PFS-SSP galaxy survey workshop (IPMU; 2015/11/13)

Physical States of Galaxies across Various Environments

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Mahalo-Subaru, Gracias-ALMA, and HSC-HSC teams

A galaxy cluster RXJ0152 at z=0.83 (Subaru/Suprime-Cam)

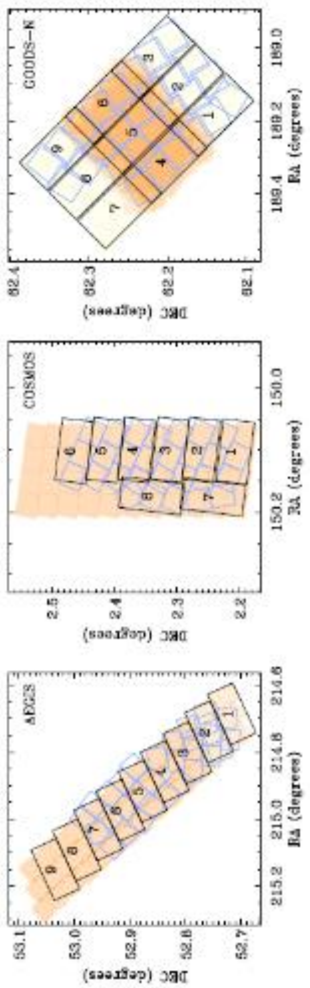
Intensive Spectroscopic Surveys in the General Field at 1.5<z<3 have been already largely done with MOSFIRE and FMOS

MOSDEF (Kriek et al. 2014)

~1500 H-selected galaxies at 1.5<z<3.8

KBSS-MOSFIRE (Steidel et al. 2014)

~800 UV-selected galaxies at 1.5<z<2.6



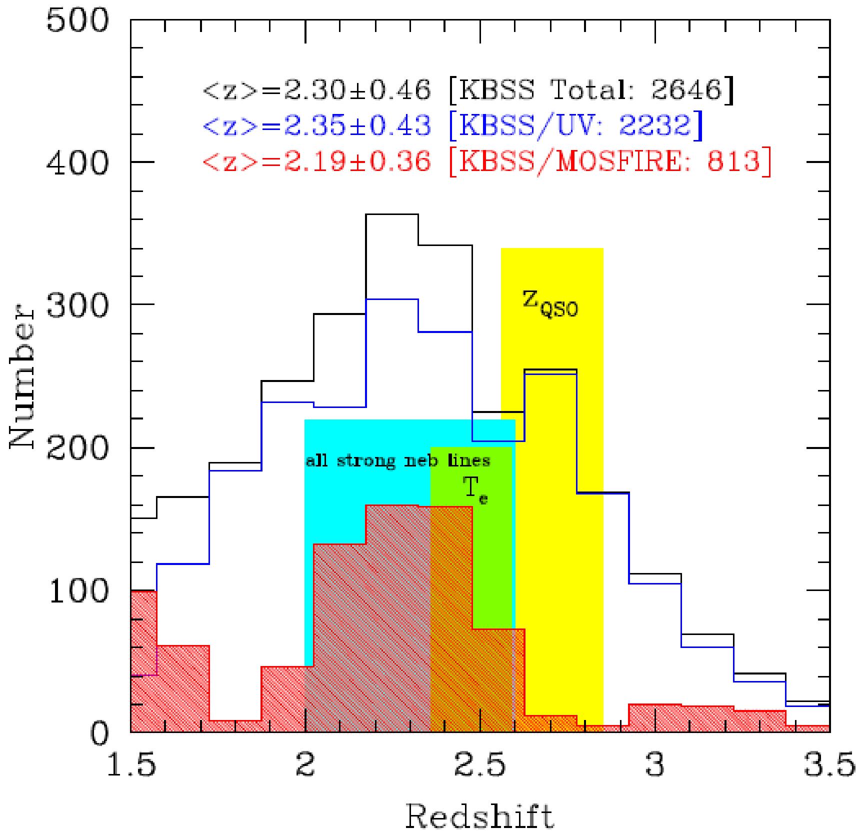
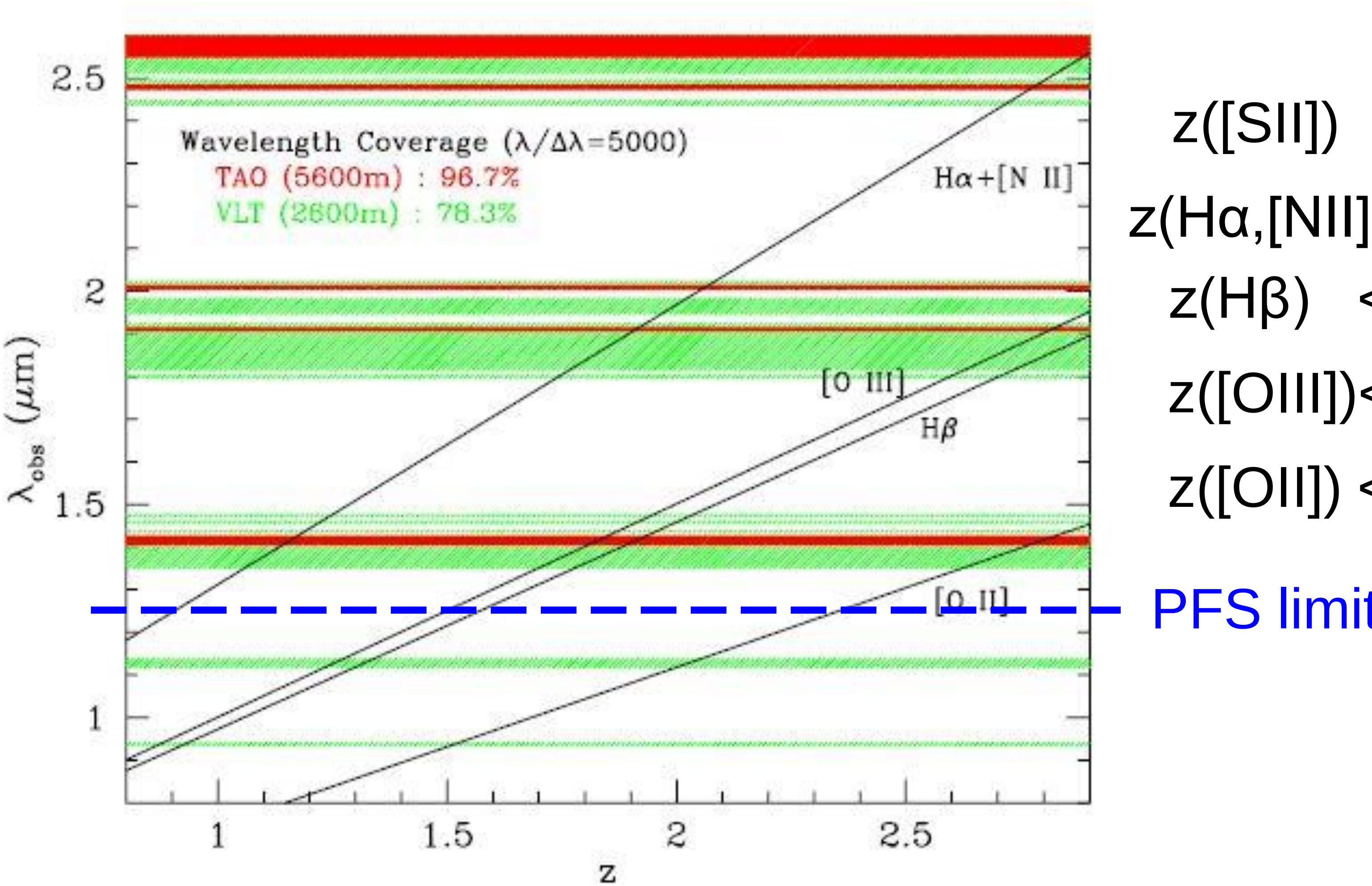


Figure 1. Redshift histogram in the KBSS survey regions as of 2014 June.

PFS (λ＜1.26μm) is best at z < 1.0-1.5



z([SII]) < 0.87

z(Hα,[NII]) < 0.92

z(Hβ) < 1.59

z([OIII])< 1.52

z([OII]) < 2.38

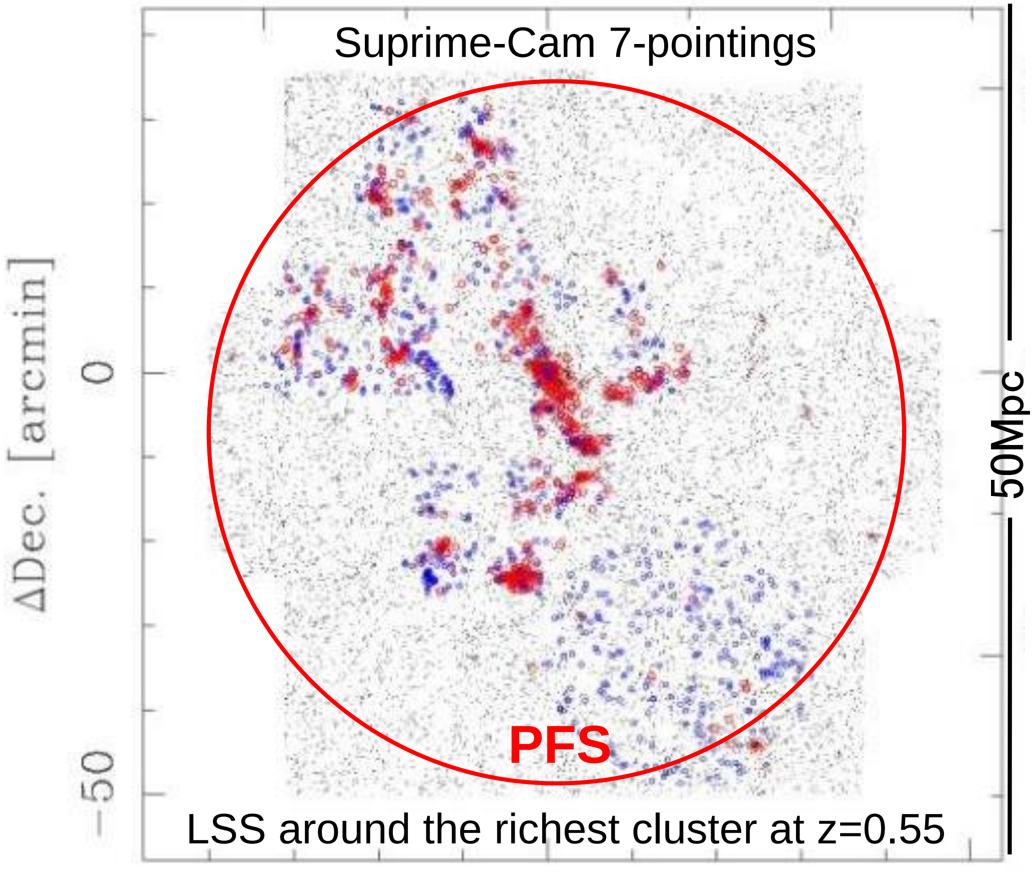
Also, “stacking analysis of weak but useful lines” benefited by super statistical sample of galaxies is the key for PFS.

HSC + PFS is powerful for clusters/LSSs

1.3° = 75 Mpc (z=1), 100 Mpc (z=1.5), 118 Mpc (z=2) in co-moving

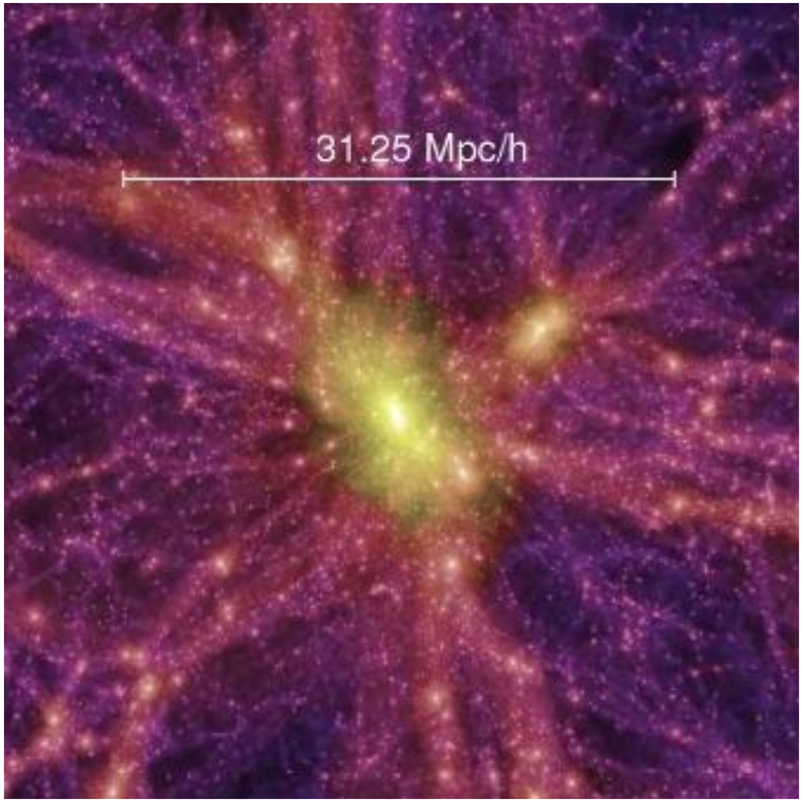
PISCES

CL0016 cluster (z=0.55)
(Tanaka, M. et al. 2009)



~1,200 redshifts from spectroscopy
red are cluster members, while blue are non-members

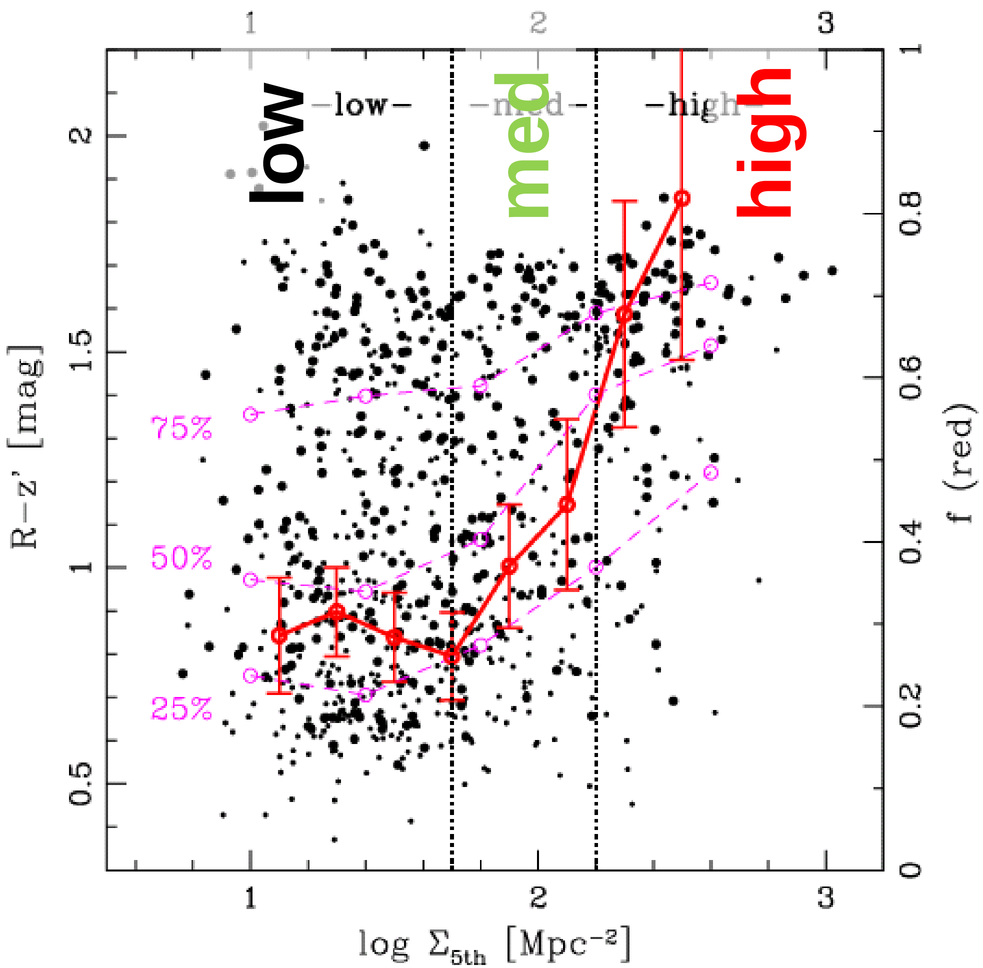
Millenium Simulation
(Springel et al. 2005)

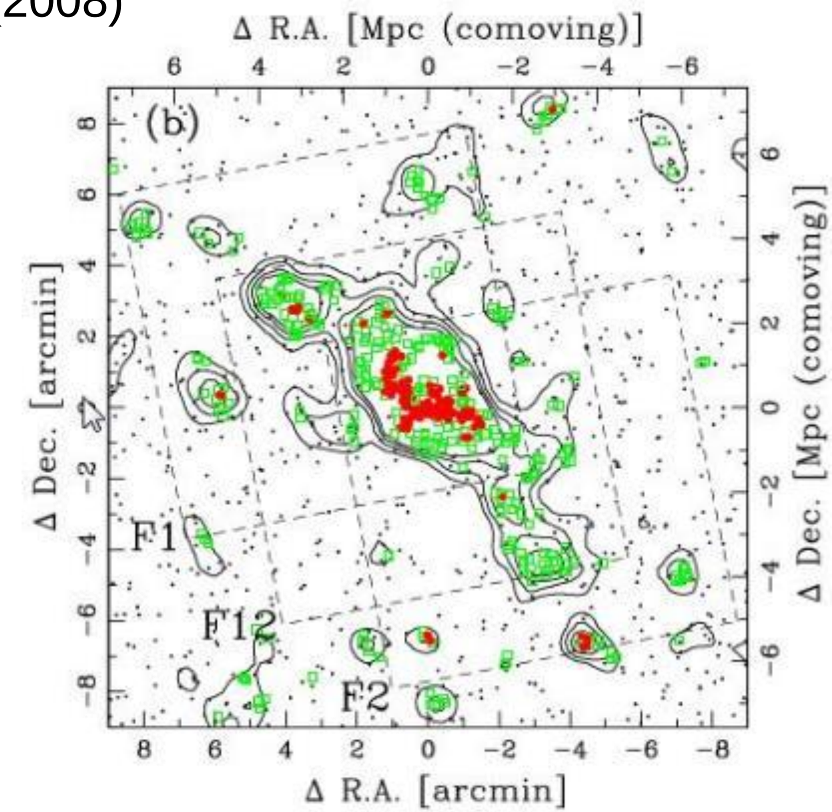


Cluster outskirts is the key environment at z<1

RXJ1716 cluster (z=0.81)

Koyama et al. (2008)





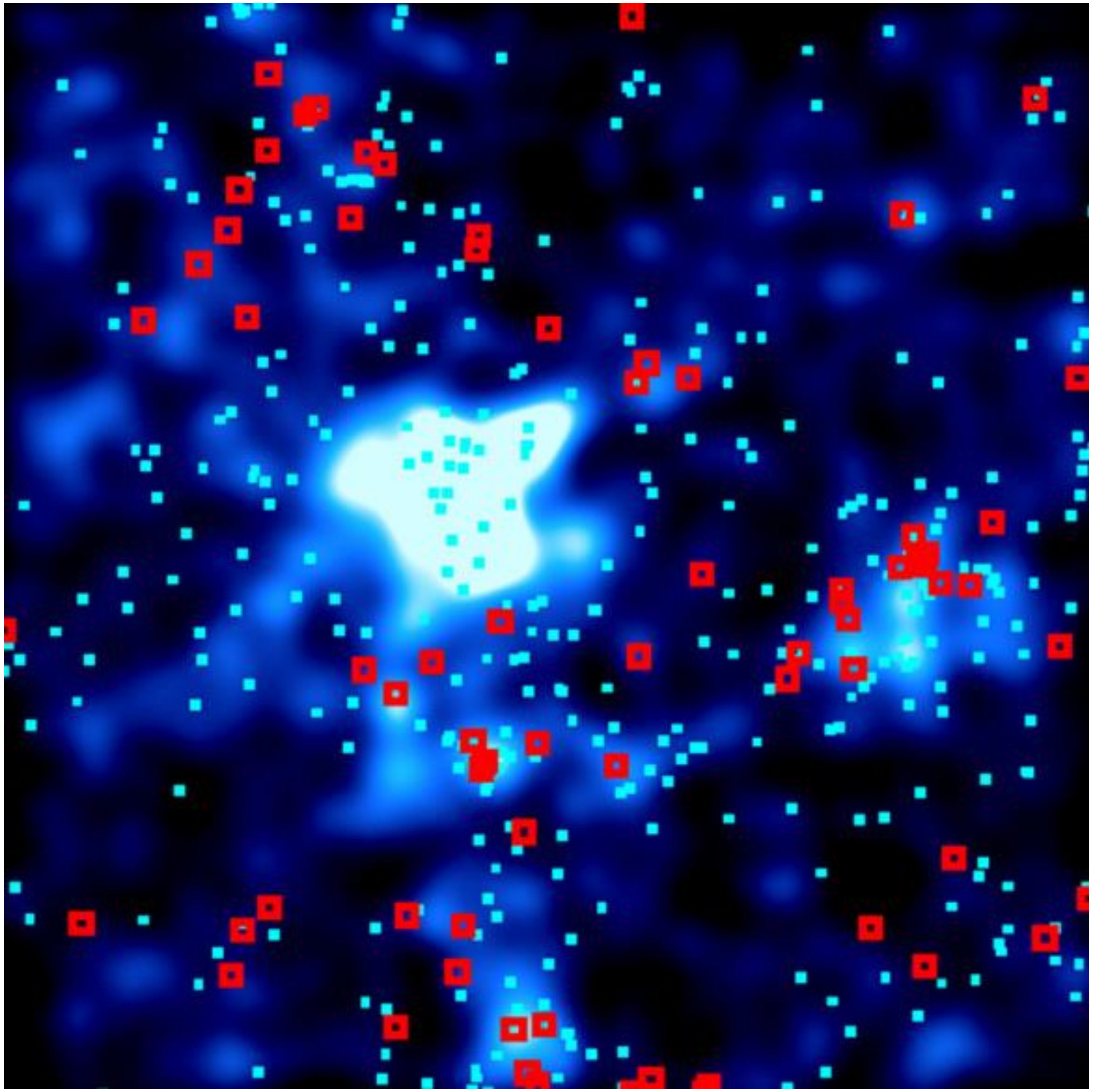
high ~ cluster core

med ~ group / filament

low ~ field

Quenching is taking place on in cluster outskirts!

Dusty SF or Quenching (Red/Green HAEs) are seen in cluster outskirts



□ red/green HAEs

■ blue HAEs

SFR>0.75$M_{\odot}$/yr

Such population always preferentially reside in the most active environment at any epoch!

(eg., cores in proto-clusters at z>1.5)

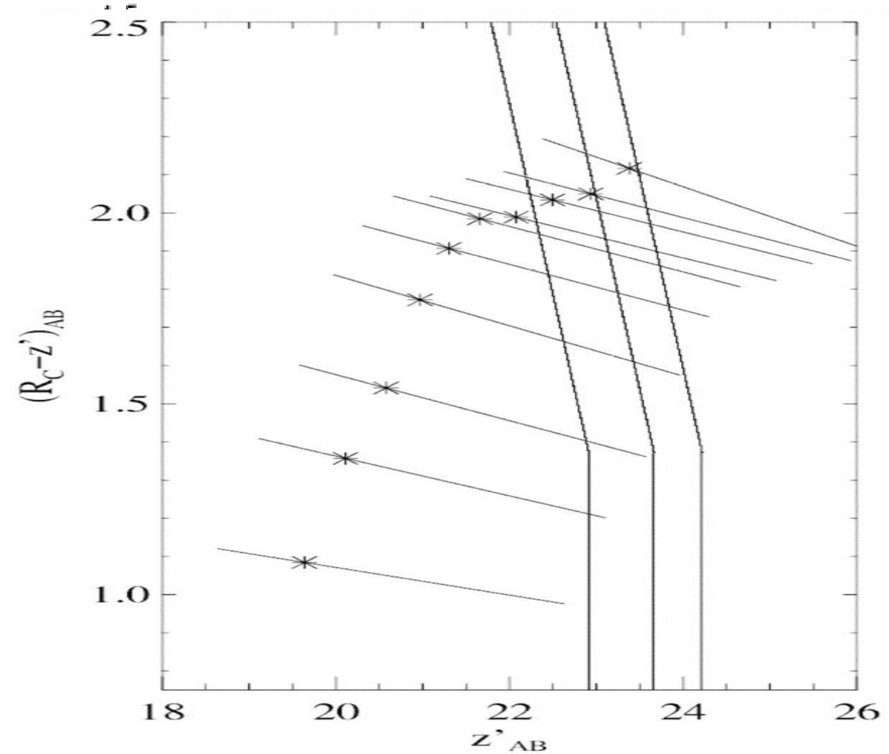
“Octopus” cluster (CL0939@z=0.41)

Koyama et al. (2011)

Hybrid Search for Clusters with HSC (HSC^2)

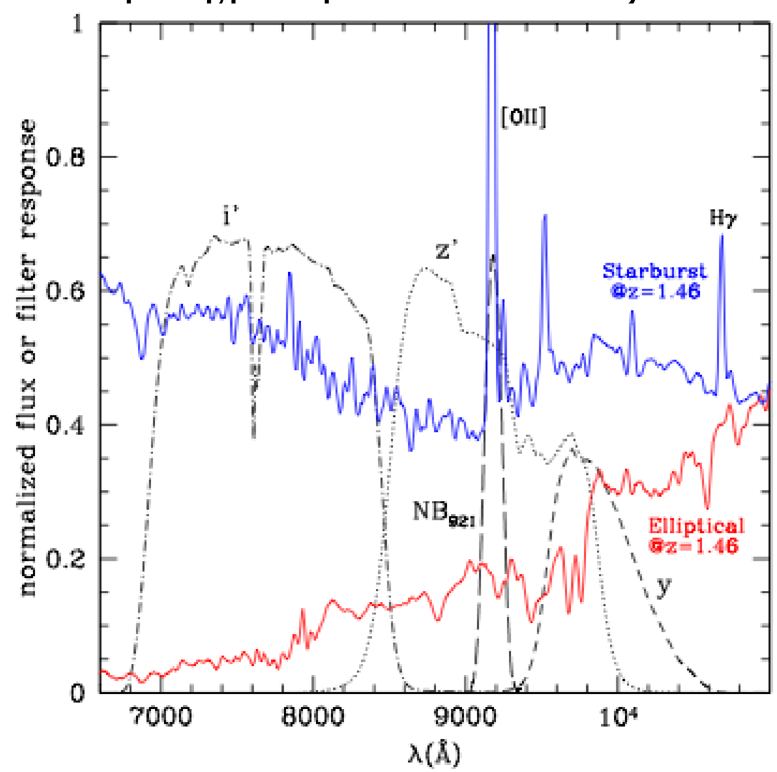
"red sequence" survey (passive galaxies)

phot-z (or color-color) survey to z~1.5



"blue coud" survey (SF galaxies)

NB [OII],[OIII] emitter survey to z~1.7



HSC NB filters

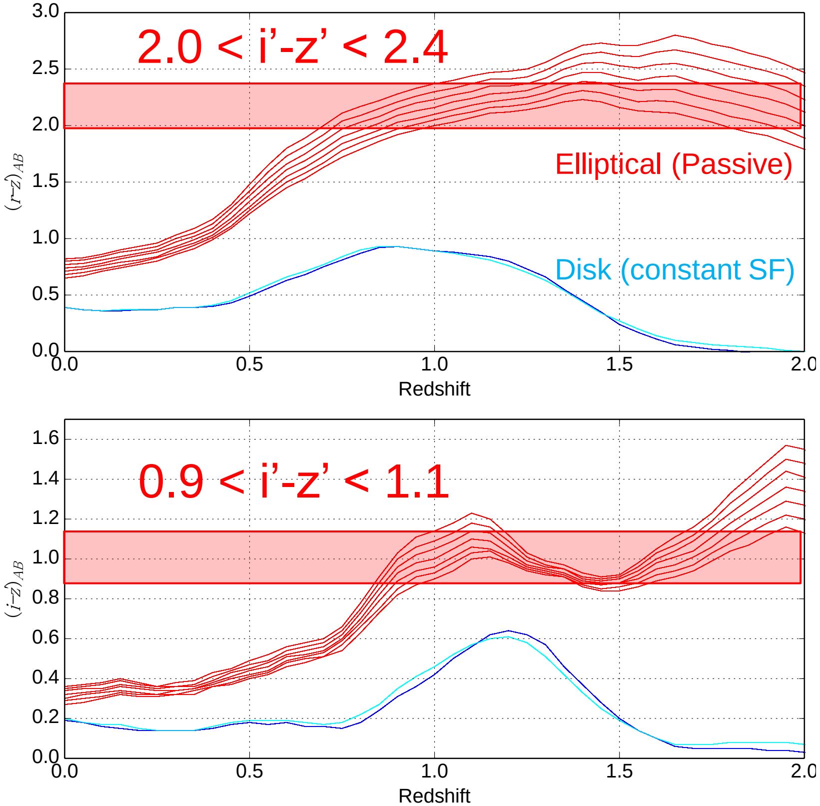
Filter	CW [Å]	FWHM [Å]	z(Lyα)	z([OII])	z(Hβ)	z([OIII])	z(Hα)
NB816	8160	120	5.711±0.049	1.189±0.016	0.679±0.012	0.630±0.012	0.243±0.009
NB921	9210	131	6.574±0.054	1.471±0.018	0.895±0.013	0.839±0.013	0.403±0.010
NB973	9730	138	7.002±0.057	1.611±0.019	1.002±0.014	0.943±0.014	0.483±0.011
NB101	10095	143	7.302±0.059	1.709±0.019	1.077±0.015	1.016±0.014	0.538±0.011

Red sequence cluster survey with HSC at z~1

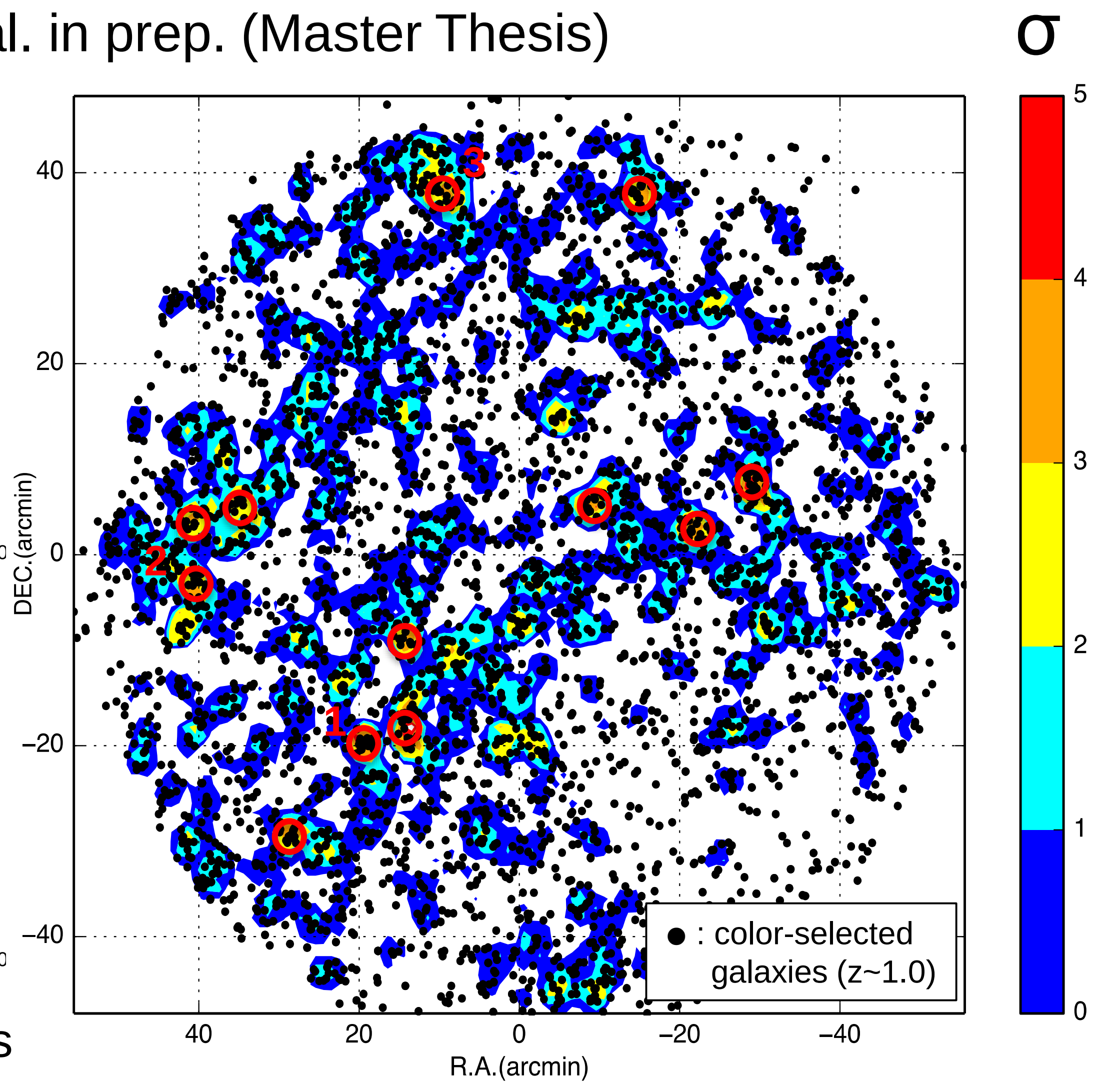
HSC-Udeep field in COSMOS (=1 HSC pointing)

Yamamoto et al. in prep. (Master Thesis)

Colour cuts for the red sequence at z~1



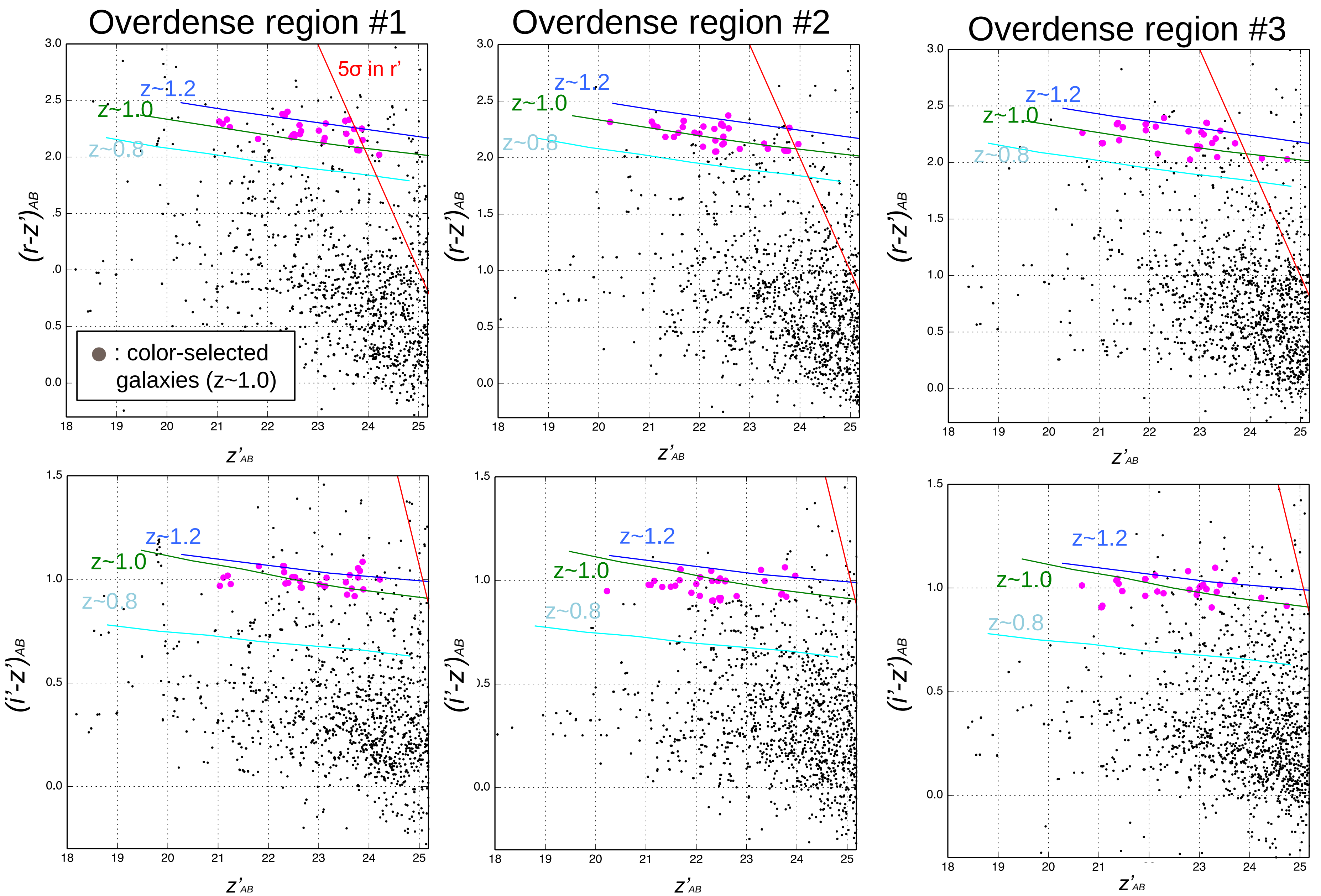
Evolutionary colour tracks of galaxies (Kodama & Arimoto 1998 ; zf =5)



~ 12 overdense regions (>3σ) are discovered

Best examples of z~1 cluster candidates so far

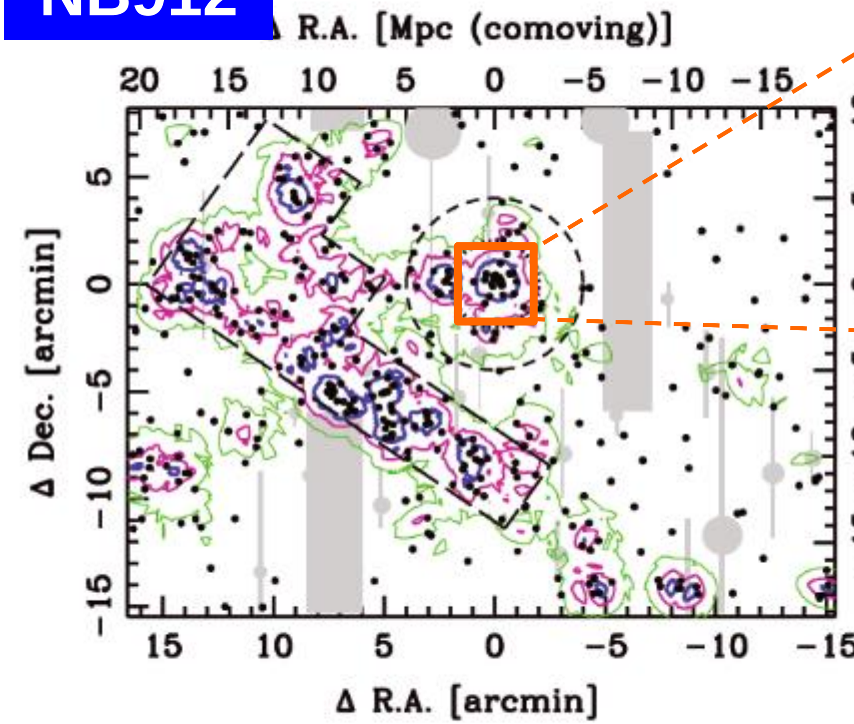
Yamamoto et al. in prep.

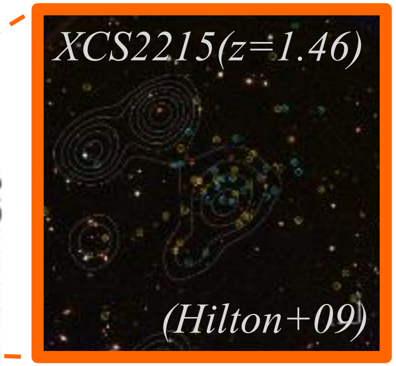


LSSs around two x-ray clusters at z~1.5 traced with [OII] emitters

Suprime-Cam/Subaru
30’ ~ 30-40 Mpc
(co-moving) on a side

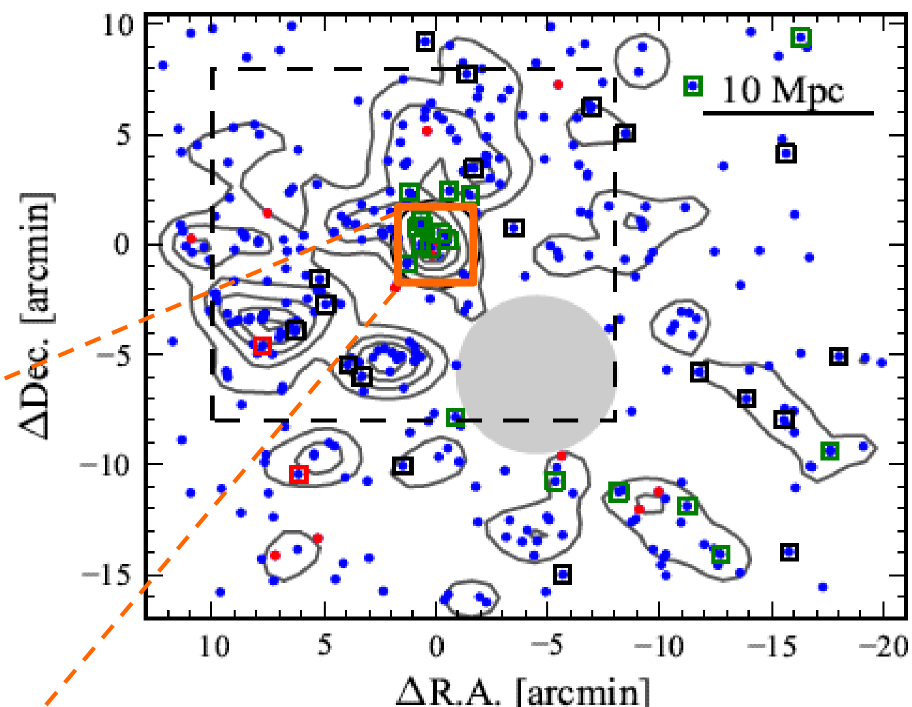
NB912





Hayashi et al. (2011)

NB973



Tadaki et al. (2012)

Subaru-HSC Legacy Surveys

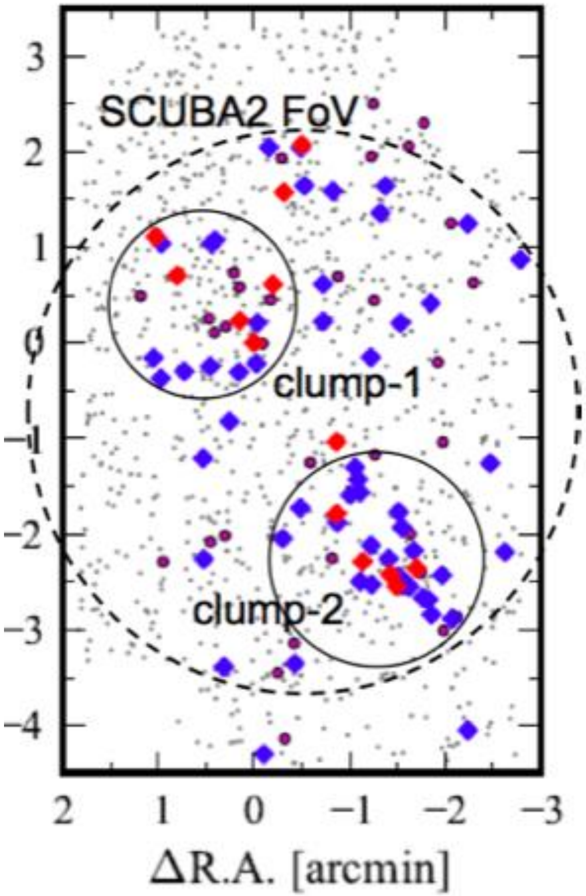
Layer	Area [deg^2]	# of HSC fields	Filters & Depth	Comoving volume [h^{-3}Gpc^3]
Wide	1400	916	$grizy$ ($r \simeq 26$)	$\sim 4.4\,(z < 2)$
Deep	27	15	$grizy$+3NBs ($r \simeq 27$)	$\sim 0.5\,(1 < z < 5)$
Ultradeep	3.5	2	$grizy$+3NBs ($r \simeq 28$)	$\sim 0.07\,(2 < z < 7)$

survey	area	cluster number (dn/dz)
HSC-Deep	27 deg^2	200 (>10^{14} $M_\odot$) at z=1
		6 (>$10^{14.5}$$M_\odot$) at z=1
HSC-Wide	1400 deg^2	10,000 (>10^{14} $M_\odot$) at z=1
		300 (>$10^{14.5}$$M_\odot$) at z=1

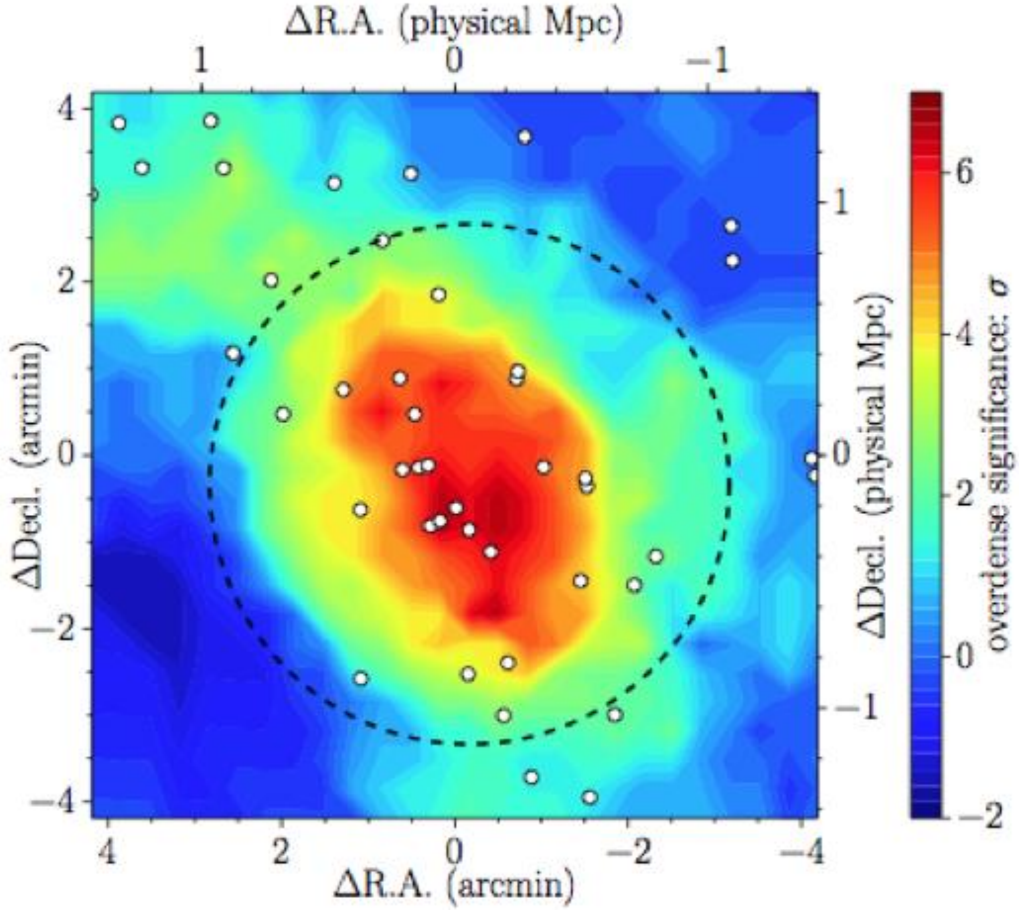
MAHALO-SCUBA2

A coordinated program with JCMT to map dusty starbursts in proto-clusters (15AB; Kodama et al.)

USS1558-003 (z=2.53)



UV(LBG)-selected proto-cluster (z=6.01) in SDF



14hrs on-source integration with SCUBA-2 in DAISY mode (FoV~6')

→ 1.26mJy (3σ)=220M⊙/yr at center, 1.7mJy=300M⊙/yr at edge (@850μm)

“Emission line diagnostics” with PFS

- Resolving Star Formation History in Fine Time Scales

  Hα,Hβ＋ Balmer absorption ＋ SED — z(Hβ) < 1.59

  10^7 yr — $10^{8\text{-}9}$ yr — >10^9 yr

  Starburst? Truncation timescale? → Physical mechanisms

- Accurate Dust Extinction — z(Hα/Hβ) < 0.97

  Hα/Hβ (Balmer decrement) →Dust extinction

- Chemical Evolution of Interstellar Gas — z(R23) < 0.97

  N2, R23, [SII]/[NII], [OIII]λλ4959,5007/[OIII]λ4363 (T_e) → Metallicity

- Ionization States, AGN / SB Separation — z(O32) < 1.52

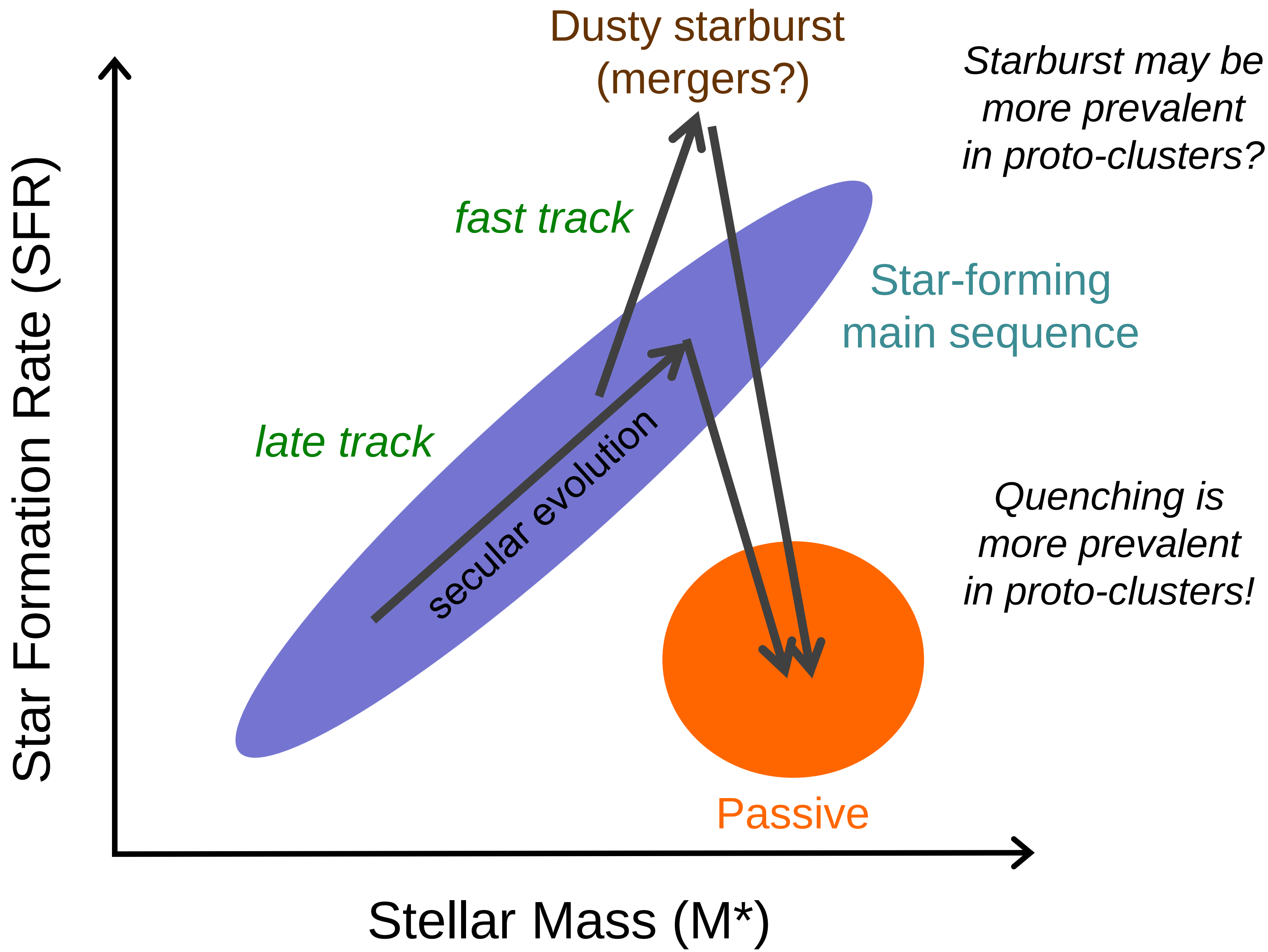
  [OIII]/[OII], [OIII]/Hβ-[SII]/[NII], BPT → Ionization parameter, AGN

- Electron Density — z([OII]) < 2.38

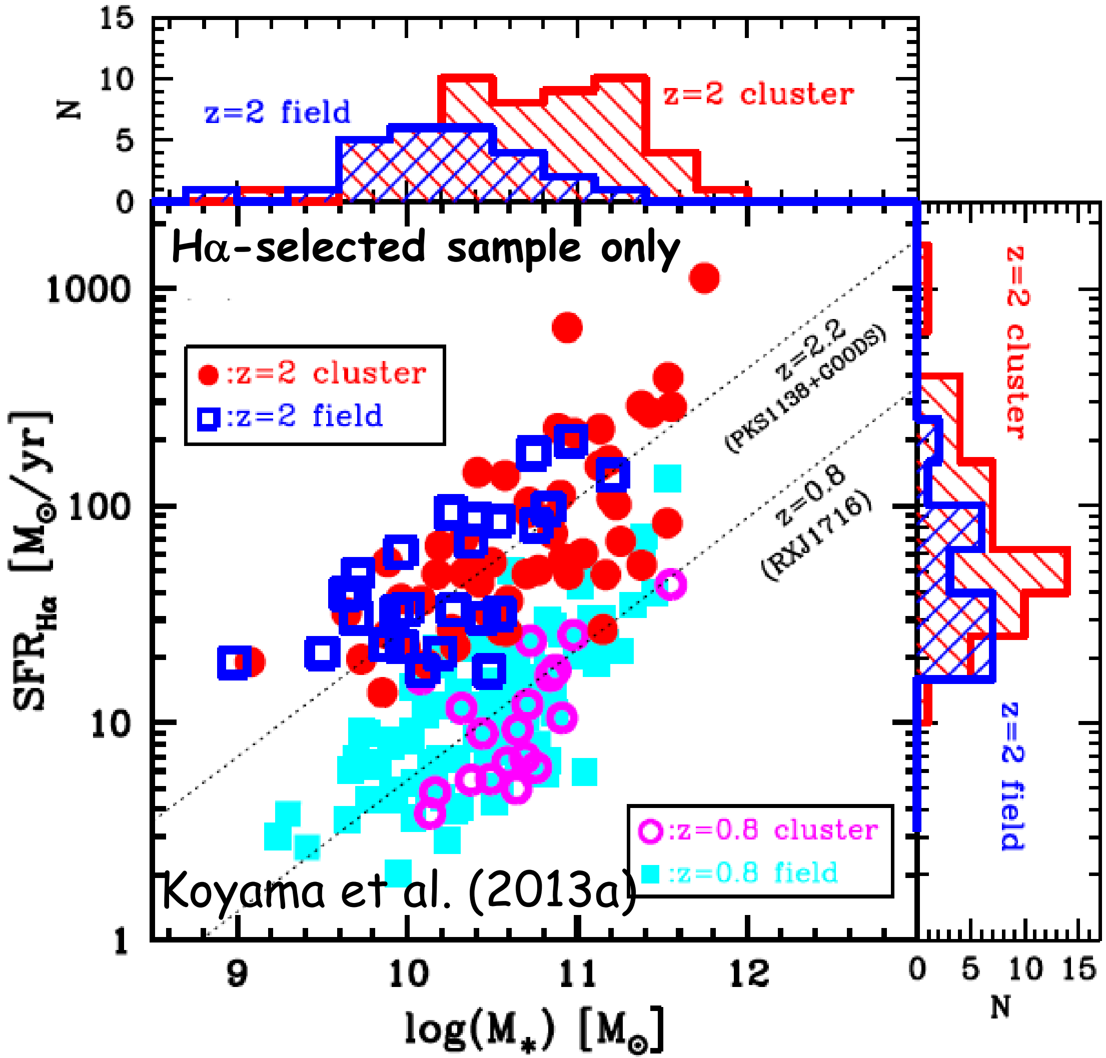
  [OII]λ3726,3729, [SII]λ6716,6731 → e- density of HII-R and PDR

Galaxy evolution on the main seq. and its environ. dependence

→ Large scatter around the MS for cluster galaxies?



Environmental dependence of the Star-Forming Main-Sequence?



M*-scaled dust correction for Hα is applied.
(Garn & Best 2010)

No environmental dependence in the location of the main sequence.

But cluster galaxies tend to be more massive.

Scatter analysis is hard due to short timescale and uncertain dust correction.

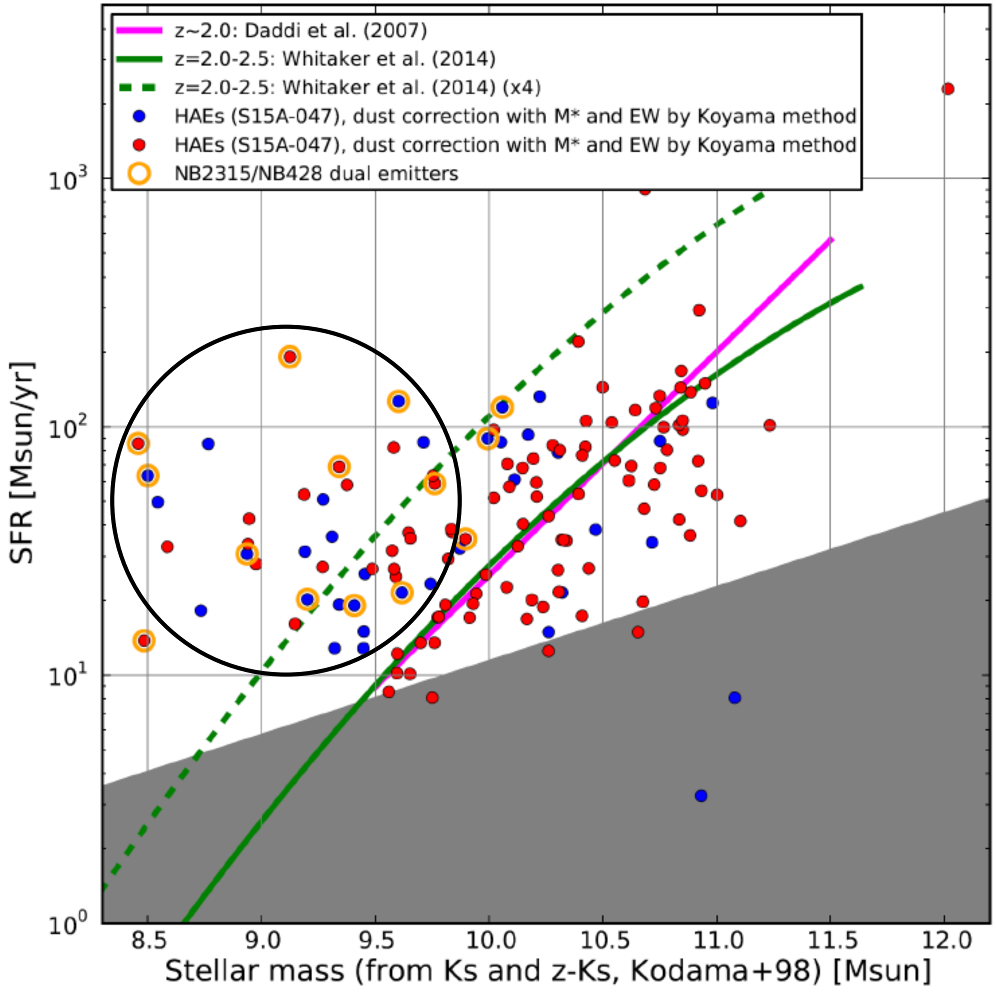
→ Great statistics and accurate dust correction are the keys.

PFS + Balmer decrement is the solutions to z~1 !

MAHALO-Deep on two z~2 proto-clusters

10 hrs exposure at NB (~1 x 10^{-17} erg/s/cm^2), 3 hrs in Ks, etc.

SFR



Preliminary !

USS1558-003 (z=2.53)

Hayashi et al. in prep.

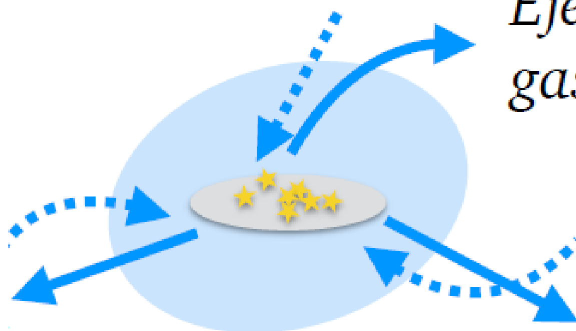
M_{stars}

Less massive galaxies ($<10^{9.5}M_\odot$) show significantly larger sSFR!

Inflow and outflow processes may well depend on environment !

General field

Stochastic, rapid, cold gas accretion through filaments



Ejecting enriched gas selectively

Metal dilution by primordial gas inflow

(Proto)cluster

Recycling of metal enriched gas

Stripping of metal poor gas from the reservoir

Steady but slow(?) gas accretion from a common halo

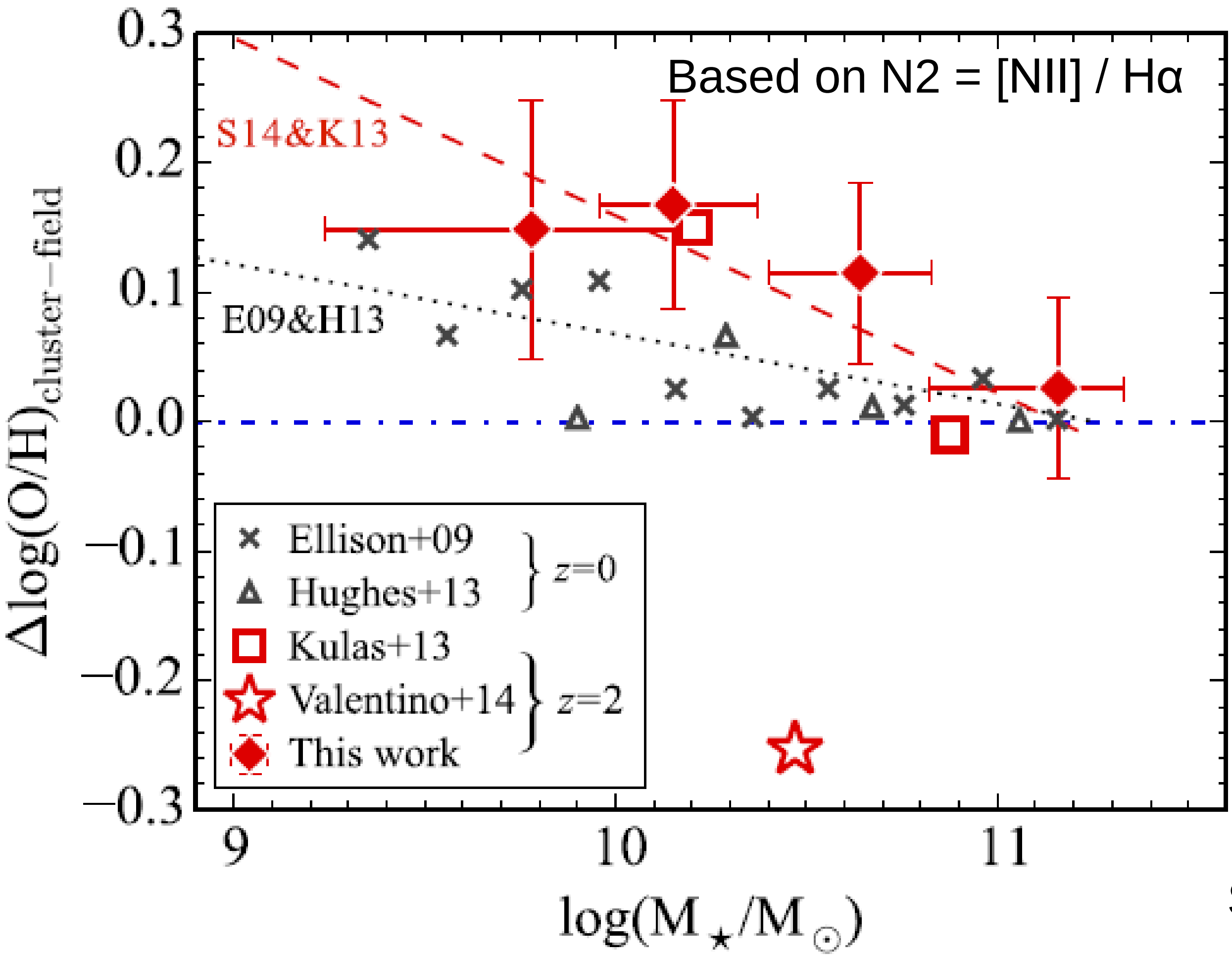
Stripping outer metal-poor gas

enriched gas falls back

(Dave+ '11; Kulas+ '13)

Environmental and Mass Dependence of Gaseous Metallicity

Highly Controversial !



Measurement errors?

or

Intrinsic scatter due to different phase of inflow/outflow?

Shimakawa et al. (2015a)

More statistical study is clearly needed with PFS.

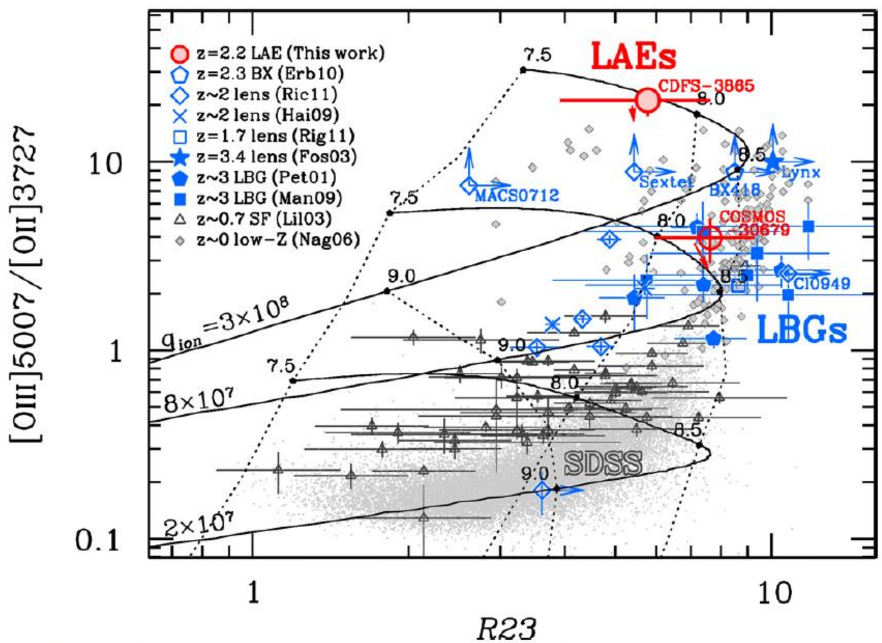
ALMA observation is also needed to measure M(gas) and better constrains the gas in-/outflows!

Any better metallicity measurements?

Separation between ionization parameter (q) and metallicity (O/H)

[OIII]/[OII] vs. R23

Nakajima+ (2013)

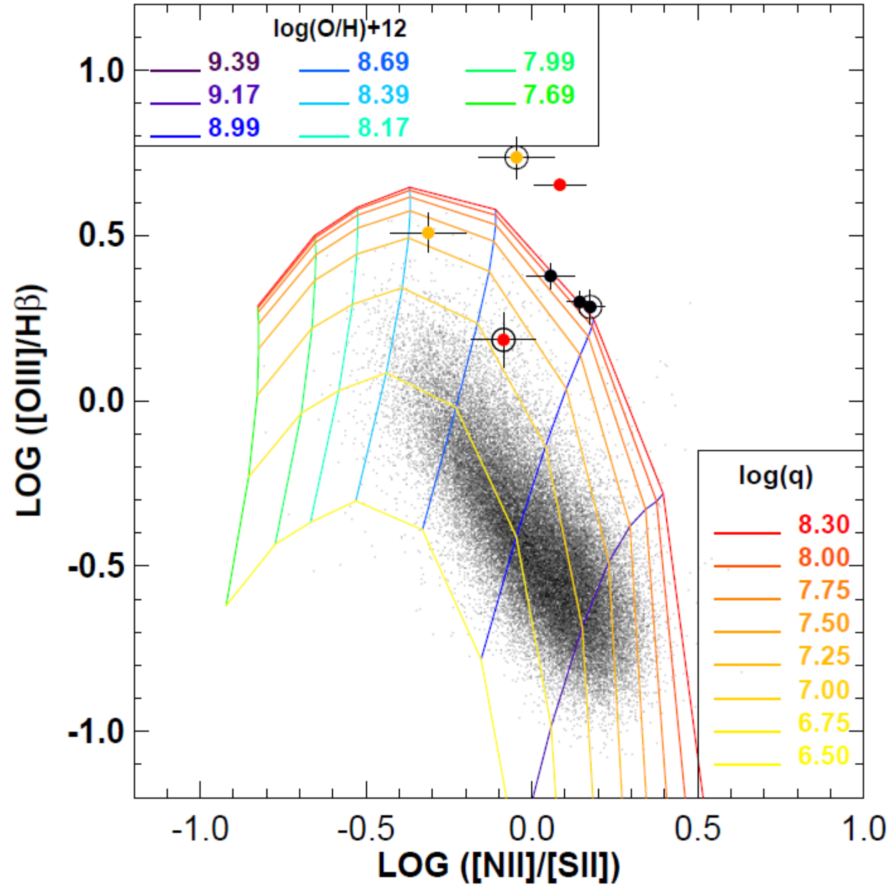


= ([OIII]+[OII]) / Hβ

z<1.5 with PFS

[OIII]/Hβ vs. [NII]/[SII]

Kewley+ (2015b)



z<0.9 with PFS

Direct Method

Electron temperature (Te) measurements

from [OIII]λλ4959,5007/[OIII]λ4363 → Gaseous Metallicity (Z)

However, [OIII]λ4363 is ~1/100 of [OIII]λ5007 → Stacking of 10,000 galaxies!

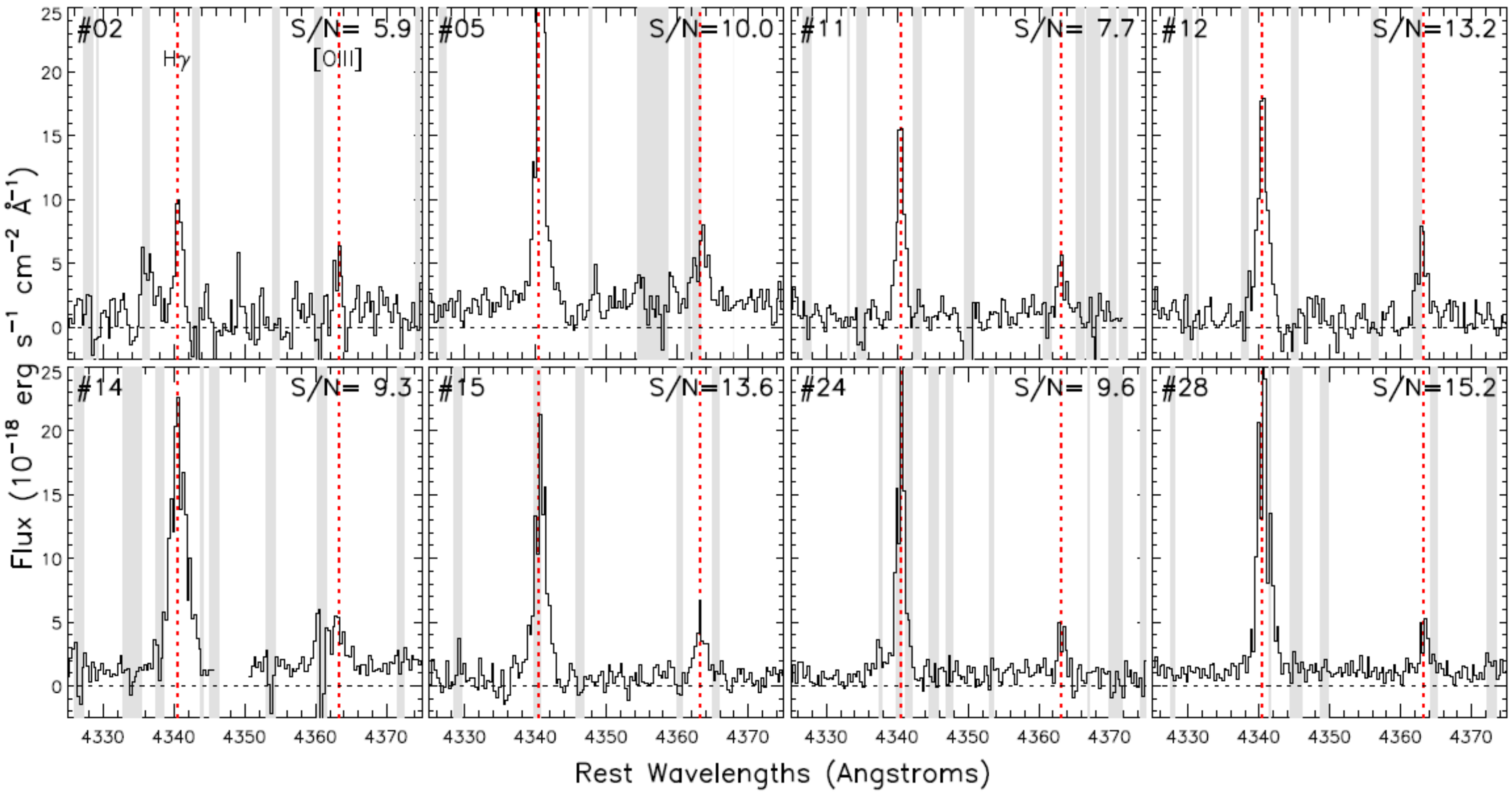


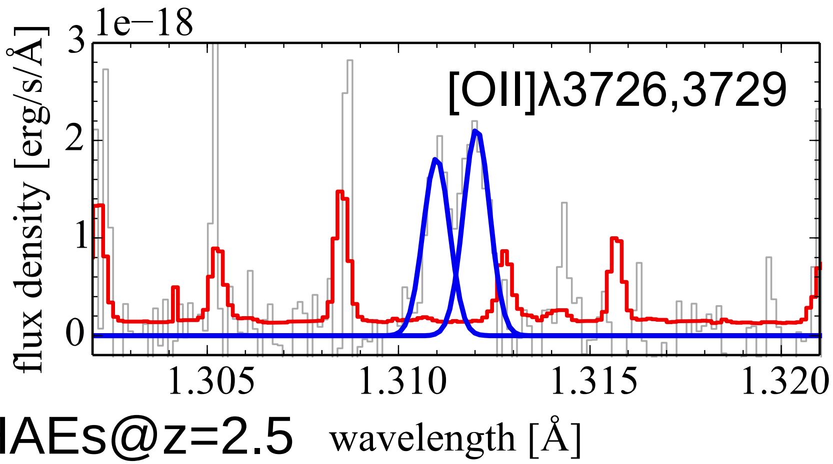
FIG. 1.— Detections of [O III]λ4363 in $z \sim 0.8$ DEEP2 galaxies. The Keck/DEIMOS spectra for 8 of 28 galaxies are shown by the solid black lines, with vertical red dashed lines indicating the locations of Hγλ4340 and [O III]λ4363. OH skylines are indicated by the grey shaded regions. The signal-to-noise of [O III]λ4363 detections is reported in the top right.

z=0.8 DEEP2 galaxies, Ly et al. (2014), Keck/DEIMOS

Electron Density (n_e)

[OII] doublet

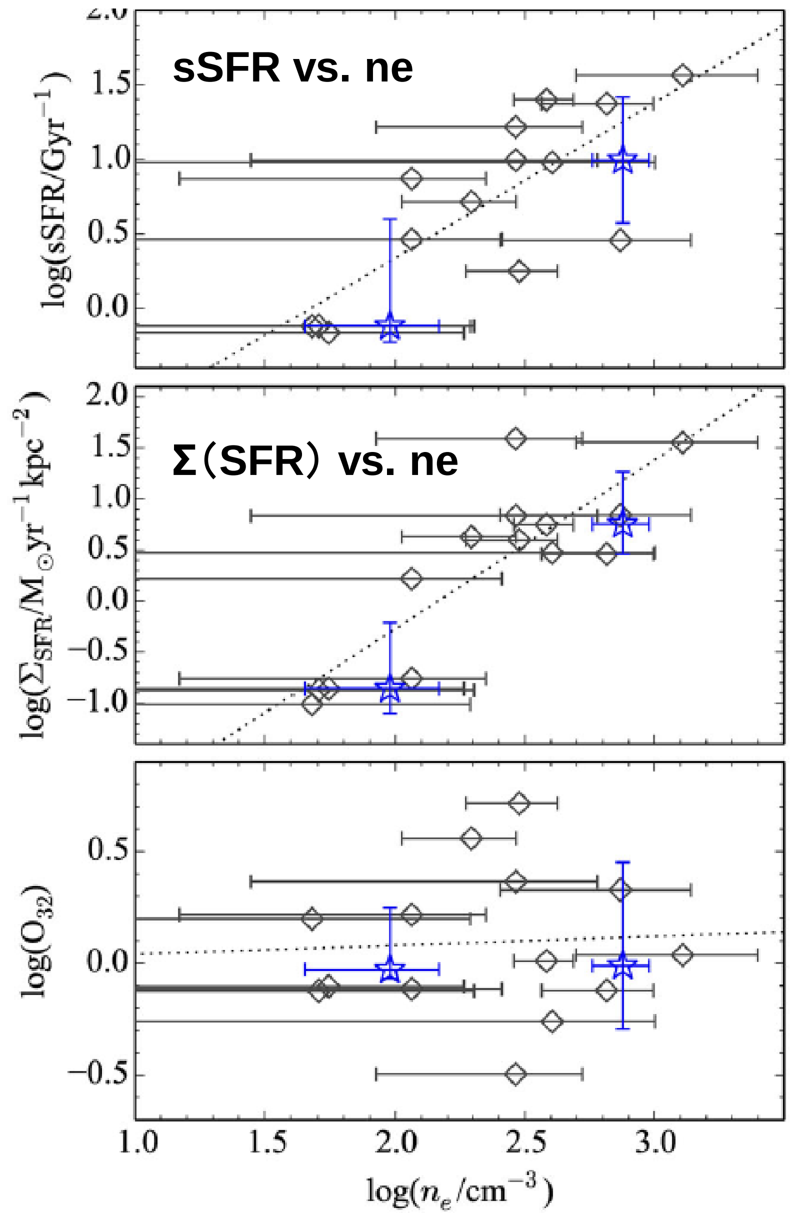
Shimakawa+ (2015b)



HAEs@z=2.5

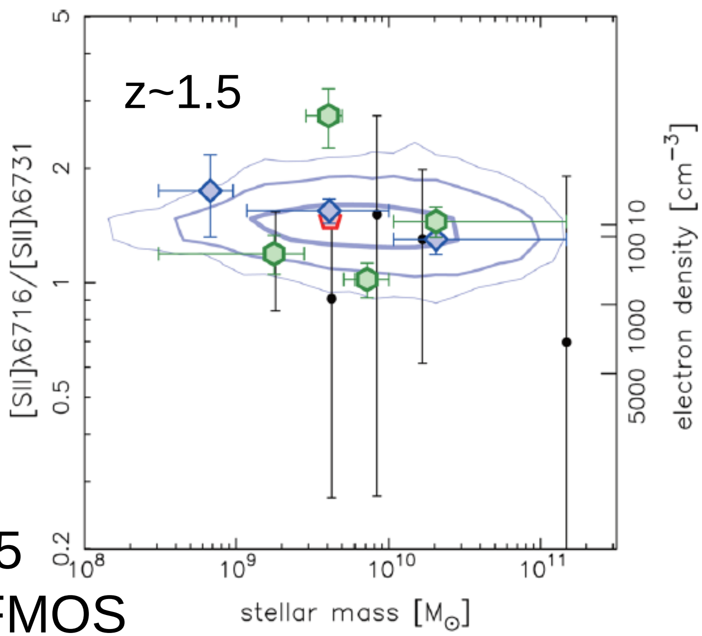
Keck/MOSFIRE

Shimakawa+ (2015b)



Electron density

[SII] doublet

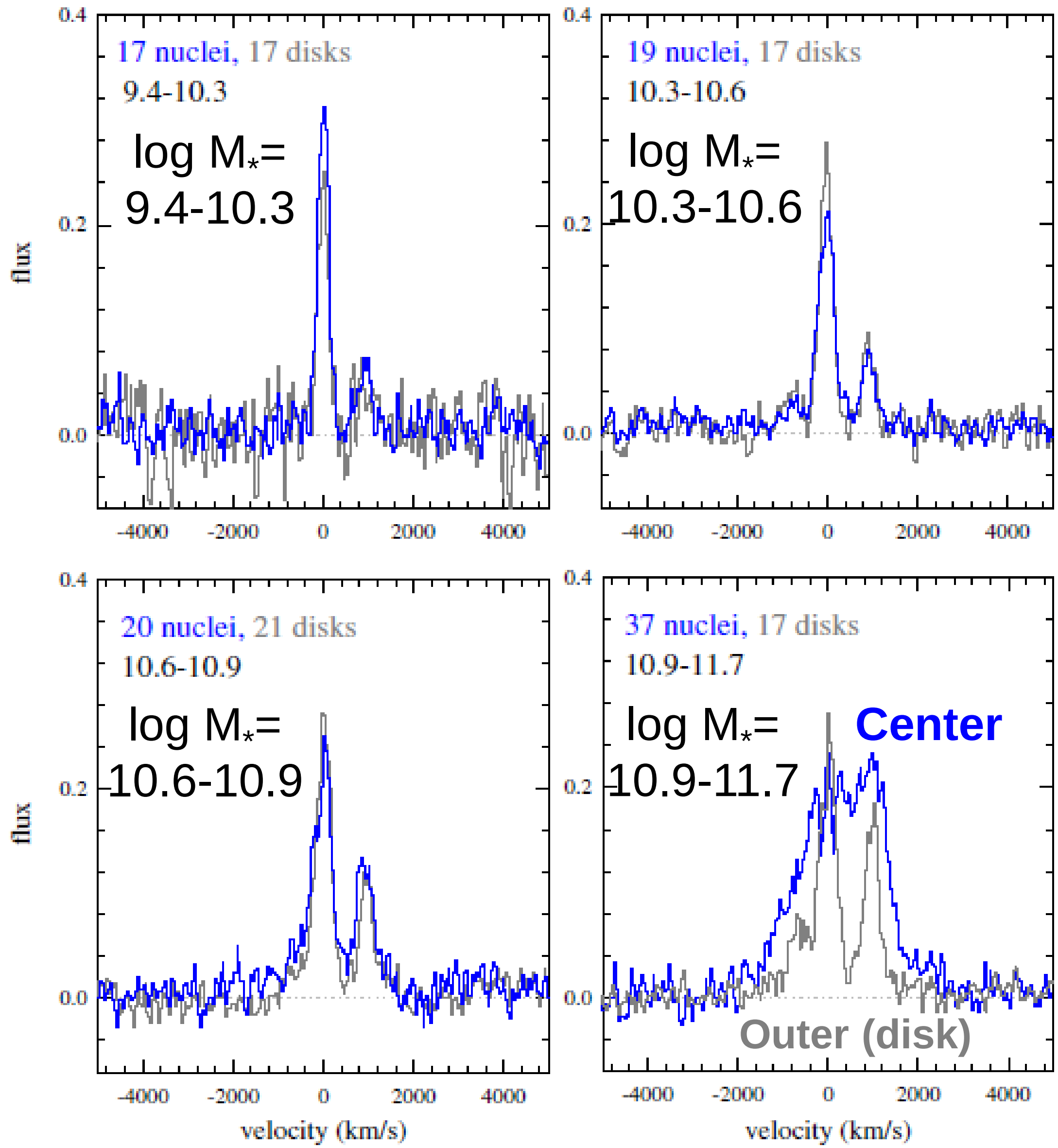


z~1.5

Subaru/FMOS

Hayashi+ (2015)

Line profiles (Outflow, AGN, M_{dyn})



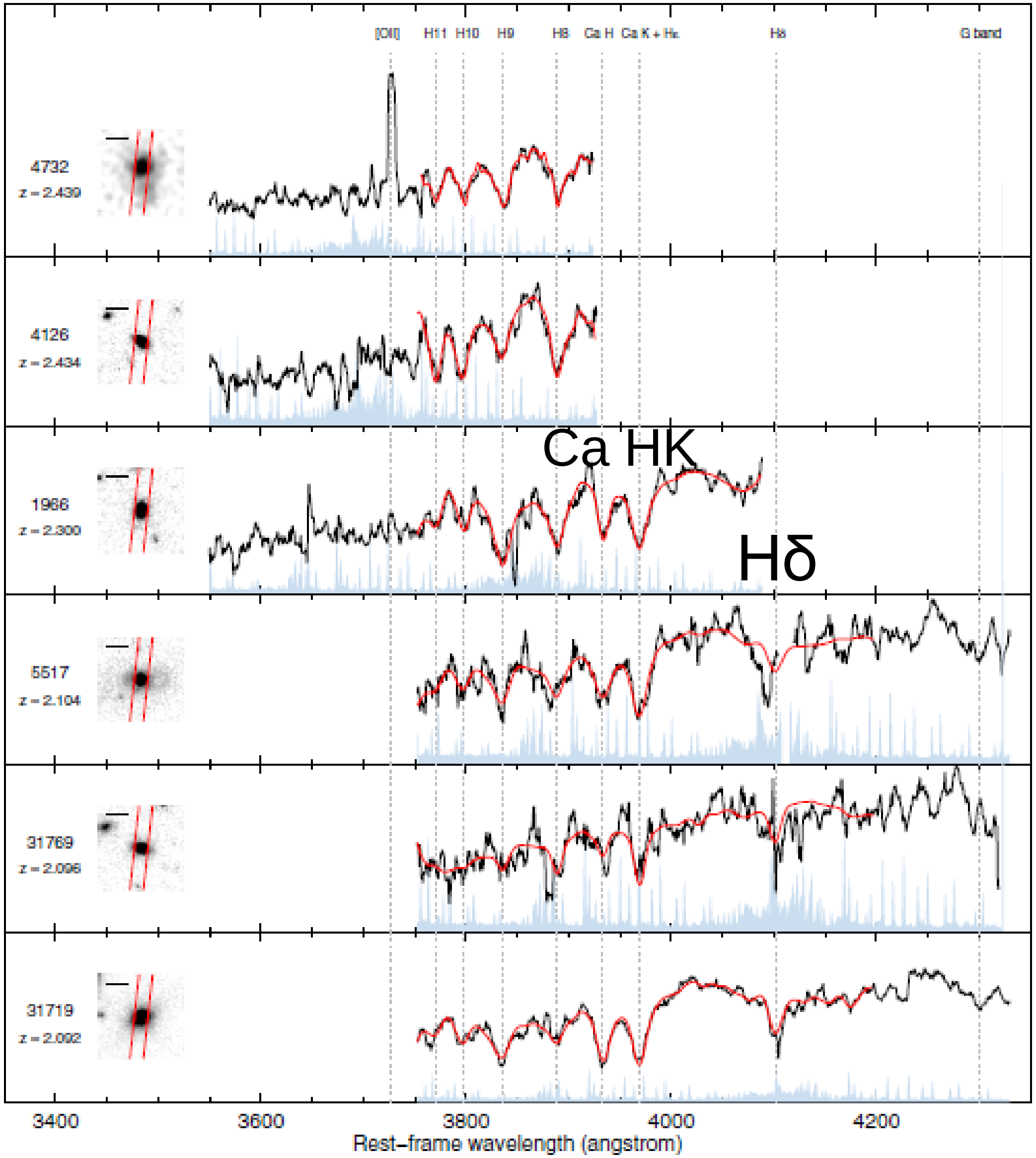
Low-mass (log M*<10.9)
SFR driven outflow
(Δv_{broad}~300km/s)

High-mass (log M*<10.9)
AGN driven outflow

PFS: R=3000-5000 ⇔ ΔV=60-100km/s

Genzel et a. (2014)

“Absorption line diagnostics” for passive galaxies



z~2

MOSFIRE

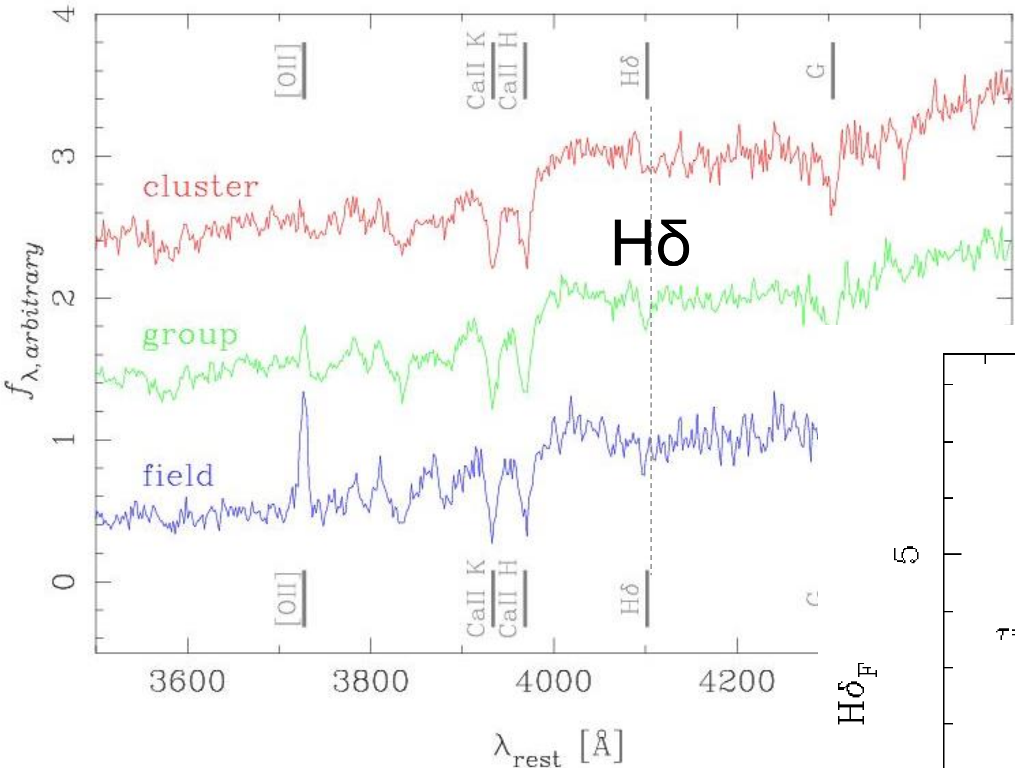
Exposure time = 8 hr 20 min

Belli et al. (2014)

MOSFIRE ABSORPTION LINE SPECTROSCOPY OF $z > 2$ QUIESCENT GALAXIES with $M_{star} > 10^{11} M_{\odot}$

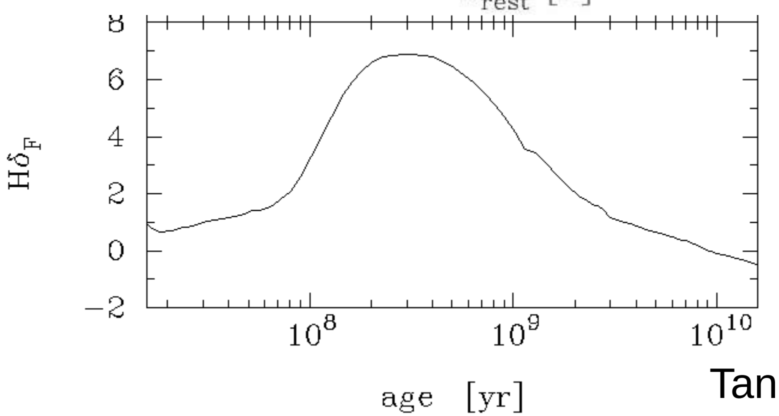
Post-starburst galaxies in groups at z~0.8

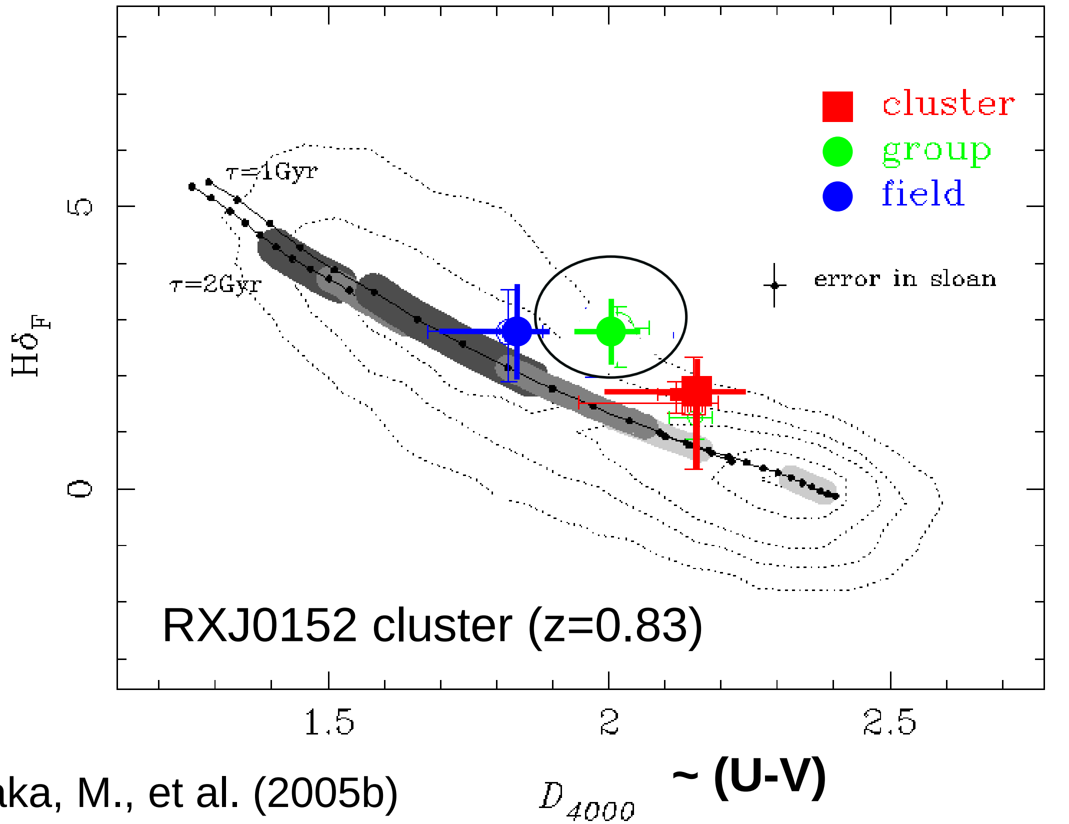
Comparison of stacked spectra of red galaxies at different environments



Stacked spectra of 10 galaxies each with 2 hrs exposure each.

Relatively strong Balmer absorption lines (E+A) are seen, suggesting recent, sharp truncation of star formation.





Tanaka, M., et al. (2005b)

What quenches star formation in cluster galaxies?

different timescales and different environments

- Ram-Pressure Stripping (～10^7 yrs)

  The gas in a galaxy is stripped off by the ram-pressure of ICM when it falls into a cluster.

- Galaxy-Galaxy Mergers (～10^8 yrs)

  The gas is stripped off by the tidal force or strong feedback from starbursts and AGN activities, or consumed rapidly during mergers.

- Suffocation/Strangulation (～10^9 yrs)

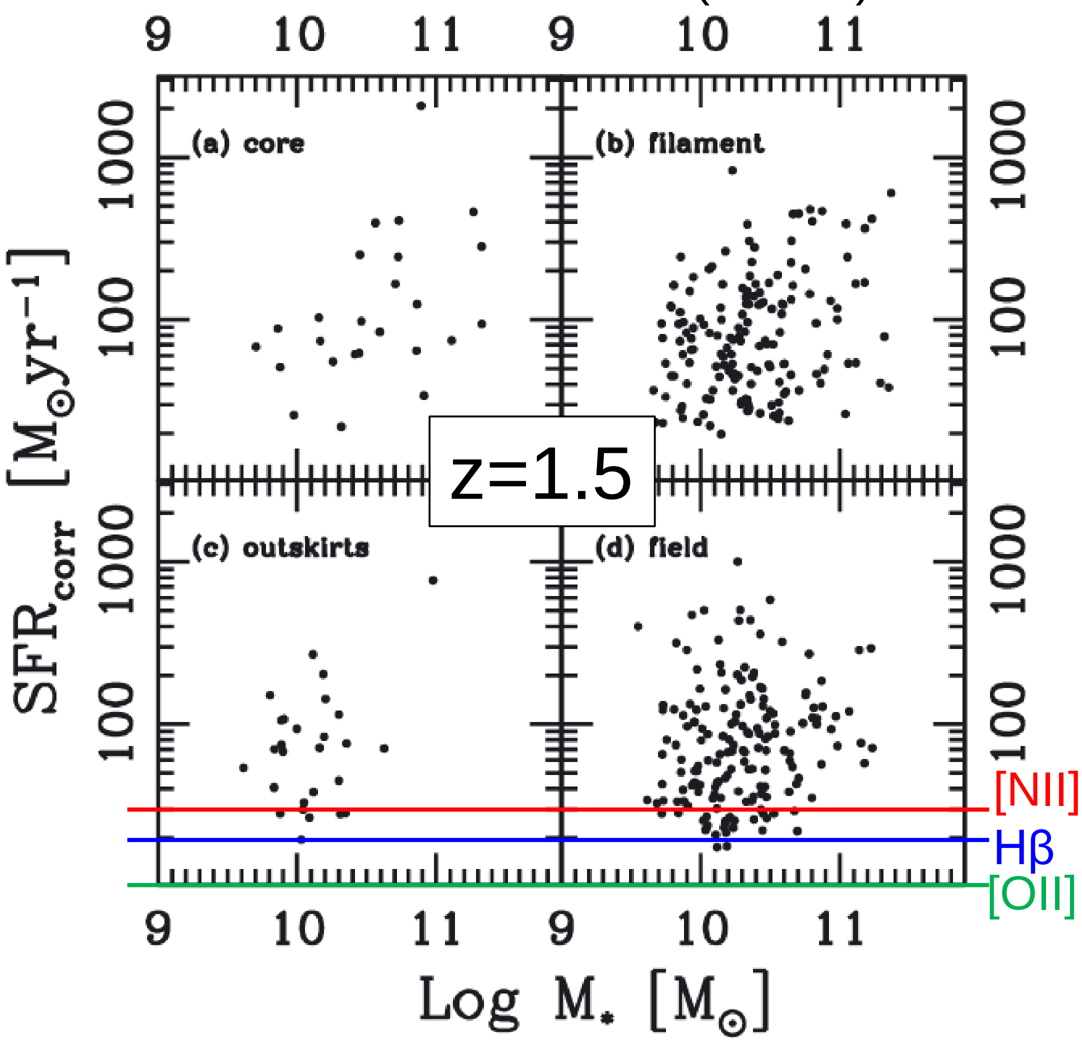
  The gas trapped weakly in galaxy haloes can be easily stripped off by tidal interactions with other galaxies or by ram-pressure of ICM. The remaining gas in the disk is consumed rapidly without a supply of fresh gas any more and the galaxy “suffocates” and the star formation is eventually truncated.

- Harassment (～10^9 yrs)

  The repeated close encounters with other galaxies have cumulative tidal effects, and a significant fraction of gas and stars are stripped. Moreover the bulge component can grow in the center as a result of angular momentum loss.

PFS 2 hour exposure ⇔ 1.2×10^{-17} erg/s/cm^2 (5σ) at 1-1.26μm
⇔ SFR(Hα, [OIII])$_{corr}$ ~ 5M$_\odot$/yr @ z=1.5

XMM2215-17 cluster (z=1.47)



Hayashi et al. (2011)

Observed line flux ratios
(no dust correction)

Hα/[OIII] ~ 1
Hα/Hβ ~ 4-5 (4)
[OIII]/Hβ ~ 2-6 (4)
Hα/[NII] ~ 3-15 (6)
Hα/[OII] ~ 2-3 (2.5)
[SII]/[NII] ~ 1
(Steidel+14,Hayashi+11,Kewley+15)

For absorption lines, 6 hrs exposure will achieve 5σ at J* (passive) at z=1.5, still requiring stacking analyses (20σ with 16 galaxies).

Summary

Panoramic **F**ollow-up **S**pectroscopy of HSC selected galaxies/clusters with **PFS** (**PFS**^{2})

Truly statistical analyses of line diagnostics for SF/Q galaxies to z<1-1.5, including stacking analyses, across various environments !

This can be largely done within the current SSP design, but we may need some additional configurations on clusters, and some extra exposures on passive galaxies?)

※Minimum fiber separation
FMOS: 12 arcsec
PFS : 30 arcsec