MAping HAlpha and Lines of Oxygen with Subaru

Mapping star formation at the peak epoch of galaxy formation and evolution

A Subaru Intensive Program for S10B-S11A, started in last Sep.

"MAHALO-Subaru"

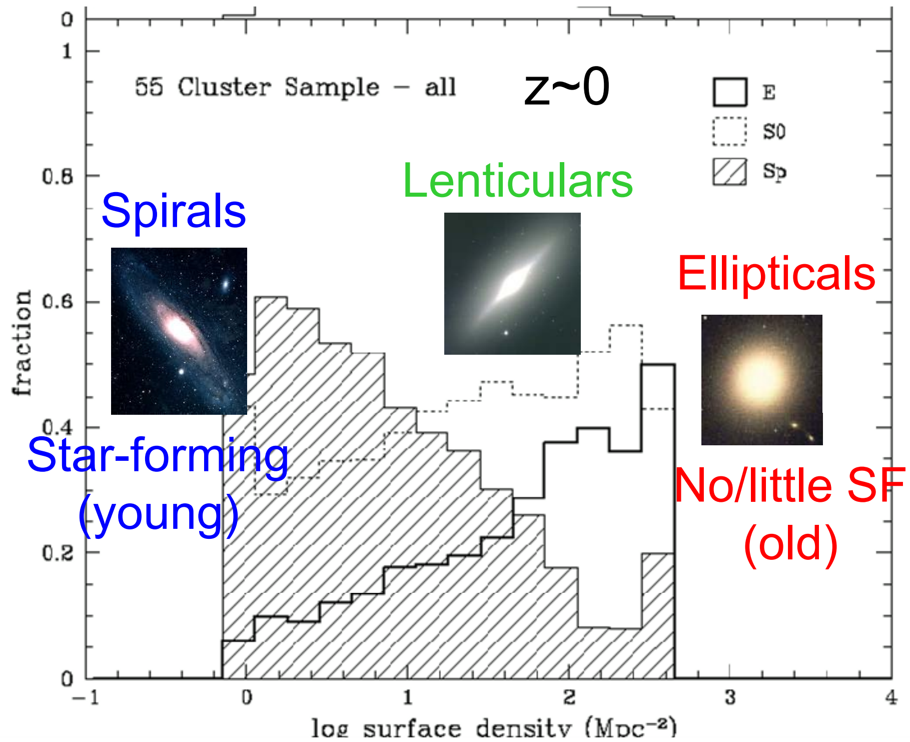
Taddy Kodama (Subaru Telescope),

Yusei Koyama (Univ of Tokyo),
Masao Hayashi (NAOJ),
Kenichi Tadaki (NAOJ/UTokyo),
Ichi Tanaka (Subaru Telescope),
et al.

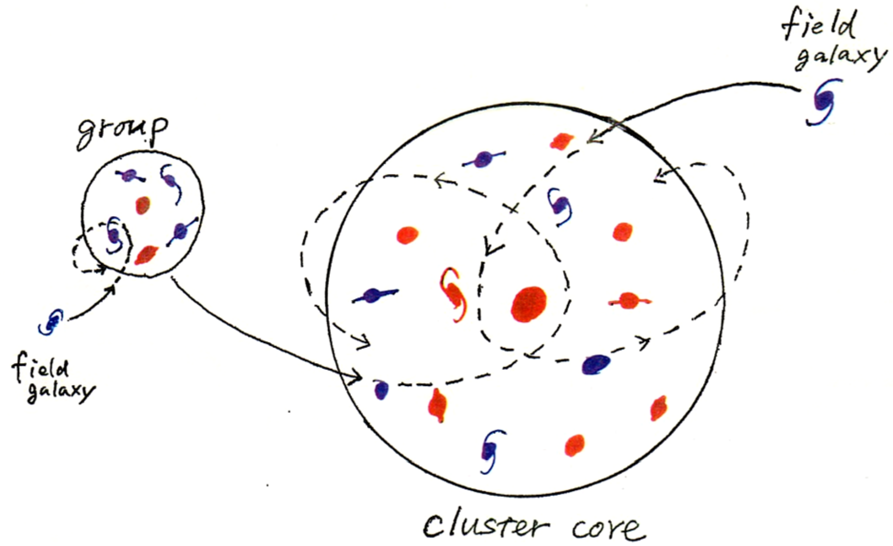
Hα survey in CL0939 (z=0.41) (**P19**)
[OII] survey in CL0332 (z=1.61) (**P20**)
[OII] survey in CL0218 (z=1.62) (**P21**)

What's the origin of the environmental dependence

morphology - density relation
(Dressler 1980)



log surface density (Mpc^{-2})



Nature? (intrinsic)

Need to go higher redshifts when it becomes more evident.

Nurture? (external)

Need to go outer infall regions to see directly what's happening there.

Panoramic Imaging and Spectroscopy of Cluster Evolution with Subaru

PISCES

~10 X-ray clusters (0.4 < z < 1.6) are completed

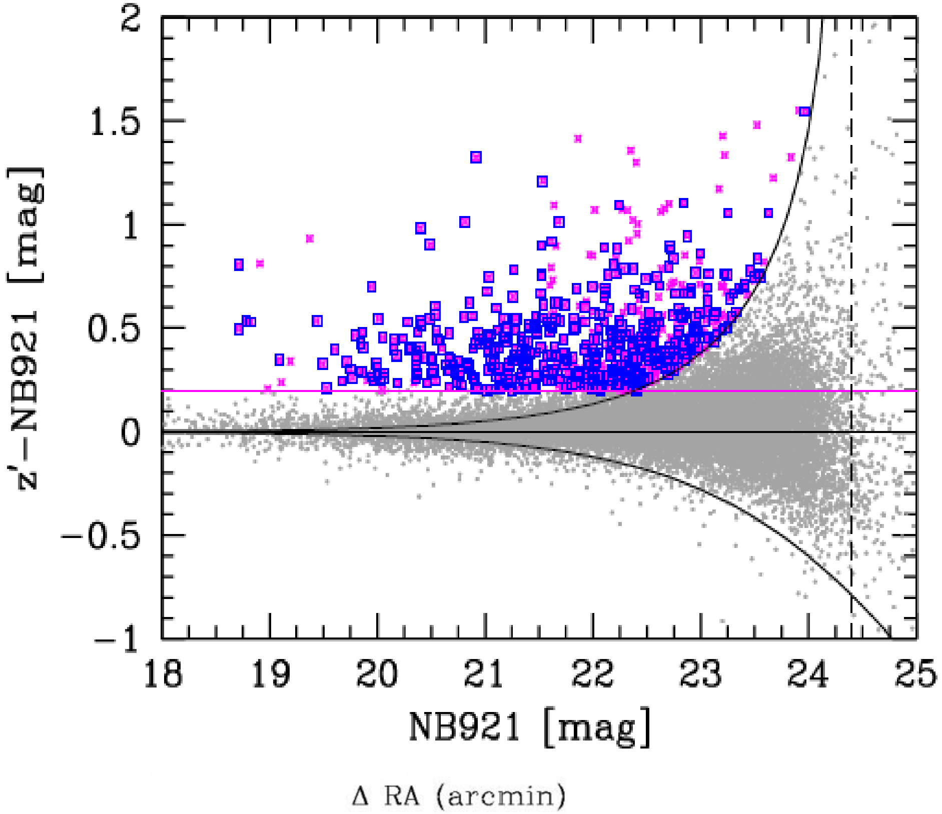
Class	Cluster	RA (J2000)	Dec (J2000)	z	L_X 10^{44}	Bands	Coordination
$z\sim0.4$	CL 0024+1654	00 26 35.7	+17 09 43.1	0.39	3.2	BRz',NB	ACS, XMM, Chandra
	CL 0939+4713	09 42 56.2	+46 59 12	0.41	9.2	$BVRI$,NB	XMM
	(RX J2228+2037)	22 28 36	+20 37 12	0.42	16.5	$BVRi'$	Chandra, S-Z
$z\sim0.55$	MS 0451.6−0305	04 54 10.9	−02 58 07	0.54	12.0	$BVRI$	ACS (3.5′), Chandra, S-Z
	CL 0016+1609	00 18 33.5	+16 26 13.4	0.546	26.0†	$BVRi'z'$	ACS (3.5′), XMM, Chandra, S-Z
	(MS 2053.7−0449)	20 56 21.8	−04 37 51.4	0.583	5.0	$BVRi'z'$	ACS (3.5′), XMM, Chandra, S-Z
$z\sim0.85$	RX J1716.4+6708	17 16 49.6	+67 08 30	0.813	2.7‡	$VRi'z'$,NB	Chandra, Astro-F target
	(MS 1054.4−0321)	10 56 59.5	−03 37 28.4	0.83	20.0	$VRi'z'$	ACS (6′), XMM, Chandra, S-Z
	RX J0152.7−1357	01 52 42.0	−13 57 52.9	0.831	16.0	$VRi'z'$	ACS (6′), XMM, Chandra, S-Z
	(RX J1226.9+3332)	12 26 58.2	+33 32 49	0.9	53.0	$VRi'z'$	XMM, Chandra, S-Z
	(CL 1604+43)	16 04 28.3	+43 16 24.0	0.9	2.0	$VRi'z'$	ACS (6′), XMM
$z\sim1.2$	RDCS J0910+5422	09 10 44.9	+54 22 08.9	1.11	2.1	$VRi'z'$	Chandra ACS(3.5')
	CL 1252−2927	12 52 54.4	−29 27 17.0	1.23	6.6	$VRi'z'$	ACS (6′), XMM, Chandra
	(RX J1053.7+5735)	10 53 43.4	+57 35 21	1.14	2.0‡	$VRi'z'$	ACS (6′) XMM
	RX J0848.9+4452	08 48 46.9	+44 56 22	1.26	2.8	$BVRi'z'$	ACS (6′), XMM, Chandra
z~1.5	XMMJ2215.9-1738	22 15 58.5	-17 38 02.5	1.45	4.4	*VRi'z'*,NB	XMM
	CIGJ0218.3-0510	02 18 21.3	-05 10 27	1.62		BVRi'z',NB	XMM

Kodama et al. (2005) +update

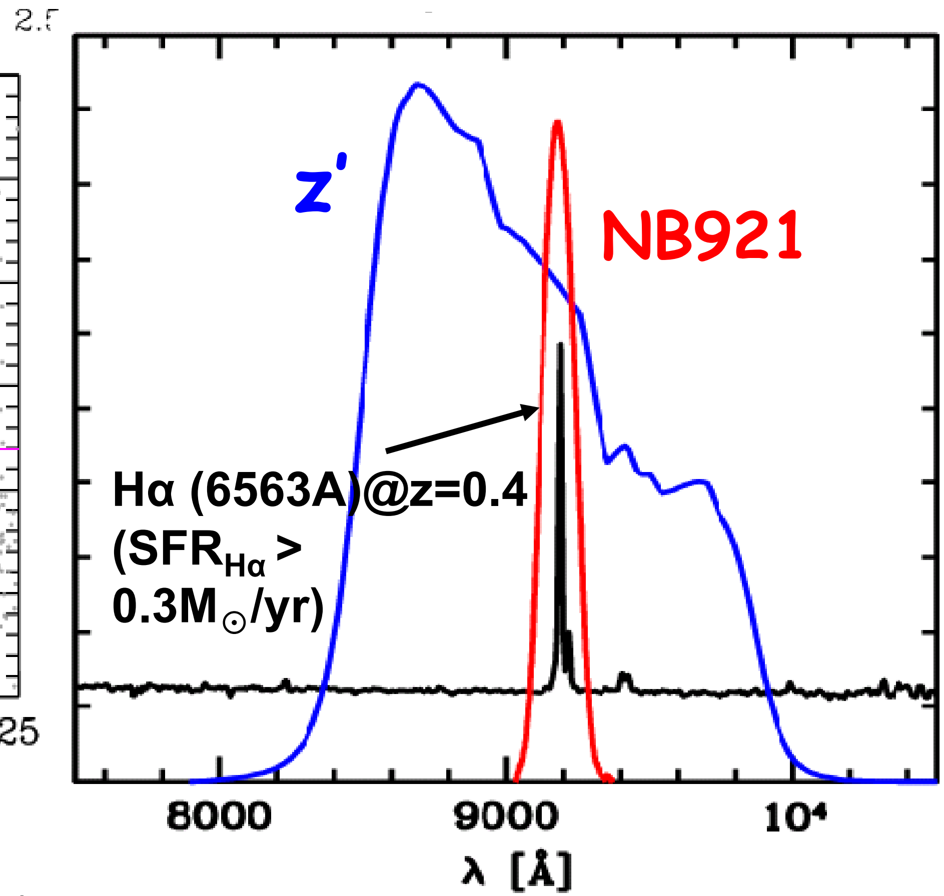
Cluster outskirts is the key environment for environmental effects

Sharp color transition in the "medium-density" regions

(i.e. cluster outskirts / groups / filaments)



"Octopus cluster " (CL0939 cluster at z=0.4)



Log Σ (galaxy number density)

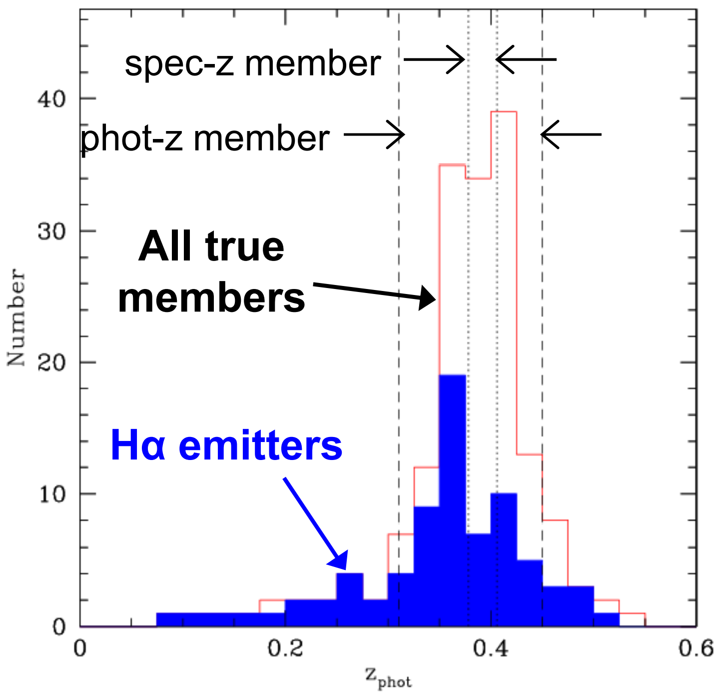
Kodama et al. (2001), see also Tanaka+05 and Koyama+08

BB selection (passive) + NB emitters (active)

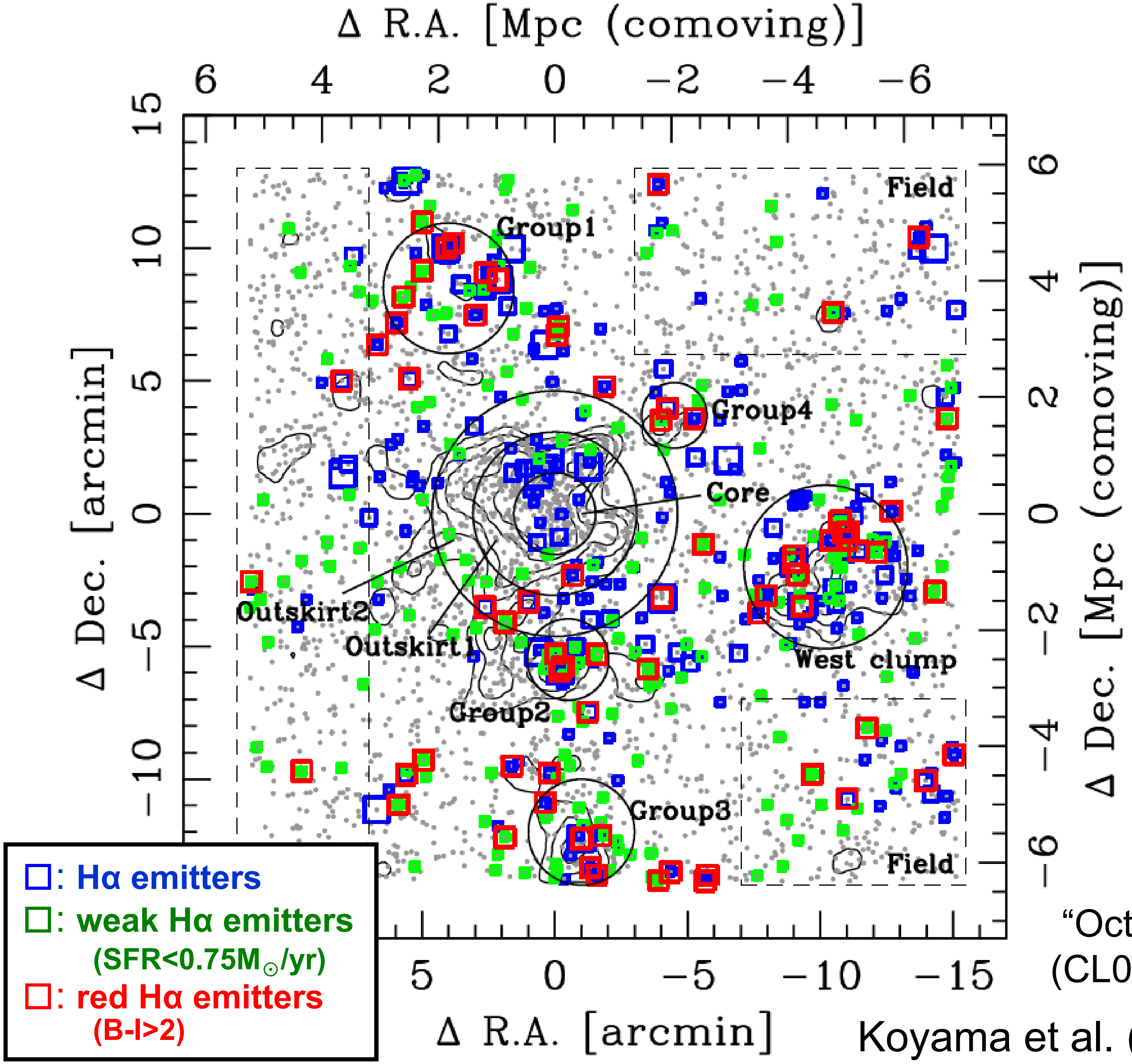
Advantages of NB survey:

(1) Good indicators of SFR, especially Hα (low reddening, well calibrated)
(2) "Unbiased" sample (no pre-selection of targets is required).
(3) "Complete" census of star forming galaxies to a certain limit in SFR.
(4) Membership can be confirmed by the presence of emitters in NB +colours.
(5) On top of the phot-z selected members (e.g. "passive" galaxies), we can pick out "active" galaxies which tend to be missed by phot-z selection.

Phot-z distribution of true members



CL0024 cluster (z=0.4)
NB912 + Suprime-Cam
Kodama et al. (2004)

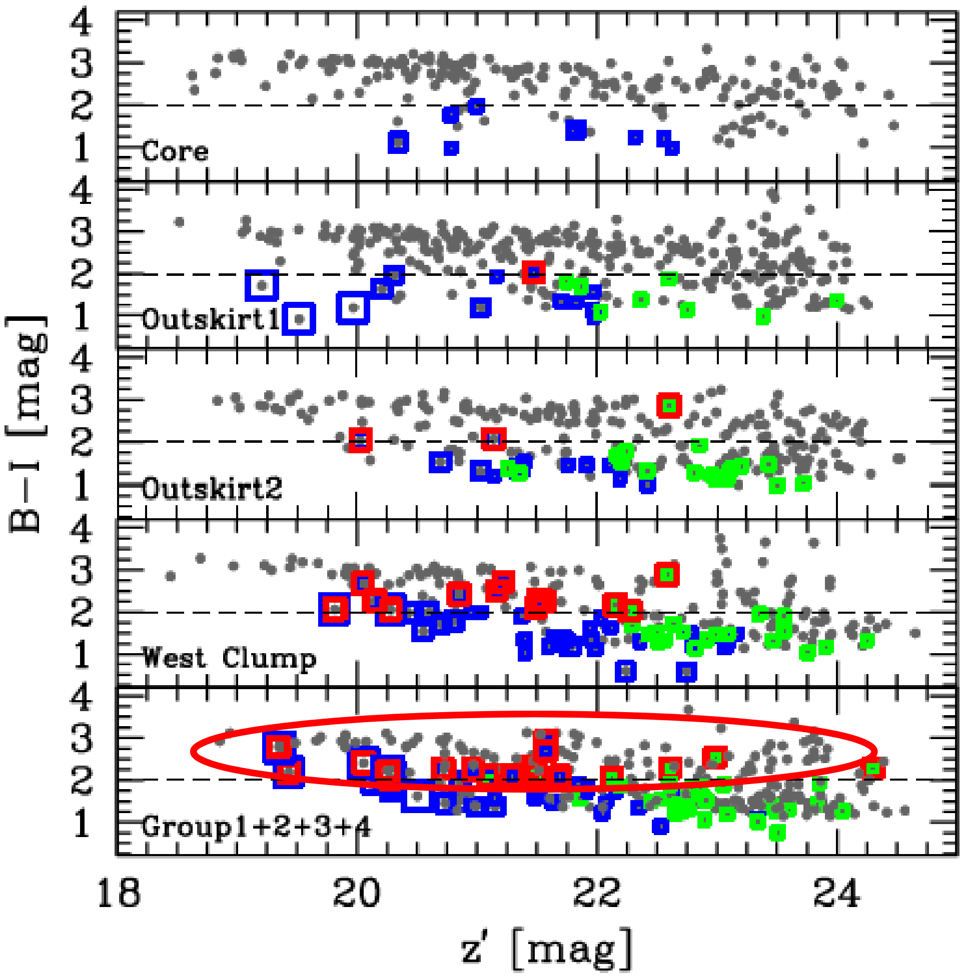


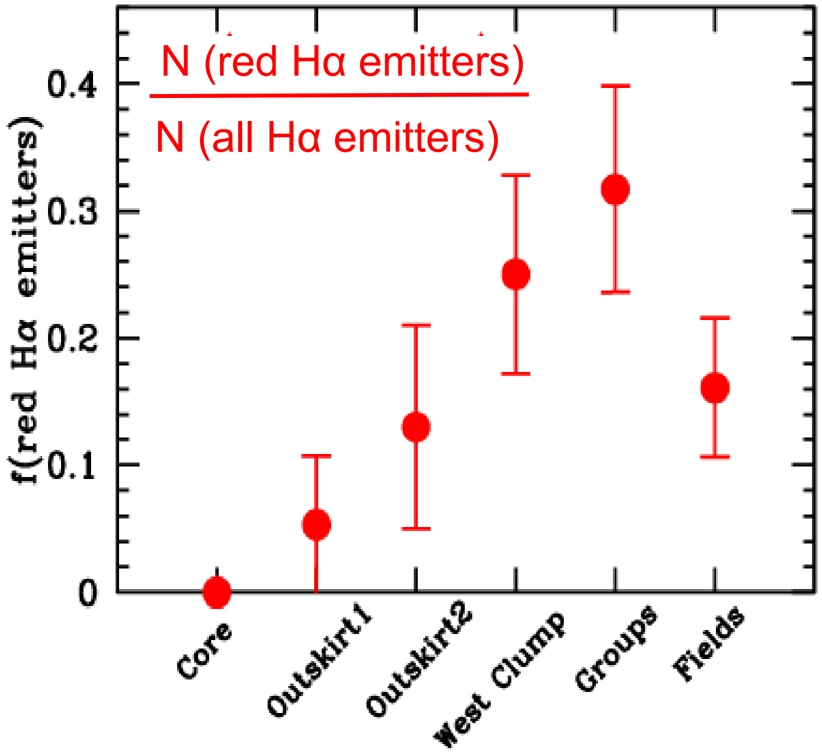
"Octopus cluster"
(CL0939@z=0.41)

Koyama et al. (2011), see **P19**

Red Hα emitters in groups !

A significant fraction of red galaxies in groups show SF activities
(dusty galaxies!)

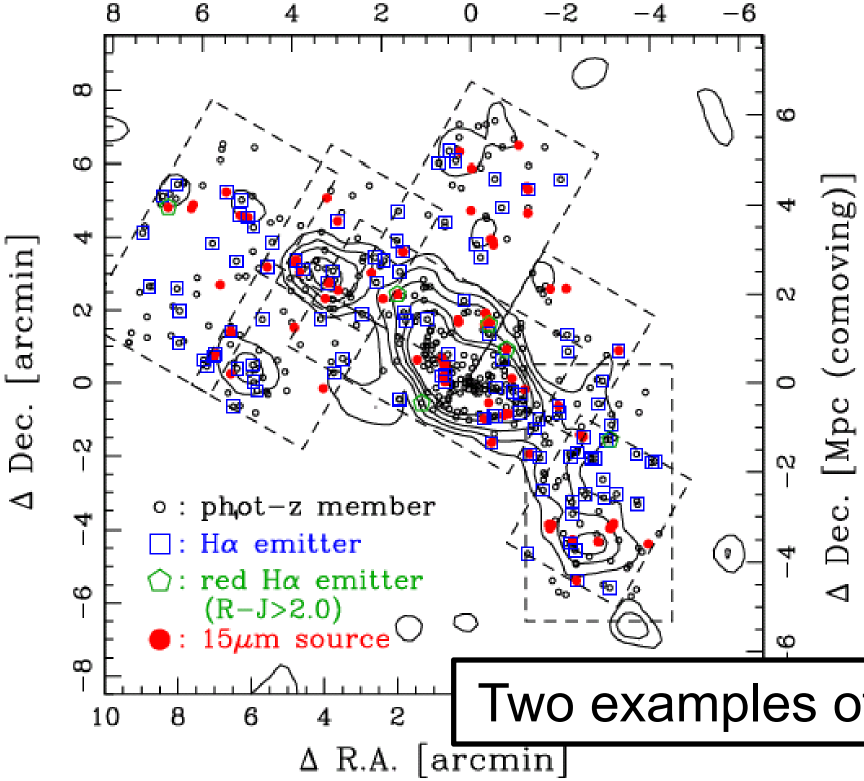




Koyama et al. (2011), see **P19**

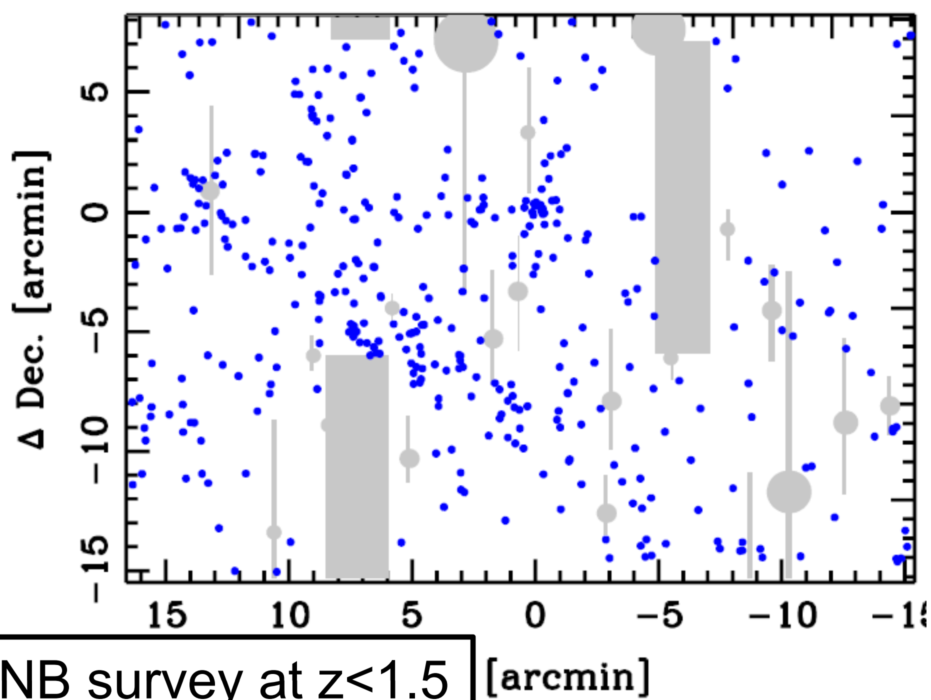
RX J1716.6+6708 (z=0.81)

MOIRCS + NB119 (Hα)

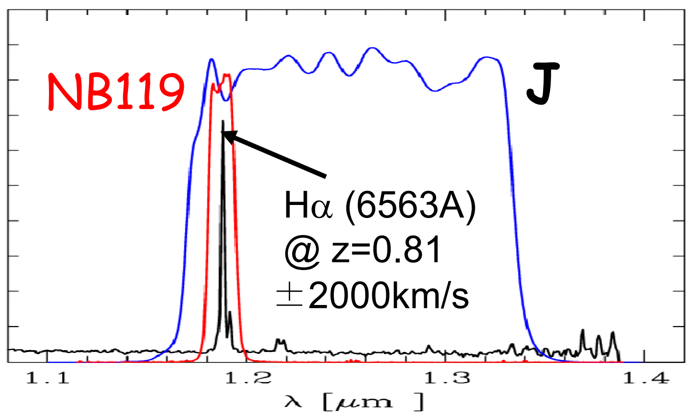


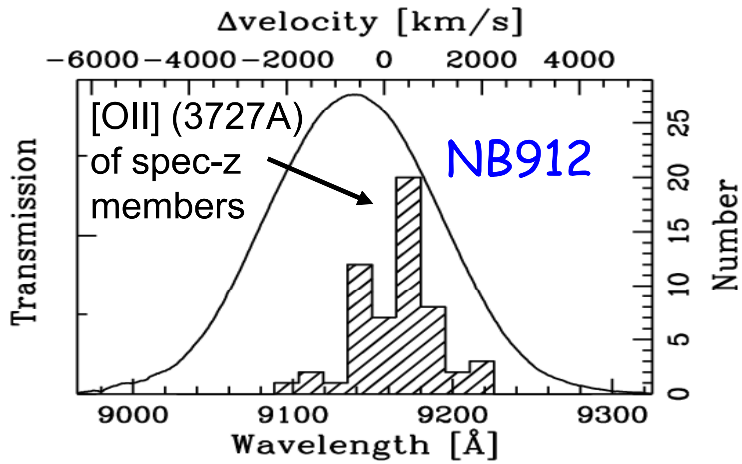
XCS J2215.9-1738 (z=1.46)

Suprime-Cam + NB912 ([OII])



Two examples of NB survey at z<1.5

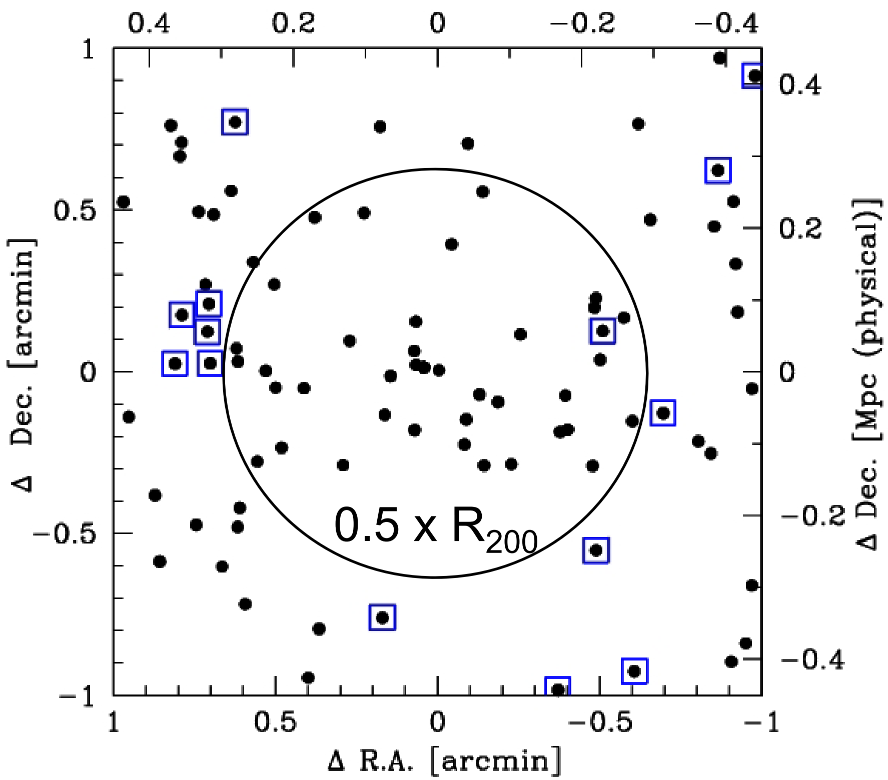




Comparison of spatial distribution of star forming galaxies in cluster cores.

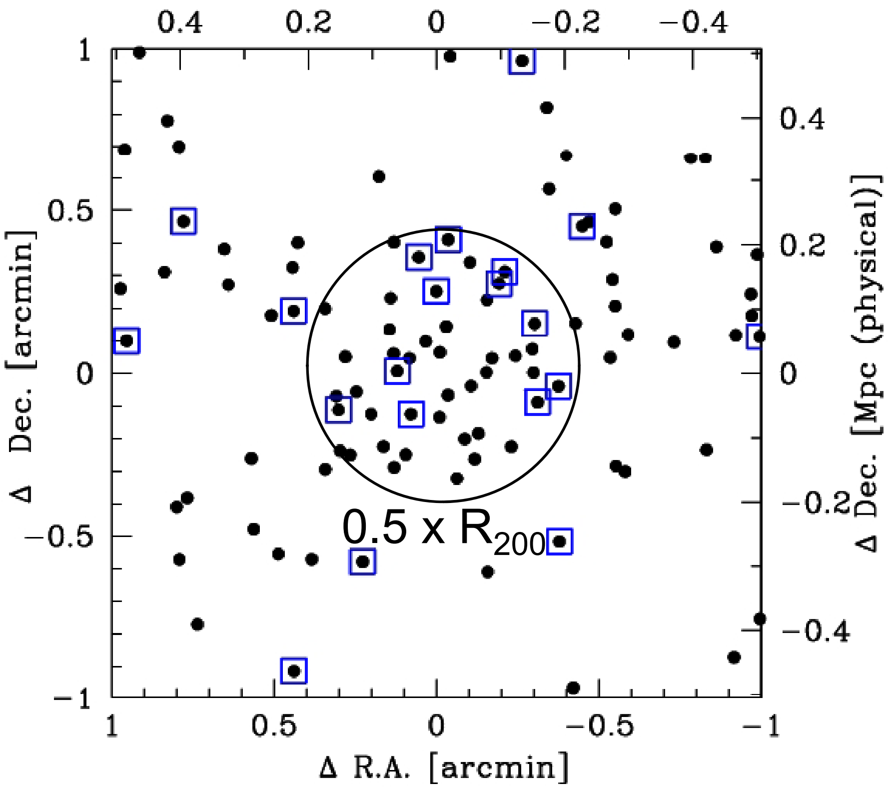
□ Hα emitters at z=0.81 (RXJ1716)   □ [OII] emitters at z=1.46 (XCS2215)

● phot-z members



Lx=2.7×10^{44} erg/s

Koyama, et al. (2010)

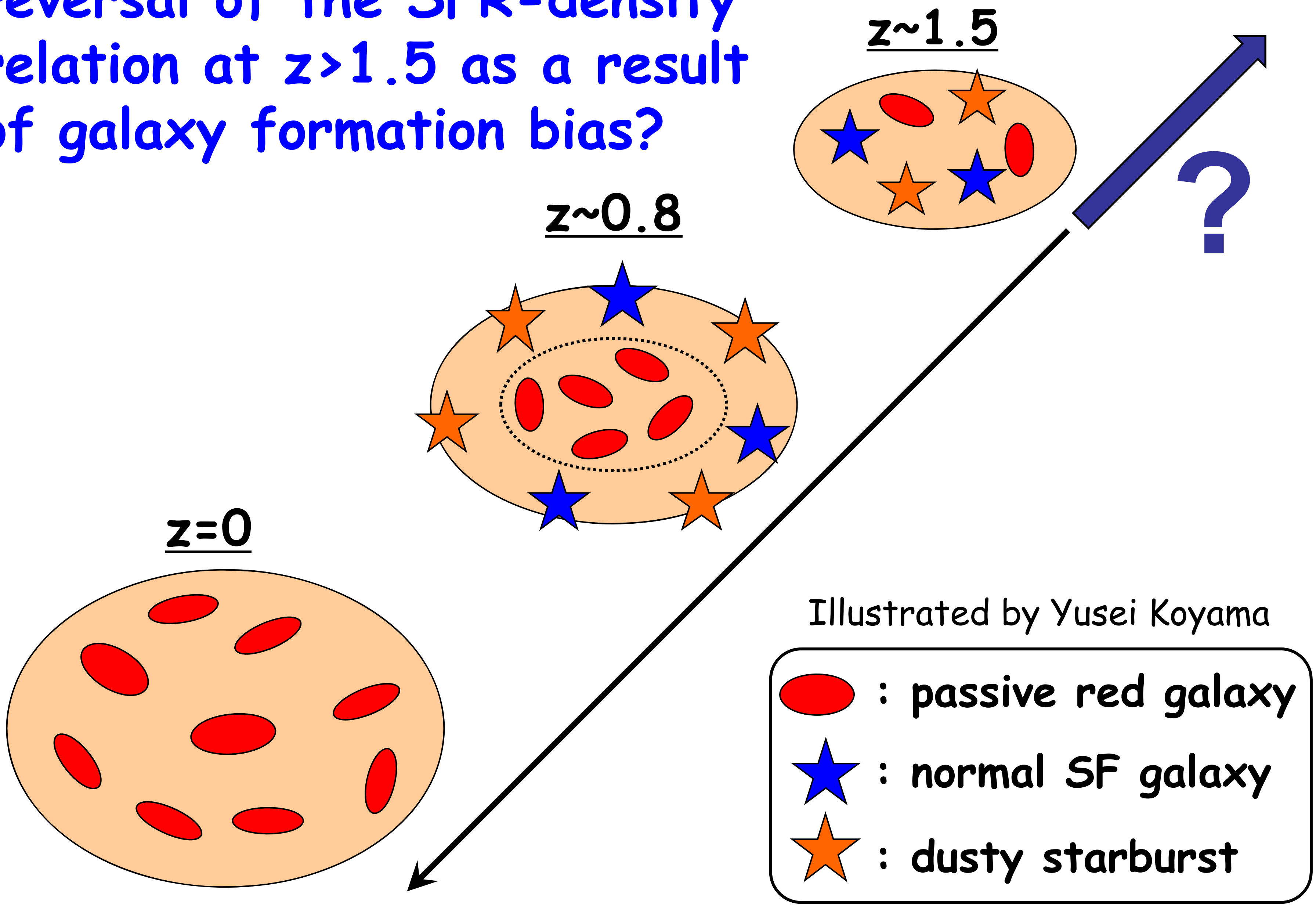


Lx=4.4×10^{44} erg/s

Hayashi, et al. (2010)

Star forming activity in the core is much higher in the higher redshift cluster!

Do we eventually see the reversal of the SFR-density relation at z>1.5 as a result of galaxy formation bias?



"MAHALO-Subaru"

MApping HAlpha and Lines of Oxygen with Subaru

Narrow-band emitters (Hα, [OII]) surveys at $0.4<z<2.5$ (primarily $z>1.5$)

Table 2: The complete list of our NB imaging surveys for star-forming galaxies, including the past observations.

environment	target	z	line	λ (μm)	camera	NB-filter	continuum	ALMA visibility	status
clusters	CL0024+1652	0.395	Hα	0.916	S-Cam	NB912	z'	Yes	Kodama+ '04
	CL0939+4713	0.407	Hα	0.923	S-Cam	NB921	z'	No	Koyama+ '11
	RXJ1716+6708	0.813	Hα	1.190	MOIRCS	NB1190	z', J	No	Koyama+ '10
	XCSJ2215–1738	1.457	[OII]	0.916	S-Cam	NB912	z'	Yes	Hayashi+ '10
	4C65.22	**1.516**	Hα	1.651	MOIRCS	NB1657	H	No	not yet
	Q1126+101	**1.517**	Hα	1.652	MOIRCS	NB1657	H	Yes	not yet
	Q0835+580	**1.534**	Hα	1.664	MOIRCS	NB1657	H	No	observed
	CL0332–2742	**1.61**	[OII]	0.973	S-Cam	NB973	z, y	Yes	observed/analysed
	CIGJ0218.3–0510	**1.62**	[OII]	0.977	S-Cam	NB973	z', y	Yes	observed/analysed
	PKS1138–262	**2.156**	Hα	2.071	MOIRCS	NB2071	K_s	Yes	scheduled in S11A
	4C23.56	**2.483**	Hα	2.286	MOIRCS	NB2288	K_s, K_{cont}	Yes	Tanaka+ '11
	USS1558–003	**2.527**	Hα	2.315	MOIRCS	NB2315	K_s, K_{cont}	Yes	scheduled in S11A
fields	GOODS-N	2.19	Hα	2.094	MOIRCS	NB2095	K_s	No	Tadaki+ '11
	(2.5 pointings)		[OII]	1.189	MOIRCS	NB1190	z', J	No	Tadaki+ '11
	SXDF	**2.19**	Hα	2.094	MOIRCS	NB2095	K	Yes	observed
	(3 pointings)		Hβ	1.551	MOIRCS	NB1550	H	Yes	not yet
			[OII]	1.189	MOIRCS	NB1190	z', J	Yes	not yet

Subaru Intensive Program for S10B-S11A

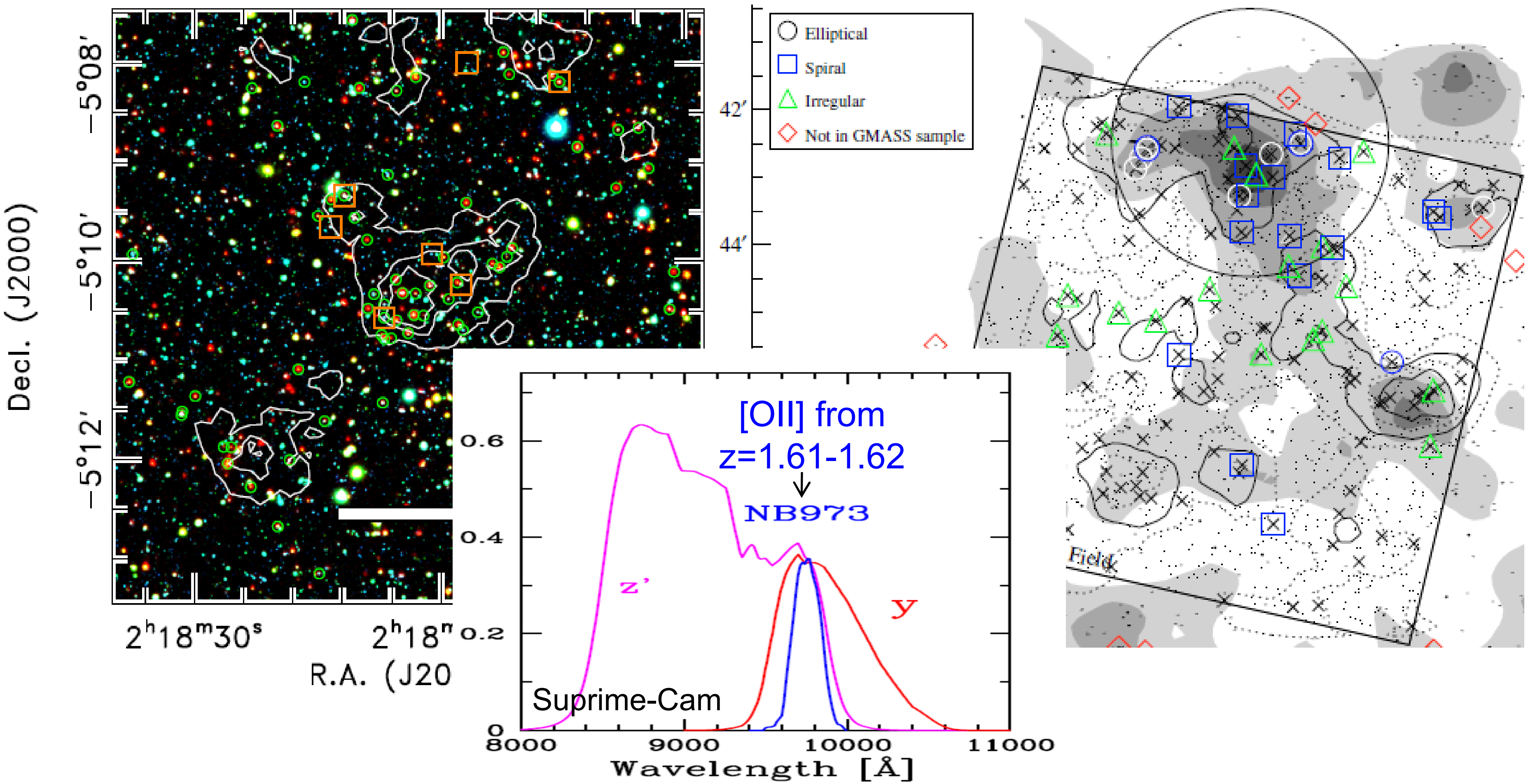
10 nights allocation (6 nights completed under clear skies, 4 nights to come)

(However, one of the MOIRCS chips was broken and FoV was halved in S10B…)

Two recently found, confirmed clusters at z~1.6

CIG J0218.3-0510 (z=1.62) in SXDF

CL0332-2742 (z=1.61) in GOODS-S



9 spec-z members, σ=540km/s

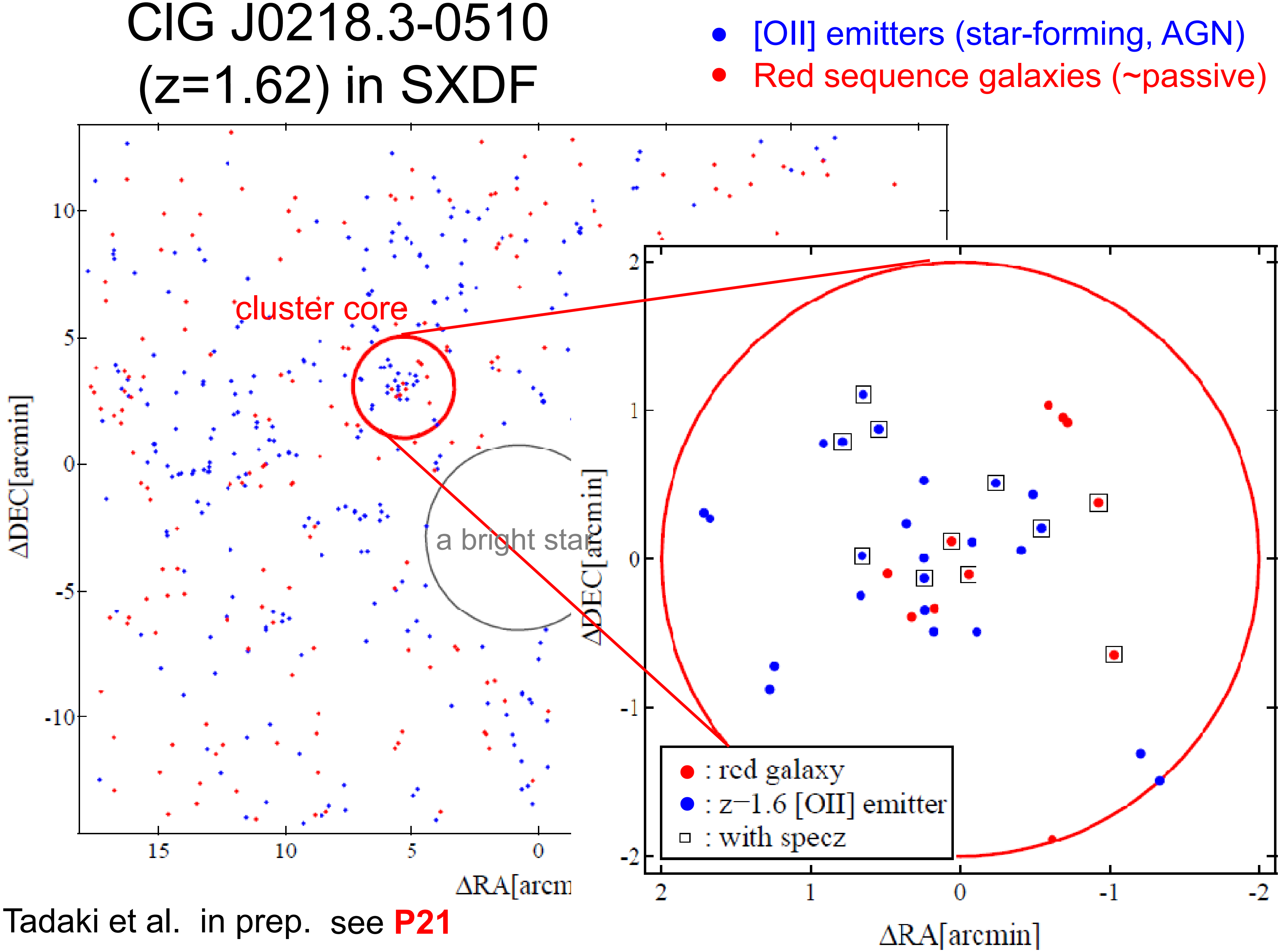
X-ray detection (4.5σ)

(Papovich et al. 2010; Tanaka et al. 2010)

42 spec-z members, σ=500km/s

Kurk et al. (2009)

ClG J0218.3-0510 (z=1.62) in SXDF

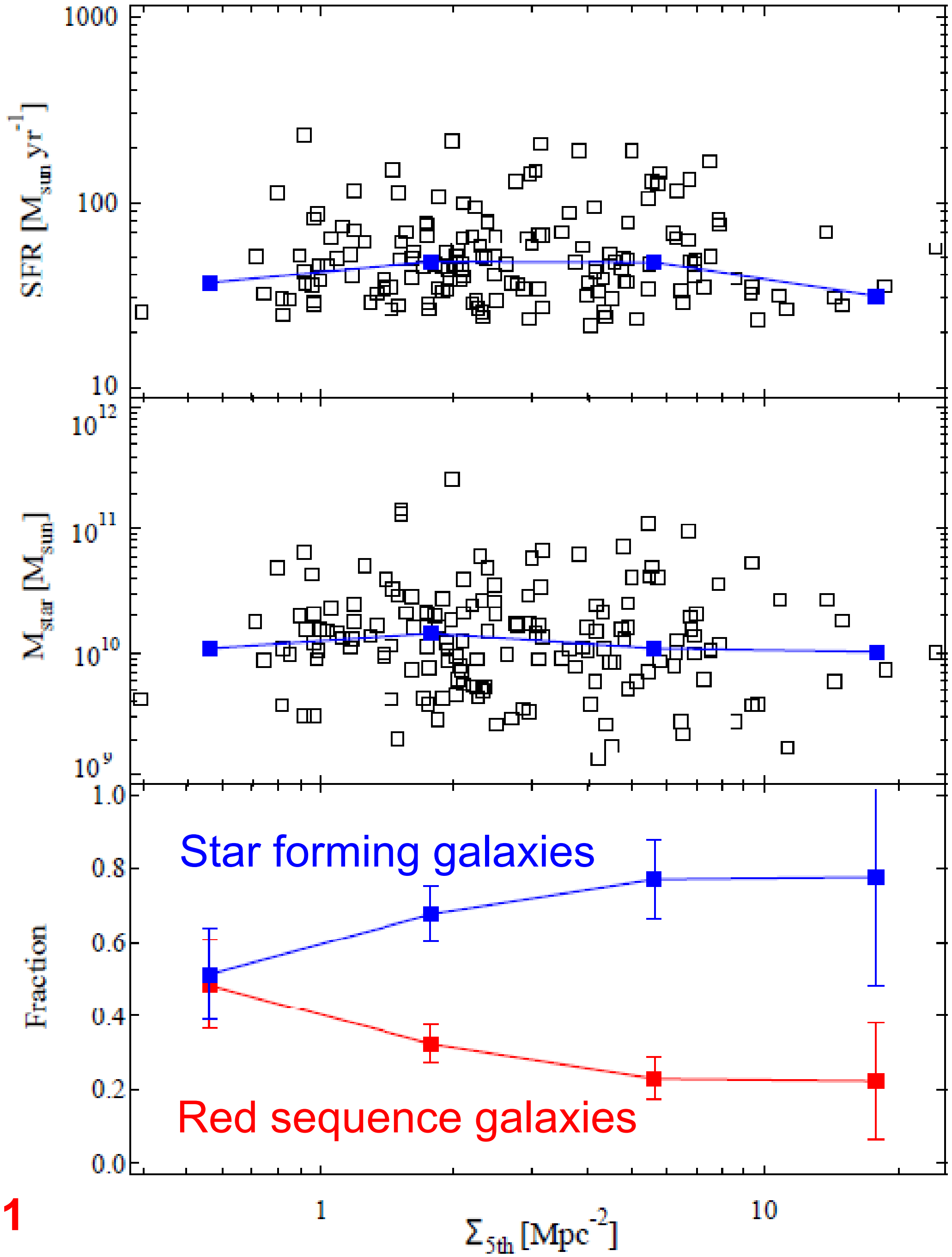


Tadaki et al. in prep. see **P21**

Environmental variation

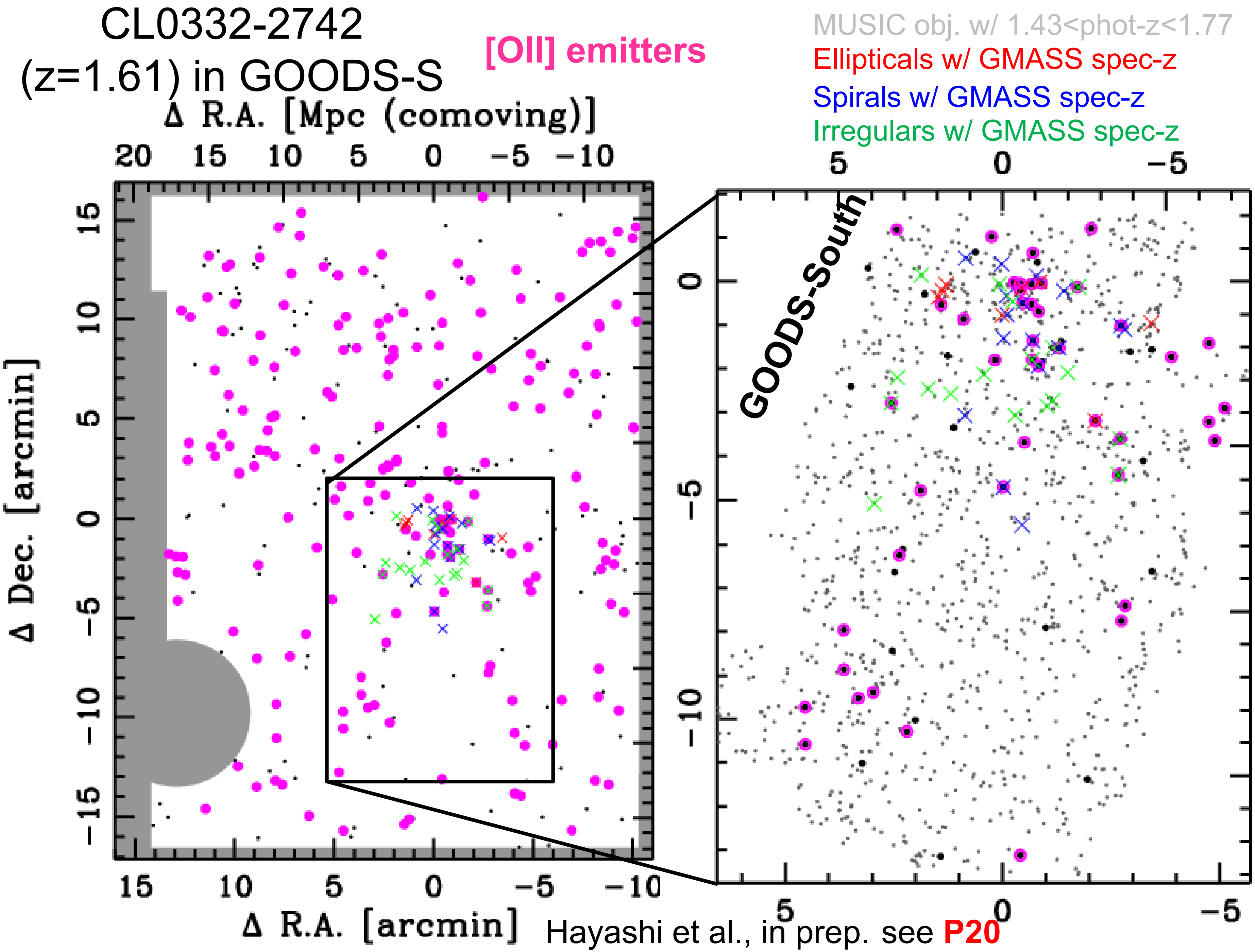
"preliminary result"

CIG J0218.3-0510
(z=1.62) in SXDF



Fraction of star forming
Galaxies is higher
in the cluster core !?

Tadaki et al. in prep. see **P21**



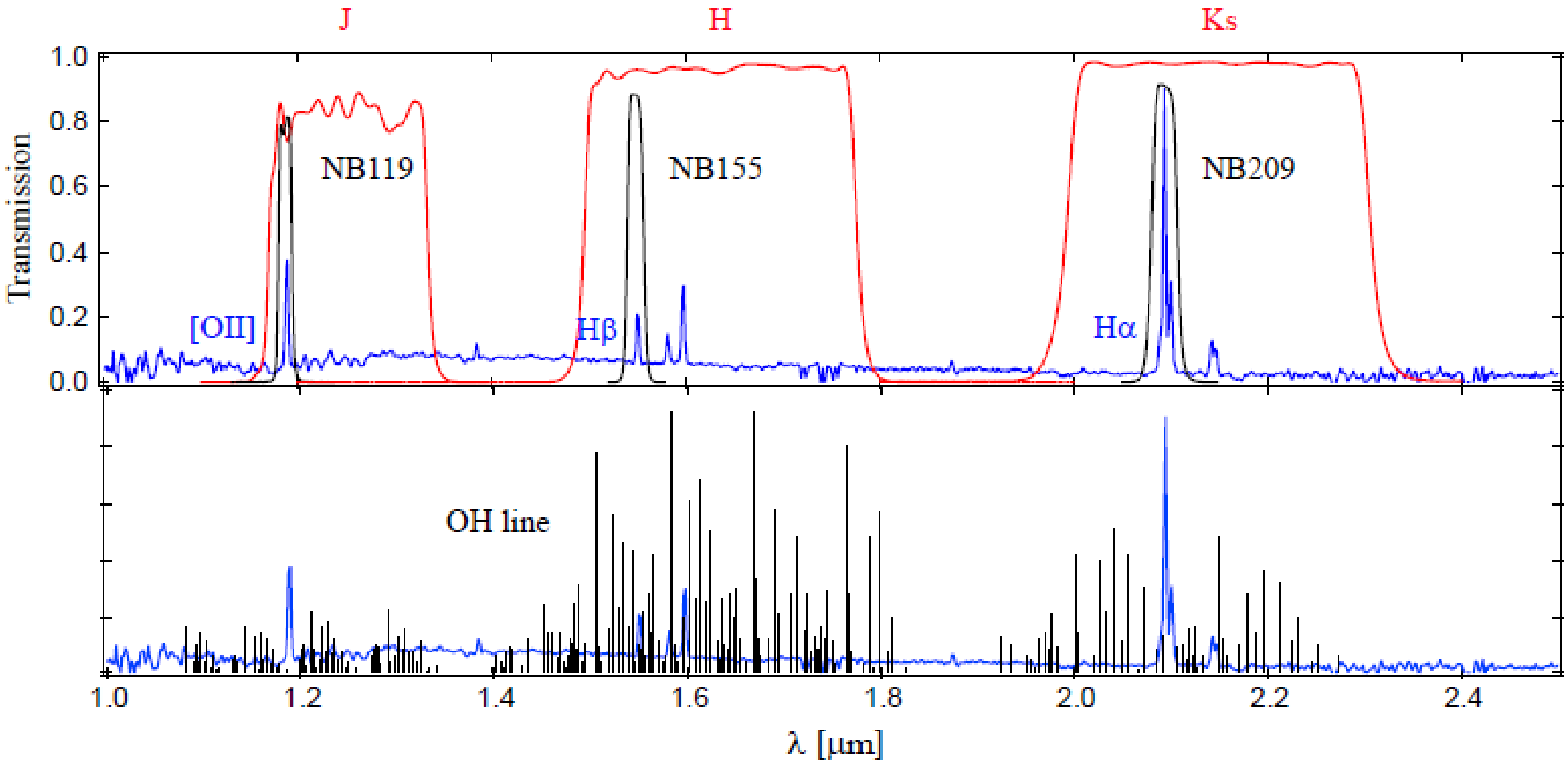
Hayashi et al., in prep. see **P20**

Brank field, multi-line NB survey at z=2.2

Our unique NB-filter system on
Subaru MOIRCS (+Suprime-Cam)
specifically designed for this purpose!

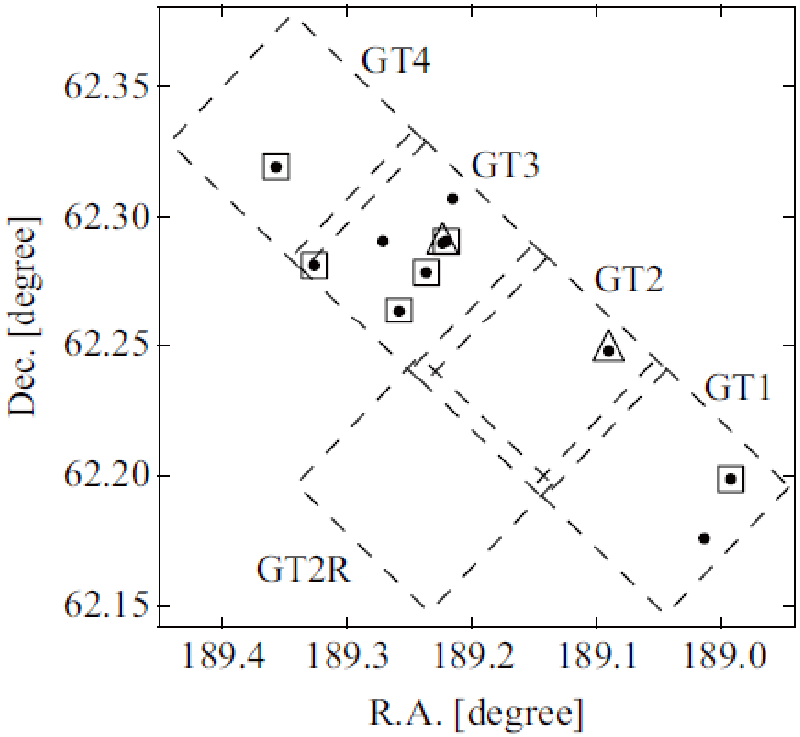
Secure redshifts of emitters
Hβ/Hα (dust extinction)
Lyα/Hα (escape fraction)

	z=0	z=2.2
Hα	6563 Å	2.09μm
Hβ	4861 Å	1.55μm
[OII]	3727 Å	1.19μm
Lyα	1216 Å	3870 Å



Hα emitters at z=2.2 traced by MOIRCS/NB209

GOODS-N

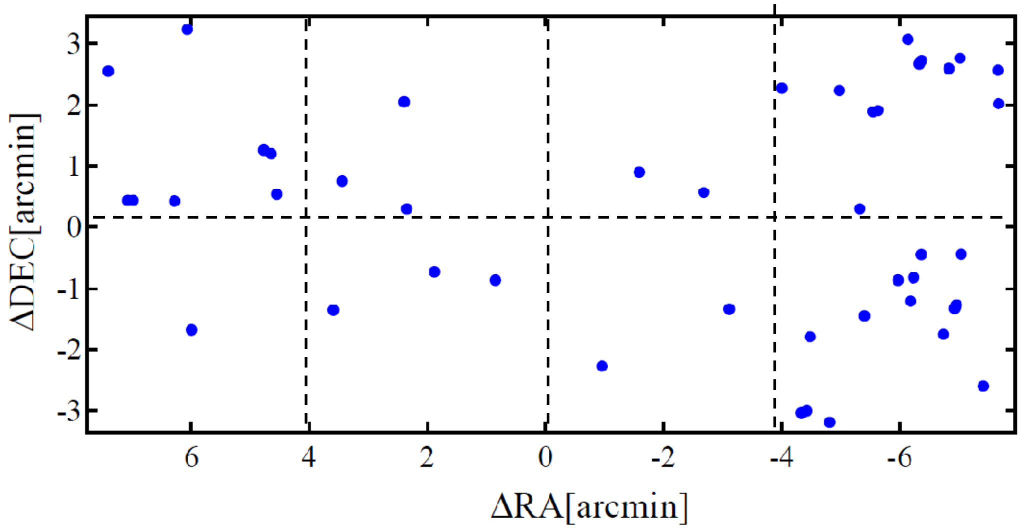


5 MOIRCS pointings

Tadaki et al. (2011), in press

SXDS

"preliminary result"



8 MOIRCS pointings

NB209: ~2.5hrs
Ks: UDS

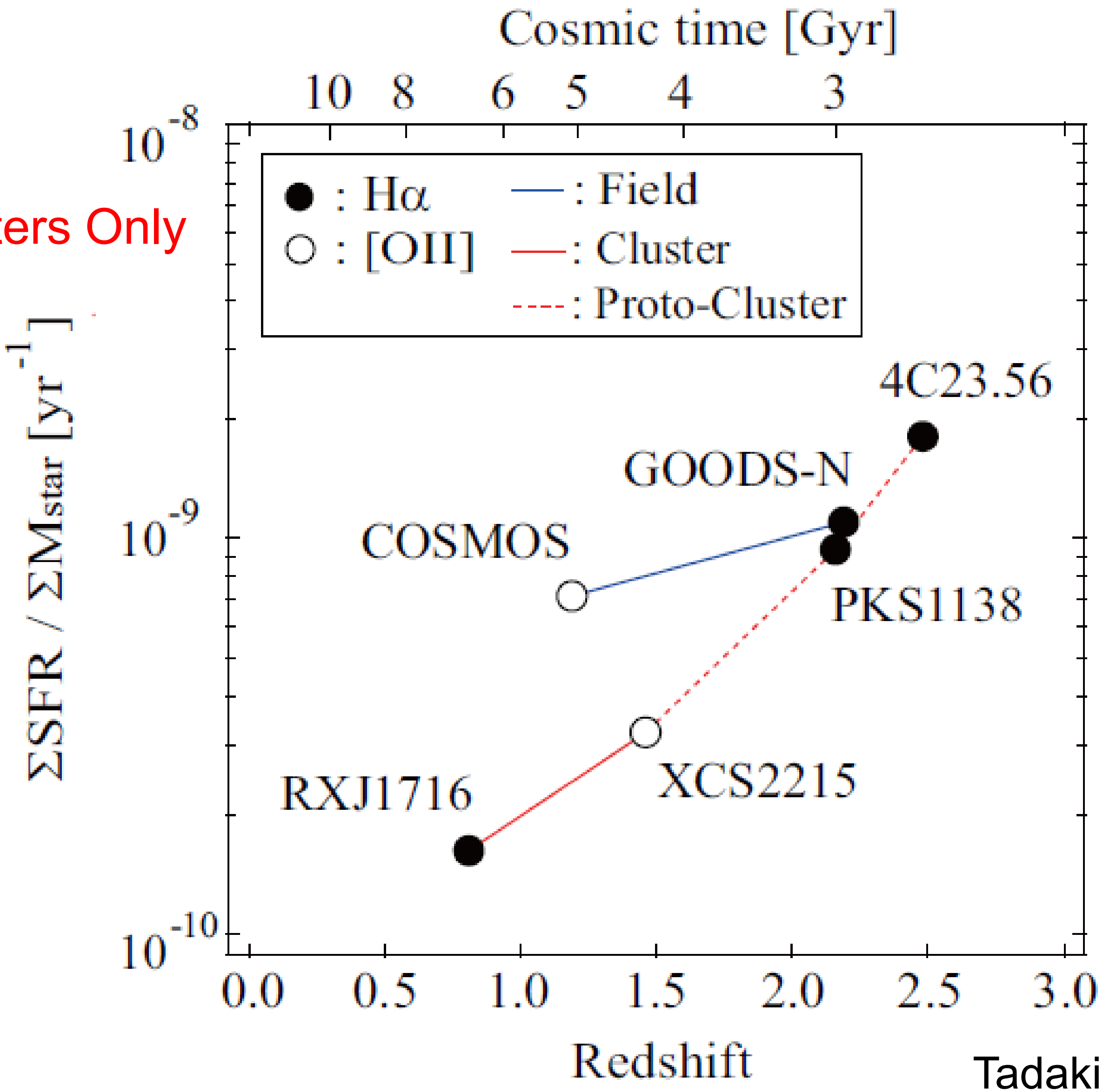
~2-3 × 10^{-17} erg/s/cm^2 ⇔ ~10-15 $M_\odot$/yr (3σ)

Tadaki et al., in preperation

"Mahalo-plot" (in analogy to "Madau-plot")

〈SSFR〉 vs. z and environment for emitters

Emitters Only



Highly uncertain yet !

incompleteness
cosmic variance
…

Tadaki et al. (2011), in press

Molecular Associations with HAlpha and Lines of Oxygen probed with ALMA

Mapping gas and dust at the peak epoch of galaxy formation and evolution

"MAHALO-ALMA"

ALMA

High density gas: CO(2→1) for z=2→1, CO(3→2) for z=3→2

at ~100GHz (Band-3), highest sensitivity & largest FoV (1')

SFR~20$M_\odot$/yr (4hrs, 5σ) with CO(2-1)@z=1.5 and CO(3-2)@z=2.5

Dust cotinuum: 850 μm – 1.1 mm, SFR~10$M_\odot$/yr at z>1.5

Internal kinematical structure: 0.01-0.1"(<1kpc) : gas in-/outflow, rotation

MApping HAlpha and Lines of Oxygen with Subaru

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[OII] survey in CL0332 (z=1.61) (**P20**)
[OII] survey in CL0218 (z=1.62) (**P21**)

Backup Slides

1.46<z<1.65 is the golden redshift range for FMOS follow-up!

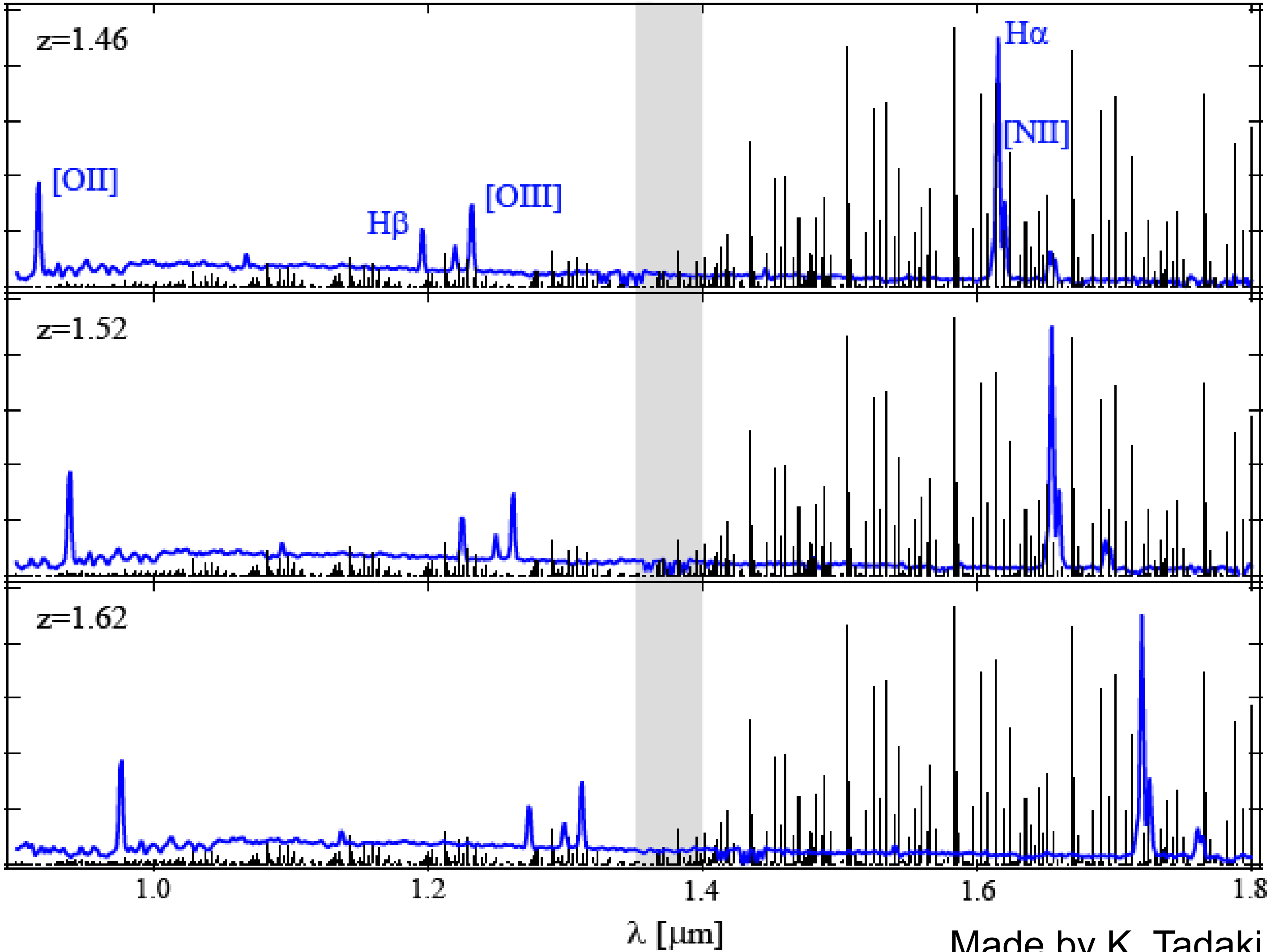
[OII] + Hβ + [OIII] + Hα + [NII]

→ Dust extinction (Hα/Hβ), Metallicity (R23, N2), AGN ([OIII], [NII])

NB921/S-Cam
[OII] @z=1.46

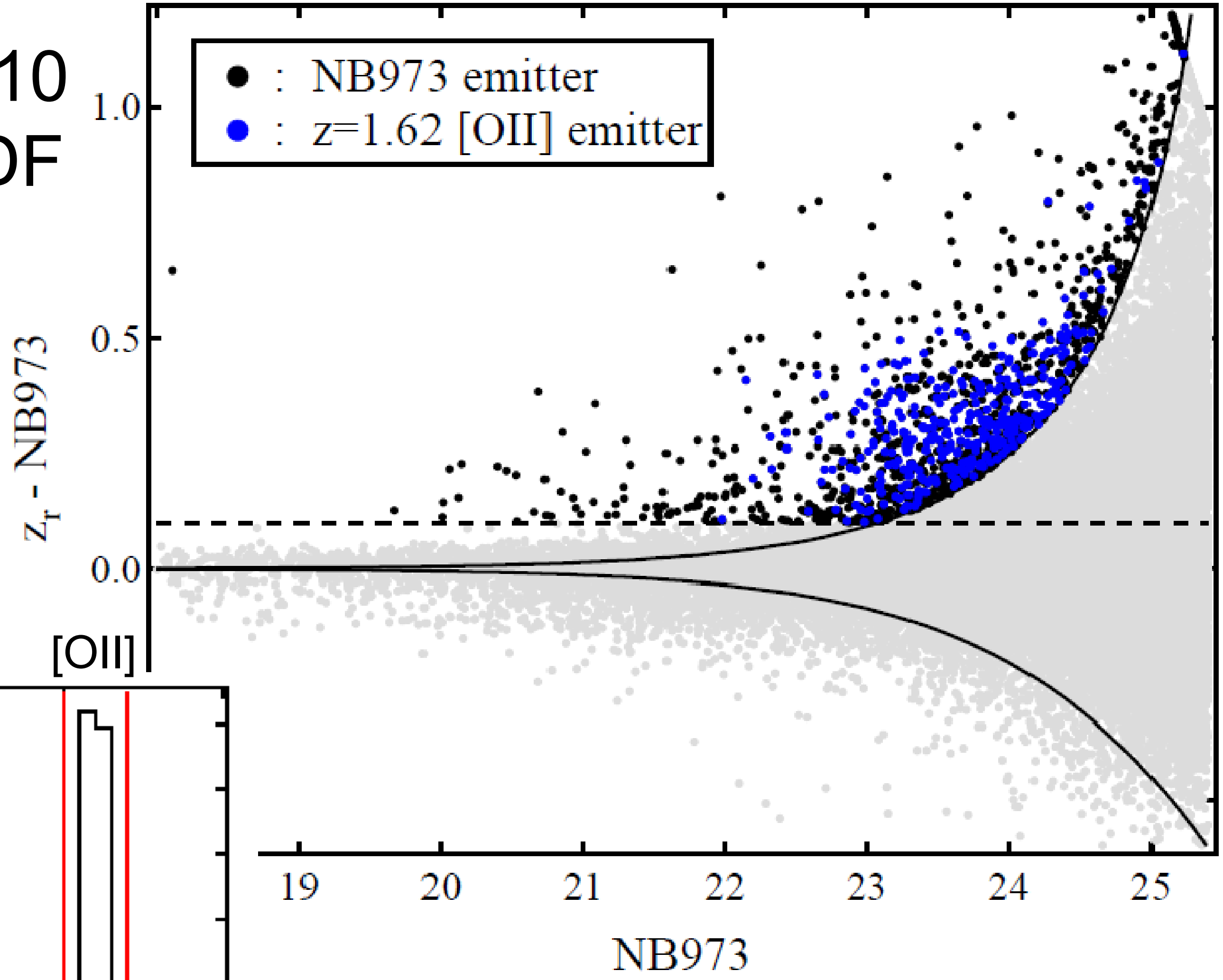
NB1657/MOIRCS
Hα @z=1.52

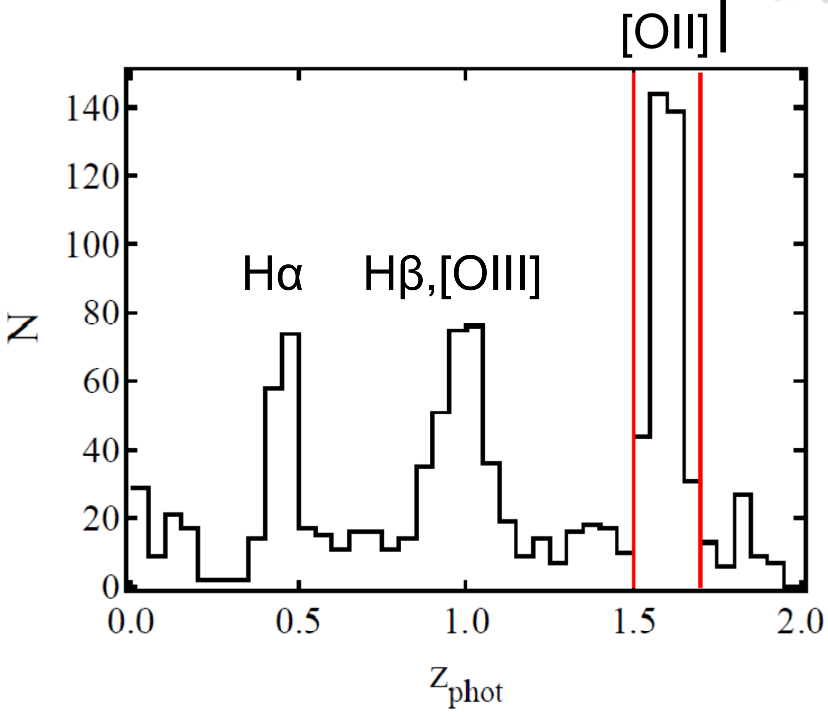
NB973/S-Cam
[OII] @z=1.62



Made by K. Tadaki

CIG J0218.3-0510 (z=1.62) in SXDF



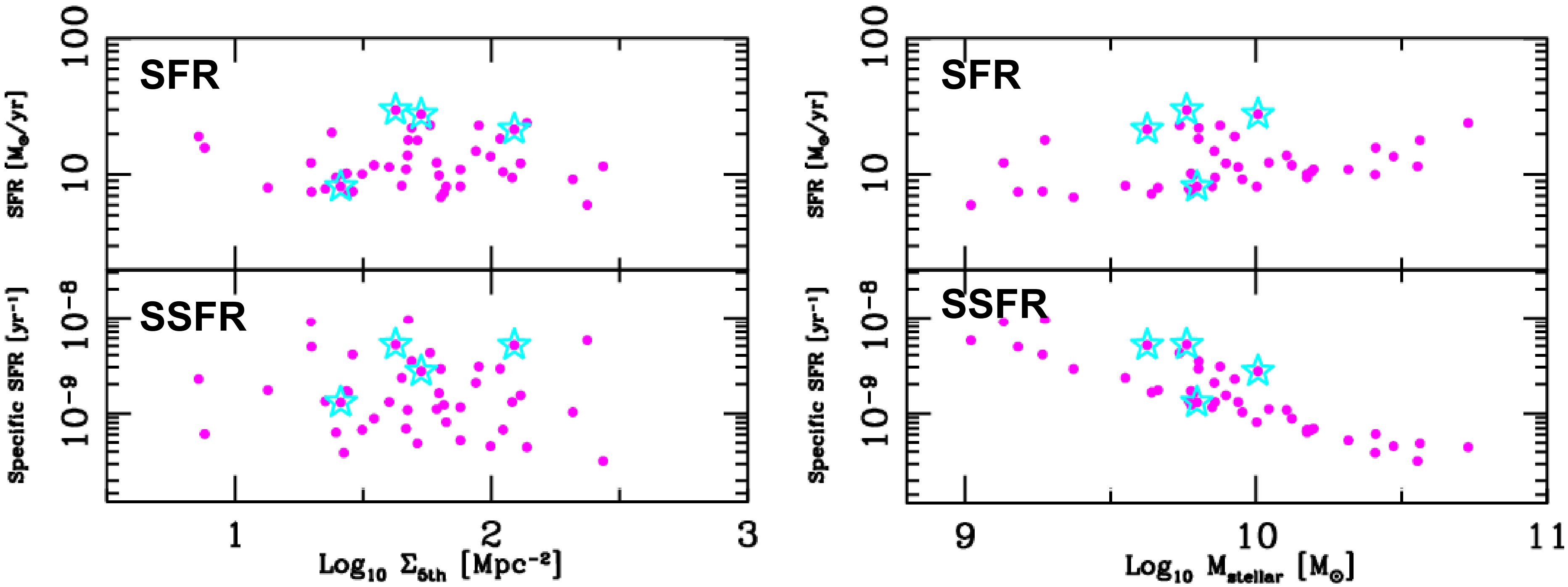


NB973: ~10 hrs (Ota et al.)
zR: 5.5hrs

Tadaki et al., in prep.

CL0332-2742 (z=1.61) in GOODS-S

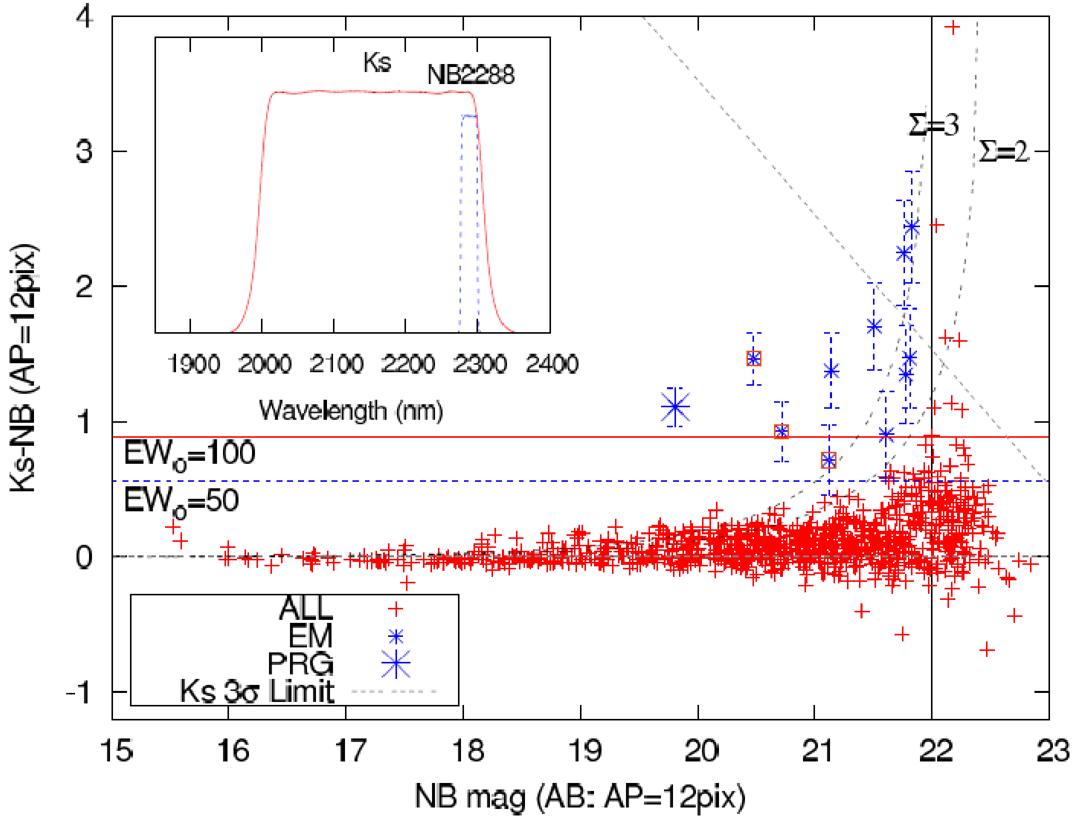
Environmental dependence　　　　Stellar-mass dependence



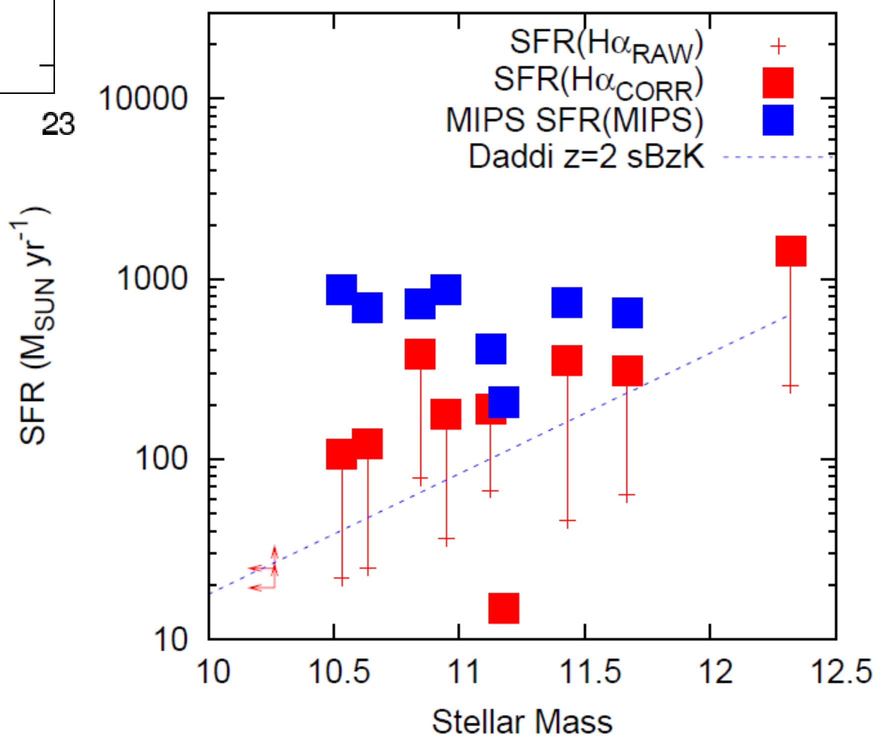
☆ close-pair galaxies

Close-pair galaxies tend to have enhanced SF activities.

Hayashi et al., in prep.



Hα emitters survey in a proto-cluster 4C23.56 at z=2.483 with MOIRCS/NB2288



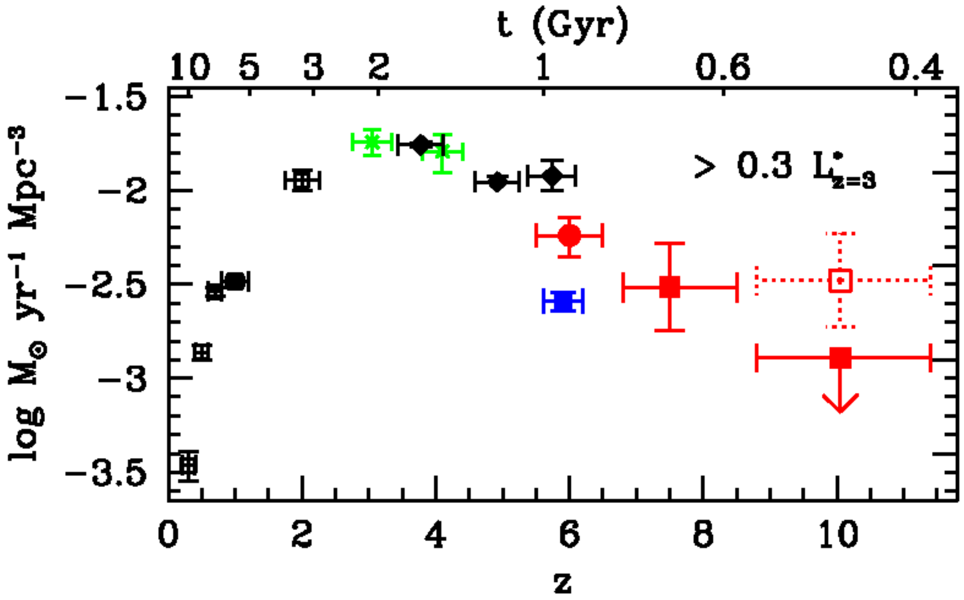
Very strong star forming activities in the high-z proto-cluster!

Tanaka, I., et al. (2011), in press

Galaxy/AGN evolution peaks at z~2

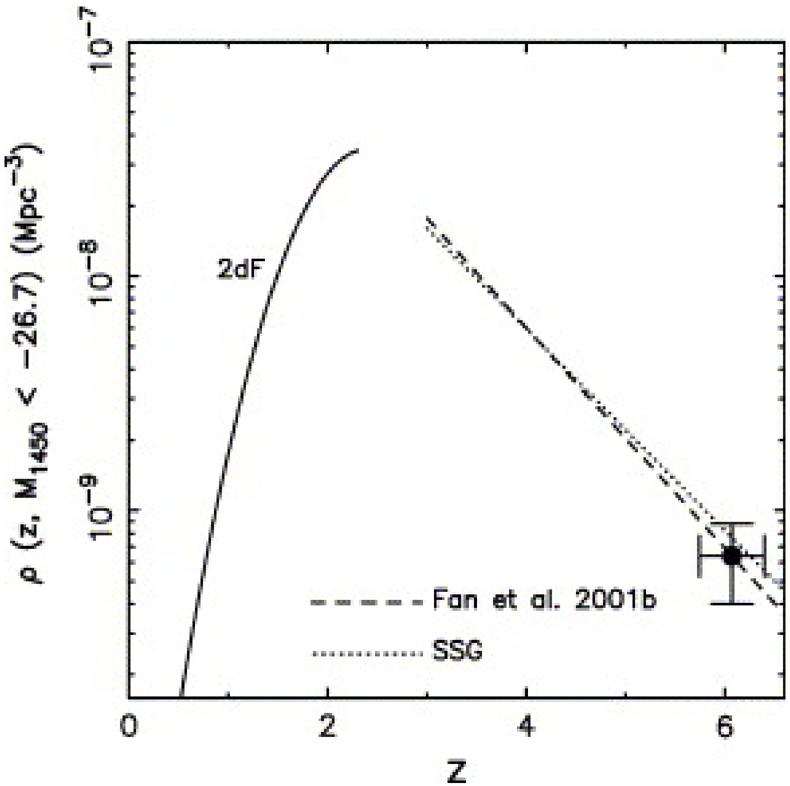
(T_{univ}= 3.5 Gyrs)

Star formation density

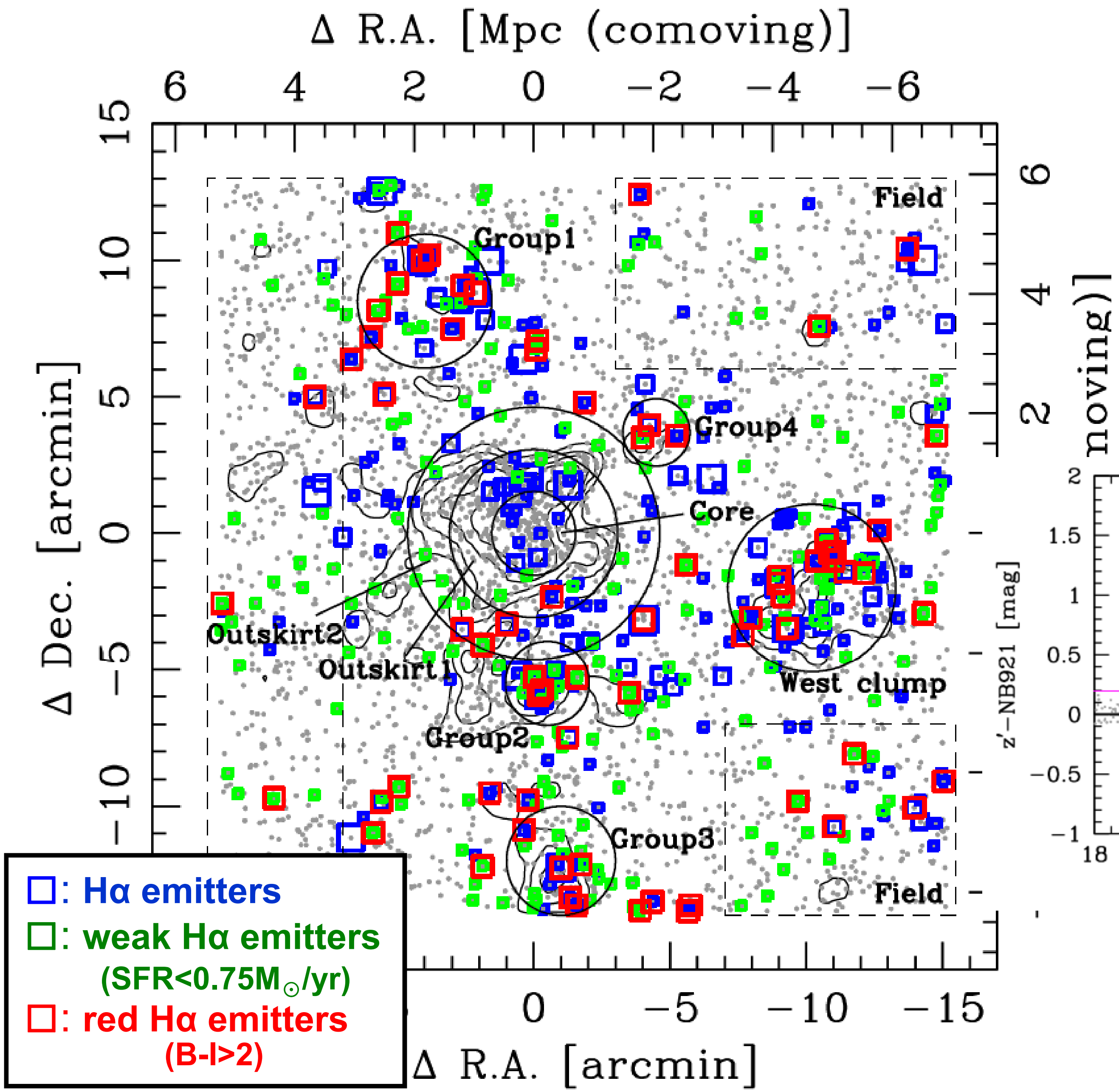


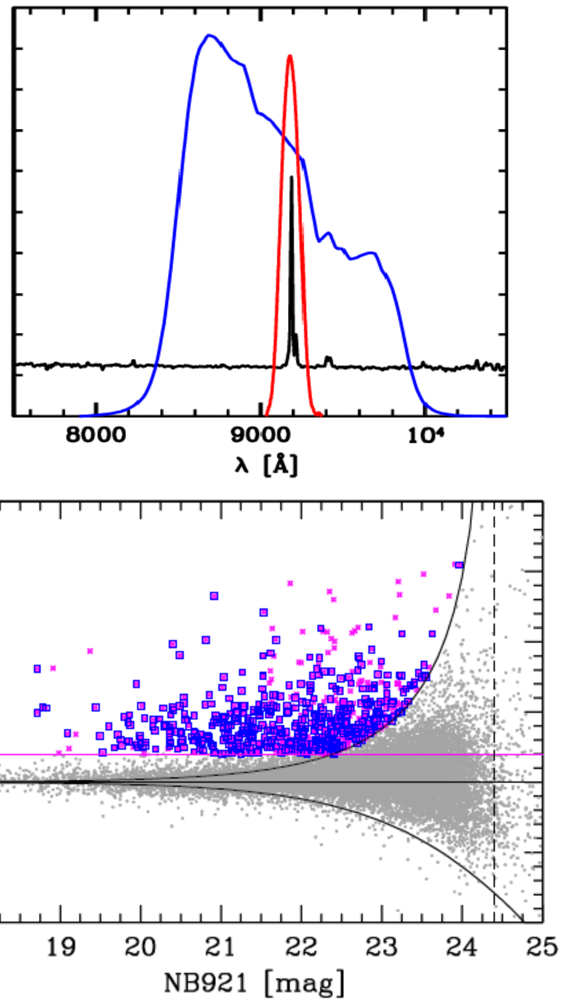
Bouwens et al. (2005)

Number density of QSOs



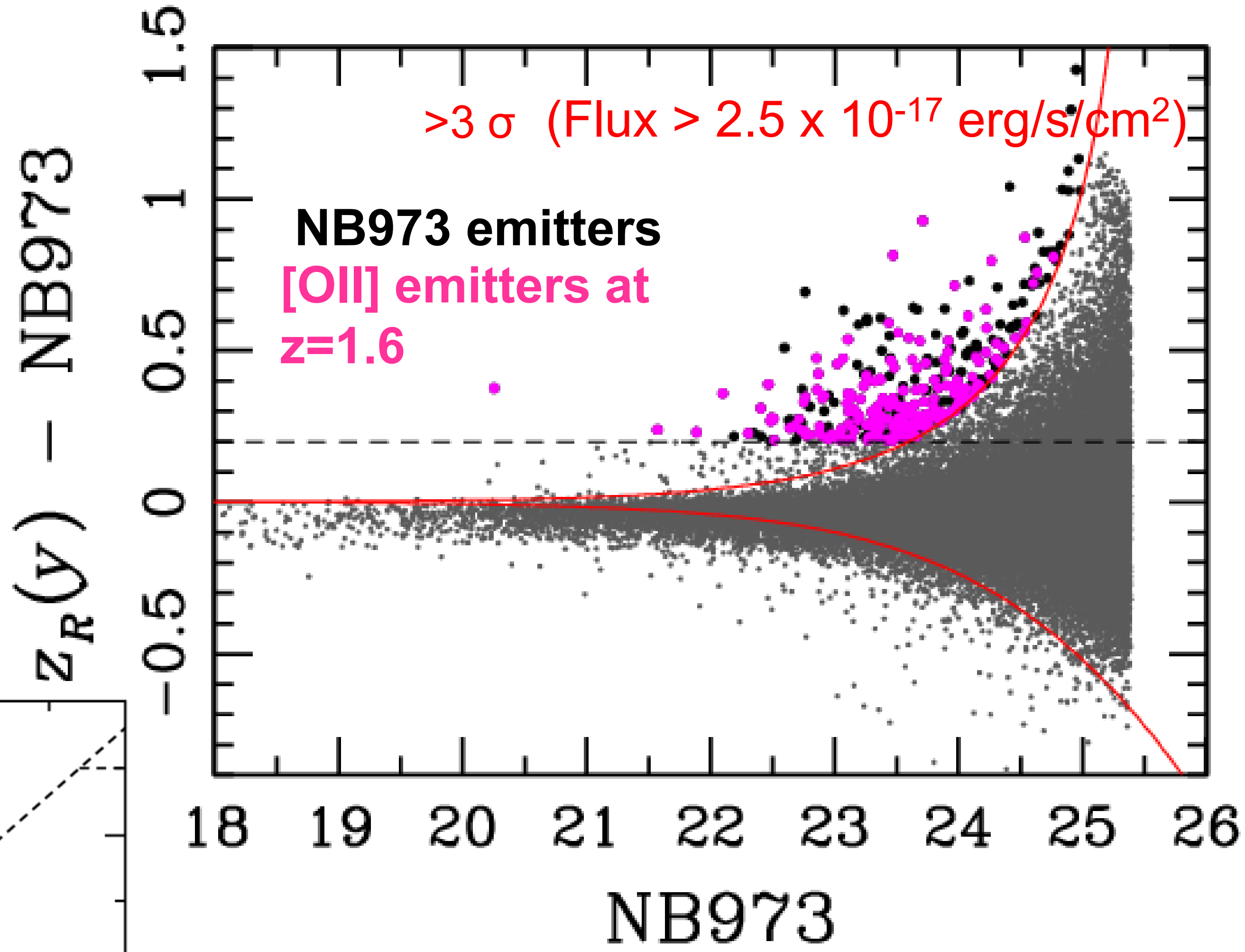
Fan et al. (2006)

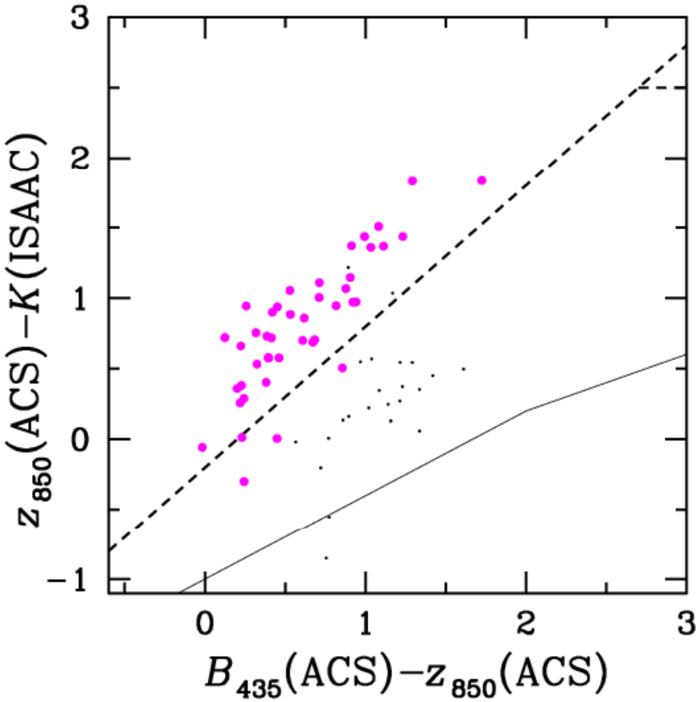




Koyama et al. (2011)

CL0332-2742 (z=1.61)
in GOODS-S

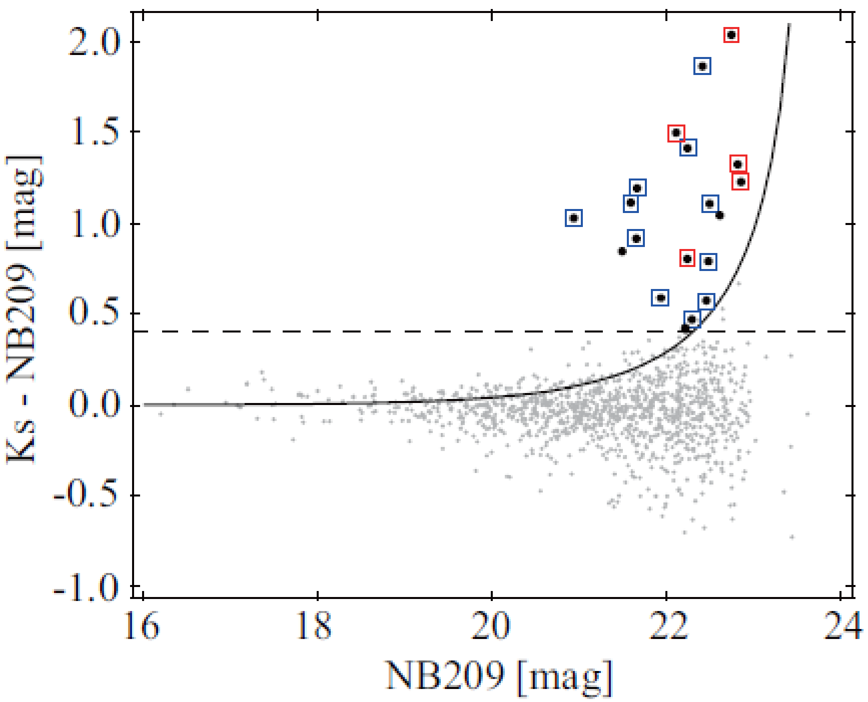


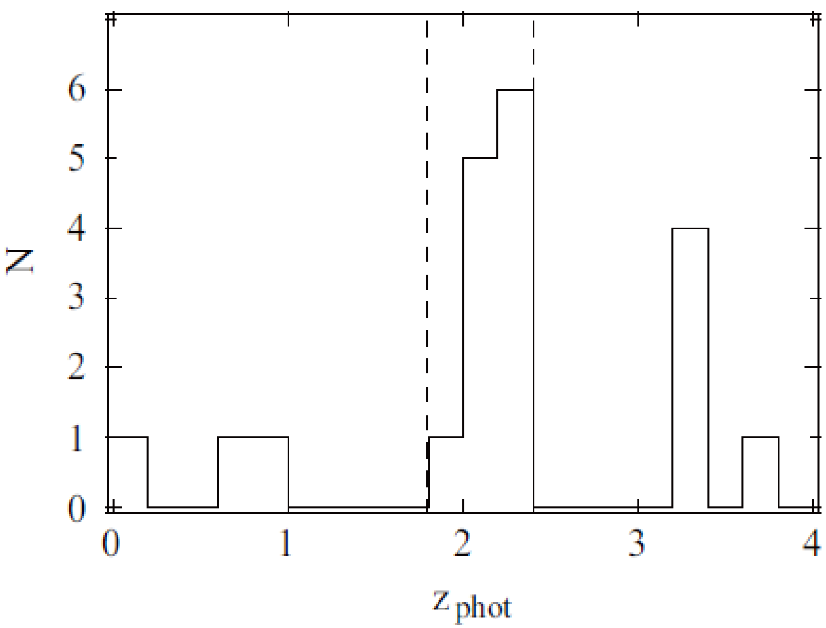


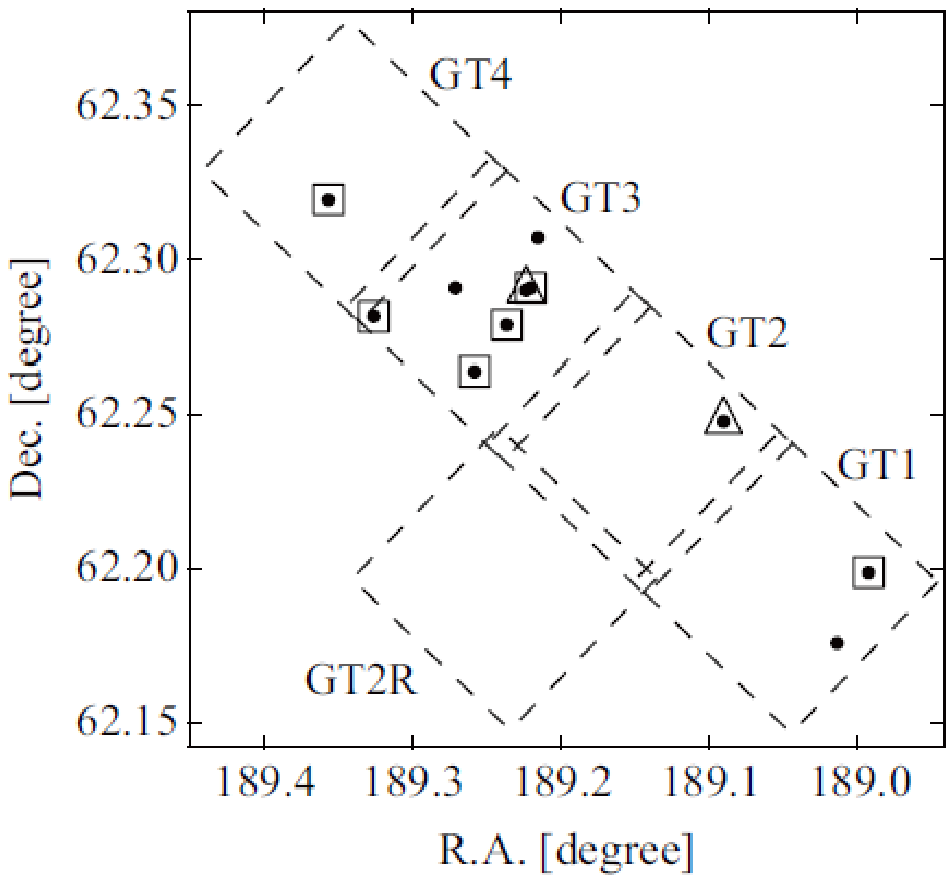
NB973: 7hrs
zR: 3hrs

Hayashi et al., in prep.

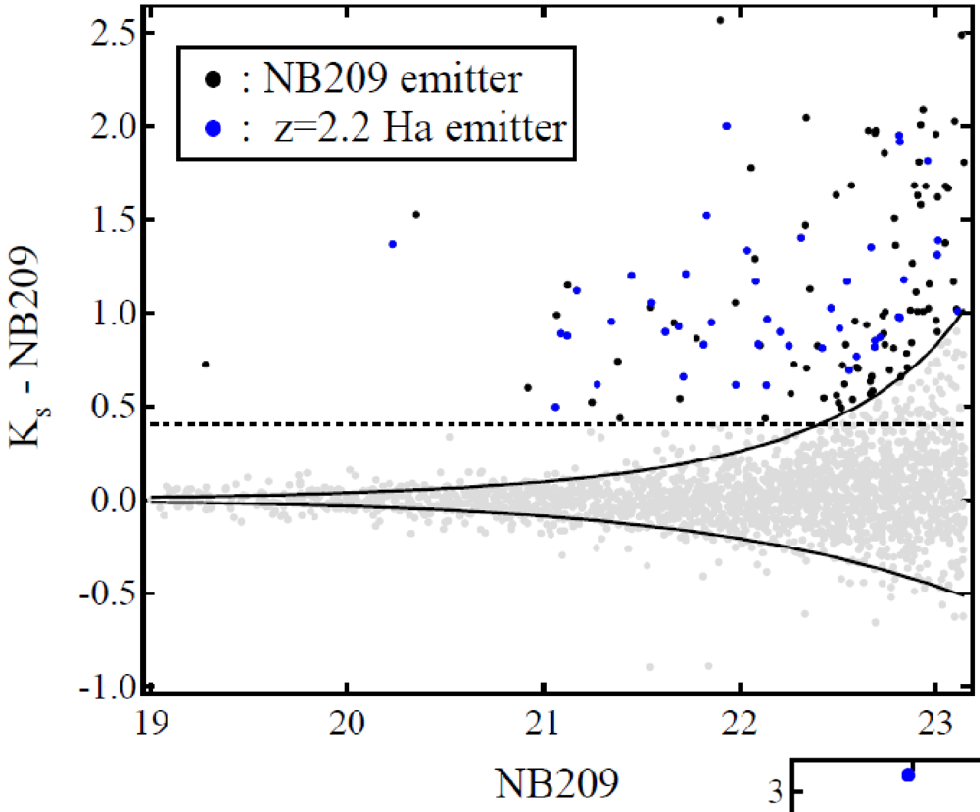
Hα emitters at z=2.2 in GOODS-N





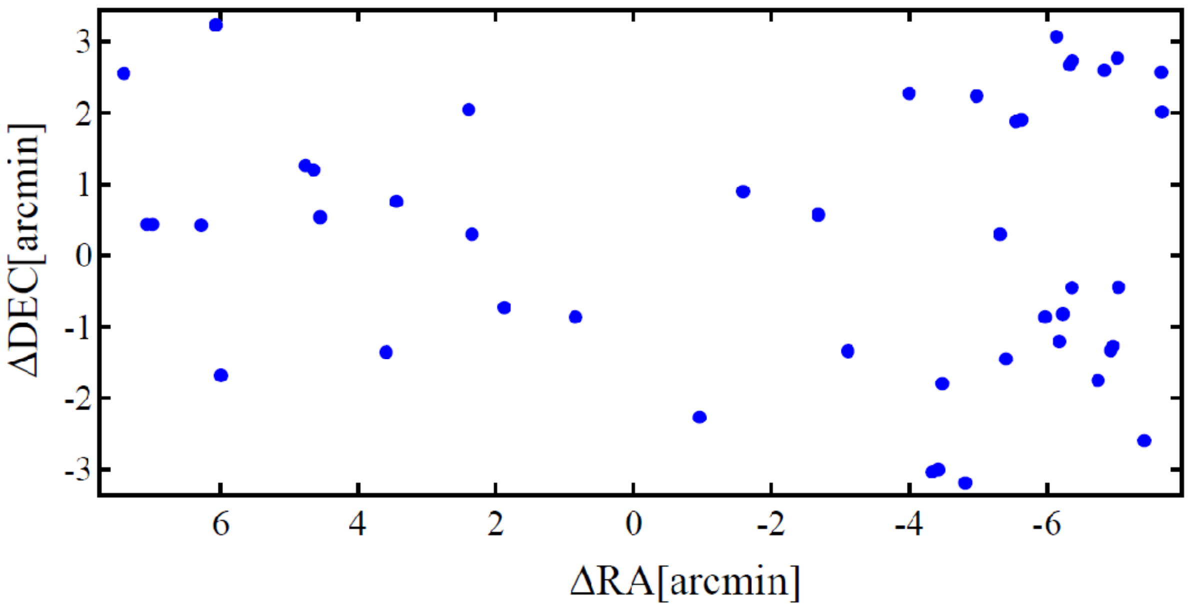


Tadaki et al. (2011), in press



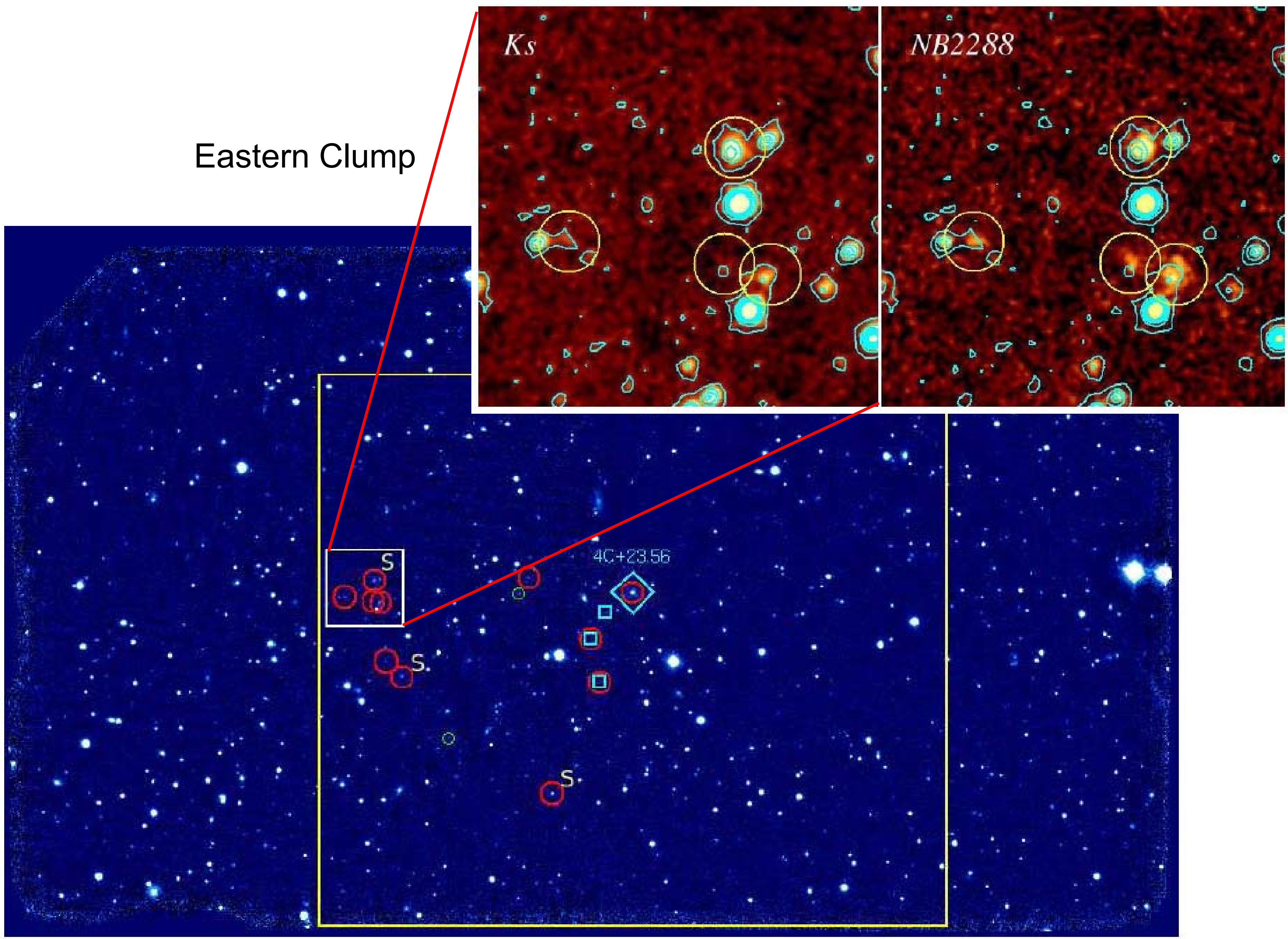
Hα emitters at z=2.2 in SXDF

16 arcmin x 6 arcmnin



NB209: ~2.5hrs
Ks: UDS

Tadaki et al . In prep.


Eastern Clump
Ks
NB2288
S
S
S
4C+23.56

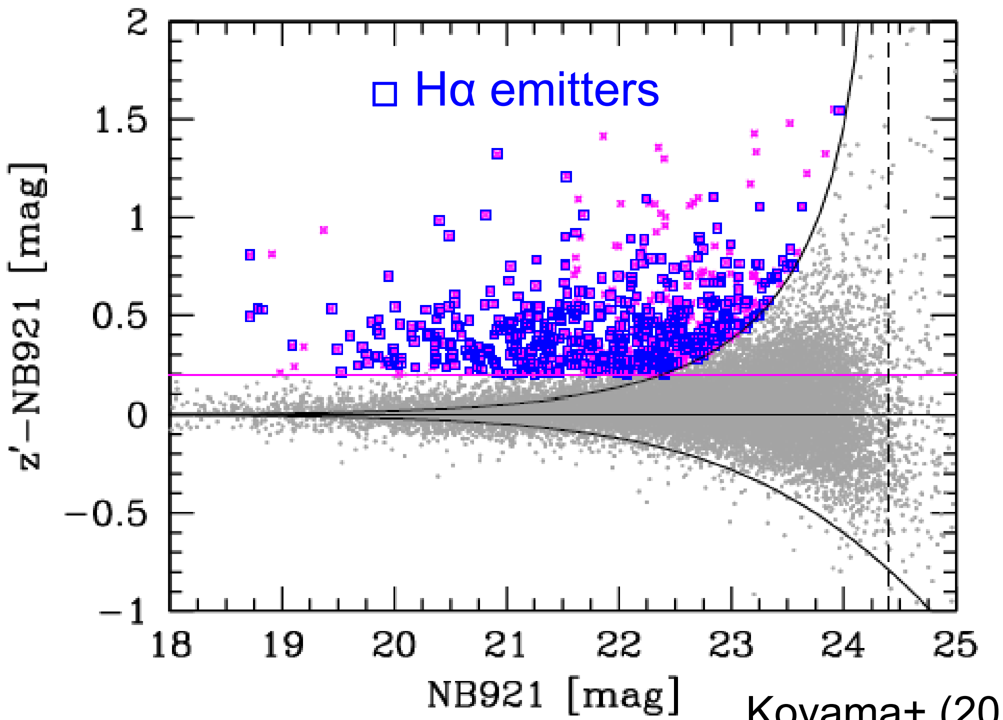
A part of the FMOS-SSP
-- to cover the highest-density regions --

Table 4 The list of our target clusters. Eight primary targets are shown by bold fonts. The targets are classified into 8 groups according to redshifts; $z \sim 0.55, 0.8, 1.2, 1.4, 1.6, 2, 2.5$, and 3, as separated by horizontal lines. These correspond to the look-back times of 5.4, 6.9, 8.5, 9.1, 9.6, 10.4, 11.1, and 11.6 Gyrs, respectively. We will use higher resolution mode (R=2200) and the number of configurations and the spectral coverages are shown in the table (Js, Jl, Hs, and Hl indicate J-short, J-long, H-short, and H-long, respectively.) Note that we have narrow-band emitter survey data for most of the primary targets, which provide excellent spectroscopic targets for FMOS. Lyα emitter surveys are also available for most of the higher-z targets at $z > 2$. Note also that all of our targets, except for two (1716 and 0848), are visible from ALMA for future coordinated observations.

Cluster	z	Lx44	NB	$M_\odot$/yr (5σ)	cfg.	spectra	expected lines	imaging
CL 0016+1609	**0.55**	26.0	Hα	**1.0 (1hr)**	**6**	Js	Hα,[NII]	$BVRi'z'$
MS 0451.6−0305	0.55	12.0	—	1.0 (2hr)	2	Js	Hα,[NII]	$BVRI$
RX J1716.4+6708	**0.81**	2.7	Hα, [OII]	**1.7 (2hr)**	**2**	Jl	Hα,[NII]	$VRi'z'JK$
RX J0152.7−1357	0.84	16.0	—	1.9 (2hr)	2	Jl	Hα,[NII]	$VRi'z'K$
RDCS J1252−2927	**1.24**	6.6	—	**3.2 (5hr)**	**2**	Hs,Js	Hα,[NII],[OIII],Hβ	$VRi'z'K$
RX J0848.9+4452	1.26	2.8	—	3.3 (5hr)	2	Hs,Js	Hα,[NII],Hβ	$BVRi'z'JK$
XMM2235.3−2557	1.39	3.0	—	4.2 (5hr)	2	Hs,Jl	Hα,[NII],[OIII],Hβ	$VRi'z'JK$
XCS2215.9−1738	**1.46**	4.3	[OII]	**4.7 (5hr)**	**2**	Hl,Jl	Hα,[NII],[OIII],Hβ	$BRi'z'K$
CL0332−2742	1.61	—	[OII]	6.0 (5hr)	2	Hl,Jl	Hα,[NII],[OIII],Hβ	$BVizJHK$
CIGJ0218.3−0510	**1.62**	3.4	[OII]	**6.1 (5hr)**	**2**	Hl,Jl	Hα,[NII],[OIII],Hβ	$BVRi'z'JHK$
PKS 1138−262	**2.16**	—	Hα, Lyα	**15 (10hr)**	**1**	Hs,Jl	[OII],[OIII],Hβ	$BVRIJHK$
4C 23.56	**2.48**	—	Hα Lyα	**22 (10hr)**	**1**	Hl,Jl	[OII],[OIII],Hβ	$Bz'JHK$
USS 1558−003	2.53	—	Hα	23 (10hr)	1	Hl,Jl	[OII],[OIII],Hβ	$Bz'JHK$
USS 0943−242	2.92	—	Lyα	32 (10hr)	1	Hs	[OII]	$VIJHK$
SSA22	**3.09**	—	Lyα	**37 (10hr)**	**1**	Hs	[OII]	$BVRi'z'JHK$
MRC 0316−257	3.13	—	Lyα	38 (10hr)	1	Hs	[OII]	$BVRIJHK$

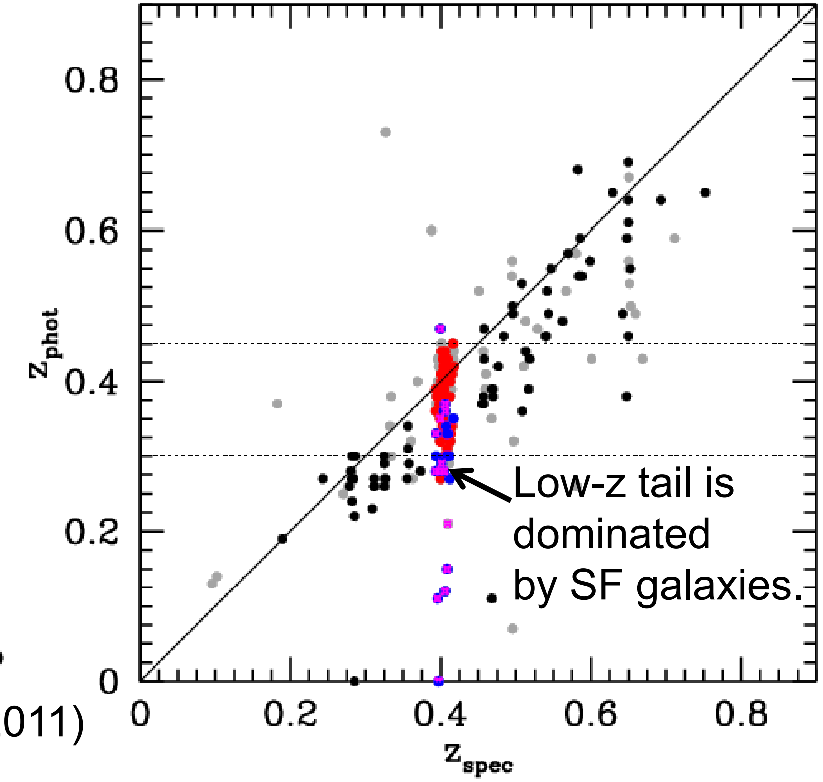
Advantages of narrow-band surveys (Hα, [OII])

CL0939 cluster (z=0.4)



Koyama+ (2011)

Blue galaxies tend to be missed by phot-z selection.



(1) Good indicators of SFR, especially Hα (low reddening, well calibrated)
(2) "Unbiased" sample (no pre-selection of targets is required).
(3) Membership can be confirmed by the presence of emitters in NB +colours.
(4) On top of the phot-z selected members (e.g. "passive" galaxies), we can pick out "active" galaxies which tend to be missed by phot-z selection.