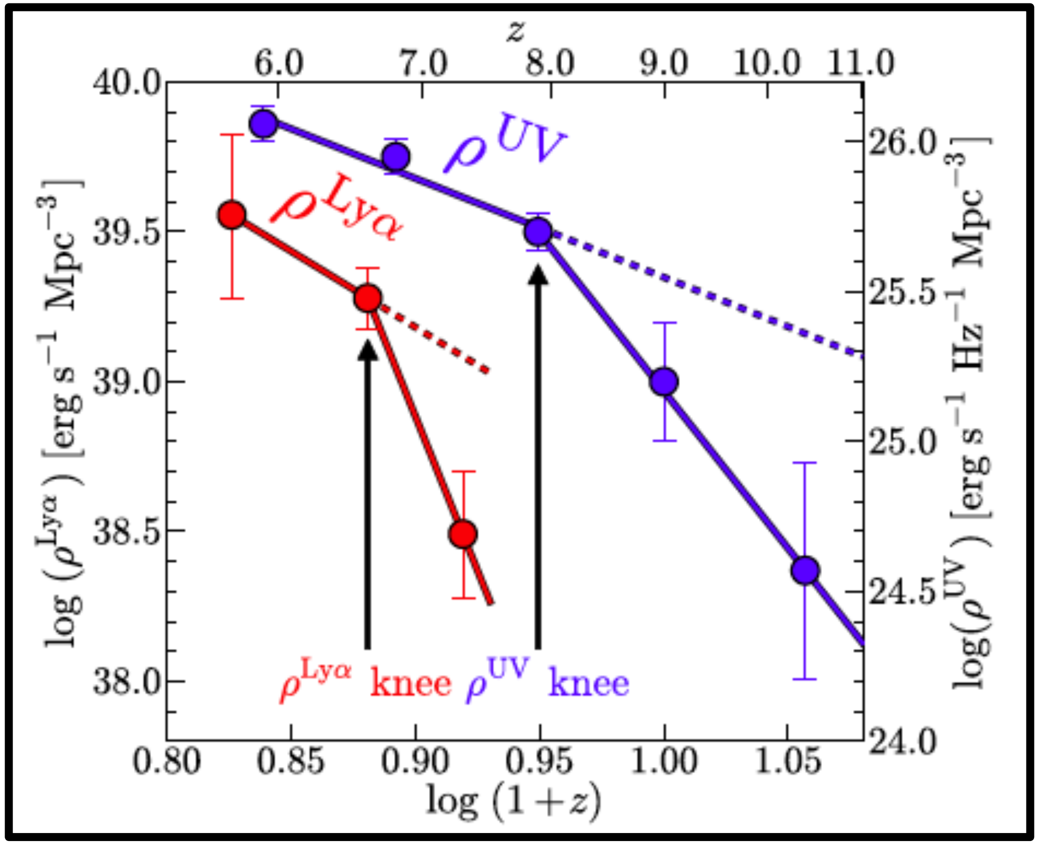
Lya Emitter Observations: Progresses and Future



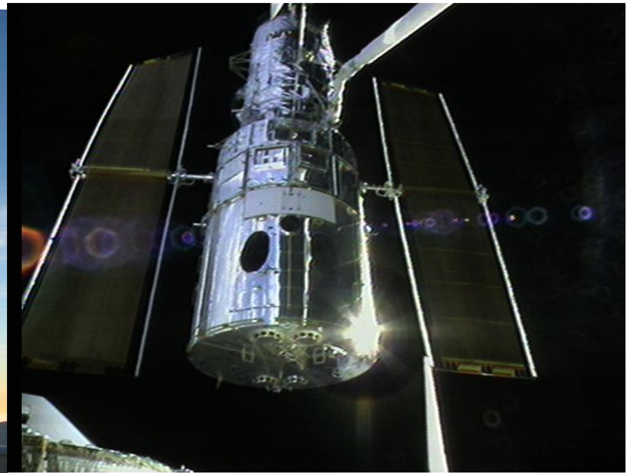
Konno, MO et al. (2014)

Masami Ouchi

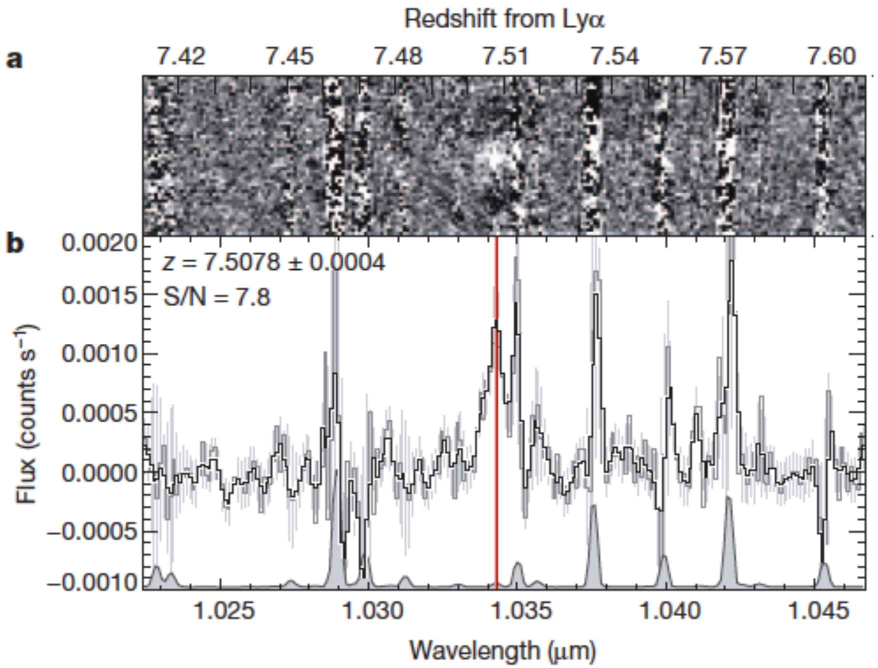
The University of Tokyo

Outline

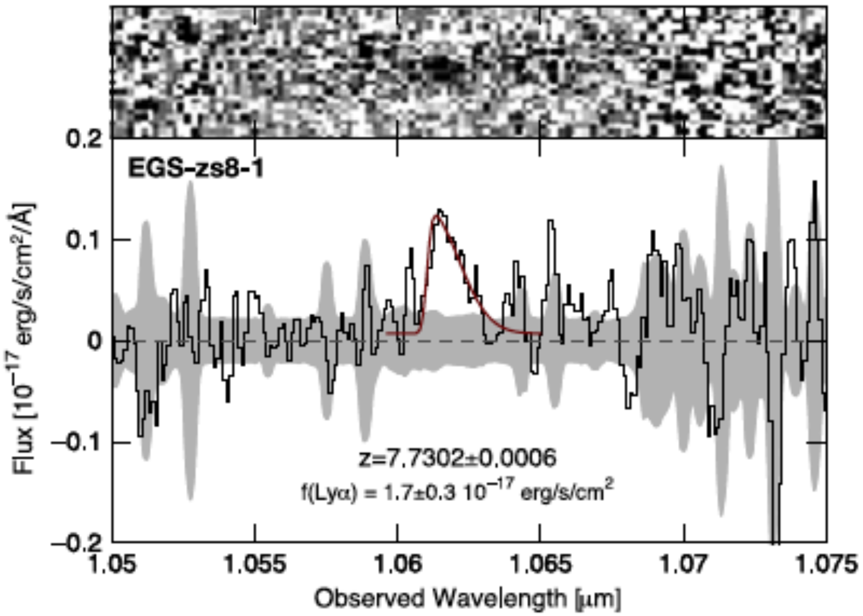
- I review recent observational results of Lya emitters
  - Discussing reionization and galaxy formation, showcasing the latest results from the Subaru/Keck, HST, and ALMA observations.
- Future/On-going LAE surveys of Subaru/HSC,PFS (+ HETDEX, MUSE)



Galaxy Observational Frontier Pushed by Spec. Obs. for Lya Emitters(LAEs)



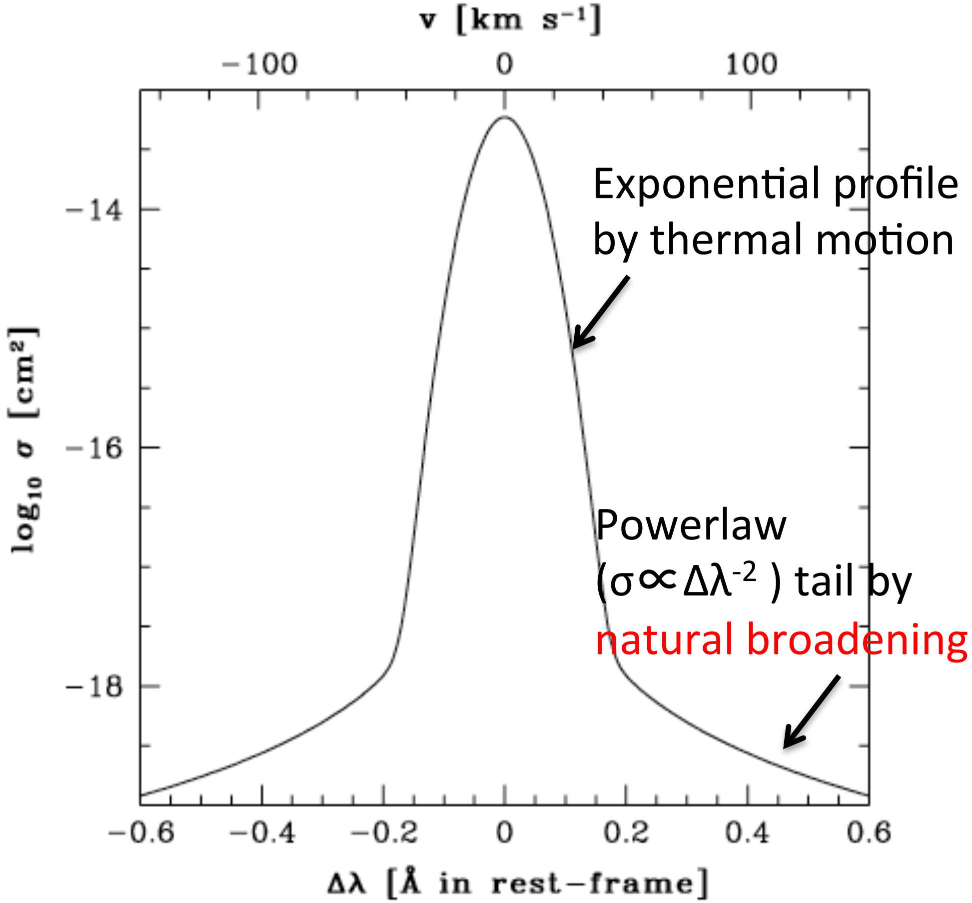
Finkelstein et al. (2013)



Oesch et al. (2015)

- Up to z~7.7, near the hart of the EoR epoch (Plank2015)
  - (cf. photometric sample of LBGs/dropouts up to z~10)
- A number of spec. confirmed galaxies at z=7-7.7

Lya Damping Wing Absorption for a Probe of Reionization

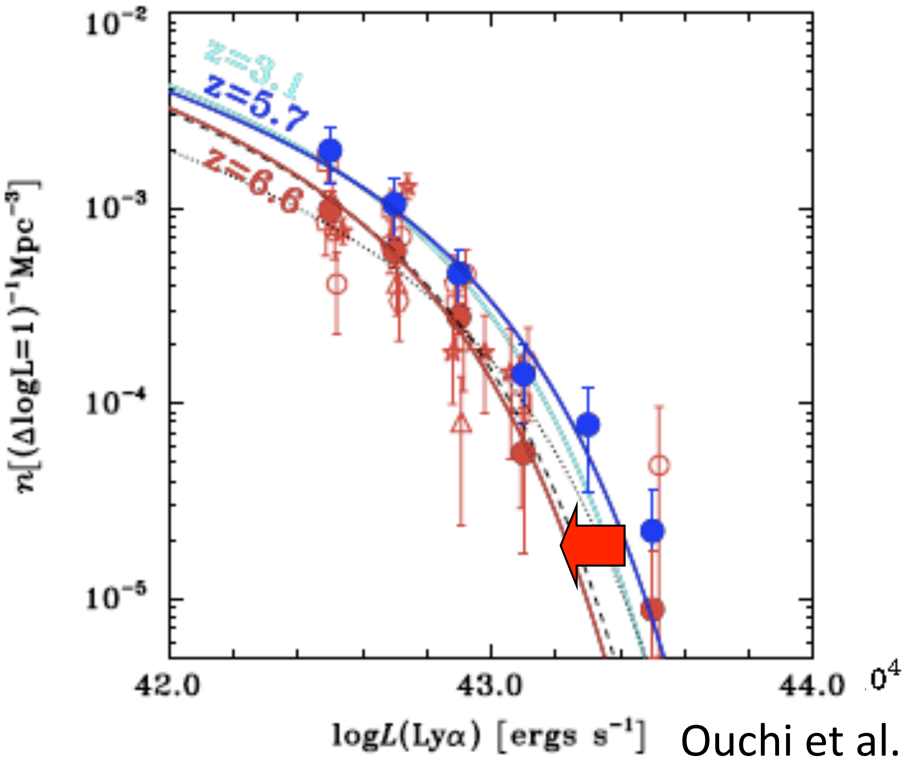


$$\sigma_{\rm V}(\nu) = \int_{-\infty}^{\infty} M(v)\sigma_{\rm N}(\nu - \nu_\alpha v/c)\,{\rm d}v,$$

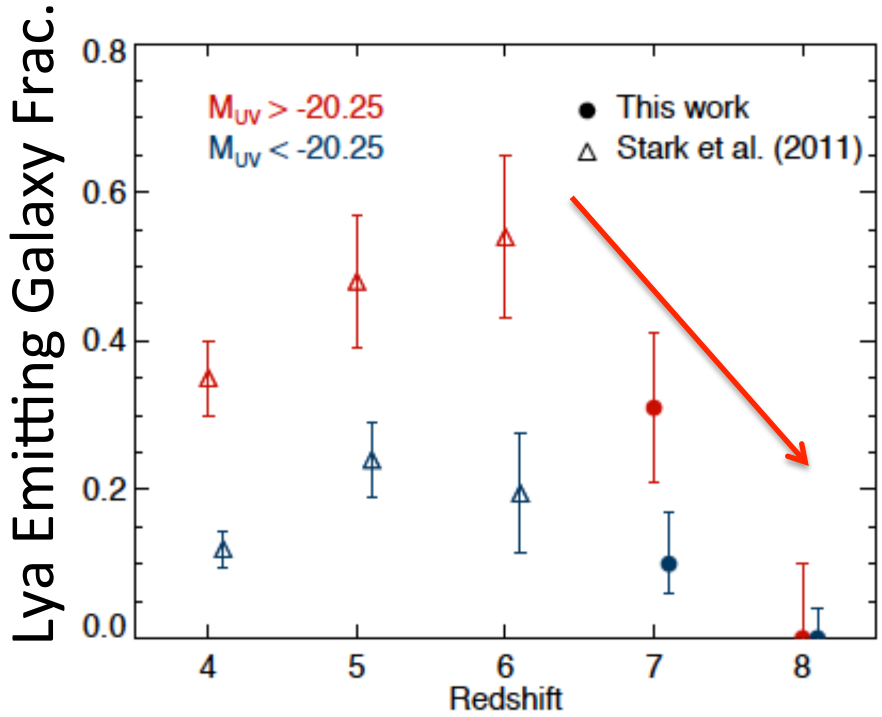
$$\sigma_{\rm N}(\nu) = \frac{3\lambda_\alpha^2 A_{21}^2}{8\pi}\frac{(\nu/\nu_\alpha)^4}{4\pi^2(\nu-\nu_\alpha)^2 + \left(A_{21}^2/4\right)(\nu/\nu_\alpha)^6},$$

Evolution of Lya Emission Properties
Signature of Reionization?

Lya Luminosity Function (Lya LF)



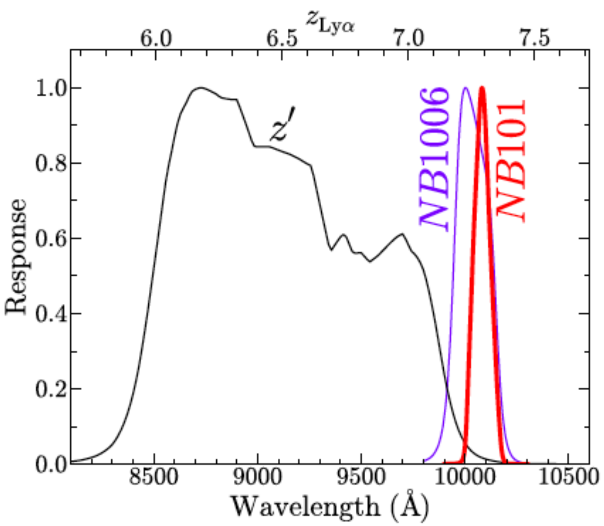
Ouchi et al. (2010)

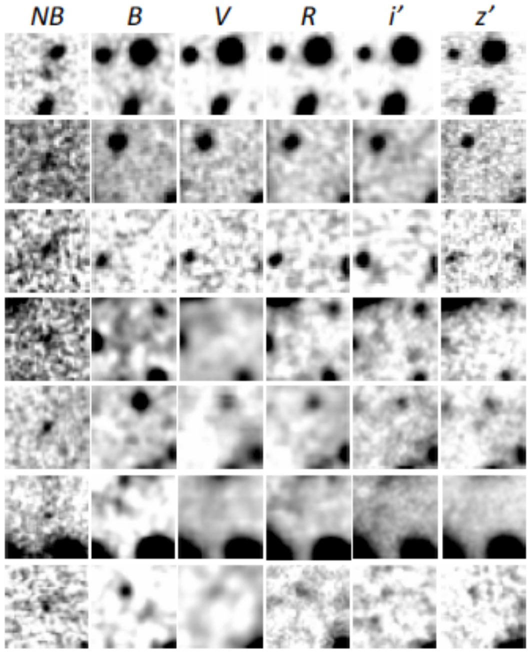


Schenker et al. (2014)

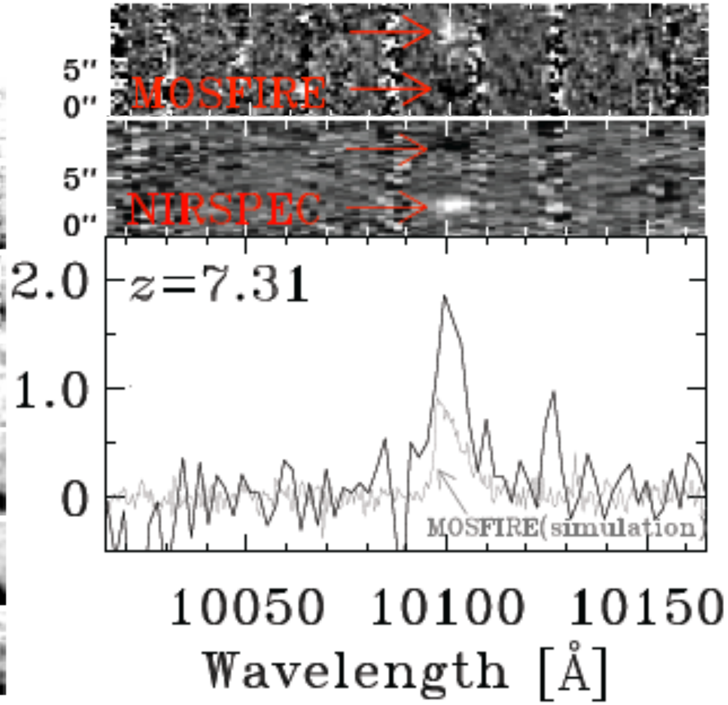
- Galaxy Lya luminosity function (LF) decreases faster than UV LF decrease from z=5.7 to 6.6 (e.g. Kashikawa+06,11, Ouchi+10).
- Dropping the fraction of Lya emitting to all galaxies (e.g. Pentericci+11,14, Ono+12, Schenker+12,14, Treu+13).
- Strong damping wing abs in QSO and GRB spectra up to z~7 (Mortlock+11, Totani+14)

Ultra-Deep Subaru NB Imaging
Keck Spectroscopy for z=7.3 LAEs





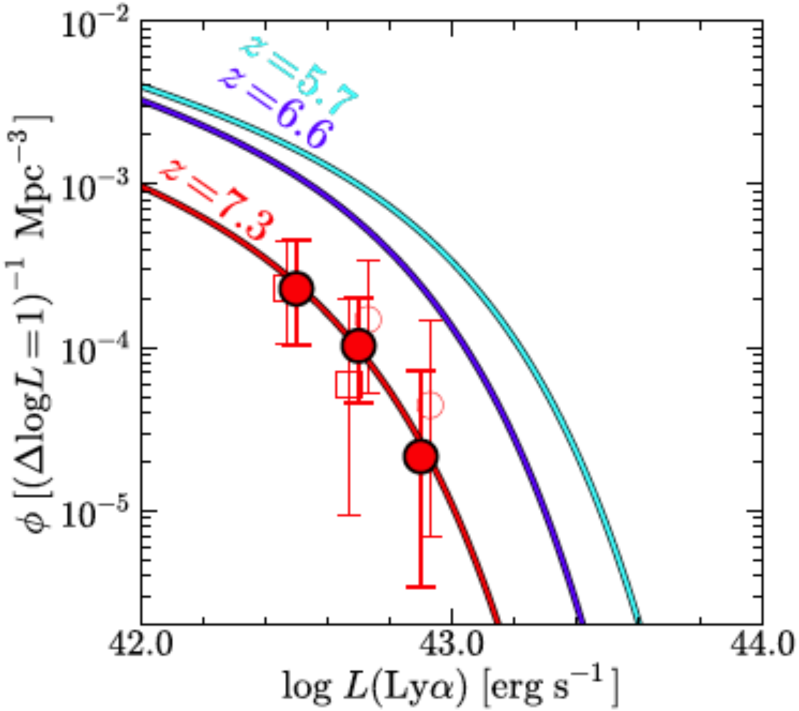
Konno, MO et al. (2014)

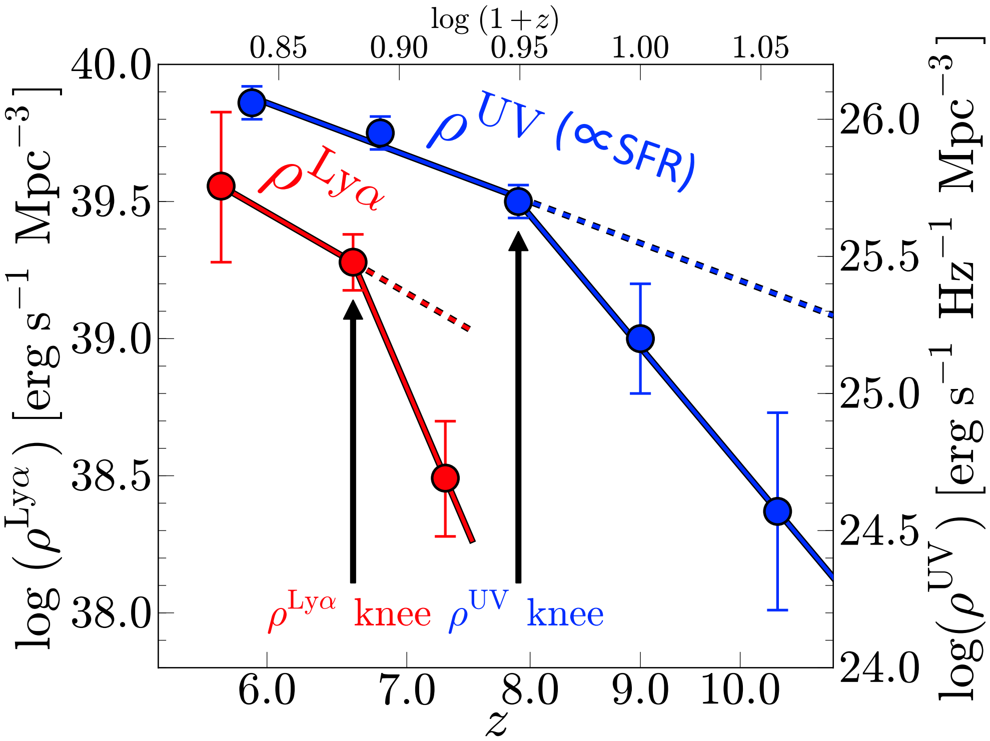


- Ultra-deep Lya emitter (LAE) survey for ~0.5 deg^2 with Subaru (106 hour integ.). At z=7.3, Konno+14 accomplish a comparable Lya lum. depth as previous lower-z (z=3-6) survey. However, only 7 sources… ~1/10 of the expected num if no evolution from z=6.6.

Accelerated Evolution of Lya Luminosity at z>~7

Lya Luminosity Function (Lya LF)

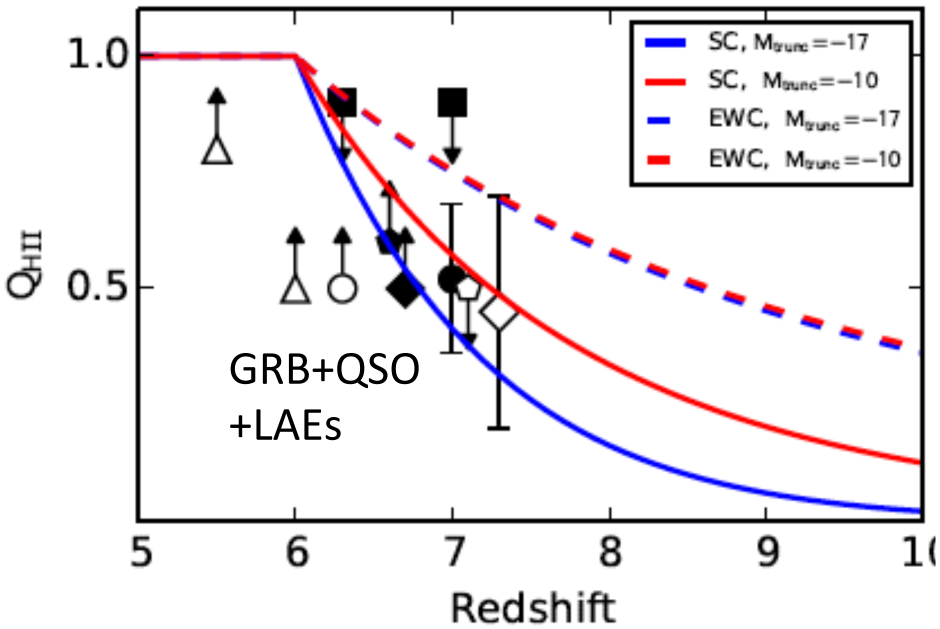


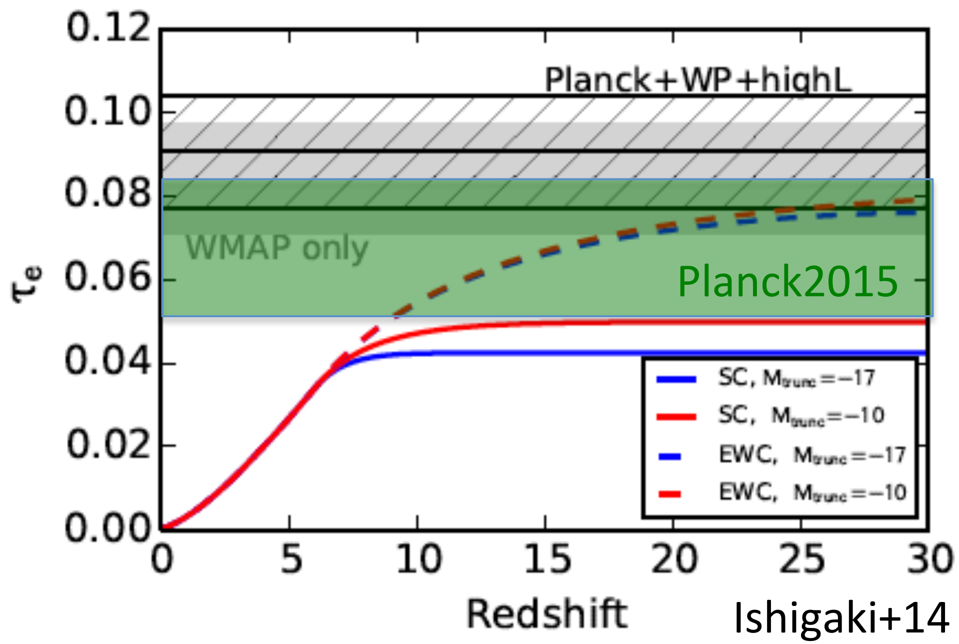


Konno, MO et al. (2014)

- Decreasing Lya LFs (and ρ_{Lya}) from z=6.6 even to 7.3. Moreover, the Lya LF (and ρ_{Lya}) is accelerated at z>~7.
- No accelerated evol. of UV LFs(ρ_{UV}) at z~7, but only at z>8.
- If it is really caused by IGM abs. (cosmic reionization), the evolution of x_{HI} is rapid at z~7.

CMB τ_e Comparison: Tension??

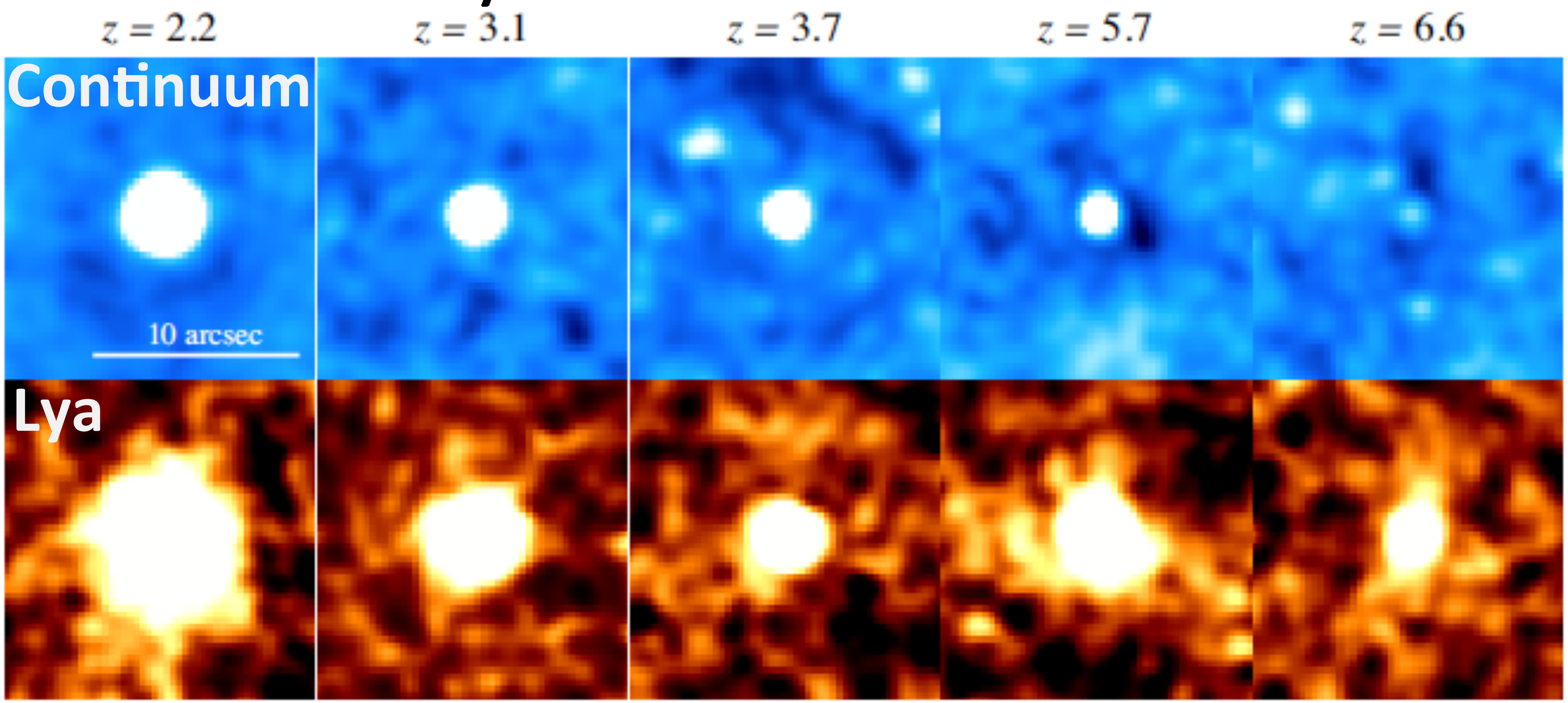




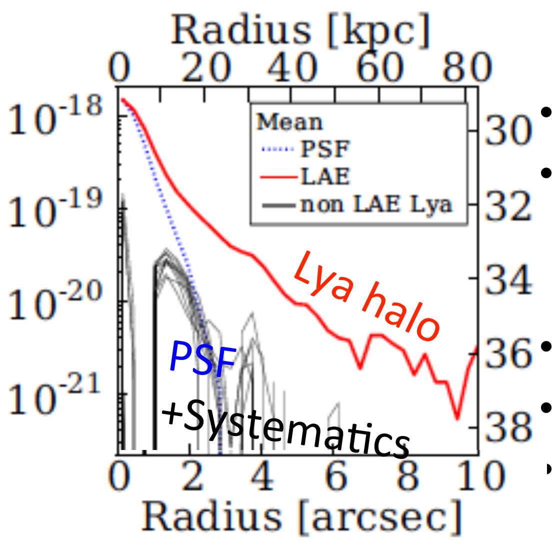
Ishigaki+14

- Q_{HII} (=1-x_{HI}) estimates from the accelerated Lya evolution.
  - Prefer moderately low Q_{HII} at z~7. Late reionization.
- Tension w high τ_e from CMB of WMAP & Planck2013.

Extended Lya Emission around SF Galaxies



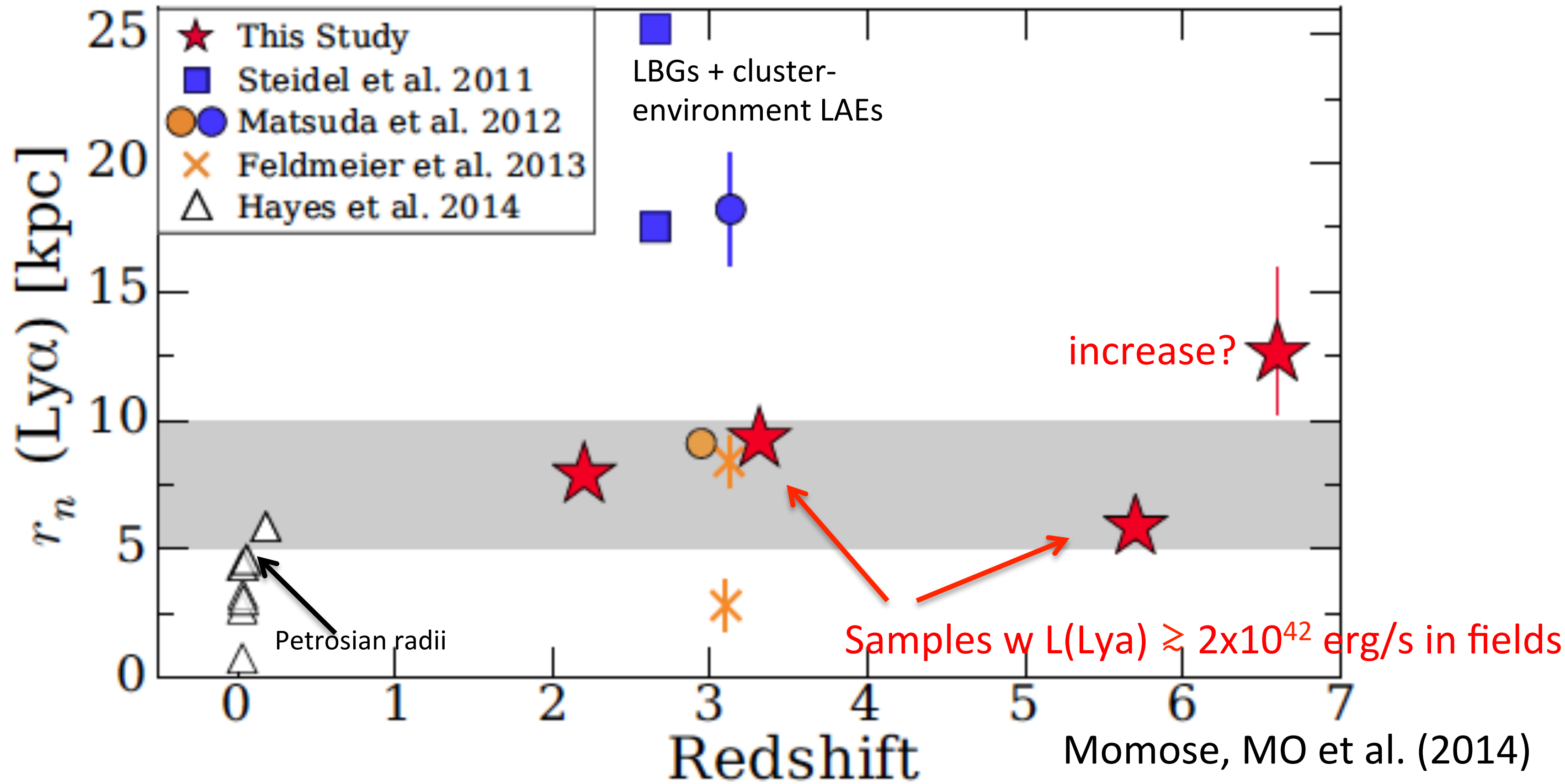
Momose, MO et al., 2014



- Clumpy/filamentary HI clouds scatter Lya→ Diffuse Lya halo on average
- Lya halos made by CGM are already known for SF galaxies at around z~2-3 via stacking of Lya data (Hayashino+04, Steidel+11, Matsuda+12).

- The next step is to look at the evolution up to EoR (z>6).
- Very difficult, due to its faintness.
- Momose+14 use samples of 4500 Subaru LAEs at z=2.2-6.6 for evolution that is 10-100 times larger than previous studies.

Evolution of Extended Lya Emission

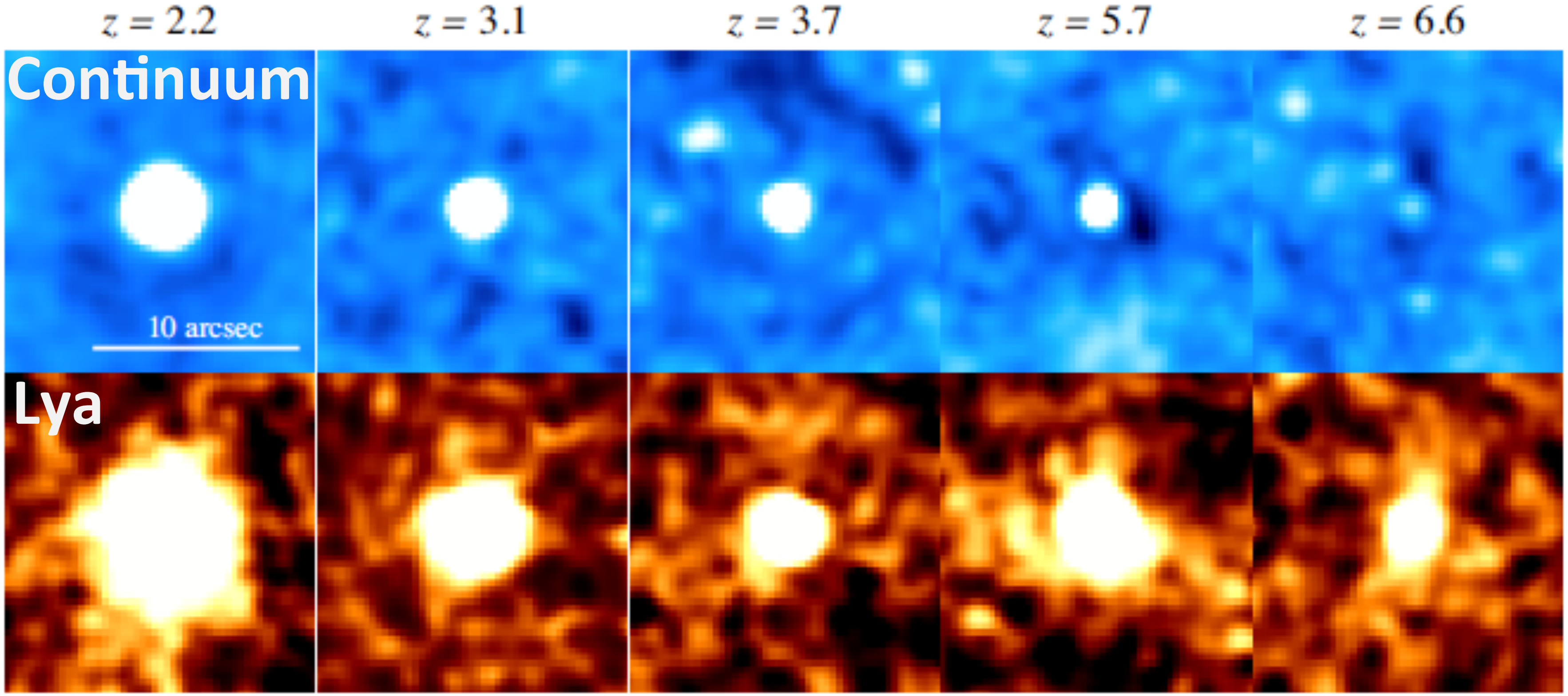


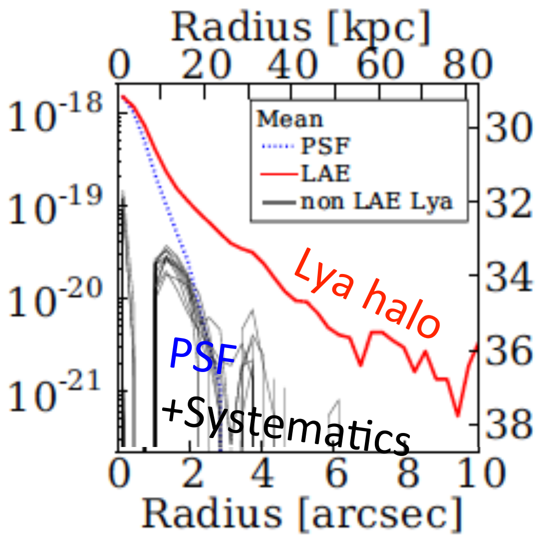
Momose, MO et al. (2014)

- Lya profile is fit by exponential scale length, r_n, defined by $S=C_n \exp(-r/r_n)$
- For homogeneous samples of galaxies w L(Lya) ≳ 2×10^{42} erg/s at z=2.2-6.6.
  - r_n is nearly constant (5-10kpc) over z=2.2-5.7
  - A hint of increase from z=5.7 to z=6.6. Signature of increasing HI CGM that scatter Lya? Or just an up-scatter data point? (→HSC survey).

Lya halo origin→unclear. CGM/IGM scattering, cold accretion, satellite galaxies? (Lake+15)

Extended Lya Emission around SF Galaxies





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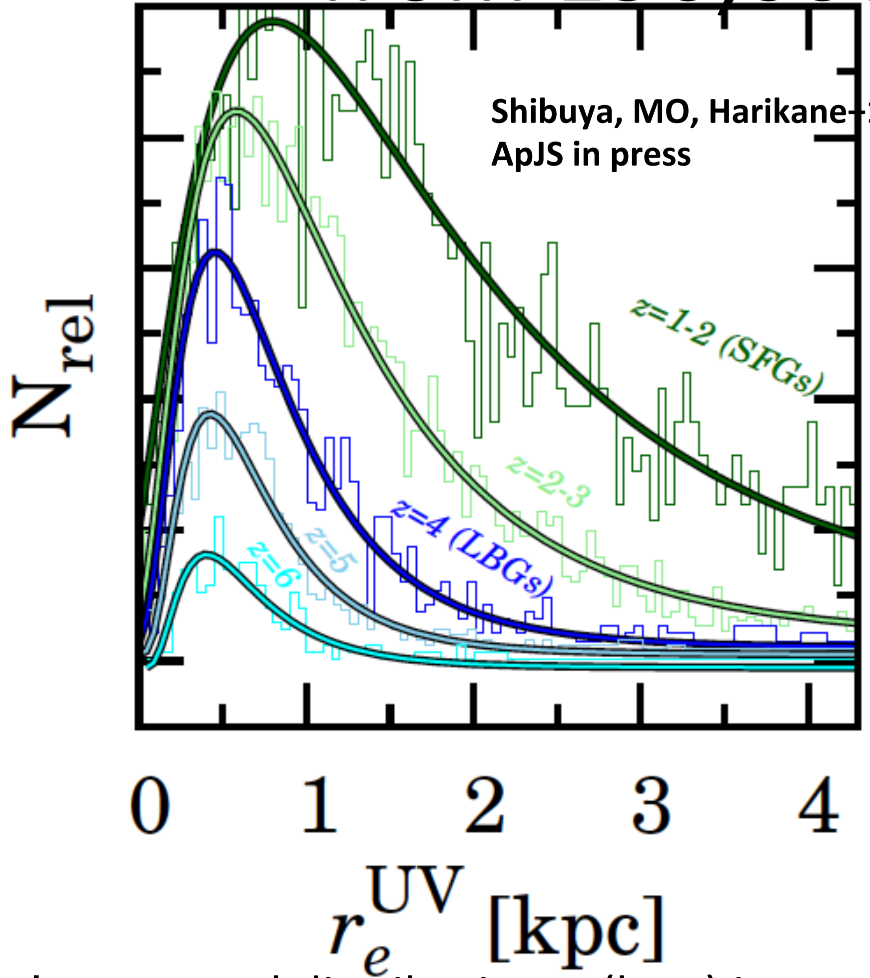
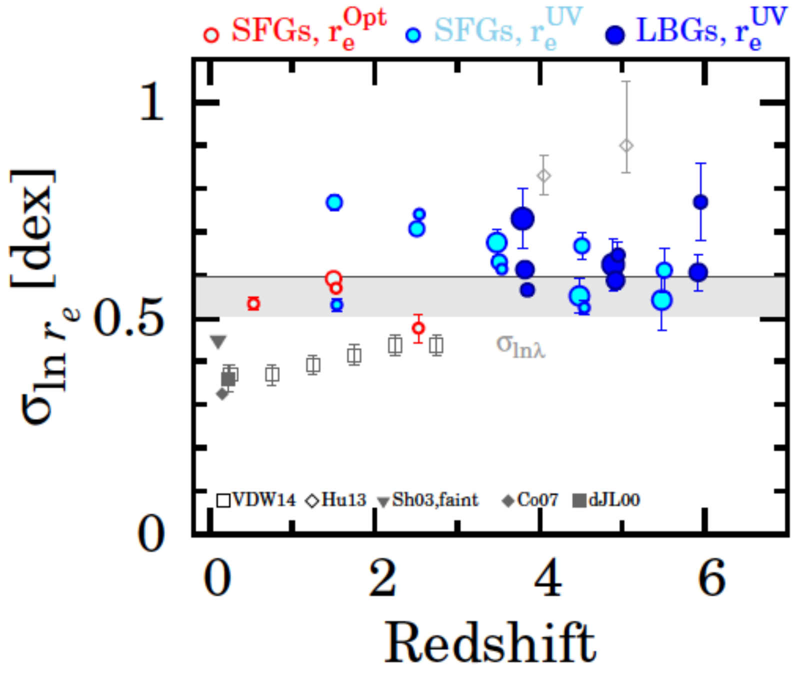
Galaxy Size Evolution at z~0-10 from 190,000 HST Galaxies

Shibuya, MO, Harikane+15, ApJS in press

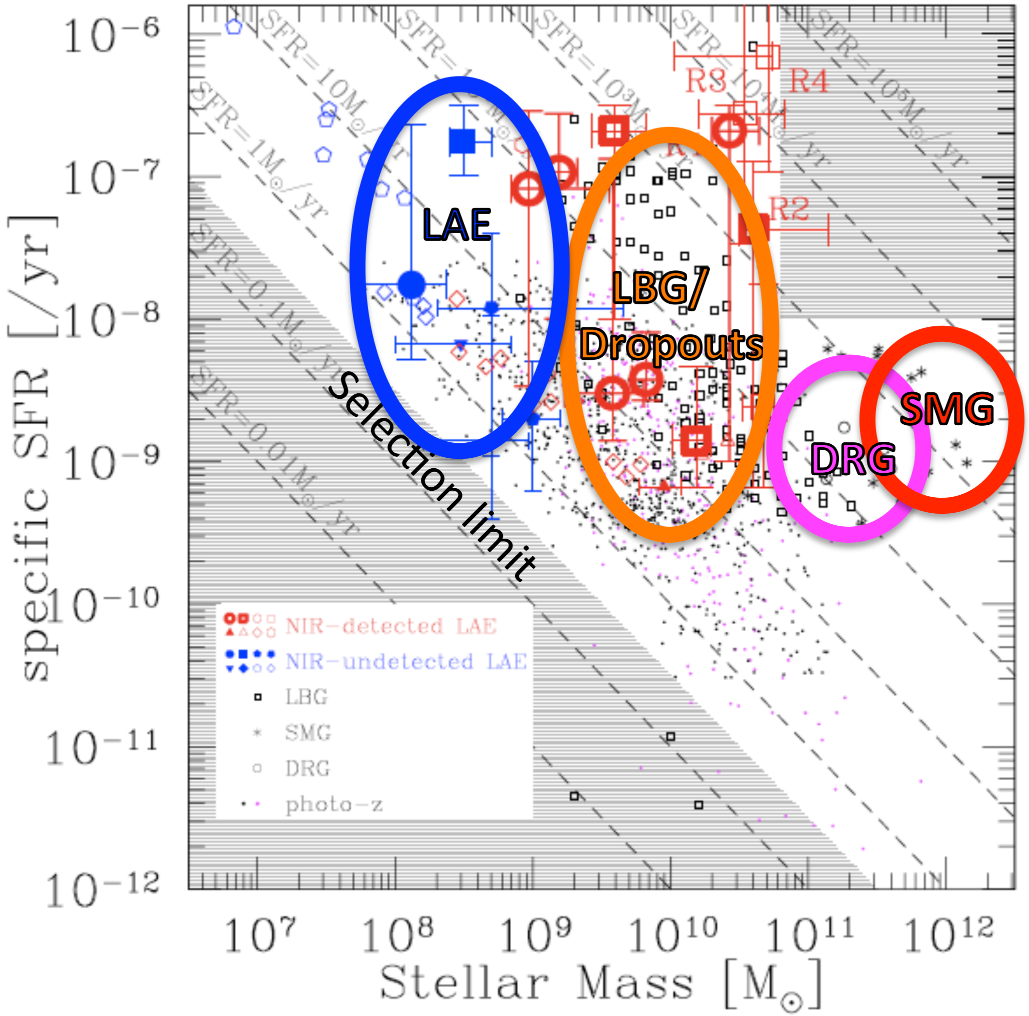




- Log-normal distribution. $\sigma(\ln r_e)$ is nearly constant ~0.6.
  - -Similar to λ of halos from simulations. r_e related to halo kinematics→ dominant rot. motion
  - -Median Sersic index n=1.5.

→High-z SF galaxies have disk-like stellar components in dynamics and morphology.
Specific angular momentum j_d/m_d=~0.5

LAEs as Probes of High-z Low Mass Galaxy

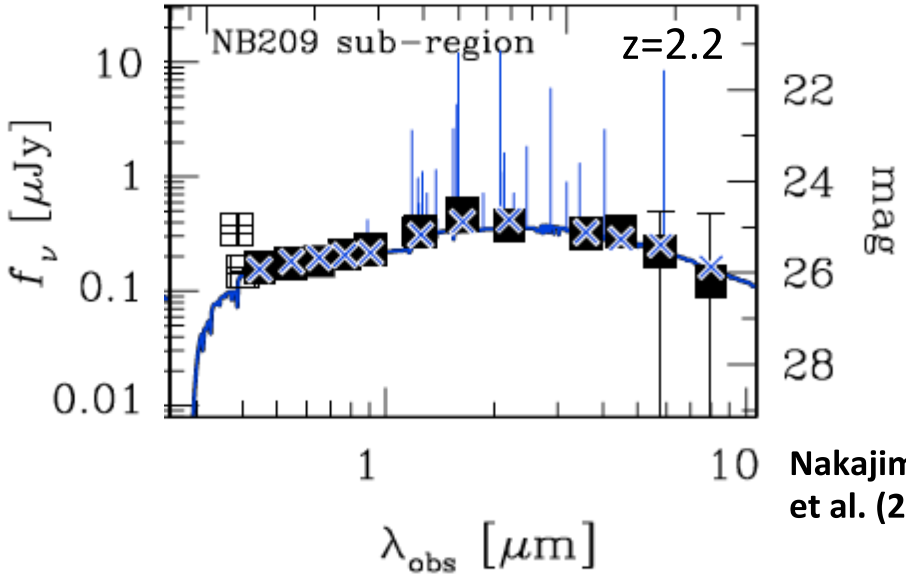


LAEs: Ono+10a, Finkelstein+09, Pirzkal+07, Lai+07, Gawiser+06
LBGs: Shapley+03, Papovich+01, Iwata+05
DRGs: van Dokkum+05
SMGs: Borys+05, Chapman+05

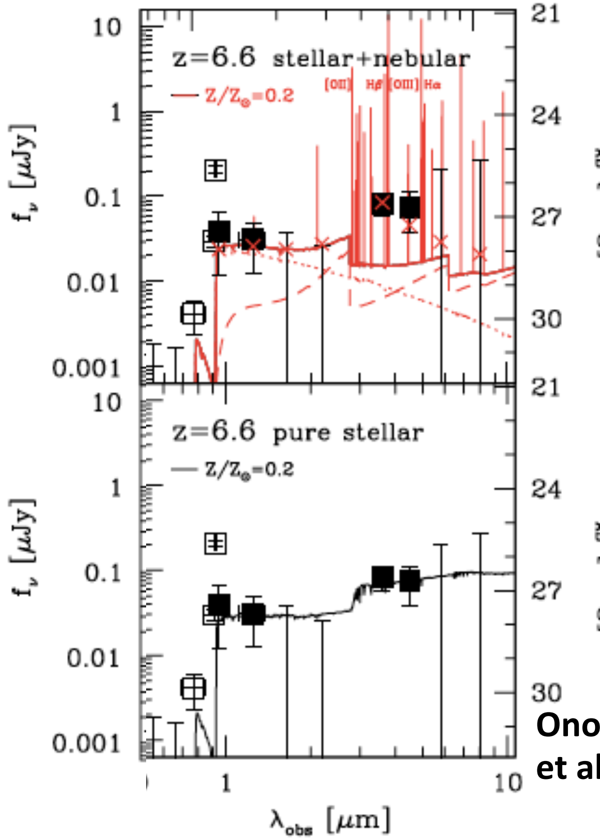
Ono, MO et al. (2010a)

- At z~3, LAEs are the least massive population among high-z galaxies, i.e. LBGs, DRGs and SMGs. The avg. mass of M_*~$10^{8\text{-}9}$ Mo at z~3. High-z analog of dwarf galaxy.

Stellar population
w BC+Nebular Emission model



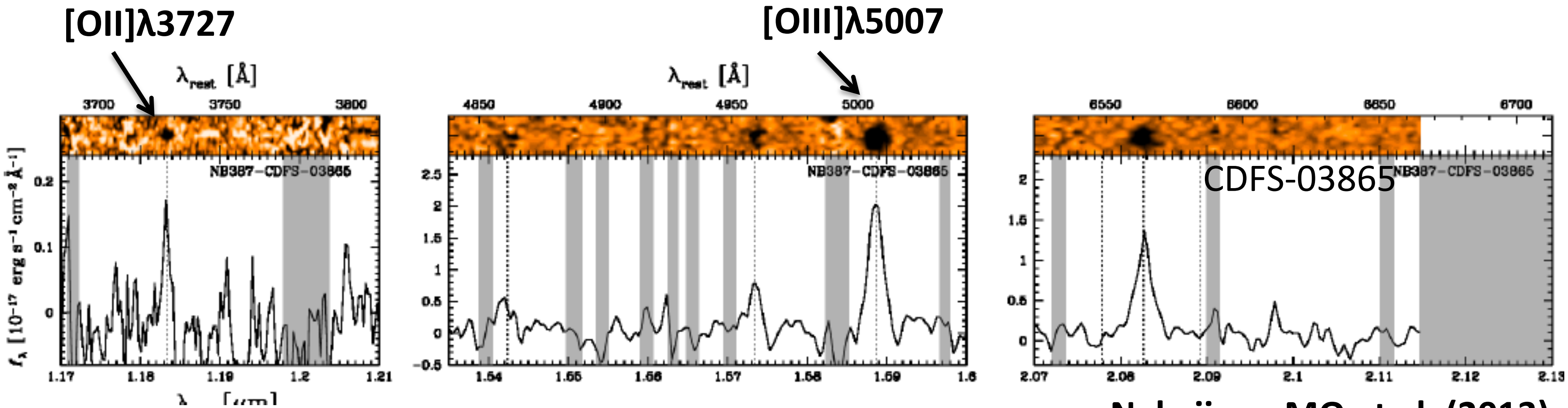
Nakajima, MO et al. (2011)



Ono, MO et al.(2010b)

- Average LAEs at z=2-7 (>~3x10^{42}erg/s)
  - Stellar Mass: 10^8-10^9 Mo
  - E(B-V)~0-0.2; low extinction
  - SFR~1-10 Mo/yr; medium low SFR
  - Stellar age~10 Myr; young age

Very High f[OIII]/f[OII] ratio for LAEs?



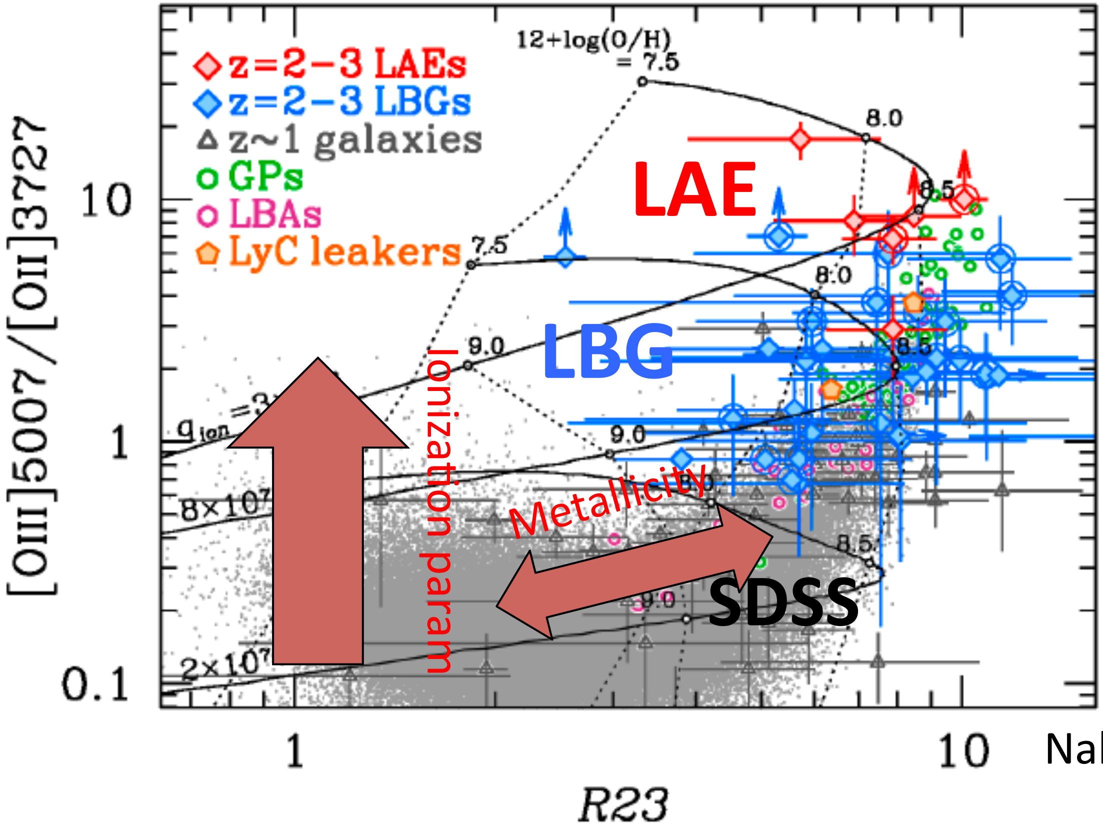
Nakajima, MO et al. (2013)

- Deep NIR Spectra of Keck and Subaru for z~2 LAEs.
- Very large f[OIII]/f[OII]~10. (cf. Local galaxies <~1)
- No AGN (from the BPT diagram)

- Extinction? Extinction corrected by Balmer decrement.

→ what does it mean?

High Ionization Parameter at z~2-3

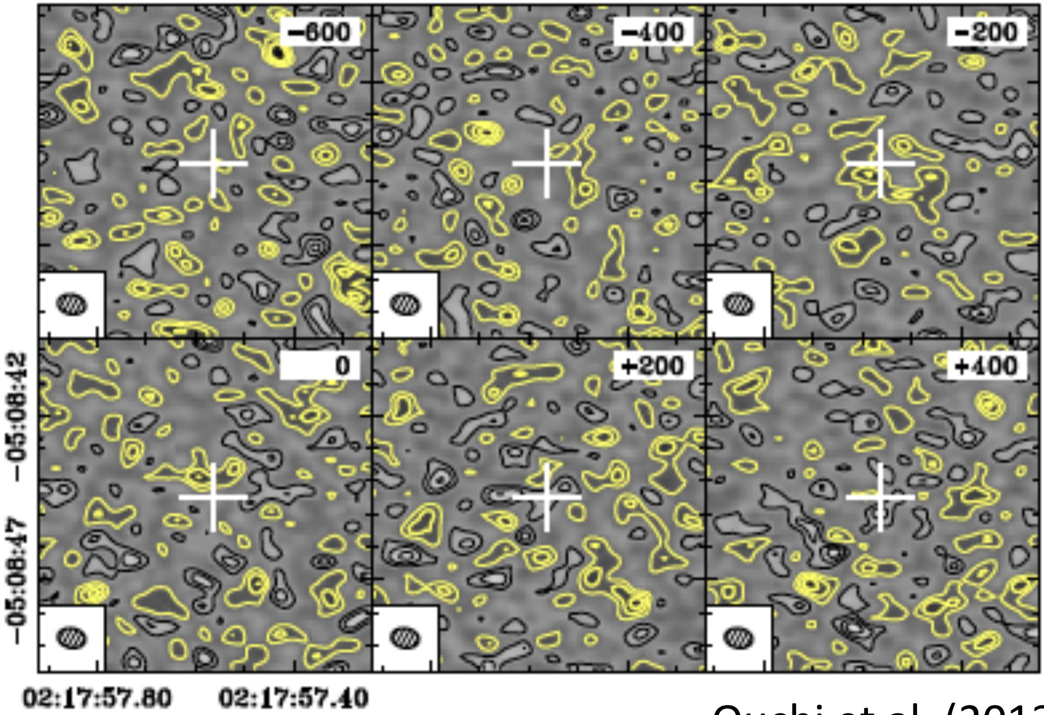


Nakajima & MO (2014)

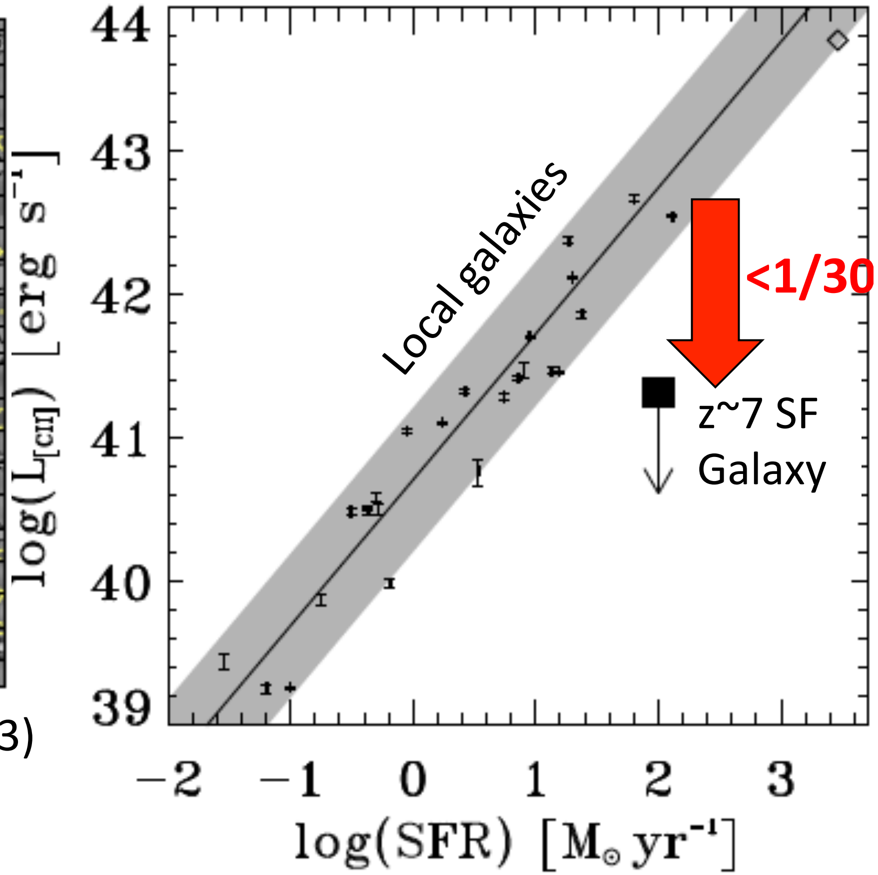
- f[OIII]/f[OII] ratios of z~2-3 LBGs/LAEs are ~x10-100 higher than SDSS galaxies
  - High ionization parameter, Log(q_{ion} /cm s^{-1})~ 8-9 (Nakajima,MO+13,Nakajima&MO +14;See also Kewley+13)

- Average ionization parameter increases towards high-z.
  - Very efficient ionizing photon production, due to young stellar population w a given hydrogen mass. → ISM state different from typical low-z dwarf galaxies

ALMA Obs for [CII] 158μm of z~7 SF Galaxy



Ouchi et al. (2013)



No [CII]. L([CII])<5.4x10^{7}Lo.

- Lying off from the local L([CII])-SFR relation by ~1/30x.
- Very weak [CII]. Possibilities are

→ 1) AGN, 2) a large column density of dust (No, due to no detection of dust cont.),

3) low metallicity (e.g. IZw18. Local [CII]-metallicity rel.; de Looze+14)

4) high density PDR (e.g. z~0.5 ULIRGs, e.g. Rigopoulou+14)

5) small size of PDR due to high ionization state(e.g. z~2-3 gal; Nakajima+13, Kewley+13)

High Escape Fraction of Ionizing Photons?

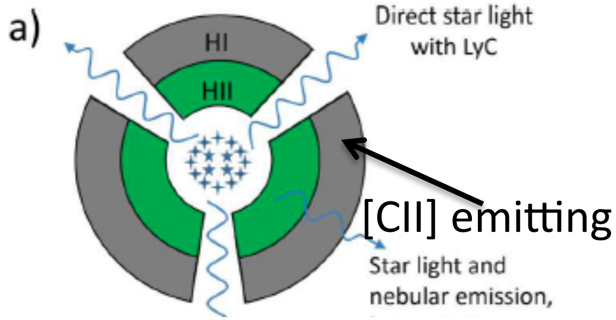
- Increase of ionization parameters towards high-z : more ionizing photons per hydrogen atoms (Nakajima&MO+14)

- [CII] emission of a z~7 SF galaxy weaker: small PDR? (Ouchi+13, Ota+14, Maiolino+15)

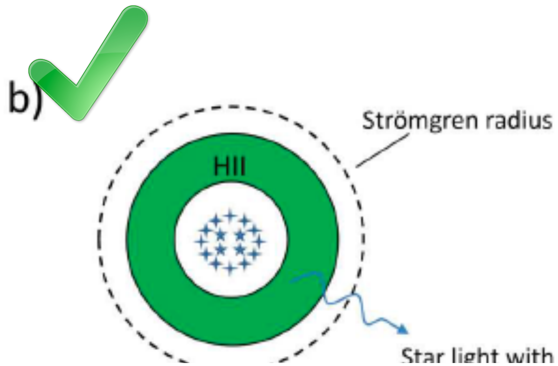
→ Both obs results are explained by the density-bounded nebula of ISM. If so, f_{esc} is high and Lya production is low.

- Photoionization (Cloudy) models for density-bounded nebulae→ There is a sharp decrease of Lya emission for a high f_{esc}. (Nakajima&MO 2013; see also Dijkstra et al. 2014)

Zakkrisson+13



Ionization-bounded nebula



Density-bounded nebula

Density-bounded nebula

FUTURE/ON-GOING LAE SURVEYS

Large Surveys for LAEs

- HETDEX
  - ~1 million LAEs at z=2-4

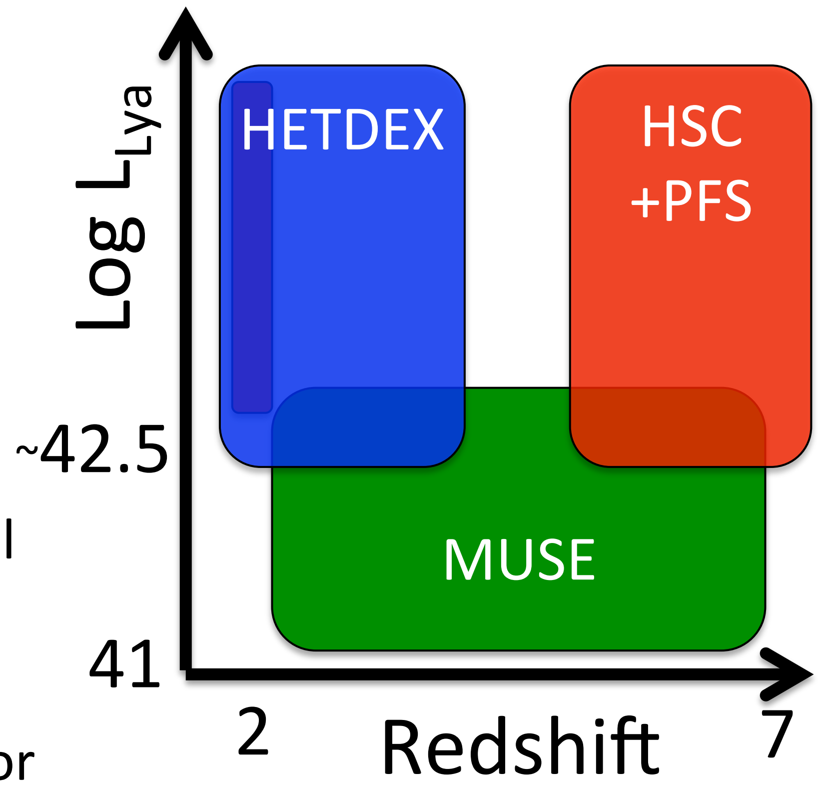
  Goals: LAE evol + environment

- Subaru/HSC+PFS
  - ~9k LAEs at z~2 (40 z=7.3 LAEs)
  - ~10k LAEs at z=5.7 and 6.6
  - ~1k LABs at z=2-7 etc.

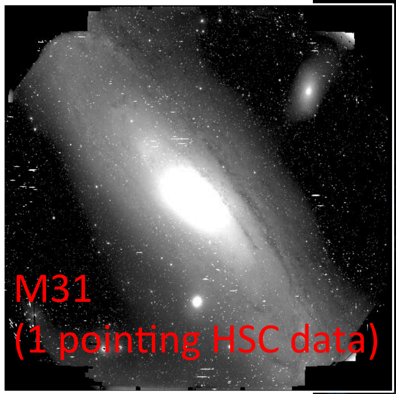
  Goals: 1. x_{HI}, B-Topology 2. LAE/LAB evol

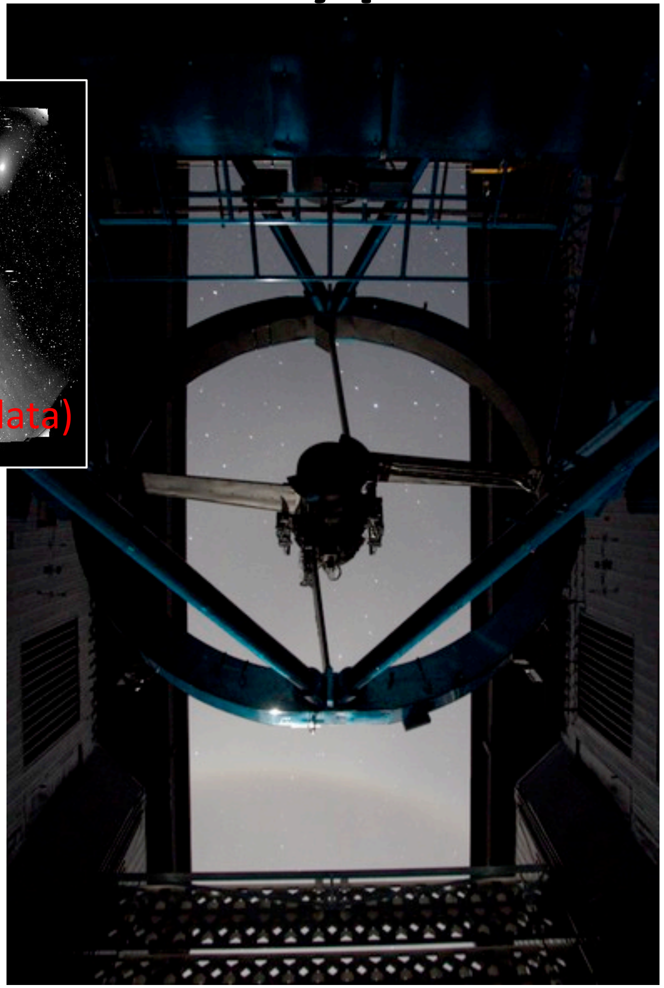
- VLT/MUSE (+Keck/CWI)
  - ~200 night obs: ~6k for z=3-4, ~800 for z=5-6 of LAEs (z=2.8-6.6) down to ~1/10 F(Lya;NB)

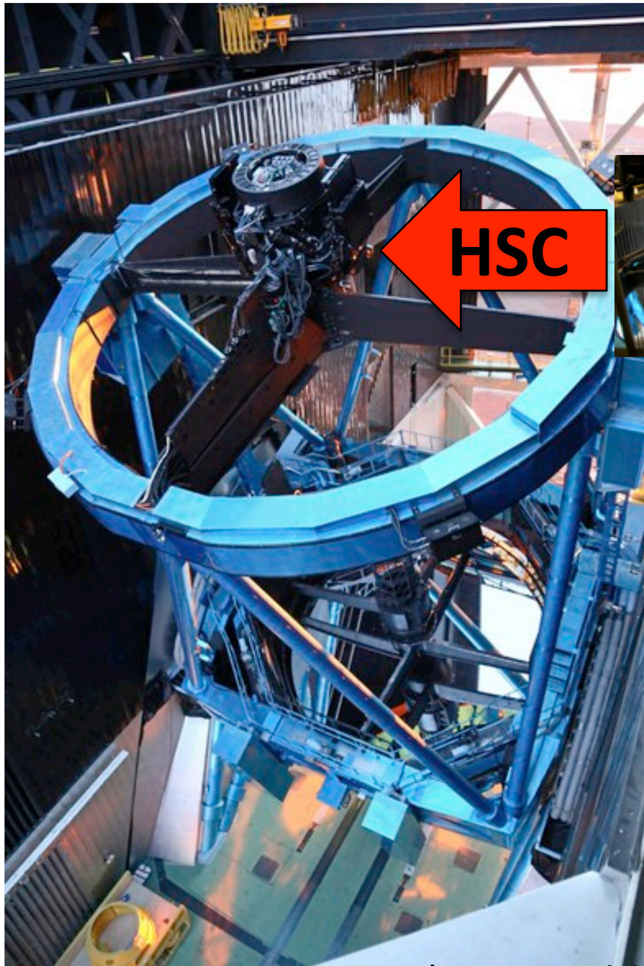
  Goals: LAEs at the faint-end LF



Subaru/Hyper Suprime-Cam (HSC)







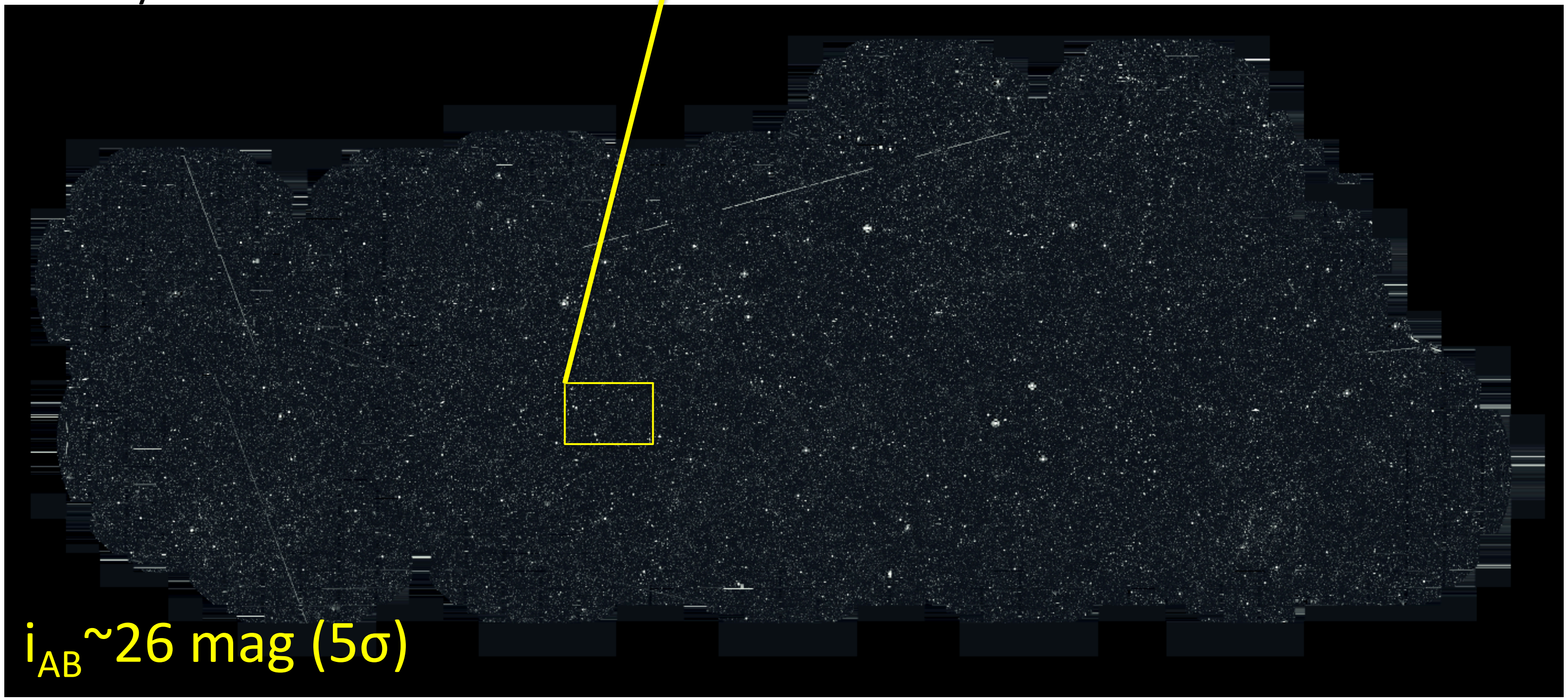
Suprime-Cam

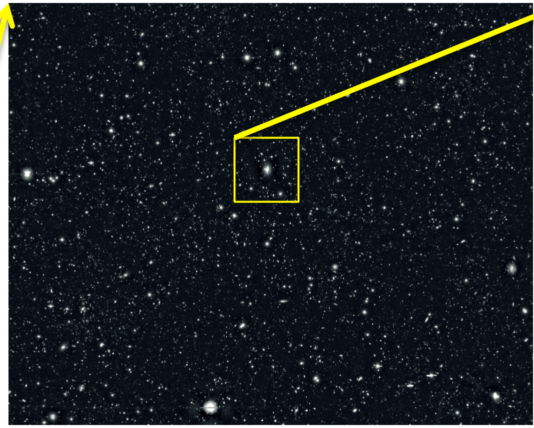
c) HSC Builder's blog

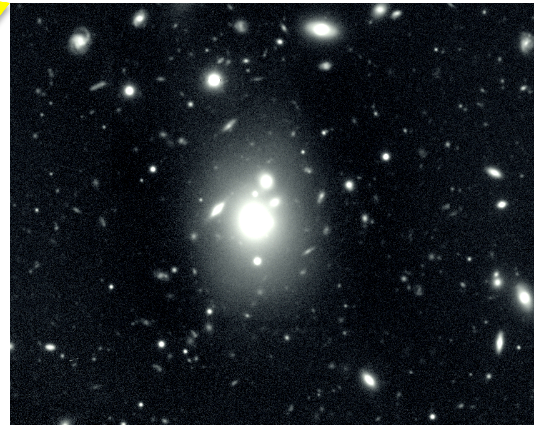
- Subaru optical imager w a 1.5deg-diamter FoV, 7x larger than previous Suprime-Cam.
- Subaru/HSC survey has started since spring 2014 under the collaboration of JP/US/TW.
- Spending 300 nights in 5 years
- Slowly started. ~10 % of observations are completed so far. But, now observations are conducted faster than the past year.

First HSC Survey Data

Miyazaki et al.

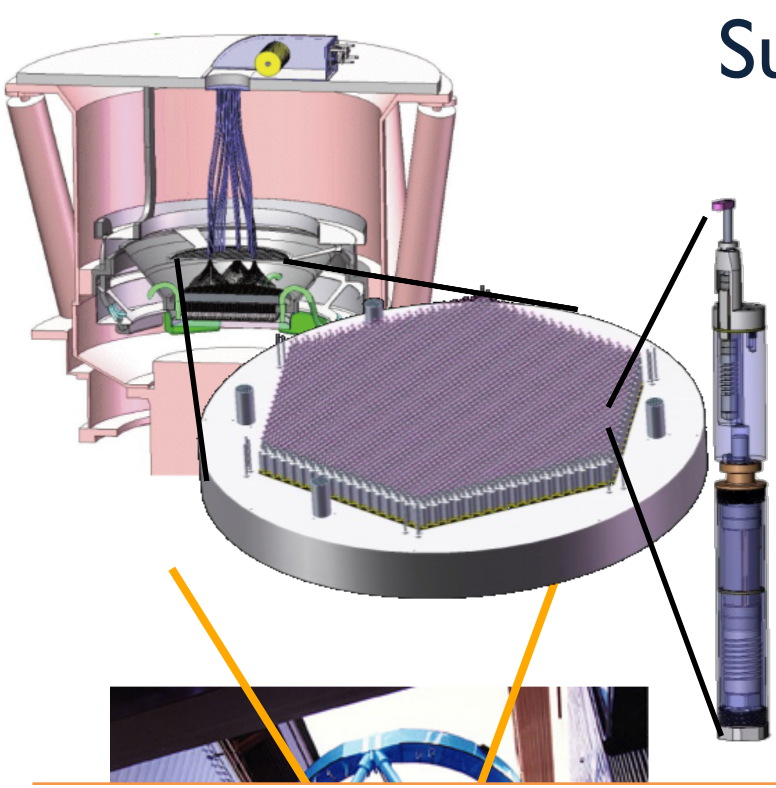






- HSC 20 deg^2 data in GAMA field (one of HSC survey fields).
- It took only ~3 hours! Seeing: 0.4-0.6 arcsec (FWHM).
- See Harikane's talk for the early HSC results.

Subaru/Prime Focus Spectrograph (PFS)



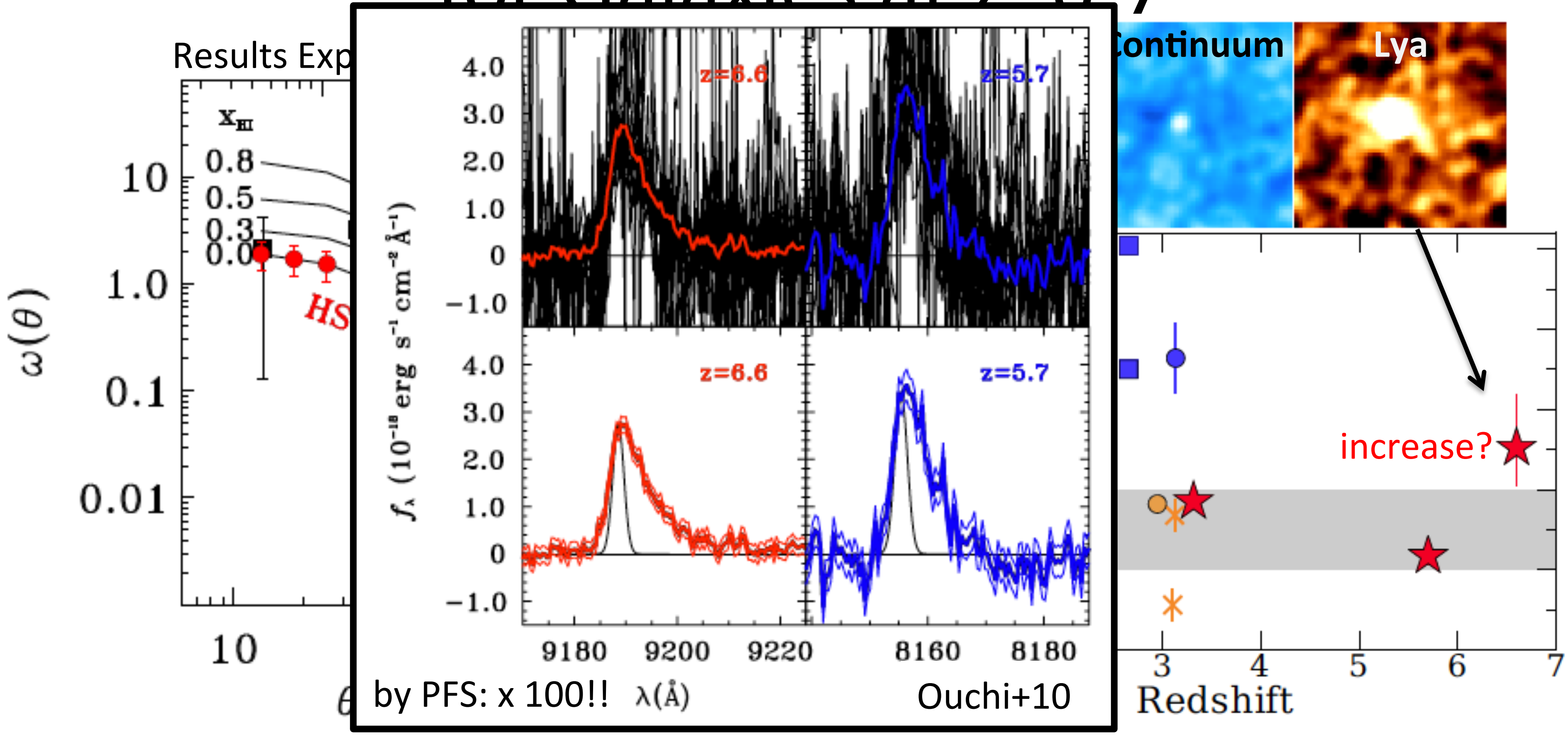
- Multi-object fiber spectrograph for Subaru under the collaboration of Japan, Princeton, JHU, Caltech/JPL, LAM, Brazil, ASIAA. Planned first light in 2018
- Share WFC with HSC→→

Fiber density: 2200/sq. degs (⇔ ~140 for BOSS; ~570 for DESI)

Number of fibers	2400		
Field of view	1.3 deg^2 (hexagonal-diameter of circumscribed circle)		
Fiber diameter	1.13" diameter at center	1.03" at the edge	
	Blue	Red	NIR
Wavelength range [nm]	380-650	630-970 (706-890)	940-1260
Central resolving power	~2350	~2900 (~5000)	~4200
Detector type	CCD	CCD	HgCdTe

Approved by Preliminary Design Review (2013)

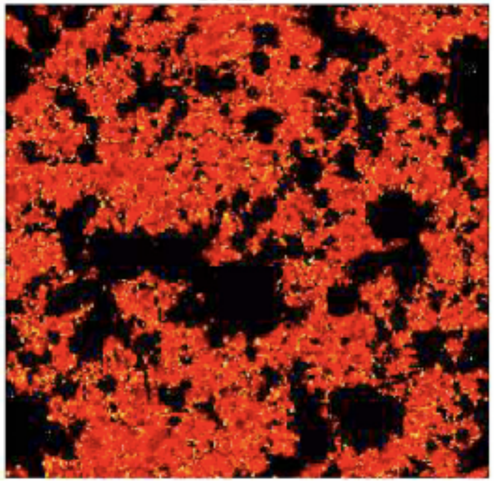
Subaru/HSC+PFS Surveys for Galaxies at z~6-7



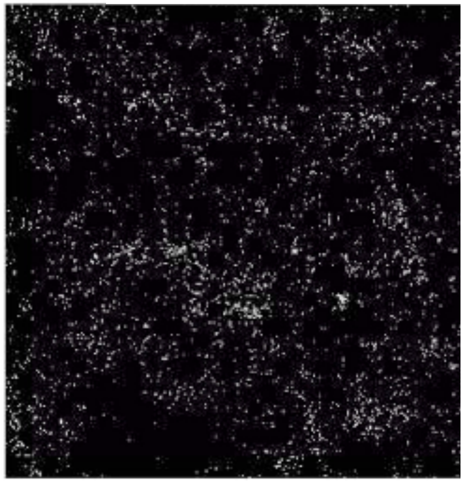
- HSC survey: Clustering of LAEs→ imprint of ionized bubble of IGM (e.g. McQuinn+07, Ouchi+10).
- HSC survey w 10k LAEs at z=6-7→δx_{HI}=0.1. Bubble topology →Physical processes (inside-out, filament-last, etc.)
- Testing for HI cloud absorbers from the combination of Lya LF and clustering via numerical models (see Mesinger's talk)
- Lya halo evolution at z>6.

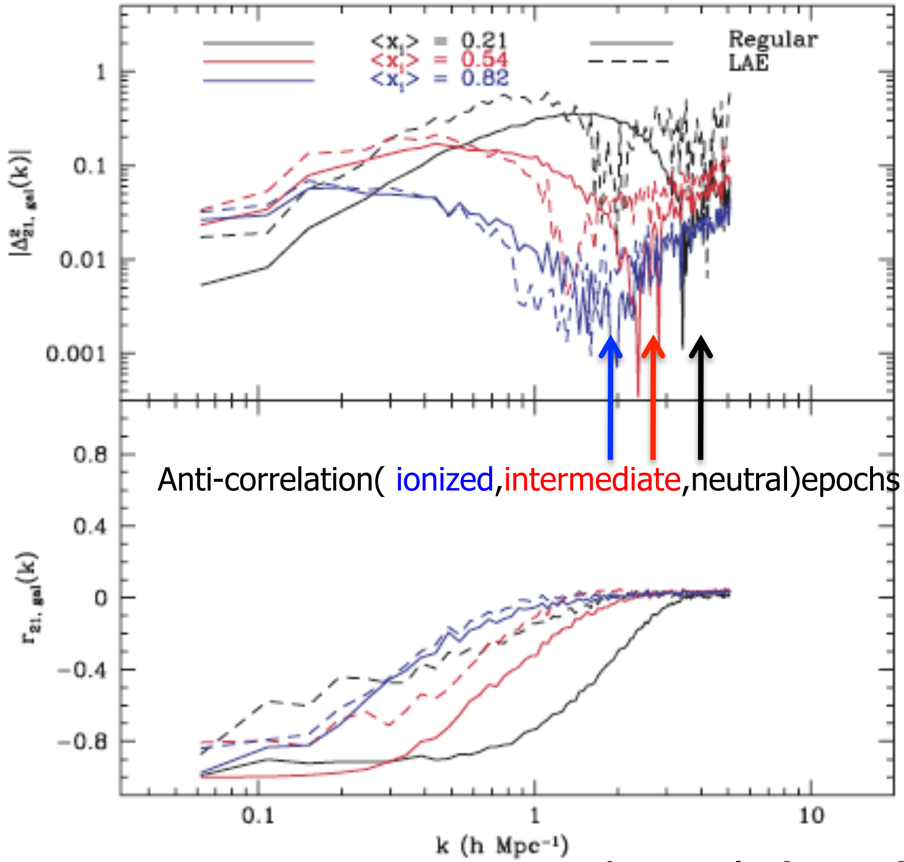
Subaru/HSC x LOFAR 21cm

21cm



Galaxies





Lidz et al. (2009)

- Collaboration with LOFAR team (Zaroubi et al.)
- HI distributions (from 21cm) and galaxies (from optical) anti-correlate.
- Distance scales of anti-correlation→ ~Inside-out (typical sizes of ionized bubbles at the epoch)
- 21cm-galaxy cross-power spectrum. LOFAR 21cm+ Subaru/HSC(+PFS) survey in ELAIS-N1→~3σ detection of signal (Lidz+09).

Summary

- Lya emitters as for a reionization probe
  - Subaru ultra-deep survey

  → accelerated evolution of the Lya LFs at z>~7
  - Late reionization. Tension between x_{HI} and τ_e estimates?
    → Consistent w Planck2015 results
  - A possible increase of Lya halo scale lengths at z>6?

- Lya emitter physical properties and ionizing photon escape
  - Increase of ionization parameters towards high-z
  - [CII] emission of z~7 SF galaxy weaker singnificantly

  → Density-bounded nebula? Making a f_{esc} larger?

- On-going surveys of Subaru/HSC,PFS (+ HETDEX and MUSE). HSC+PFS program's goals and Progresses.