Metal deficiency in cluster star-forming galaxies at z=2

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(submitted to ApJ, arXiv:1410.1437)

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Valentino et al. 2014

Nature vs nurture: a (still) interesting story to tell

- How important is the environment in shaping galaxy properties?

Density →

Known density trends at z=0: red, massive, early-type, and quiescent galaxies generally reside in the core of (virialized, X-ray emitting) clusters

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Nature vs nurture: a (still) interesting story to tell

Metallicity keeps record of galaxy formation and evolution processes

"Metallicity" here is intended as **gas-phase oxygen abundance 12+log(O/H)**. It is estimated from emission lines of **ionized interstellar medium** in star-forming galaxies.

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Nature vs nurture: a (still) interesting story to tell

- Do we observe a relation between surrounding density and galaxy metal content at z=0?

"We find that at a given stellar mass, **there is a strong dependence of metallicity on over-density for star-forming satellites** (i.e. all galaxies members of groups/clusters which are not centrals). […] Instead, **for star-forming centrals no correlation is found**." (Peng & Maiolino, 2014)

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Instead
Maiolin

"We find that there is **a strong relationship** between metallicity and environment such that **more metal-rich galaxies favour regions of higher overdensity**." (Cooper et al. 2008)

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Nature vs nurture: a (still) interesting story to tell

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"Taken together, these results show that **galaxies in clusters are, on average, slightly more metal rich than the field, but that this effect is driven by local overdensity** and not simply cluster membership." (Ellison et al. 2009)

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Nature vs nurture: a (still) interesting story to tell

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Maiolin

"We find that there is a strong relationship between metallicity

"Taken together, these results show that galaxies in clusters are, on

avera

driver

meml

"Although **some cluster galaxies are gas-deficient objects, statistically the stellar-mass metallicity relation is nearly invariant to the environment**, in agreement with recent studies." (Hughes et al. 2013)

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Nature vs nurture: a (still) interesting story to tell

- Do we observe a relation between surrounding density and galaxy metal content at z=0?

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"Considering environments ranging from voids […] to the periphery of galaxy clusters […] **we find no dependence of the relationship between galaxy stellar mass and gas-phase oxygen abundance,** along with its associated scatter, on local galaxy density." (Mouhcine et al. 2007)

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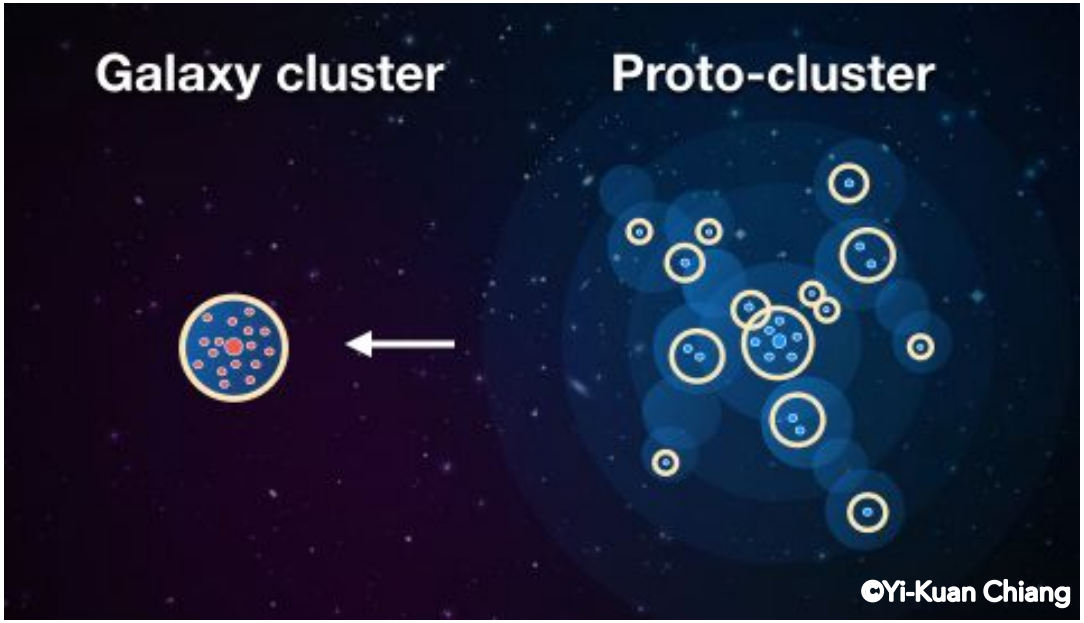
Nature vs nurture: a (still) interesting story to tell

- What about the high-redshift Universe (z>1.5-2)?

- Estimating metallicities becomes challenging
- We approach an epoch where structures were **instrinsically different**



Protocluster star-forming galaxies are found to be **more metal rich than field counterparts at z≈2.15-2.5** (Kulas et al. 2013, Shimakawa et al. 2014).

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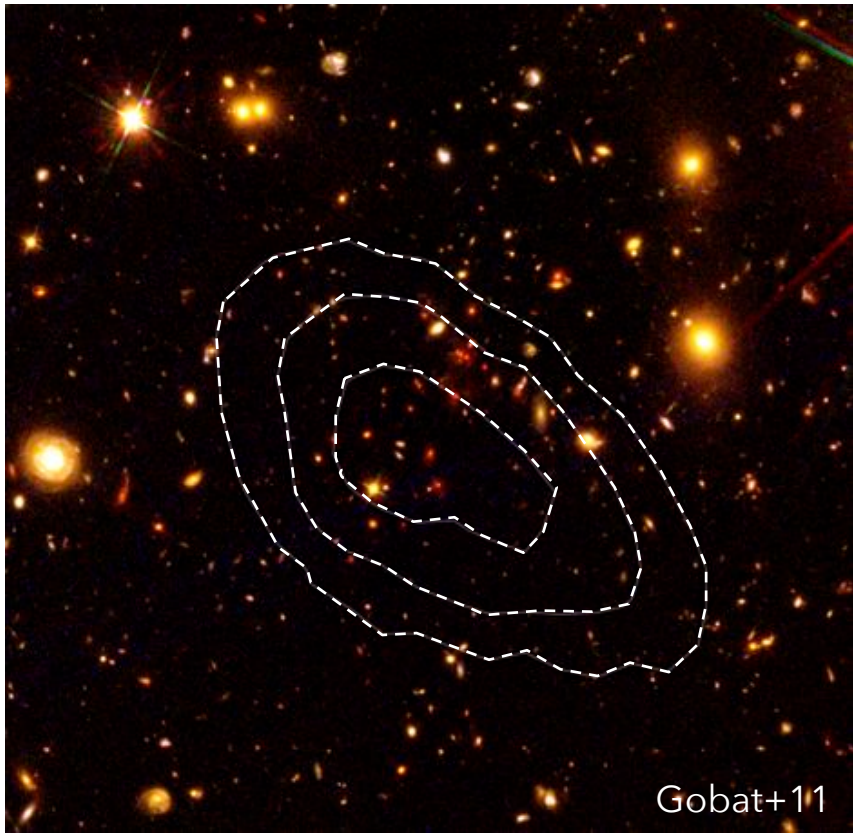
The remarkable case of CL J1449+0856 at z=1.99

A **relatively evolved cluster** (red, massive, quiescent galaxies in the core, diffuse X-ray emission), which hosts **a significant fraction of active galaxies** (Gobat et al. 2011, 2013, Strazzullo et al. 2013).

Extensively followed-up:

- 13-band photometry (**SED modelling**)
- HST/WFC3 slitless spectroscopy ([O II], Hβ, [O III] at z~2)
- **Subaru/MOIRCS HK spectroscopy of star-forming galaxies**



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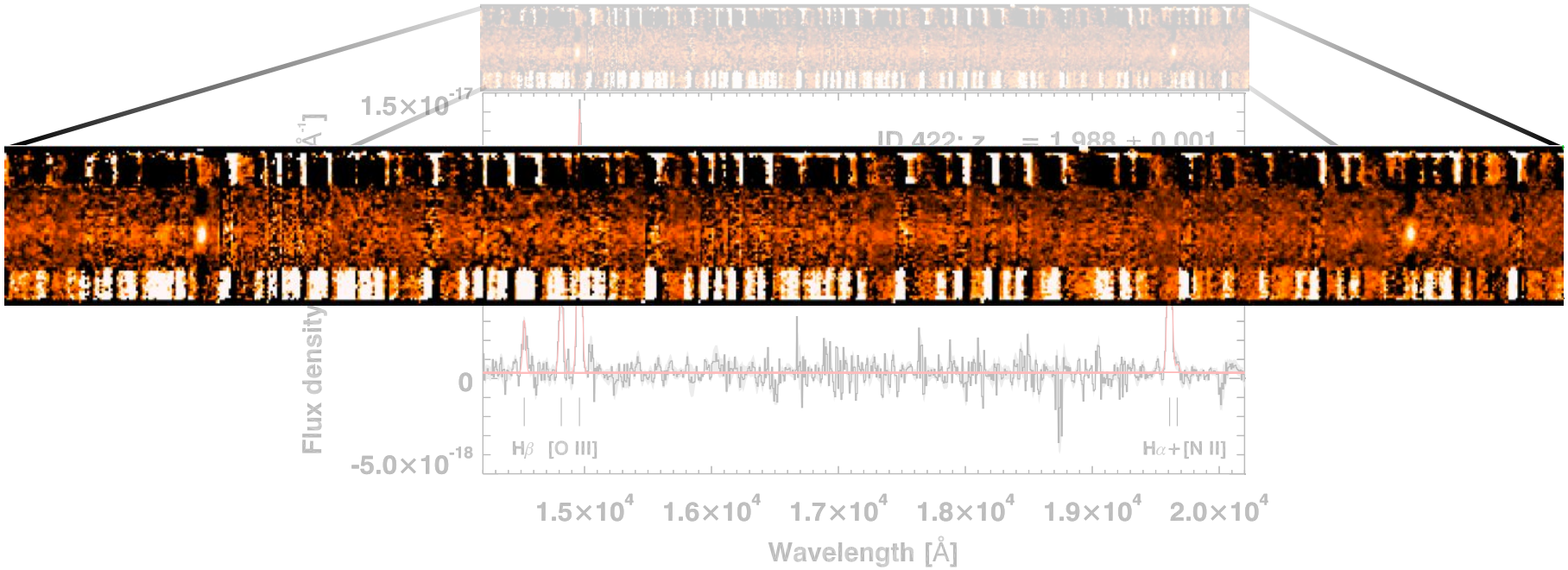
Near-infrared vision: MOIRCS follow-up

- Follow-up of 110 SFGs (including 10 cluster members) to primarily detect Hα and [N II]λ6583Å.
- 71% success rate in detecting Hα (3σ, minimum flux ≈ 1.4×10^{-17} erg cm^{-2} s^{-1}), 20% in detecting [N II]. Upper limits on the remaining sample detected in Hα.
- [O III] and Hβ in the wavelength range according to redshift or from WFC3 G141.



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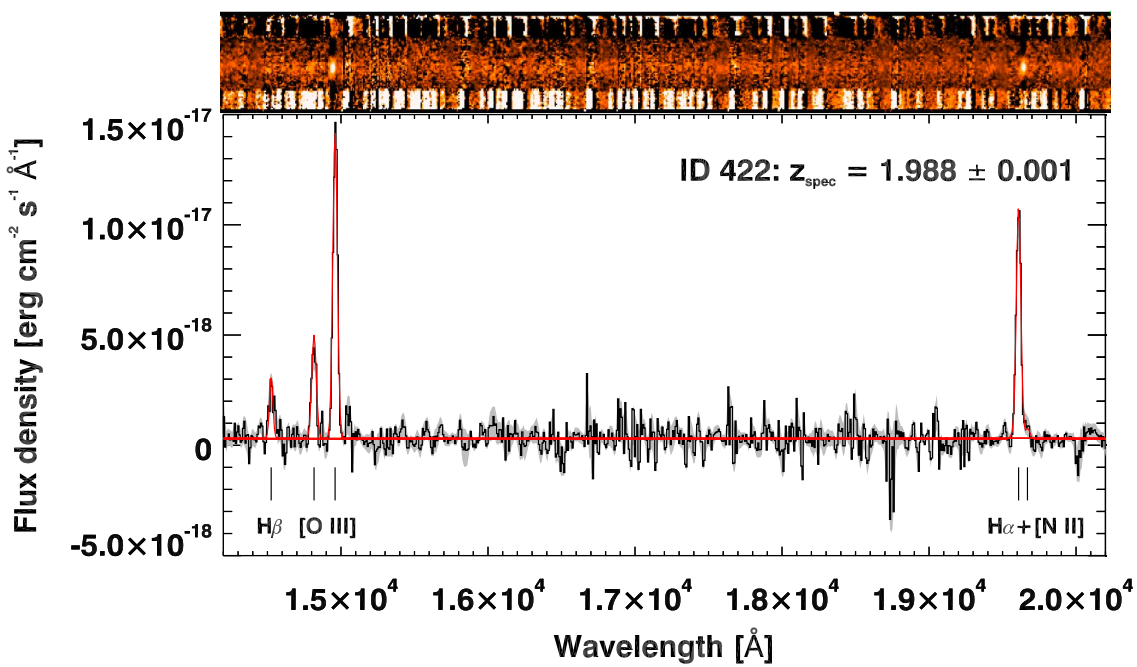

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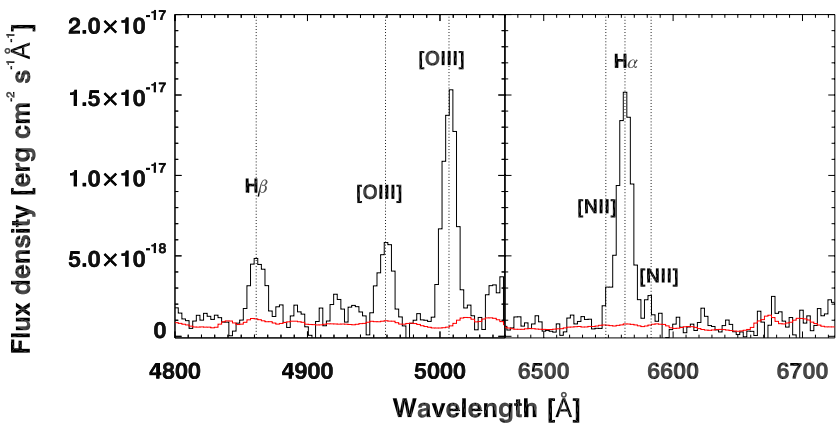
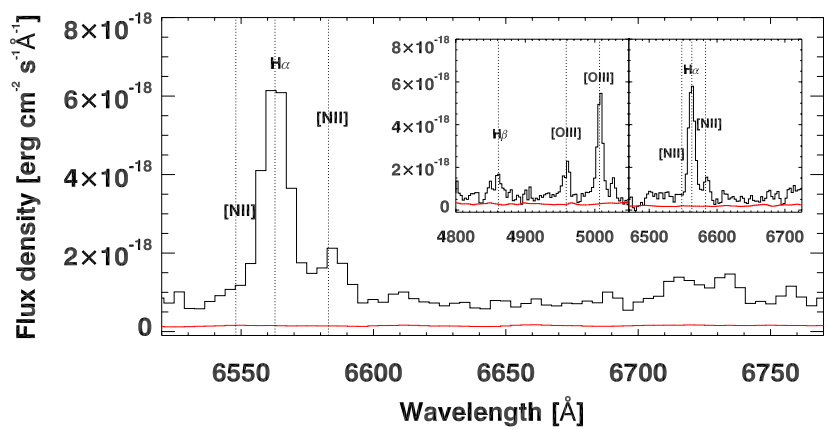
Near-infrared vision: MOIRCS follow-up

Stacking individual spectra in the **mass range $10^{10} \leq M_\star/M_\odot \leq 10^{11}$**: 6 cluster sources, 31 field sources (with [N II], Hα in the observed range).

For a cluster subsample of 5/6 galaxies we could stack WFC3 spectra, having access to [O II]λ3727Å emission line.





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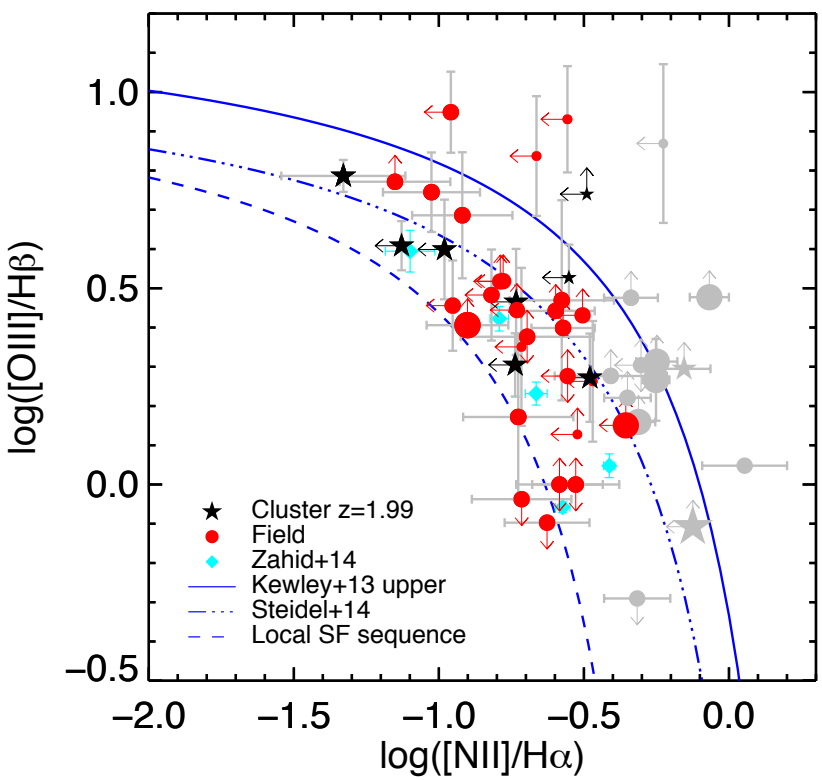
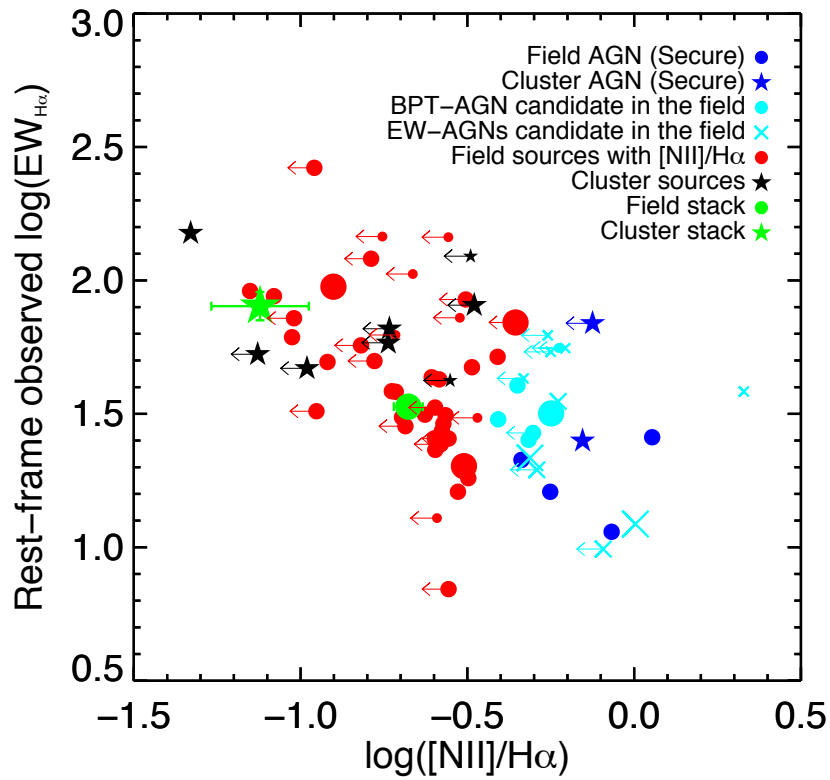
Near-infrared vision: MOIRCS follow-up

AGN rejection combining X-ray emission, BPT (Baldwin et al. 1981) and [N II]/Hα-EW(Hα) diagrams (Cid Fernandes 2010).





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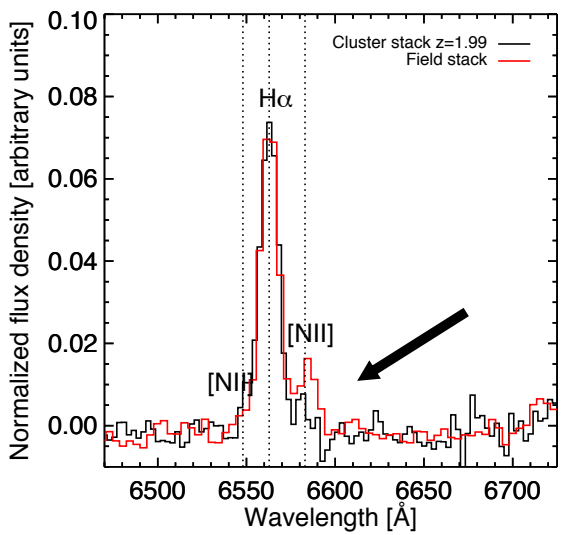
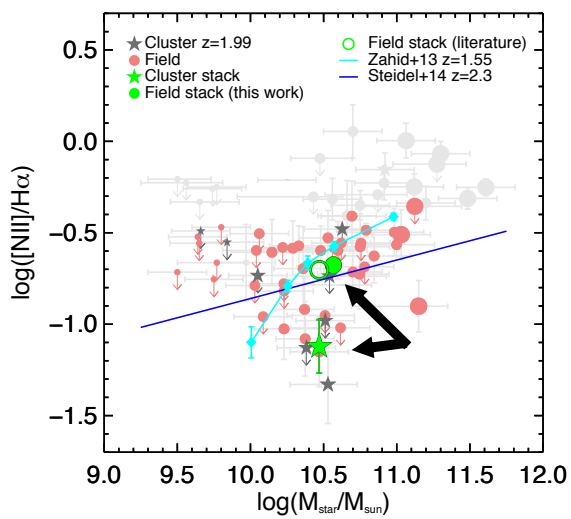
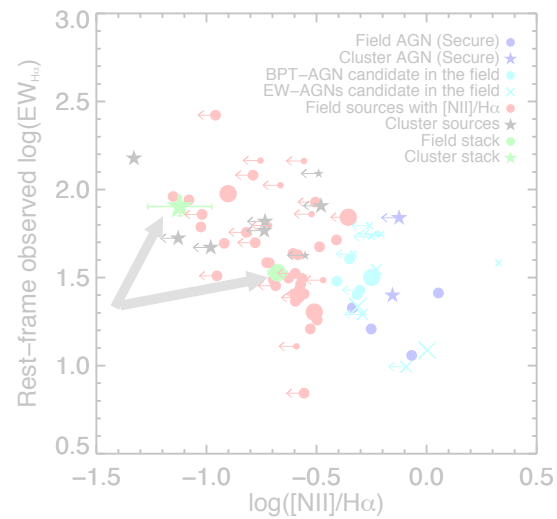
Observing an environmental signature

We detect a **≈4σ significant lower [N II]/Hα ratio in the cluster stacked sample** than in the mass-matched field sample (while [O III]/Hβ is compatible between the two).

We detect a **≈4.7σ significant higher observed EW(Hα) in the cluster stacked sample** than in the mass-matched field sample.







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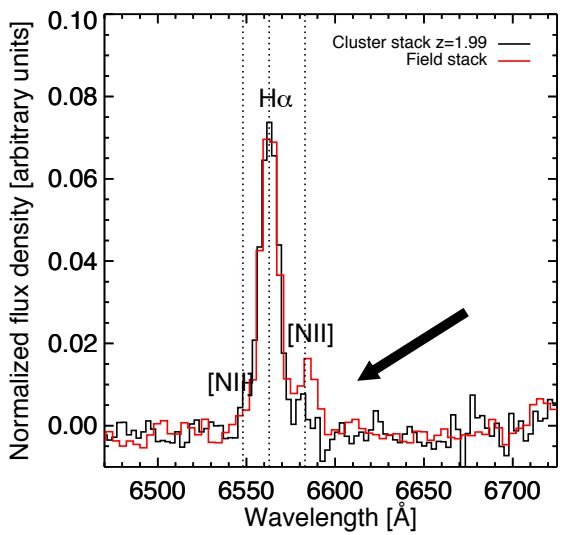

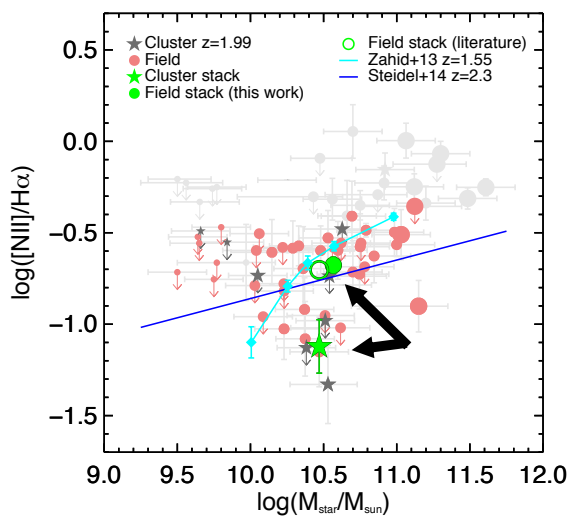

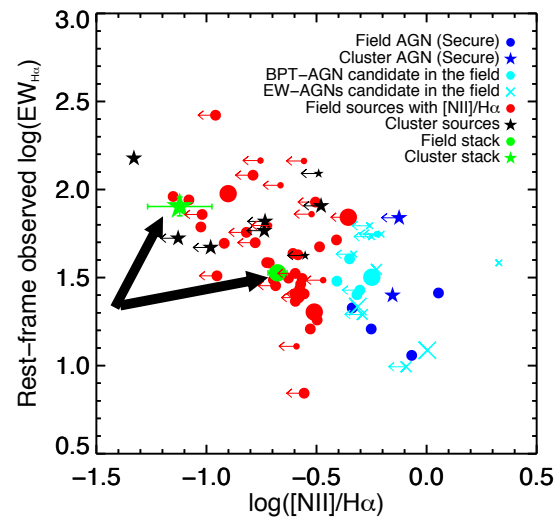

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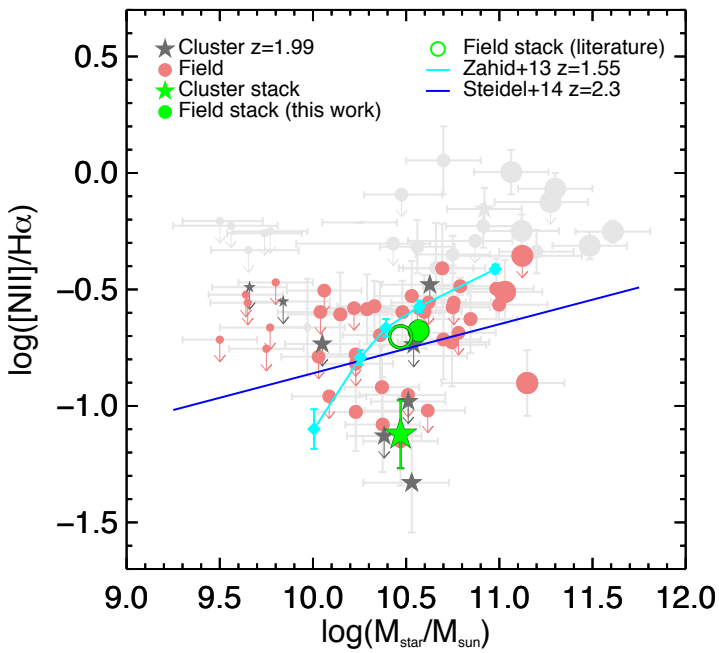
Gaining physical insight

We can convert [N II]/Hα in **gas-phase oxygen abundance 12+log(O/H)** by means of a proper calibration (e.g., Pettini & Pagel 2004, Steidel et al. 2014).

$$12+\log(O/H) = a + b\times\log([N\,II]/H\alpha)$$



Thus, star-forming galaxies in CL J1449+0856 are on average more metal poor than mass-matched field counterparts (by ≈0.09-0.25 dex, according to the calibration or indicator used)

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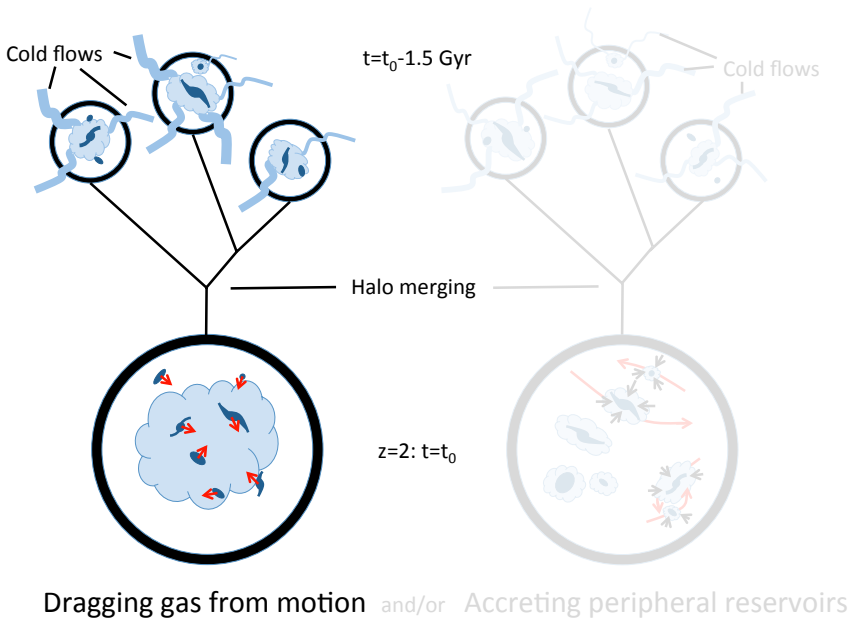
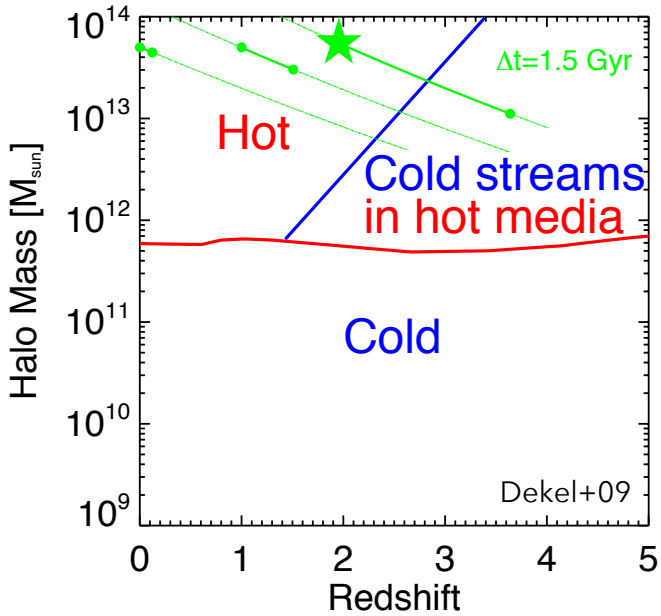
A speculative picture of the situation

We ascribe lower metallicities in cluster star-forming galaxies to **the accretion of pristine gas** from the surroundings, facilitated by the **"gravitational focusing effect"** (Martig & Bournaud 2007):





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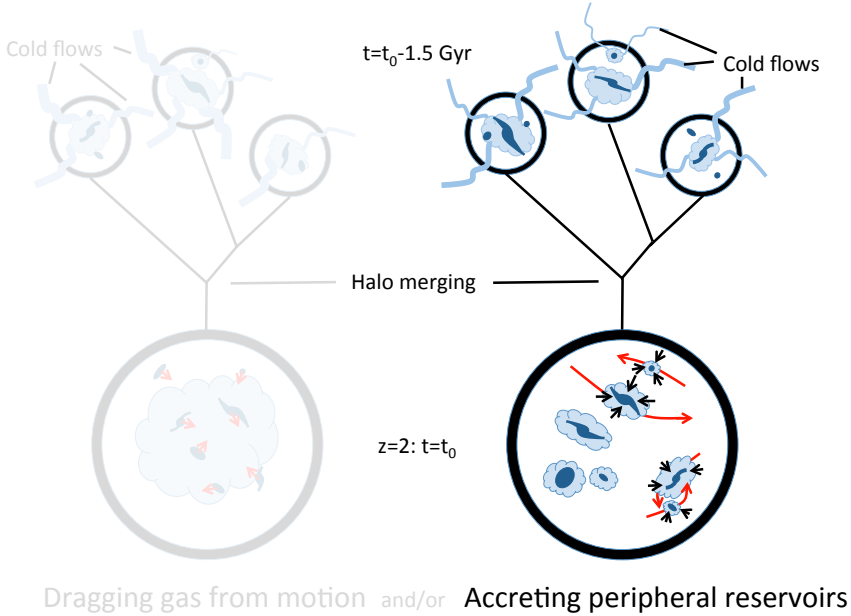

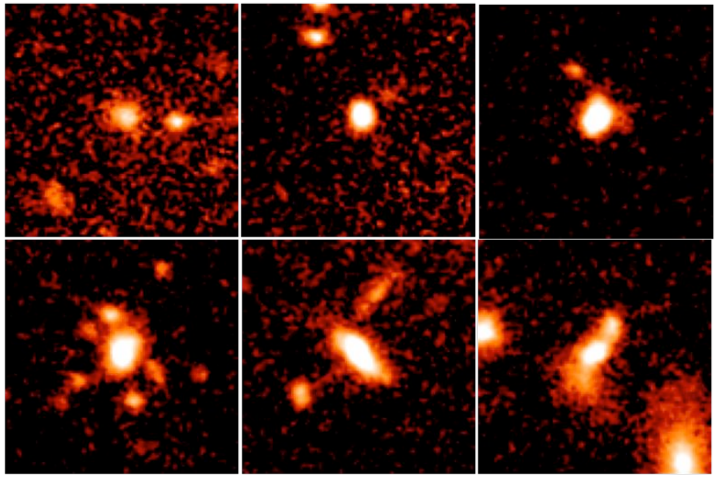

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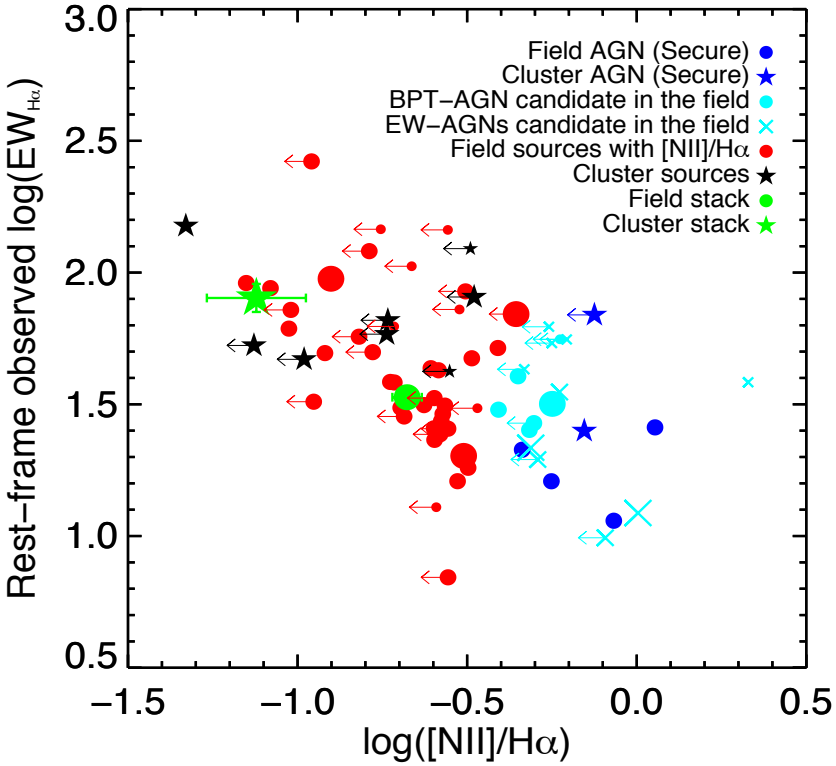
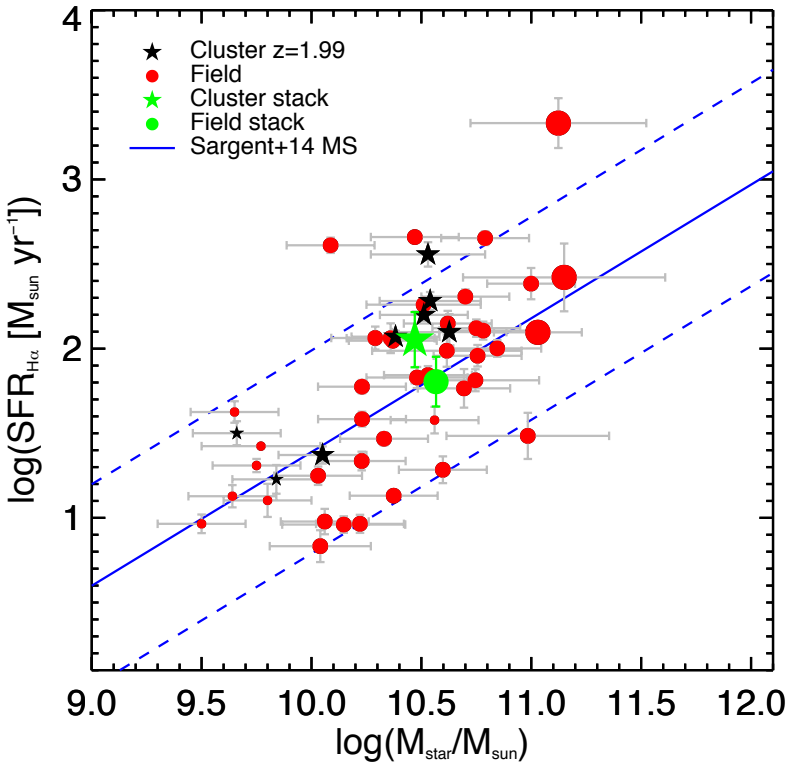
A possible enhancement of sSFR

This picture could explain also the higher observed EW(Hα) - **a proxy for the sSFR** - in cluster star-forming galaxies: **the accreted pristine gas would be triggering extra-star formation**. However, a firm conclusion is prevented by the uncertainties on the reddening correction.





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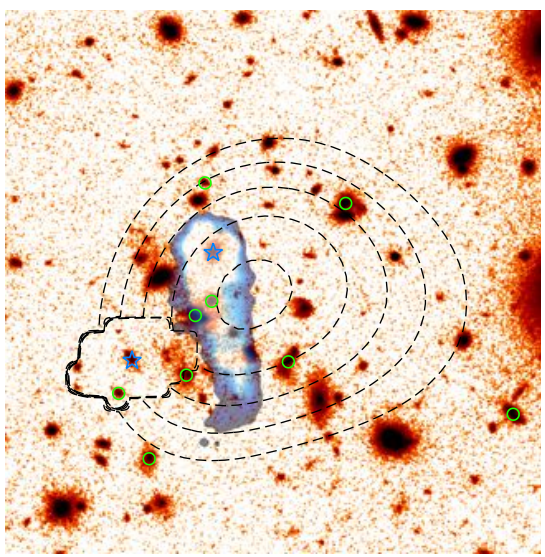
What does the future hold for us?

- Searching for similar clusters at $z \approx 2$: **overdensities of red, massive, and quiescent galaxies** (Strazzullo et al. submitted)

  > VLT/KMOS accepted program to confirm a candidate structure at $z \approx 2.2$ in COSMOS and measure [N II]/Hα

- Diffuse gas in the structure

  > **Lyα diffuse halo detected in the cluster core** with Keck/LRIS narrow-band imaging (Valentino et al. in prep.)



"Warm" diffuse gas (>150 kpc, T ≈ $10^{4\text{-}5}$ °K), possibly ionized by a soft X-ray AGN.
> Is it metal enriched material ejected by the AGN? Or metal poor accreted gas? What is its relation with the hot X-ray emitting medium?
> VLT/X-Shooter P95 proposal

Valentino et al. 2014

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- Look for **signatures of enhanced gas fractions** in cluster galaxies and census of total star-formation rate in the core

  > ALMA continuum at 850μm and CO[3-2] observations ongoing (PI: Strazzullo)

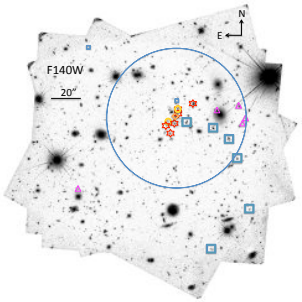
- **Morphological analysis** of the cluster and field sample to assess the incidence of mergers

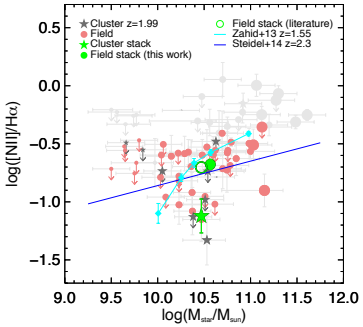
Valentino et al. 2014

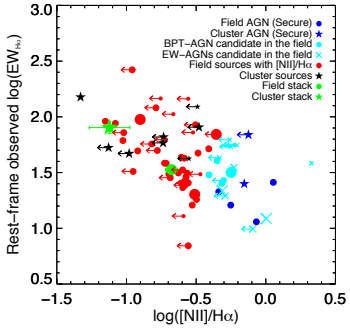
Summary

- Subaru/MOIRCS follow-up of cluster SFGs in CL J1449+0856 at z=1.99
- Through stacking **we detect significant (>4σ) lower [N II]/Hα ratio and higher observed EW(Hα) in cluster SFGs than in a mass-matched field sample** at comparable redshift ($10^{10} \leq M_\star/M_\odot \leq 10^{11}$)
- We interpret the lower [N II]/Hα as **lower gas-phase metallicity** in cluster SFGs ionized medium
- We ascribe these effects to the **accretion of pristine gas** on cluster scales and/or due to mergers, both facilitated by the gravitational focusing effect

Further details in Valentino et al. 2014 (arXiv:1410.1437)







Back up

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Gaining physical insight

We can convert [N II]/Hα in **gas-phase oxygen abundance 12+log(O/H)** by means of a proper calibration (e.g., Pettini & Pagel 2004, Steidel et al. 2014).

Known issues:

- Different calibrations give different absolute metallicities (Kewley & Ellison 2008)
- Standard calibrations are based on low-redshift galaxies
- Nitrogen-to-oxygen ratio is involved
- [N II]/Hα is sensitive to the ionization parameter

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- We are measuring **relative** differences
- We apply alternative line ratio metallicity indicators when possible (*O3N2* and O_{32}, R_{23} for the cluster only). They are all in agreement with a low metal content in cluster star-forming galaxies.

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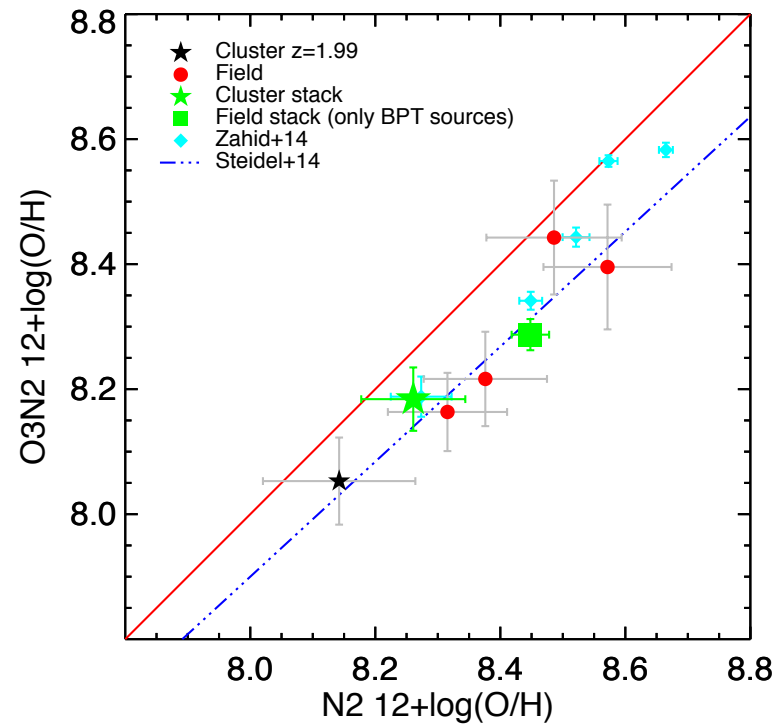

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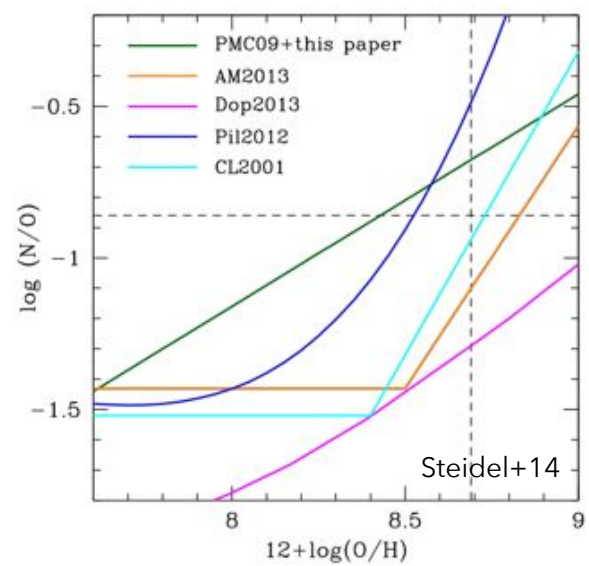
We estimated N/O from [N II]/[O II] for the cluster only (Perez-Montero & Contini 2013):

log(N/O) = -1.18±0.19



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- Nitrogen-to-oxygen ratio is involved
- [N II]/Hα is sensitive to the ionization parameter $\mathcal{U}$

For the cluster only, we could estimate $\mathcal{U}$ from O_{32}, R_{23} following Kobulnicky & Kewley 2004:

$$\mathcal{U} \cong -2.61$$

which is comparable with values measured in high redshift field galaxies

($-2.9 < \mathcal{U} < -2.0$)

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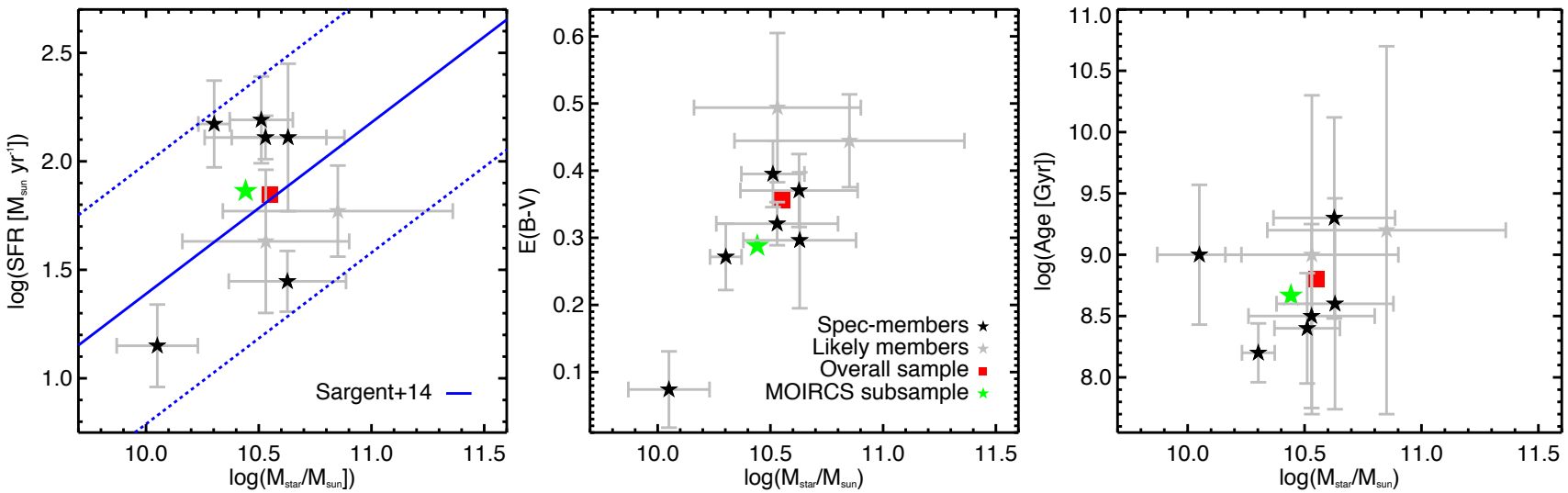
Possible selection effects



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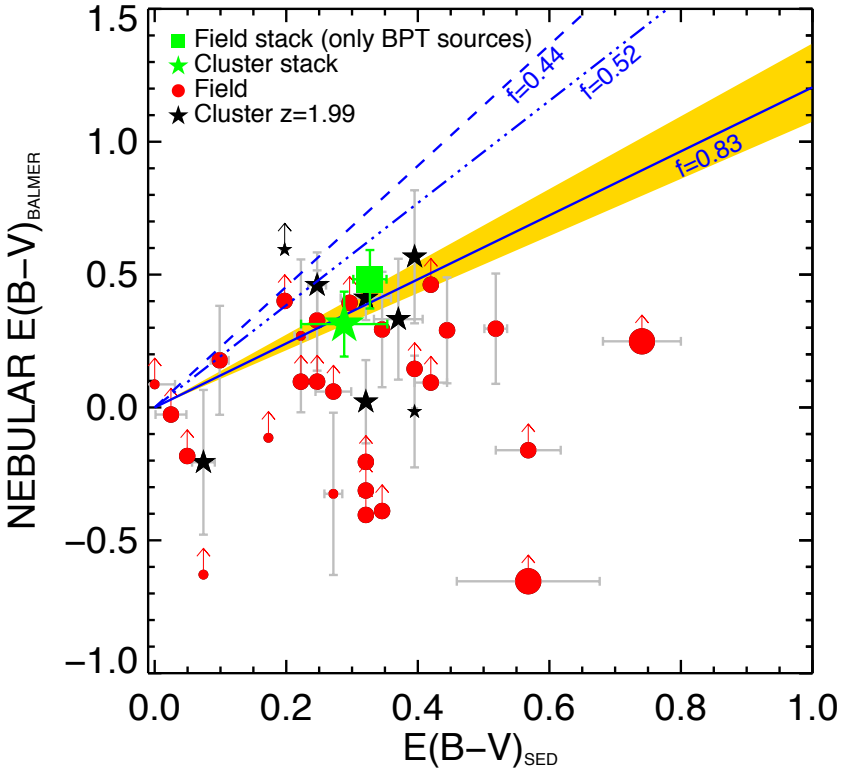
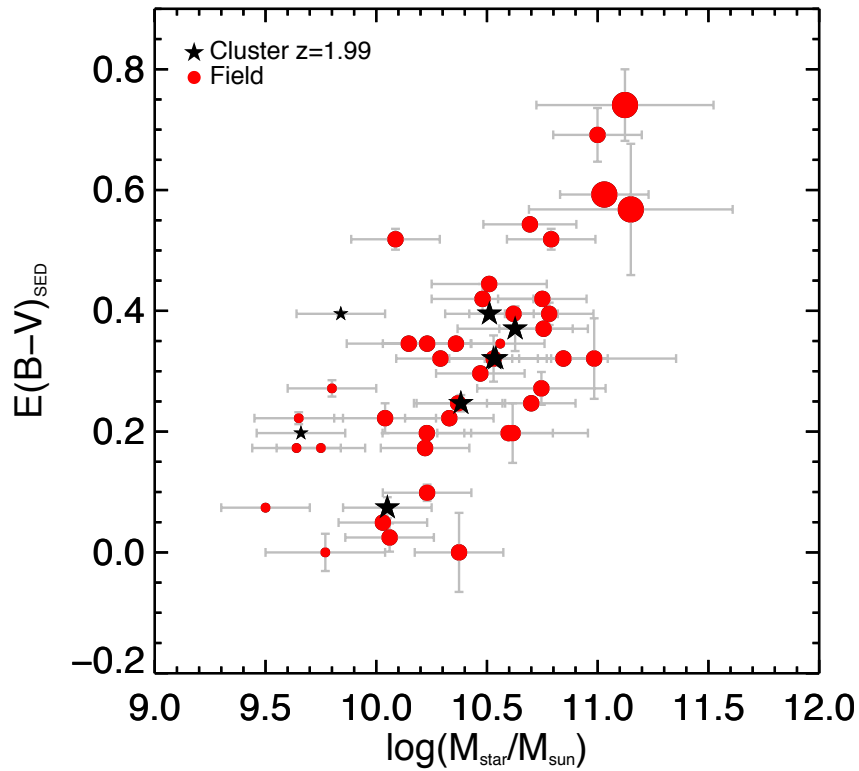
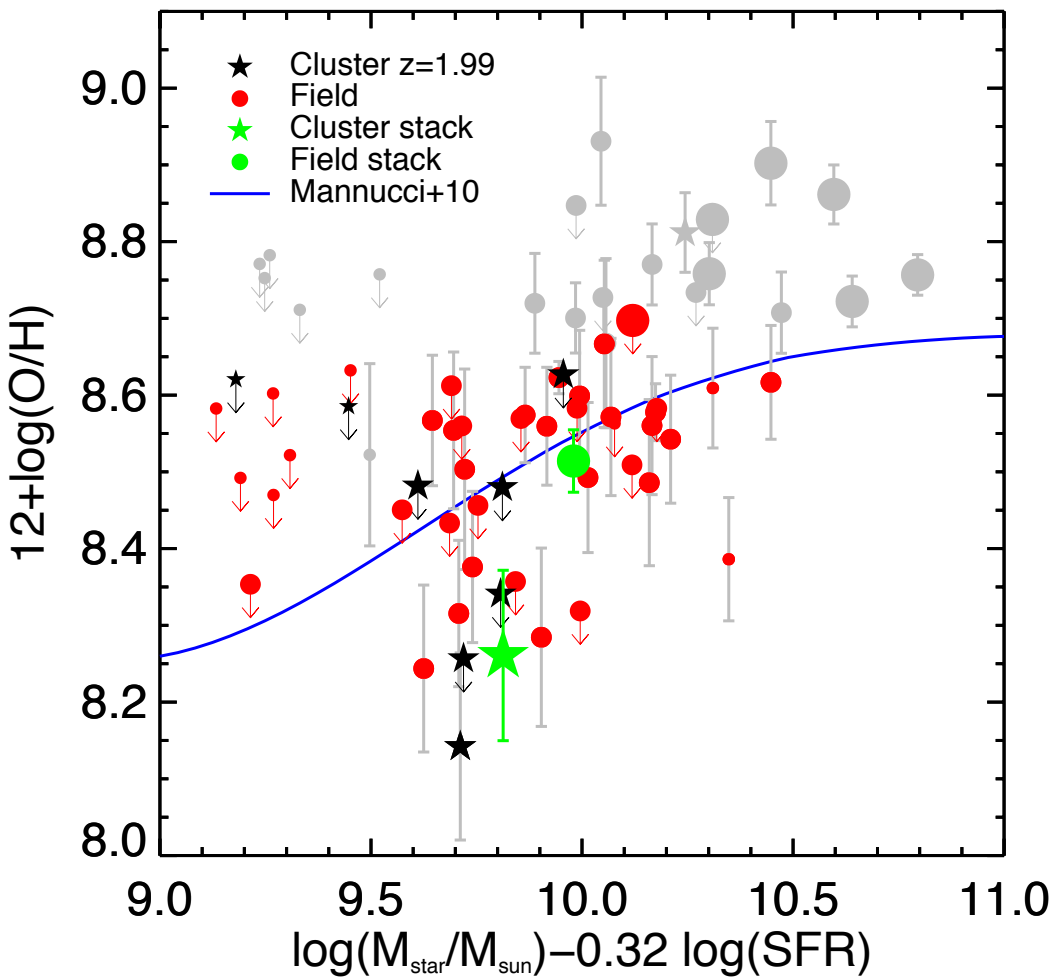
Nebular reddening





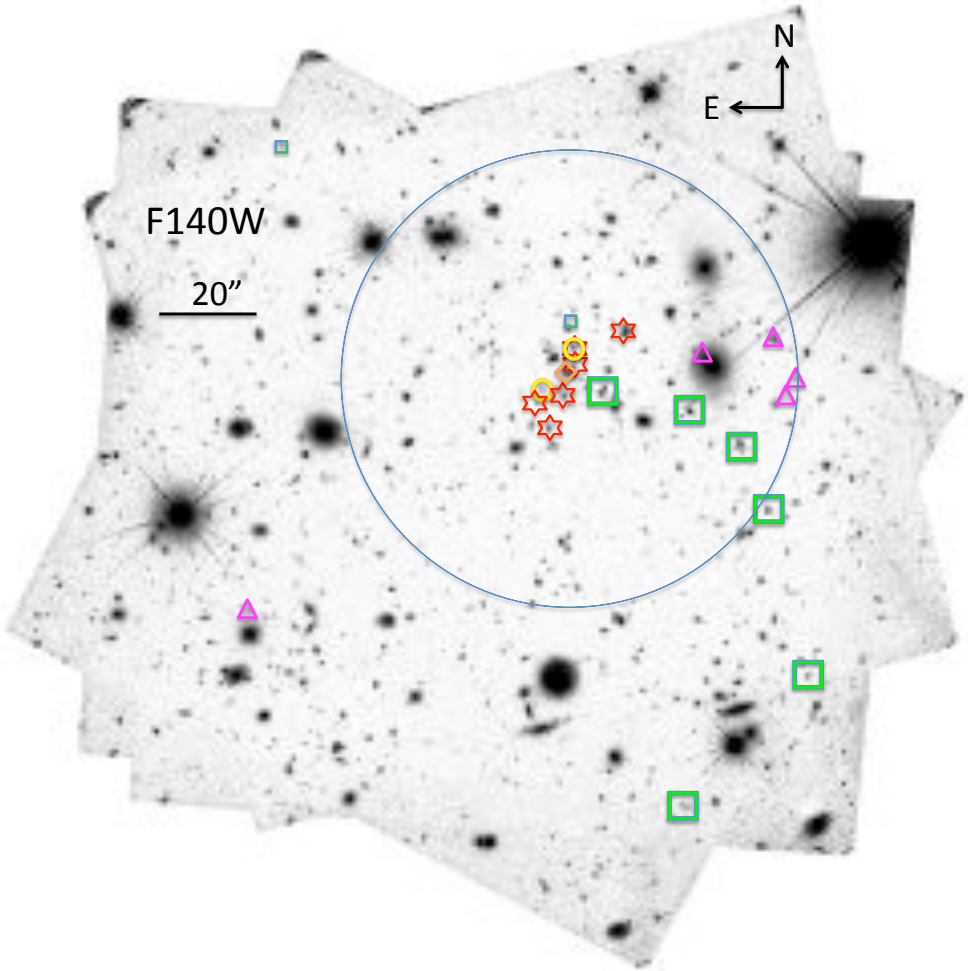
Valentino et al. 2014

Fundamental Metallicity Relation



Valentino et al. 2014

A speculative picture of the situation



Assembling/accreting feature?