宇宙再電離期近くの銀河探査
と
環境効果の検証

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RESCEU/DENET Summer School, Kochi Palace Hotel,
(29 Aug.-1 Sept, 2010)

Survey for Galaxies near Reionization Epoch and Verifying the Environmental Effects

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RESCEU/DENET Summer School, Kochi Palace Hotel,
(29 Aug.-1 Sept, 2010)

Part I

宇宙再電離期近くの銀河探査

Survey for Galaxies near Reionization Epoch

Kashikawa, Shimasaku, SO et al. 2006, ApJ, 648, 7-22

Shimasaku, Ouchi, SO et al. 2006, PASJ, 58, 313

Ouchi, Shimasaku, SO et al. 2008, ApJS, 176, 301-330

Ouchi, Shimasaku, SO et al. 2009, ApJ, 696, 1164-1175

Ouchi, Shimasaku, SO et al. 2009, ApJ, 706, 1136-1151

Ono, Ouchi, Shimasaku, SO et al. 2010, MNRAS, 402, 1580

Ono, Ouchi, Shimasaku, SO et al. 2010, astroph/1004.0963

Ouchi, Shimasaku, SO et al. 2010, astro-ph/1007.2961

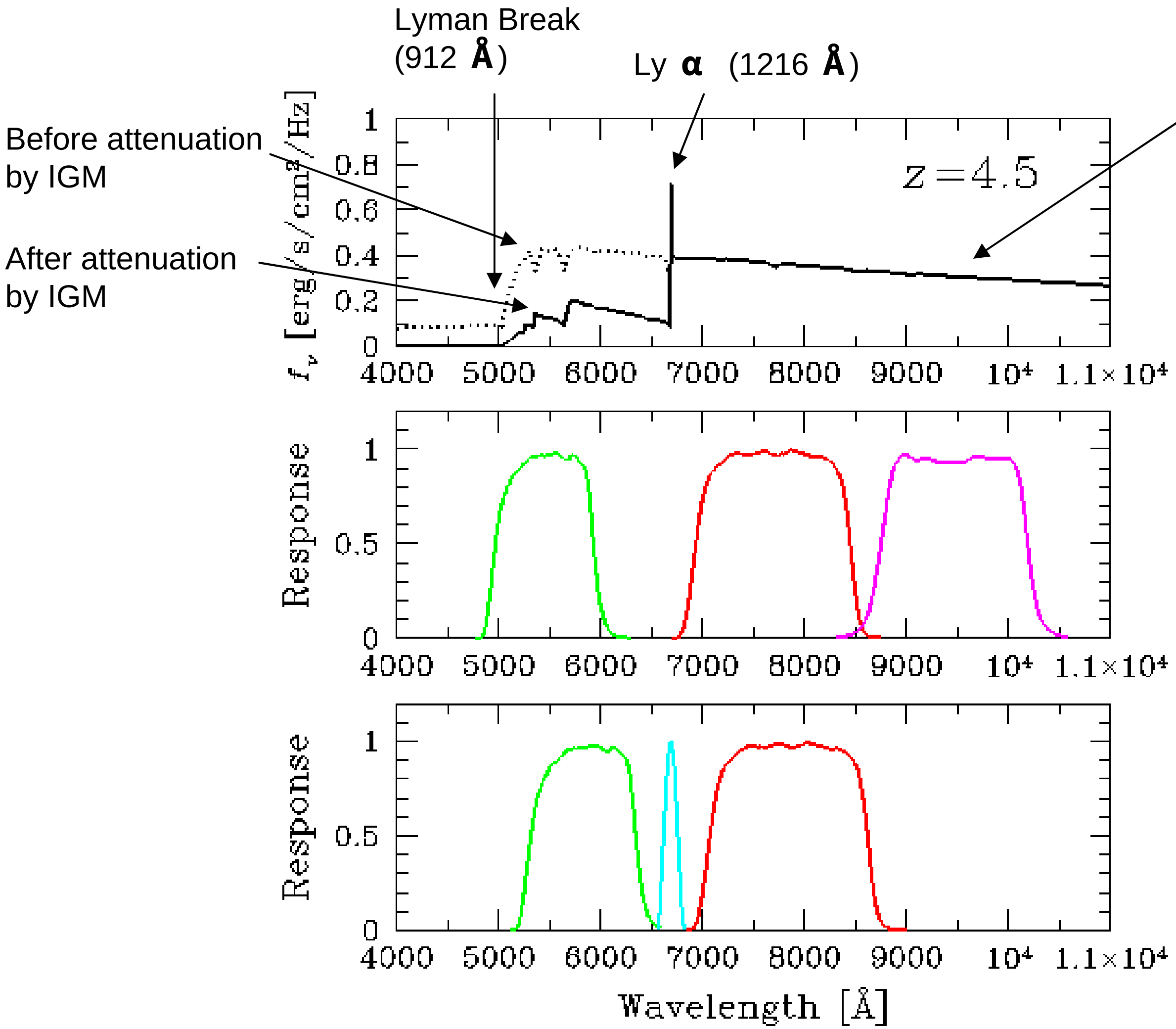
Summary of Part I

- We may be seeing real building blocks of present-day galaxies (z~6 -7 LAEs)

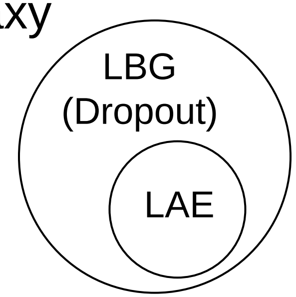
- However, z~6-7 LAEs are heterogeneous. Small number of exceptions (Himiko, red massive LAEs with high SFR, etc) may reveal unknown stories.

- Probably, galaxies at z=7 had properties different from those of present-day galaxies (f(esc)>0.2, lower z, flatter IMF, etc)

Lyman Break Galaxies (LBG: dropout) and Lyman α Emitters (LAE)



Spectrum of a typical z=4.5 galaxy



Selection by broadband colors (continuum shape)

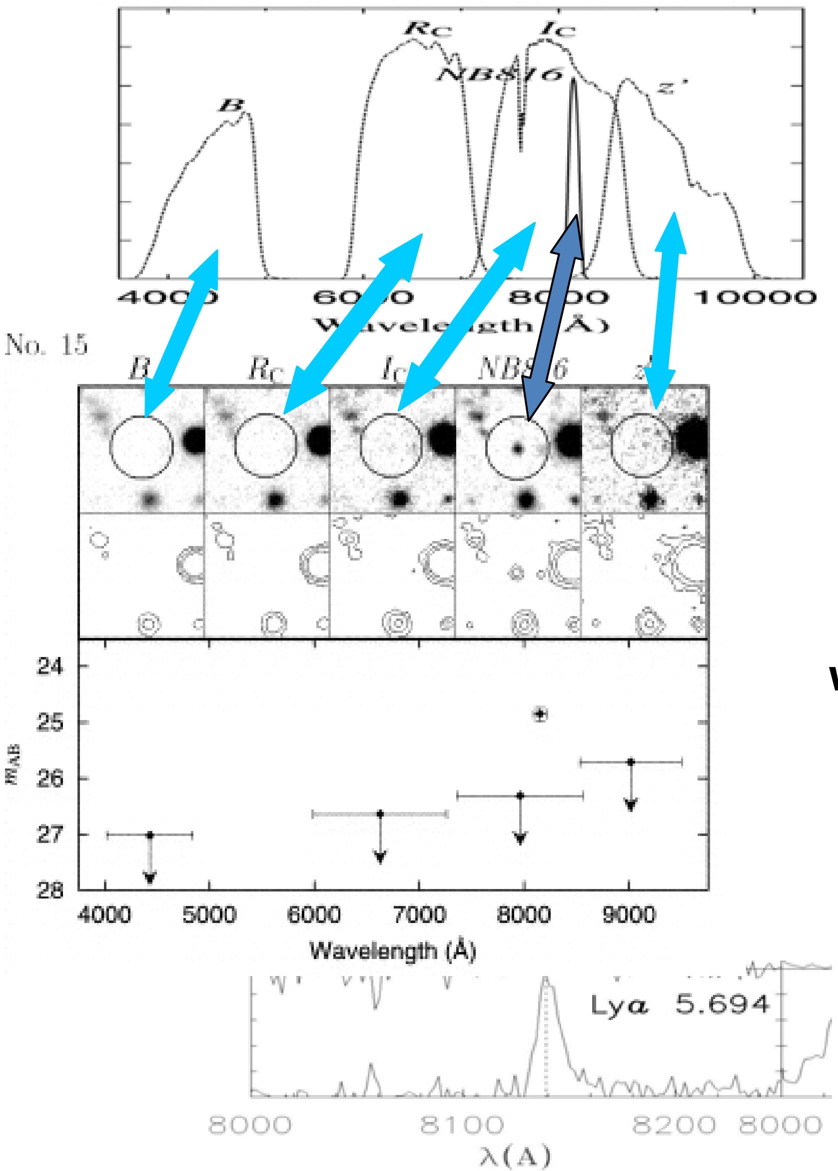
LBG (○- dropout)
i', *z'*

Selection by narrowband excess (emission line)

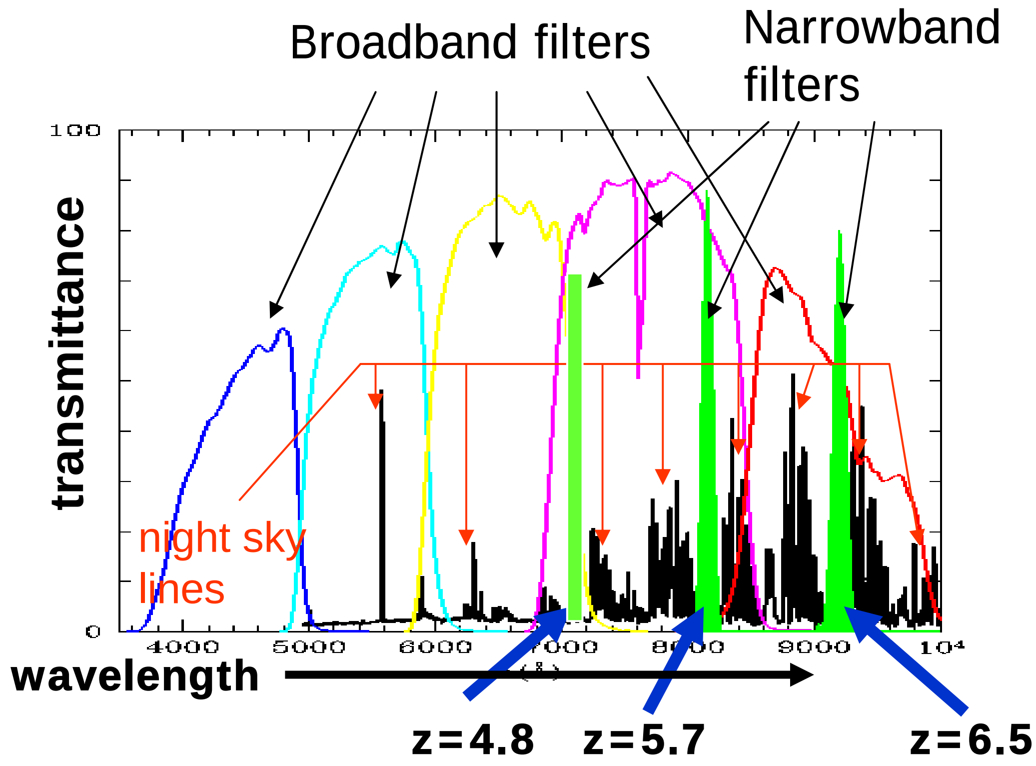
LAE

main topic

LAE Survey with Subaru/Suprime-Cam



Ajiki et al. 2003, AJ, 126, 2091

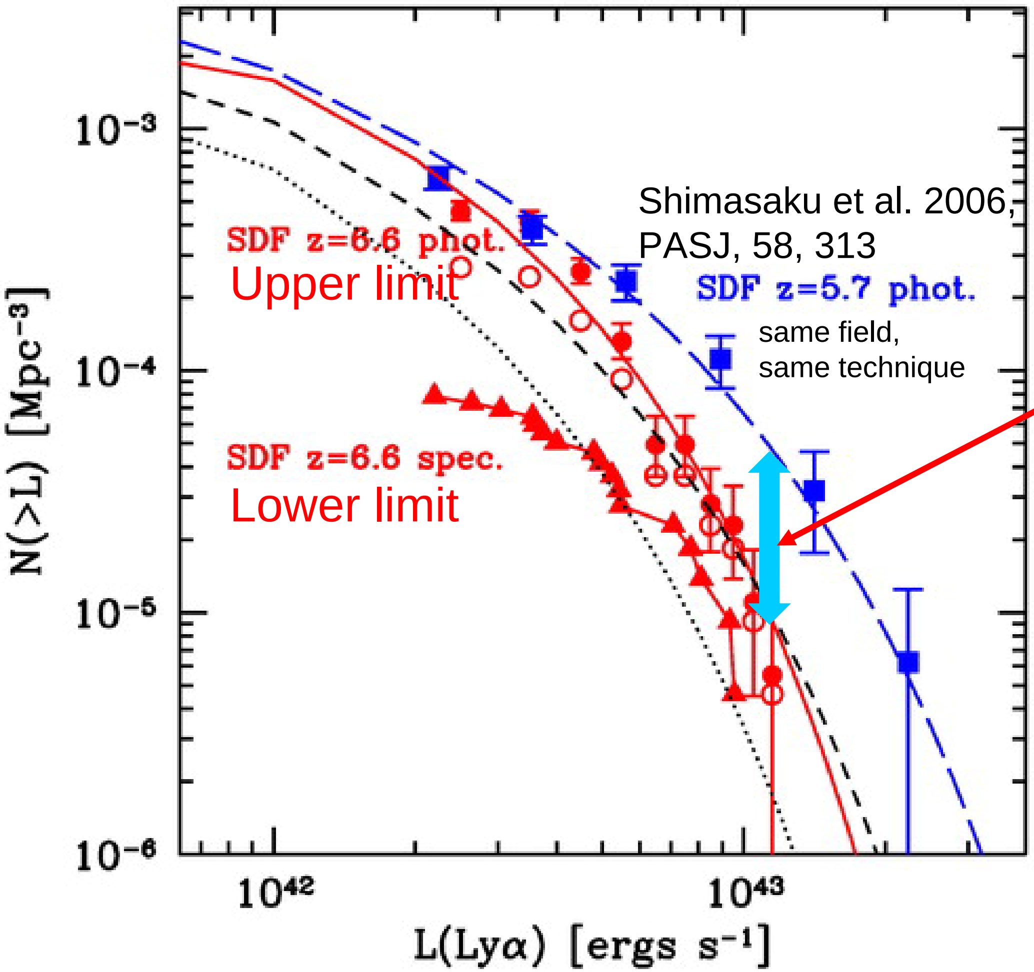


Valleys of OH emission lines

Kashikawa, Shimasaku, SO et al. 2006, ApJ, 648, 7

“The End of the Reionization Epoch Probed by Lyα Emitters at z=6.5 in the Subaru Deep Field”

(Probably) the first paper that explicitly mentioned ‘reionization’ based on Subaru LAE surveys



LF evolution? Cosmic Variance??

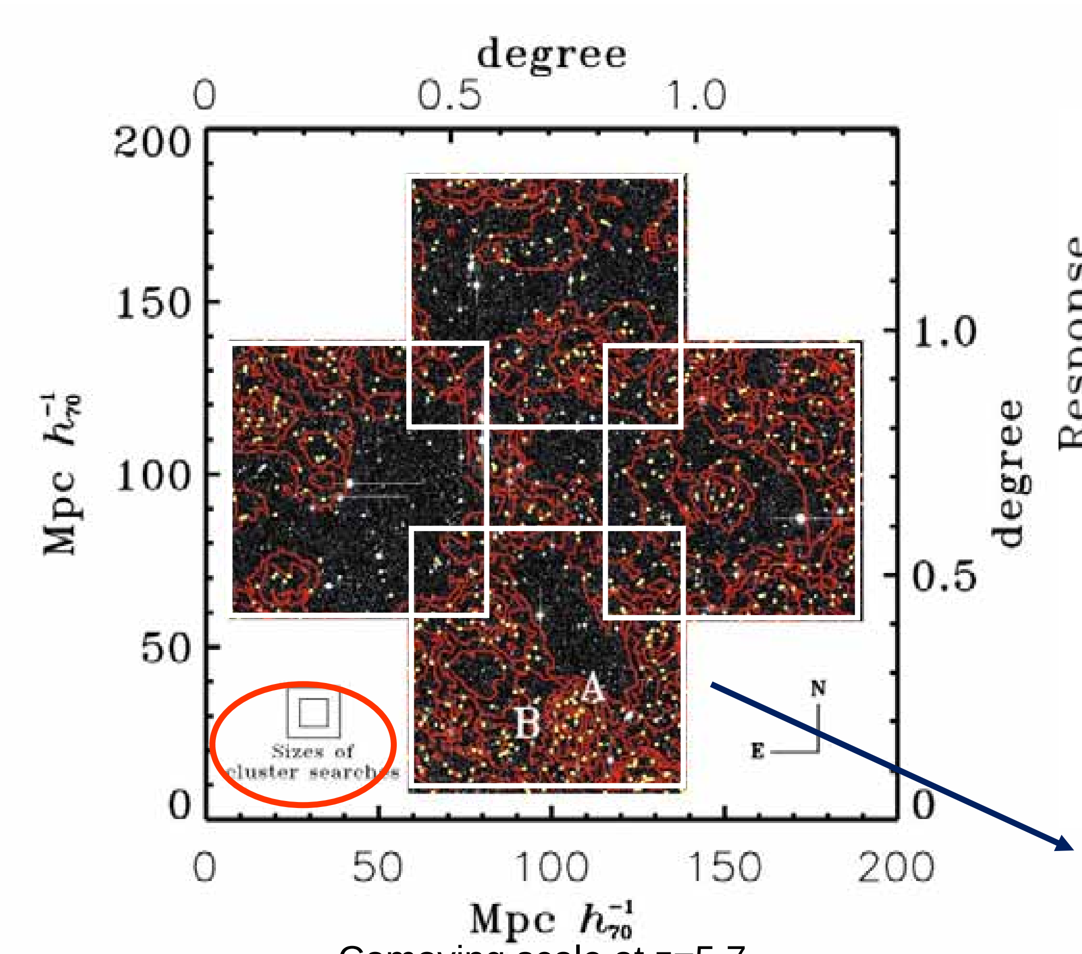
Lyα emitters at z=6.5
17(spec.)+58(photo.)

Deficit of bright end LF
(∼0.75 mag fainter in L*)

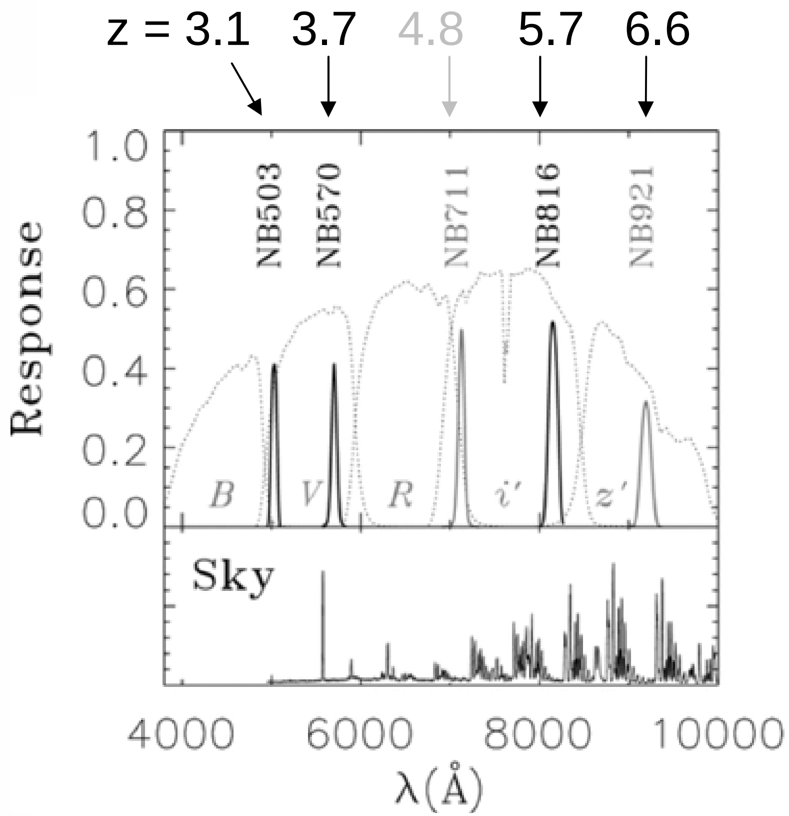
Rest-UV continuum LF shows no significant change between z=5.7 and 6.5

The decline of number density could be due to change of reionization state

Systematic Survey in Subaru/XMM-Newton Deep Survey (SXDS) Field



Comoving scale at z=5.7

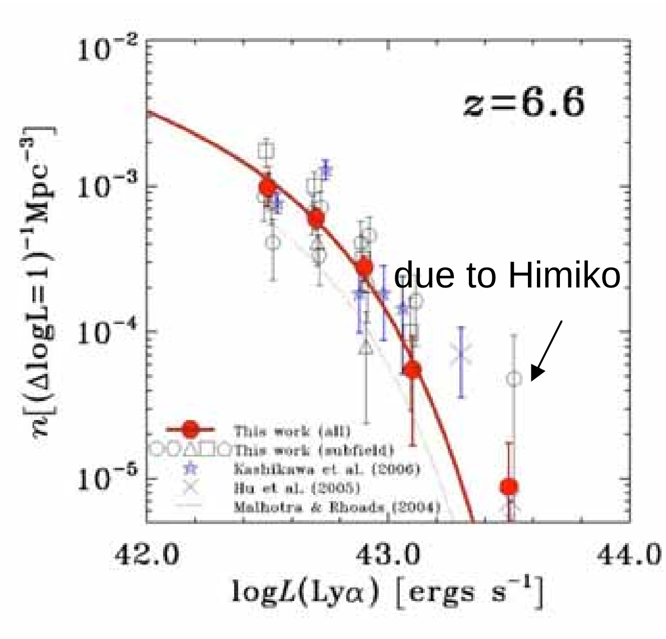


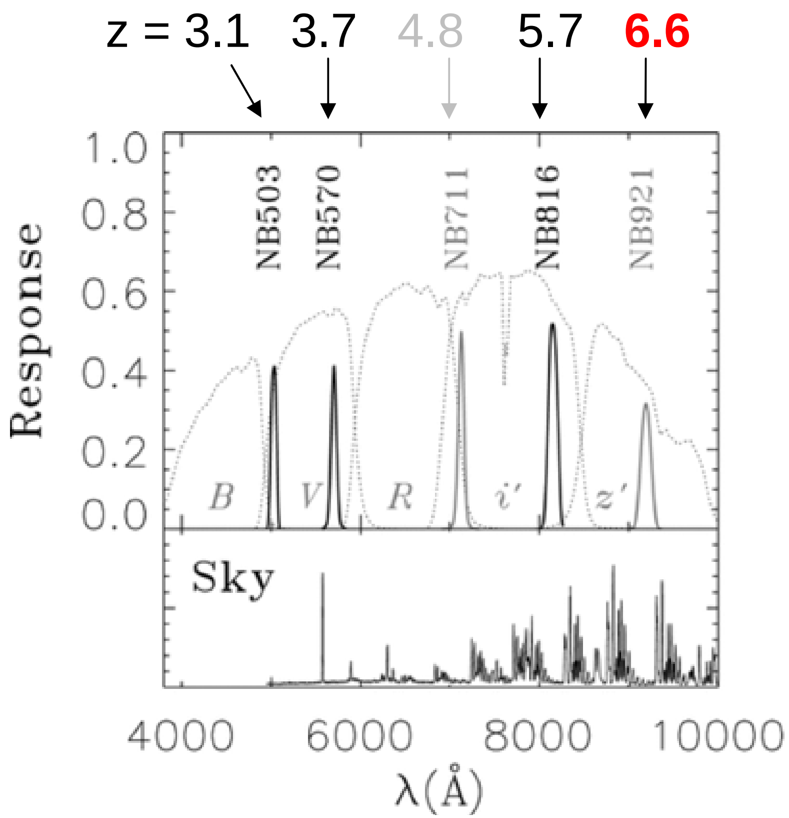
Treat 5 fields separately

infer cosmic variance

By far the widest survey for z>2 galaxies

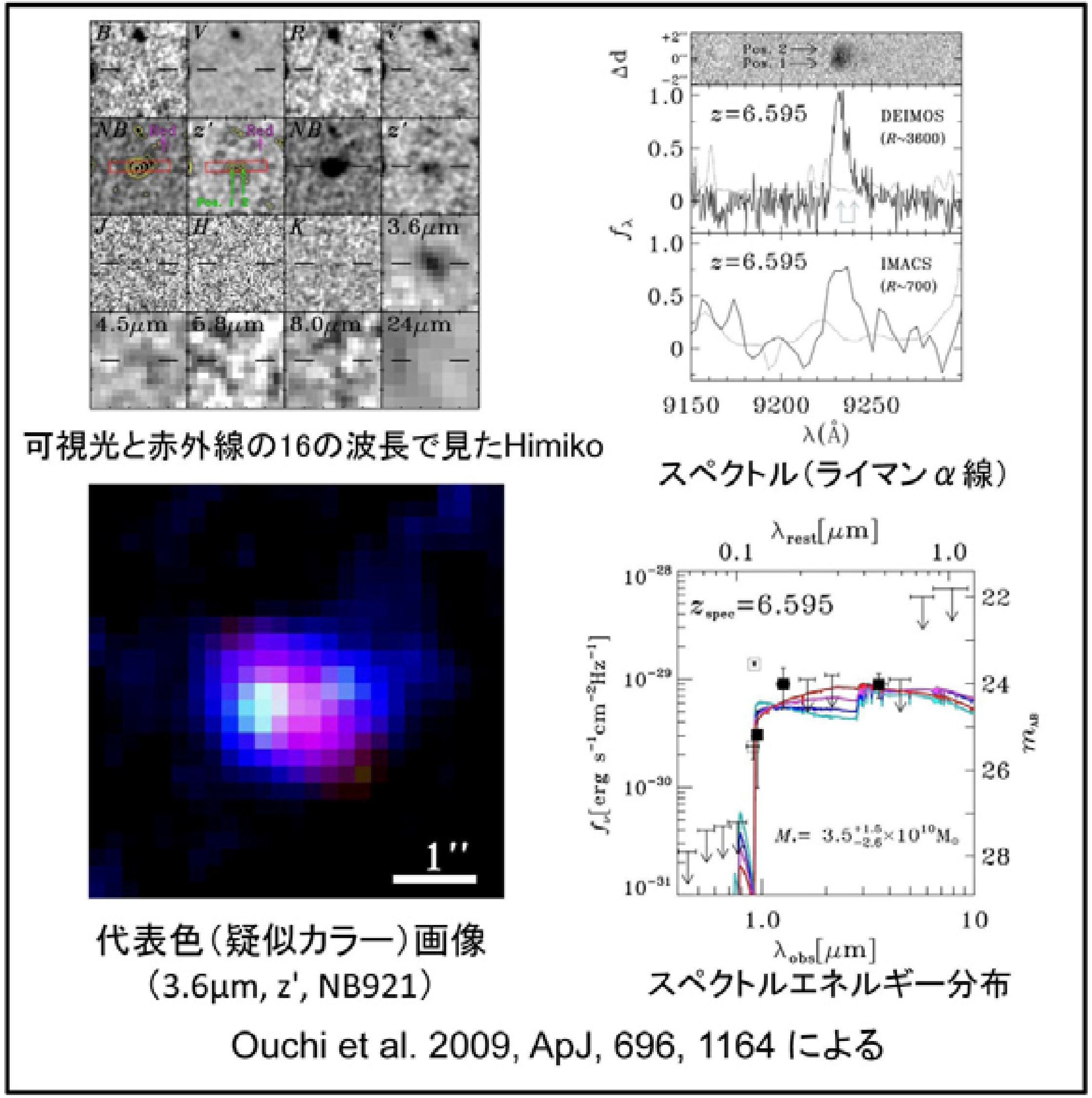
Ouchi, Shimasaku, SO et al. 2010, astro-ph/10072961
"Statistics of 207 Ly α Emitters at a Redshift Near 7: Constraints on Reionization and Galaxy Formation Models"





Discovery of a Giant Ly α Emitter Near the Reionization Epoch

Ouchi, Shimasaku, SO et al. 2009, ApJ, 696, 1164



Subaru/SXDS field

↓

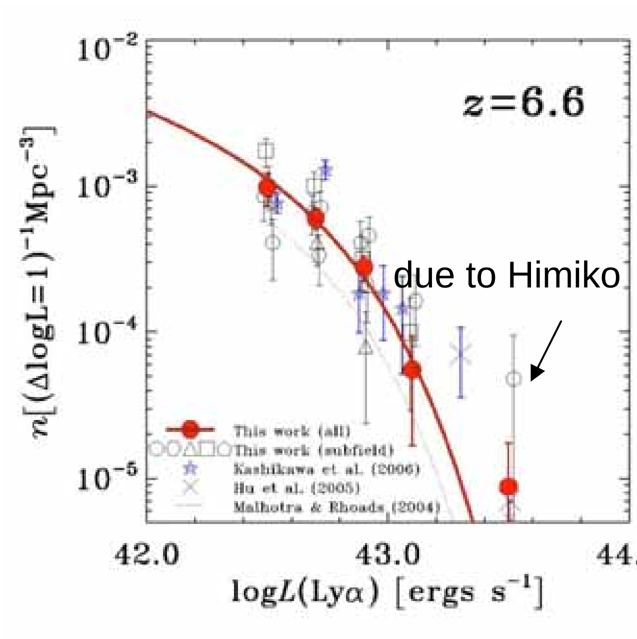
Follow-up

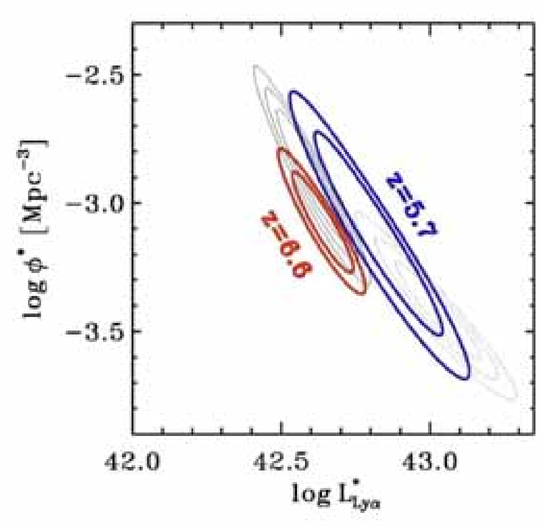
Spitzer/IRAC
Keck/DEIMOS
Magellan/ IMACS
UKIDSS/UDS
Spitzer/IRAC

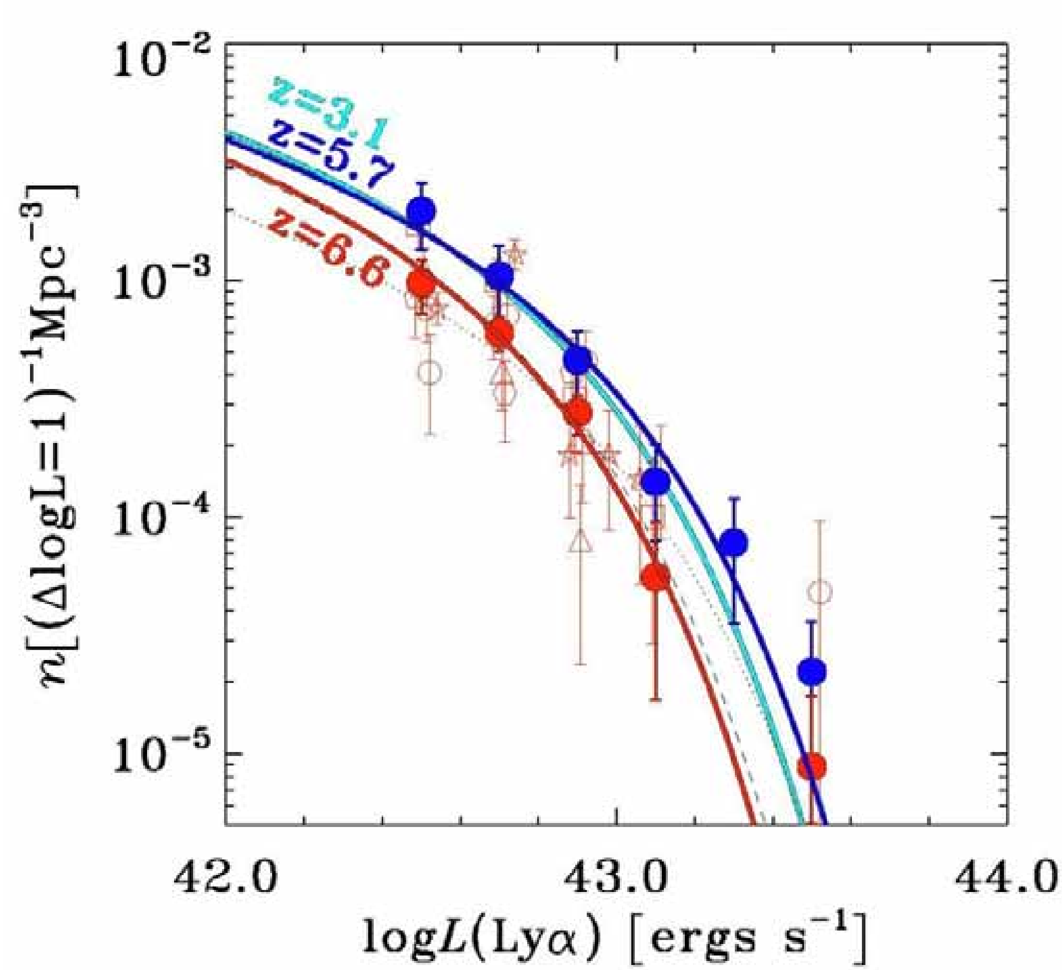
- z=6.595
- bright (3.9x10^{43} erg/s)
- extended (>17kpc)
- stellar mass
  (0.9-5)x10^{10} Msun
- SFR > 34 Msun/year
- E(B-V) not constrained
- no AGN

Brightest in 10^6 Mpc^3

Ouchi, Shimasaku, SO et al. 2010, astro-ph/10072961
“Statistics of 207 Ly**α** Emitters at a Redshift Near 7: Constraints on Reionization and Galaxy Formation Models”







Ly**α** LF: constant over z = 3 - 5.7
decreases : z = 5.7 → z = 6.6

Stellar Populations of Lyα Emitters

Ono, Shimasaku, SO et al. 2010, MNRAS, 402, 1580

z = 3 - 4

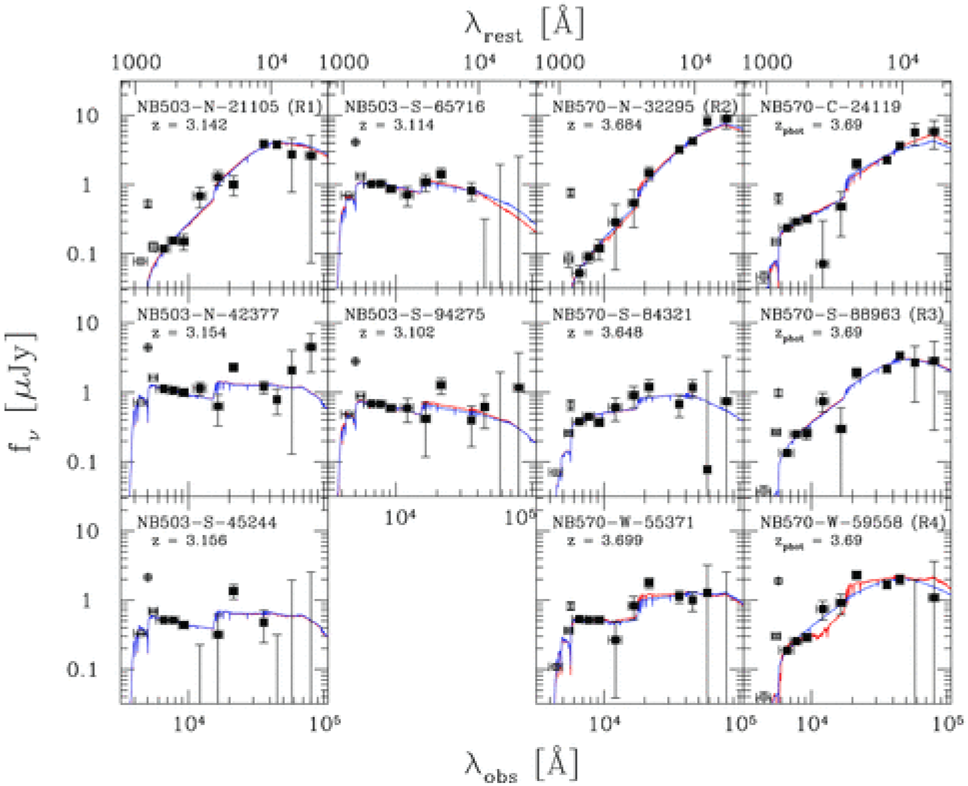
- Subaru-SXDS/UKIDSS-UDS field 0.65 deg^2

  Subaru+UKIRT+Spitzer legacy survey

  302 LAEs (224 for z=3.1, 78 for z=3.7)

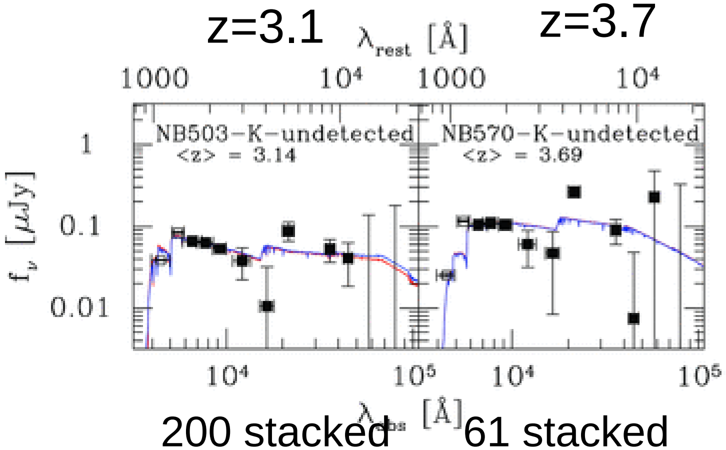
- only 11 are K-detected 8/11 spec. confirmed

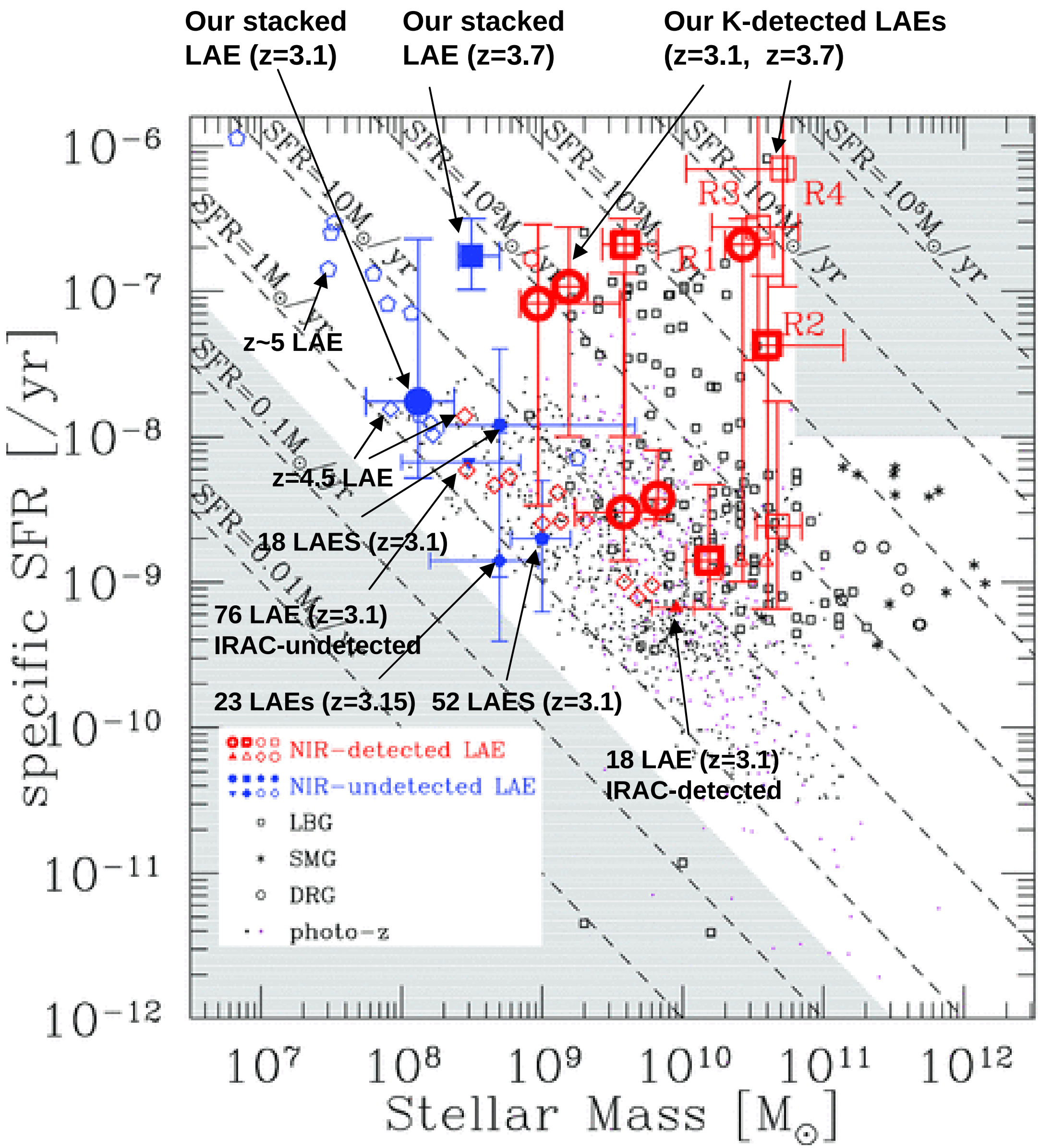
- 11 K-detected LAE



Stacking!

2 stacked LAEs





Ono, Shimasaku, SO et al. 2010, MNRAS, 402, 1580

- Typical LAEs (stacked LAEs) at z=3-4

low-mass ($10^{(8-8.5)}$ Msun),
modest SFR (1-100 Msun/y)
modest extinction E(B-V)<0.2

- 4 K-detected LAEs

red color
reddening E(B-V)=0.3

two reddest ones resemble local ULIRGs

- Comparison with LBG, DRG, etc

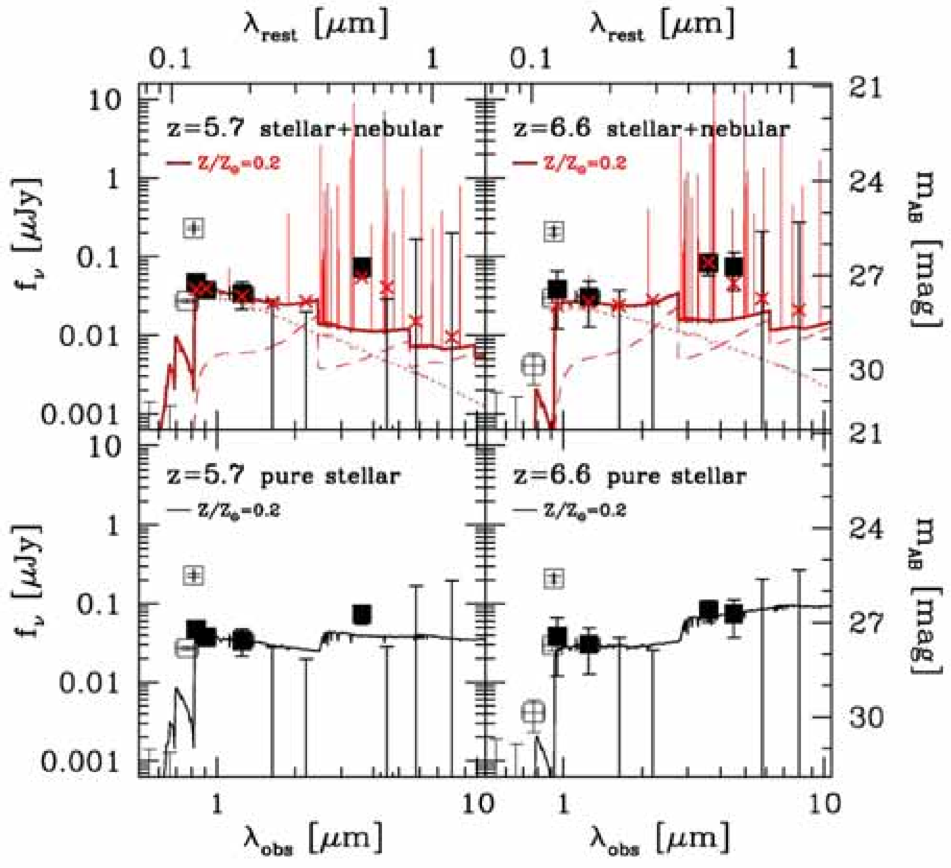
LAEs are the least massive population with modest SFR

Ono, Ouchi, Shimasaku, SO et al. 2010, submitted to ApJ (astro-ph/1004.0963)

z = 6 – 7 LAEs

Subaru-SXDS/UKIDSS-UDS field 0.65 deg^2

Subaru+UKIRT+Spitzer SupUDS program



165 LAEs (z=5.7) 91 LAEs (z=6.6)

First SED detected for z=6-7 galaxies !!

low stellar mass (3-10)x10^7 Msun,
very young age (1-3) Myr,
log (SFR)~(1-2) Msun,
log (SSFR)~ -6,
negligible dust extinction, and
strong nebular emission

building blocks of present day galaxies

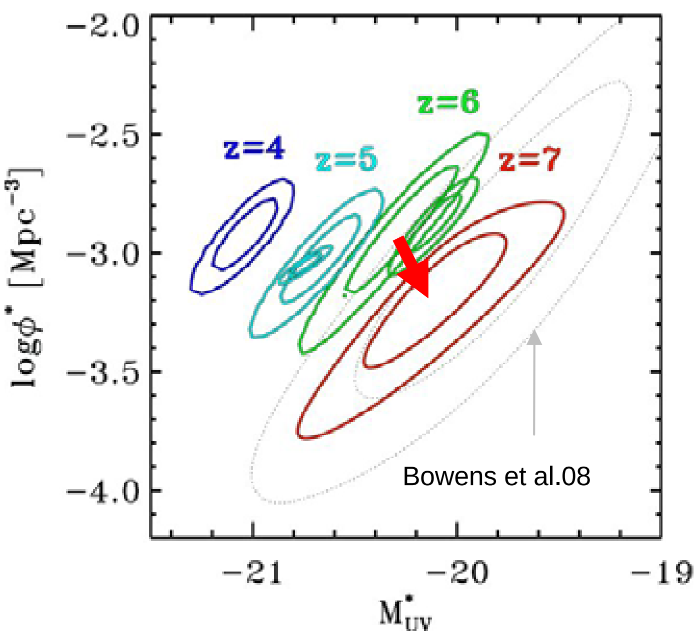
z’-dropout galaxies at z=7

Ouchi, Shimasaku, SO et al. 2009, ApJ, 706, 1136

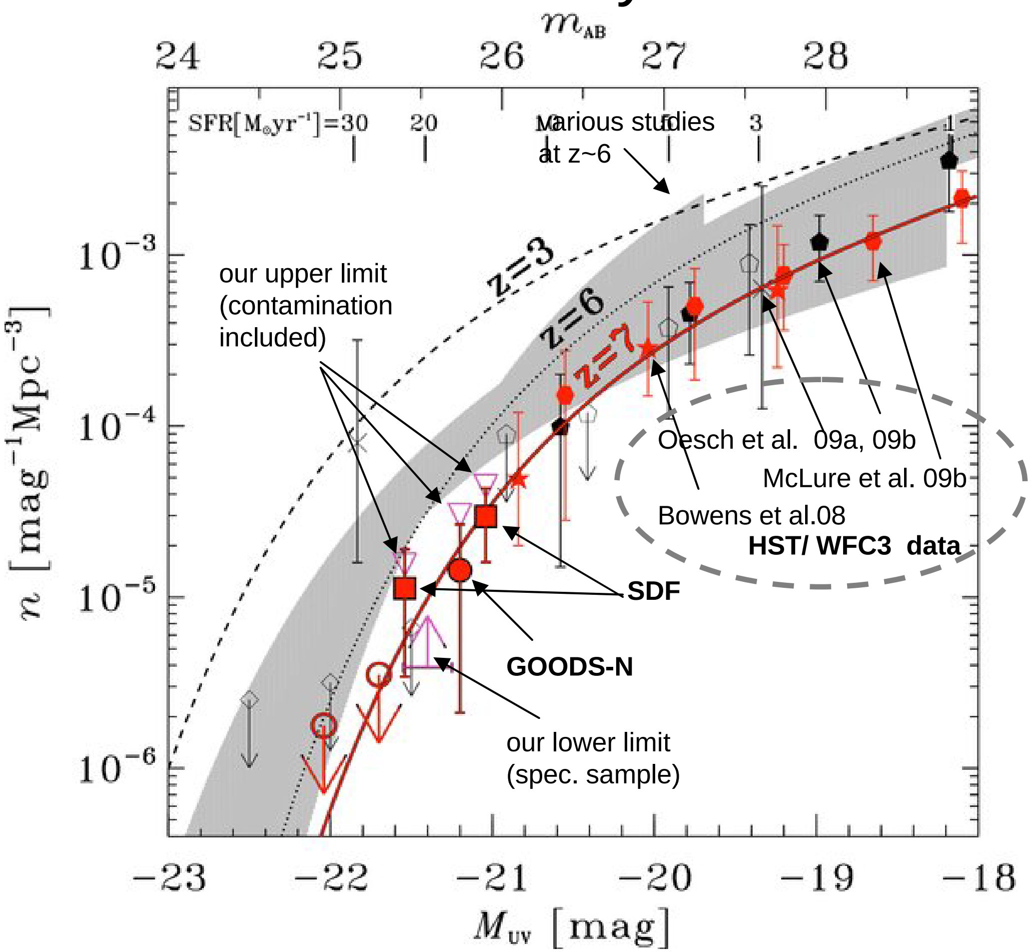
1568 $arcmin^2$ in SDF and GOODS-N fields.

Suprime-Cam z’-band + HST data

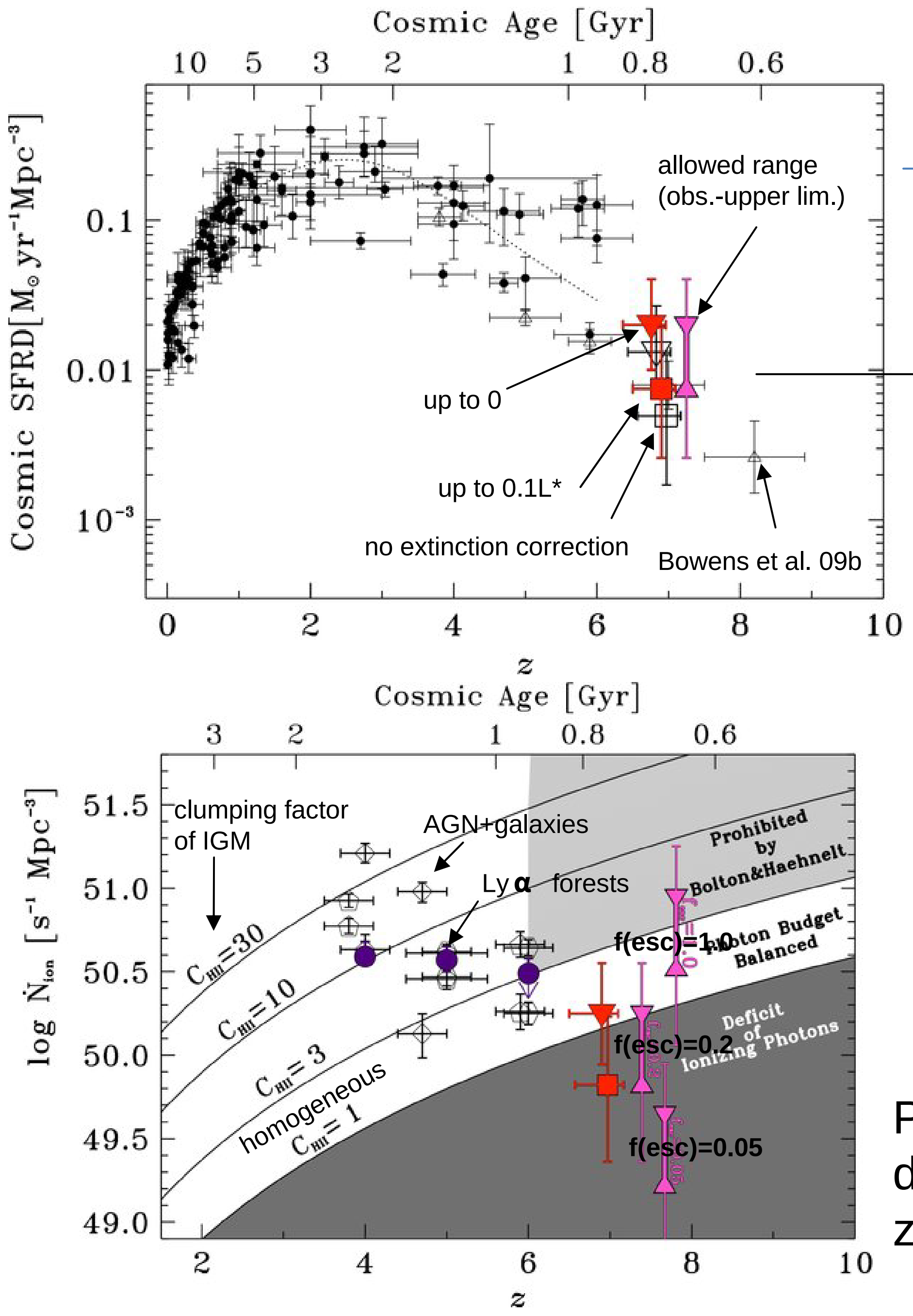
22 bright z-dropout galaxies
(down to y = 26)



UV Luminosity Function



Ouchi, Shimasaku, Okamura et al. 2009, ApJ, 706, 1136



Cosmic SFRD decreases by a factor of ~10, but not larger than ~100

Emission rate of ionizing photons per comoving Mpc^3 (Madau et al. 1999)

Universe could not be ionized by galaxies only at z=7

Probably, galaxies at z=7 had different properties (f(esc)>0.2, lower z, etc)

Summary of Part I

- We may be seeing real building blocks of present-day galaxies (z~6 -7 LAEs)

- However, z~6-7 LAEs are heterogeneous. Small number of exceptions (Himiko, red massive LAEs with high SFR, etc) may reveal unknown stories.

- Probably, galaxies at z=7 had properties different from those of present-day galaxies (f(esc)>0.2, lower z, flatter IMF, etc)

Part II

環境効果の検証

Verifying the Environmental Effects

Tanaka, Kodama, SO, Shimasaku et al. 2005, MNRAS, 362, 268

Hayashi, Kodama, Shimasaku, SO et al. 2010, MNRAS, 402, 1980

Koyama, Kodama, Shimasaku, SO et al. 2010, MNRAS, 403, 1611

Koyama, Nakata, Kodama, Shimasaku, SO 2010, to be submitted

Summary of Part II

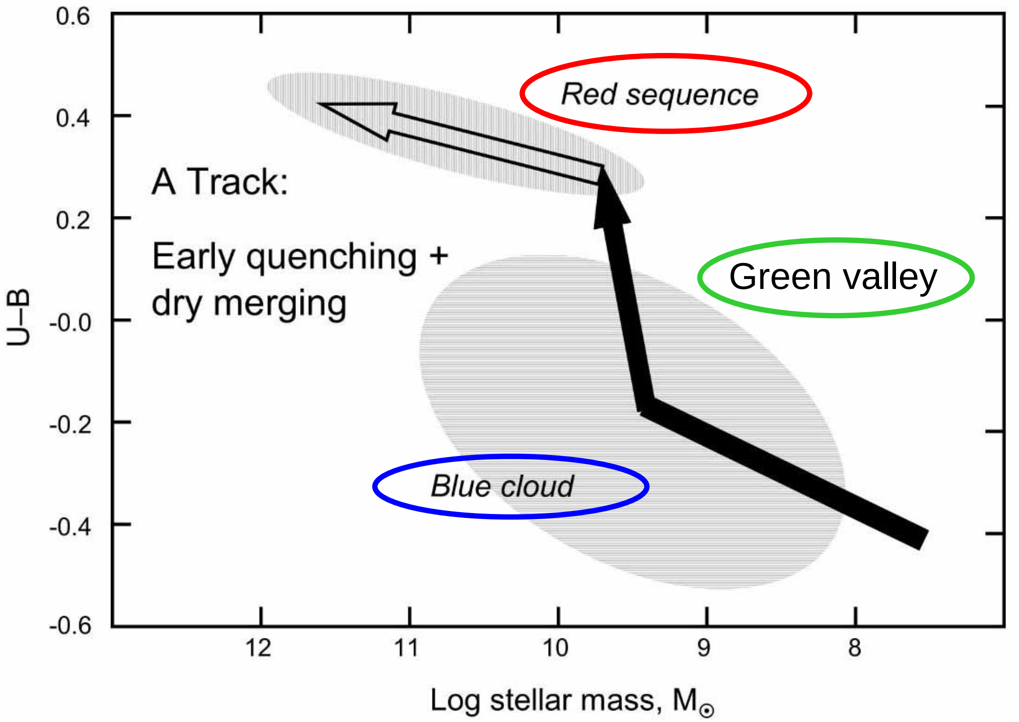
- We may be entering the epoch when galaxies are actively forming stars in the high-density core of galaxy clusters.

- Environment of intermediate density is a key to the understanding of truncation of star formation.

- There is significant star formation hidden in the optical surveys.

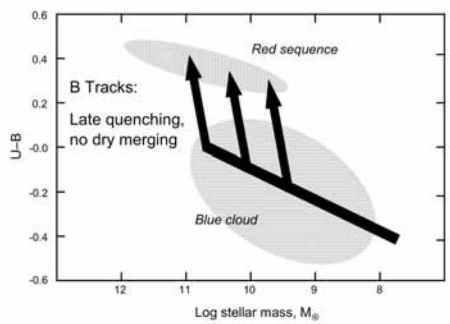
環境効果の検証
Verifying the Environmental Effects

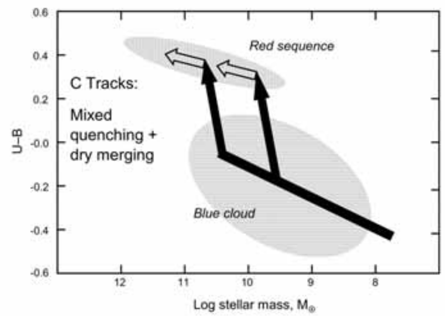
- How and by which mechanism were galaxy properties modified during cluster assembly?
- When, where and how was SF activity quenched?



(magnitude)

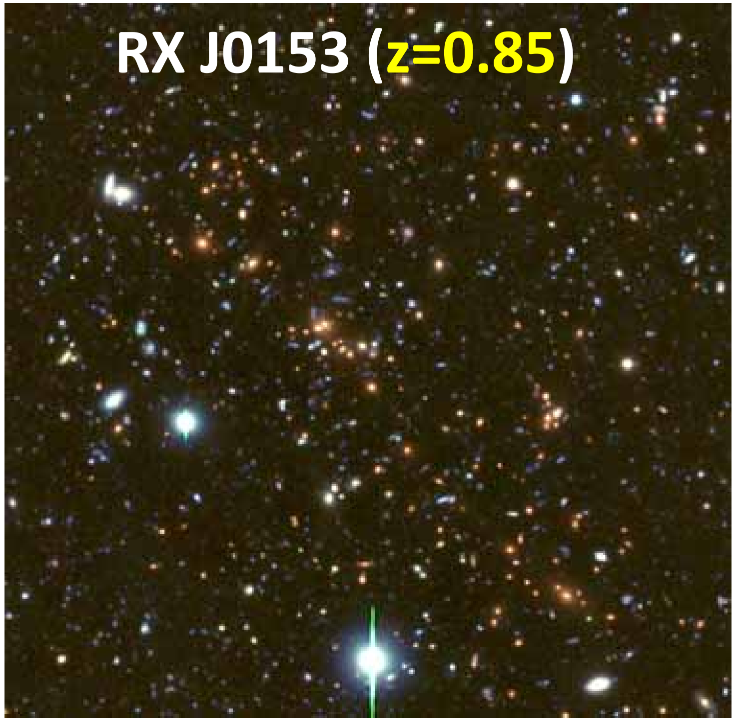
Faber et al. 2007, ApJ, 665, 265

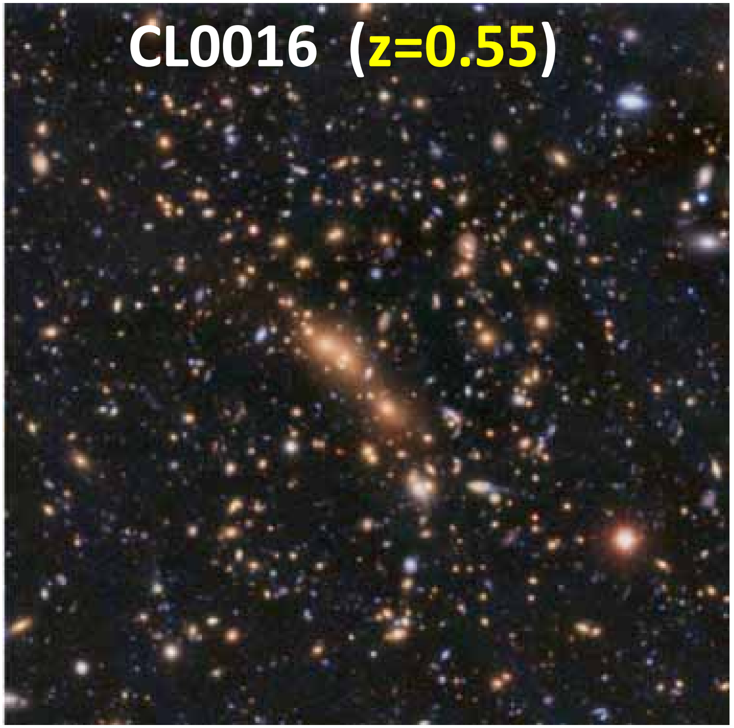




“The Build-up of the Color-Magnitude Relation as a Function of Environment”

Tanaka, Kodama, SO, Shimasaku et al. 2005, MNRAS, 362, 268





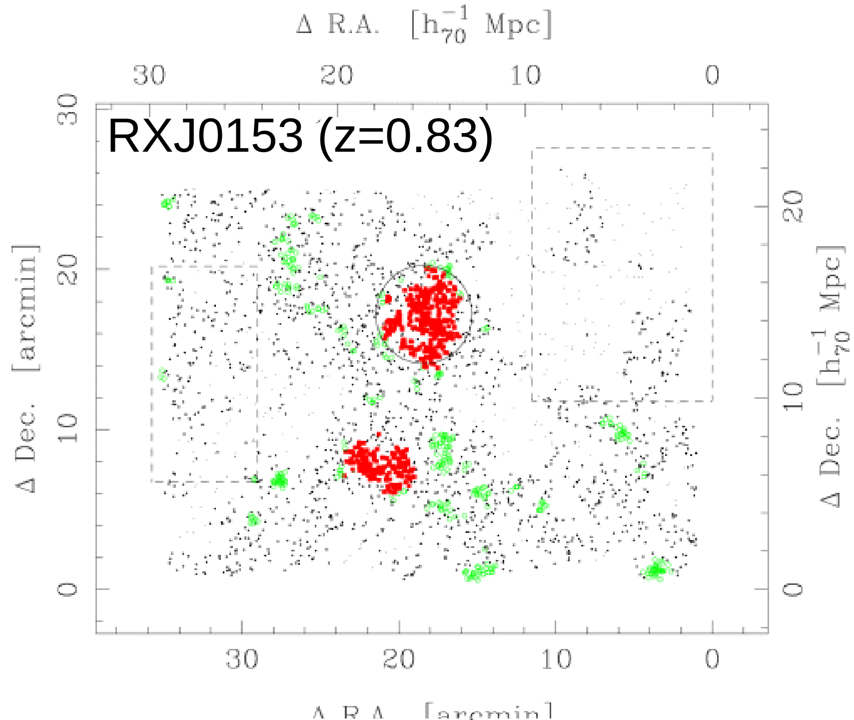
SDSS
(z=0)

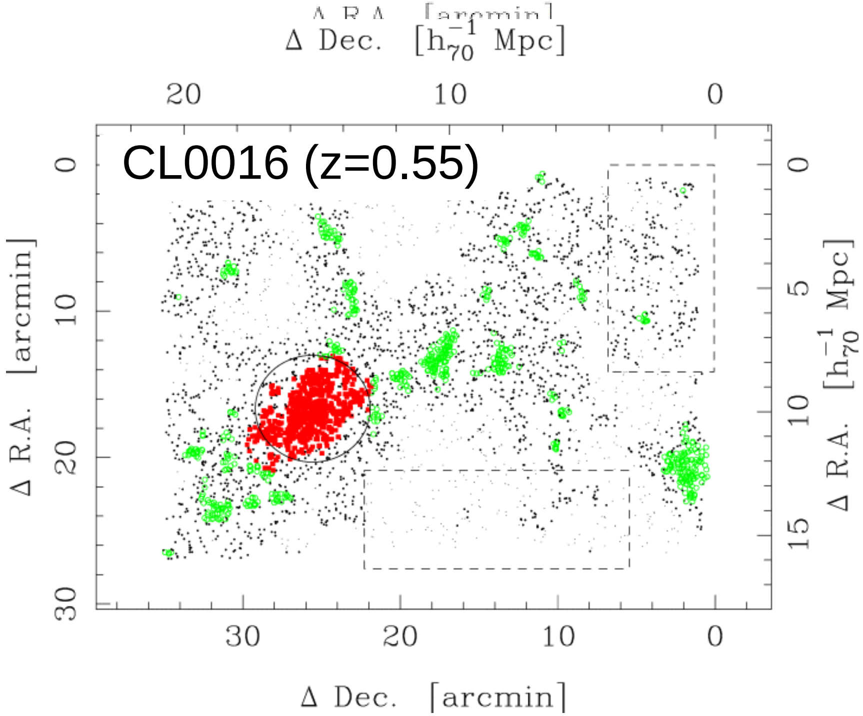
t

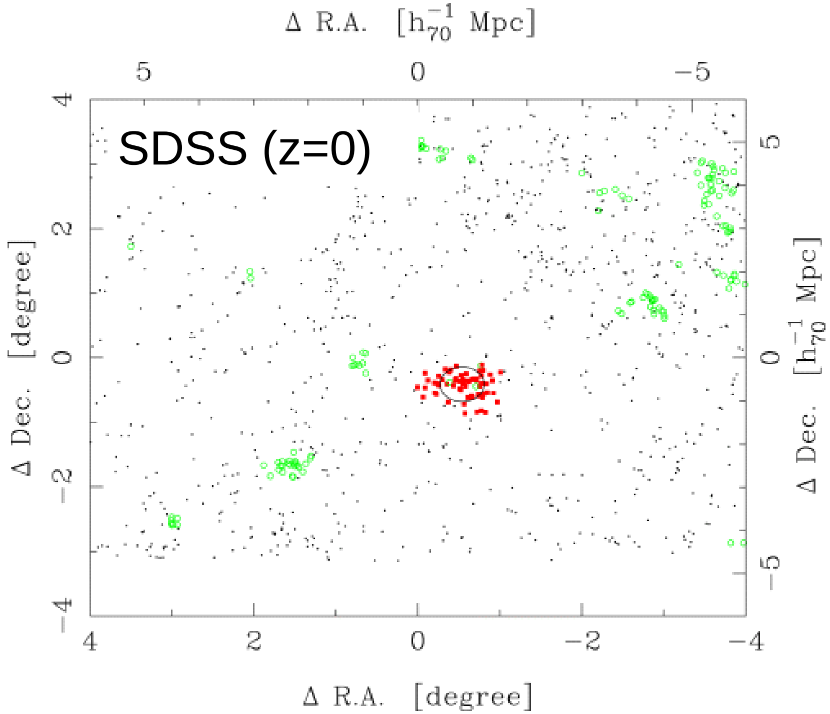
Cosmic time

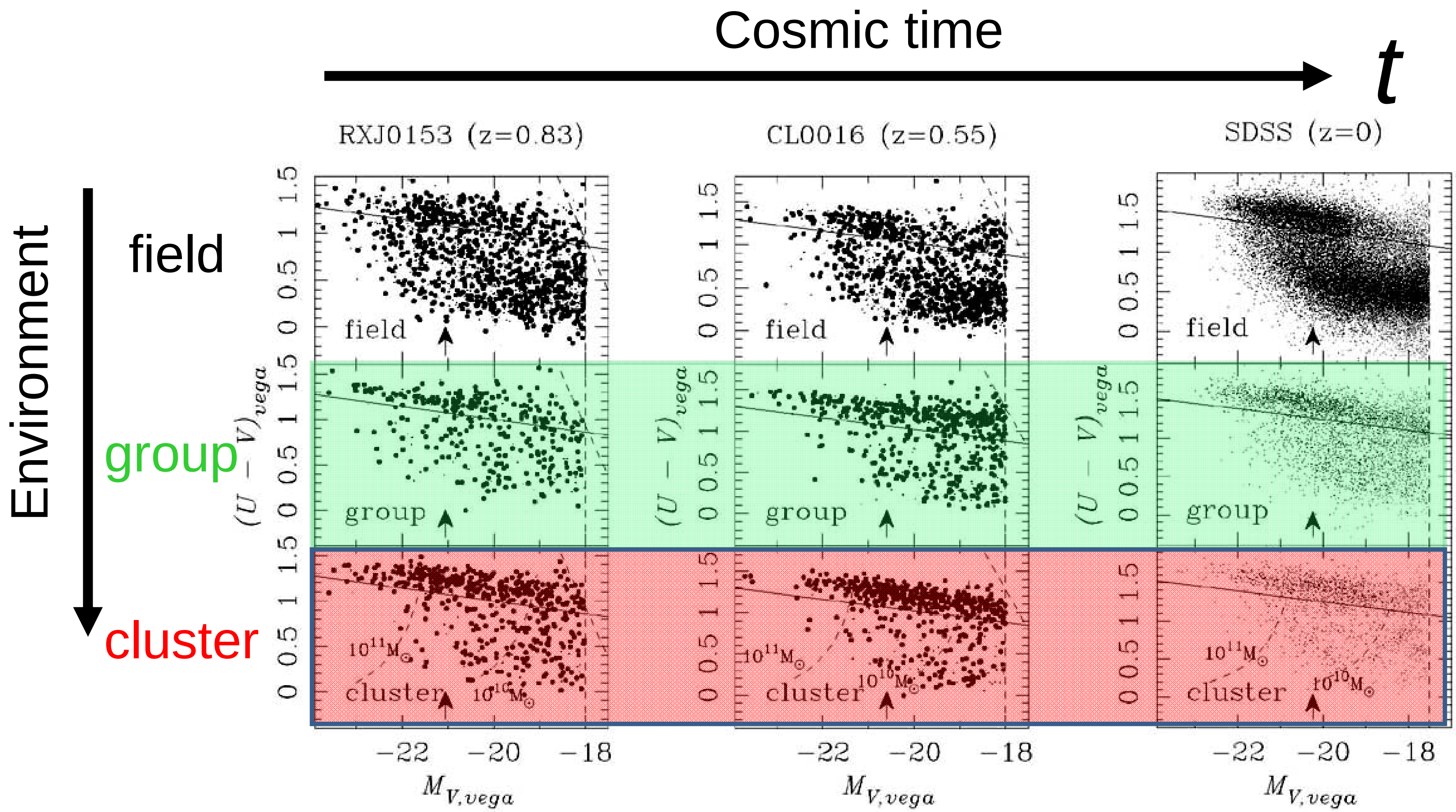
Three environments are defined at each epoch (z=0, 0.55, and 0.83)

- field (black)
- group (green)
- cluster (red)









- bright end of the red sequence forms first (at any environment)
- bright part of the blue cloud gradually fades (down-sizing)
- speed of evolotion: cluster (fastest) → group→ field(slowest)

New observations to prove star formation activity

- XMMXCS J2215.9-1738 (z=1.46)

  Hayashi, Kodama, Shimasaku, SO et al. 2010, MNRAS, 402, 1980

  Subaru/Suprime-Cam(+MOIRCS) [OII] λ3727x(1+z)=9200A→NB912

  44 [OII] emitting galaxies

- RXJ1716.4+6708 (z=0.81)

  Koyama, Kodama, Shimasaku, SO et al. 2010, MNRAS, 403, 1611

  Subaru/MOIRCS(+AKARI) Hα λ6563x(1+z)=1.2μm→NB119(MOIRCS)

  114 Hα emitters+15μm-detected sources

- CL0939+4713 (A859) (z=0.4)

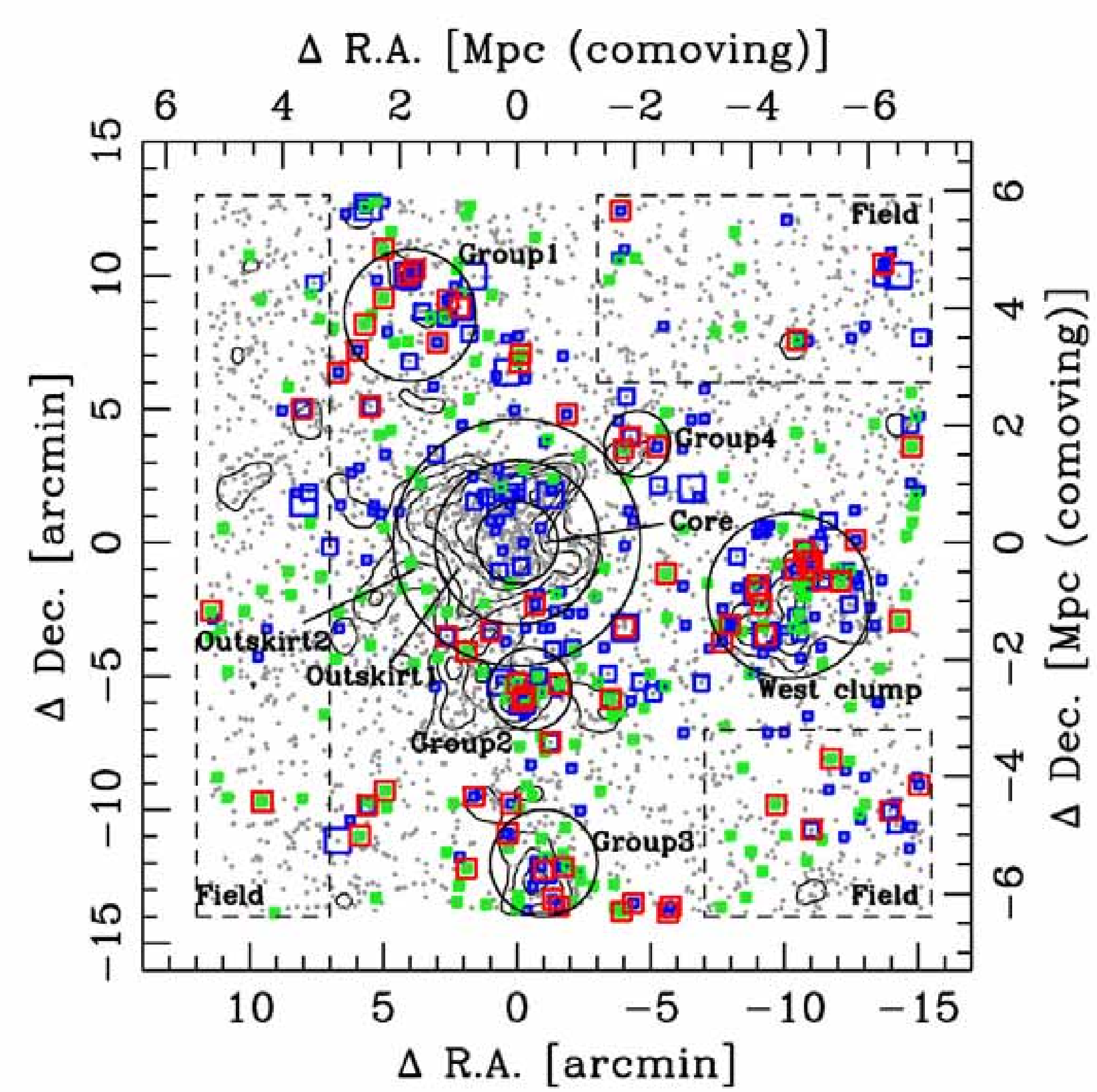
  Koyama, Nakata, Kodama, Shimasaku, SO 2010, to be submitted soon

  Subaru/Suprime-Cam

  445 Hα emitters Hα λ6563x(1+z)=9190A→NB912

CL0939+4713 (A859) (z=0.4)

Koyama, Nakata, Kodama, Shimasaku, SO 2010, to be submitted



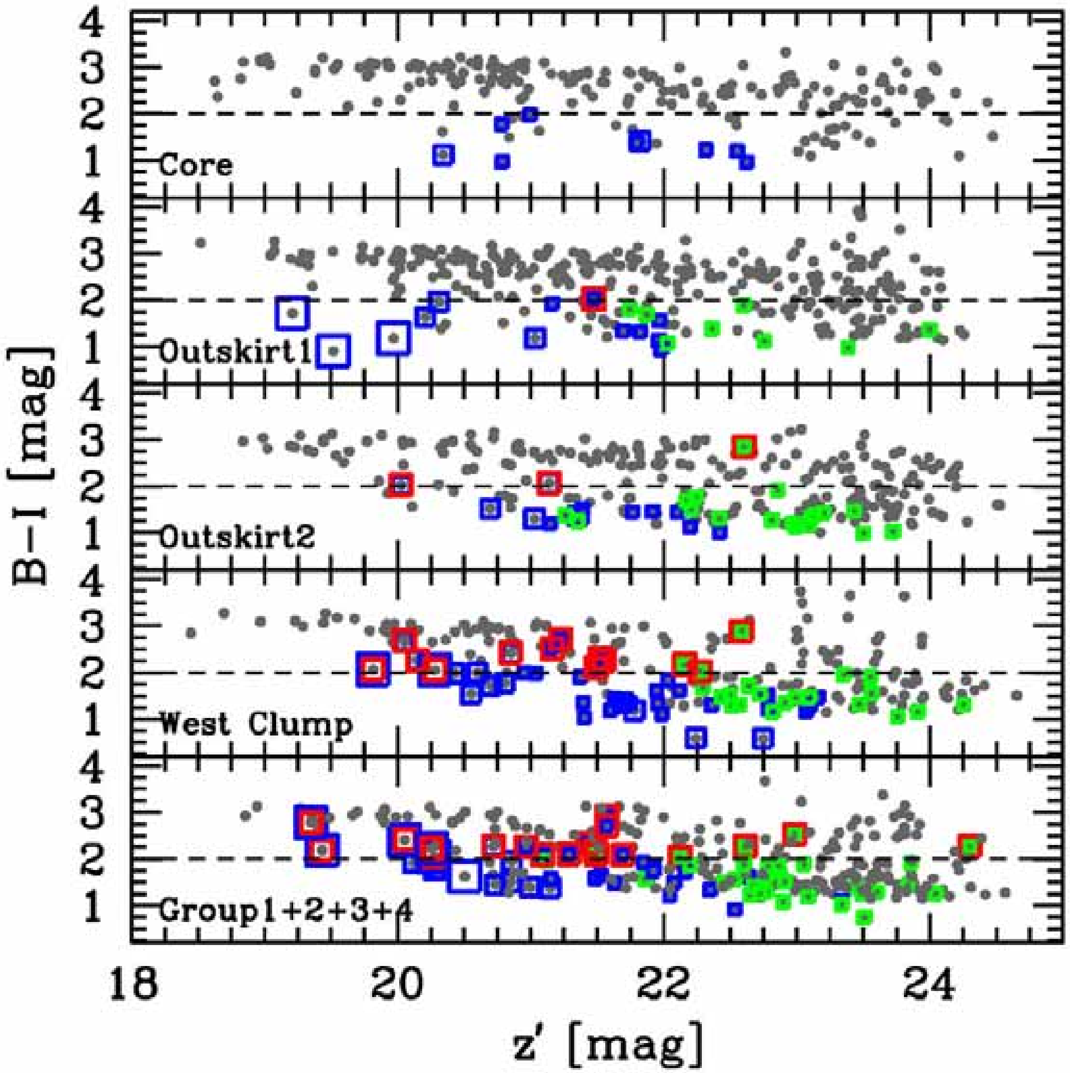
blue sqares: Hα emitters (SFR>0.75 Ms)

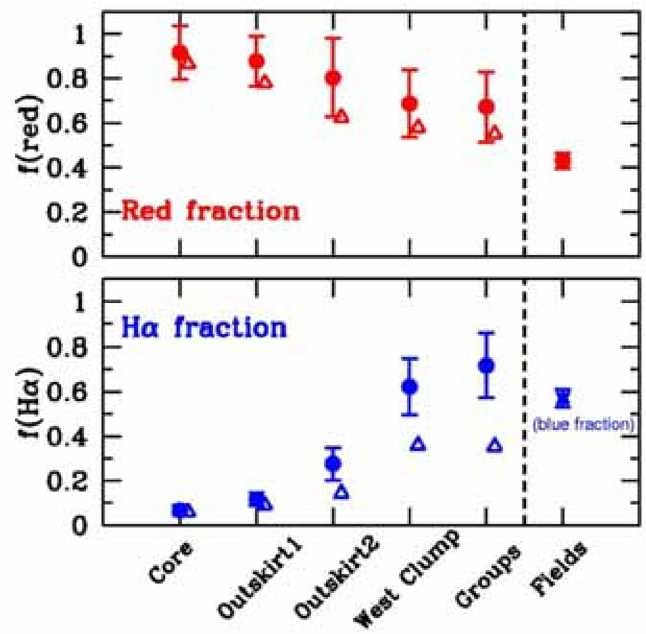
green squares: Hα emitters (SFR<0.75 Ms)

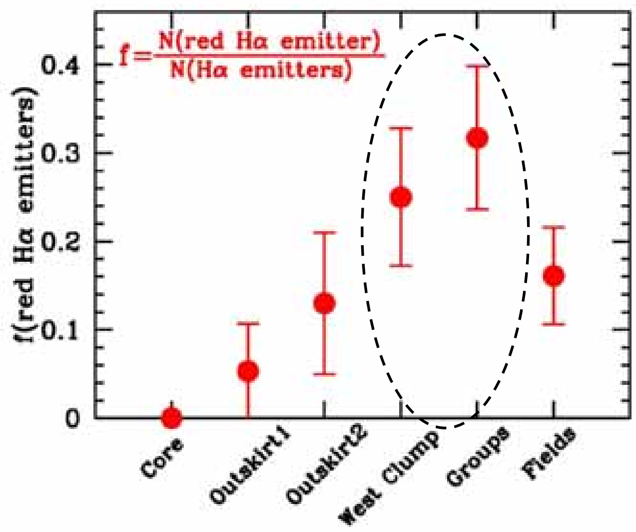
red squares: red Hα emitters (B-I)>2

CL0939+4713 (A859)   (z=0.4)

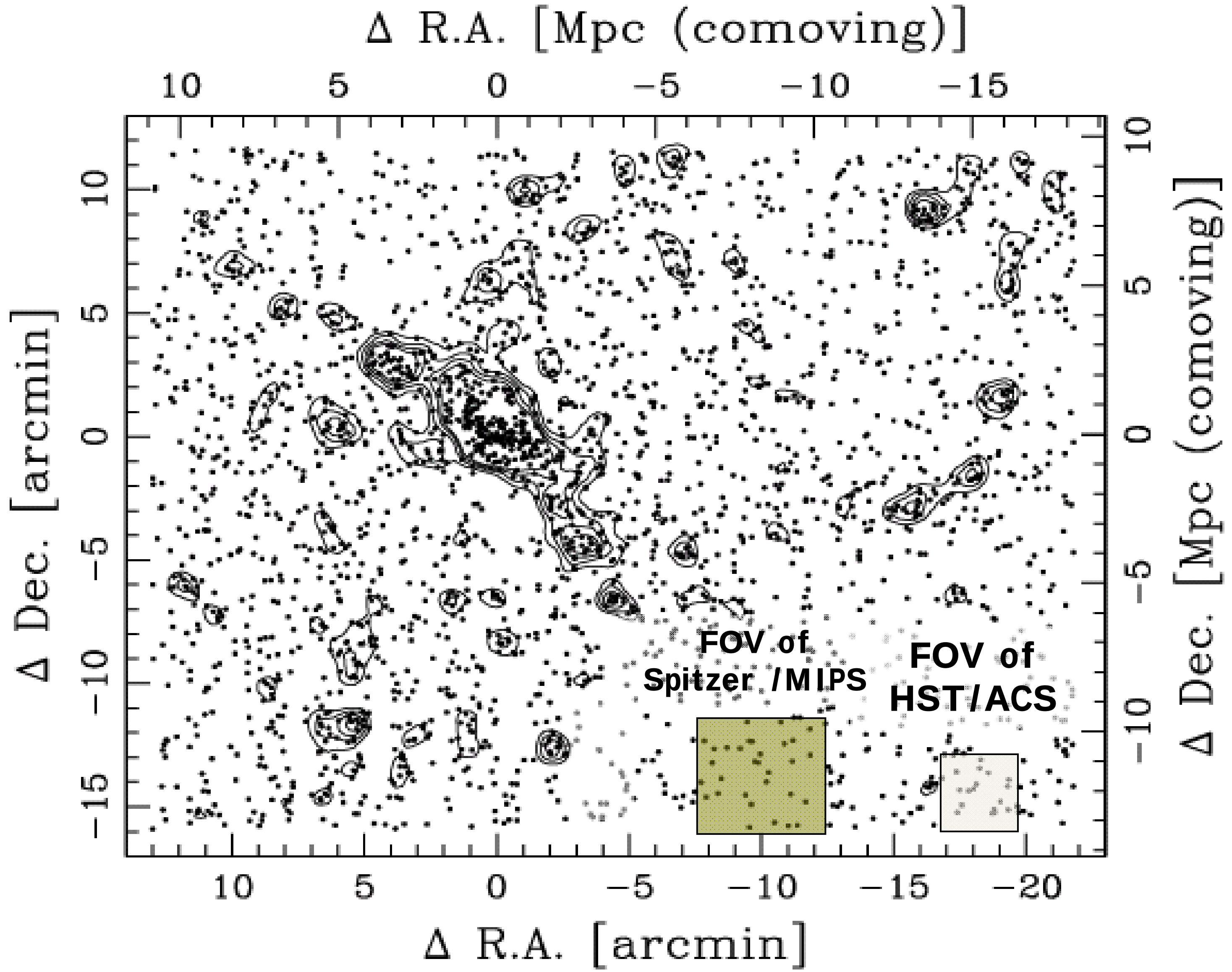
Koyama, Nakata, Kodama, Shimasaku, SO   2010,   to be submitted





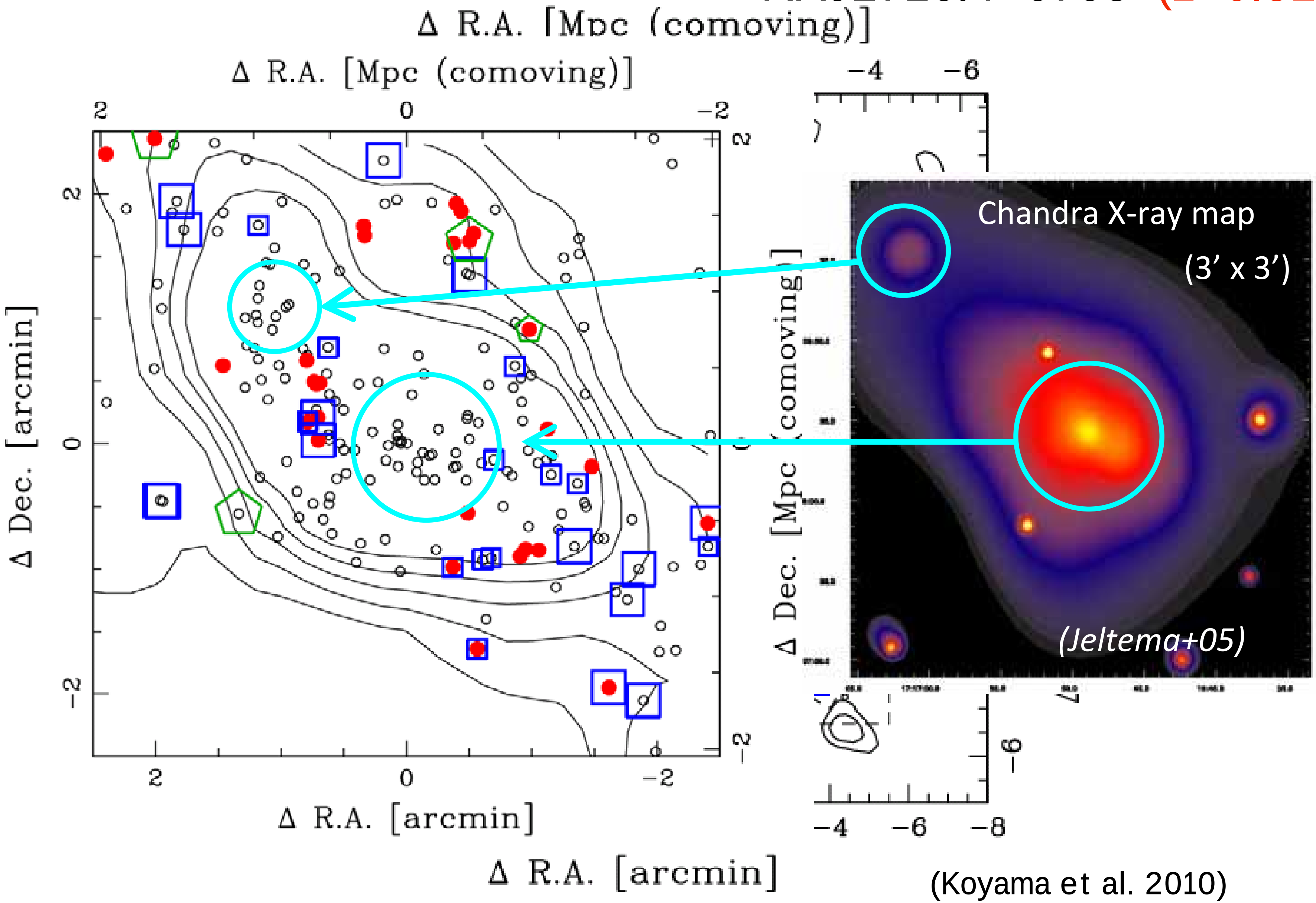


Target: RXJ1716+6708 cluster at z=0.81



Spatial distribution of Hα emitter MIR source

RXJ1716.4+6708 (z=0.81)

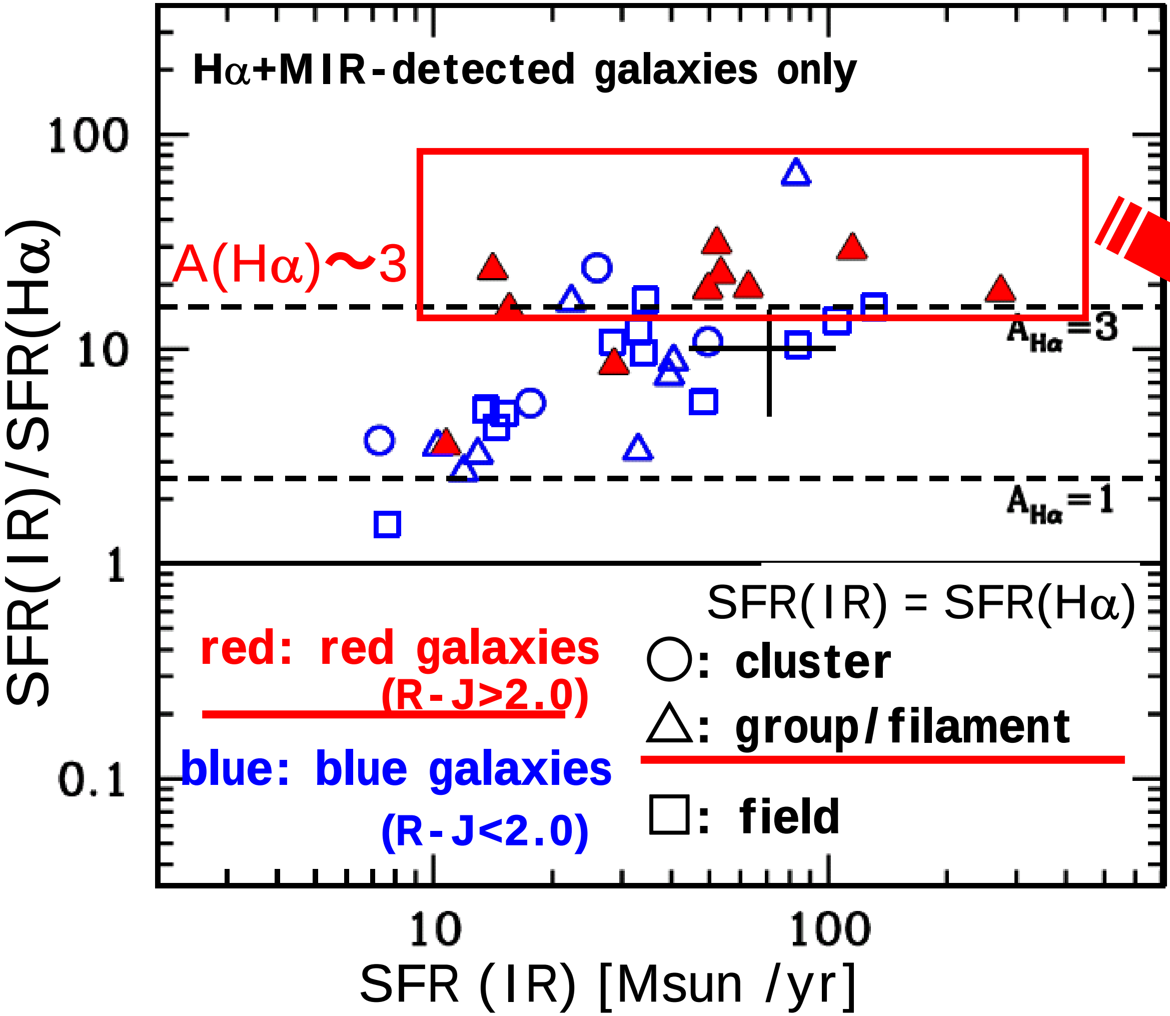


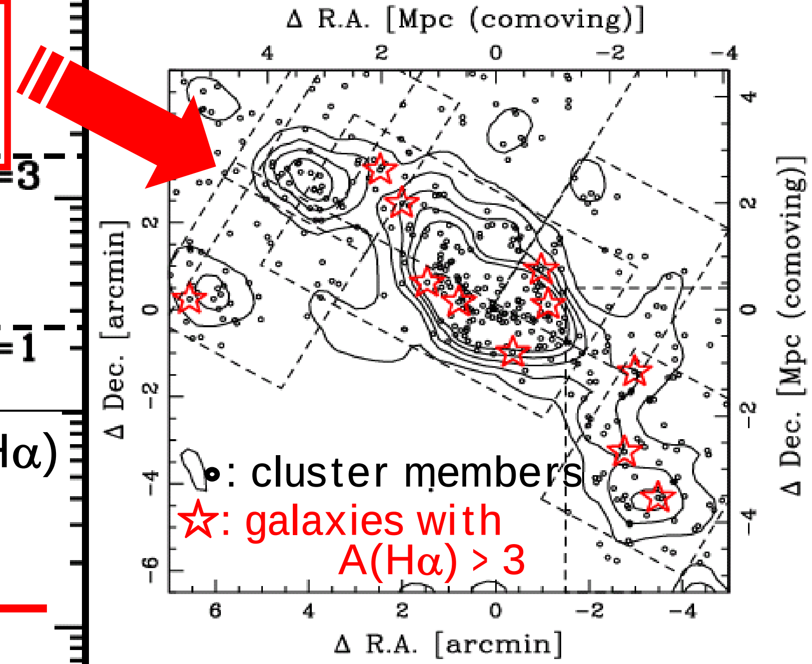
(Koyama et al. 2010)

Evidence for the hidden star formation

Even Hα-derived SFRs are sometimes severely underestimated !!

RXJ1716.4+6708 (z=0.81)

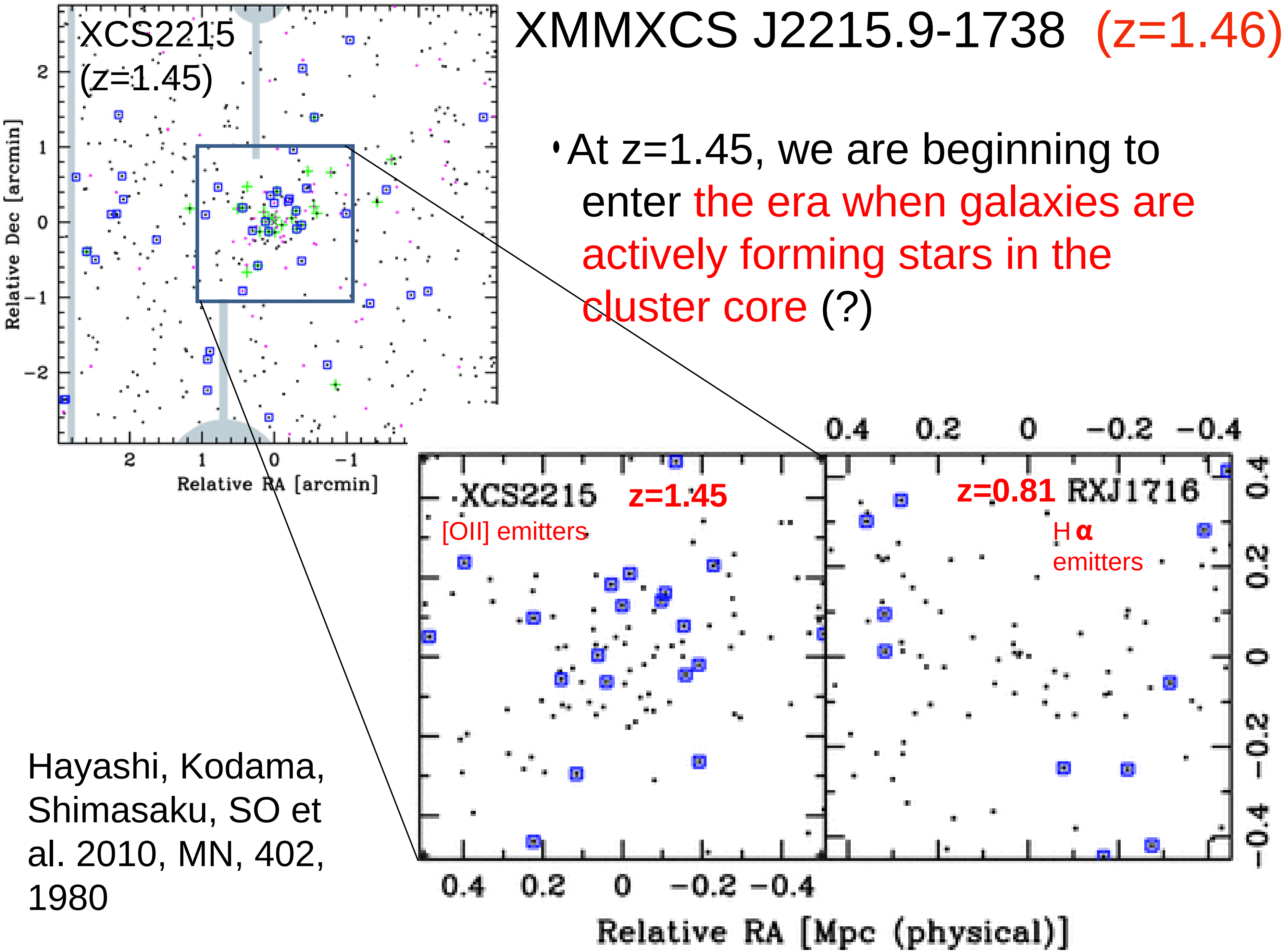




Dusty galaxies are preferentially found in the cluster outskirts

XMMXCS J2215.9-1738 (z=1.46)

- At z=1.45, we are beginning to enter the era when galaxies are actively forming stars in the cluster core (?)



Hayashi, Kodama, Shimasaku, SO et al. 2010, MN, 402, 1980

Summary of Part II

- We may be entering the epoch when galaxies are actively forming stars in the high-density core of galaxy clusters.
- Environment of intermediate density is a key to the understanding of truncation of star formation.
- There is significant star formation hidden in the optical surveys.