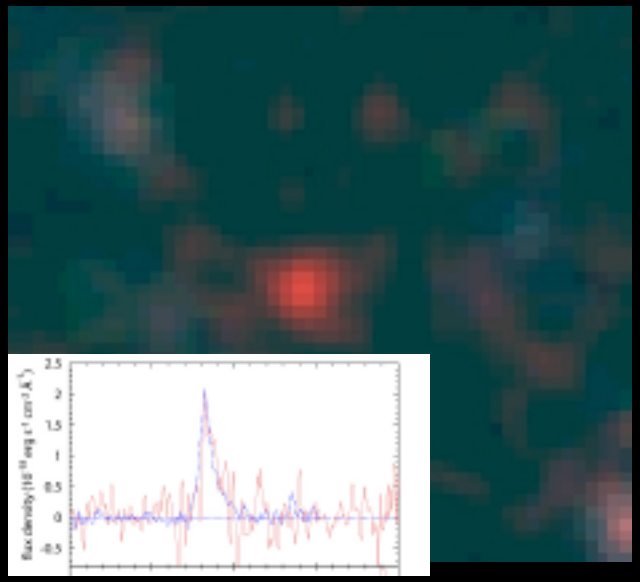
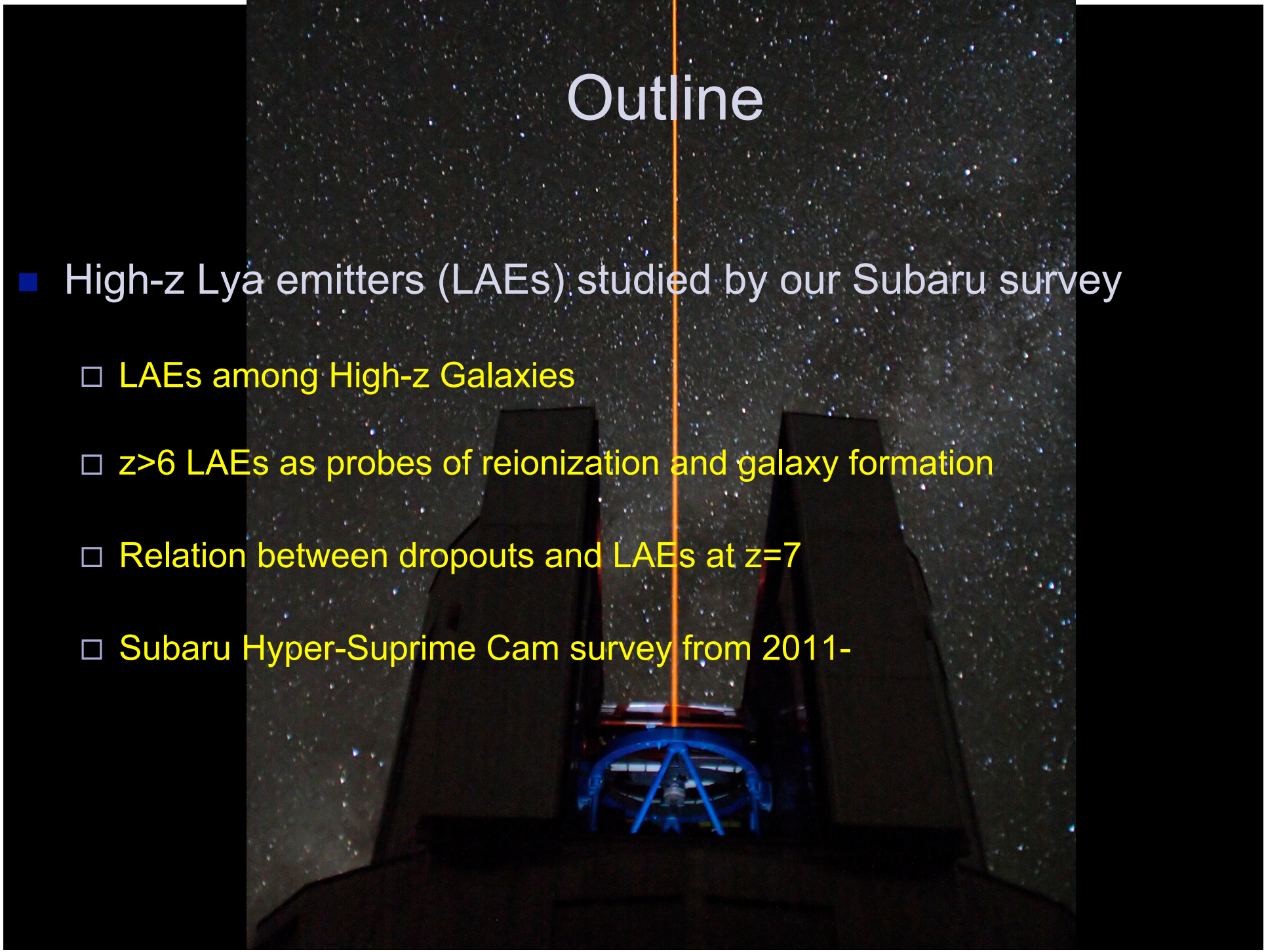
High Redshift Galaxies as Probes of Reionization



First z-dropout galaxy with a spectroscopic redshift of z=6.964 (**Ouchi et al. 2009b**)

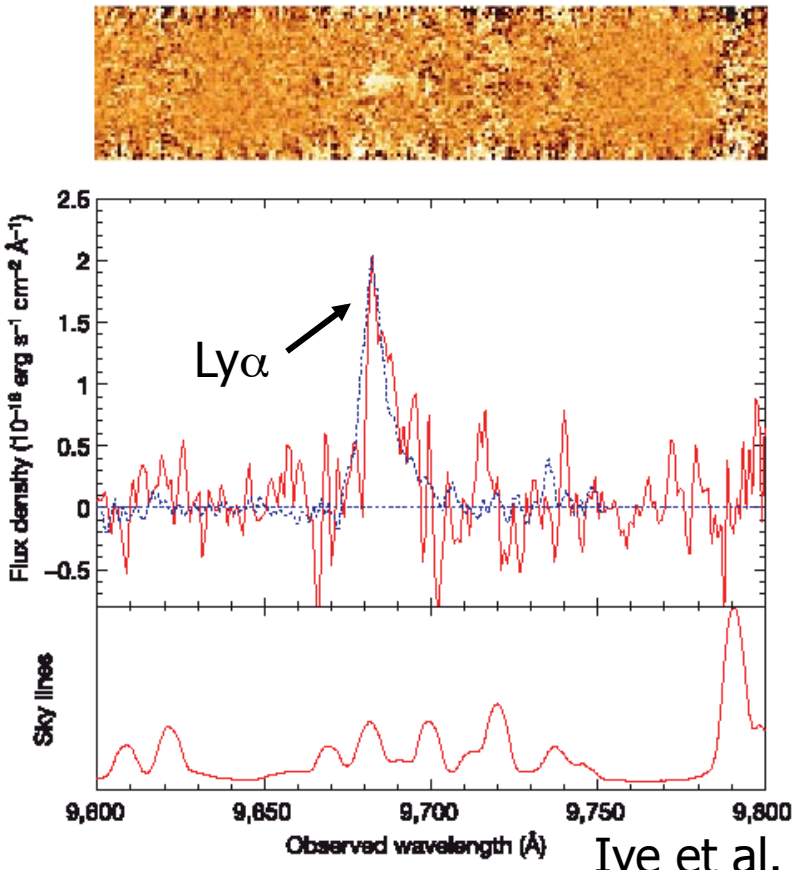
Masami Ouchi
(Carnegie)



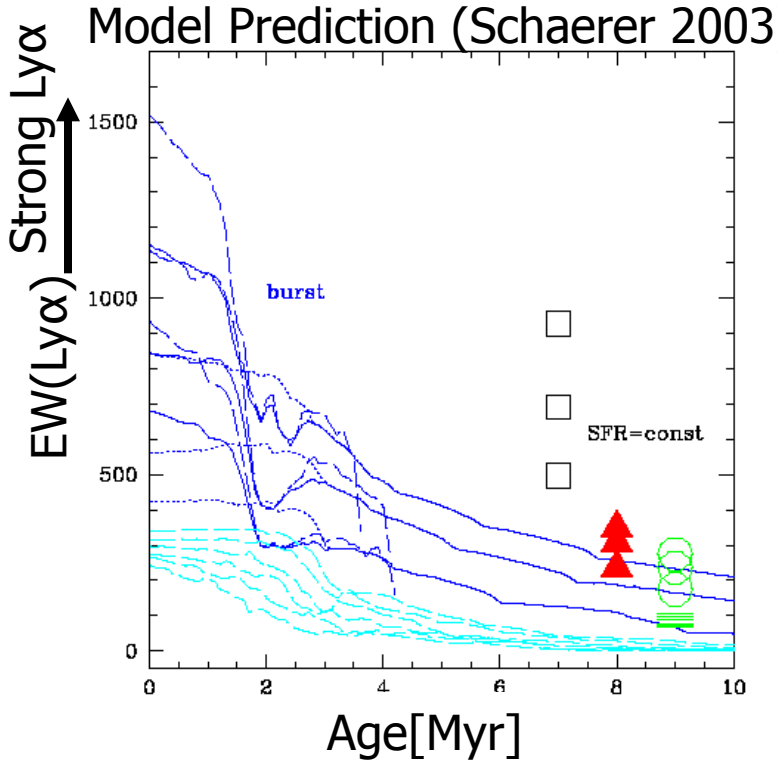
Outline

- High-z Lya emitters (LAEs) studied by our Subaru survey
  - LAEs among High-z Galaxies
  - z>6 LAEs as probes of reionization and galaxy formation
  - Relation between dropouts and LAEs at z=7
  - Subaru Hyper-Suprime Cam survey from 2011-

What are Lyα Emitters (LAEs)?



Iye et al. (2006)



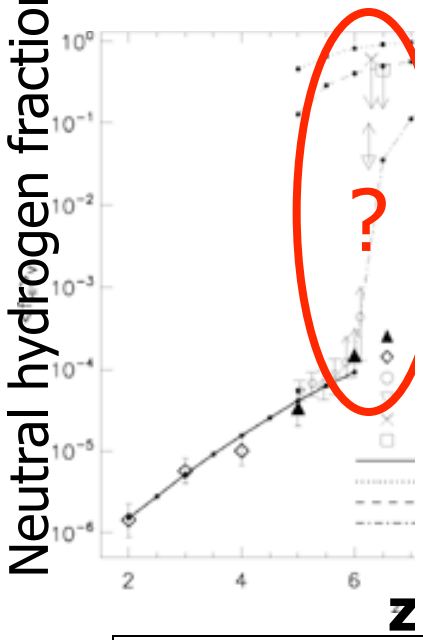
i) Strong Lyα→ Very young (≲10-100Myr) and dust/metal poor star-formation.

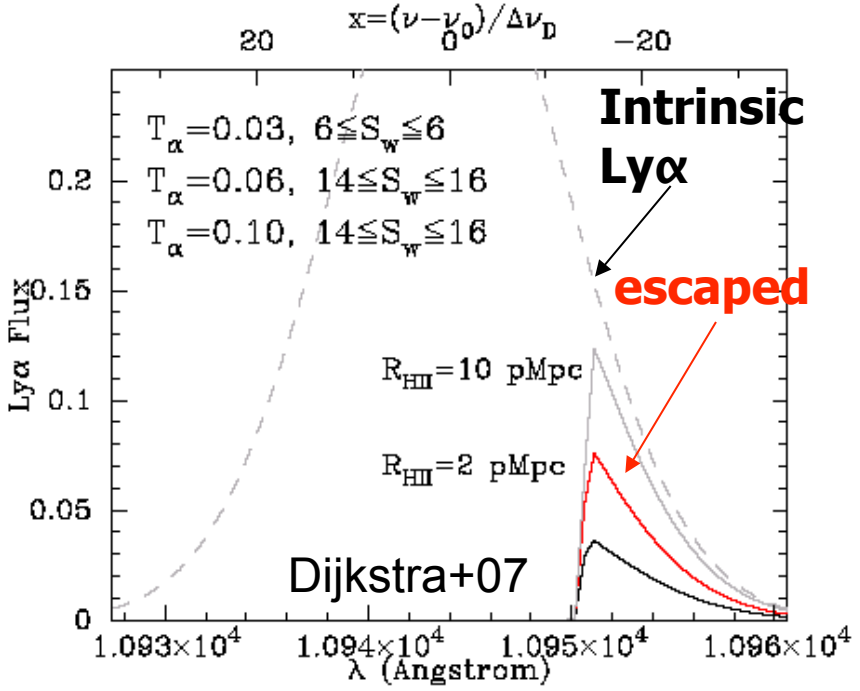
ii) Faint continuum→high-z less-massive population with the avg. mass of M*~10^8 Mo at z~3 (Gawiser+07, Parzkal+07, Nilsson+07, Lai+08, Ono+09)

Typical LAEs are High-z young dwarf galaxies with SF

Lyα Emitters (LAEs) at z>6:

as a Prob[illegible]tion





onization predicted by
sfer model (Iliev et al. 2006)

- O
  - Probing neutral hydrogen fraction indicated by the absorption of Lya damping wing, using LAEs at z>6
    - At the neutral IGM universe, less Lya lines will be escaped and observed.
  - How long reionization epoch extend?
  - What are major sources of reionization?

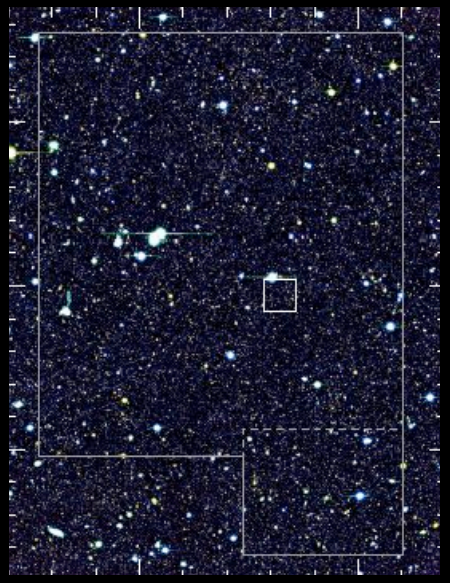
Galaxies (blue dots) and ionized bubbles (orange)

EoR: Redshift >~6 (Fan+06; cf. Becker+07)
z~10-11: WMAP7+inst. model(Larson+10)
QSO spectra are completely damped at z>~6 (e.g. Becker's talk)

1. Subaru Surveys

SXDF a.k.a UKIDSS/UDS
(1 deg^2;i=27.0)
[$2^h18^m00^s$,$-5^o00'00''$]
5 pointings of Suprime-Cam

SDF(0.2 deg^2;i=27.4)
[$13^h24^m39^s$,$+27^o29'26''$]
1 pointing of Suprime-Cam



At z=3-7
~150 Mpc (comoving)

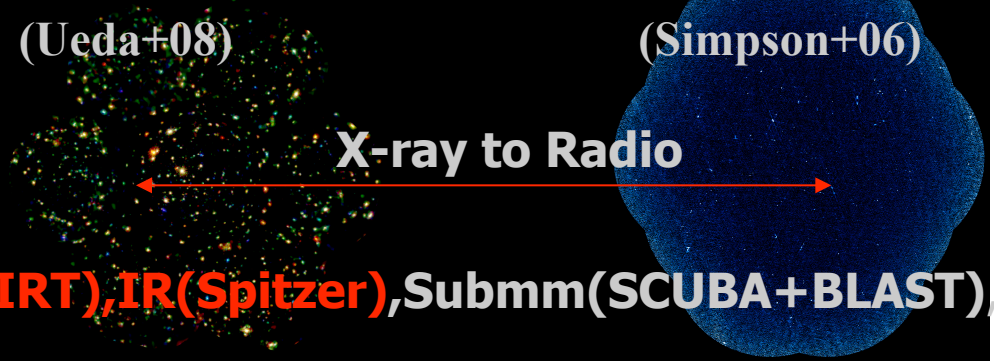
(Furusawa+08)

(Ouchi+04,Kashikawa+04)

Size of GOODS-S

XMM-Newton 0.5-2
(Ueda+08)

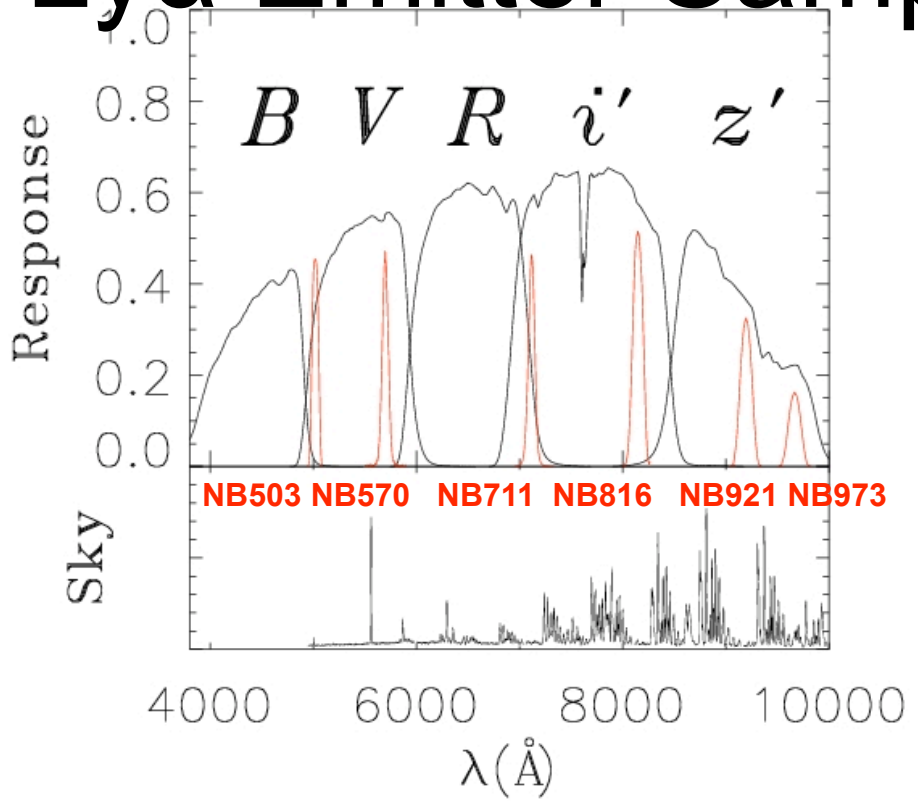
VLA 1.4 GHz
(Simpson+06)



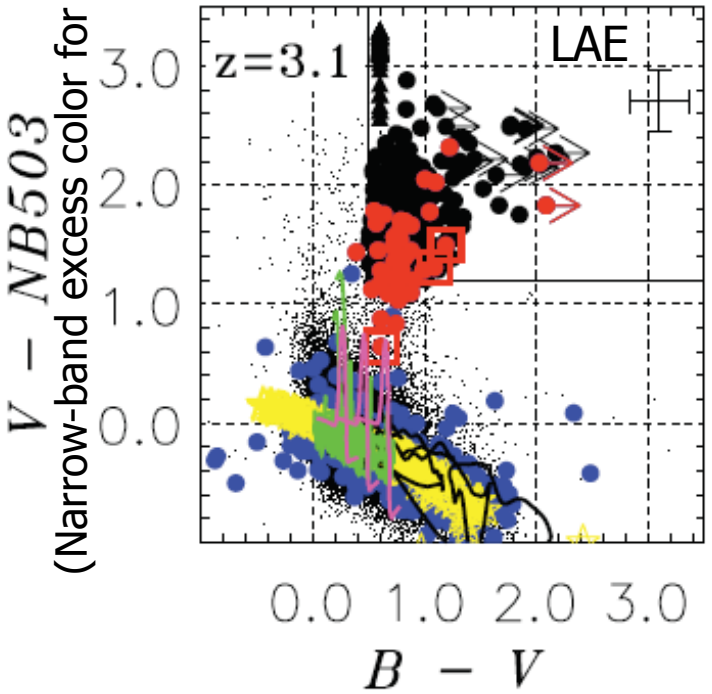
X-ray to Radio

X-ray(XMM), UV(GALEX), NIR(UKIRT),IR(Spitzer),Submm(SCUBA+BLAST),
Radio(VLA,GMRT)

Lyα Emitter Samples



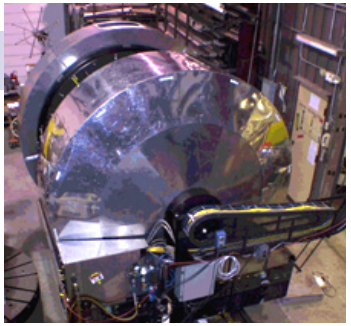
E.g. photometric selection for z=3.1 LAEs



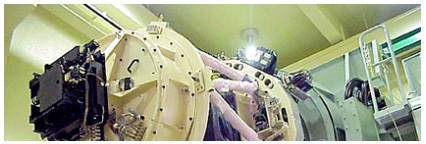
- Lyα Emitter (LAE) with log L(Lya)≳42.3 erg/s

	SDF	SXDF
z=3.1:	**-**	**356**
z=3.7:	**-**	**101**
z=4.9:	**87**	**-**
z=5.7:	**89**	**401**
z=6.6:	**58**	**207**
z=7.0:	**2**	**3**

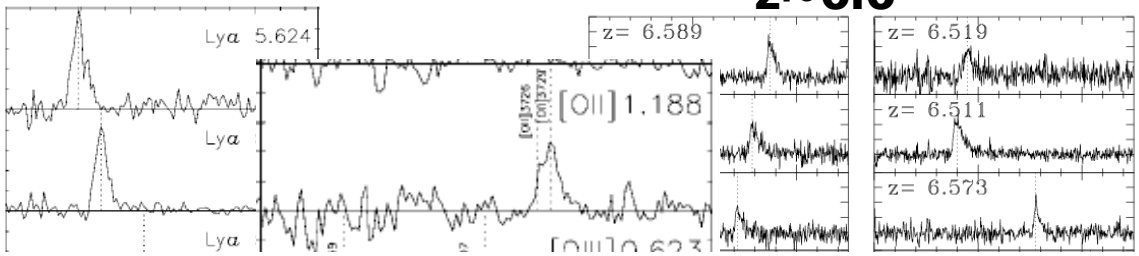
Spectroscopic Confirmation



Keck/DEIMOS

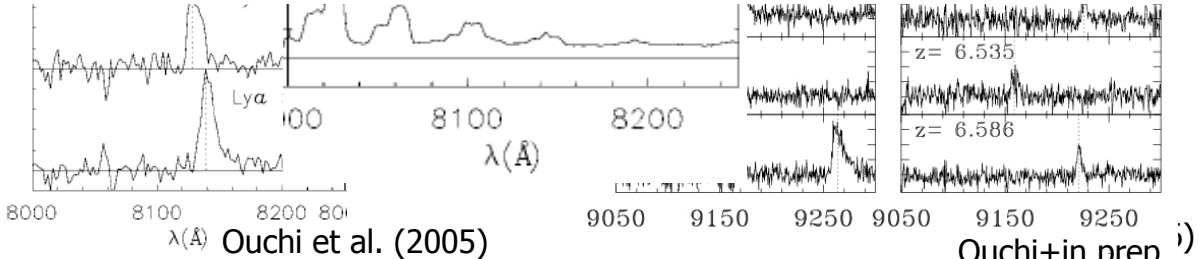


Examples



Thanks to the deep & wide field data, we have obtained

1,304 LAEs (216 spec. confirmed) at z=3.1-7.0



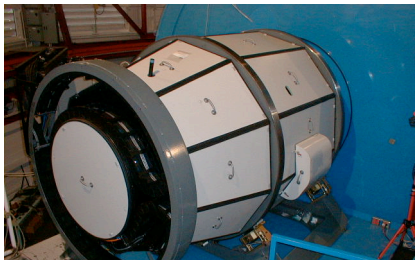
Ouchi et al. (2005)

Ouchi+in prep

VLT/VIMOS

- Lyα Emitter (LAE) with log L(Lya)≳42.3 erg/s

	SDF	SXDF
z=3.1:	-	356(56)
z=3.7:	-	101(39)
z=4.9:	87(5)	-
z=5.7:	89(27)	401(93)
z=6.6:	58(19)	207(28)
z=7.0:	2(1)	3



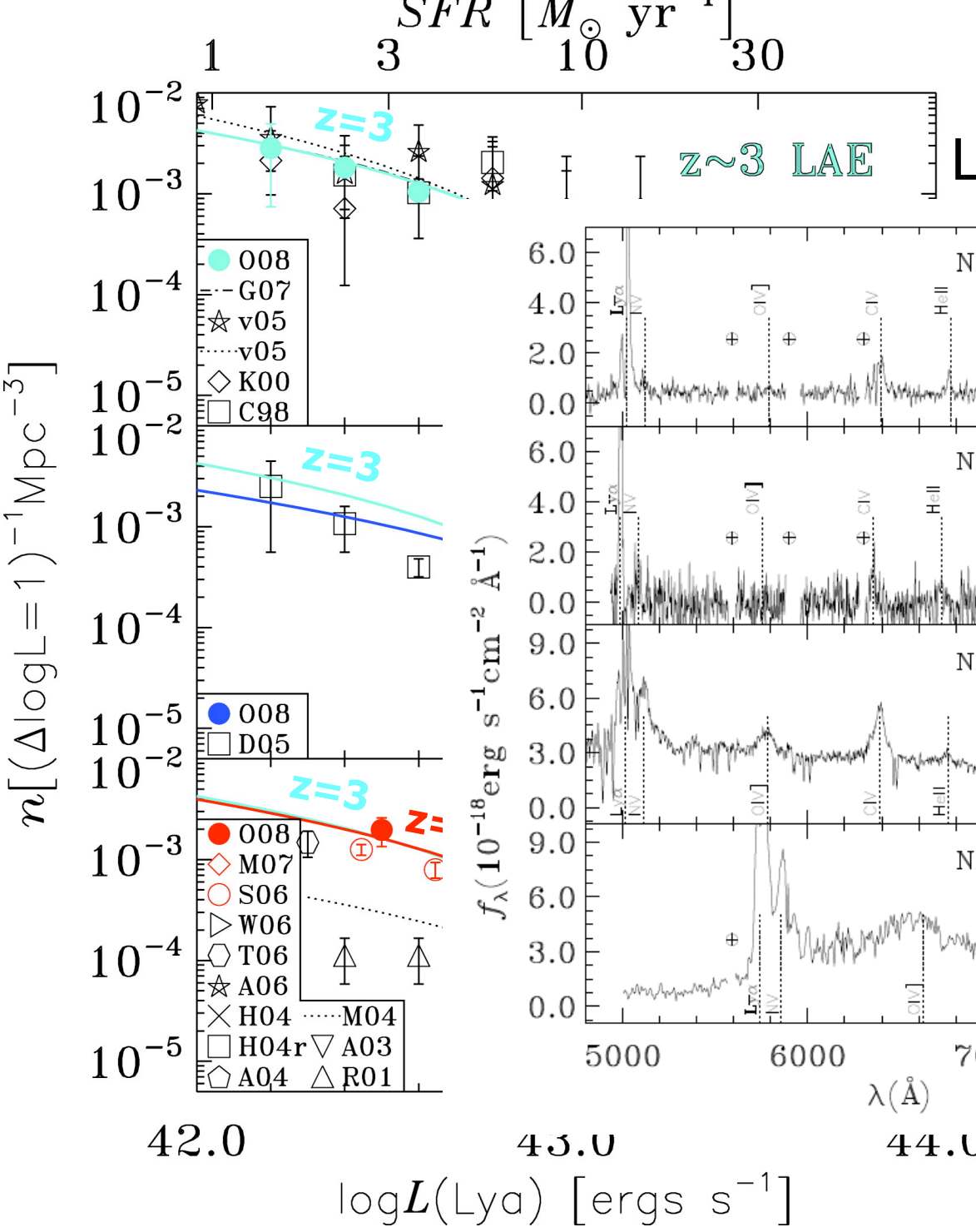
Magellan/IMACS

Numbers in () are the ones of spectroscopically identified objects

Fraction of contamination (foreground interloper) <~0.1

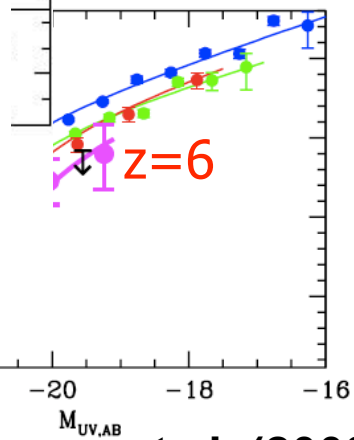
2. LAEs among High-z Galaxies

Lyα Luminosity Function
3 to 6



hows no
3.1 to 5.7,
f 2 in L*
factor of 3 in φ*)
or+cos. variance

ary tendency
ive system of
UV LF (e.g.
ens+07, McLure

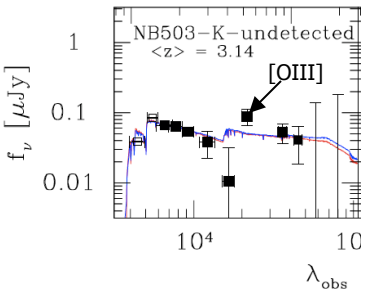


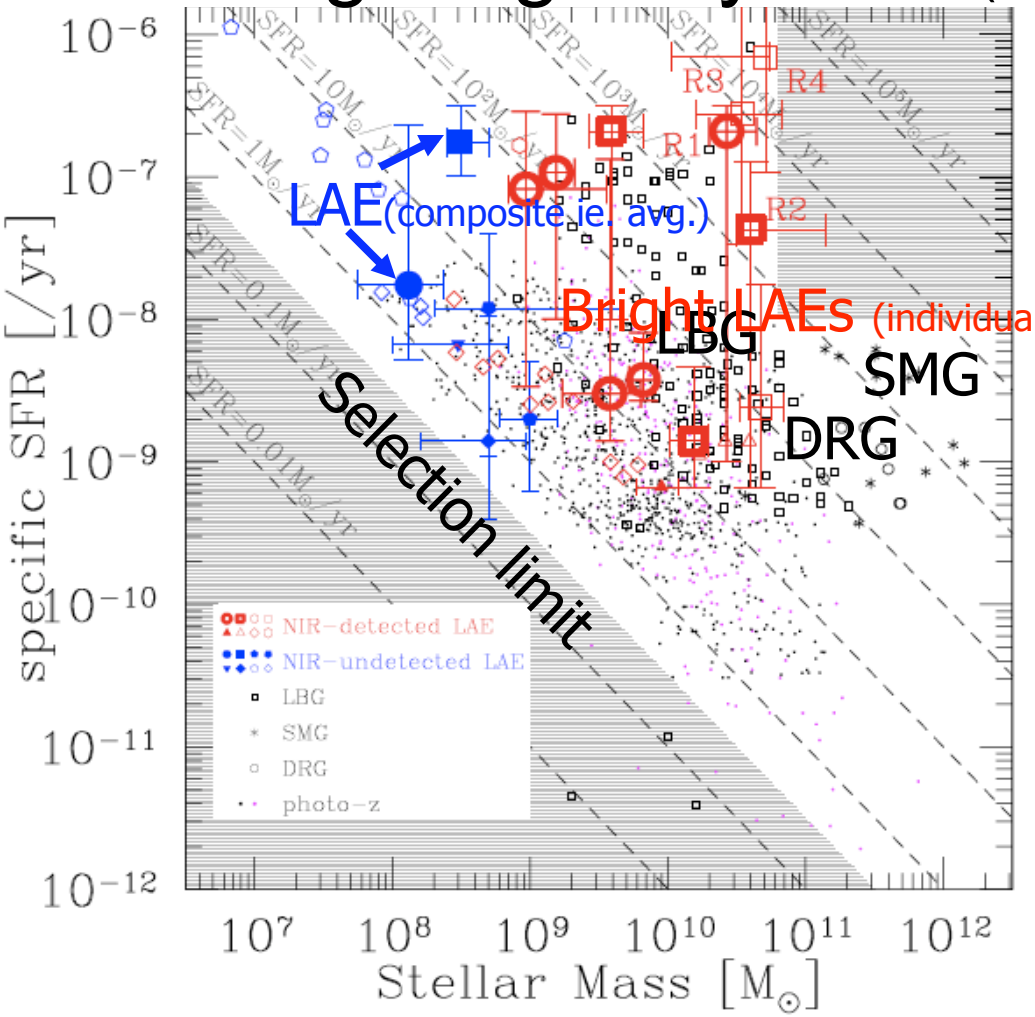
Ouchi et al. (2008)

Bouwens et al. (2008)

Lyα Emitters in high-z galaxy zoo (Comparison at z~3)

Largest area study, to date, for LAE stellar population with Subaru, UKIDSS-UDS, and Spitzer legacy SpUDS data.





LAEs (Ono+09, Finkelstein+09, Pirzkal+07, Lai+07, Gawiser+06)

□:LBGs (Shapley+03, Papovich +01, Iwata+05)

○:DRGs (van Dokkum+05)

*: SMGs (Borys+05,Chapman+05)

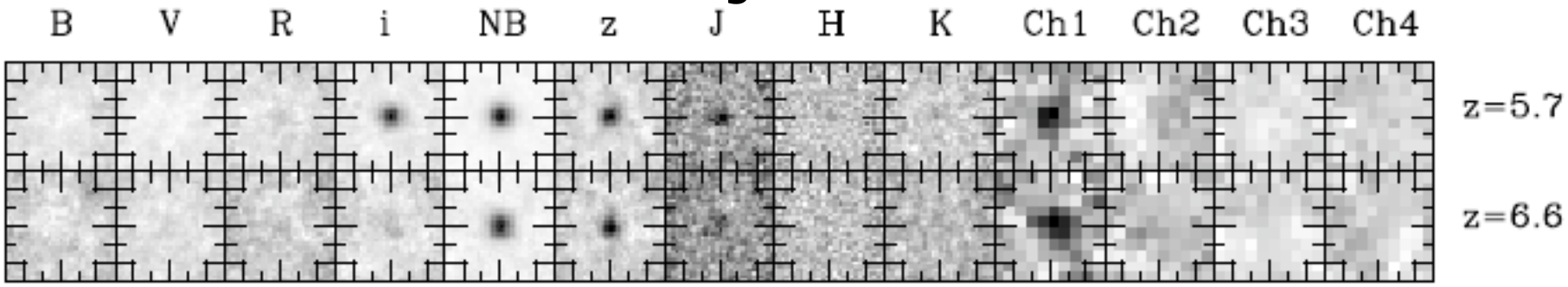
Ono, Ouchi et al. (2010)

- LAE sample is the least massive one among z~3 galaxies (LBG, SMG, DRG, photo-z) with a relatively high sSFR by their selection
- However, stellar population of *bright LAEs* is similar to those of LBGs at $M_*>10^{10}M_\odot$.

Average Stellar pop. of z~6-7 LAEs

- The past studies only estimate stellar pop. of the brightest LAEs with individual NIR detection→ exceptionally massive (~10^9-10^{10}Mo) well-evolved pop. (~100 Myr; Chary+05,Lai+07)
- Large sample→ *For the first time*, typical LAE population by stacking (J~28 mag, IRAC1/2~26-27 mag; comparable to HUDF data)

Stacked images of LAEs at z~6-7



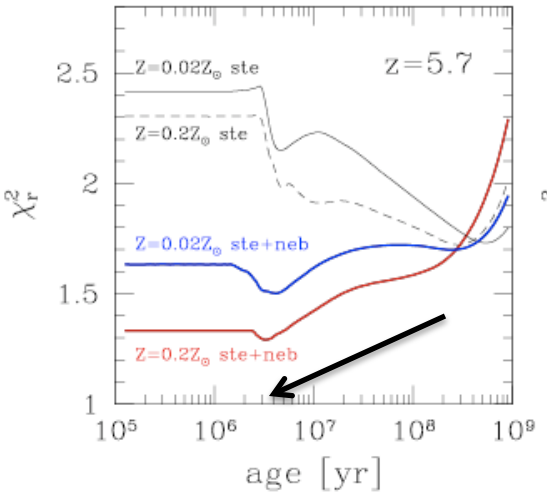
Ono, Ouchi et al. in prep.

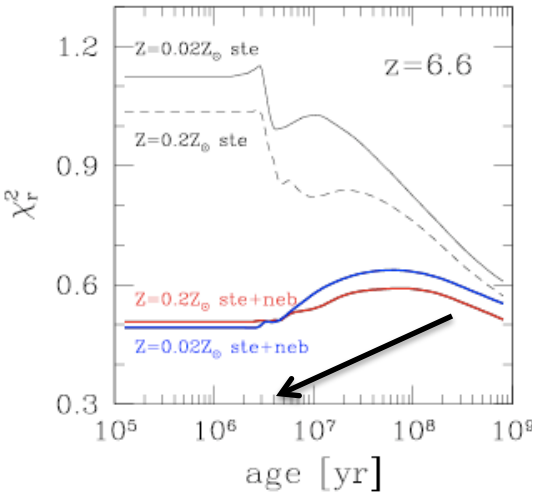
Average Stellar Pop. of z~6-7 LAEs

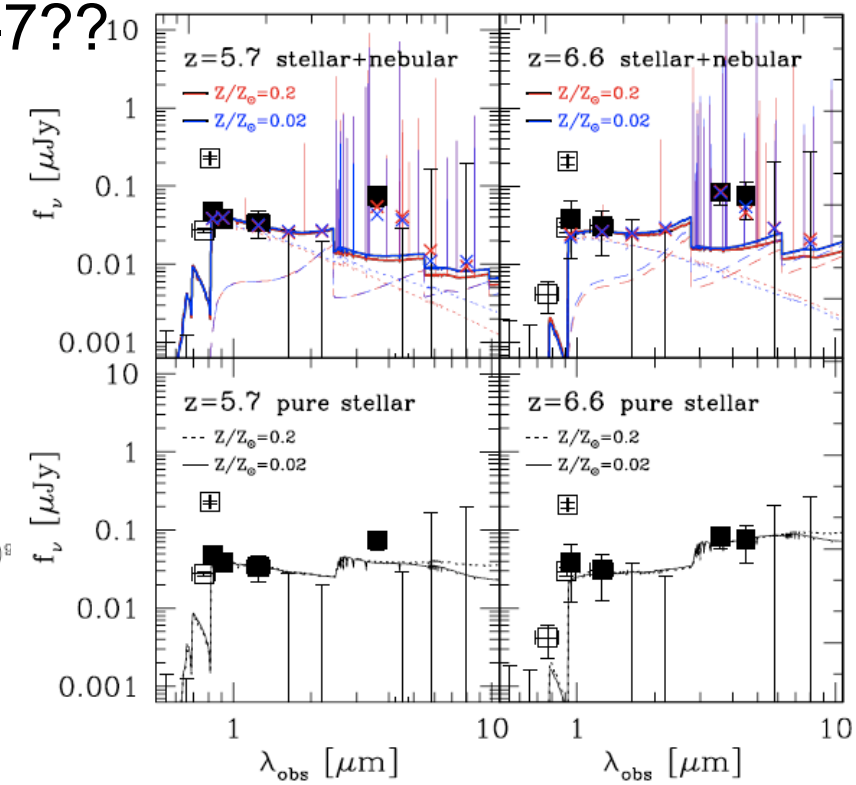
- Results of SED fitting for our z=6-7 LAEs
  - Stellar mass=3-9x10^7Mo,
  - SFR~10 Mo/yr
  - E(B-V)~0.0,
  - age=0.9-3 Myr (BC03+nebular emission and Z=0.2Zo)

cf. Bright LAEs with individual IR detections: massive (~10^9-10^{10}Mo) well-evolved pop. (~100 Myr; Chary+05,Lai+07)

→ very young and less massive SF galaxies.
Forming building blocks at z~6-7??





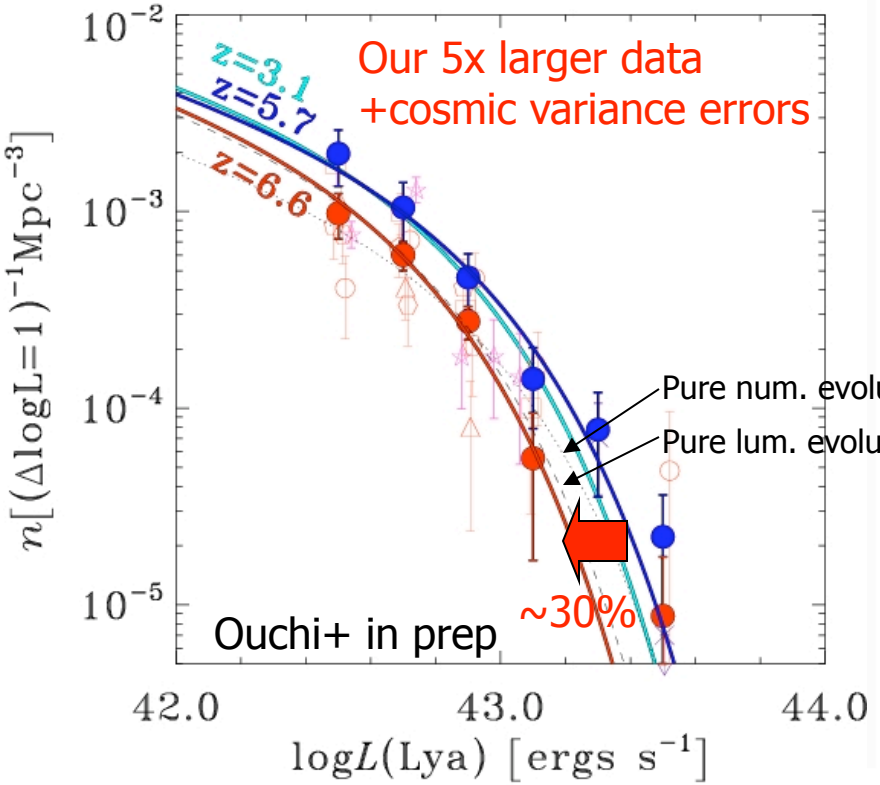


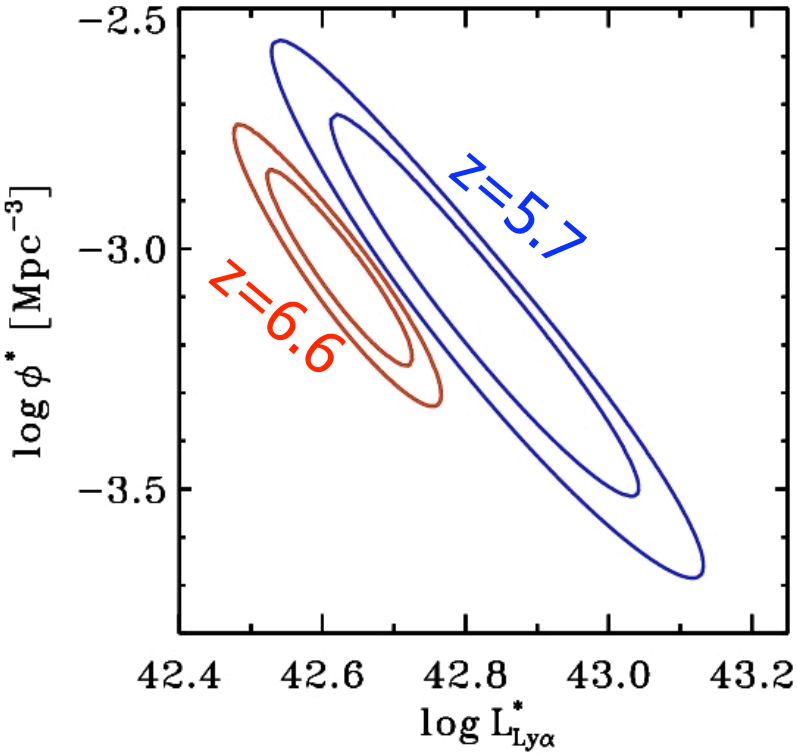
Ono, Ouchi et al. in prep.

3. LAEs for Reionization&GF

a) Lya LF Evolution from z=5.7 to z=6.6: Signature of Reionization or Galaxy Evolution?

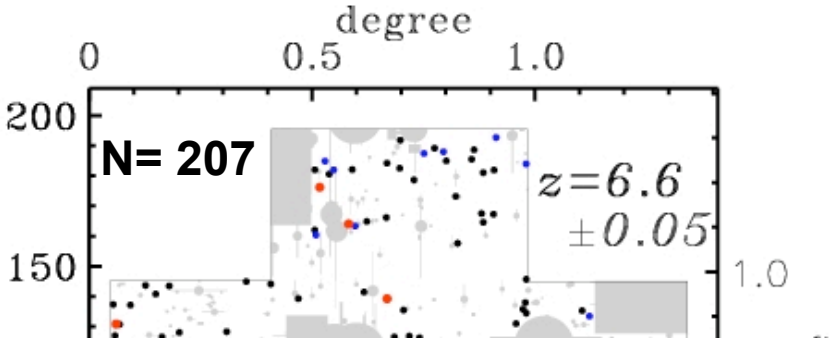
Lya Luminosity Function (Lya LF)

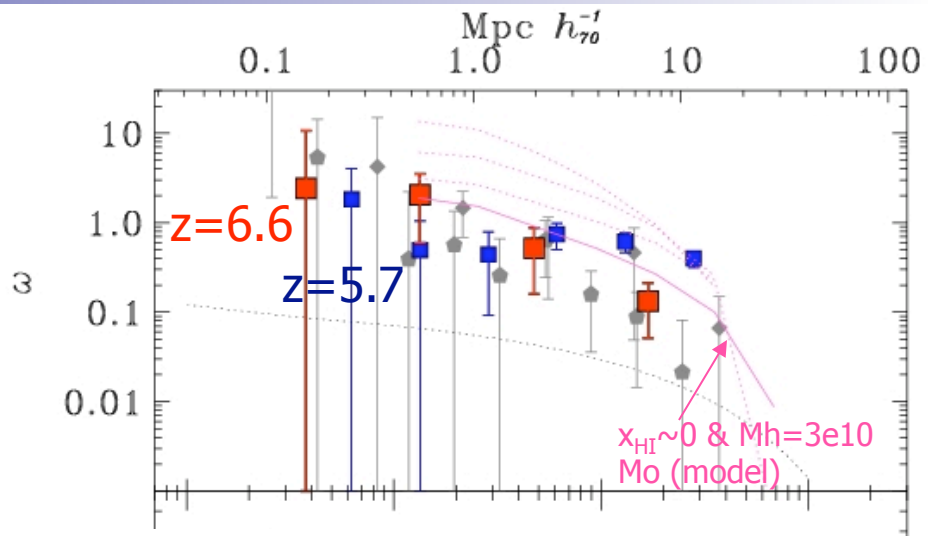




- Lya LF decreases from z=5.7 to 6.6 (SDF 0.2deg^2 survey;Kashikawa+06/+08).
  - Signature of IGM absorption? Based on L* evolution,
- But, explained by cosmic variance?? (cf. smaller data of Hu+06,Malhotra+04).
- On our 5x data in independent cosmic volumes show the decrease of LF from z=5.7-6.6 is found at >90% CL (Ouchi+ in prep.). Statistically, pure lum. dimming by 30% is more preferable. Signature of galaxy formation and/or reionization? Galaxy formation effect (10-30%, assuming UV LF evolution; Bouwens+08, Ouchi+09, Oesch+10). $x_{HI} \lesssim$ **0.2−0.3** (S04 model)

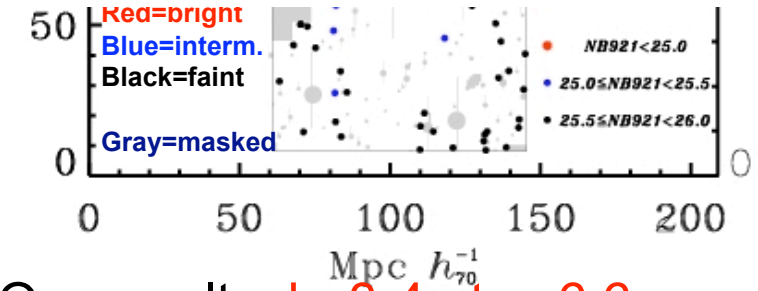
b) Clustering at z=6.6

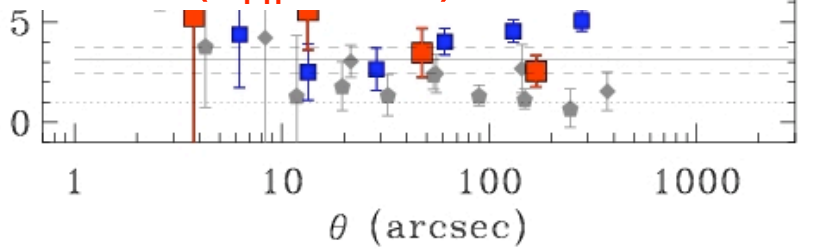




From the results of (a) LF and (b) clustering:

the Universe is *NOT* highly neutral at z~7 ($x_{HI} \lesssim 0.3$).





Ouchi et al. in prep.

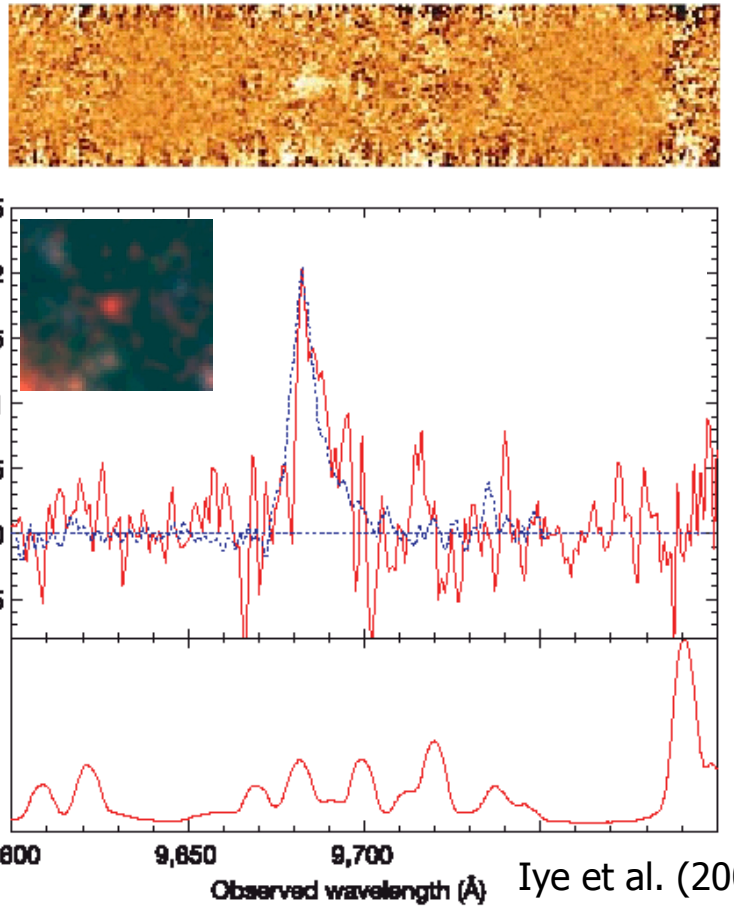
- Our results: b~3-4 at z=6.6
- At z=5.7: b=3.4±1.8 (Ouchi+05).
  - We see no clear evolution of clustering from z=5.7
    →No signature of strong absorption by neutral IGM
  - x_{HI}~0 and M(halo)=3e10 Mo(McQuinn+07); $x_{HI} \lesssim 0.3$ (Furlanetto+06)

→ x_{HI} is consistent with the result of the Lya LF analysis

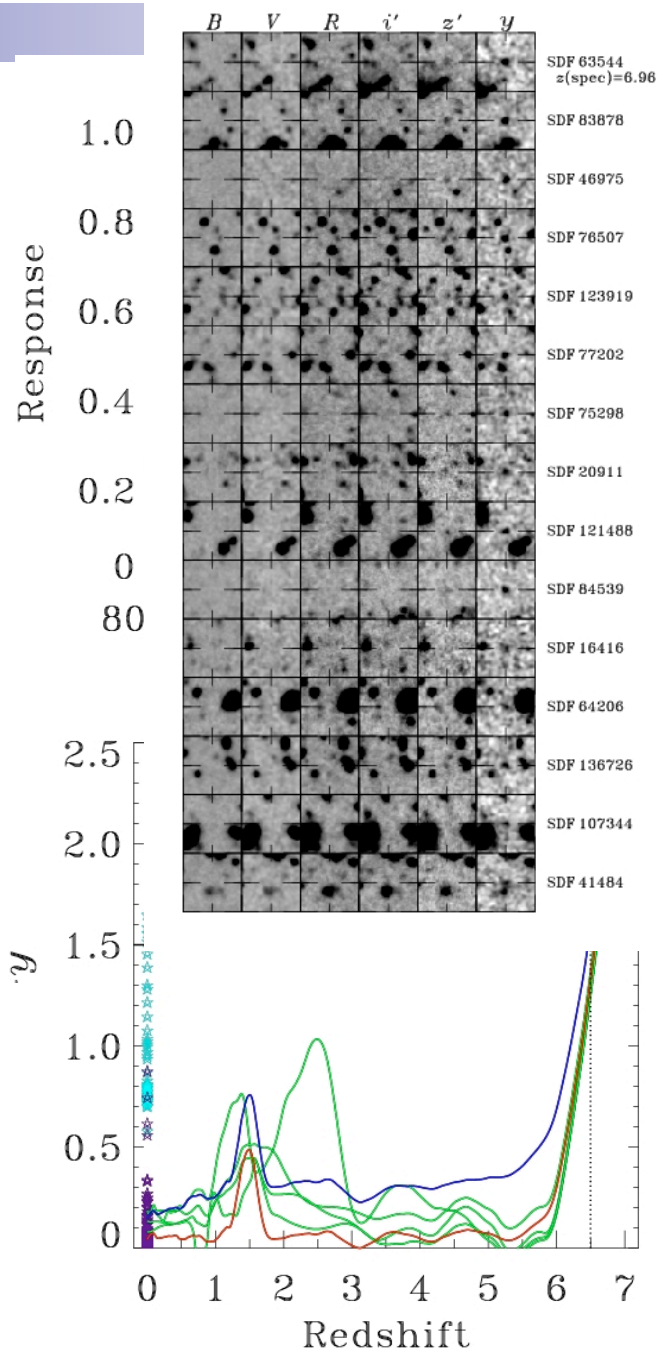
4. Search for z~7 z-dropouts complementing z~7 LAEs

Subaru z-dropout samples

- Sample
  - 1568 a
    shallo
    than H
  - z-drop
    - 22 z
- Foregro
  - Red fc
    Galact
    colors

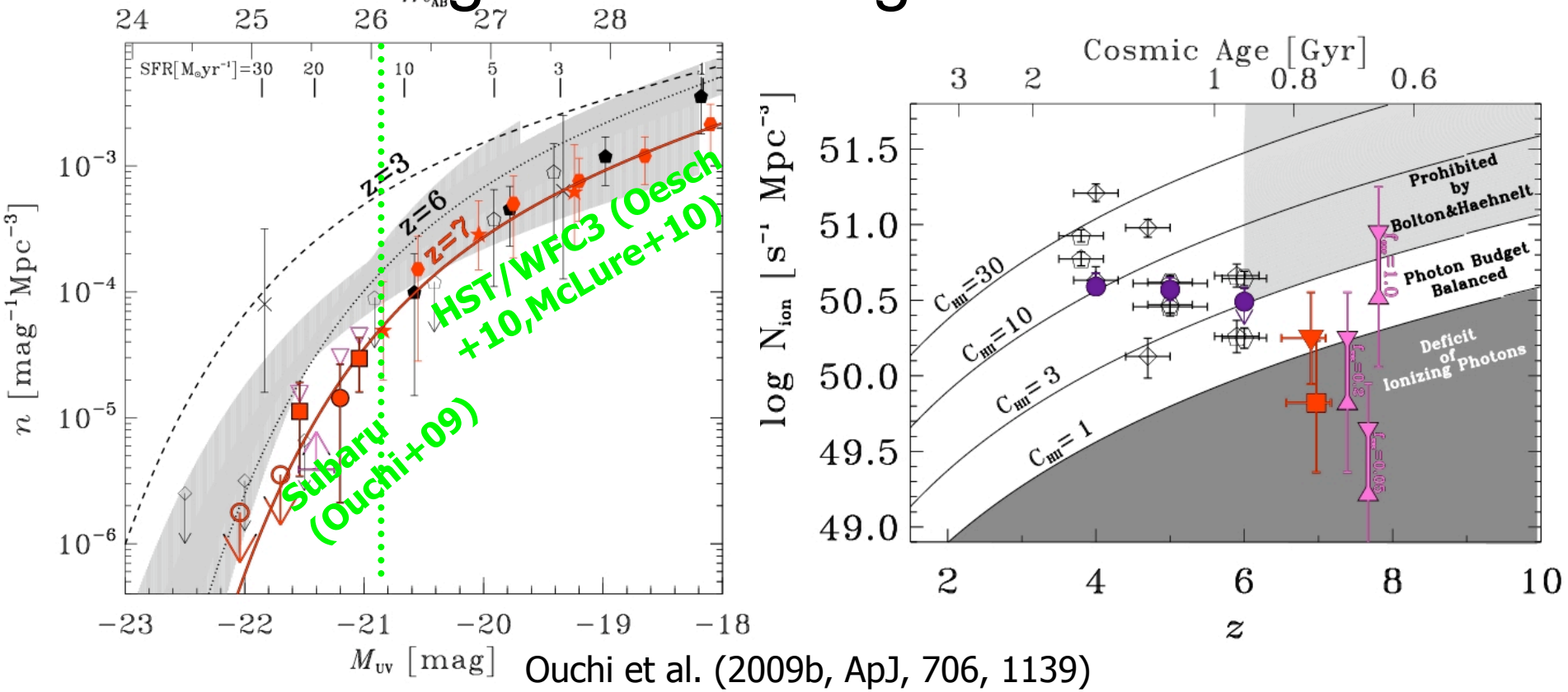


Iye et al. (2006)



- One confirmed dropout at z=6.96,
  - The first z-dropout with spec. redshift
  - None of the candidates have z_spec of z<6.5.

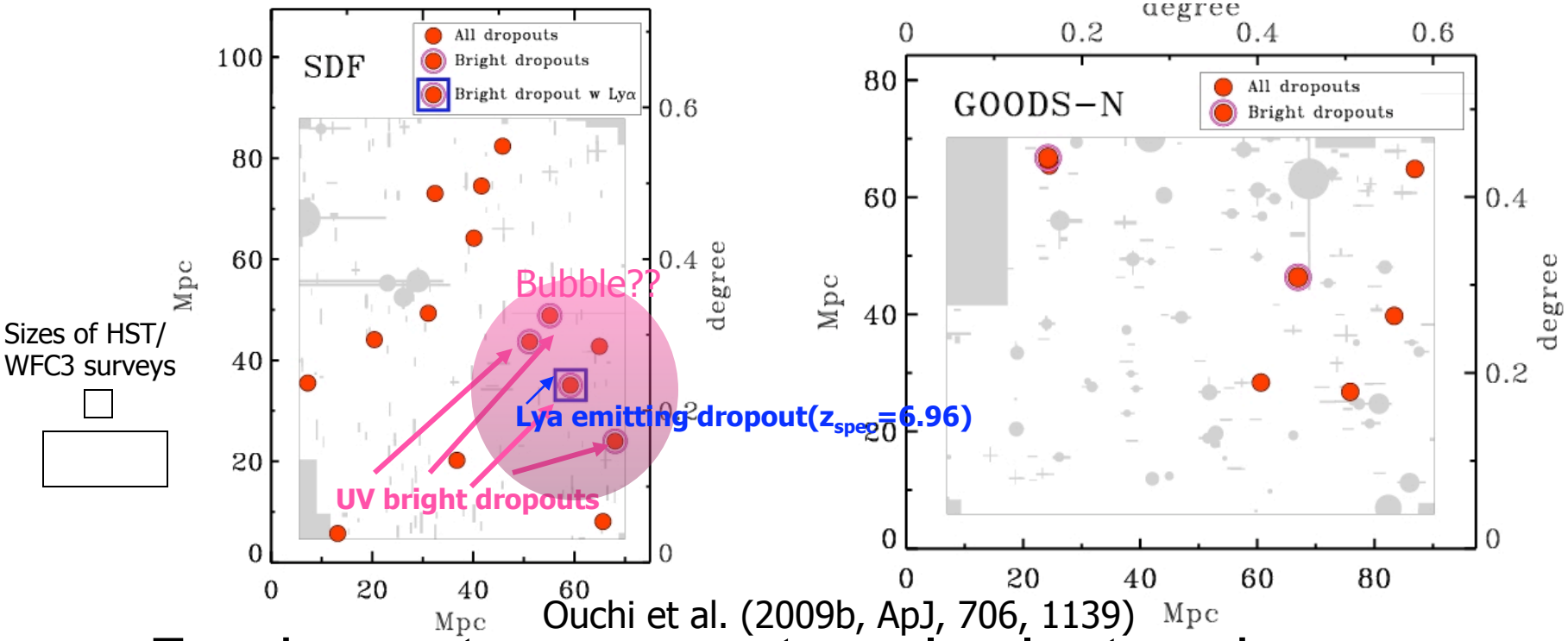
Further UV LF decrease
Ionizing Photon Budget Problem??



Ouchi et al. (2009b, ApJ, 706, 1139)

- Decrease of UV LF (>95%CL) from z=6 to 7 (see also, e.g., Oesch+10, McLure+10, Bunker+09) → at z=7, ρ_{UV}+Bolton07 model
  - The Universe could not be totally ionized by only galaxies??
  - Undetected faint population plays a major role? α<-1.9?
  - Properties of galaxies are different from those at low-z having, e.g., a larger fesc(>~0.2), a lower metallicity, and/or a flatter IMF etc?

Indication of Ionized Bubble??

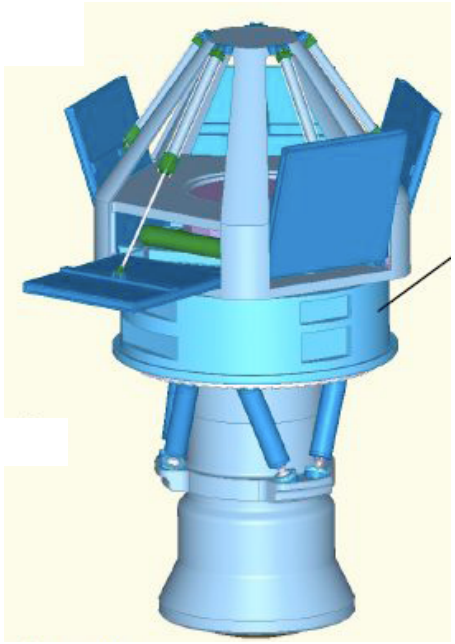


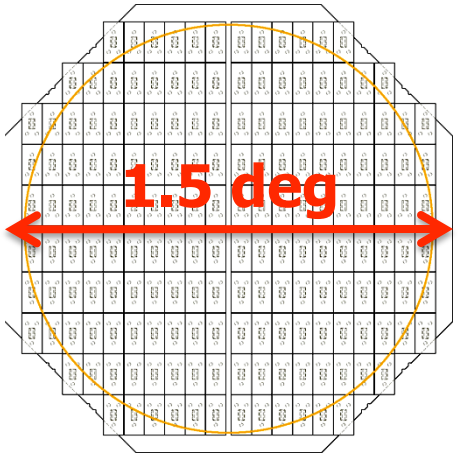
Ouchi et al. (2009b, ApJ, 706, 1139)

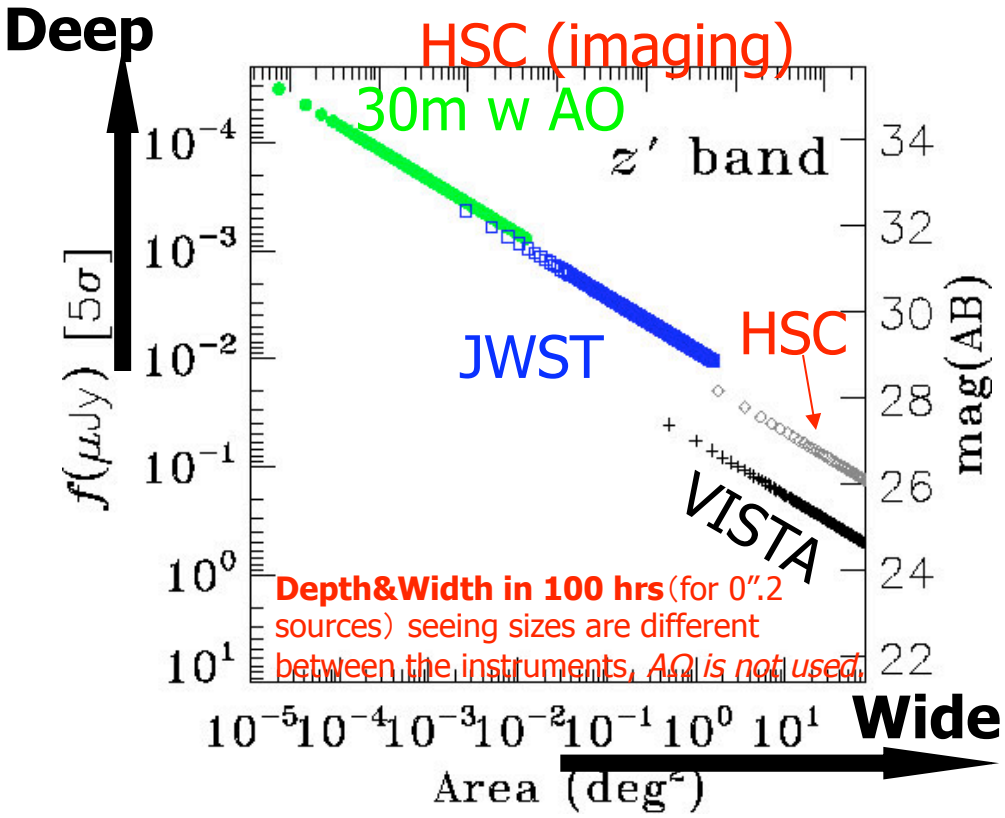
- z~7 z-dropouts appear strongly clustered.
  - Filamentary structure in SDF?
  - Lya emitting dropout sits at the center of overdense region of 4 UV brightest galaxies (~30Mpc). Why?
    - Reason?: The overdense region might make a well-established ionized bubble (>30Mpc) that allows Lya to escape from the galaxy in partially neutral Universe??

5. Near Future LAE studies with Subaru

Subaru Hyper Suprime-Cam (HSC: 2011-)

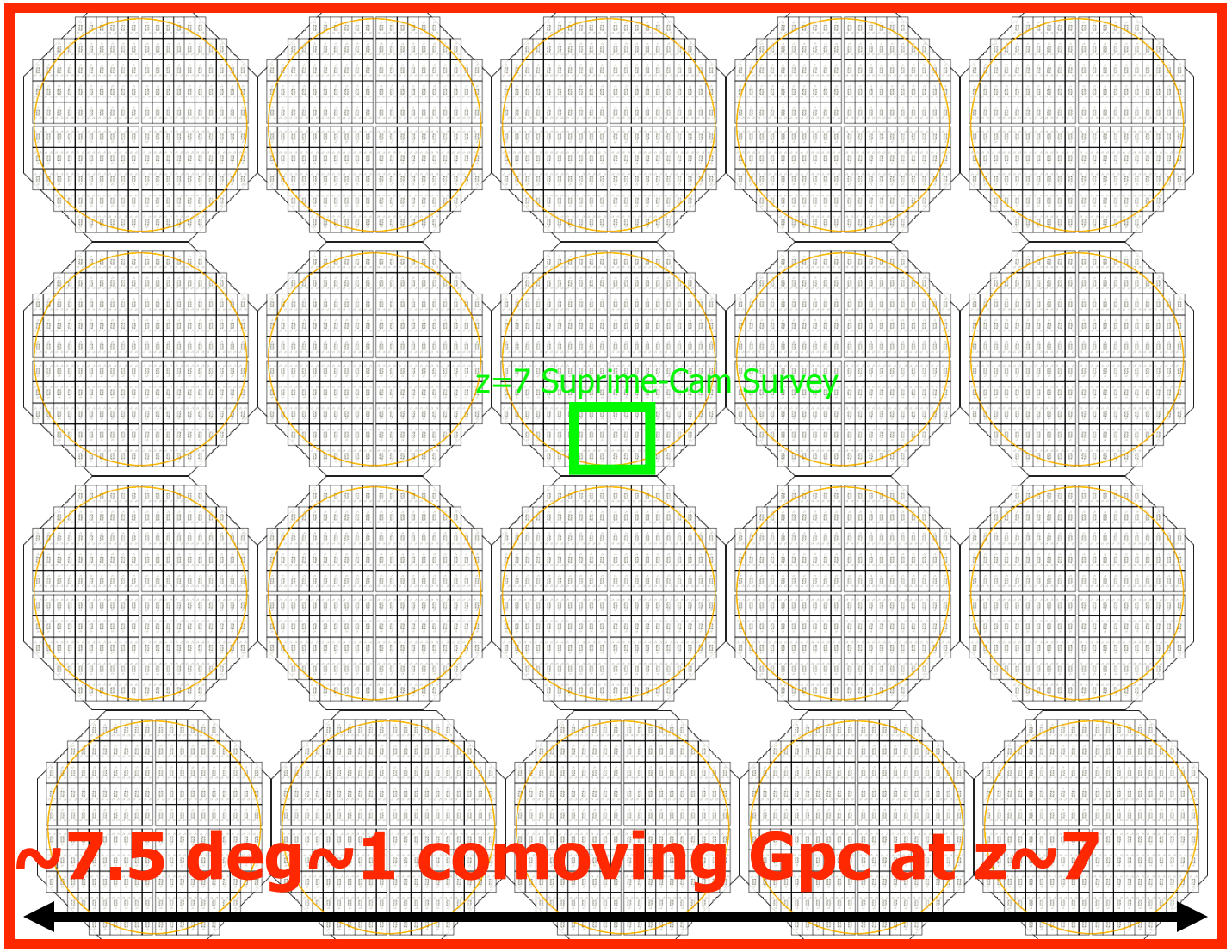


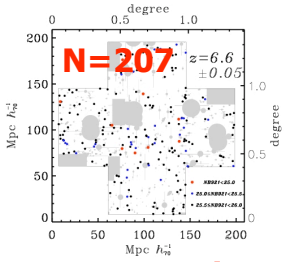




HSC: ~10x faster survey speed than Suprime-Cam (Miyazaki+). Being developed under Japan, Princeton, Taiwan collaboration

Subaru HSC Survey from 2011- (planned)





Current obs. (Ouchi+) x50

Model (Trac&Cen05) x100

- Reionization and ionizing sources are constrained with num. density and distribution of 10 K LAEs at z~7 (100x larger than today's sample) in a total of 1Gpc x 1Gpc area (TBD).
- Constraining ionizing bubble topology and reionizing sources vs. neutral hydrogen distribution.

Summary

- High-z Lya emitters (LAEs) studied by our Subaru survey
  - LAEs among High-z Galaxies
    - •LAEs have less mass+higher sSFR than others by their selection. No significant difference between dropouts and LAEs at a given stellar mass/magnitude.
    - •No significant evolution of Lyα LF(z=3-6)→Different evolutionary trend between dropouts (decreasing) and LAEs (const). Emergence of Lyα emitting population?
  - z>6 LAEs as probes of reionization and galaxy formation
    - •Decrease of Lyα LF from z=6 to 7
    - •No clear signature of clustering increase →Not highly neutral at z~7 ($x_{HI} \lesssim 0.3$).
  - Relation between z~7 dropouts and z~7 LAEs
    - •First spec. comfirmed z-dropout
    - •fesc>~0.2 would be required to explain Universe ionized by galaxies at z~7.
    - •Distribution of LAE and dropouts is indicative of ionizing bubble??
  - Subaru Hyper-Suprime Cam survey (2011-)