第4回 銀河進化研究会＠大阪大学 2017.06.07-09

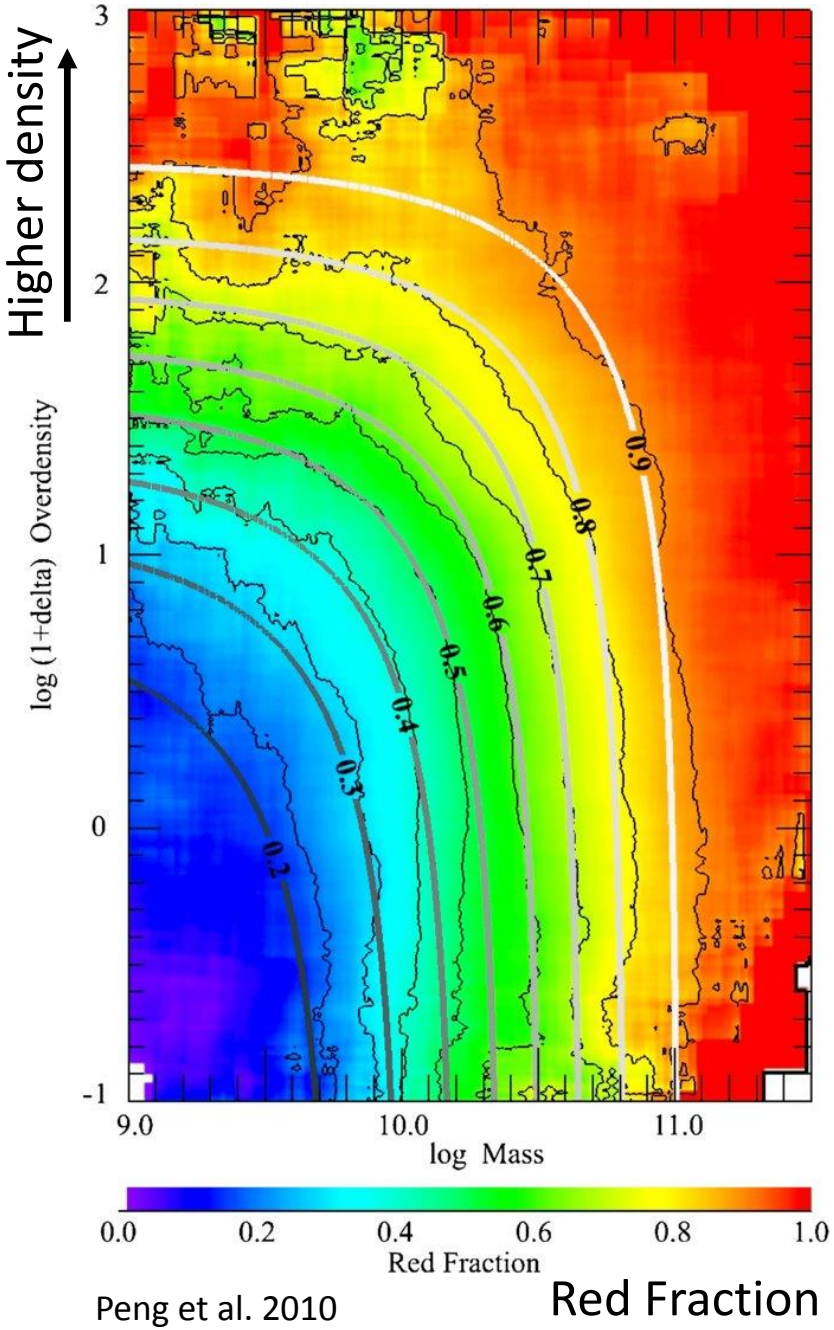
Evolutionary phases of gas-rich galaxies in a galaxy cluster at z=1.46

赤方偏移1.46の銀河団におけるガスリッチ銀河の進化段階

Hayashi et al., 2017, ApJL, 841, L21

Masao Hayashi (NAOJ)
林 将央 (国立天文台)

児玉忠恭(東北大), 河野孝太郎, 山口裕貴(東京大),
但木謙一(国立天文台), 廿日出文洋(東京大),
小山佑世(国立天文台), 嶋川里澄(Lick Observatory),
田村陽一(名古屋大), 鈴木智子(国立天文台)



Peng et al. 2010

Quenching of star formation in galaxies

High density regions such as galaxy clusters must play a vital role in quenching the star formation activity.

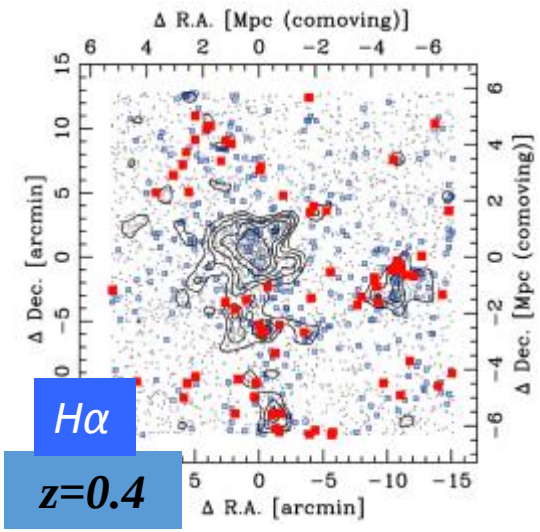
Possible mechanisms

- Major or minor mergers
- Ram-pressure stripping
- Strangulation
- … … …

When and how does cluster galaxies quench the star formation activity?

Star-formation in high-z galaxy clusters

MAHALO-Subaru

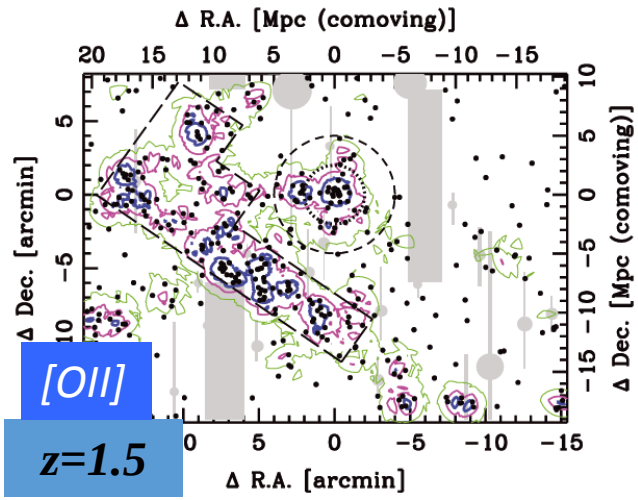


Hα

z=0.4

CL0939 *(Koyama+11)*

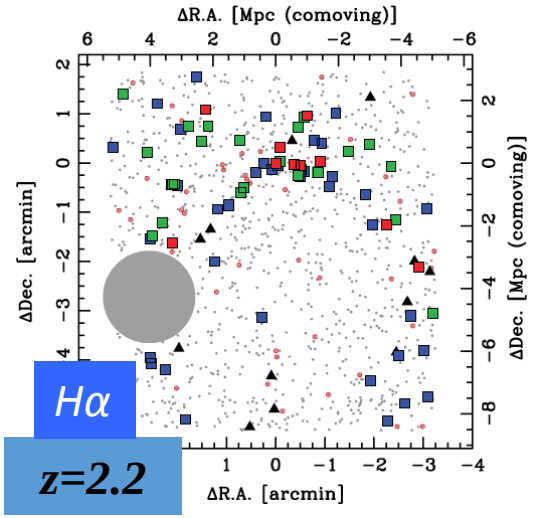
(Hayashi+10, 11)



[OII]

z=1.5

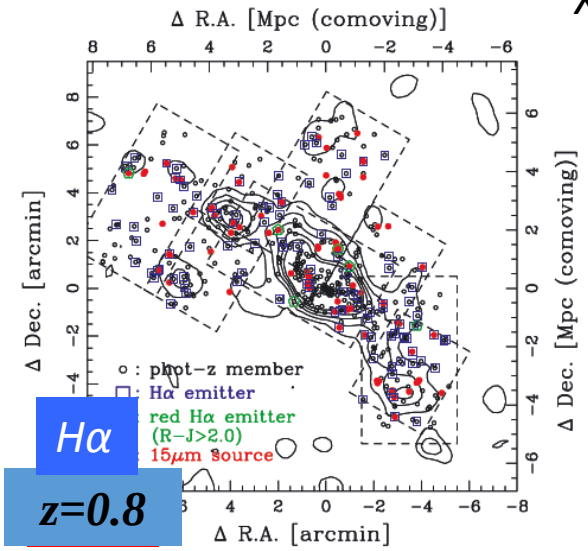
XCSJ2215 *(Tadaki+12)*



Hα

z=2.2

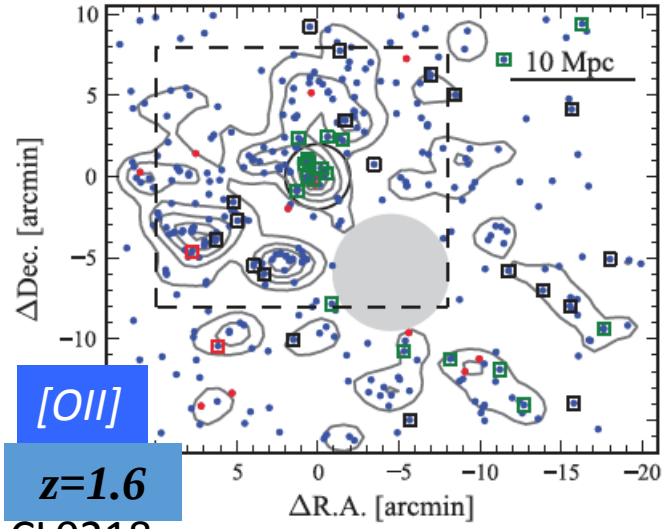
PKS1138 *(Koyama+13)*



Hα

z=0.8

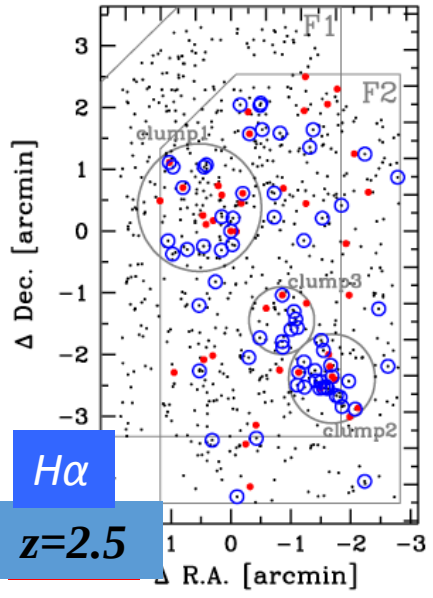
RXJ1716 *(Koyama+10)*



[OII]

z=1.6

CL0218



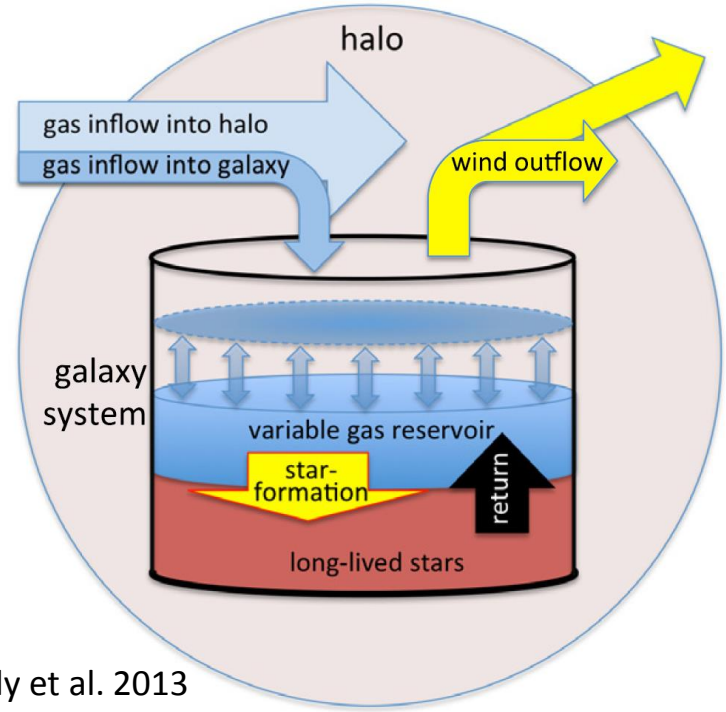
Hα

z=2.5

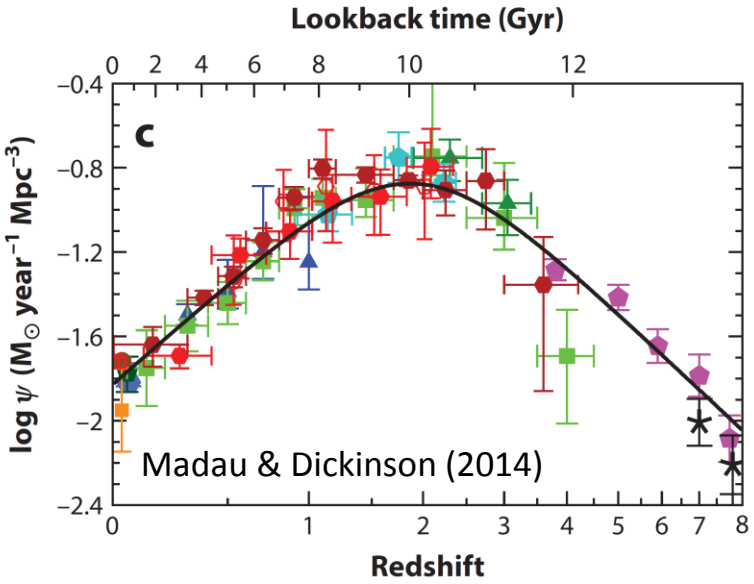
USS1558 *(Hayashi+12)*

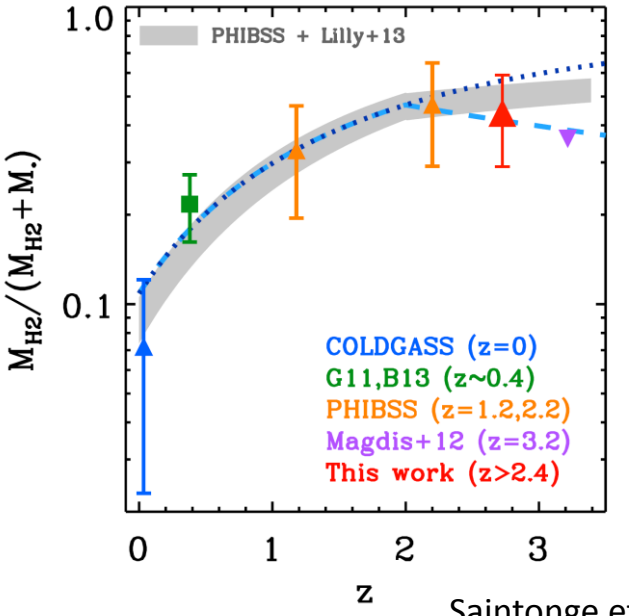
Role of gas in galaxy evolution

Gas-regulated model



Lilly et al. 2013





Saintonge et al. 2013

- Gas amount ?
- Efficiency to convert gas to stars ?

GRACIAS-ALMA

Galaxy Resolved Anatomy with CO Interferometry
And Submm observations with ALMA

Mapping/resolving molecular gas and dust contents of high-z SF galaxies

CO line @ Band-3 (~100GHz) SFR~50$M_\odot$/yr (2.7hrs, 5σ) @1<z<3

Dust continuum@ Band-6-9 (450 μm–1.1 mm) SFR~15$M_\odot$/yr (50min, 5σ)

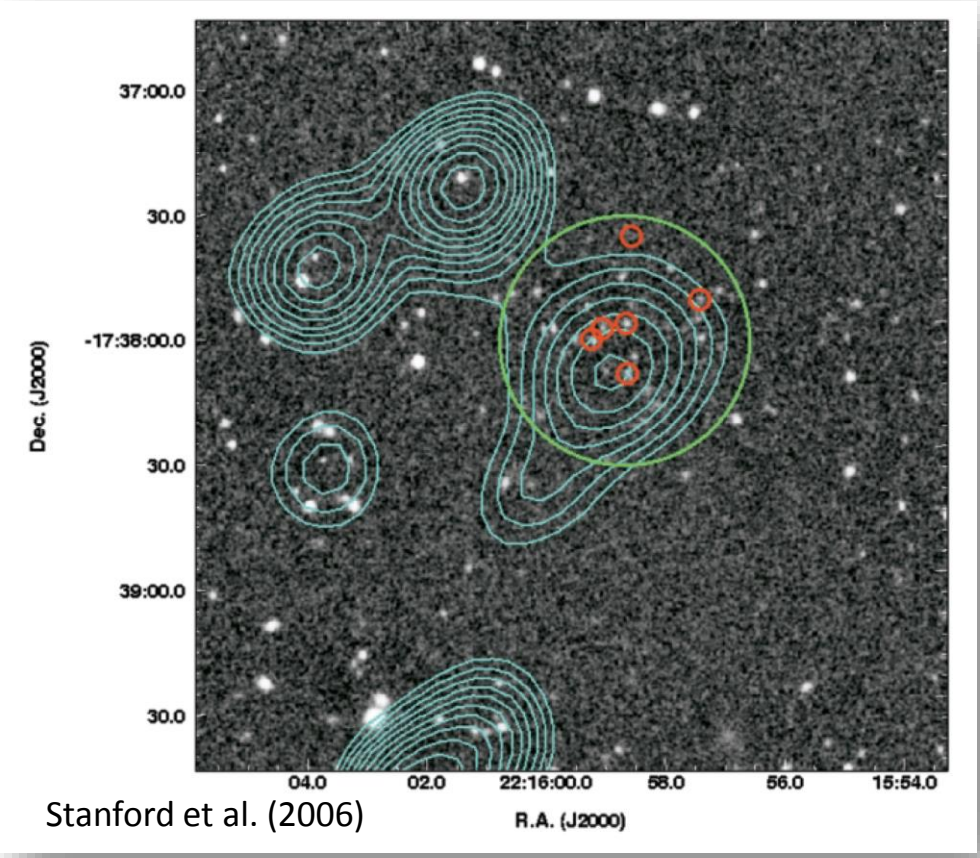
Spatial resolution: 0.1-0.2" (~1kpc)

		Mahalo-Subaru				Gracias-ALMA		ALMA status	
target	z	line	μm	NB-filter	Camera	Continuum	Line@GHz(band)	proposals	results
2215–1738	1.46	[OII]	0.916	NB912	S-Cam	B7,9	CO(2-1)@94 (B3)	Hayashi+	1st
0332–2742	1.61	[OII]	0.973	NB973	S-Cam	B7,9	CO(2-1)@89 (B3)	not yet	
0218.3–0510	1.62	[OII]	0.977	NB973	S-Cam	B7,9	CO(2-1)@88 (B3)	not yet	
1138–262	2.16	Hα	2.071	NB2071	MCS	B6,7,9	CO(3-2)@110 (B3)	Koyama+	1st
4C23.56	2.48	Hα	2.286	NB2288	MCS	B6,7,9	CO(3-2)@99 (B3)	Suzuki+	1st
1558–003	2.53	Hα	2.315	NB2315	MCS	B6,7,9	CO(3-2)@98 (B3)	Kodama+	2nd
SXDF	2.19	Hα	2.094	NB2095	MCS	B6,7,9	CO(3-2)@108 (B3)	Tadaki+	1st
-CANDELS	2.53	Hα	2.315	NB2315	MCS	B6,7,9	CO(3-2)@98 (B3)	Tadaki+	1st

We can spatially resolve dusty star formation and gas distribution within galaxies.
f(gas) and SFE(=SFR/M_{gas}) are essential quantities to characterize the mode of SF.
Relations between red clumps ~ dusty starbursts ~ bulge formation ~ environment

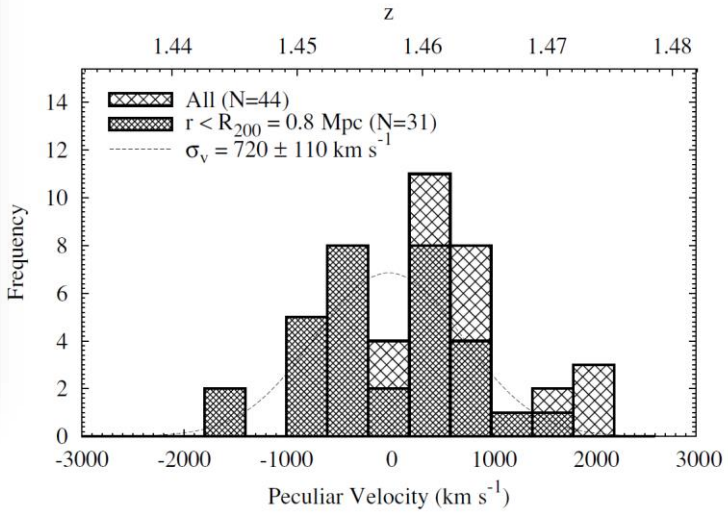
From Kodama-san's slide

Galaxy cluster: XMMXCS J2215.9-1738



Stanford et al. (2006)

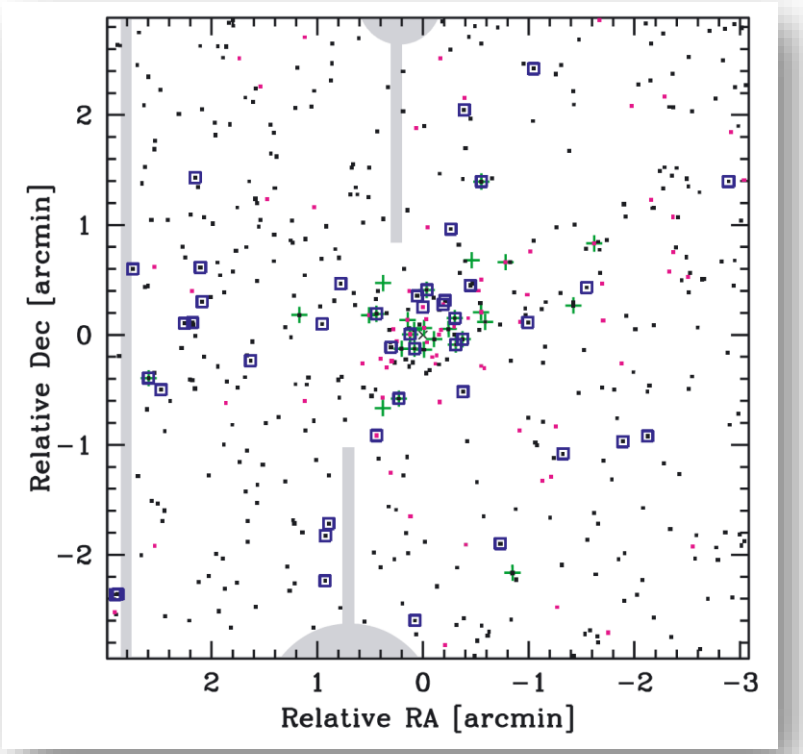
- z = 1.457
- Extended X-ray emission
- R_{200} = 0.8 Mpc
- σ_v = 720 +/- 110 km/s
- Mcl = 2.8 x 10^{14} Msun



Hilton et al. (2010)

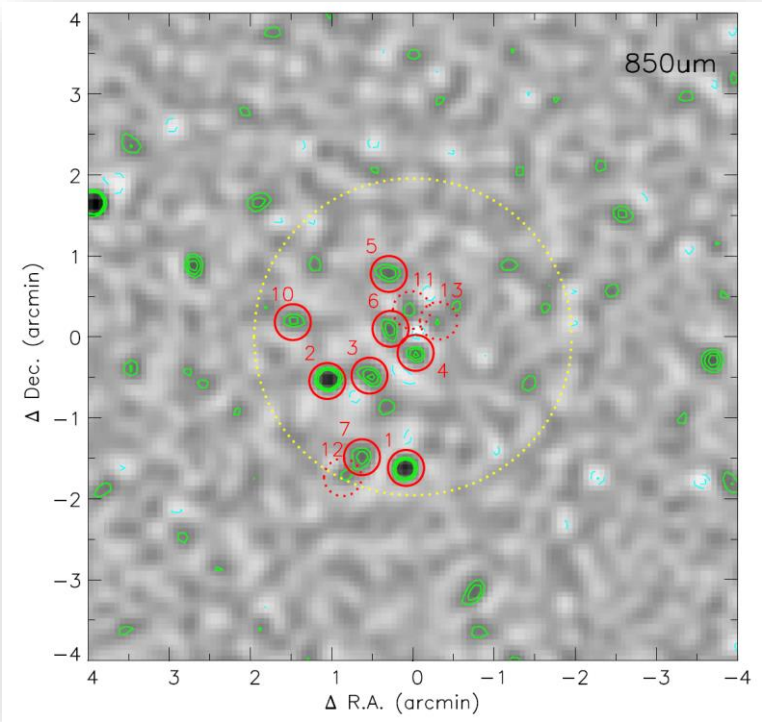
Active star formation in the central region

[OII] emission line galaxies detected by Subaru/Suprime-Cam narrowband imaging



Hayashi et al. (2010, 2014)

850um sources detected by JCMT/SCUBA-2 imaging



Ma et al. (2015)

Several 24um sources are also detected by Spitzer/MIPS imaging (Hilton et al. 2010)

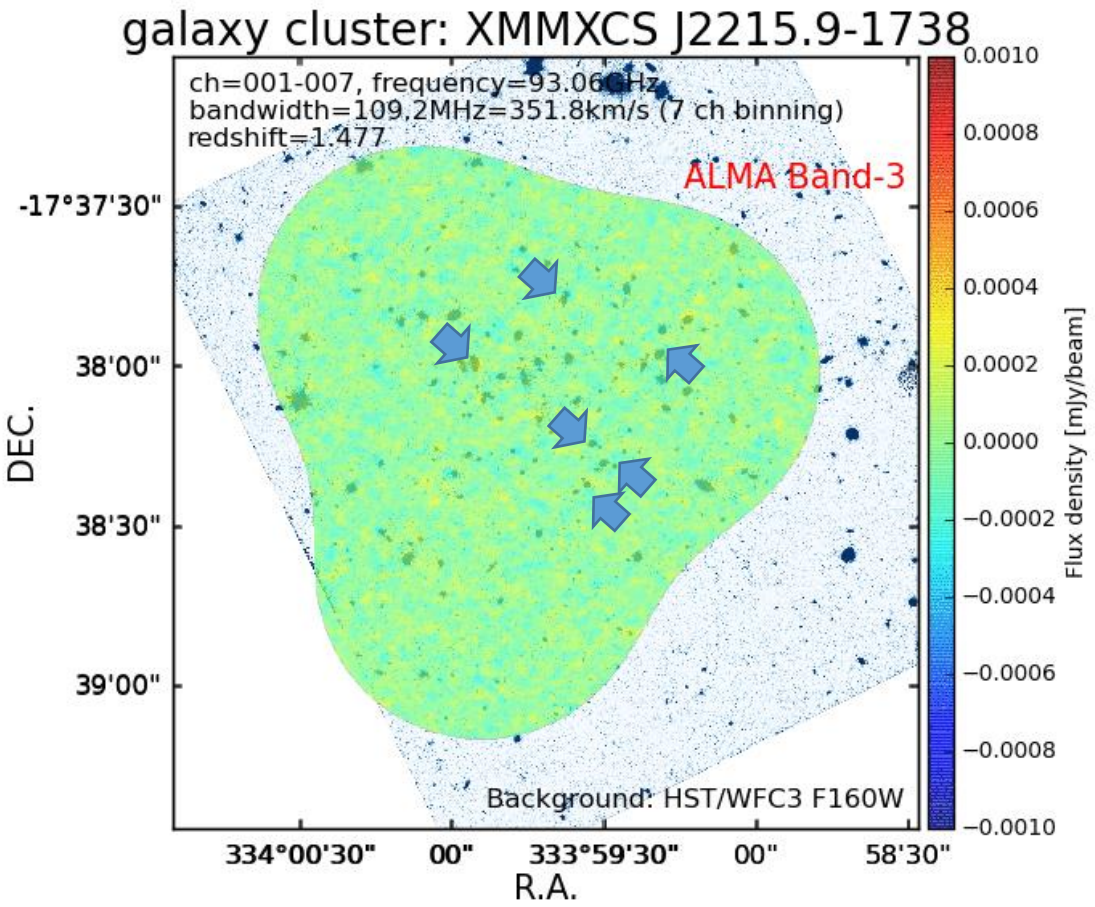
ALMA observations

Band-3: 93-95 GHz

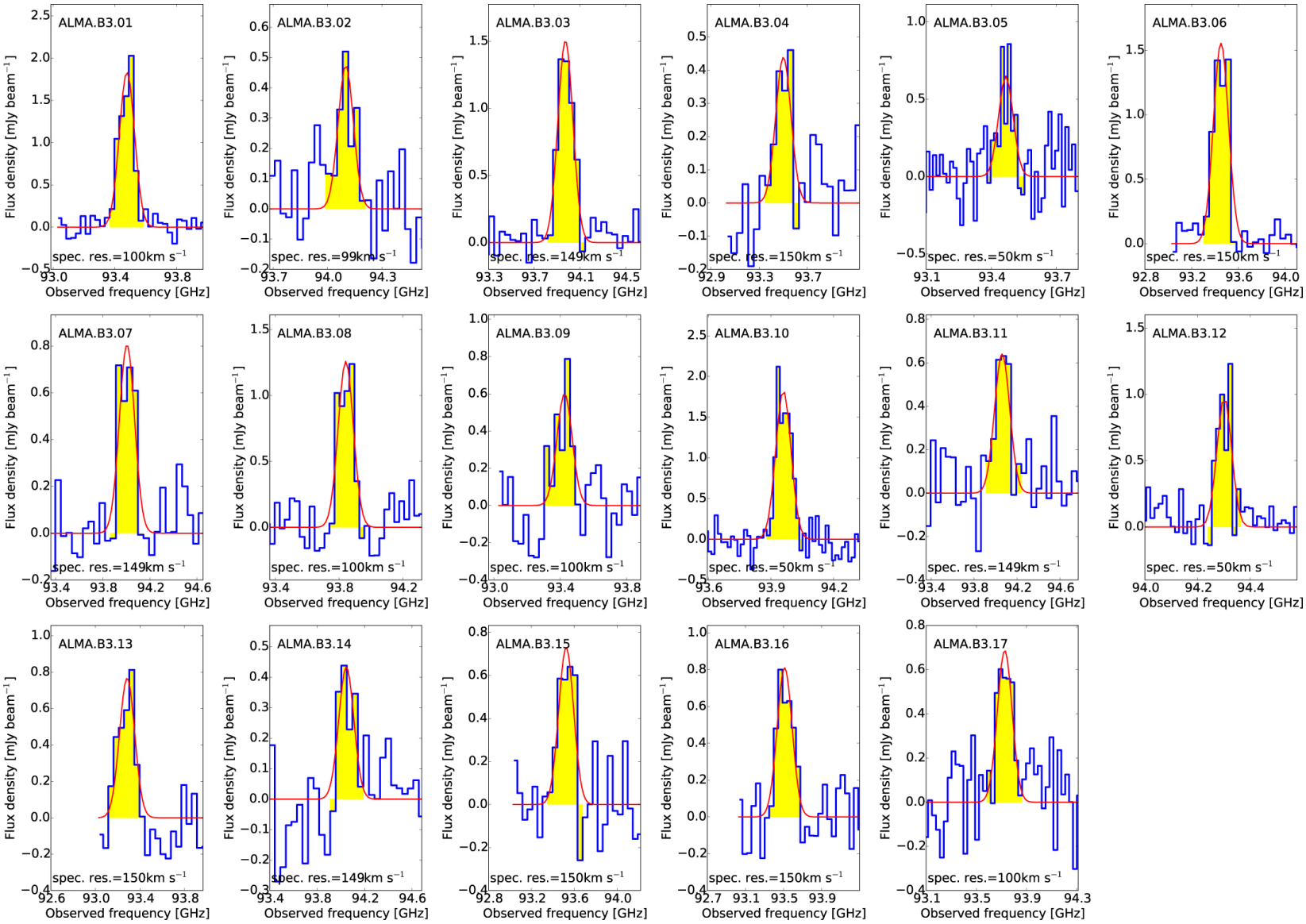
CO(2-1) emission line from galaxies at z=1.430-1.478

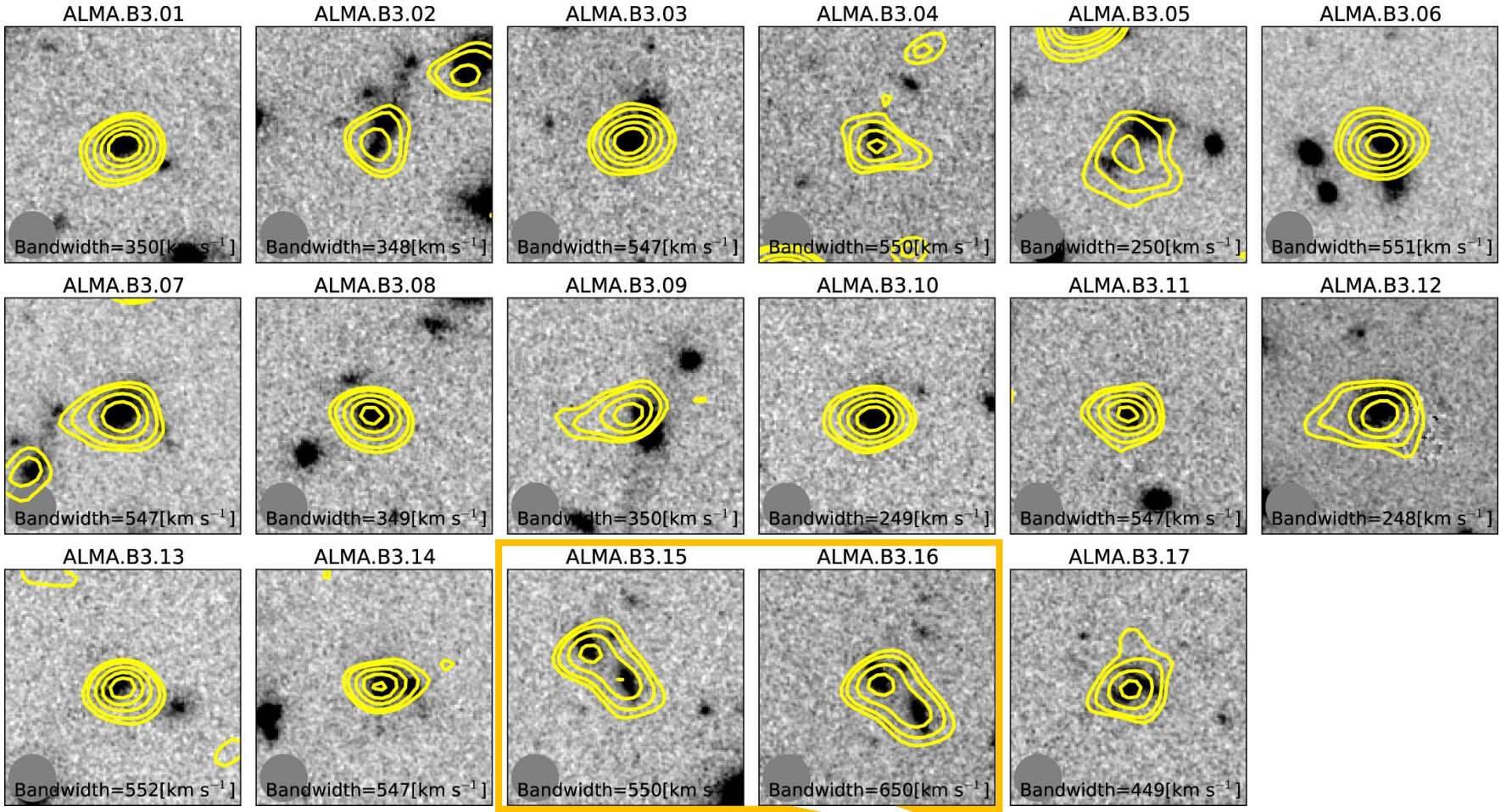
- Cycle 3
- May 2016

- 3 pointings (2.33 arcmin^2)
- 1.04 hour integration per each pointing



Detection of CO(2-1) emission lines from 17 cluster member galaxies





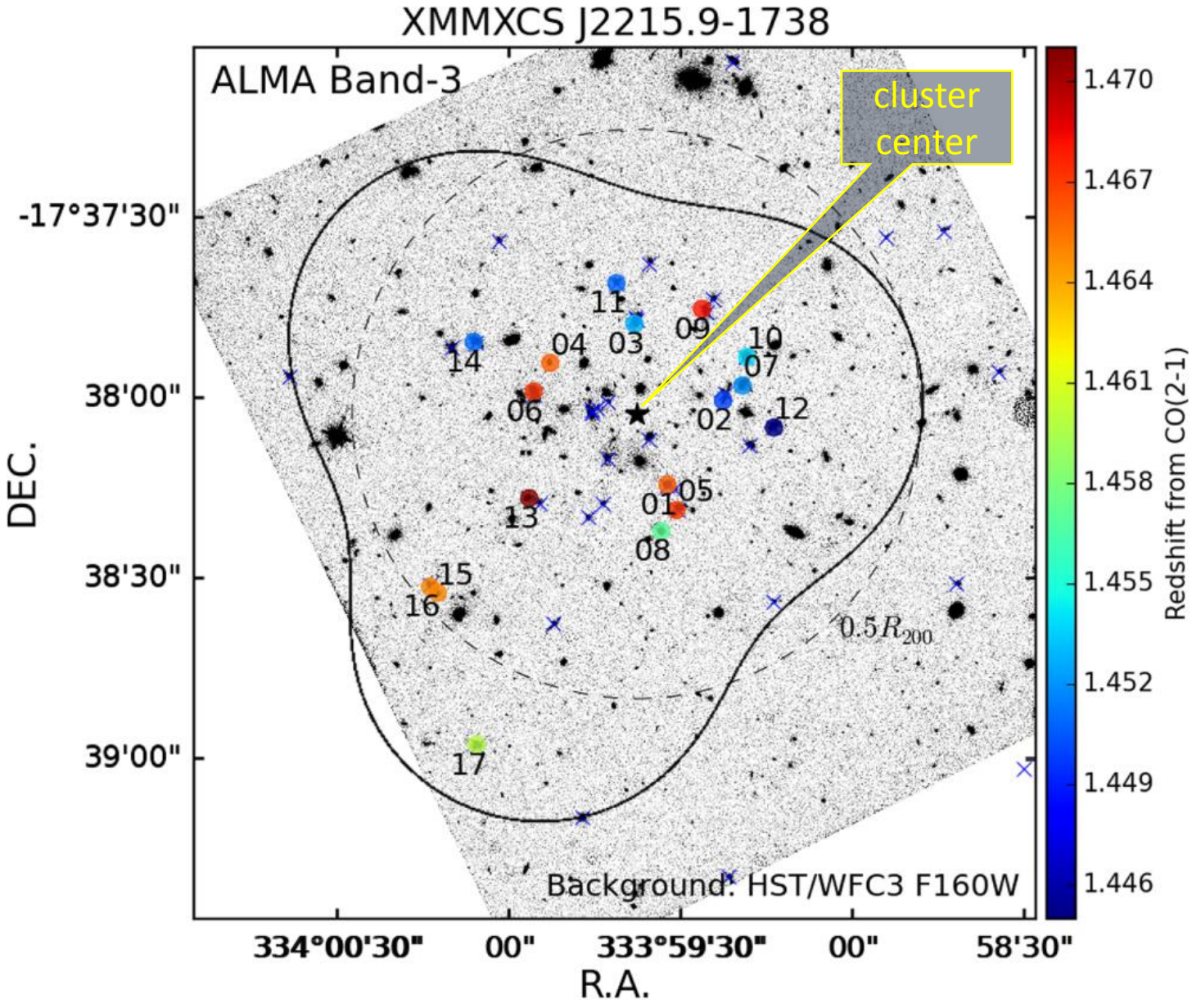
Intensity map of CO(2-1) emission lines

A pair of two galaxies

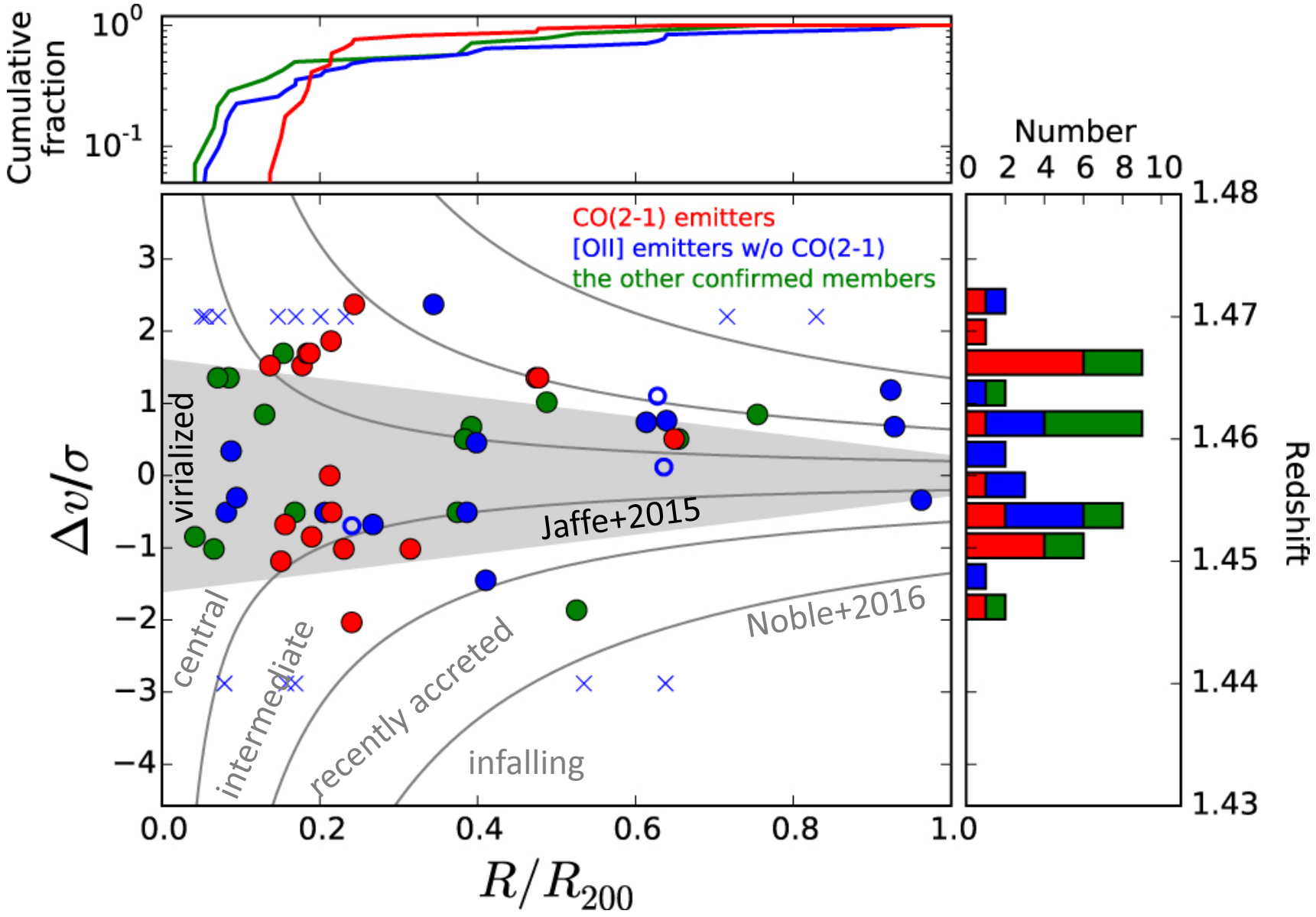
All of the 17 CO(2-1) emitters have optical-NIR counterparts

- ✓ 5 galaxies are sBzKs
- ✓ 11 galaxies are [OII] emitters
  - 6 galaxies have spec-z
  - 5 galaxies have redshifts from NB912/NB921

Spatial distribution of galaxies with CO(2-1) emission line detected



Phase space diagram



Implications for the evolution of cluster galaxies

- ram pressure stripping
- strangulation

  Stop feeding the fuel to the infalling galaxies

Assumption:

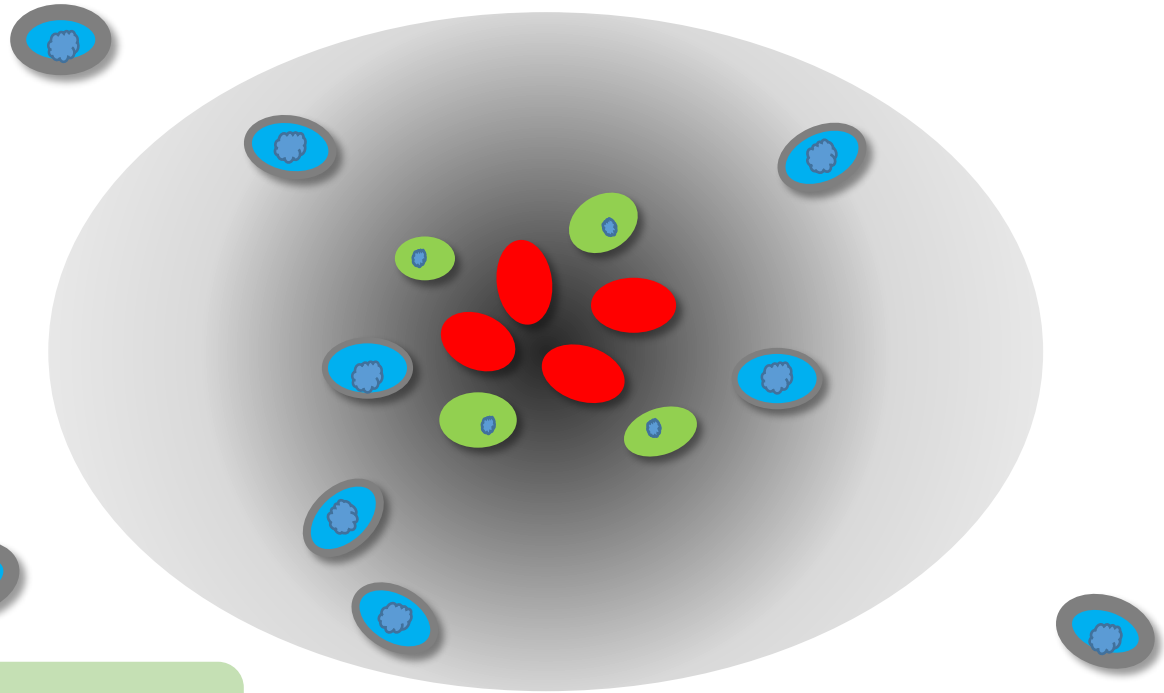
L'CO(2-1)/L'CO(1-0)=1

α_{CO} = 4.36

M_{H2} = 2-9 x 10^{10} Msun

SFR([OII]) ~ 100 Msun / yr

Depletion time ~ 10^{9} yr



- Star formation

  Exhaust the fuel for forming new stars

Hayashi et al., 2017, ApJL, 841, L21

Summary

- XMMXCS J2215.9-1738 galaxy cluster at z=1.457
- ALMA cycle-3 observations in Band 3
- 17 CO(2-1) emission lines from the member galaxies
- Phase space diagram
  - ✓ CO emitters disappear from the very center of the cluster
  - ✓ The gas-rich galaxies enter into the cluster more recently than gas-poor SF galaxies or passive galaxies