Exploring early galaxies and cosmic structures with Subaru, HST, and ALMA

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Credit:NASA, ESA and the HST Frontier Fields team (STScI)

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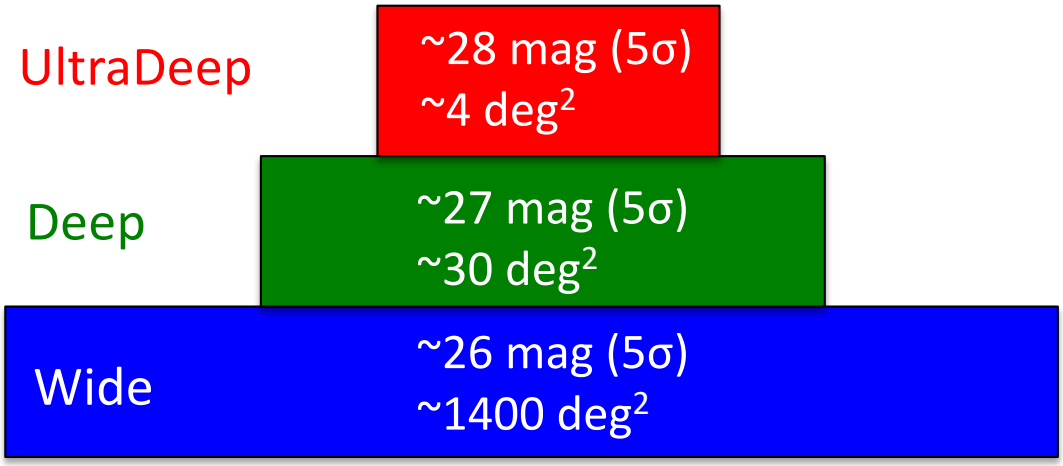
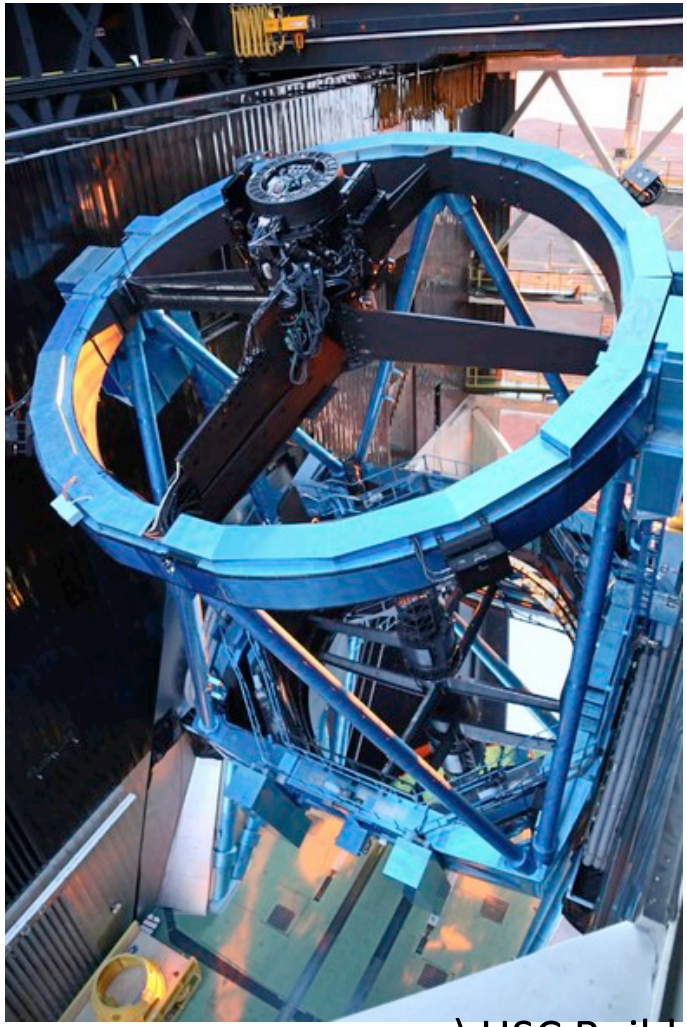
Subaru Hyper Suprime-Cam (HSC) Survey



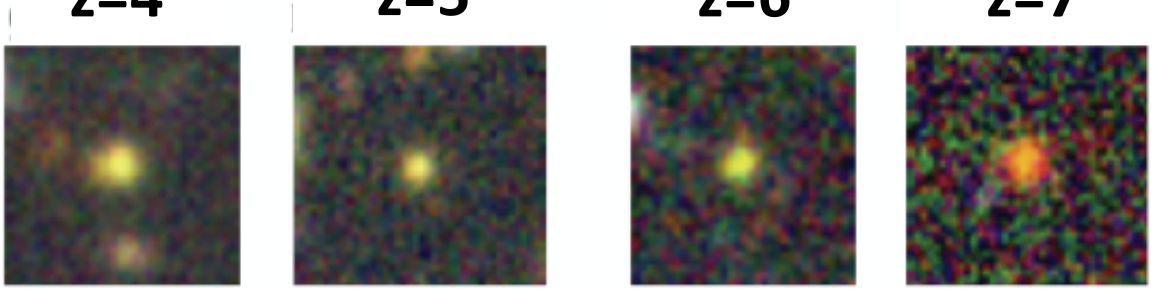


c) HSC Builder's blog

- HSC SSP survey has started since 2014 under the collaboration of Japan, Princeton, and Taiwan.

Largest Sample of High-z Galaxies at z=4-7

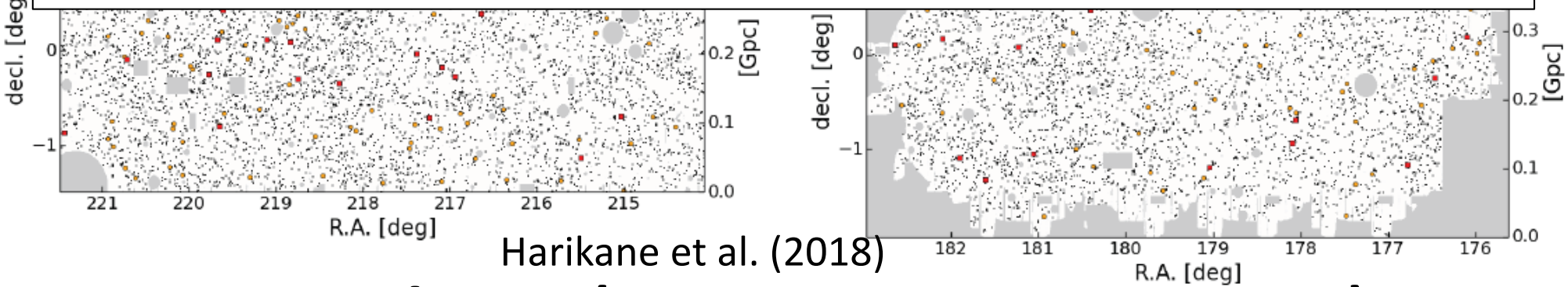
Examples



Ono et al. (2018)

～100 times larger than prev. samples

First cosmological probe of z≳4 galaxies



Harikane et al. (2018)

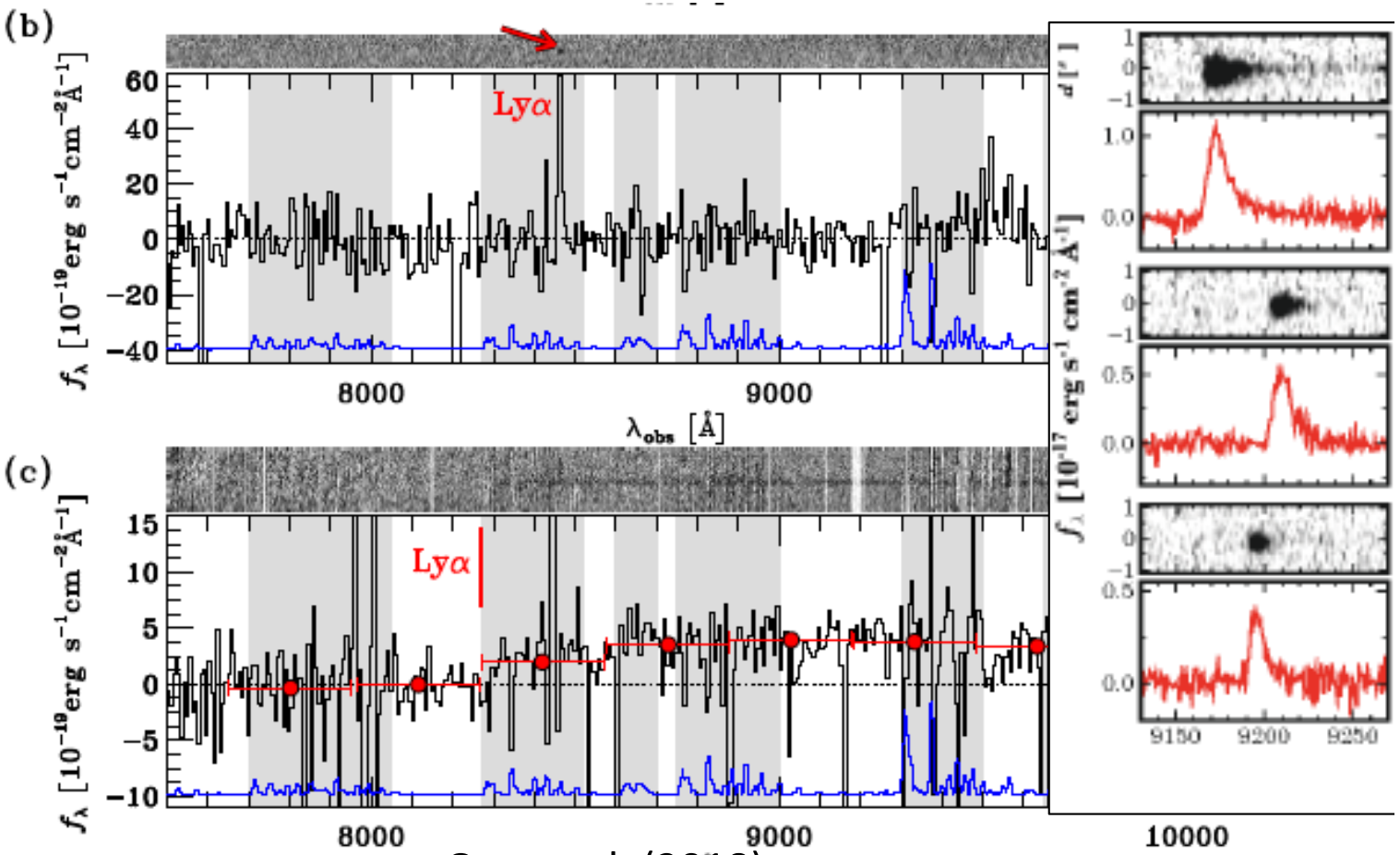
- **579,565 galaxies (+ 2354 Lya emitters; LAEs) over 100 deg^2 → 1.4 Gpc^3 (cosmology scale)**

Spectroscopic Follow-up Observations

Keck

Subaru

Magellan



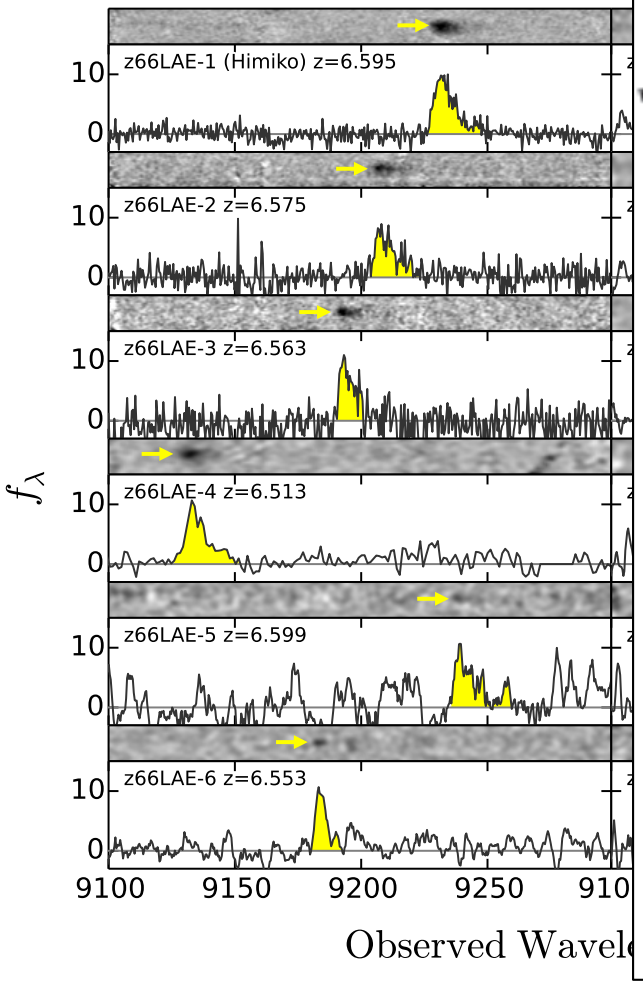
Ono et al. (2018)

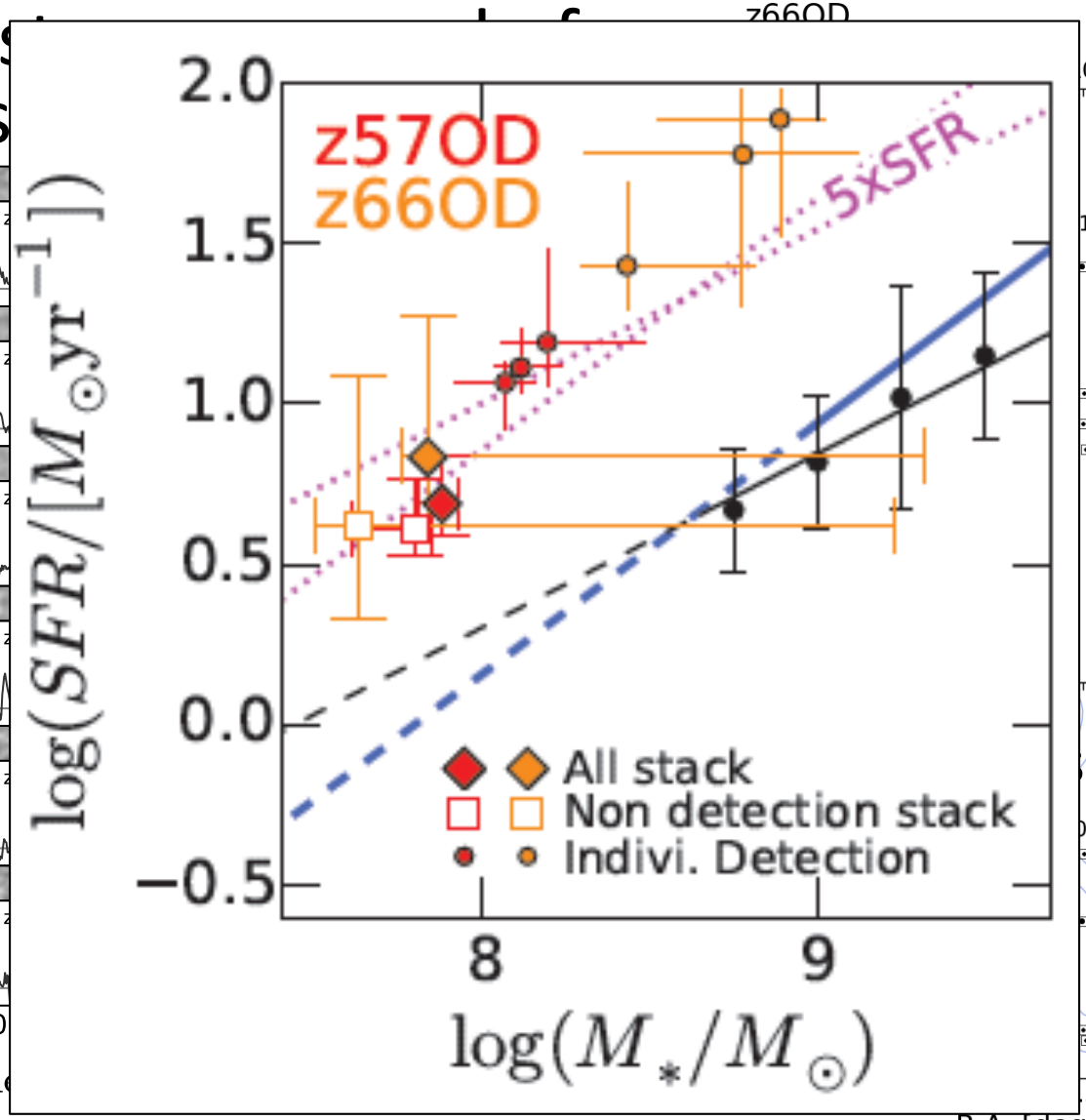
Shibuya et al. (2018)

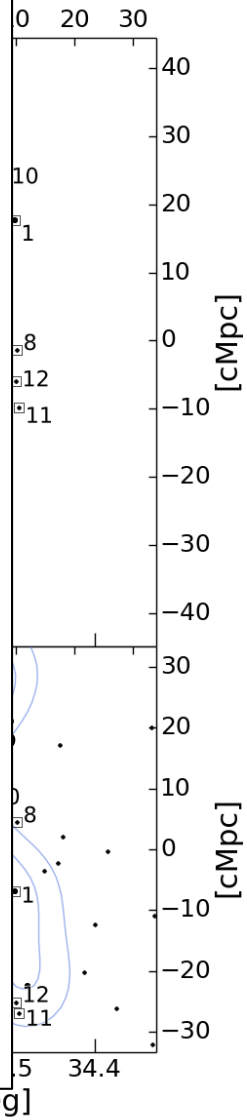
- On-going Keck, Subaru & Magellan spectroscopy → Subaru/PFS spec.
- A total of 348 dropouts at z=3-7 and 174 LAEs at z=6-7 (at the EoR).
- In 1 deg^2 of SXDS LAEs: >80% spec. completeness (log L_{Lya}>43.0 erg s^{-1})

3D Large Scale Structure & Protocluster at z~7

- z66OD: Protoclus… … z66OD
  12 galaxies at z(s…

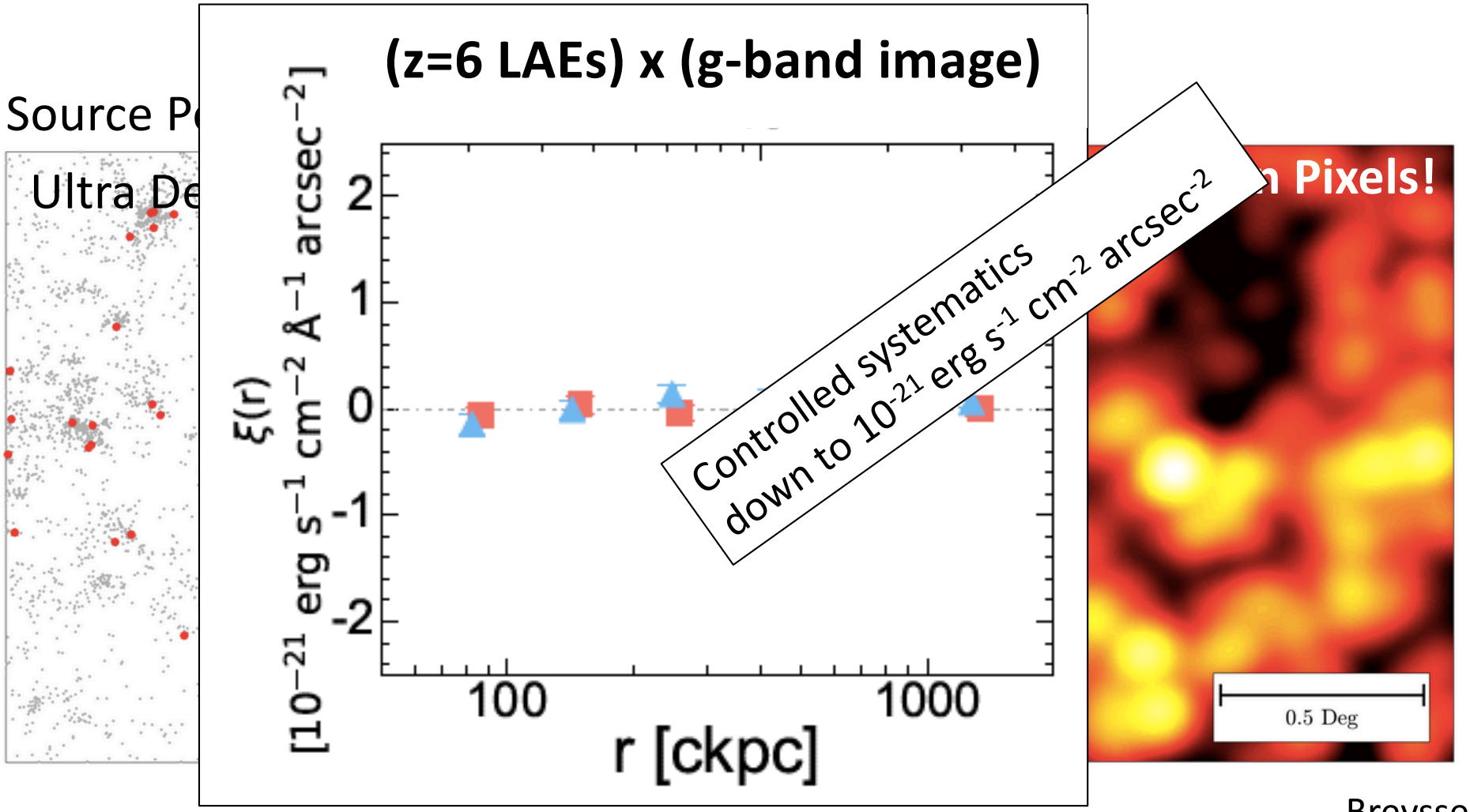






Harikane+19

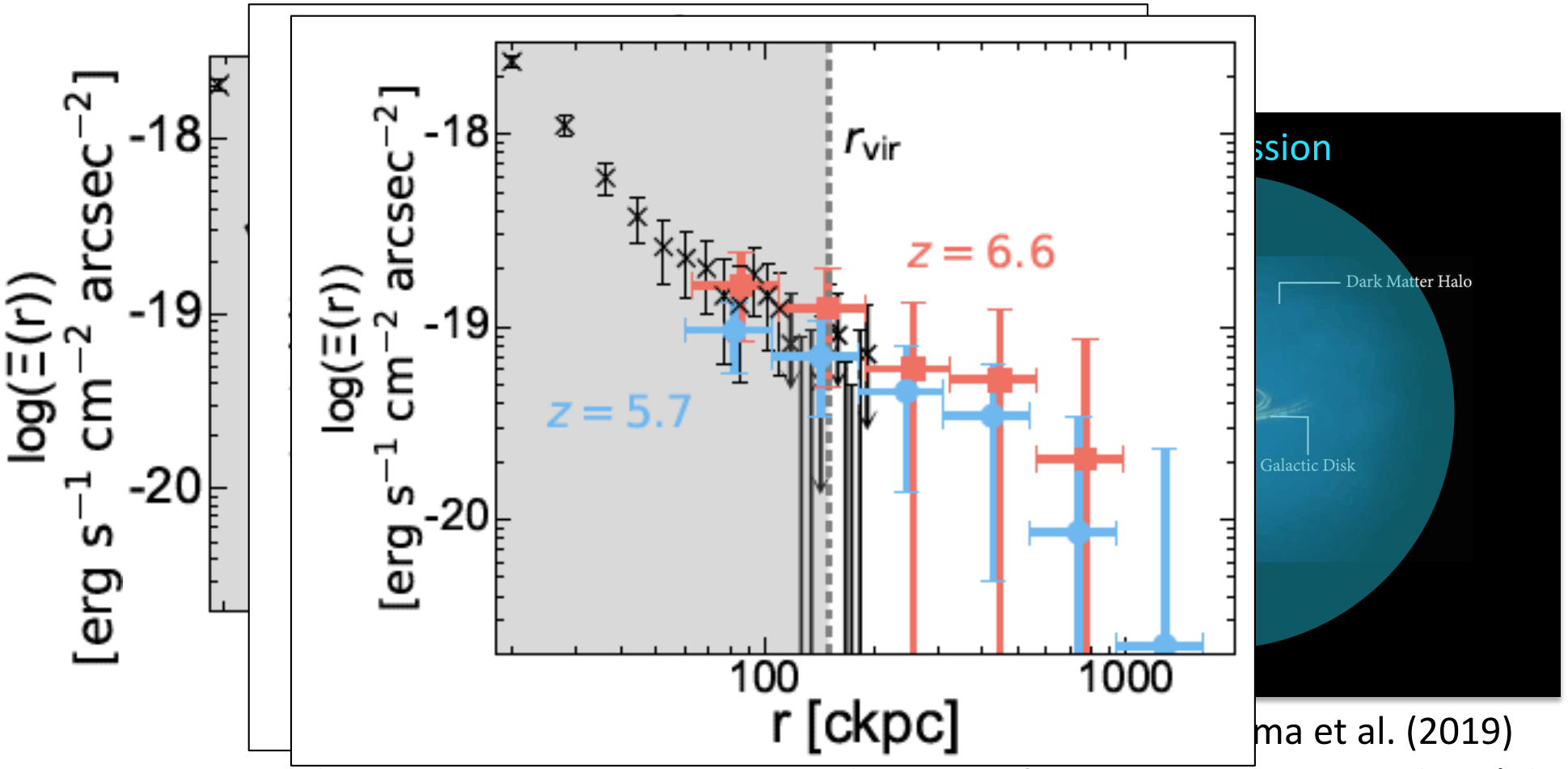
Lyα Intensity Mapping
Cross-Correlation with the LAEs



Breysse+16

- Careful evaluation of systematics w uncorrelated sources for calibration (Kakuma et al. 2019)

Lyα Intensity Mapping
Cross-Correlation with the LAEs



ma et al. (2019)

- HSC: Largely extended Lyα emission with a size of 200-1000 comoving kpc (about 5 times larger than virial radius of dark matter halo).

  → Physical origin? Lyα resonance of associated dwarf galaxies/cold accretion?

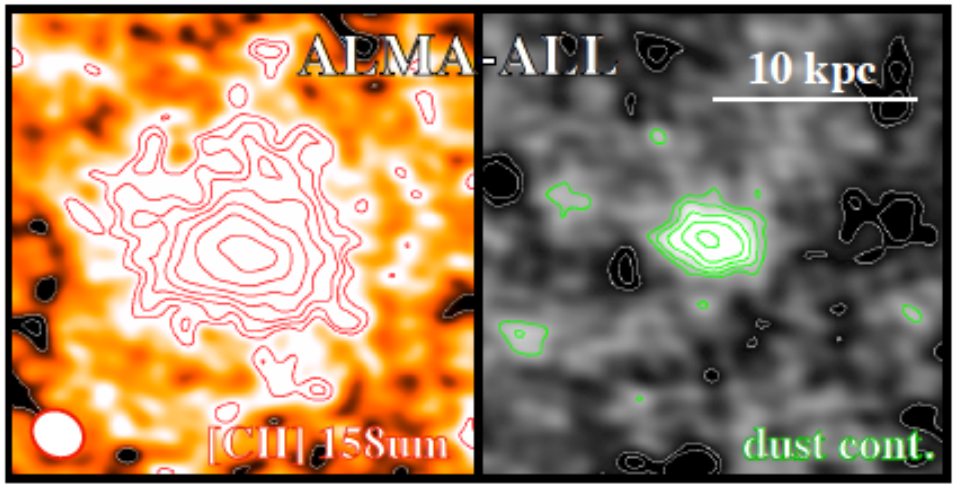
Reionization effects? -> Comparison with z=5.7 and 6.6 results

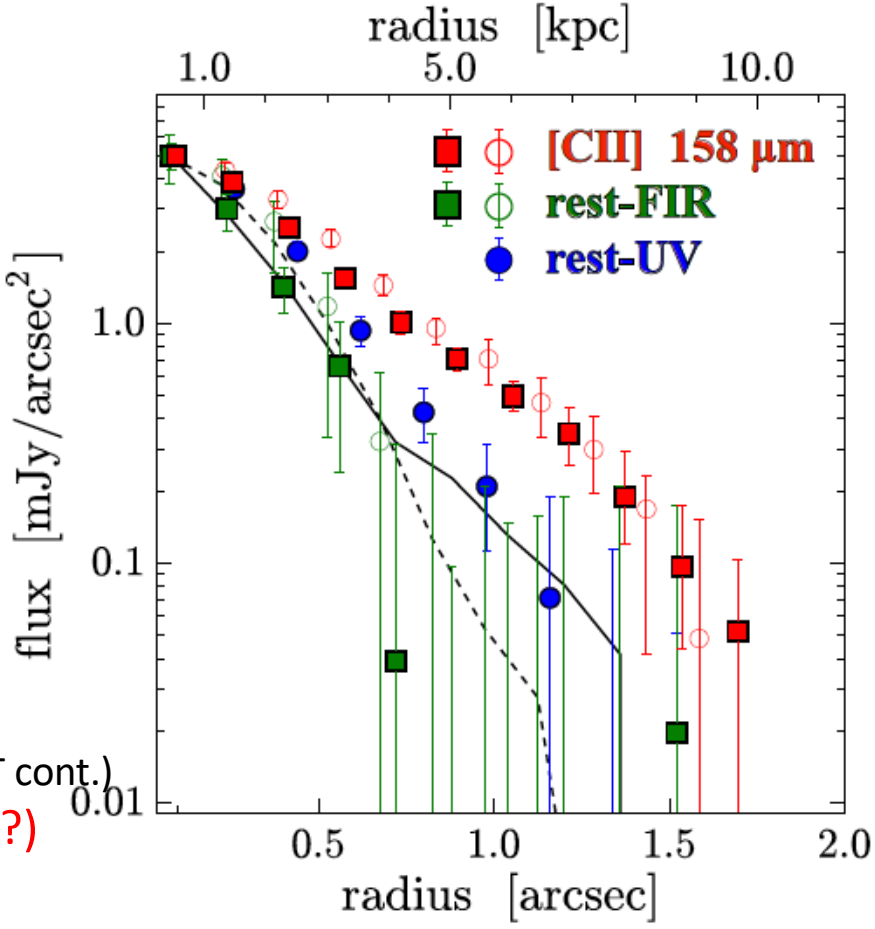
Metal Halo Suggested by ALMA obs

Fujimoto et al. (2019)

FIRST IDENTIFICATION OF 10-kpc SCALE [C II] 158μm HALOS AROUND STAR-FORMING GALAXIES AT $z = 5 - 7$

Seiji Fujimoto[1], Masami Ouchi[1,2], Andrea Ferrara [3,4], Andrea Pallottini[3], R. J. Ivison[5,6], Christoph Behrens[3], Simona Gallerani[3],

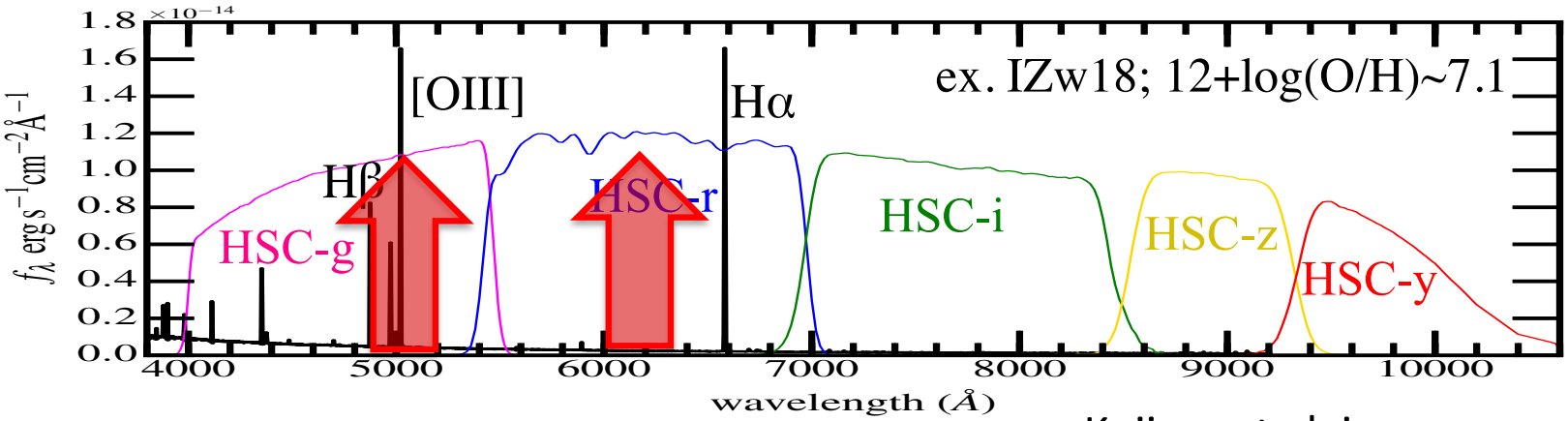




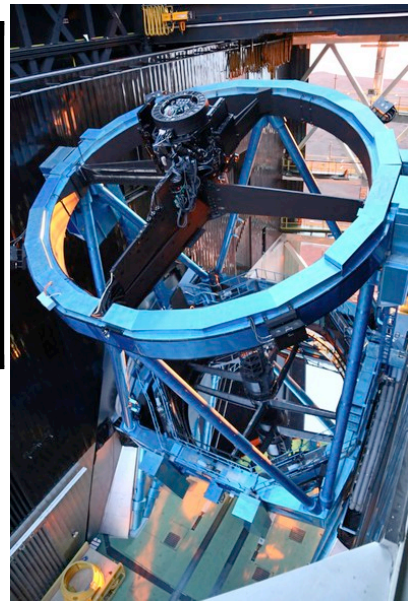
- 10-kpc [CII]158µm halo at z=5.153-7.142
  - C^+ gas extends 5x more than SFR regions (dust/HST cont.)
- Interestingly, comparable with Lya halo (HI gas?)
- Simulations do not explain the halo

→ important mechanism of outflow? (e.g. cold-mode)

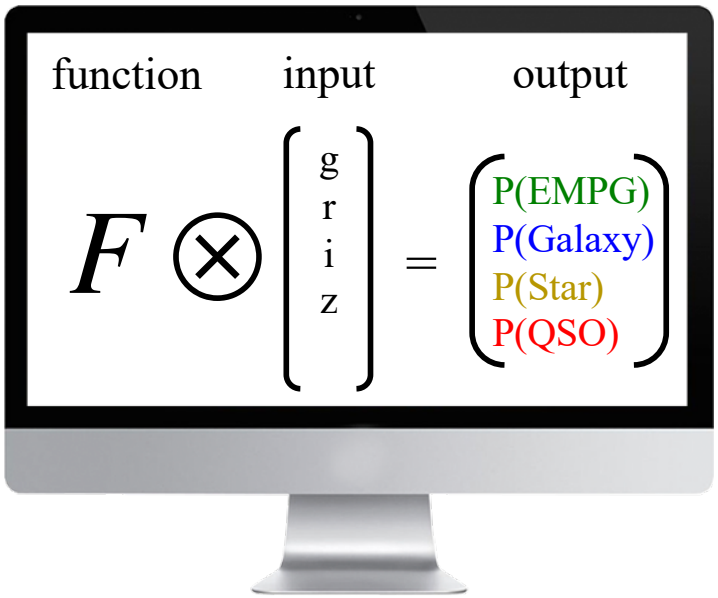
Early Galaxy ISM?
Extremely Metal Poor Galaxy at z=0



Kojima et al. in prep.



+ Machine learning technique



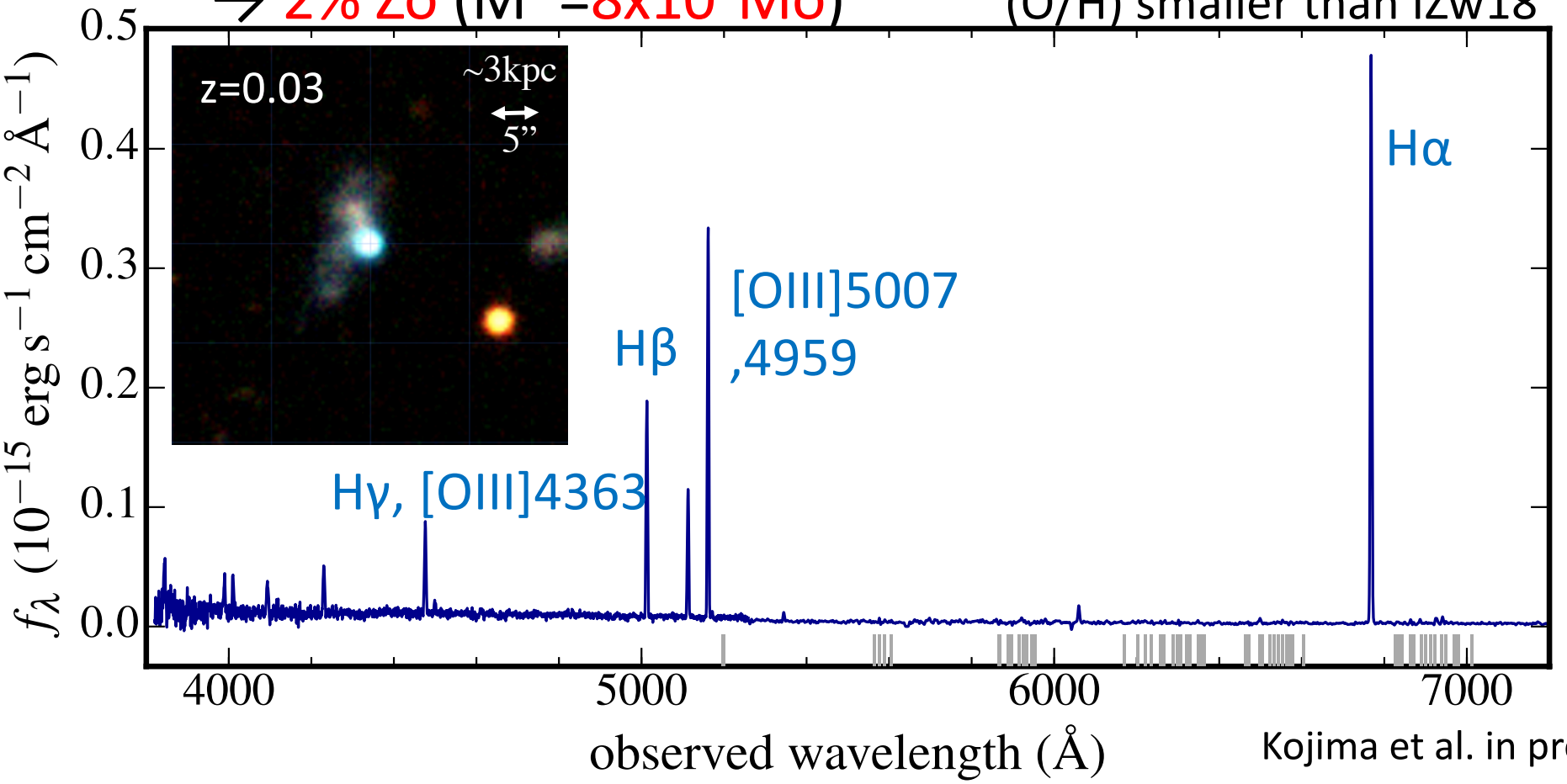
SED models (30,000 × 4)

Beagle	Chevallard & Charlot 2016
Stellar model	Castelli & Kurucz 2004
QSO composite	Selsing et al. 2016

Subaru/HSC: 10 Metal Poor Galaxies

Example: HSC J1631+4426

→ 2% Zo (M*=8x10^{5}Mo) (O/H) smaller than IZw18

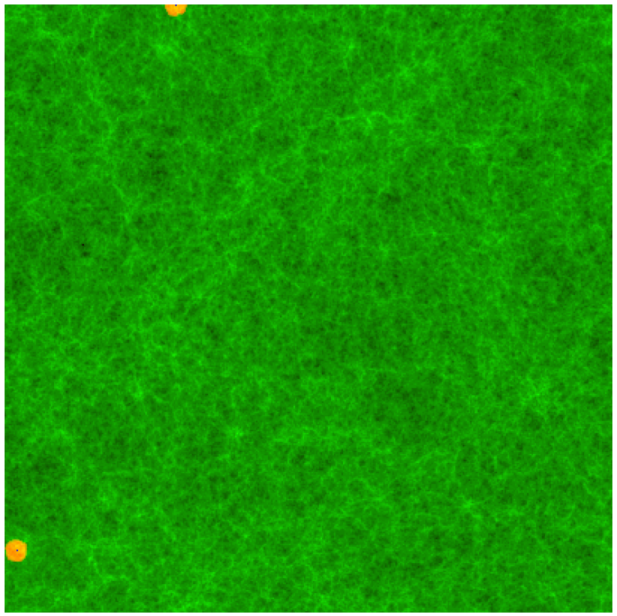


Kojima et al. in prep.

- Paper I. : Subaru/HSC+ML survey design (Kojima et al.)
- Paper II. : Gas densities and ionization states (Kojima et al.)
- Paper III.: Morphological properties (Isobe et al.)

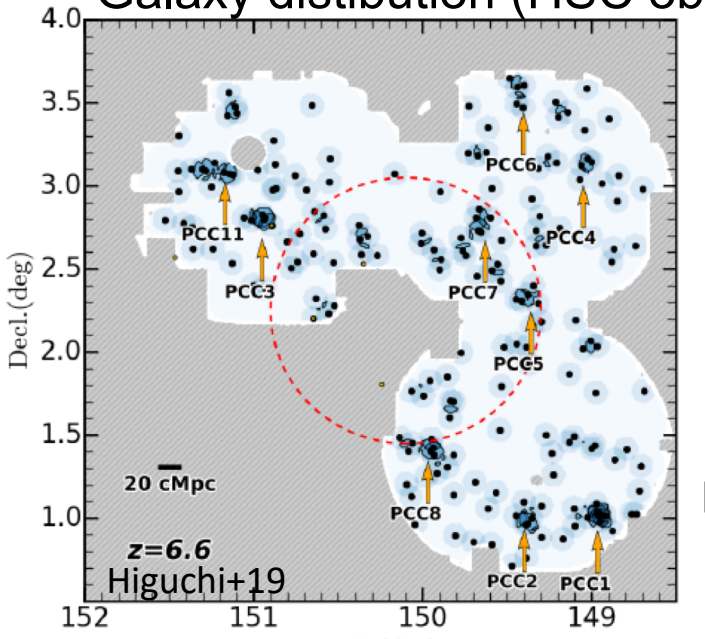
Future Prospects: Galaxy-21cm Cross Correlation

RT simulations

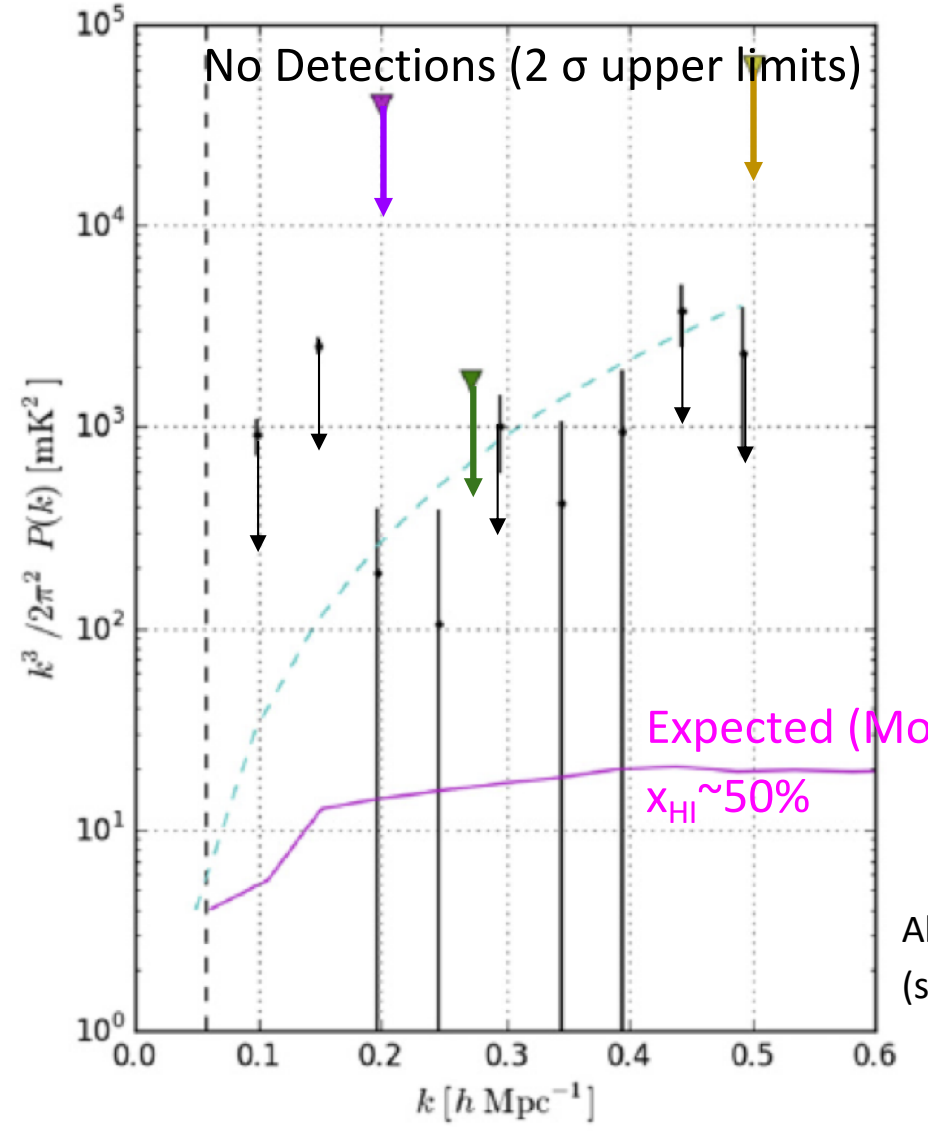


Galaxies (blue dots),ionized bubbles (orange) (Iliev+06)

Galaxy distibution (HSC obs)



Epoch of Reionization (EoR) HI 21cm Auto Power Spectrum



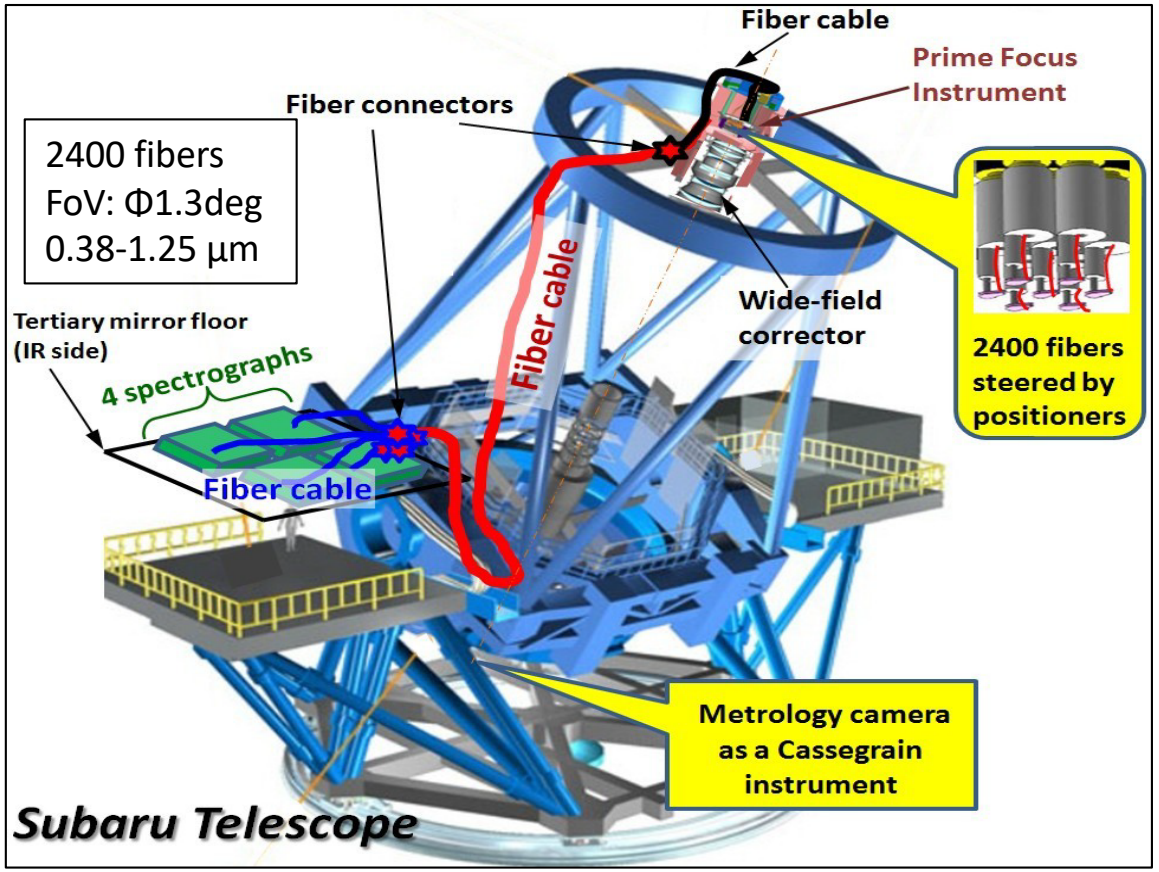
Ali+15

(see+Ali+18)

No detection of 21cm EoR signals, due to FG sys (Gehlot+18

- Cross Correlation with real signal of galaxies at EoR

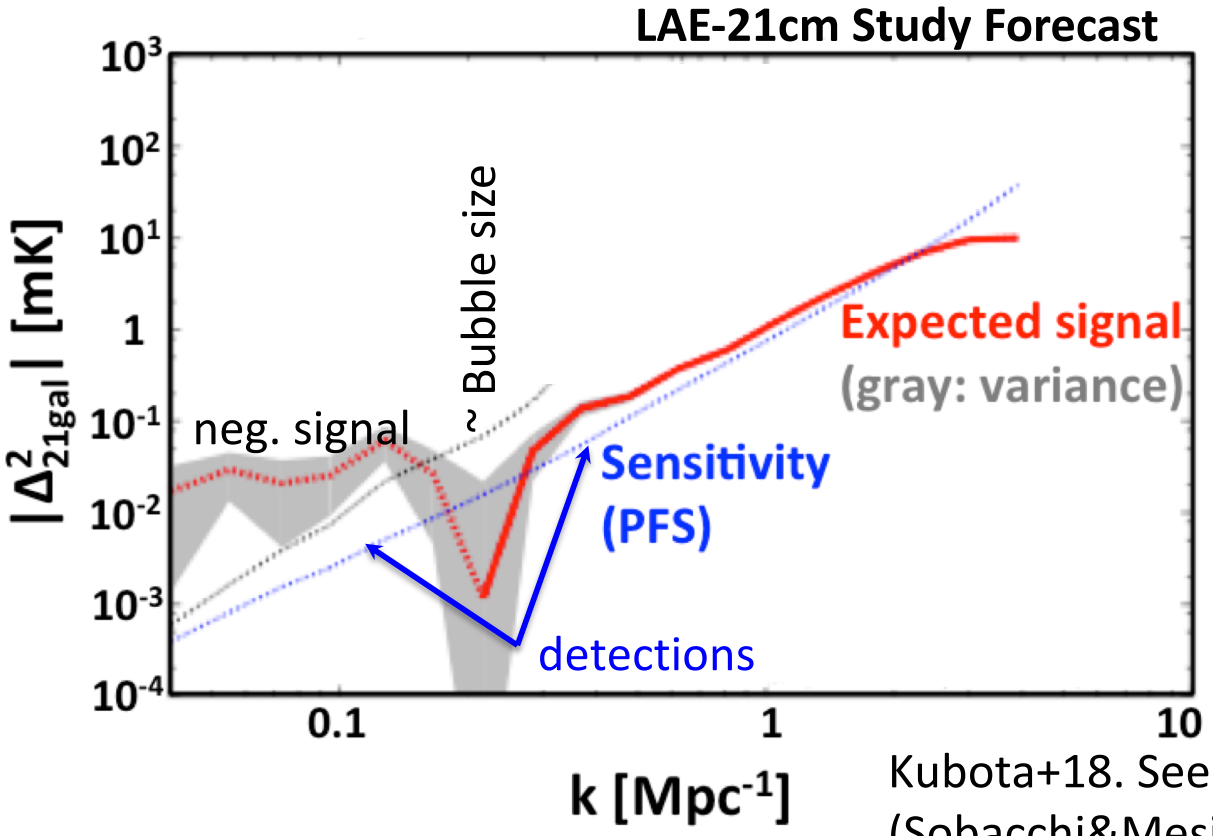
Subaru Prime Focus Spectrograph (PFS)



- Under the collaborations with many institutes over world (planned FL 2021)
- Spectroscopy for ~10,000 LAEs at the EoR (z=6-7) over 15 deg^2 area

Galaxies (PFS) and HI 21cm (MWA, SKA) → Cross-correlation signals

First Detection of EoR HI 21cm Signal by Galaxy-21cm Cross Correlation



21cm: SKA

Kubota+18. See similar predictions (Sobacchi&Mesinger+16, Hutter+18)

- Goal-1: Detection of the cross-correlation signals -> Evidence of early cosmic HI struc.
  - Positive cross-correlation at k~0.4 Mpc^{-1} at ~5 sigma
  - Negative cross-correlation at k~0.1 Mpc^{-1} at ~3 sigma

- Goal-2: Determination of the transition scale at z=6.6 with Δk=~0.1 Mpc^{-1} accuracy
  - First definitive evidence of cosmic ionized bubbles

Summary

- Recent studies of early galaxies and reionization
  - Subaru HSC survey (579,565 gals at z=4-7 in 100 deg^2)

1) 3D galaxy map at z=6.6 → proto-cluster at z=6.585
2) Detection of Lyα emission beyond r_{vir}, 200-1000 ckpc
3) ALMA identification of extended [CII] halo (10 pkpc)
4) Extremely metal poor galaxies at z=0 incl. 2% Zo

- Subaru/HSC+PFS survey and 21cm observations
  - Identifying EoR 21cm signals and ionized bubbles