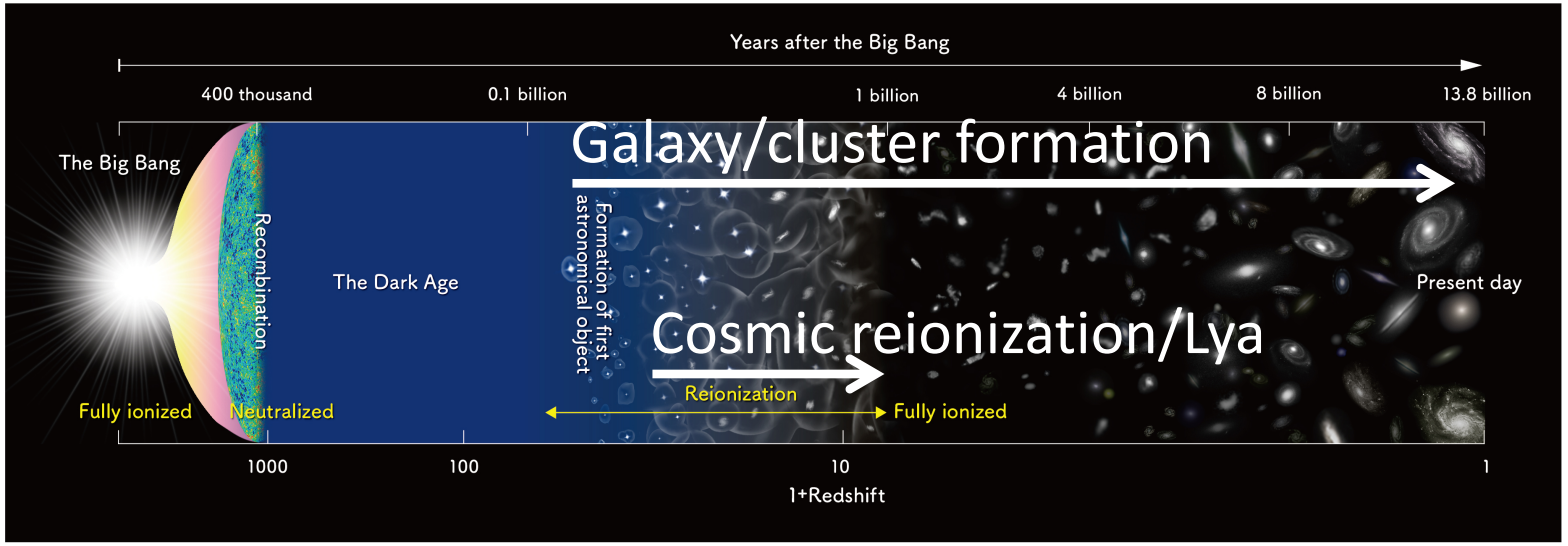
すばる望遠鏡による銀河観測

Yuichi Harikane (University of Tokyo)

High Redshift Universe

- Review of recent observations
  1. Galaxy/cluster formation
  2. Cosmic reionization/Lya emission
- Future prospects



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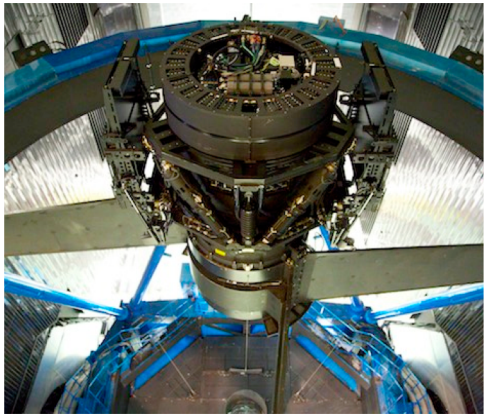
Recent Updates

- Subaru/Hyper Suprime-Cam (HSC)
  - Wide field optical imager (1.5 deg^2)
  - Statistics (luminosity function; LF)
  - Rare objects (proto-cluster)
- Hubble space telescope
  - Gravitational lensing
- Keck/MOSFIRE
  - Deep near-infrared spectroscopy
- VLT/MUSE, Keck/KCWI
  - Deep optical integral field spectroscopy

Subaru/HSC



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Hubble Space Telescope

NASA/ESA

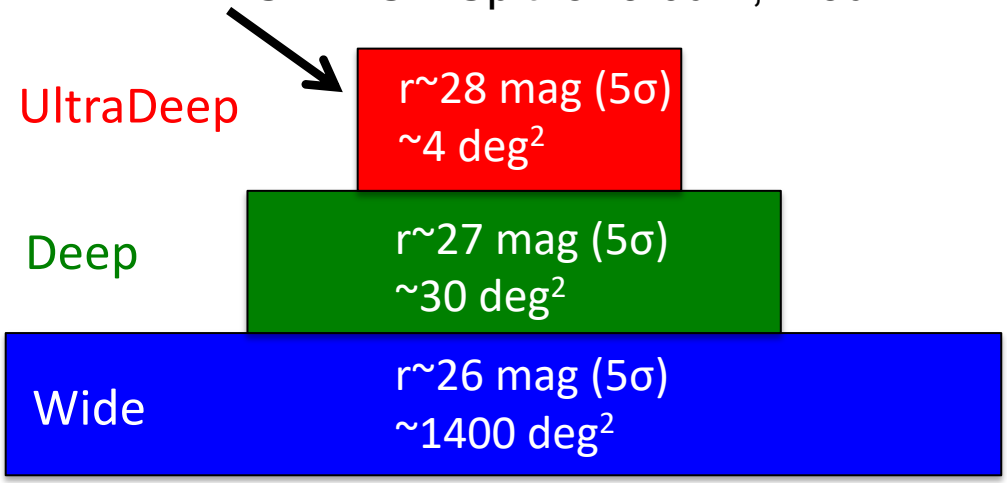
Keck/MOSFIRE

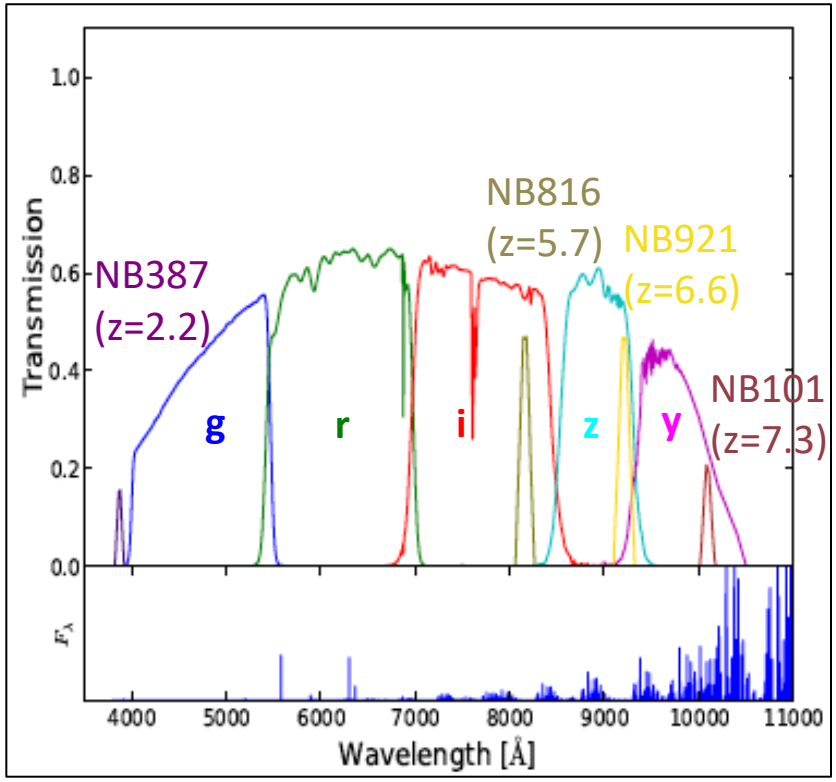
UCLA

Subaru/HSC Survey

- Large area optical imaging survey
- 5 year survey from 2014 to 2019 (PI: Miyazaki)
  - 3 layers (UltraDeep, Deep, Wide)
  - 50% complete (2018 May)

- CHORUS (Inoue-san's talk)
  NB527, NB718, IB945, NB973
- SPLASH Spitzer 3.6um, 4.5um





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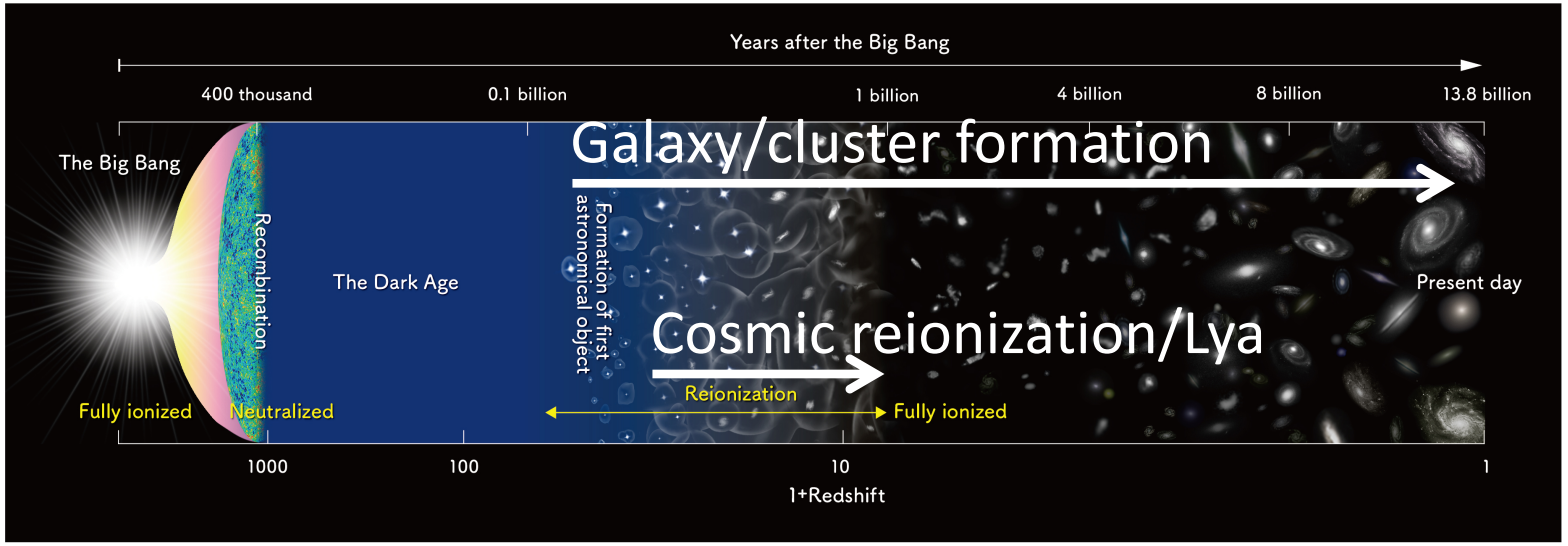

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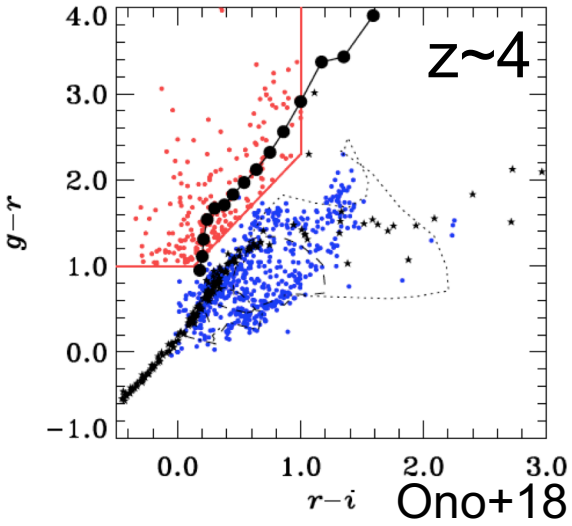
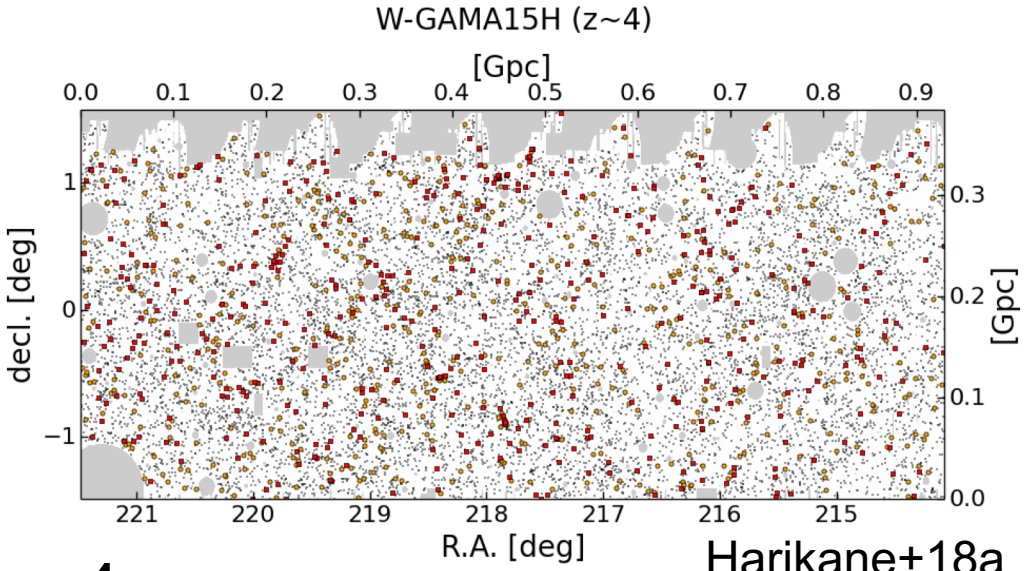
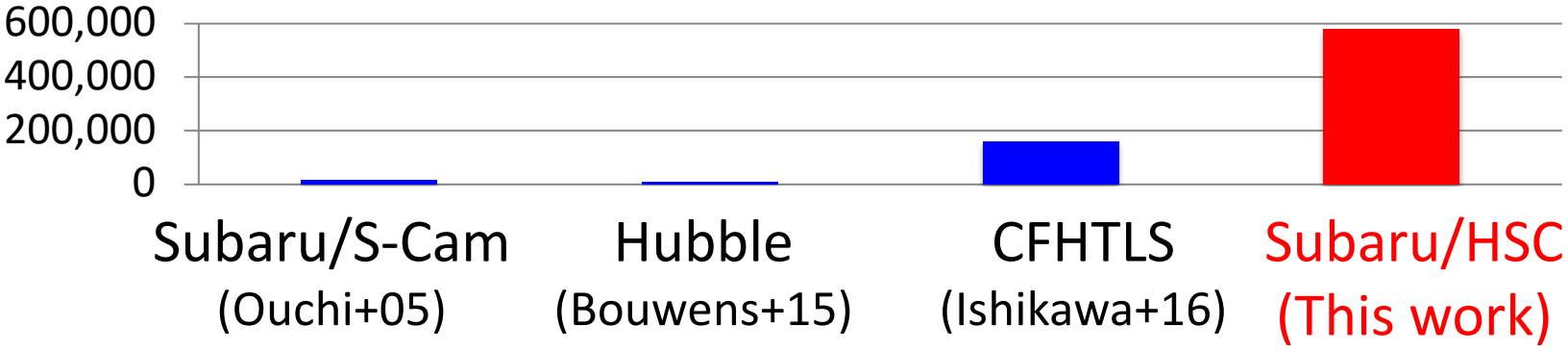
Half-Million LBGs at z~4-7

- ~100 deg^2 grizy images with r_{lim}~26 mag



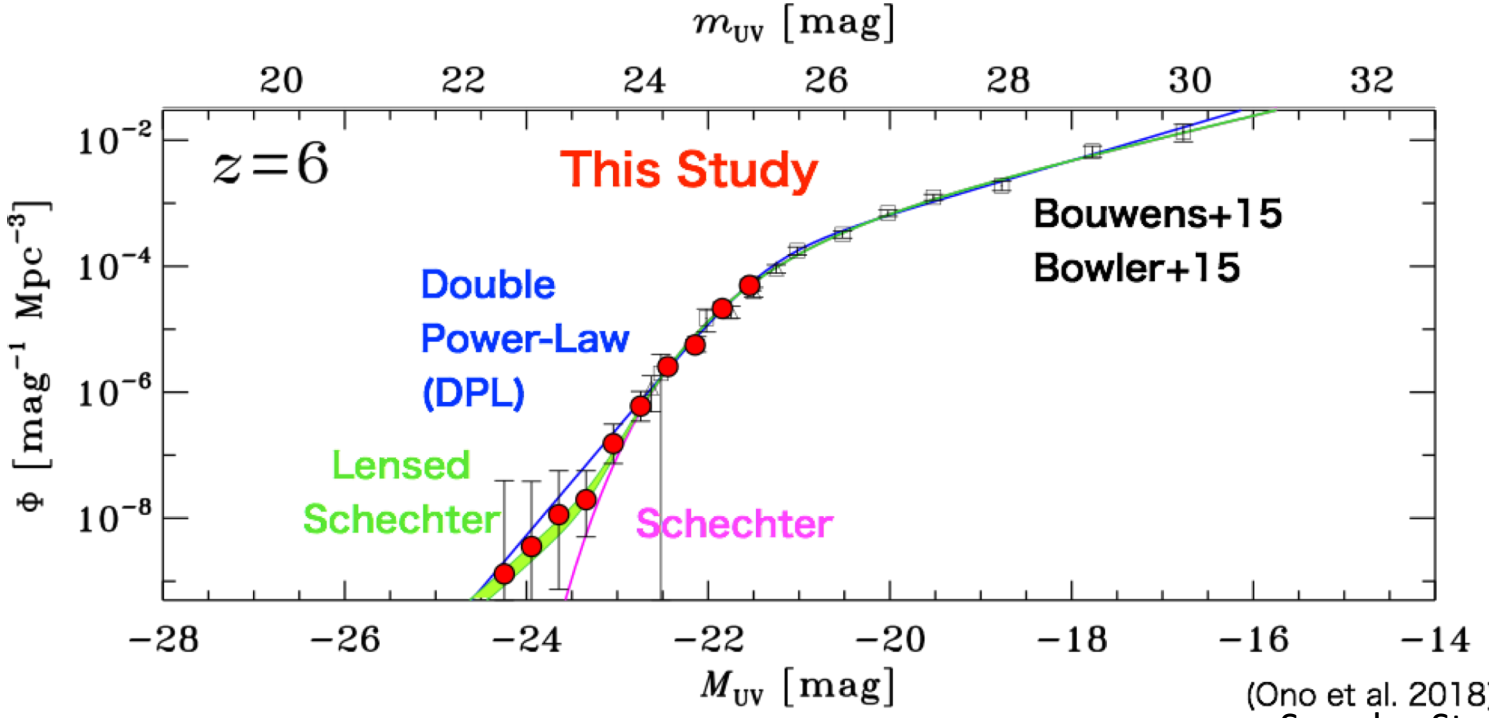


- 579,565 LBGs at z>4



UV Luminosity Function (LF)

- Bridging galaxy and AGN LFs
- Bright end excess after subtracting AGN LF
  - Double power-law or lensed Schechter functions
  - Weak AGN feedback?

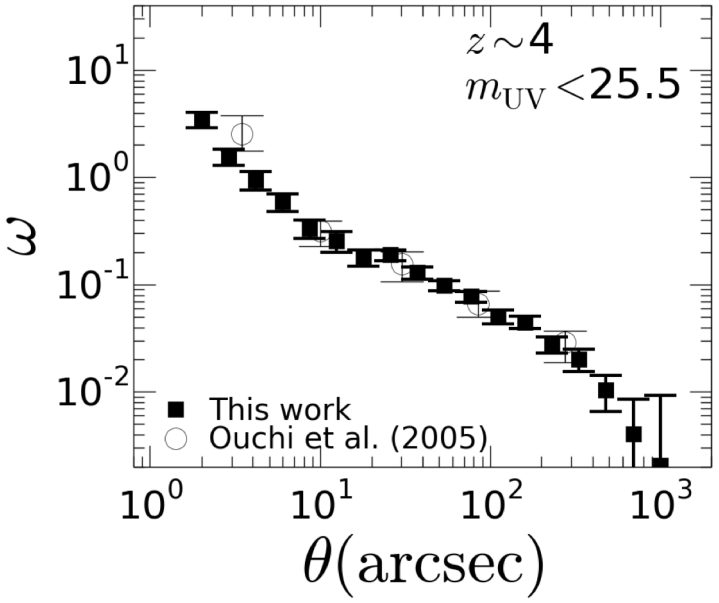


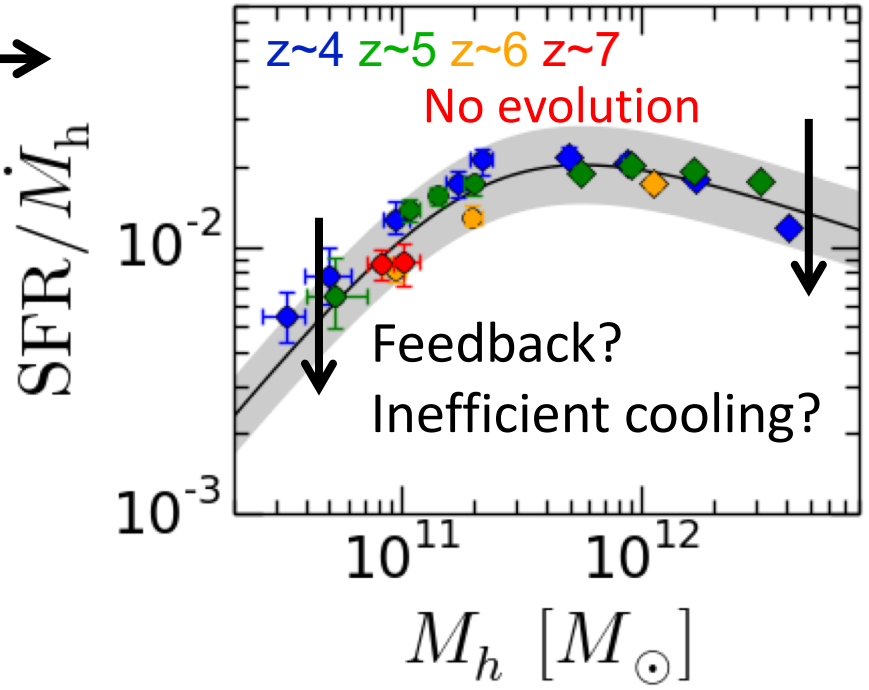
(Ono et al. 2018)

See also Stevans+18

Correlation between Galaxy and Halo Growth

- Angular correlation functions -> halo mass (M_h)
- SFR/ dark matter accretion rate (dM_h/dt)
  - No significant evolution beyond 0.15 dex

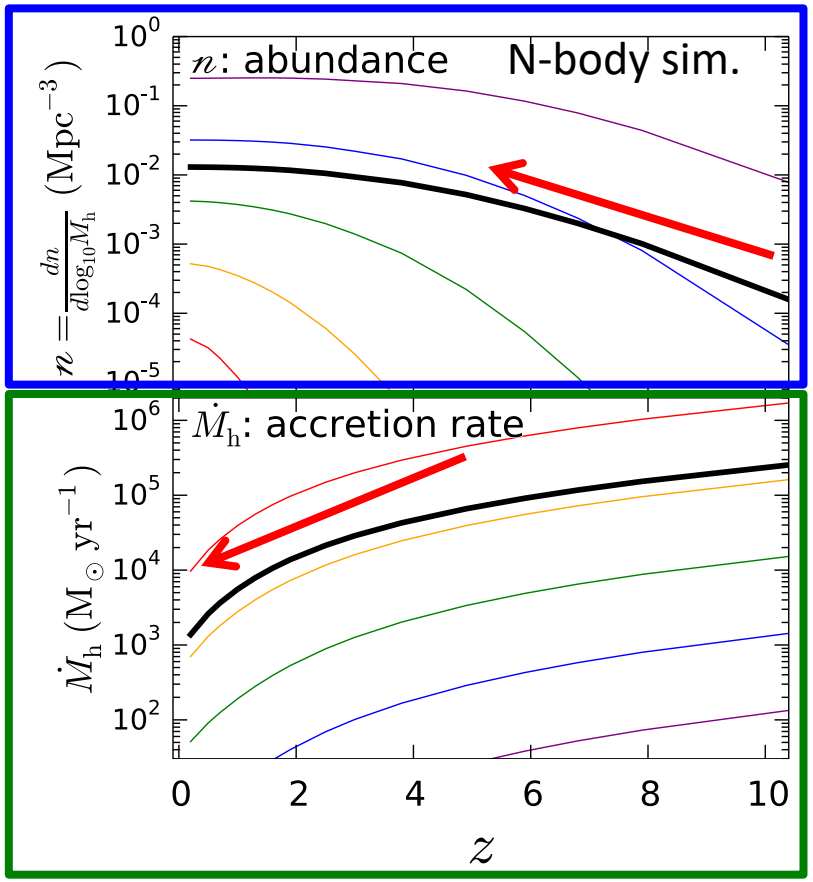


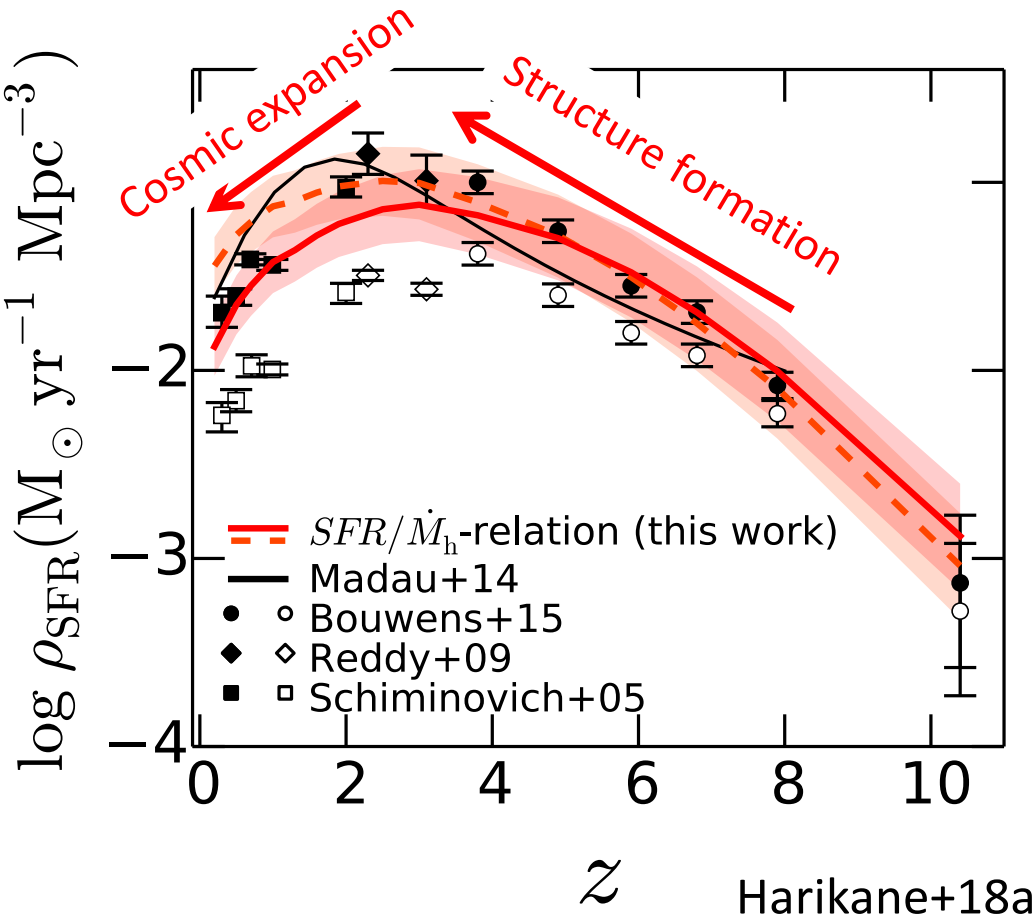


Harikane+18a

Explaining cosmic SFR density

$$\rho_{\rm SFR} = \int dM_{\rm h} \frac{dn}{dM_{\rm h}} SFR = \int dM_{\rm h} \boxed{\frac{dn}{dM_{\rm h}}} \boxed{\dot{M}_{\rm h}(M_{\rm h}, z)} \boxed{\frac{SFR}{\dot{M}_{\rm h}}}$$

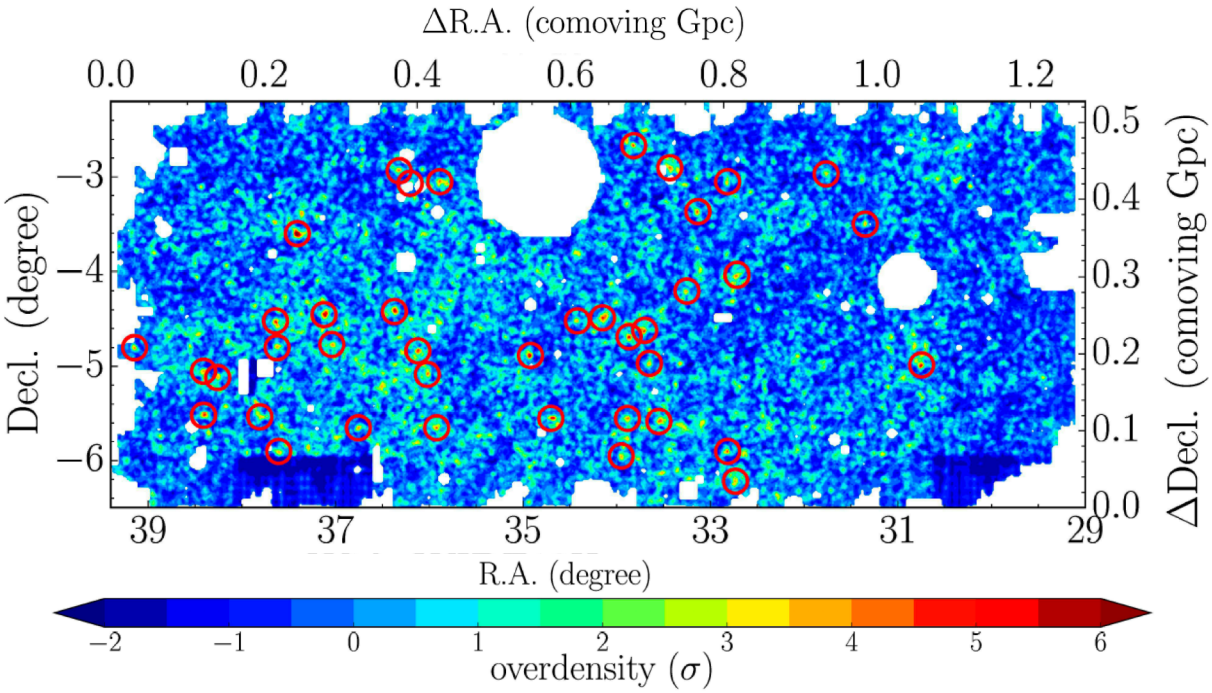


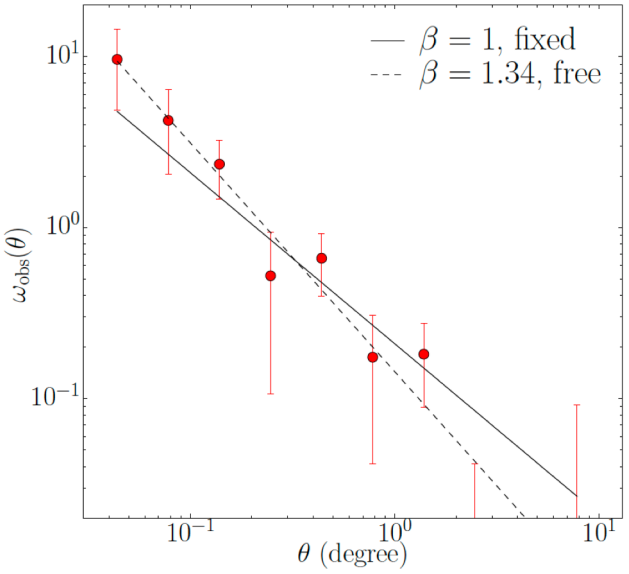


Harikane+18a

Protocluster Candidates

- >200 protocluster candidates identified w/ HSC
- Correlation length similar to present rich clusters

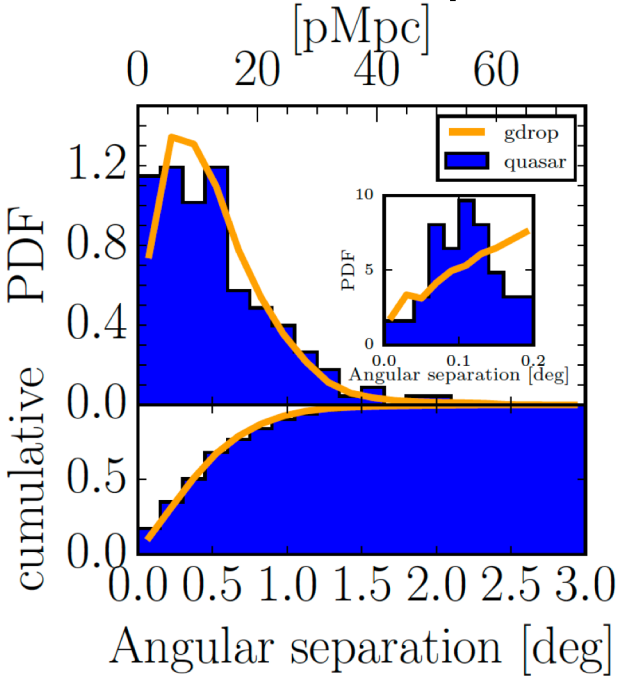




Toshikawa+18

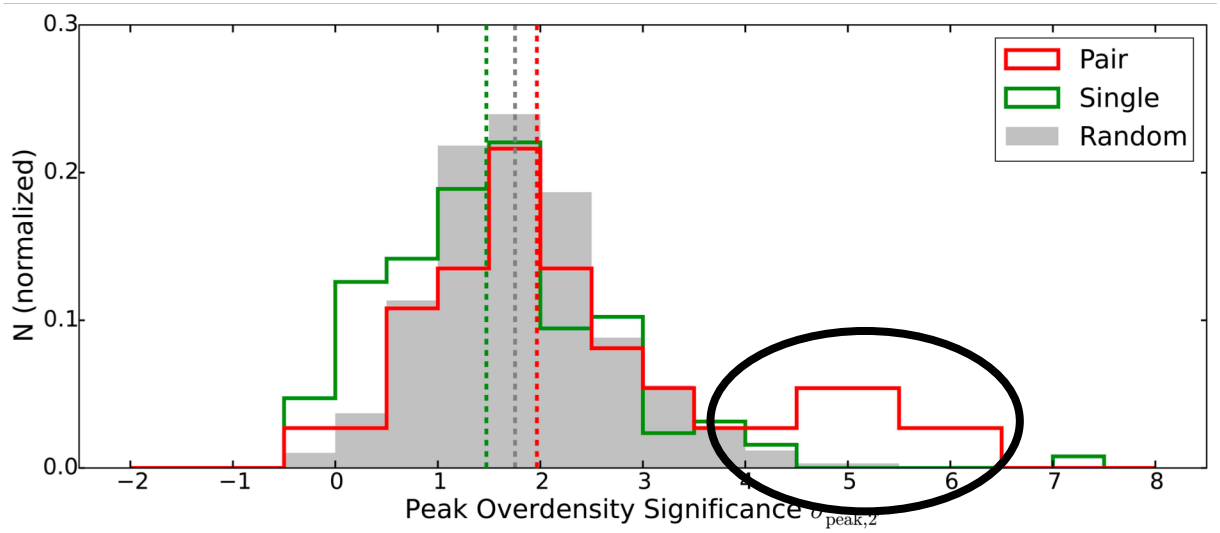
Correlation with Quaser

- A luminous quaser does not living in the most overdense regions (only 2/151 quasers)
- But quaser pairs tend to reside in overdensity
  - Quaser pair triggered by merger?



Separation to Overdensity

Uchiyama+18



Onoue+18

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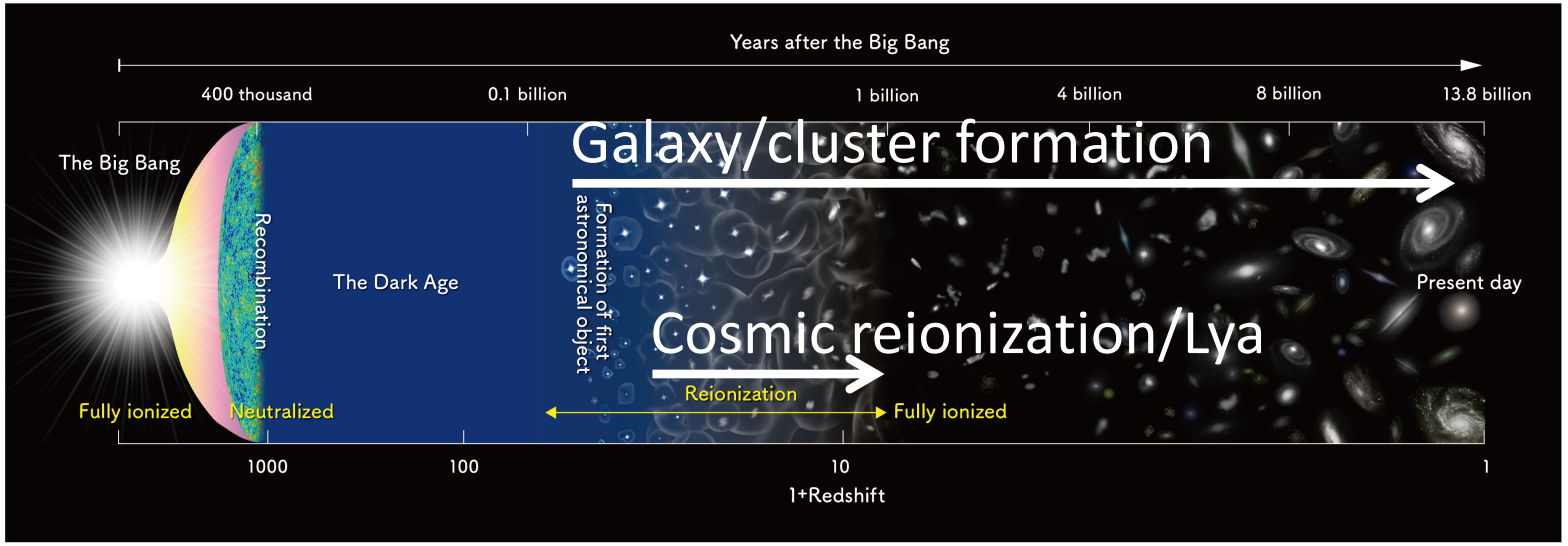

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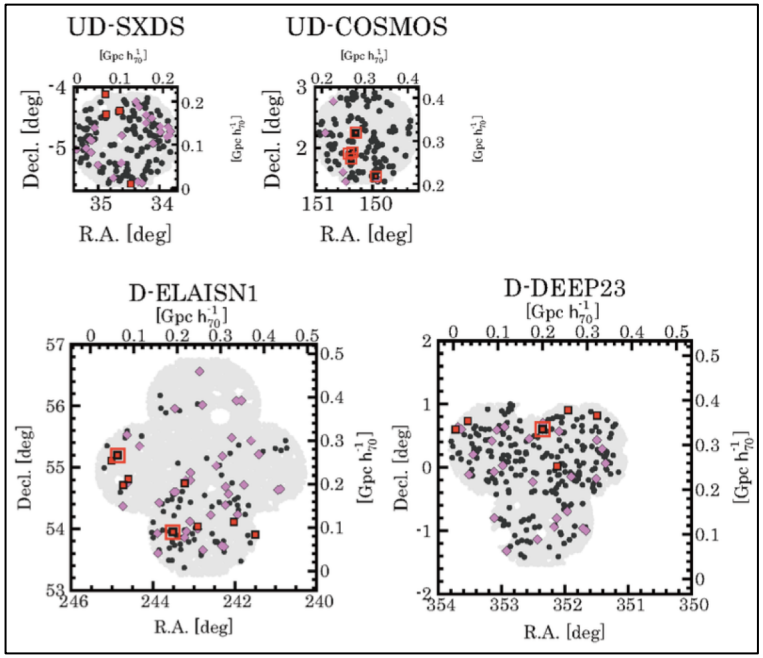
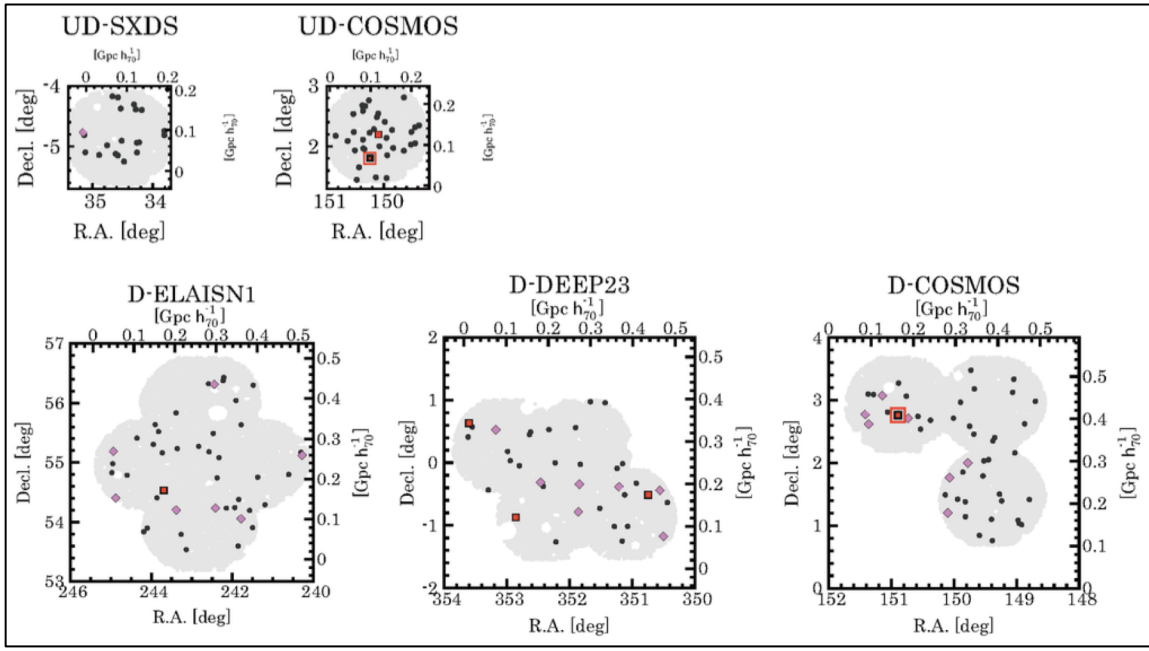
LAE Samples

- 2525 HSC LAEs at z=4.9, 5.7, 6.6 and 7.0 (Ouchi+18, Shibuya+18a, Itoh+18, Zhang+in prep.)
- ~100 spectroscopically confirmed LAEs

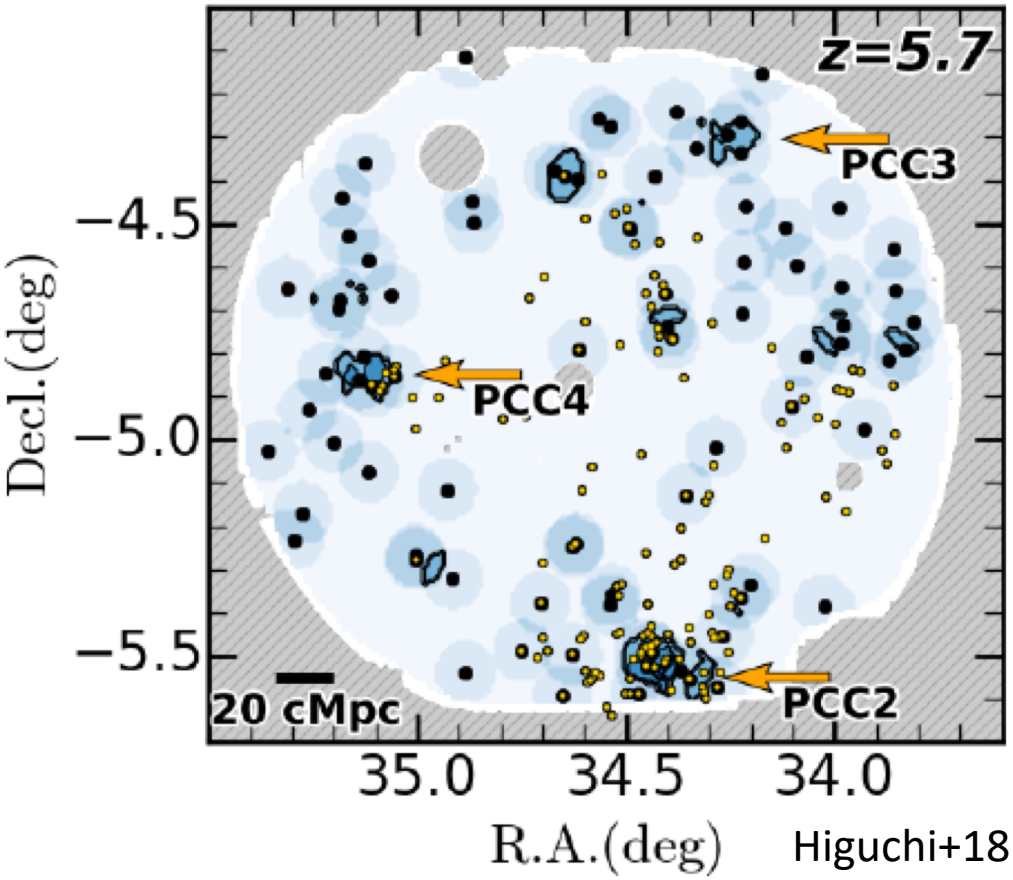




Shibuya et al. (2018a)

LAE Protoclusters

- 42 overdensities identied at z=5.7, 6.6
  - Numerical simulations: >50% will grow to 10^{14} M_o halo



Higuchi+18

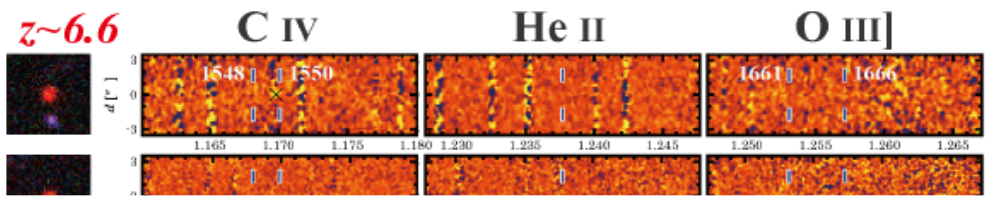
Large Scale Structures

- Obtained with 167 spec-z LAEs at z~5.7, 6.6
  - Filaments with the highest-z overdensities (z=6.585)
- >5sigma correlation with dusty SMGs

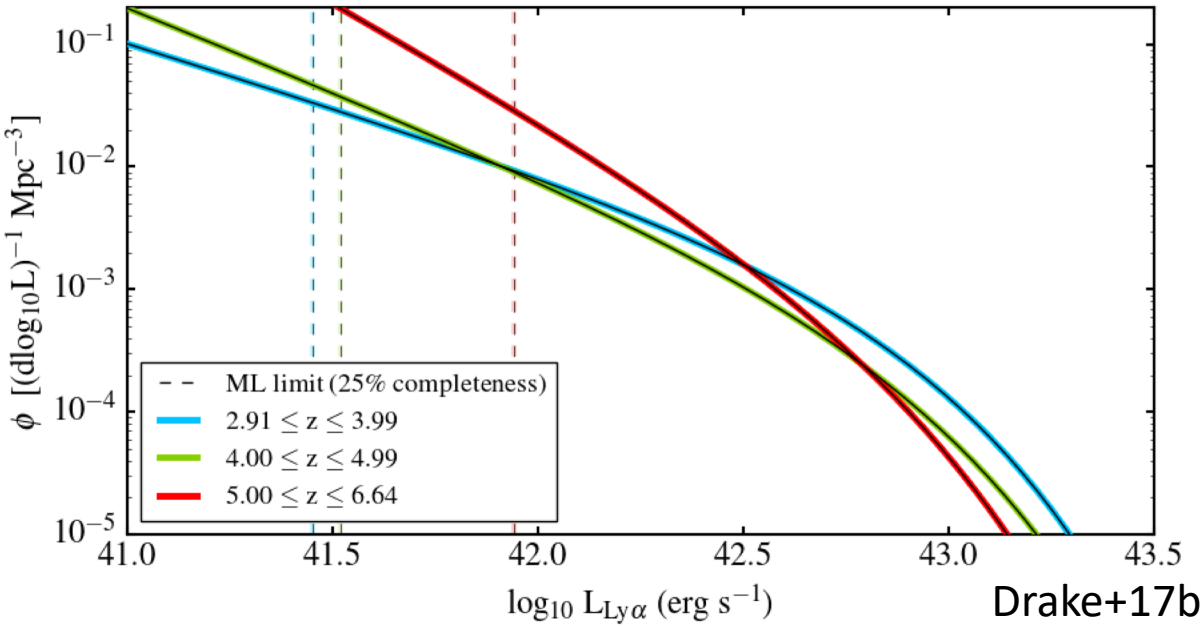
Harikane+ in prep.

Lya LF

- Bright end
  - no AGN signature w/ Keck/MOSFIRE (Shibuya+18b)
- Faint end
  - very ste



(Drake+17b)

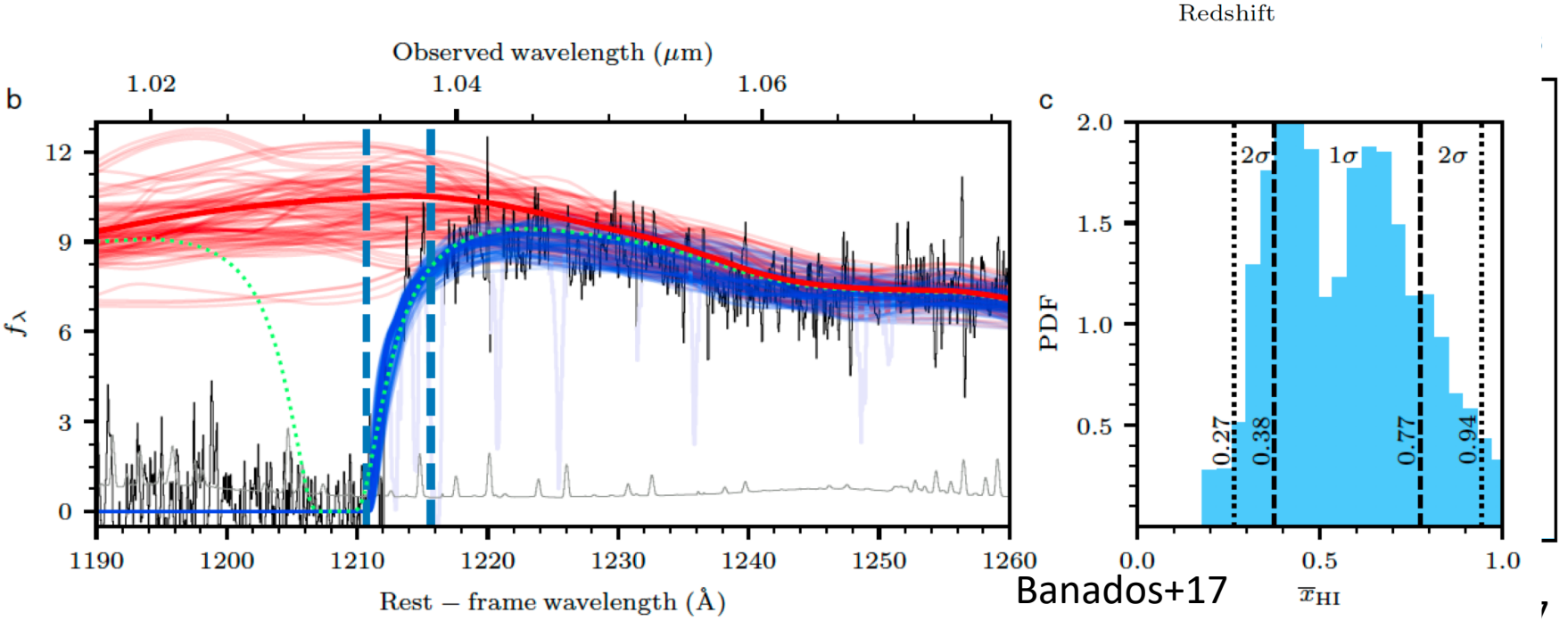


Drake+17b

see also Itoh+18

Reionization History

- x_{HI}: neutral hydrogen fraction in IGM
  - Lya LF: x_{HI}=0.3+/-0.2 (z=6.6), 0.55+/-0.25 (z=7.3)
  - QSO dumping wing: x_{HI}=0.56+0.21-0.18 (z=7.5)
- Reionization history well constrained



Banados+17

Ionized Hydrogen Fraction $Q_{HII}(=1-x_{HI})$

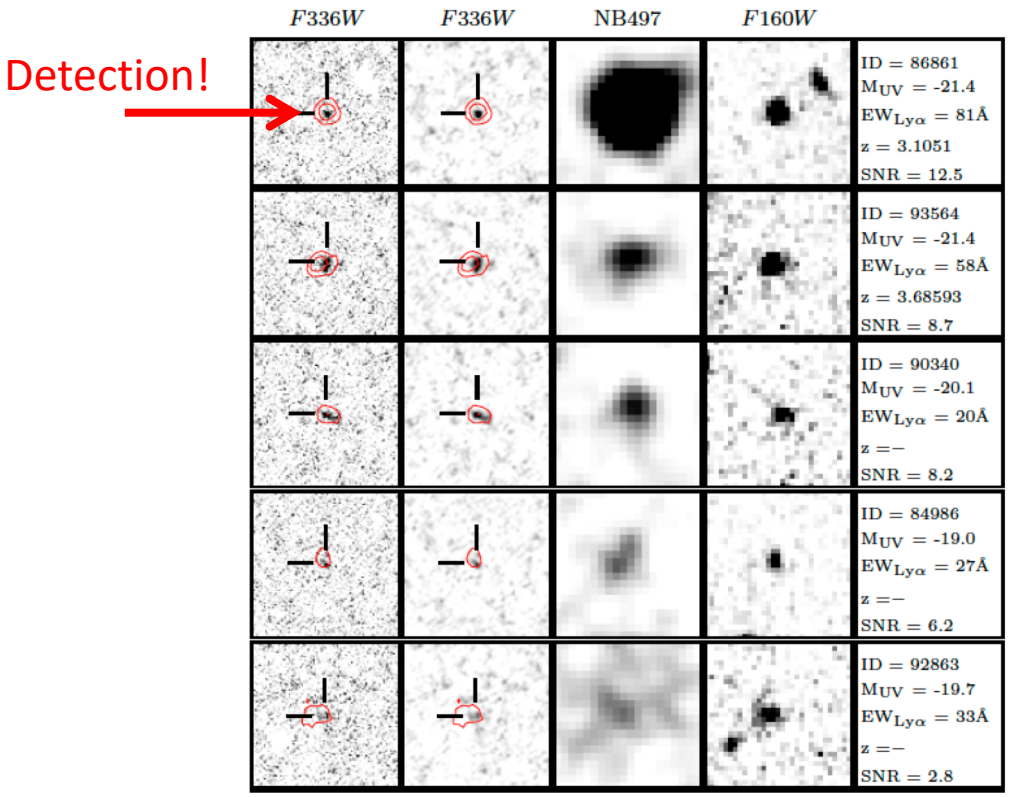
$$\dot{Q}_{\mathrm{H\,II}} = \frac{\dot{n}_{\mathrm{ion}}}{\langle n_{\mathrm{H}} \rangle} - \frac{Q_{\mathrm{H\,II}}}{t_{\mathrm{rec}}}$$

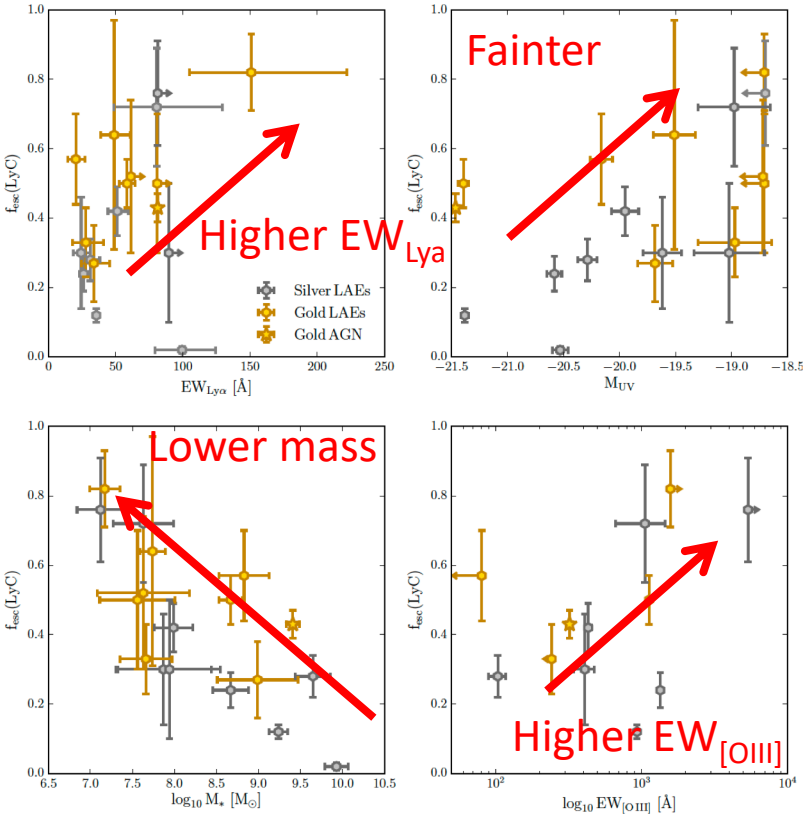
- Ionizing photon production rate: $\dot{n}_{\mathrm{ion}} = \langle f_{\mathrm{esc}} \xi_{\mathrm{ion}} \rangle \, \rho_{\mathrm{UV}}$

- Key quantities:
  - ρ_{UV}: UV luminosity density (from UVLF)
  - f_{esc}: ionizing photon escape fraction from galaxies
  - ξ_{ion}: ionizing photon production efficiency (conversion factor between UV luminosity density and ionizing photon number density)

Ionizing Photon Escape

- Hubble/WFC3 F336 imaging for 61 z=3.1 LAEs
  - 30% detection of ionizing photon escape
  - f_{esc}=20 % on average

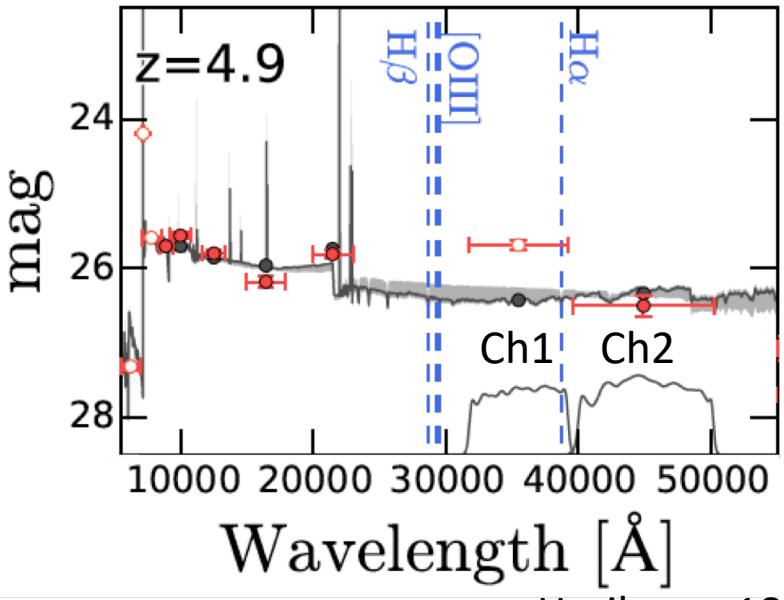




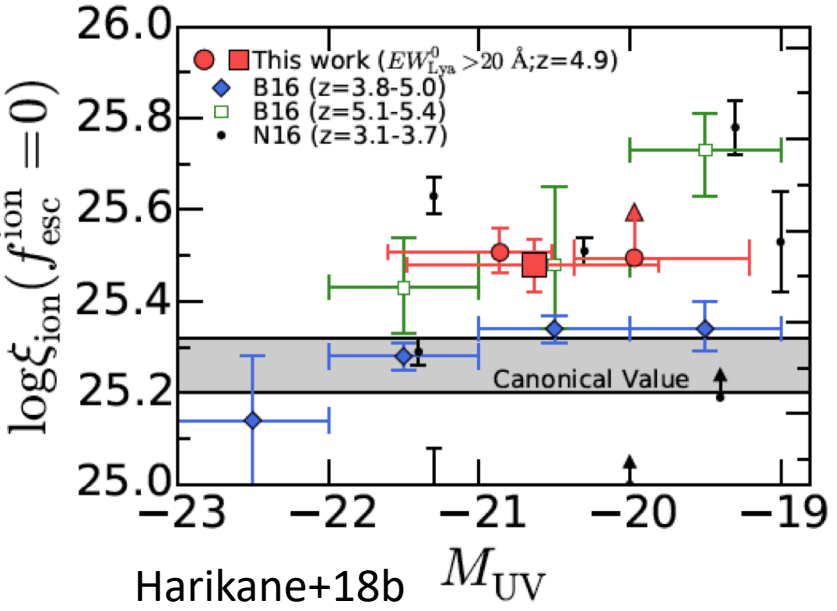
Fletcher+18

Ionizing Photon Production Efficiency

- Ionizing photon production efficiency ξ_{ion}
  - $\xi_{ion}/[\mathrm{Hz\ erg^{-1}}]=N(H^0)/L_{UV}$, $L_{Ha}=1.36\times10^{-12}N(H^0)$
- Ha at z>4: constrained with Spitzer photometry
  - ξ_{ion}~25.3 (LBG), 25.5 (LAE), enough for reionization



Harikane+18b

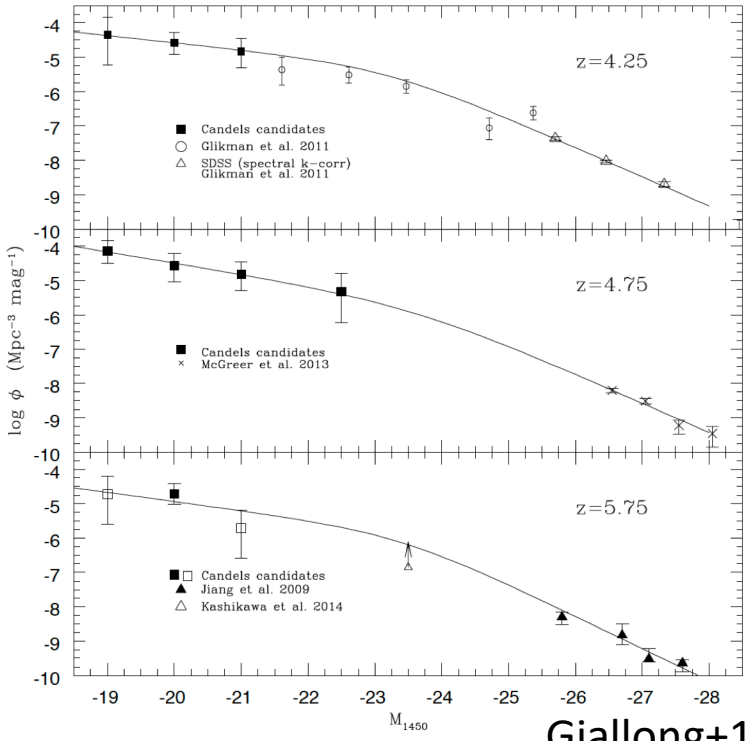


Harikane+18b

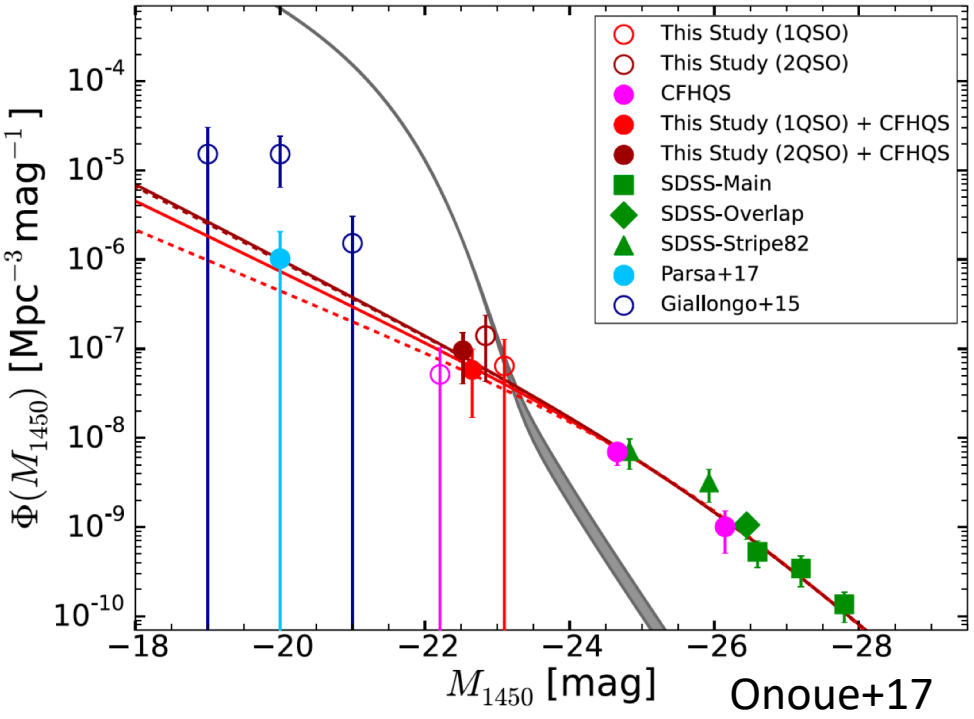
See also Nakajima+18, Bouwens+16

Contribution from AGNs

- Giallongo+15: faint AGNs can explain reionization
- Onoue+17, Parsa+18: not so many faint AGNs



Giallong+15

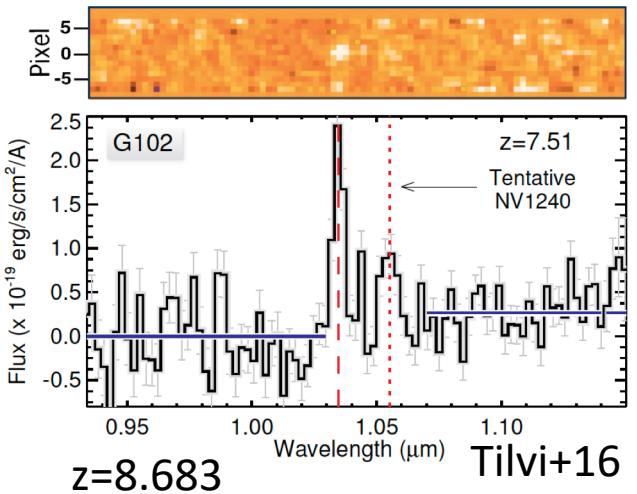


Onoue+17

NV1240 Emission from High-z LAEs

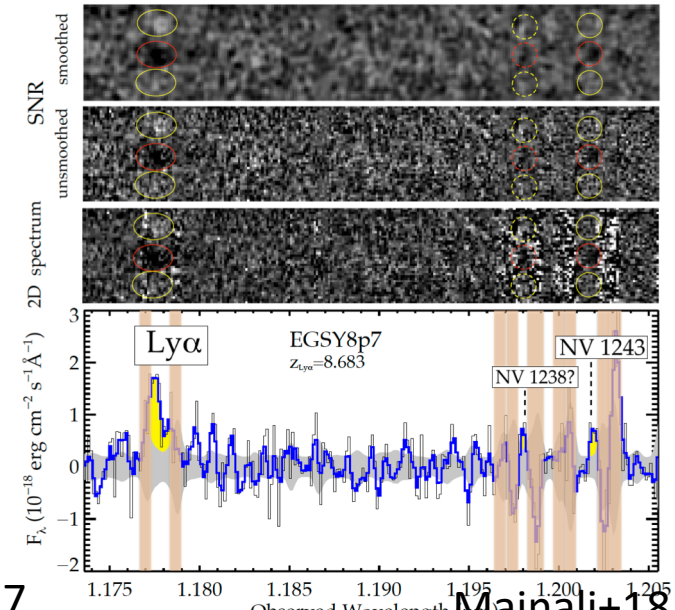
- NV reported in 4 z>~7 LAEs
  - >77 eV photon needed
    AGNs or fast radiative shock?
  - Such intense radiation enhance
    Lya transmission?

z=7.508



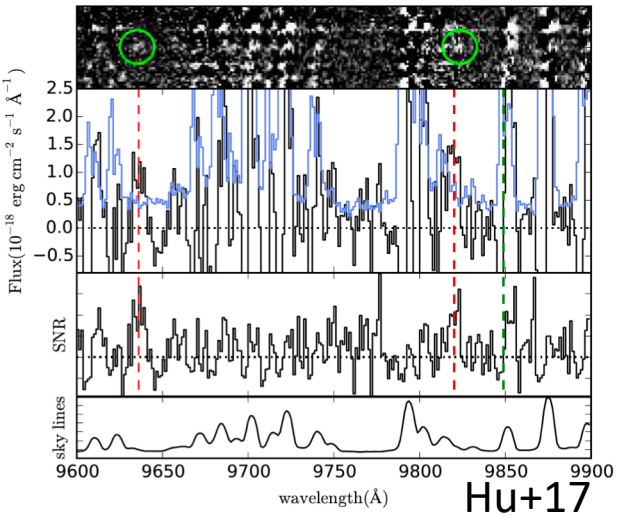
Tilvi+16

z=8.683



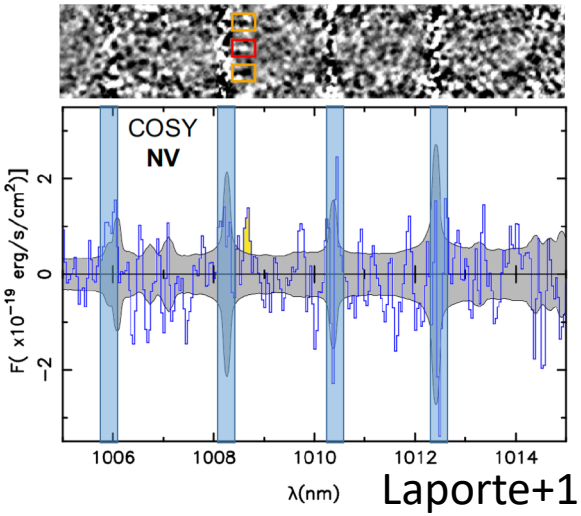
Mainali+18

z=6.925



Hu+17

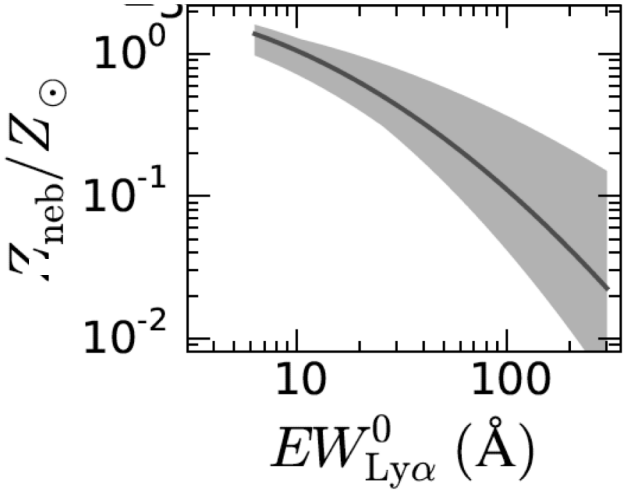
z=7.149

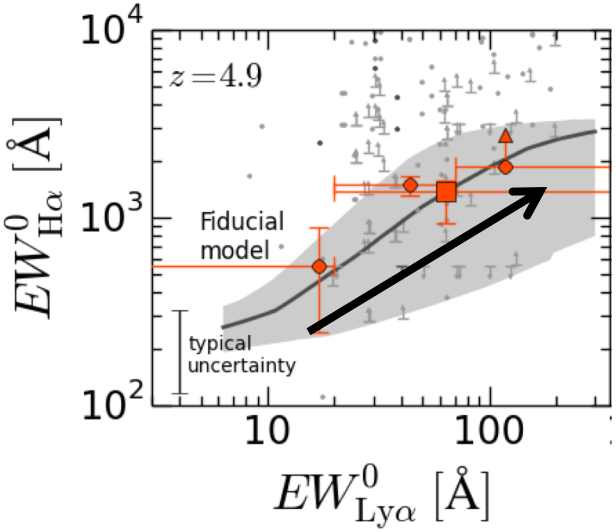


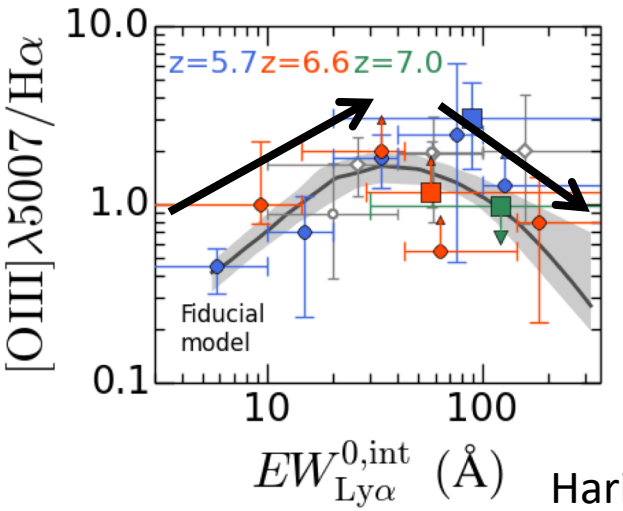
Laporte+17

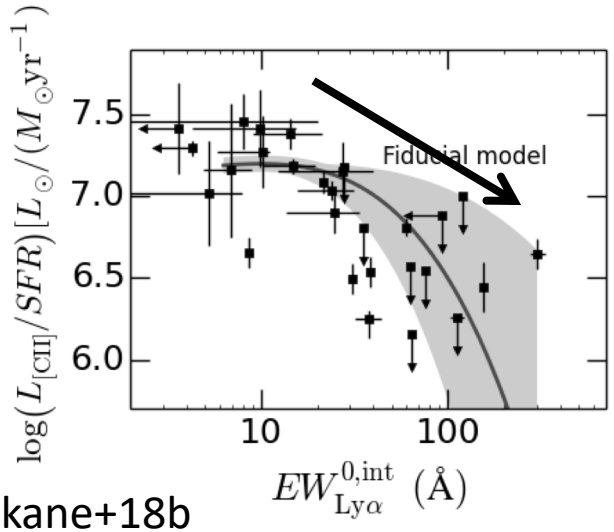
Chemical Properties

- Ha EW, [OIII]/Ha, [CII]/SFR of LAEs at z~5-7
  - EW_{Lya} –metallicity anti correlation
  - Z~0.03 Z_o with EW_{Lya}~200 A
  - Metal-poor galaxies (Kojima+)





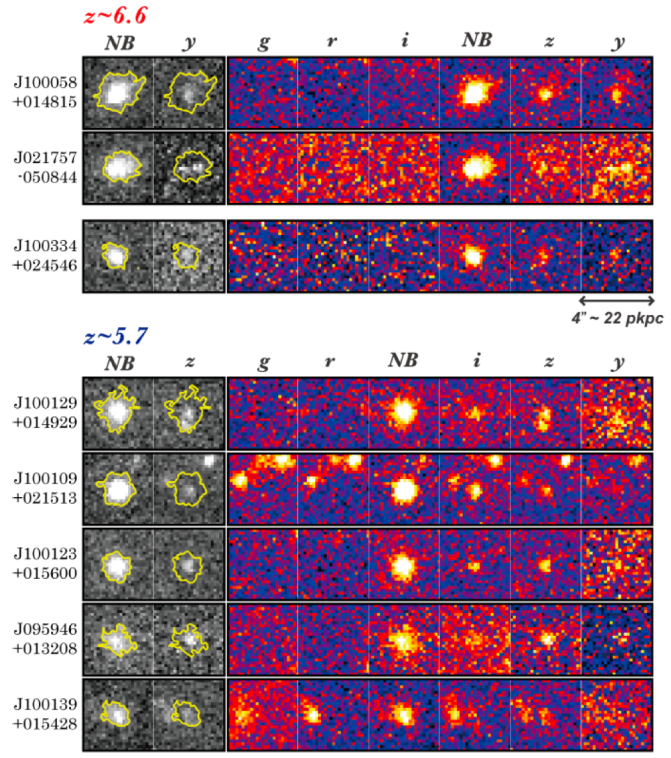




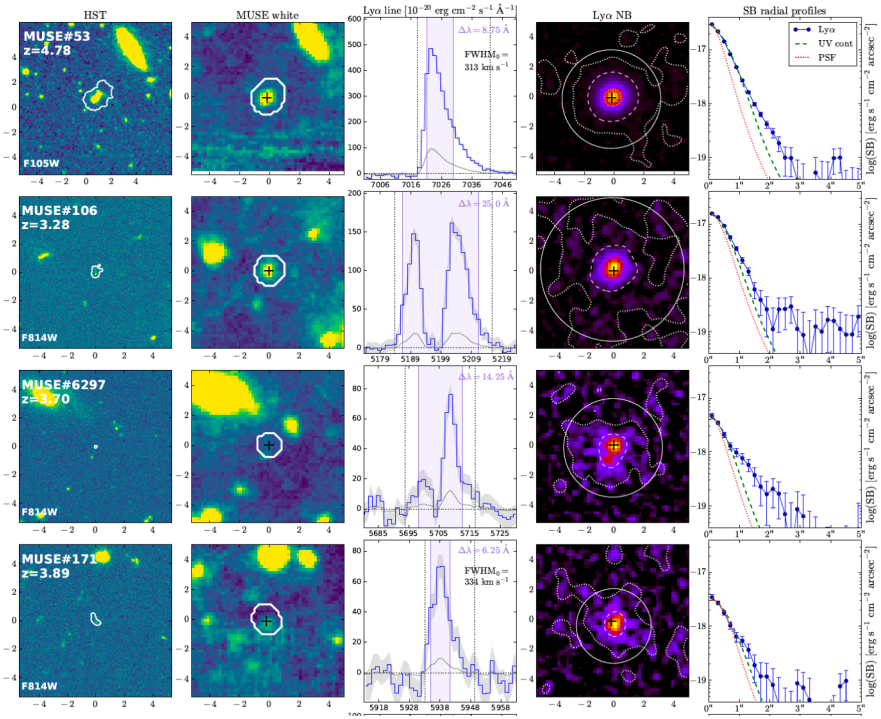
Harikane+18b

Extended Lya Emission

- >10 Lyman alpha blobs (LABs) at z~5-7 in HSC
- Lya halo of individual LAEs w/ VLT/MUSE
  - Scattering, cold stream, satellites, fluorescence



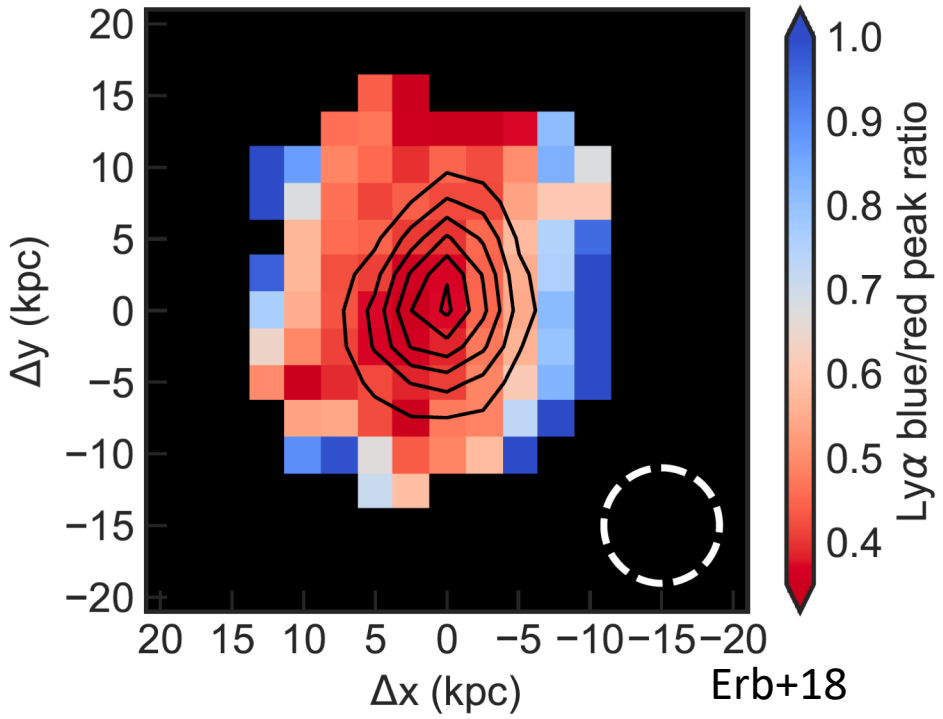
Shibuya+18a, Zhang+in prep.



Leclercq+17 see also Momose+14,16

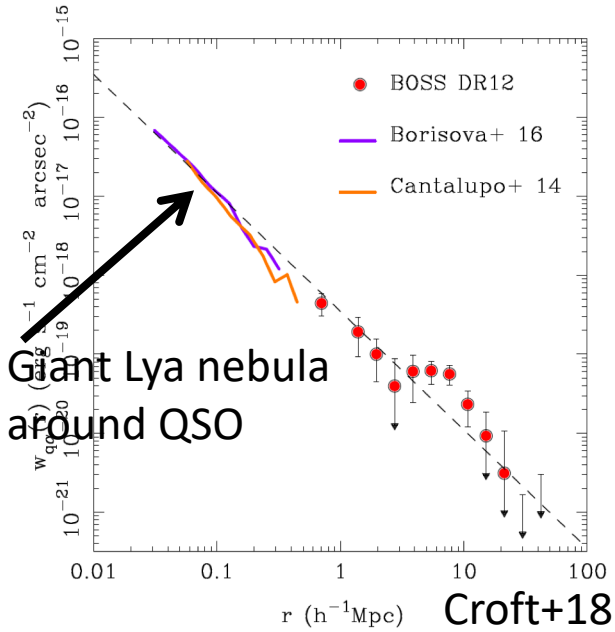
Integral Field Spectroscopy for LAE

- Keck/KCWI observation for a LAE at z=2.3
  - Extened Lya halo detected
  - Red peak in center, blue peak in outer regions
  - Due to radial component of outflow velocity



Large Scale Lya Emission

- Intensity mapping: using unresolved emission
- Croft+16,18: SDSS QSO x Lya (pixel value)
  - Lya emission around QSOs (to 10 cMpc) at z=2-3.5
- Kakuma+in prep.: HSC LAEs x Lya
  - Lya emission detected (to 1 cMpc) at z=5.7, 6.6



Croft+18

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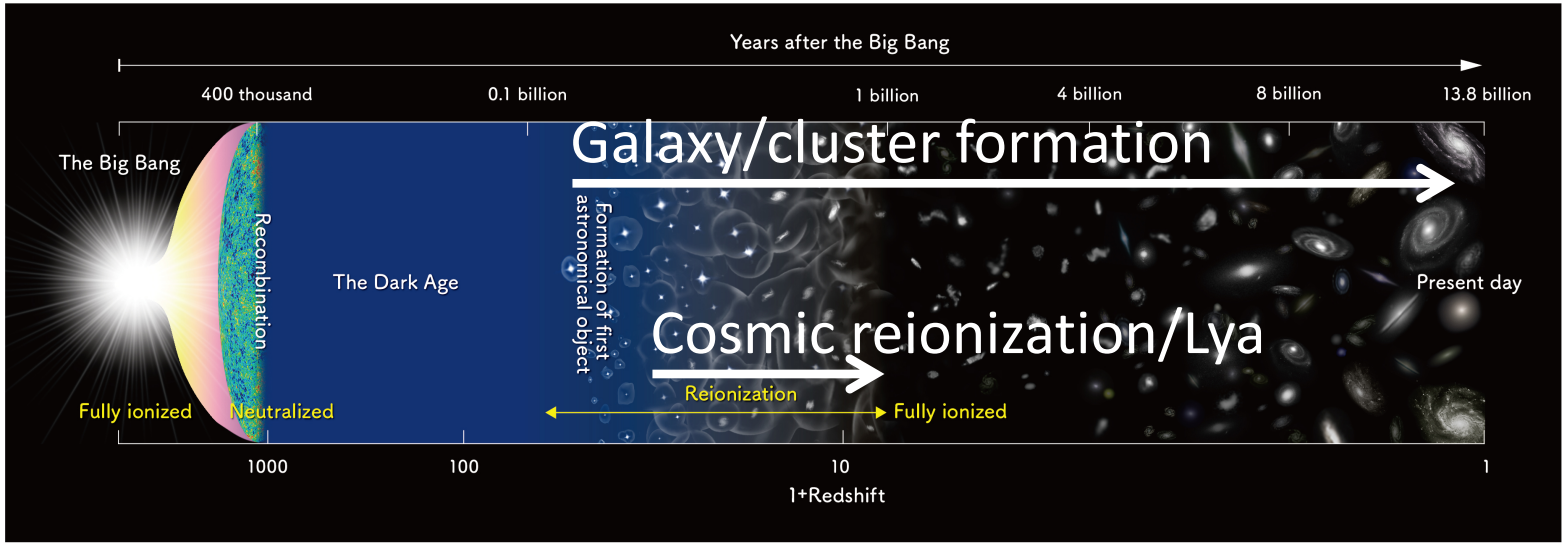

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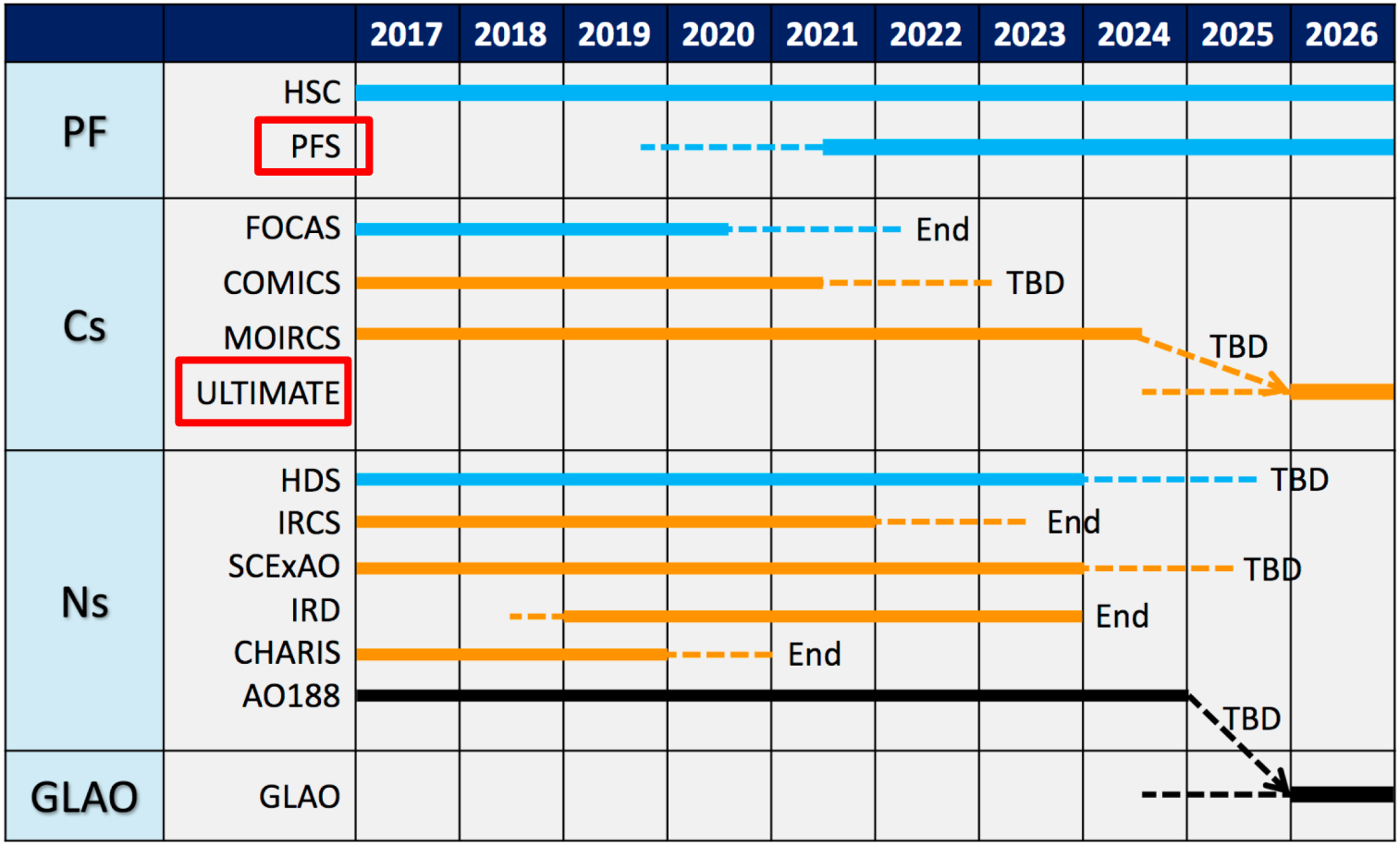
Future Prospects

- HSC SSP Survey will complete in 2019-2020



From Yoshida-san's slide

Subaru/Prime Focus Spectrograph (PFS)

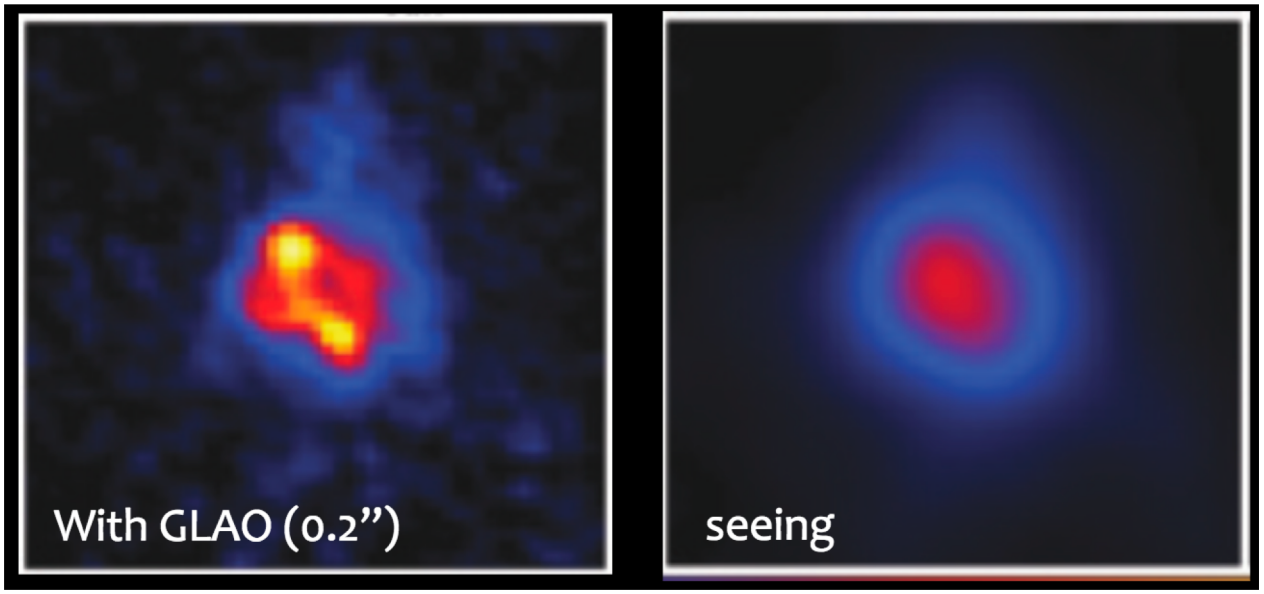
IPMU

- Multi fiber spectroscopy
  - 2396 fibers, FoV 1.3 deg2
  - 0.36-1.26 um with three arms
- High-z sciences
  - HI tomography at z=2.1-2.5 (25.5k gals.)
  - Topoplogy of reionization (15k LAEs x HI cross corr.)
  - ISM of high-z galaxies at z=3.5-7 (25k gal., outflow)
  - Bright end of UV LFs

Blue	380-640 nm	R~2500
Red	640-955 nm	R~3200, 5000
Near-IR	955-1260 nm	R~4500

ULTIMATE - Subaru

- ULTRA WIDE FIELD LASER TOMOGRAPHIC IMAGER and MOS with AO for TRANSCENDENT EXPLORATION by SUBARU
  - AO+IR instrument, imaing & MOS/IFU
  - FoV 14'x14', high spatial resolution (0.2")



From Koyama-san's slide

Summary

- Galaxy/cluster formation
  - UVLF determined from -24 to -16 mag
  - Origin of SFRD evolution
  - Proto-clusters, quaser environments
- Cosmic reionization/Lya
  - Lya LF: no AGN in bright end, steep in faint end
  - Reioniztion history is constrained well
  - Ionizing source: star-forming galaxies? (fesc, ξion)
  - Hard ionizing photon in high-z galaxies (NV)
  - Extend/large-scale Lya emission detected
- Future prospects