

# すばるHSC/PFS広域遠方銀河探査と ケック深分光観測のシナジー

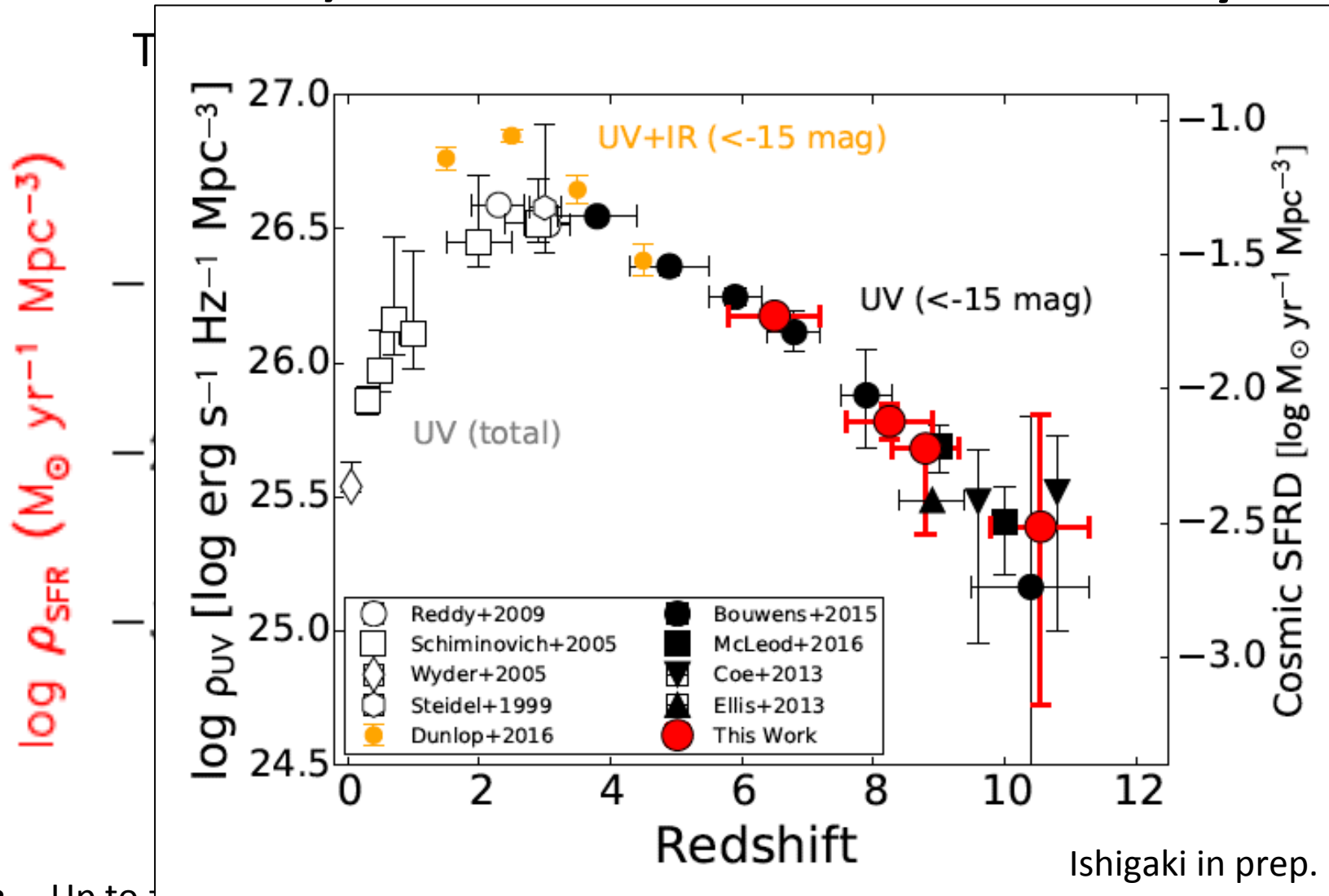
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# High-z Galaxy Studies

- Subaru+Keck: powerful for high-z galaxy studies.
- Our past/on-going Subaru+Keck studies → Future
- High-z galaxy studies: 3 major goals
  - 1) Stars: SFR history, stellar pop.,  $M^*$  assembly
  - 2) Gas/Dust: ISM (chemical/kinematic) evolution
  - 3) Connection w IGM: Radiation/Matter exchange via CGM

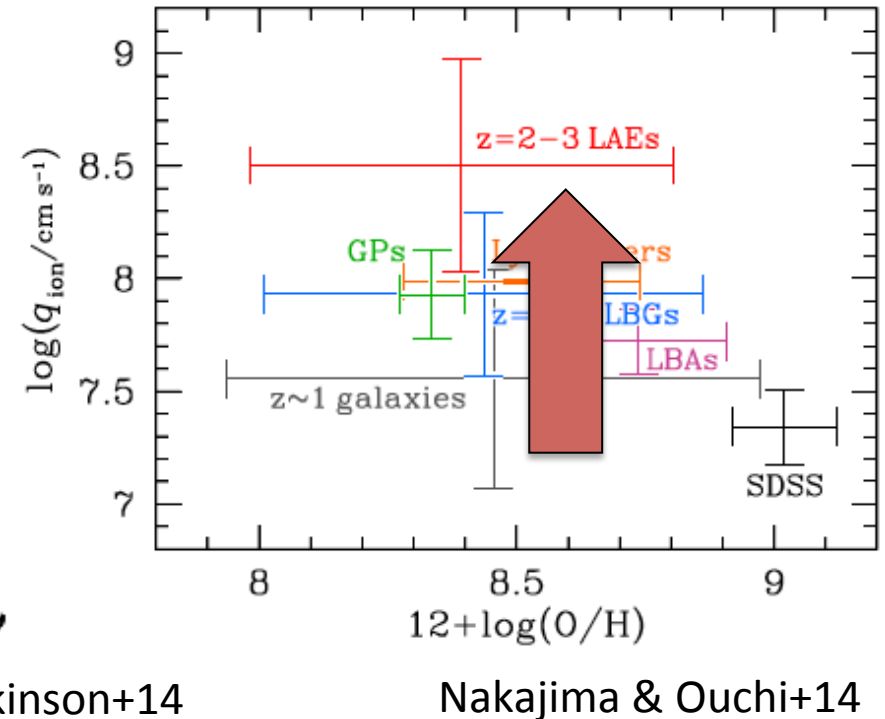
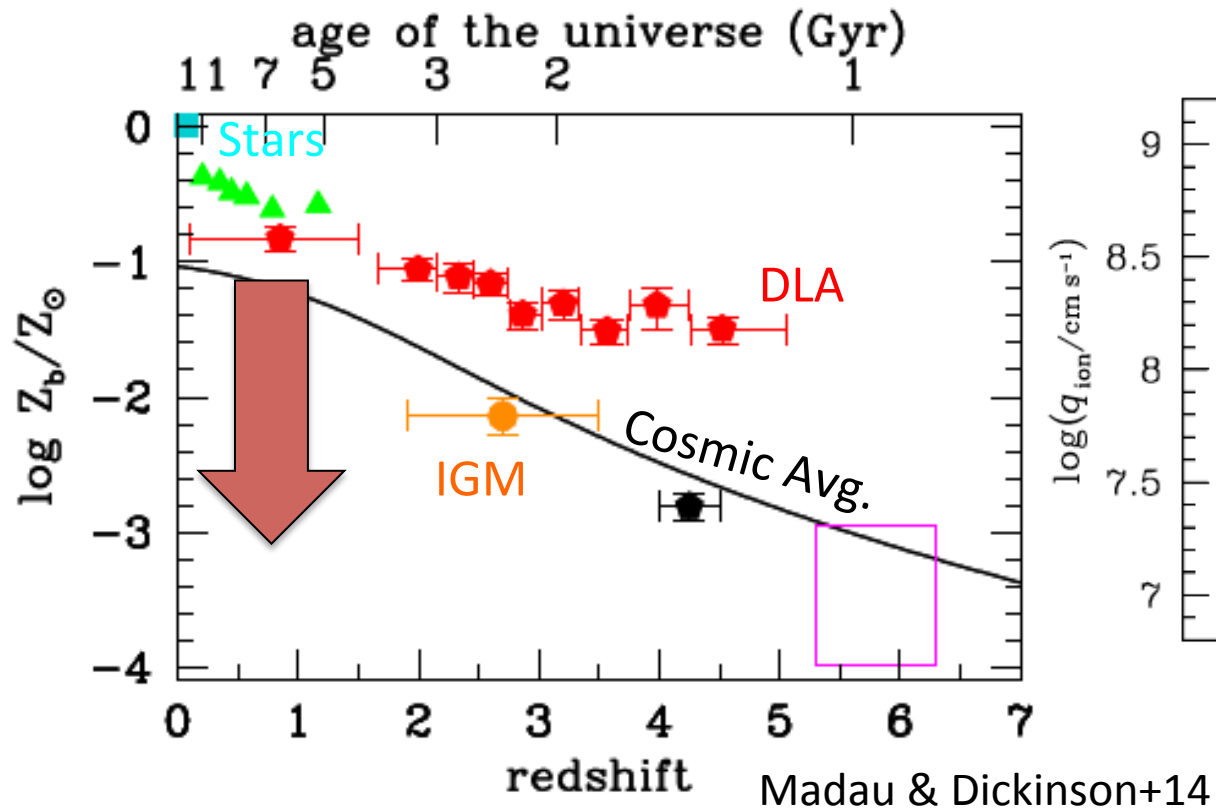
# 1) Star Formation History



- Up to  $z \sim 11$ , peaking at  $z \sim 2$
- Decreasing from  $z \sim 2$  towards higher redshift
  - Rapid decrease at  $z > 8$ ? More data
  - > Disappearing. Smooth evolution

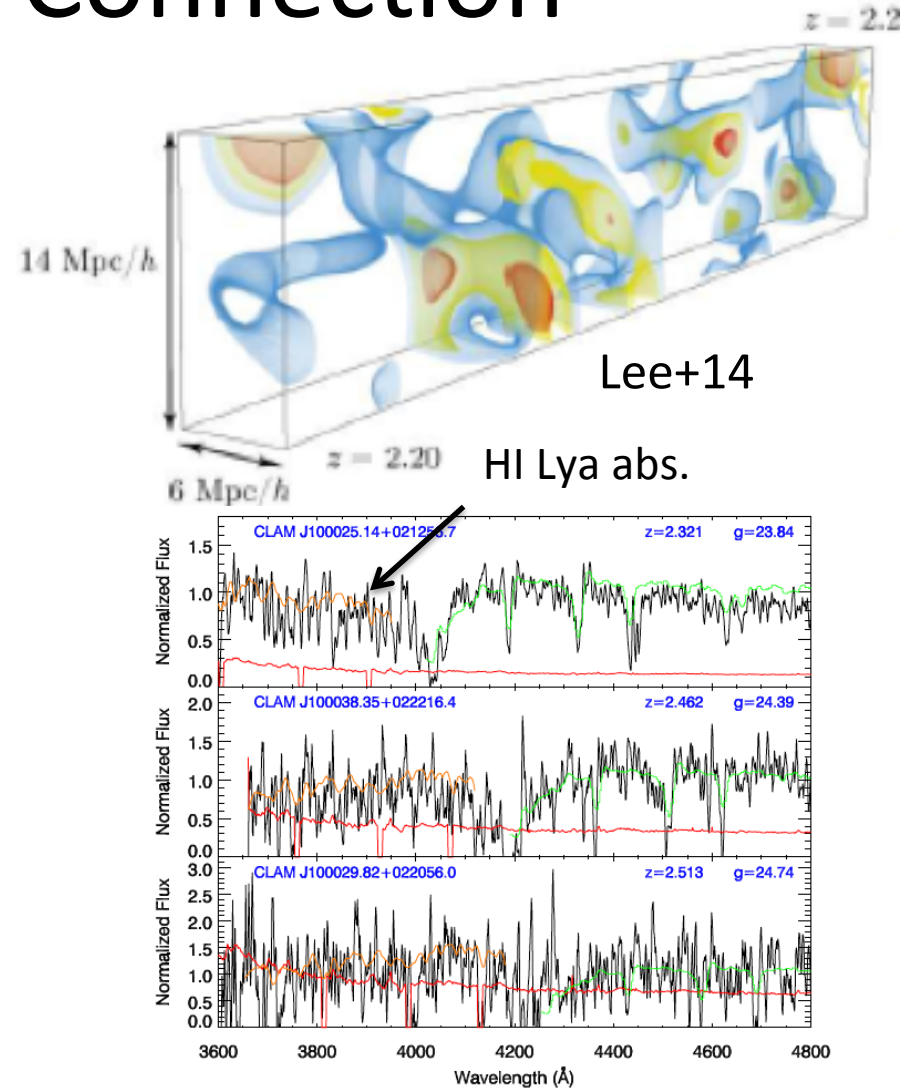
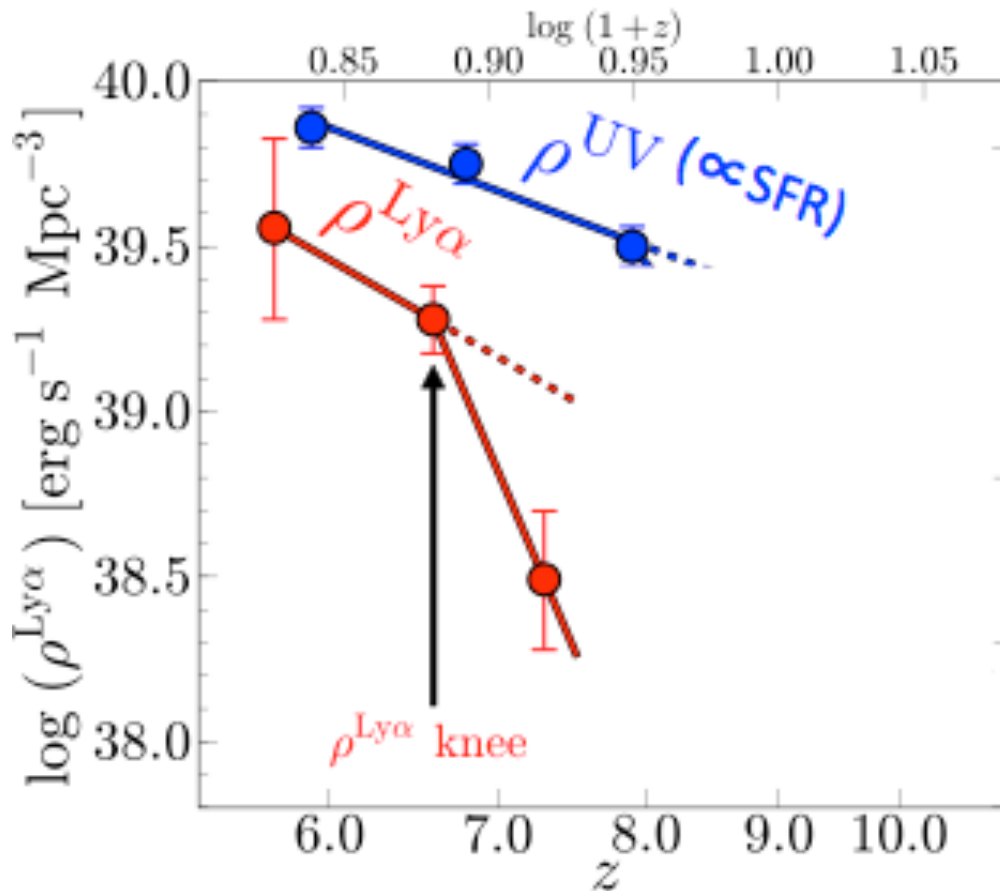
Ishigaki in prep., Oesch+15, McLeod+15)

## 2) ISM Evolution



- ISM state (deep opt/NIR spec+ALMA; See Onodera+/Kashino+16)
  - Metal abundance (ratio)
  - Ionization state
  - Dust
  - Kinematics

# 3) Galaxy-IGM Connection



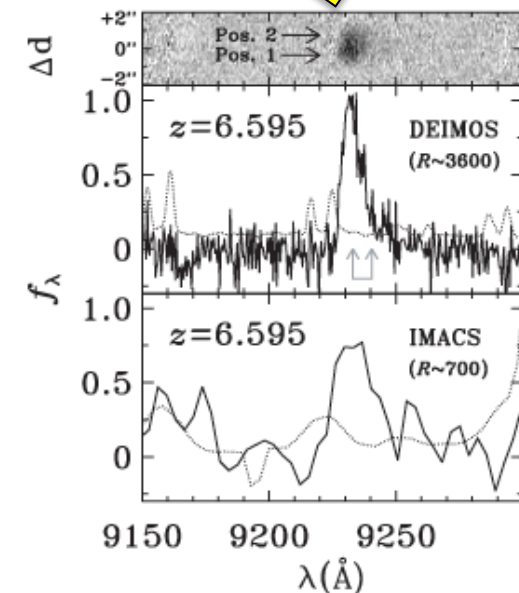
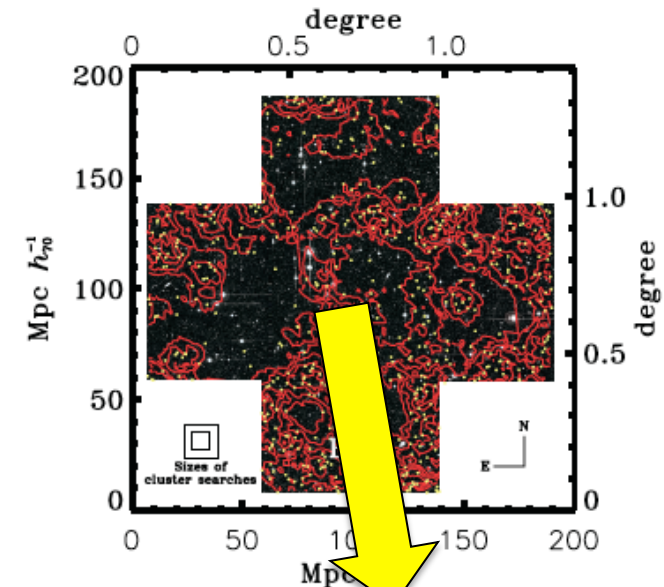
- Reionization: Constraints on  $x_{\text{HI}}(z)$  by Ly $\alpha$  DW abs. Ion phot escape (see Iwata-san's talk)
- Galaxy-IGM gas connection: 3-4 Mpc res. map by tomography (Lee+14) (see Shimakawa-san's talk)

# Past Subaru-Keck Time Exchange Prog.

- Past Subaru-Keck programs?
- Subaru wide-field imaging  
→ Supplying Spec. targets at  $z \lesssim 7$
- Keck/DEIMOS deep spec. (conf/prof)
- Goals 1) and 3)

## High impact papers (as of Jan. 2017)

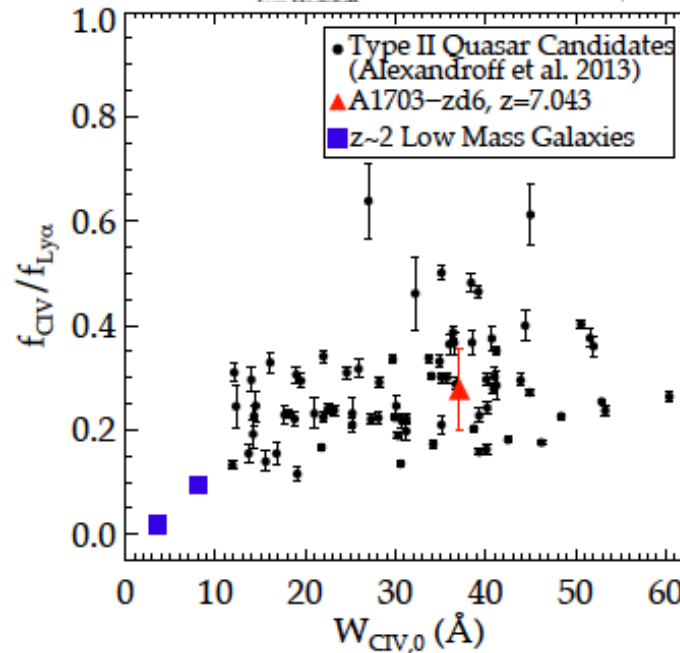
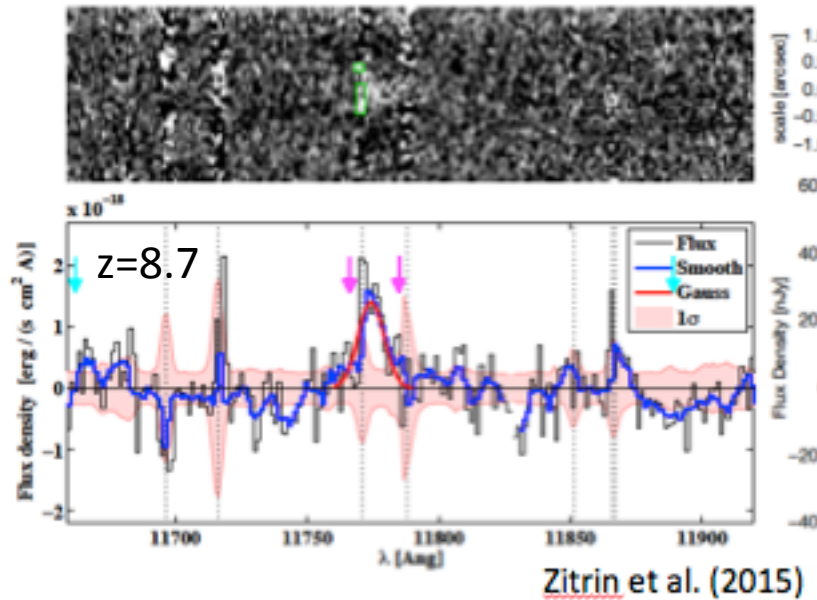
- Shimasaku et al. 2006----- 236
  - Kashikawa et al. 2006----- 307
  - Ouchi et al. 2010----- 297
- Another 3 papers w 100-200 citations



# Subaru's Role Among the Other Programs

(Opt) Subaru/Suprime-Cam objects at  $z \lesssim 7$  -> Keck/DEIMOS

After 2014: (NIR) Hubble (+lens) targets at  $z \gtrsim 7$  -> Keck/MOSFIRE



- Transitions to the next generation tel./inst.
  - 2019: JWST
  - 2020: PFS SSP
  - Late 2020s: TMT
  - Late 2020s: WFIRST

Stark+16

# The Role of Subaru and Keck in the late 2010s (and 2020s)

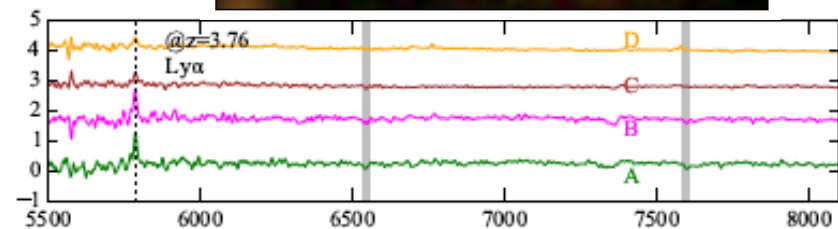
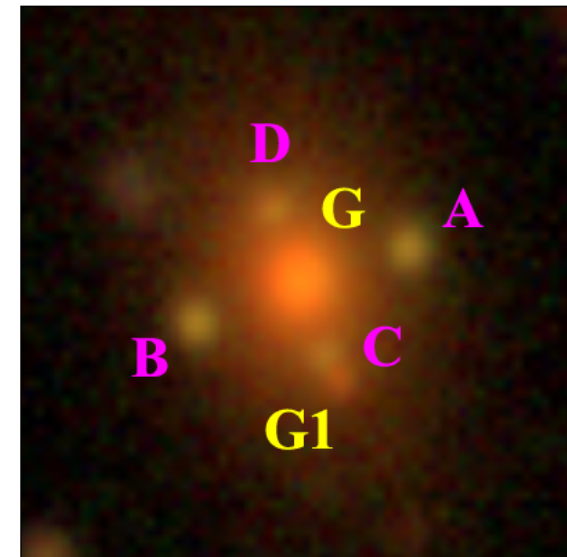
- Subaru/HSC imaging:  $\sim 1 \rightarrow 10\text{-}1000 \text{ deg}^2$
- **Unexplored** (rare) galaxies at  $z < \sim 7$   
Important formation period (lensed  $L^*$ ) gal.

- a) Statistics of Ly $\alpha$  blobs (bright LAEs)
- b) Galaxy outflow evol.
- c) ISM (chemical) evol.
- d) Galaxy-IGM connection

- $\rightarrow$  Keck/**LRIS, MOSFIRE, CWI** spec.  
for goals 2) and 3)

- Complementary to JWST  $z > 8$  studies
- Supplying  $z < \sim 7$  targets to JWST

More et al. 2017



$i=22\text{-}23\text{mag}$  LAE (w low L AGN?)

## a) Bright Ly $\alpha$ Emitters (blobs) at $z \sim 6-7$

- Following the HSC collaboration policy, we have removed the figures and text about HSC results.

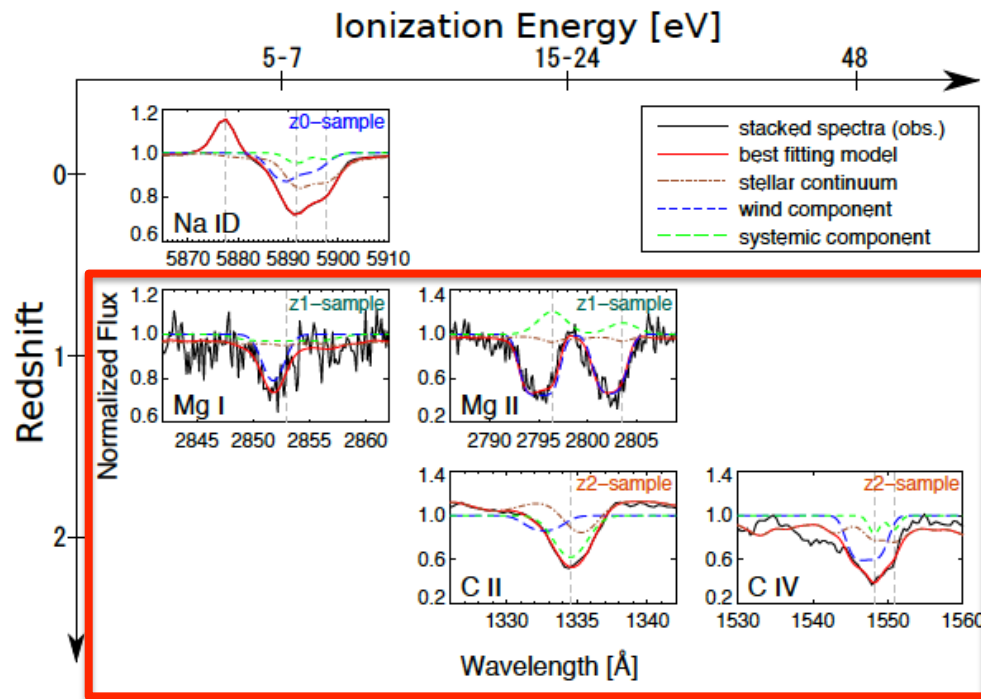
## a) Very Metal Poor Star-Formation?

- Following the HSC collaboration policy, we have removed the figures and text about HSC results.

## b) HSC Bright Continuum Galaxies

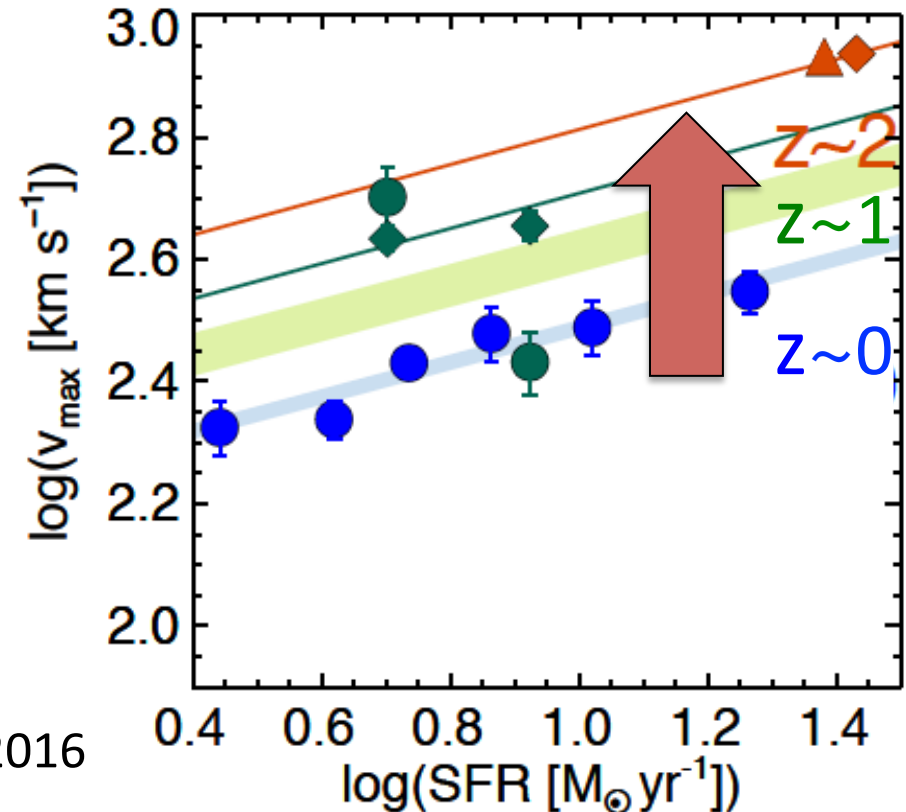
- Following the HSC collaboration policy, we have removed the figures and text about HSC results.

# b) Evolution of Outflow Velocity



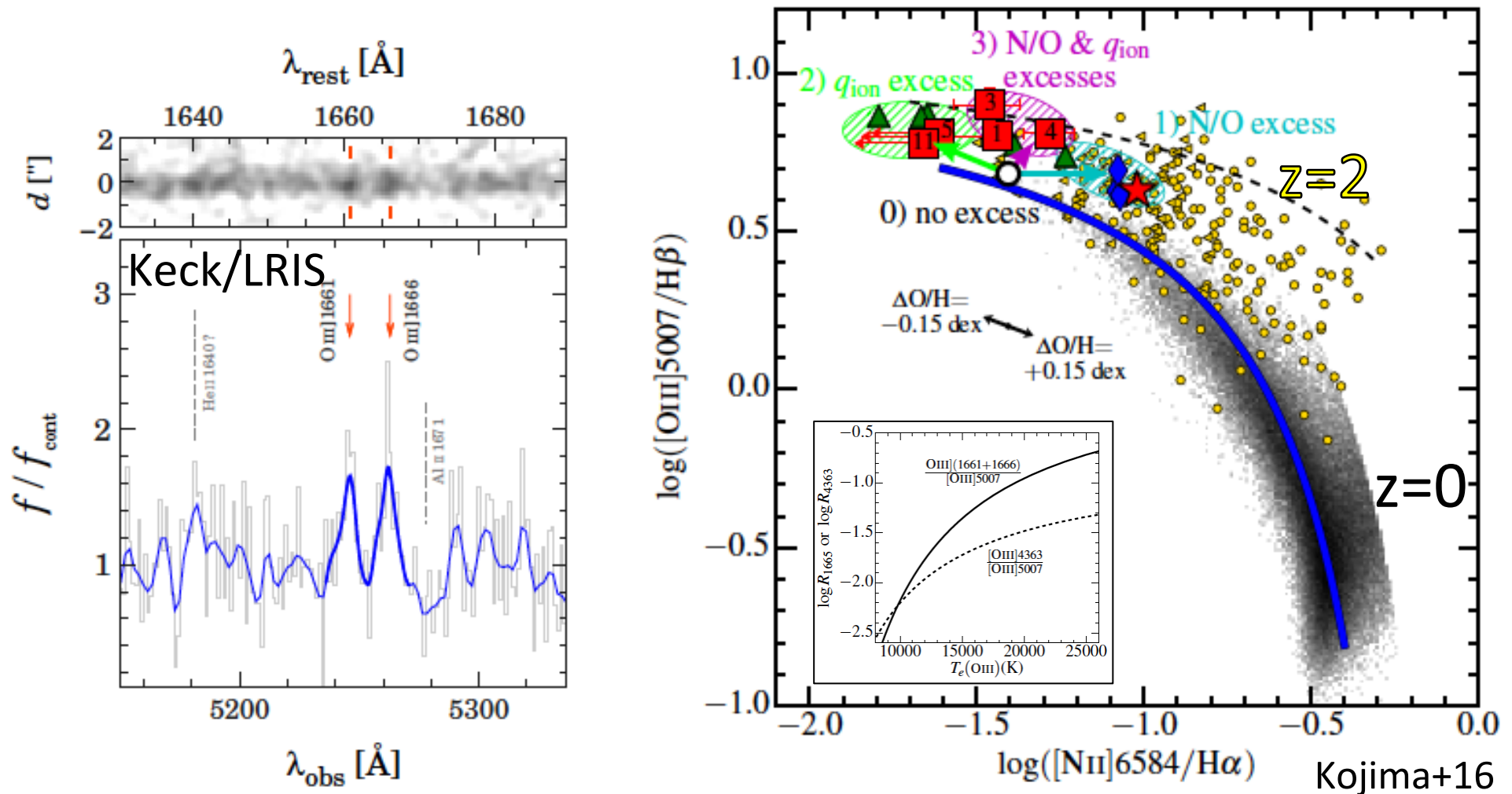
Keck Spectra

Sugahara 2016



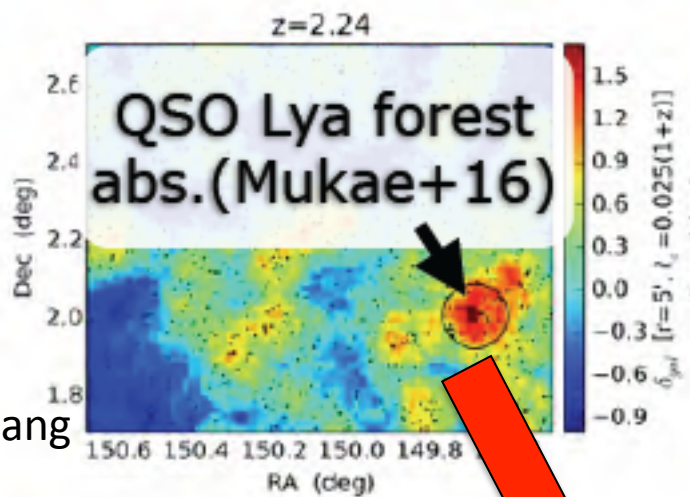
- High quality Keck spectra (resolution+sensitivity)
- Increase of outflow velocities and  $\eta$  from  $z \sim 0$  to 2 (Sugahara16)
  - Towards  $z \sim 2$ , more feedback, while more SFRD? Suggest gas increase?
- Further increase? Or decrease following SFRD?  $\rightarrow z > \sim 3$  w **Keck/LRIS+DEIMOS**

# c) ISM State Evolution



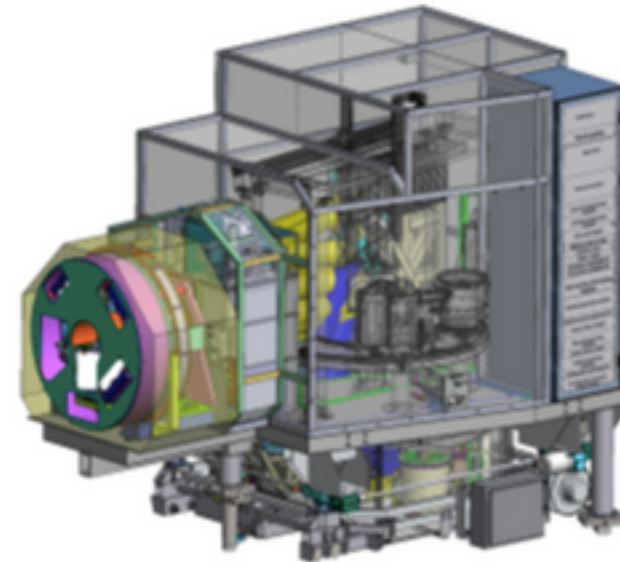
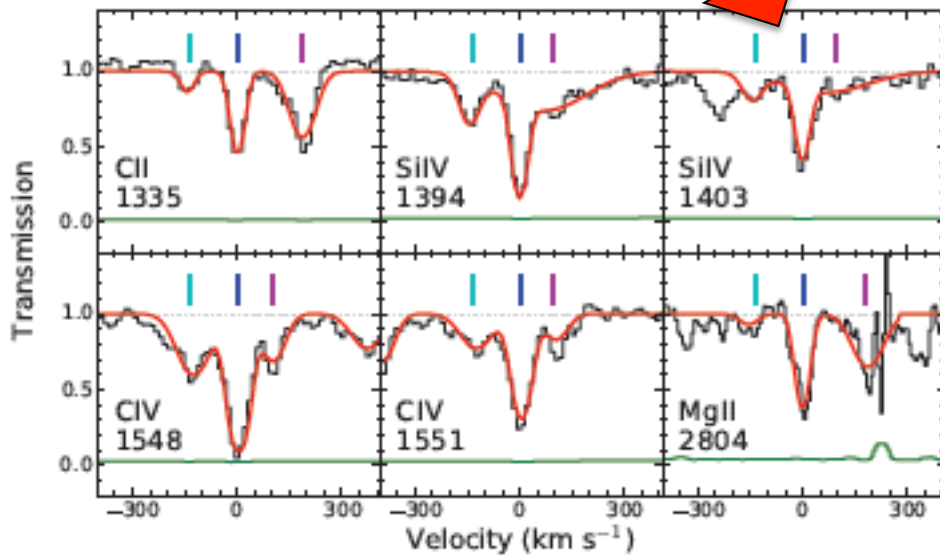
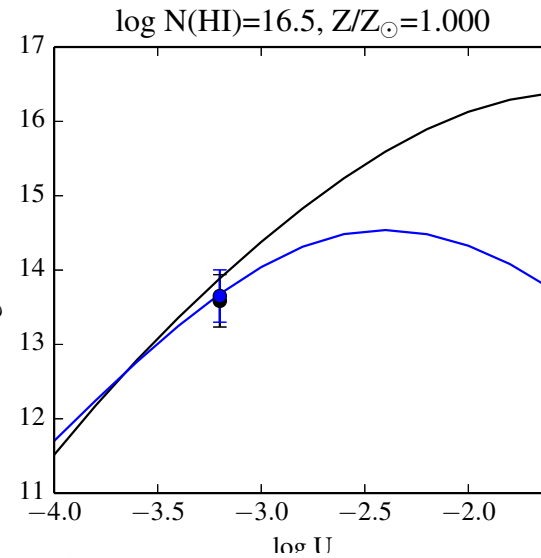
- BPT offset at  $z \sim 2 \rightarrow$  combination of N/O and  $q$  excesses (see+Onodera+16, Kashino+16)
- ISM state (O/H, N/O ratio,  $q$ ) with no systematics  $\rightarrow T_e$  determination
- Detections of weak lines (OIII]1665, [OIII]4363) are necessary  $\rightarrow$  Keck spectroscopy
- Handful number of high- $z$  galaxies  $\rightarrow$  Statistical study by systematic surveys

# d) Galaxy-CGM-IGM Relation



credit: Chiang

Mukae+16



Keck/KCWI  
(KCWI team)

- First identification of multiple metal line system in proto-cluster cand: 1 LLS and 2 CGM systems.
- **Keck/CWI**: Discussion w Chris Martin for possible HSC+KCWI collaborations

# What Should We Do First?

- Timeline
  - 2019: JWST
  - 2020: PFS SSP
  - Late 2020s: TMT
  - Late 2020s: WFIRST
- Most urgent issue: supplying targets to JWST
  - Many consortiums are forming now for early release science (ERS) program (recent call for NOI of JWST).
- Making targets by Mar. 2018 (ERS Aug. 2017)

# Subaru+Keck Collaboration for JWST

## 1) Caltech + JPL Colleagues

- C3R2 program under HSC-JPL/IPAC MOU
  - Photo-z calibration for HSC survey objects
  - Stimulate science between HSC-IPAC/JPL groups
- 9 Pasadena colleagues incl.
  - Peter Capak, Dan Masters (Caltech/IPAC), Dan Starn (NASA/JPL)
- C3R2 program (15 out of 40 nights awarded by Caltech+NASA)
- Spectroscopy for 5,000 objects down to  $r_{iz} \sim 25$  mag (randomly selected in the color space)
- HSC dropouts/LAEs are included. After the data taken, we start working together.



P. Capak

# Subaru+Keck Collaboration for JWST

## 2) Univ. California (UC) Colleagues

- Crystal Martin (UC Santa Barbara)
- Keck SAC (last year)
  - “Shall we start collaborative work with Keck and Subaru for a future large program?”
- HSC Project 84 (w EC status)
  - Follow up spectroscopy for HSC Ly $\alpha$  emitters
  - Keck/LRIS spectroscopy is already approved.



C. Martin

# Summary

- Subaru+Keck synergistic programs
  - 3 major goals for high-z galaxies
  - past subaru+keck program
- Our interests: Keck spec. for HSC high-z galaxies
  - Rare, but Important form period/state (lensed L\*) sources
  - a) Statistics of Ly $\alpha$  blobs (bright LAEs)
  - b) Galaxy outflow evol.
  - c) ISM (chemical/kinematic) evol.
  - d) Galaxy-IGM connection
- Target preparation for JWST is urgent.
  - Keck/DEIMOS spec in C3R2 program of HSC-Caltech/NASA collaboration
  - Keck/LRIS spec. in collab. of U. California collaboration  
(possible collaboration w KCWI team?)