



Concluding the census of LAEs at the reionization epoch w/Subaru+Keck

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reionization

- The reionized process of IGM after the "dark ages".
- The HII bubble expands around each object, making overlap each other to occupy the ionized region in the universe.

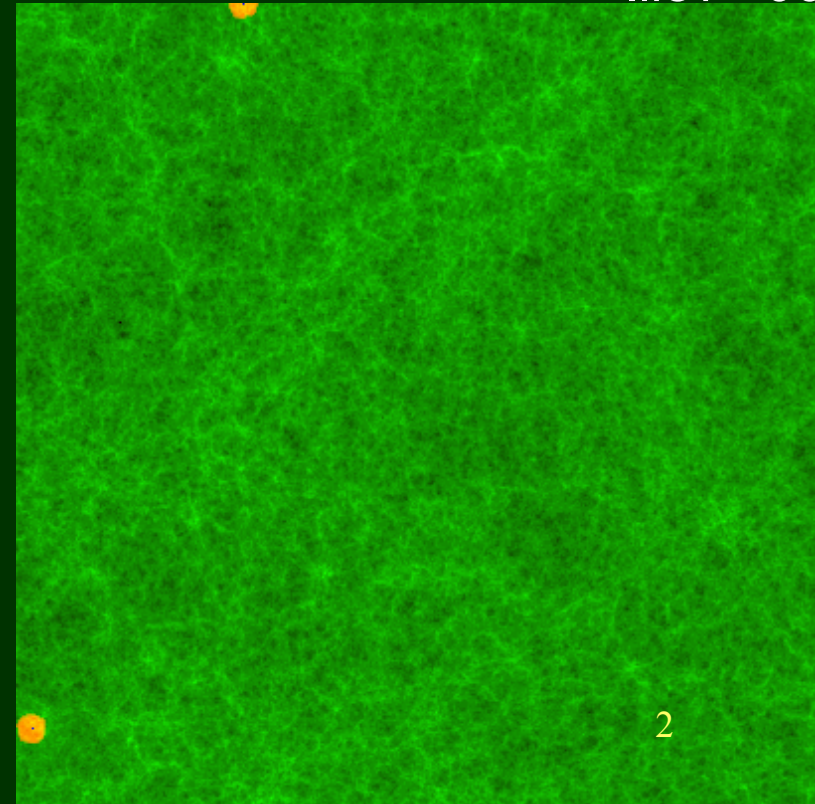
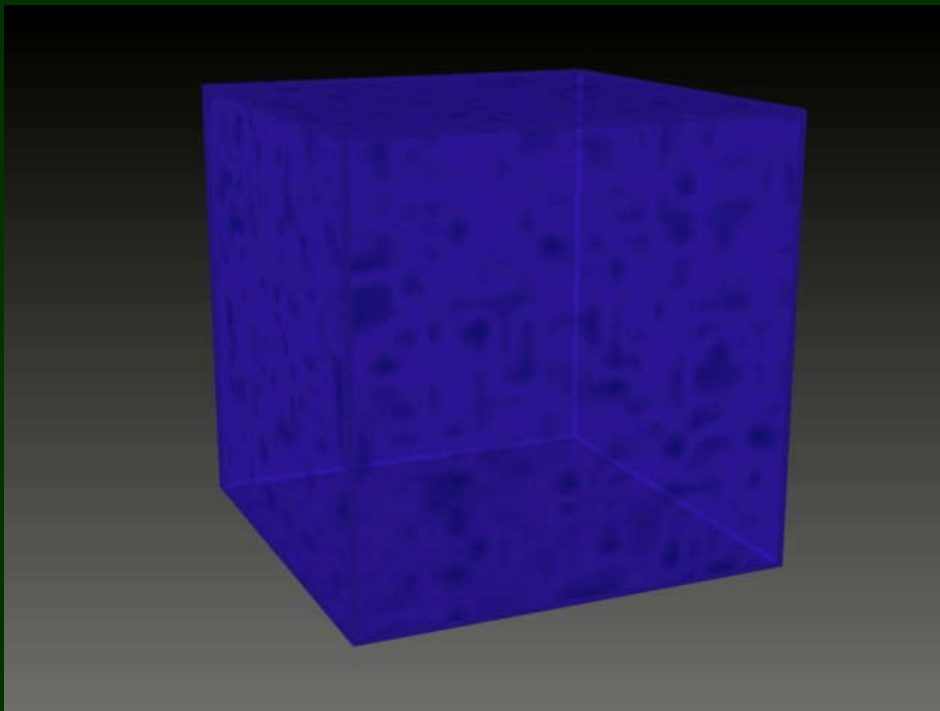
■ **When ?** $6 < z < 11$?

Green: H I

■ **What ?** QSO, LBG/LAE, popIII ?

Orange: H II Iliev+ 06

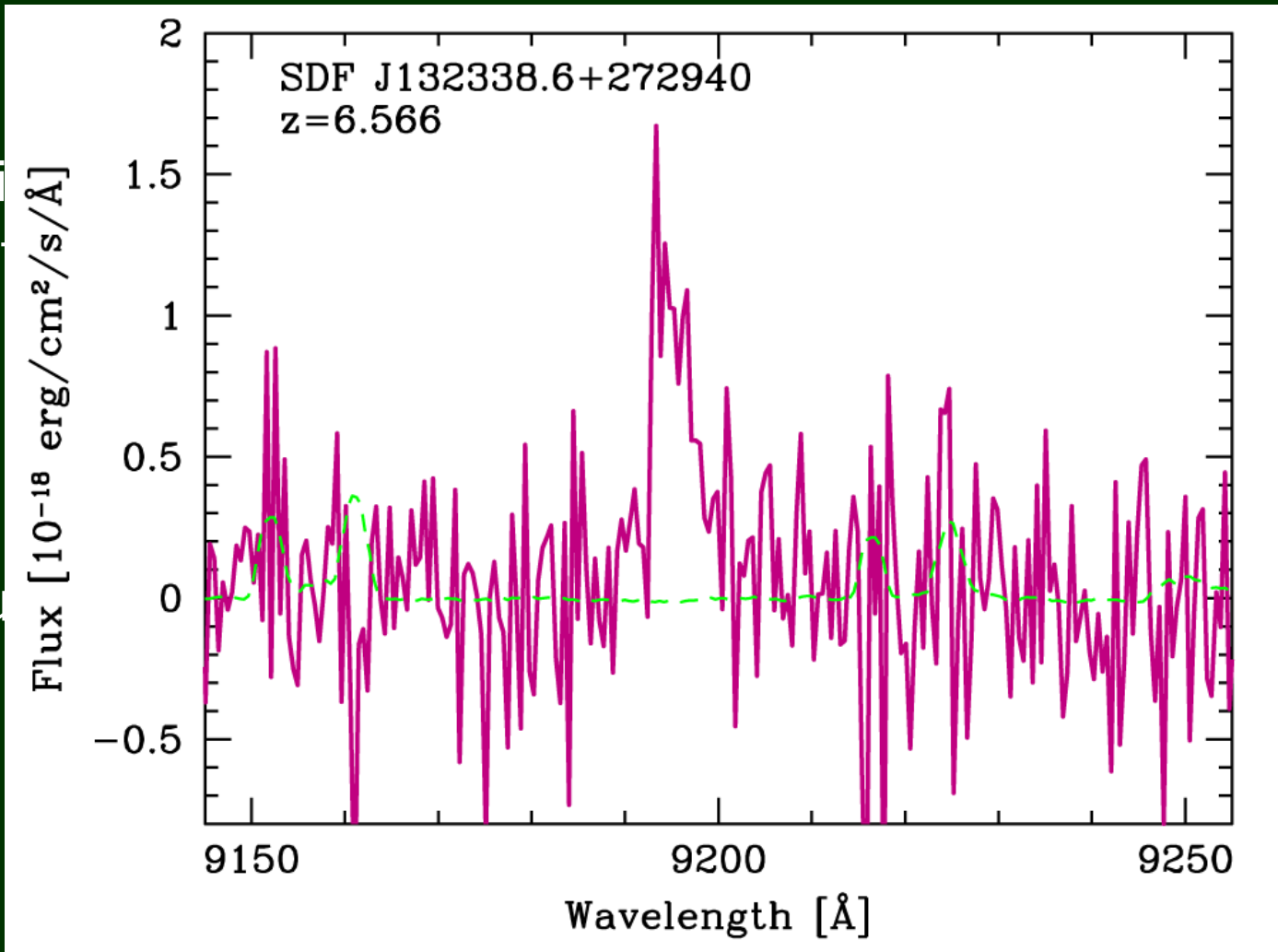
■ **How ?** inhomogeneous?



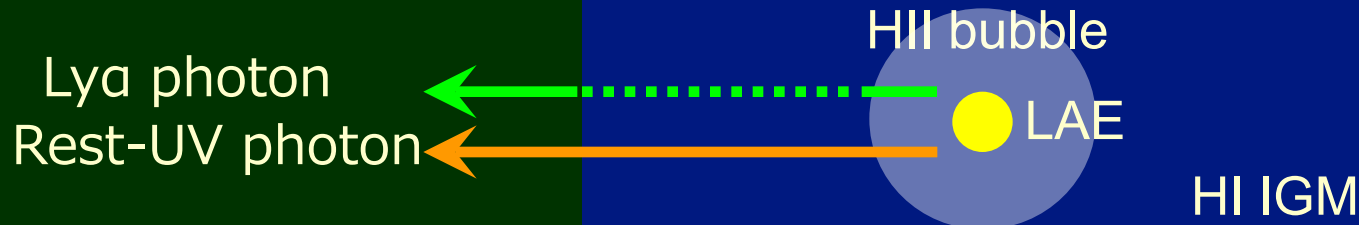
EoR proved by LAEs

Lya emission
line profile

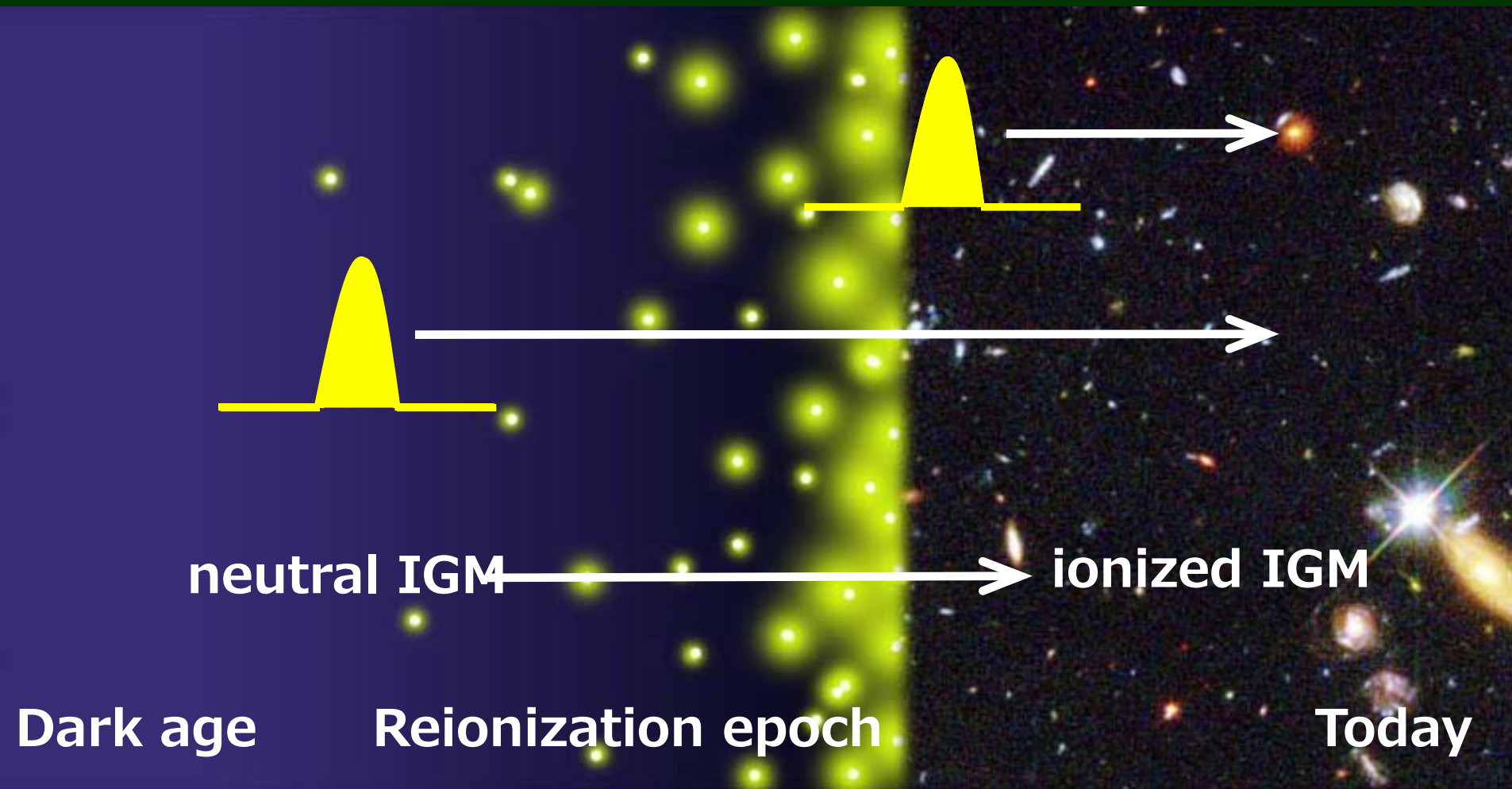
Optical
distribution



an+ 02



EoR proved by LAEs



- Significant decline of **LAE-LF** suggests IGM attenuation
(Haiman & Spaans 99, Malhotra & Rhoads 04)

LAE - a unique reionization probe

■ LAE test

■ Advantages

- Sensitive at $x_{\text{HI}} > 10^{-3}$ (\Leftrightarrow GP test)
- Statistical estimate (\Leftrightarrow GRB)

■ Disadvantages

- Hard to distinguish w/ galaxy evolution

■ Ly α LF has no evolution during $3 < z < 6$

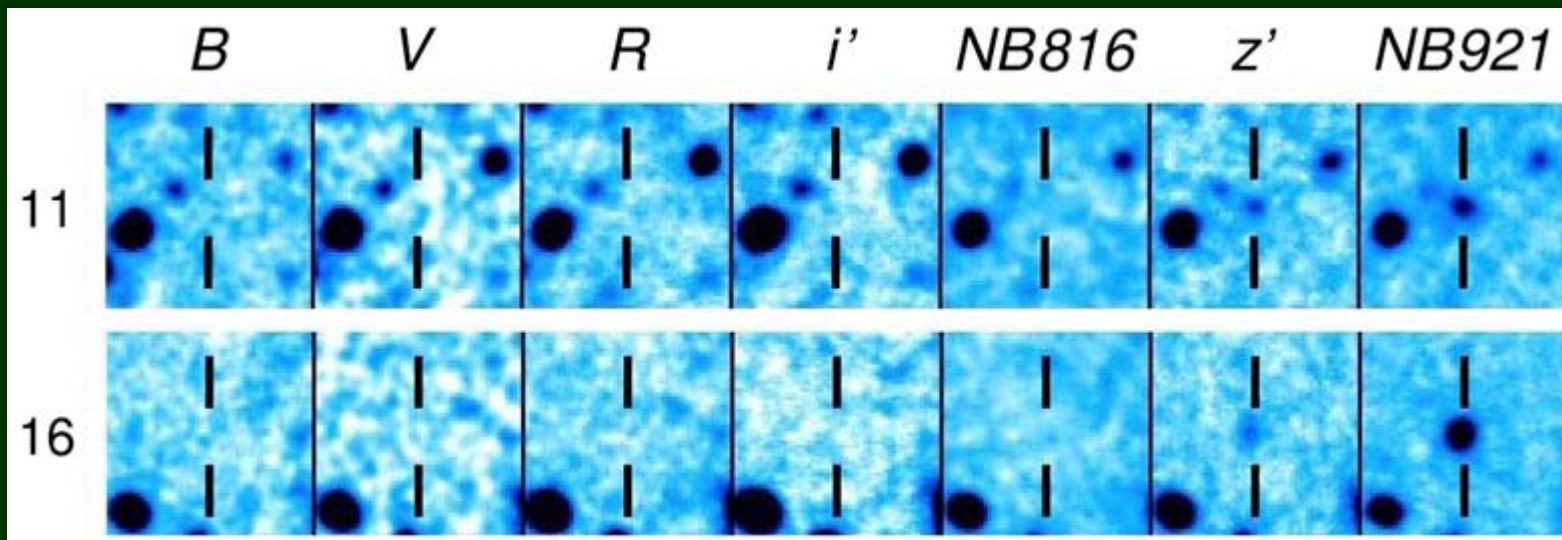
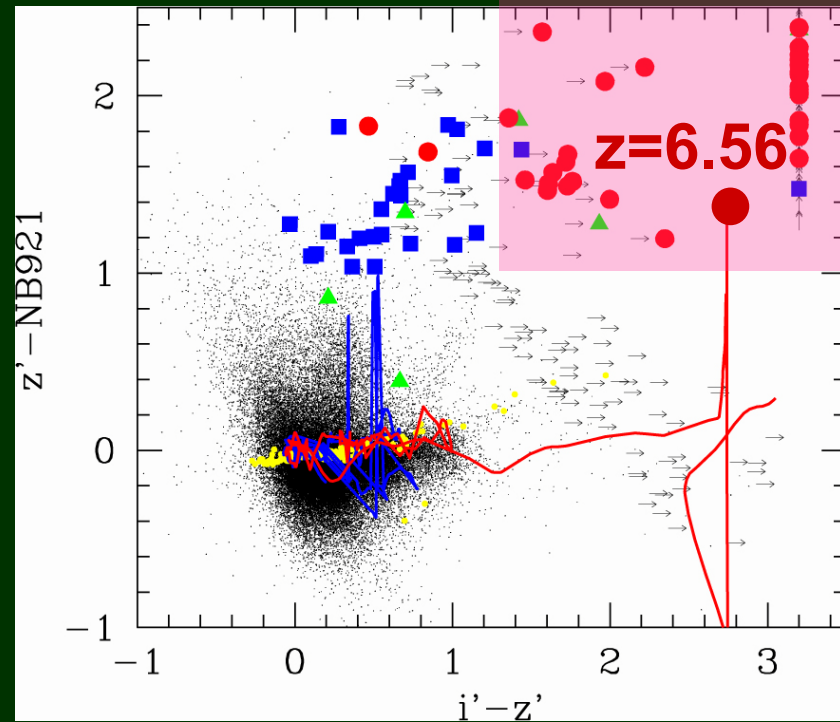
- Confirmed by systematic wide survey (e.g., Ouchi+ 08)
- Contrary to LBG evolution
- Balance between mass assembly and dust evolution? (Stark+ 10)

■ Important to draw the UV LF simultaneously

- The rest UV (1255Å) photons are not attenuated by neutral IGM

Search for LAEs at $z=5.7$ and 6.5 w/S-Cam

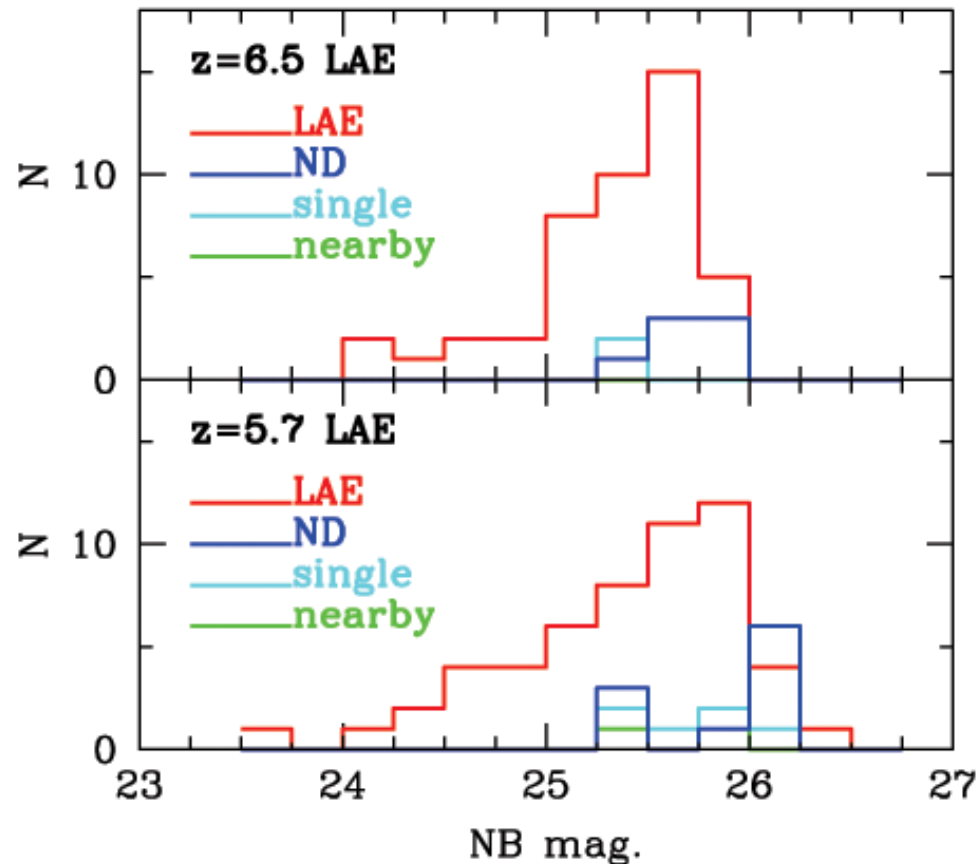
- Optical Deep imaging w/S-Cam
- $z=5.7 \rightarrow$ NB816 < 26.0 (10.0hr)
- $z=6.5 \rightarrow$ NB921 < 26.0 (15.0hr)
- **photometric sample:**
NB-excess & red in BB
 - $z=5.7 \rightarrow$ 89個
 - $z=6.5 \rightarrow$ 58個



Spectroscopic follow-ups

■ w/Subaru-FOCAS and Keck-DEIMOS

	z=6.5 LAE	z=5.7 LAE
photometric sample	58	89
confirmed LAE	42	46
nearby emitter (OII/OIII/H α)	1	4
single emitter	2	6
ND	7	10
wo/ spec.	6	23
serendipitous LAE	3	8
total LAE (as of today)	45	54
(as of 2006)	17	28
completeness of phot. sample	89.5%	81.8%



Comparison of Ly α LF between $z=6.5$ and 5.7

Possible decline of Ly α LF at $z=6.5$ compared w/ $z=5.7$

Reionization has not completed at $z=6.5$

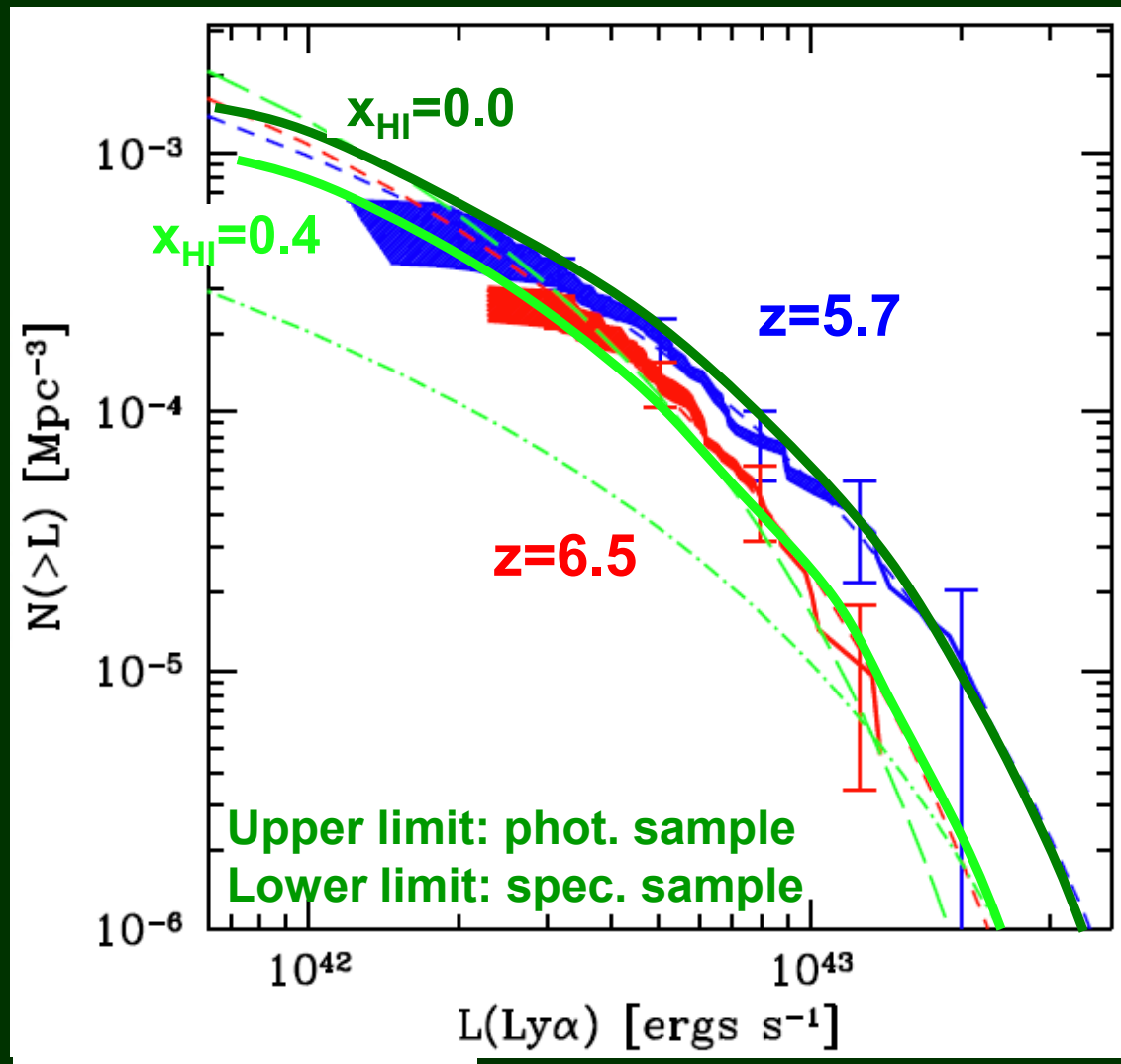
L^* difference implies

$\rightarrow x_{\text{HI}} < 0.35$
(Santos 04)

$\rightarrow x_{\text{HI}} = 0.20$
(Kobayashi+ 07)

$\rightarrow x_{\text{HI}} < 0.50$
(Dijkstra+ 07)

$\rightarrow x_{\text{HI}} < 0.32$
(McQuinn+ 07)

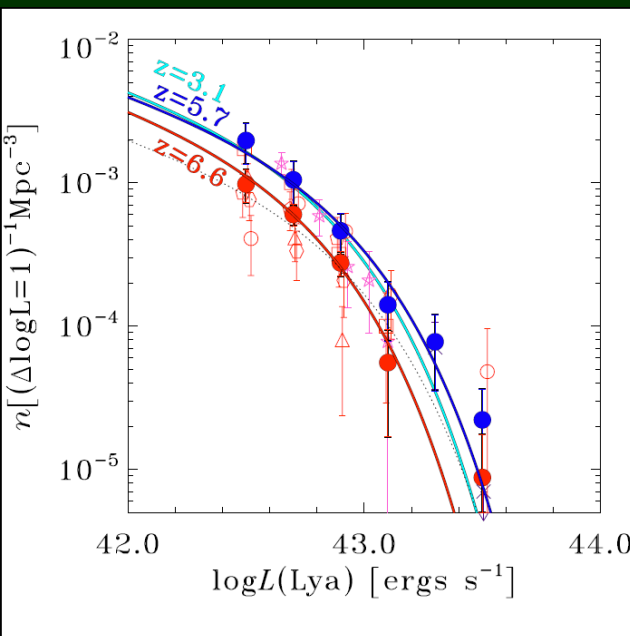


NK+ apj submitted

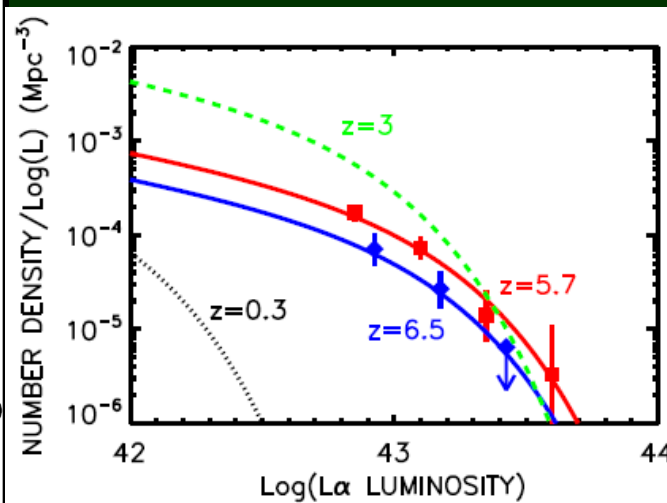
LF decline caused by cosmic variance?

- Ouchi+ 2010: 1deg², photo, 30% decline of L^*
- Hu+ 2010: 1.16deg², spec, 44% decline of Φ^*
- Nakamura+ 2010: 0.25deg², photo, 80% decline of L^*
- Variance due to patchy reionization?

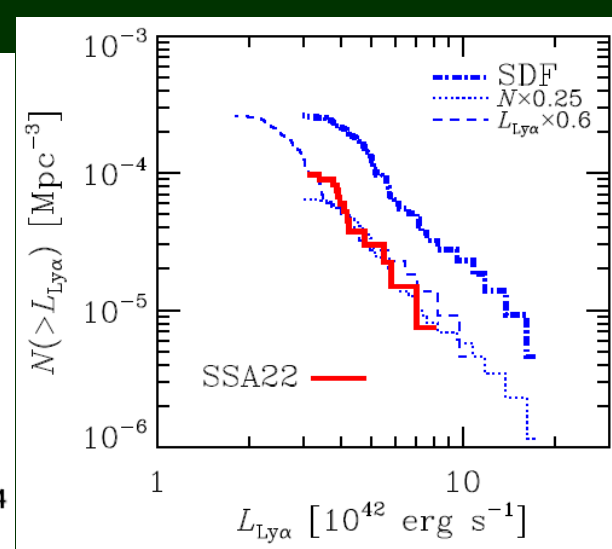
Ouchi+ 10



Hu+ 10

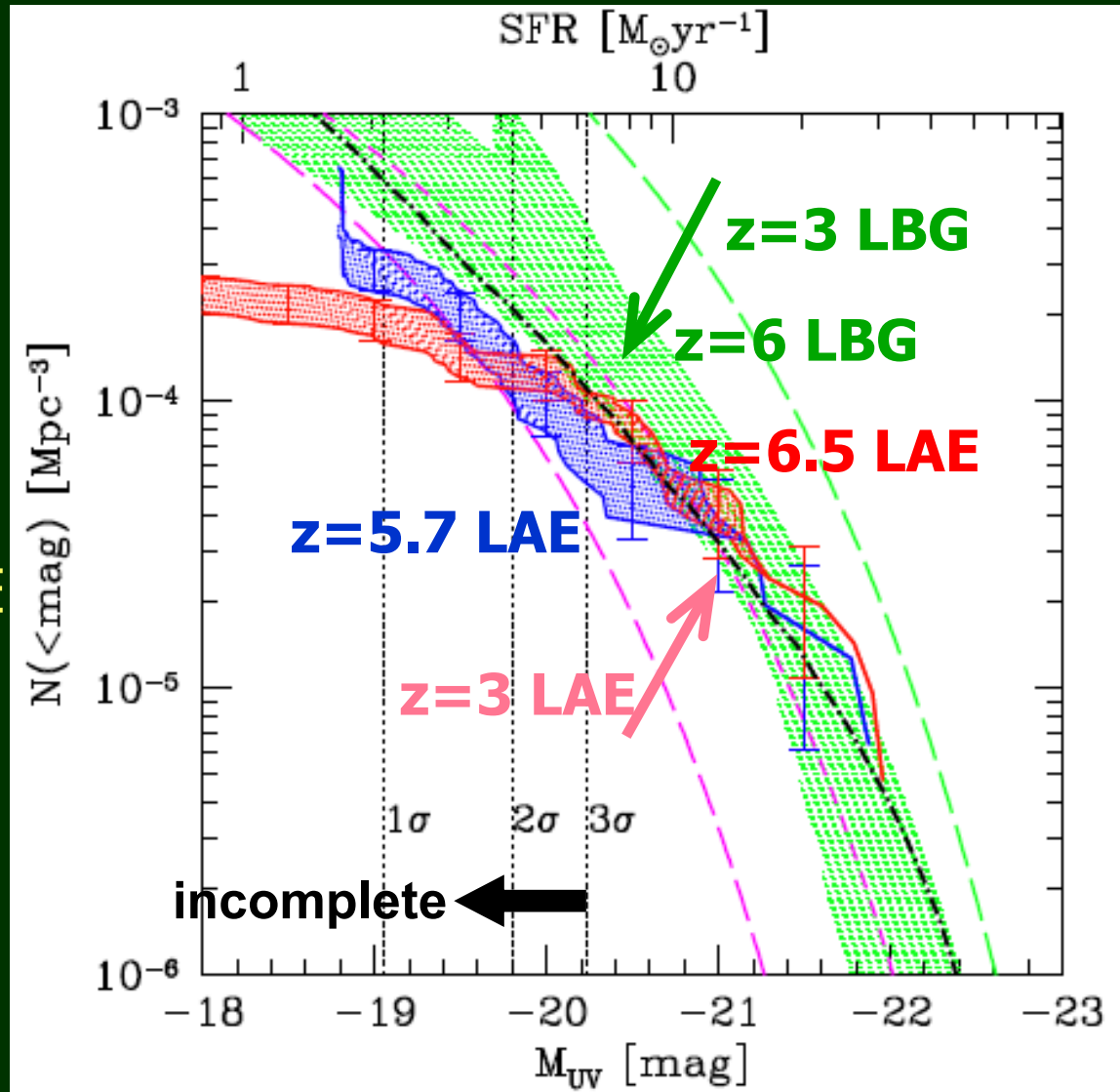


Nakamura+ 10



The rest-UV LFs of LAEs

- LyA LF difference is caused by IGM attenuation ?
vs.
galaxy evolution ?
- The rest UV (1255Å) flux is not sensitive to neutral IGM
- The rest-UV LF of LAE at $z=6.5$ agrees w/ LAEs at $z=5.7$
- But ,large uncertainty
- **Constraint on the photon budget ?**

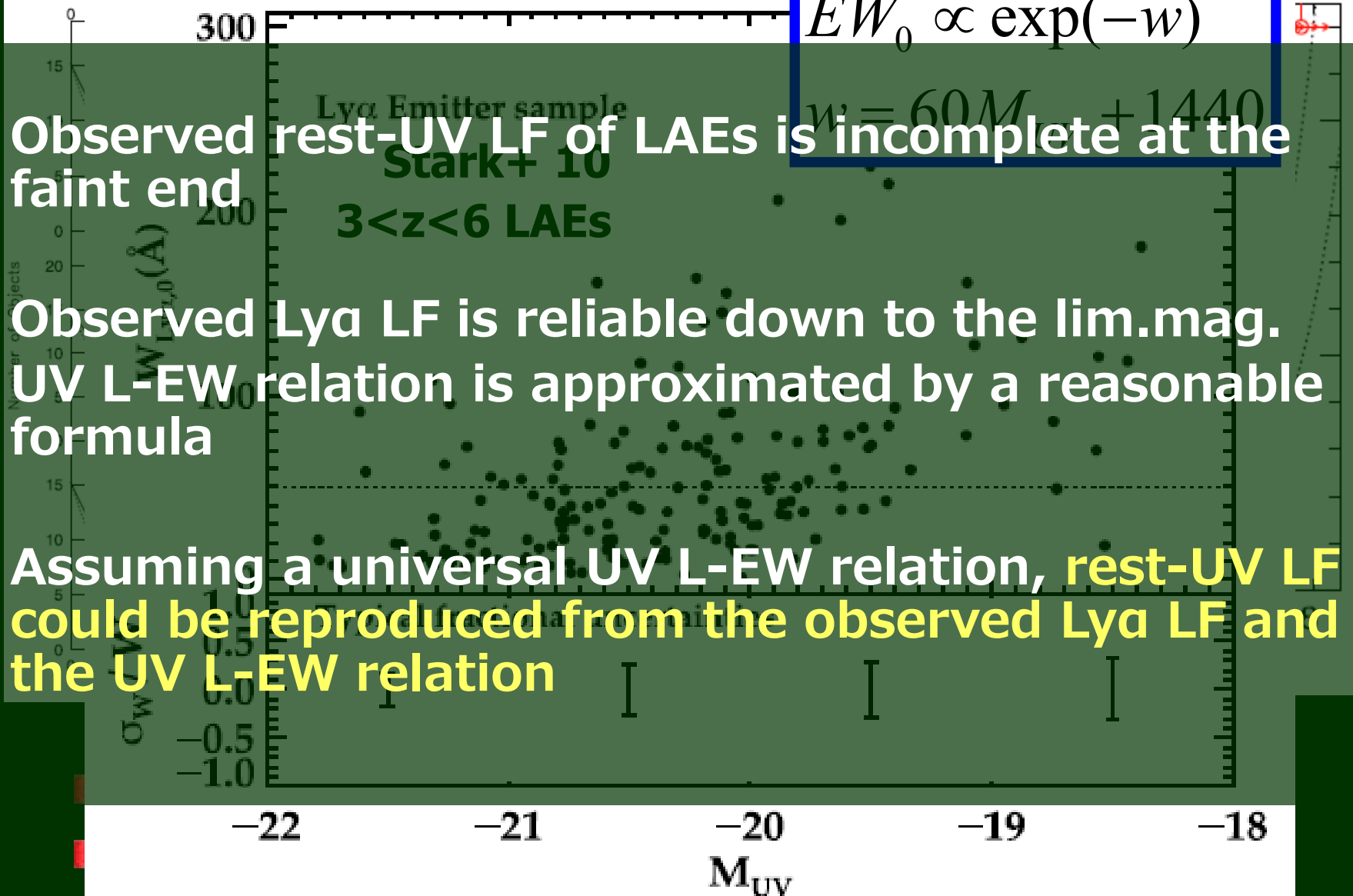


UV L-EW relation

$$EW_0 \propto \exp(-w)$$

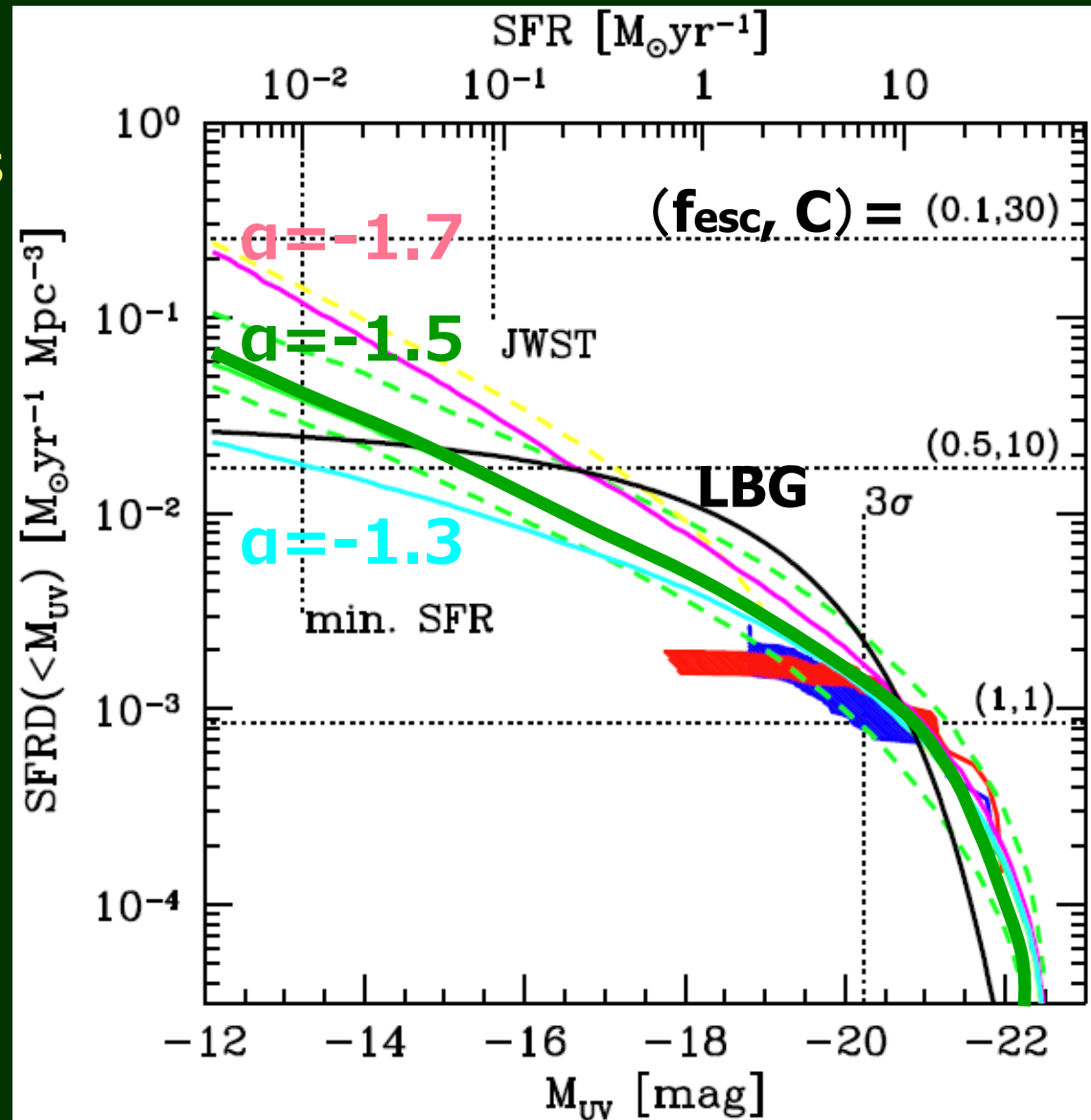
$$w = 60 M_{UV} + 1440$$

- Observed rest-UV LF of LAEs is incomplete at the faint end
- Observed Ly α LF is reliable down to the lim.mag.
- UV L-EW relation is approximated by a reasonable formula
- Assuming a universal UV L-EW relation, rest-UV LF could be reproduced from the observed Ly α LF and the UV L-EW relation



Photon Budget

- The first measure of the contribution of LAEs to the photon budget
- Contribution of LAE's to the photon budget among LBGs significantly increases towards faint mags
- Strongly depends on the uncertain faint-end slope of the Ly α LF



NK+ apj submitted

Reionization probed by Ly α emission line

■ When did the reionization take place ?

- Ly α LF can be used to constrain the reionization
- The Ly α LF at $z=6.5$ has a deficit compared w/5.7
- The UV-LF has almost unchanged
- Intrinsic large CV of LAEs or patchy reionization ?

■ What ionized the universe ?

- LAE's contribution to the photon budget
- Key: Faint end of the UV (Ly α) LF of LAEs

■ Deep NIR NB survey for higher- z w/JWST+TMT & Wide NB survey w/HSC

■ **Acknowledgement: all the Subaru+Keck staffs for their helps with the observations**