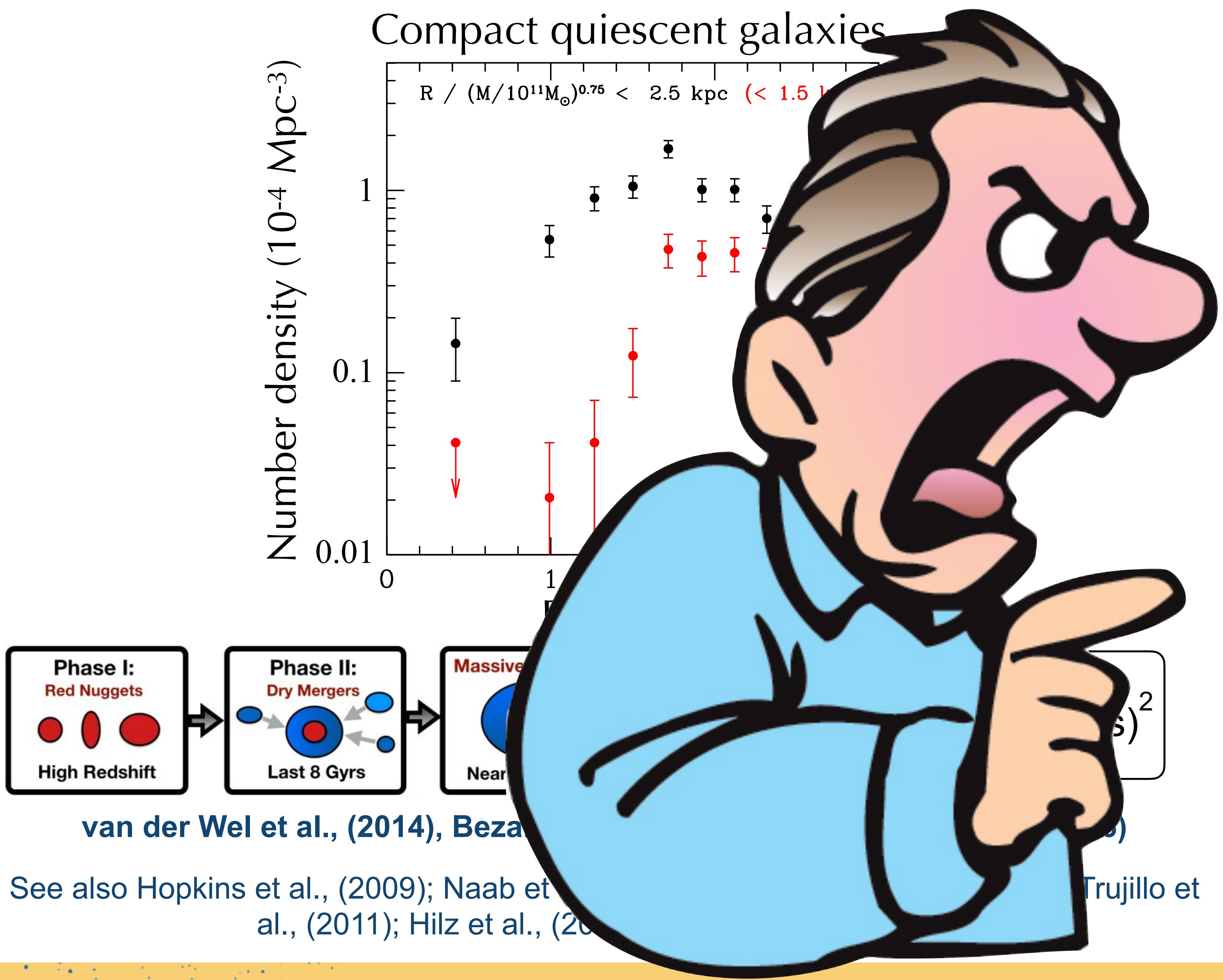


Carollo et al., (2013)

See also
van der Wel et al., (2009);
Valentinuzzi et al., (2010);
Cassata et al., (2011);
Newman et al., (2012);
Poggianti et al., (2013)
and
Belli et al.,(2015)

Explanations for this size growth

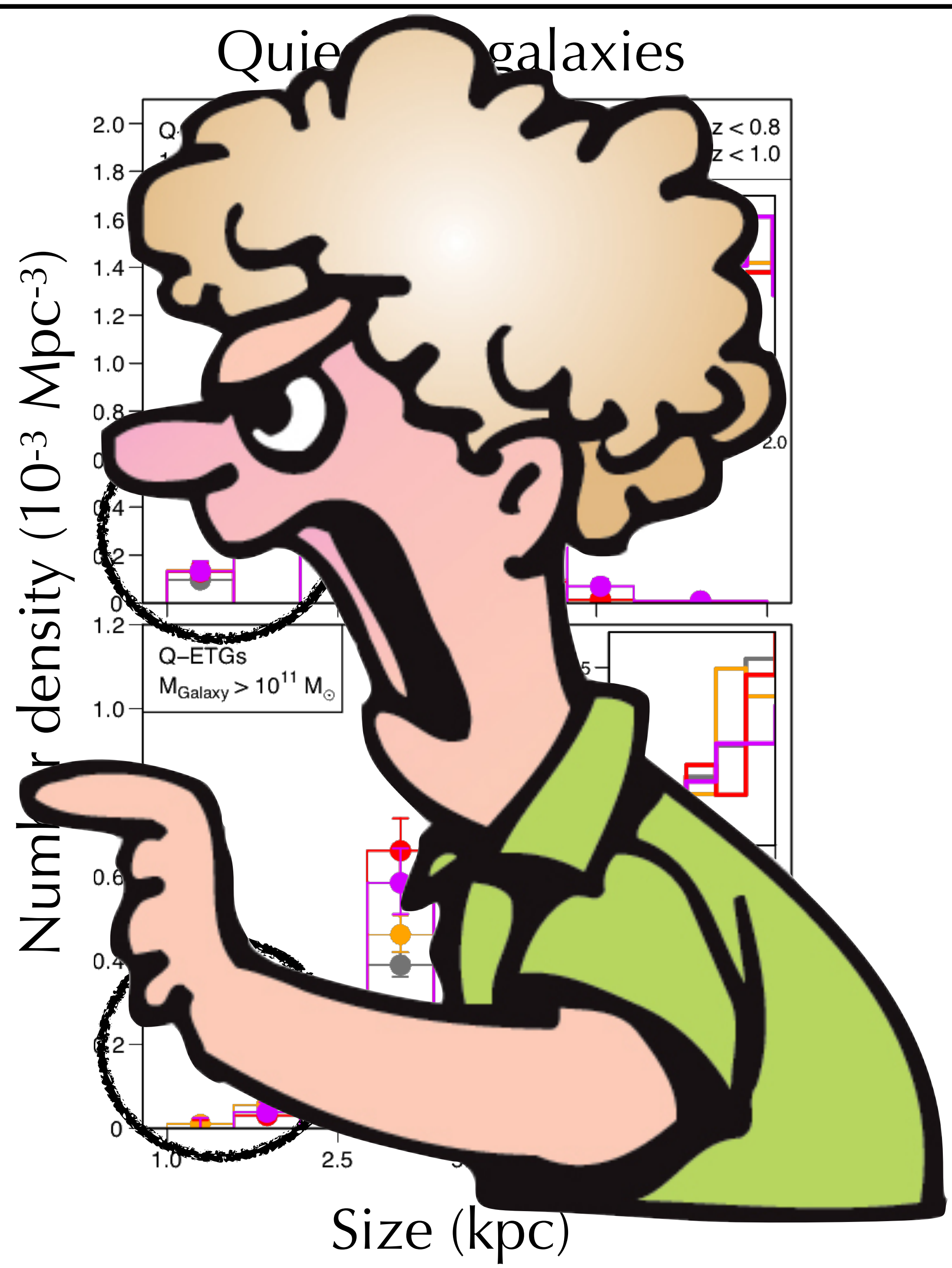
Minor mergers



van der Wel et al., (2014), Beza ...)

See also Hopkins et al., (2009); Naab et ... Trujillo et al., (2011); Hilz et al., (20...

Recently quenched galaxies

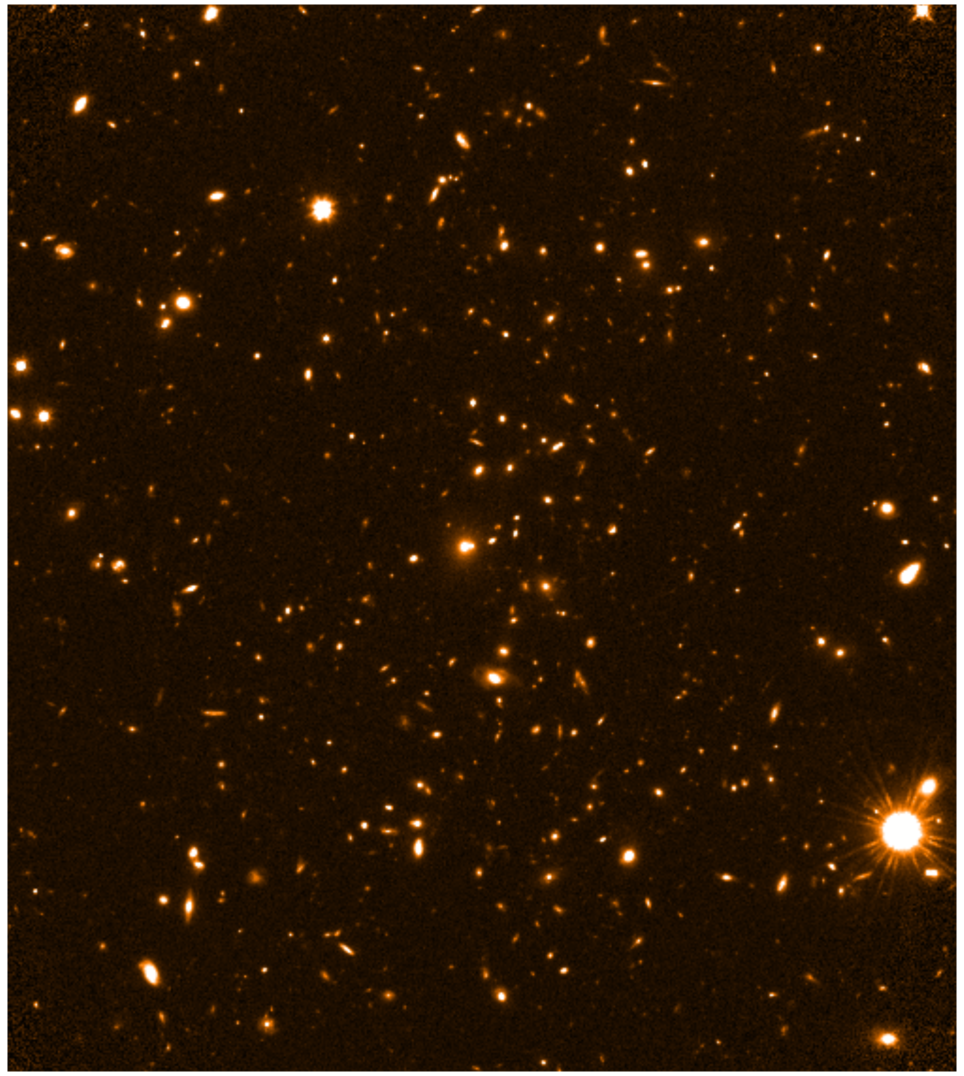


Carollo et al., (2013)

See also
van der Wel et al., (2009);
Valentinuzzi et al., (2010);
Cassata et al., (2011);
Newman et al., (2012);
Poggianti et al., (2013)
and
Belli et al.,(2015)

Environment

Clusters ($M_{200} \sim 10^{14}\ M_{\odot}$)

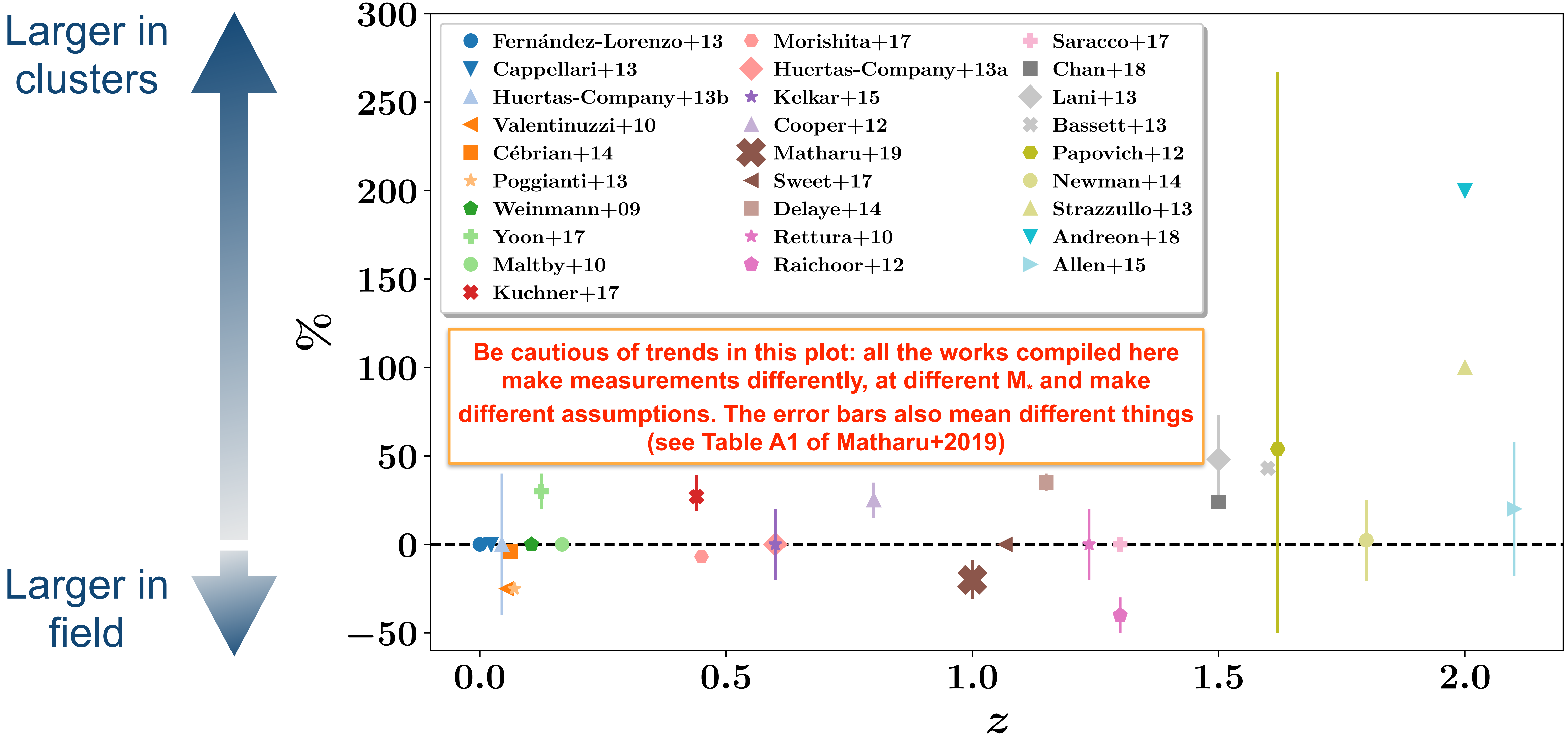


- Satellite galaxies are moving at high speeds.
- Mergers are rare.

Field (Small groups)

- Galaxies are moving more slowly.
- Mergers are likely.

Previous results for quiescent galaxies



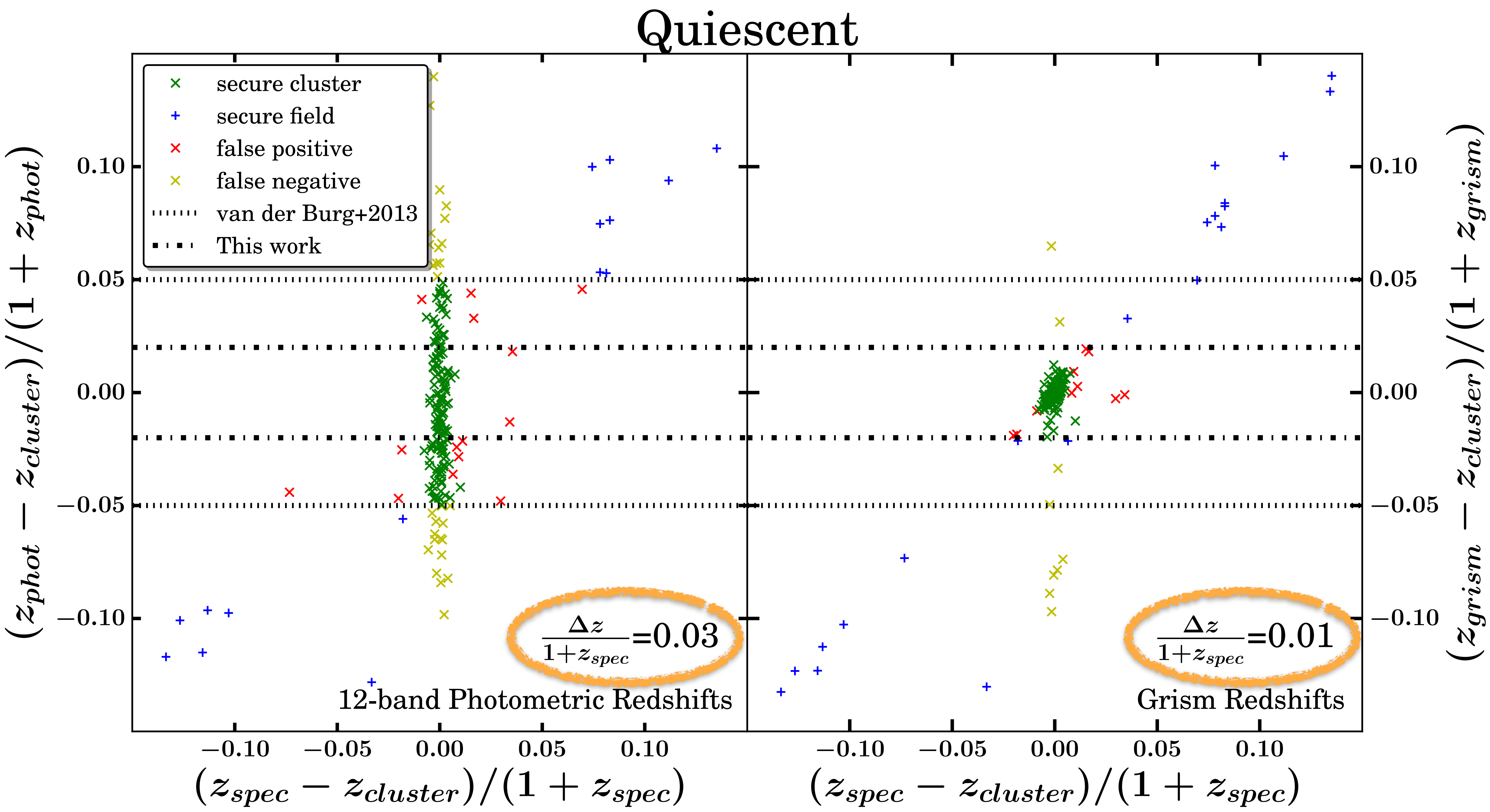
Matharu et al., (2019)

The Gemini Cluster Astrophysics Spectroscopic Survey (GCLASS)

- Spectroscopic survey of **10** rich, IR-selected clusters at **0.86 < z < 1.34**.
- ~ **500** cluster members altogether.
- Now has 38 orbits worth of **HST WFC3** grism follow-up.

Muzzin et al., (2012); van der Burg et al., (2013) and Muzzin (2016)

Grism spectroscopy increased our sample size

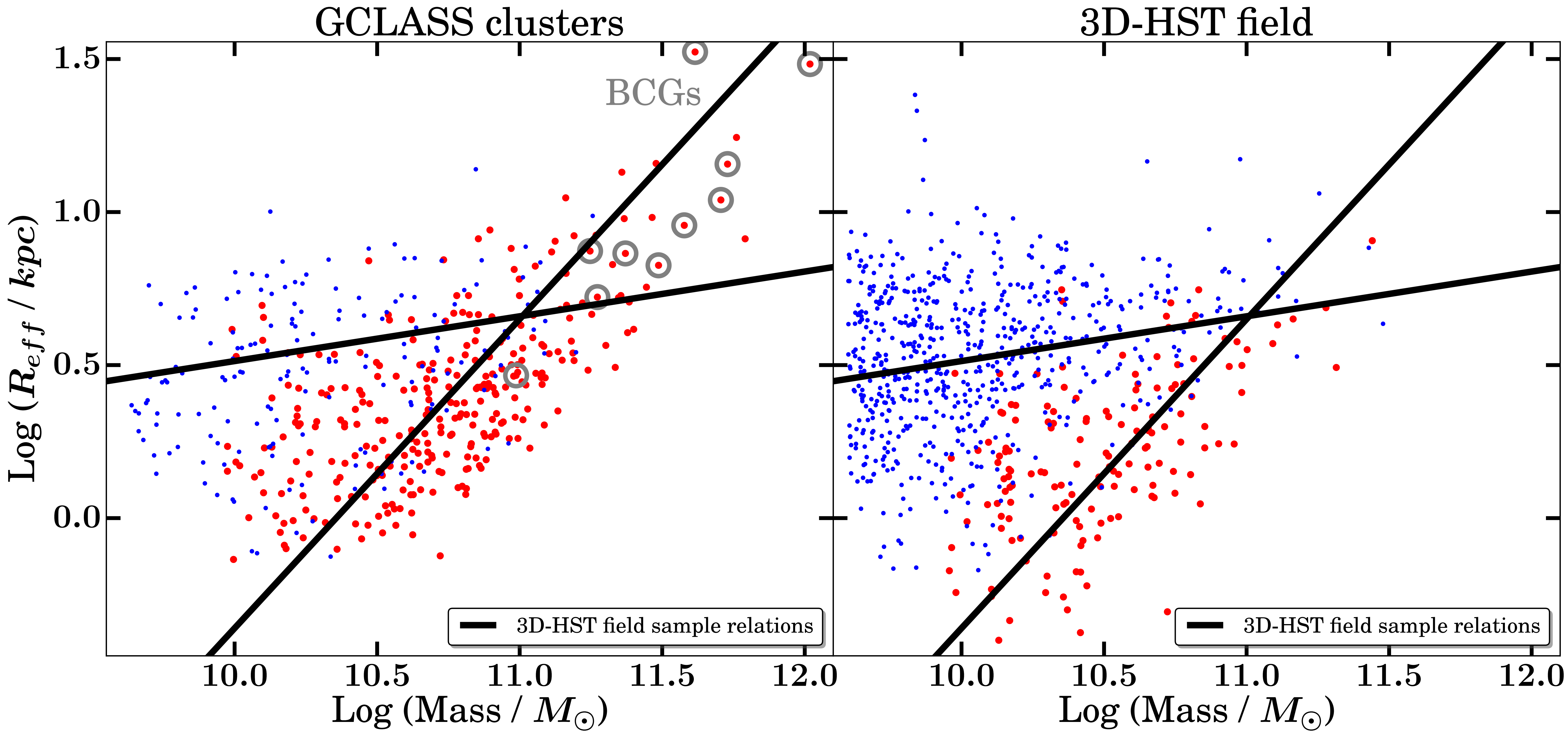


Matharu et al., (2019)

How the GCLASS HST data will reduce inconsistencies…

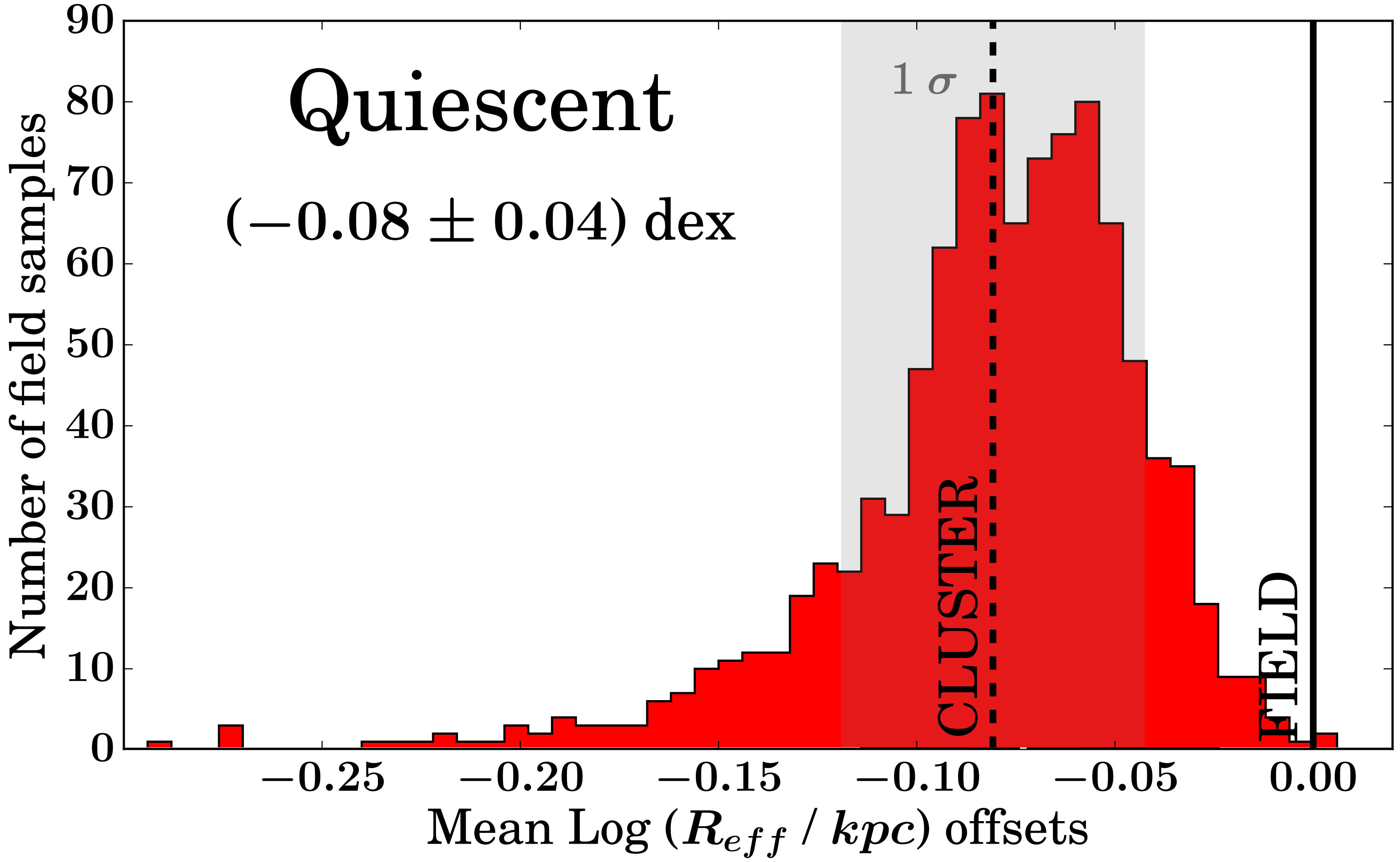
- **Largest sample** of star-forming and quiescent **cluster galaxies at z ~ 1** to date.
- HST observations, data reduction and analysis **done in the same way as our field sample** from the 3D-HST/CANDELS survey.
- High spatial resolution of HST imaging allows for **reliable measurements**.

The cluster and field stellar mass-size relations at z ~ 1

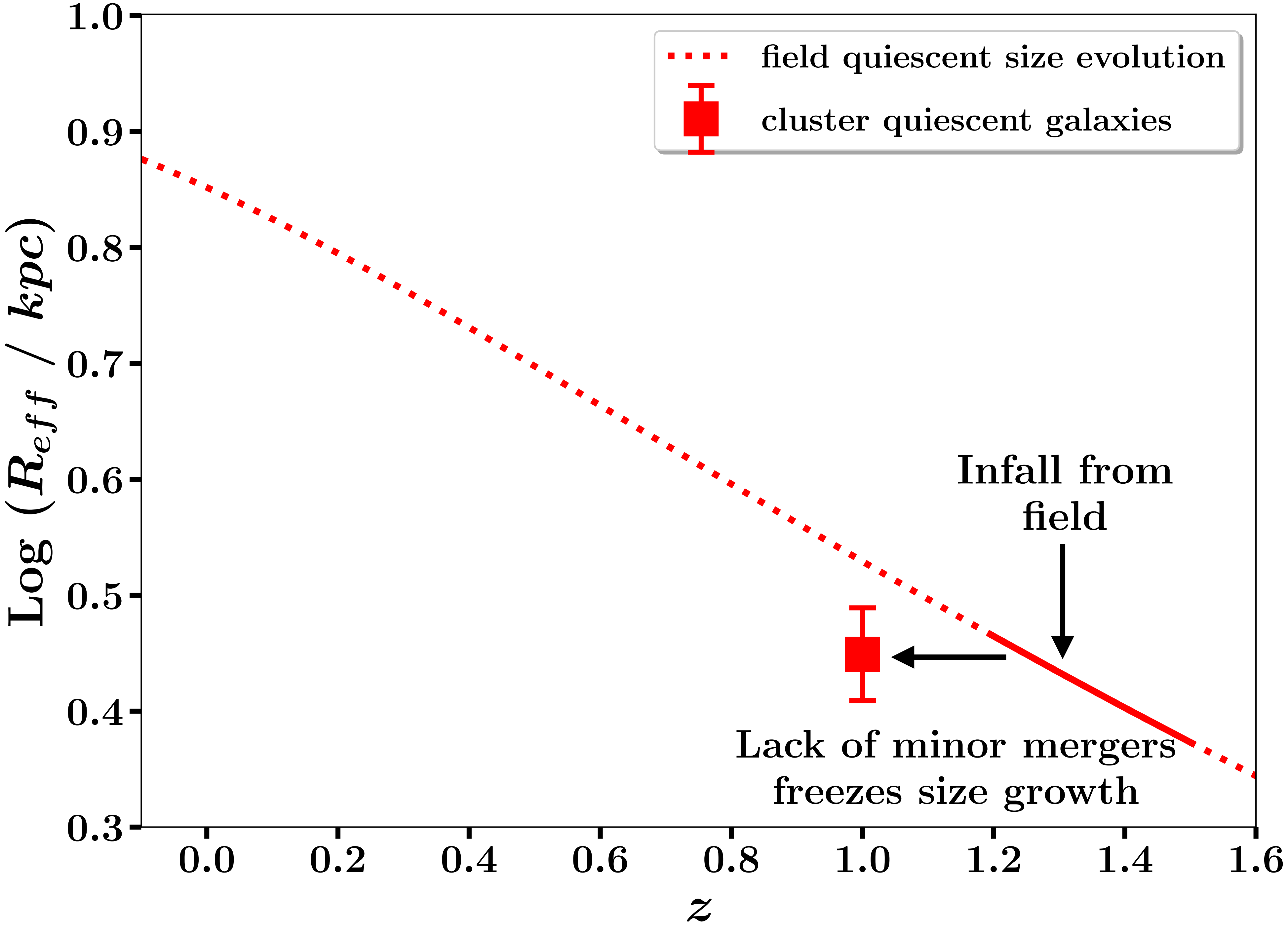


Matharu et al., (2019)

The cluster and field stellar mass-size relations at z ~ 1

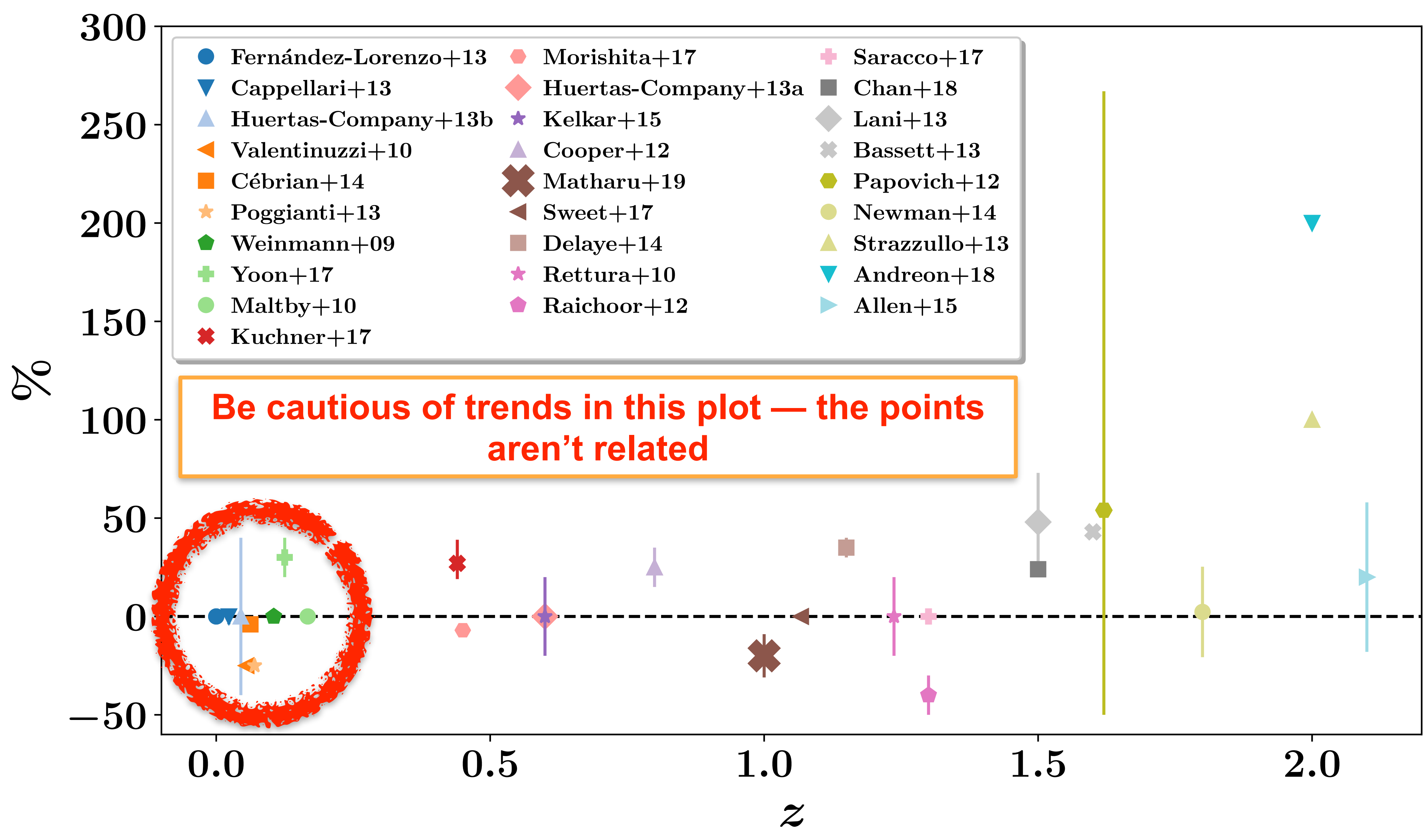


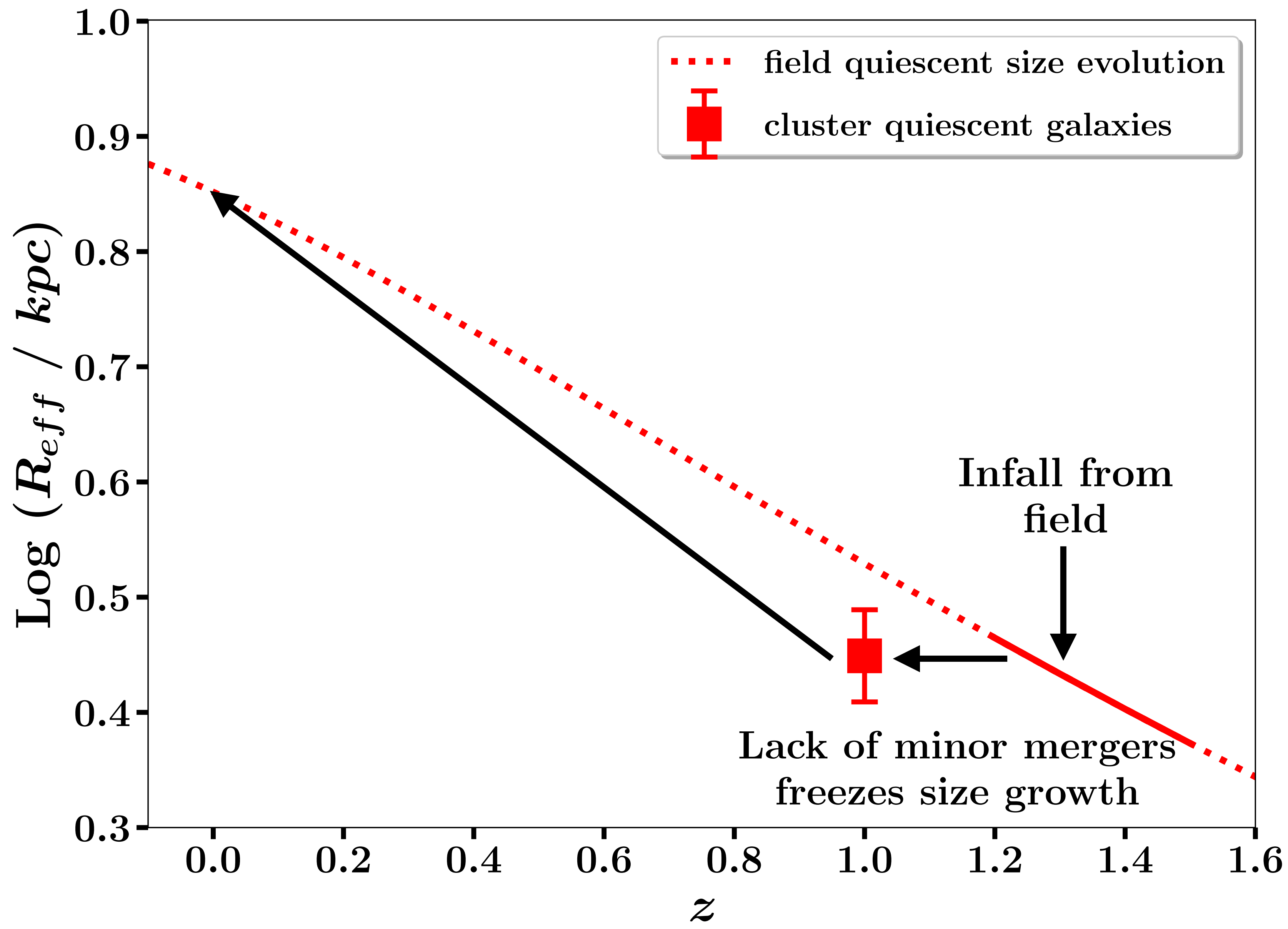
Quiescent cluster galaxies are **~20% smaller** than quiescent field galaxies (at fixed M_*).



Matharu et al., (2019)

What does this mean for the evolution of the stellar mass-size relation?

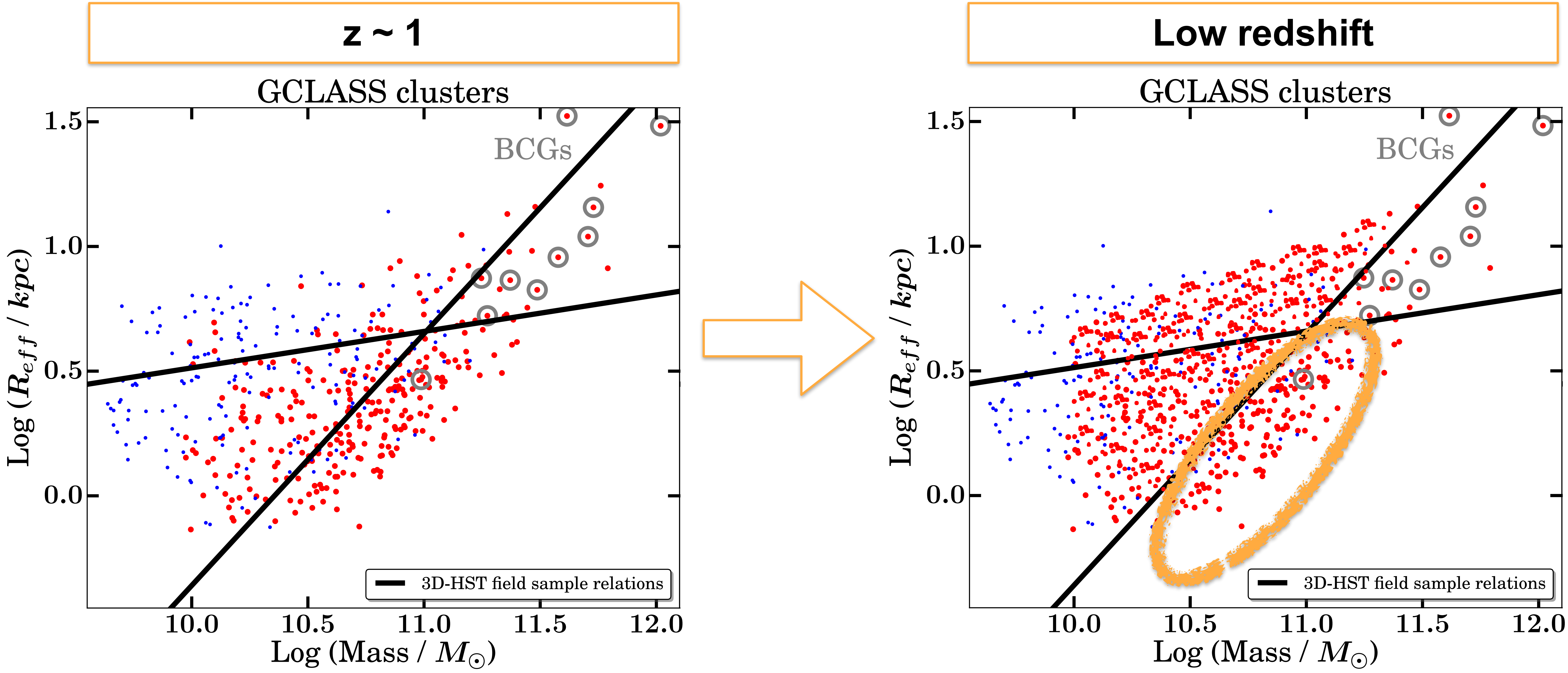




Note: I am suggesting the opposite "trend" to what the literature compilation is suggesting — *cluster* sizes need to *increase* to catch up with the field (if we are to believe the low redshift results).

Matharu et al., (2019)

Lack of minor mergers = build-up of compact quiescent cluster galaxies

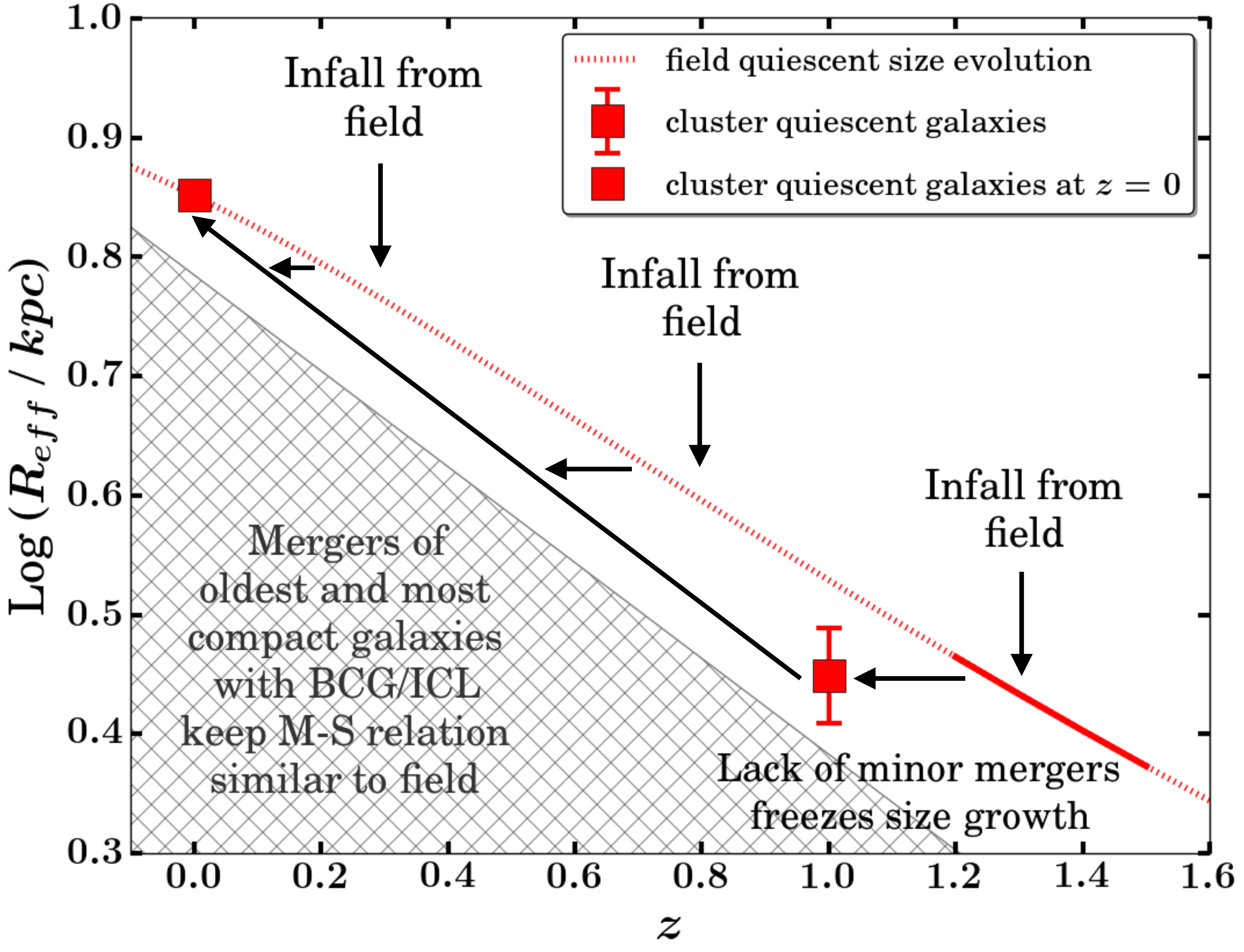


What are the physical processes reconciling the cluster & field mass-size relations?

- Using a **toy model** we show that the low-redshift field & cluster quiescent mass-size relations can be reconciled if **~40% of compact quiescent cluster galaxies merge with the BCG and the remaining ~60% are tidally destroyed into the ICL.**

- This is **in agreement with the observed stellar mass growth of BCGs between 0 < z < 1** and the **ICL stellar mass fraction at z ~ 0.**

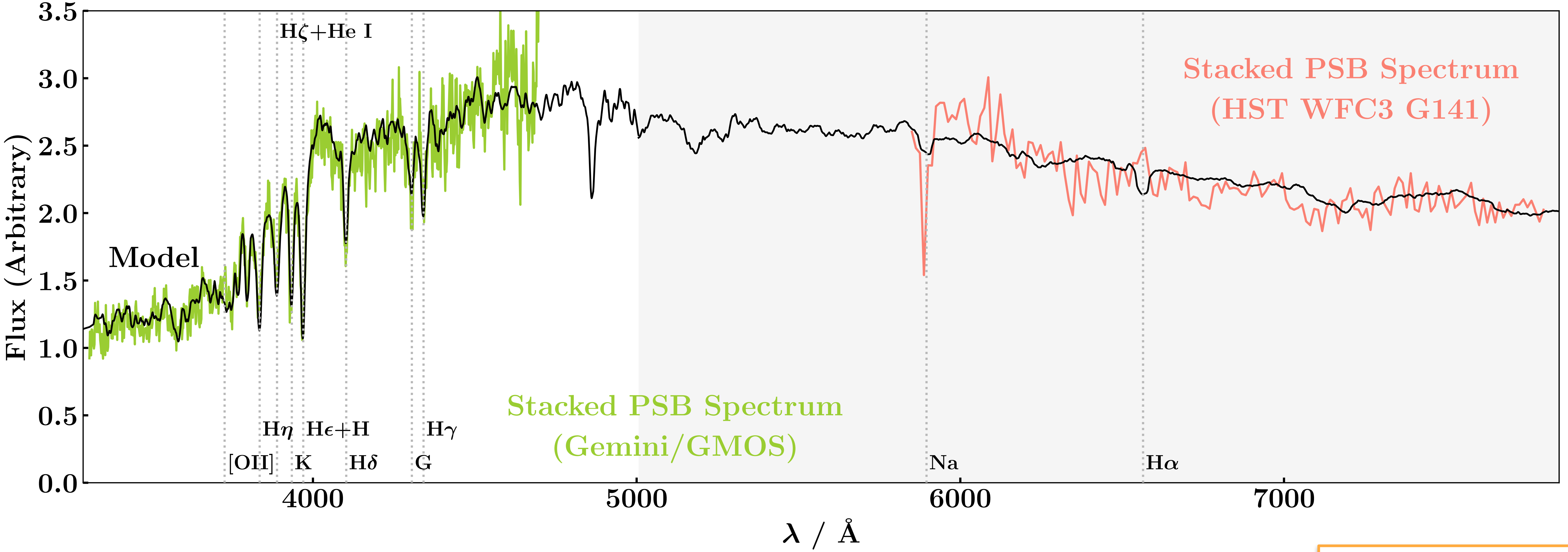
- However, **we must consider that between z ~ 1 and z ~ 0, larger galaxies from the field will fall into the cluster.**



Matharu et al., (2019)

What about recently quenched galaxies?

Absence of [O II] emission, 1.0 < D(4000) < 1.45

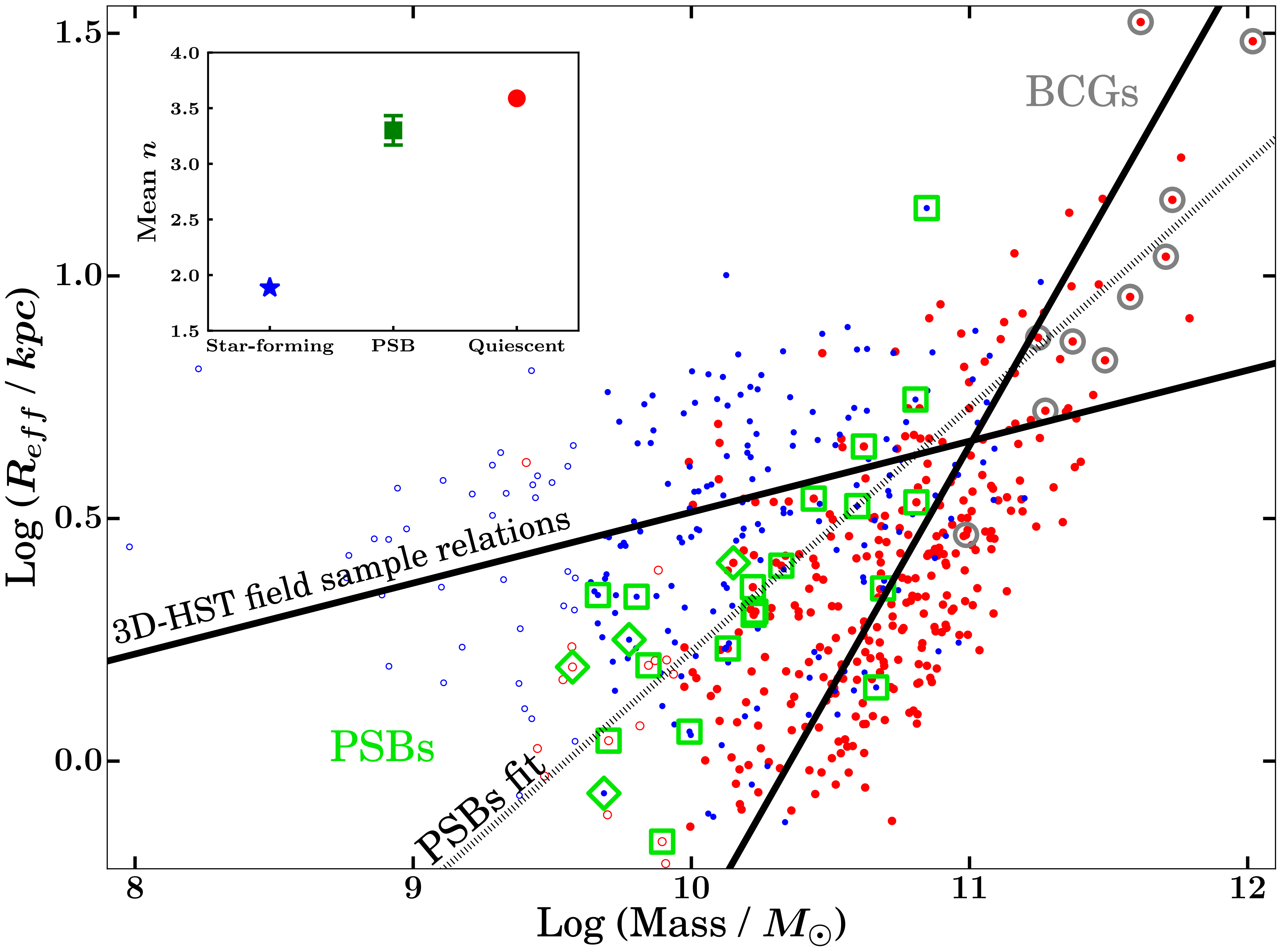


- Lack of ongoing star formation.
- Contain young stellar populations (A-stars, < 1 Gyr old).

These are the same PSBs from Muzzin et al., (2014) Rhea-Silvia Remus spoke about yesterday

Matharu et al., (2020)

The mass-size relation of recently quenched cluster galaxies

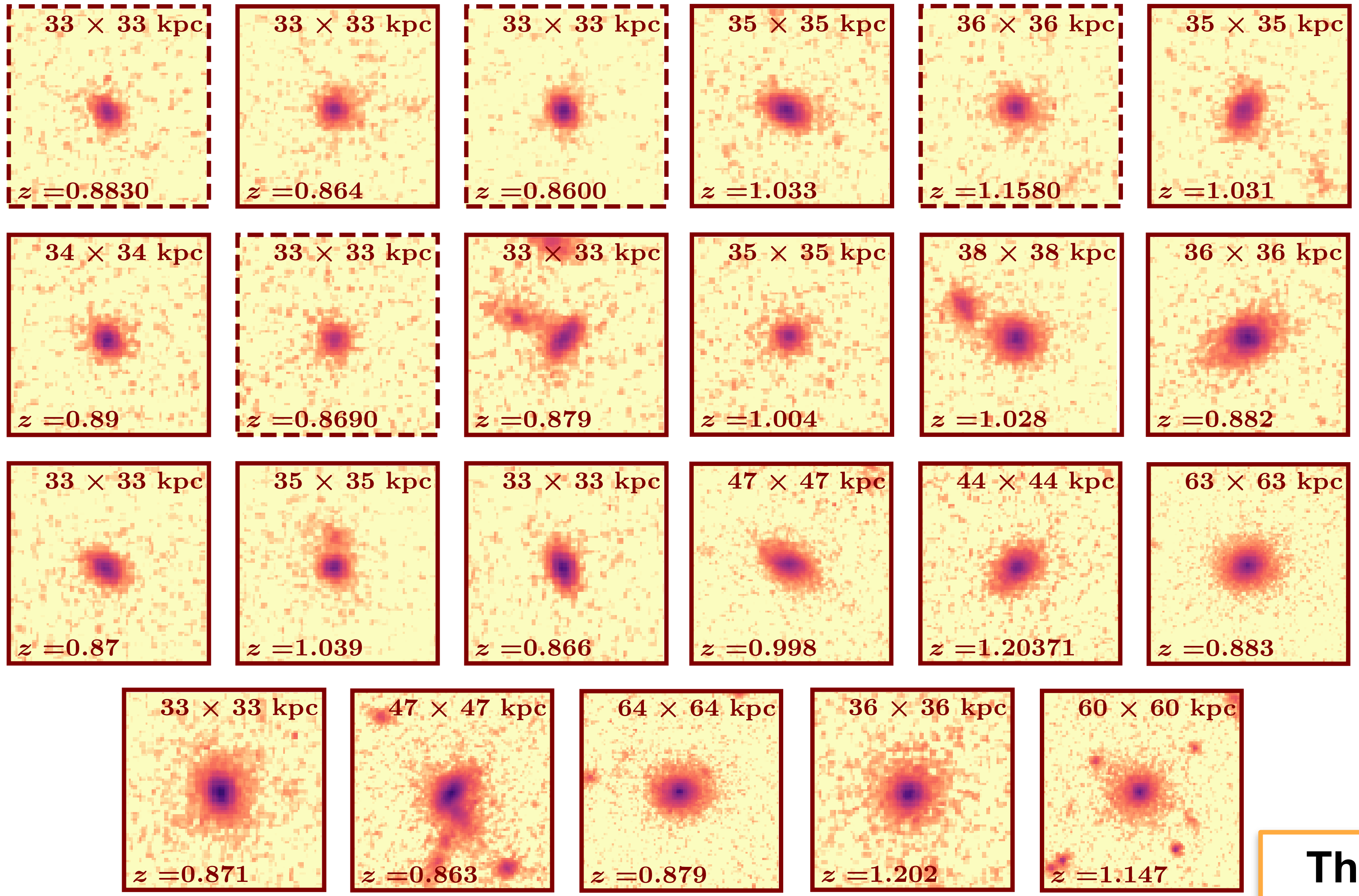


These are the same PSBs from Muzzin et al., (2014) Rhea-Silvia Remus spoke about yesterday

Matharu et al., (2020)

How did these galaxies quench?

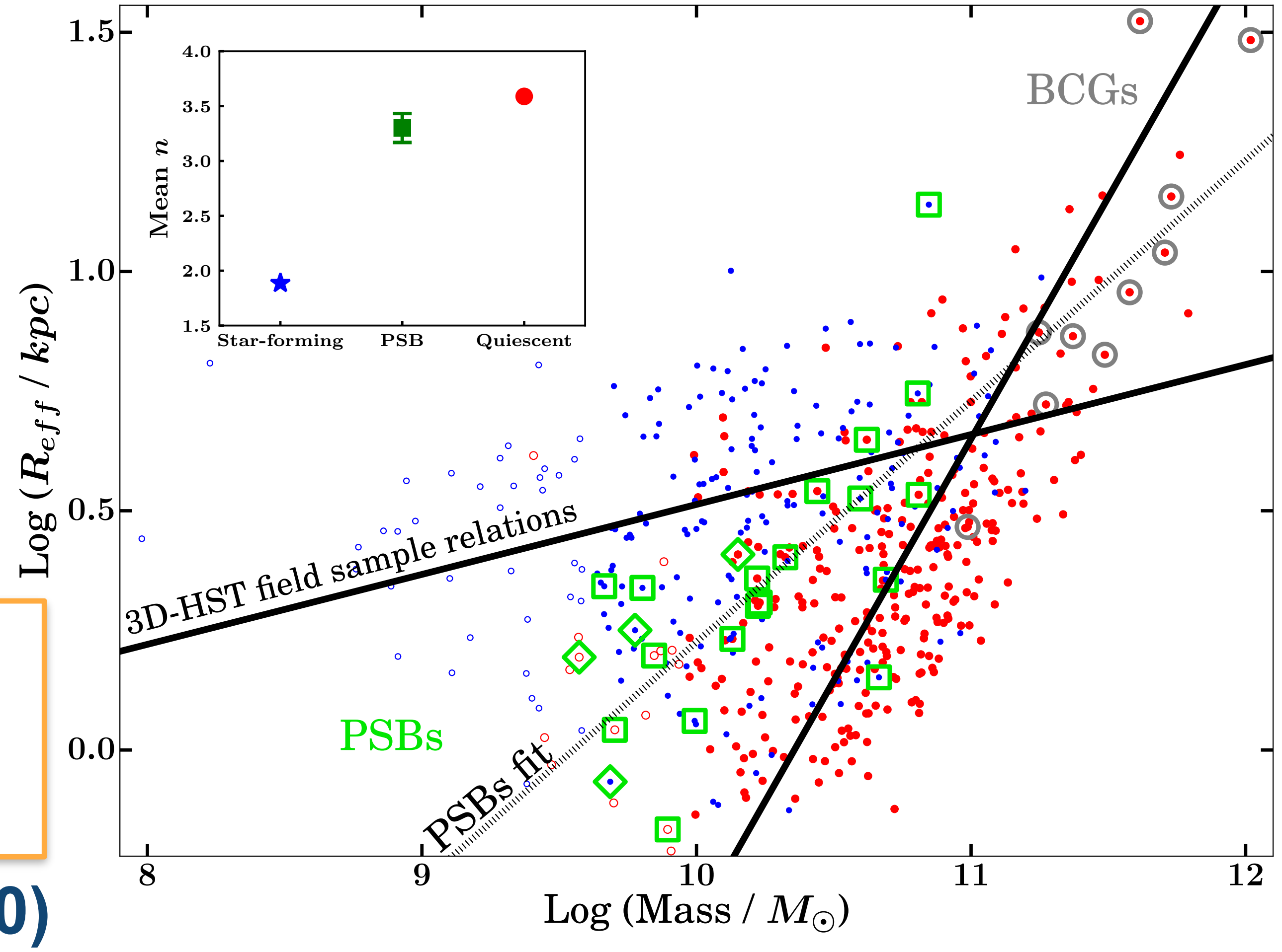
High resolution imaging of stellar light
Mostly symmetrical, undisturbed morphologies



Mass-size relation & Morphology

- PSB mass-size relation lies midway between SF and Q relations.
- Mean Sersic index is intermediary, closer to Q population (rapid change in light profile).
- Toy modeling suggests only “outside-in” fading can reproduce the PSB mass-size relation.

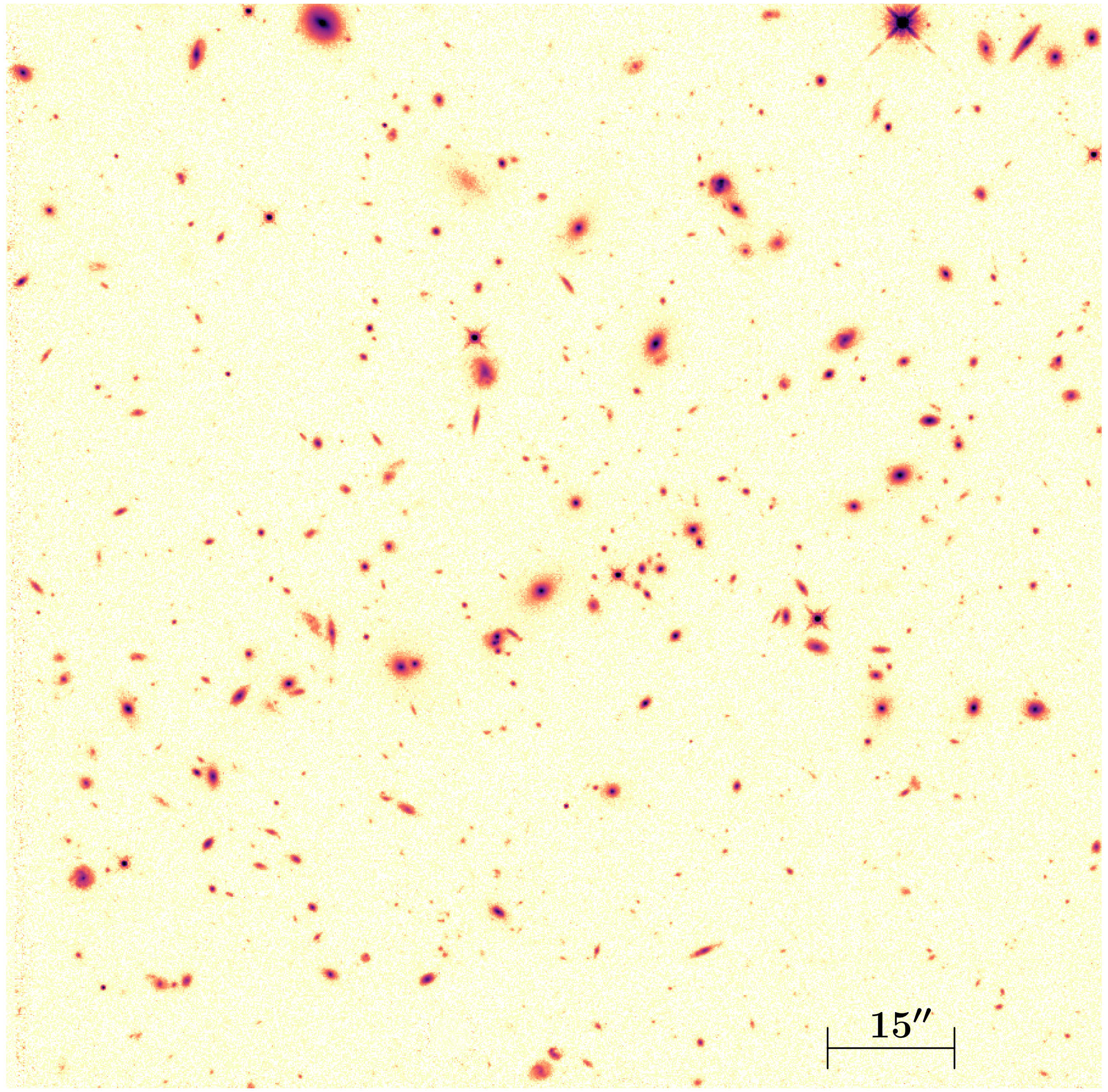
These are the same PSBs from Muzzin et al., (2014) Rhea-Silvia Remus spoke about yesterday



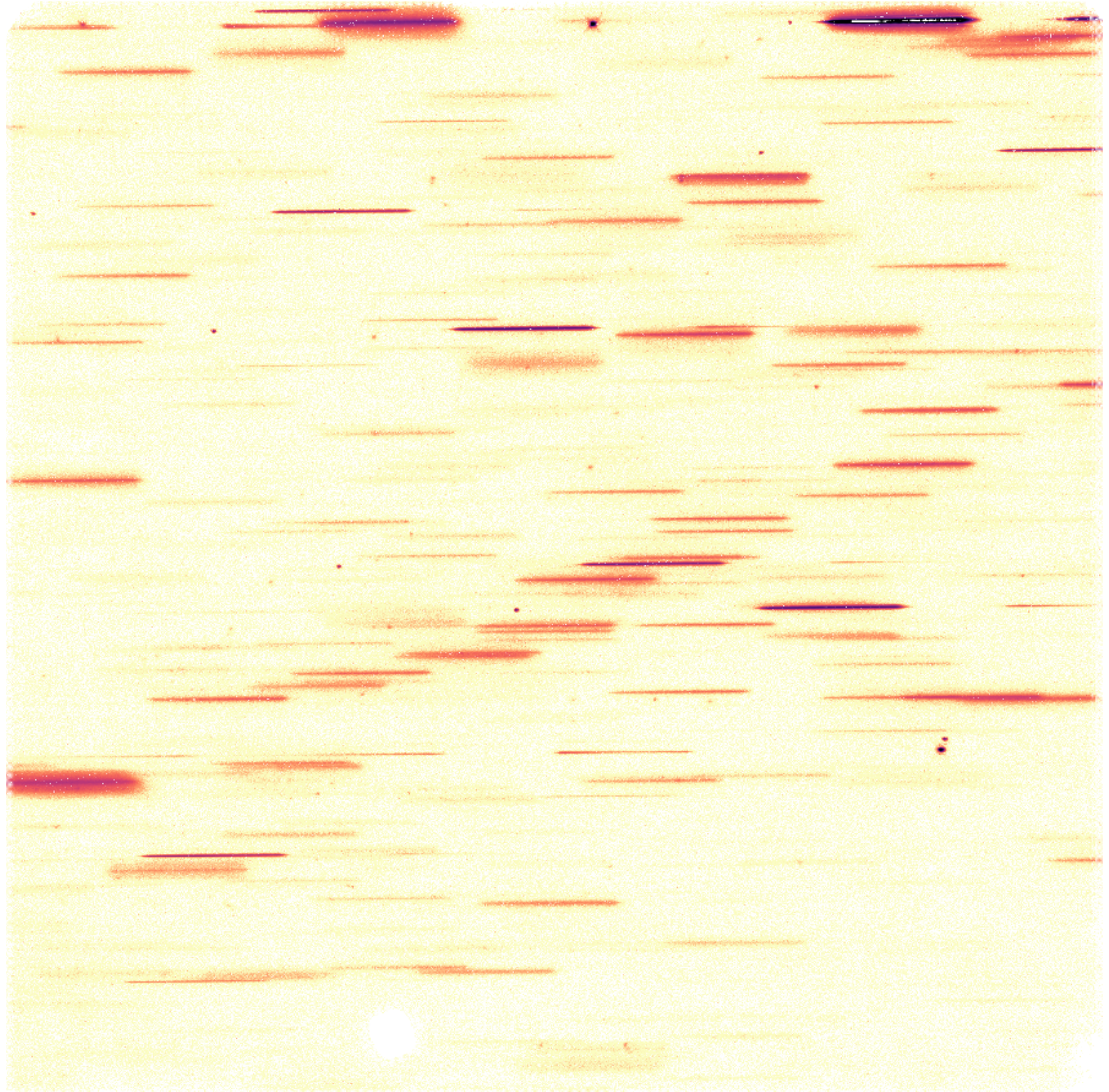
Matharu et al., (2020)

Directly observing environmental quenching at z ~ 1: Space-based grism spectroscopy

HST WFC3 image

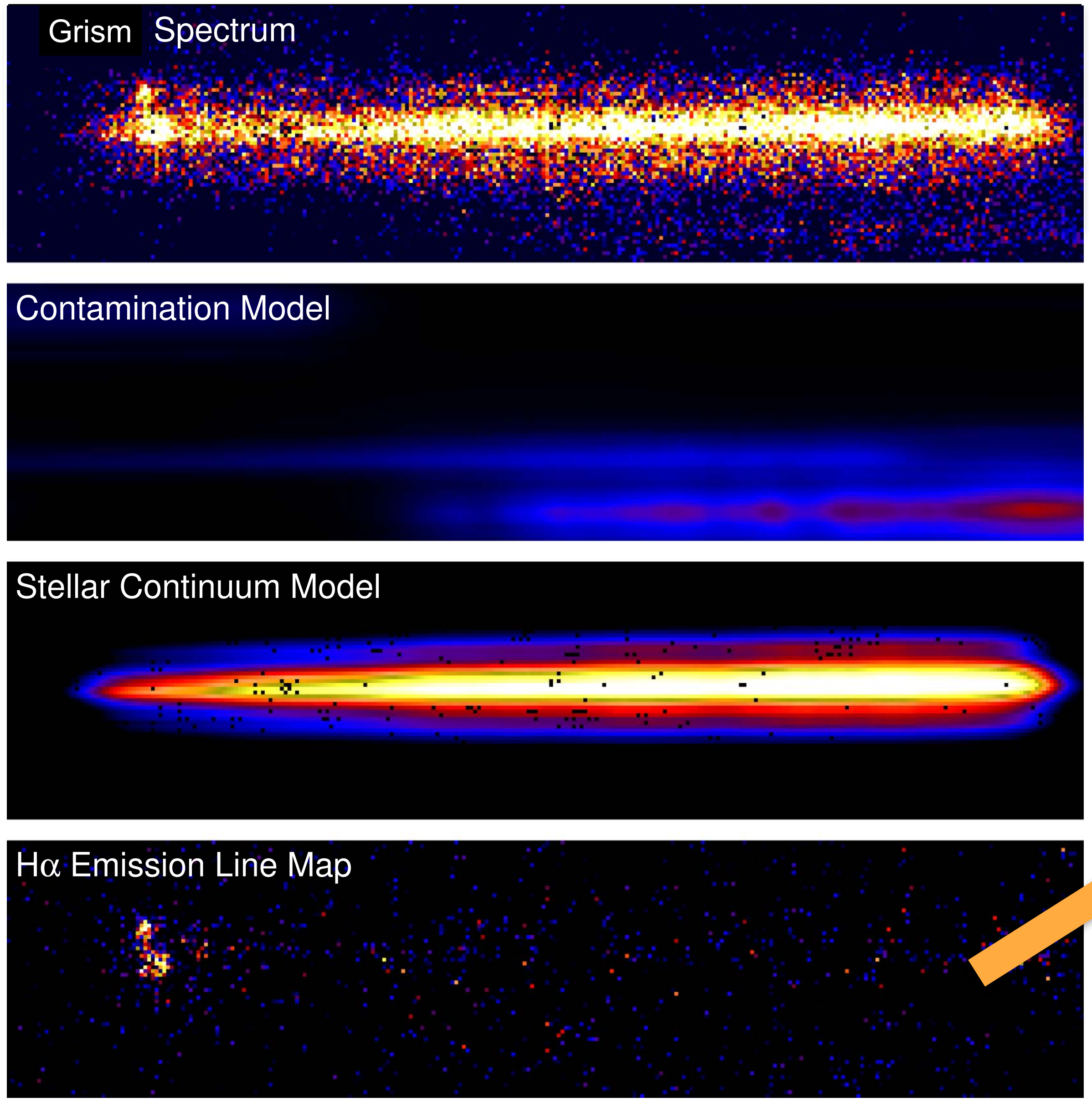


HST WFC3 grism spectra



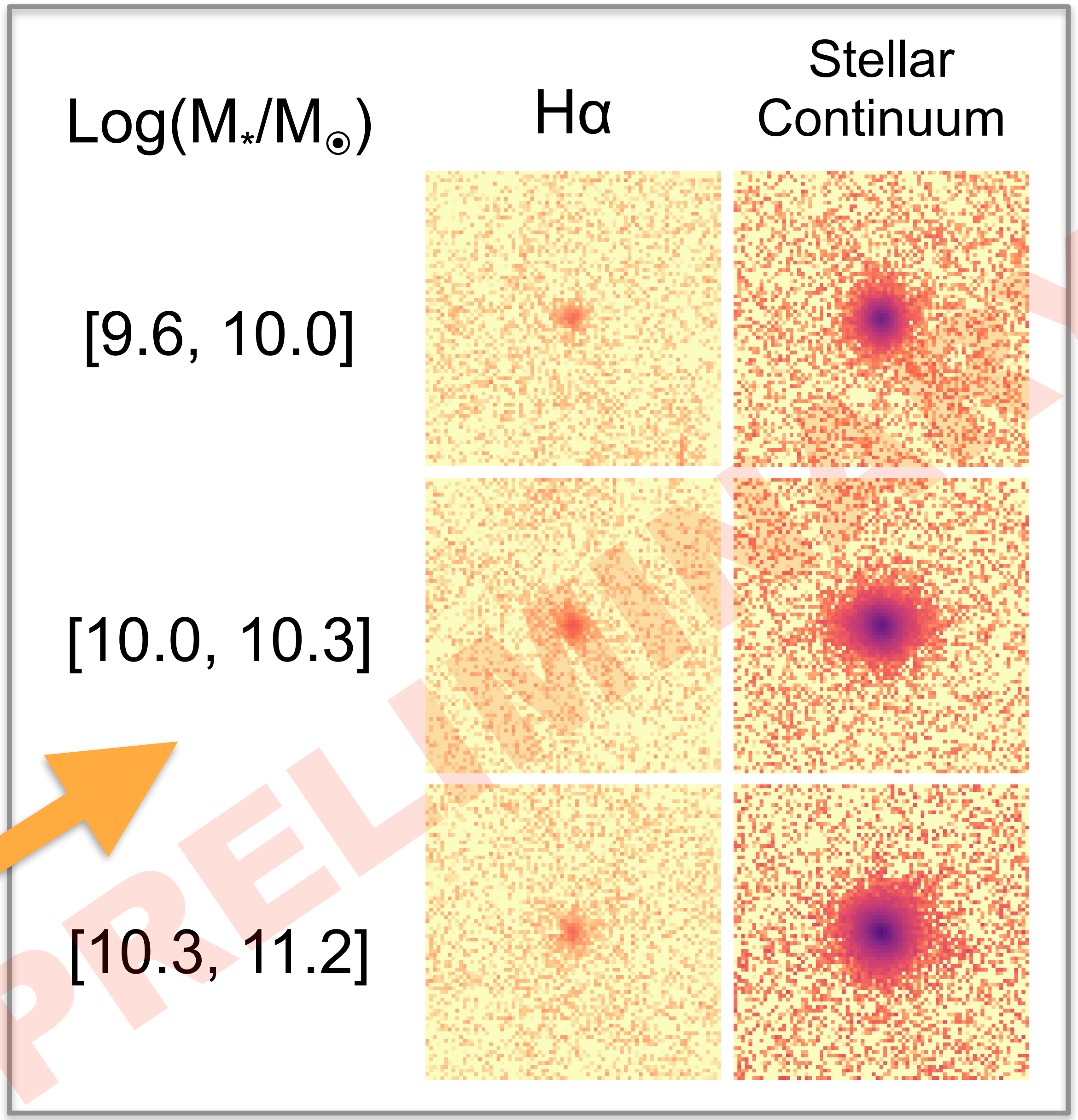
Matharu et al., (2019)

Spatially resolved star formation as a function of environment at high redshift



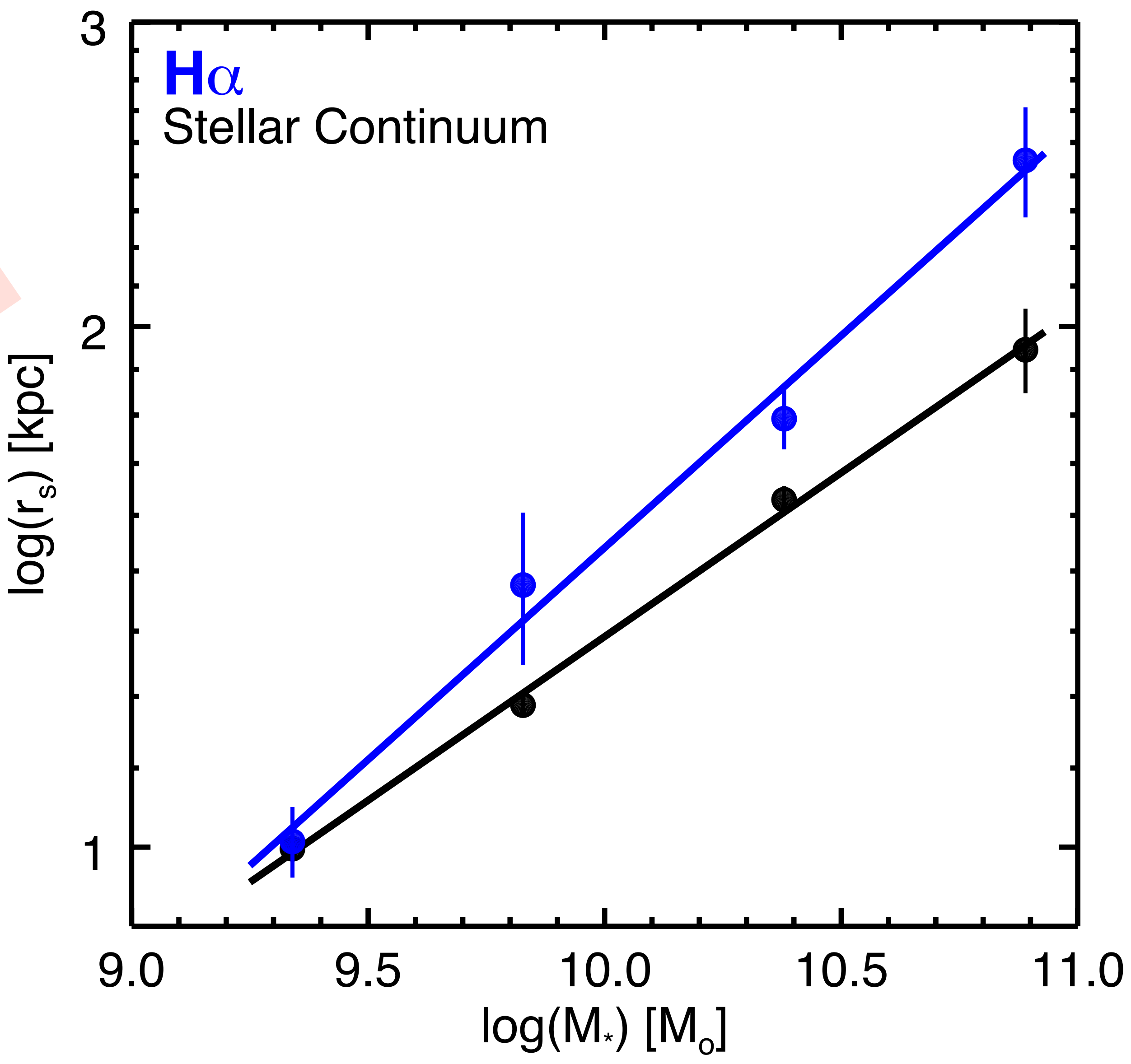
Nelson et al., (2016)

z ~ 1 Clusters



Matharu et al., (in prep)

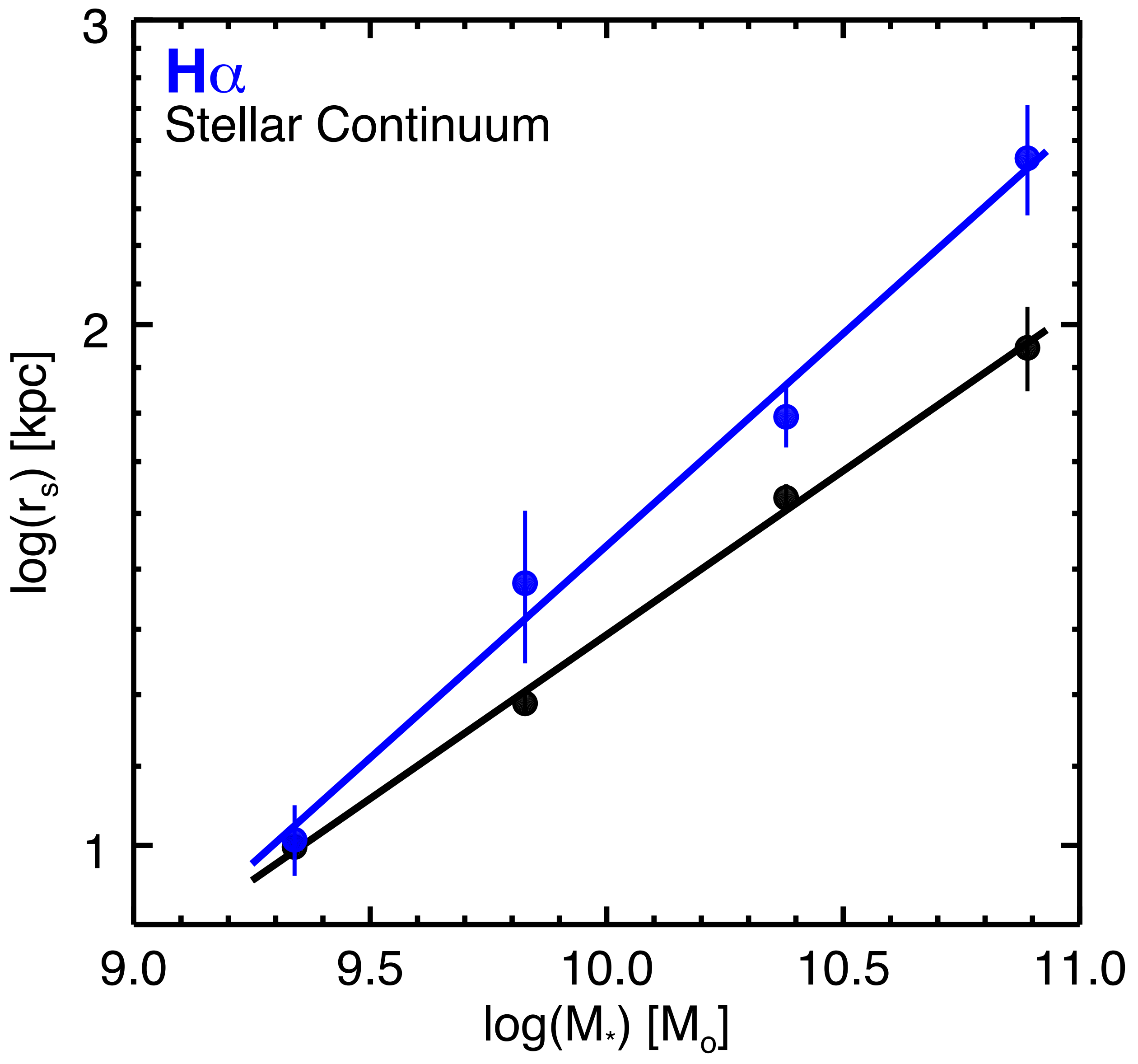
z ~ 1 Field



Nelson et al., (2016)

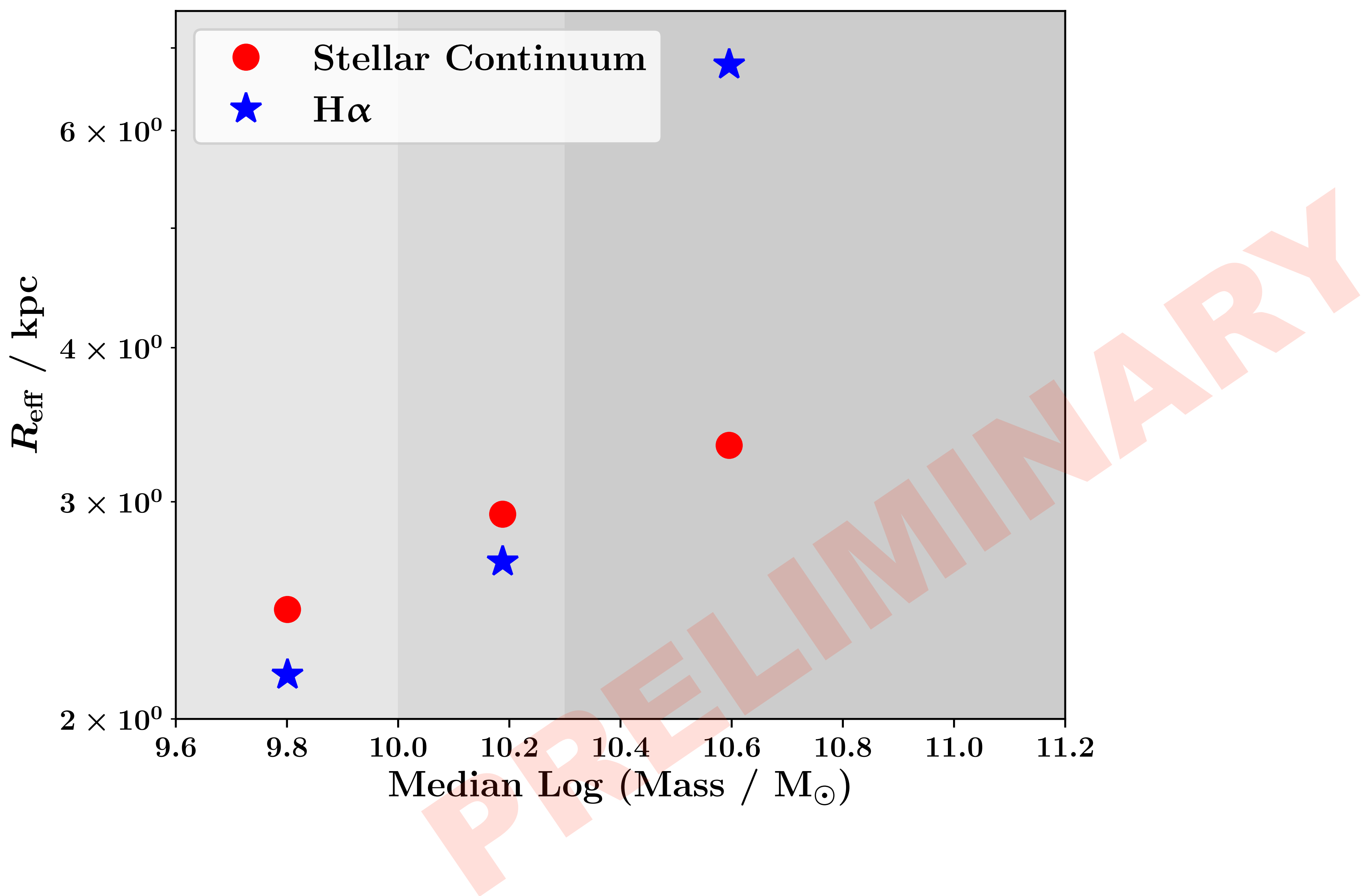
Spatially resolved star formation as a function of environment at high redshift

z ~ 1 Field



Nelson et al., (2016)

z ~ 1 Clusters



Matharu et al., (in prep)

Conclusions

- **Grism-derived redshifts have a precision of 2000 kms^{-1}, a factor 4 improvement over photometric redshifts.**
    - Added 182 new cluster members to the sample.

- Quiescent cluster galaxies are *smaller* than their field counterparts at fixed stellar mass and redshift.
    - The magnitude of this offset is consistent with the sizes of quiescent field galaxies at $1.2 < z < 1.5$.
    - **The cluster environment has inhibited size growth via minor mergers between this period and z ~ 1.**

- The low redshift field and cluster quiescent mass-size relations can be reconciled if compact cluster galaxies are destroyed by either becoming part of the BCG or ICL.

- **Recently quenched galaxies also contribute to size growth in the quiescent population with decreasing redshift.**

- **Preliminary evidence of possible outside-in quenching signature seen in $\log(M_*/M_\odot) < 10.3$ star-forming cluster galaxies at z ~ 1**:
    - Stellar mass dependence to environmental quenching efficiency (e.g. Kawinwanichakij+2018, Papovich+2018, Old+2020)?
    - Dust inflating Hα size measurements at high stellar mass (e.g. Nelson+2016)?
    - Change in the dominant environmental quenching mechanism with stellar mass e.g. radially-independent “Overconsumption” (McGee+2014)?
    - Environmental quenching efficiency higher for higher stellar mass galaxies in clusters (e.g. van der Burg+2020) — difficult to detect an outside-in quenching signal in high mass star-forming cluster galaxies?

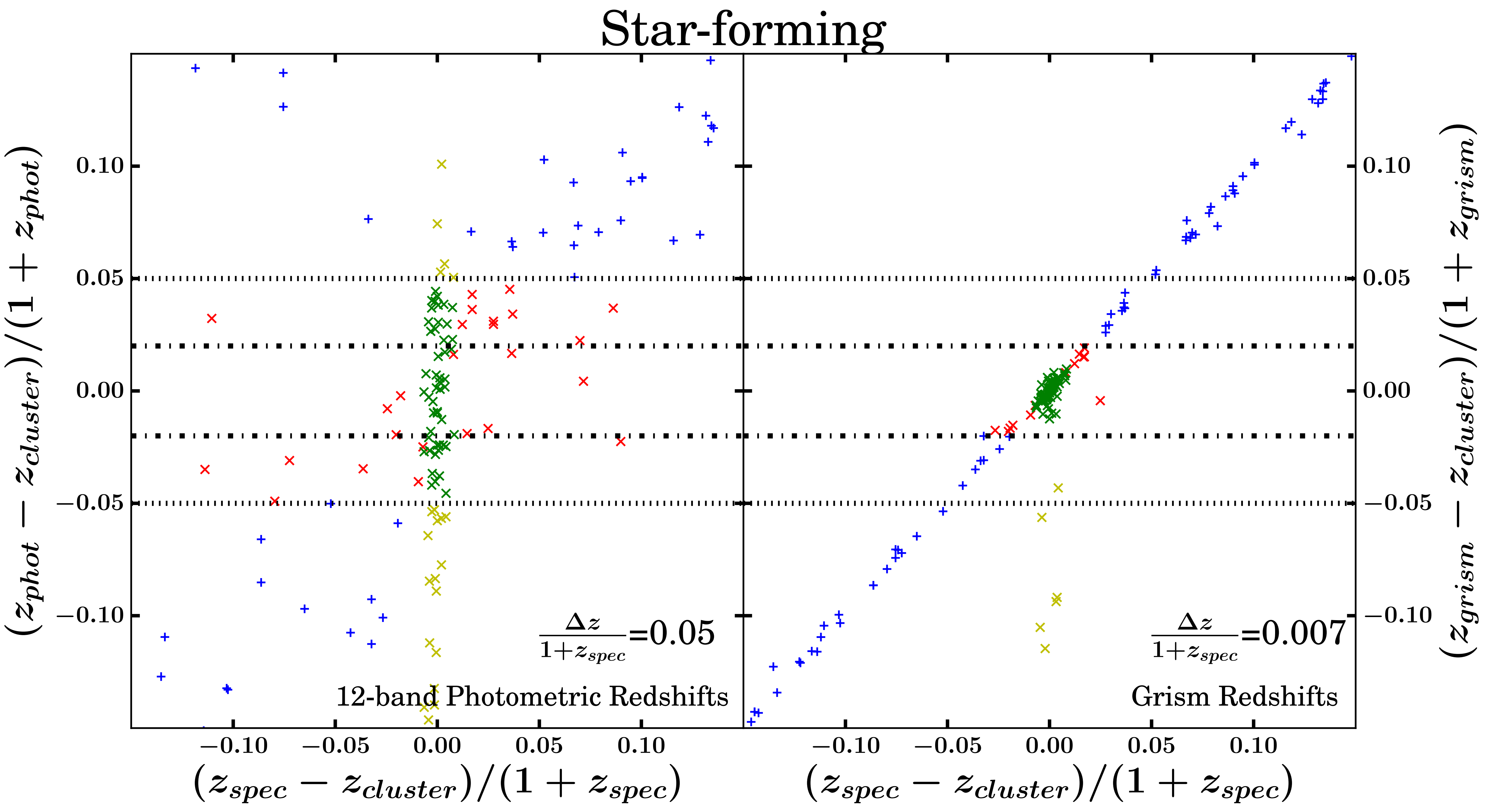
Contact me

Website: jkmatharu.github.io

Email: jmatharu@tamu.edu

@DrJMatharu

Grism spectroscopy increased our sample size



Matharu et al., (2019)

Since the most compact quiescent cluster galaxies can't grow, **they must be destroyed**

Merge with the BCG

(BCG: brightest cluster galaxy - sits at the centre of the cluster)

CONSTRAINTS

- BCGs double their stellar mass between $0 < z < 1$.

Lidman et al., (2012, 2013); Lin et al., (2013) and Bellstedt et al., (2016)

Tidally disrupted into the ICL

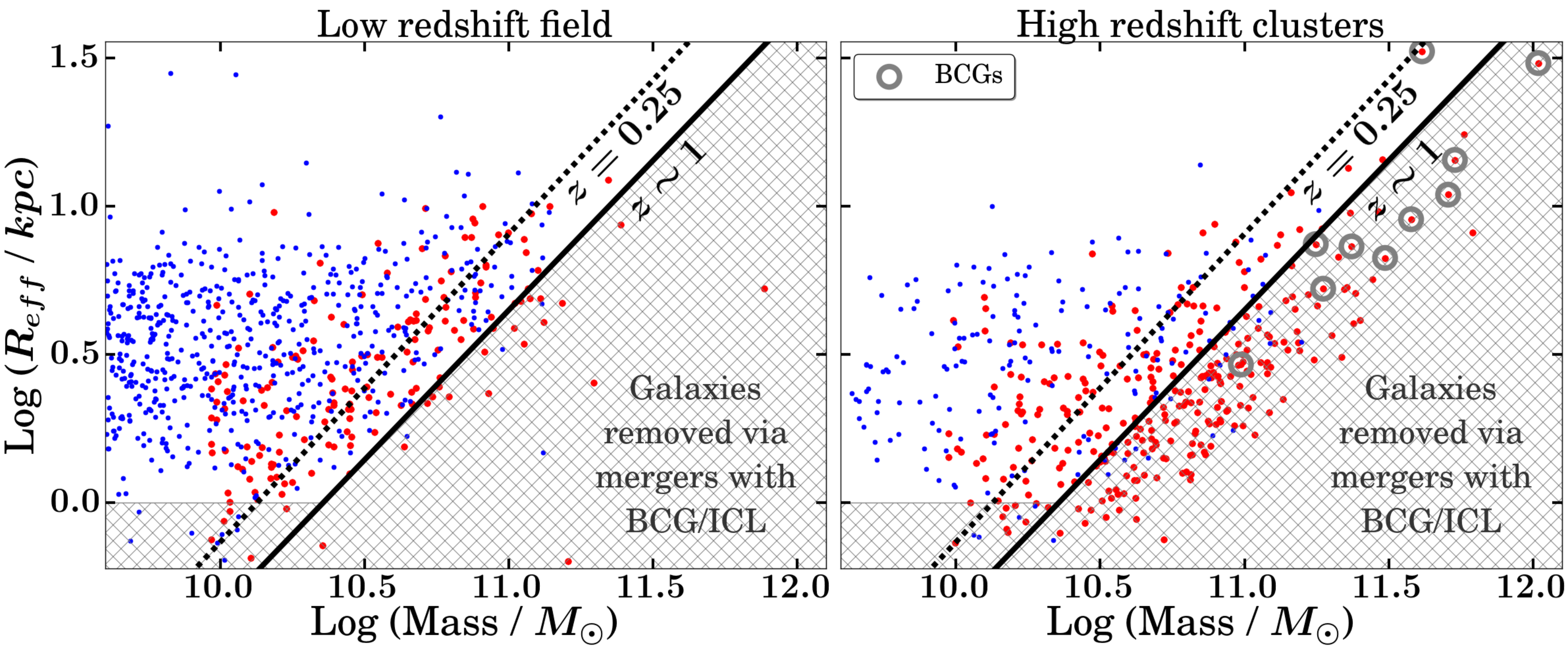
(ICL: intra-cluster light - stars bound to the cluster but not part of a galaxy)

CONSTRAINTS

- At low redshifts, ICL stellar mass is 6 - 23% of total stellar mass within R_{500}.

Presotto et al., (2014); Montes & Trujillo (2014) and Giallongo et al., (2014)

Toy model assumptions

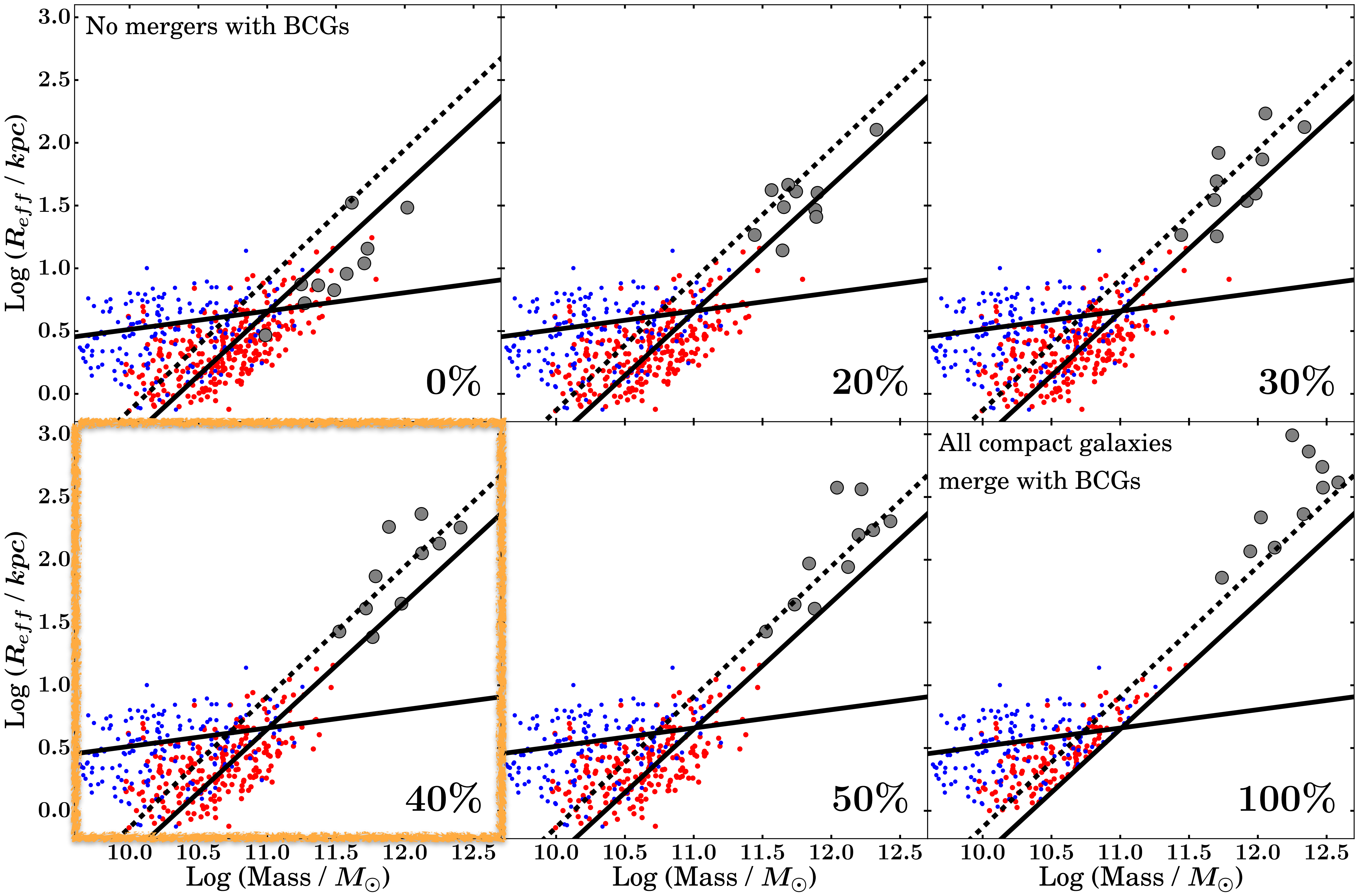


Matharu et al., (2019)

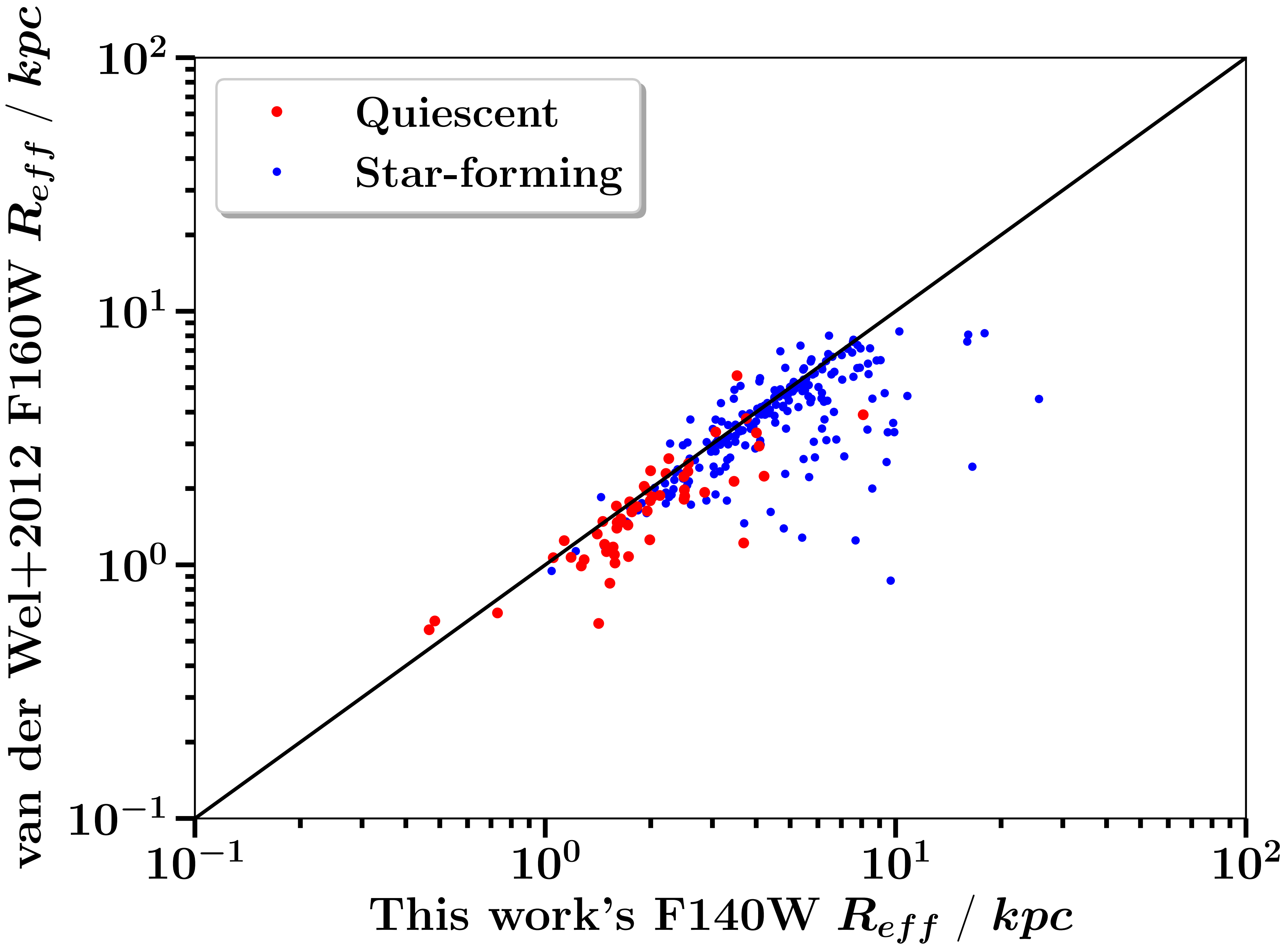
Toy model

Size α (Stellar mass)^2

Matharu et al., (2019)



The effect of differing filters on galaxy size measurements

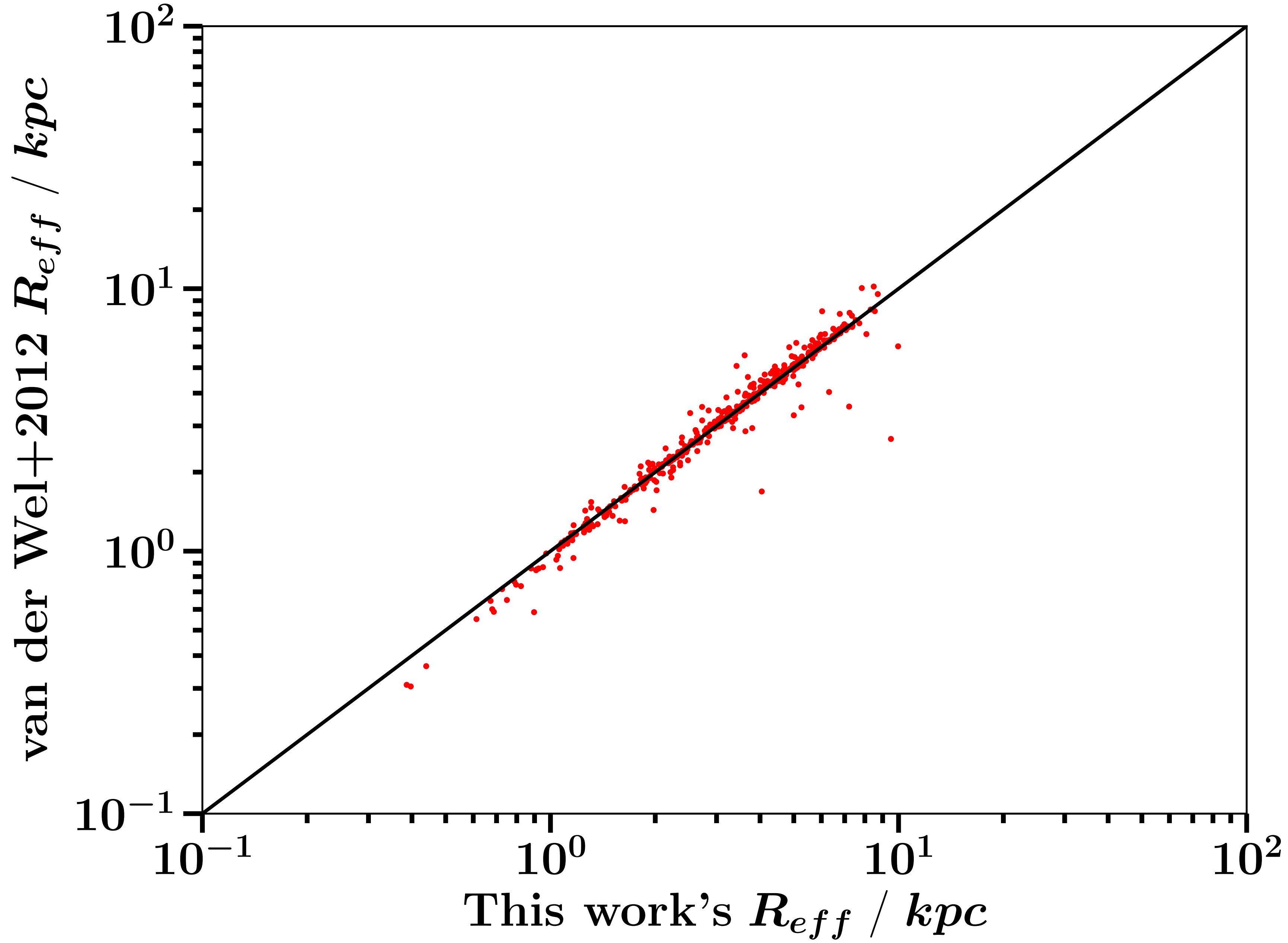


- Galaxies are ~13% smaller in F160W vs. F140W.
- If we used the same filter as for the field, our size offset would actually increase, bringing the result more in favour with the minor mergers hypothesis of size growth.

Matharu et al., (2019)

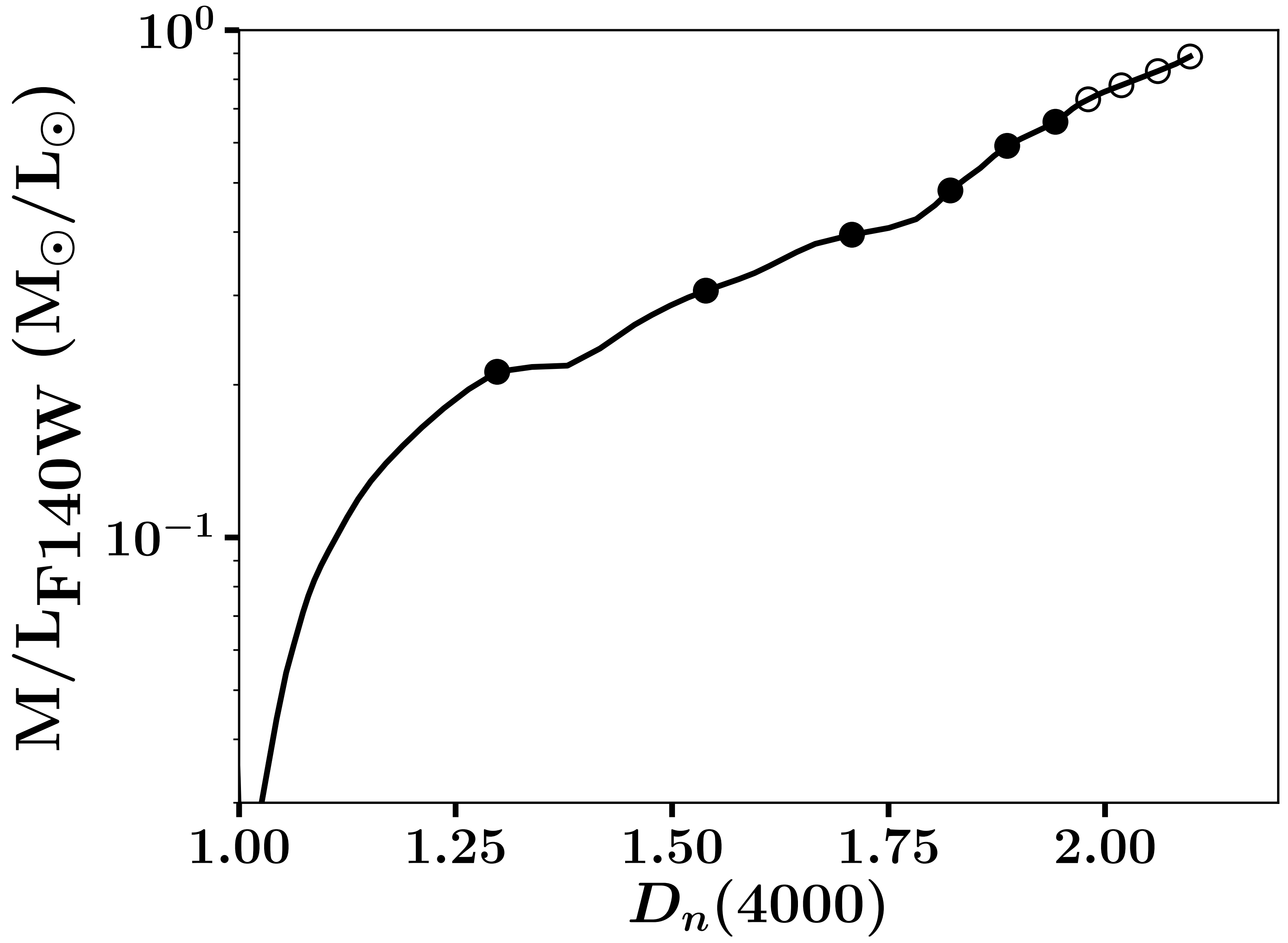
Size agreement with van der Wel et al., (2012)

- Our size measurements are 0.28 % smaller for the same set of galaxies in F160W.



Matharu et al., (2019)

Modeling disc-fading across the mass-size plane

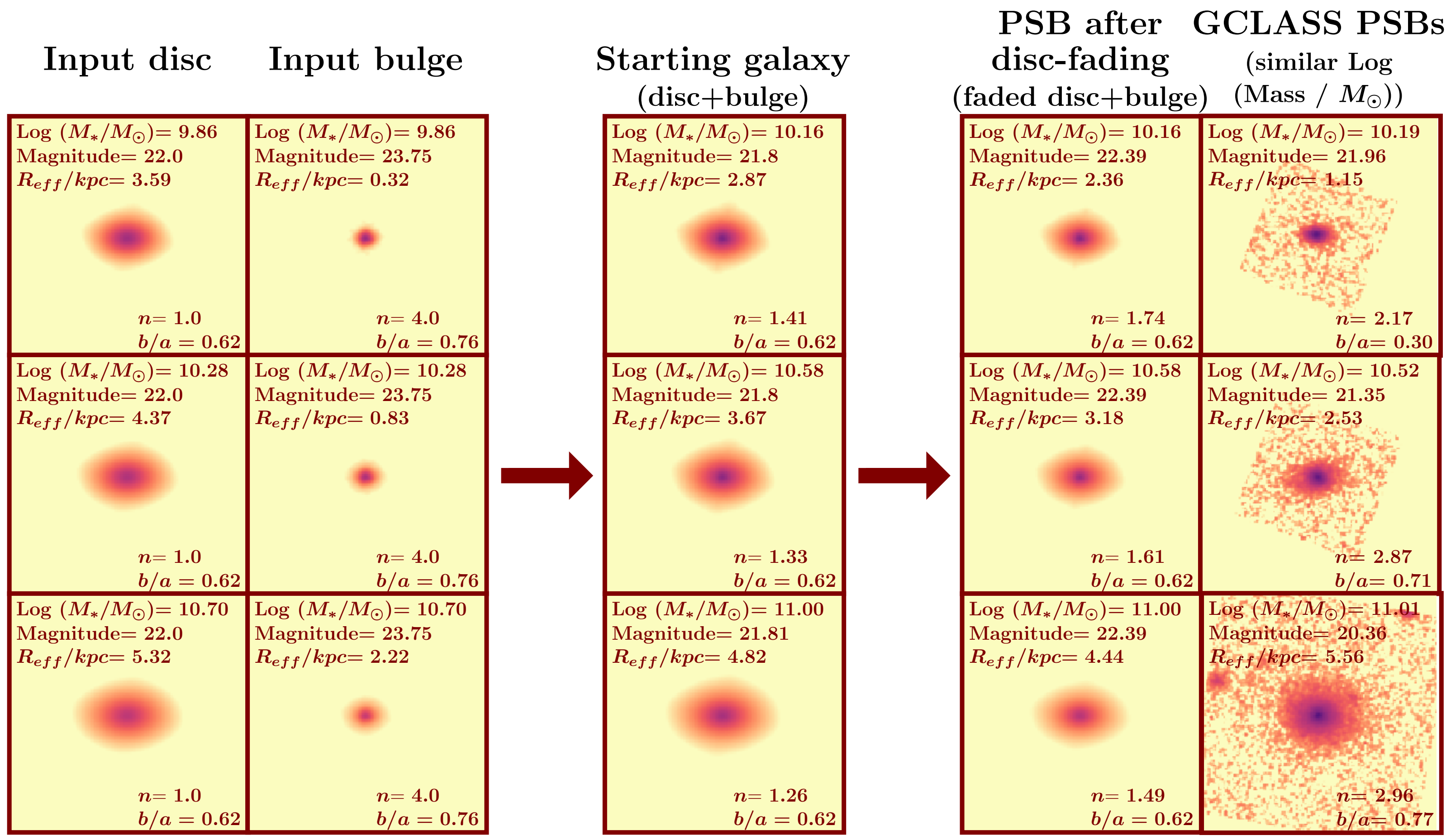


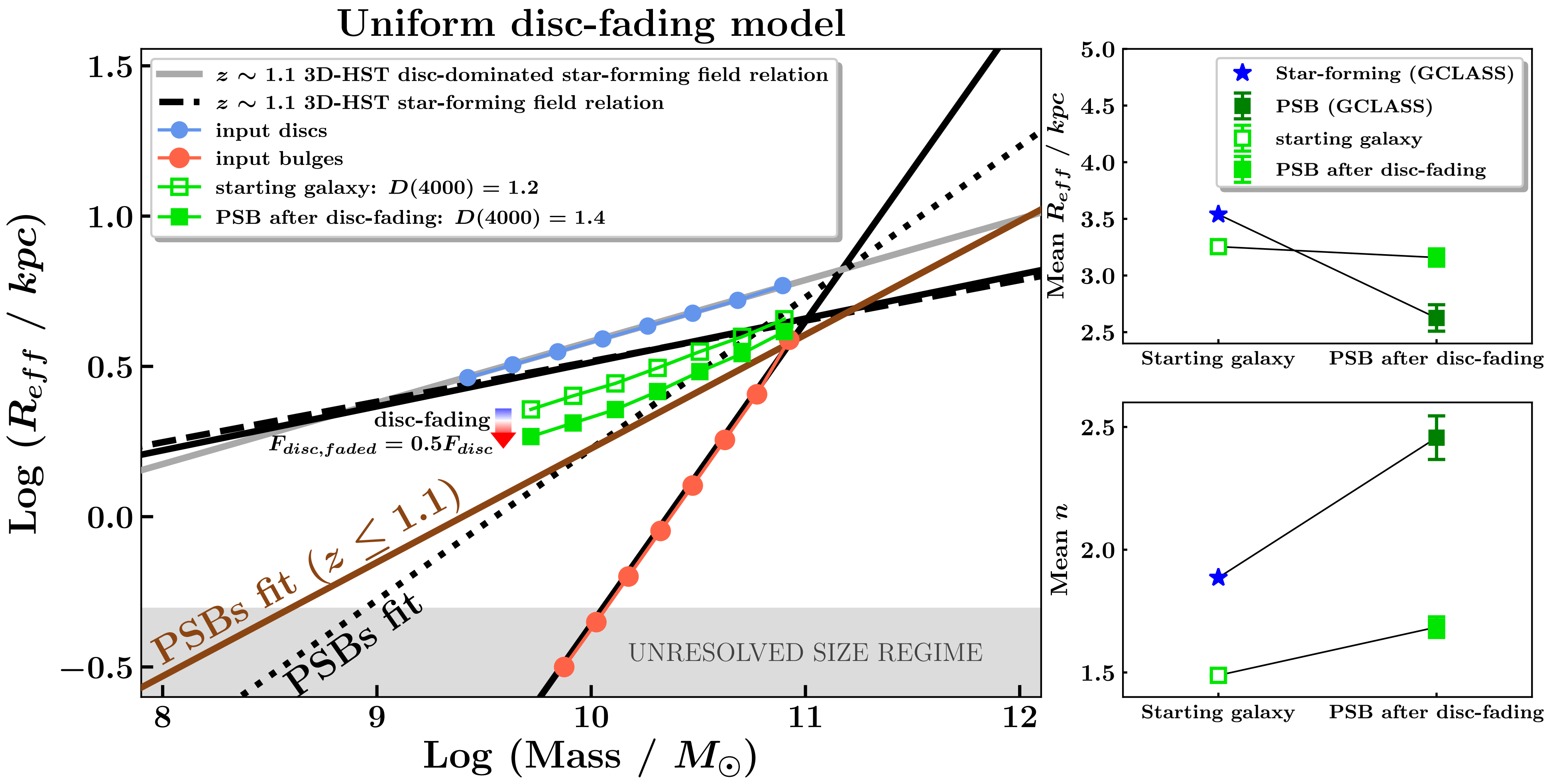
- We use the relation between D(4000) and the F140W stellar mass-to-light-ratio for the best-fit star formation history model to GCLASS (Muzzin+2012) to determine the relative brightness of our starting and faded galaxy models.

- We use the average D(4000) of similar galaxies in our cluster sample.

Matharu et al., (2020)

Uniform fading of the disc

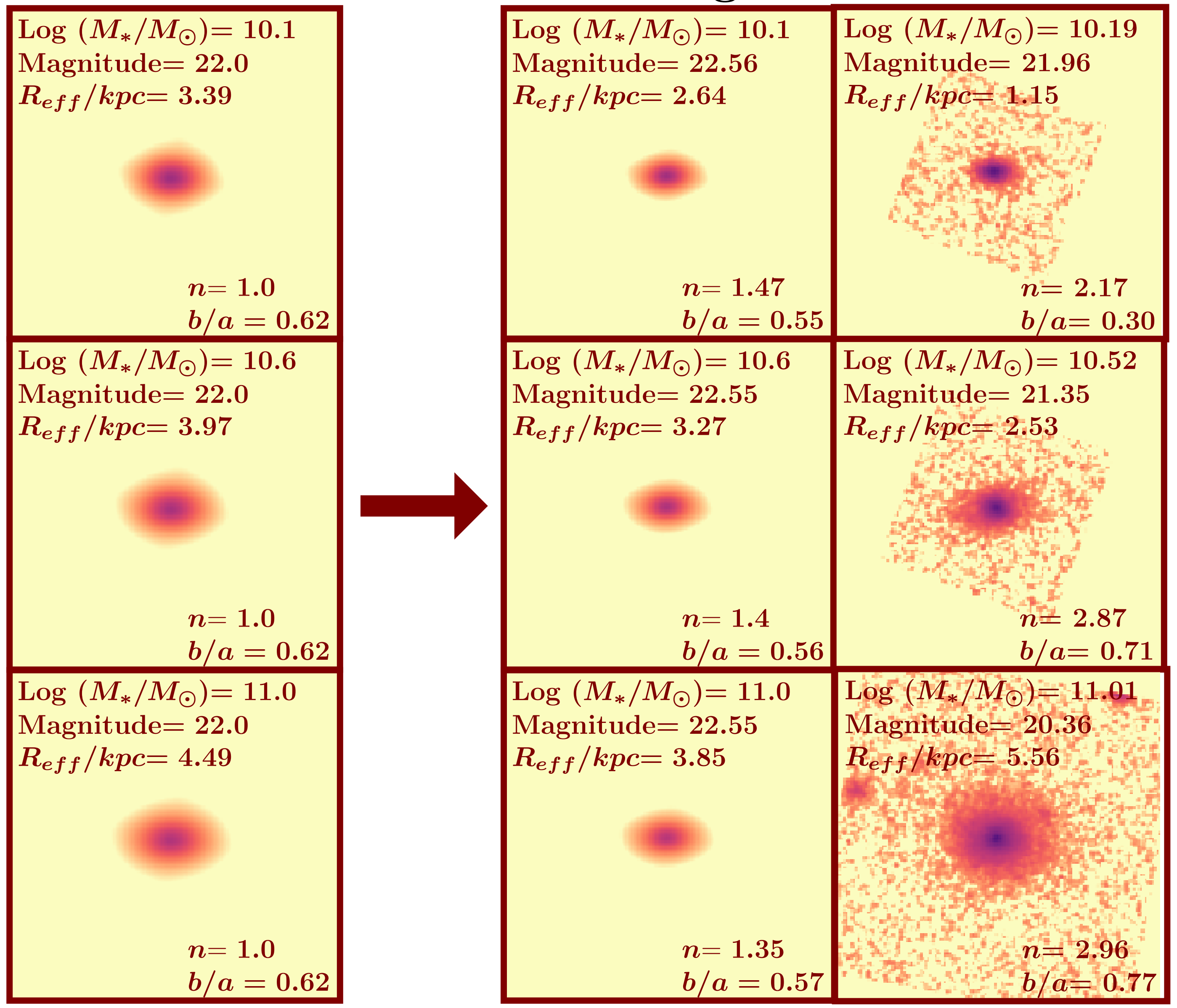


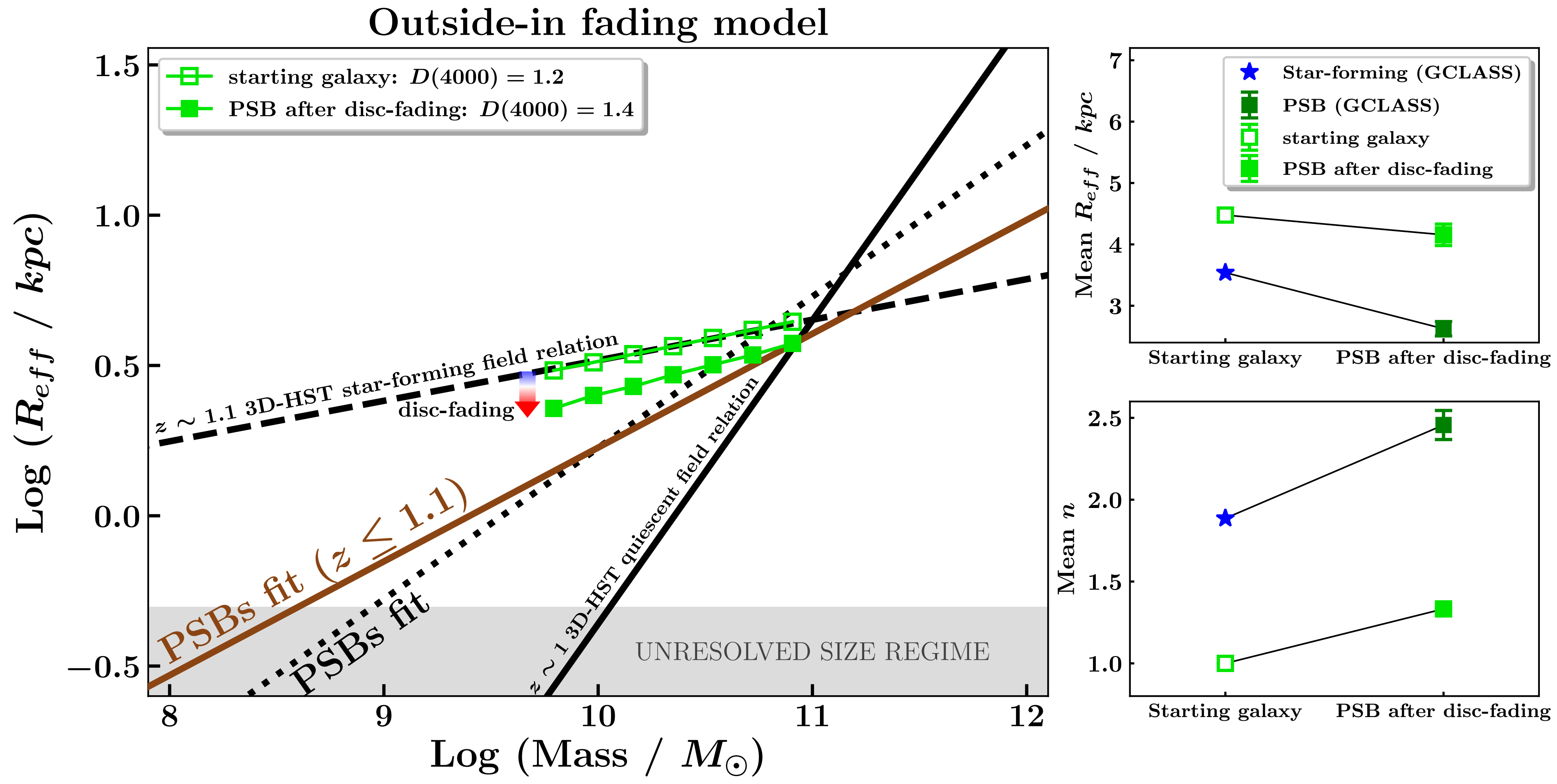


Matharu et al., (2020)

Outside-in fading of a disc-dominated galaxy

Starting galaxy | PSB after outside-in fading | GCLASS PSBs (similar Log (Mass / $M_\odot$))

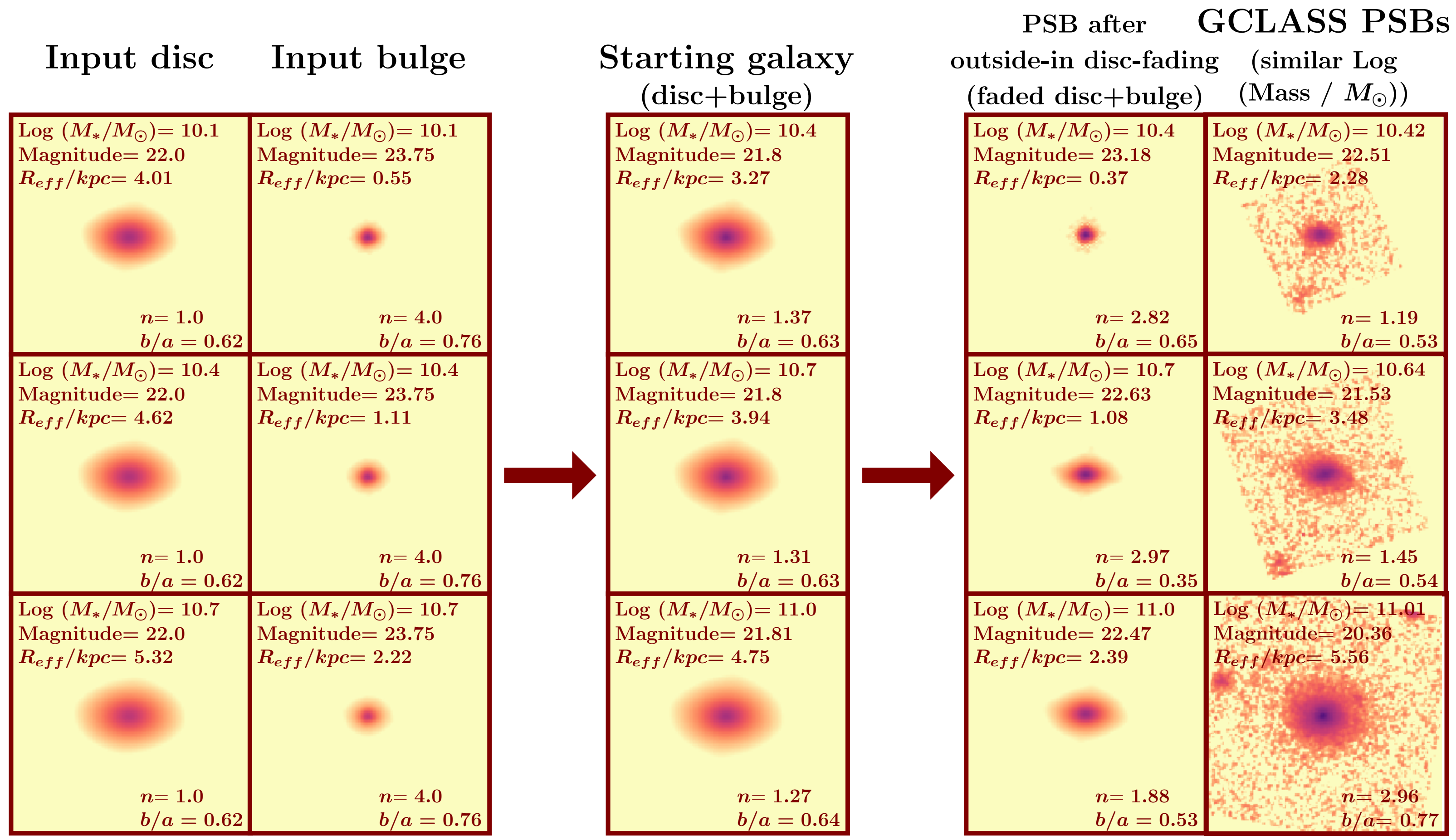


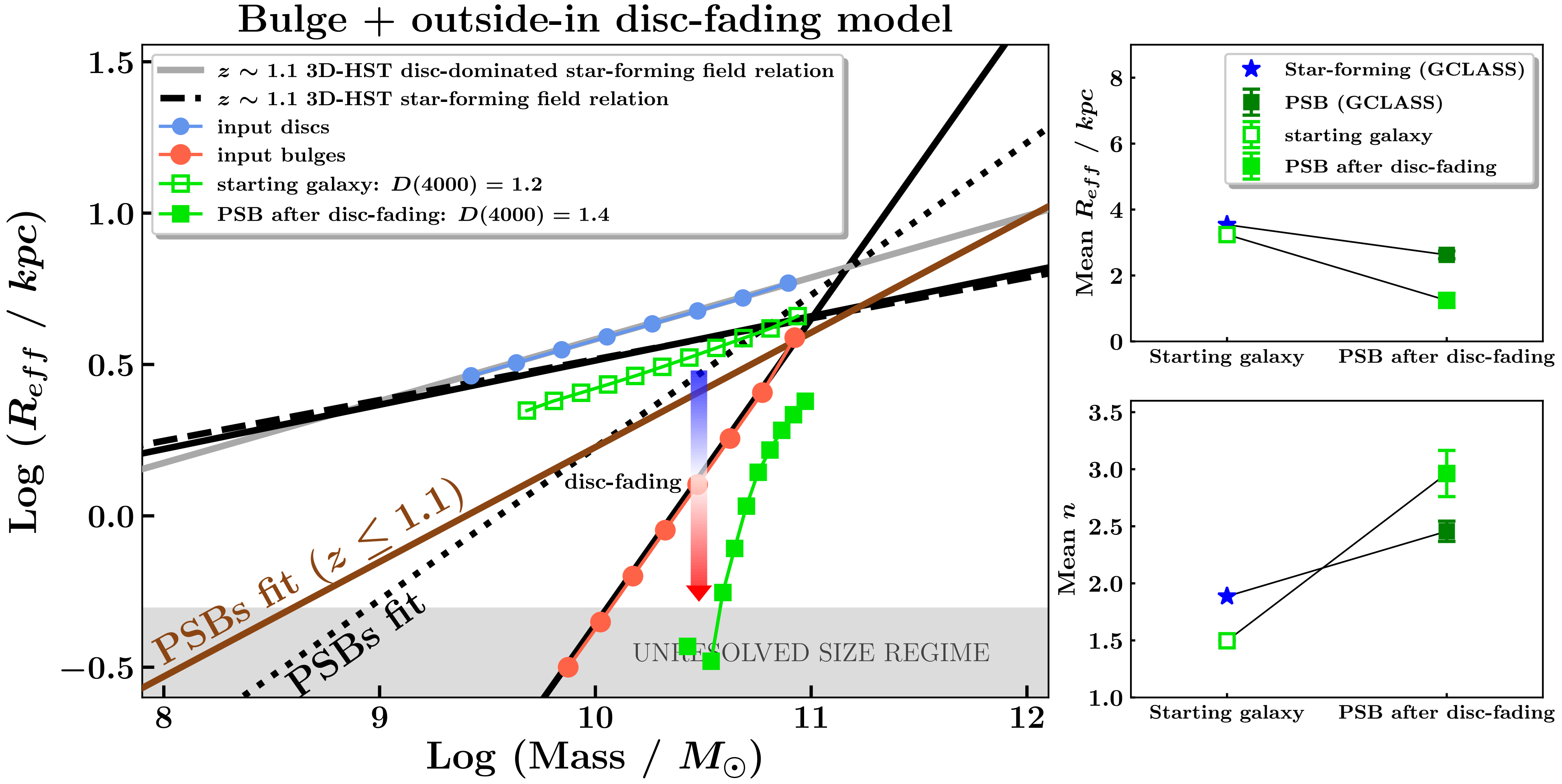


- Central regions faded to PSB level. Outskirts faded based on observations of outside-in fading in NGC 4330 from Fossati+2018.
- In between, fading levels are found by linearly-interpolating.

Matharu et al., (2020)

Outside-in fading of the disc
(combination of previous two models)

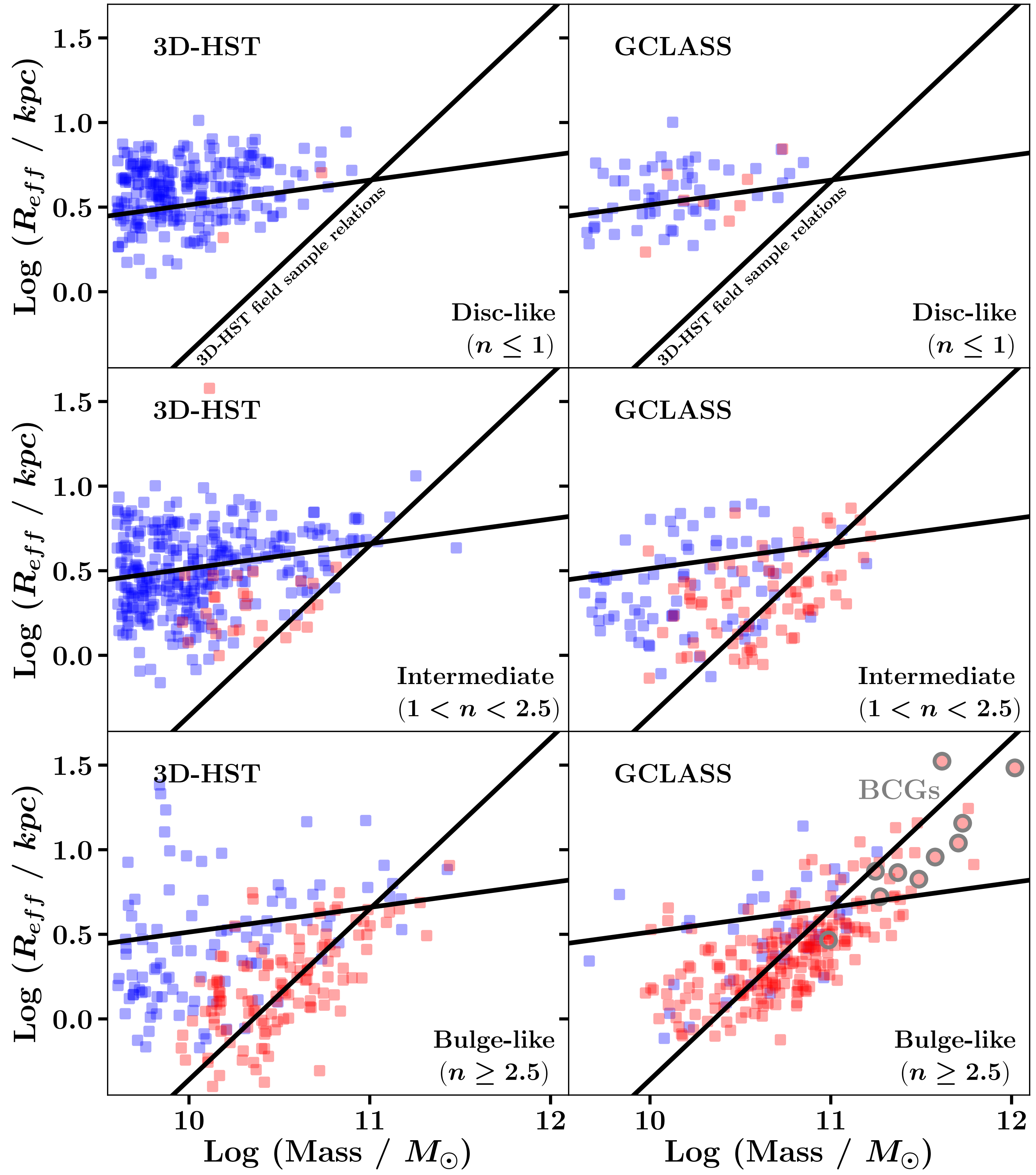


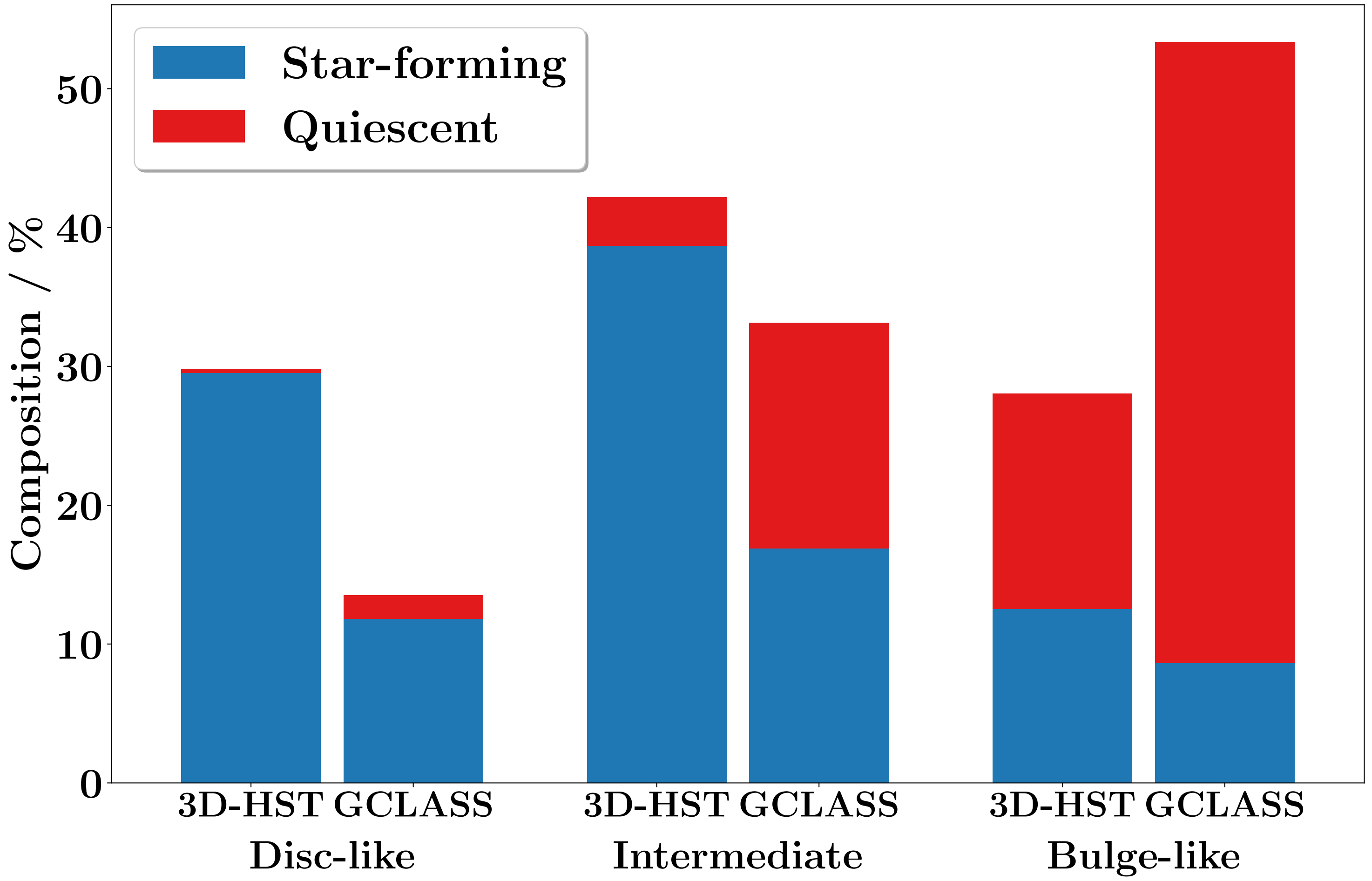


- Central pixel is not faded. We first check what the total brightness of the disc is when it is uniformly faded.
- We check how much the disc needs to fade at the "boundary" of outside-in fading as determined by observations of NGC 4330 in Fossati+2018.
- We then adjust the slope of our linearly interpolated fading accordingly.
- Leads to steep fading gradients, rapid contraction of size. But surpasses the PSB relation — outside-in fading has the potential to explain the PSB mass-size relation with further exploration of fading gradients.

Matharu et al., (2020)

Morphology as a function of environment across the mass-size plane at z ~ 1





- Larger population of quiescent intermediate-type galaxies in clusters compared to the field.
- Subsequently thought to be responsible for the larger population of bulge-likes galaxies in clusters compared to the field — **there is a direct morphological consequence of environmental quenching**.

Matharu et al., (2019)