IPMU seminar, 24/02/2011

Panoramic mapping of star formation in/around distant clusters of galaxies

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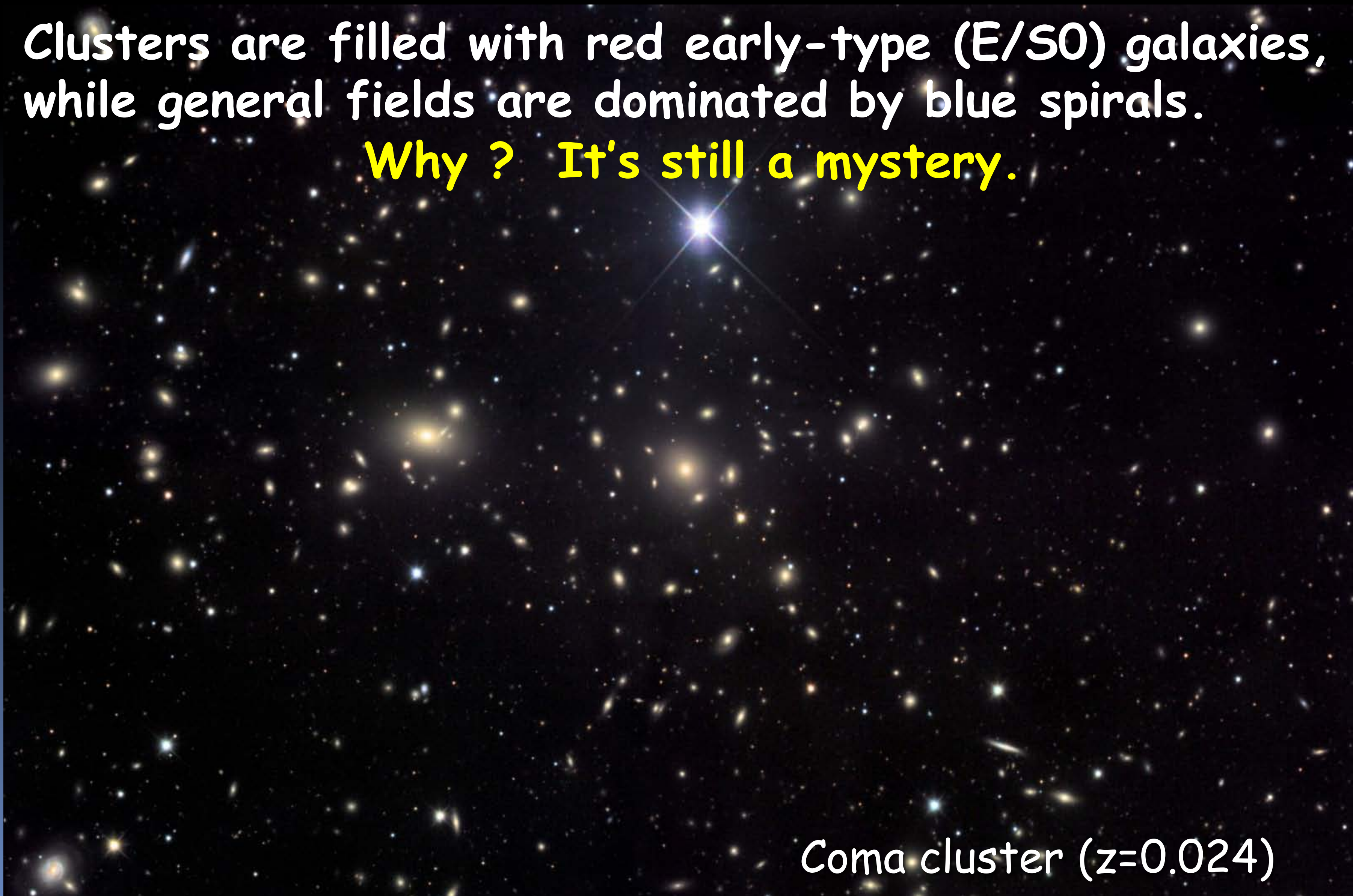
Outline

1. Introduction
2. Hα mapping of a z=0.4 cluster with Suprime-Cam
3. Hα + MIR mapping of a z=0.8 cluster with MOIRCS/AKARI
4. MAHALO-Subaru
5. Summary

Galaxy Clusters

Clusters are filled with red early-type (E/S0) galaxies, while general fields are dominated by blue spirals.

Why ? It's still a mystery.

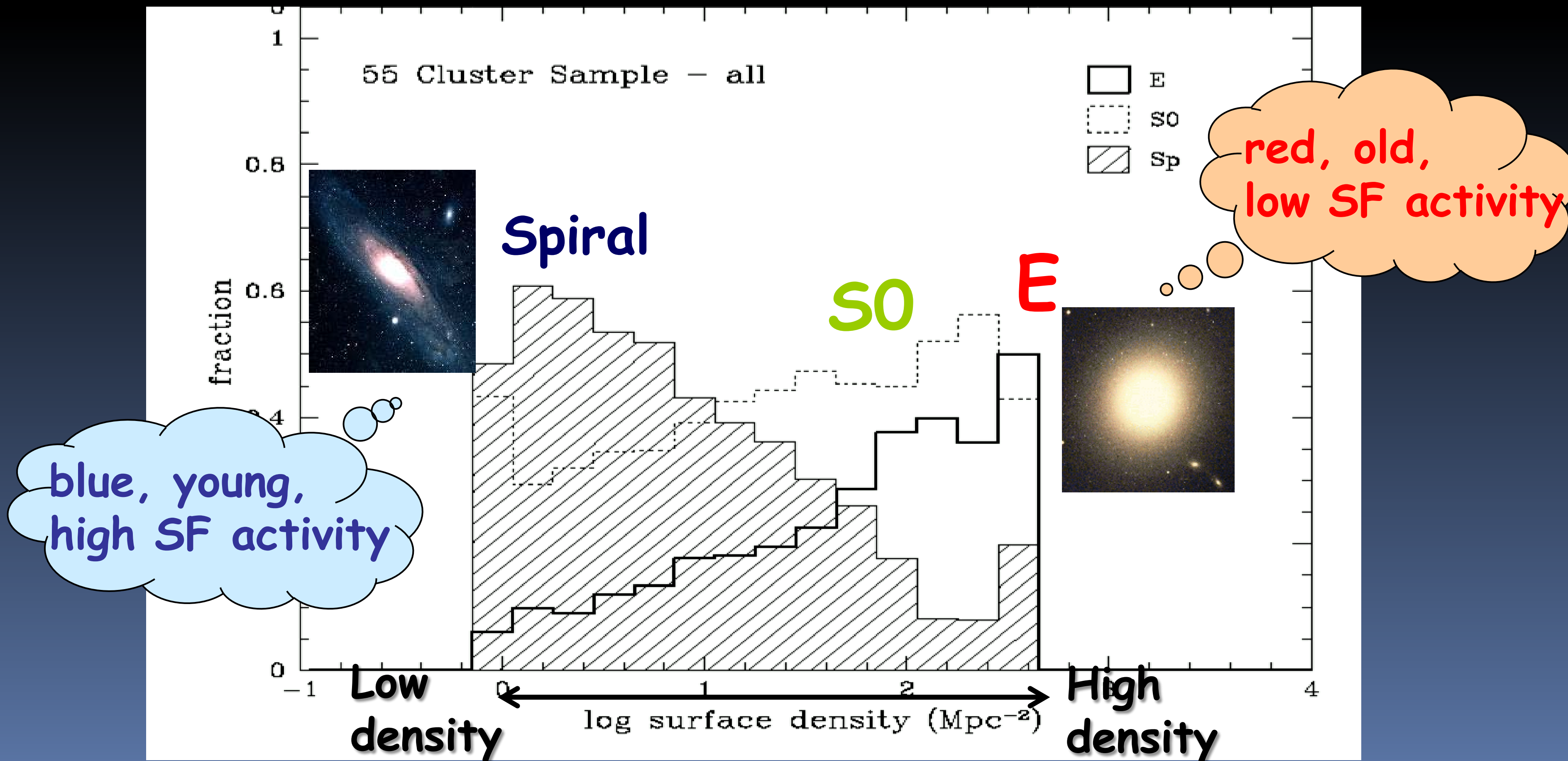


Coma cluster (z=0.024)

Galaxy properties vs. Environment

“ Morphology–Density Relation (Dressler 1980) ”

Early-types (E/S0) are in cluster, late-types (Sp/Irr) are in field



c.f. morphology/colour/SF-density relation from SDSS (e.g. Goto+03, Gomez+03, Tanaka+04, Balogh+04)

Environment changes galaxy properties ?

Physical mechanism ?

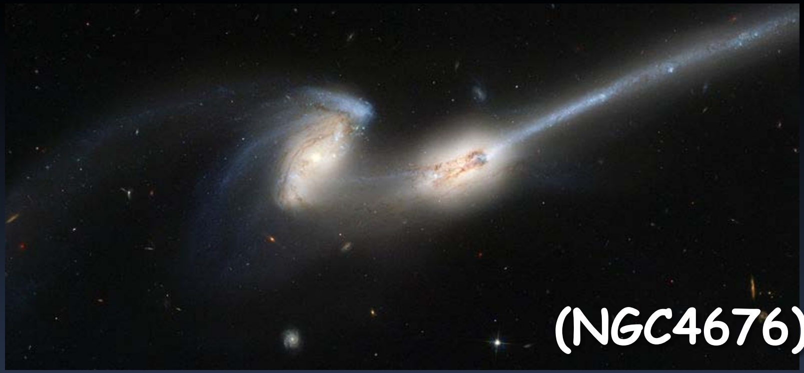
- Galaxy-galaxy interaction
  (*Toomre & Toomre 1972*)
- Ram-pressure stripping
  (*Gunn & Gott 1972*)
- Strangulation
  (*Larson et al. 1980*)

…. etc.

Environmental effects (examples)

* merger/interaction

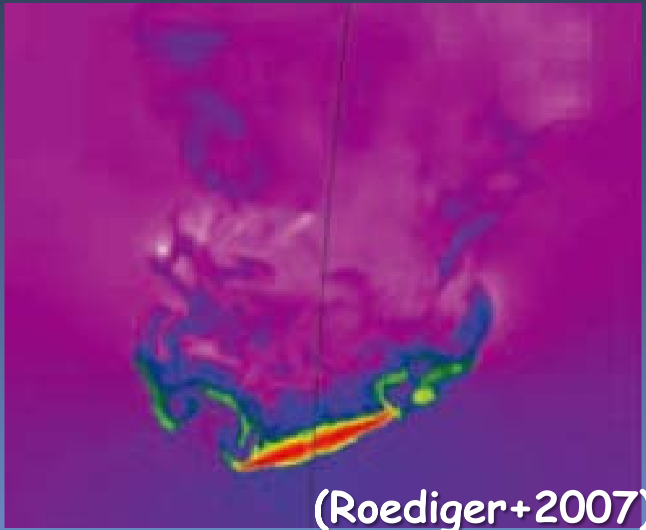
(produce Es after intense starburst ?)



(NGC4676)

* ram-pressure stripping

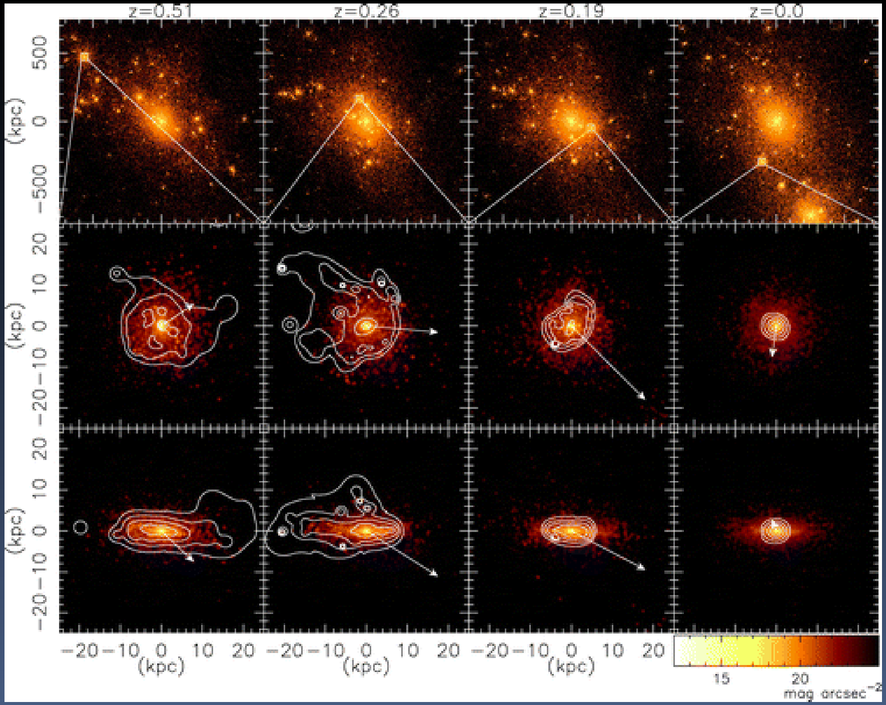
(stripping cold gas by cluster hot gas)



(Roediger+2007)

* Strangulation

(mildly stripping the gas in galaxies)

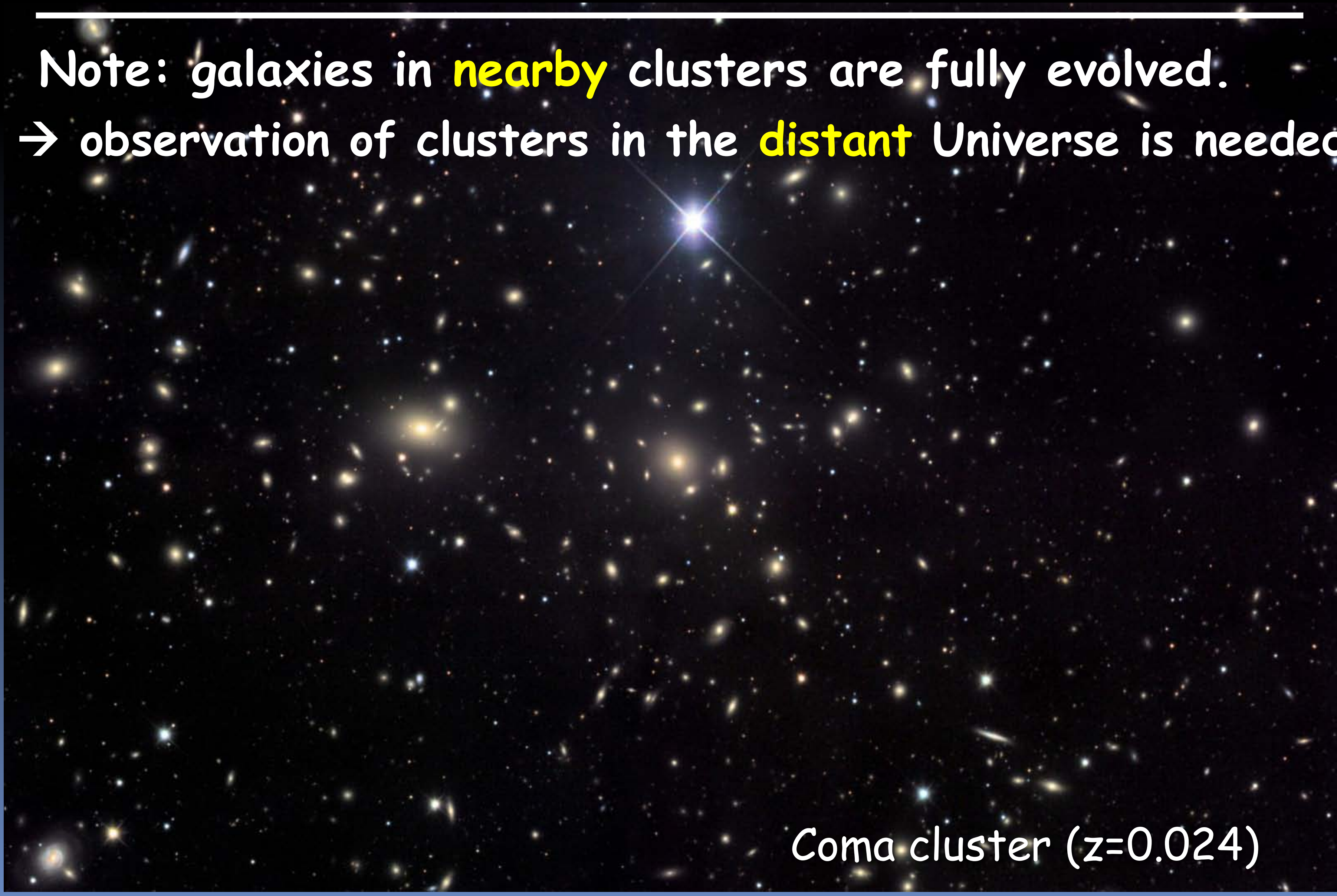


(Kawata & Mulchaey 2008)

Galaxy Clusters as "laboratories" for the environmental effects

Note: galaxies in nearby clusters are fully evolved.

→ observation of clusters in the distant Universe is needed



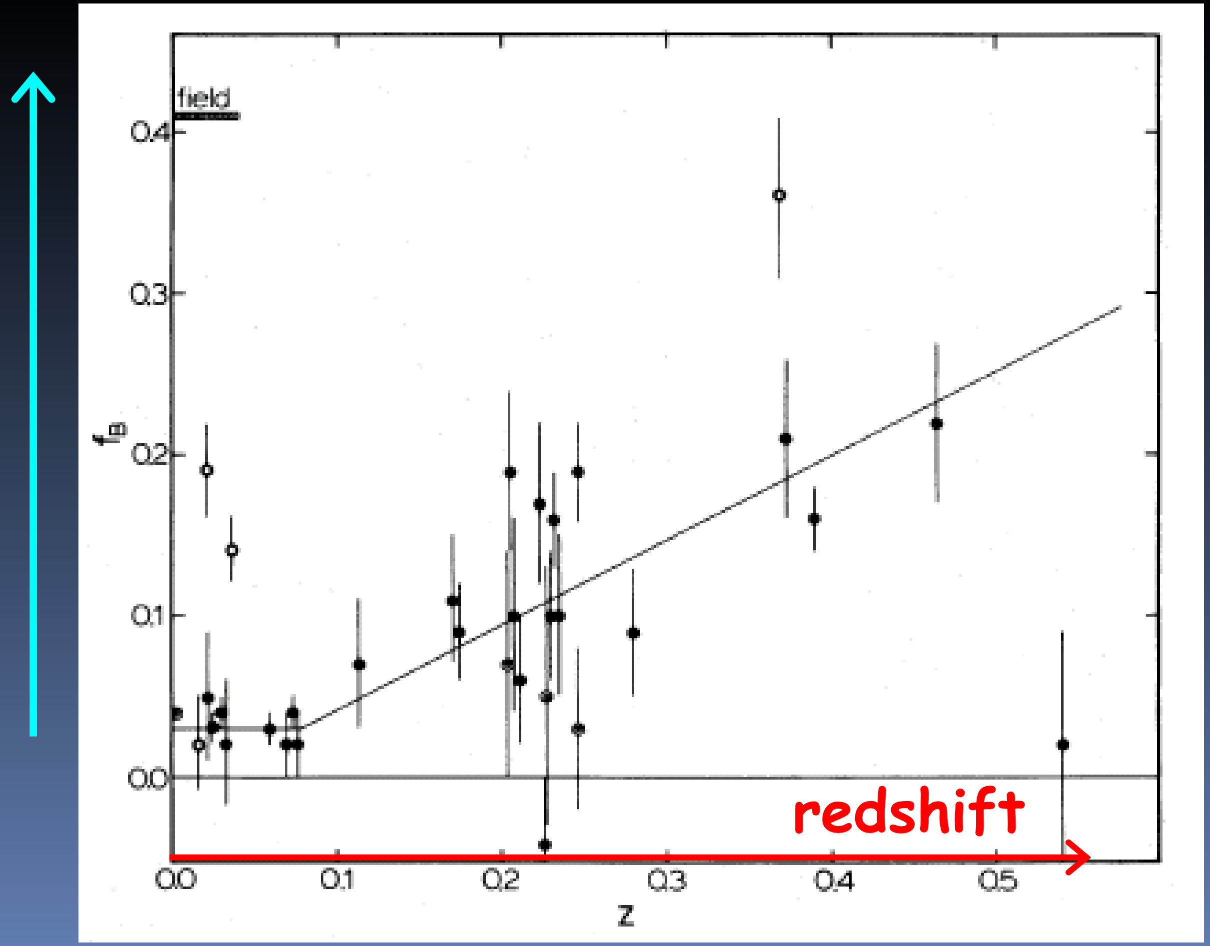
Coma cluster ($z=0.024$)

SF activity in distant clusters

Butcher-Oemler effect (BO-effect)

Discovery of a high fraction of blue galaxies in distant clusters

f(blue) for each cluster

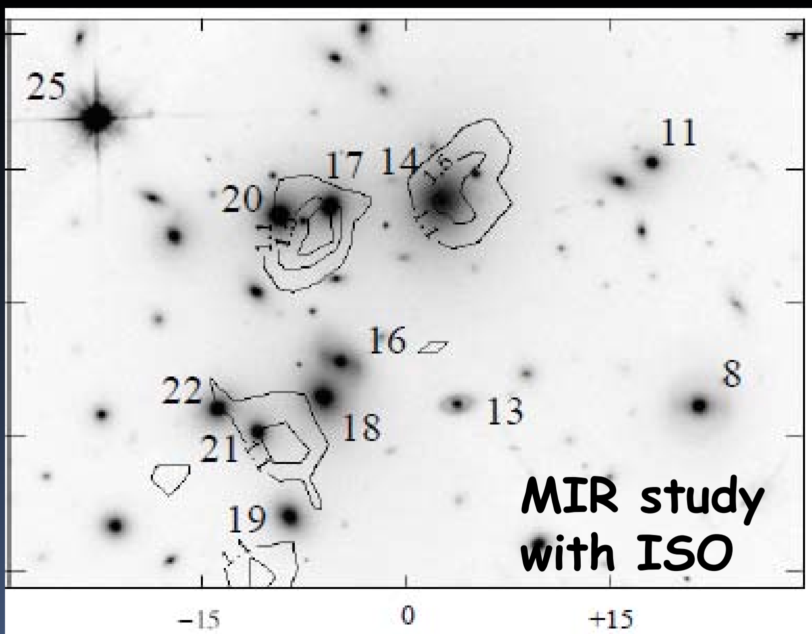


(Butcher & Oemler 1984)

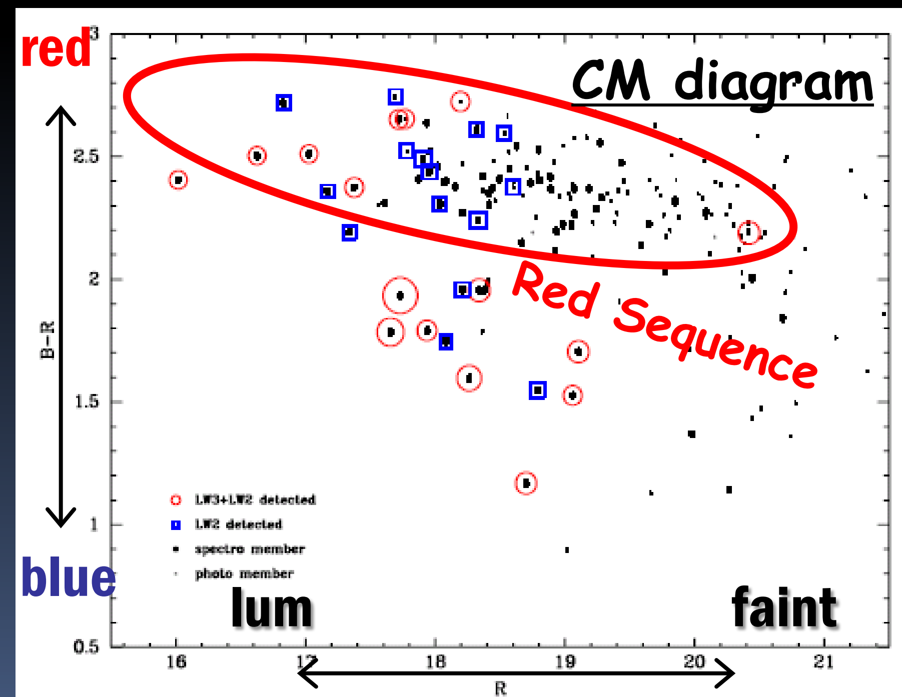
Optical colour information is insufficient

Some red galaxies also have significant SF (dusty red galaxies)

ex.) Abell 1689 cluster at z=0.18



(Fadda et al. 2000)

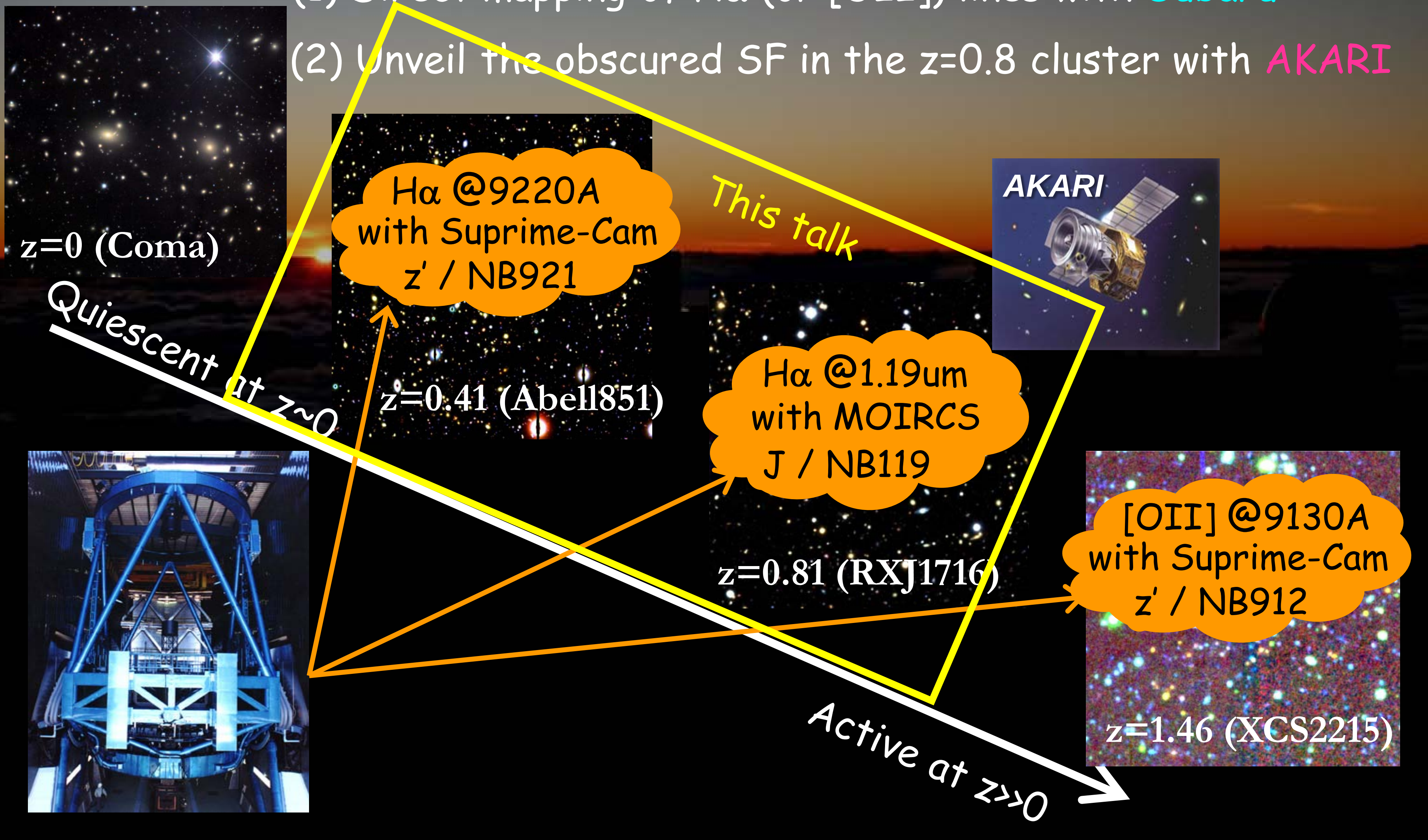


(Duc et al. 2002)

This talk

(1) Direct mapping of Hα (or [OII]) lines with Subaru

(2) Unveil the obscured SF in the z=0.8 cluster with AKARI

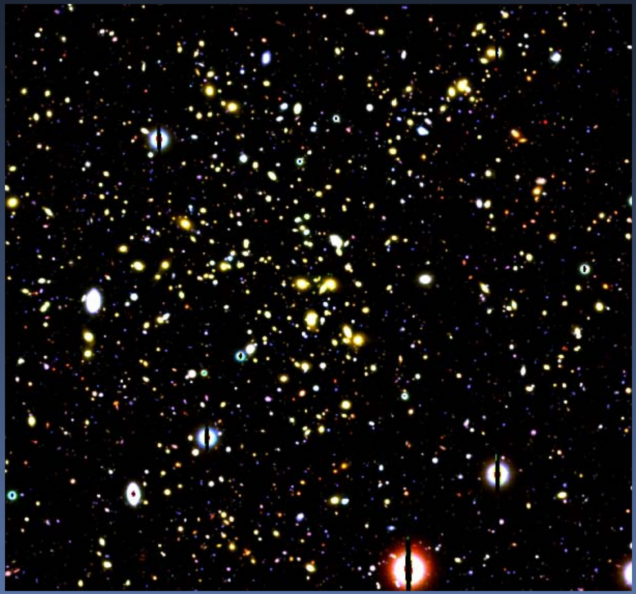


Hα imaging survey for the Abell851 cluster at z=0.41 with Suprime-Cam

(~4Gyr ago)

(Koyama et al. 2011, ApJ, submitted)

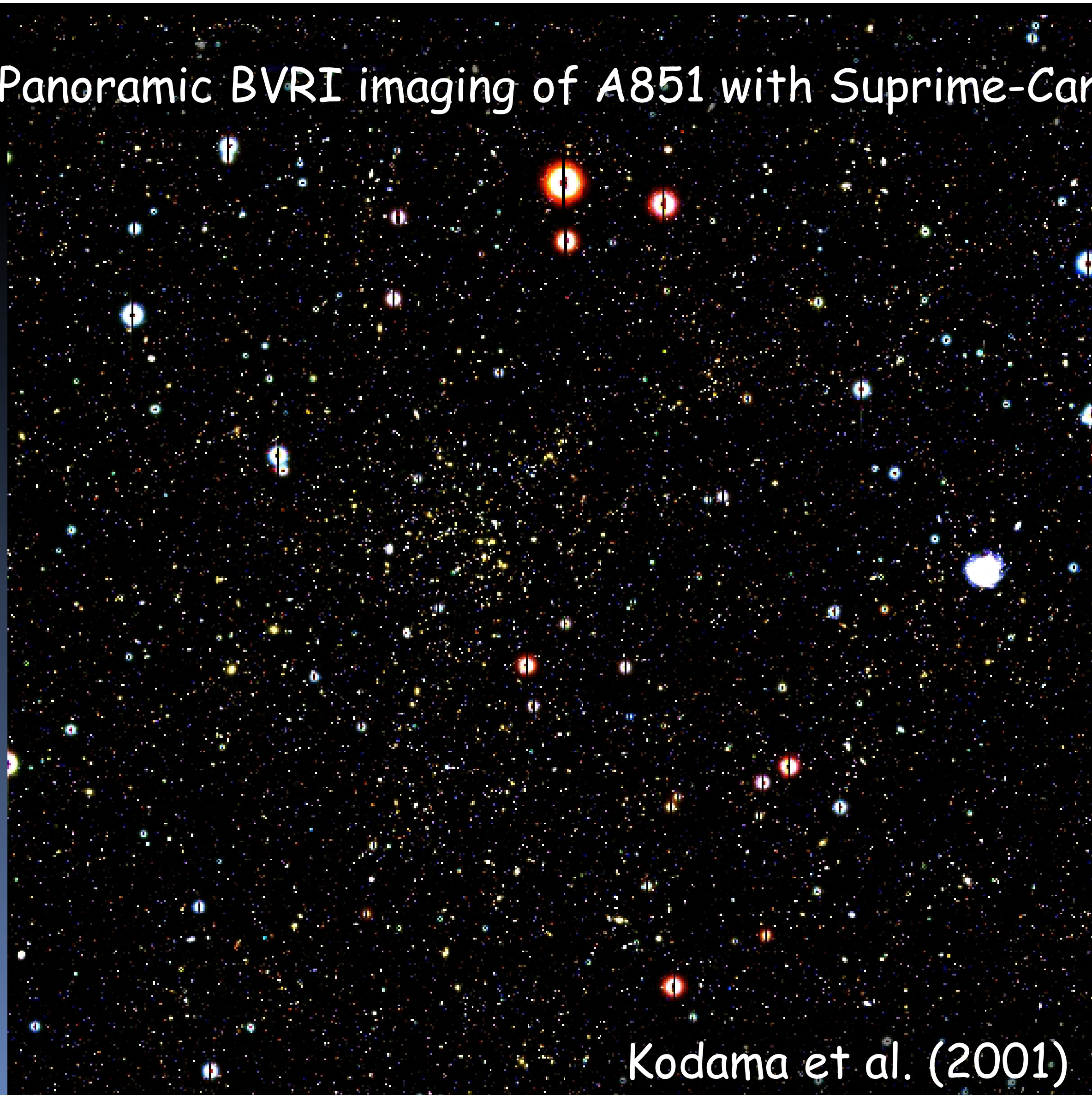
Suprime-Cam



Abell851

The Abell851 cluster at z=0.41

30’
=
~12Mpc
@ z=0.4



The Abell851 cluster at z=0.41

30’
=
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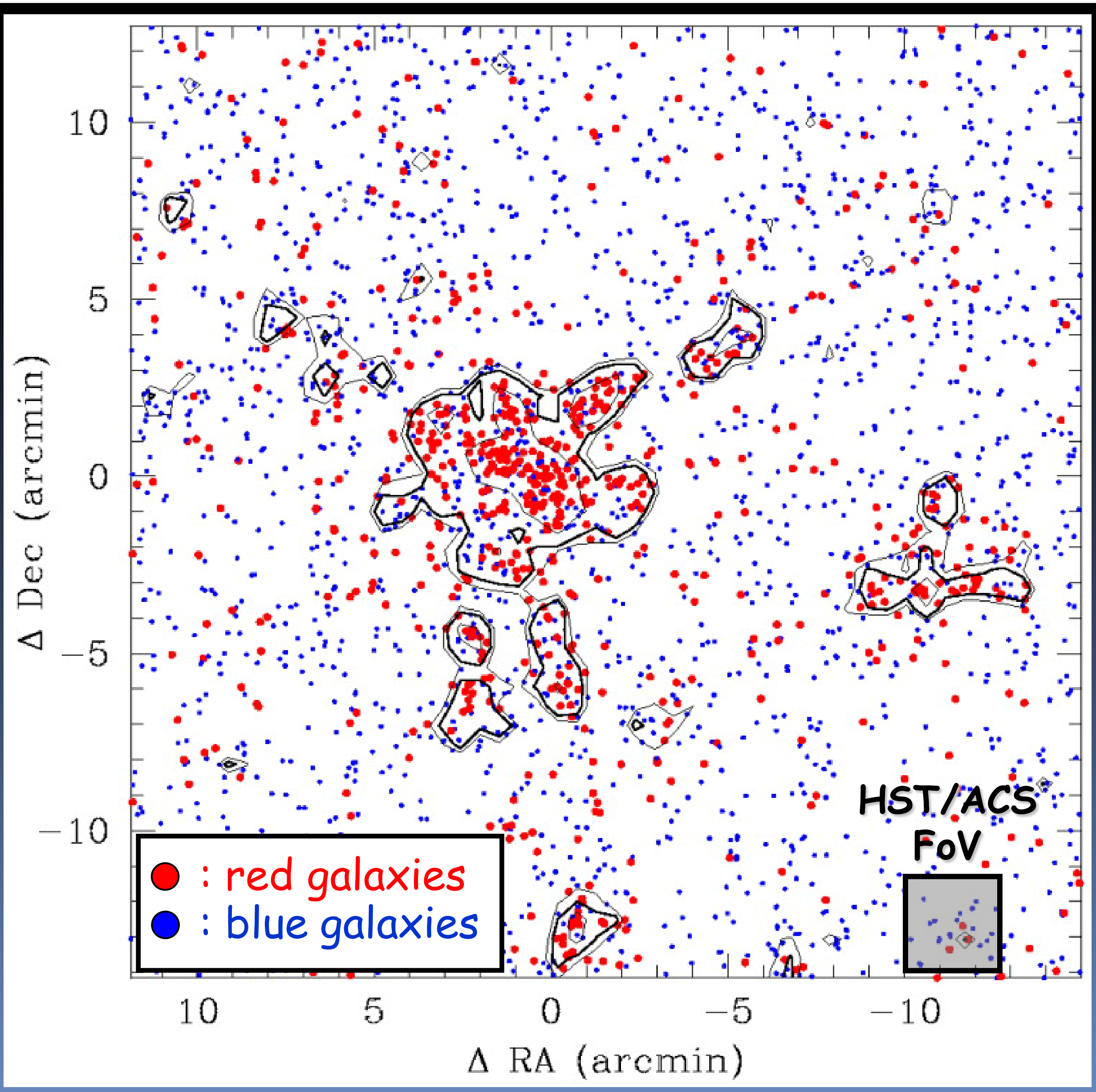
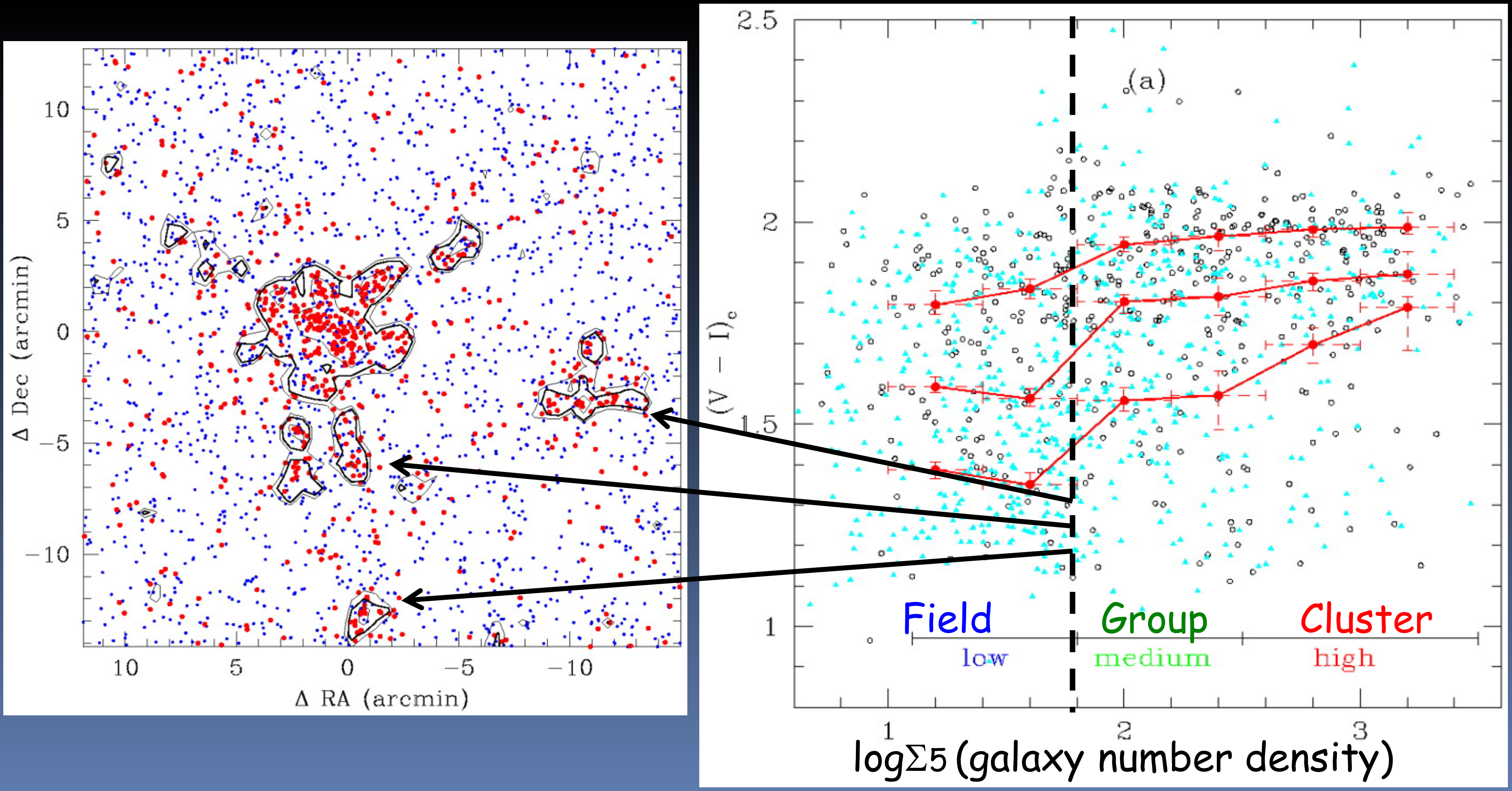
@ z=0.4



Important role of cluster outskirts

Sharp color transition in the "medium-density" regions.
Group is key environment for evolution of cluster galaxies ?



Kodama et al. (2001), *see also Tanaka+05 and Koyama+08 for other redshifts*

Important role of cluster outskirts

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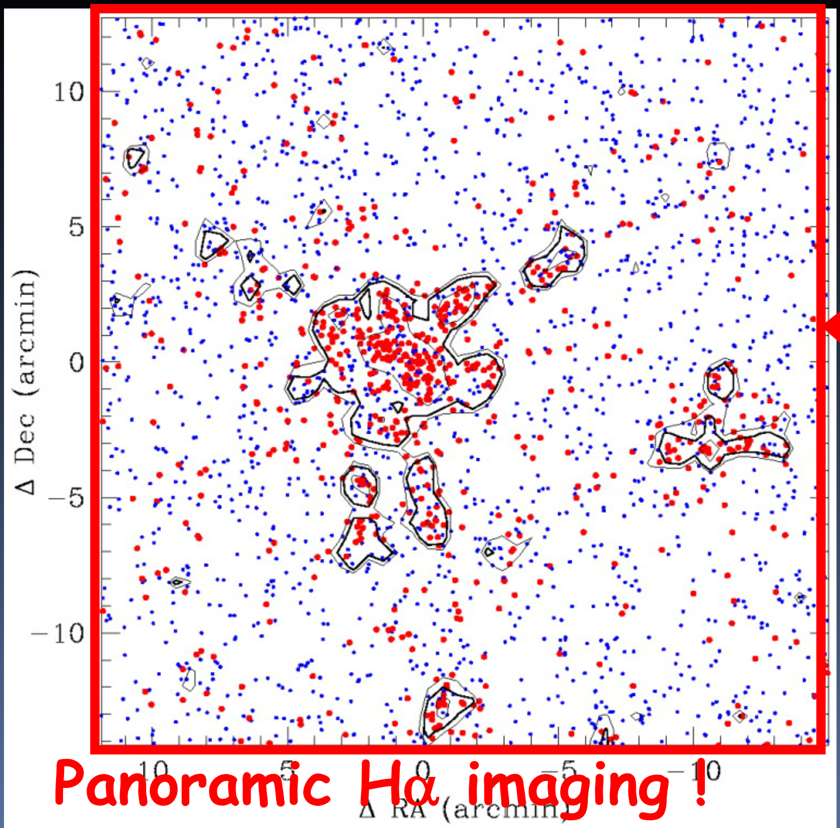
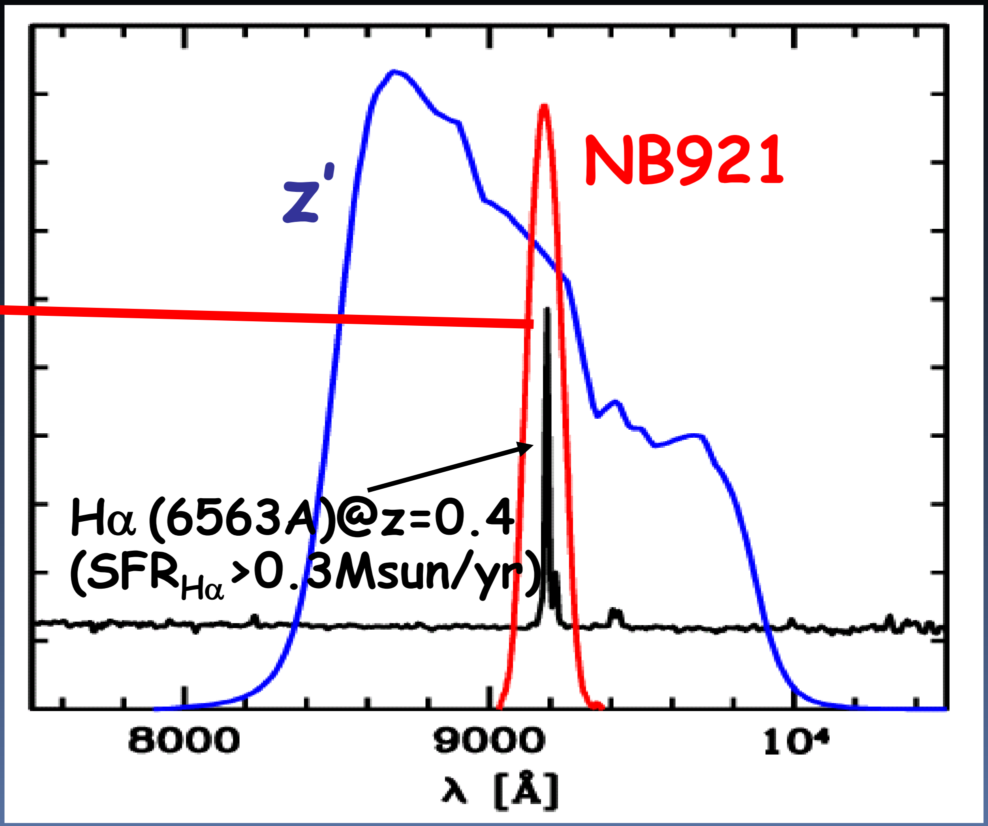
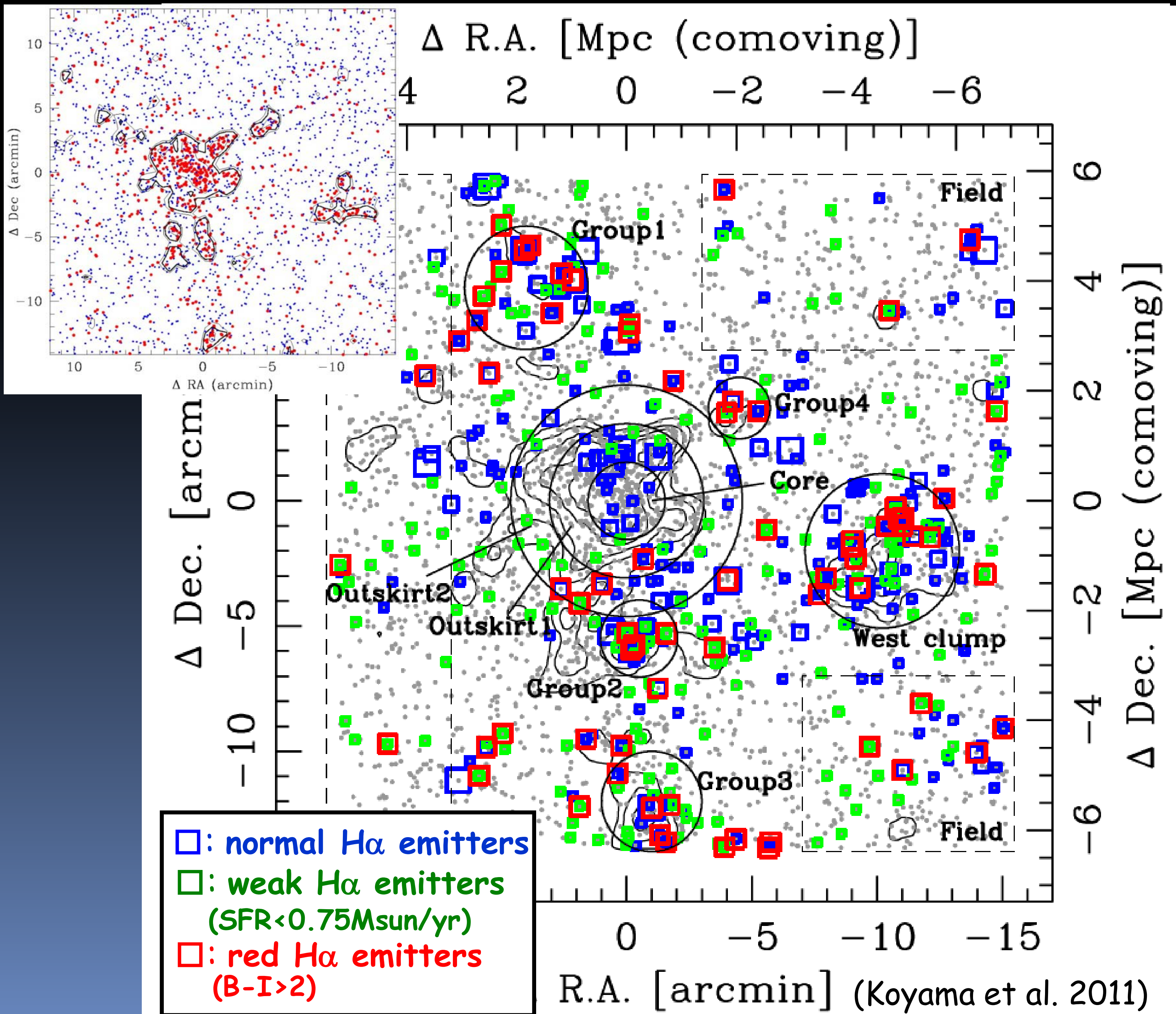
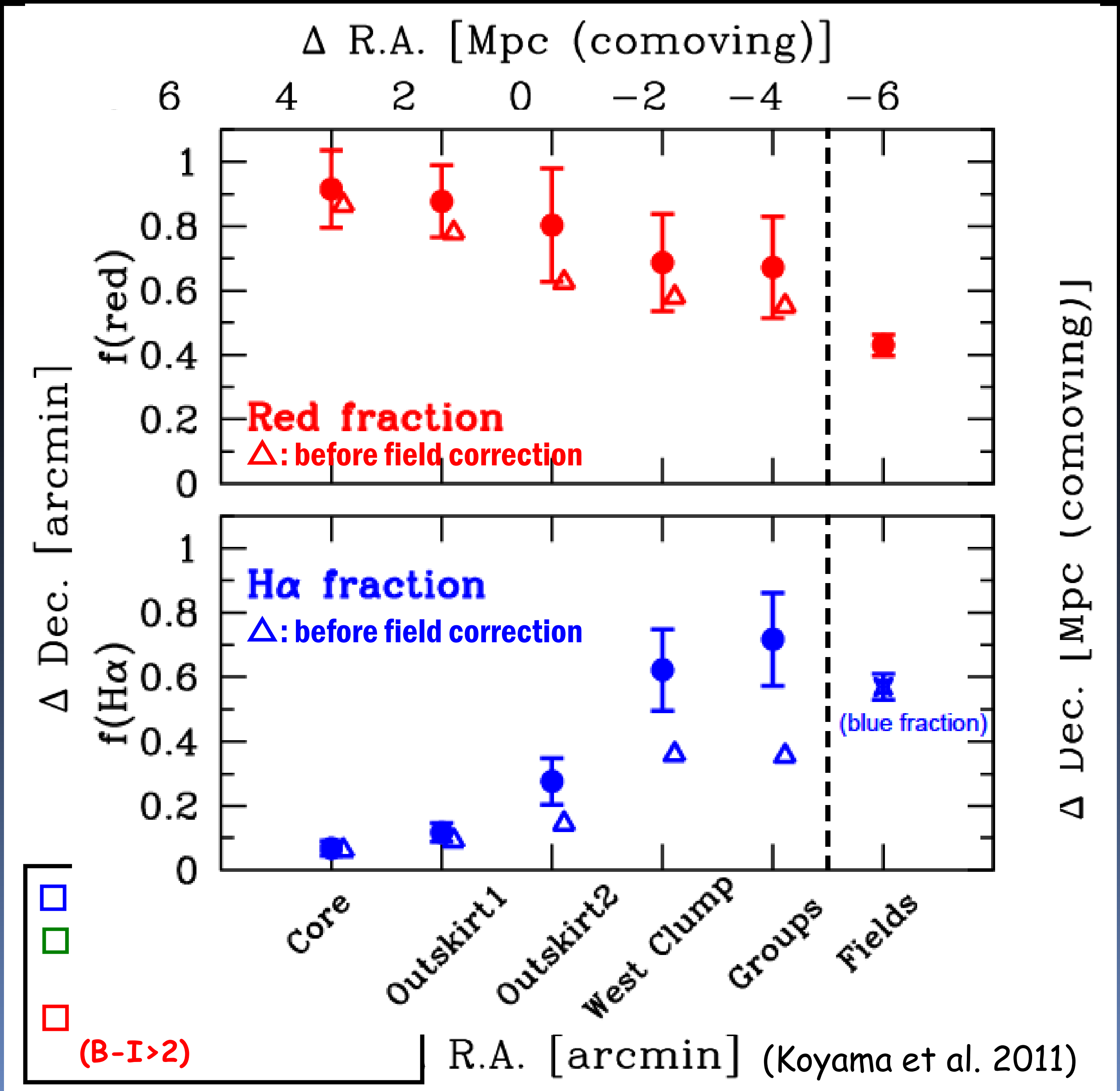




Kodama et al. (2001), *see also Tanaka+05 and Koyama+08 for other redshifts*

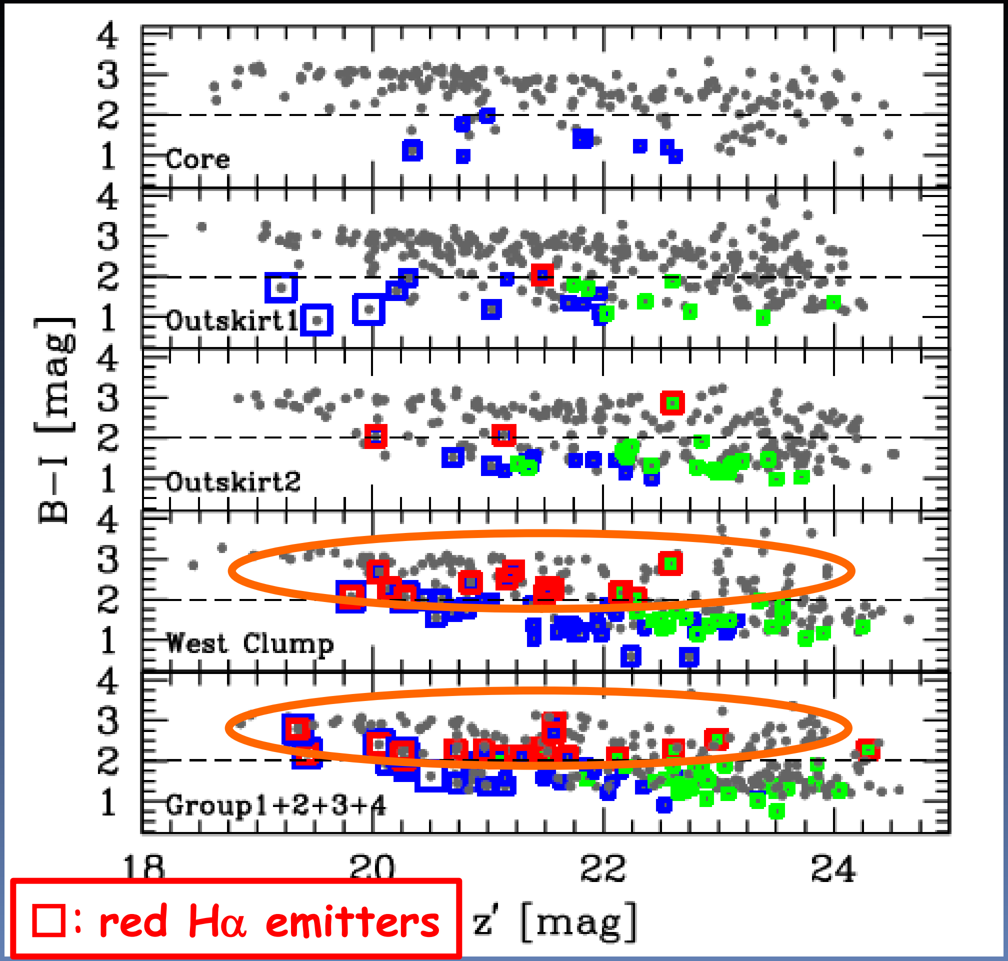


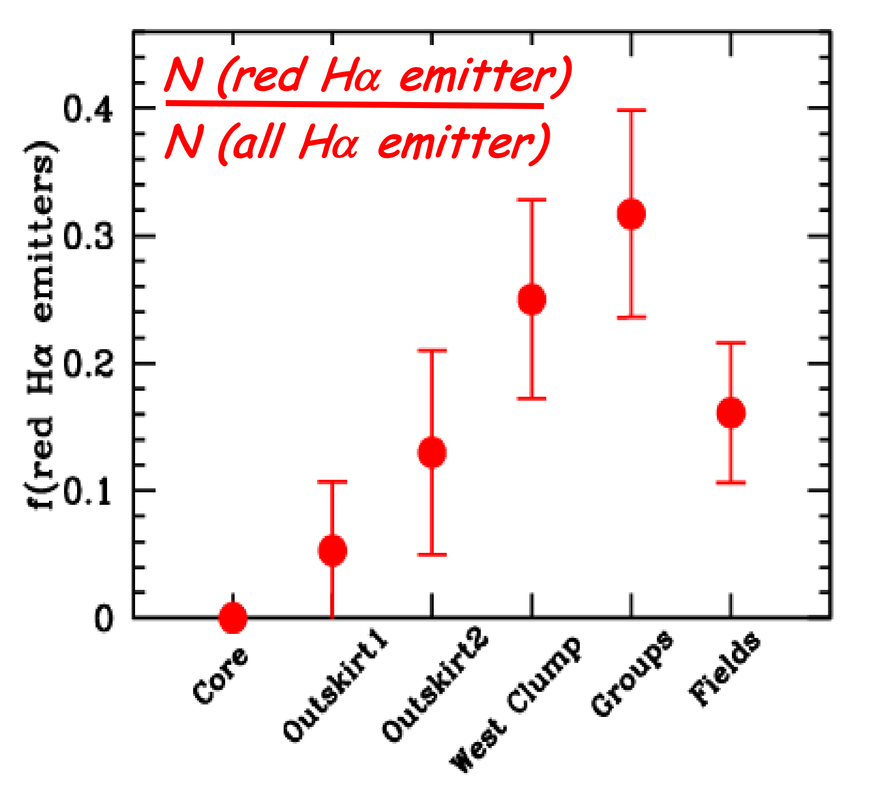
(Koyama et al. 2011)


Δ R.A. [Mpc (comoving)]
6 4 2 0 −2 −4 −6
f(red)
Red fraction
△: before field correction
f(Hα)
Hα fraction
△: before field correction
(blue fraction)
Core
Outskirt1
Outskirt2
West Clump
Groups
Fields
Δ Dec. [arcmin]
Δ Dec. [Mpc (comoving)]
R.A. [arcmin]
(B-I>2)
(Koyama et al. 2011)

Environment of red Hα emitters

Red Hα emitters are most numerous in group-size environment.
and ~ 20-30% of Hα emitters in groups have red colours.





Koyama et al. (2011)

Hα+MIR imaging for RXJ1716+6708 cluster at z=0.81 with MOIRCS/AKARI

(~7Gyr ago)

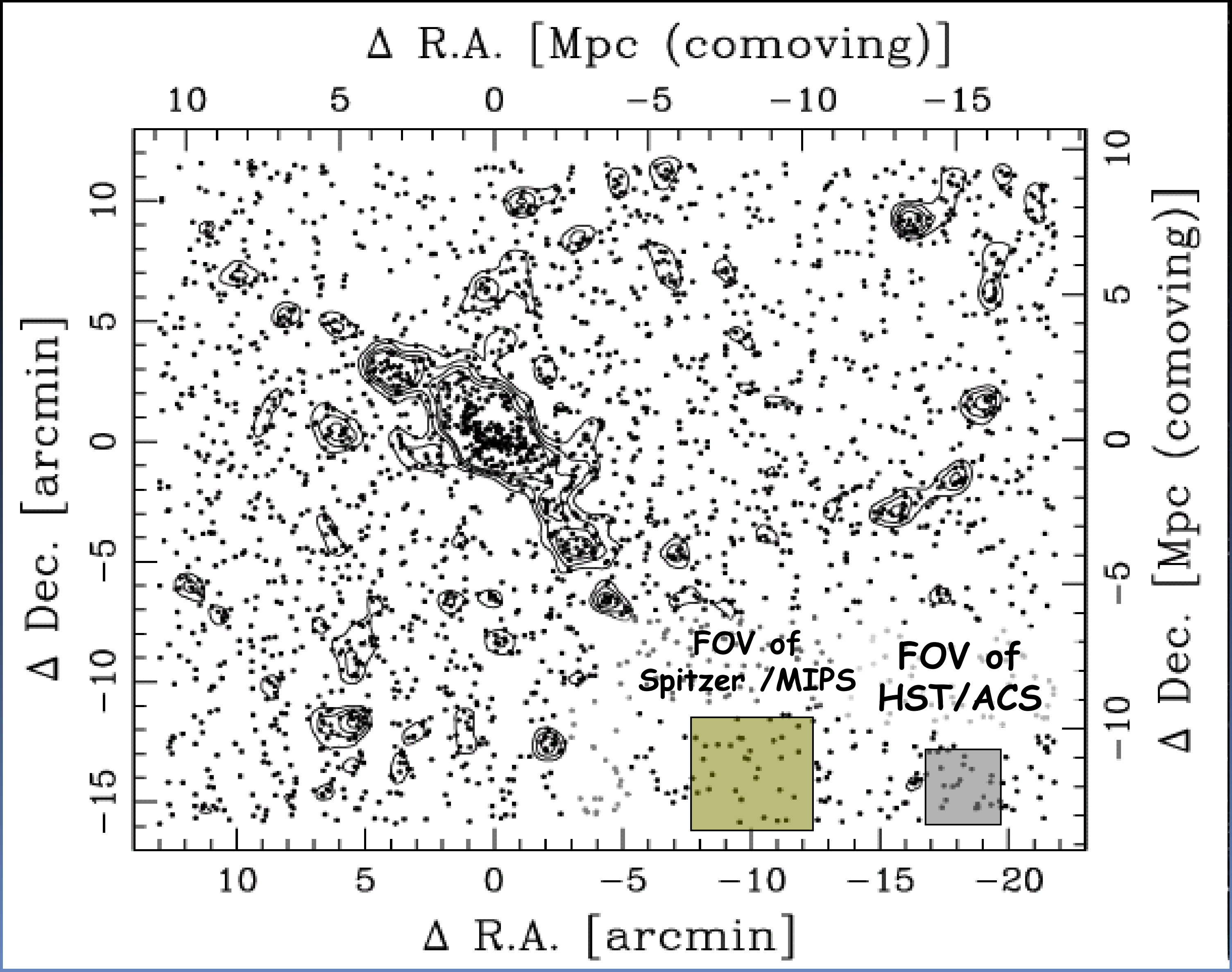
(Koyama et al. 2010, MNRAS, 403, 1611)

MOIRCS

RXJ1716

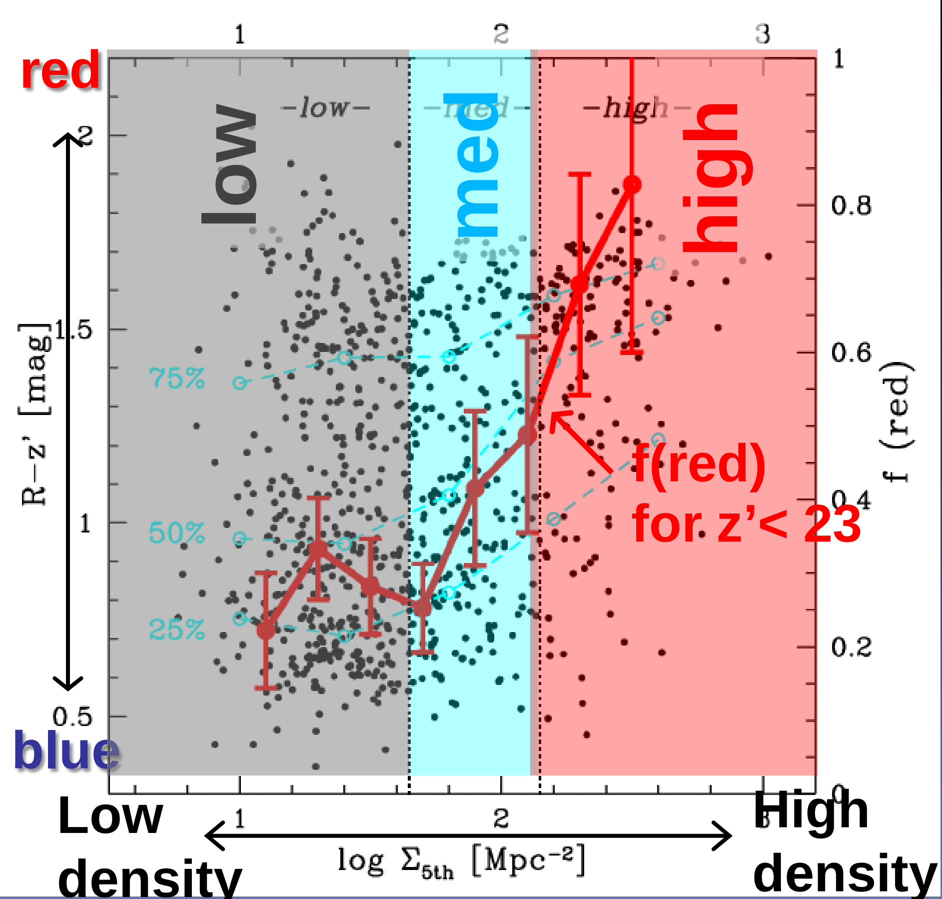
Target: RXJ1716+6708 cluster at z=0.81

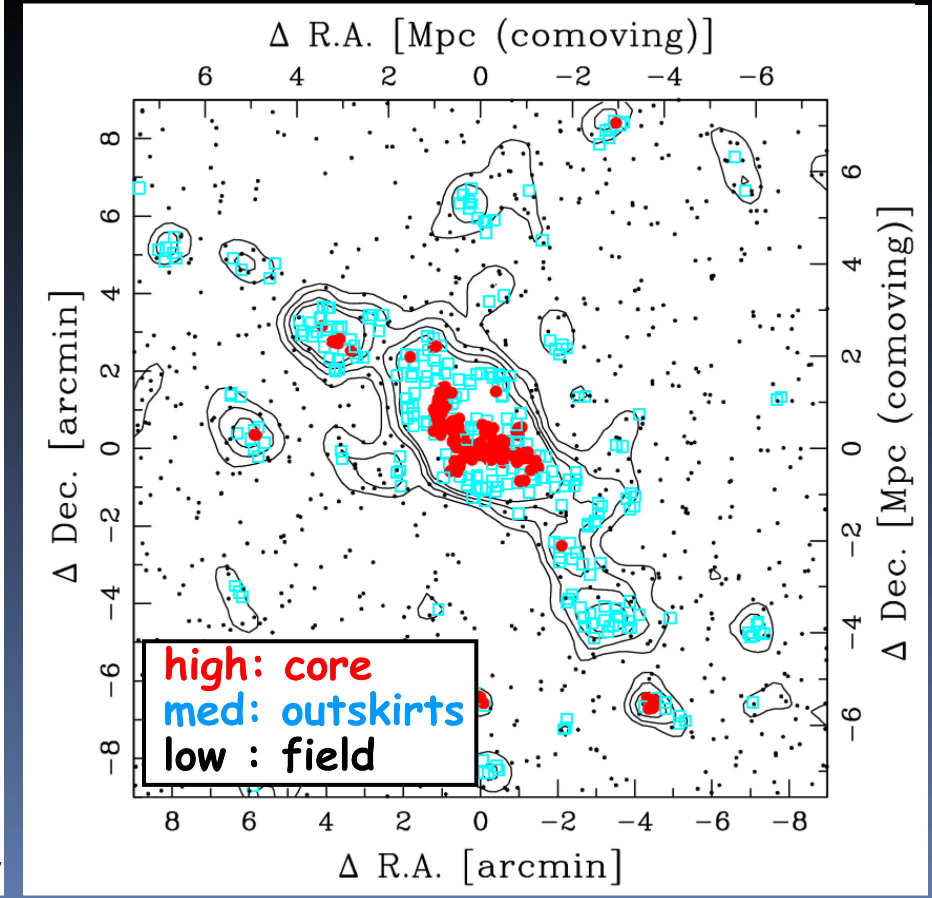
30' ~ 25Mpc @z=0.8



Color-density plot for RXJ1716 (z=0.8)

Again, sharp color transition in the "medium-density" environment
(i.e. cluster outskirts / groups / filaments)



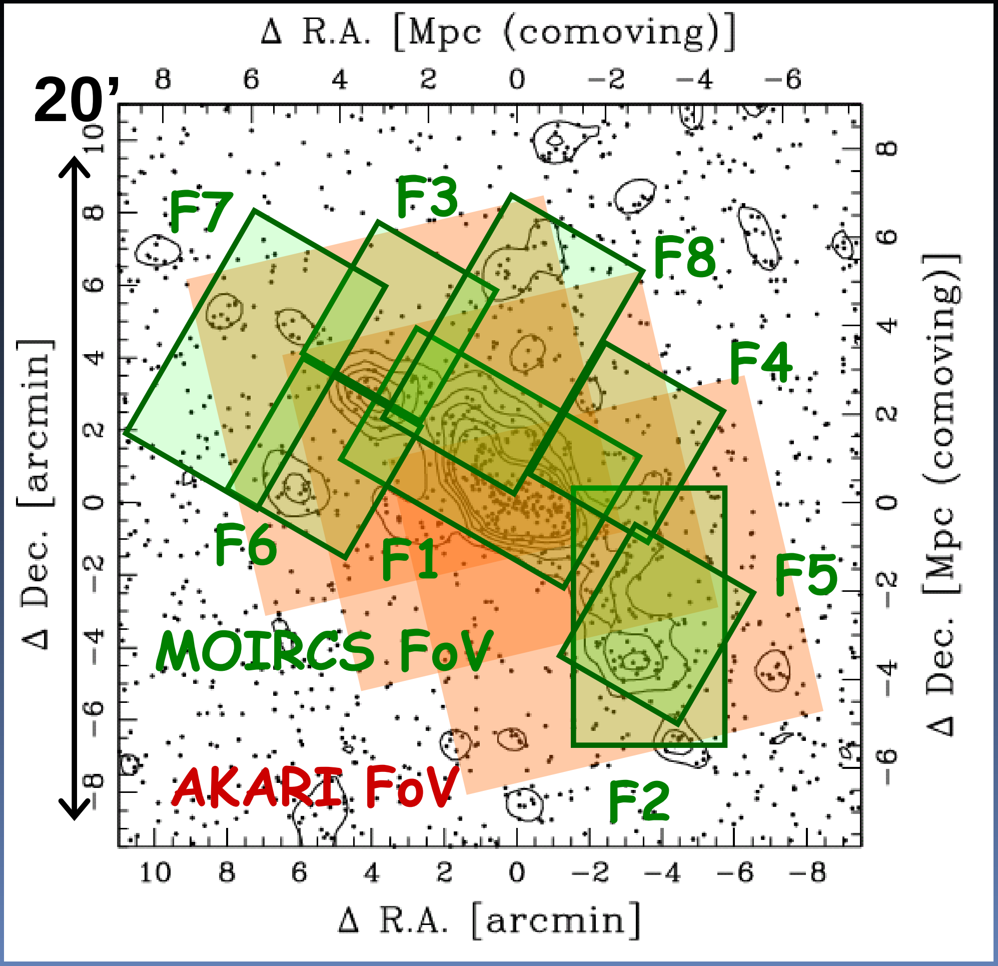


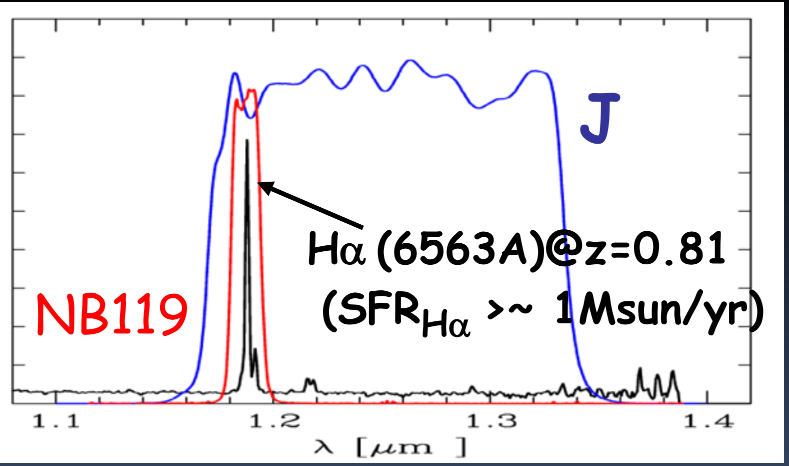
galaxy density (environment)

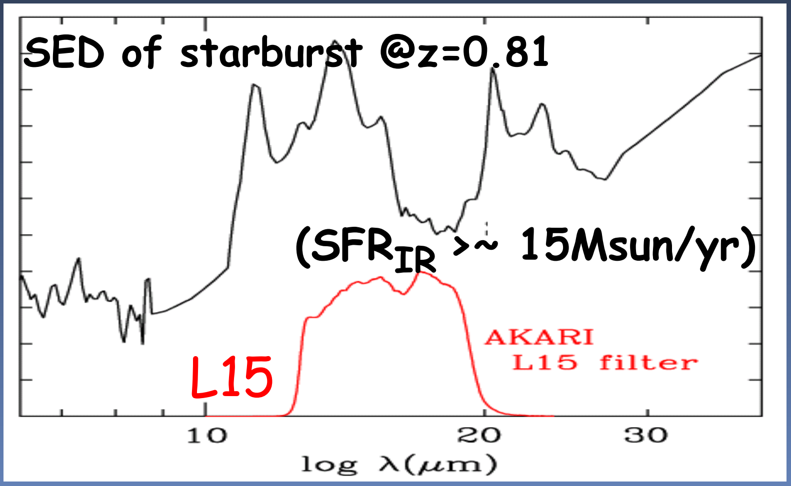
Mapping star formation around the RXJ1716 cluster at z=0.81 with Hα and MIR

Subaru/S-Cam (*VRi'z'*) MOIRCS (*J, NB119*) AKARI/IRC (*N3,S7,L15*)

Subaru / AKARI Joint Survey



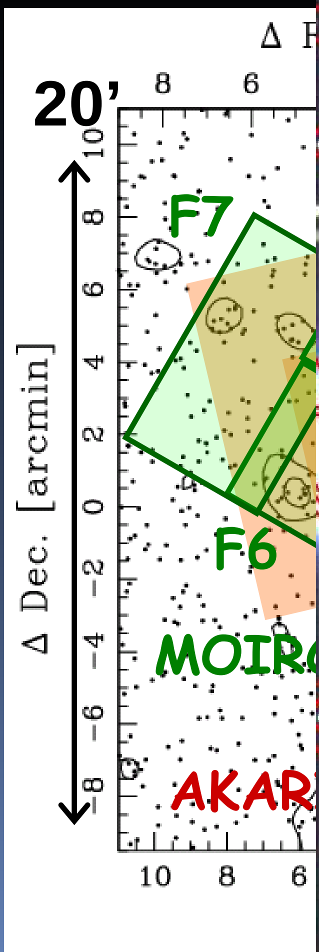


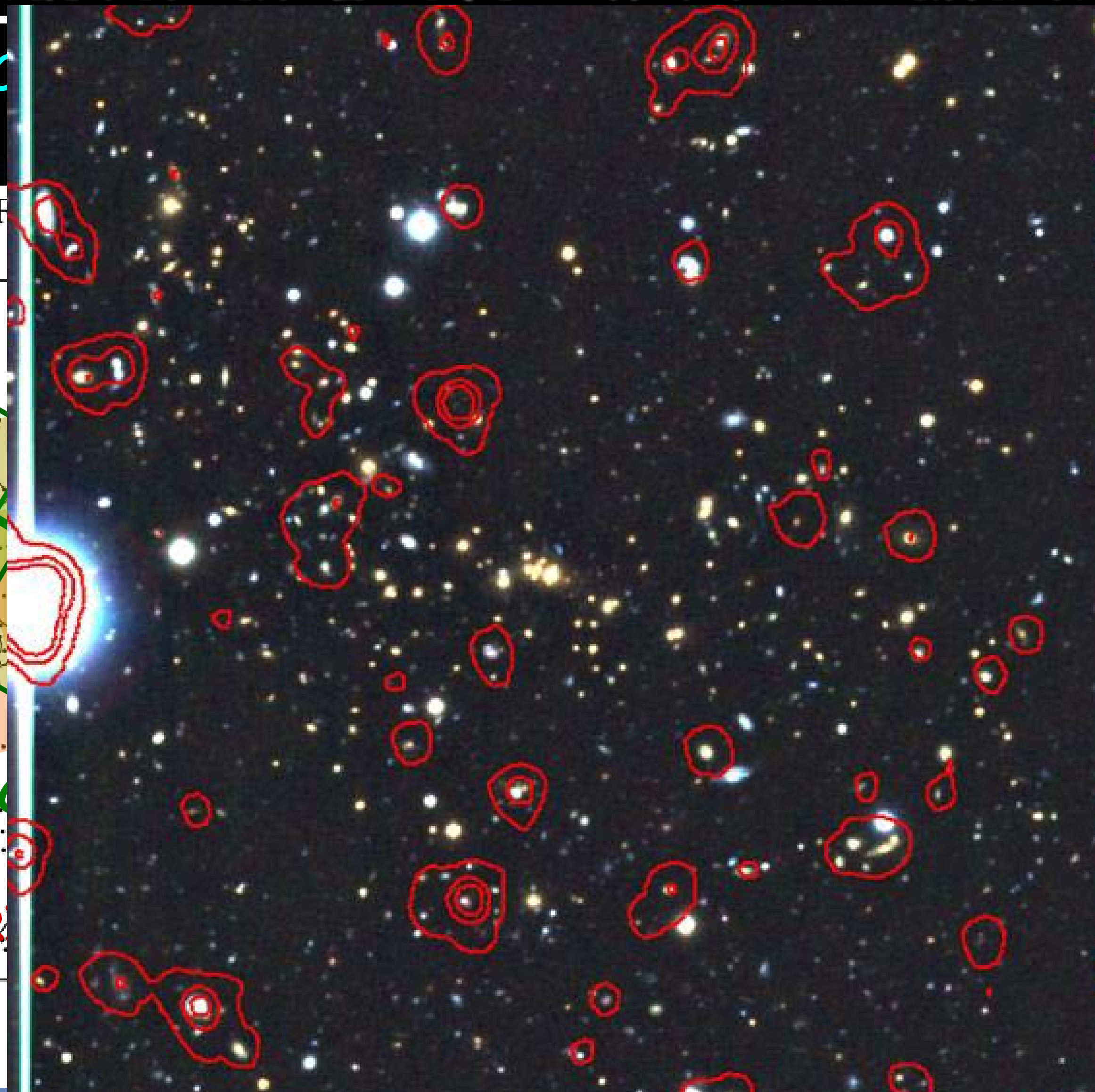


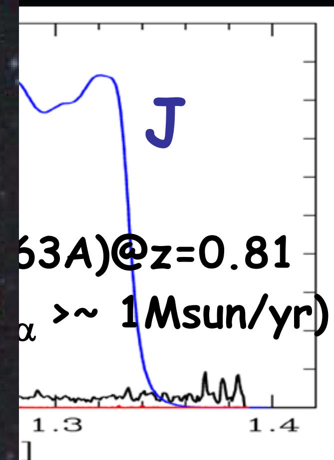
(Koyama et al. 2010, MNRAS, 403, 1611)

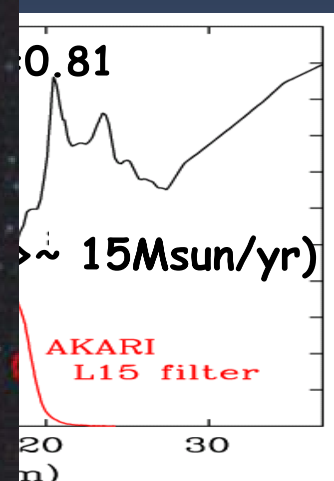
Mapping star formation around the RXJ1716 cluster at z=0.81 with Hα and MIR

Subaru/S-C … RC (*N3,S7,L15*)



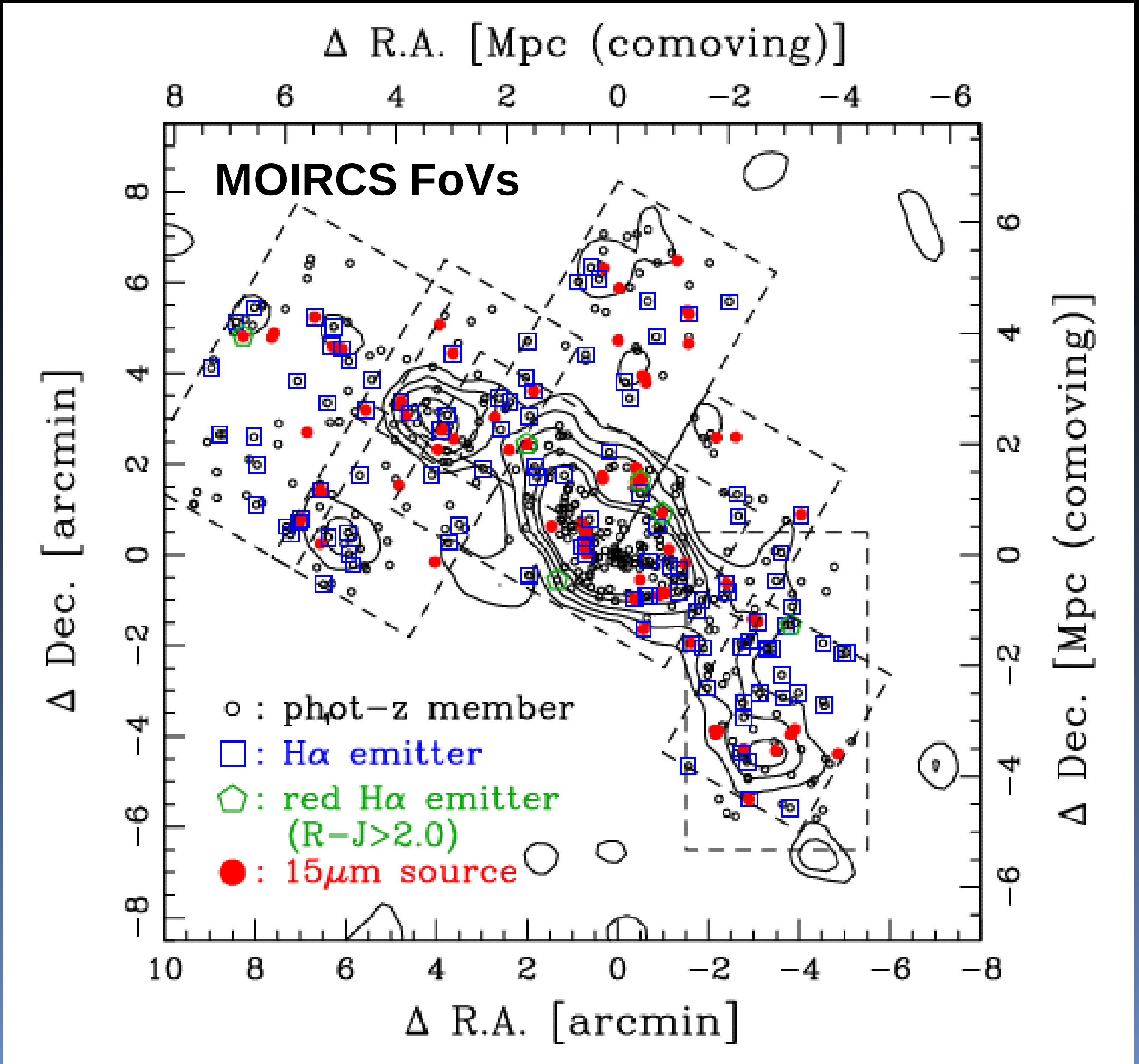






(Koyama et al. 2010, MNRAS, 403, 1611)

Spatial distribution of Hα emitter/MIR source



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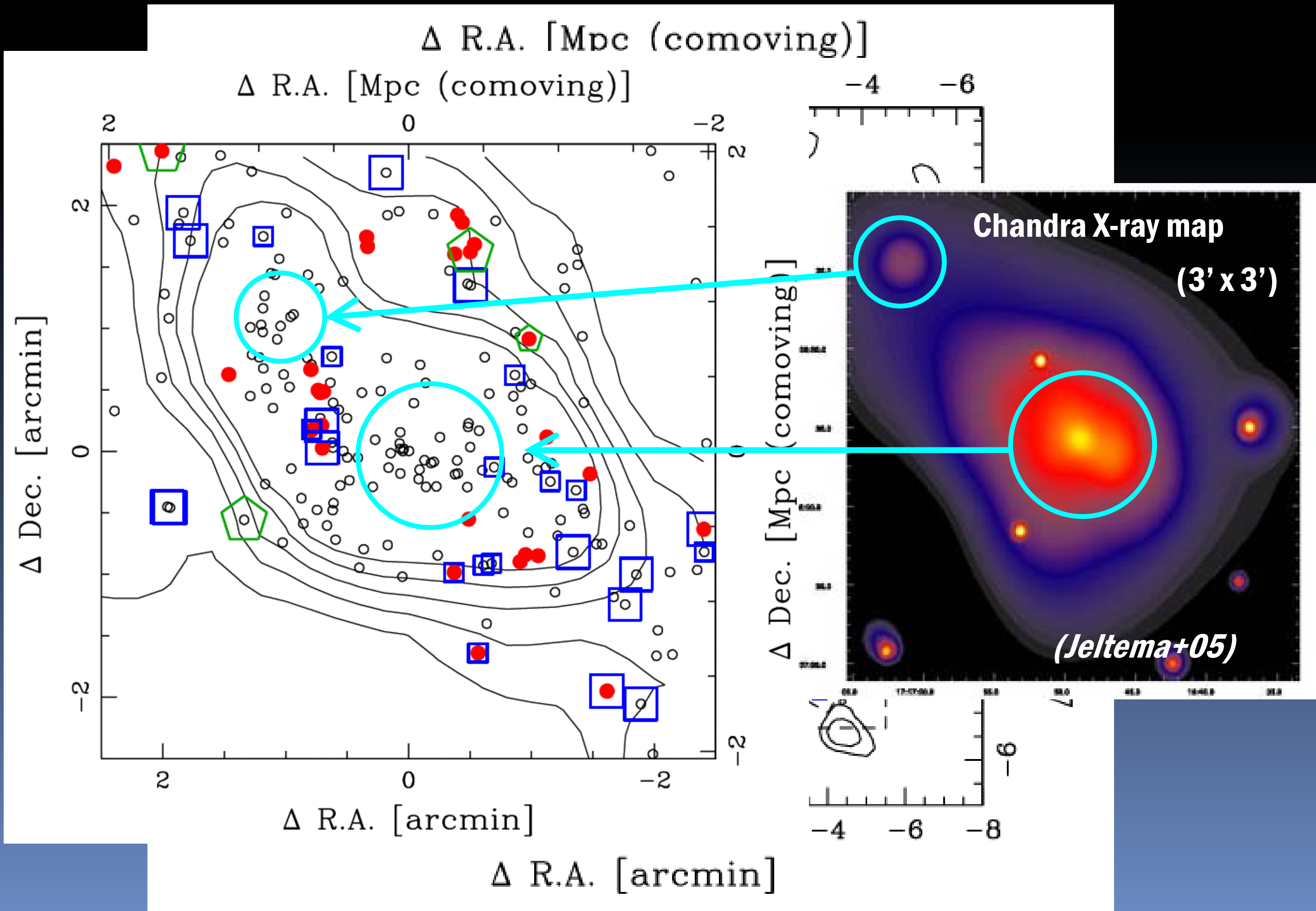
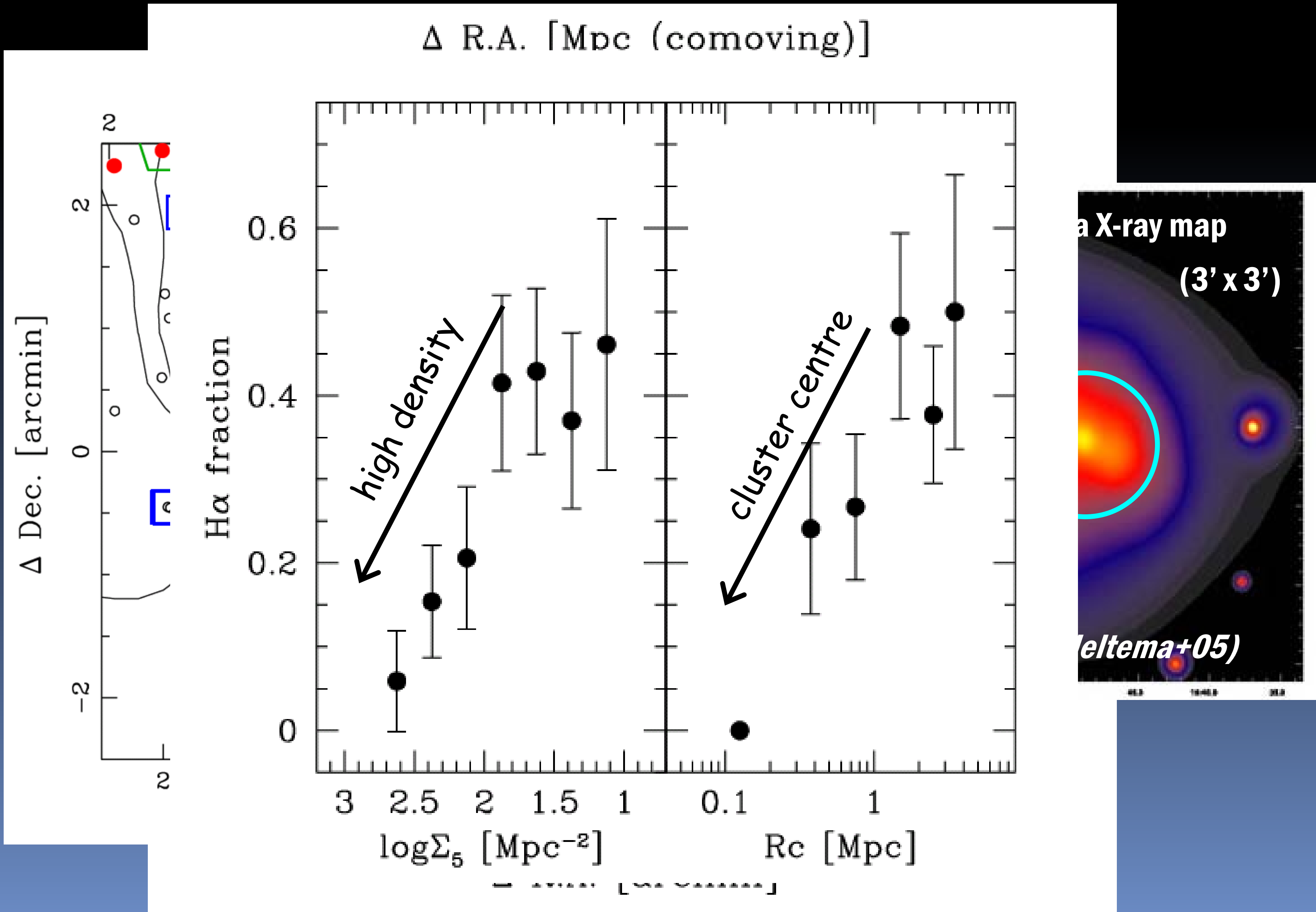


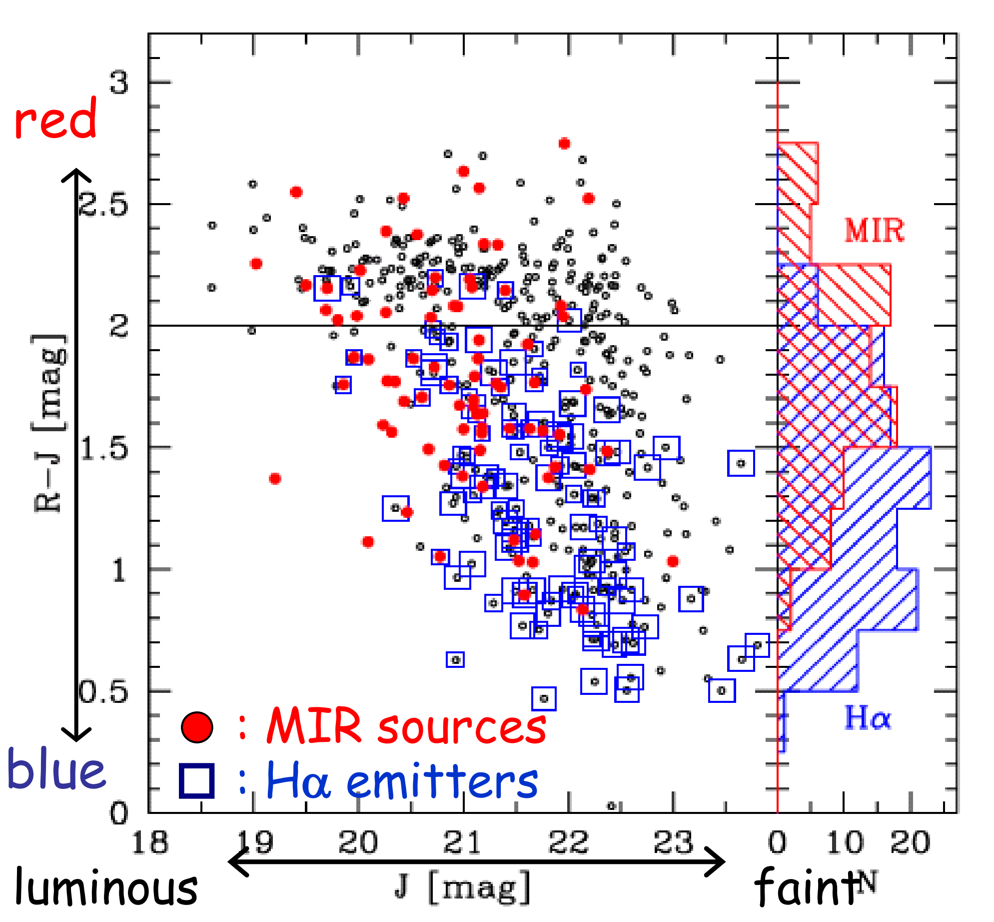
Spatial distribution of Hα emitter/MIR source

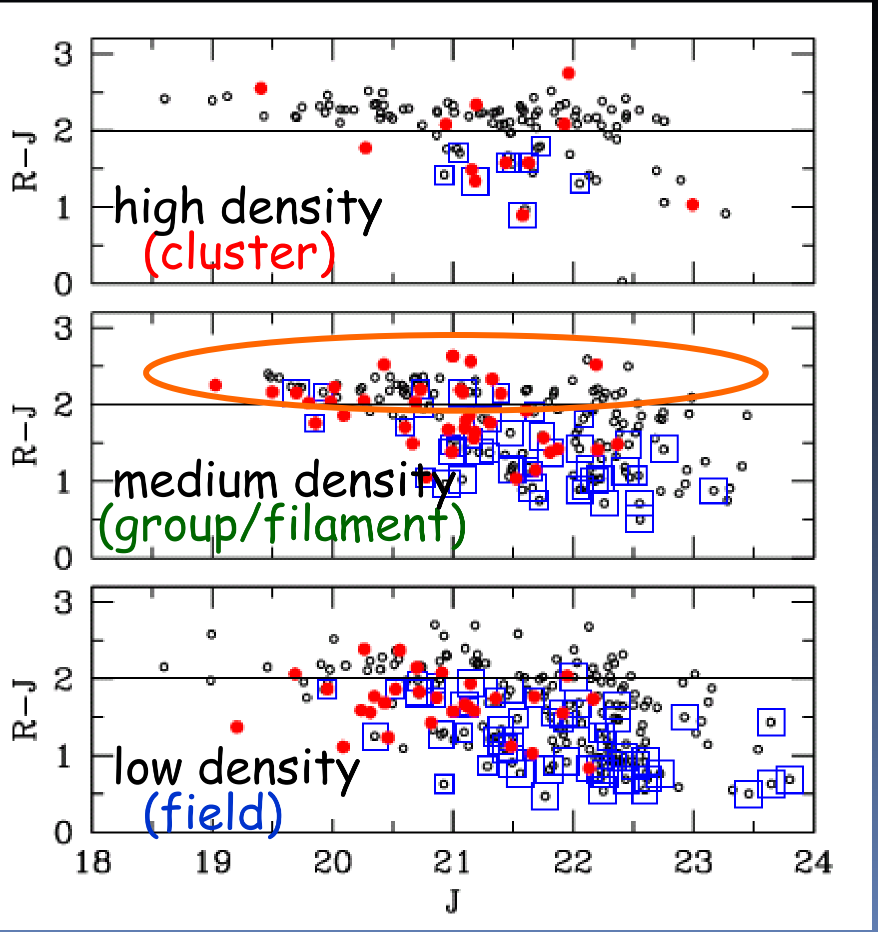


Optical colours of Hα emitters/MIR sources

MIR galaxies are dusty and tend to be redder than Hα emitters.

Red SF galaxies are preferentially found in groups/filaments.

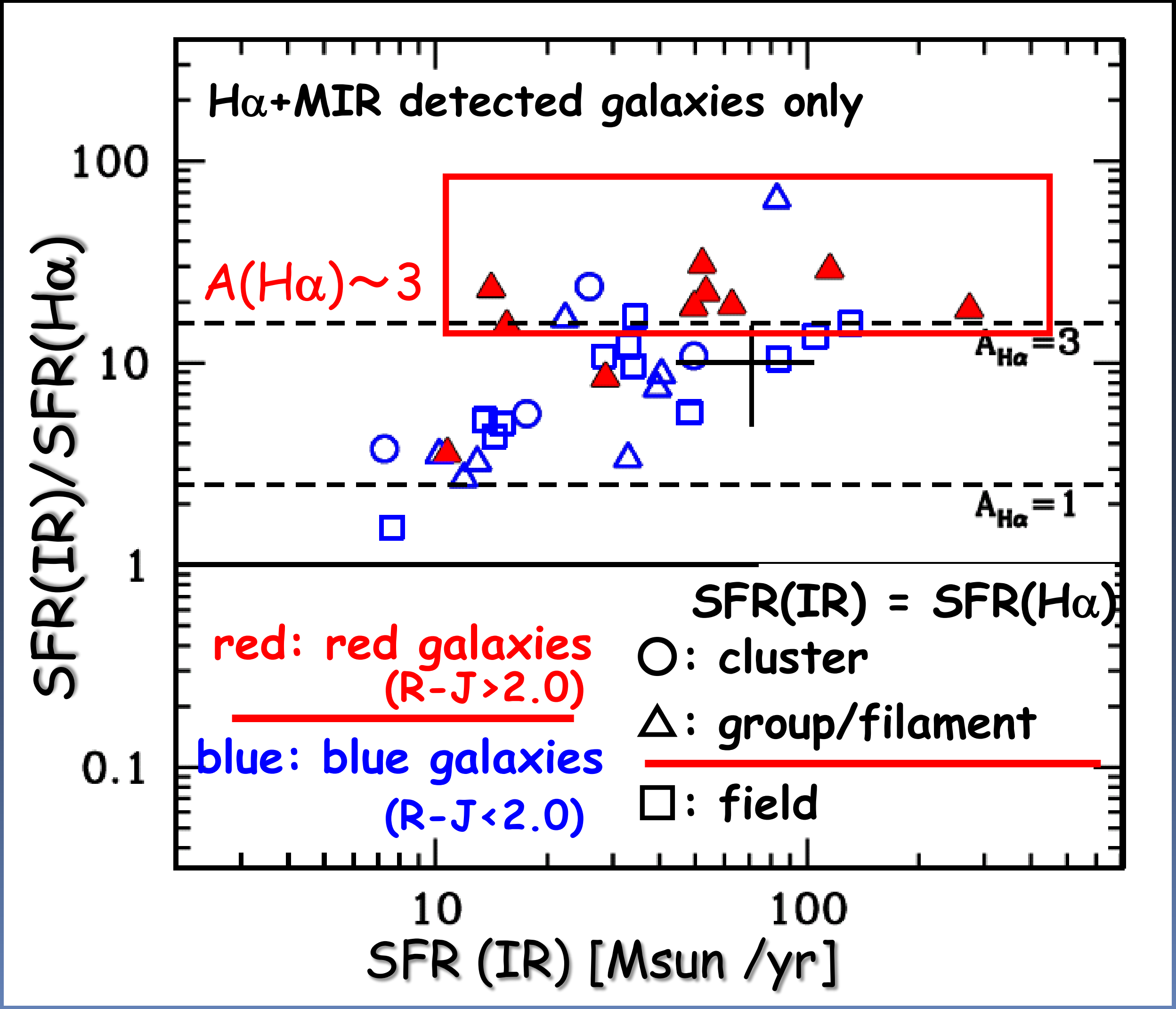




(Koyama et al. 2010)

SFR(Hα) vs SFR(IR)

SFR(Hα) is underestimated especially for group/filament galaxies



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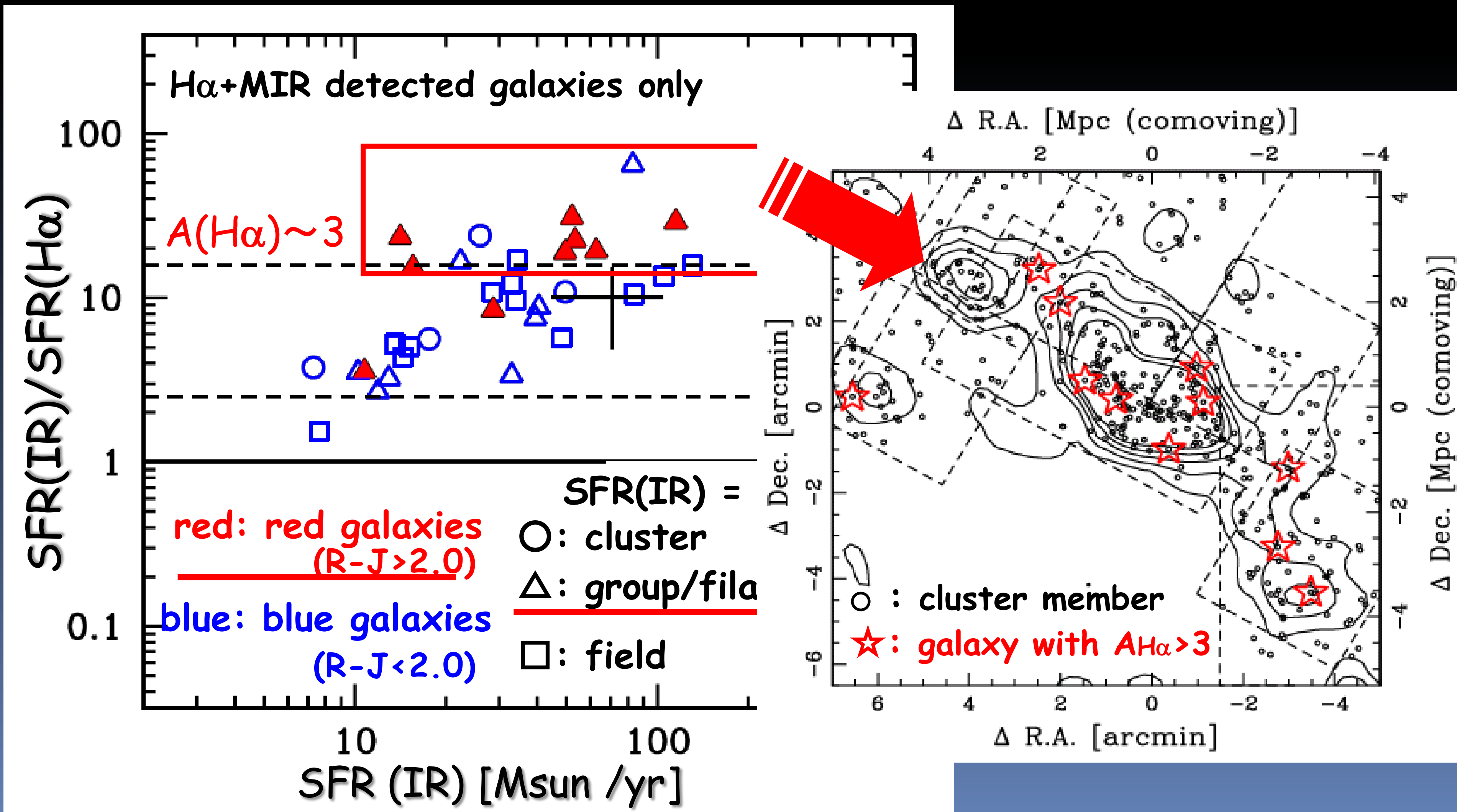
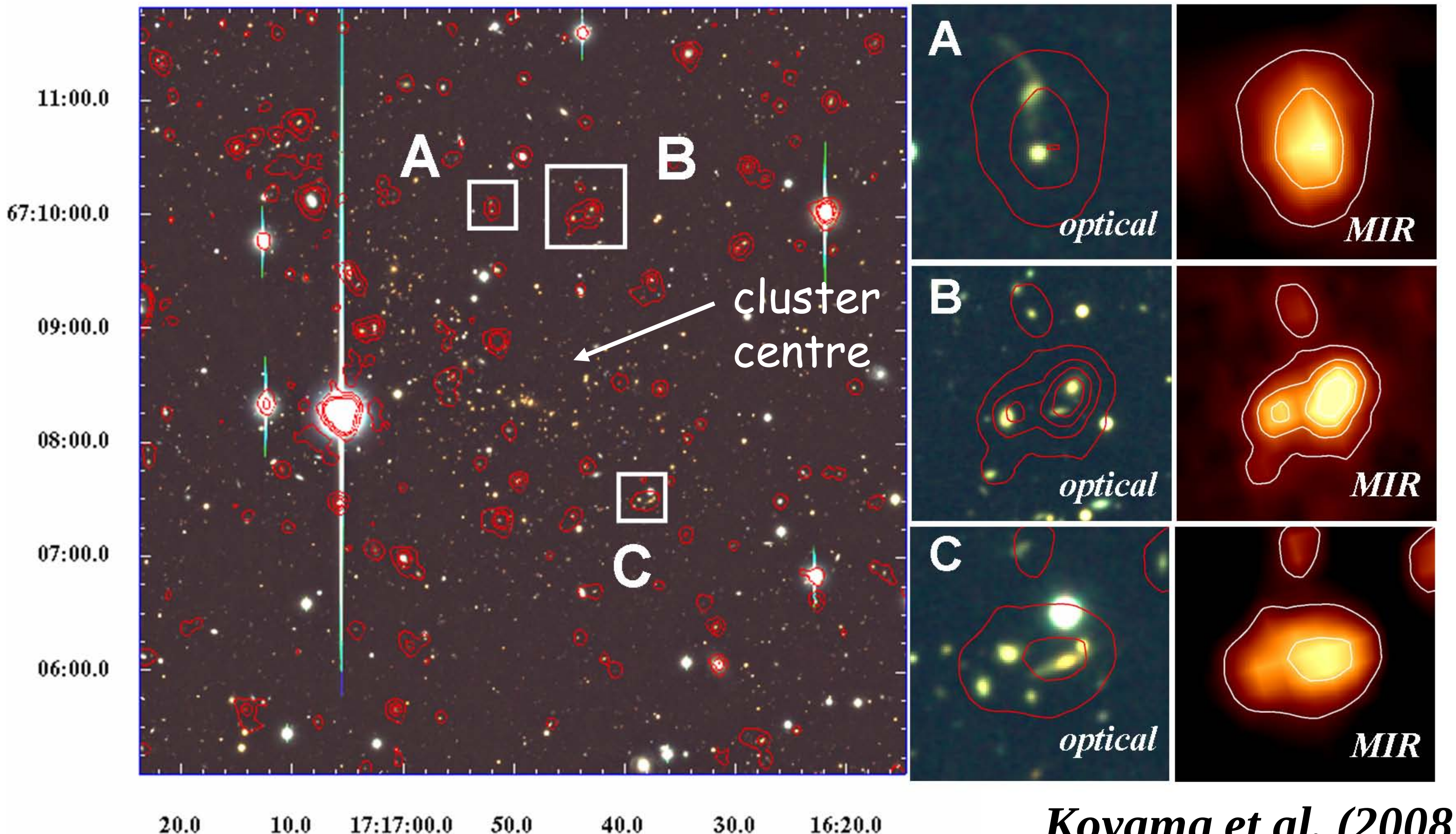


What is the trigger of starbursts ?

Image: Subaru optical / Contour: AKARI MIR



Koyama et al. (2008)

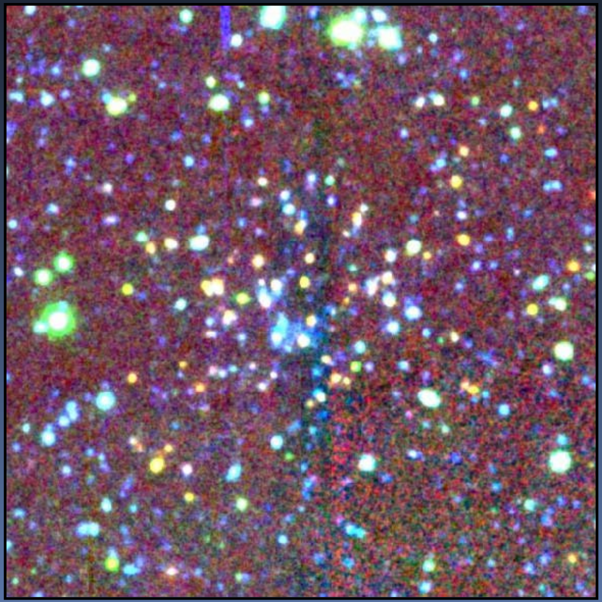
galaxy-galaxy interactions in small in-falling groups should contribute to gas consumption and SF quenching (at least partly)

[OII] imaging survey for XCS2215 cluster at z=1.46 with Suprime-Cam

(~9Gyr ago)

(Hayashi et al. 2010, MNRAS, 402, 1980)

Suprime-Cam

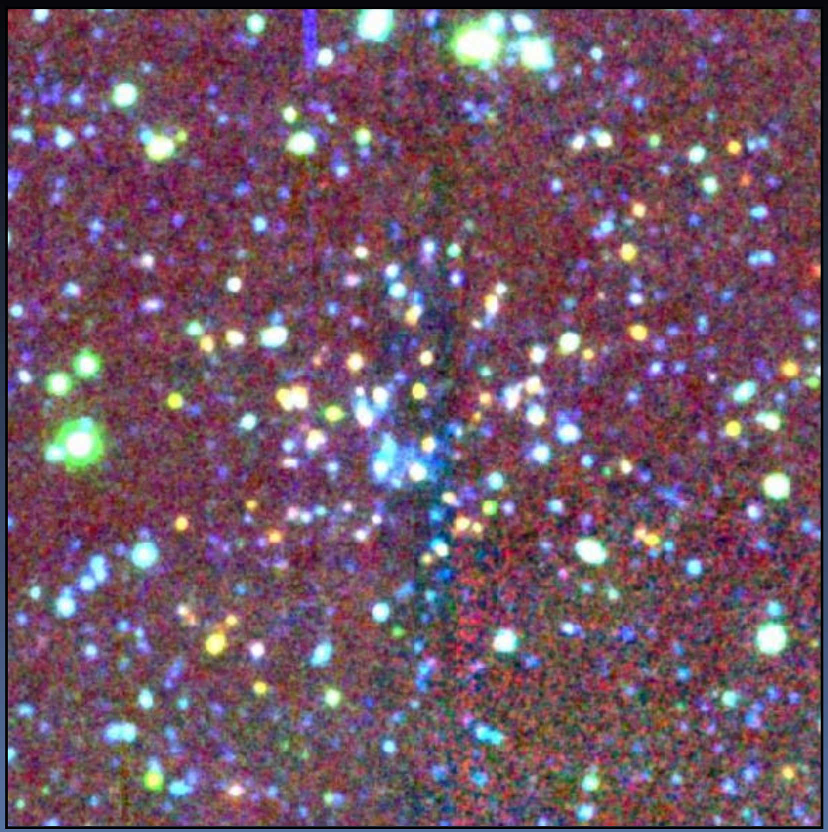


XCS2215 cluster

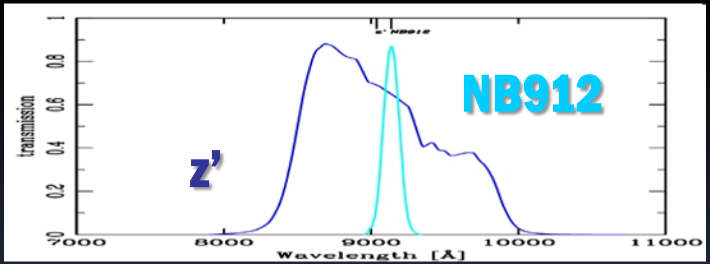
SF activity in z ~ 1.5 cluster

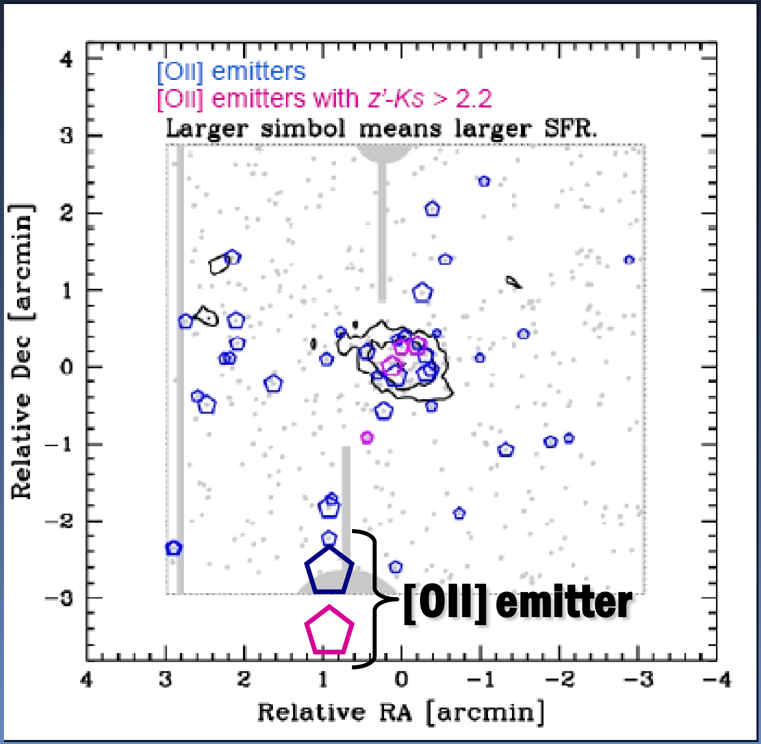
XCS2215: one of the most distant X-ray detected clusters

SF activity is surprisingly high even in the cluster core !



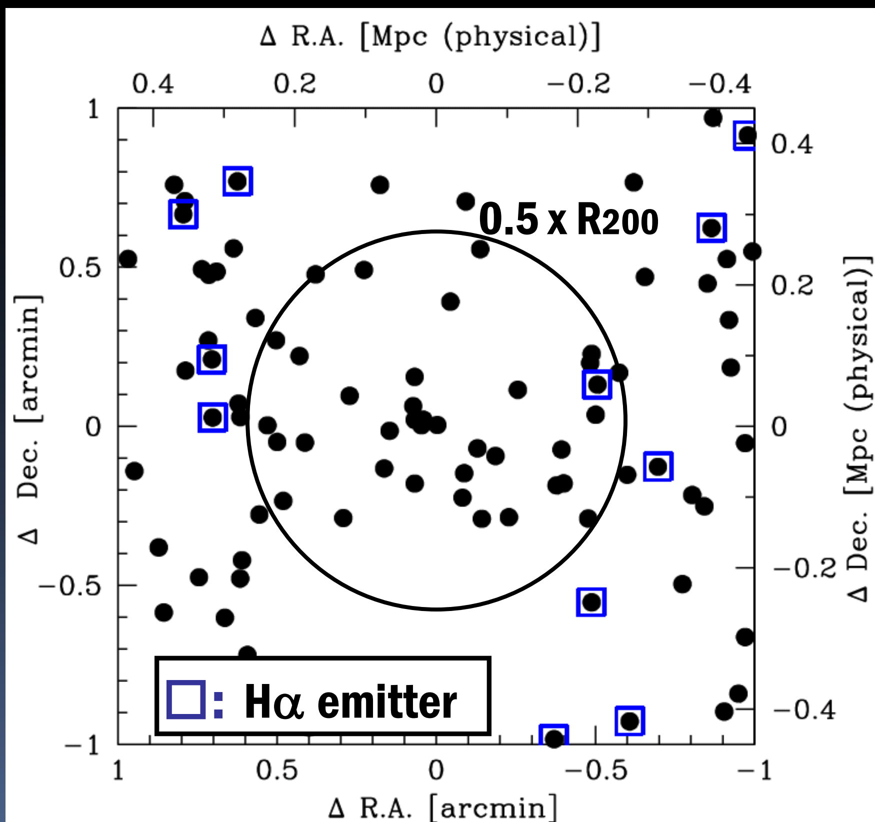
(Hayashi et al. 2010)





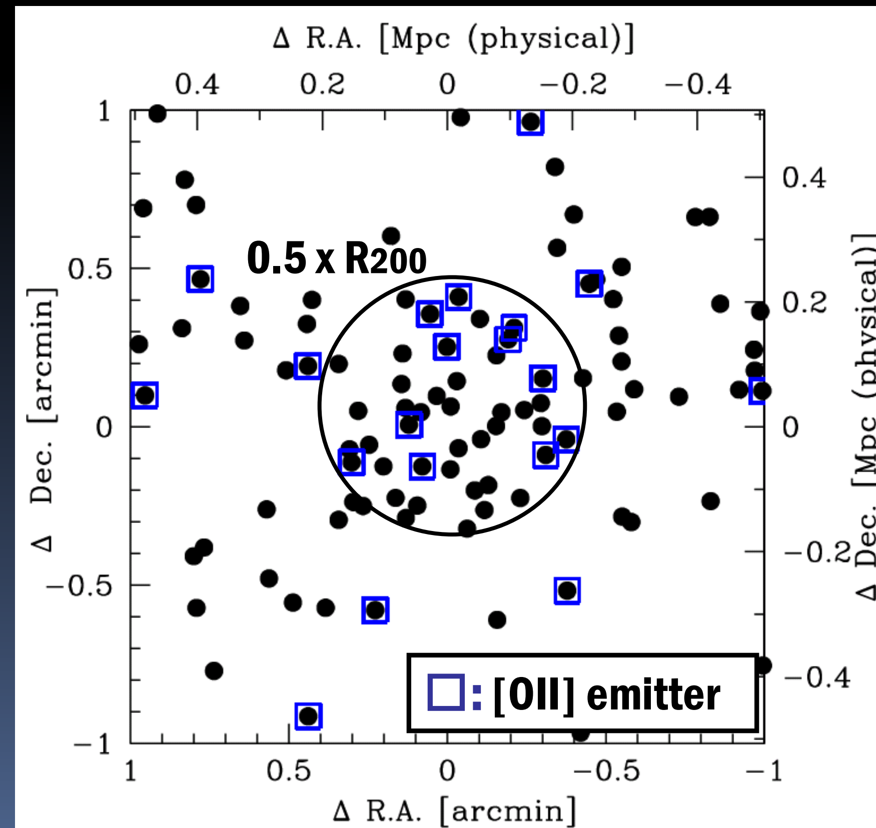
High SF activity in z=1.5 cluster

Hα emitters at z=0.81 (RXJ1716)



Koyama et al. (2010)

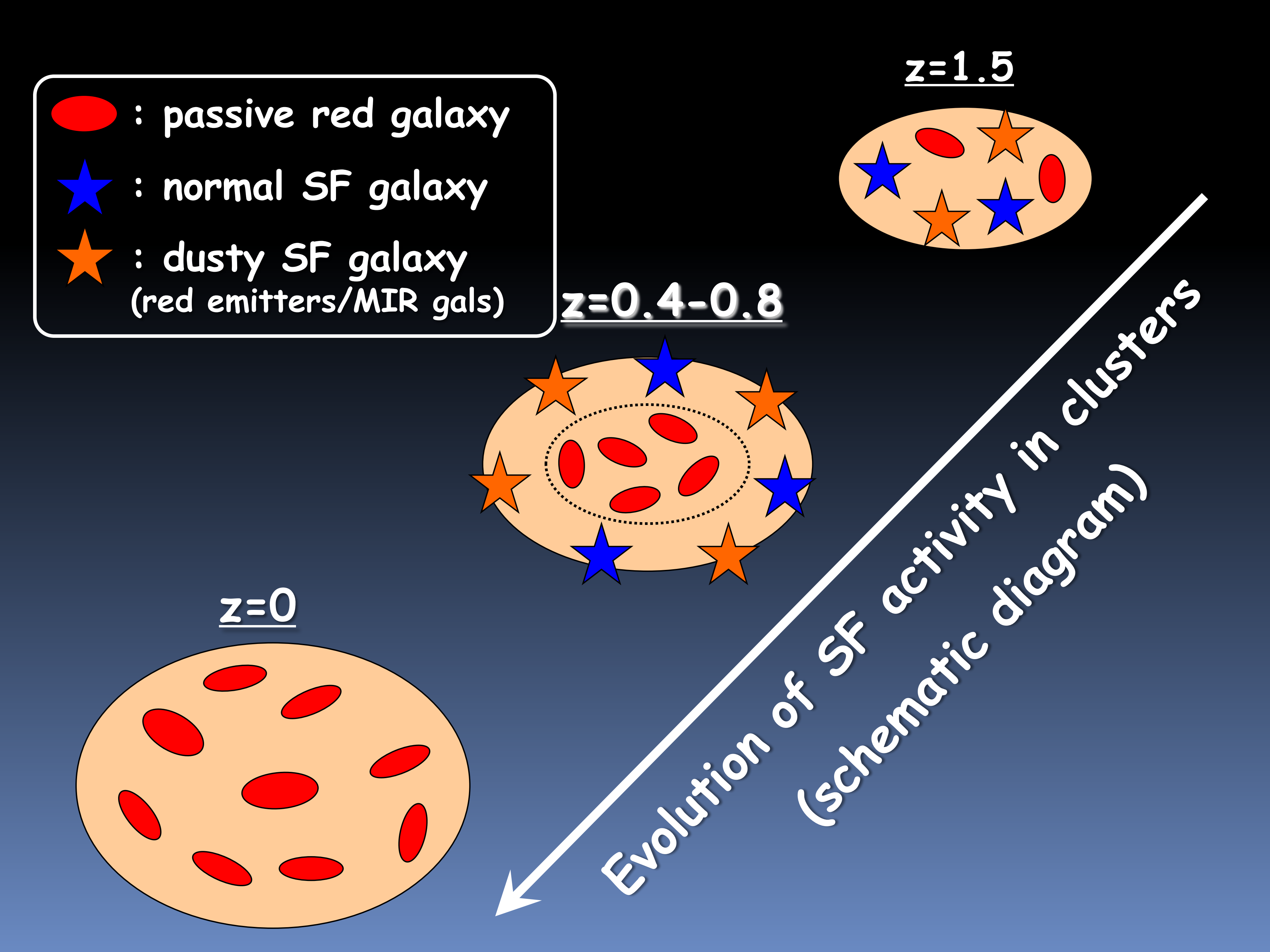
[OII] emitters at z=1.46 (XCS2215)



Hayashi et al. (2010)

Propagation of active SF site from centre to outer region ?

(*active SF in cluster core @z=1.5 → outskirt/groups @z=0.8*)

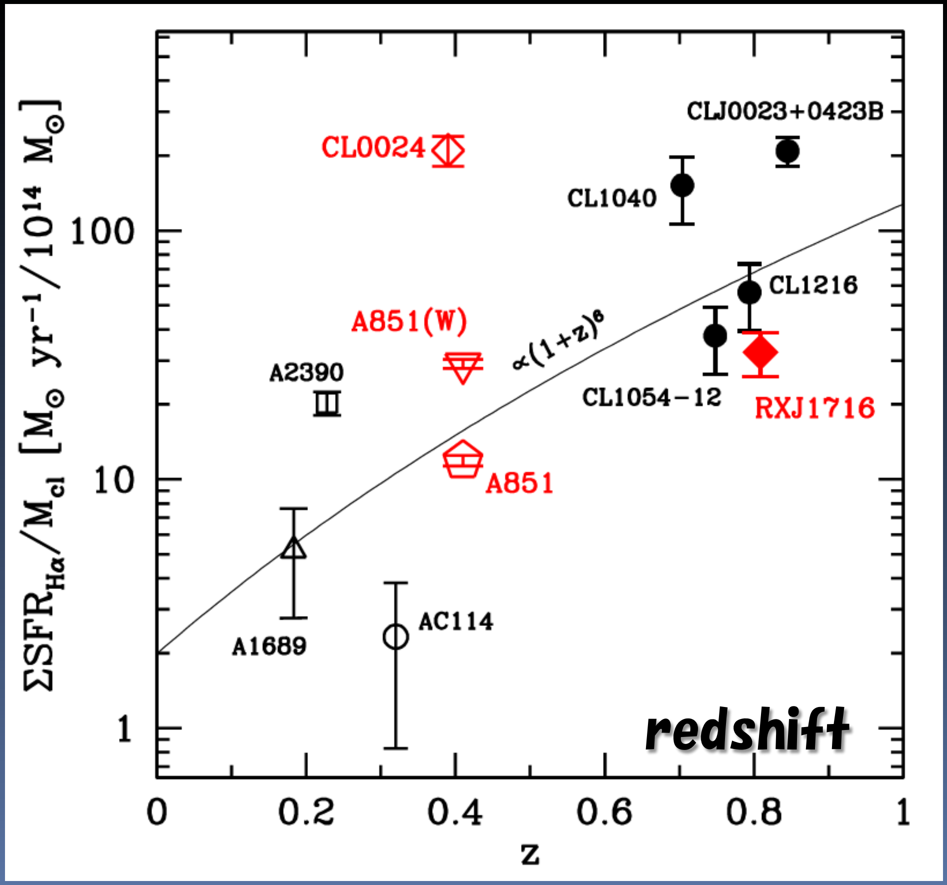


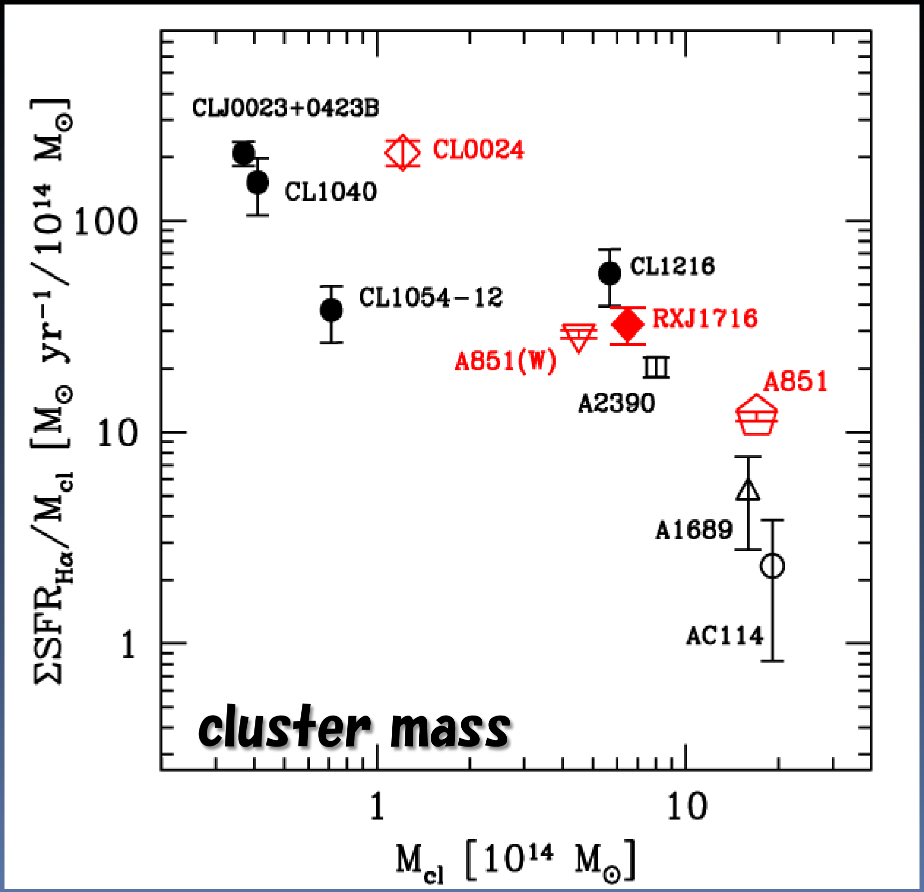
: passive red galaxy
: normal SF galaxy
: dusty SF galaxy
(red emitters/MIR gals)
z=1.5
z=0.4-0.8
z=0
Evolution of SF activity in clusters
(schematic diagram)

Global evolution of SF activity in clusters

Sharp decline in cluster-mass-normalized SFR (ΣSFR/Mcl) since z~1.

(Note: this trend is steeper than that for general field).





Need a larger sample, and in particular, higher redshift cluster sample !

MAHALO-Subaru Quick Overview

(PI: T. Kodama)

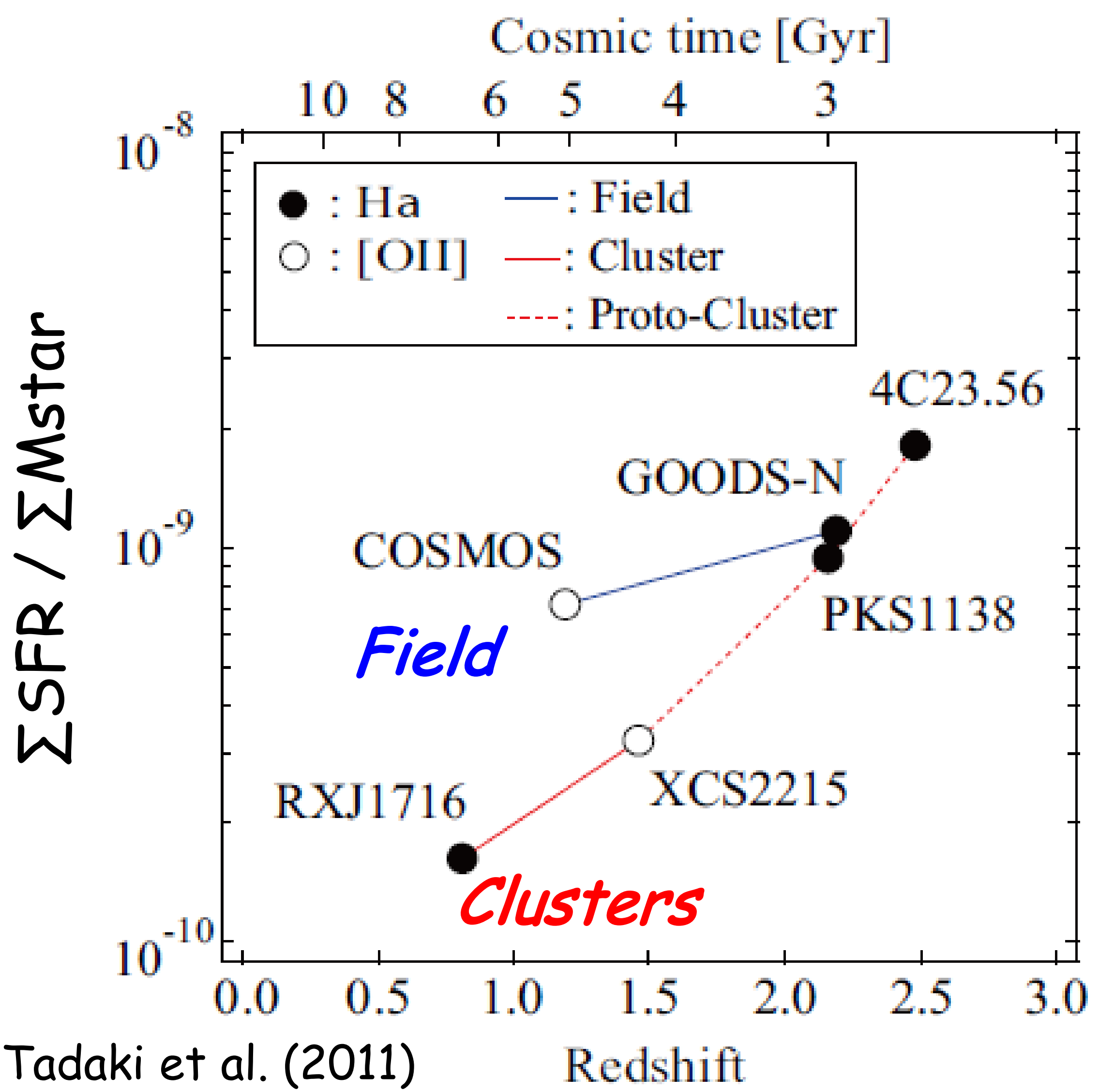
MApping H-Alpha and Lines of OII with Subaru

Narrow-band emitters (Hα, [OII]) surveys at 0.4<z<2.5

Table 2: The complete list of our NB imaging surveys for star-forming galaxies, including the past observations.

environment	target	z	line	λ (μm)	camera	NB-filter	continuum	ALMA visibility	status
clusters	CL0024+1652	0.395	Hα	0.916	S-Cam	NB912	z'	Yes	Kodama+'04 [13]
	CL0939+4713	0.407	Hα	0.923	S-Cam	NB921	z'	No	Koyama+'10,'11
	RXJ1716+6708	0.813	Hα	1.190	MOIRCS	NB1190	z', J	No	
	XCSJ2215–1738	1.457	[OII]	0.916	S-Cam	NB912	z'	Yes	Hayashi+'10 [15]
	4C65.22	**1.516**	Hα	1.651	MOIRCS	NB1657	H	No	
	Q1126+101	**1.517**	Hα	1.652	MOIRCS	NB1657	H	Yes	
	Q0835+580	**1.534**	Hα	1.664	MOIRCS	NB1657	H	No	
	CL0332–2742	**1.61**	[OII]	0.973	S-Cam	NB973	z, y	Yes	
	IRC0218-A	**1.62**	[OII]	0.977	S-Cam	NB973	z', y	Yes	approved
	PKS1138–262	**2.156**	Hα	2.071	MOIRCS	NB2071	K_s	Yes	
	4C23.56	**2.483**	Hα	2.286	MOIRCS	NB2288	K_s, K_{cont}	Yes	
	USS1558–003	**2.527**	Hα	2.315	MOIRCS	NB2315	K_s, K_{cont}	Yes	
fields	GOODS-N	2.19	Hα	2.094	MOIRCS	NB2095	K_s	No	Tadaki+'10 [27]
	(2.5 pointings)		[OII]	1.189	MOIRCS	NB1190	z', J	No	Tadaki+'10 [27]
	SXDF	**2.19**	Hα	2.094	MOIRCS	NB2095	K	Yes	
	(3 pointings)		Hβ	1.551	MOIRCS	NB1550	H	Yes	approved
			[OII]	1.189	MOIRCS	NB1190	z', J	Yes	

Final goal of MAHALO-Subaru project



Tadaki et al. (2011)

Conclusions

- **Panoramic mapping of SF activity in distant clusters**
  - Hα (+MIR) mapping of z=0.4/0.8 clusters with Subaru and AKARI
- **Dusty galaxies in the cluster surrounding environment**
  - Dusty red galaxies (red Ha emitters and/or MIR sources) are most numerous in group-scale environment
  - Ha also underestimate SFR (A(Ha)>3 in extreme cases)
  - Probably progenitors of present-day cluster early-types.
- **Sharp decline in cluster SFR since z~1.5**
  - SF site changes from core (z~1.5) to outskirt (z~0.8) ?
  - "MAHALO-Subaru" cultivates the frontier redshift.