Anatomy of an X-ray detected cluster at z = 2: low metallicities and enhanced specific star formation rates in star-forming galaxies.

F. Valentino[1], E. Daddi[1], V. Strazzullo[1,2], R. Gobat[1,3], F. Bournaud[1], S. Juneau[1], A. Zanella[1] et al.

[1] CEA-Saclay, [2] LMU-Munich, [3] KIAS-Seul

(ApJ, 801, 132)

Contact email: francesco.valentino@cea.fr

Dissecting Galaxies Near and Far, Santiago, March 23rd

Valentino et al. 2015

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

- How important is the environment in shaping galaxy properties (and quenching)?

Density →

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

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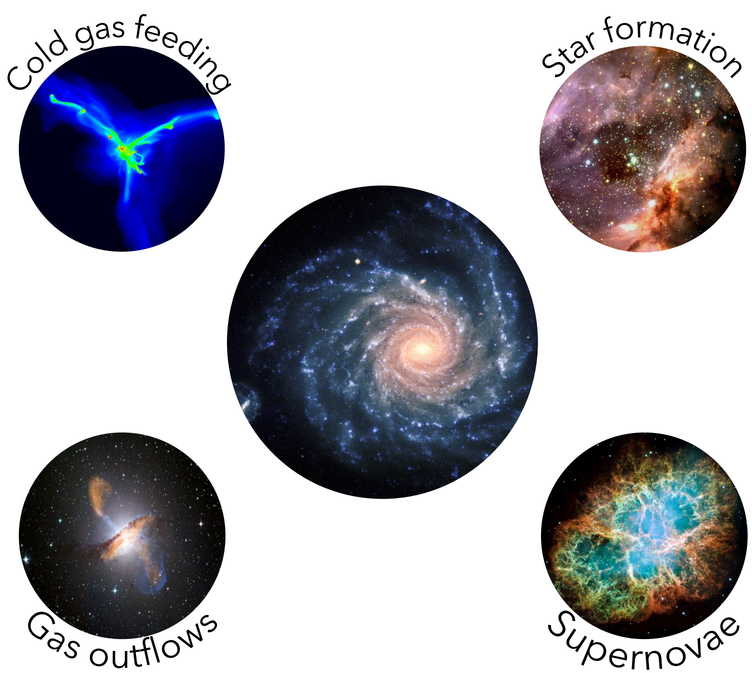
Nature vs nurture: a (still) interesting story to tell

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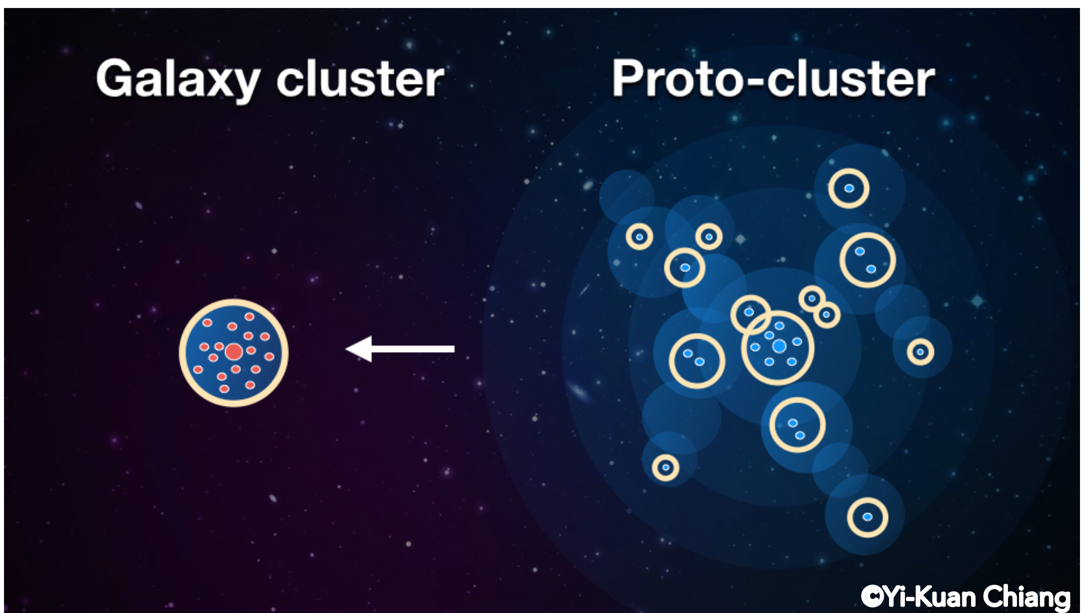
Nature vs nurture: a (still) interesting story to tell

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

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



Protoclusters' 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).

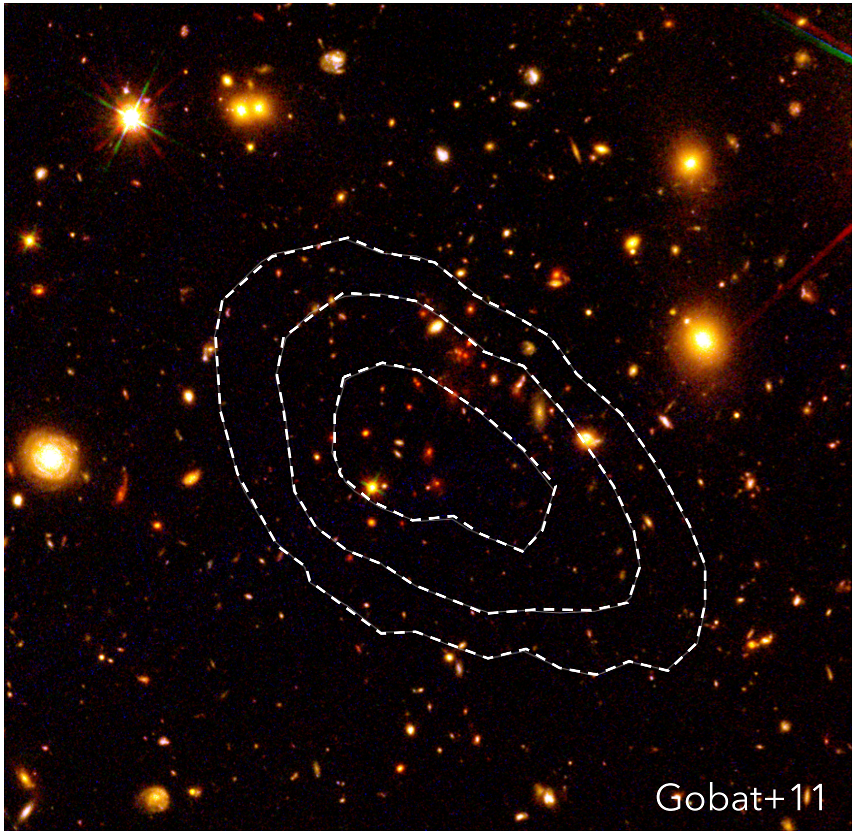
Valentino et al. 2015

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**



Valentino et al. 2015

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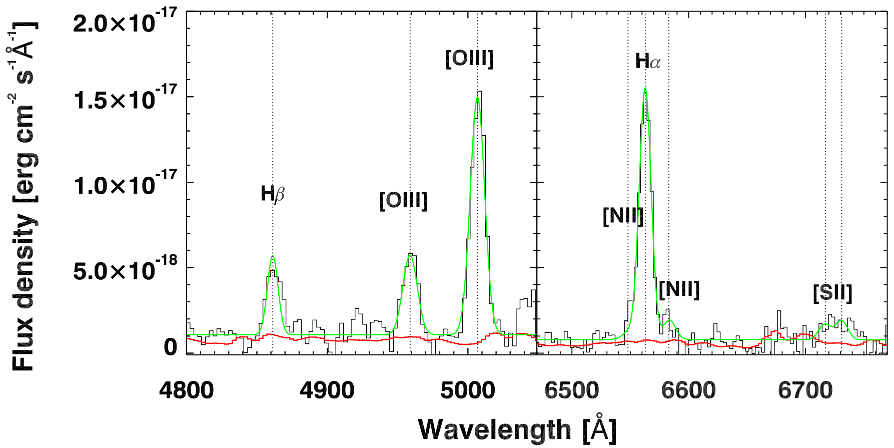
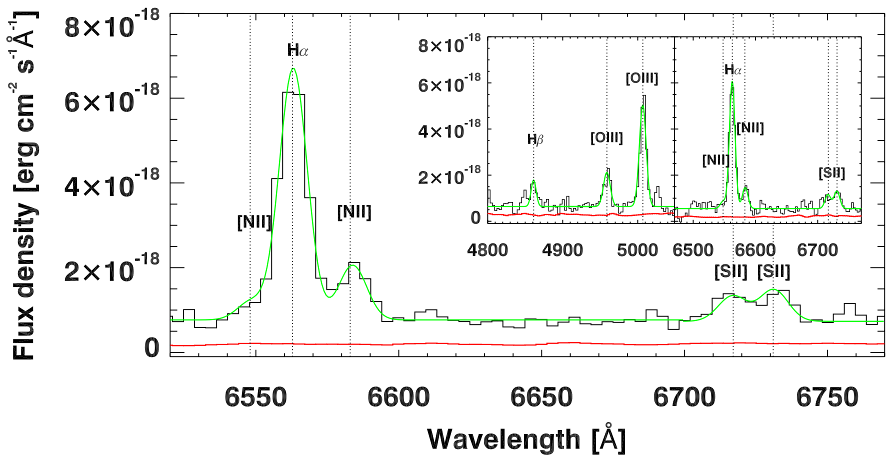


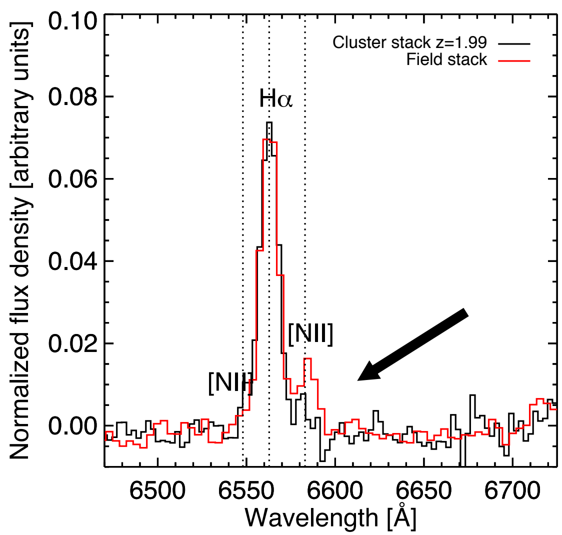


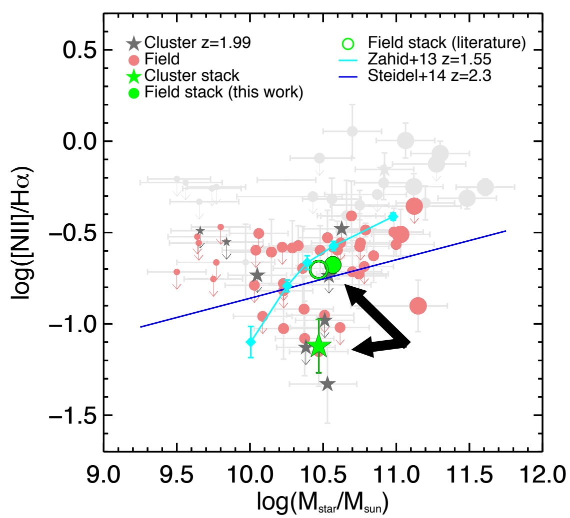
Valentino et al. 2015

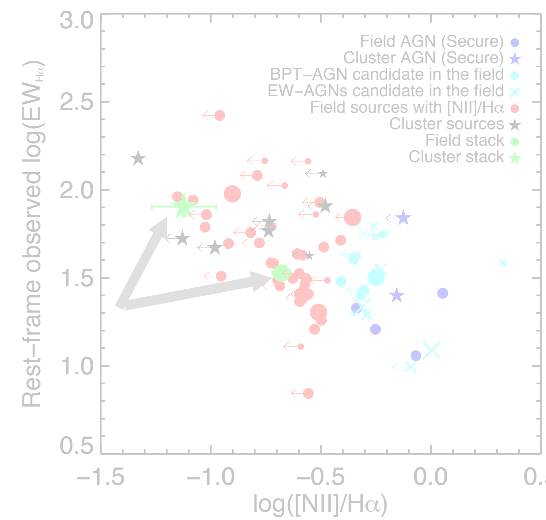
Observing an environmental signature

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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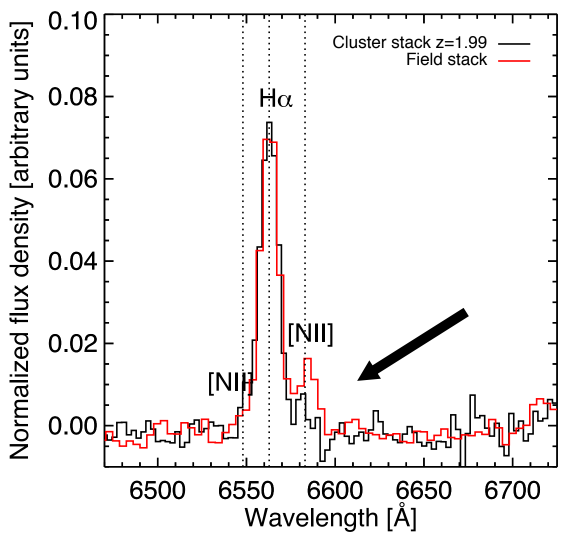
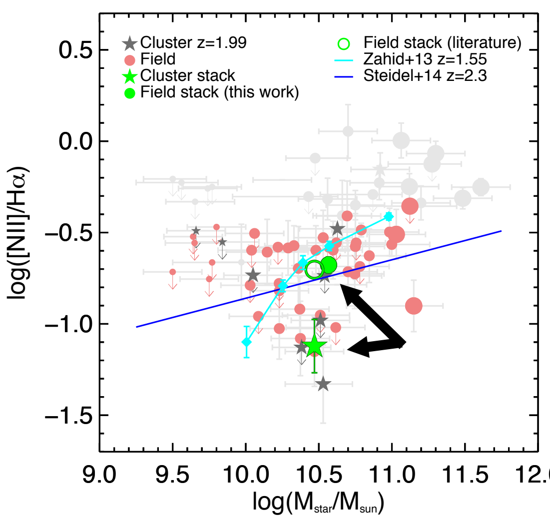
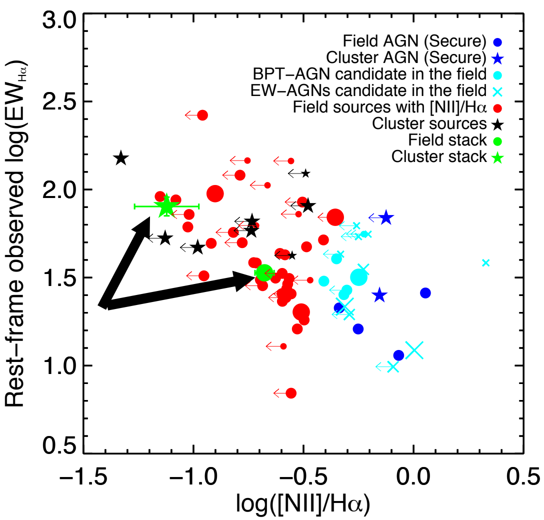




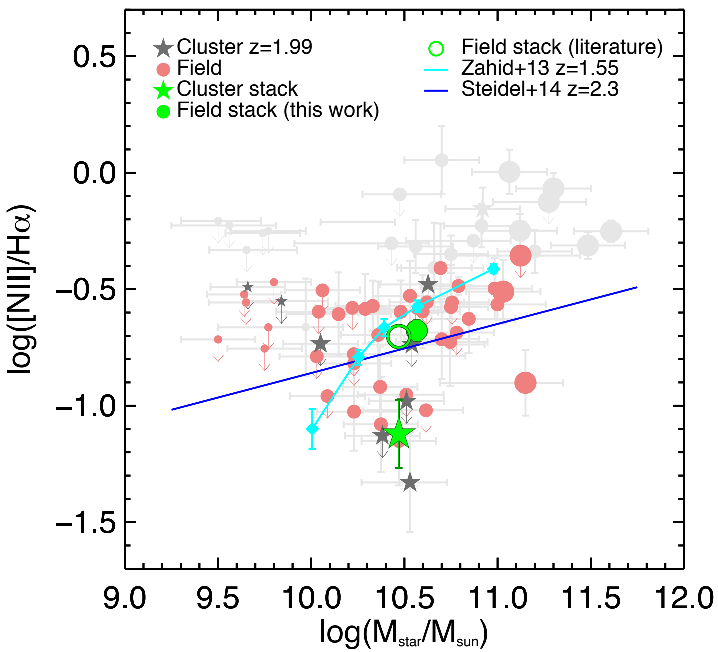


Valentino et al. 2015

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).

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



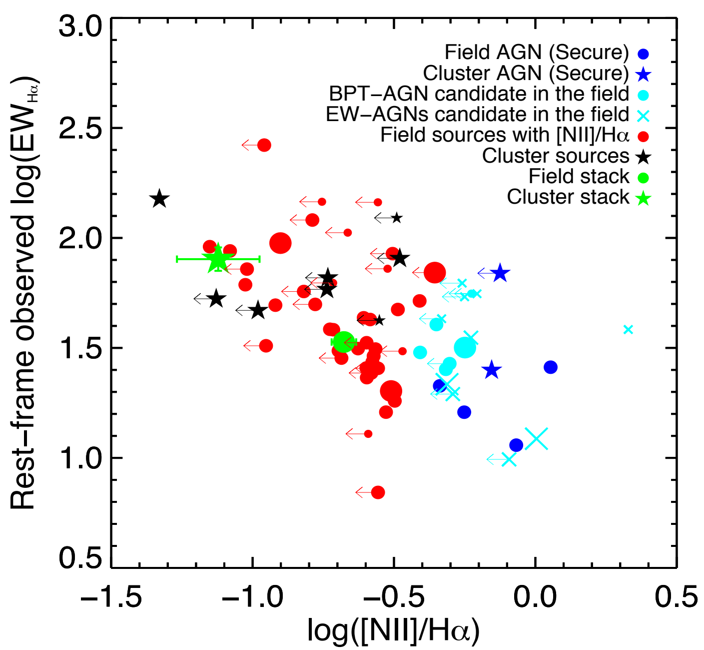
Thus, star-forming galaxies in CL J1449+0856 are on average more metal poor than mass-matched field counterparts (by ≈0.09-0.25 dex, according to the calibration or indicator used)

Valentino et al. 2015

Gaining physical insight

We can interpret the higher EW(Hα) as **a proxy for the sSFR.**

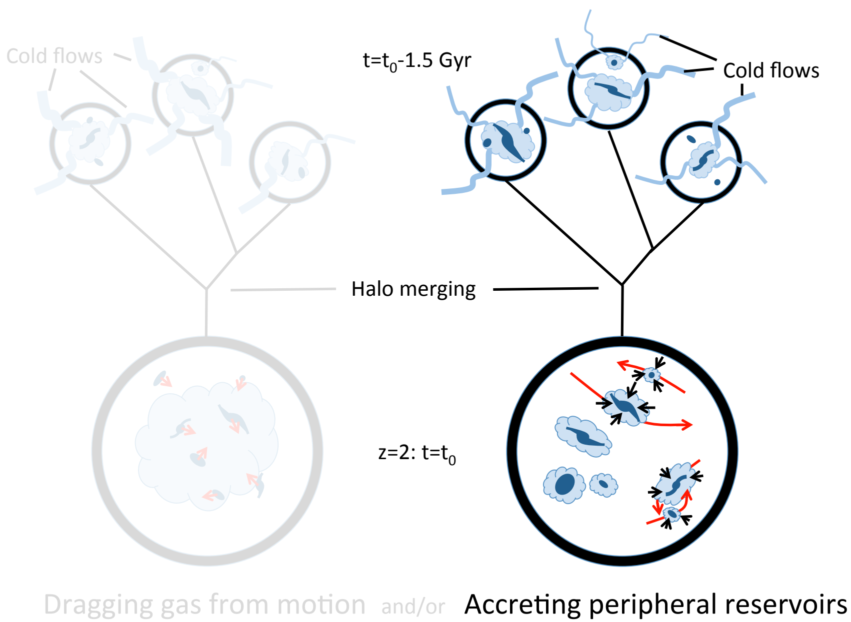
$$EW(H\alpha) \approx sSFR \times 10^{0.4E(B-V)*k(H\alpha)*(1/f-1)}$$

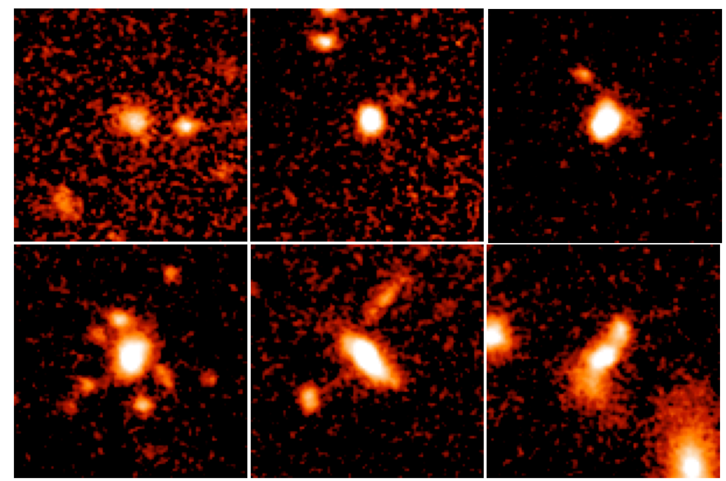


Thus, star-forming galaxies in CL J1449+0856 have higher sSFRs (the significance of this result depends on the adopted reddening correction)

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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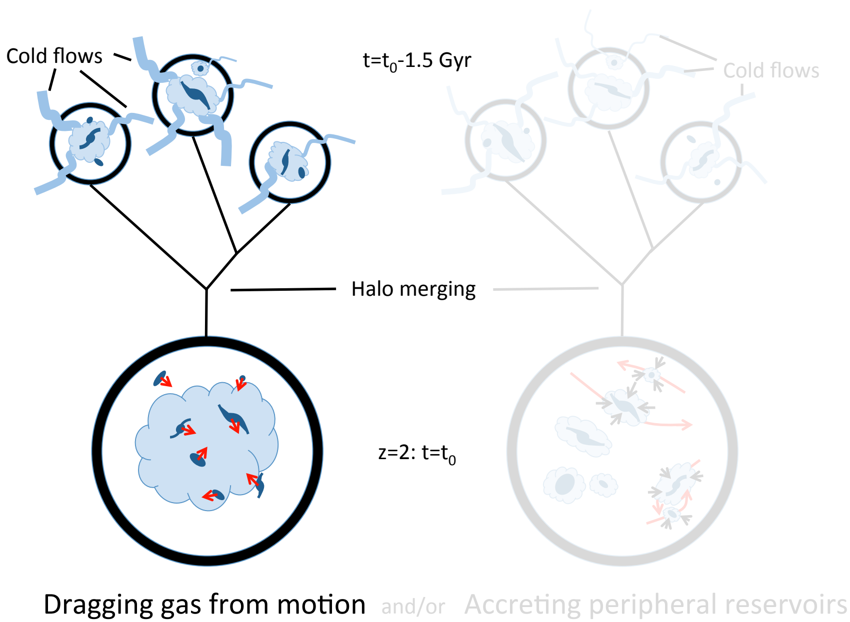
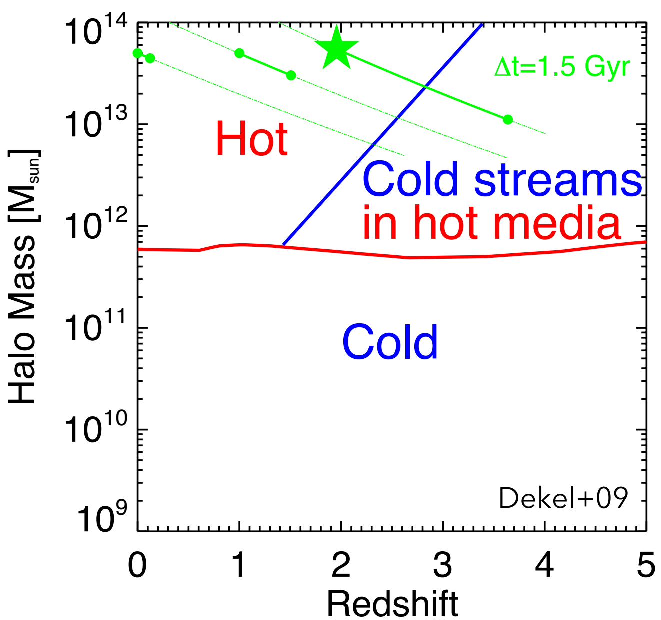


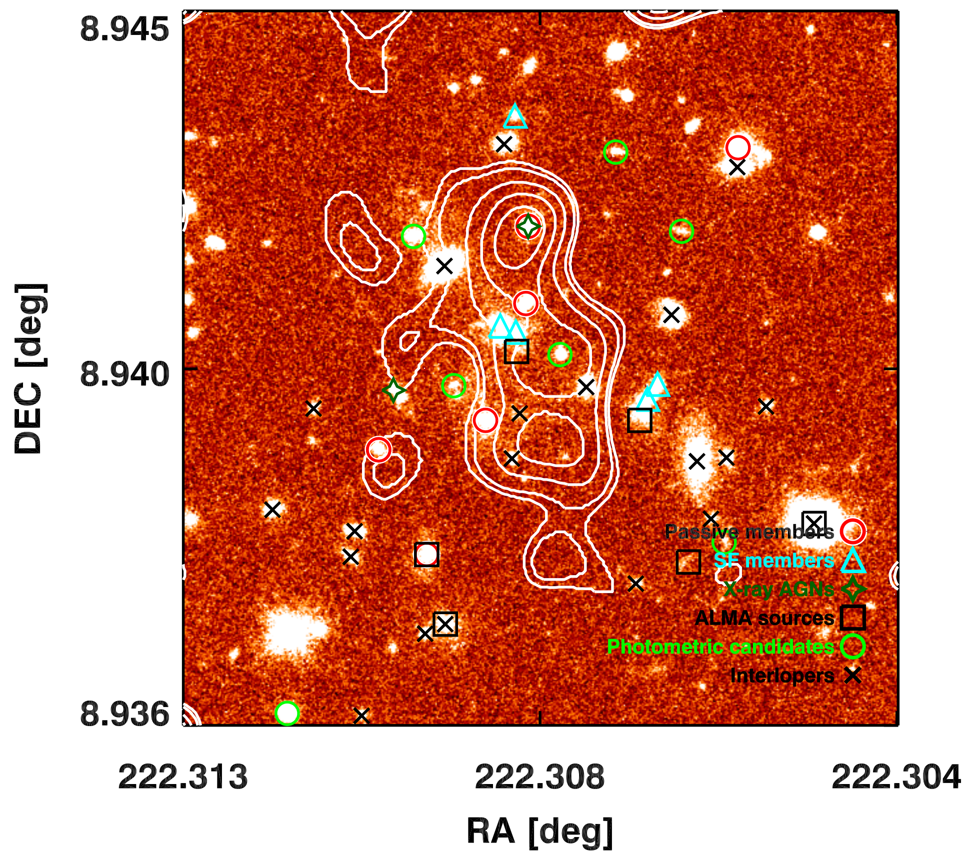


Valentino et al. in prep.

A giant Lyα nebula in the core

“Warm” diffuse gas (>150 kpc, T ≈ 10^{4-5} °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?
- **Is this gas going to cool down and be accreted by galaxies (i.e., forming BCG)?** Are these blobs ubiquitous in compact clusters at high z? **What is their role in setting galaxy star-formation/quenching in the cluster core?**



Deep *HST* F140W

What does the future hold for us?

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

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

- Accepted KMOS proposal P95A:

  > Full census of SFR with a unique tracer (Hα)

  > Emission line maps to trace **metallicity gradients**

A powerful tool to test gas accretion and metal enrichment scenarios

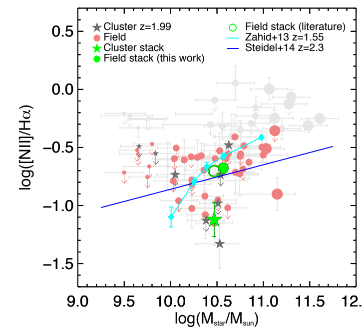
Summary

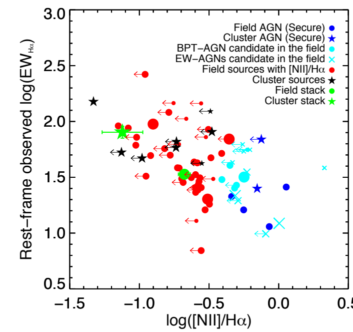
- Subaru/MOIRCS follow-up of cluster SFGs in CL J1449+0856 at z=1.99
- **Lower gas-phase metallicity, higher sSFR** in cluster SFGs
- We ascribe these effects to the **accretion of pristine gas** on cluster scales and/or due to mergers, both facilitated by the gravitational focusing effect

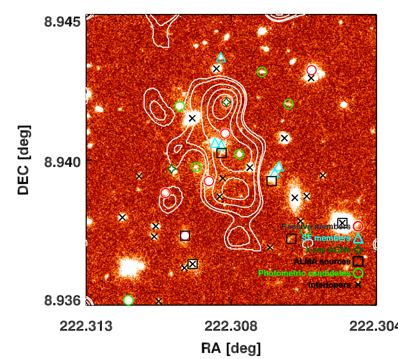
Further details in Valentino et al. 2015 (ApJ, 801, 132)

- Keck/LRIS NB imaging revealed a giant Lyα nebula in the cluster core, a large warm gas reservoir.

Open questions on its role in tuning star formation/quenching in dense environments







Back up

Valentino et al. 2015

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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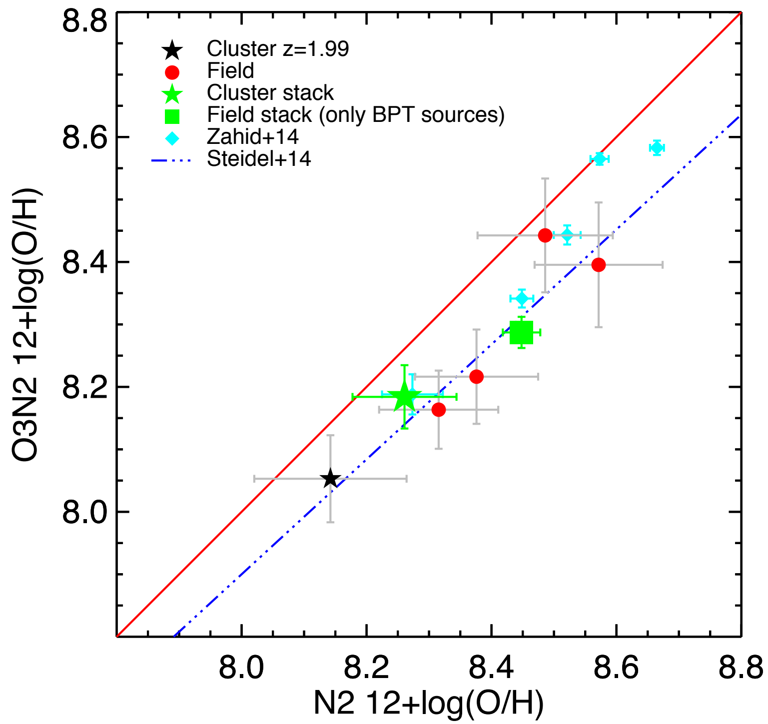

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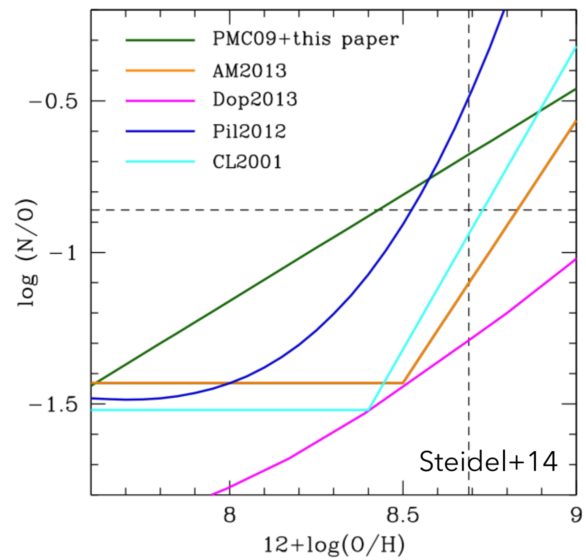
We estimated N/O from [N II]/[O II] for the cluster only (Perez-Montero & Contini 2013):

$$\log(N/O) = -1.18 \pm 0.19$$



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

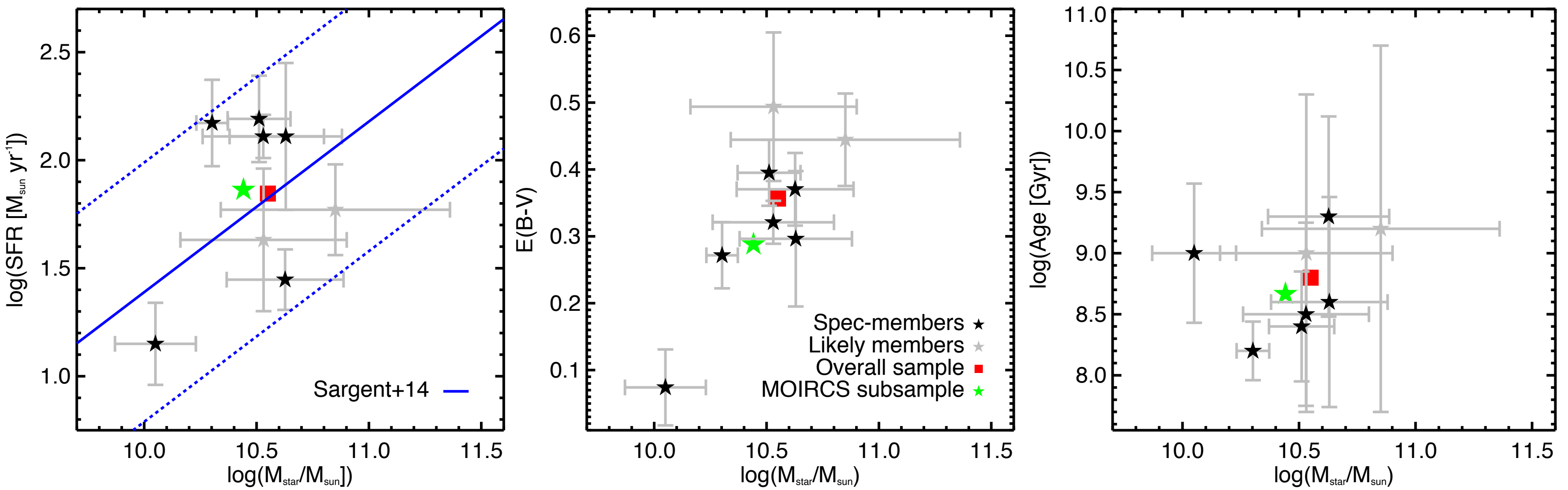
For the cluster only, we could estimate $\mathcal{U}$ from O_{32}, R_{23} following Kobulnicky & Kewley 2004:

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

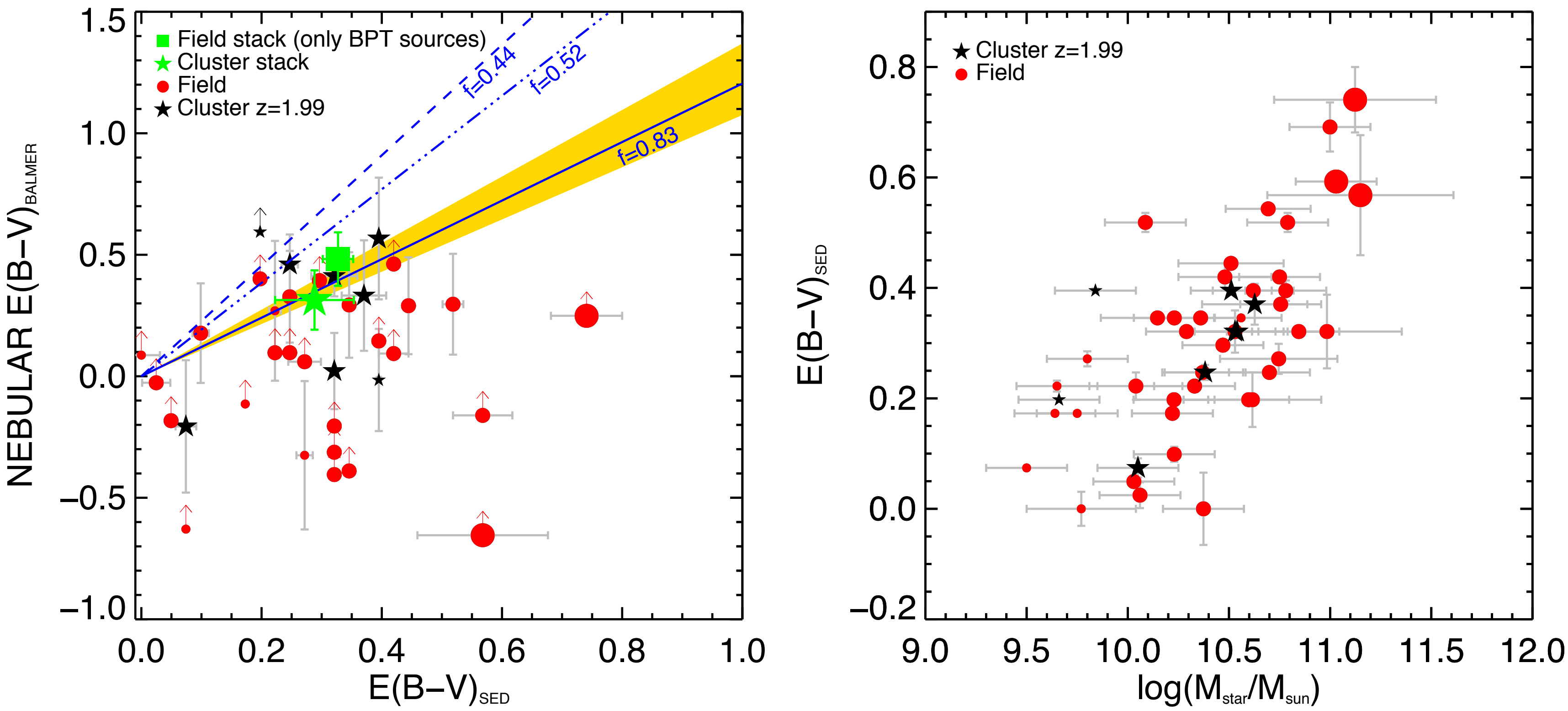
which is comparable with values measured in high redshift field galaxies ($-2.9 < \mathcal{U} < -2.0$)

Valentino et al. 2015

Possible selection effects

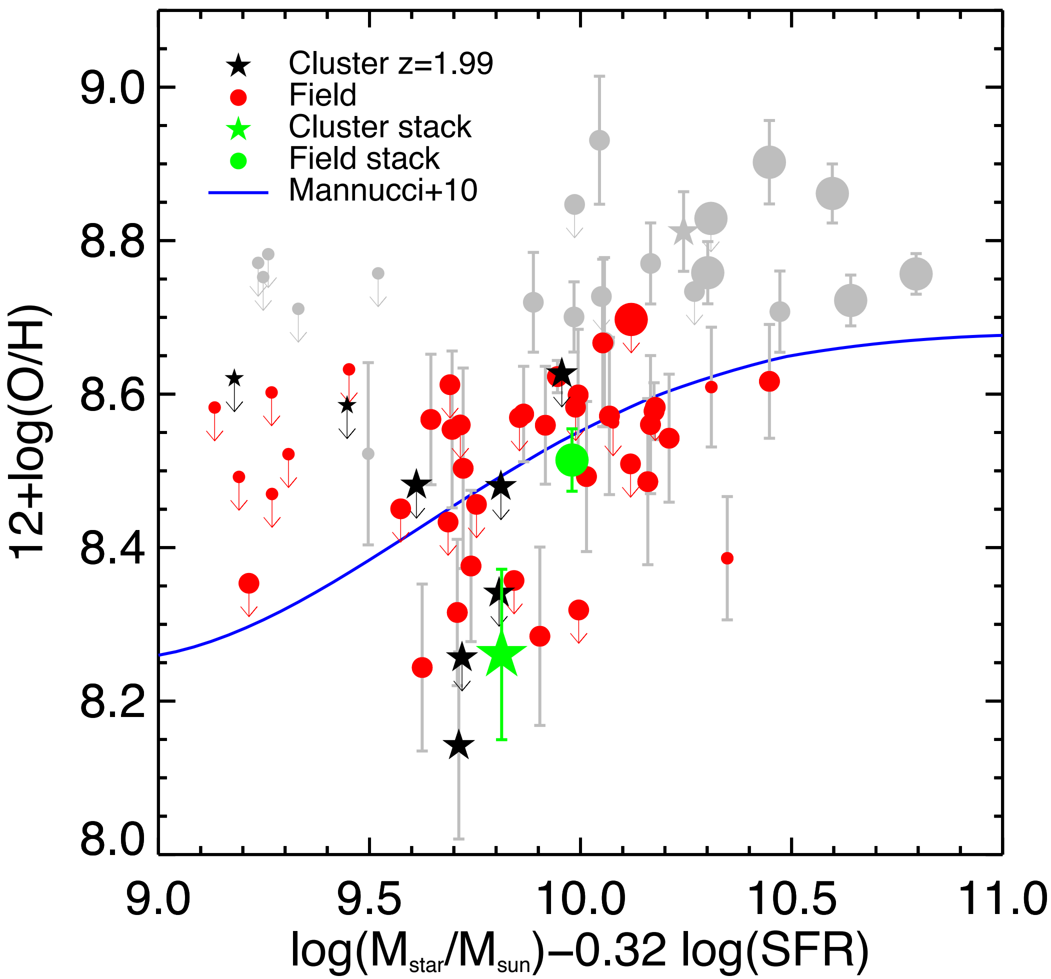


Nebular reddening



Valentino et al. 2015

Fundamental Metallicity Relation



Valentino et al. 2015

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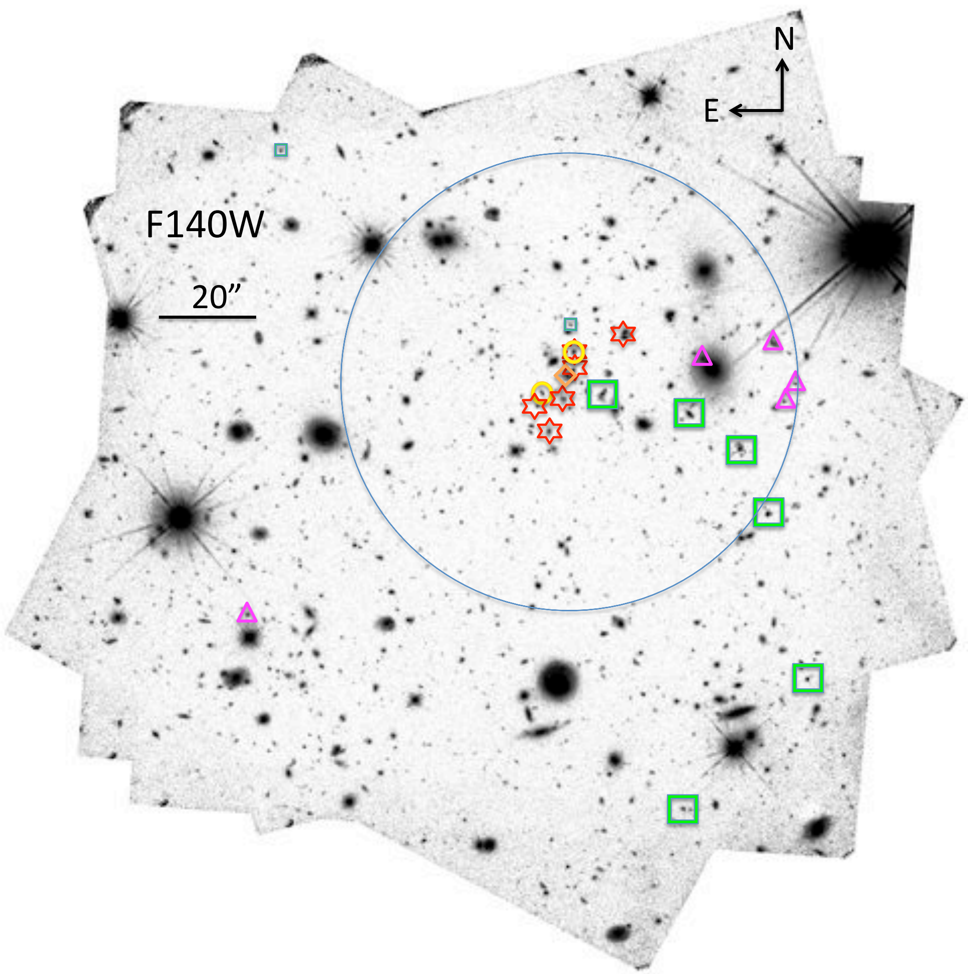
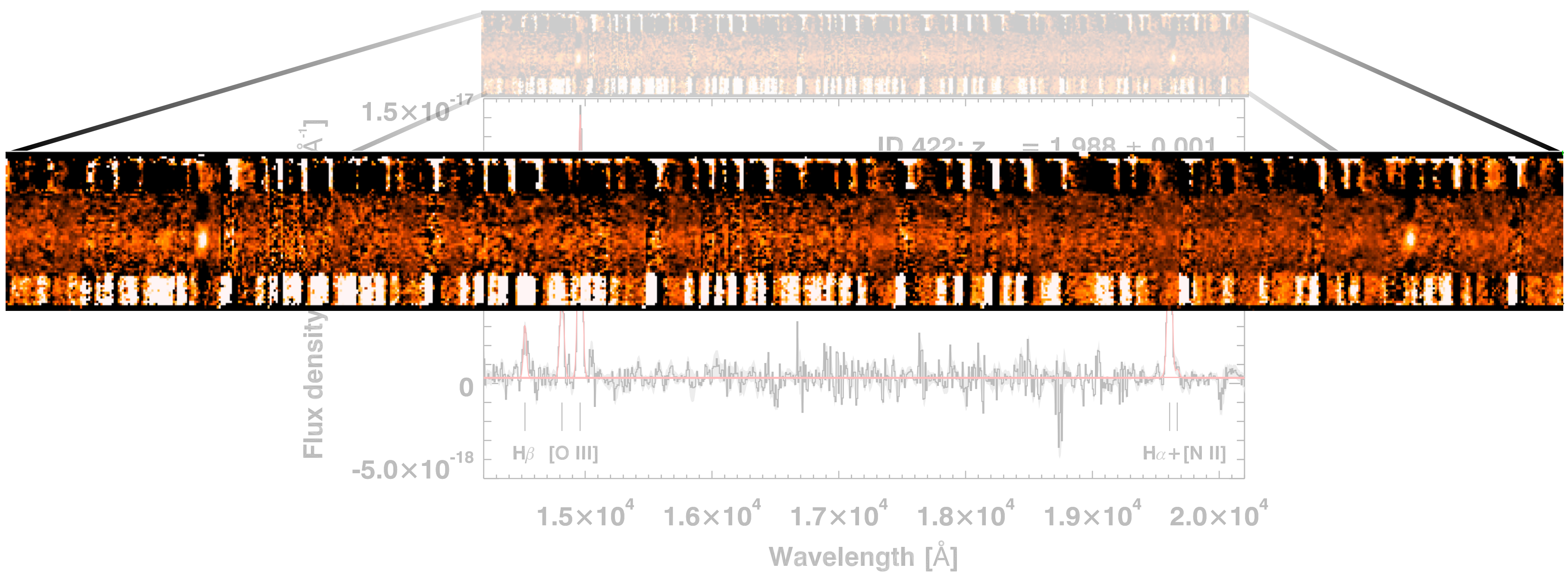


Assembling/accreting feature?

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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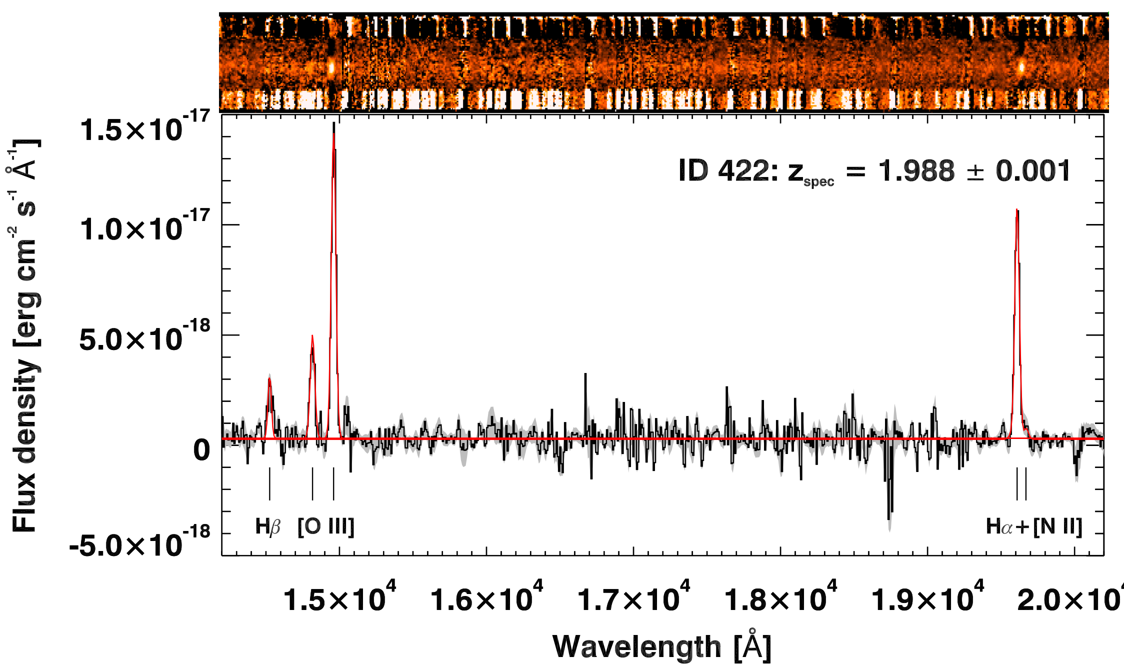
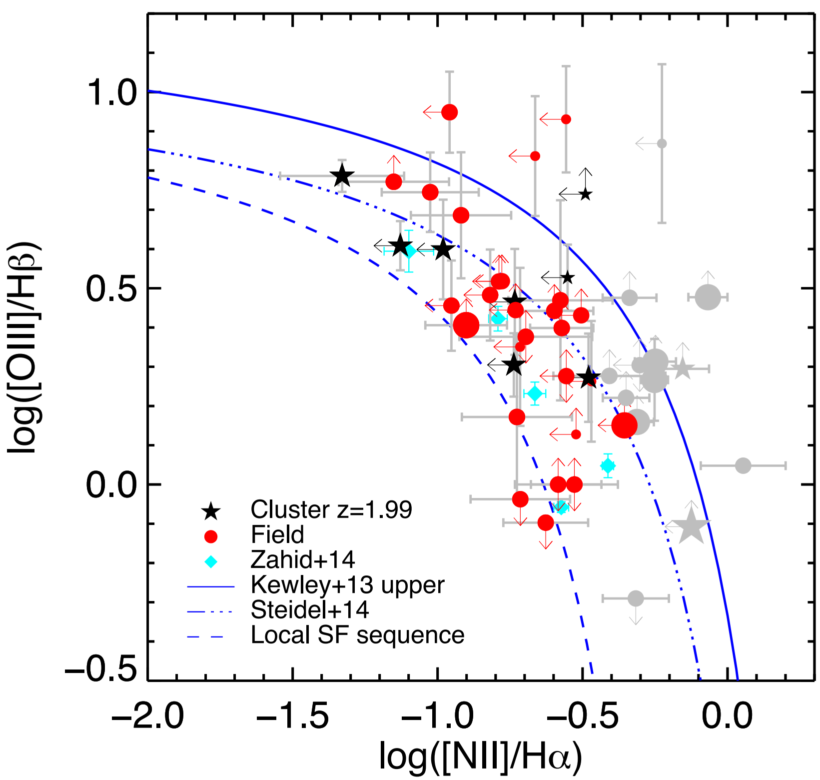
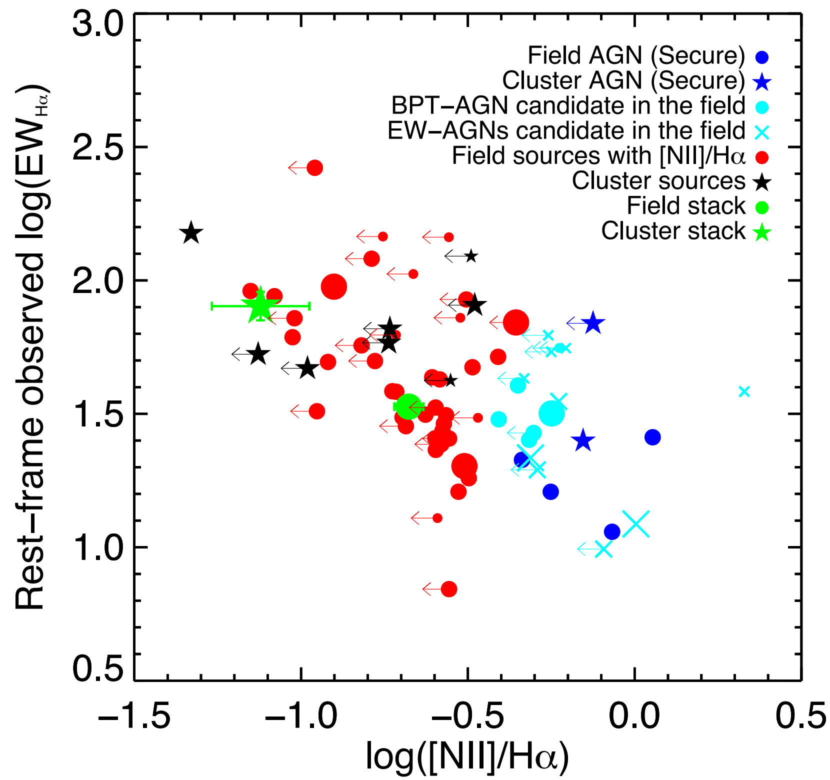


Valentino et al. 2015

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).

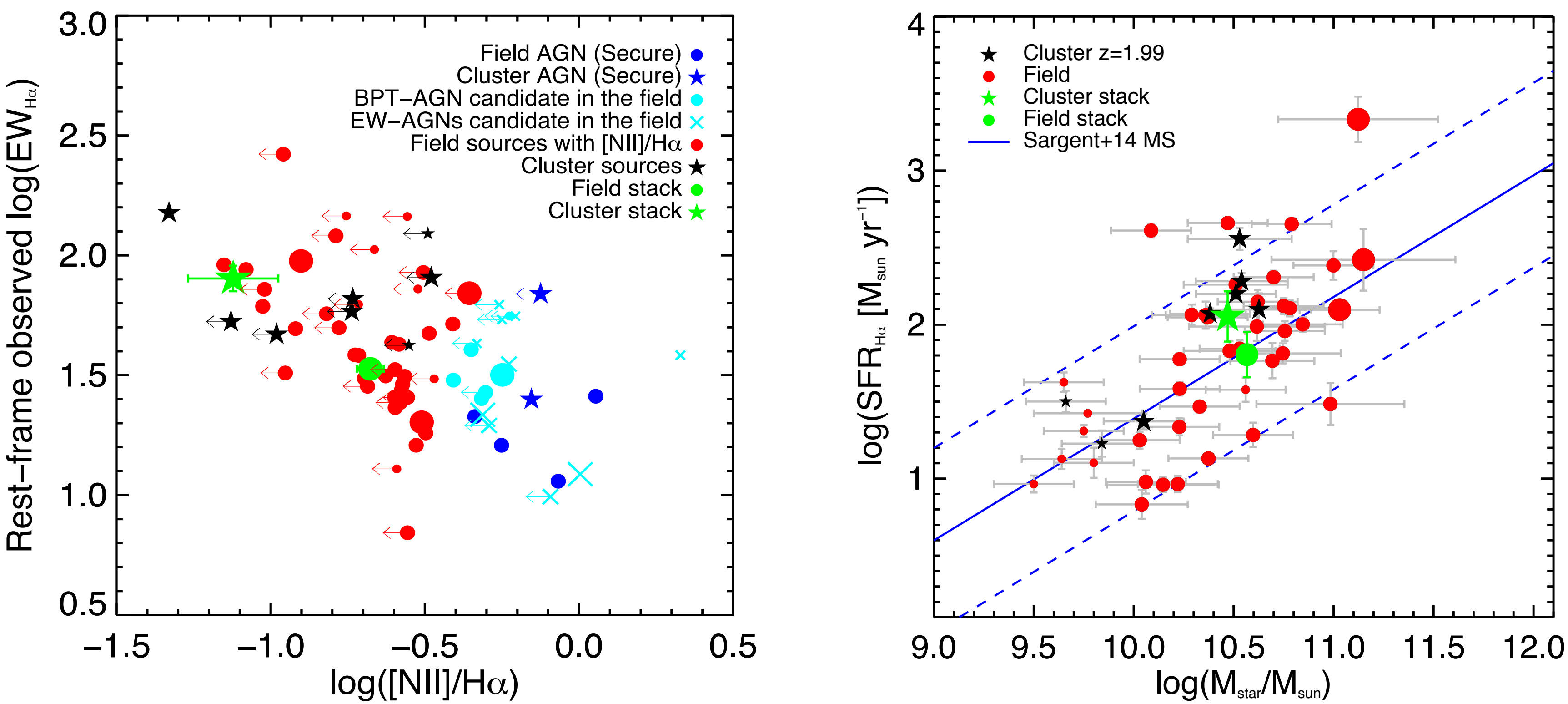




Valentino et al. 2015

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.**



Valentino et al. 2015

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)

Valentino et al. 2015

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"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)

Valentino et al. 2015

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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 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)

Valentino et al. 2015

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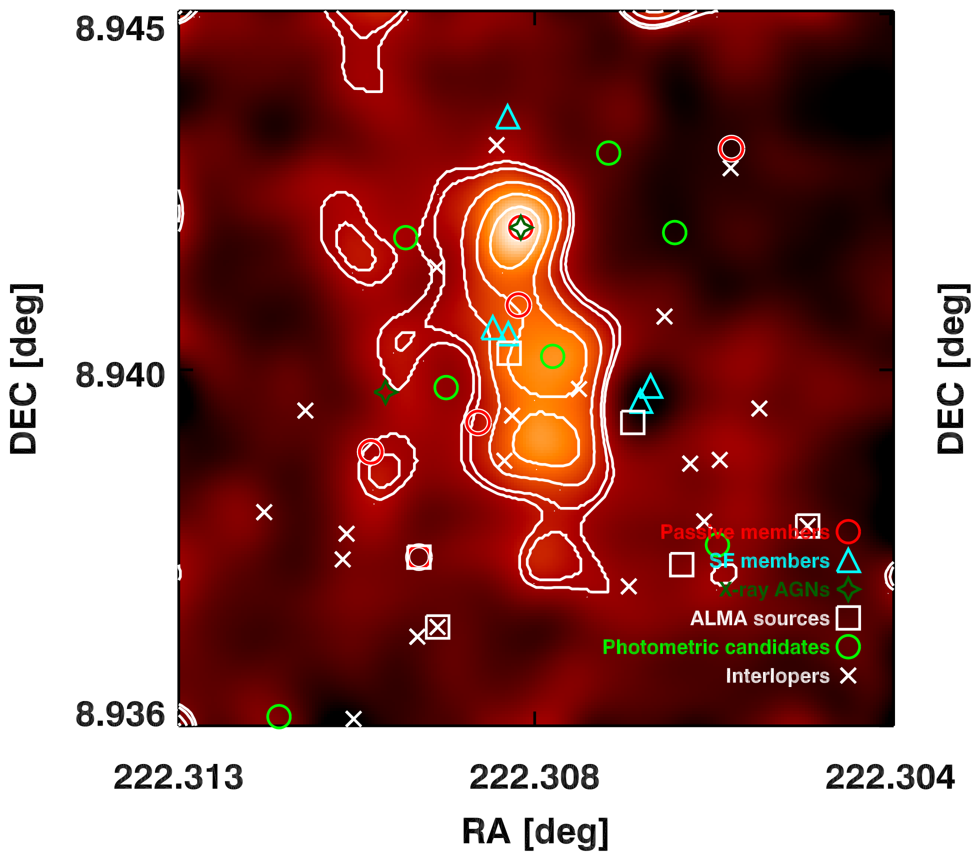
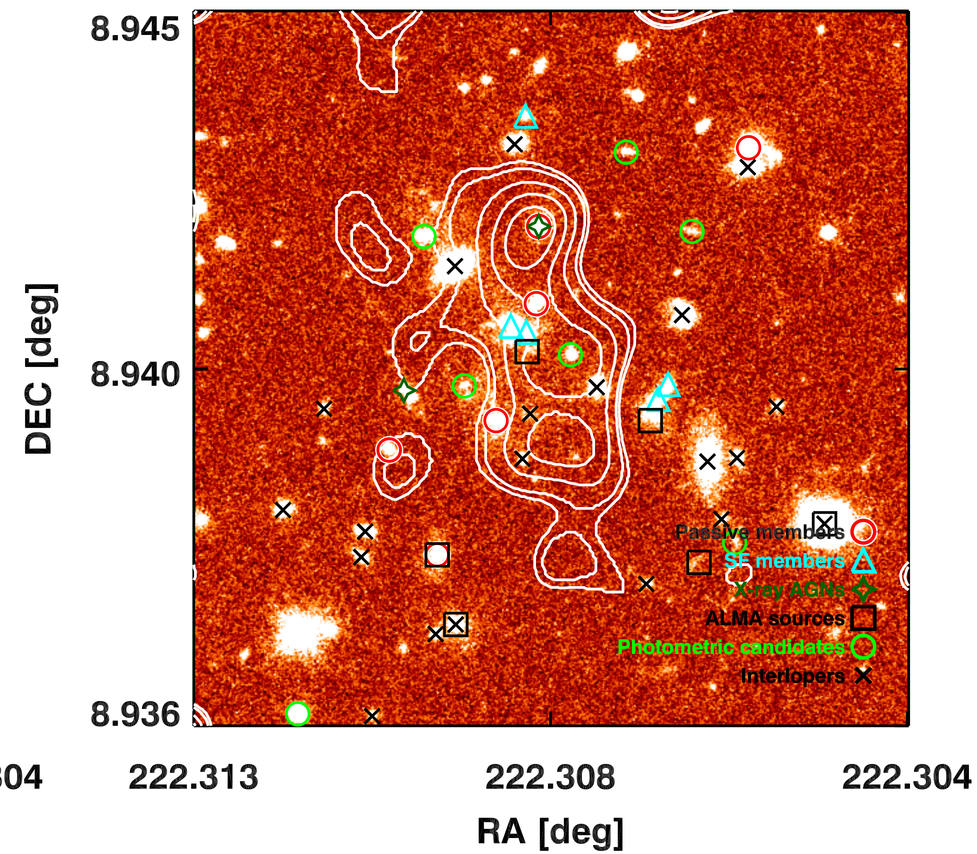
"Considering environments ranging from voids […] to the periphery of galaxy clusters […] **we find no dependence of the relationship between galaxy stellar mass and gas-phase oxygen abundance,** along with its associated scatter, on local galaxy density." (Mouhcine et al. 2007)

Valentino et al. in prep.

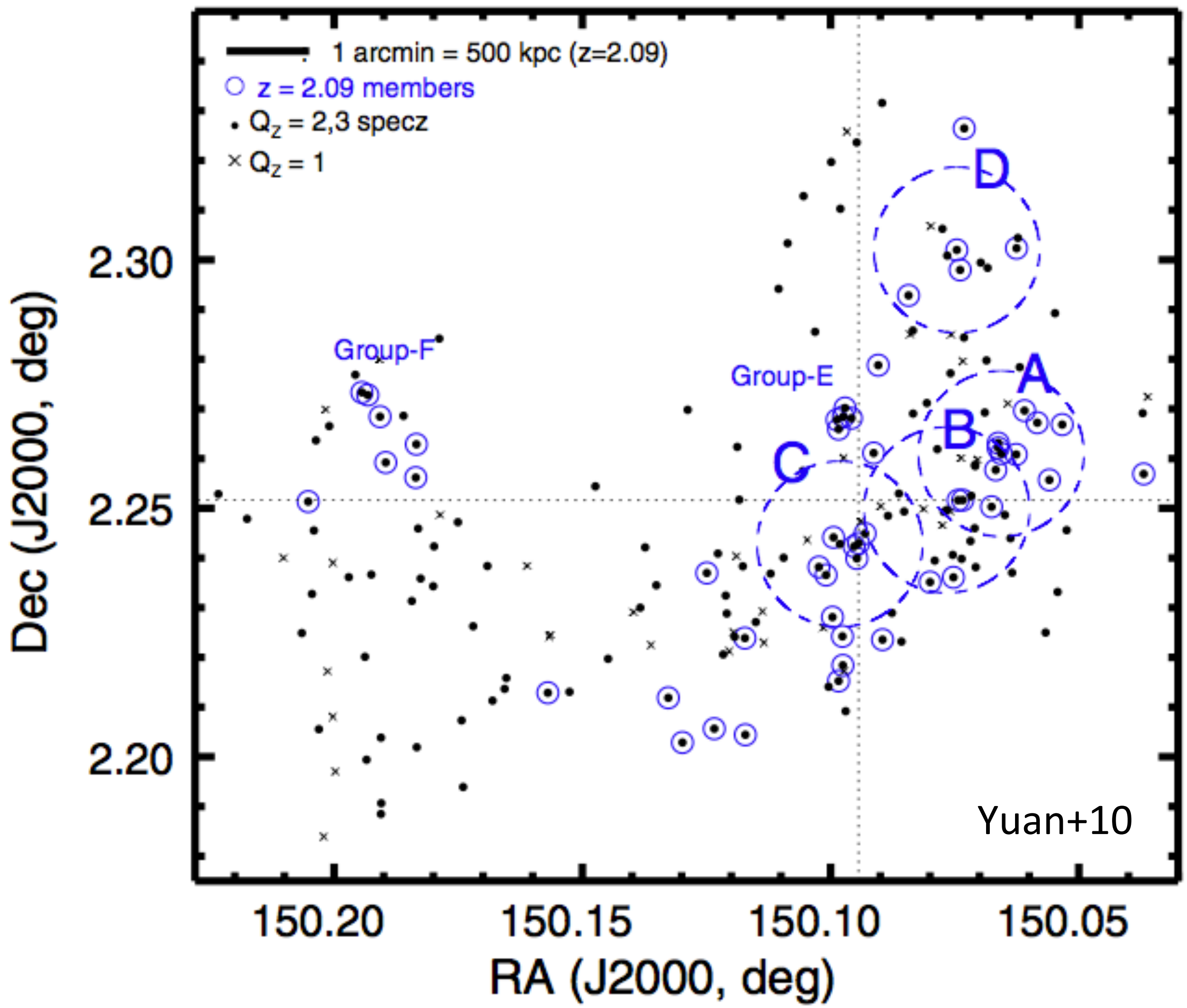
A giant Lyα nebula in the core



Lyα = {Keck/LRIS narrow band}
-
{U band}



Deep *HST* F140W



1 arcmin = 500 kpc (z=2.09)
z = 2.09 members
Q_z = 2,3 specz
Q_z = 1
D
A
B
C
Group-F
Group-E
Yuan+10
2.30
2.25
2.20
Dec (J2000, deg)
150.20
150.15
150.10
150.05
RA (J2000, deg)