

# THE GAS CONTENT AND STAR FORMATION ACTIVITY IN GALAXY PROTOCLUSTERS: *EVIDENCE OF ENVIRONMENTAL QUENCHING?*

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C. CASEY AND THE COSMOS  
COLLABORATION

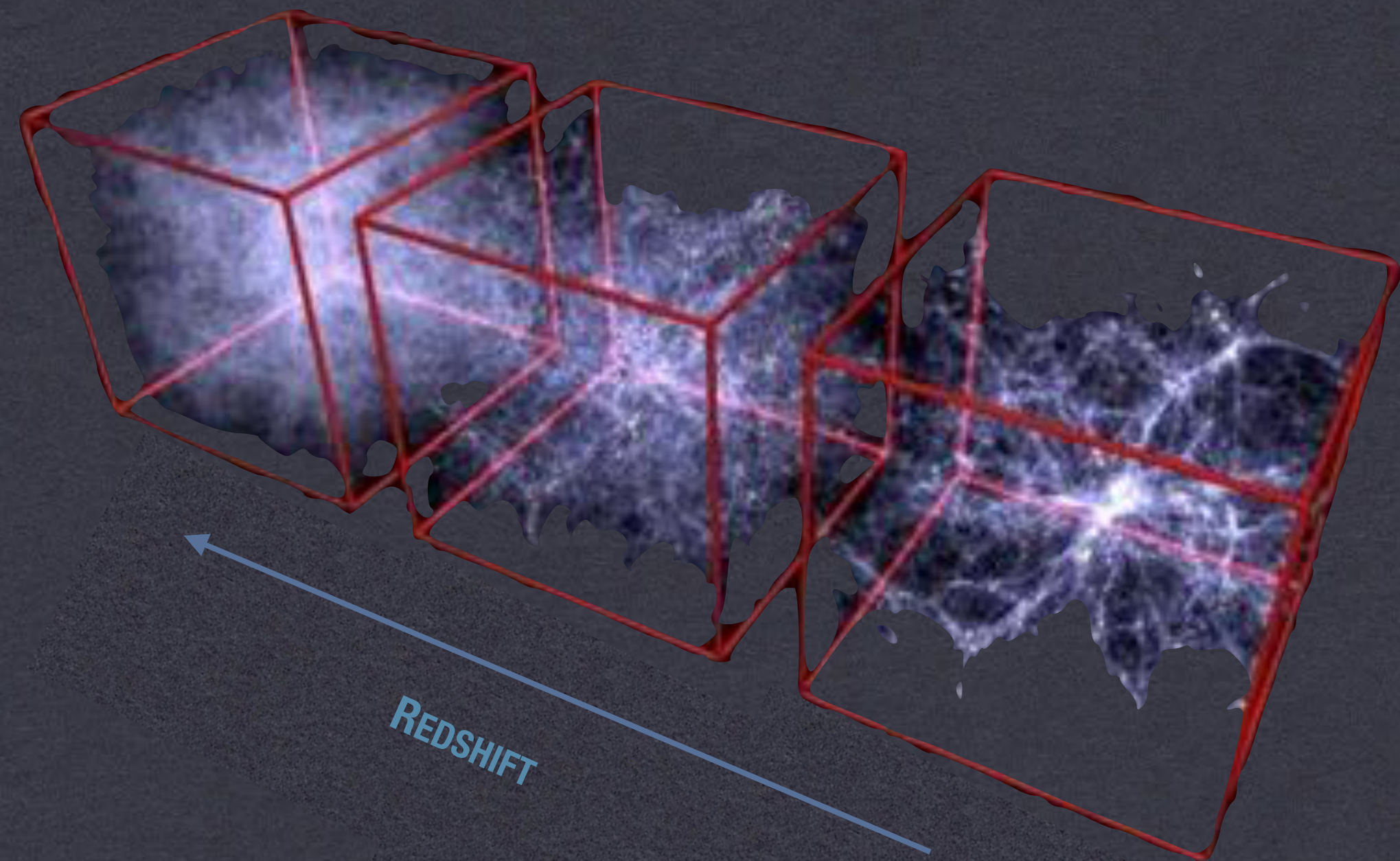


Image: [https://www.ucl.ac.uk/star/research/stars\\_galaxies/high\\_redshift\\_galaxies](https://www.ucl.ac.uk/star/research/stars_galaxies/high_redshift_galaxies)



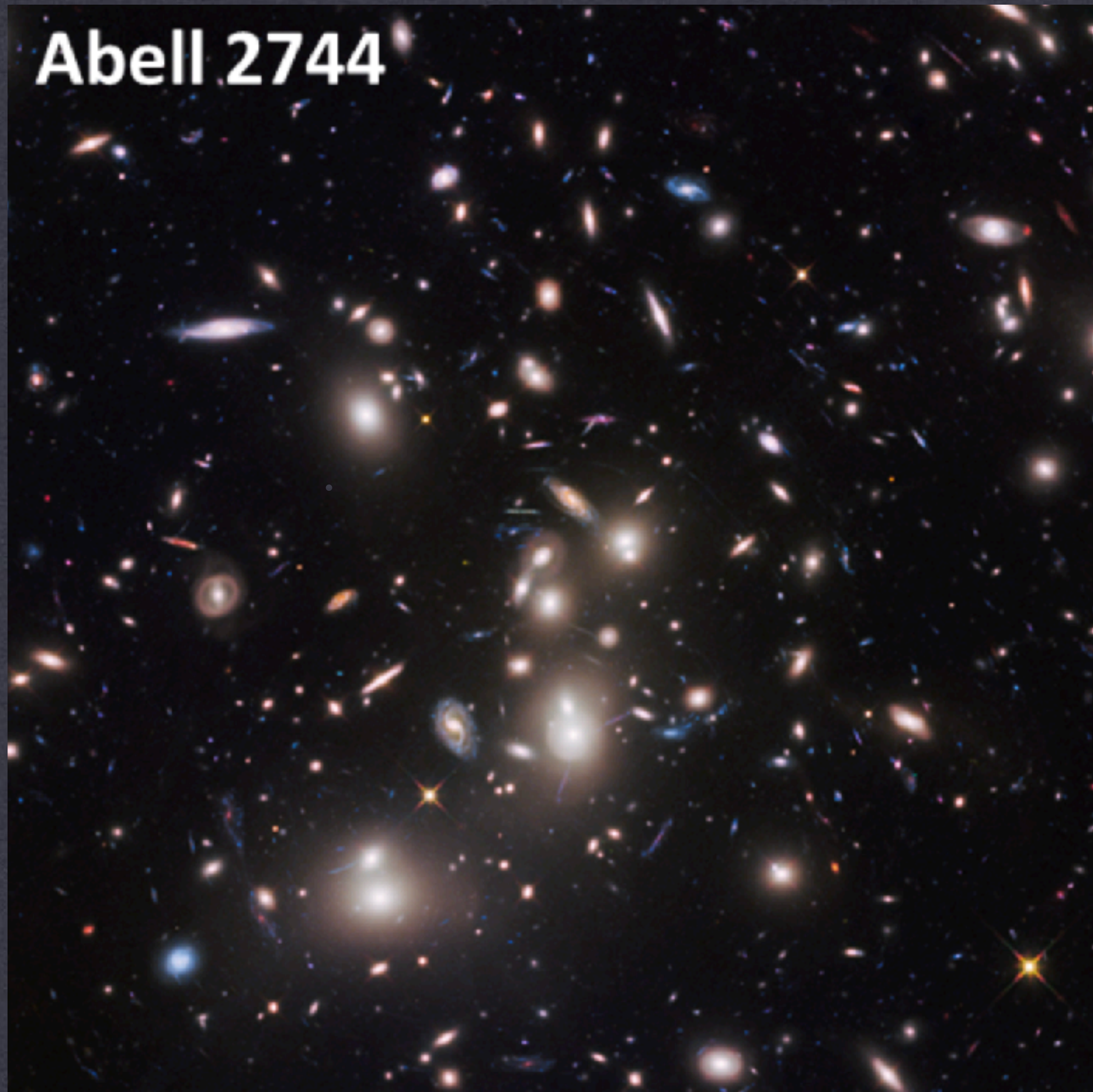


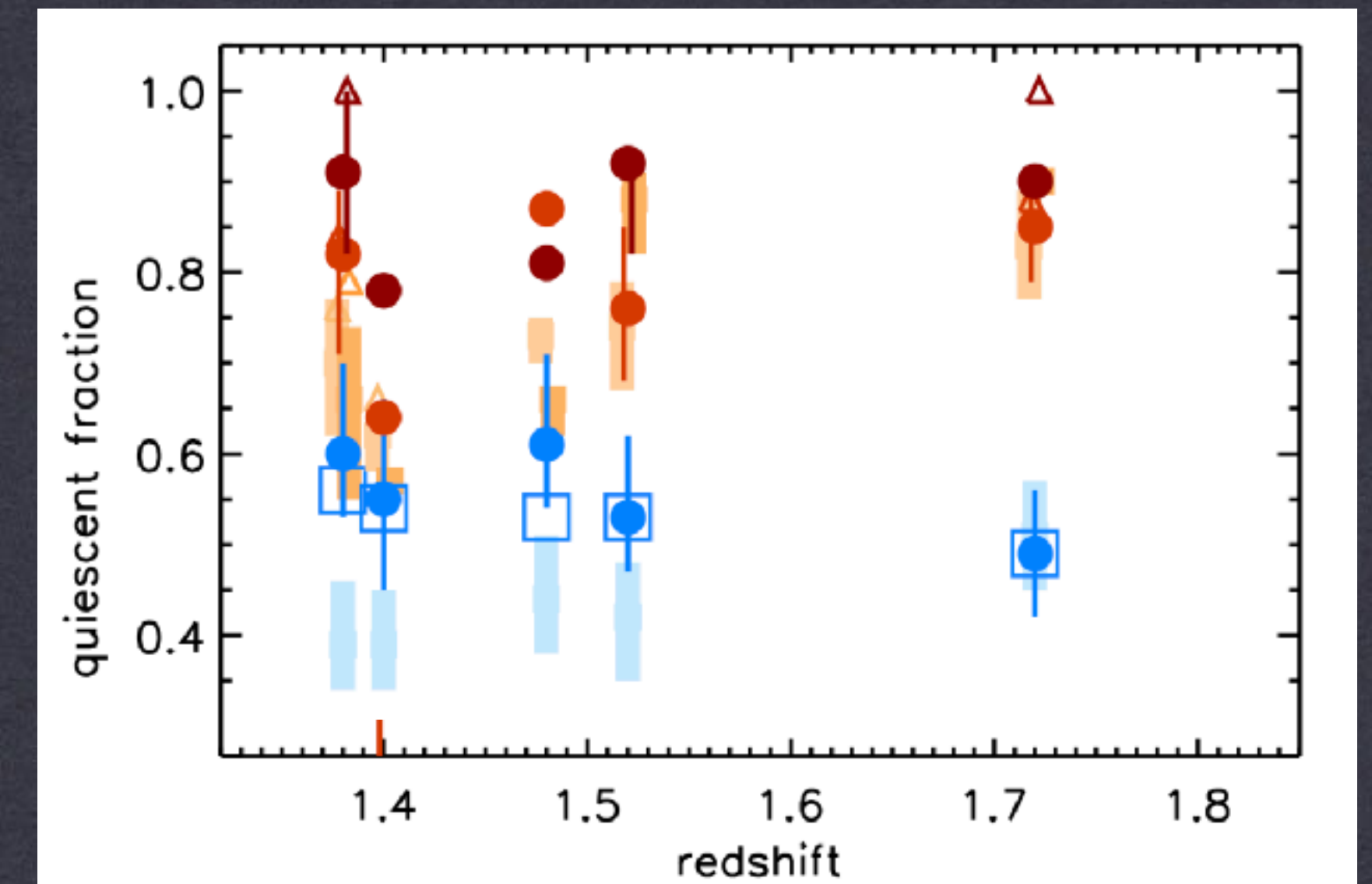
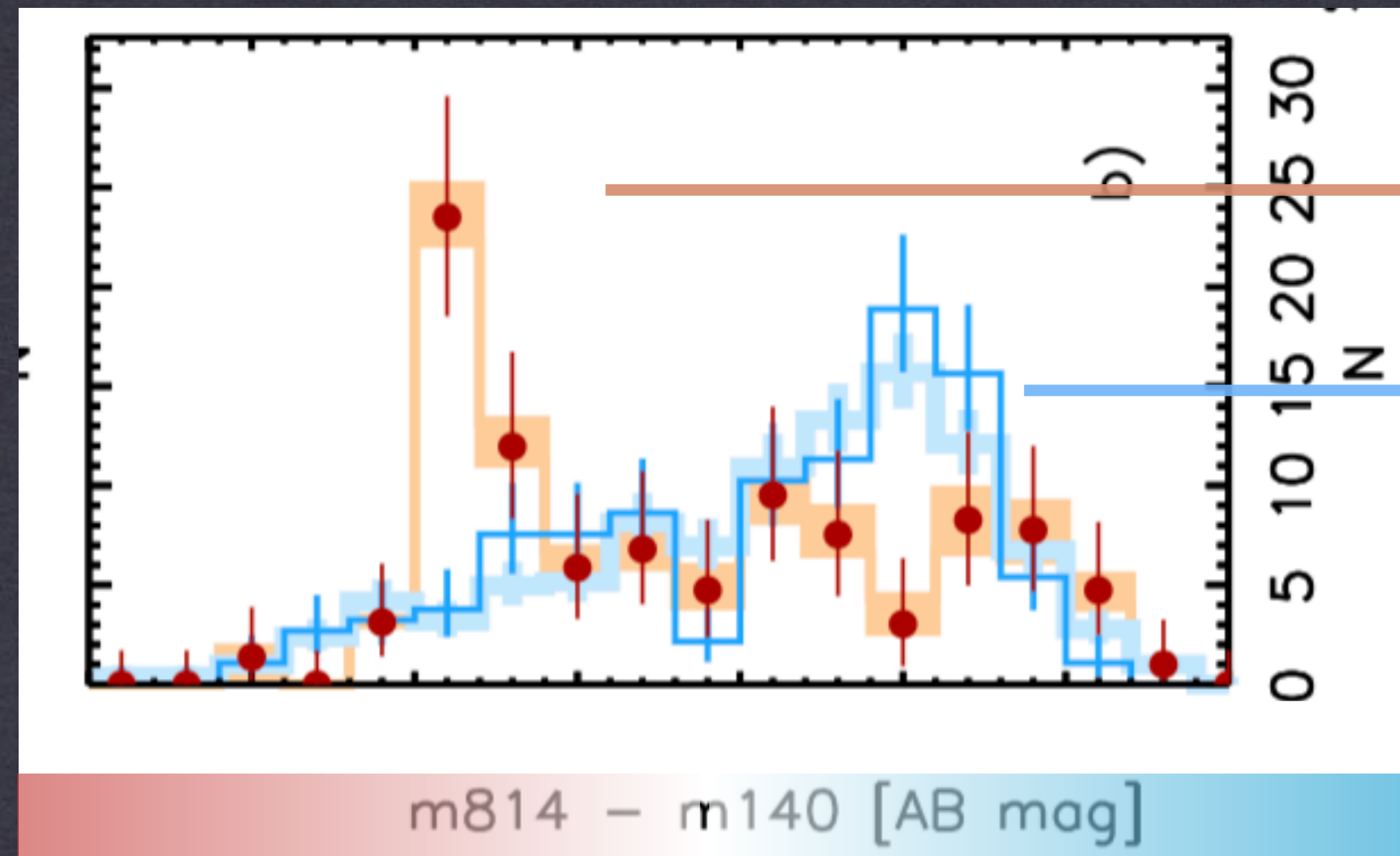
Image: <https://frontierfields.org/category/observations/>

*"Nebulae of all types except the irregular are represented among its members, but elliptical nebulae and early spirals are relatively much more numerous than among the nebulae at large. The predominance of early types is a conspicuous feature of clusters in general [...]"*

*Hubble & Humason (1931)*



## Clusters at $z \sim 1-2$



Strazzullo et al. 2018 (see also Muzzin et al. 2012; Newman et al. 2014; Lee-Brown et al. 2017; Ji et al. 2018; and others)

- How does environment affect the evolution of galaxies?
- When does quenching occur? What is the typical timescale?
- Does the SFE vary with environment?

**Effects already in place at  $z \sim 1.5$ !**



## Clusters at $z \sim 1-2$



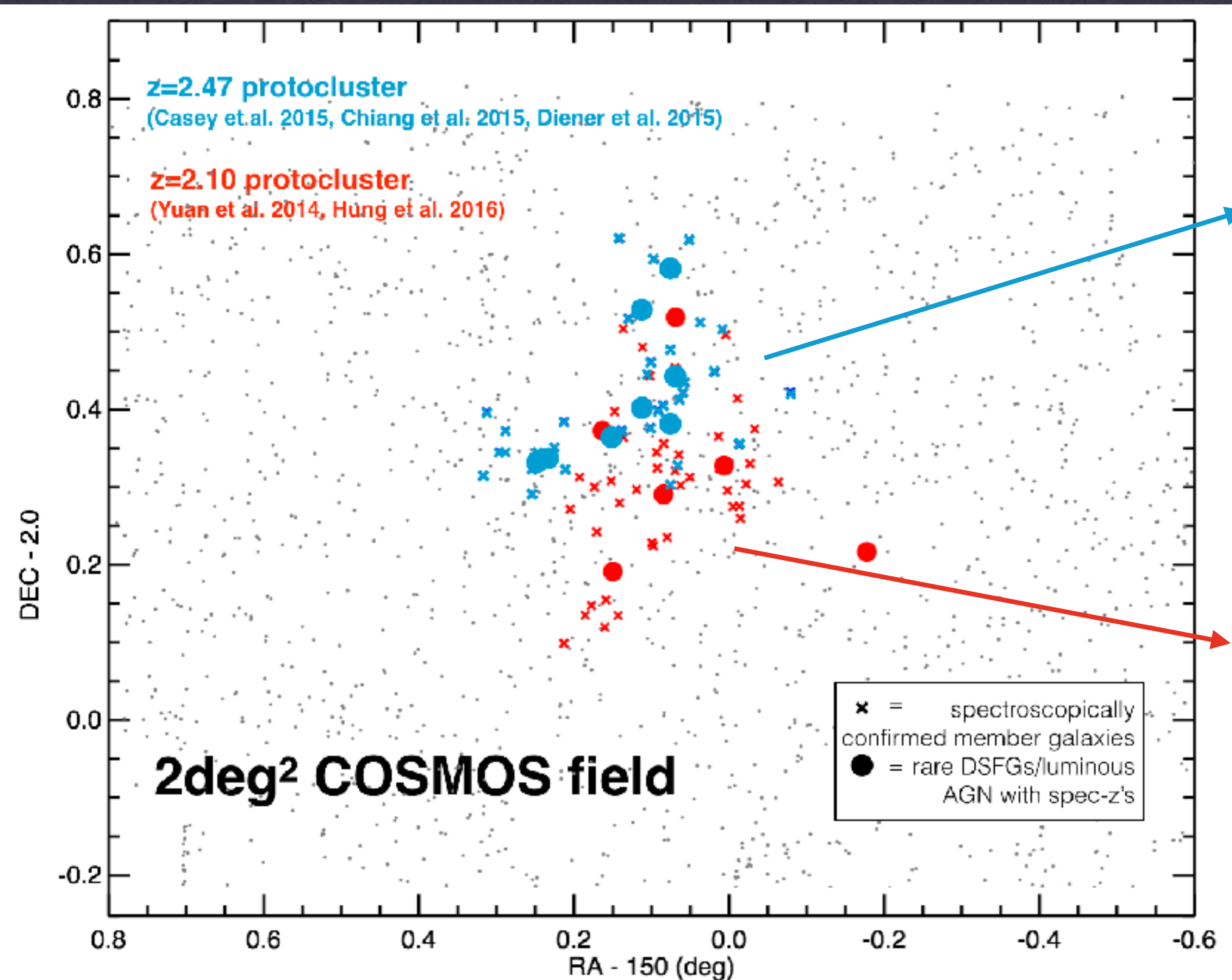
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# The COSMOS $z=2.47$ and $z=2.10$ structures



**$z=2.47$ ;  $N \sim 60$ ;  $SFR \sim 4500 M_{\odot}/\text{yr}$ ;  
 $V = 15000 \text{ cMpc}^3$**

Casey et al. 2015, 2016; Diener et al. 2015; Chiang et al. 2015; Wang et al. 2016, 2018, Gomez-Guijarro 2019; Zavala et al. 2019; Champagne et al. in prep.

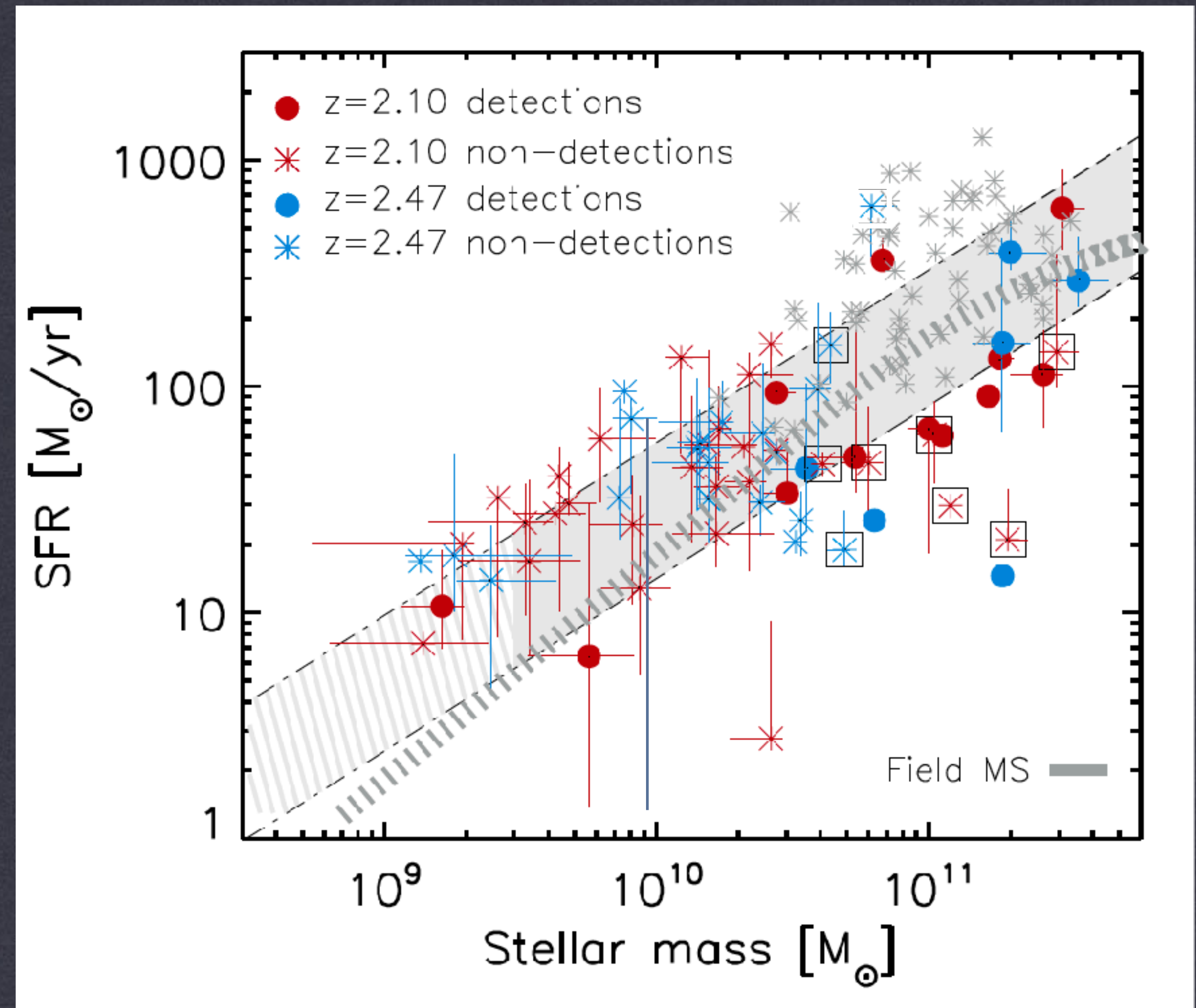
**$z=2.10$ ;  $N \sim 100$ ;  $SFR \sim 5300 M_{\odot}/\text{yr}$ ;  
 $V = 15000 \text{ cMpc}^3$**

Yuan et al. 2014; Casey et al. 2016; Chiang et al. 2016



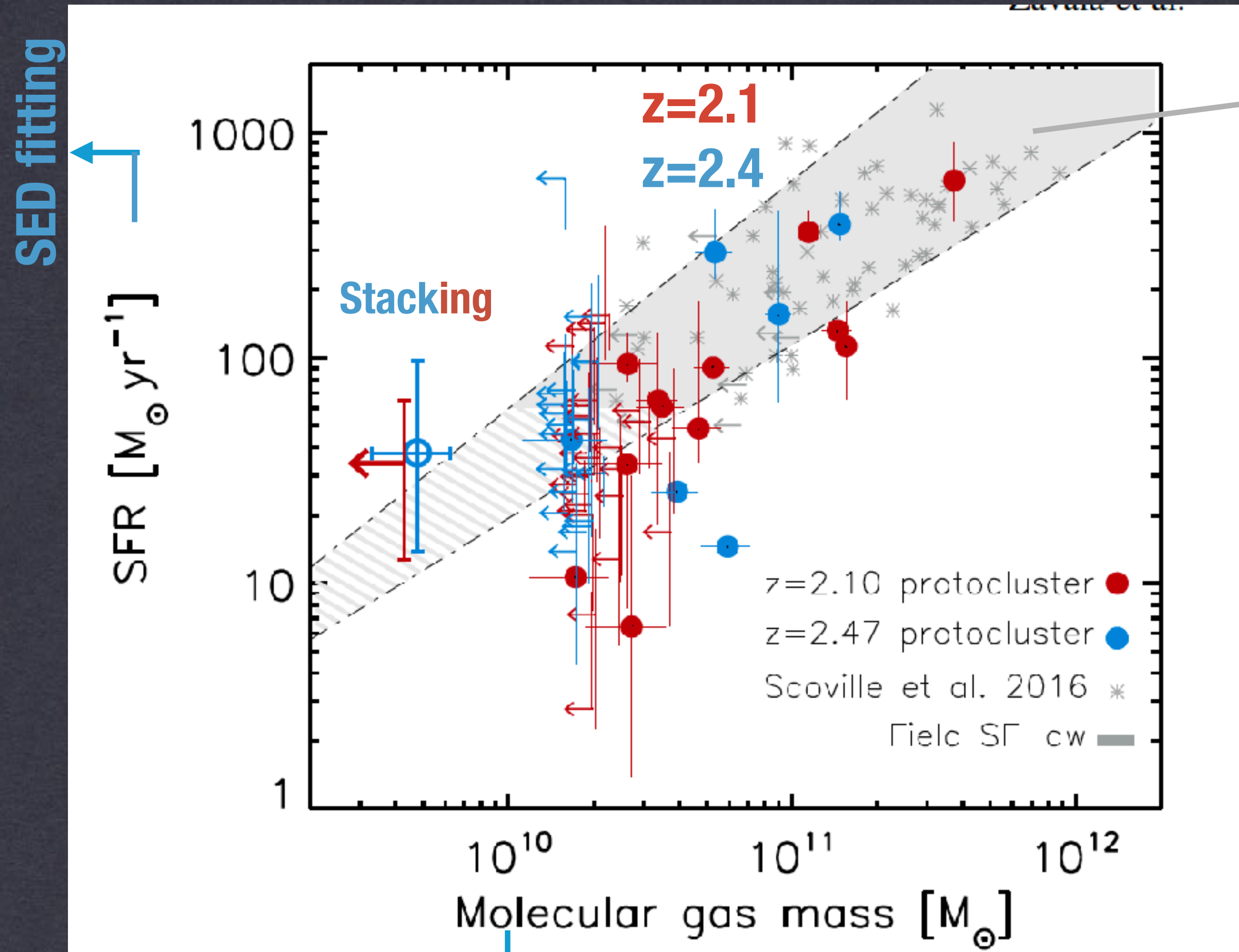
# ALMA continuum observations as tracer of molecular gas

- We conducted ALMA Band 6 (1.2mm) observations of ~65 (spectroscopically confirmed) protocluster members with an average depth of  $\sigma \sim 40 \mu\text{Jy}$ .
- Most of them are main-sequence galaxies (no extreme DSFGs)
- Tracing the Rayleigh-Jeans regime ( $\lambda_{\text{rest}} \sim 350 \mu\text{m}$ )  $\rightarrow$  gas mass tracer (e.g. Scoville et al. 2014, 2016)
- Complete sample at  $M_* \gtrsim 1 \times 10^{10} M_\odot$ .





# The ISM and the SFE



Zavala et al. 2019

From ALMA 1.2mm

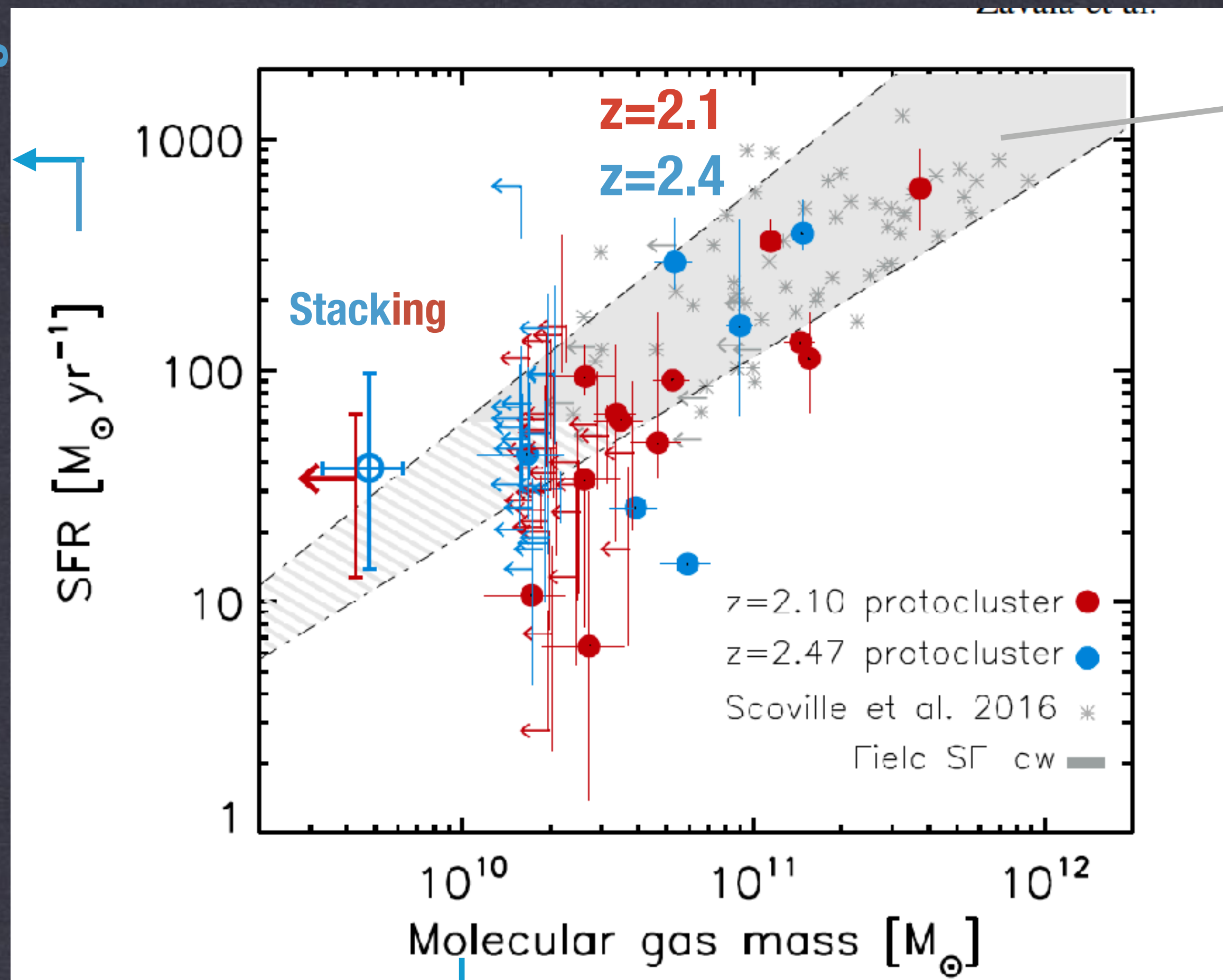
Control sample &  
Field Star formation law  
Scoville et al. 2016

Protocluster member galaxies does not show  
an increased star formation efficiency



# The ISM and the SFE

SED fitting



Zavala et al. 2019

From ALMA 1.2mm

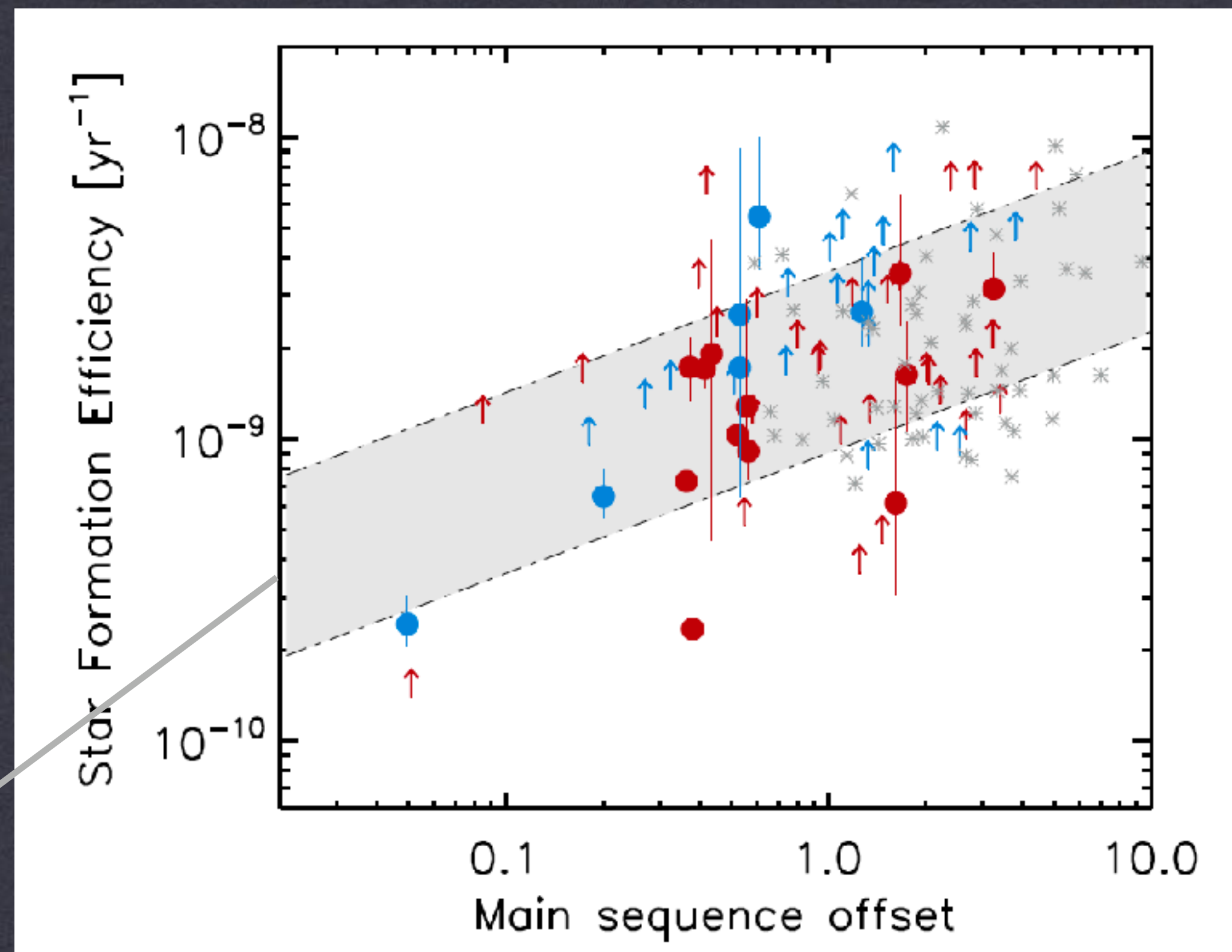
Tacconi et al. 2018 relation

Control sample &

Field Star formation law

Scoville et al. 2016

Protocluster member galaxies do not show an increased star formation efficiency

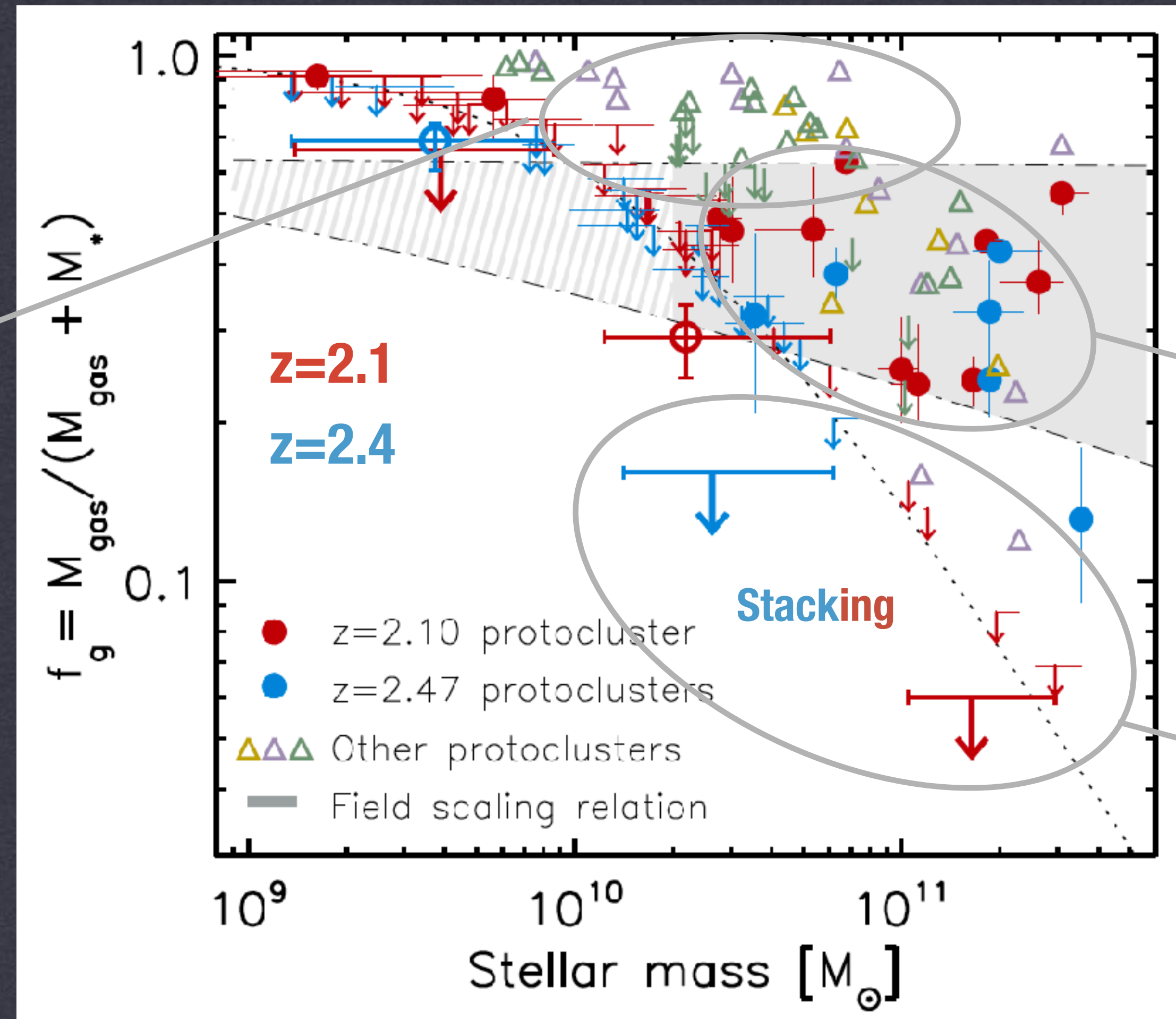




# Gas fractions

Cluster-to-cluster variations  
-> different evolutionary  
stages (even at fixed  $z$ )

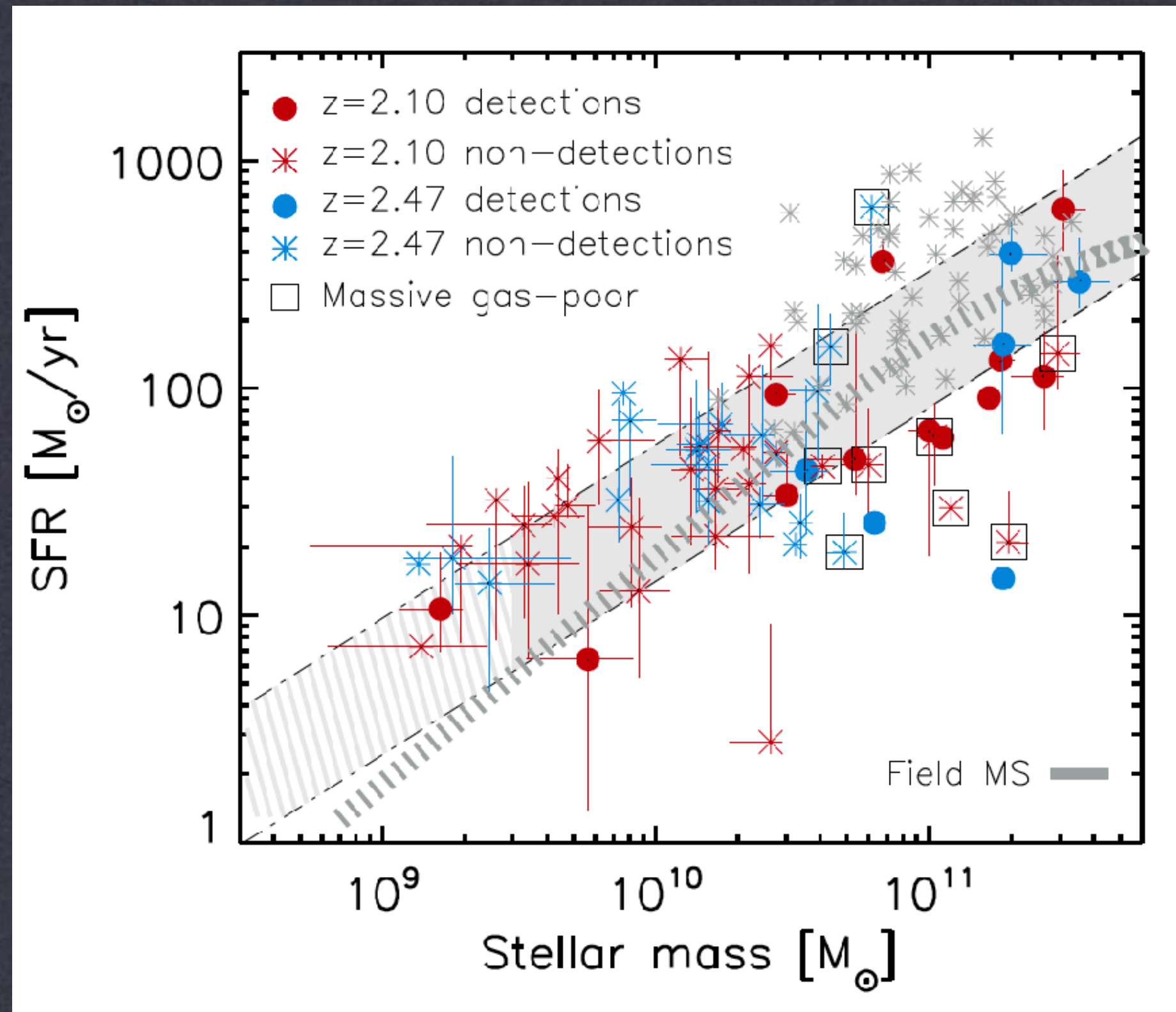
Lee et al. 2017; Gomez-Guijarro et al. 2019;  
Tadaki et al. 2019



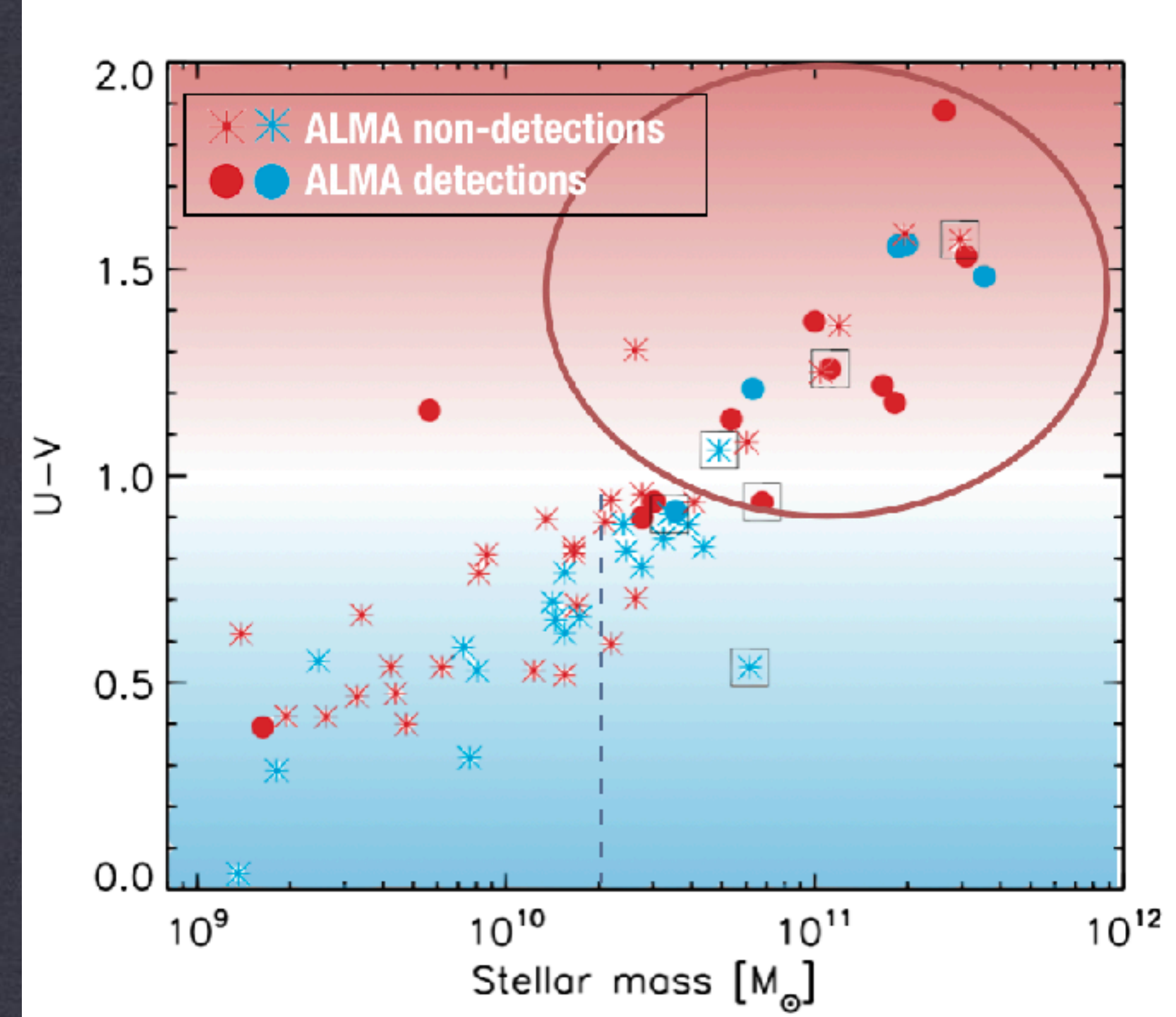
Zavala et al. 2019



# Evidence of a quiescent population of galaxies?



Zavala et al. 2019

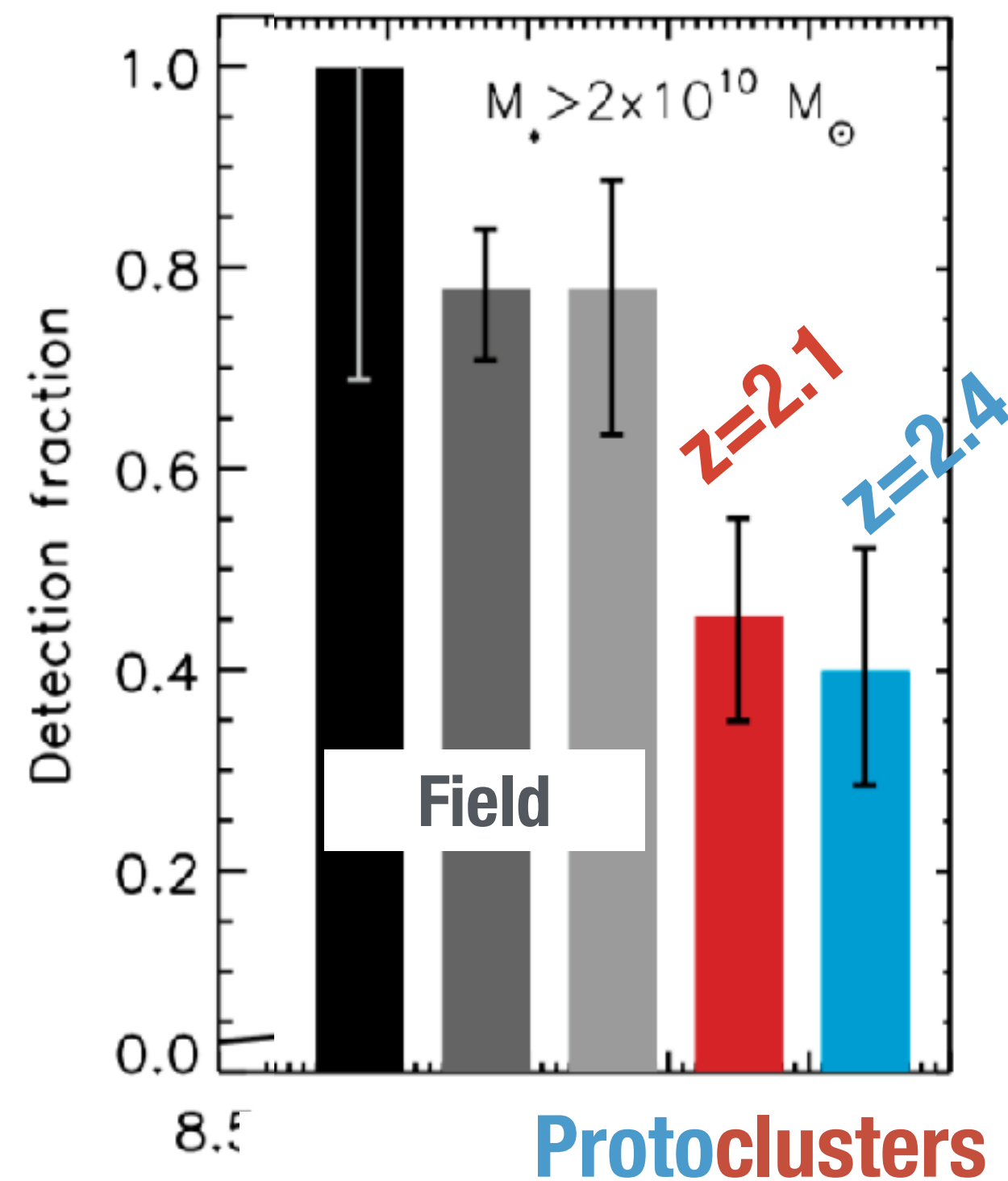


A **quiescent** population of galaxies (massive, red, and gas-poor) in an overdense environment at  $z \sim 2.5$ !



# Evidence of environmental quenching?

■ Bouwens+2016  
■ Scoville+2016  
■ Dunlop+2017



Zavala et al. 2019

The fraction of detected galaxies in blind surveys or field galaxies is higher than the one found for the protocluster member galaxies (80% vs 40%)

(same  $z$ ,  $M_*$ , and  $\sigma_{\text{rms}}$ )

An excess of high-mass passive (gas-poor) galaxies in the protocluster structure!

Accelerated evolution, even before virialization

Timescale for environmental quenching:  $\Delta t < 800$  Myr



## Take-home messages:

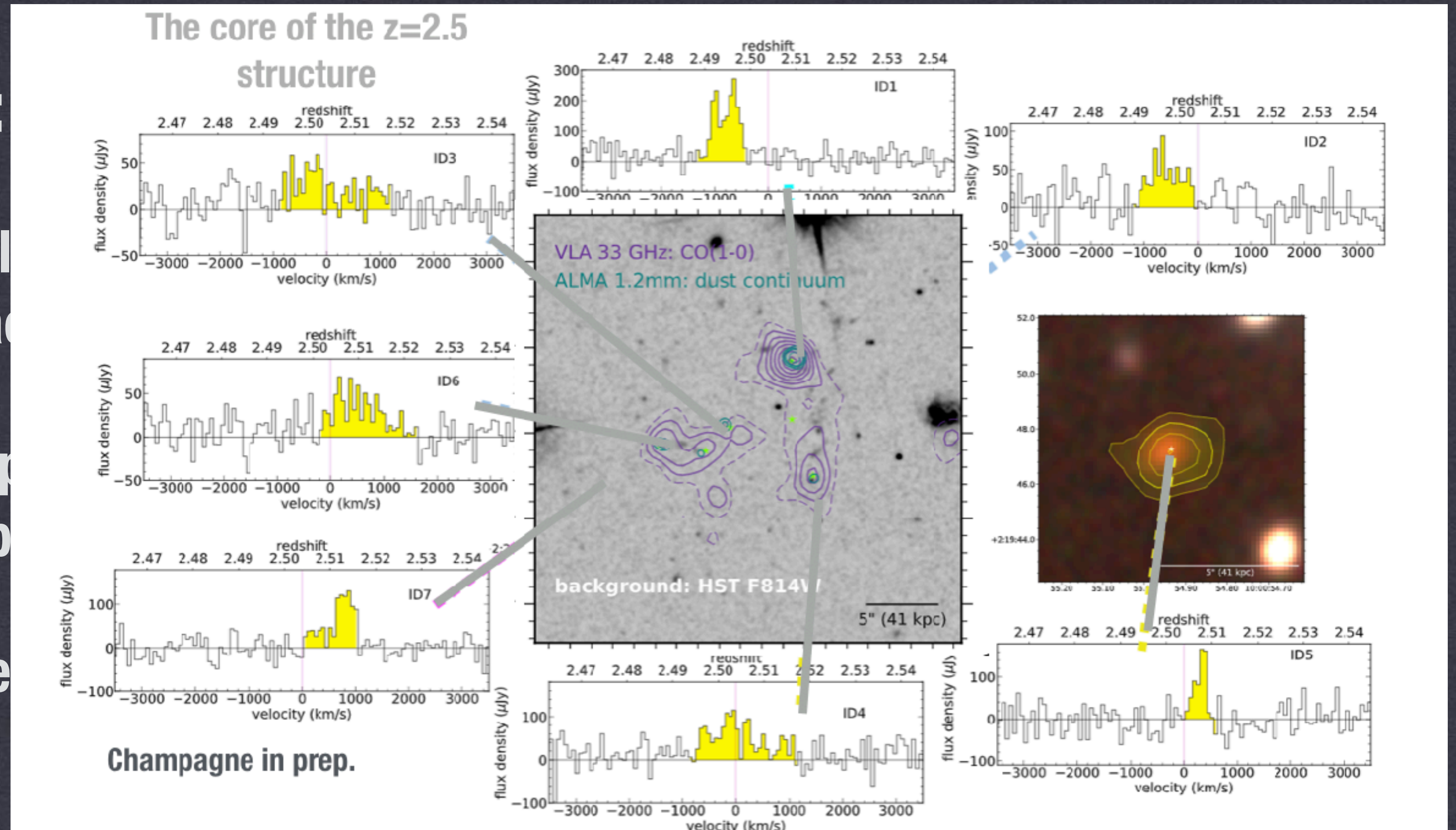
- Protocluster member galaxies do not show an increased star formation efficiency nor an enhanced gas fraction when compared with the field.
- Protocluster galaxies experience an accelerated evolution which results in an excess of massive gas-poor galaxies (even at  $z=2-2.5$ ).
- Timescale for environmental quenching:  $\Delta t < 800 \text{ Myr}$  (before cluster virialization!)

Mergers? AGN feedback? Ram pressure stripping?  
Enhanced gas volume density?



## Take-home messages:

- Protocluster member galaxies nor an enhanced gas fraction
- Protocluster galaxies exhibit an excess of massive gas-phase dust
- Timescale for environmental effects



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## Take-home messages:

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¡Gracias!