Environmental effects on galaxy evolution in the distant Universe

Francesco Valentino

Advisor: Dr. Emanuele Daddi

Journées des thésards, Saclay, July 1st 2015

All you want to know about me

First name, family name: **Francesco Valentino**

All you want to know about me

Cursus: Bachelor and Master's degree in **Astronomy** at **Università di Padova**

All you want to know about me

How did CEA happen? Through collaboration with scientists in Padova

Galaxy ethology

From the Merriam-Webster:

Nature: *the way that a person or animal behaves : **the character or personality** of a person or animal*

Nurture: *The sum of the **environmental factors** influencing the behavior and traits expressed by an organism*

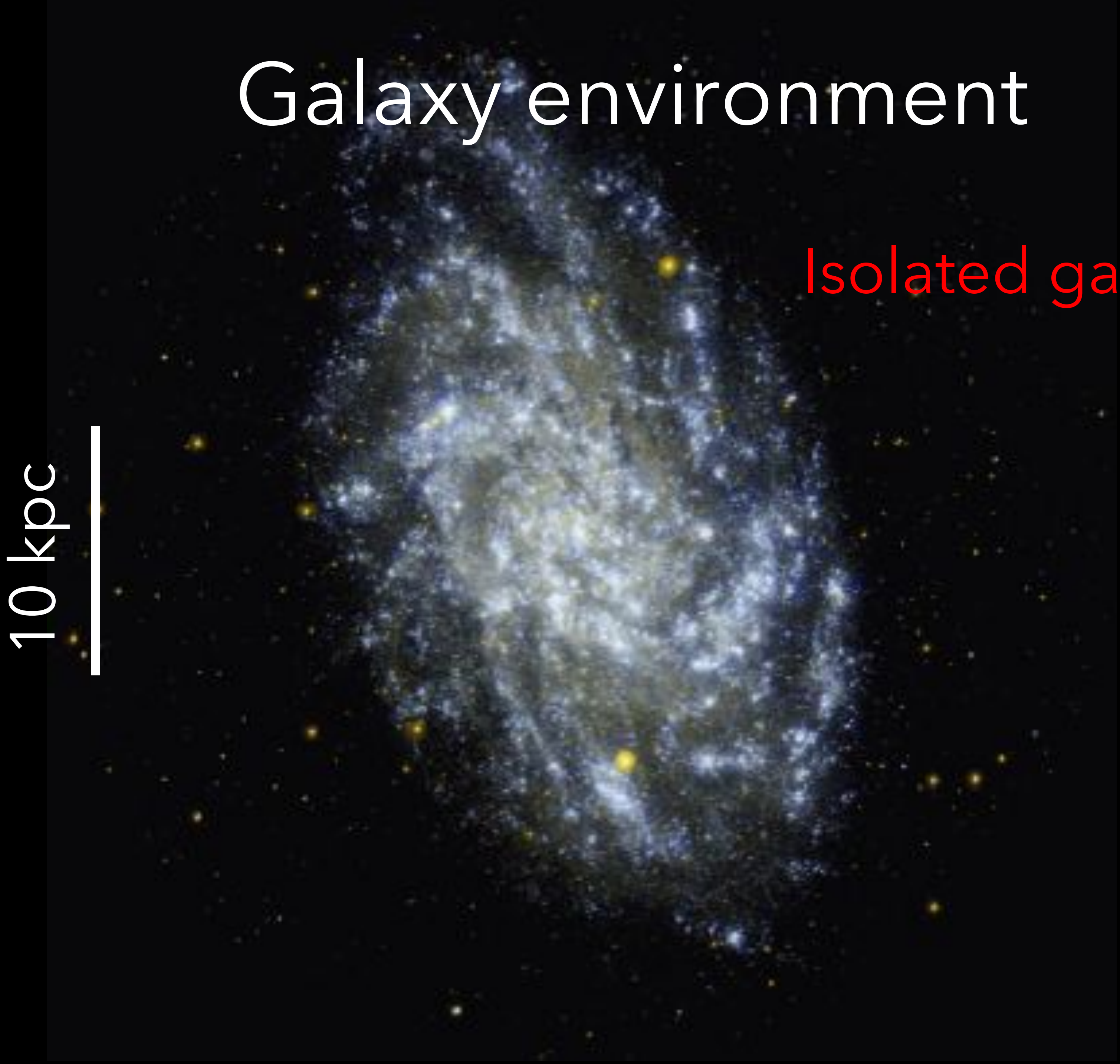
Galaxy ethology

This thesis:

Nature: *the way that a* ***galaxy*** *behaves:* ***internal properties*** *of* ***a galaxy***

Nurture: *The sum of the* ***environmental factors*** *influencing the behavior and traits expressed by* ***a galaxy***

Galaxy environment



Isolated galaxy

Galaxy environment

Pair, group

Galaxy environment

Galaxy environment

Isolation

Pair, group

Cluster

Density

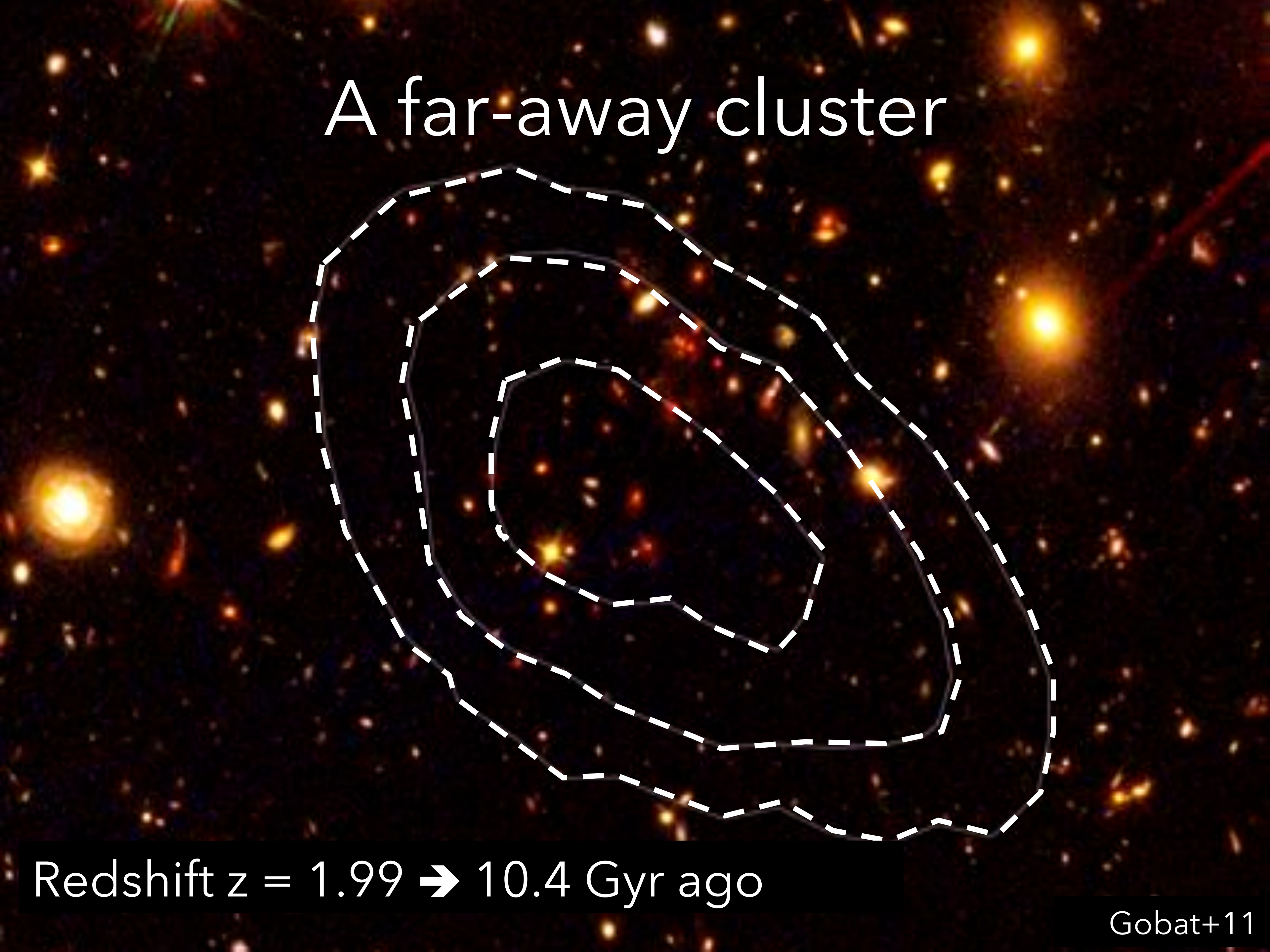
Galaxy morphologies, colors, luminosities, star formation rates, masses, sizes(?) change with the environment **in the local Universe.**

Galaxy environment

Galaxy morphologies, colors, luminosities, star formation rates, masses, sizes(?) change with the environment **in the local Universe.**

Is this true in the younger, far-away Universe?
When did this process started?
How did it happen?
How do far-away dense environments look like? What do we know about them?
[…]

A far-away cluster



Redshift z = 1.99 ➔ 10.4 Gyr ago

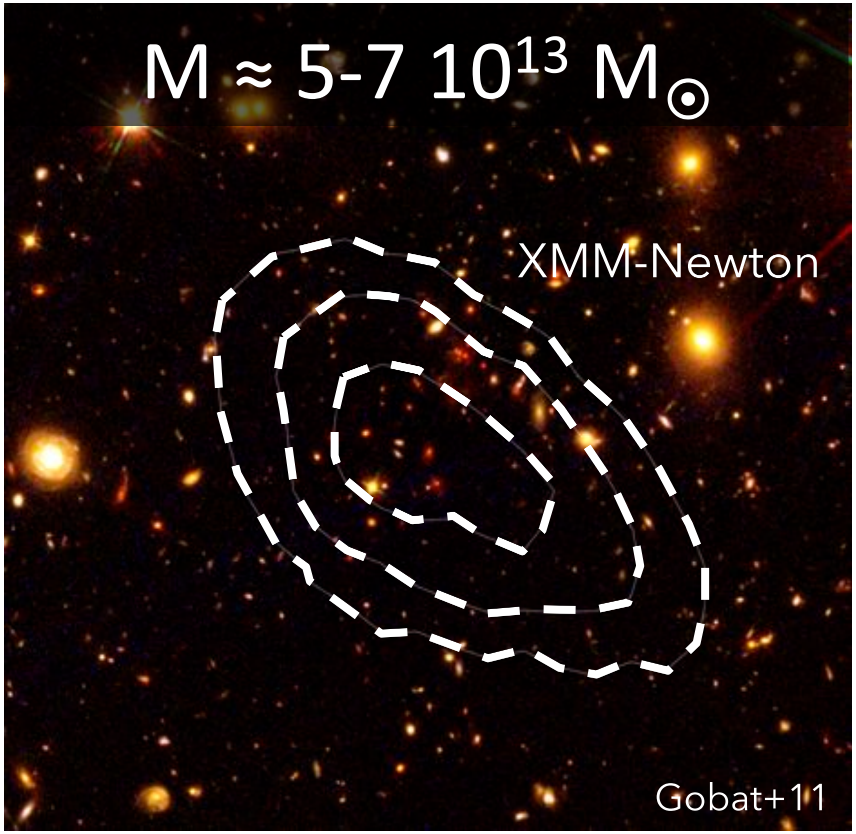
Gobat+11

A far-away cluster

A **relatively evolved cluster** that hosts **a significant fraction of active galaxies** (Gobat+2011, 2013, Strazzullo +2013).

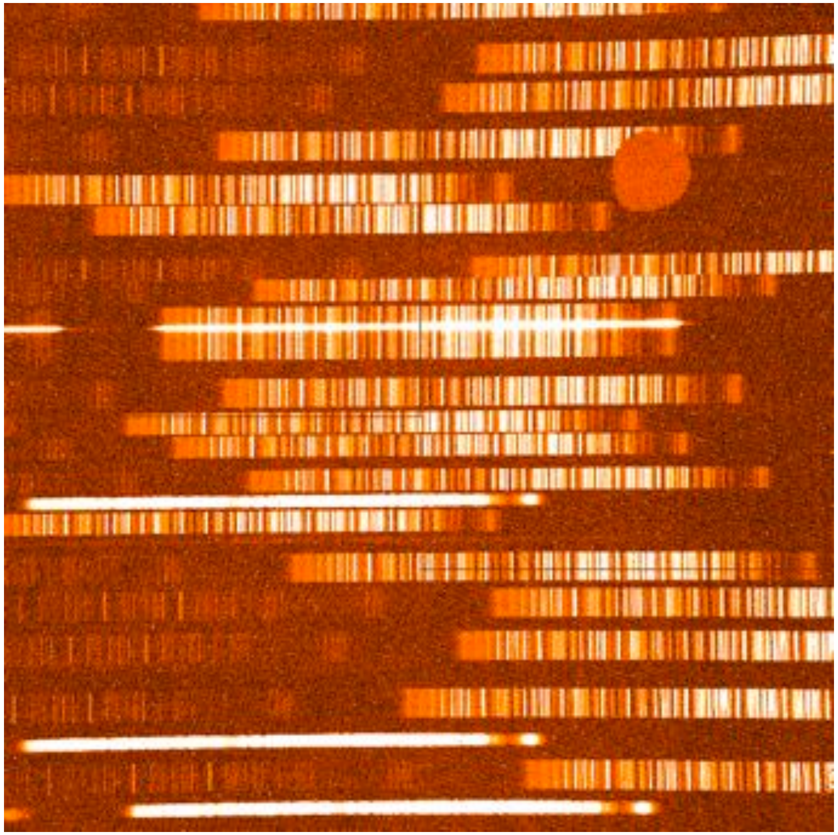
Extensively followed-up:

- **Imaging** in 13 bands
- **Spectroscopy** of star-forming galaxies to study the properties of ionized gas


$M \approx 5\text{-}7\ 10^{13}\ M_\odot$

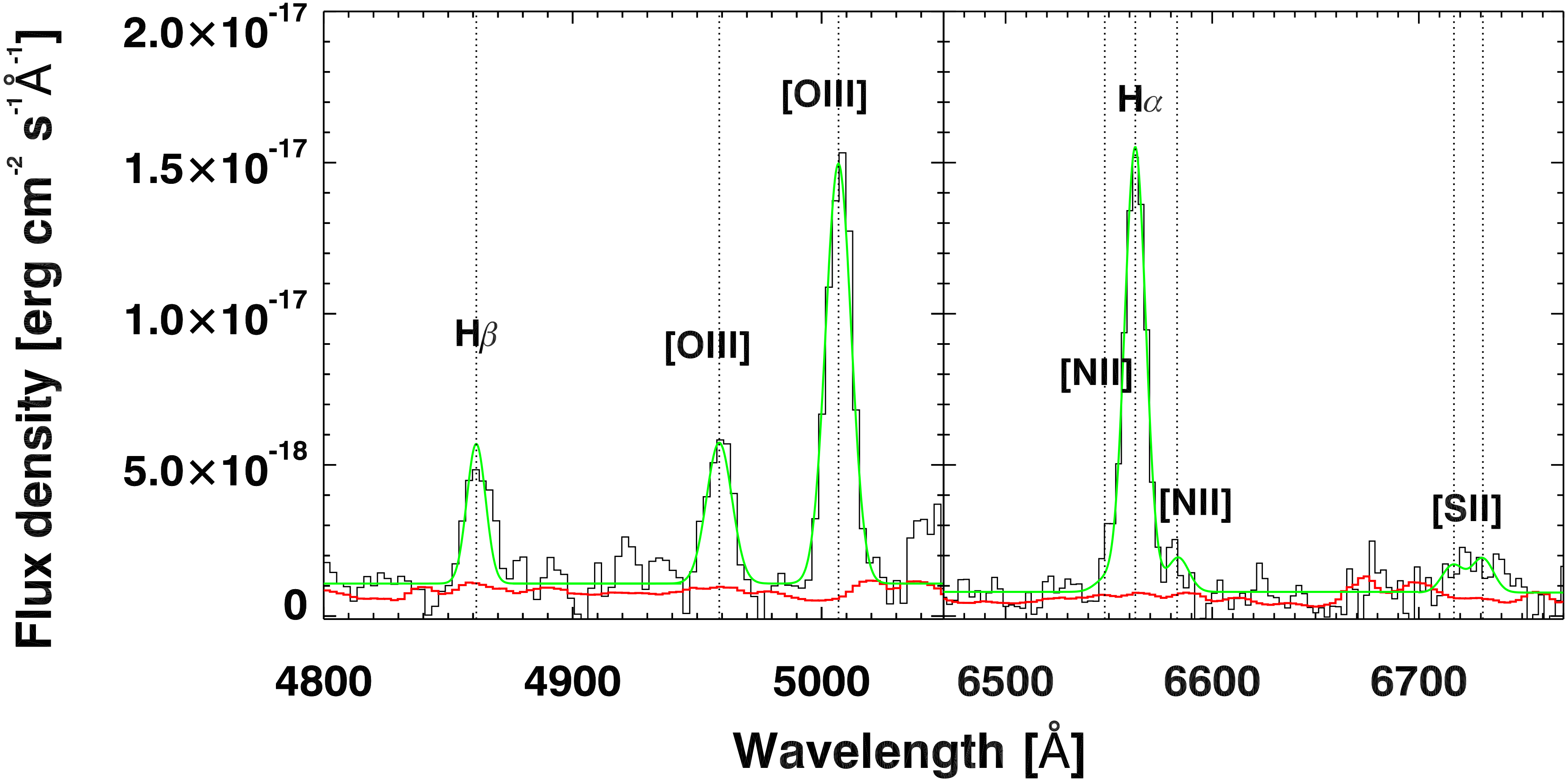
Gobat+11

A far-away cluster



Numbers:
3: Subaru/MOIRCS nights (April 2013)
7.5: total hours of usable integration time per mask on the cluster (2 masks)
10: Observed cluster star-forming galaxies
78(%): success rate in detecting Hα (>3σ significance)
6(%): success rate in detecting [NII] λ6583 Å (>3σ significance)
110: extracted and fully reduced spectra from raw data to flux calibration

A far-away cluster

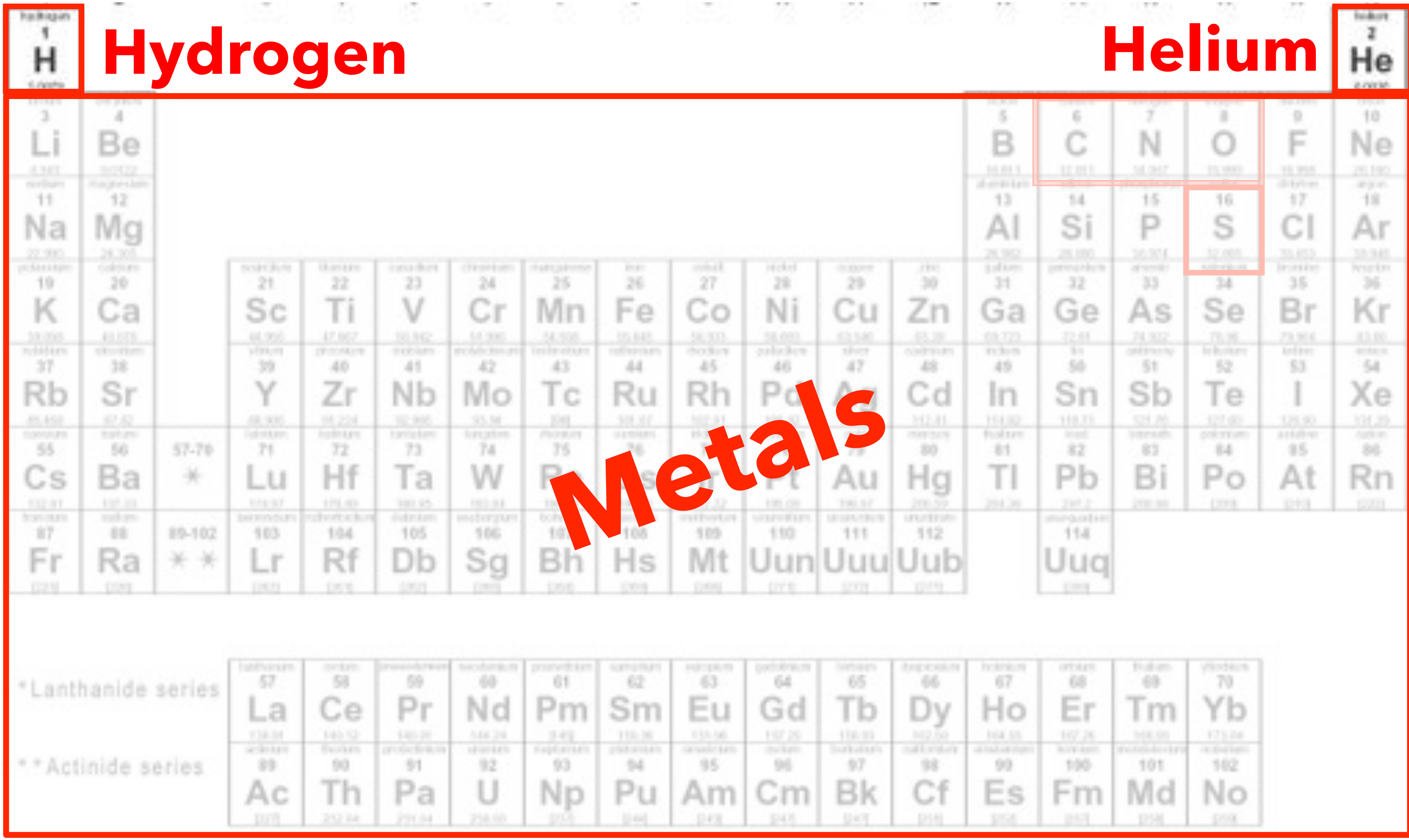


Chemistry

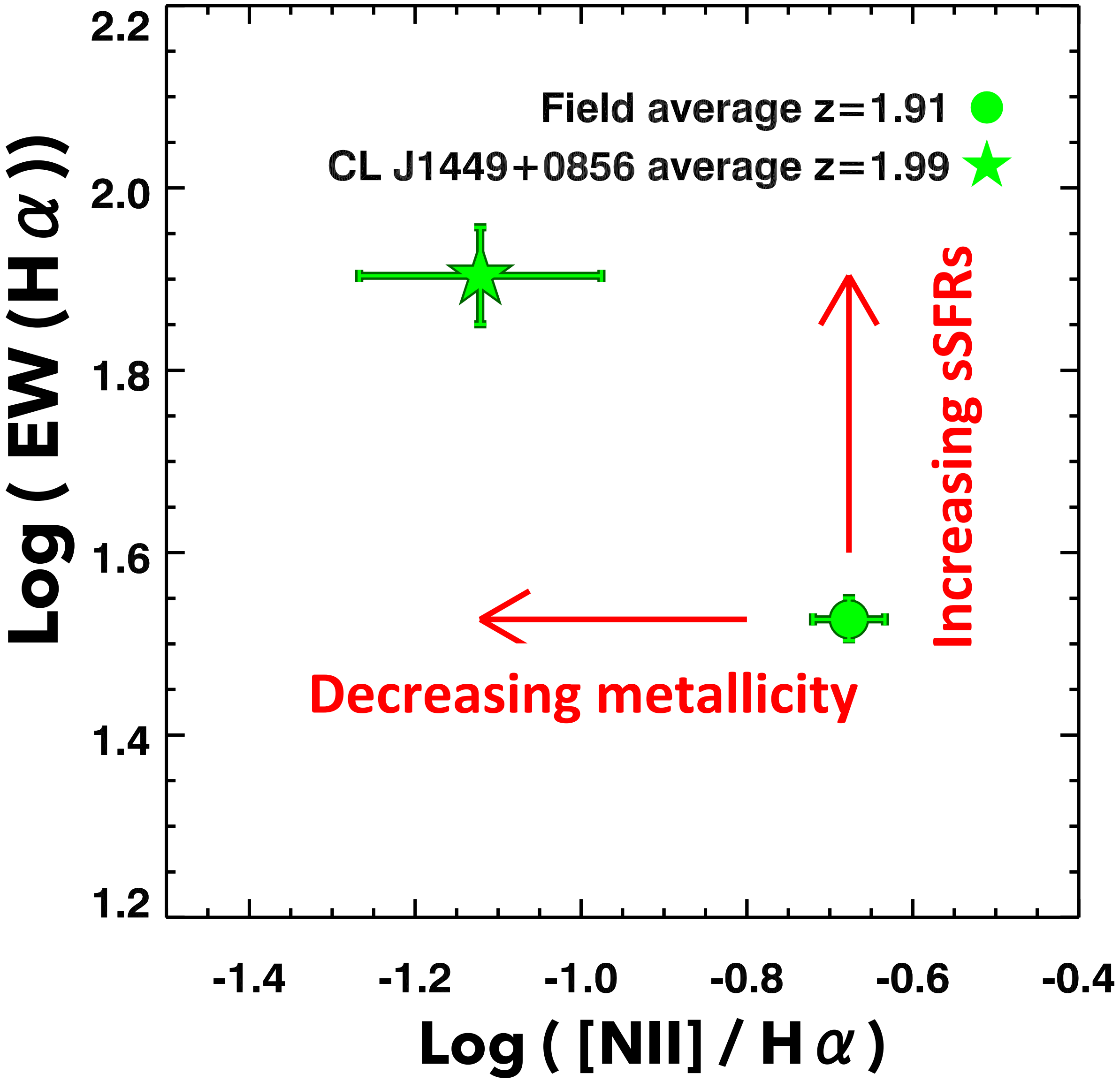
1 H																		2 He
3 Li	4 Be												5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg												13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca		21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr		39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57-70 *	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89-102 * *	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Uun	111 Uuu	112 Uub		114 Uuq				

*Lanthanide series	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
* *Actinide series	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No

Galactic chemistry

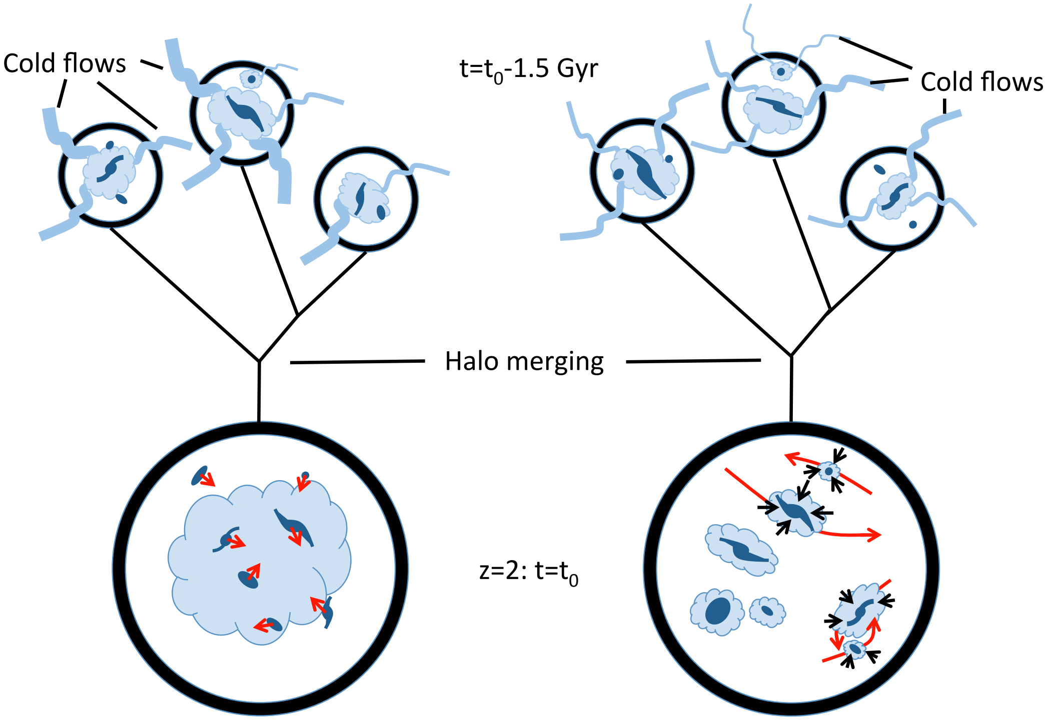


What do we *observe*?



A speculative picture of the situation

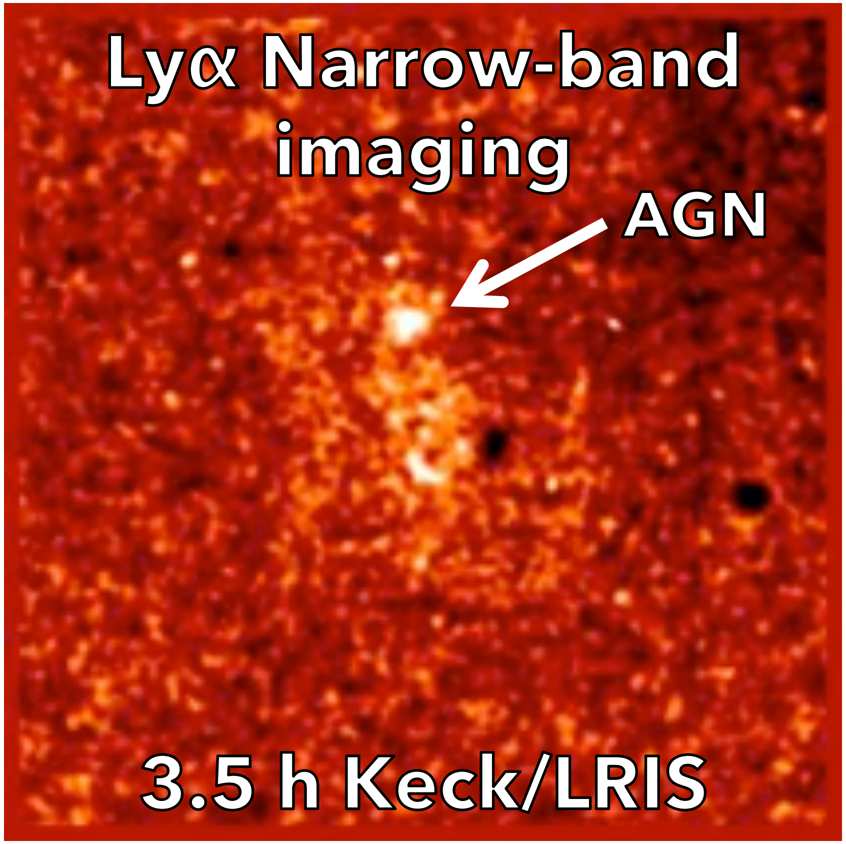
We ascribe lower metallicities in cluster star-forming galaxies to **the accretion of low-metallicity gas** from the surroundings



Dragging gas from motion and/or Accreting peripheral reservoirs

A prime discovery

“Warm” (10^4 °K) diffuse gas (**>100 kpc**) +
“Hot” (10^7 °K) extended atmosphere detected



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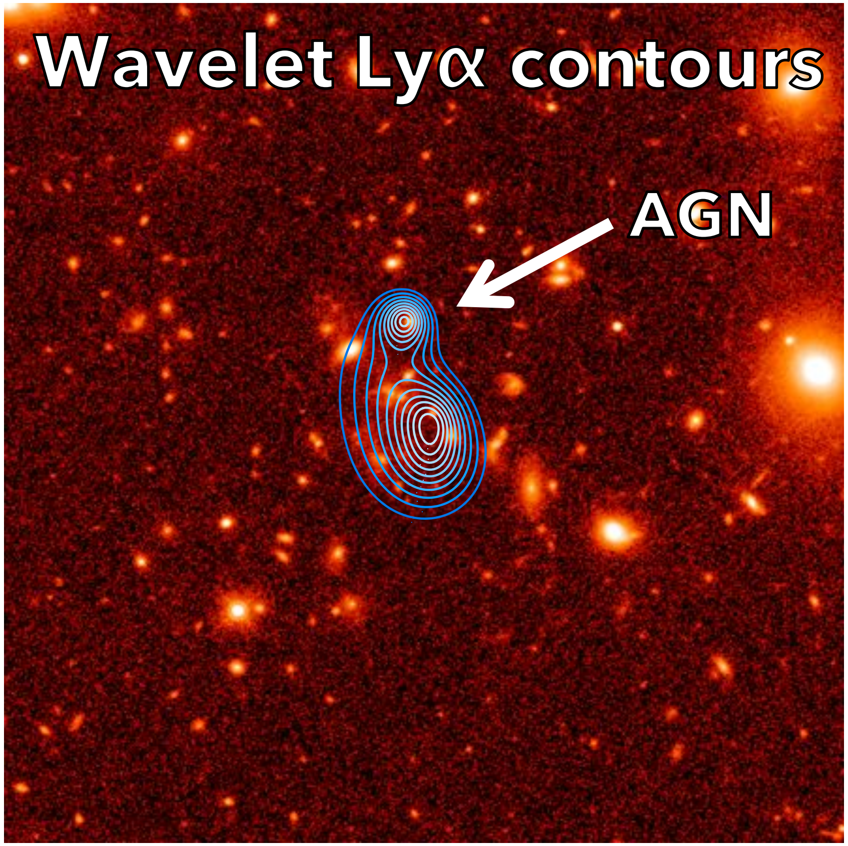
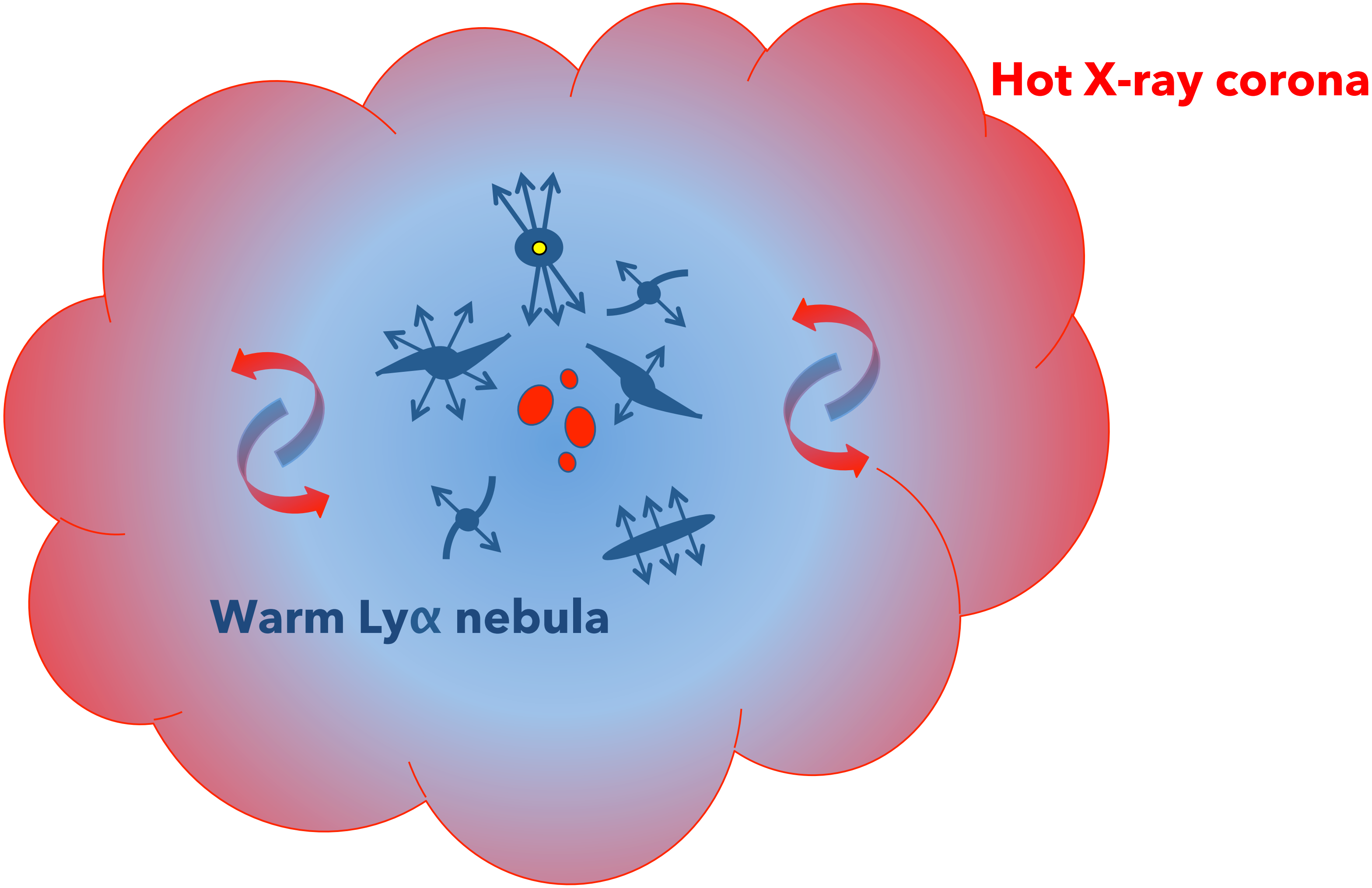
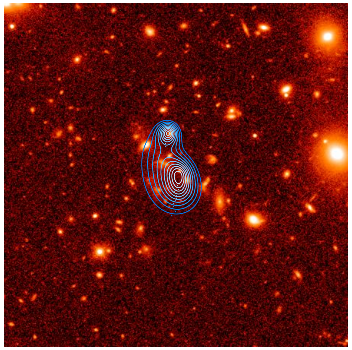


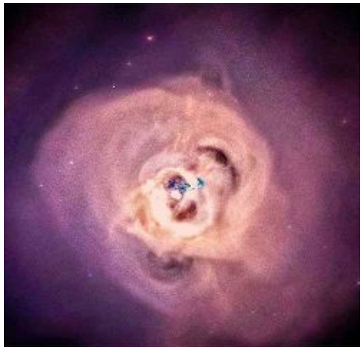
A prime discovery



Three hot questions in astrophysics



Giant Lyα nebulae



Early energy injection in clusters

Galaxy activity in far-away clusters

Putting observational constraints on all these issues with a single process:

“A giant Lyα nebula revealing early energy injection in the hot intracluster medium”

(Valentino et al. in prep.)

Preparing the future

Athena X-ray telescope (~2030) > Here at CEA!

So far so good

Articles:

- *“Metal deficiency in Cluster Star-Forming Galaxies at z=2”* (**Valentino et al. 2015, Astrophysical Journal, 801, 132**)
- *“The gravitational collapse of a giant clump in a primordial galaxy”* (Zanella et al. 2015, Nature, 521, 54)
- *“Passive galaxies as tracers of cluster environments at z≈2”* (Strazzullo et al. 2015, Astronomy & Astrophysics, 576, L6)
- *“Quenching of star formation in groups at z≈1.8”* (Gobat et al. 2015, submitted)

Accepted **proposals:**

- ESO VLT/KMOS near-IR spectroscopy: 5+7.5 h (PI: Valentino)
- ESO VLT/MUSE optical spectroscopy: 1.5 h (PI: Valentino)
- IRAM/NOEMA sub-mm spectroscopy: 50 h (PI: Valentino)
- Several CoI-ed proposals for time at major telescope facilities (Gemini, IRAM, ALMA, Subaru,…)

So far so good

October, 1st 2013: PhD start

Conferences and workshops:

- November, 17th-21st 2014: **Contributed talk** at the *"Third Workshop on Numerical and Observational Astrophysics: Linking the Local Universe to the Early One"* in Buenos Aires
- November, 25th-26th 2014: **Contributed talk** at the *"Journées Nationales PNCG 2014"* in Paris
- March, 23rd-27th 2015: **Contributed talk** at the *"Dissecting galaxies near and far: high resolution views of star formation and the ISM"* conference at ESO headquarters, Santiago de Chile
- April, 1st 2015: **Regular seminar** at the Universidad de Concepción
- June, 8th-12th 2015: **Contributed talk** at the *"IGM@50: is the intergalactic medium driving star formation?"* workshop at the Abbazia di Spineto
- June, 16th-19th 2015: **Contributed talk** at the *"Let's group: the life cycle of galaxies in their favorite environment"* workshop at MPA, Münich

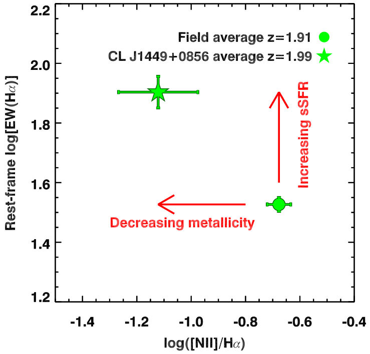
So far so good

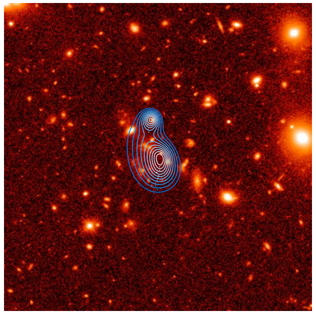
And more!

- FMOS – Spectroscopic survey with the Subaru Telescope (Japan – France - Italy collaboration)
  - Hundreds of galaxies at z~1.5
  - Still ongoing
  - First papers coming out now
- Redshift confirmation of a z=2.2 cluster (KMOS program)
- Line diagnostics and evolution of ISM conditions
- Tracing of star formation rate with Hα in far-away clusters (KMOS program) and reversal of SFR-density relation

Summary

- Effect of nurture on gas properties in star-forming galaxies in a far-away cluster (Valentino et al. 2015, Astrophysical Journal, 801, 132)
- A giant Lyα nebula probing energy injection in far-away clusters (Valentino et al. in prep.)
- Long- and short-term projects





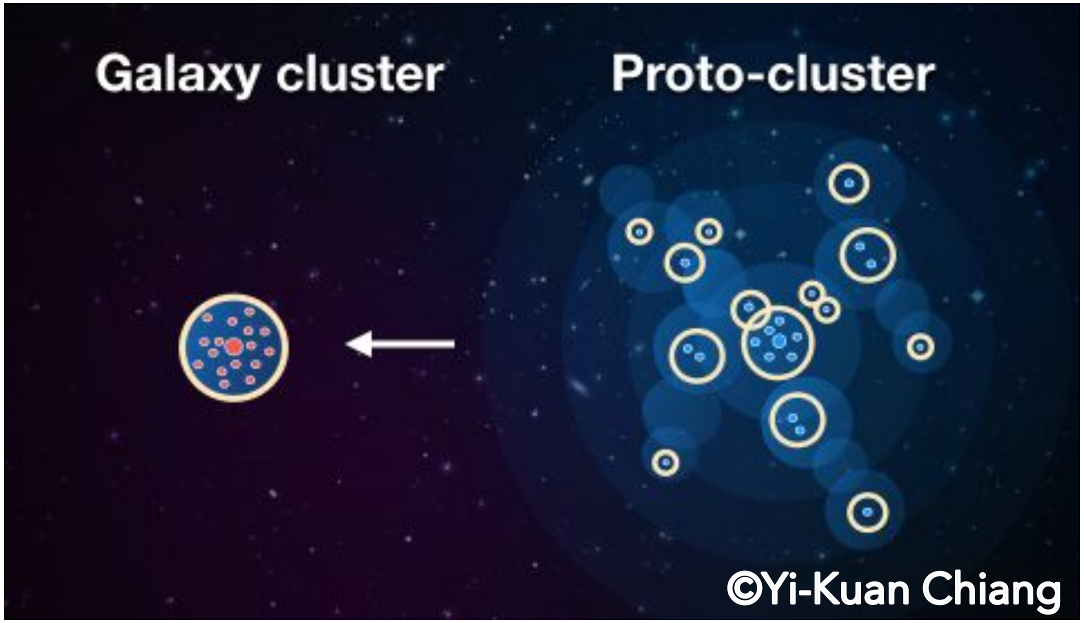
Back up

Valentino et al. 2015

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**



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Contradictory results at high redshift (Kulas et al. 2013, Shimakawa et al. 2015 **vs** Kacprzak et al. 2015).

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

Valentino et al. 2015

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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.

Valentino et al. 2015

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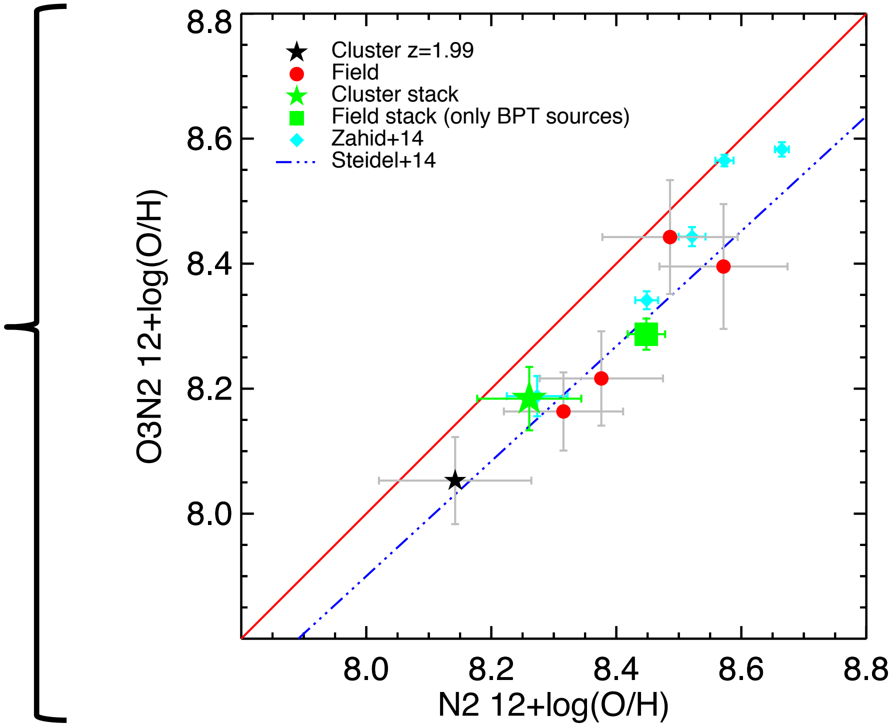

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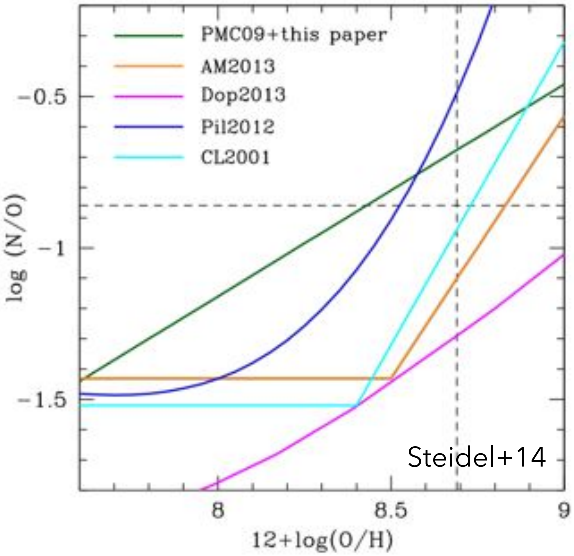
We estimated N/O from [N II]/[O II] for the cluster only (Perez-Montero & Contini 2013):

log(N/O) = -1.18±0.19



Steidel+14

Valentino et al. 2015

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Known issues:

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- Standard calibrations are based on low-redshift galaxies
- 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:

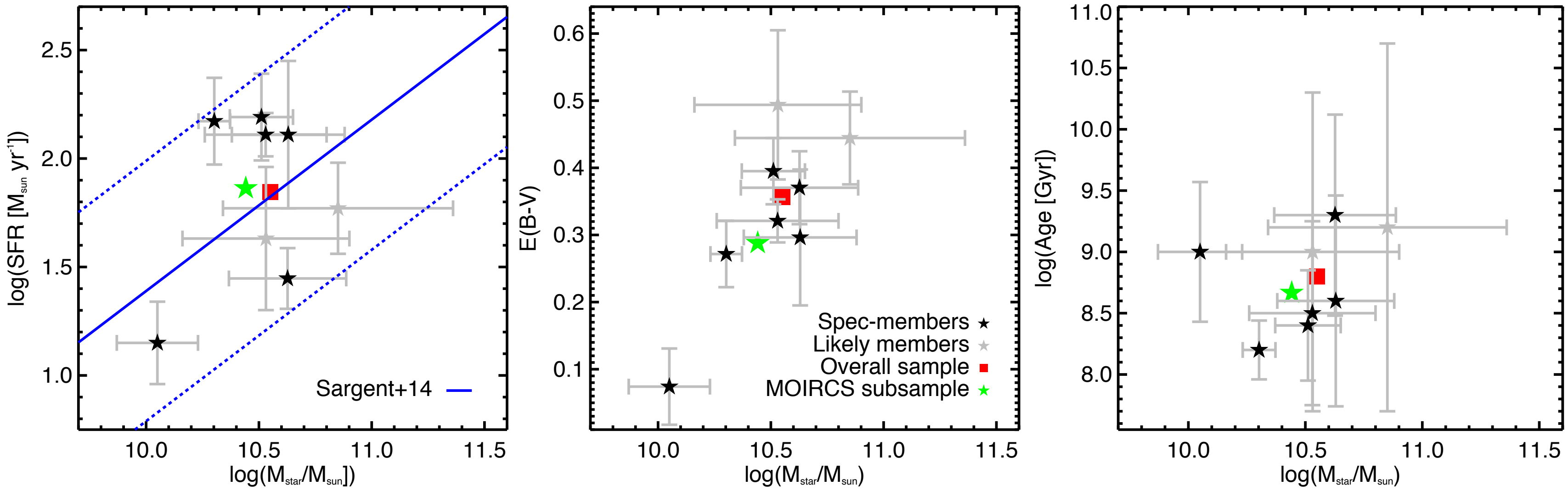
$$\mathcal{U} \cong -2.61$$

which is comparable with values measured in high redshift field galaxies

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

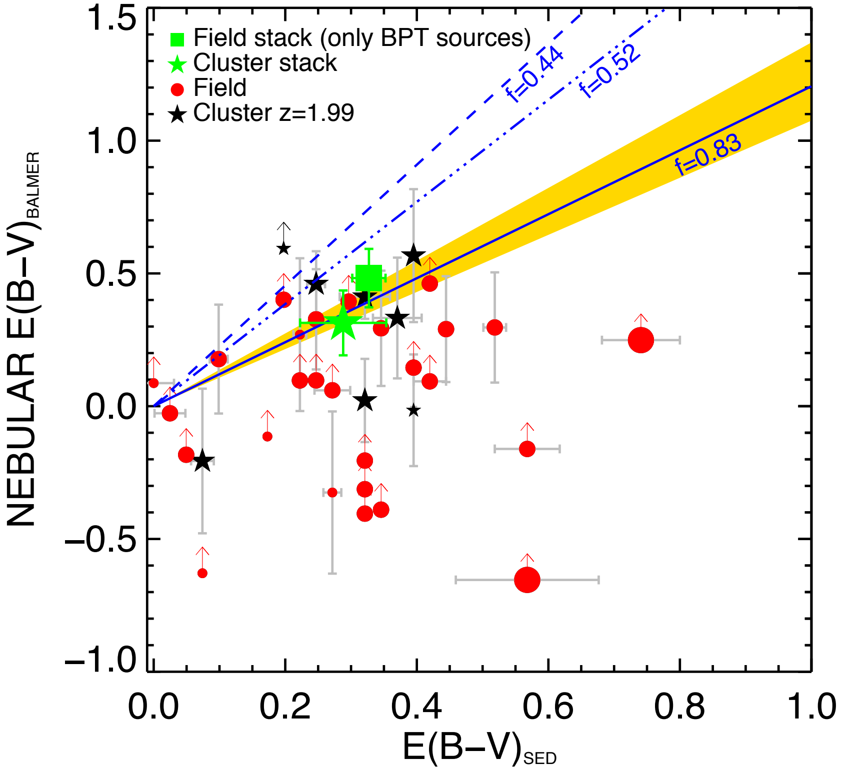
Valentino et al. 2015

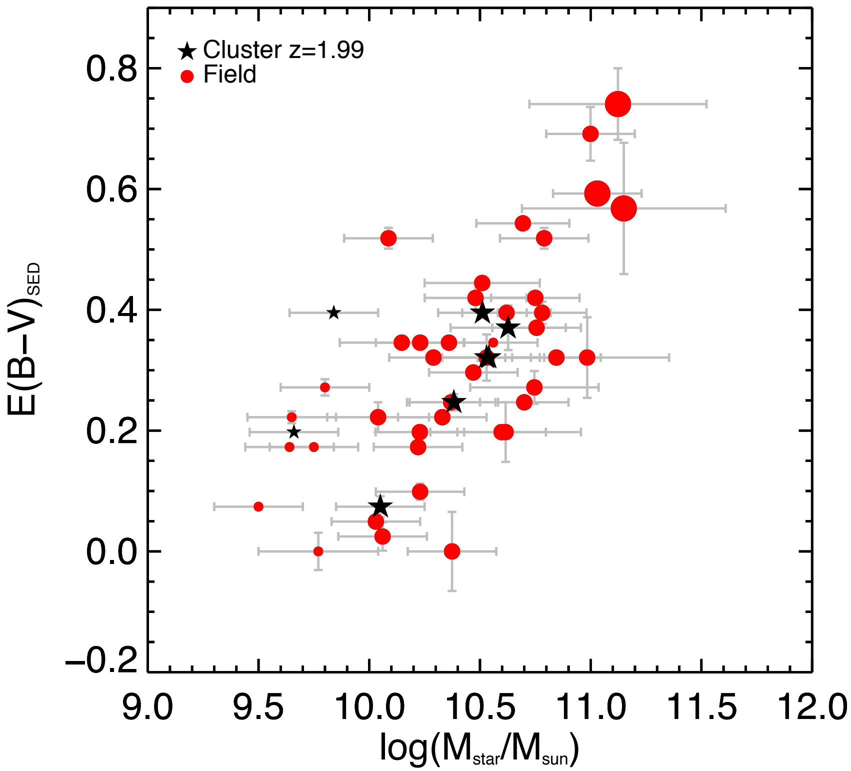
Possible selection effects



Valentino et al. 2015

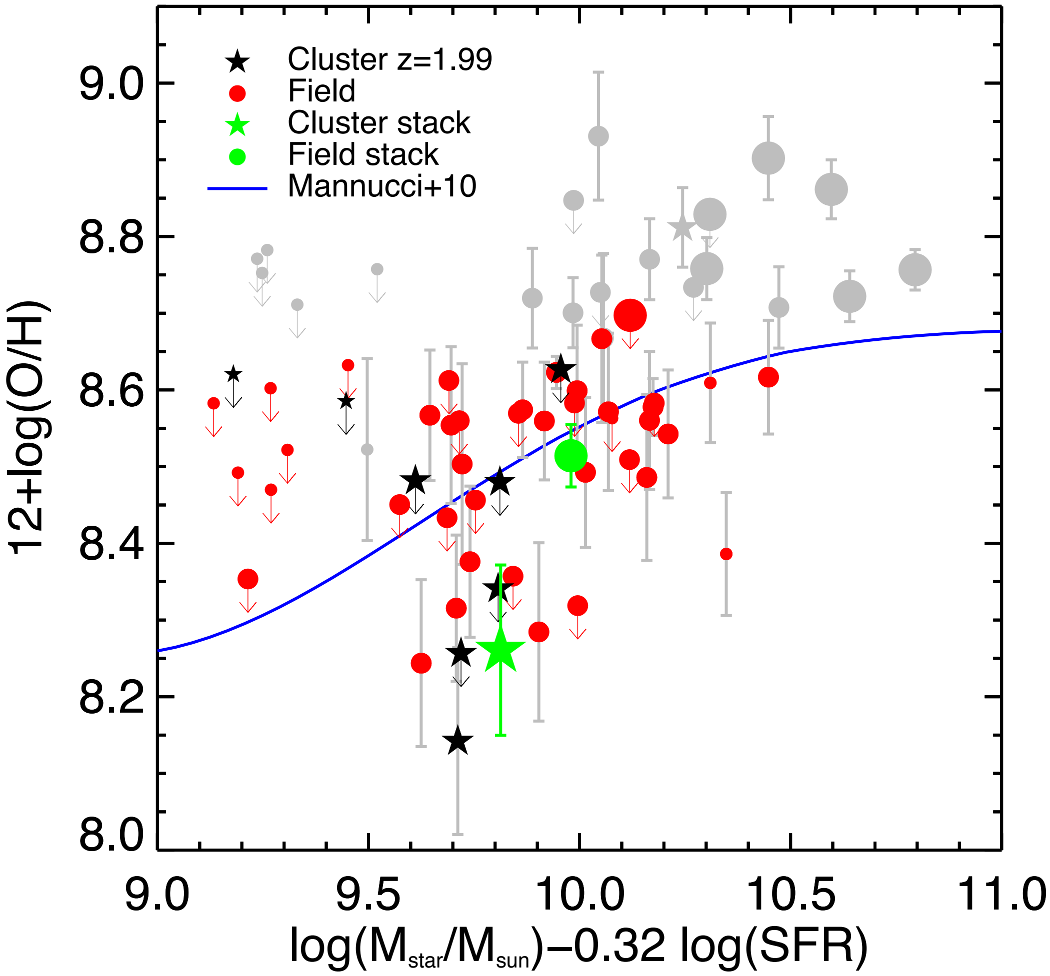
Nebular reddening





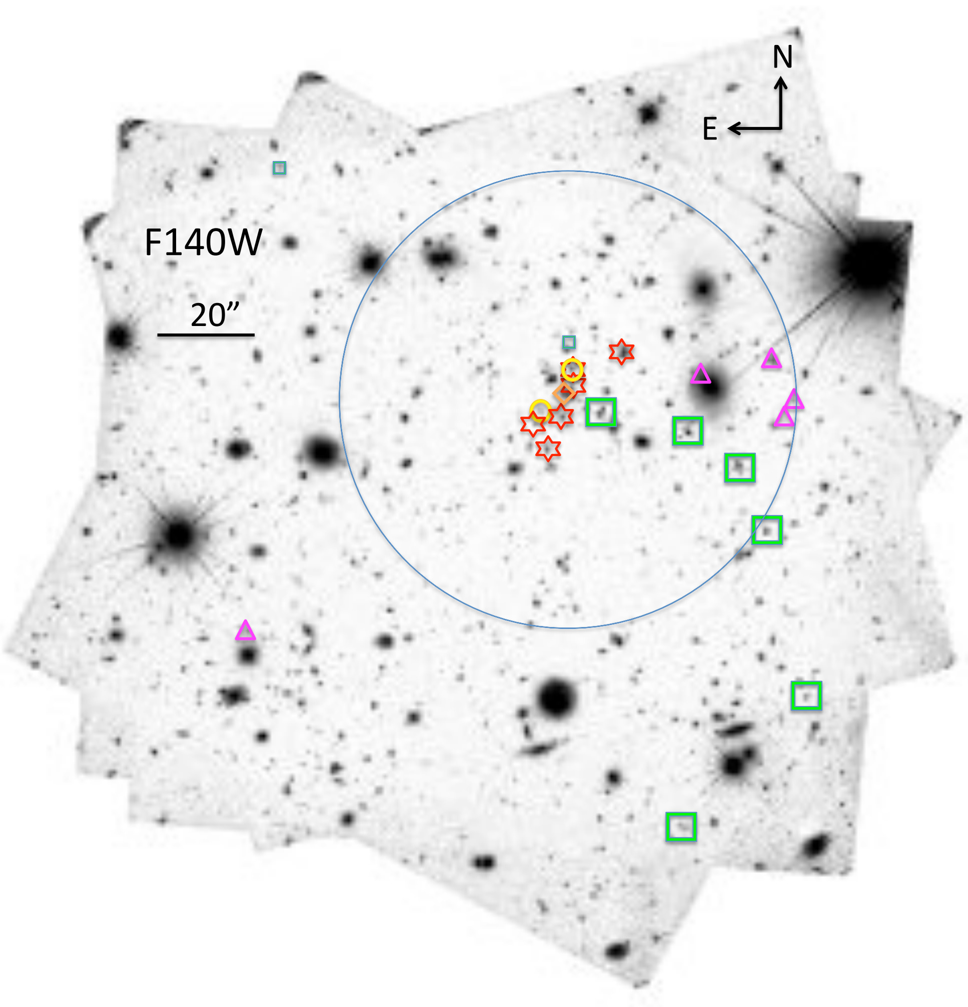
Valentino et al. 2015

Fundamental Metallicity Relation



Valentino et al. 2015

A speculative picture of the situation

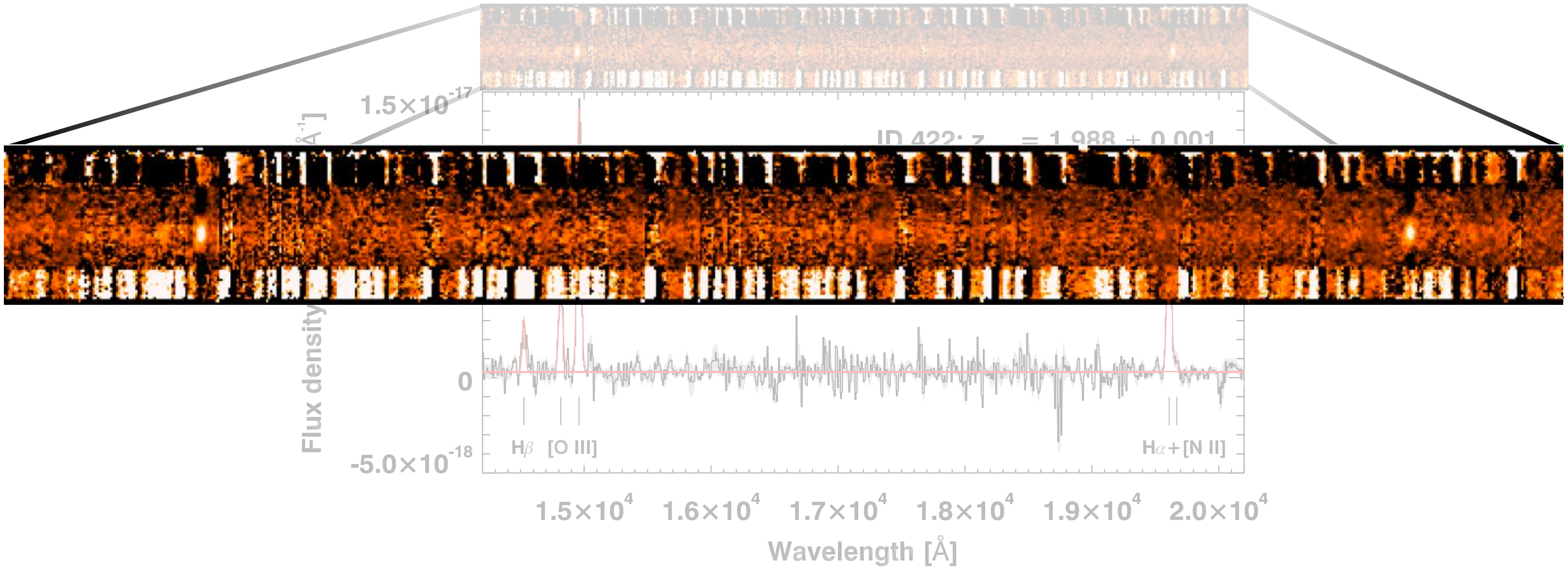


Assembling/accreting feature?

Valentino et al. 2015

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.



Valentino et al. 2015

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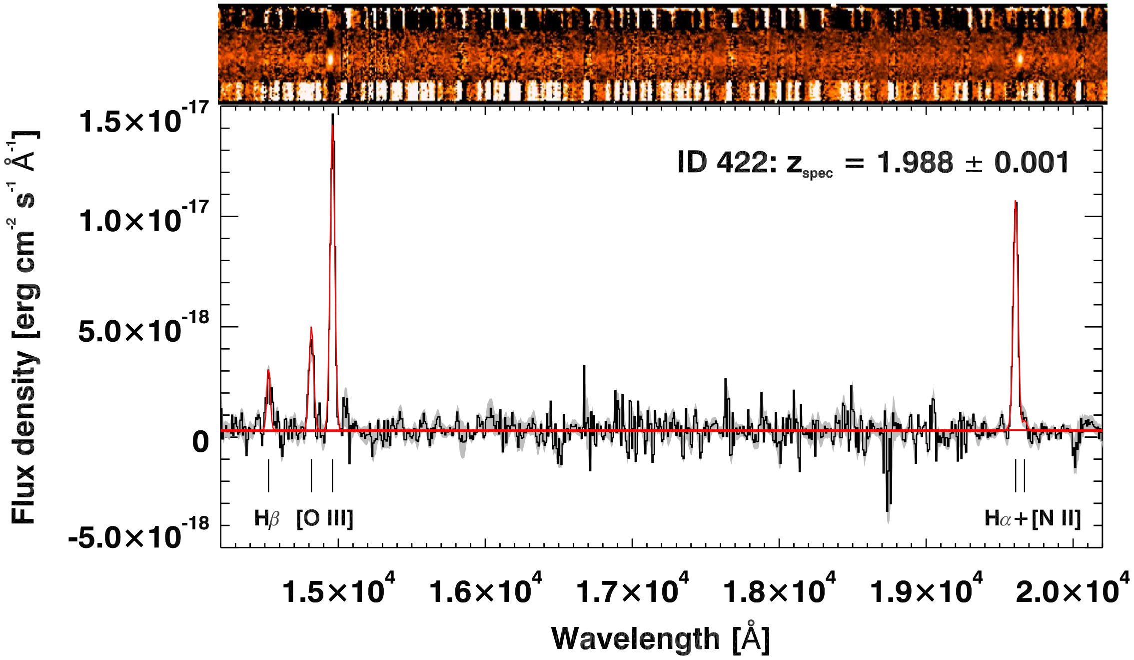
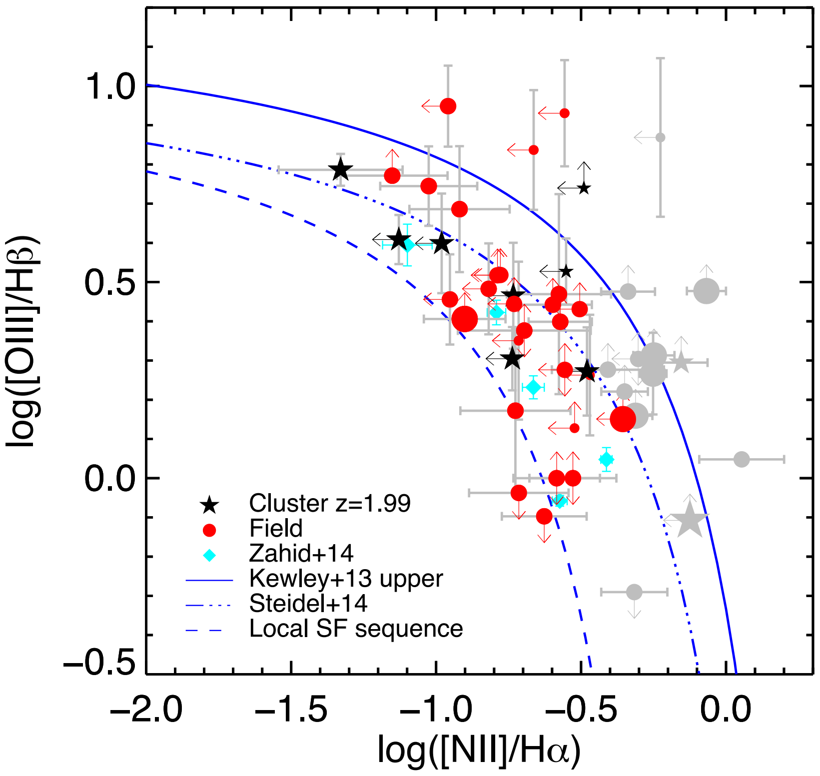
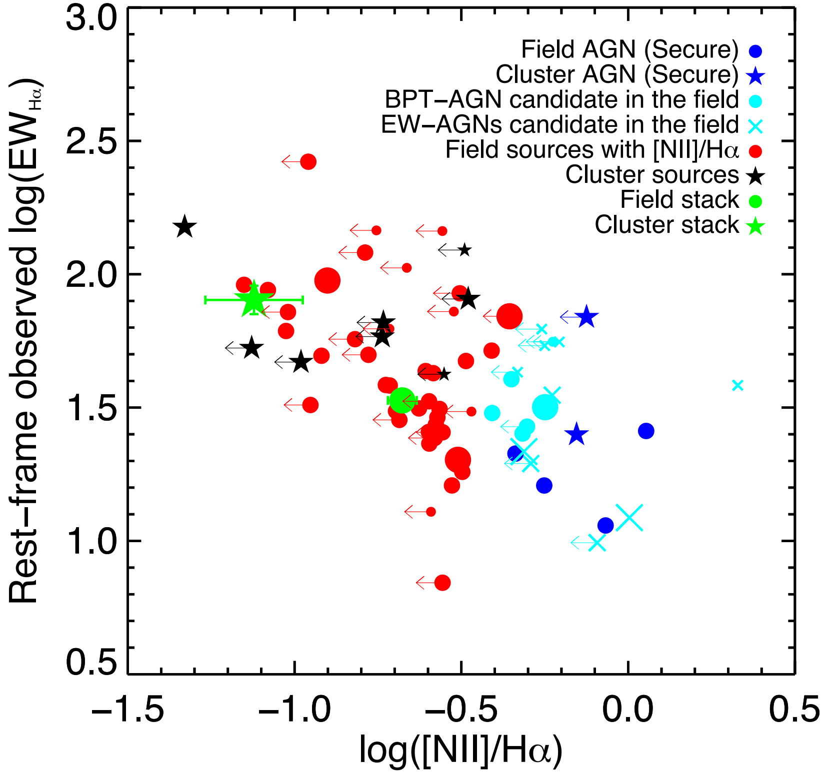


Valentino et al. 2015

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).

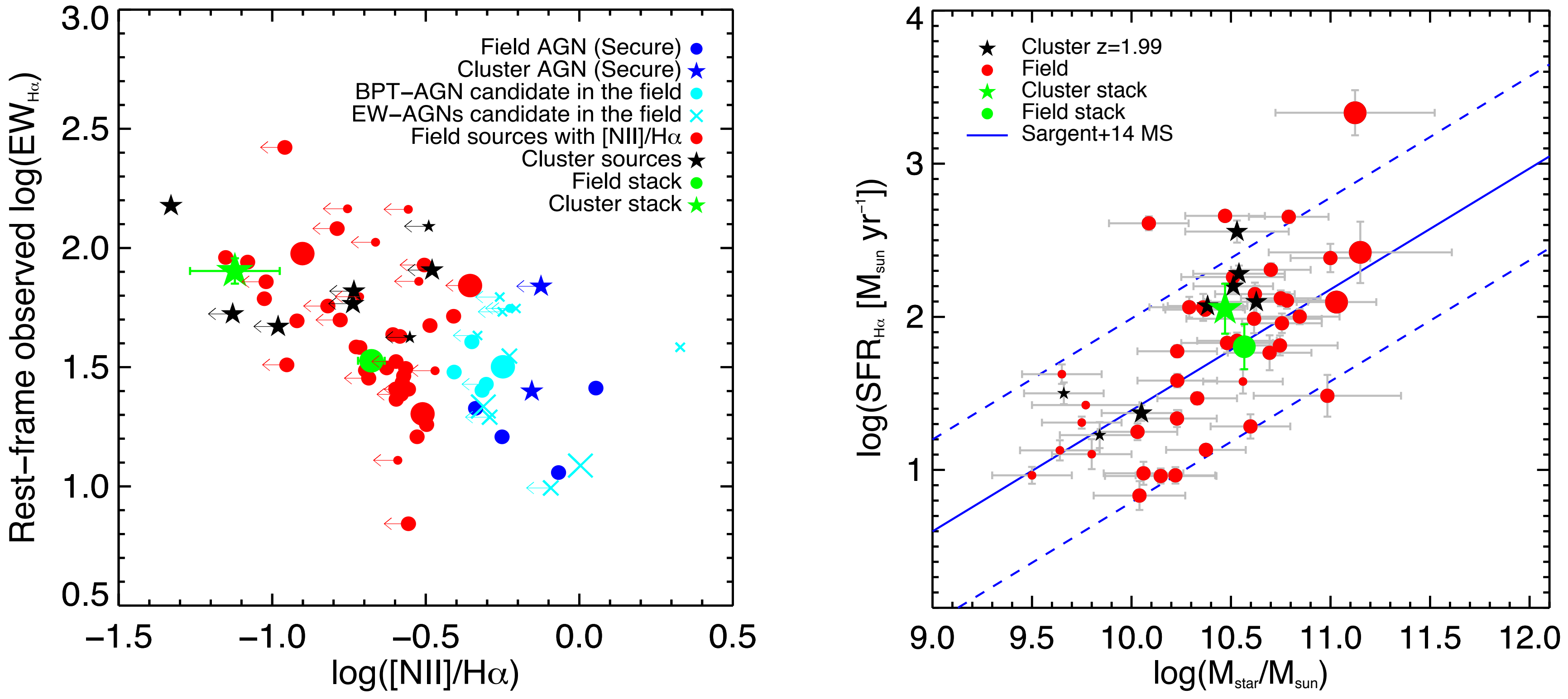


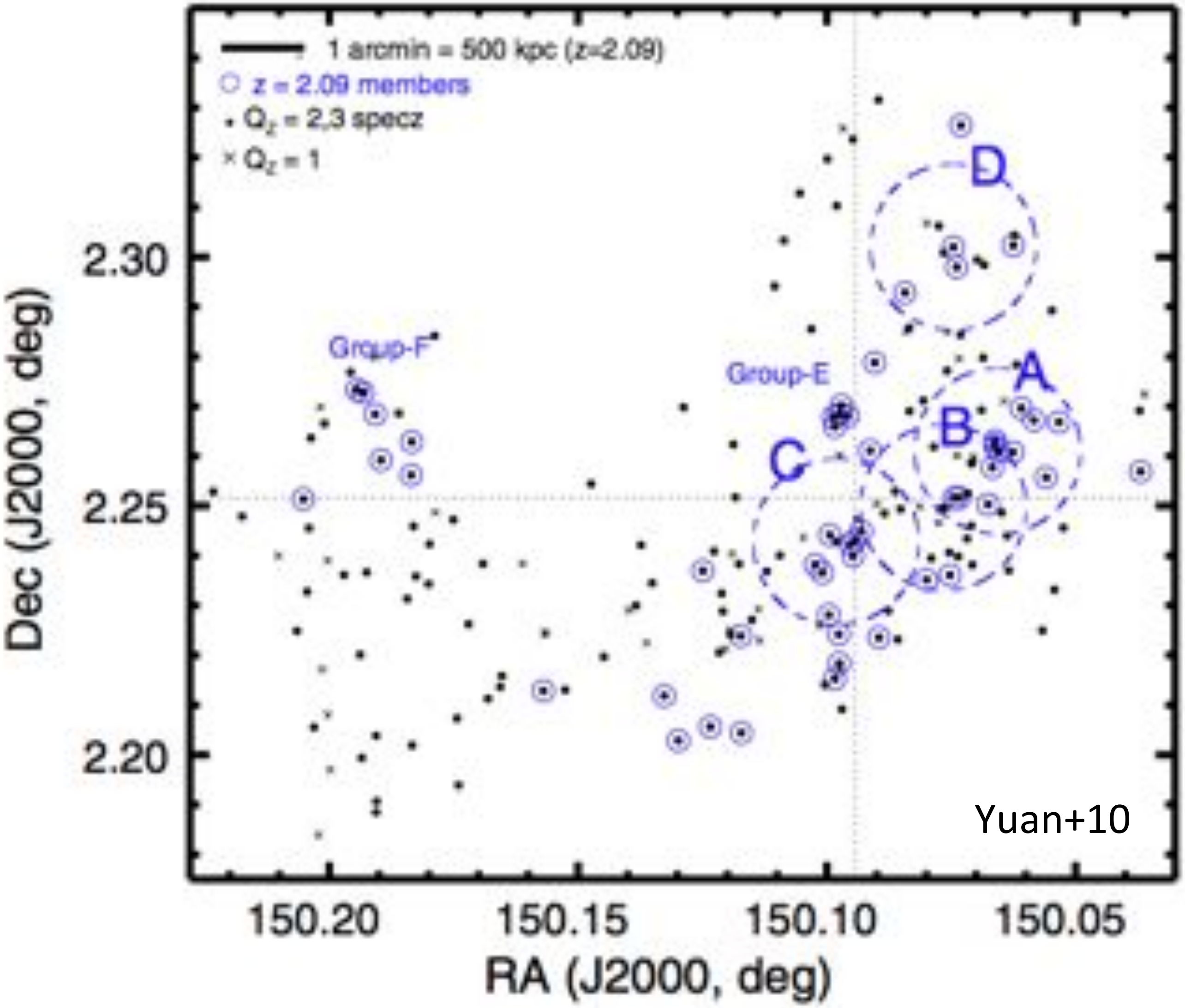


Valentino et al. 2015

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.**




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
2.30
2.25
2.20
Dec (J2000, deg)
150.20
150.15
150.10
150.05
RA (J2000, deg)

Yuan+10

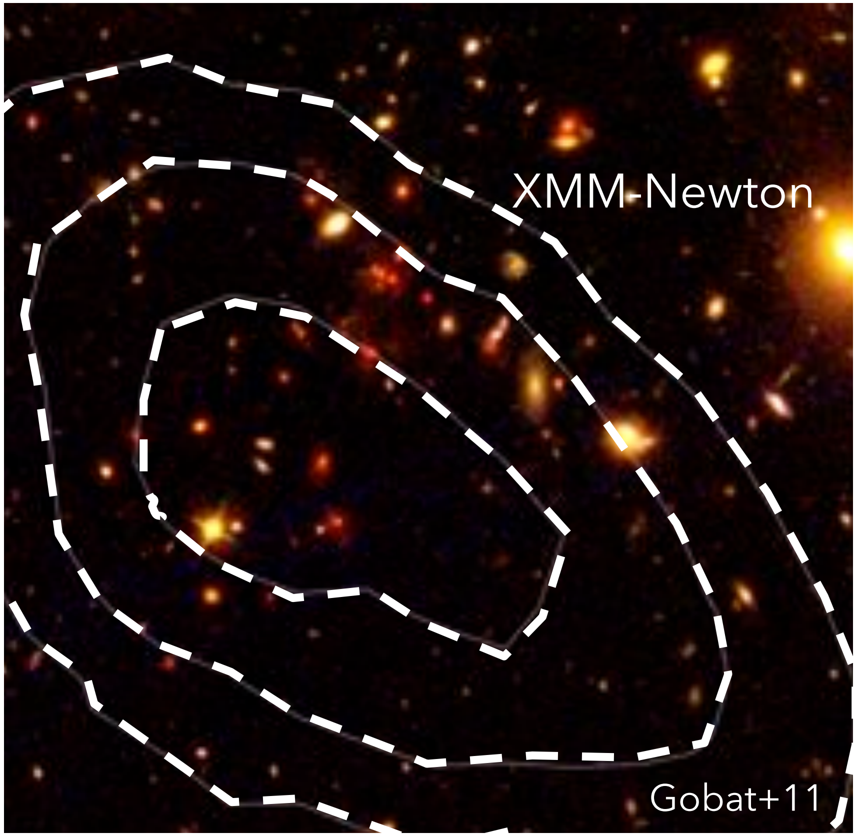
Valentino et al. 2015

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

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

Extensively followed-up:

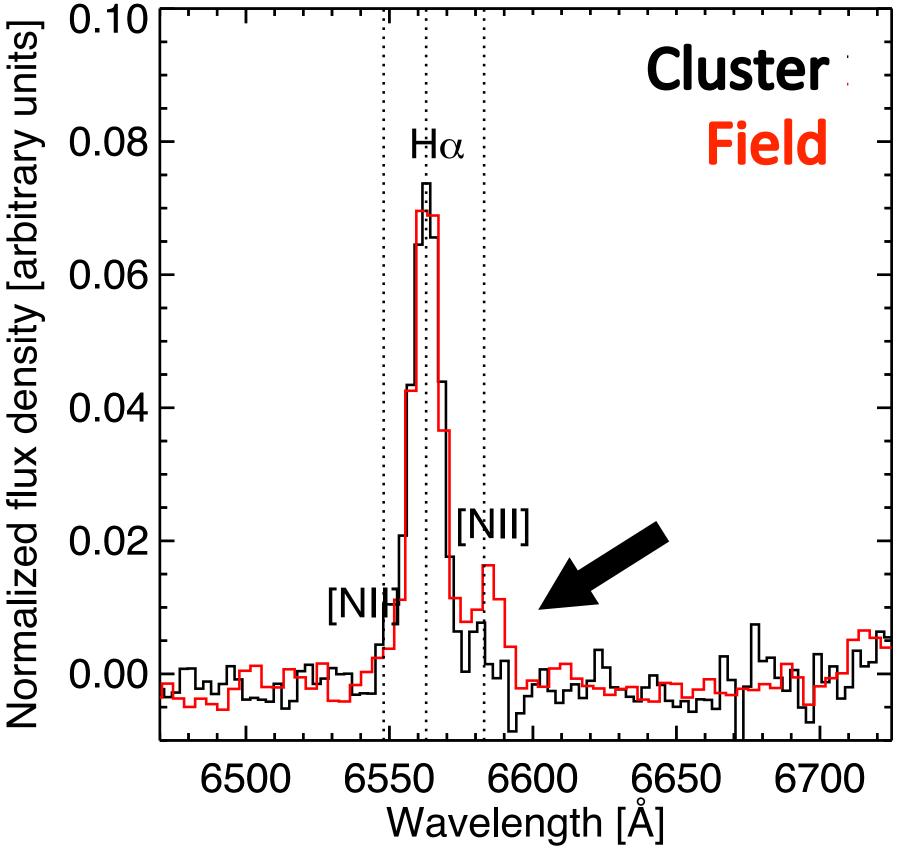
- 13-band photometry (**SED modelling**)
- HST/WFC3 slitless spectroscopy ([O II], Hβ, [O III] at z~2)
- **Subaru/MOIRCS HK spectroscopy of star-forming galaxies**



Valentino et al. 2015

Observing an environmental signature

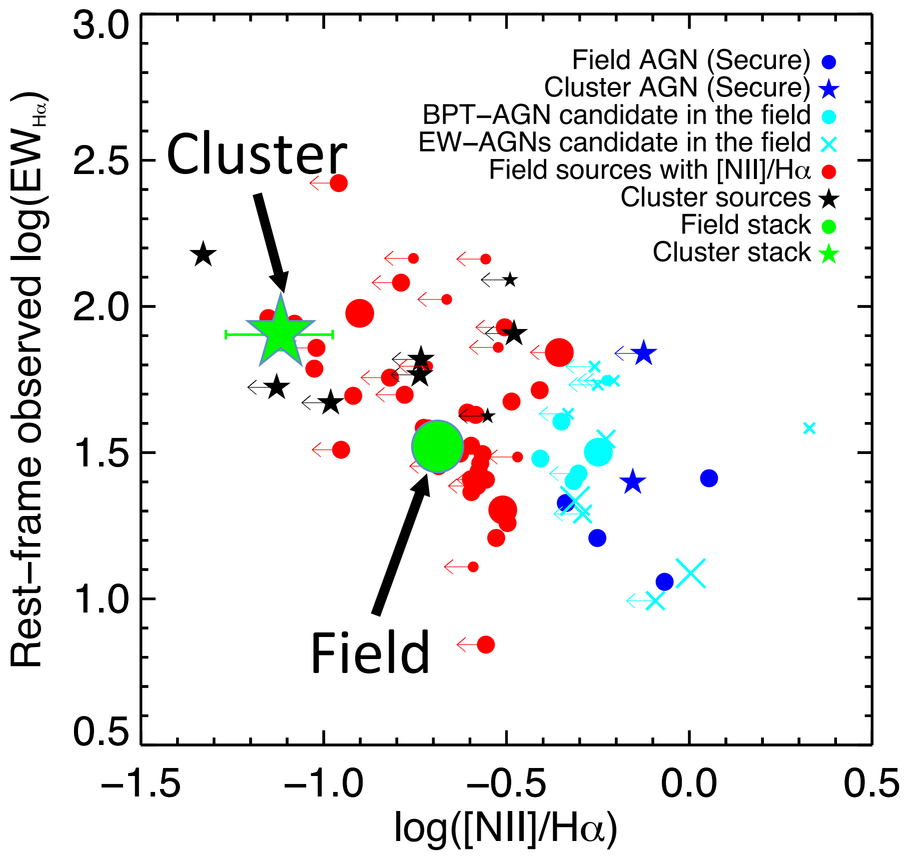
We detect a **≈4σ significant lower [N II]/Hα ratio in the cluster stacked sample** than in the mass-matched field sample (while [O III]/Hβ is compatible between the two).



Valentino et al. 2015

Observing an environmental signature

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

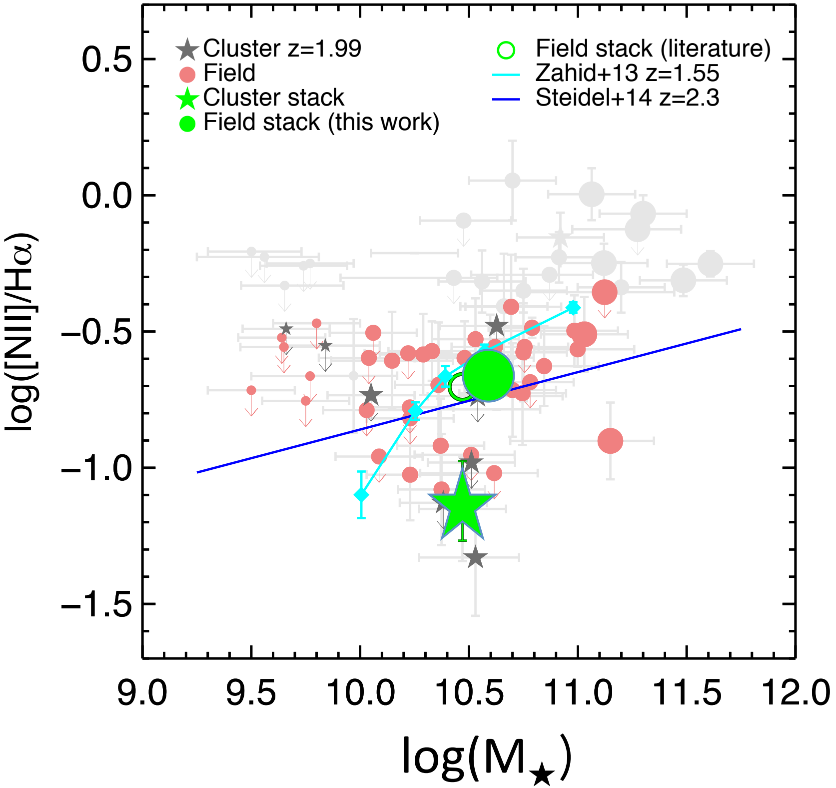


Valentino et al. 2015

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).

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



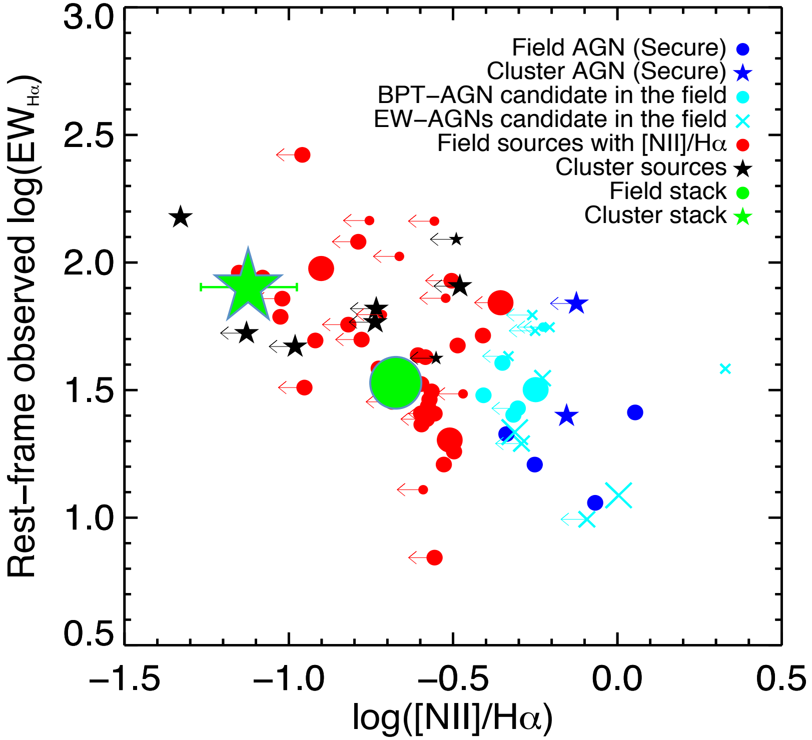
Thus, star-forming galaxies in CL J1449+0856 are on average more metal poor than mass-matched field counterparts (by ≈0.09-0.25 dex, according to the calibration or indicator used)

Valentino et al. 2015

Gaining physical insight

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

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



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

Valentino et al. 2015

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):