CLASH-VLT: Enhancement of (O/H) in z~0.35 RXJ 2248-4431 cluster galaxies

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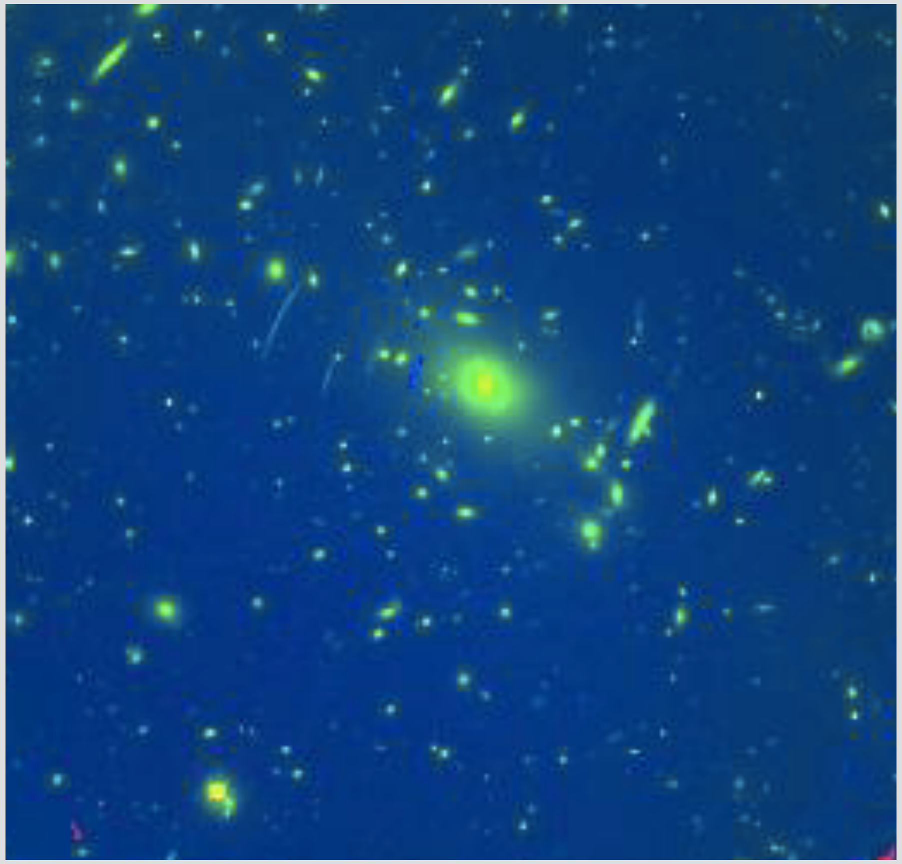

Based on master thesis

Supervisors: **Bodo Ziegler; Christian Maier**

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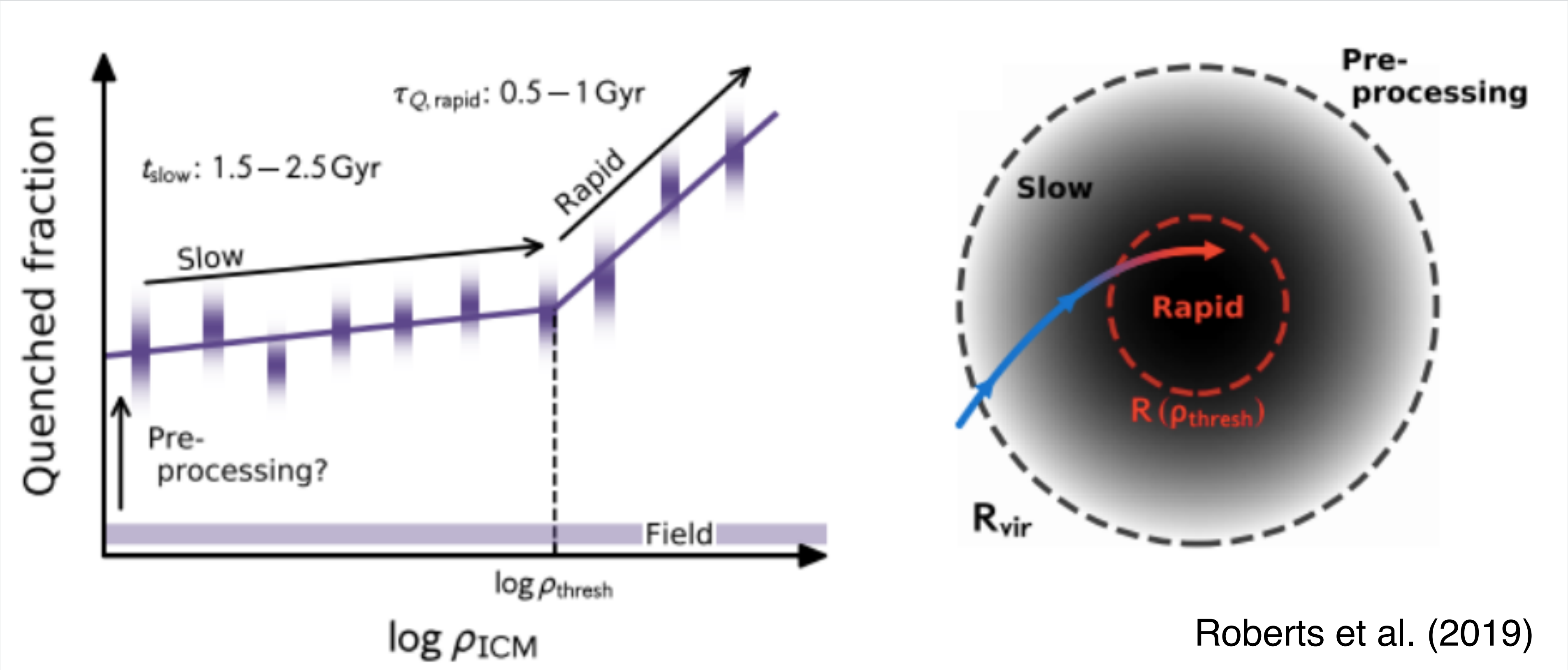
Outline & motivation

Spectroscopic study CLASH RXJ2248-4431 (z=0.35) cluster +field galaxies

1.Specific Star Formation Rate-Mass relation (sSFR-M)

2.Mass-Metallicity relation (MZR) → **strangulation**

3.Fundamental metallicity relation (FMR)



Roberts et al. (2019)

Maier et al. (2019a), Roberts et al. (2019): Galaxies fly towards the center of the cluster:

I. at R200: **slow quenching** initiated (ram pressure stripping of halo gas i.e. strangulation)

II. above an ICM threshold: **rapid quenching** (ram pressure stripping of cold disk gas)

Data-set:

CLASH-VLT VIMOS spectra: ➡947 galaxy spectra - field+ RXJ2248-4431 cluster

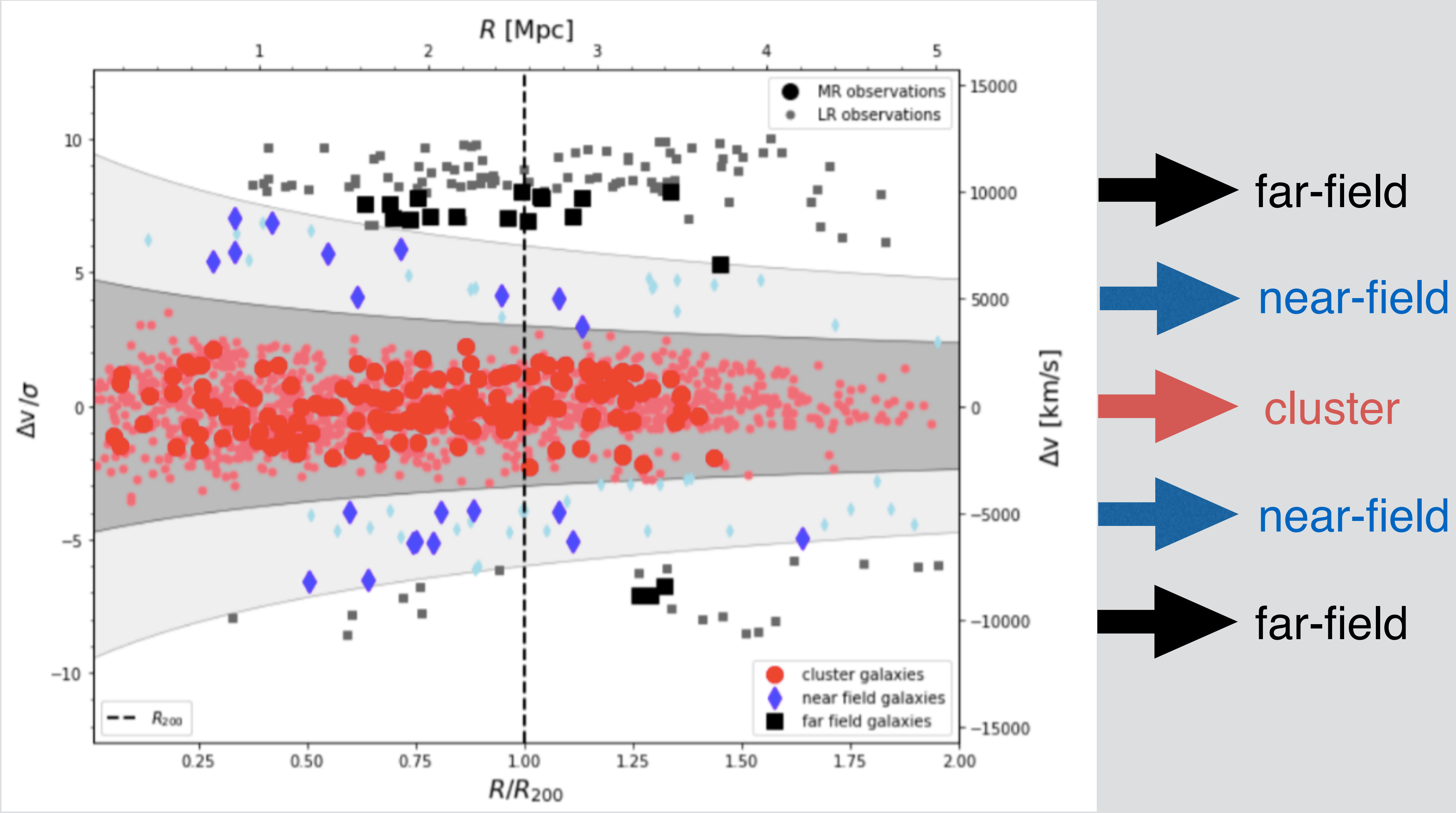
WFI photometry: ➡UBVRIz for 636 galaxies - field+ RXJ2248-4431 cluster

➡ ***Final sample: 121 cluster members (0.33<z<0.36); 37 CLASH field galaxies (0.3<z<0.4); 93 zCOSMOS field galaxies (0.3<z<0.4)***

★For metallicity study: matched local comparison sub-sample of SDSS emission line galaxies ($0.04 < z < 0.08$) (Maier et al. 2016)

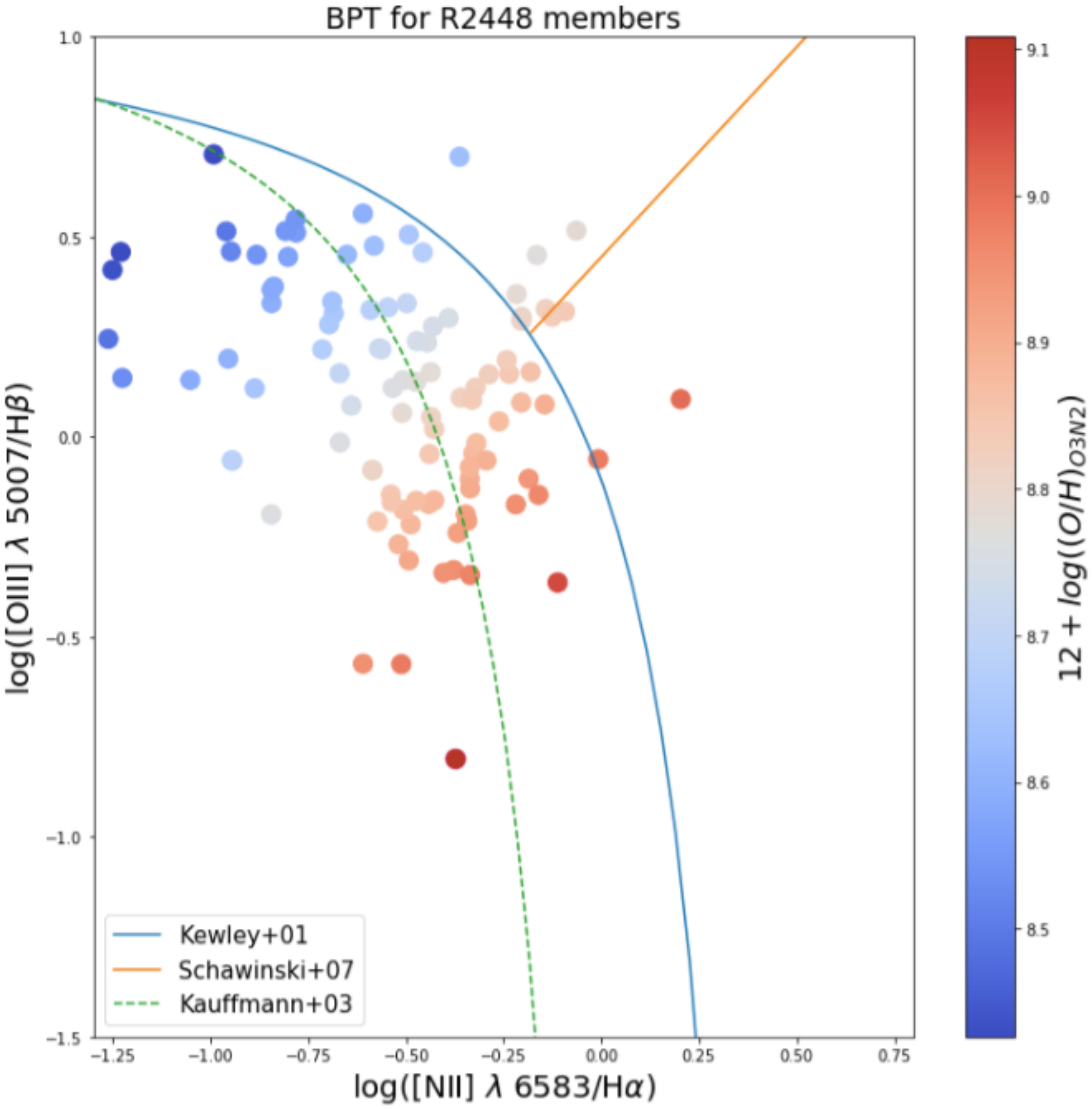
Phase Space diagram:

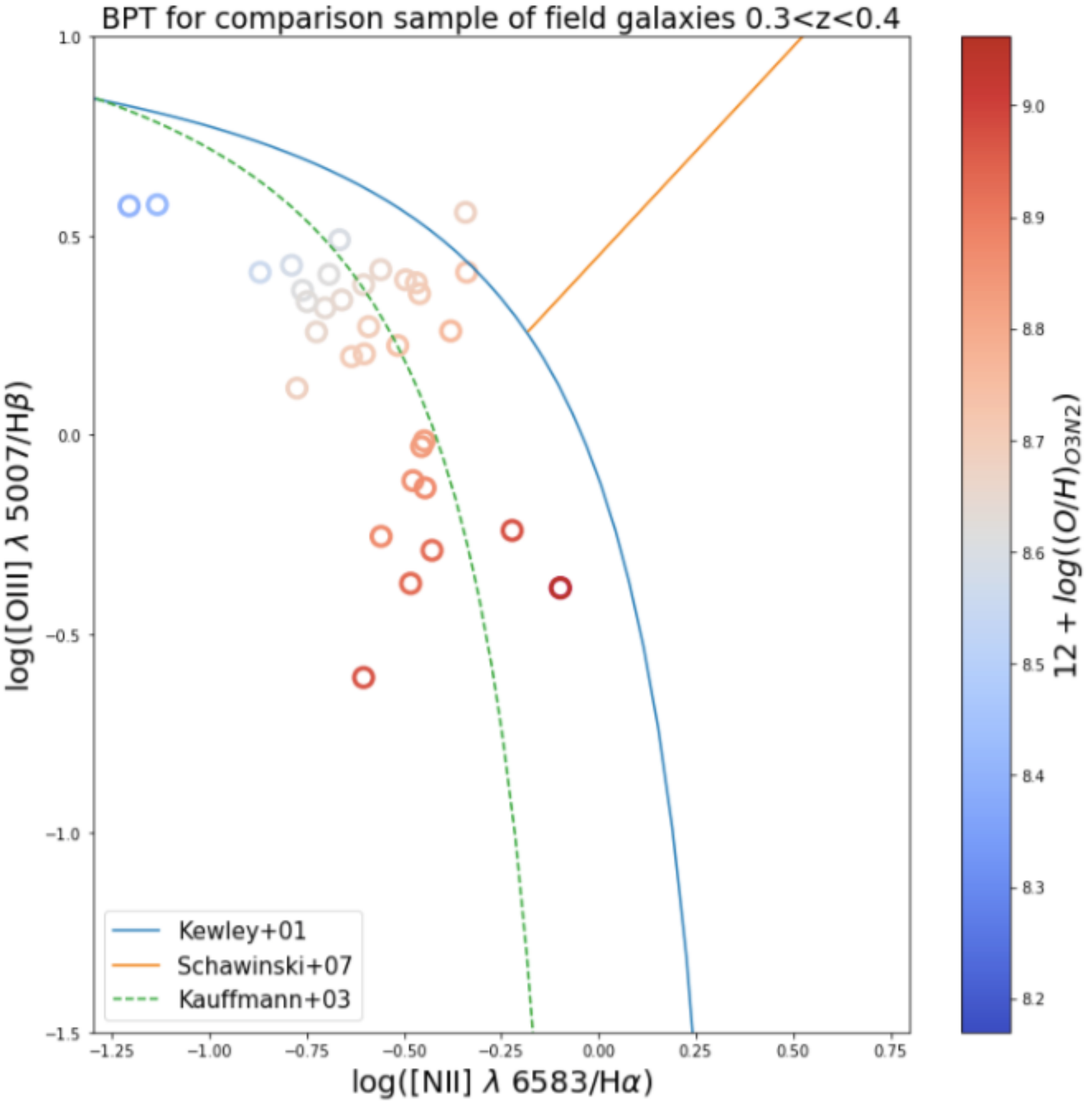
Cluster-centric radius vs. line-of-sight velocity relative to cluster redshift



- Mass model: Carlberg et al. (1997)
- **z = 0.345**; $R_{200} = 2.57$ Mpc; $M_{200} = 1.7 \cdot 10^{15}\ M_\odot$

Star formation or AGNs?





➡ BPT Baldwin, Phillips and Terlevich et al. (1981)

➡ Seyfert II & LINERs **excluded** from the sample

Results: specific SFR-Mass relation

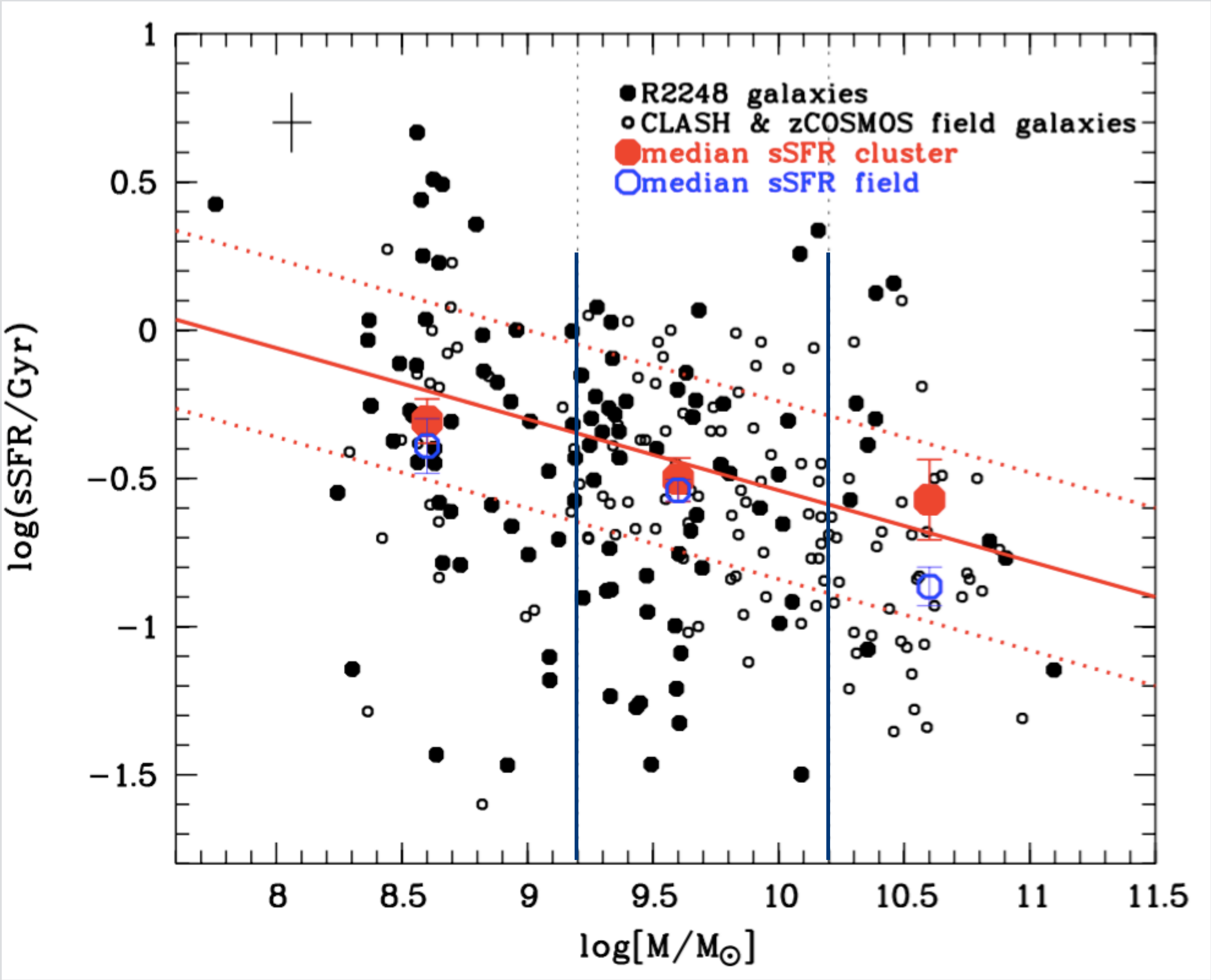
SFR from Hα:

➡ Kennicutt (1998) conversion

➡ Hα/Hβ extinction correction (Brocklehurst et al. 1971)

➡ Hβ absorption correction (Kobulnicky et al. 1999)

➡ apperture correction (Maier et al. 2009)



➡ Mass complete bin: 9.2 < logM/M⊙ < 10.2

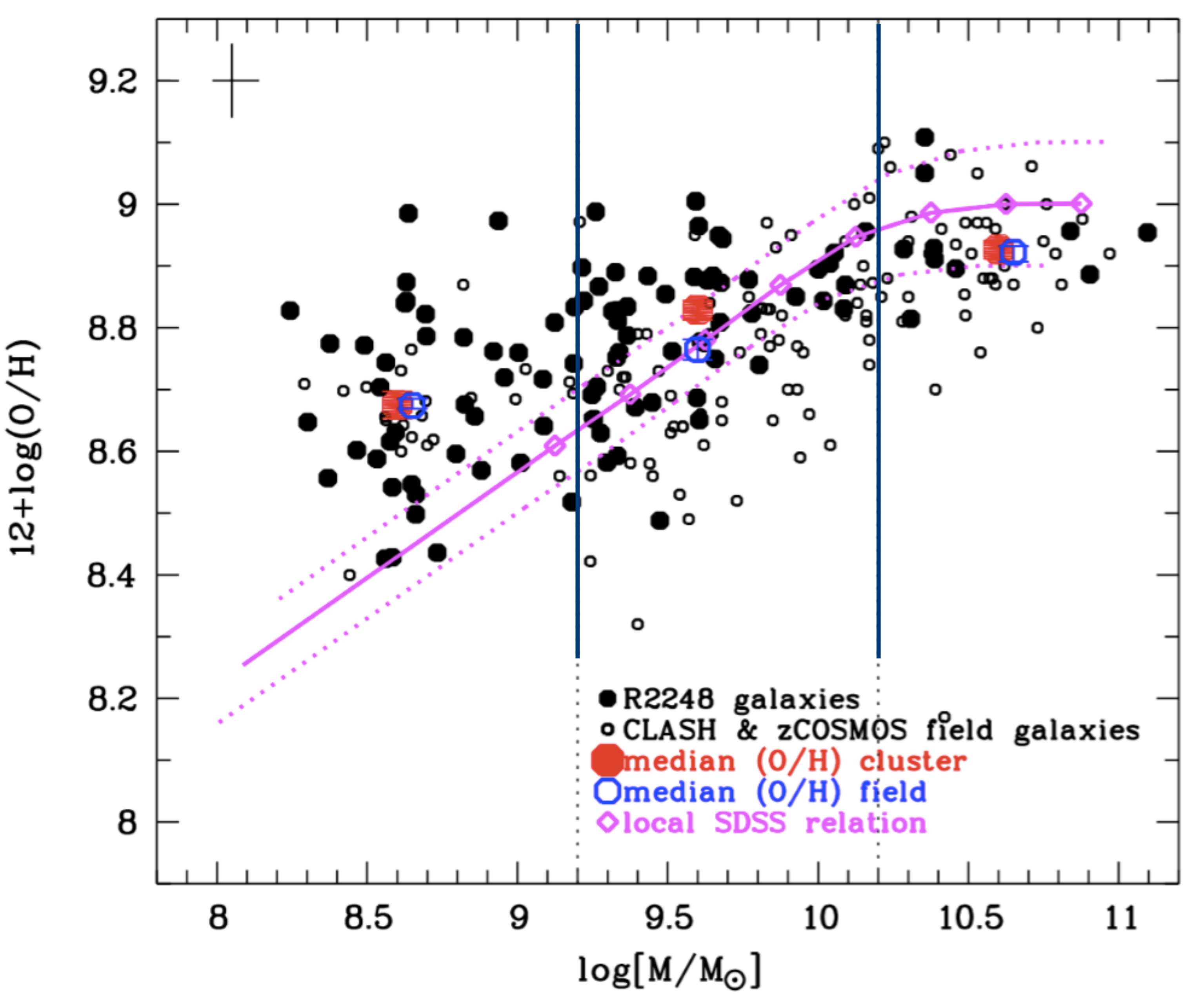
➡cluster & field - “Main Sequence” SF galaxies (between red dotted lines)

➡specific SFR-Mass: independent of environment

Results: Mass-Metallicity Relation

(O/H):

- ➡**O3N2** calibration Kewley et al. 2013
- ➡SDSS local relation: SDSS catalogue, (O/H) consistently through O3N2, extrapolation to lower masses



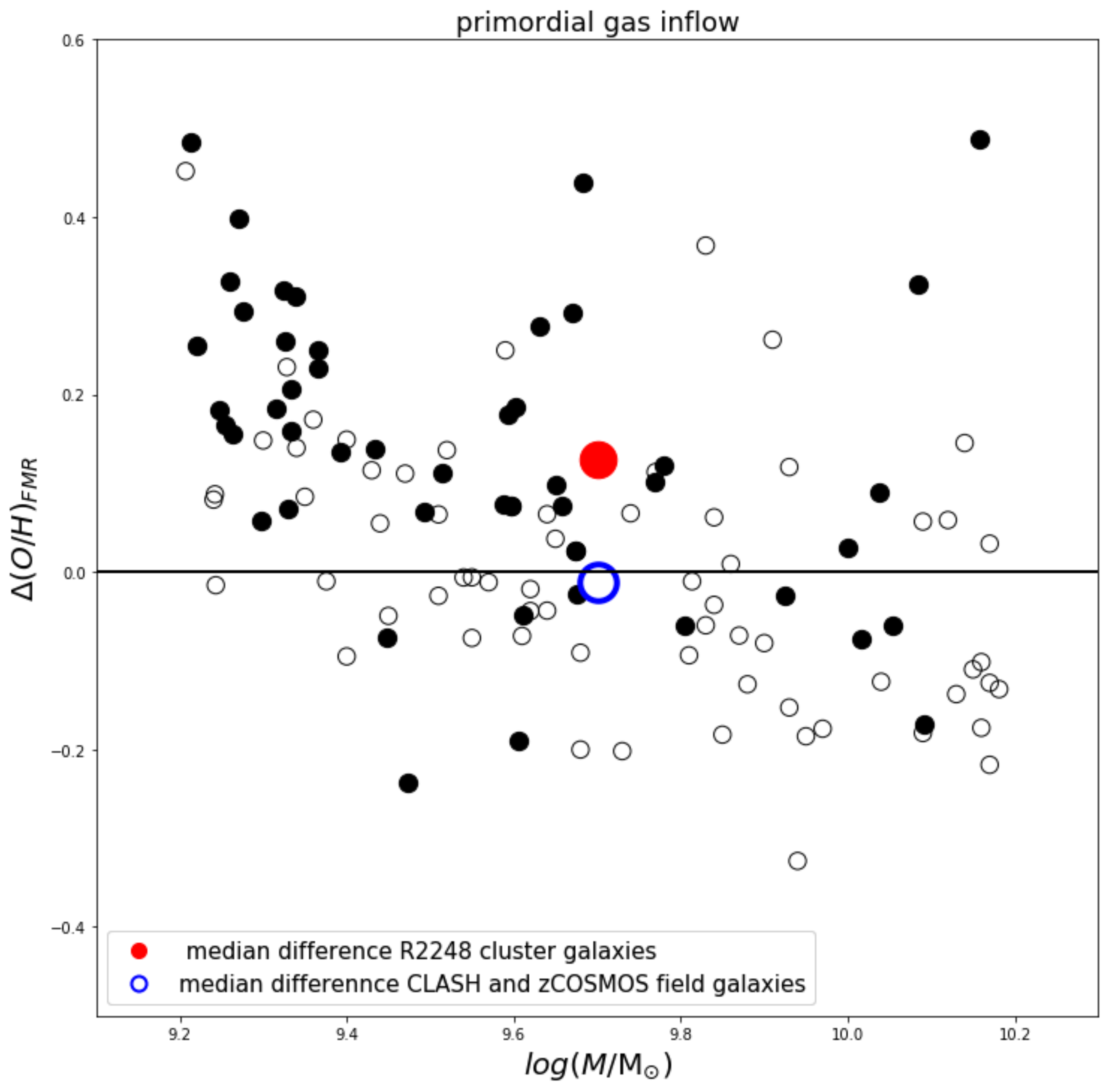
➡Mass complete bin: $9.2 < \log M/M_\odot < 10.2$

➡cluster galaxies in the mass complete bin - more enhanced metallicities than field galaxies: by 0.065 dex with ~ 1.8σ significance

Results: Environmental effects - FMR (Lilly et al. (2013))

$$Z_{eq} = Z_0 + y \cdot (1 - R) \cdot \frac{SFR}{\Phi}$$

Z_{eq} : *equilibrium value for metallicity*
Z_0 : *metallicity of the infalling gas*
y : *yield(mass of metals returned to ISM per unit mass locked up into long lived stars)*
R : *fraction of metals returned to the ISM*
Φ : *gas inflow rate*



- ➡Suppressed Φ or enhanced Z_0 can enhance metallicities!
- ➡model of primordial gas inflow $Z0/y = 0$

➡ Mass complete bin: $9.2 < \log M/M_\odot < 10.2$

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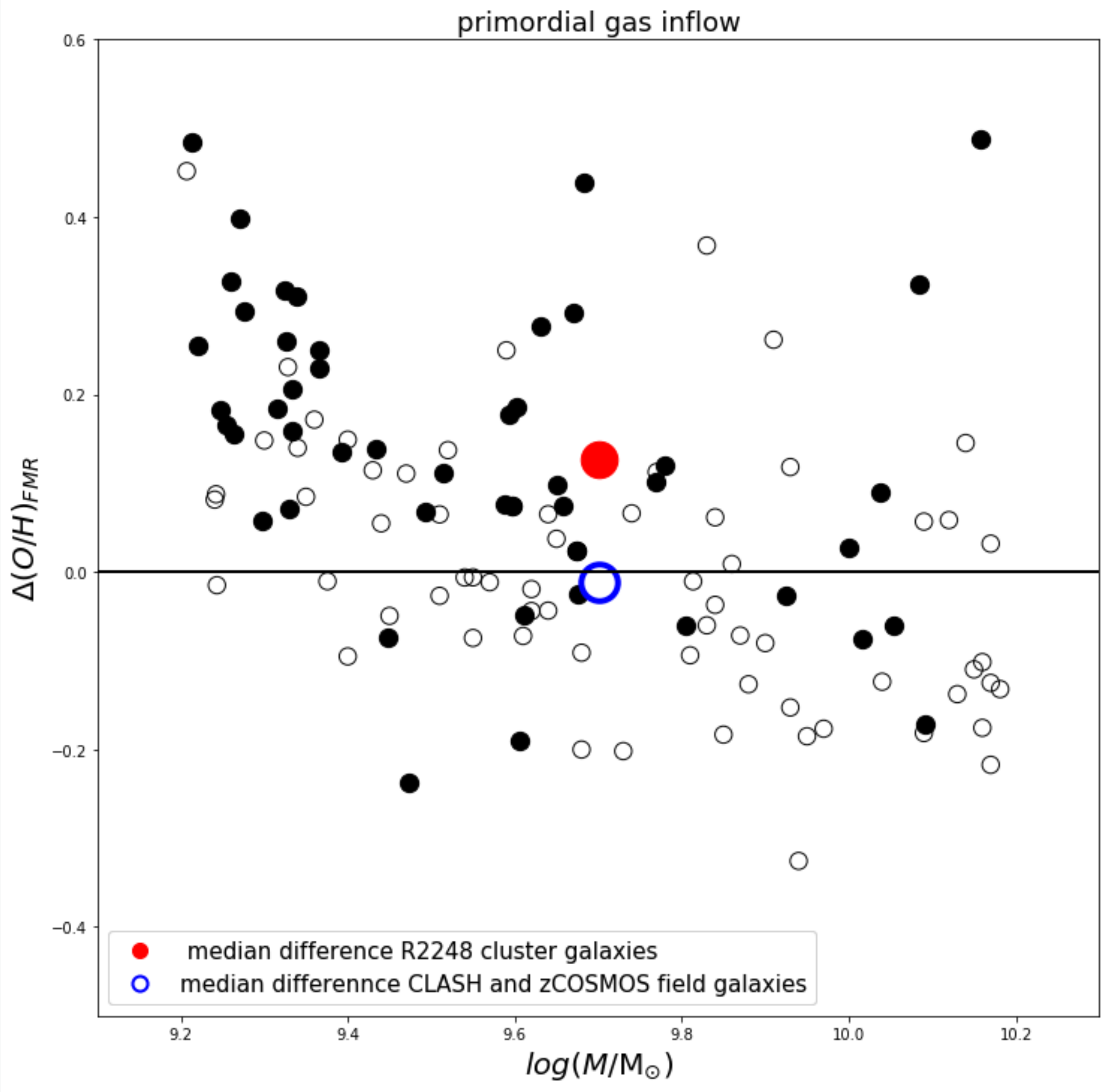


➡(O/H)s of cluster galaxies deviate strongly from the FMR model predictions (by ~ 0.12 dex)

➡(O/H)s of field galaxies in good agreement to FMR model predictions

➡explanation: strangulation

➡see this also in, e.g., Peng & Maiolino et al. (2014), Maier et al. (2016), Maier, Ziegler et al. 2019a

Discussion: Environmental effects

Strangulation is a slow star formation quenching process (Peng et al. 2015, Maier et al. 2016, 2019b, Maier, Ziegler et al. 2019a)

- supply of pristine gas is halted
- SF continues using the cold gas available in the disk
- the quenched galaxies accumulate metals produced by massive stars

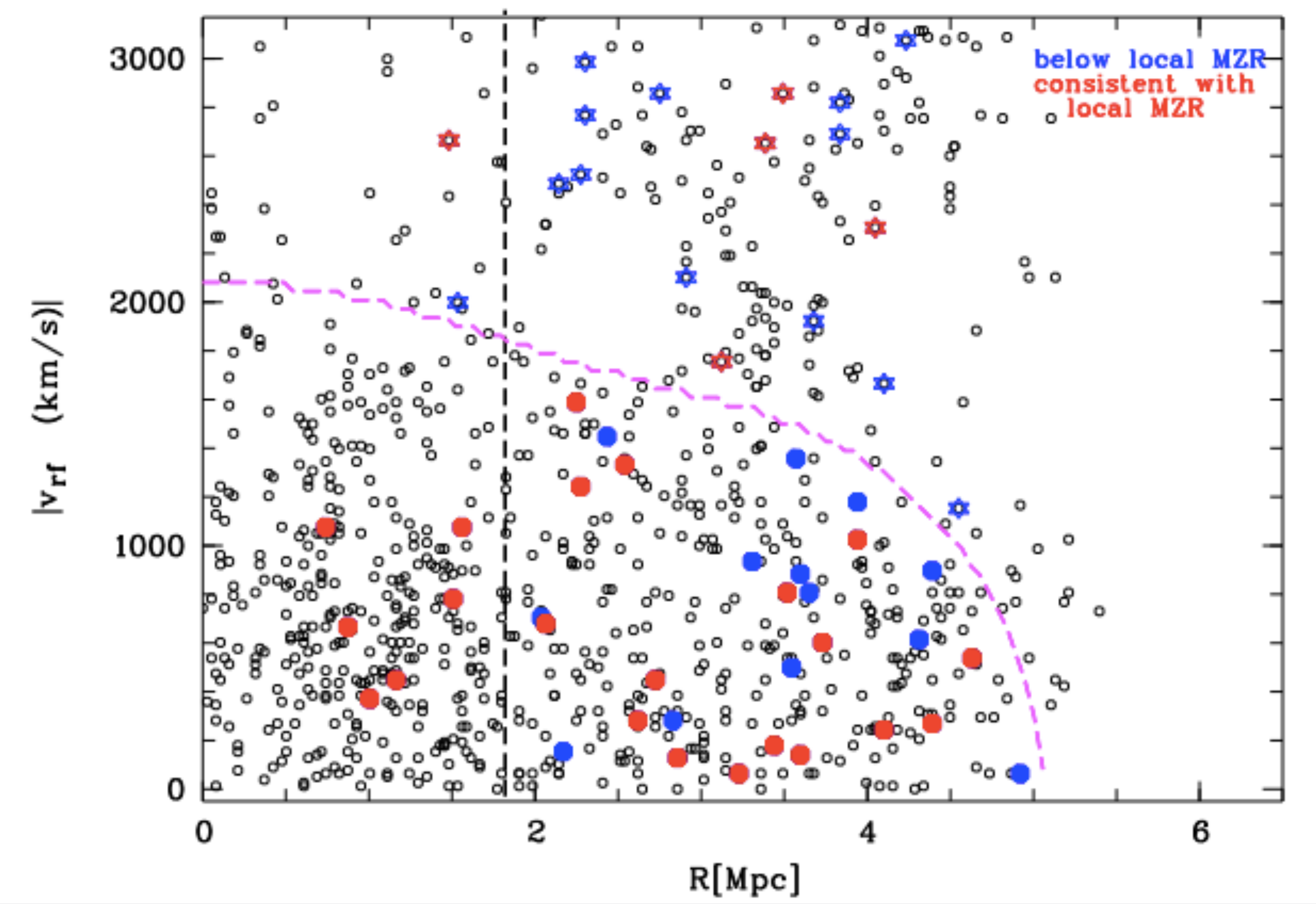
➡ O/H increases

- Ram pressure stripping when $P_{RAM} > P_{restoring}$ (Gott and Gunn et al. 1972)
- P_{RAM} at R_{200} too low to strip cold gas, but sufficient to strip hot gas (Bahé et al. 2013)
- after gas inflow is cut off, O/H can increase ~0.2 dex on time scales of ~1 Gyr (Maier et al. 2006)

Do we see this in other clusters?

CLASH-VLT: MACS J0416.1-2403 **z = 0.39** (Maier et al. 2016)

Phase -space:

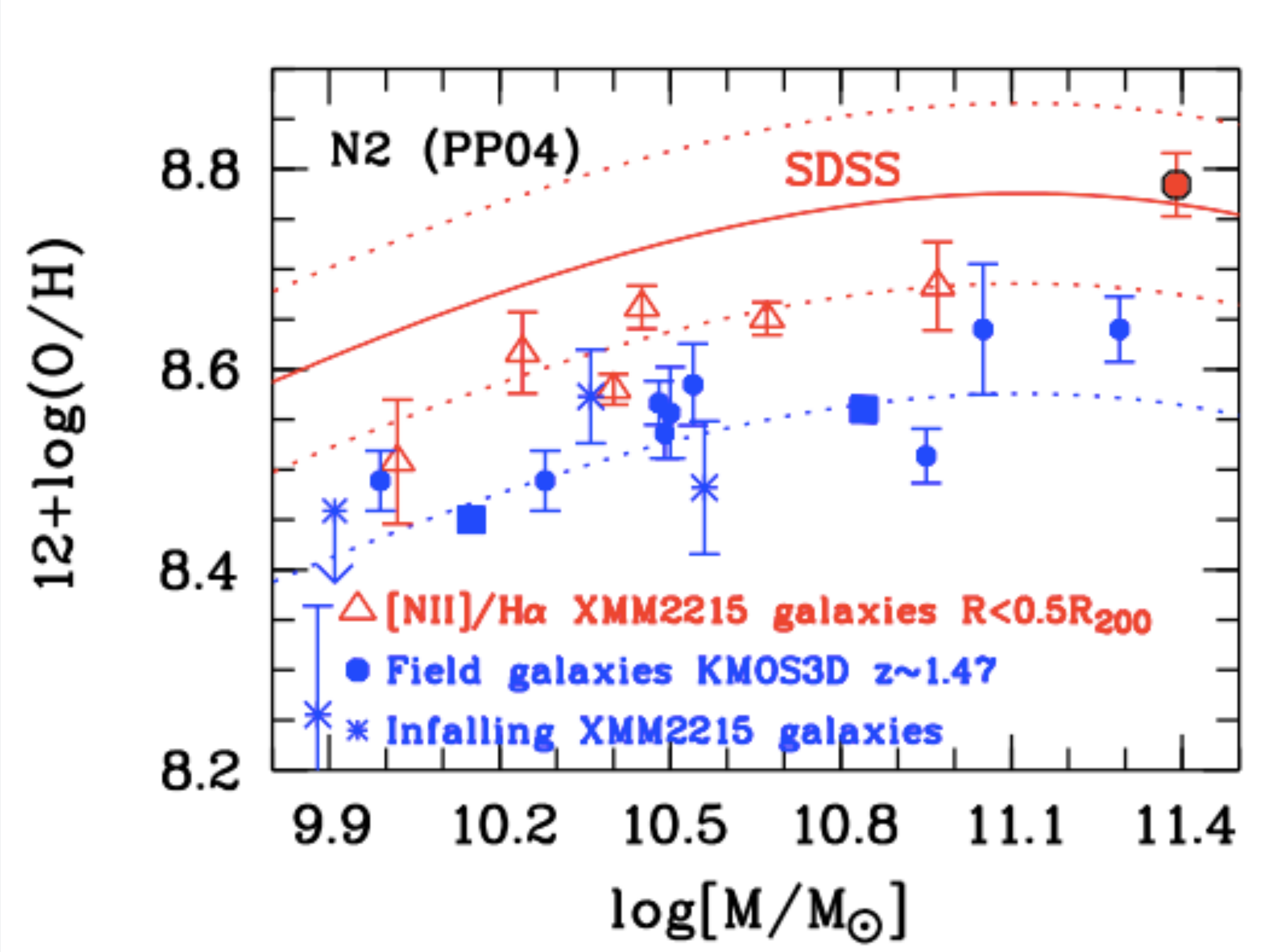


➡Mass complete bin: 9.2 < logM/M⊙ < 10.2

➡accreted galaxies have higher O/H than infalling galaxies in a high mass CLASH cluster

XMMXCS J2215.9-1738 **z ~ 1.5** (Maier et al. 2019b)

MZR:



- ➡galaxies found in higher density environments have higher metallicities than their counterparts residing at lower densities
- ➡we see this effect in a high mass cluster even at high redshifts z~1.5

Conclusion

1. sSFR-M: cluster & field are **“Main sequence” SF galaxies**

2. MZR: in mass complete bin - **more enhanced (O/H)s of cluster galaxies than field galaxies**

3. FMR: in mass complete bin - **cluster galaxies deviate strongly from FMR expectations, while field galaxies are in good agreement**

➡STRANGULATION

Thank you for your attention!

Ciocan, Maier, Ziegler & Verdugo
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Extra: Measurements - Spectroscopy

Emission line fluxes: **[OII] 3727 Å; Hβ 4861 Å; [OIII] 5007Å; Hα 6563 Å; [NII] 6584 Å**

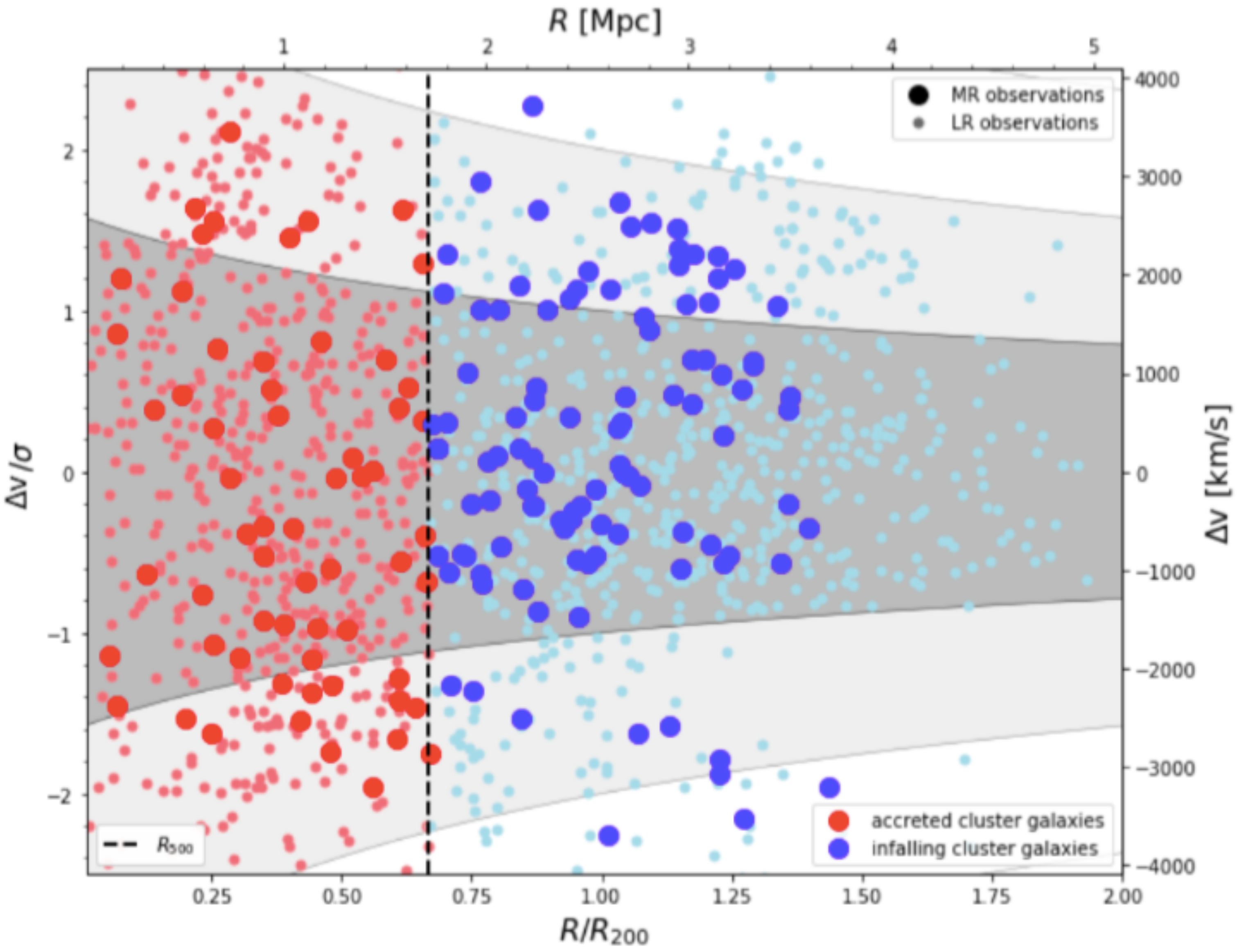
- ➡ **VIPGI** - VIMOS Interactive Pipeline and Graphical Interface
- ➡ **splot in IRAF** - interactive facility to display and analyse spectra
- ➡ population spectral synthesis code **FADO** (Gomez & Papaderos et al. (2017))

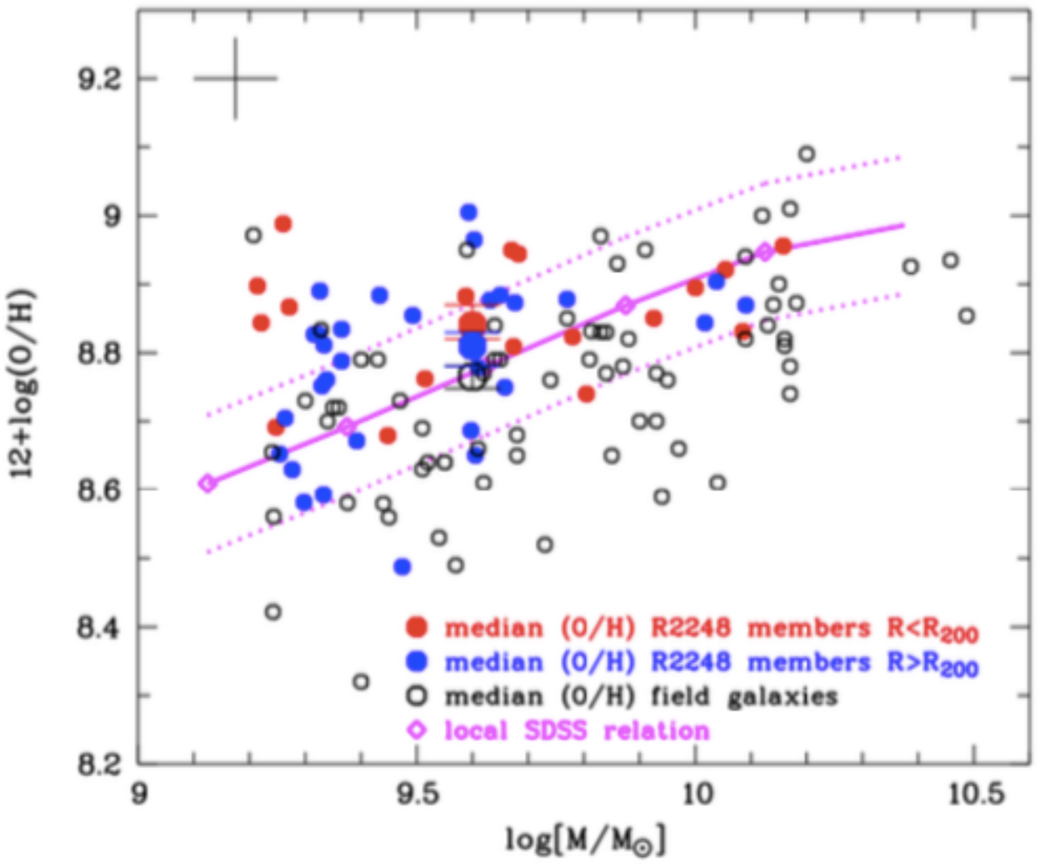
Measurements: Photometry

Stellar Masses:

- ➡ Code LePhare of Arnouts and Ilbert et al. (2011)

Extra Results: Environmental effects





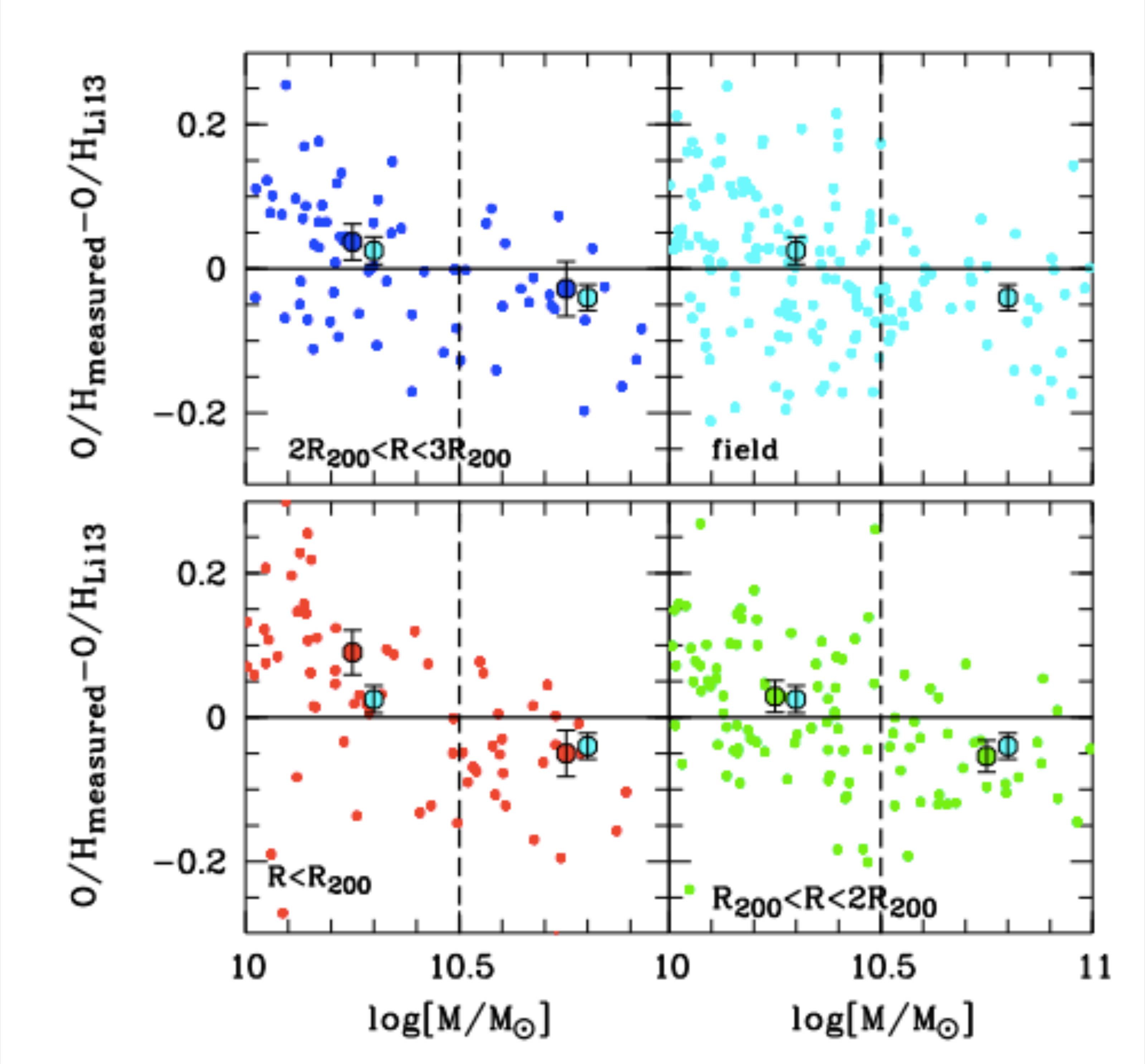
O/H:

➡"accreted" and "infalling" galaxies - comparable O/Hs

➡O/Hs of $R < R_{500}$ galaxies higher than field ~ 1.9σ significance

Extra:LoCuSS: 7 clusters **0.15 < z < 0.26** (Maier et al. 2019a)

FMR:



➡lower M galaxies residing in high density environments deviate most strongly from FMR