



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***

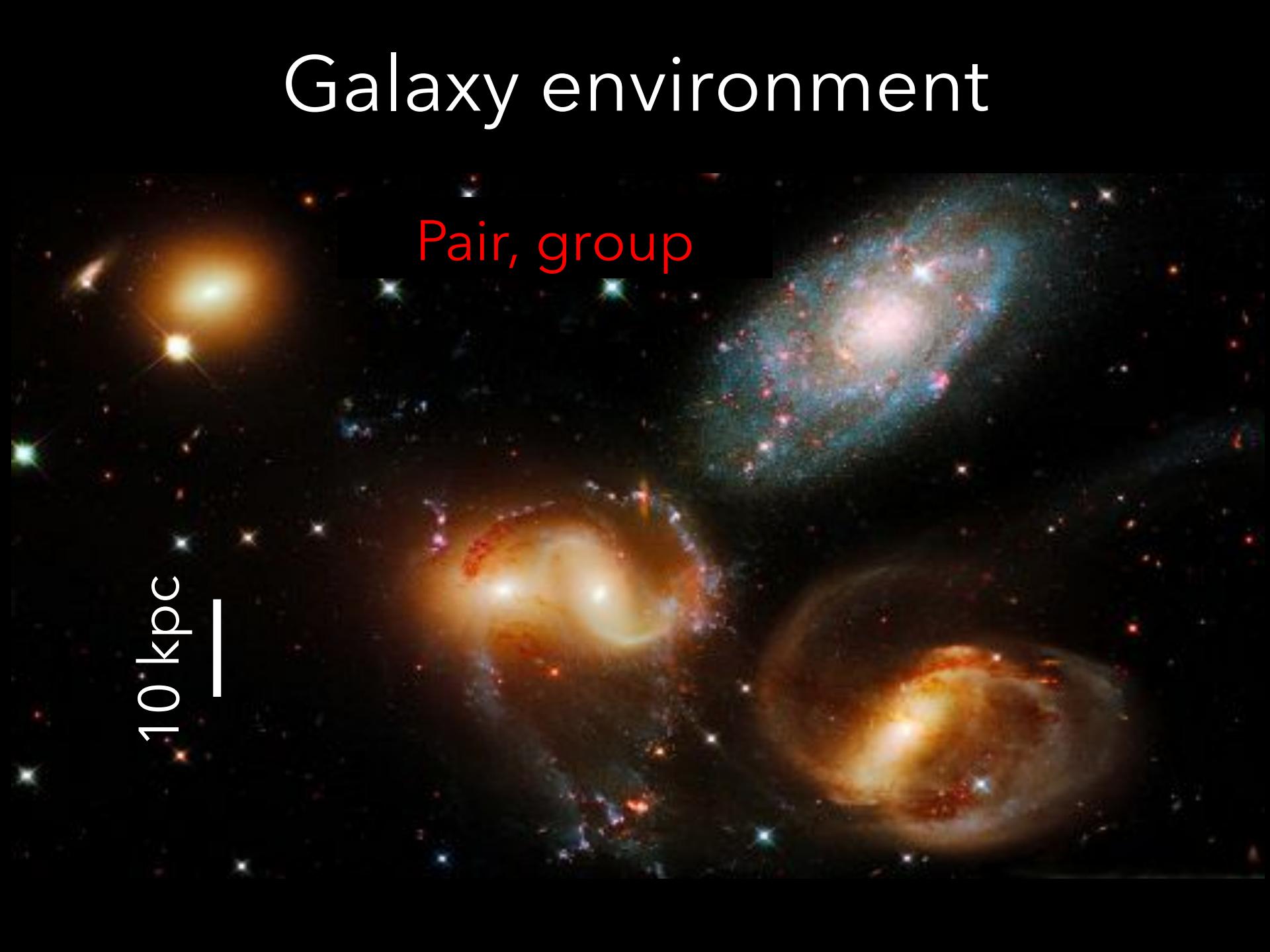
Galaxy environment



Isolated galaxy

10 kpc

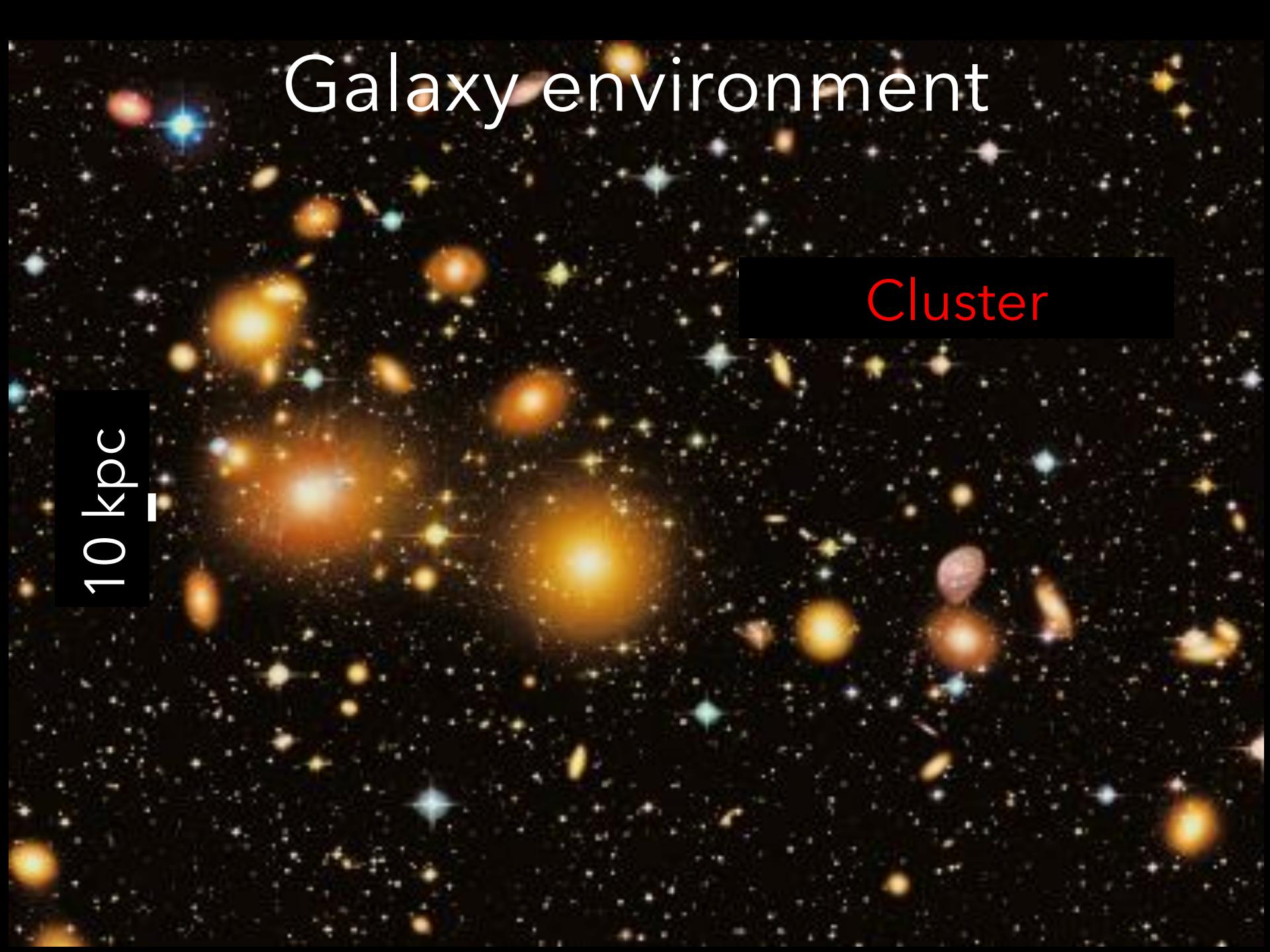
Galaxy environment



Pair, group

10 kpc |

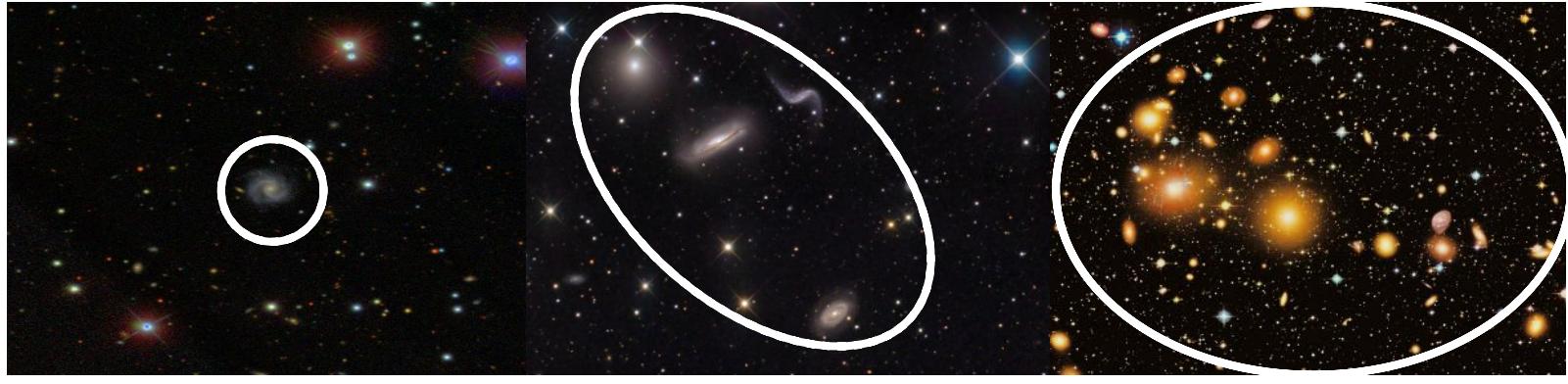
Galaxy environment

A photograph of a galaxy cluster against a dark background. The cluster contains numerous galaxies of various sizes and colors, primarily yellow and orange, with some blue and red ones interspersed. A prominent, larger yellow-orange galaxy is visible on the left side. A smaller, less luminous cluster of galaxies is located on the right. A scale bar labeled "10 kpc" is positioned in the bottom-left corner.

Cluster

10 kpc

Galaxy environment



Isolation

Pair, group

Cluster



Density

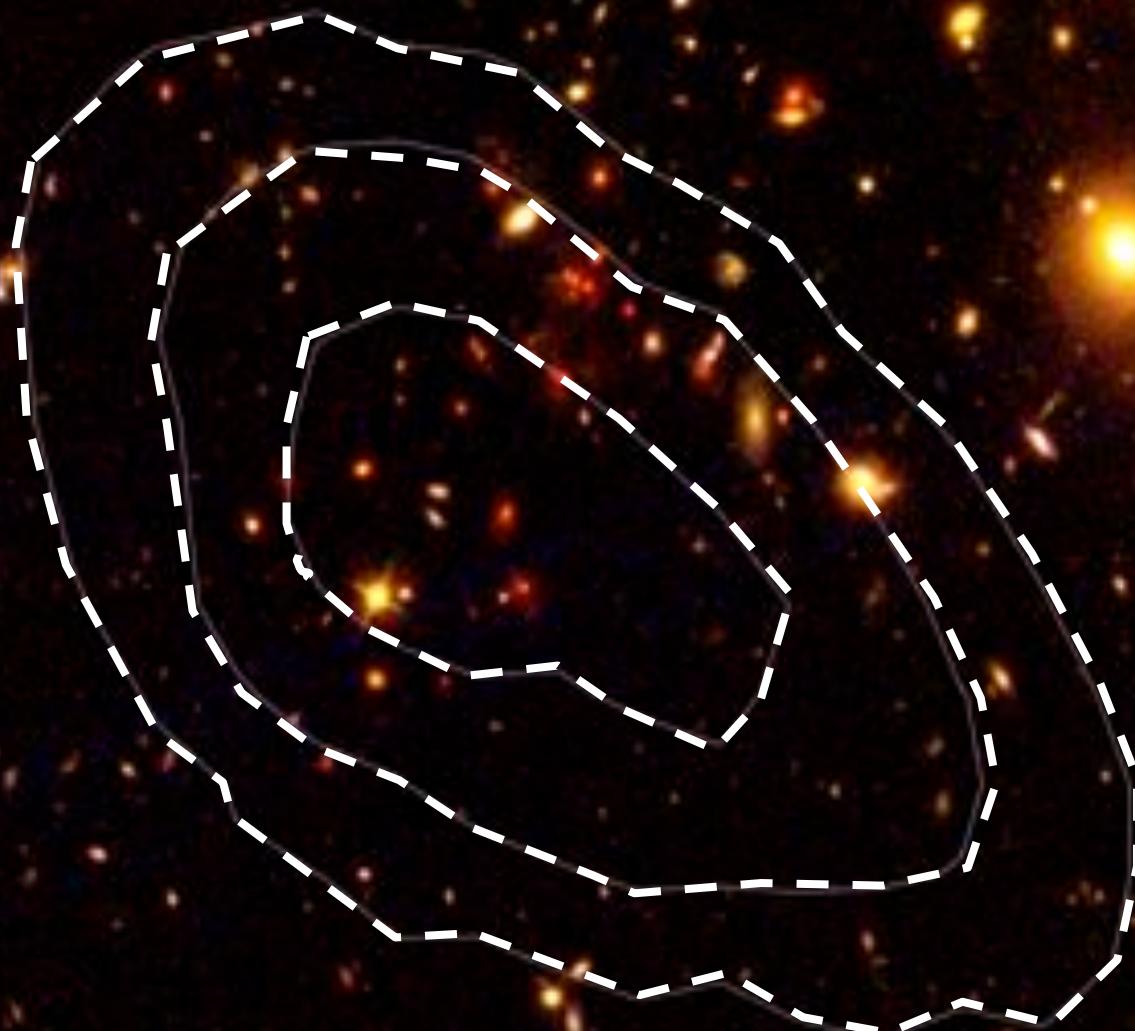
Galaxy morphologies, colors, luminosities, star formation rates, masses, sizes(?) change with the environment **in the local Universe.**

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 $z = 1.99 \rightarrow 10.4$ Gyr ago

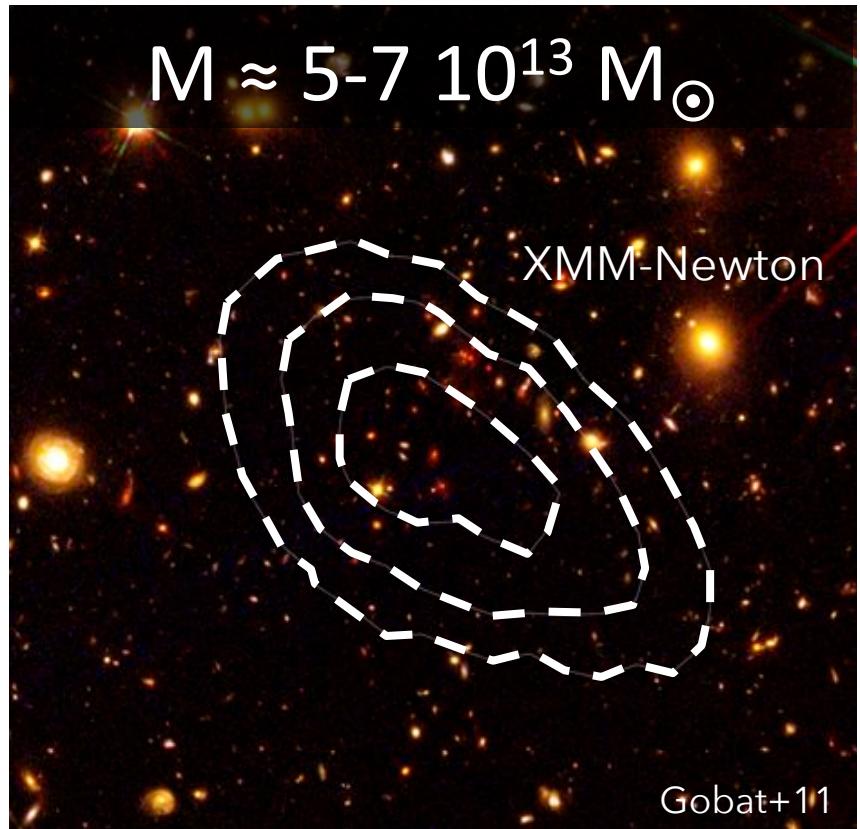
Gobat+11

A far-away cluster

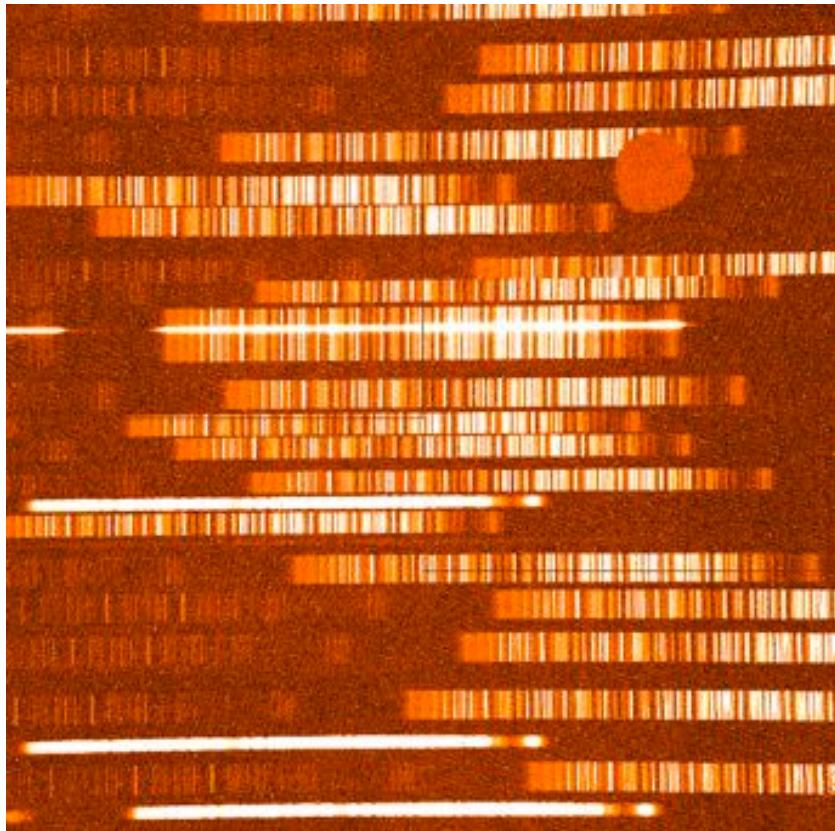
A **relatively evolved cluster**
that hosts **a significant
fraction of active galaxies**
(Gobat+2011, 2013, Strazzullo
+2013).

Extensively followed-up:

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



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)

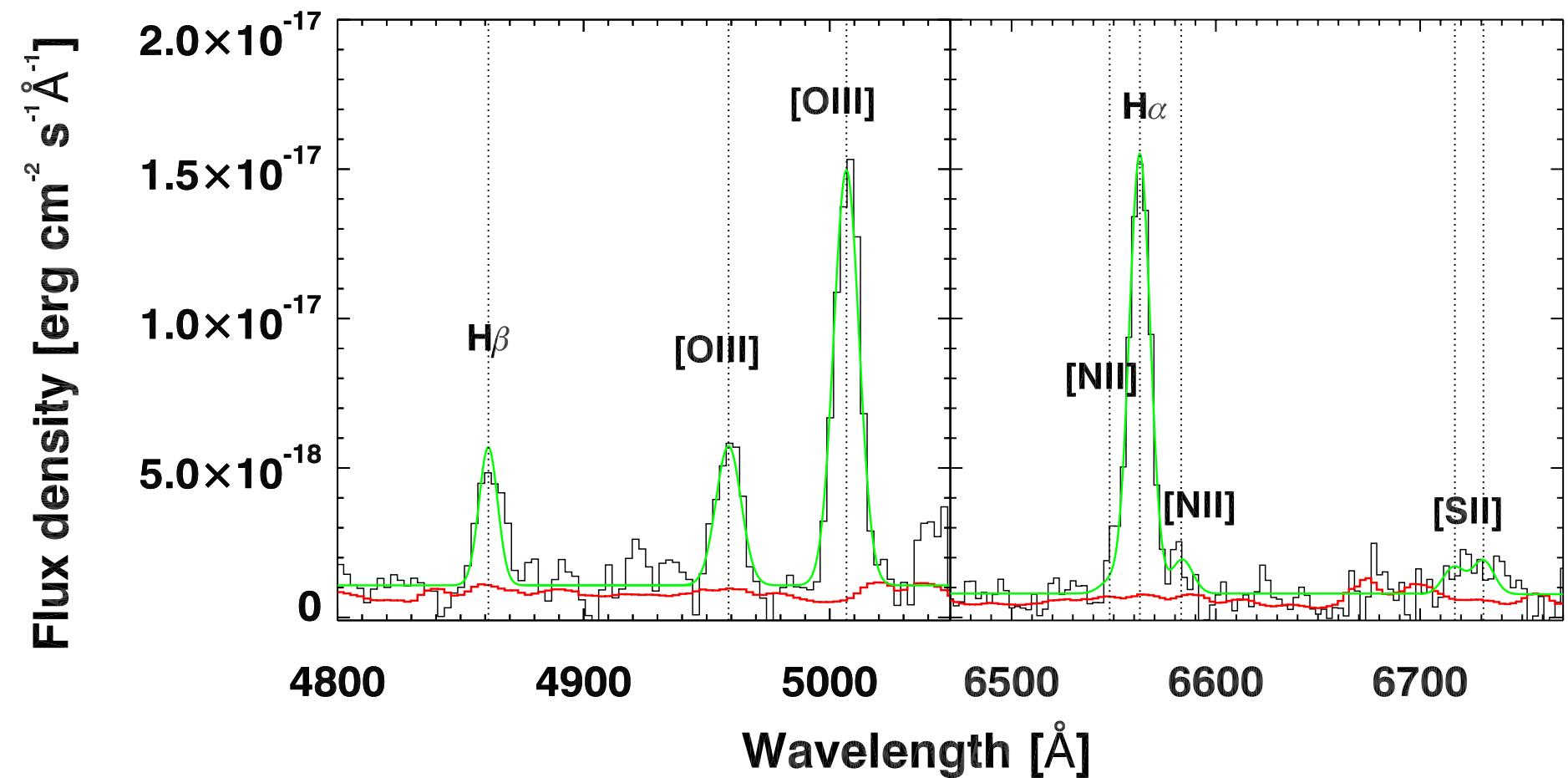
10: Observed cluster star-forming galaxies

78(%): success rate in detecting H α ($>3\sigma$ significance)

6(%): success rate in detecting [NII] $\lambda 6583 \text{ \AA}$ ($>3\sigma$ significance)

110: extracted and fully reduced spectra from raw data to flux calibration

A far-away cluster



Chemistry

Hydrogen 1 H 1.0079	Helium 2 He 4.003
Li 3 Boron 11 Sodium 22 Potassium 19 Rubidium 37 Cesium 55 Francium 87	Be 4 Boron 12 Magnesium 12 Mg 12 Calcium 20 Strontium 38 Barium 56 Radium 88 Lanthanum 57 Ce 58 Pr 59 Nd 60 Pm 61 Sm 62 Eu 63 Gd 64 Tb 65 Dy 66 Ho 67 Er 68 Tm 69 Yb 70
Na 12 Mg 12 28.085 Mg 28.085 Ca 20 K 19 Ca 20 Sc 21 Ti 22 V 23 Cr 24 Mn 25 Fe 26 Co 27 Ni 28 Cu 29 Zn 30 Ga 31 Ge 32 As 33 Se 34 Br 35 Kr 36 Y 39 Zr 40 Nb 41 Mo 42 Tc 43 Ru 44 Rh 45 Pd 46 Ag 47 Cd 48 In 49 Sn 50 Sb 51 Te 52 I 53 Xe 54 Lu 71 Hf 72 Ta 73 W 74 Re 75 Os 76 Ir 77 Pt 78 Au 79 Hg 80 Tl 81 Pb 82 Bi 83 Po 84 At 85 Rn 86 Fr 87 Ra 88 Fr 89-102 Lanthanide series Actinide series	Al 13 Si 14 P 15 S 16 Cl 17 Ar 18 Ga 21 Ge 22 As 23 Se 24 Br 25 Kr 26 In 27 Sn 28 Sb 29 Te 30 I 31 Pb 32 Bi 33 Po 34 At 35 Rn 36 Lu 71 Hf 72 Ta 73 W 74 Re 75 Os 76 Ir 77 Pt 78 Au 79 Hg 80 Tl 81 Pb 82 Bi 83 Po 84 At 85 Rn 86 Fr 87 Ra 88 Fr 89-102 Lanthanide series Actinide series
Li 12 Be 12 Sodium 12 Magnesium 12 Mg 12 Calcium 20 Strontium 38 Barium 56 Radium 88 Lanthanum 57 Ce 58 Pr 59 Nd 60 Pm 61 Sm 62 Eu 63 Gd 64 Tb 65 Dy 66 Ho 67 Er 68 Tm 69 Yb 70	Al 26.982 Silicon 28.085 Phosphorus 30.973 Sulfur 32.065 Chlorine 35.453 Argon 36.966 Gallium 69.721 Germanium 72.611 Antimony 74.947 Bromine 79.904 Krypton 83.800 Rubidium 85.462 Strontium 87.62 Barium 132.91 Radium 138.91 Lanthanum 138.91 Ce 140.12 Pr 140.91 Nd 141.24 Pm 141.91 Sm 142.96 Eu 145.96 Gd 147.96 Tb 148.93 Dy 142.90 Ho 144.93 Er 147.26 Tm 148.90 Yb 173.04 Lanthanide series Actinide series
Li 12 Be 12 Sodium 12 Magnesium 12 Mg 12 Calcium 20 Strontium 38 Barium 56 Radium 88 Lanthanum 57 Ce 58 Pr 59 Nd 60 Pm 61 Sm 62 Eu 63 Gd 64 Tb 65 Dy 66 Ho 67 Er 68 Tm 69 Yb 70	Al 26.982 Silicon 28.085 Phosphorus 30.973 Sulfur 32.065 Chlorine 35.453 Argon 36.966 Gallium 69.721 Germanium 72.611 Antimony 74.947 Bromine 79.904 Krypton 83.800 Rubidium 85.462 Strontium 87.62 Barium 132.91 Radium 138.91 Lanthanum 138.91 Ce 140.12 Pr 140.91 Nd 141.24 Pm 141.91 Sm 142.96 Eu 145.96 Gd 147.96 Tb 148.93 Dy 142.90 Ho 144.93 Er 147.26 Tm 148.90 Yb 173.04 Lanthanide series Actinide series

Lanthanide series	Lanthanum 57 La 138.91	Cerium 58 Ce 140.12	Praseodymium 59 Pr 140.91	Neuropium 60 Nd 141.24	Promethium 61 Pm 141.91	Samarium 62 Sm 145.96	Europium 63 Eu 145.96	Gadolinium 64 Gd 147.96	Tytanum 65 Tb 148.93	Dysprosium 66 Dy 142.90	Holmium 67 Ho 144.93	Erbium 68 Er 147.26	Thulium 69 Tm 148.90	Ytterbium 70 Yb 173.04
Actinide series	Actinium 89 Ac 132.91	Thorium 90 Th 132.94	Protactinium 91 Pa 131.94	Uranium 92 U 134.96	Nopactinium 93 Np 134.96	Plutonium 94 Pu 134.96	Amberium 95 Am 134.96	Curium 96 Cm 134.96	Berkelium 97 Bk 134.96	Cf 98 Cf 134.96	Es 99 Es 134.96	Fermium 100 Fm 134.96	Mendelevium 101 Md 134.96	No 102 No 134.96

Galactic chemistry

Hydrogen

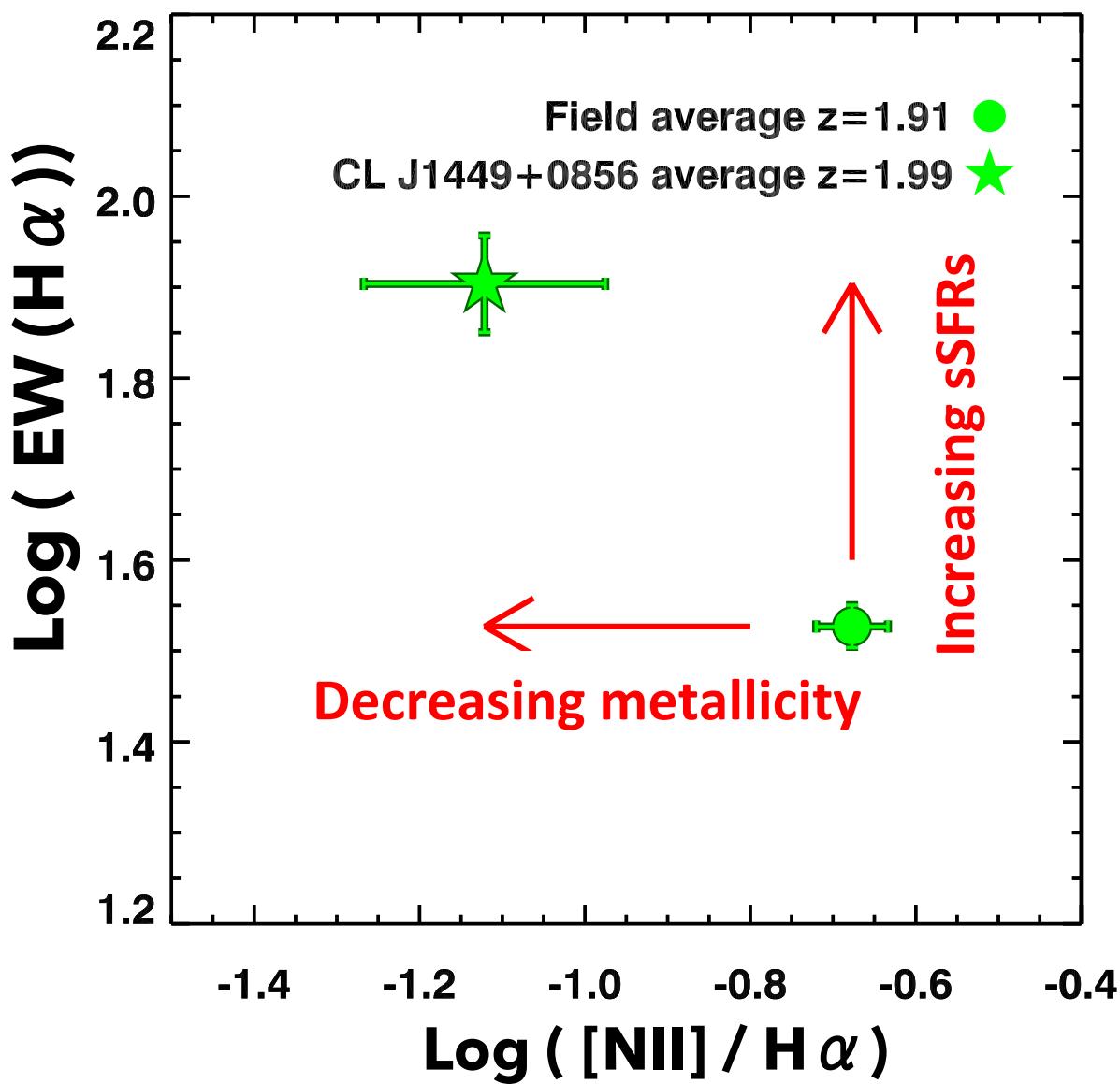
Helium

Metals

Hydrogen 1 H 1.008																									Helium 2 He 4.003
Li 3 12.991	Be 4 9.012																								
Na 11 22.990	Mg 12 24.305																								
K 19 39.098	Ca 20 40.078																								
Rb 37 64.950	Sr 38 67.62																								
Cs 55 132.911	Ba 56 137.91																								
Fr 87 138.91	Ra 88 139.91	*																							
Lu 103 174.967	Hf 104 178.95	Ta 105 180.95	W 106 182.91	R 107 183.90	Pt 108 190.96	Au 109 196.97	Hg 110 200.99	Tl 111 204.99	Pb 112 209.98	Bi 113 210.98	Po 114 219.98	At 115 219.93	Rn 116 222.91												
Lr 107 173.91	Rf 108 175.91	Db 109 179.91	Sg 110 180.91	Bh 111 183.91	Hs 112 184.91	Mt 113 186.91	Uun 114 187.91	Uuu 115 187.91	Uub 116 187.91	Uuq 117 187.91															

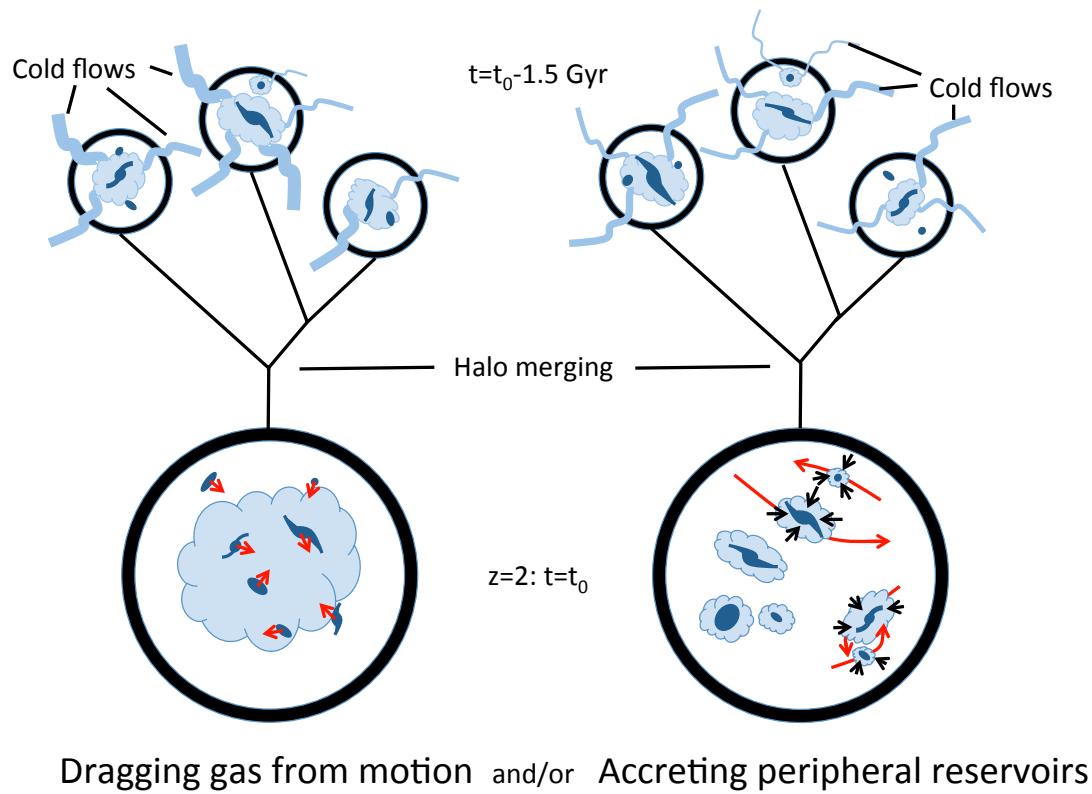
* Lanthanide series	lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 141.94	promethium 61 Pm 141.91	samarium 62 Sm 150.96	europium 63 Eu 151.96	gadolinium 64 Gd 157.96	thulium 65 Tb 158.93	dysprosium 66 Dy 162.93	holmium 67 Ho 164.93	erbium 68 Er 167.96	thulium 69 Tm 168.99	yterbium 70 Yb 173.94
** Actinide series	actinium 89 Ac 151.96	thorium 90 Th 152.94	protactinium 91 Pa 151.94	uranium 92 U 158.95	neptunium 93 Np 158.95	plutonium 94 Pu 159.96	americium 95 Am 159.96	curium 96 Cm 160.96	bcurium 97 Bk 161.96	californium 98 Cf 162.96	eserrium 99 Es 163.96	fermium 100 Fm 164.96	mendelevium 101 Md 165.96	nobelium 102 No 166.96

What do we observe?



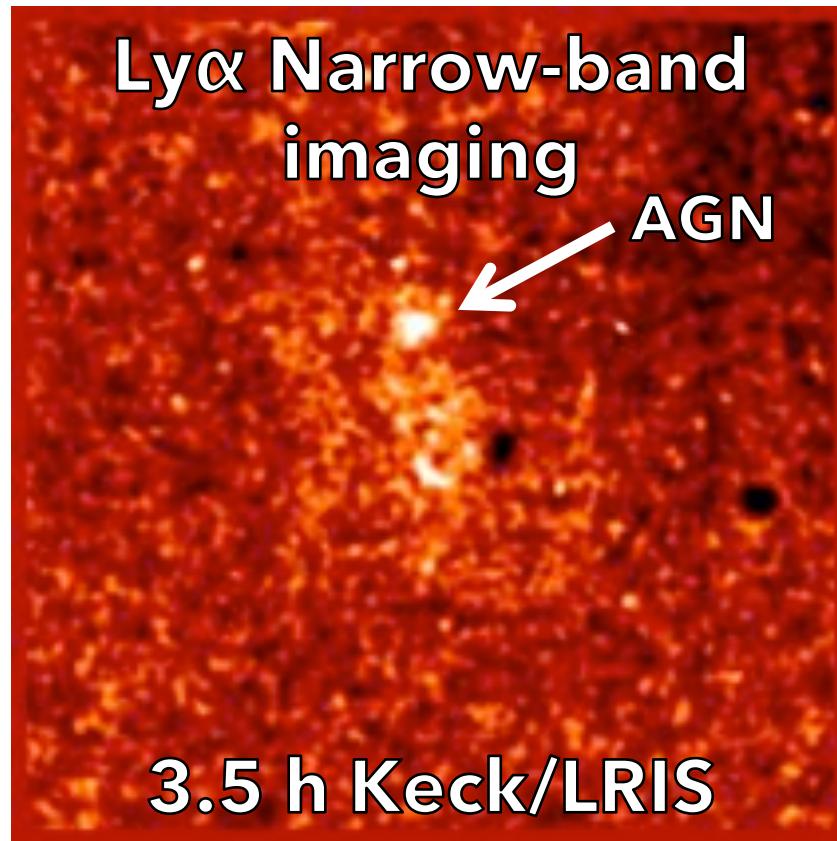
A speculative picture of the situation

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



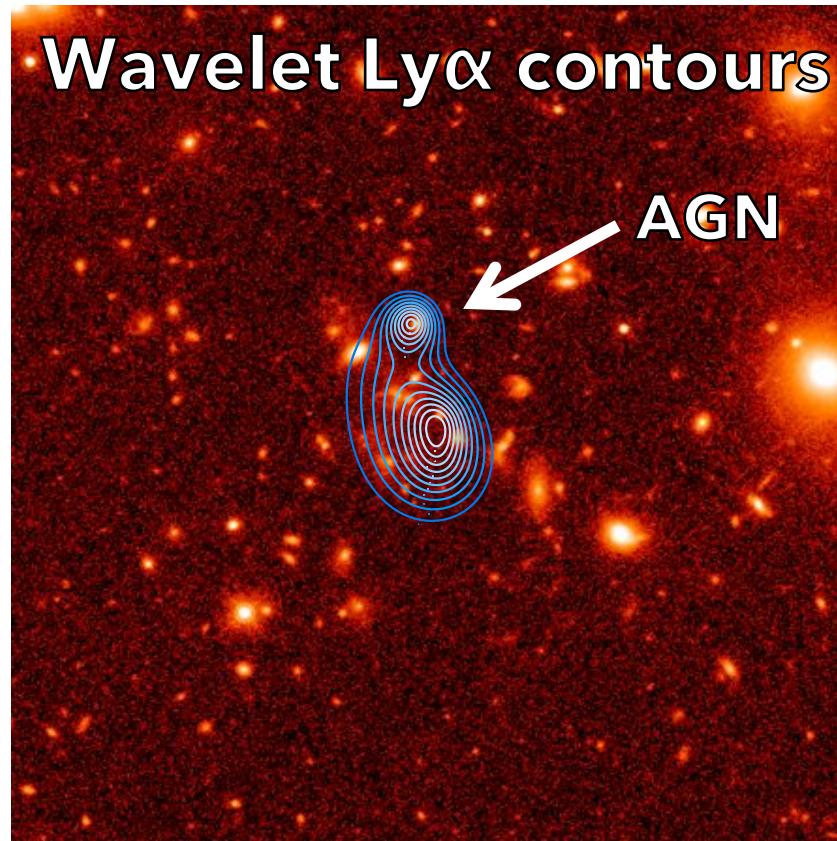
A prime discovery

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

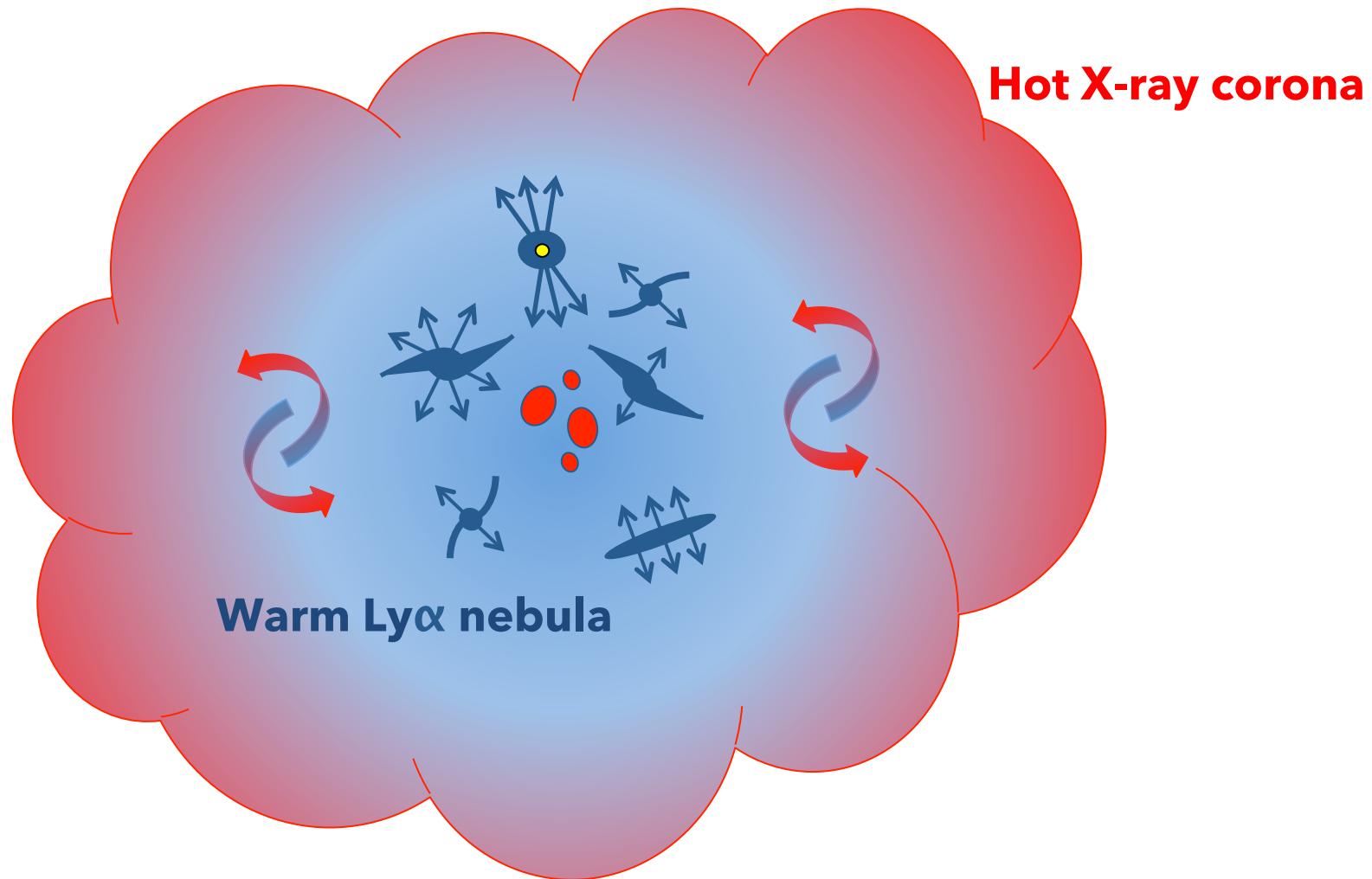


A prime discovery

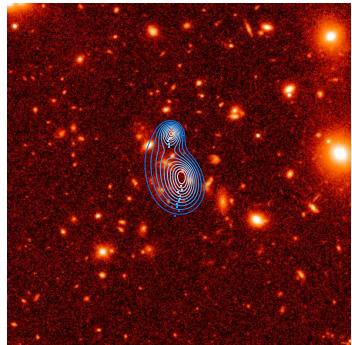
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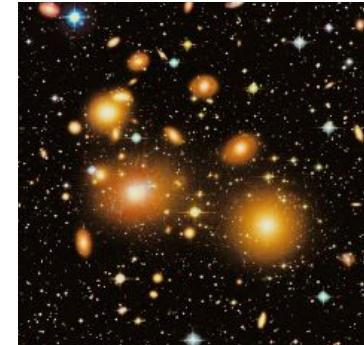
Three hot questions in astrophysics



Giant Ly α 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 Ly α nebula revealing early energy injection
in the hot intracluster medium"**

(Valentino et al. in prep.)

A photograph of the Athena X-ray telescope satellite in space. The satellite is white with blue solar panels and a large gold-colored mirror. It is positioned in front of a colorful, nebula-like background of stars and galaxies.

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 Col-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, München

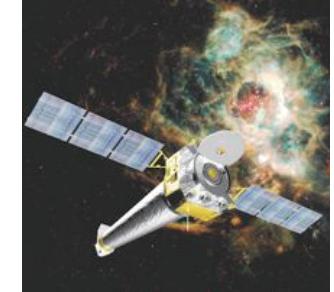
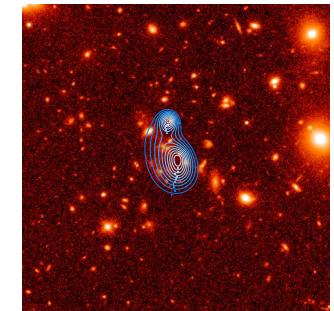
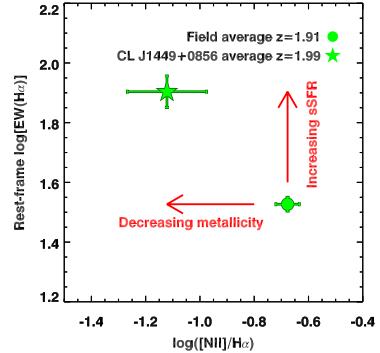
So far so good

And more!

- FMOS – Spectroscopic survey with the Subaru Telescope
(Japan - France - Italy collaboration)
 - Hundreds of galaxies at $z \sim 1.5$
 - 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 $\text{H}\alpha$ in far-away clusters
(KMOS program) and reversal of SFR-density relation

Summary

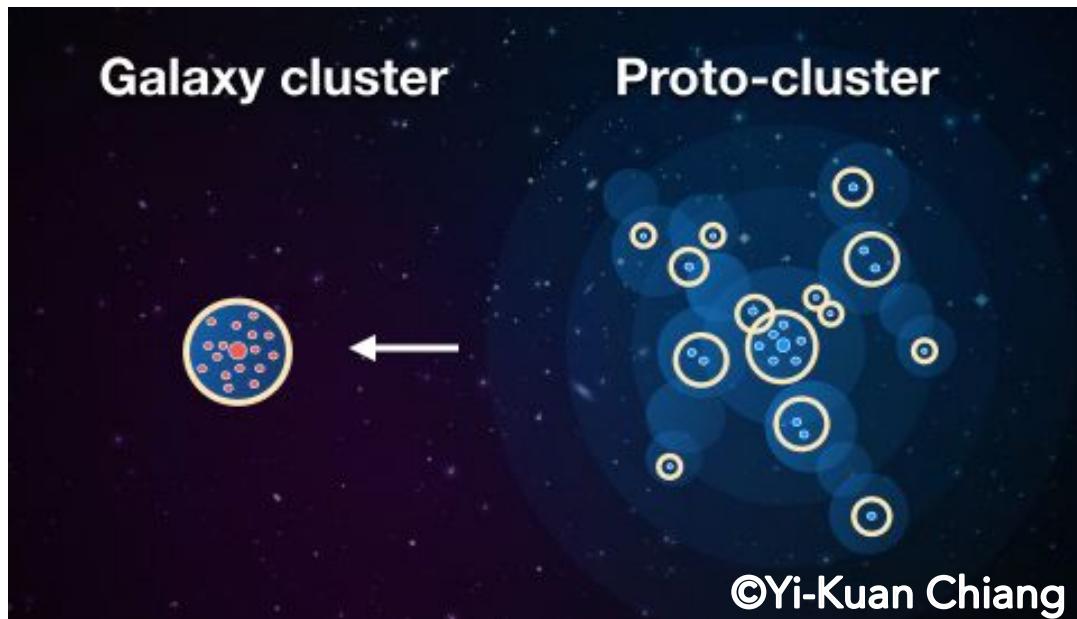
- Effect of nurture on gas properties in star-forming galaxies in a far-away cluster (Valentino et al. 2015, *Astrophysical Journal*, 801, 132)
- A giant Ly α nebula probing energy injection in far-away clusters (Valentino et al. in prep.)
- Long- and short-term projects



Back up

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 **intrinsically different**



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

Gaining physical insight

We can convert $[\text{N II}]/\text{H}\alpha$ in **gas-phase oxygen abundance $12+\log(\text{O/H})$** 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
- $[\text{N II}]/\text{H}\alpha$ is sensitive to the ionization parameter

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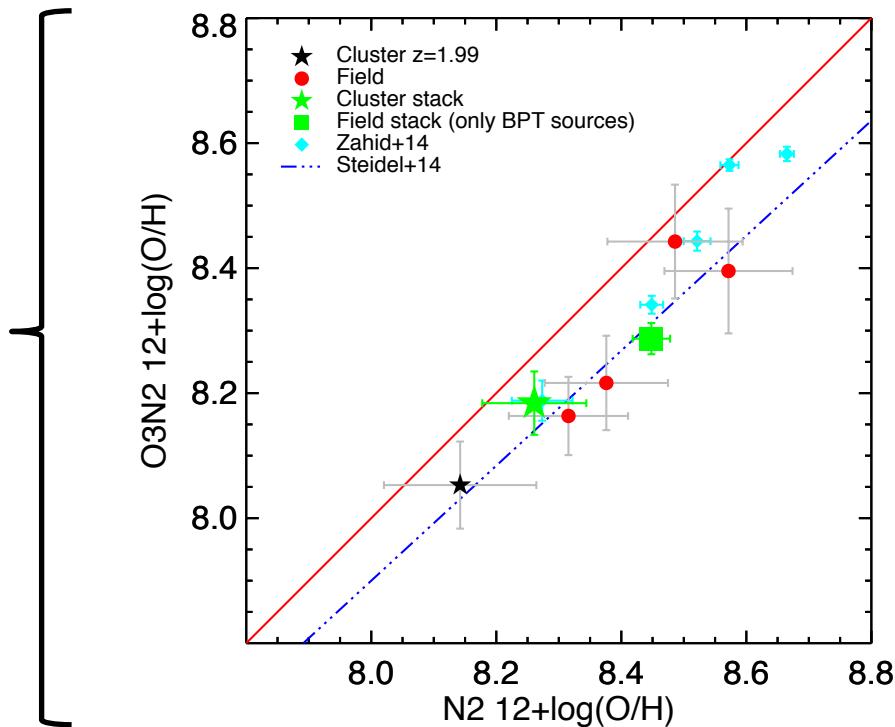
- We are measuring **relative** differences
- We apply alternative line ratio metallicity indicators when possible (O3N2 and O_{32} , R_{23} for the cluster only). They are all in agreement with a low metal content in cluster star-forming galaxies.

Gaining physical insight

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Gaining physical insight

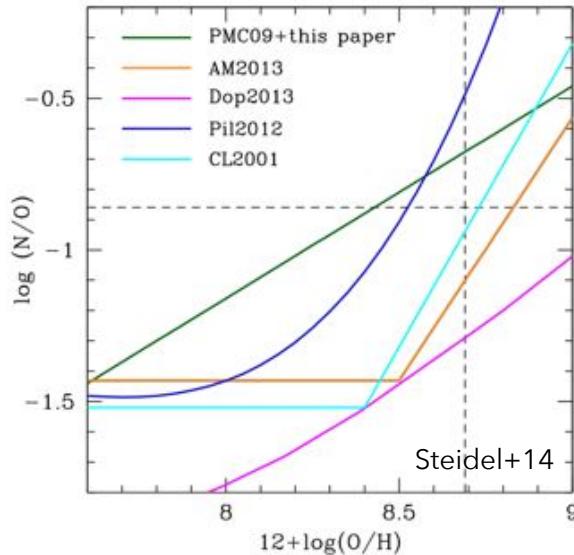
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We estimated N/O from $[\text{N II}]/[\text{O II}]$ for the cluster only (Perez-Montero & Contini 2013):

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



Gaining physical insight

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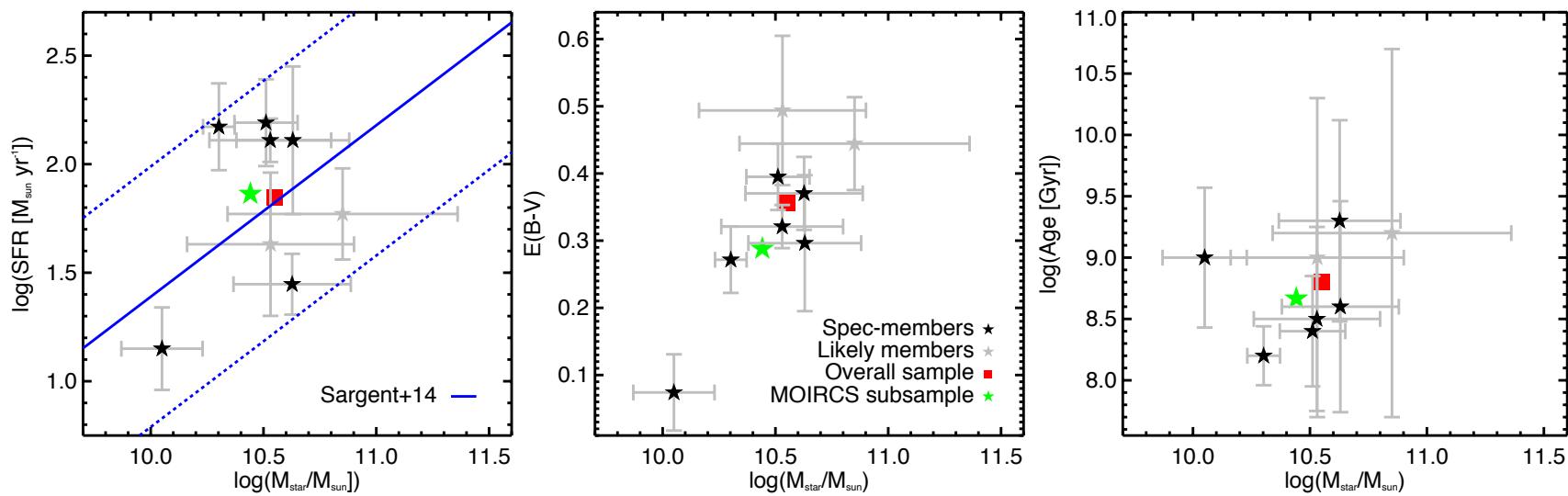
- Different calibrations give different absolute metallicities (Kewley & Ellison 2008)
- Standard calibrations are based on low-redshift galaxies
- Nitrogen-to-oxygen ratio is involved
- $[\text{N II}]/\text{H}\alpha$ is sensitive to the ionization parameter \mathcal{U}

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

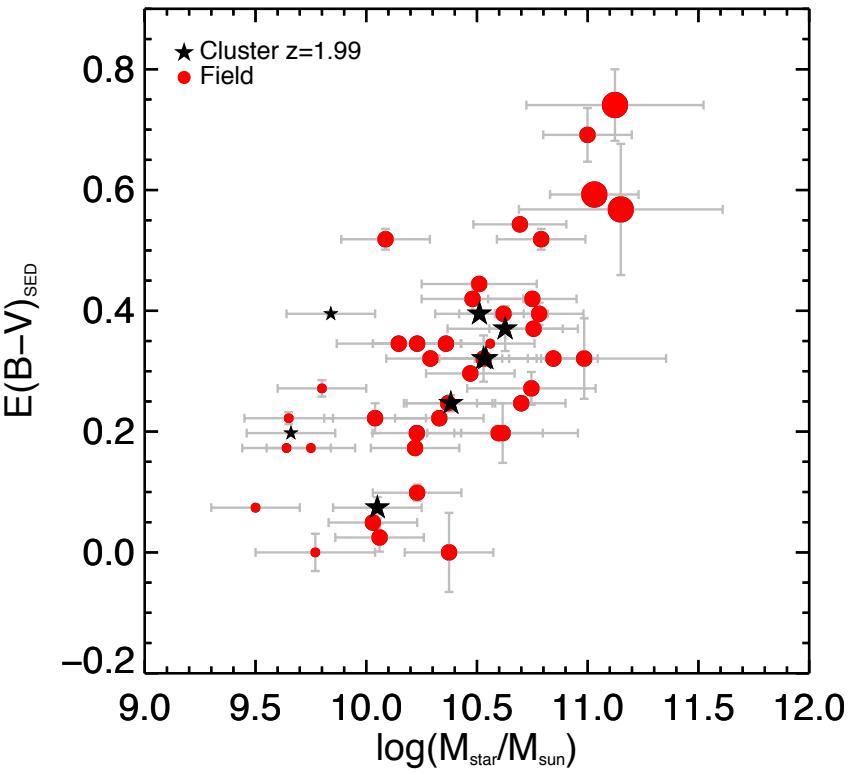
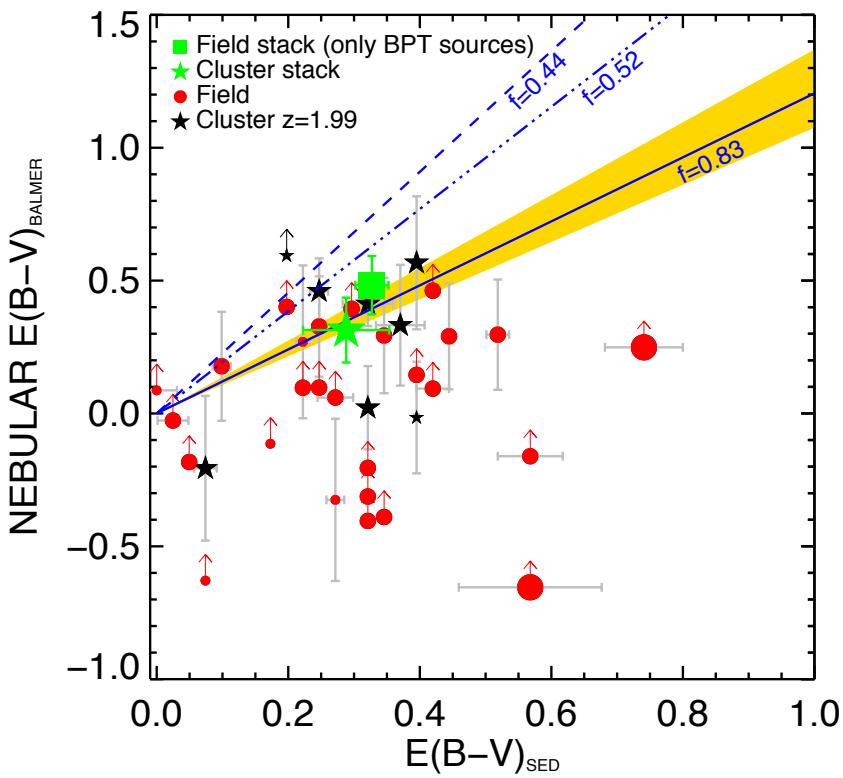
$$\mathcal{U} \approx -2.61$$

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

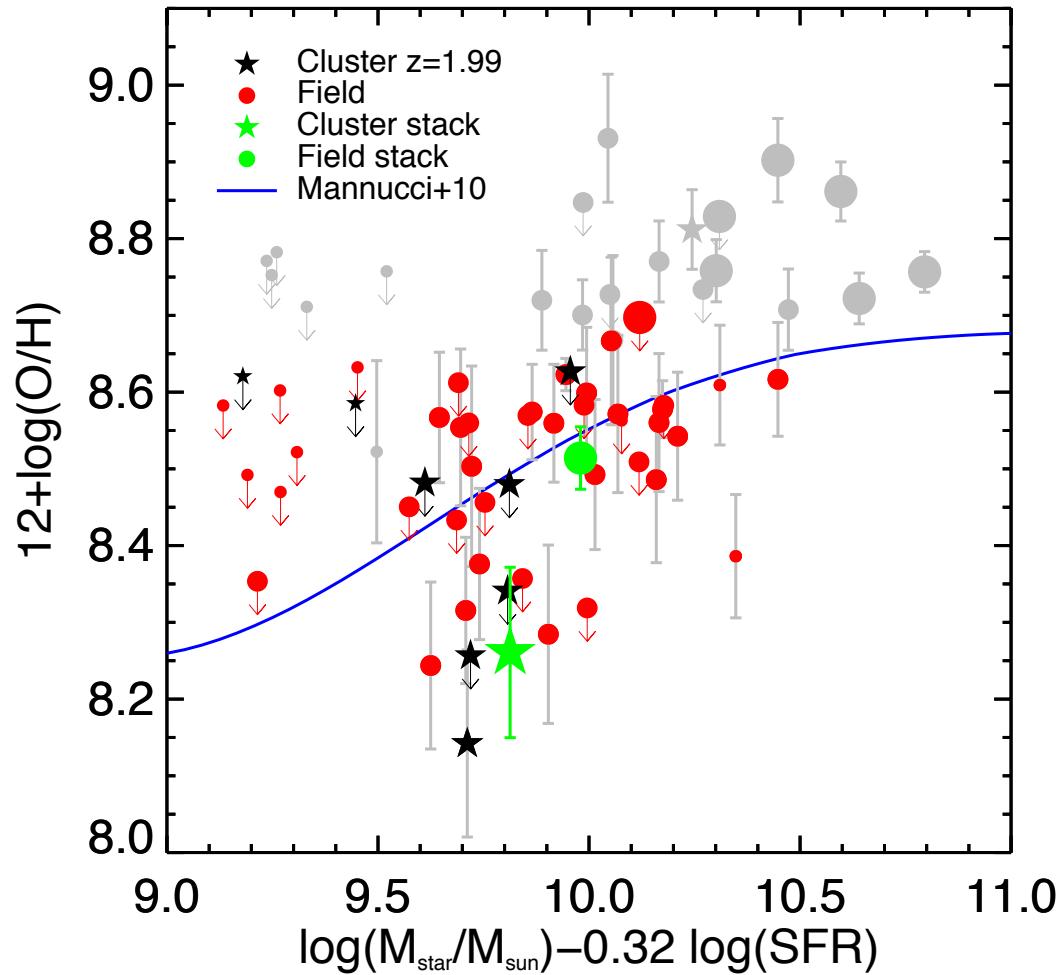
Possible selection effects



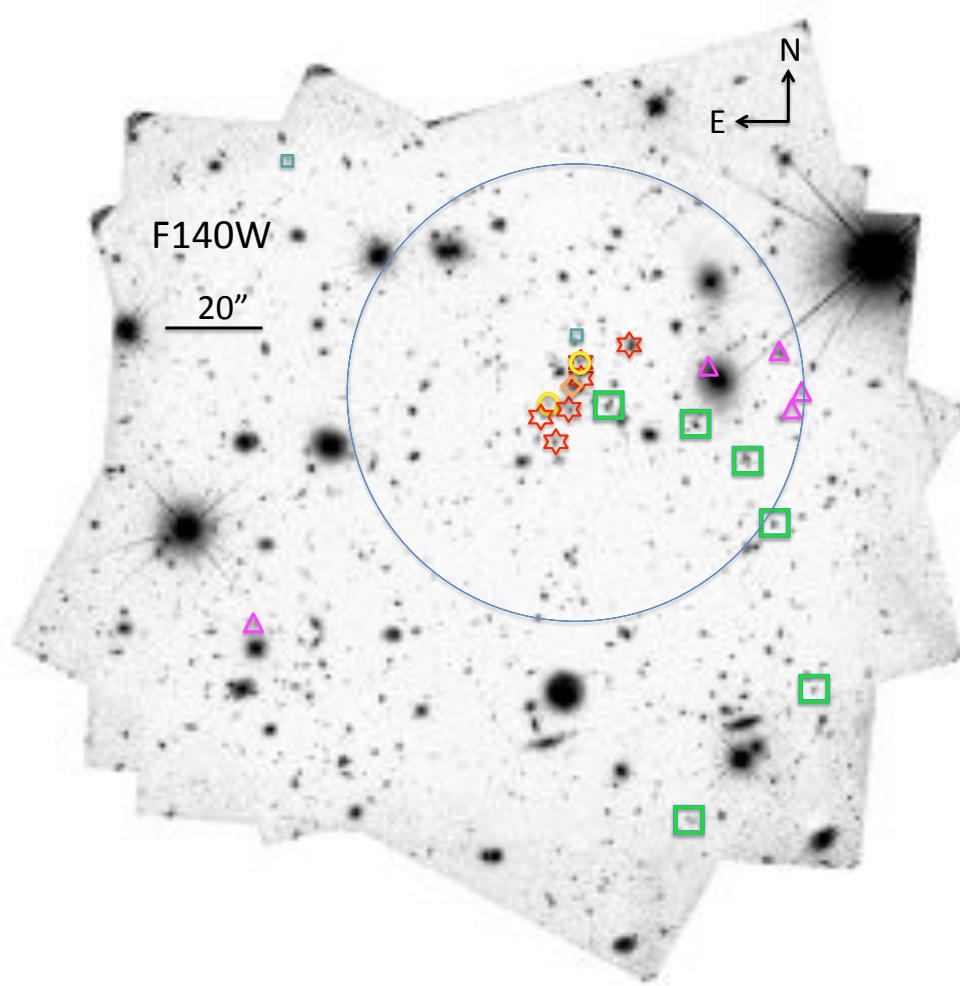
Nebular reddening



Fundamental Metallicity Relation



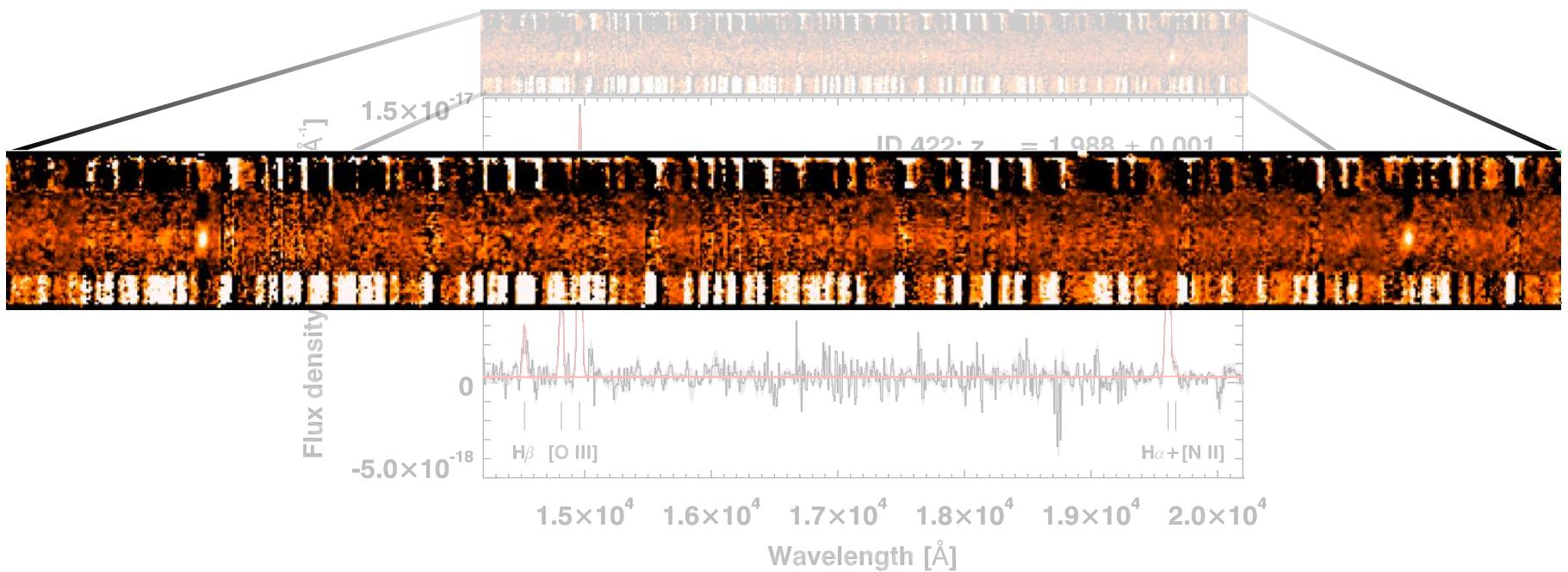
A speculative picture of the situation



Assembling/accreting
feature?

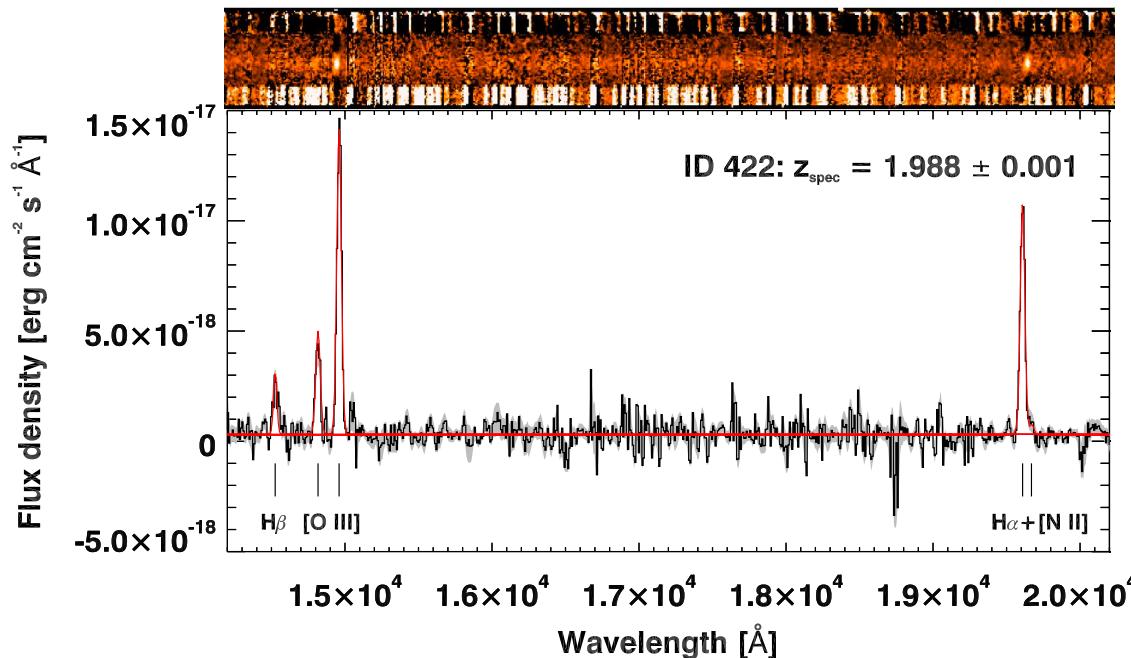
Near-infrared vision: MOIRCS follow-up

- Follow-up of 110 SFGs (including 10 cluster members) to primarily detect H α and [N II] λ 6583Å.
- 71% success rate in detecting H α (3σ , minimum flux $\approx 1.4 \times 10^{-17}$ erg cm $^{-2}$ s $^{-1}$), 20% in detecting [N II]. Upper limits on the remaining sample detected in H α .
- [O III] and H β in the wavelength range according to redshift or from WFC3 G141.



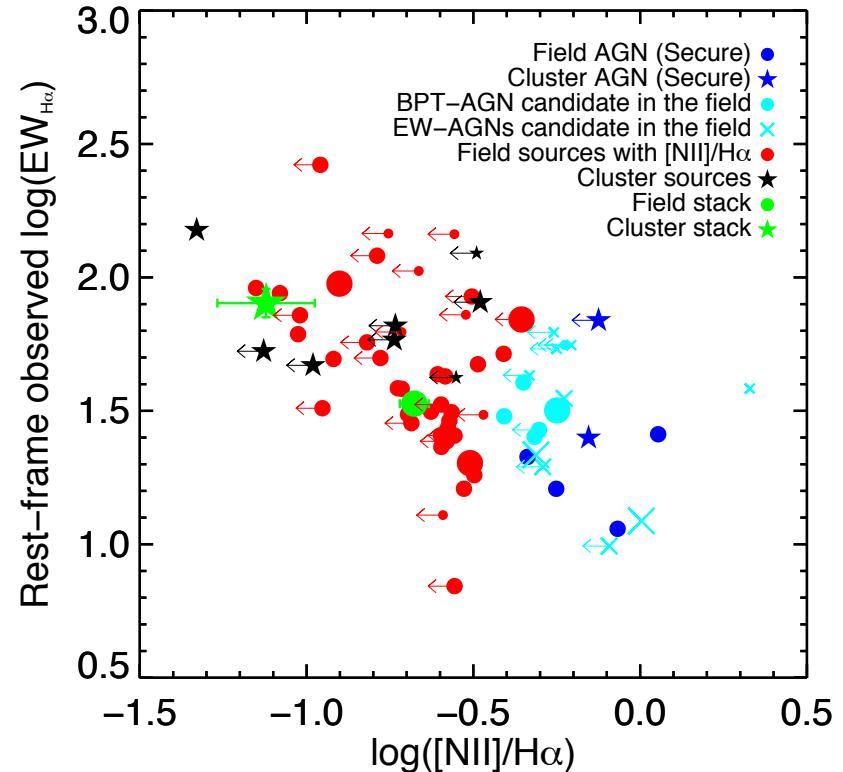
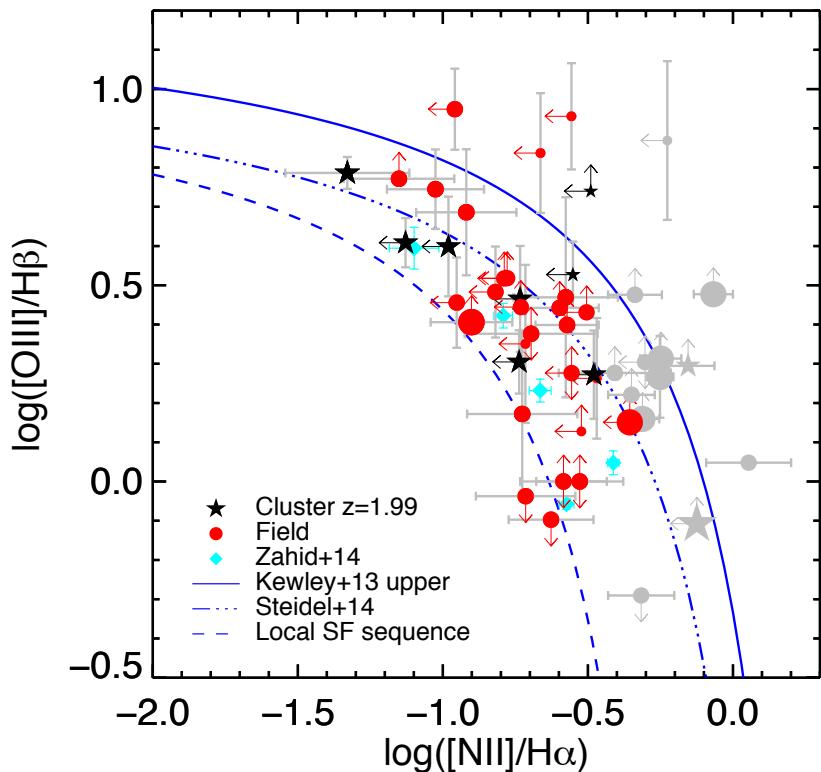
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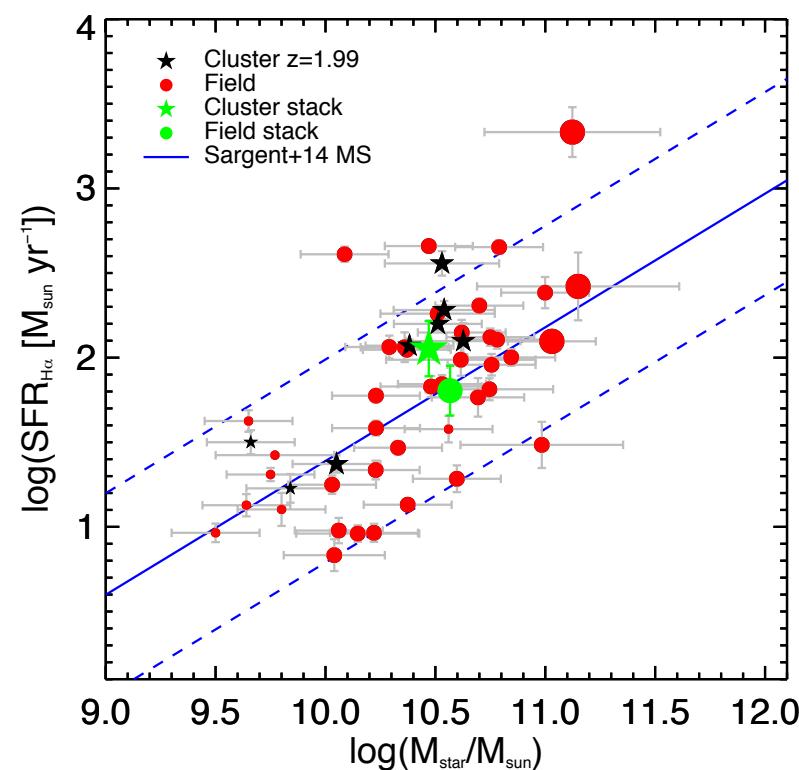
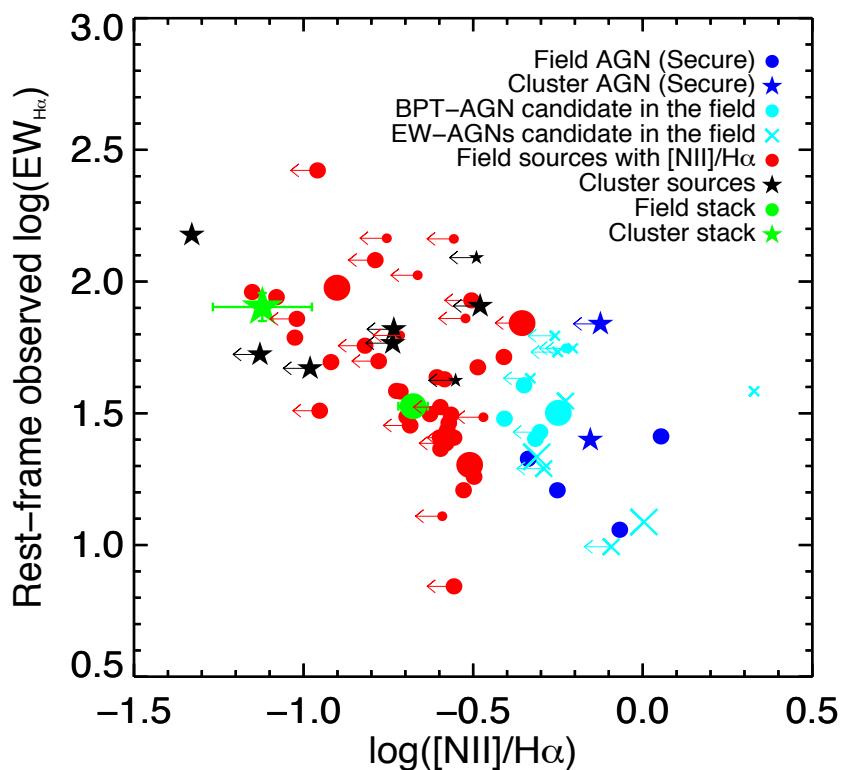
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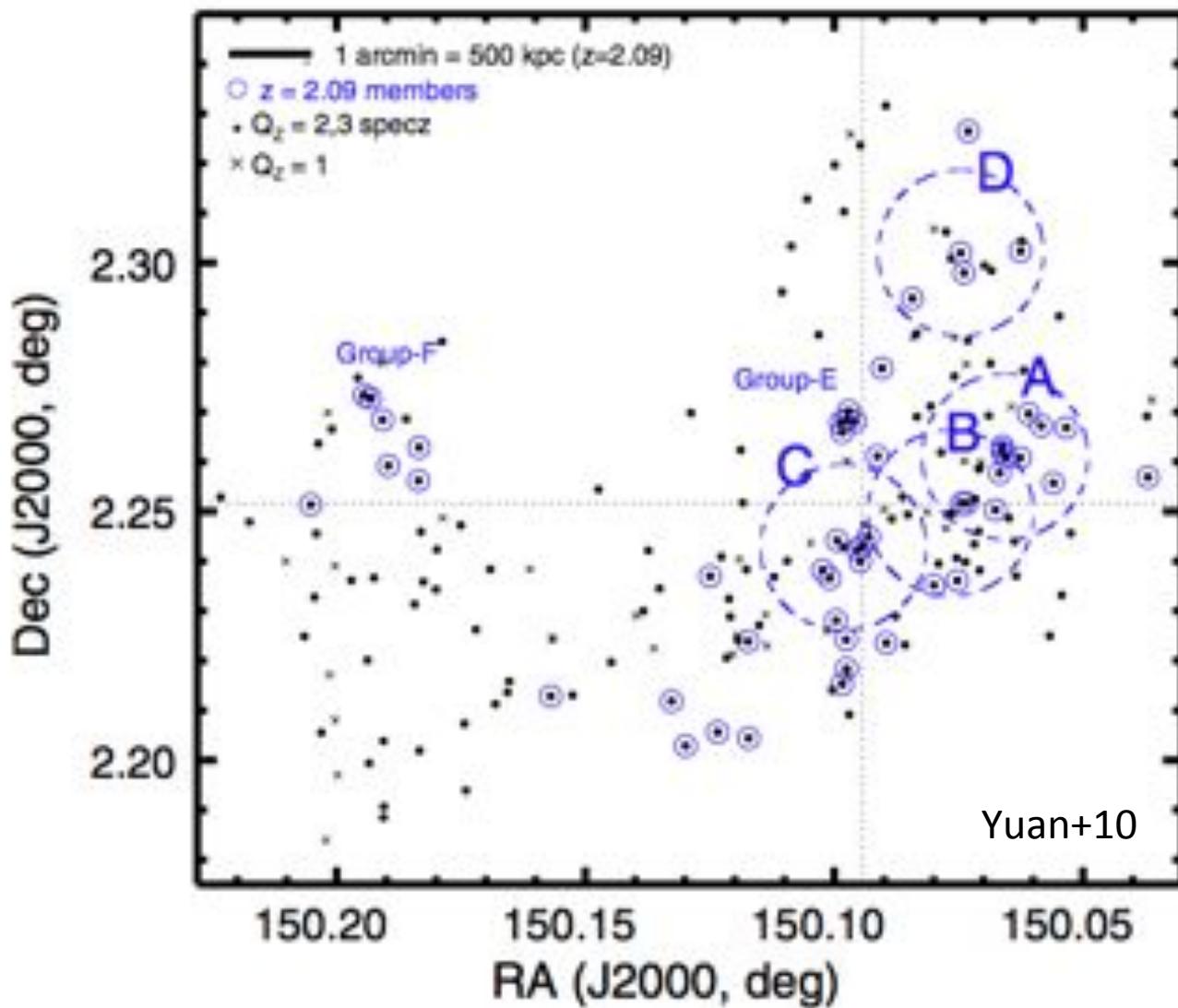
AGN rejection combining X-ray emission, BPT (Baldwin et al. 1981) and [N II]/H α -EW(H α) diagrams (Cid Fernandes 2010).



A possible enhancement of sSFR

This picture could explain also the higher observed $\text{EW}(\text{H}\alpha)$ - **a proxy for the sSFR** - in cluster star-forming galaxies: **the accreted pristine gas would be triggering extra-star formation.**



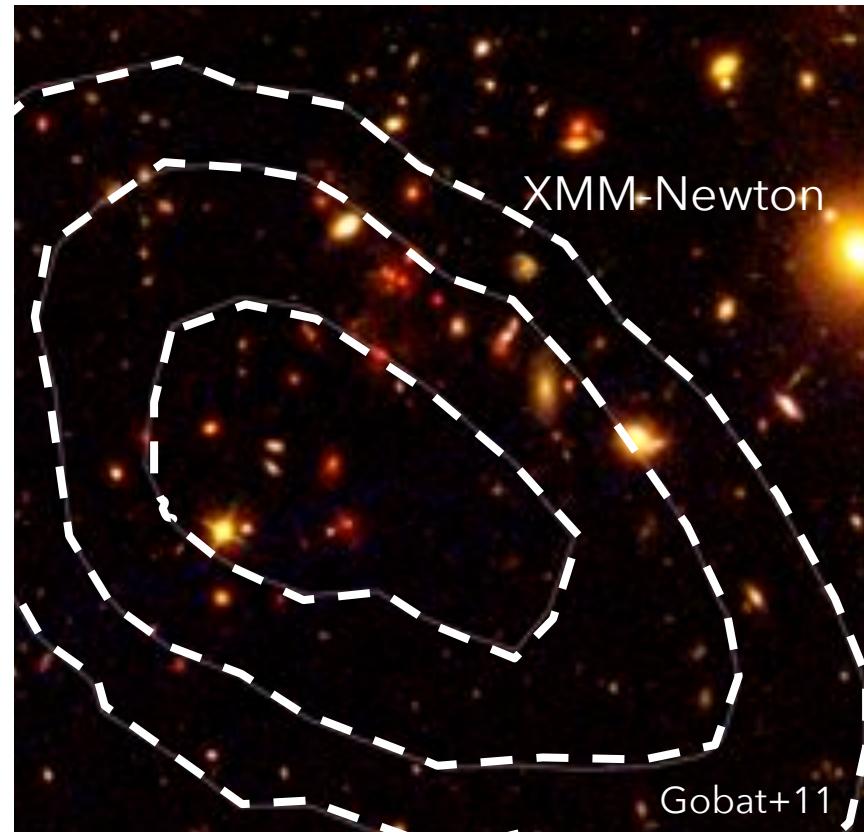


The remarkable case of CL J1449+0856 at $z=1.99$

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).

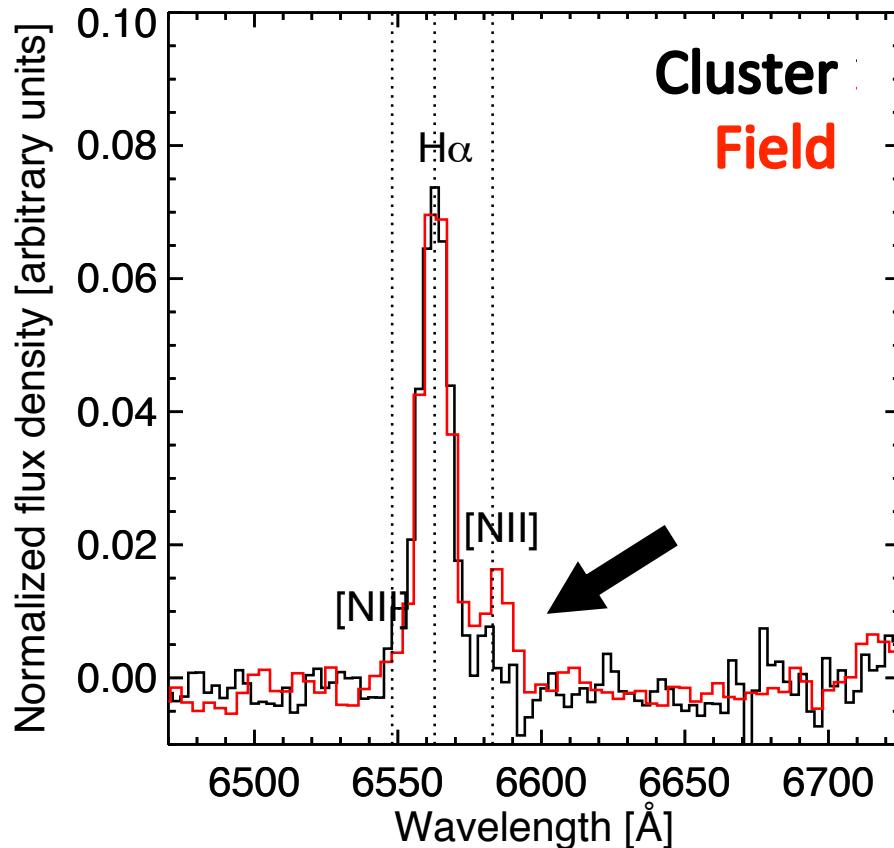
Extensively followed-up:

- 13-band photometry (**SED modelling**)
- HST/WFC3 slitless spectroscopy ($[\text{O II}]$, $\text{H}\beta$, $[\text{O III}]$ at $z \sim 2$)
- **Subaru/MOIRCS HK spectroscopy of star-forming galaxies**



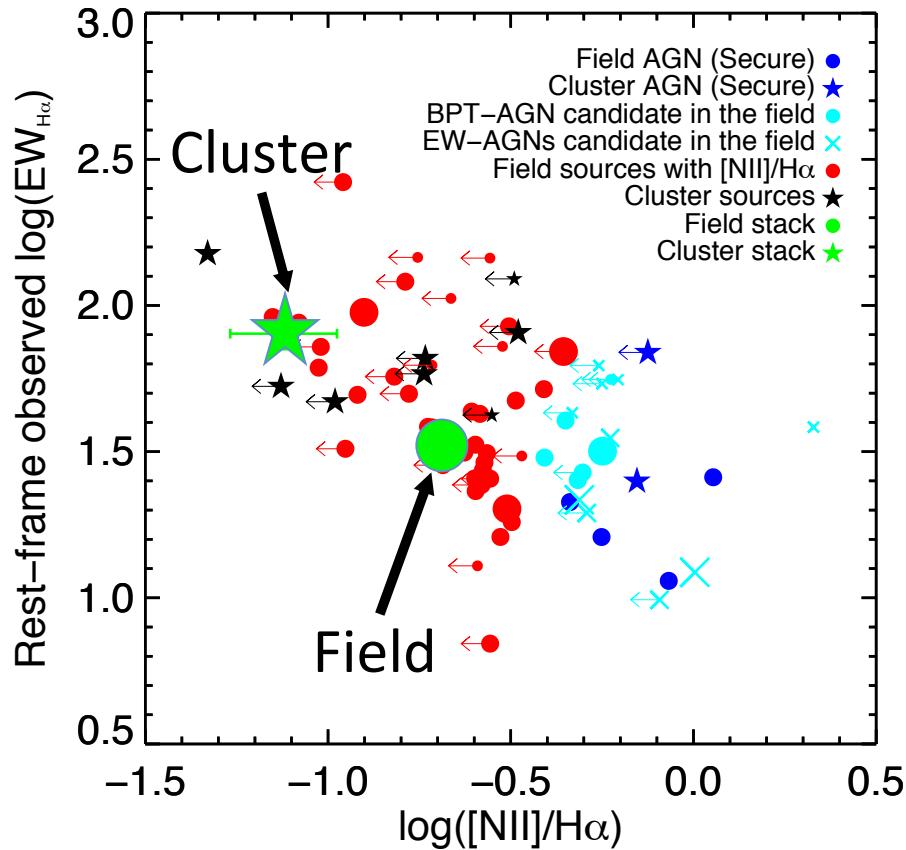
Observing an environmental signature

We detect a **$\approx 4\sigma$ significant lower $[\text{N II}]/\text{H}\alpha$ ratio in the cluster stacked sample** than in the mass-matched field sample (while $[\text{O III}]/\text{H}\beta$ is compatible between the two).



Observing an environmental signature

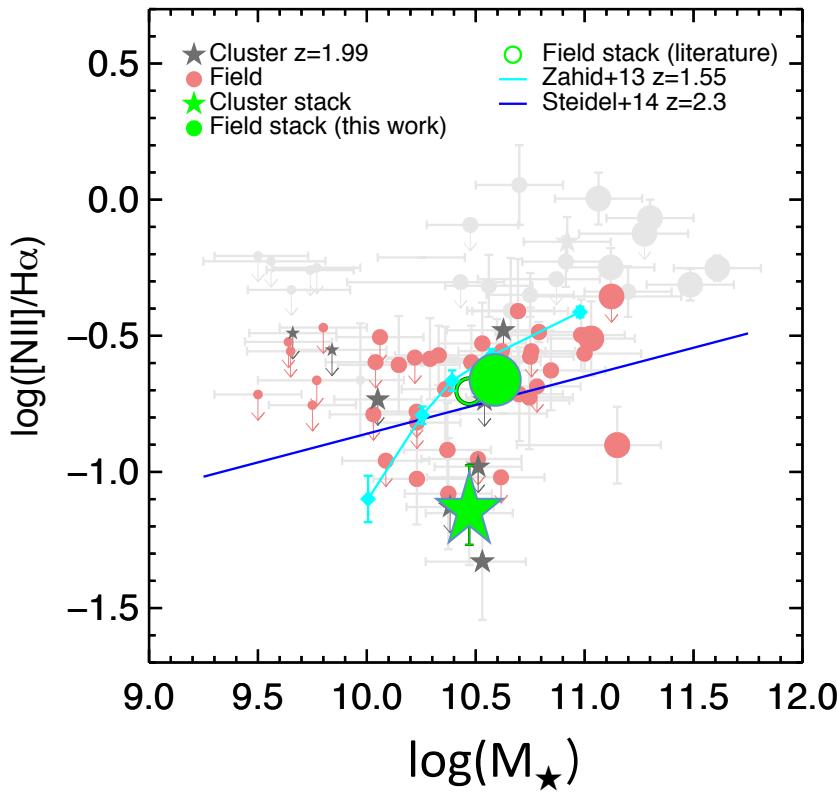
We detect a **$\approx 4.7\sigma$ significant higher observed EW(H α) in the cluster stacked sample** than in the mass-matched field sample.



Gaining physical insight

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

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

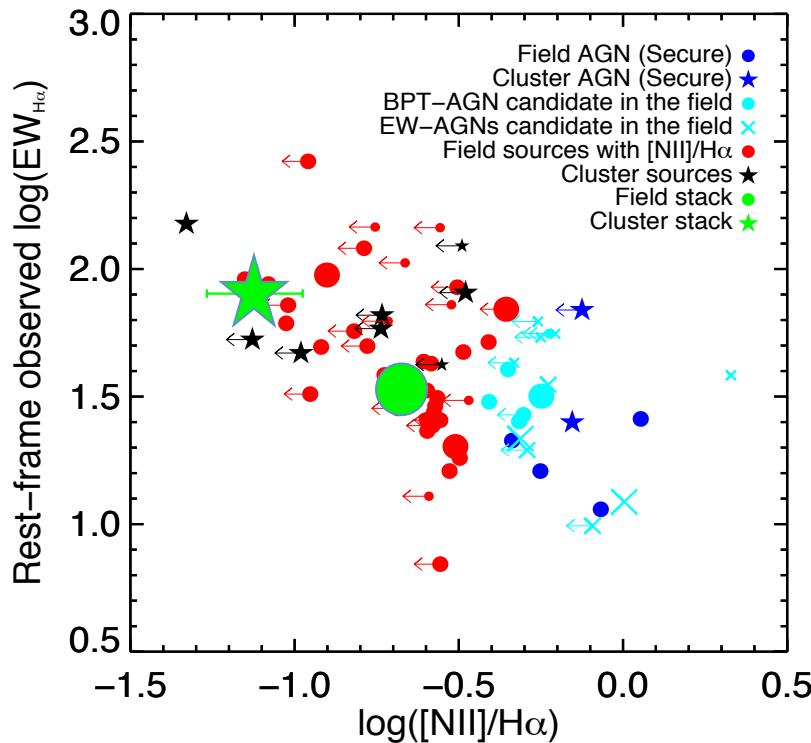


Thus, star-forming galaxies in CL J1449+0856 are on average more metal poor than mass-matched field counterparts (by $\approx 0.09-0.25$ dex, according to the calibration or indicator used)

Gaining physical insight

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

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



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):

