UITIMATE-Subaru mini workshop, July 29th, 2014 @ NAOJ

Science Cases for High-*z* Universe

Institute for Cosmic Ray Research (ICRR)
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Outline

Focus mainly on

- ✓LAEs, LBGs@*z*=2-8 (LABs→Matsuda-san?)
- ✓IGM / CGM
- ✓Cosmic Reionization

High-z: Open Questions

✓How did reionization occur?

✓Properties of low-mass galaxies

✓Physical state of CGM/IGM

✓Abundance of low-mass (high Lyα EW) galaxies at $z \geqq 7$

High-z: Open Questions

✓How did reionization occur?

→Simple spec follow-up for $z{\sim}7$ galaxies §1

✓Properties of low-mass galaxies

→Kinematics, metallicity, ionization state §2

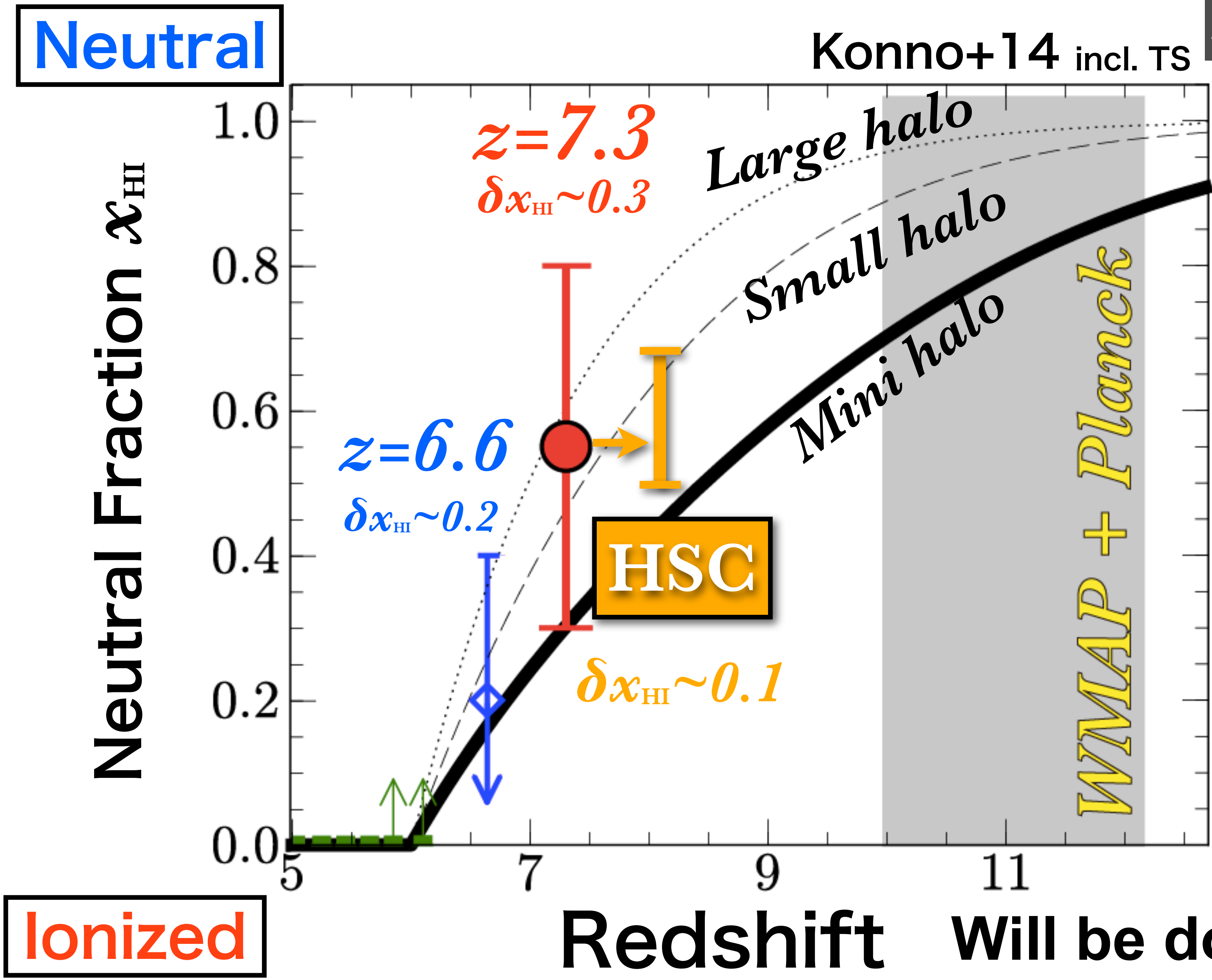
✓Physical state of CGM/IGM

→Lyα halo at $z \geqq 7$ §3

✓Abundance of low-mass (high Lyα EW) galaxies at $z \geqq 7$

→Deep spec-imaging survey §4

§1 Cosmic Reionization



HSC (x7 SCam)

HSC Survey

LAEs

z~2.2, 5.7, 6.6, 7.3

LBGs

BX/BM

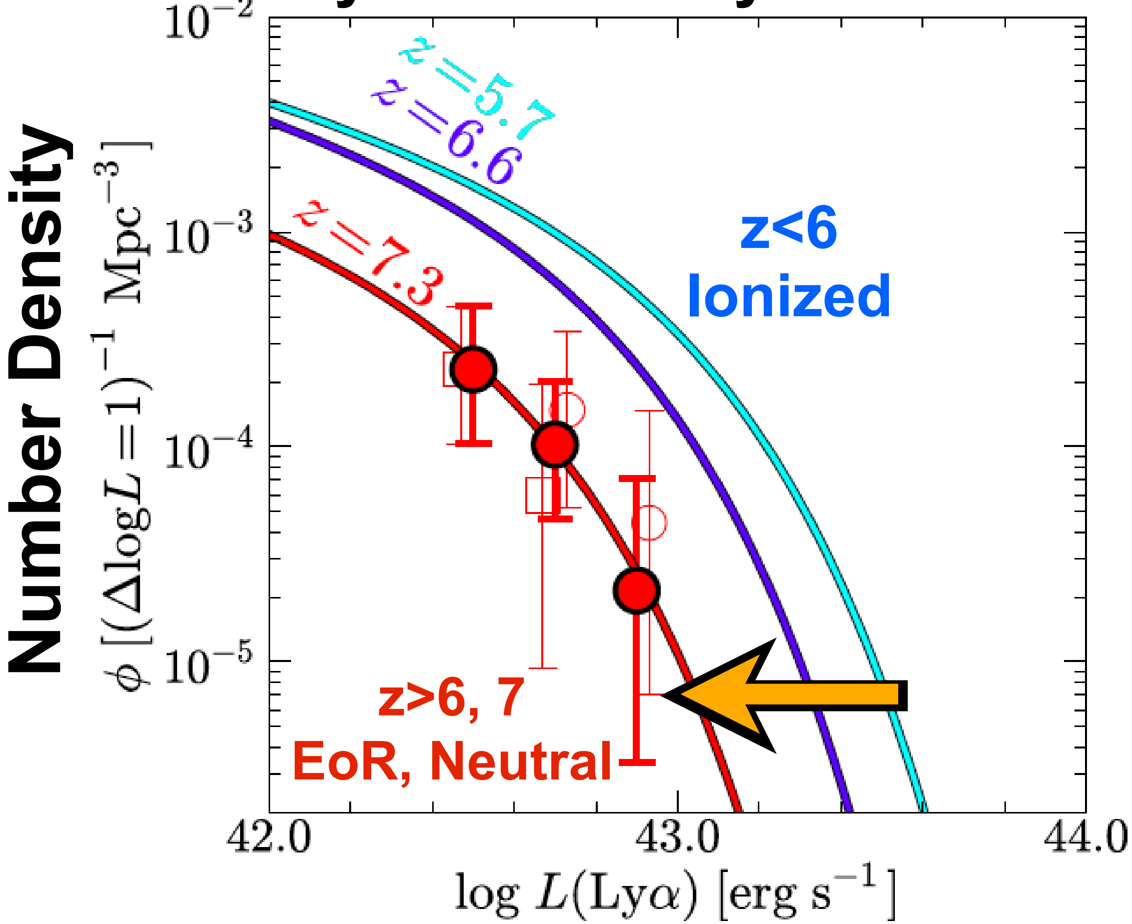
ugrizy-drop

Will be done in 2019(?)

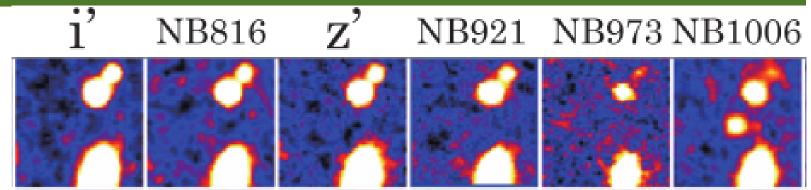
Simple Spec follow-up for $z \geqq 7$

Lyα of **LAEs**

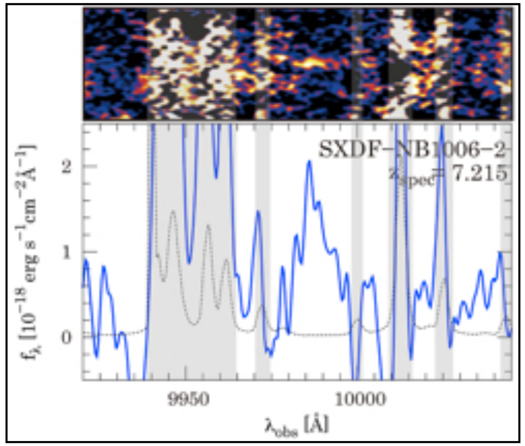
Lyα Luminosity Function



Konno+14



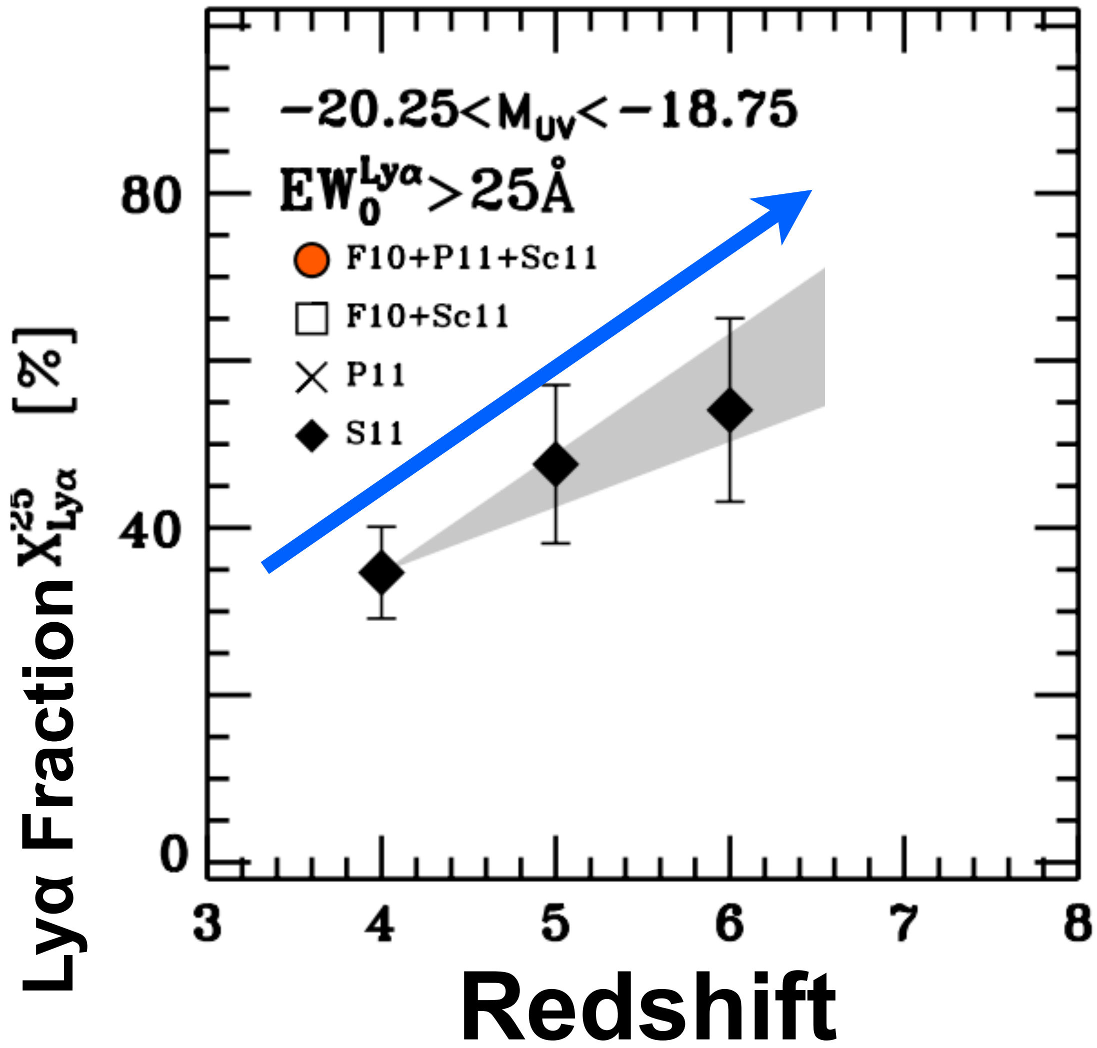
Shibuya+12

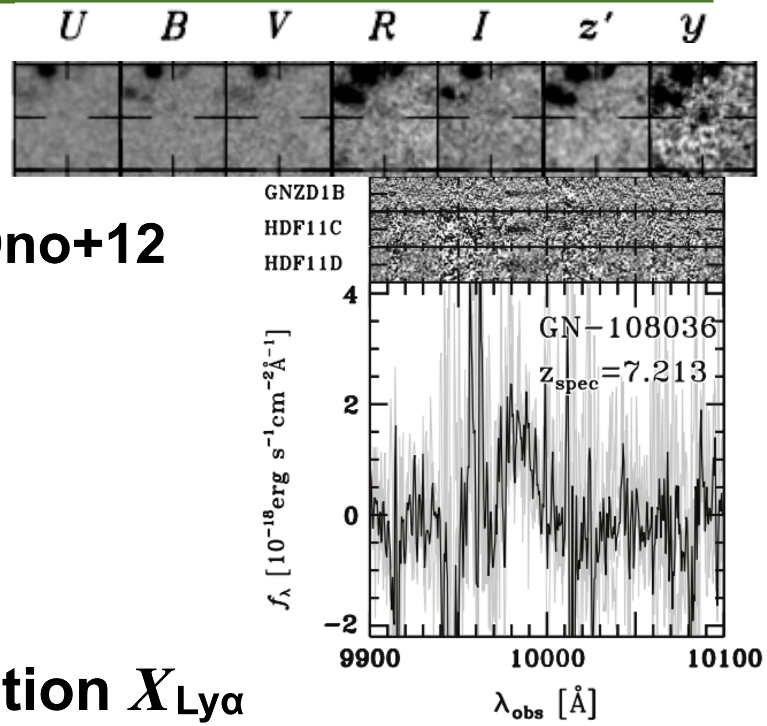


- ✓HSC+NB101
- ✓39 LAEs@z=7.3
- ✓≦ 1 LAE in Φ*13".5* FoV

Simple Spec follow-up for $z \geqq 7$

Lyα of LBGs





Ono+12

Lyα Fraction $X_{\text{Lyα}}$

$$= \frac{\text{\# of Lyα emitting LBGs}}{\text{\# of LBGs}}$$

✓HSC, z-dropouts

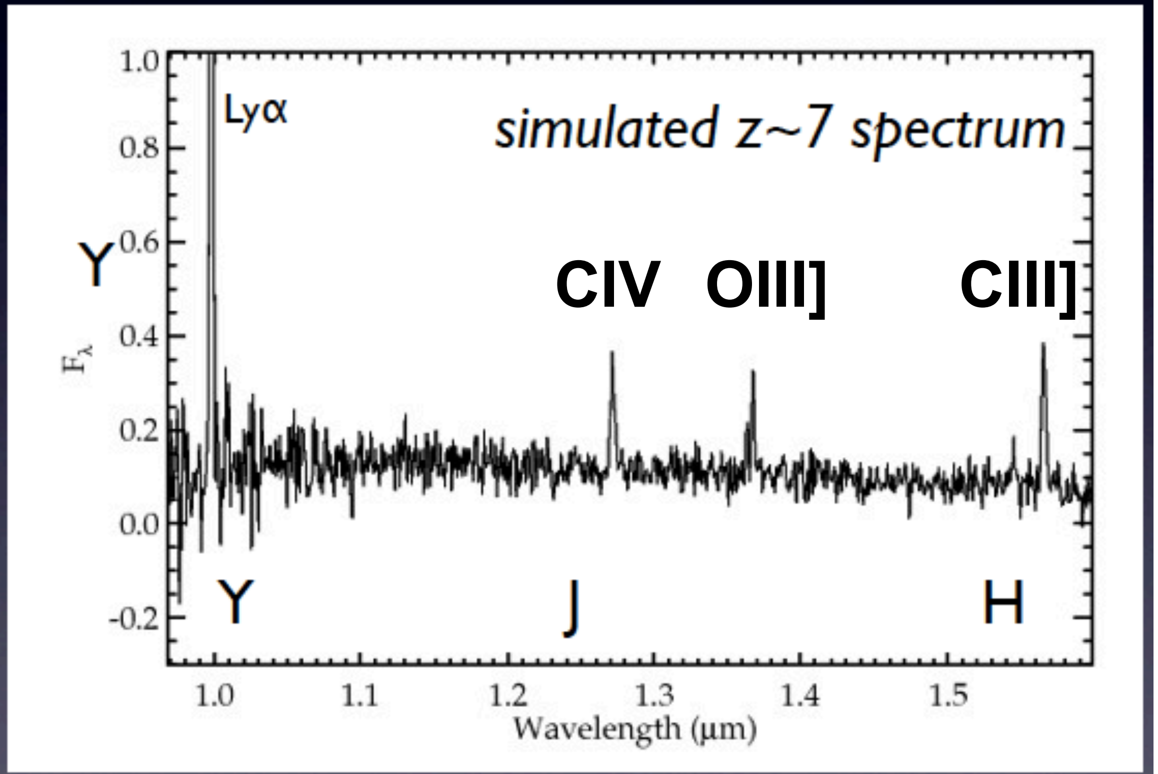
✓→700 LBGs@z~7 (UD)

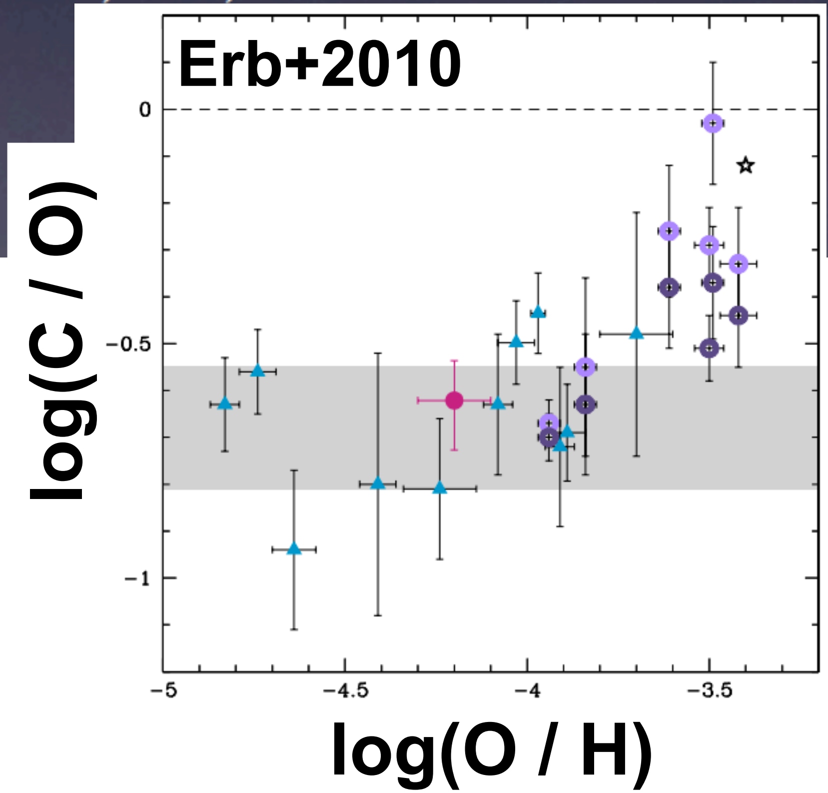
✓→~8 LBGs in Φ*13”.5* FoV

New Probe of z≧6 Galaxies

Current generation near-IR spectrographs can detect CIII] in bright z~7 galaxies.

Composite stack will yield constraints/detections of CIV He II, OIII, and CIII.





Dan Stark's slide

✓NIR spec. for CIII] z~6-7

✓Ionization parameter

✓Chemical abundance

✓Systemic redshift

Summary of §1

Advantage

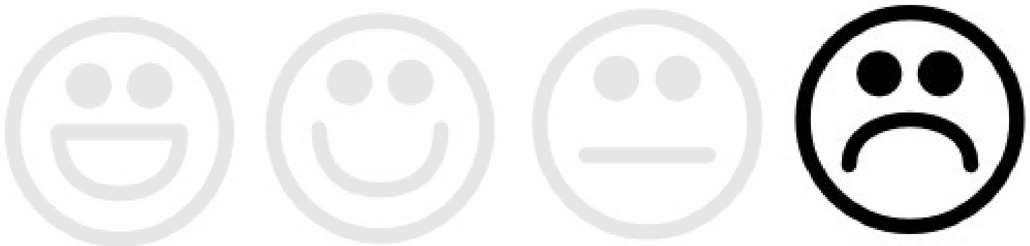
✓Subaru's unique high-z samples

Disadvantage

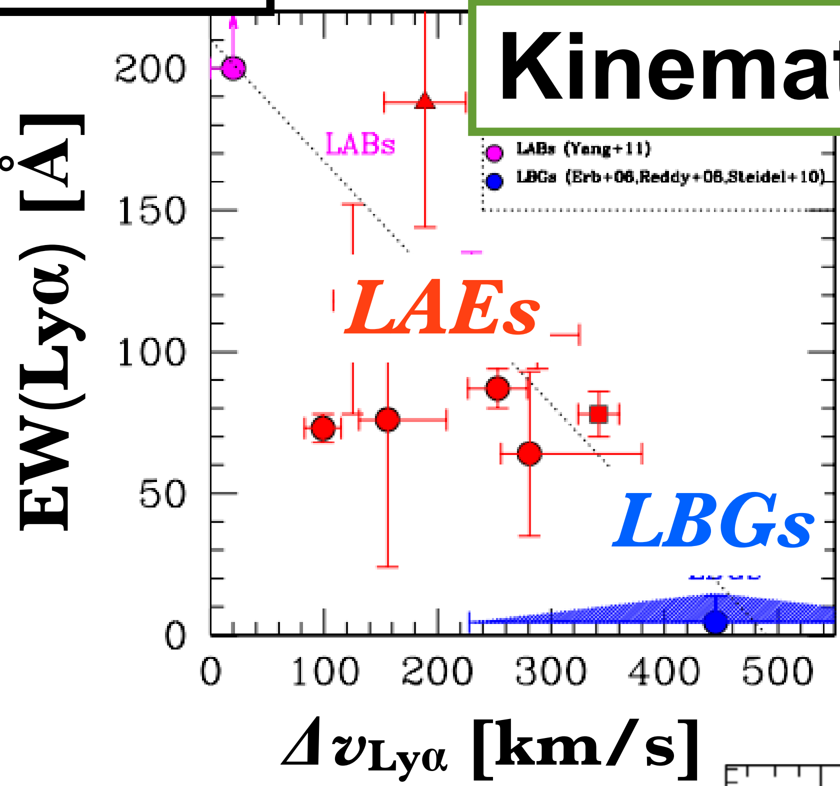
✓A handful of LAEs$_{(1)}$/LBGs$_{(8)}$ in Φ13.5 FoV

✓Small galaxy-size→$_{\text{(Basically)}}$ No need for IFU

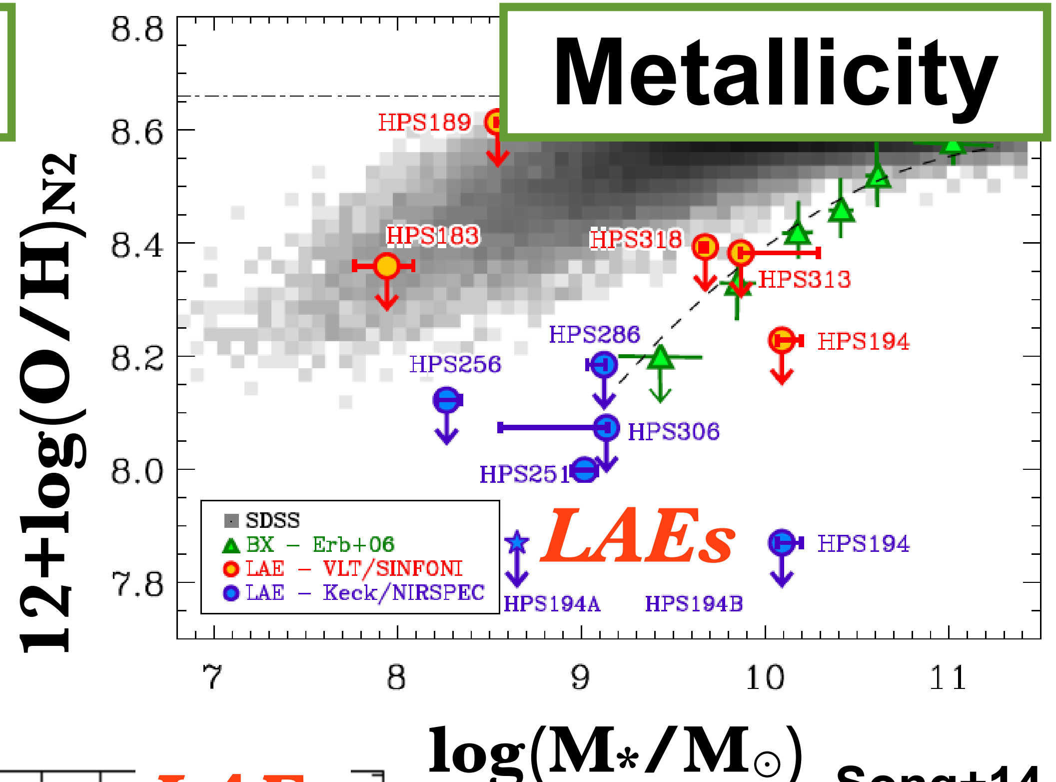
✓MOSFIRE can also do. (will work better?)



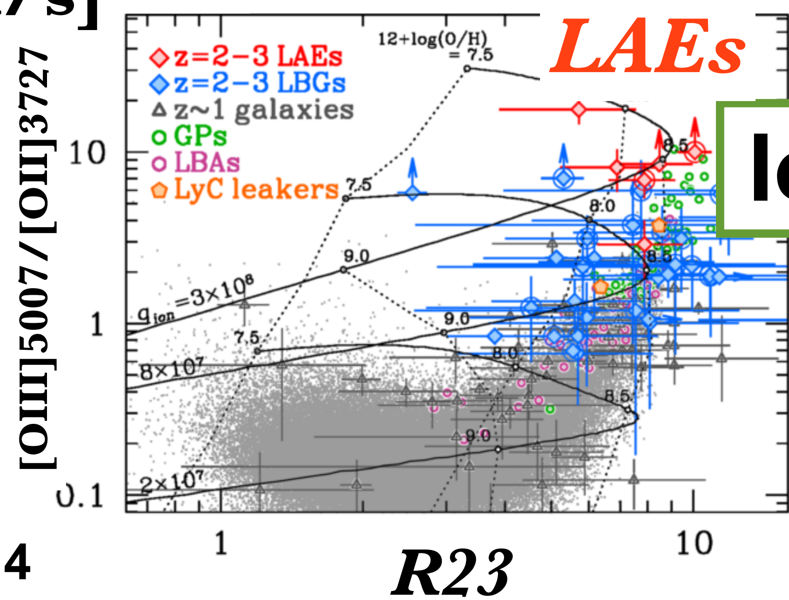
§2 Low-mass Galaxies



Hashimoto+13

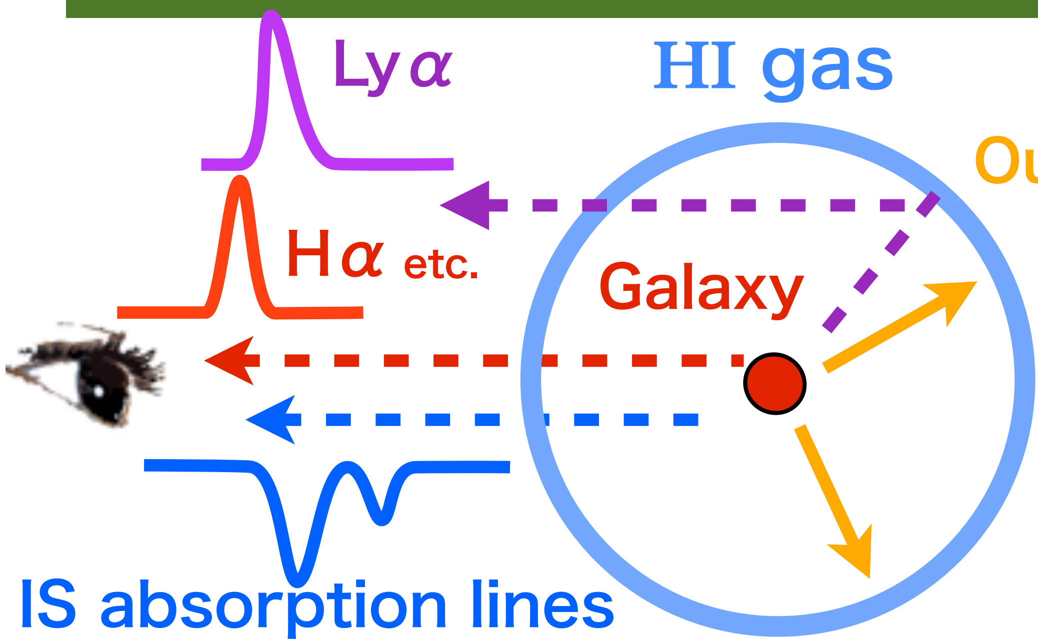


Song+14

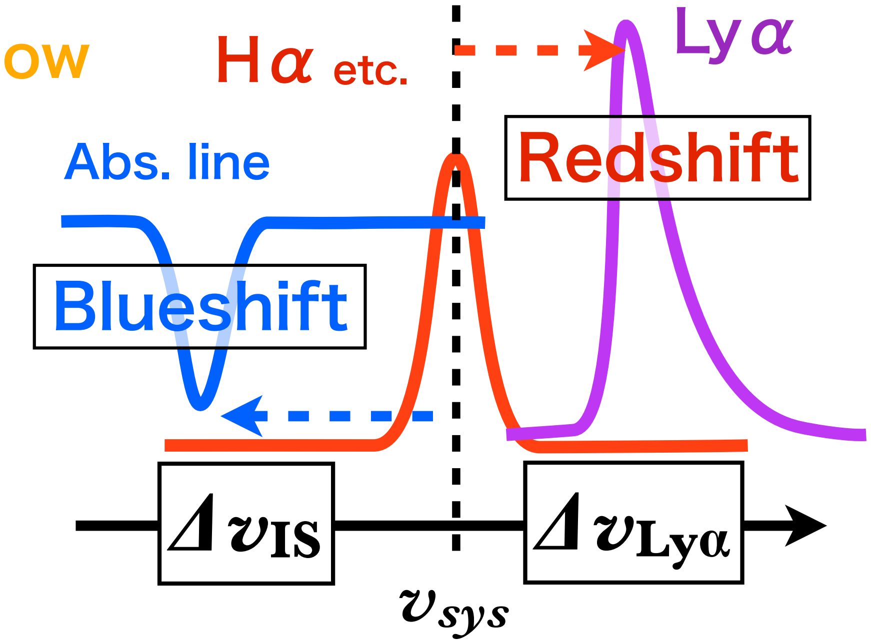


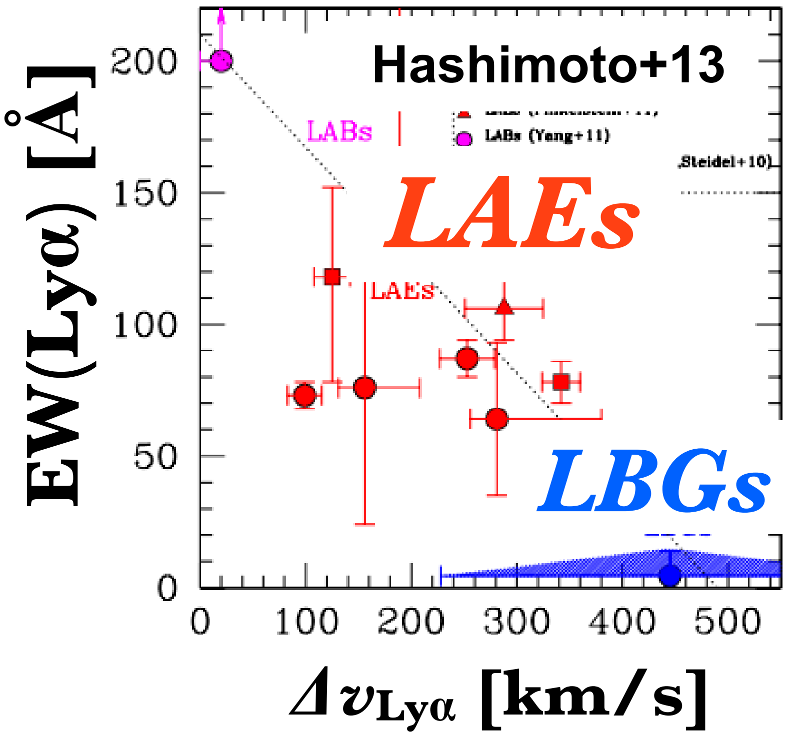
Nakajima+14

Small $\Delta v_{\mathrm{Ly\alpha}}$ in LAEs



In the case of outflow,





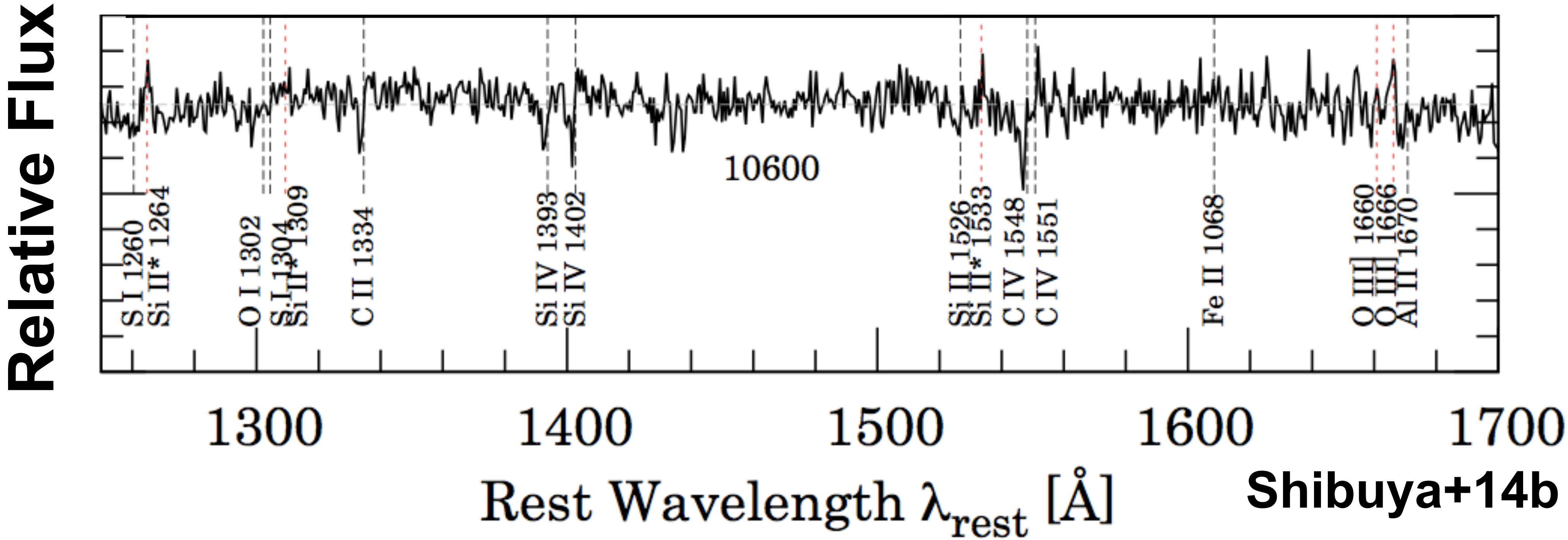
Why small $\Delta v_{\mathrm{Ly\alpha}}$ in LAEs?

- ✓Outflow velocity
- ✓HI column density

both → enhance $\Delta v_{\mathrm{Ly\alpha}}$

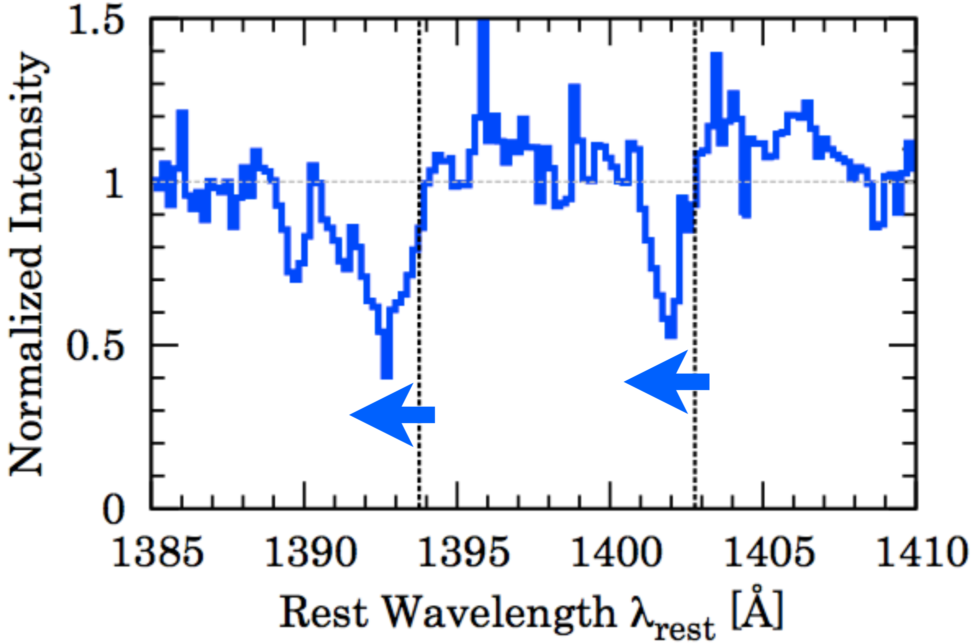
Need to measure more directly outflow velocity in LAEs

UV abs lines of LAEs

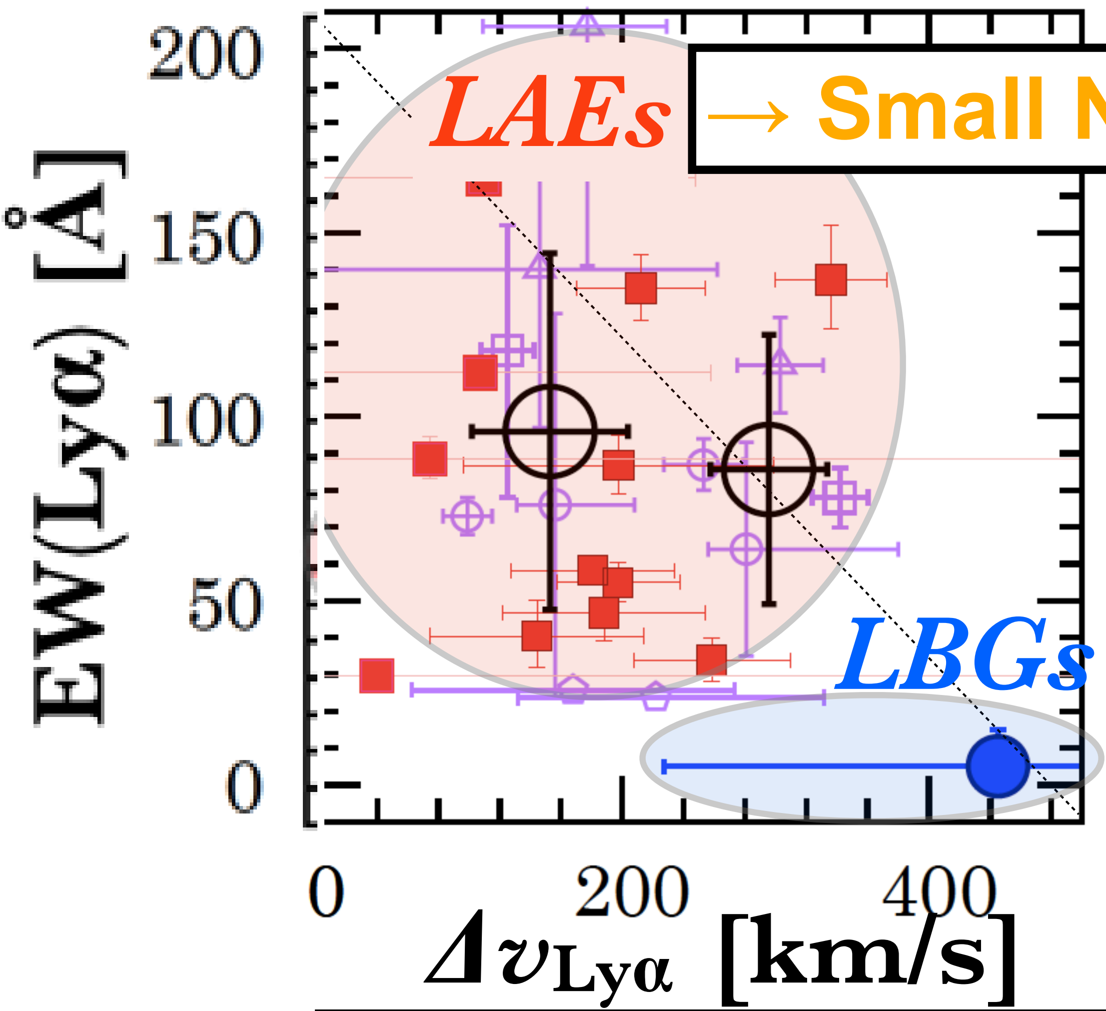


Shibuya+14b

- ✓**Keck/LRIS long obs.**
- ✓**Detect many IS abs lines from NB-selected objects**
- ✓**Abs lines are blueshifted**



Outflow Velocity of LAEs



→ Small N_{HI} ?

HI column density N_{HI}

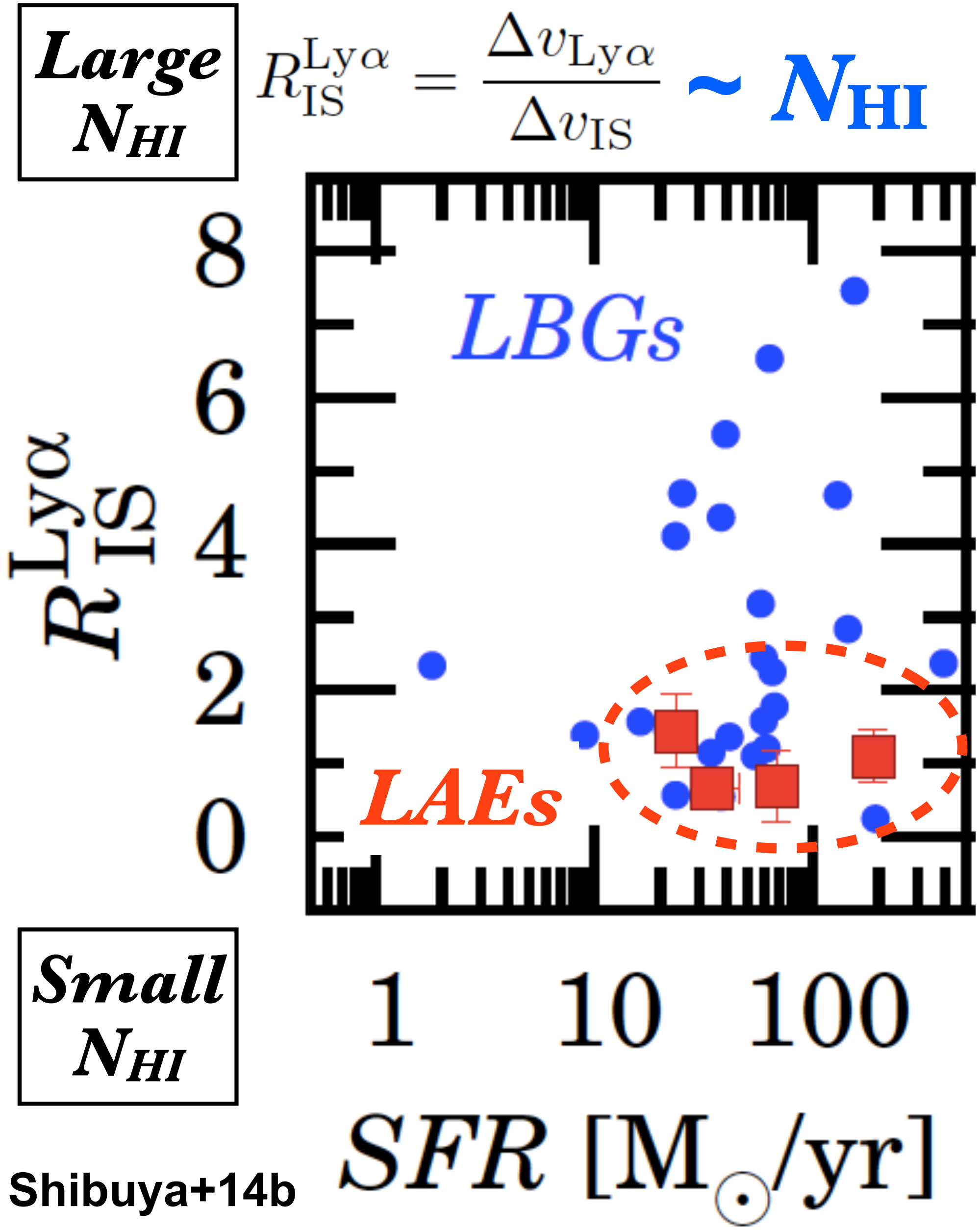
and/or

Outflow Velocity

Shibuya+14b

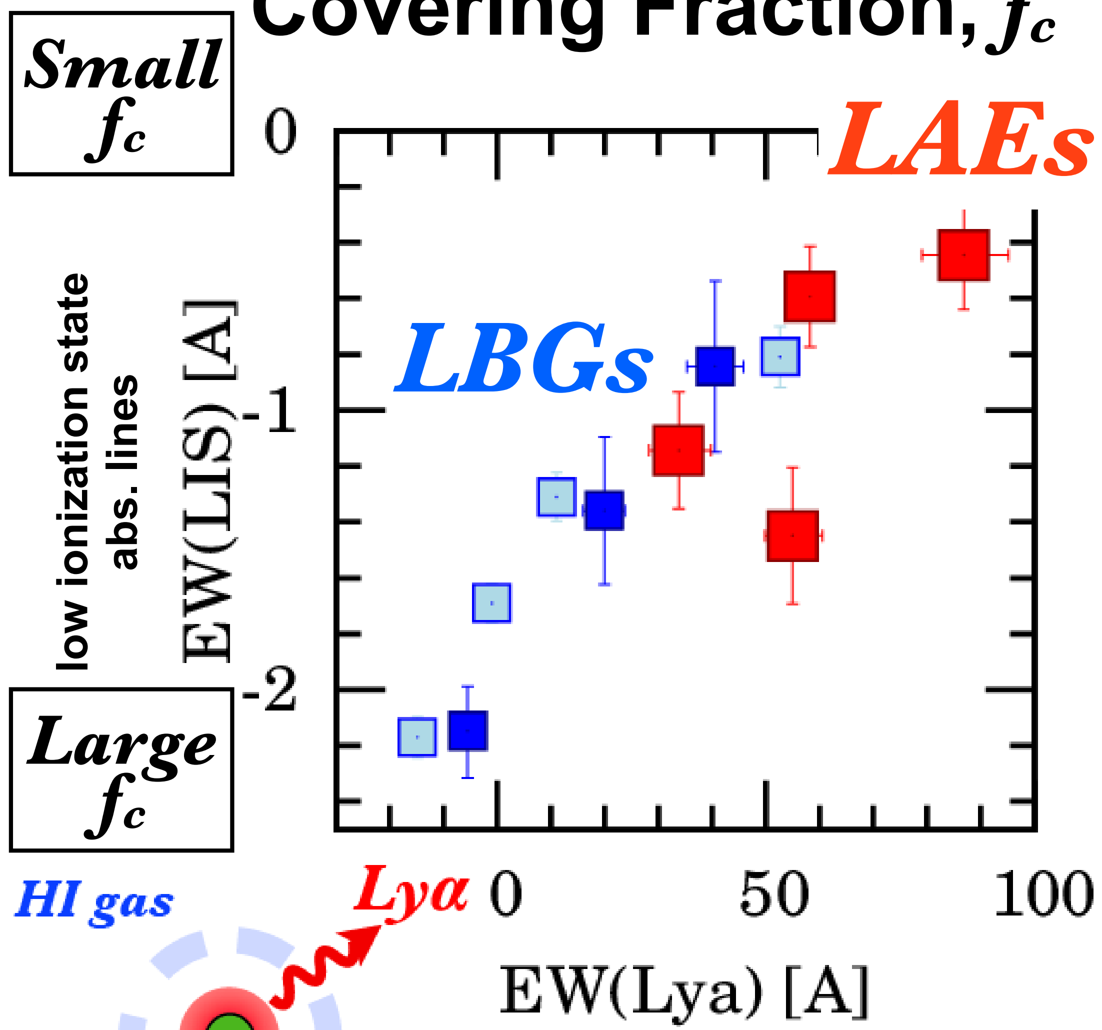
Why small $\Delta v_{Ly\alpha}$ in LAEs?

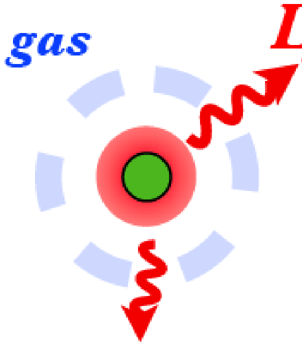
$R_{IS}^{Ly\alpha} = \frac{\Delta v_{Ly\alpha}}{\Delta v_{IS}}$ ~ N_{HI}



Shibuya+14b

Covering Fraction, f_c





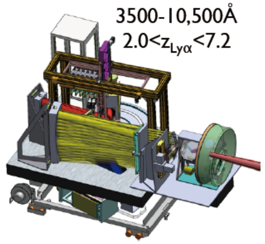
→ Low HI column density (N_{HI}) in LAEs

Dual IFU Observation

Opt IFU (or MOS Spec.)

✓VLT/MUSE (AO)
✓Keck/KCWI
✓LRIS, DEIMOS...

KCWI
Keck
3500-10,500Å
$2.0<z_{Ly\alpha}<7.2$



↓

(Spatially-resolved)
Lyα, IS abs. lines

NIR IFU

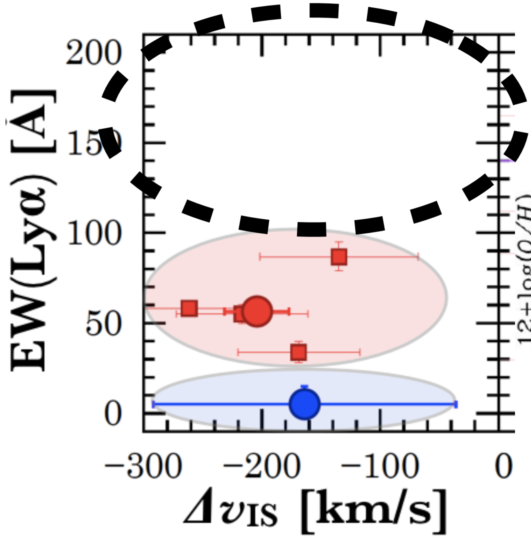
✓ULTIMATE-Subaru

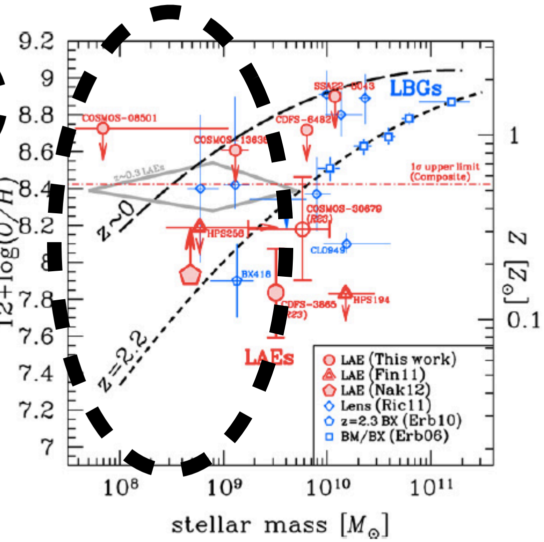
↓

Spatially-resolved
[OII], [OIII], Hβ

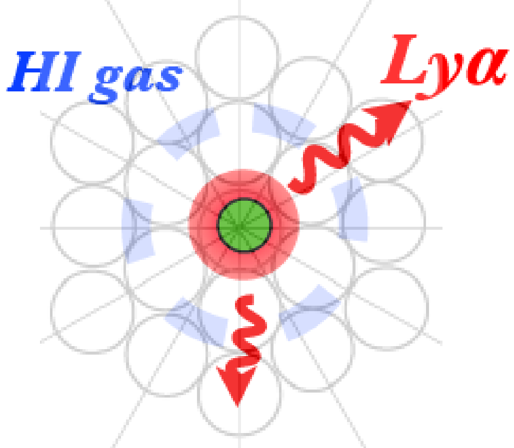
⇔

For example,





✓→4000 LAEs@z=2.2 (UD)
✓→~50 LAEs in Φ*13".5* FoV



Spat.-resolved
✓$\Delta v_{Ly\alpha, IS}$
✓EW(IS)
✓metallicity
✓ionization

Summary of §2

Advantage

✓Subaru's unique high-z samples

✓Multi- IFU spec. (~50 z~2 LAEs in FoV)

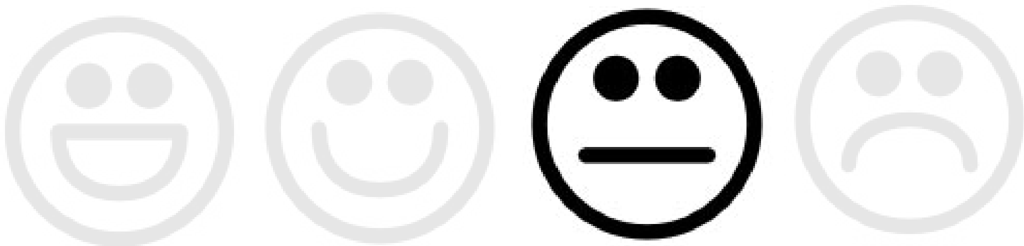
Disadvantage

✓Depend on optical IFU/MOS obs. for Lyα/abs lines

✓Already been started by MOSFIRE (e.g., Erb+in prep.)

✓Small galaxy-size of low-M & high Lyα EW galaxies

→ (Basically) no need for IFU?



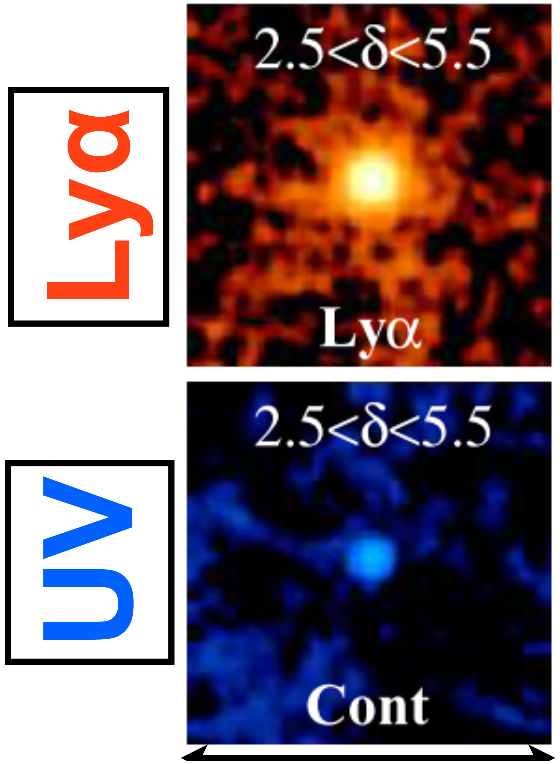
§3 Lyα Halo

✓→ Diffuse spatially-extended Lyα emission around galaxies

✓Very diffuse.

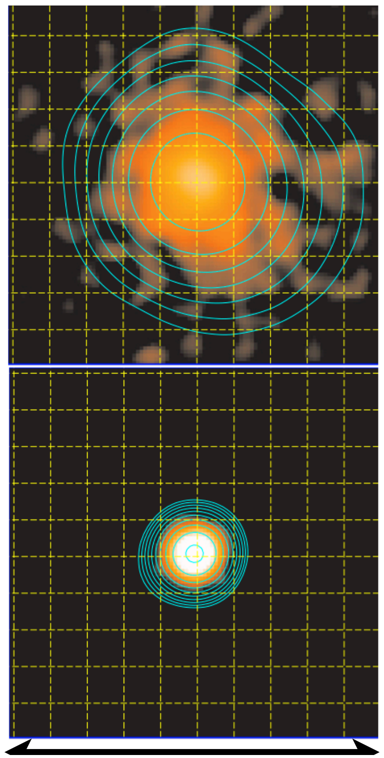
✓Can be detected in stacked NB images

z=3.1 LAEs 100-1000 obj stacking Matsuda+12



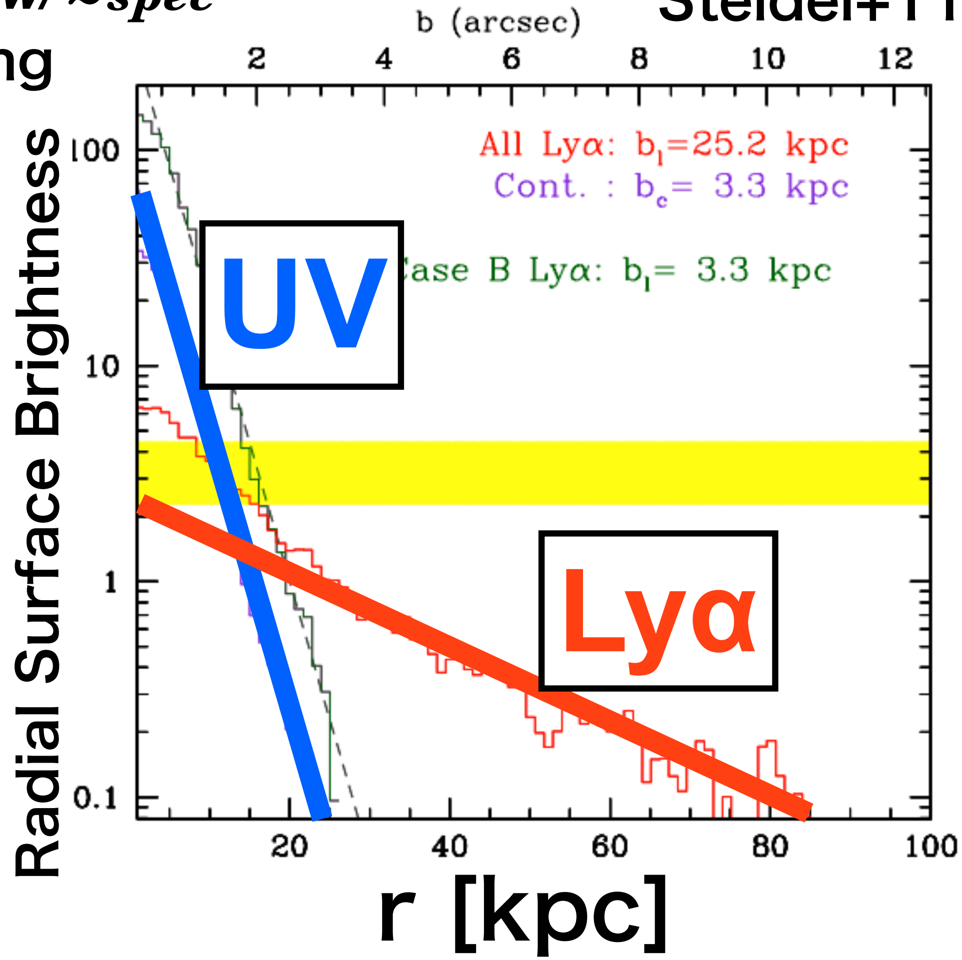
20”~150 kpc

z=2.1 LBGs w/ z_{spec} 92 obj stacking Steidel+11

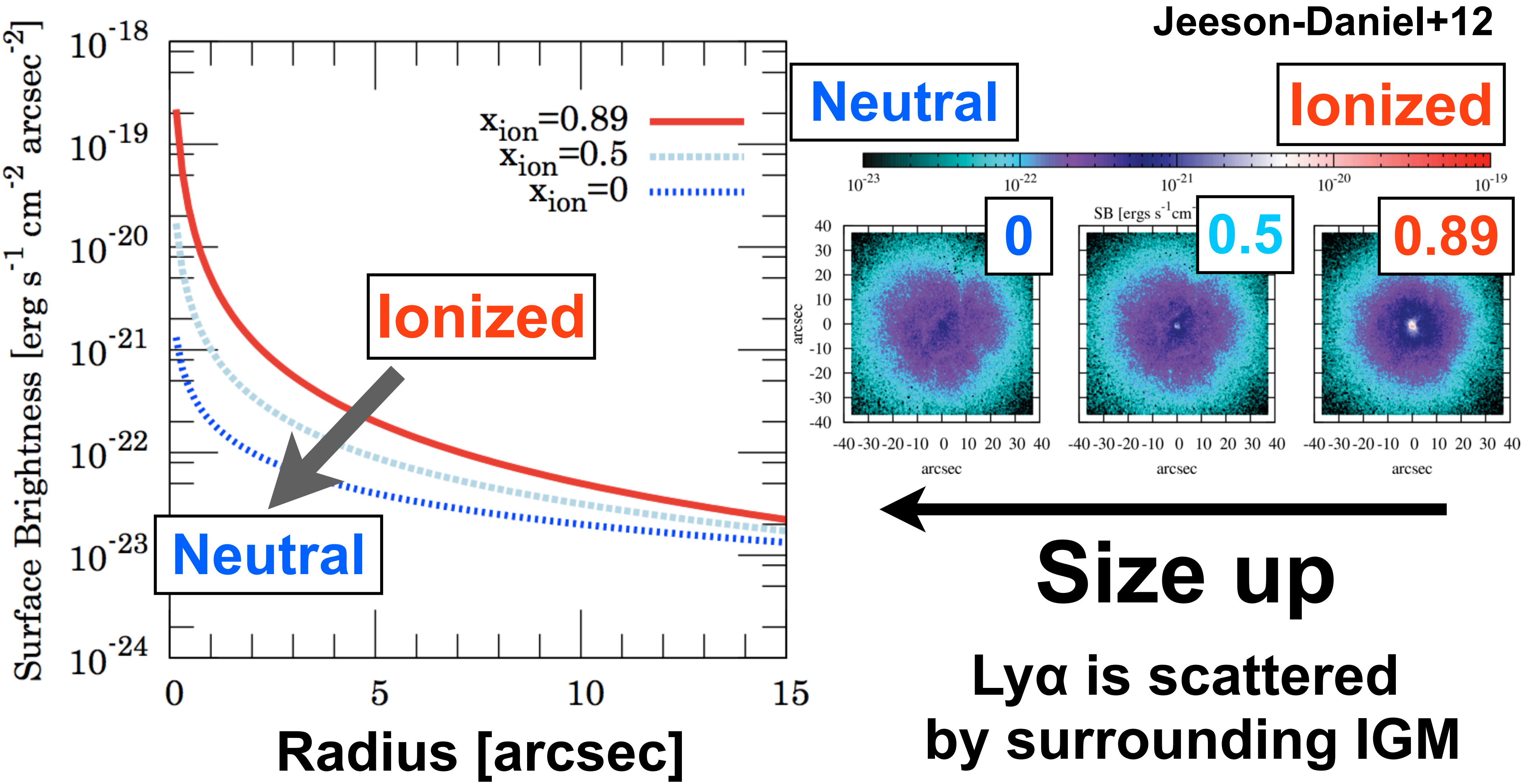


20”~160 kpc

Steidel+11

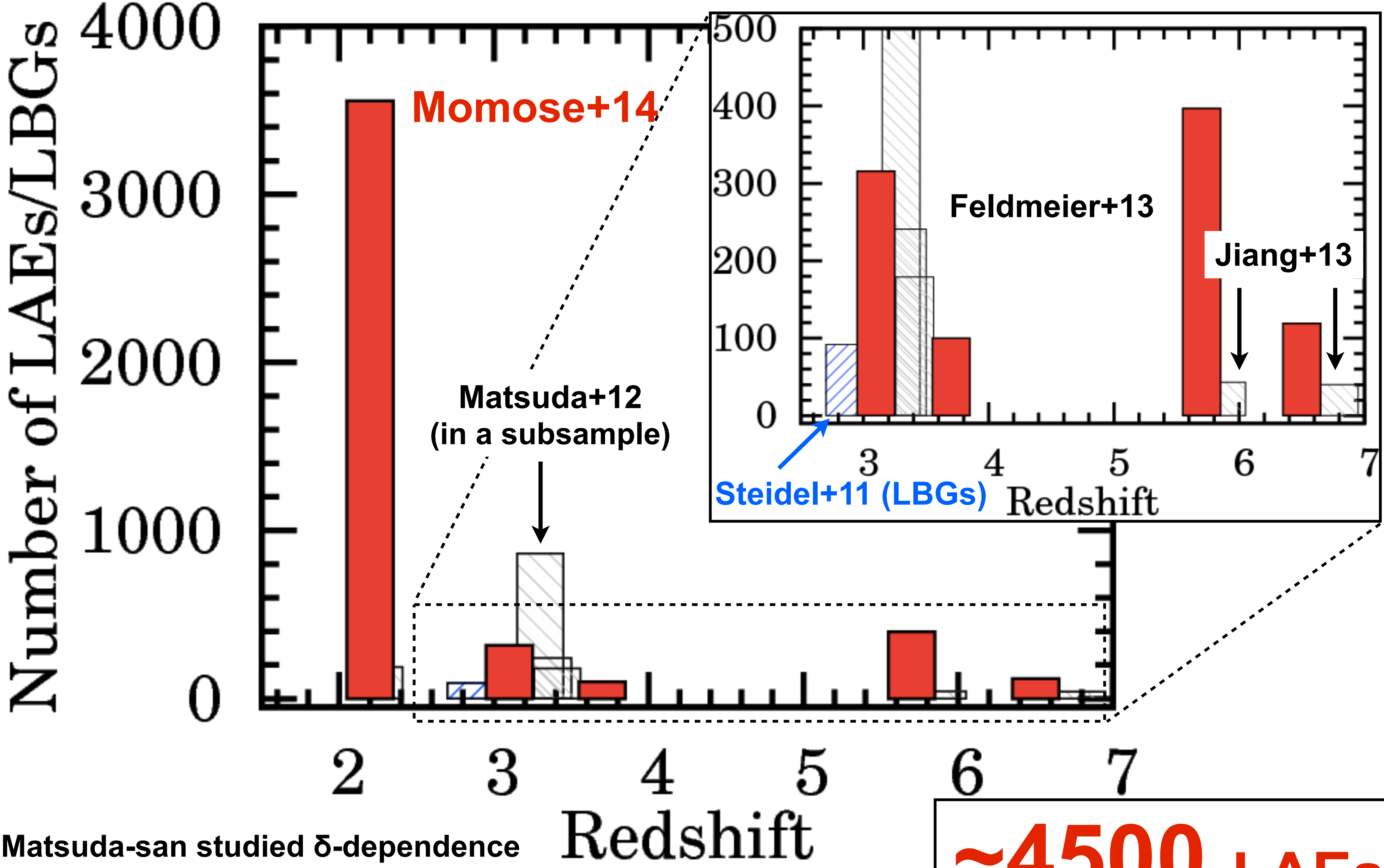


Reionization Probed by Lyα Halo



Lyα halo is more extended in the neutral Universe
→ z-evolution of Lyα halo size

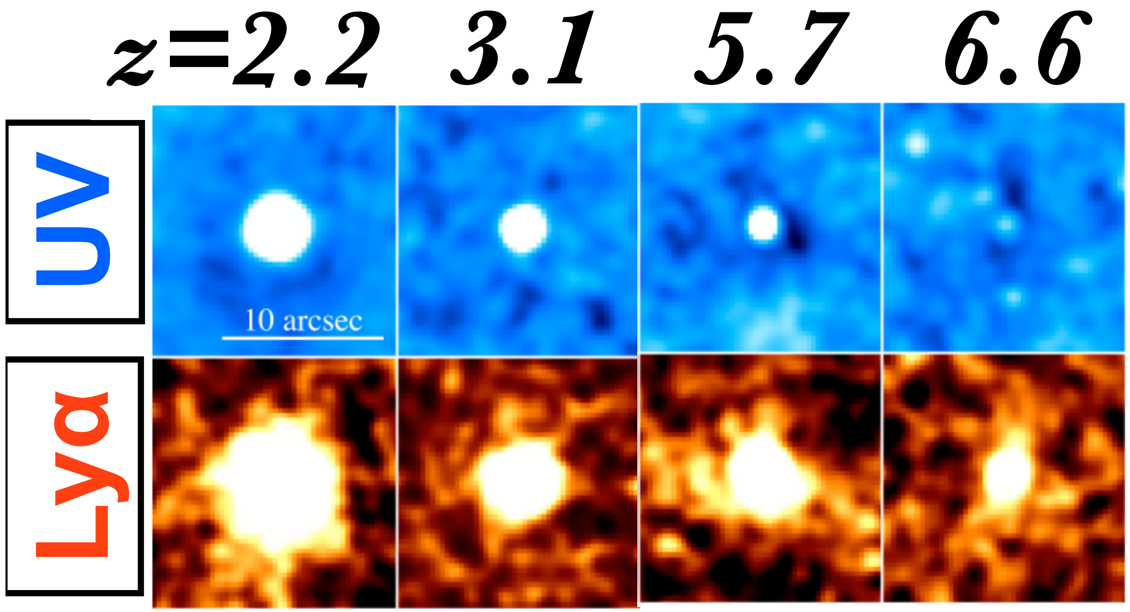
Subaru's Large LAE Sample



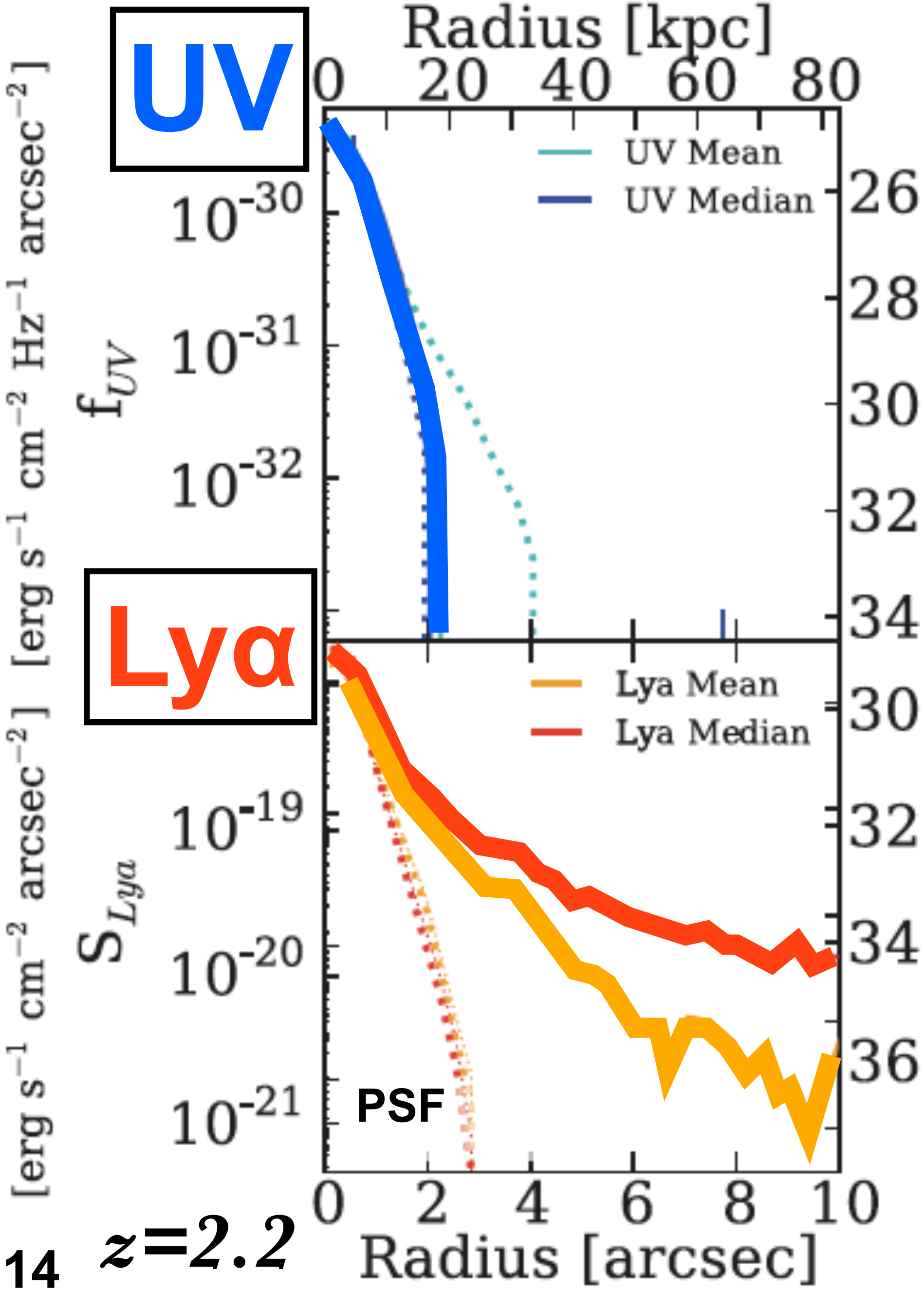
Matsuda-san studied δ-dependence
using ~2000 LAEs at z~3.1

~4500 LAEs

Lyα Halo Size

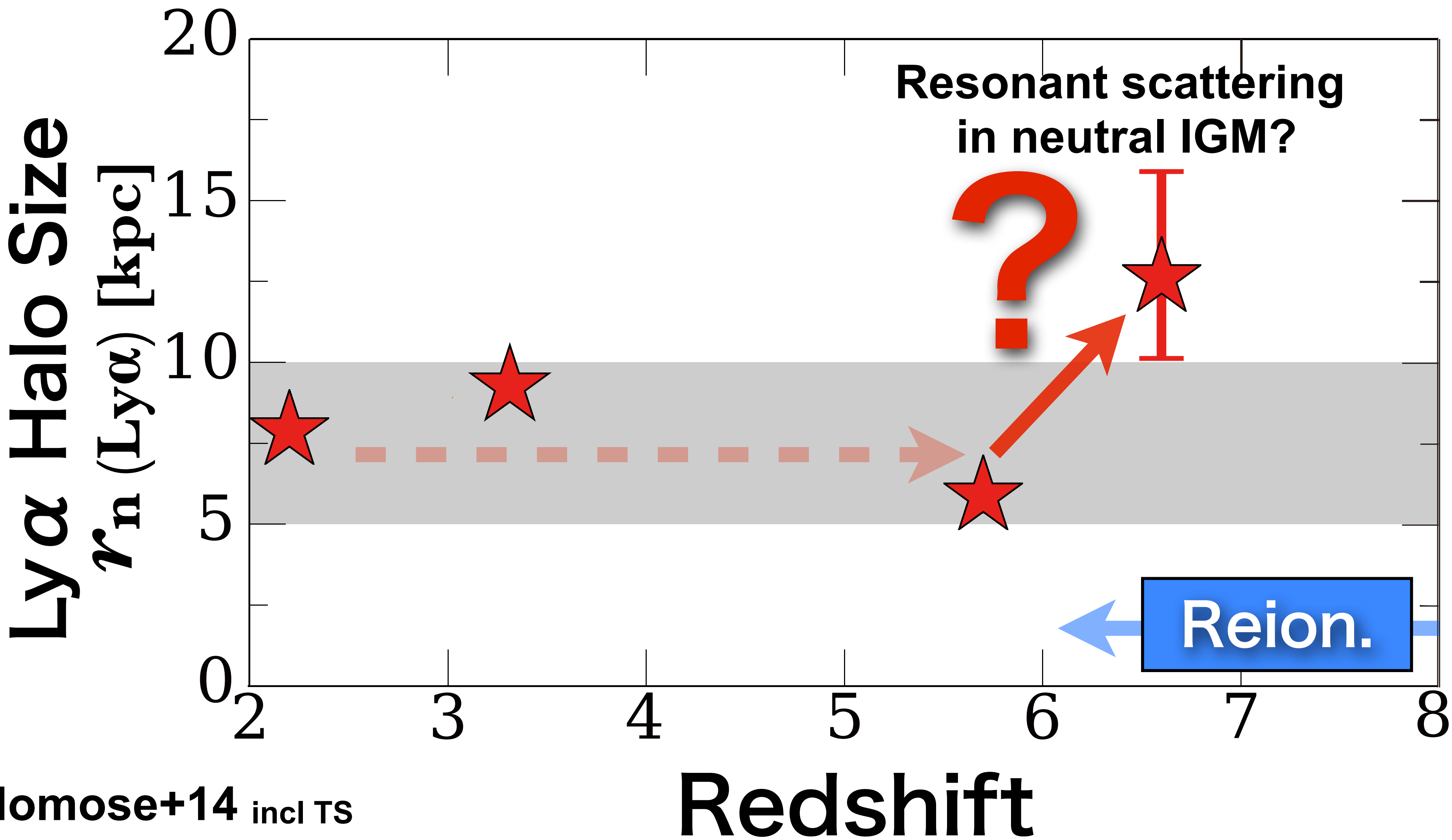


- ✓Detect Lyα halo@z=2.2-6.6
- ✓Fit by $S_{Ly\alpha} \propto \exp(-r / r_n)$
- ✓Compare r_n b/w z=2.2-6.6



Momose+14

z-Evolution of Lyα Halo Size

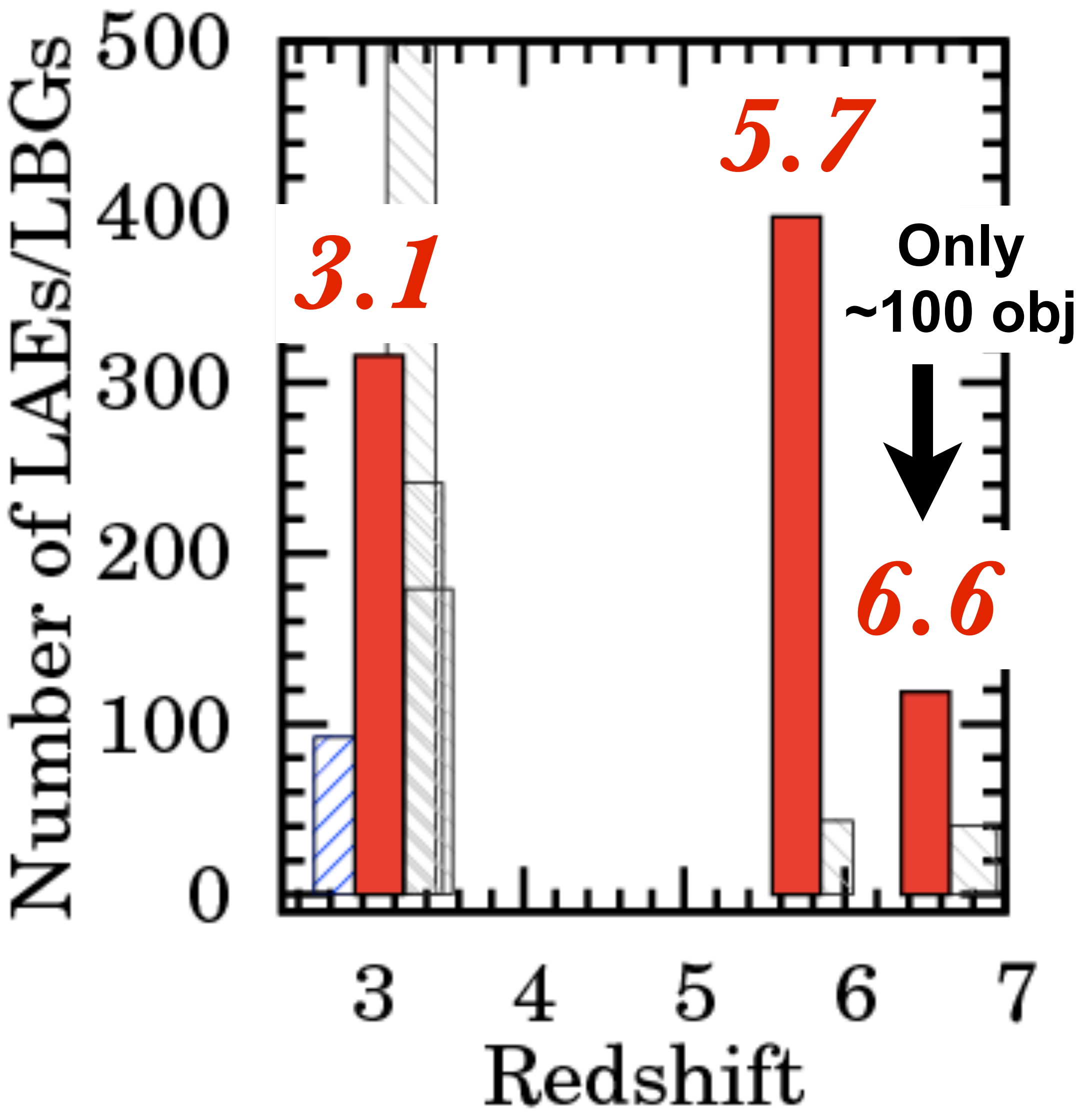


Momose+14 incl TS

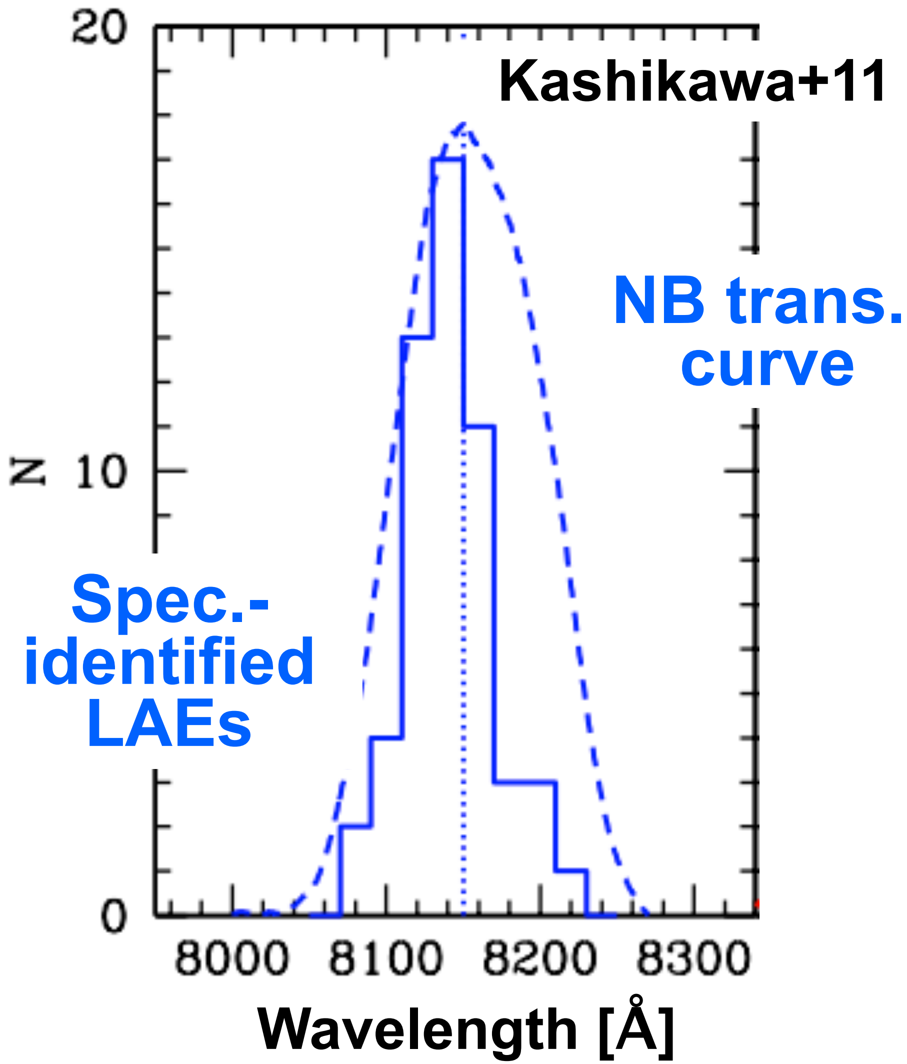
Size up at $z \geqq 6$? But, large error

Causes for Large Error@$z \geqq 6$

Small sample@$z=6.6$

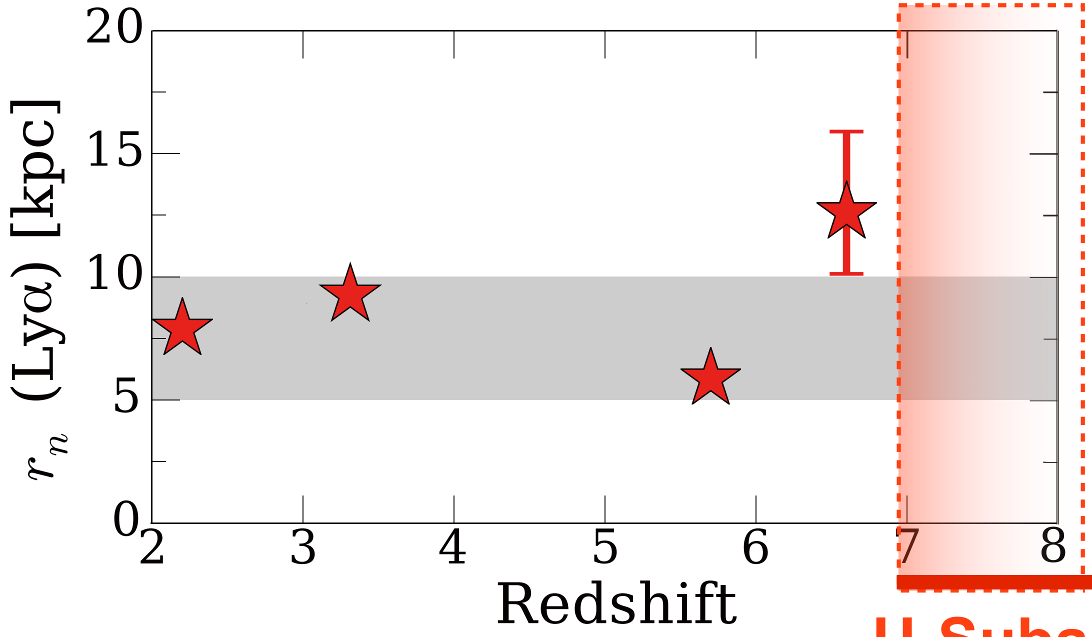


z-distribution



Lyα Halo @$z \geqq 7$

Stacking of IFU images



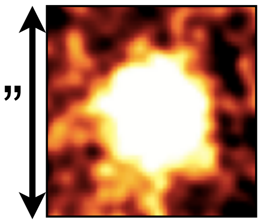
U-Subaru

Subaru/HSC+NB and/or MUSE

Sample

✓HSC dropout & NB samples
✓700 LBGs @z~7
✓39 LAEs @z~7.3

~15”



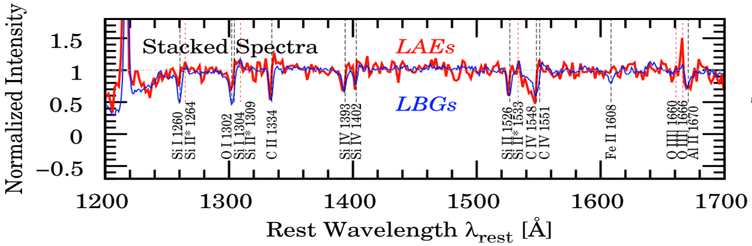
IFU obs.

✓~10 bundles/obj
✓Lyα EW & mag cuts for fair comparison

↓

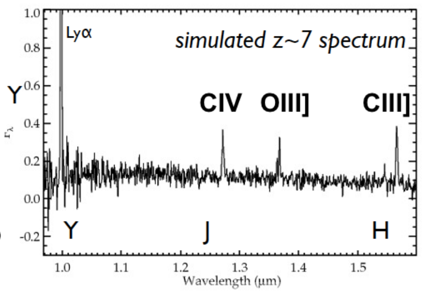
✓Lyα halo size
✓IS abs. & nebular emi. in stacked spectra
✓→ Detailed kinematics of Lyα halo@z~7

IS abs. lines



Shibuya+14b

Nebular lines@rest-UV



Stark+in prep.

Summary of §3

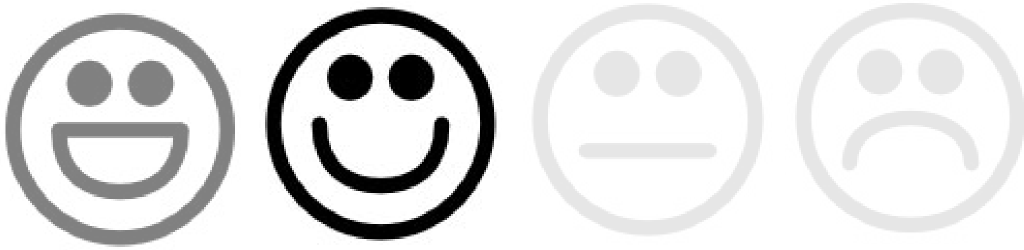
Advantage

✓Subaru's unique high-z samples

✓Can detect Lya halo in stacked IFU data

✓Difficult to be achieved by other next-generation instruments

→ A key project in $z \geqq 7$ science cases of (Fiber IFU+GLAO) ULTIMATE-SUBARU (?)



Requirement

✓Minimum separation < 10" Very difficult?

§4 U-Subaru Deep Field

ULTIMATE-Subaru

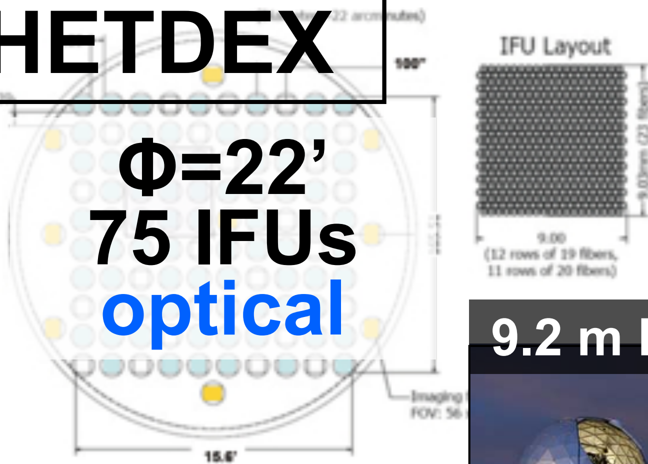
Φ=13'.5
30~100 IFUs
NIR (+GLAO)

8.2 m Subaru

Similar spec.

HETDEX

Φ=22'
75 IFUs
optical



9.2 m HET

High line EW galaxies

Surveys for LAEs w/ a high Lyα EW

HETDEX

420 deg^2

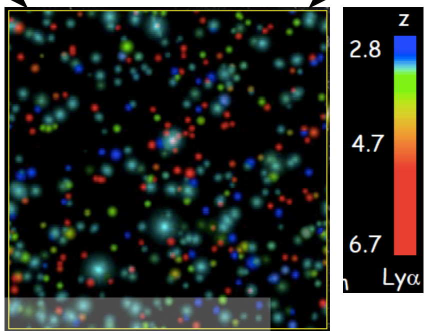
z=1-3

MUSE

	Exp. Time	Flux Limit
SF	1h	5 10^{-18}
MDF	10h	1.1 10^{-18}
DF	80h	3.9 10^{-19}
UDF	80h	1.3 10^{-19}

Guiderdoni's slide

~1'



z=3-7

U-Subaru

z=7-8

☺ ?

Summary

✓How did reionization occur?

→Simple spec follow-up for $z \sim 7$ galaxies

✓Physical properties of low-mass galaxies

→Kinematics, metallicity, ionization state

✓Physical state of CGM/IGM

→Lyα halo at $z \geqq 7$

Requirement:
Min. sep. <10”

✓Abundance of low-mass (high Lyα EW) galaxies at $z \geqq 7$

→Deep spec-imaging survey ?

Picture: Subaru Next-Generation AO Working Group, Science Report

My Answers to Questions

	Follow-up	low-M	Lyα Halo	Deep Field
Q1	Config2	Config2	Config2	Config2
Q2	>8	>50	50-100	~70
Q3	J	J, H	J	J
Q4	~2000	~2000	~2000	~2000
Q5	-	-	-	-
Q6	-	-	-	-
Q7	-	-	-	-
Q8	See slide	See slide	See slide	See slide
Q9	No	No	See slide	See slide