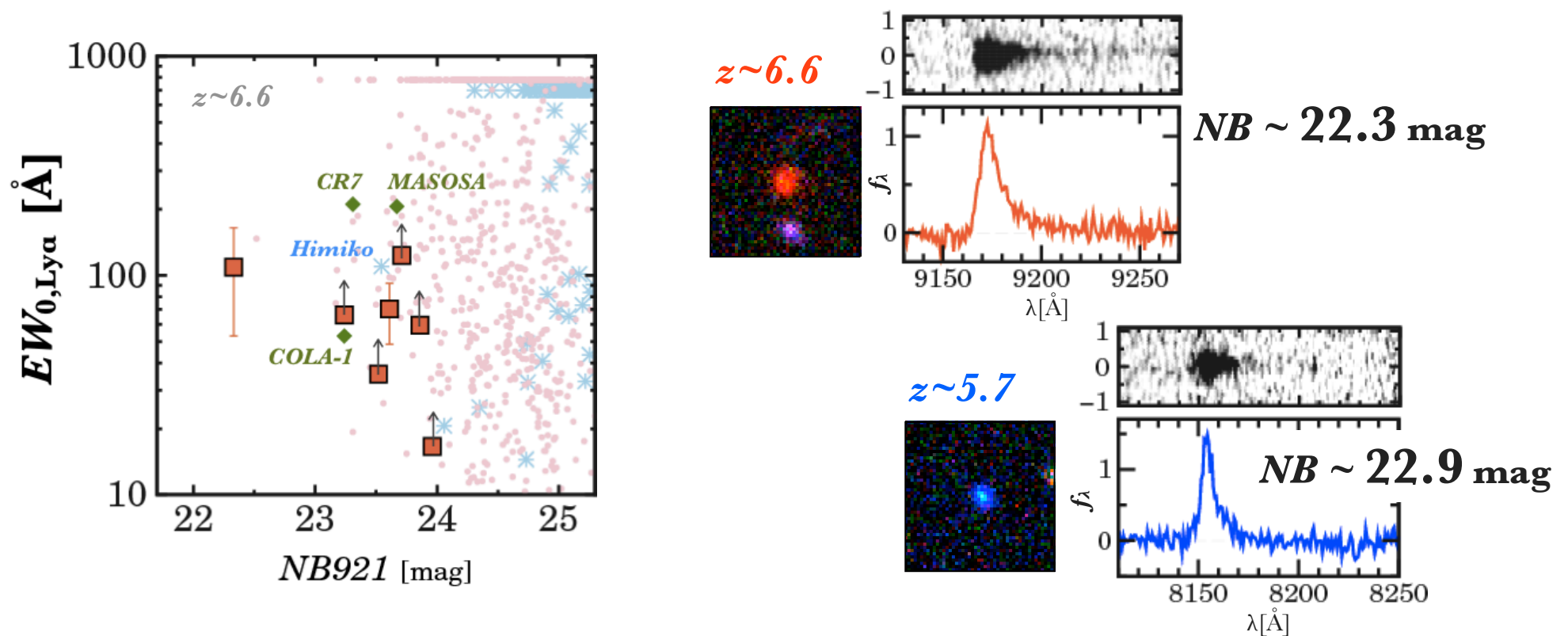


First demographics of very bright LAEs at $z \sim 6-7$

uncovered by
the large area Subaru HSC NB imaging
and deep spectroscopy



Takatoshi Shibuya (Univ. of Tokyo) **et al.**

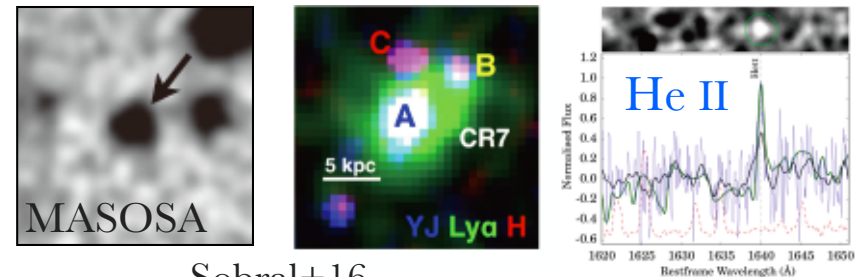
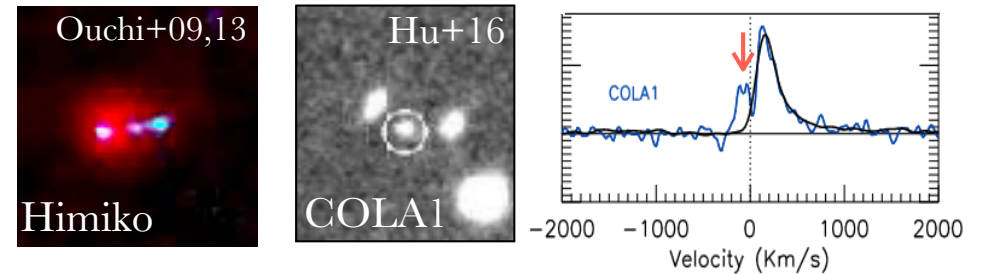
+ HSC Project 84, 85, and 197 Members

Very rare & bright Ly α Emitters

Ly α -bright objects at high- z

- ✓ Candidates of very young galaxies, Pop III, AGNs, DCBHs etc.
- ✓ Spatially-extended? UV multiple? Double-peak Ly α ? He II emitting?
- ✓ Only 4 sources
 - Need large-area NB data

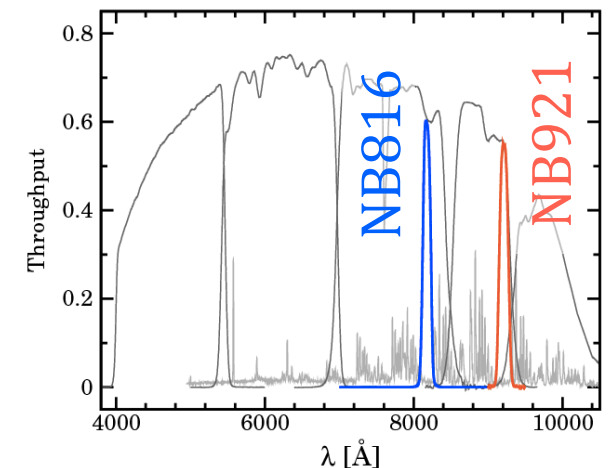
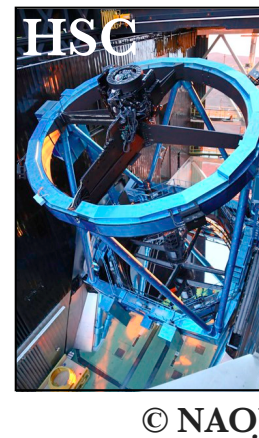
Bright SCam-LAEs ($\log L_{\text{Ly}\alpha} > \sim 43$ erg/s)



(See also, Bowler+16)

Hyper Suprime-Cam (HSC)

- ✓ 1 FoV ~ 1.8 deg 2 ($\sim 7 \times \text{FoV}_{\text{SCam}}$)
- ✓ HSC-SSP Survey
- ✓ $z \sim 2.2, 5.7, 6.6, 7.3$



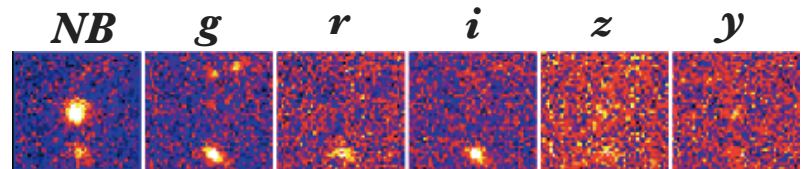
Number of HSC-LAEs

	<i>NB921</i>	<i>NB816</i>
UD-SXDS	60	224
UD-COSMOS	435	202
D-ELAISN1	351	232
D-DEEP23	178	423
D-COSMOS	249	---
Total	1273	1081

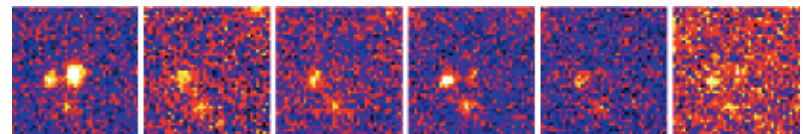
NB $M_{\text{lim}} \sim 25.5 \text{ mag (UD)},$
 $25 \text{ mag (D)} (5\sigma, 1.''5)$

Examples

z ~ 6.6



z ~ 5.7



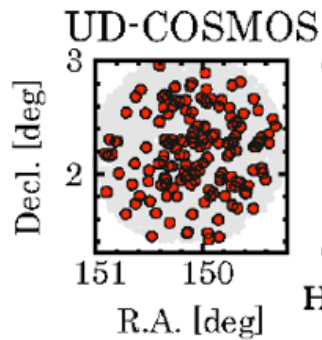
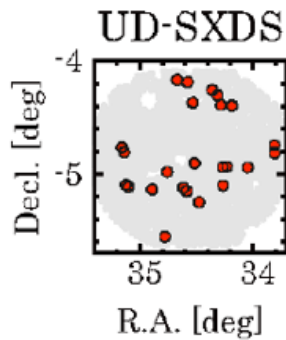
- ✓ **~2400** LAEs are identified w S16A data
- ✓ Very rare and bright LAEs (T. Shibuya+, This talk)
- ✓ Ly α LFs, cosmic reionization (A. Konno+'s talk in Subaru-UM)
- ✓ Faint AGNs (Higuchi+)

Survey Area Comparison

HSC

(S16A data)

$z \sim 6.6$



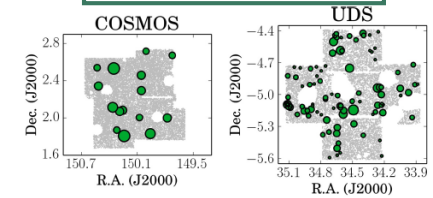
$\sim 21.2 \text{ deg}^2$

HSC 1FoV

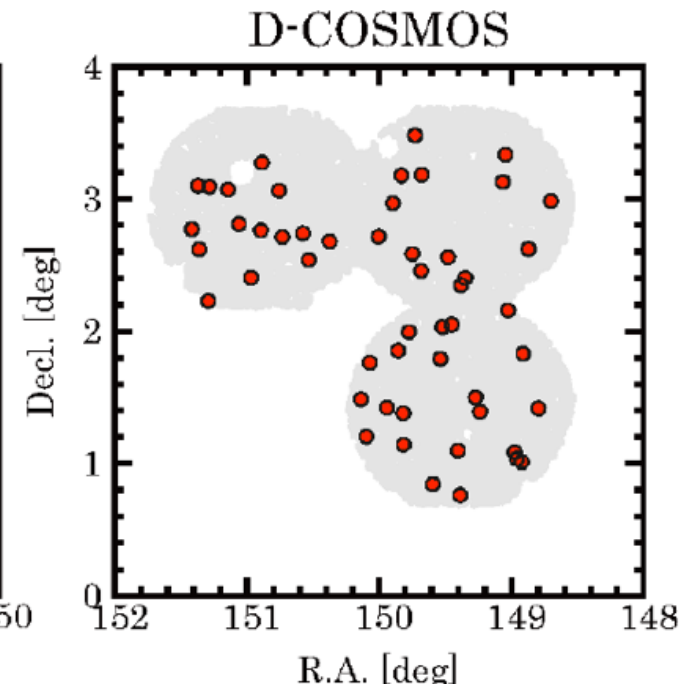
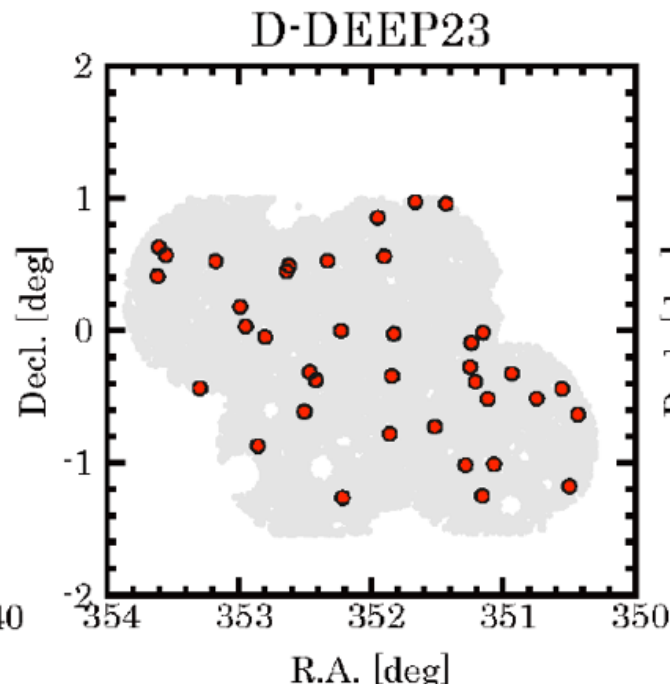
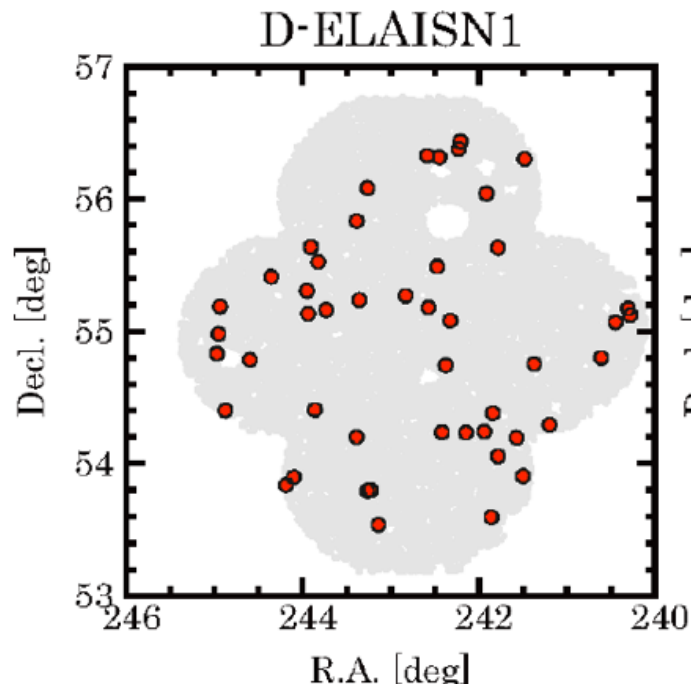
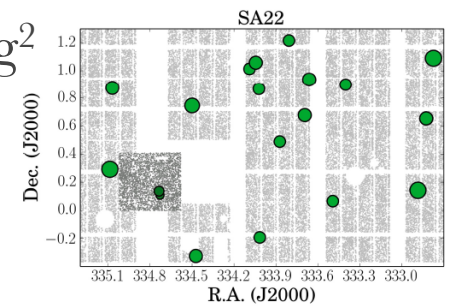
$\sim 4 \times$

SCam

e.g.,
Kashikawa+06, 11
Ouchi+10,
Matthee+15



$\sim 5 \text{ deg}^2$

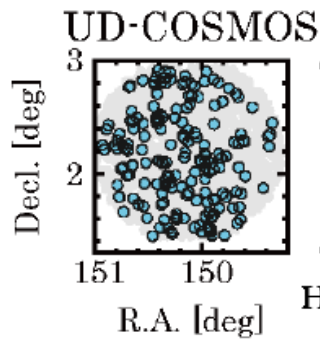
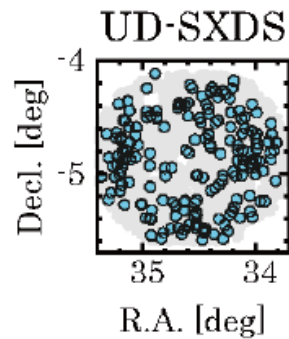


Survey Area Comparison

HSC

(S16A data)

$z \sim 5.7$



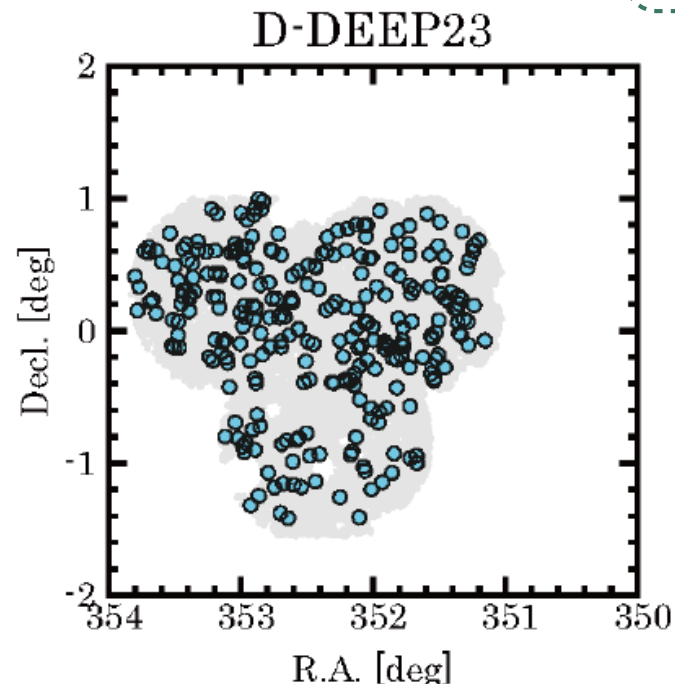
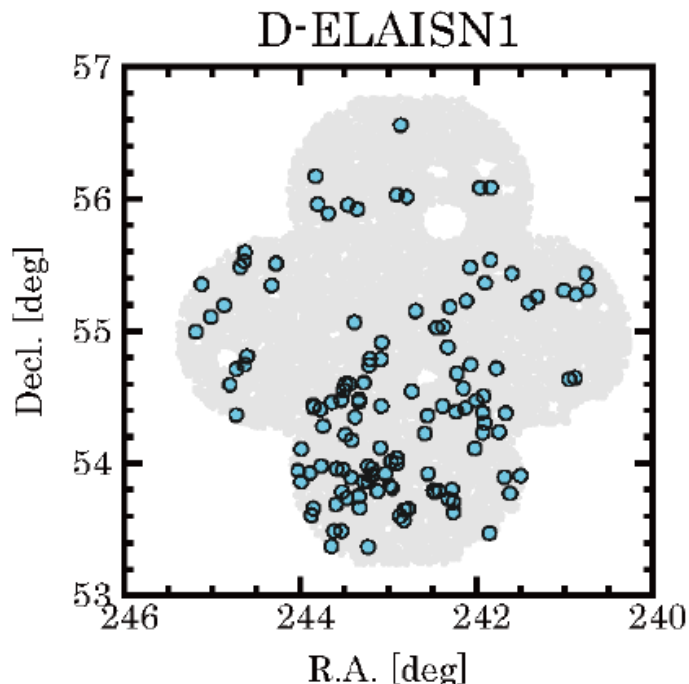
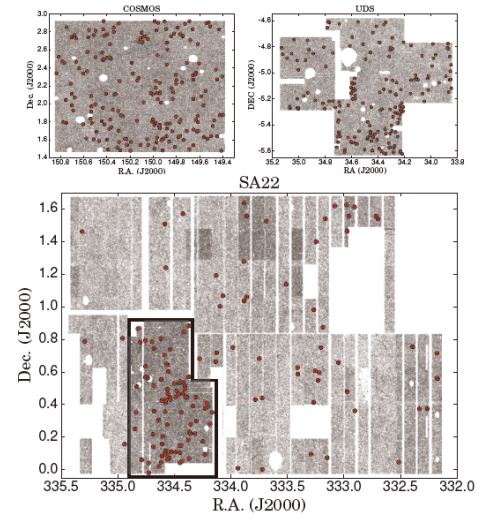
HSC 1FoV

$\sim 13.8 \text{ deg}^2$

$\sim 2.5 \text{ deg}^2$

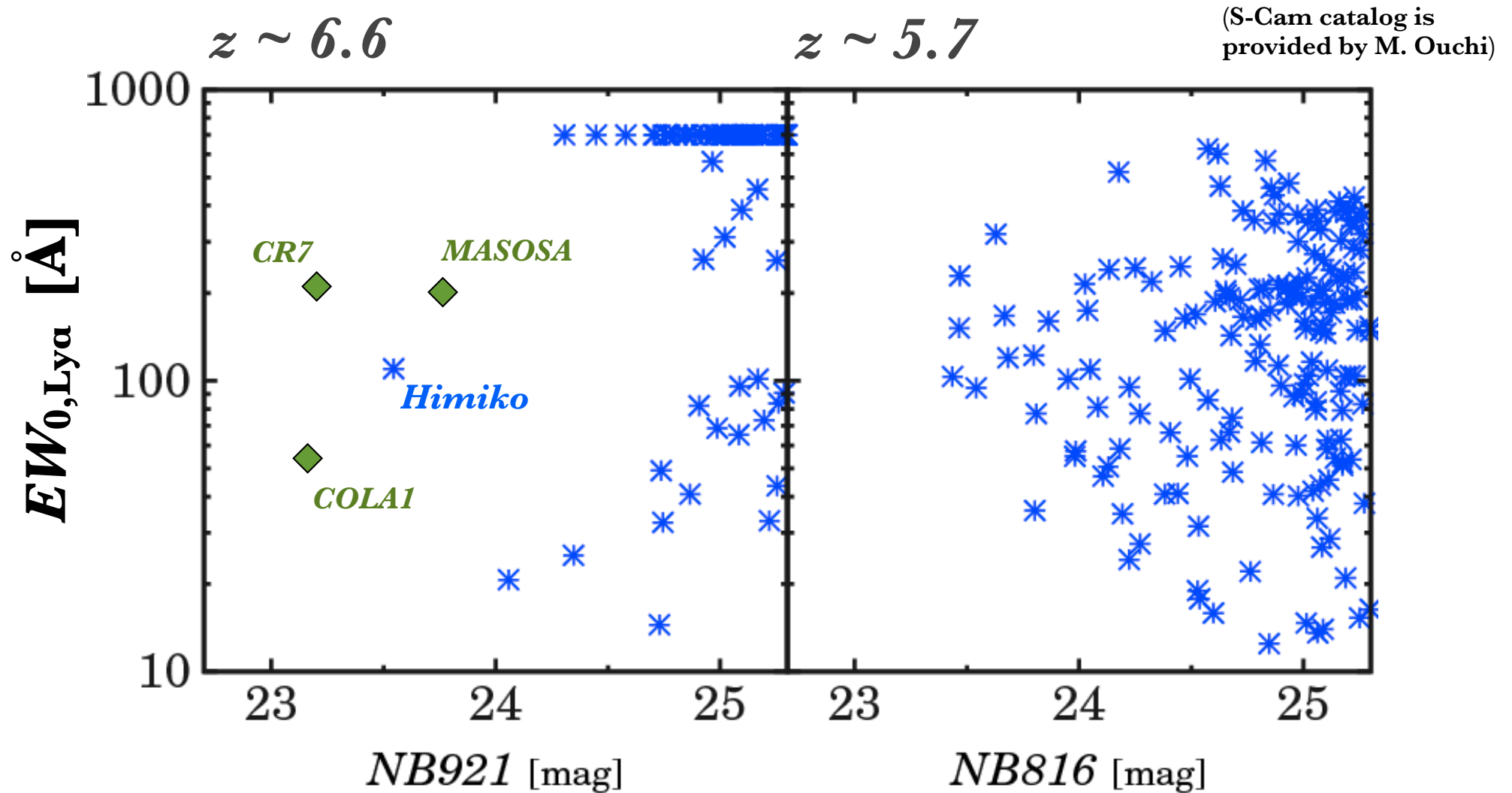
$\sim 5 \times$

SCam



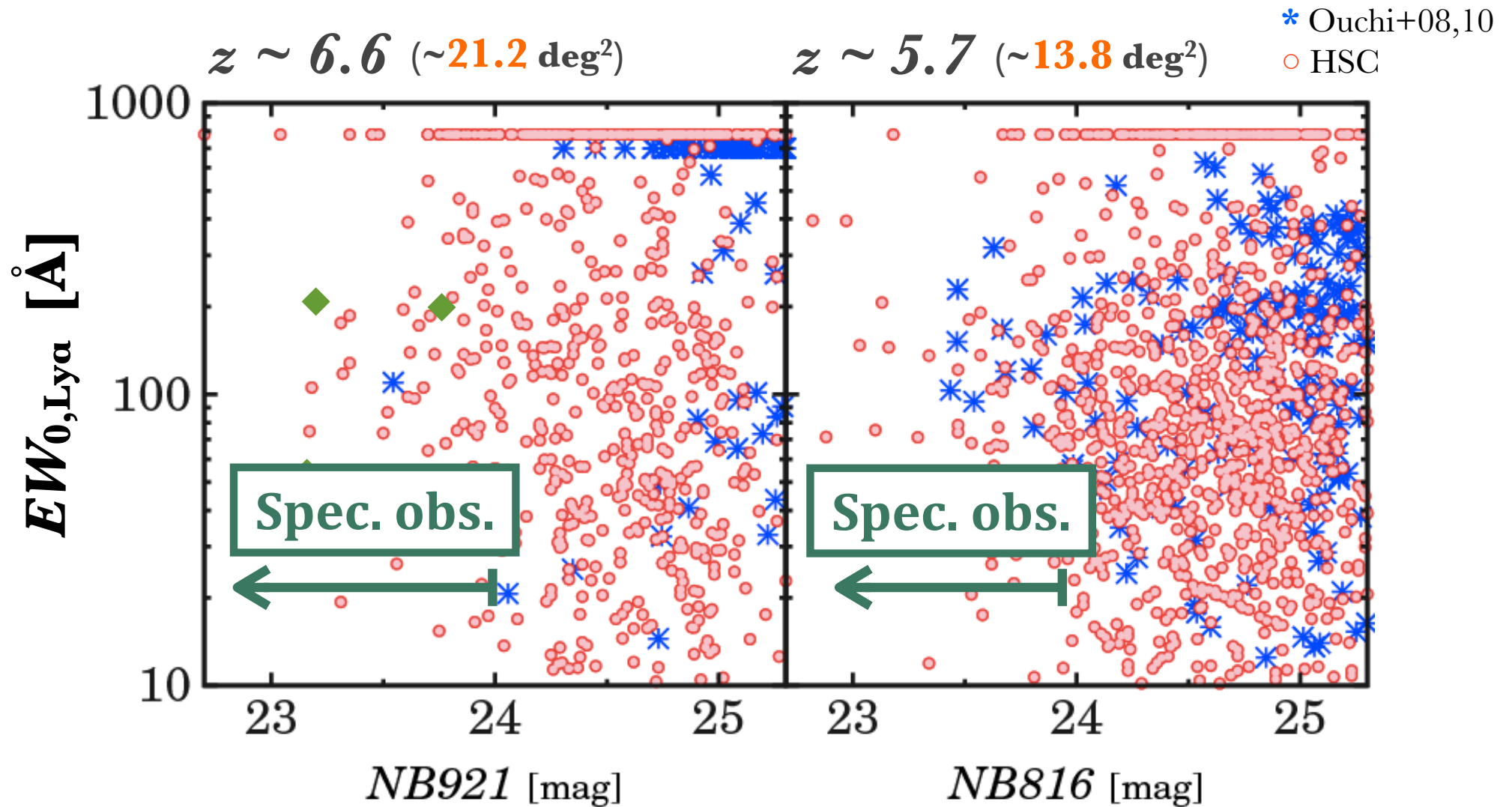
e.g.,
Shimasaku+06
Murayama+07
Ouchi+08,
Hu+10
Santos+16

Era of Subaru/SCam



(See also, e.g., Murayama+, Taniguchi+, Shimasaku+, Kashikawa+, Hu+, Matthee+, Santos+)

Era of Subaru/HSC



✓ Many LAEs at $NB < 24$ thanks to HSC large survey area

Optical Spec Observations

Subaru open-use obs.

✓ Subaru/FOCAS (VPH900+SO58)

2016 May, 2 nights (clear sky)

2016 Sep., 1 night (clear sky)

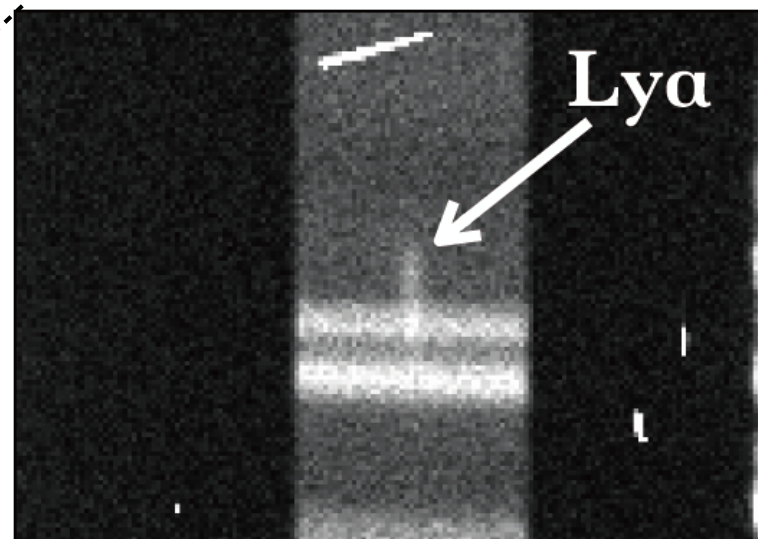
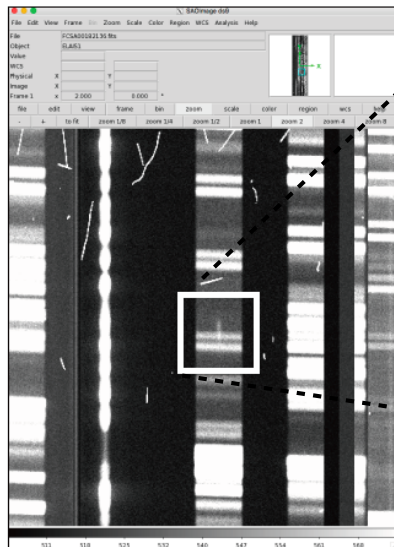
16 LAE cands@ $z \sim 5.7-6.6$

$\sim 1-2$ hr / obj.



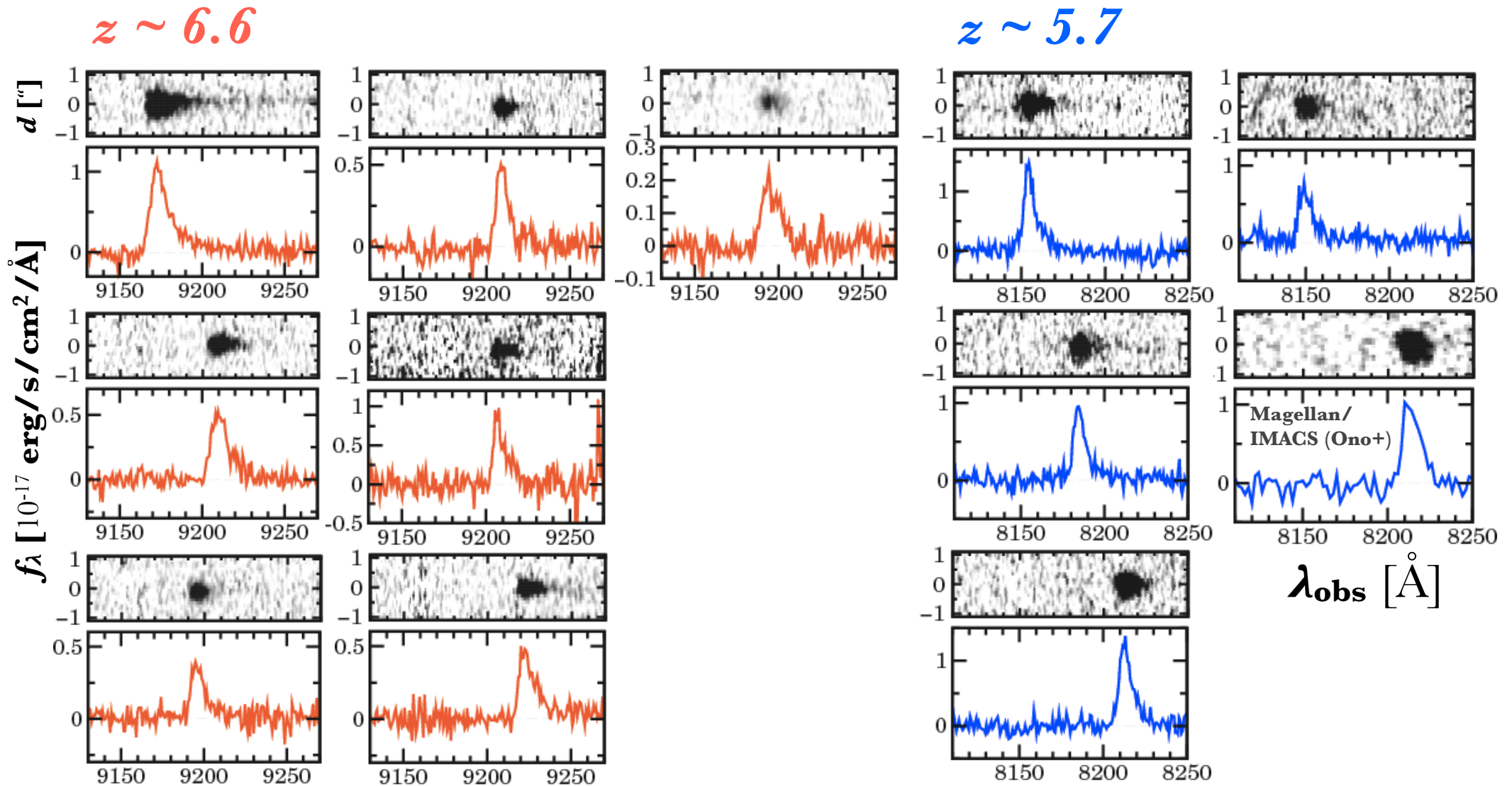
© NAOJ

Raw data just taken on the observatory



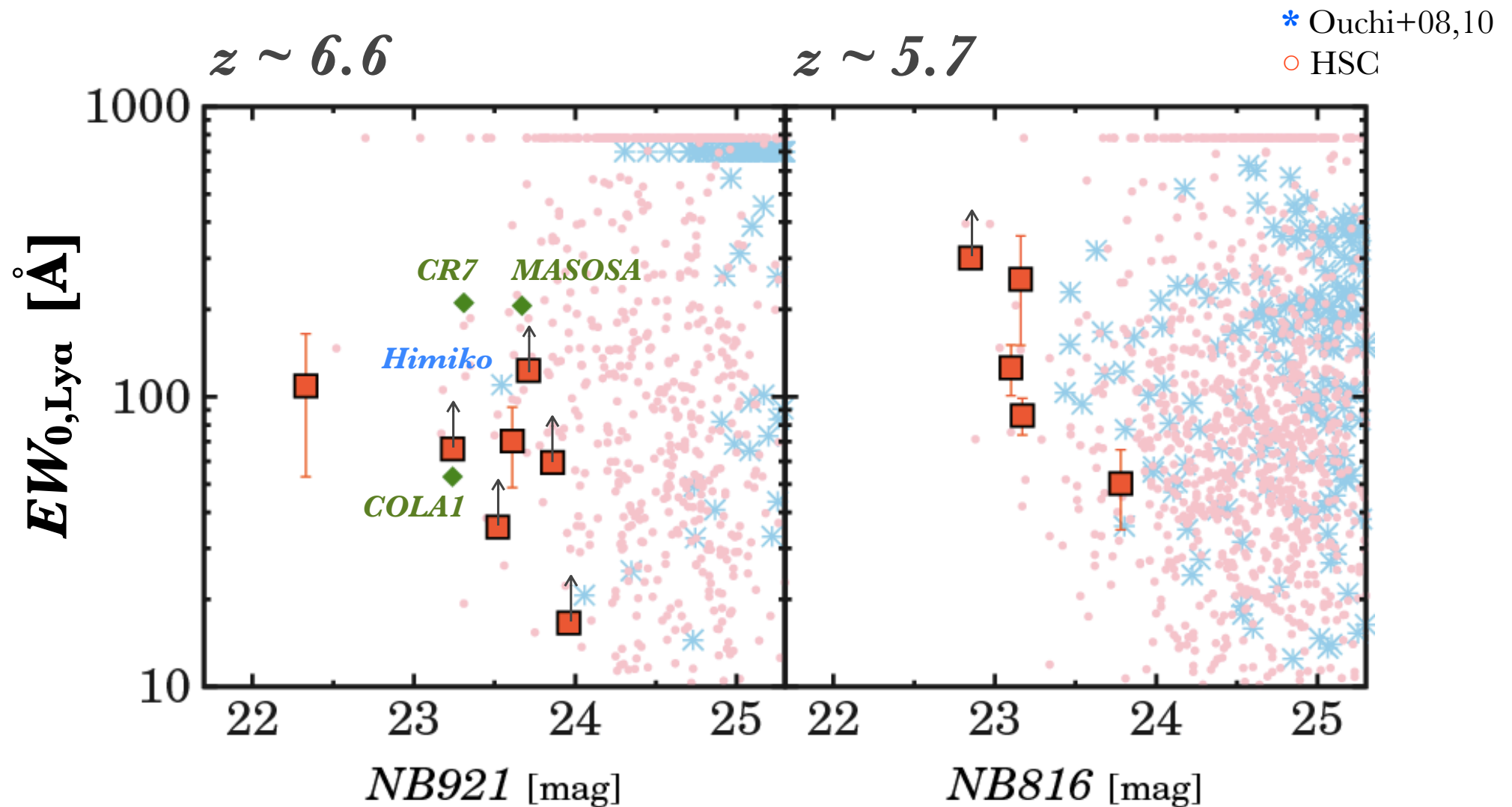
20-min exposure spectrum
before data reduction !!

Spec-confirmed HSC-LAEs



- ✓ **12** Ly α -bright LAEs are spectroscopically confirmed
- ✓ 4 [O III] emitters@ $z \sim 0.8$

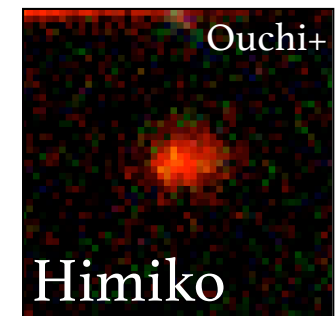
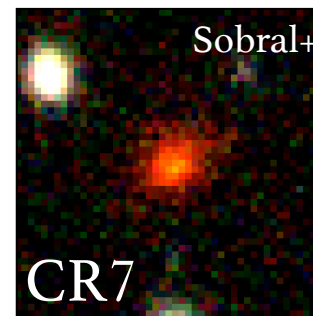
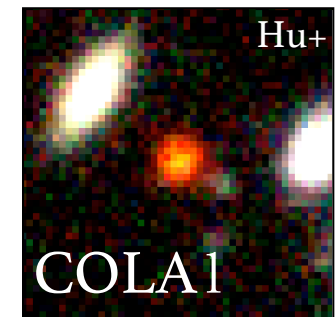
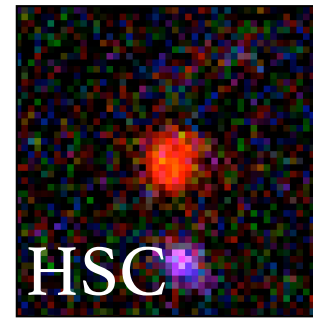
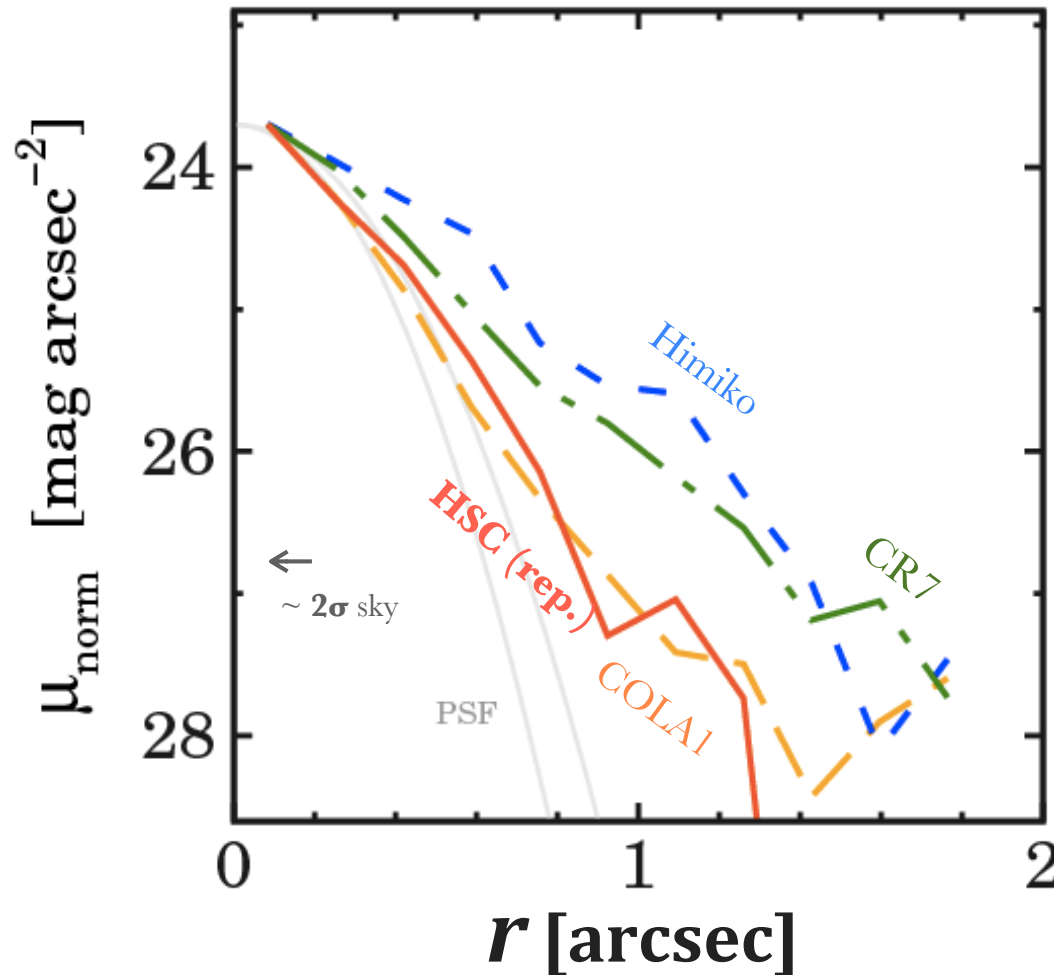
Brightness of HSC-LAEs



- ✓ HSC-LAEs are as bright as SCam-LAEs
- ✓ Ly α -bright spec LAEs : 4 obj \rightarrow 16 obj
- ✓ Statistical study on the properties of bright LAEs

Lya Radial Profile

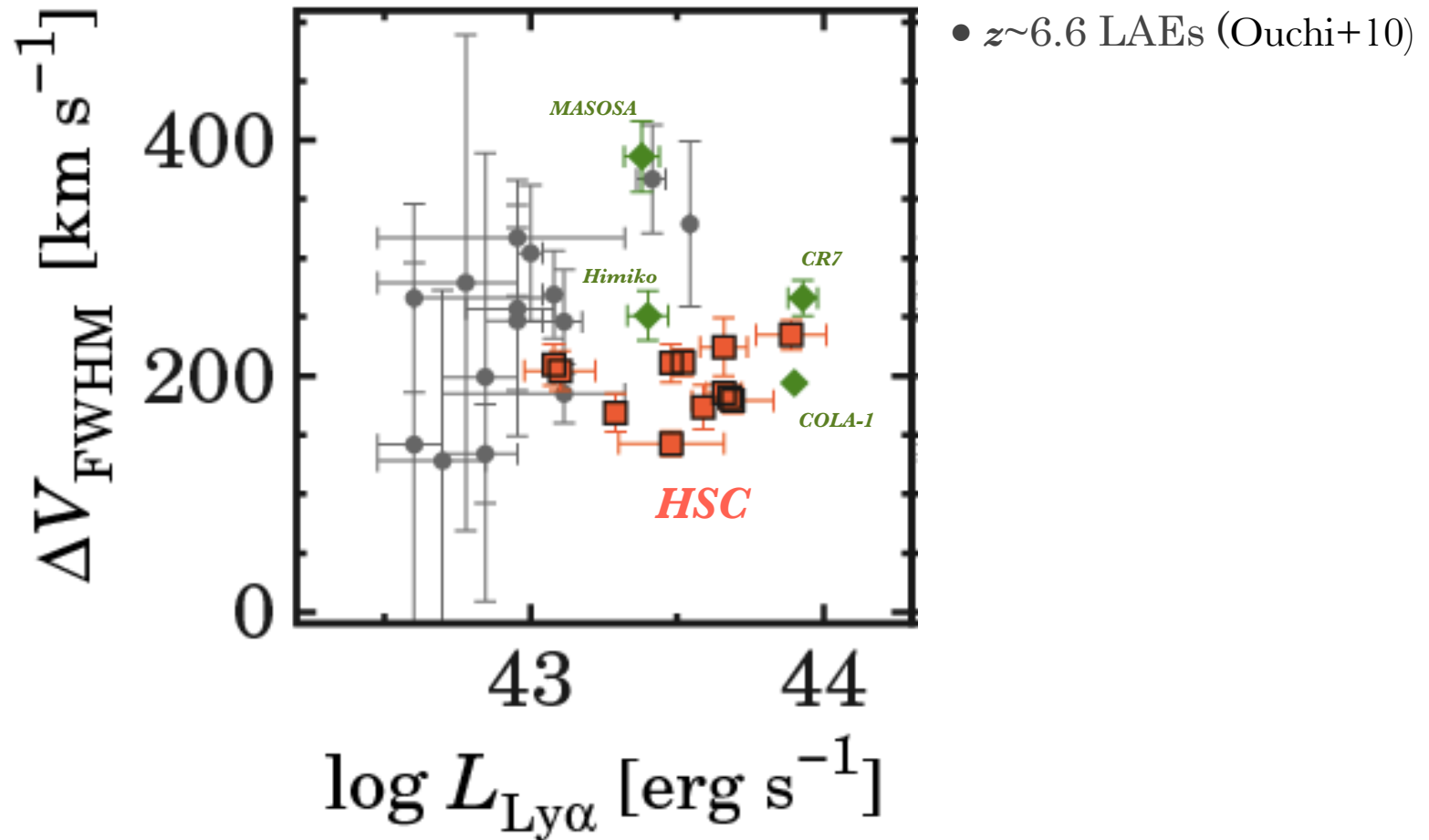
(Measured in HSC-NB images for all)



✓ **Compact Ly α emission** for most Ly α -bright LAEs

Only Himiko and CR7 are significantly extended in the spec. sample

Ly α Line FWHM



- ✓ Ly α line FWHM of bright LAEs is $\sim 200\text{-}400 \text{ km/s}$
- ✓ Unlikely to be broad-line AGNs ($< \sim 500 \text{ km/s}$)

NIR Spec Observations

Subaru open-use obs.

- ✓ Subaru/vMOIRCS (J)
2016 June, 2 nights
- ✓ Keck/MOSFIRE (Y, J)
2016 Jan., 4 hrs
2016 Sep., 1 night

7 LAEs@ $z \sim 5.7-6.6$
 $\sim 1.5-4$ hrs / obj.

Very deep,
similar to the deepest NIR obs
for $z > \sim 7$ galaxies (e.g., Stark+15).



© NAOJ



© WMKO

NIR Spec Observations

No detection

- ✓ Neither of C IV nor NV
- ✓ No clear signature of AGNs

Flux ratio

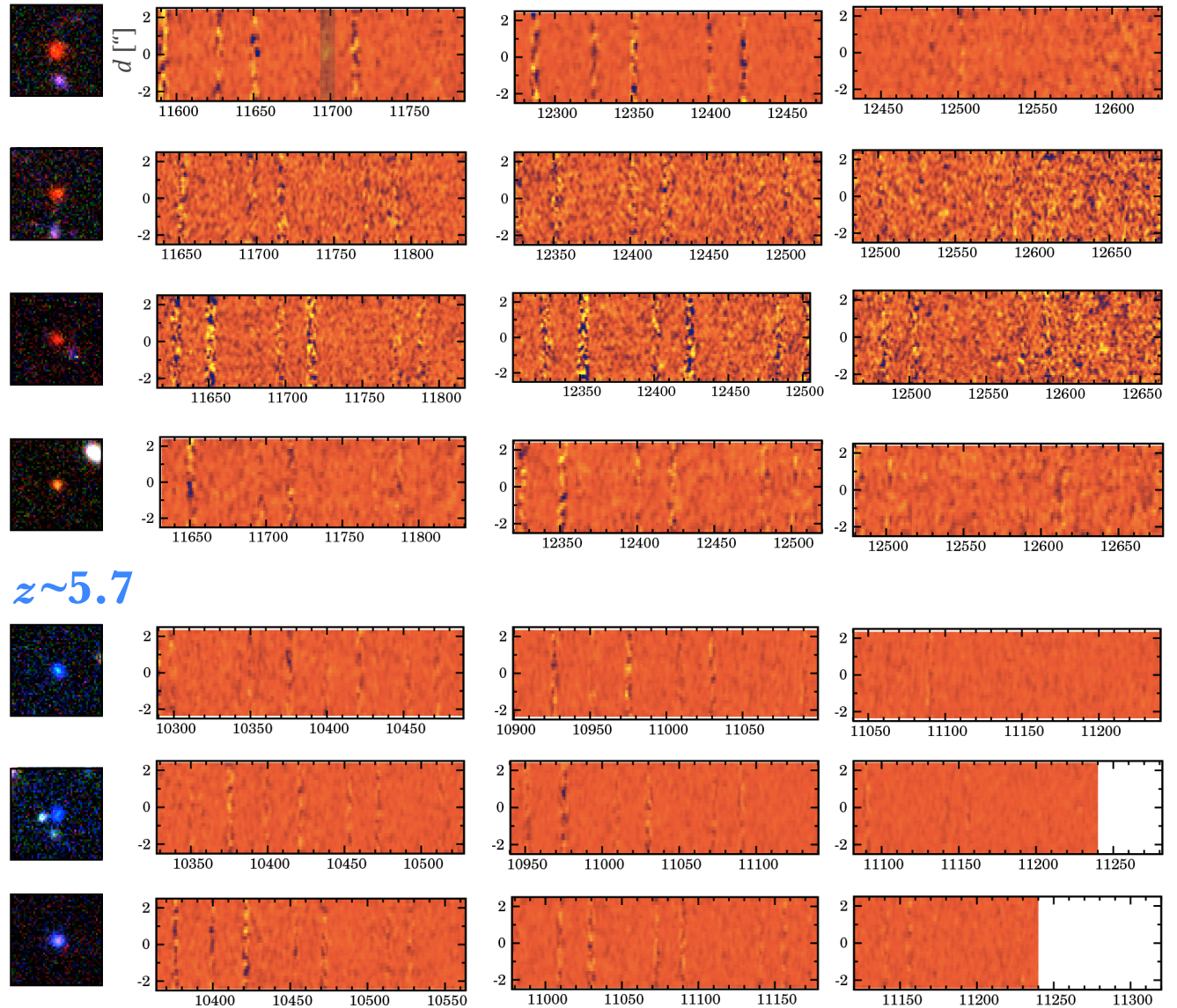
- ✓ $(C\text{IV}, He\text{II}, C\text{III]})/Ly\alpha < \sim 1\%$
- ✓ $N\text{V}/Ly\alpha < \sim 10\%$

$z \sim 6.6$

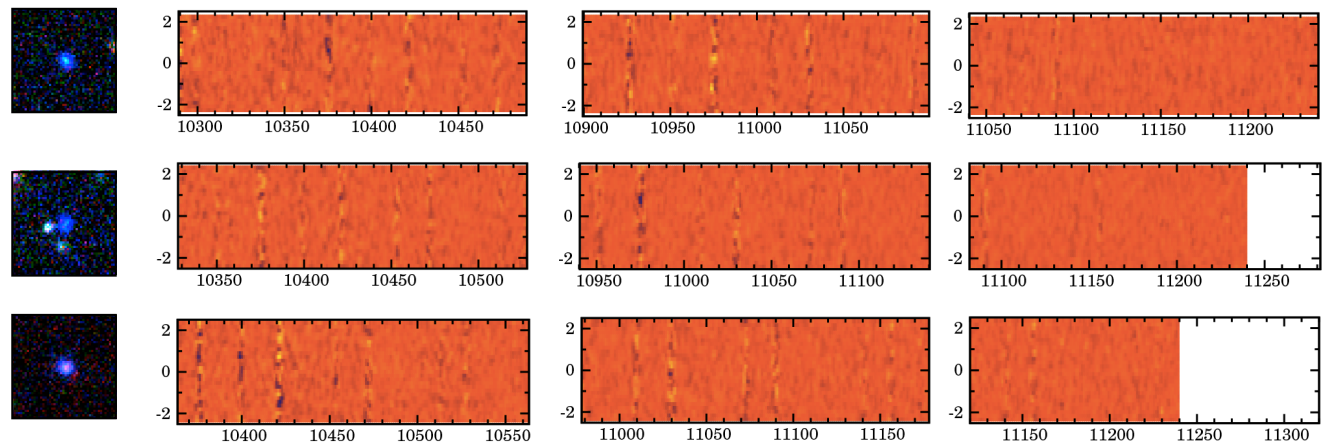
C IV

He II

C III]

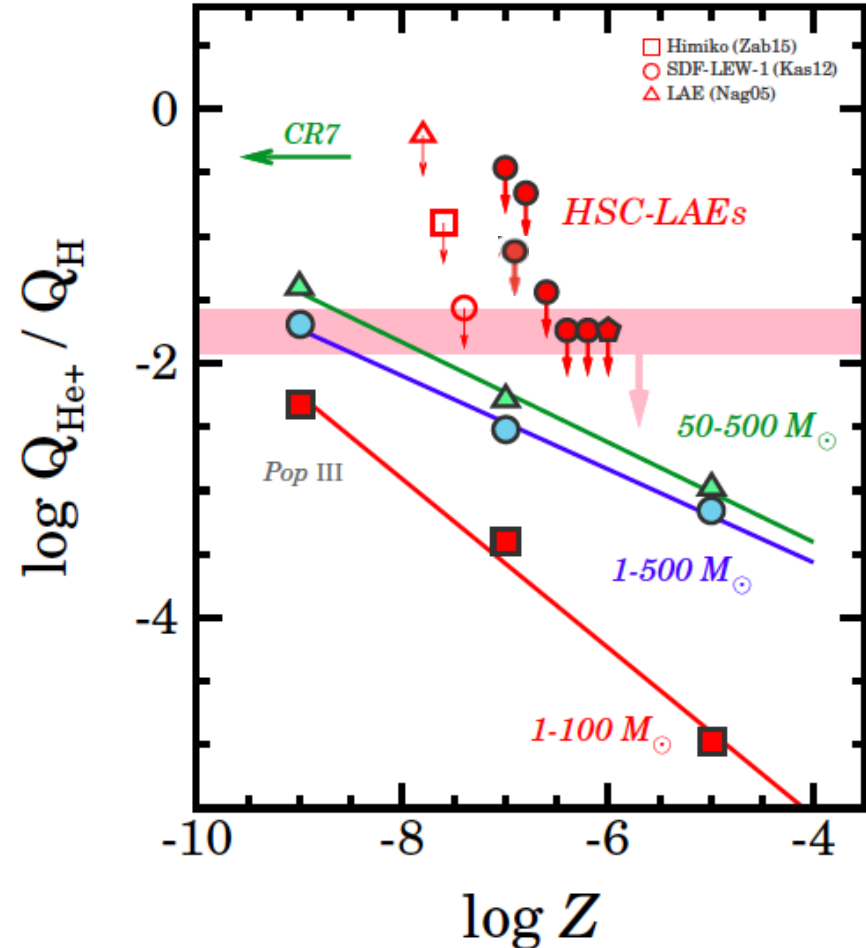
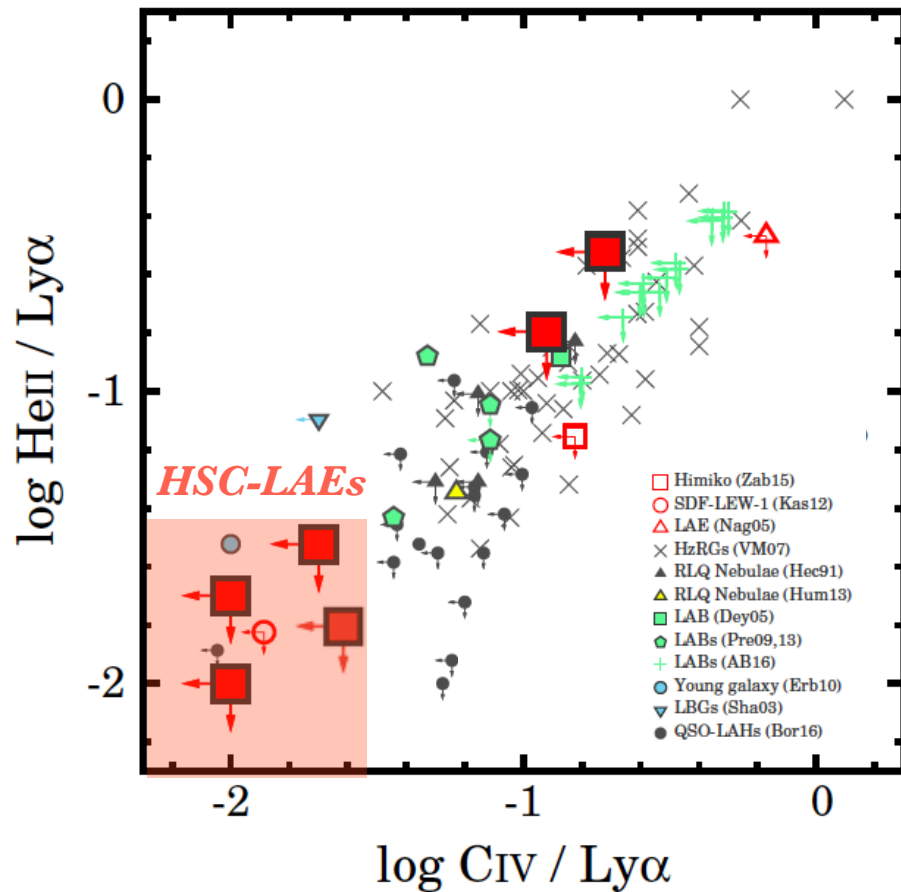


$z \sim 5.7$



$\lambda_{\text{obs}} [\text{\AA}]$

Faint UV Nebular Lines

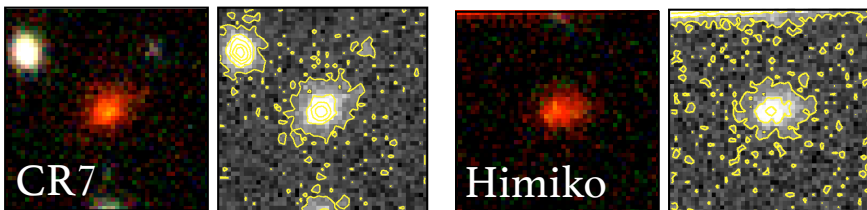
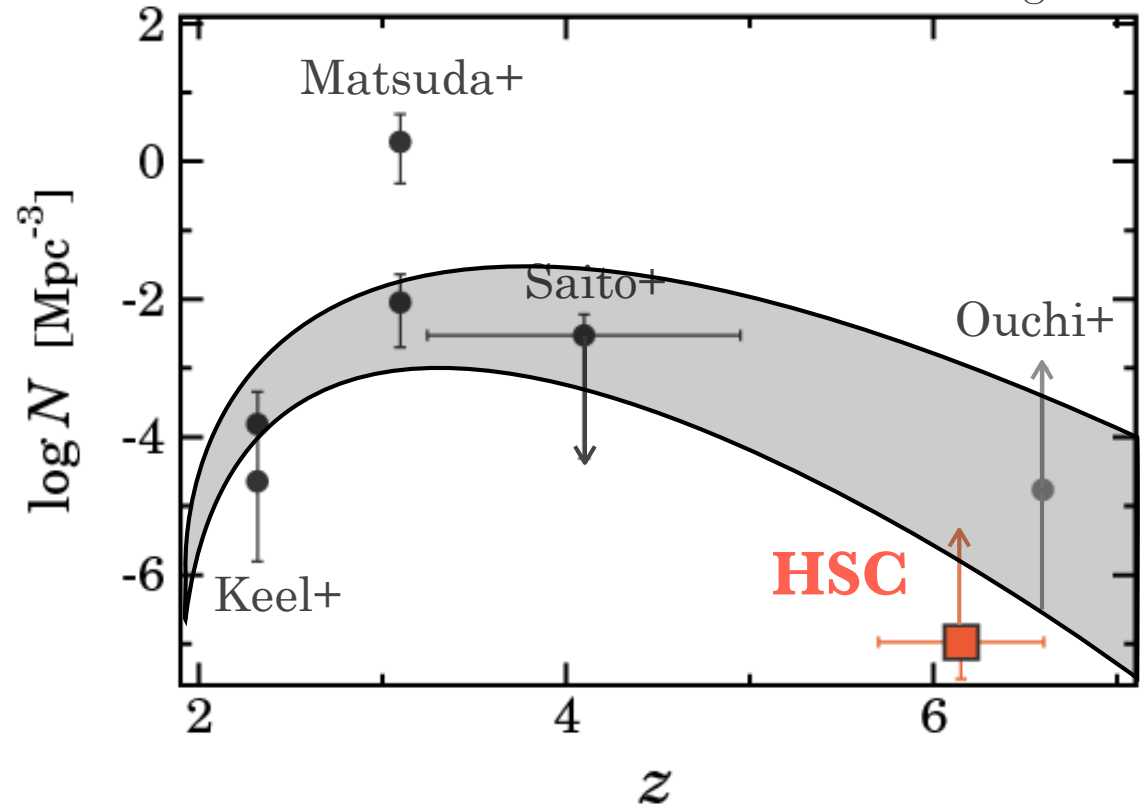
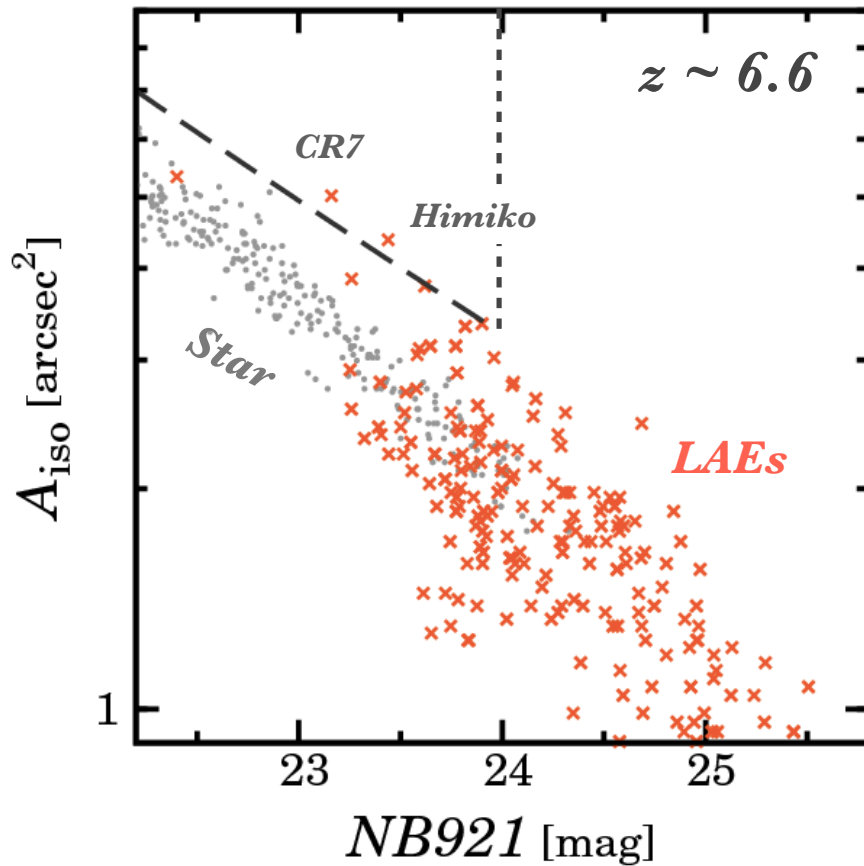


- ✓ Not clear whether galaxies or AGNs
- ✓ Comparable with AGNs, popIII, and regular SF
- ✓ Similar to Himiko, but not like CR7

Lya Blobs

$> \sim 5 \times 10^{-18} \text{ erg s cm}^{-2} \text{ arcsec}^{-2}$
Data from Yang+09

LAB candidates



- ✓ Confirm extent of Himiko & CR7
- ✓ Only 2 extended LAEs@ $z > \sim 6$?
- ✓ Evolution from $z \sim 6$?
- ✓ Need to estimate detection completeness for extended objects

Keck Spec Obs for HSC-LAEs

Targets:

Rare Ly α -emitting obj at $z \sim 2.2-7.3$ selected w HSC data

- ✓ Ly α -bright LAEs
- ✓ LABs
- ✓ LLEW galaxies

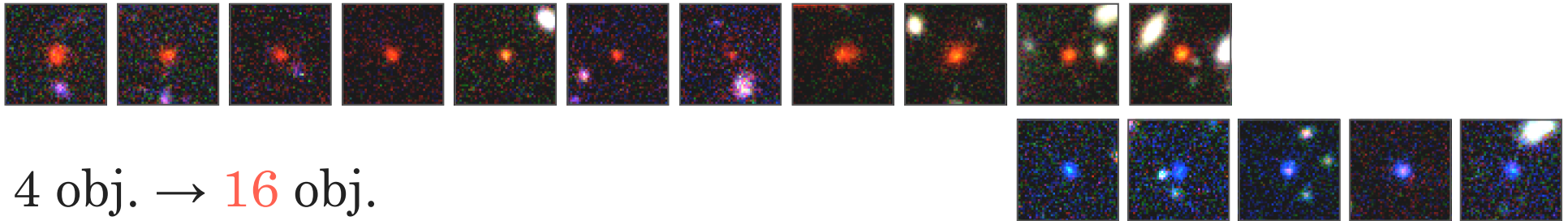
Number of e.g., Ly α -bright LAEs

	$z \sim 6.6$	$z \sim 5.7$
$\log L_{\text{Ly}\alpha} > 43.5$	~ 25	~ 40
$\log L_{\text{Ly}\alpha} > 43$	~ 110	~ 180

roughly estimated w the 1st-year HSC data

-
- ✓ Spec confirm w **LRIS, FOCAS** (Ly α)
 - ✓ Characterization w e.g., **LRIS, MOSFIRE** (UV/opt lines)
 - ✓ ISM prop. (e.g., U , O/H, n_e , \mathcal{N}_{HI} , $\Delta v_{\text{Ly}\alpha}$), **Ionizing sources ...**
 - ✓ Formation mechanisms of the rare Ly α objects
→ Good targets for *JWST*

Summary



4 obj. \rightarrow 16 obj.

Bright LAEs@ $z > \sim 6$, $\log L_{\text{Ly}\alpha} > 43$ [erg/s]

✓ $\text{EW}_{0,\text{Ly}\alpha} \sim 20\text{-}250 \text{ \AA}$ or higher

✓ Compact Ly α emission

Extended sources (CR7 and Himiko) are **minority** ($2/16 \sim 13\%$)

✓ Ly α line FWHM $\sim 200\text{-}400 \text{ km/s}$

✓ Faint UV nebular lines

$\text{NV} / \text{Ly}\alpha < \sim 10\%$, $(\text{CIV}, \text{HeII}, \text{OIII}) / \text{Ly}\alpha < \sim 1\%$

Strong UV line-emitting LAE (CR7) is rare @ $z > \sim 6$ ($1/9 \sim 11\%$)