

High star formation activity in the central region of a distant cluster at $z=1.46$

Hayashi et al., 2010, MNRAS, in press
(arXiv:0911.2530)

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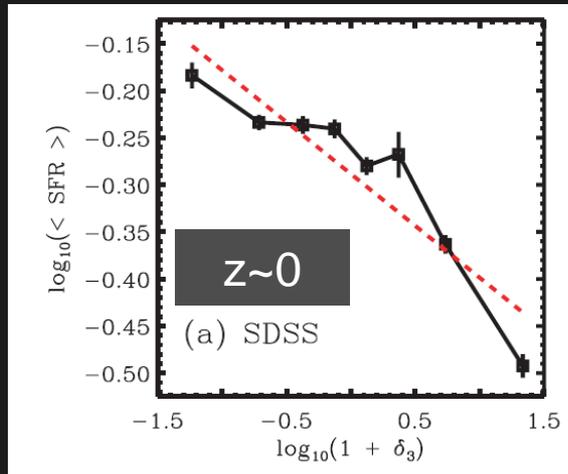
Collaborators

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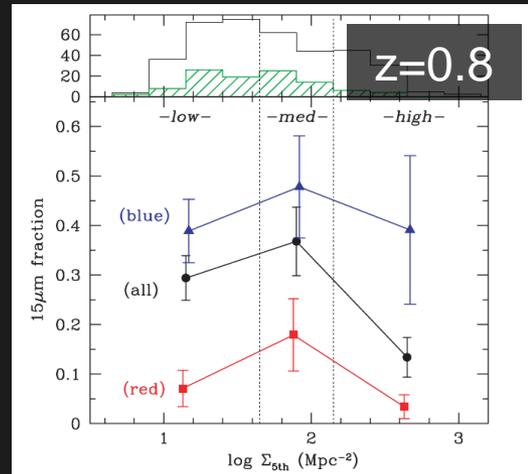
Active star formation in high-z clusters ?

Galaxies are most actively forming stars at $z \sim 1-3$. (e.g., Hopkins-Beacom 06)

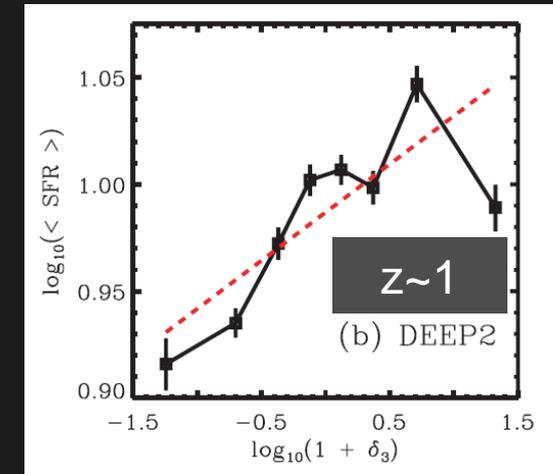
Star-formation activity ↑



(Cooper+08)



(Koyama+08)



(Cooper+08)

Lower density

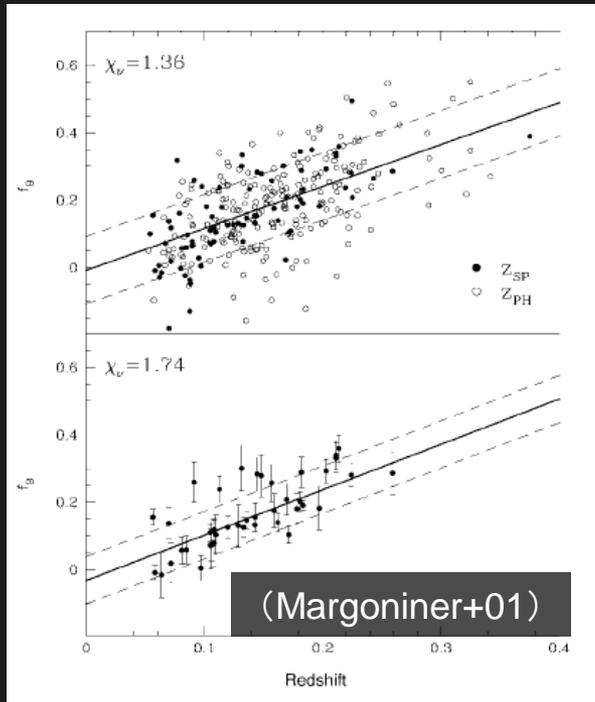
Higher density

We may witness the site where massive early-type galaxies seen in local clusters are being formed by investigating the star formation activity in clusters at $z > 1$.

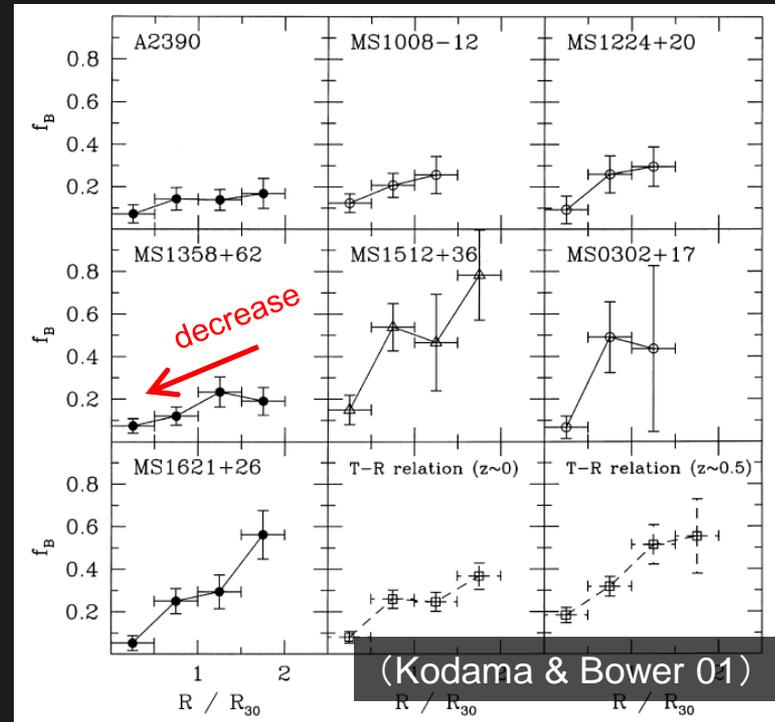
Butcher-Oemler effect

Fraction of blue galaxies is increasing in higher-z clusters.

Fraction of blue galaxies ↑



Redshift →



Radius from the cluster center →

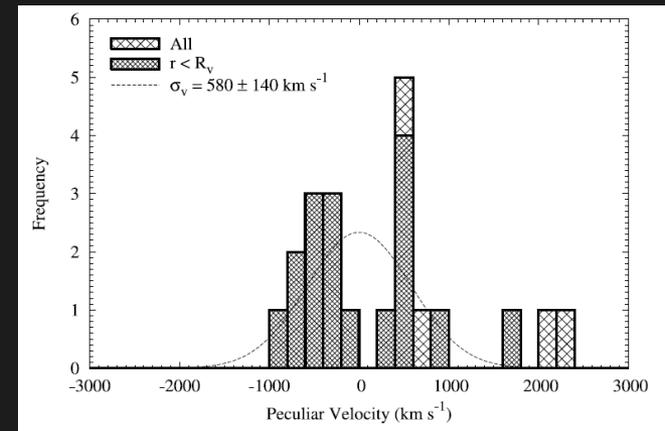
The global activities of star formation within clusters are enhanced with increasing redshifts, but those in cluster cores even at $z \sim 1$ are not yet.

XMMXCS J2215.9-1738 @ $z=1.46$

One of the most distant cluster with a detection of X-ray emission

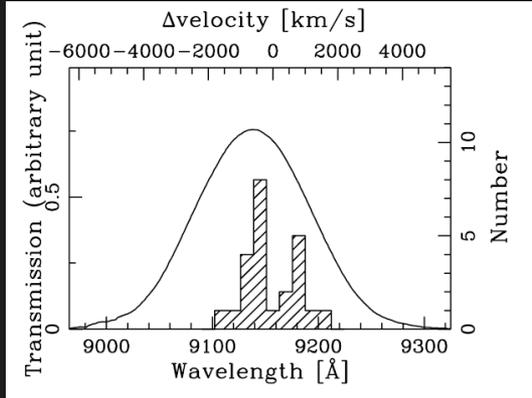


- $kT=7.4^{+2.6/-1.8}$ keV
- $L_X=4.4^{+0.8/-0.6} 10^{44}$ erg/s
(Stanford+06)
- $\sigma=580$ km/s (Hilton+07)
- 24 members are spectroscopically confirmed
(Hilton+09)



Observation of XCS2215 cluster

NB912 ($\lambda_c=9139\text{\AA}$, $\Delta\lambda=134\text{\AA}$)

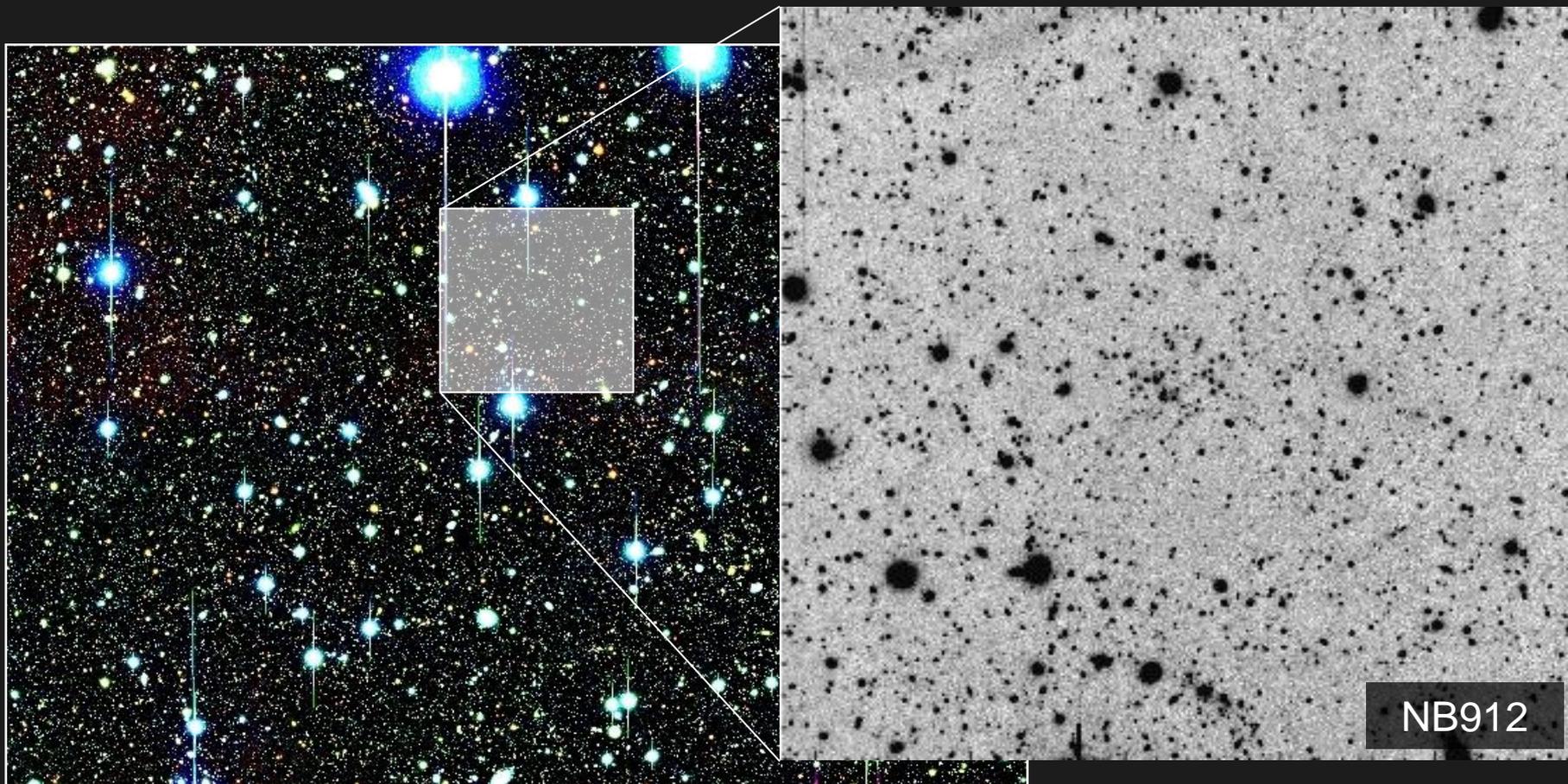


- [OII] ($z=1.46$) is observed at 9157Å
- NB912 can catch [OII] lines emitted from the cluster perfectly
- $\Delta\lambda=134\text{\AA} \Leftrightarrow \Delta v = -2800 \sim +1600 \text{ km/s}$
- velocity dispersion = $\sim 580 \text{ km/s}$ (Hilton+07)

※ 3σ , 2" diameter aperture, AB magnitude

instrument	Suprime-Cam			MOIRCS	
bandpass	B	z'	NB912	J	K_s
date	2008. 07.30-31			2008. 06.30-07.01	
pointing	1			4	
FoV	32' x 23'			6.1' x 5.8'	
limiting mag.※	27.59	25.81	25.75	23.84-24.57	23.07-23.65
Seeing	1.09"			1.09"	

NB912 image of XCS2215 cluster



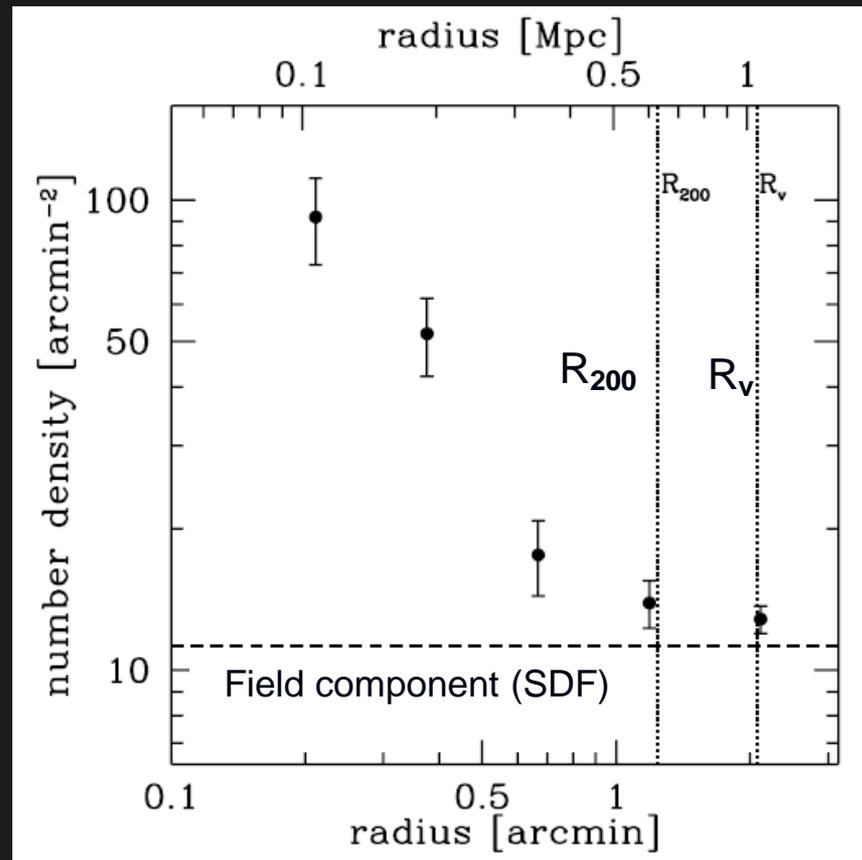
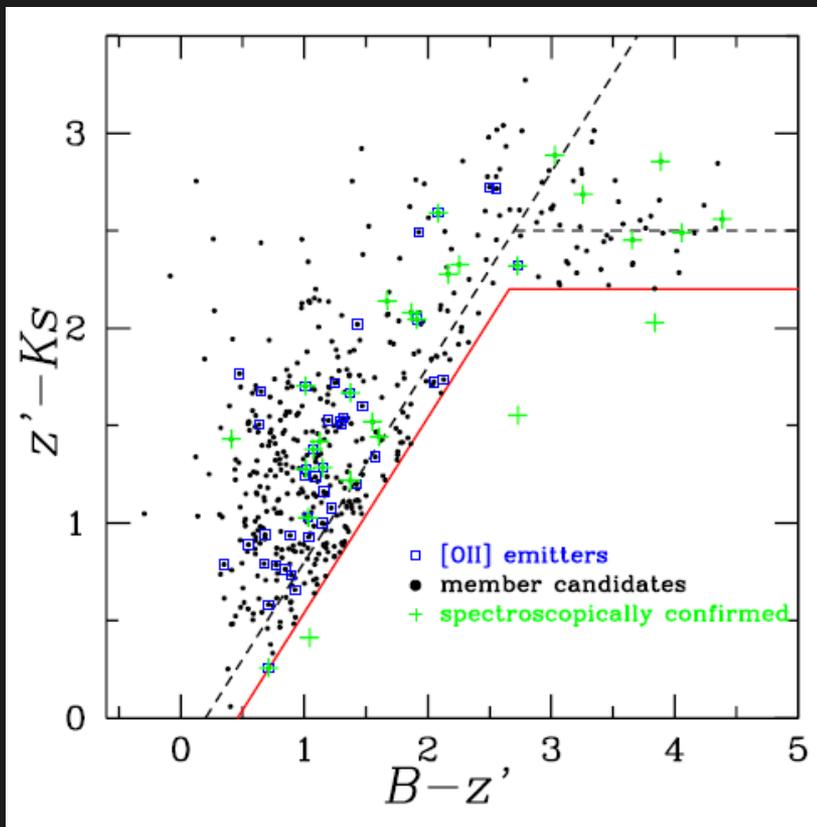
We limit analysis to only the central region (6'x6') where all the data (B,z',NB912,J,Ks) are available.

Selection of cluster members

Modified BzK color criteria for selecting candidates of cluster member

$$(z' - K_s) > (B - z') - 0.46 \cup (z' - K_s) > 2.2$$

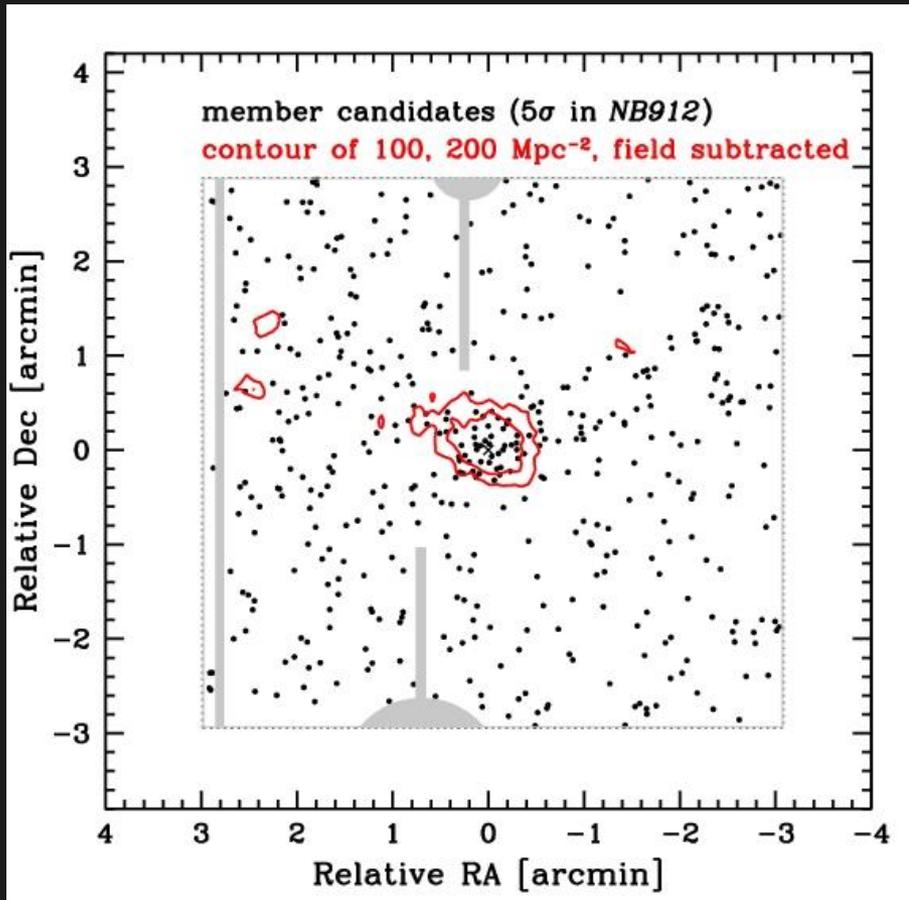
- Contribution of field galaxies is statistically subtracted using the data of the Subaru Deep Field (SDF)



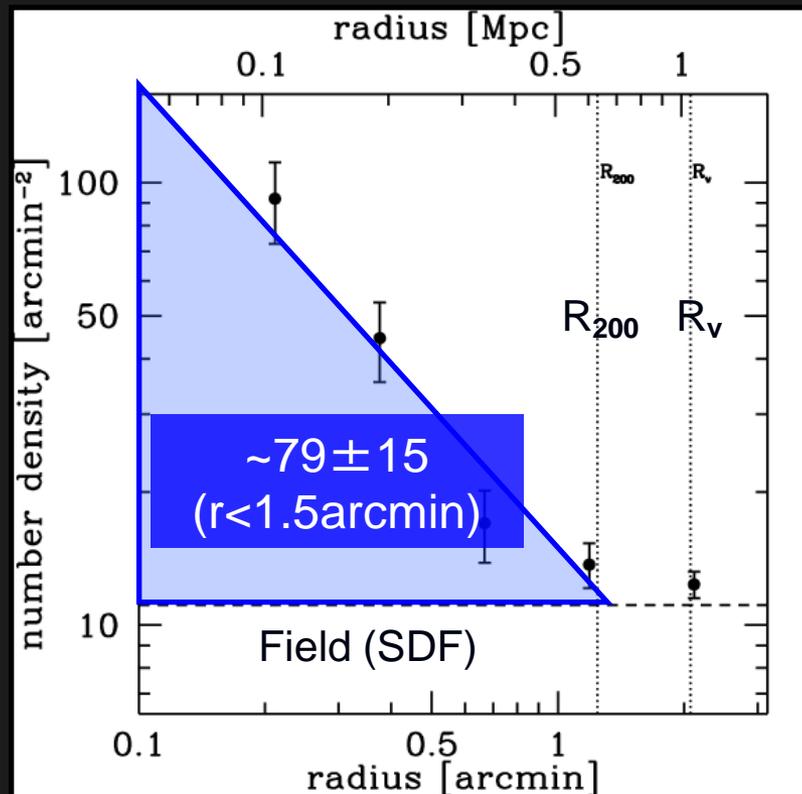
Cluster members

Candidates of cluster member

$$(z' - K_s) > (B - z') - 0.46 \cup (z' - K_s) > 2.2$$

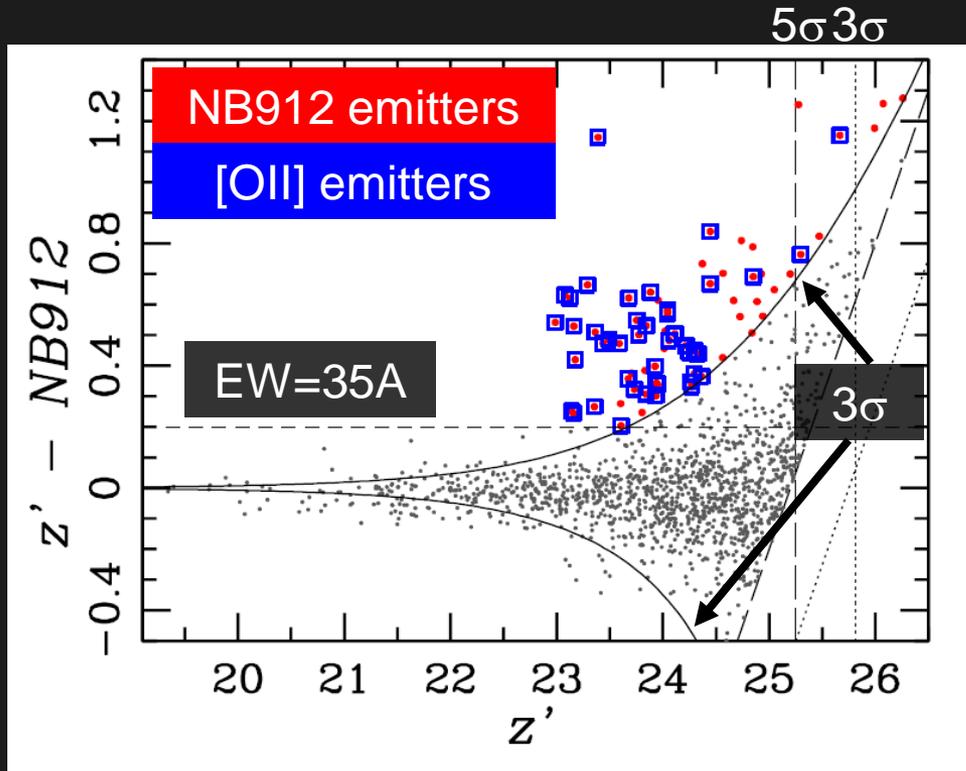


- Hilton et al. (2009)
64 members within $3.04' \times 3.04'$
(24 spec-z, 40 photo-z)
- statistical field subtraction

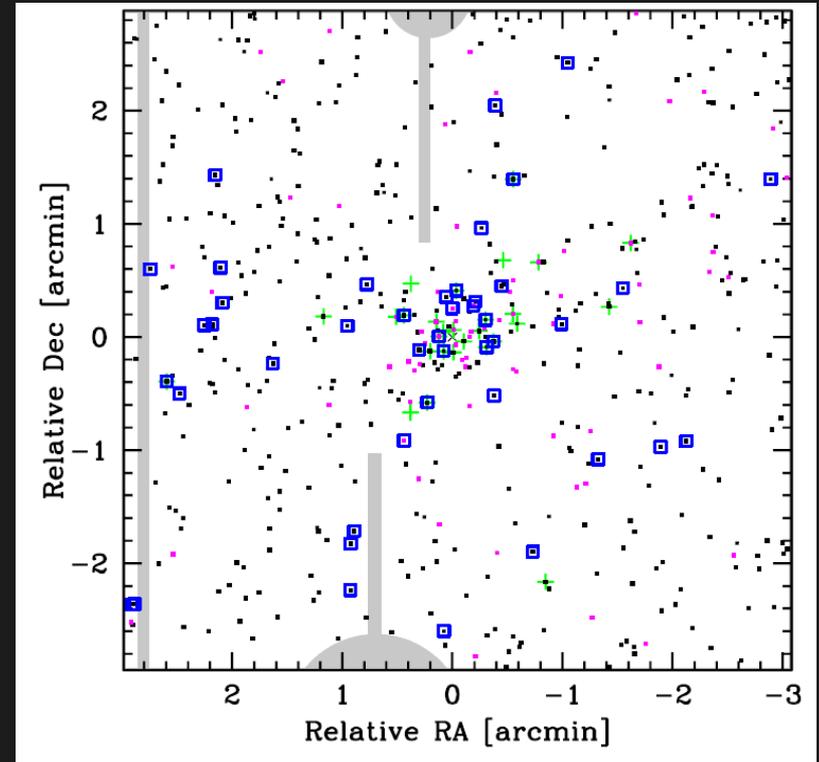


[OII] emitters in the cluster

Selection of [OII] emitters



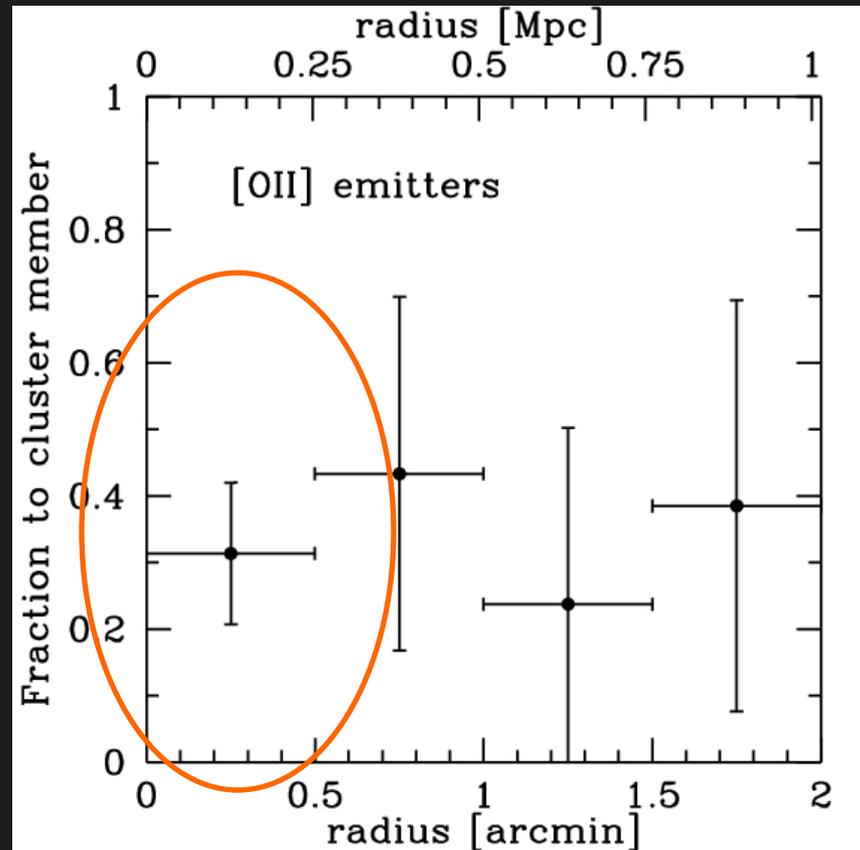
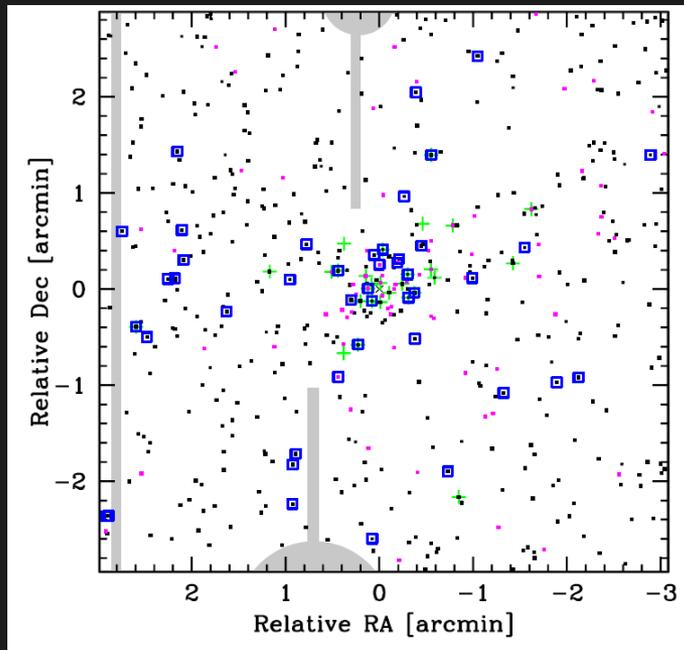
Distribution of [OII] emitters



- more than 3σ excess of NB912 to z'
 - limiting line flux (3σ) = 1.4×10^{-17} erg/s/cm²
- 44 [OII] emitters
- dust-free SFR = $2.6 M_{\text{sun}}/\text{yr}$ (Kennicutt (1998))

Fraction of [OII] emitter to member

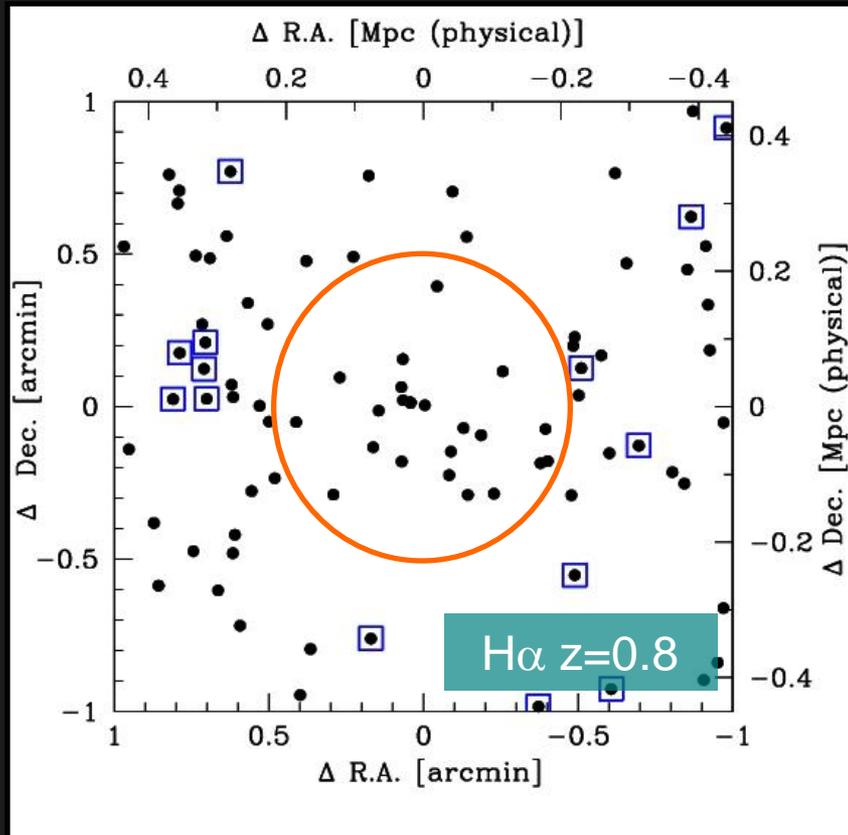
(field component is statistically subtracted)



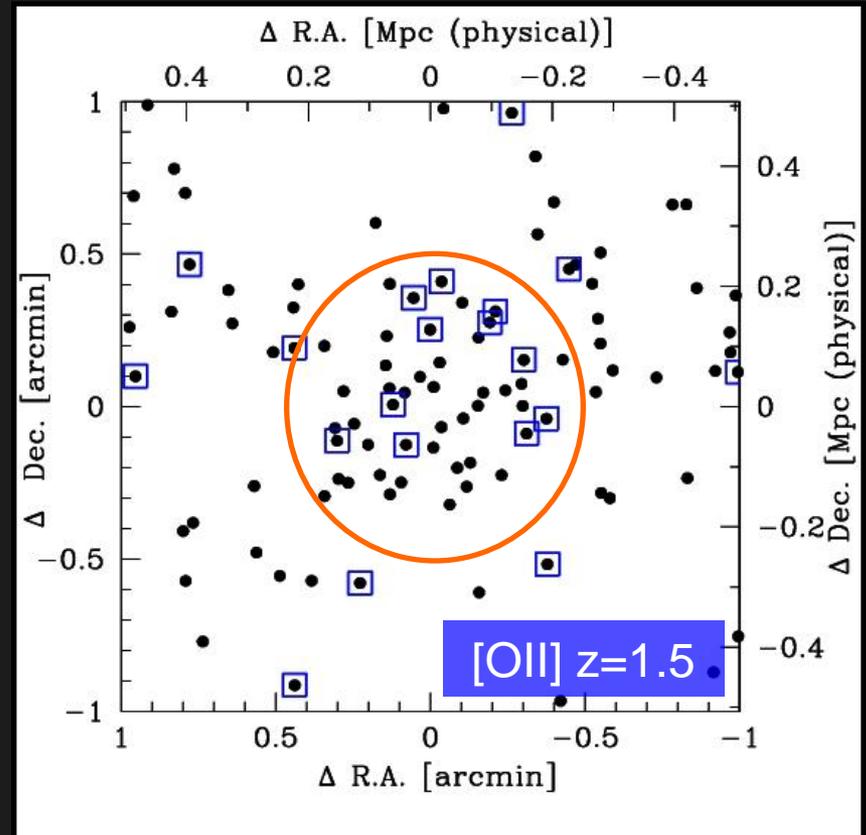
XCS2215 cluster at $z=1.46$ is actively forming stars in the central region.

Comparison with RXJ1716 cluster

- RXJ1716 cluster @ $z=0.81$
- $H\alpha$ survey with NB119 & MOIRCS
- 3σ limit: $SFR=1.5M_{\text{sun}}/\text{yr}$
- 1arcmin=0.45Mpc (physical scale)



- XCS2215 cluster @ $z=1.46$
- $[OII]$ survey with NB912 & Suprim-Cam
- 3σ limit: $SFR=2.6M_{\text{sun}}/\text{yr}$
- 1arcmin=0.51Mpc (physical scale)



SFR, SSFR and equivalent width

$$F([\text{O II}]) = f_{NB912} \Delta_{NB912} \frac{1 - (f_{z'}/f_{NB912})}{1 - (\Delta_{NB912}/\Delta_{z'})},$$

$$f_{\lambda, \text{cont}} = f_{z'} \frac{1 - (f_{NB912}/f_{z'}) (\Delta_{NB912}/\Delta_{z'})}{1 - (\Delta_{NB912}/\Delta_{z'})},$$

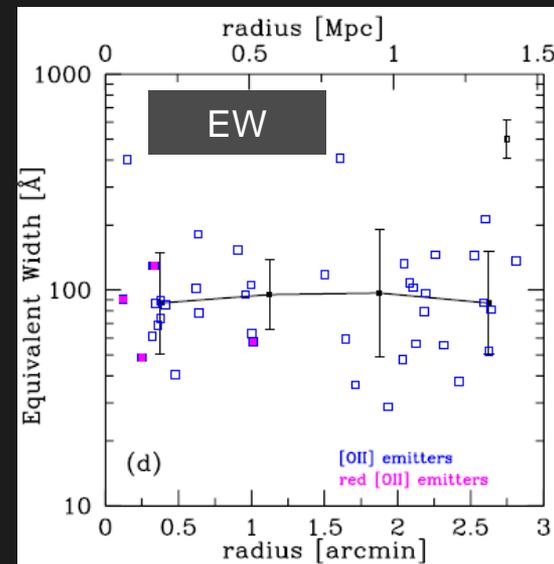
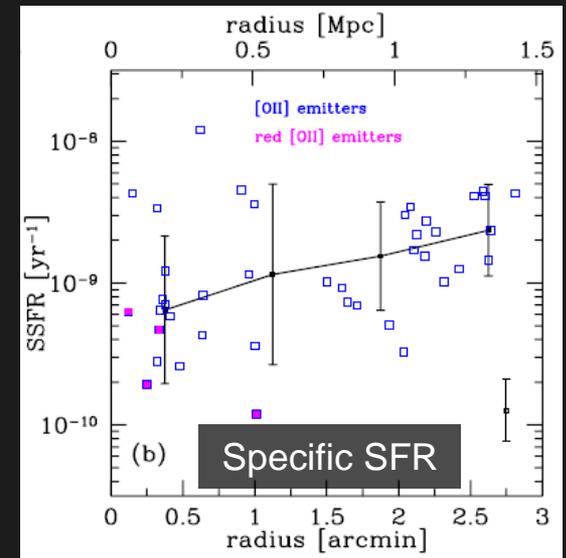
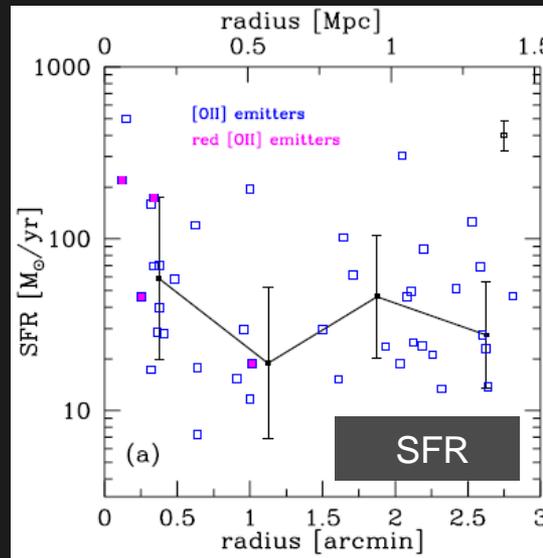
- Dust corrected SFR (Moustakas+06)

[OII] flux corrected for dust extinction and metallicity dependence using rest-frame B-band luminosity

- Stellar mass (Daddi+04)

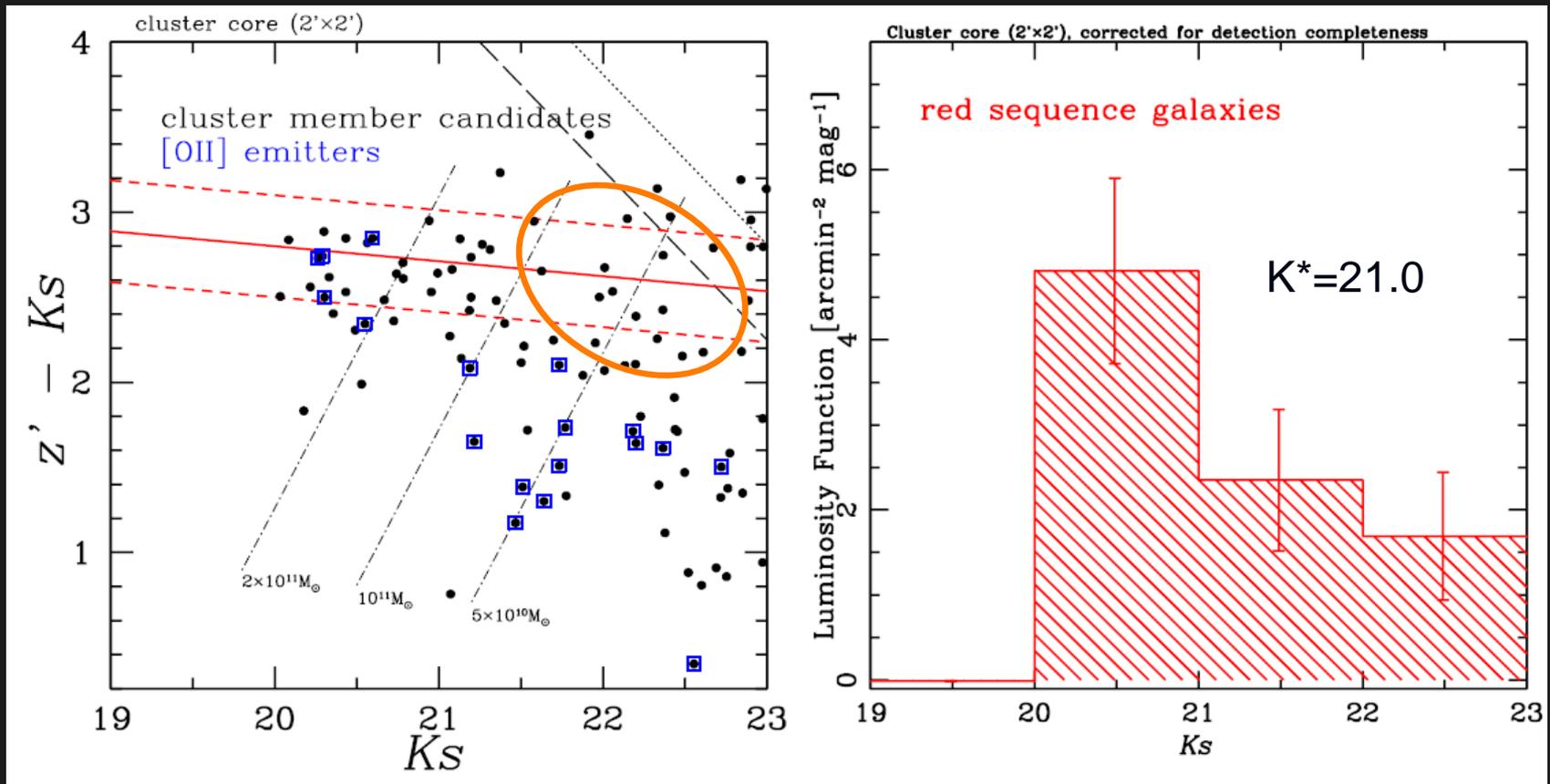
K-band luminosity corrected for M/L using z-K color

- SFRs and EWs are not correlated with radius.
- SSFRs are decreasing with the inner radius due to a trend that massive galaxies prefer to be near the center.



Color-magnitude relation

FoV: 2.0' x 2.0'



Decrease of red member galaxies is seen at $K > K^* + 0.5$

Summary

- [OII] emission survey for XMMXCS J2215.9-1738 cluster at $z=1.46$
- 44 [OII] emitters in 6'x6' central region of the cluster
- fraction of [OII] emitter to cluster member
 - Active star formation in the central high density region
 - Shift of active star-forming region to lower density region toward lower redshifts
- SFR, specific SFR and equivalent width
 - Lower SSFRs for galaxies at the inner radius due to a trend that massive galaxies prefer to be near the center.
- color-magnitude relation
 - Decrease of red member galaxies with fainter than $M^*+0.5$
 - Shift of active star formation to less massive galaxies toward lower redshifts