A star-bursting proto-cluster associated to a radio galaxy at z=2.53

Wide-field Hα emission survey around a radio galaxy at z=2.53 with Subaru

Hayashi et al., 2012, ApJ, 757, 15
(arXiv:1207.2614)

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2012.09.10-13 Growing-up at high redshift: from proto-clusters to galaxy clusters @ ESAC, Madrid

MAHALO-Subaru

"MAHALO-Subaru"

MApping HAlpha and Lines of Oxygen with Subaru

A narrow-band mapping of star forming galaxies at the peak epoch of galaxy formation at 0.4<z<2.5 (primarily at 1.5<z<2.5).

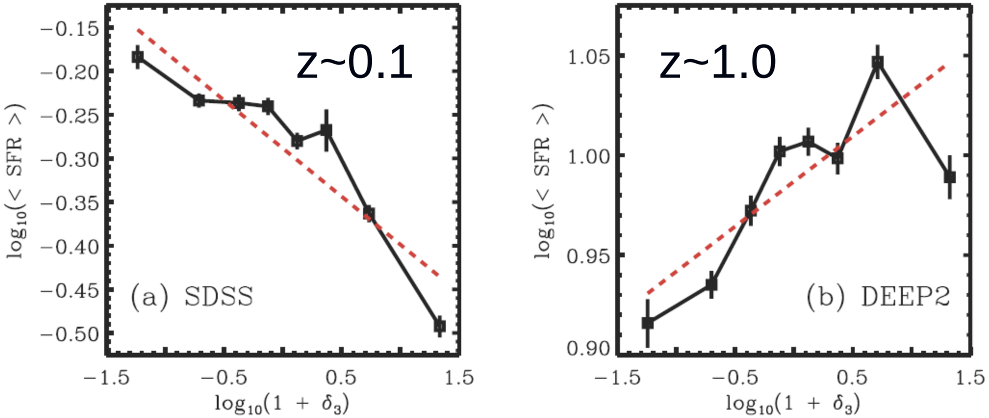
Pilot obs (5 nights) + Intensive (10 nights @S10B-11A) + Normal (3 nights @S11B)

environ-ment	target	z	line	λ (μm)	camera	NB-filter	conti-nuum	status (as of Nov 2011)
Low-z cluster	CL0024+1652	0.395	Hα	0.916	Suprime-Cam	NB912	z'	Kodama+'04
	CL0939+4713	0.407	Hα	0.923	Suprime-Cam	NB921	z'	Koyama+'11
	RXJ1716+6708	0.813	Hα	1.190	MOIRCS	NB1190	J	Koyama+'10
			[O II]	0.676	Suprime-Cam	NA671	R	observed
High-z cluster	XCSJ2215–1738	1.457	[O II]	0.916	Suprime-Cam	NB912, NB921	z'	Hayashi+'10,11
	4C65.22	1.516	Hα	1.651	MOIRCS	NB1657	H	observed
	Q0835+580	1.534	Hα	1.664	MOIRCS	NB1657	H	observed
	CL0332–2742	1.61	[O II]	0.973	Suprime-Cam	NB973	y	observed
	ClGJ0218.3–0510	1.62	[O II]	0.977	Suprime-Cam	NB973	y	Tadaki+'11b
Proto-cluster	PKS1138–262	2.156	Hα	2.071	MOIRCS	NB2071	K_s	Koyama+12, submitted
	4C23.56	2.483	Hα	2.286	MOIRCS	NB2288	K_s	Tanaka+'11
	USS1558–003	2.527	Hα	2.315	MOIRCS	NB2315	K_s	Hayashi+12
General field	GOODS-N	2.19	Hα	2.094	MOIRCS	NB2095	K_s	Tadaki+'11a
	(62 arcmin^2)		[O II]	1.189	MOIRCS	NB1190	J	observed
	SXDF	2.19	Hα	2.094	MOIRCS	NB2095	K	Tadaki+ in prep.
	(110 arcmin^2)		Hβ	1.551	MOIRCS	NB1550	H	not yet
			[O II]	1.189	MOIRCS	NB1190	J	not yet

Tadayuki Kodama (Subaru; PI), Masao Hayashi (NAOJ), Yusei Koyama (Durham), Ken-ichi Tadaki (Univ. of Tokyo), Ichi Tanaka (Subaru), et al.

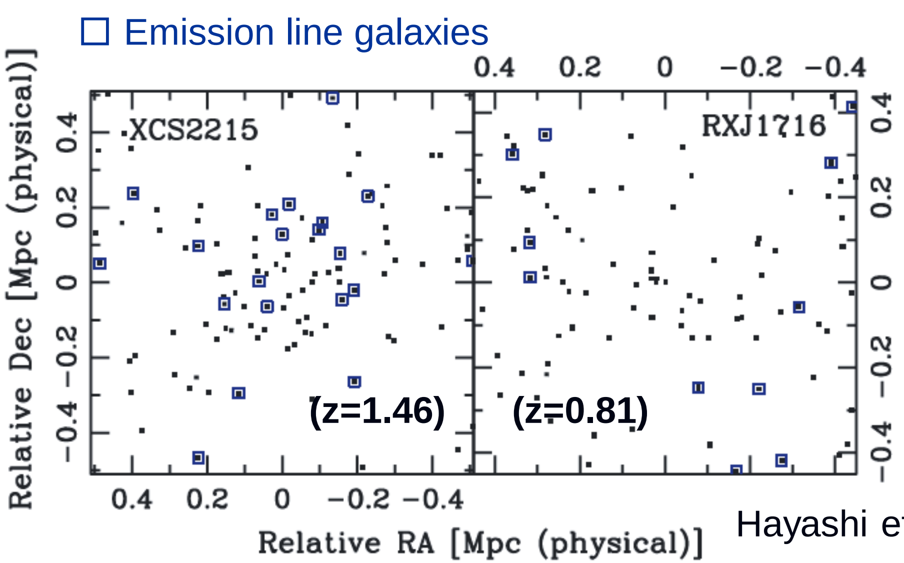
Star formation activity in high-z clusters

Reversal of SFR-density relation?



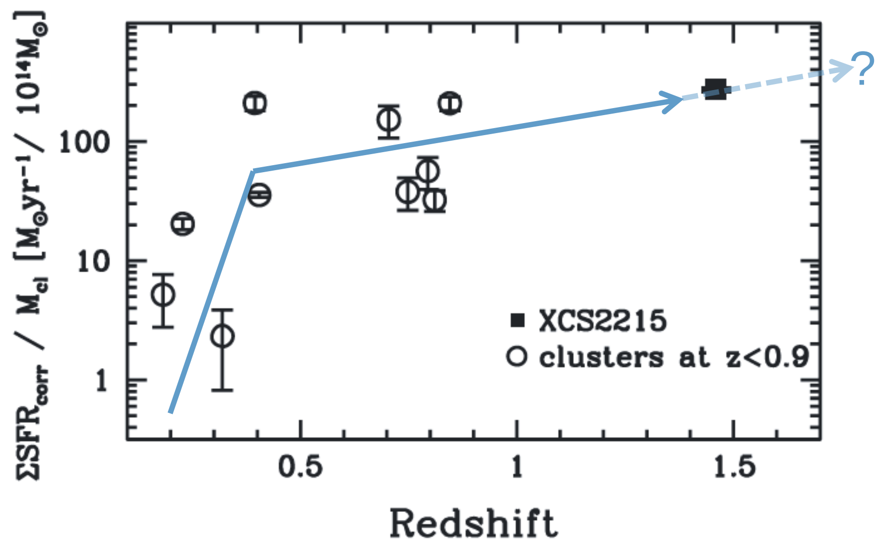
Cooper et al. (2008)

Active star formation in the cluster core



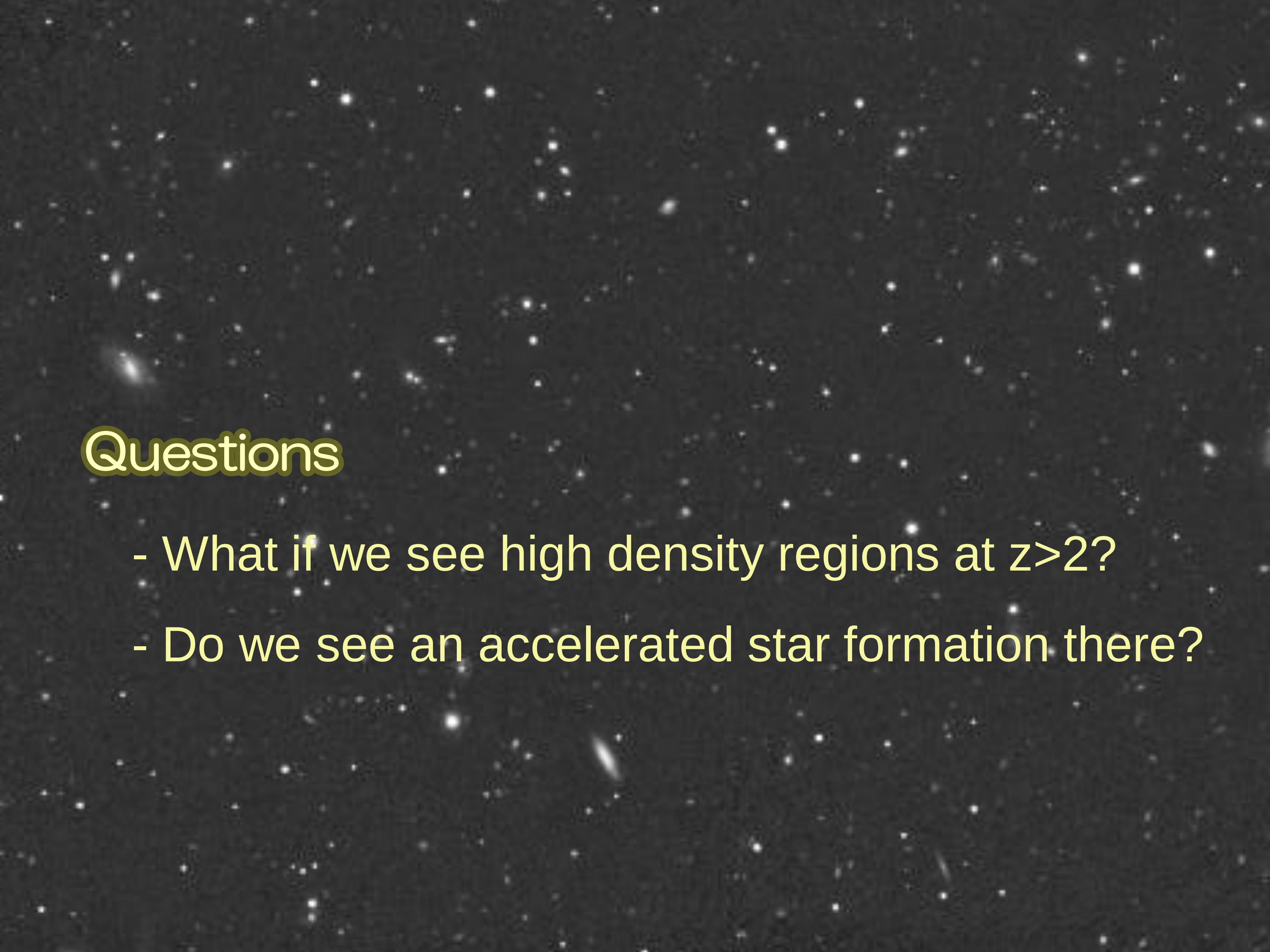
Hayashi et al. (2010)

Star formation activity of galaxy cluster



Hayashi et al. (2011)

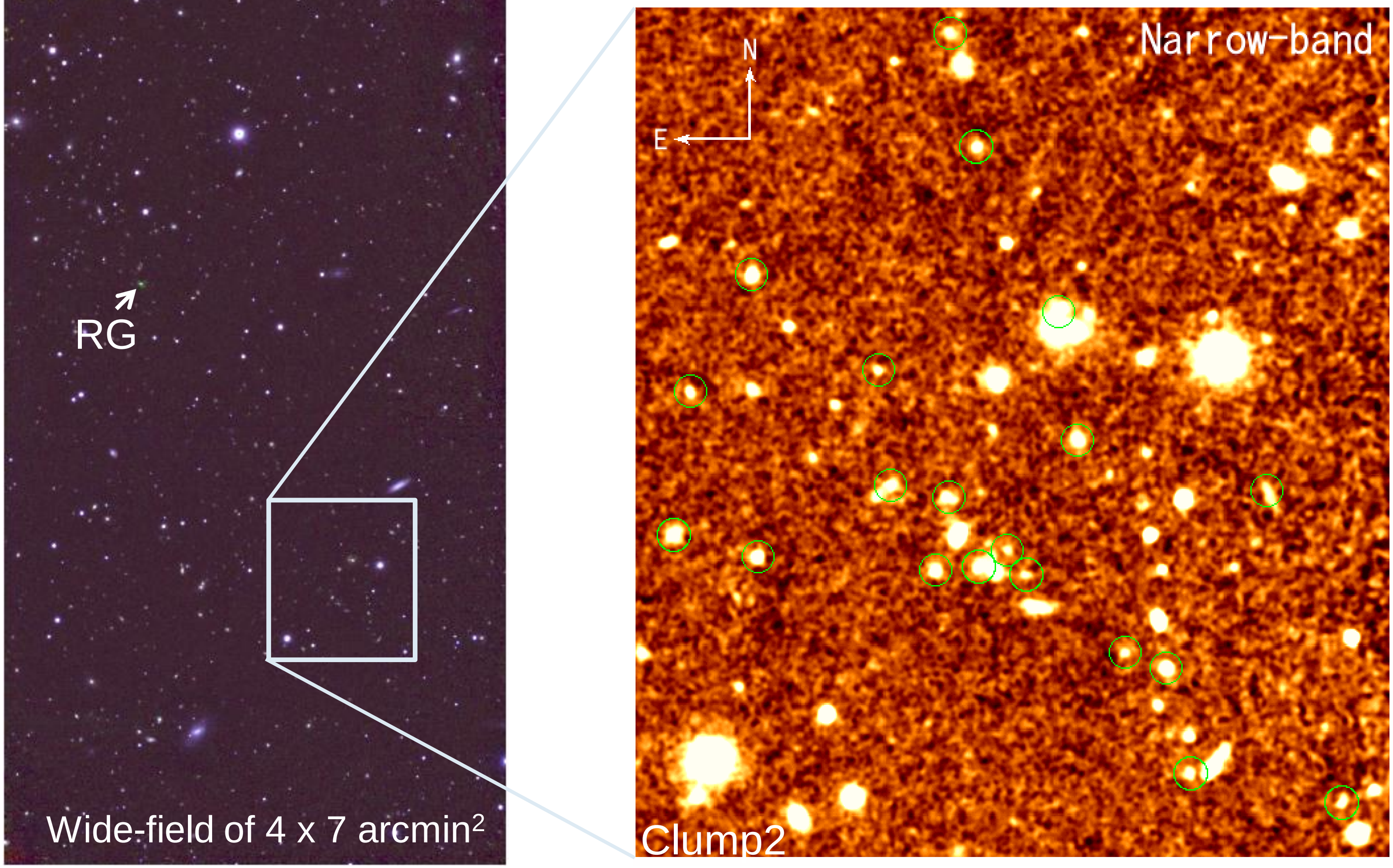
Integrated SFR per unit cluster mass as a function of redshift


Questions
- What if we see high density regions at z>2?
- Do we see an accelerated star formation there?

A proto-cluster associated to HzRG at z=2.53

- a radio galaxy, USS1558-003, at z=2.53
- known as an over-density region of Distant Red Galaxies (Kodama+2007)

Hα emission line survey with a narrow-band



Green circles show Hα emitters

Hα survey in proto-cluster at z=2.53

- **Target**
  - ✓ USS 1558-003 proto-cluster @ z=2.53 (overdensity region around a radio galaxy)
- **Data**
  - ✓ B, r’, z’ (Subaru/Suprime-Cam)
  - ✓ J, H, Ks, NB2315 (Subaru/MOIRCS)
    => aim to detect **Hα emissions from galaxies at z~2.53**
    also survey galaxies with red color in J-Ks
  - ✓ FoV ~ 4 x 7 arcmin^2
  - ✓ 5 σ limiting mag. in AB system:
    23.65 (Ks), 23.01 (NB2315)

Filter response function

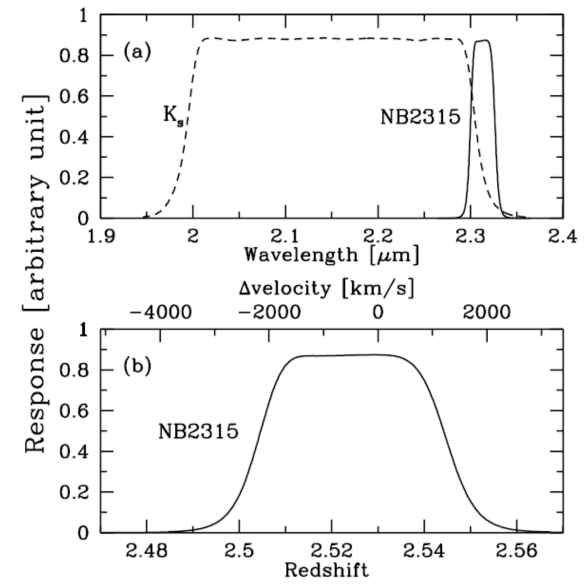


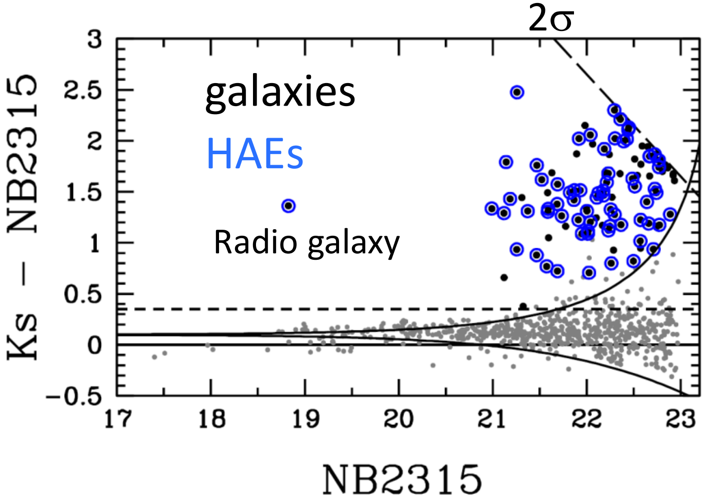
Table 1
Summary of the Optical and Near-Infrared Images

Filter	FoV[a]	Integration Time (minutes)	Limiting Mag[b] (5σ)	Seeing (arcsec)	Instrument	Observation Date
B	F1+F2	80	27.16	0.70	Suprime-Cam	2011 Apr 29
r'	F1+F2	90	26.87	0.63	Suprime-Cam	2011 Apr 29
z'	F1+F2	55	25.75	0.66	Suprime-Cam	2011 Apr 29
J	F2	75	24.18	0.42	MOIRCS	2011 Mar 11
H	F2	45	23.51	0.47	MOIRCS	2011 Mar 11
K_s	F1+F2	57	23.65	0.66	MOIRCS	2011 Mar 11, 2011 Apr 17
		(F1: 32, F2: 25)	(F1: 23.46, F2: 23.17)	(F1: 0.66, F2: 0.40)		
NB2315	F1+F2	203	23.01	0.53	MOIRCS	2011 Mar 11, 2011 Apr 17
		(F1: 133, F2: 70)	(F1: 22.74, F2: 22.35)	(F1: 0.53, F2: 0.36)		

Notes. Finally, the FWHMs of PSF in all the images are matched to 0.″66, except for the B-band image which has an FWHM of 0.″70.
[a] The pointings of F1 and F2 for K_s and NB2315 images have an offset of 1′ to the west and 1′ to the south.
[b] The limiting magnitudes are measured with a 1.″5 diameter aperture.

Selection of Hα emitters at z~2.53

NB excess galaxies

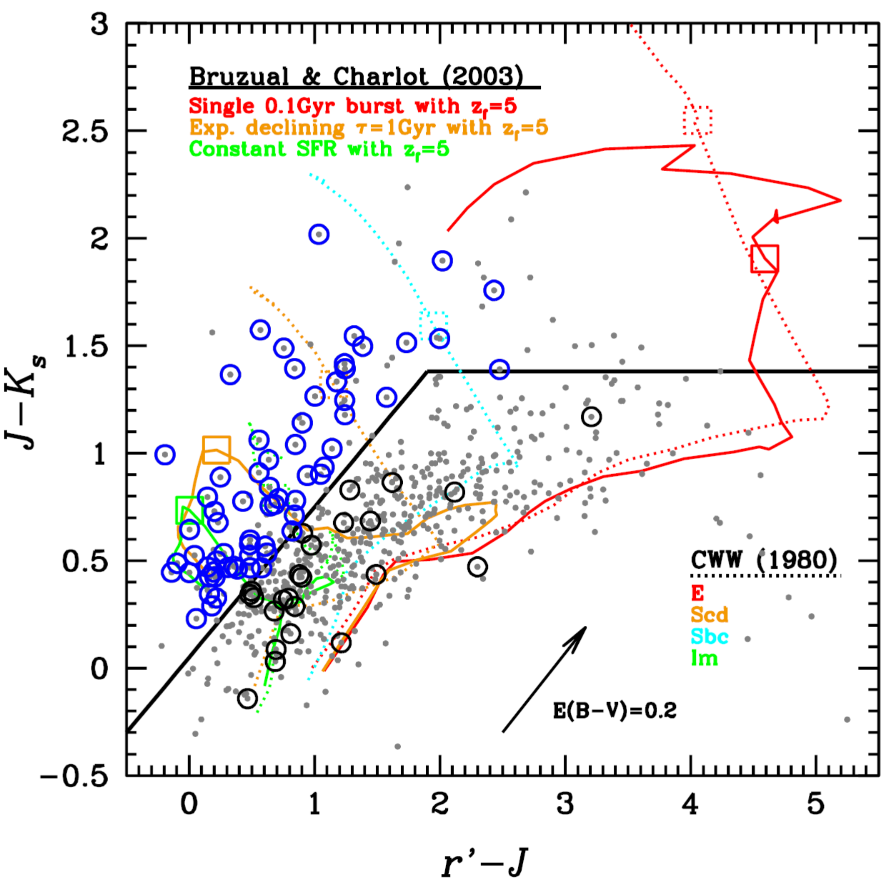


[selection criteria]
color term = 0.1
more than 3sigma color excess in Ks-NB
Ks-NB>0.35

How to select Hα emitters

- r'-J < 1.9   J-Ks > 0.7(r'-J)+0.05
- r'-J > 1.9   J-Ks > 1.38

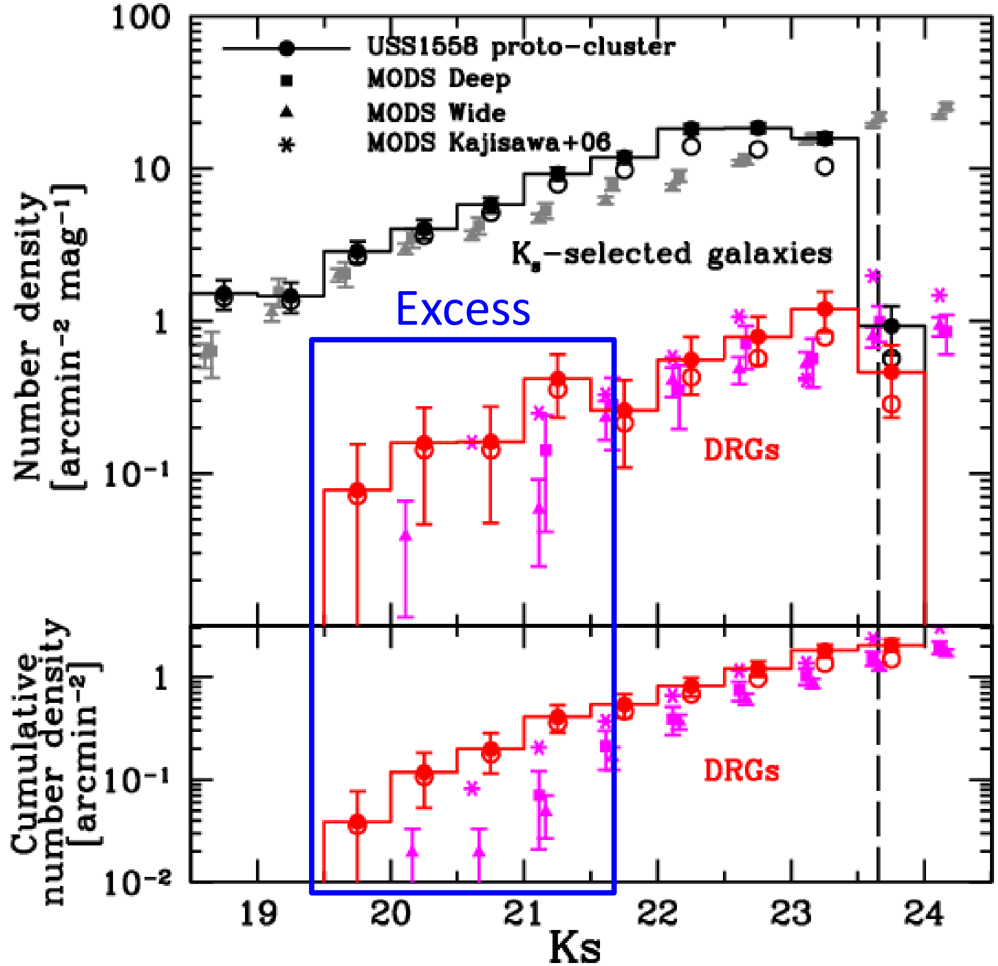
Identification of galaxies at z~2.5



68 Hα emitters at z=2.5

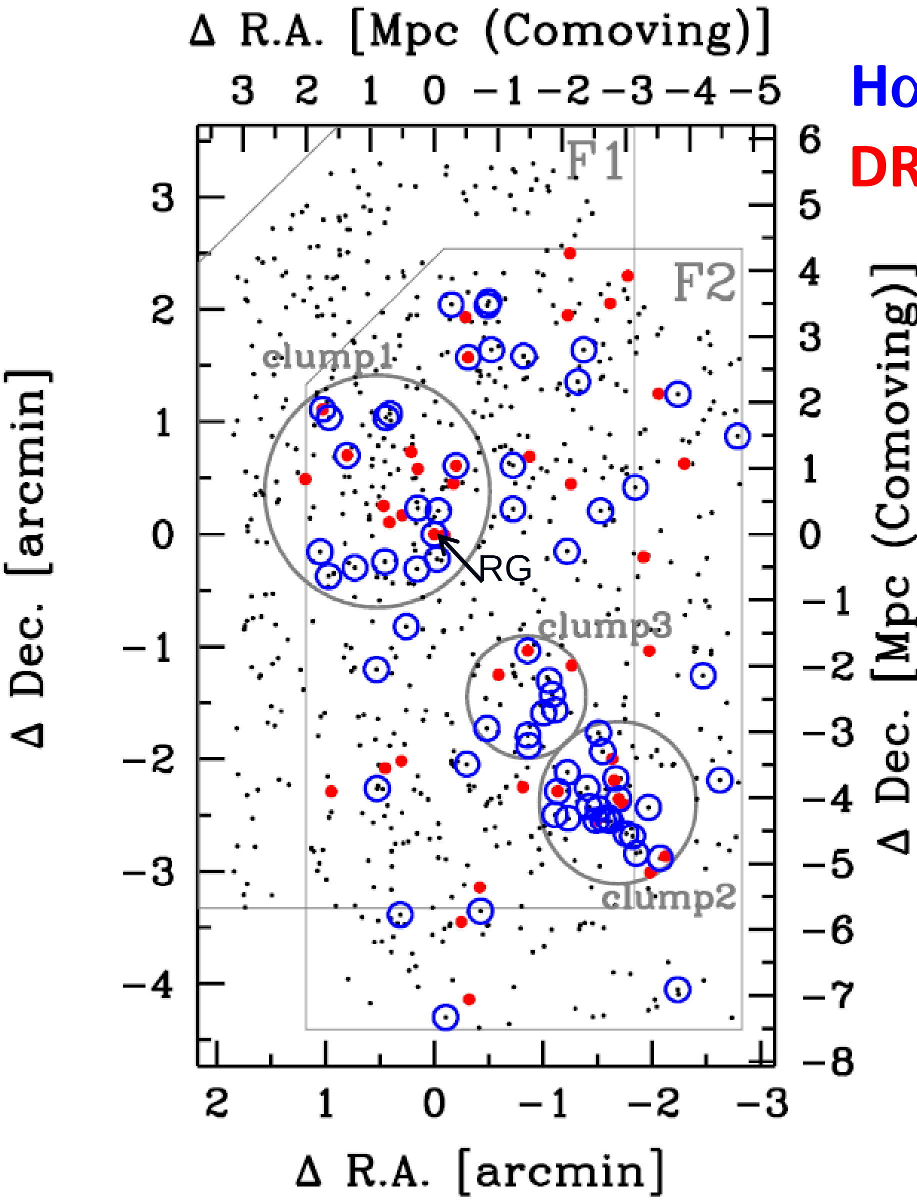
Selection of Distant Red Galaxies

Distant Red Galaxies (DRGs): galaxies with red color of **(J-Ks)vega>2.3**



This enables us to select passively evolving galaxies or dusty starburst galaxies, e.g. almost all populations belonging to the proto-cluster

Map of HAEs and DRGs



Hα emitters

DRGs

Discovery of three clumps of HAEs and DRGs around a radio galaxy at z=2.53.

Especially, the clump-2 is the most outstanding region where these populations are strongly clustered.

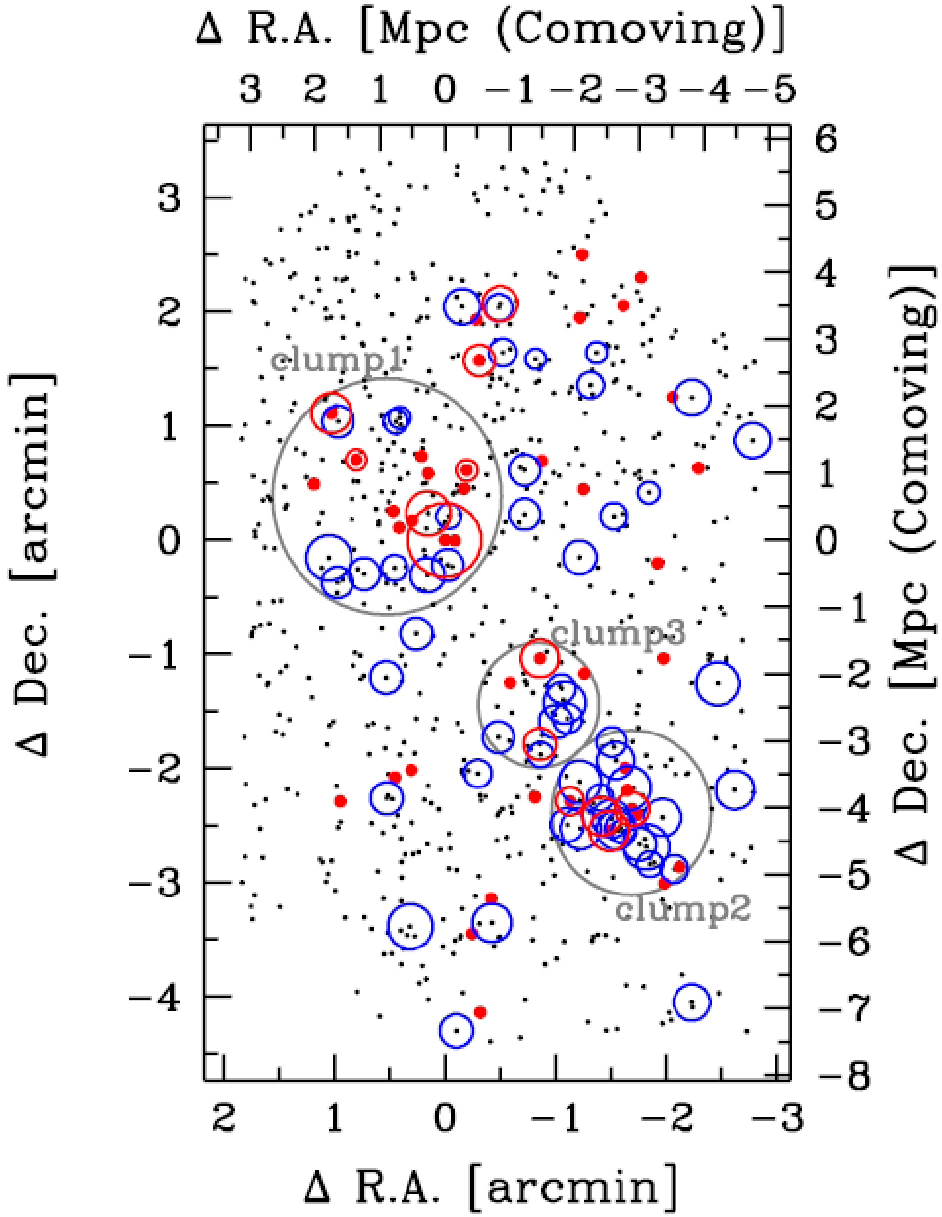
Table 2

The Number and Number Density of HAEs and DRGs

Region	Area ($arcmin^2$)	Number HAE	Number DRG	Density ($arcmin^{-2}$) HAE	Density ($arcmin^{-2}$) DRG
Clump 1	3.36	15	12	4.46 ± 1.15	3.57 ± 1.03
Clump 2	1.64	20	8	12.2 ± 2.73	4.88 ± 1.72
Clump 3	0.94	8	3	8.51 ± 3.01	3.19 ± 1.84
All clumps	5.94	43	23	7.24 ± 1.10	3.87 ± 0.81
Others	21.16	25	19	1.18 ± 0.24	0.90 ± 0.21
Entire field	27.10	68	42	2.51 ± 0.30	1.55 ± 0.24

Notes. Errors in number density are estimated based on Poisson statistics.

Red HAEs inhabiting high density regions



Red open circles shows HAEs with red colors of (J-Ks)vega > 2.3

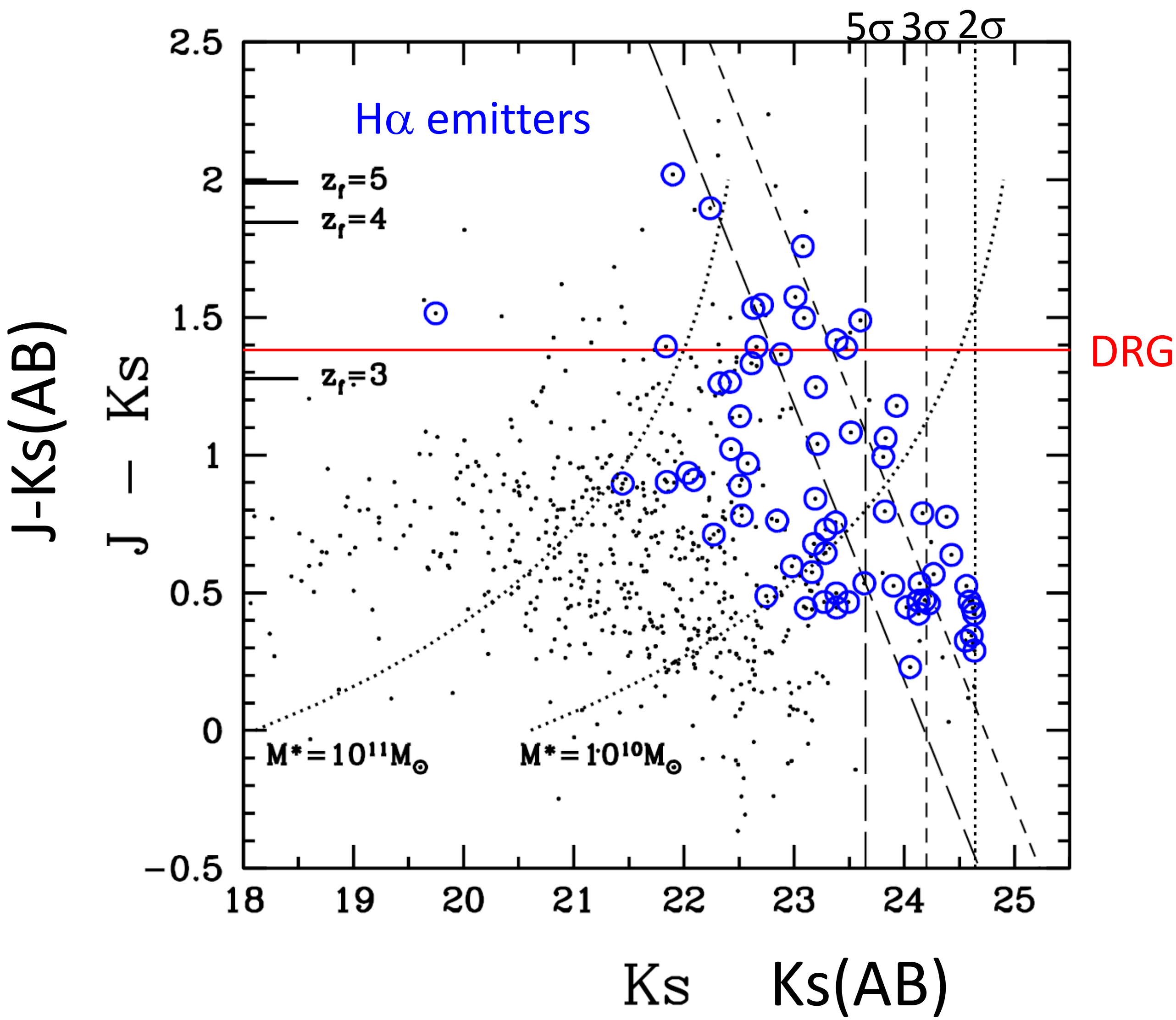
HAEs with higher SFR are shown by larger open circles

Red emission line galaxies tend to be located in clumps, which is different situation to that in lower-z clusters

Hayashi et al., 2012, ApJ, 757, 15 (arXiv:1207.2614)

Color-magnitude diagram

J(Vega)=J(AB)-0.941, H(Vega)=H(AB)-1.38, Ks(Vega)=Ks(AB)-1.86

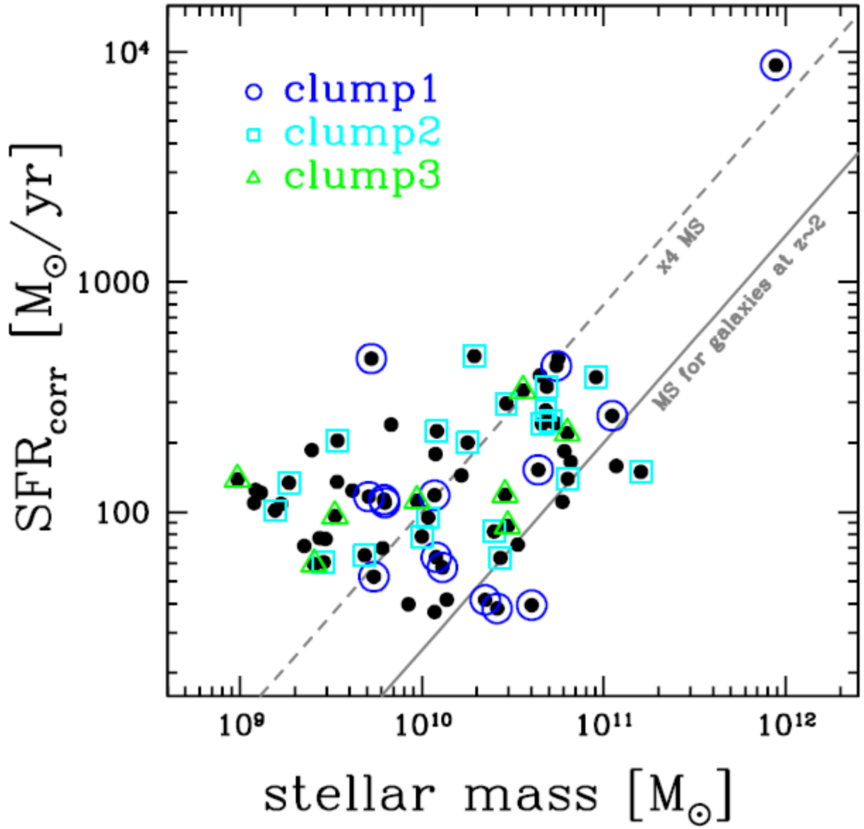


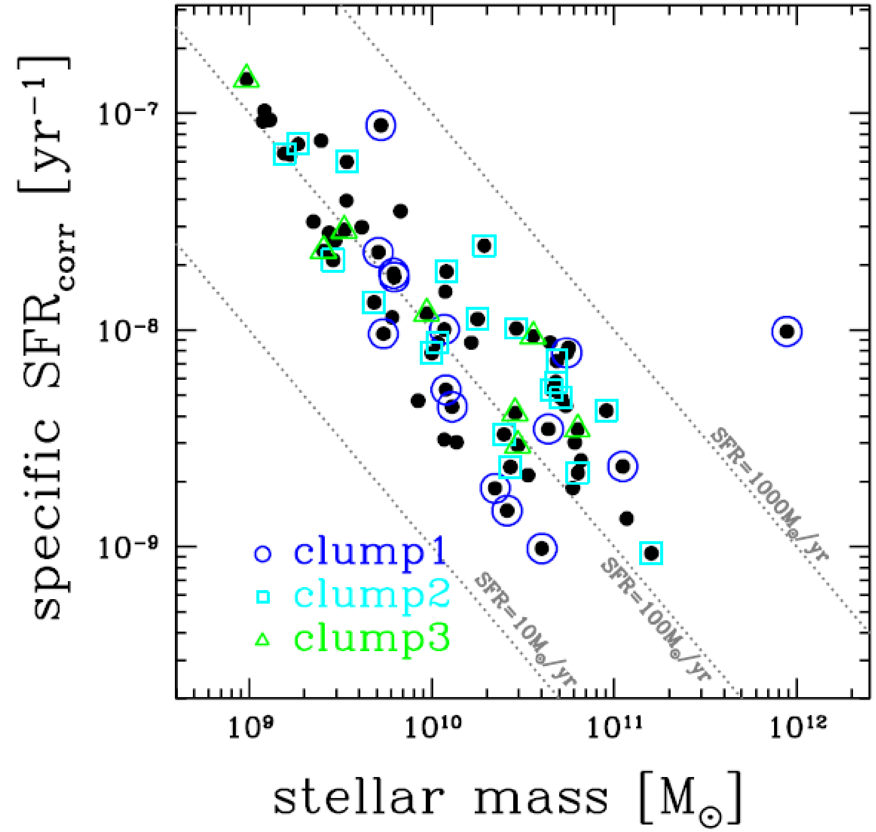
Star formation rate for HAEs

SFR is derived from Ha luminosity using the relation given in Kennicutt (1998)

Dust extinction, A(Ha): Garn et al. (2010), Contribution of [NII], NII/Ha: Sobral et al. (2011)

Specific SFR = SFR / stellar mass

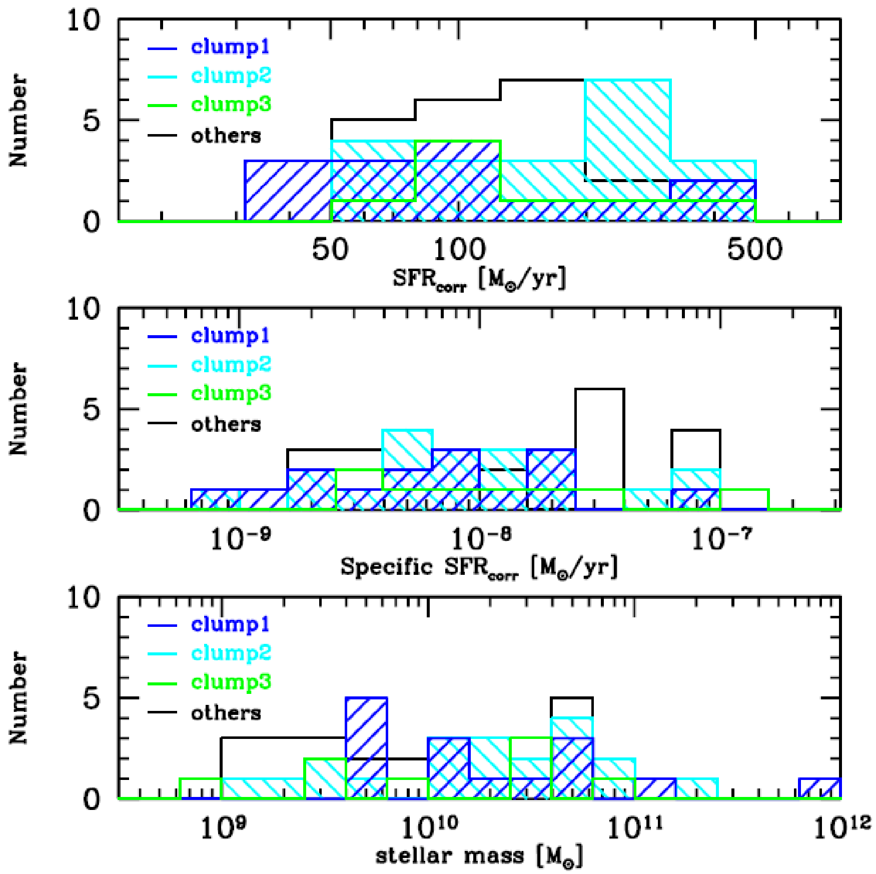




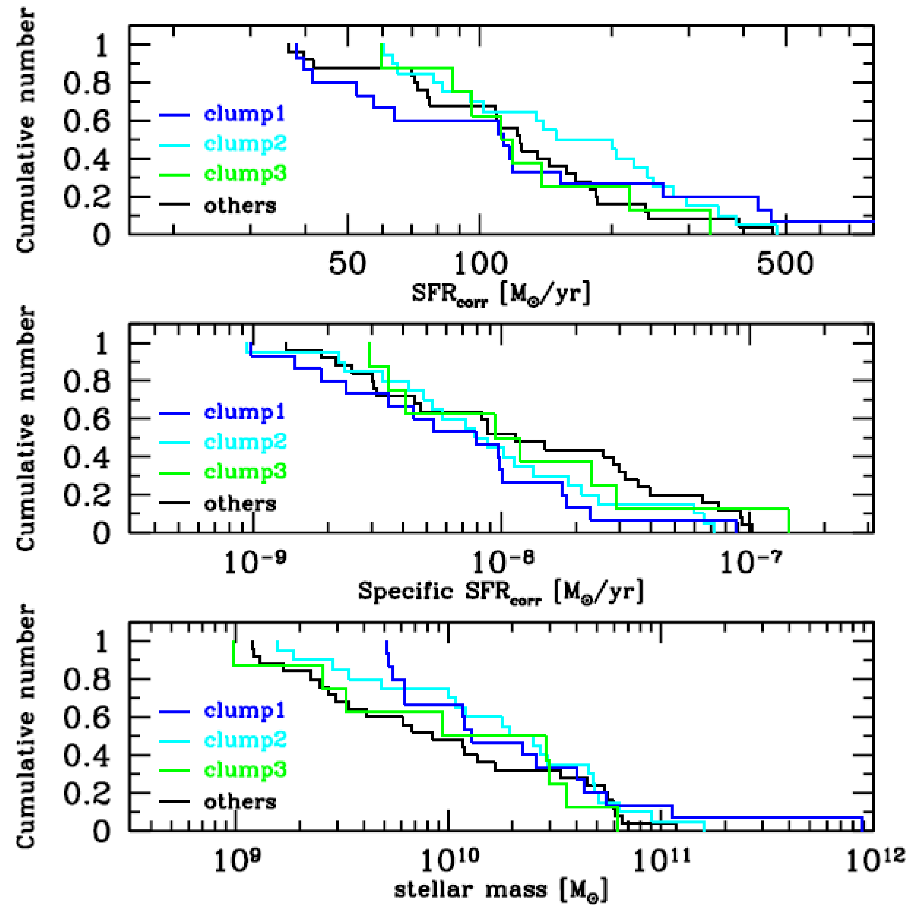
There is no strong correlation between SFR and stellar mass, but specific SFR is decreasing with larger stellar mass.

Environment dependence

Histogram of SFR, sSFR and Mstar



Cumulative number of SFR, sSFR and Mstar



There is no strong dependence of SFR, sSFR and stellar mass on environment.

Summary

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A star-bursting proto-cluster is discovered by Hα emission survey around a USS1558-003 radio galaxy at z=2.53 with MOIRCS/Subaru

- Clumps of HAEs and DRGs, which are thought to marge later and to evolve into a massive galaxy cluster
- Red HAEs, which tend to be located in clumps rather than outskirts
- Faint end of red sequence occupied by red HAEs
- No significant dependence of SF activity on environment

Future works

- Follow-up NIR spectroscopy of Hα emitters
  - ✓ Confirmation of accurate redshift
  - ✓ Metal abundance and AGN activity
- Follow-up observation with ALMA
  - ✓ Gas mass and dusty SFR