遠方銀河観測の現状

Deep Observational Data in A2744 Hubble Frontier Fields [PI: J. Lotz]　Ishigaki et al. (2015)

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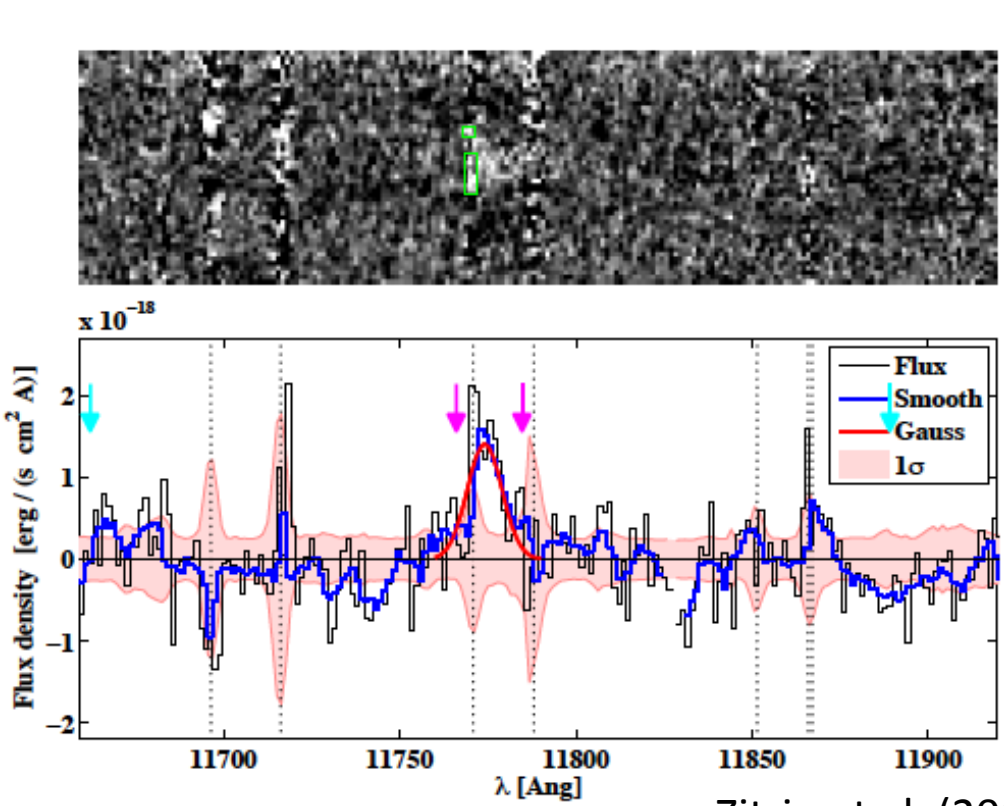
Review

- Recent obs. progresses of galaxies up to z~11

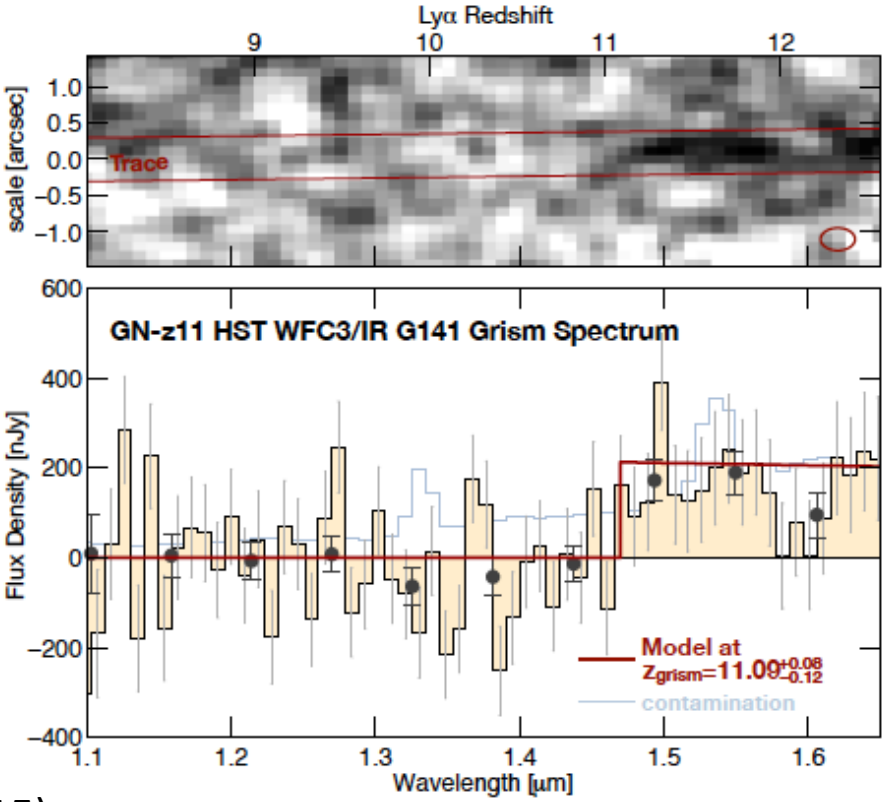
  1) Galaxy formation: SFRD, dust, morph., popIII cand.

  2) Cosmic reionization: History and reionization sources

Recent Progresses of High-z Star-Forming Galaxy Obs.



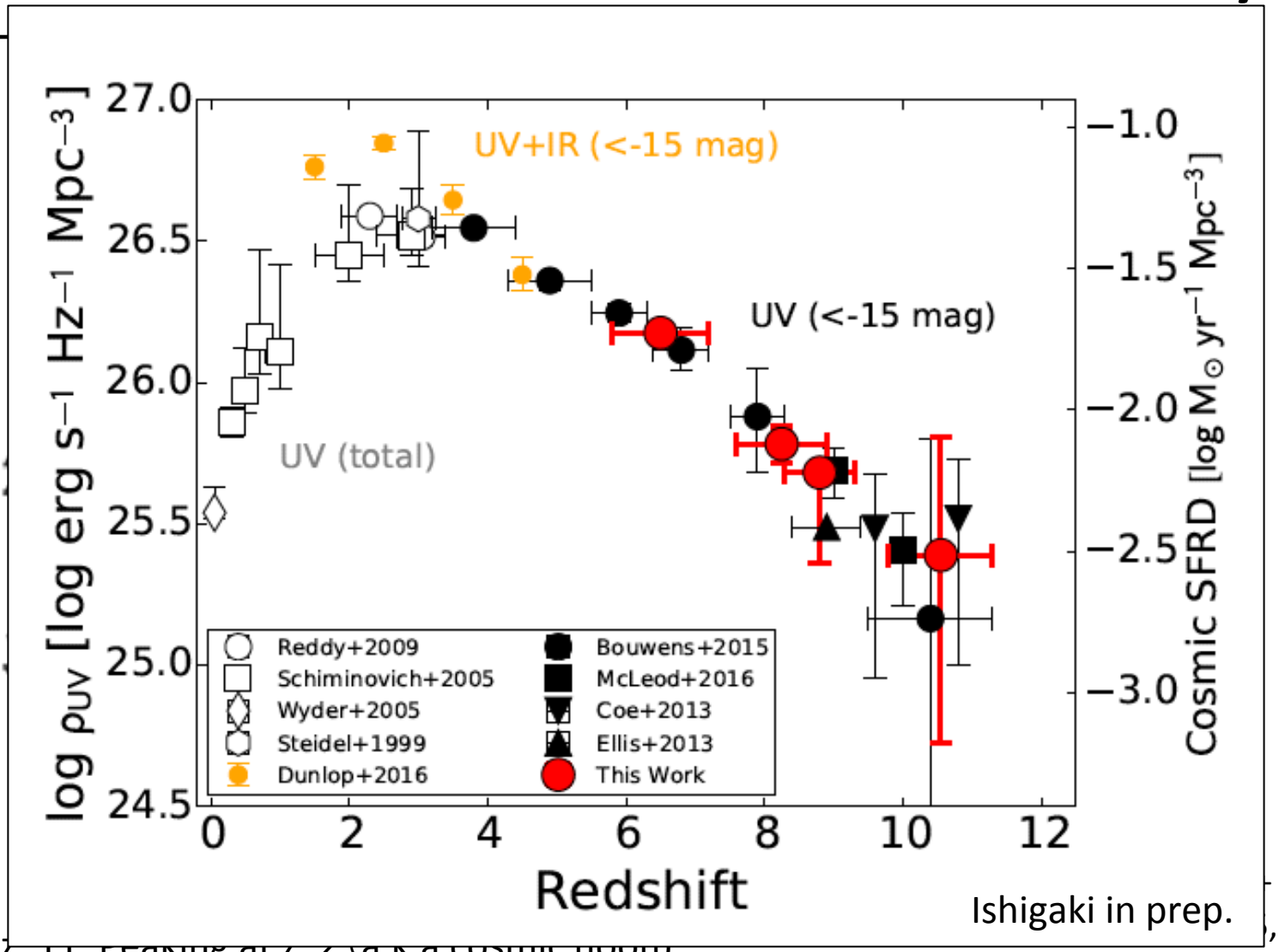
Zitrin et al. (2015)



Oesch et al. (2016)

- Deep HST and Keck observations in opt and NIR
  - up to z=8.7 (Zitrin+15) and
  - possibly z~11 ? (Oesch+16)

Cosmic Star-Formation History

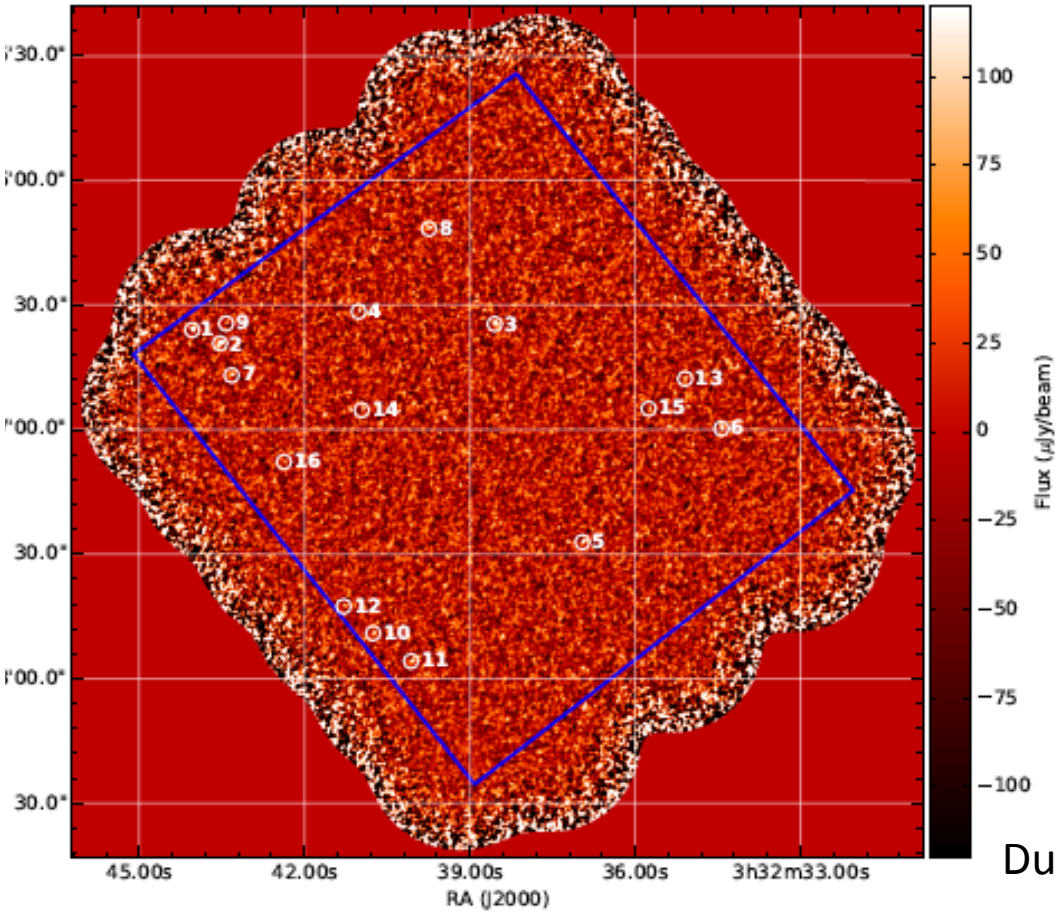


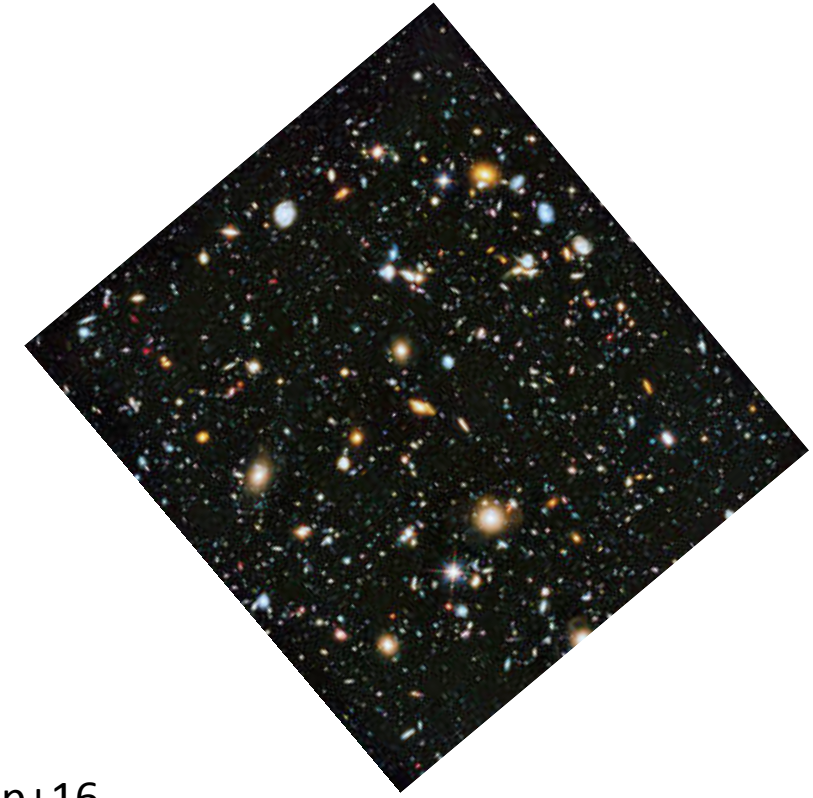
Ishigaki in prep.

- Ishigaki,MO
, Oesch+15,
Mcleaod+15)

- Up to z~11. Peaking at z~2 (a.k.a cosmic noon)
- Decreasing from z~2 towards higher redshift
  - Rapid decrease at z>8? More data
  -> Disappearing. Smooth evolution

Progresses in IR/Submm Obs. with ALMA

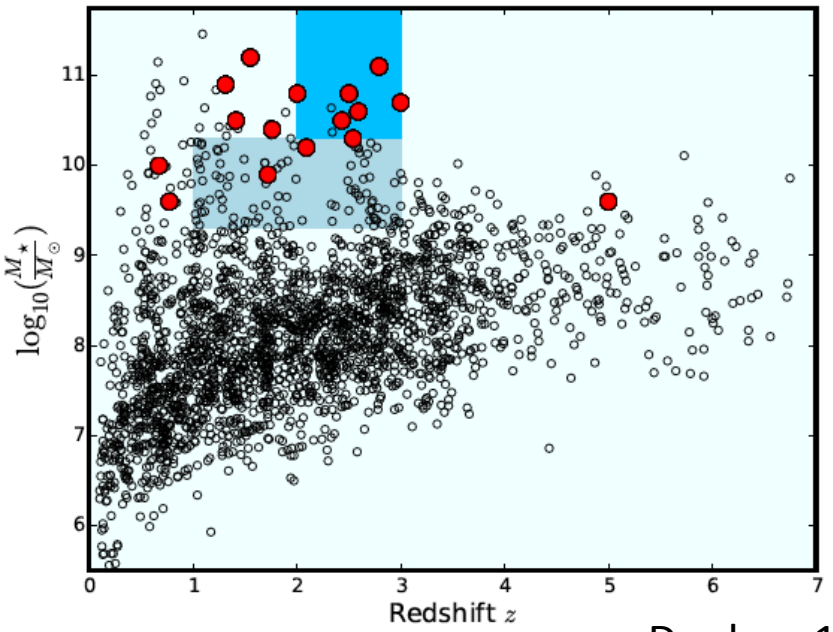




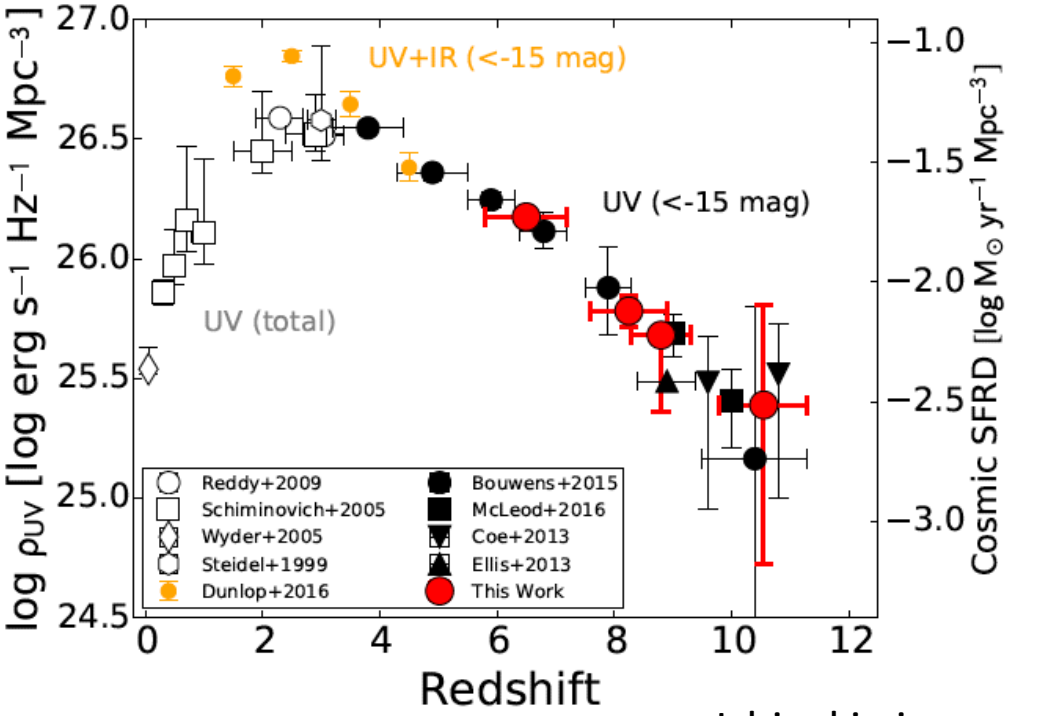
Dunlop+16

- ~50 hour ALMA mapping obs. down to $S_{1.3mm}$=35uJy (rms) in HUDF
- Only 5 sources w S/N>6
- Similarly, ASPECS (Aravena+16) and ALMA+HFF (Gonzalez-lopez+16) identify only ~10 sources.

Dusty Starbursts Do Not Significantly Contribute to SFRDs at z>~4, but z~2



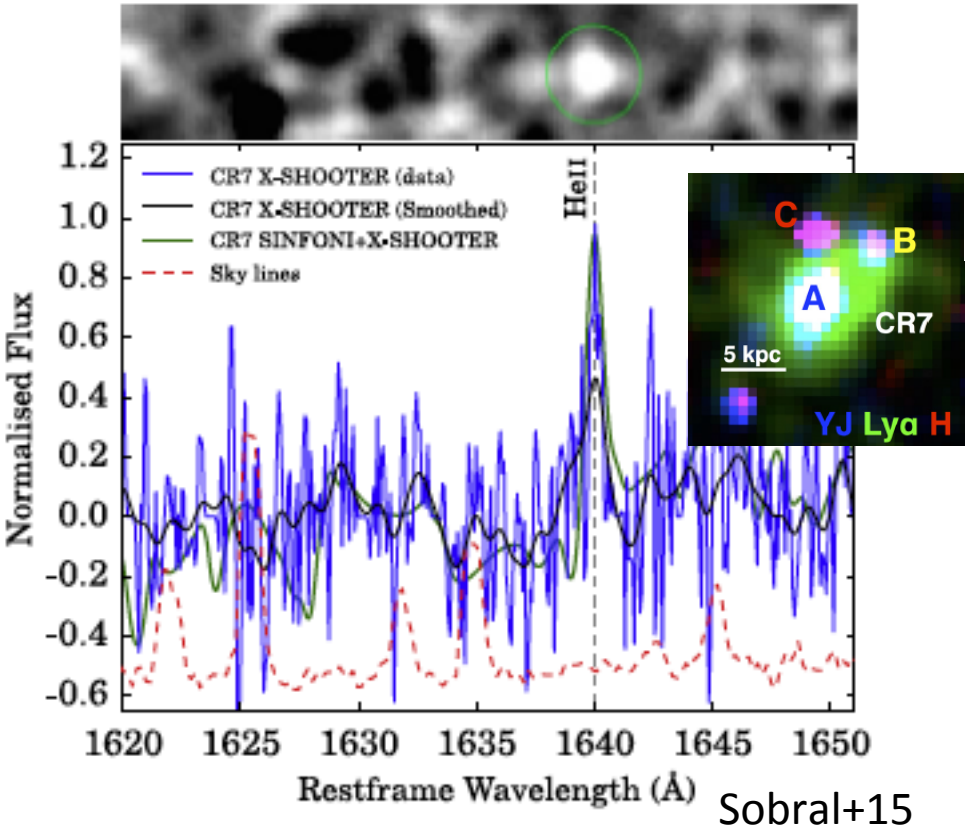
Dunlop+16



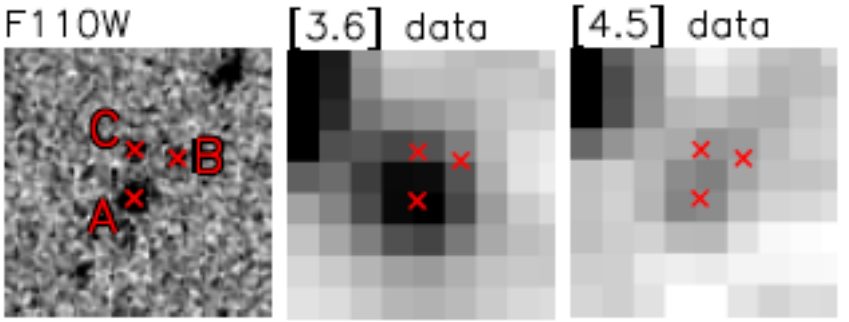
Ishigaki+ in prep

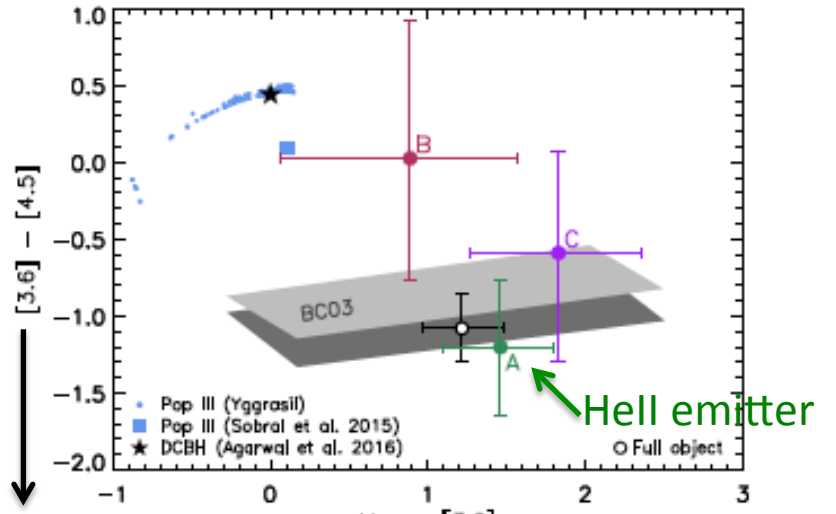
- Dusty starburst contribution to SFR density (SFRD)
  - Larger contribution than optically detected galaxies at z~2
  - No significant contribution at z>~4

Is the Pop. III Candidate True?



Sobral+15



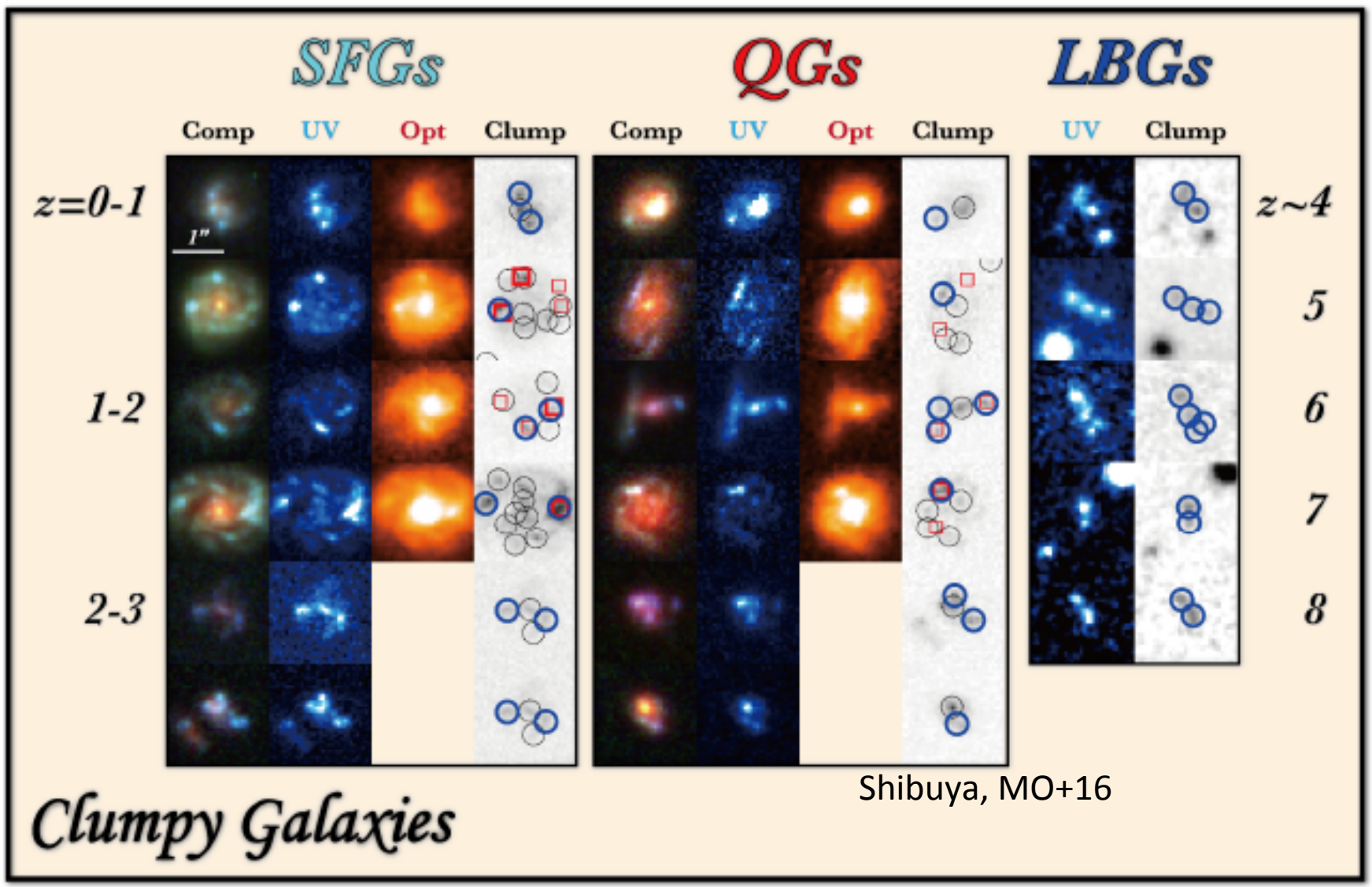


[OIII] emission

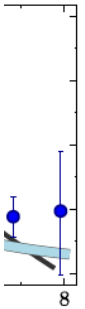
Bowler+16

- CR7: z=6.6 LAE w strong HeII1640 emission and no detections of metal lines (Sobral+15)
- [OIII]5007 identified by the IRAC ch1 excess. CR7 is neither popIII nor DCBH (Bowler+16)
- CR7 is probably a type II AGN or a low metalicity galaxy.

Evolution of Clumpy Galaxies



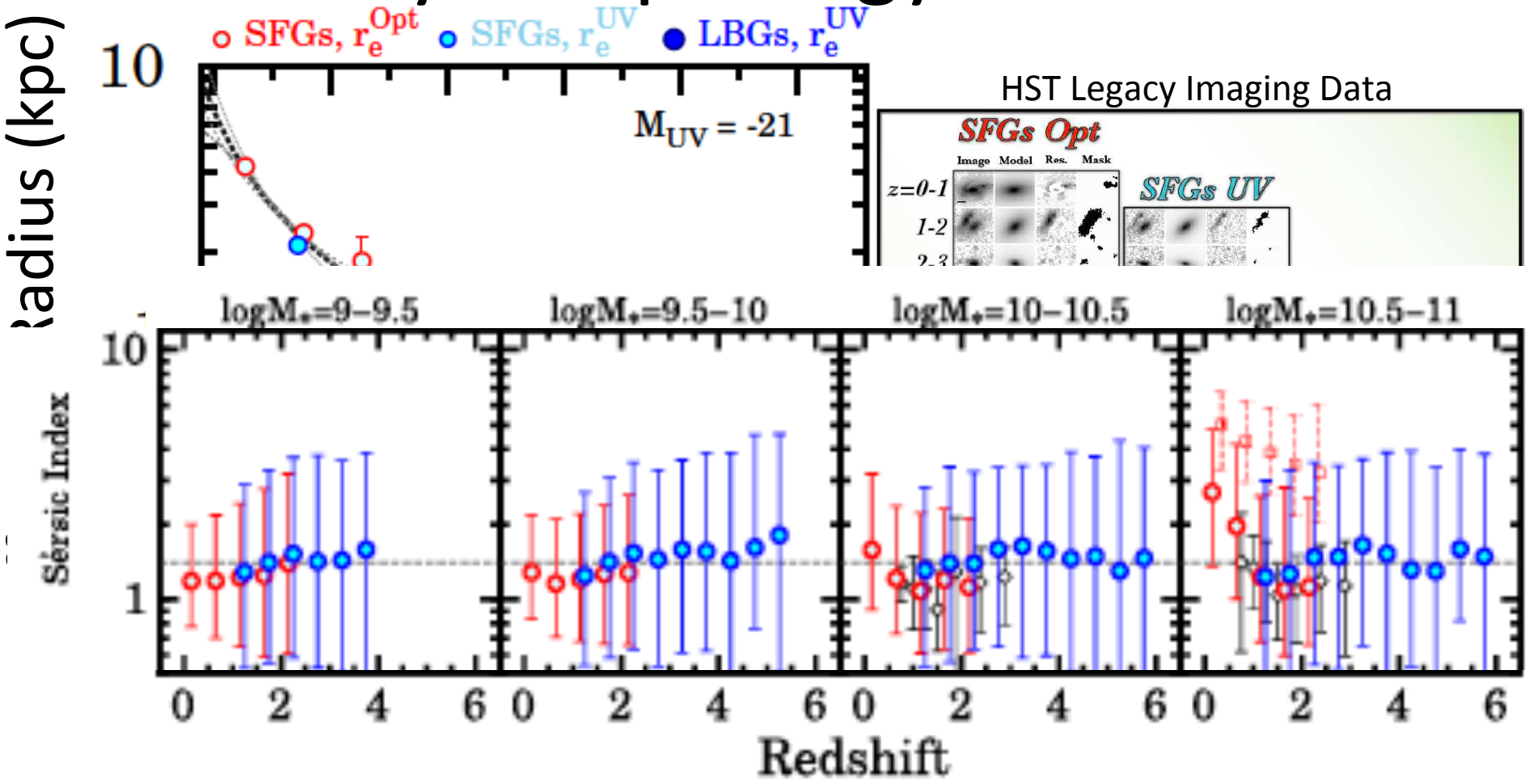
Shibuya, MO+16



on

- Merger?? But merger rate evolves by $(1+z)^{2-3}$ (Millenium/Illustris simu.).
- Rather consistent with violent disk instability scenario (Keres+05,+09)

Galaxy Morphology Evolution



- Average Sersic index for 190k gals-> n=1.5 (disk-ish profile)

  Corrected for cosmological SB dimming effects by fitting

z=0

Milky Way

M82

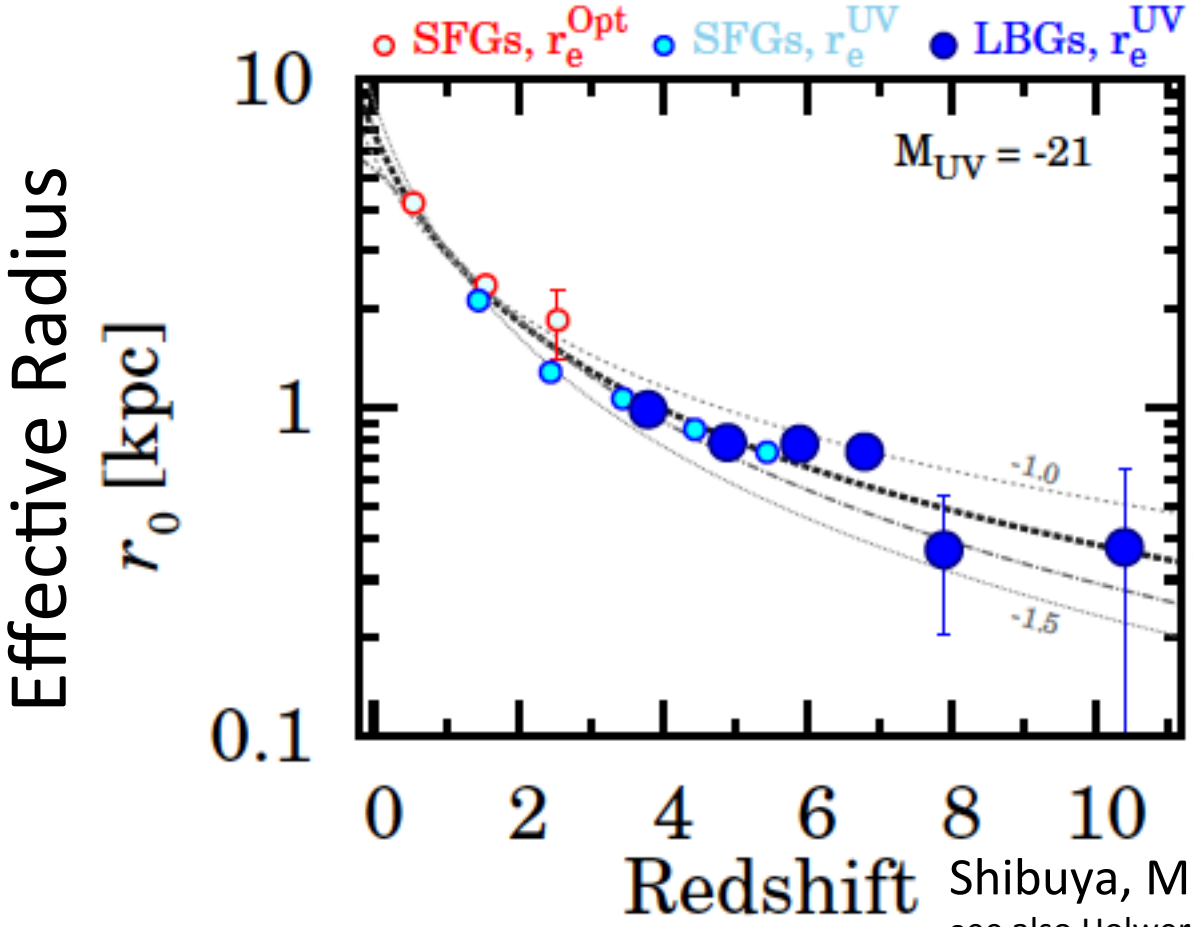
z∼10
Galaxy (Average)

Ono et al. 2012

NASA, ESA, and The Hubble Heritage Team (STScI/AURA)

Illustration
(Shogakukan)

Galaxy Size Evolution

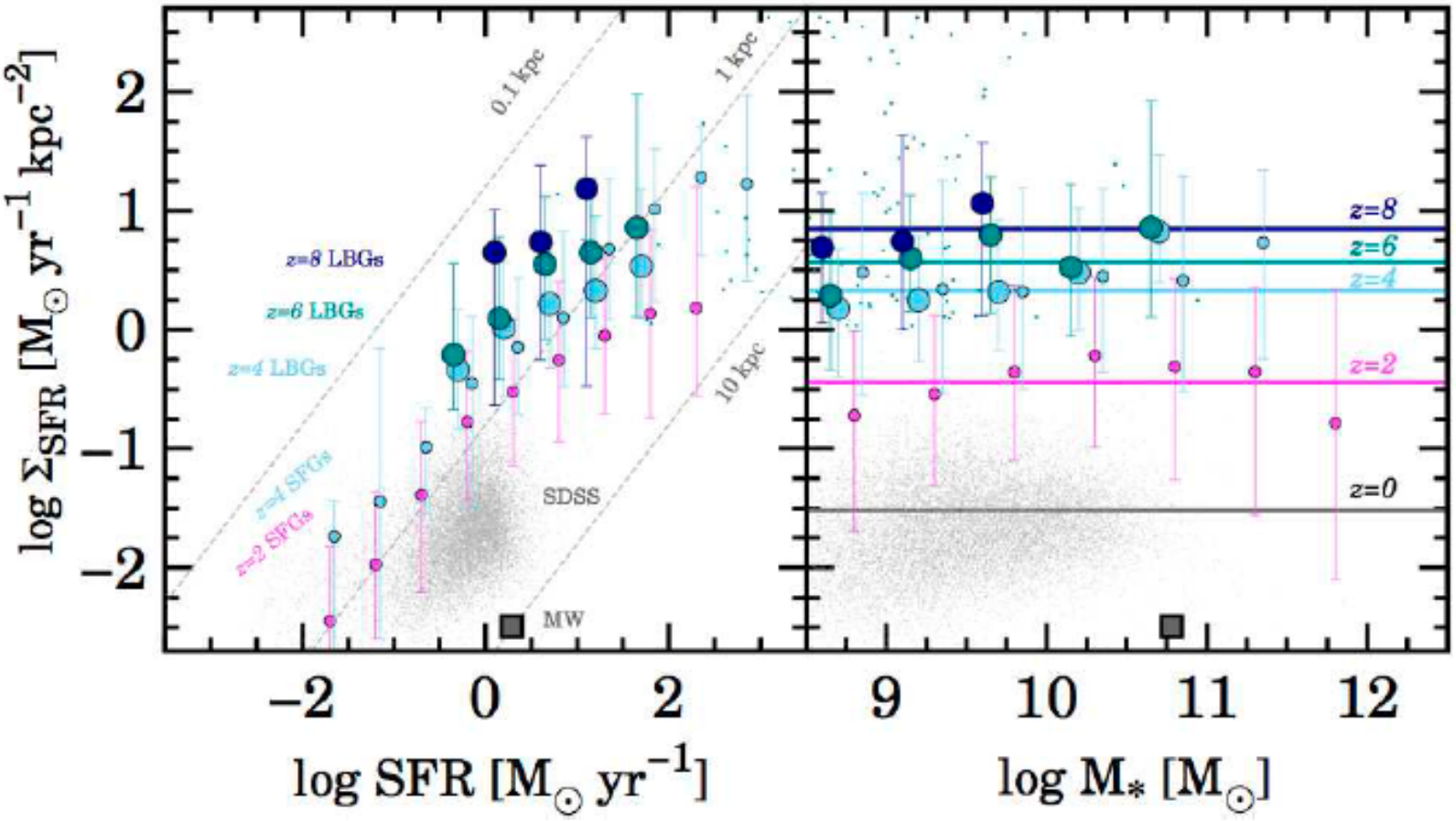


Only r_e=300-400pc
Size of MW GMA

Shibuya, MO, Harikane+15
see also Holwerda+15, Curtis-Lake+15

$$r_e \propto (1+z)^{-1.12\pm0.06}$$

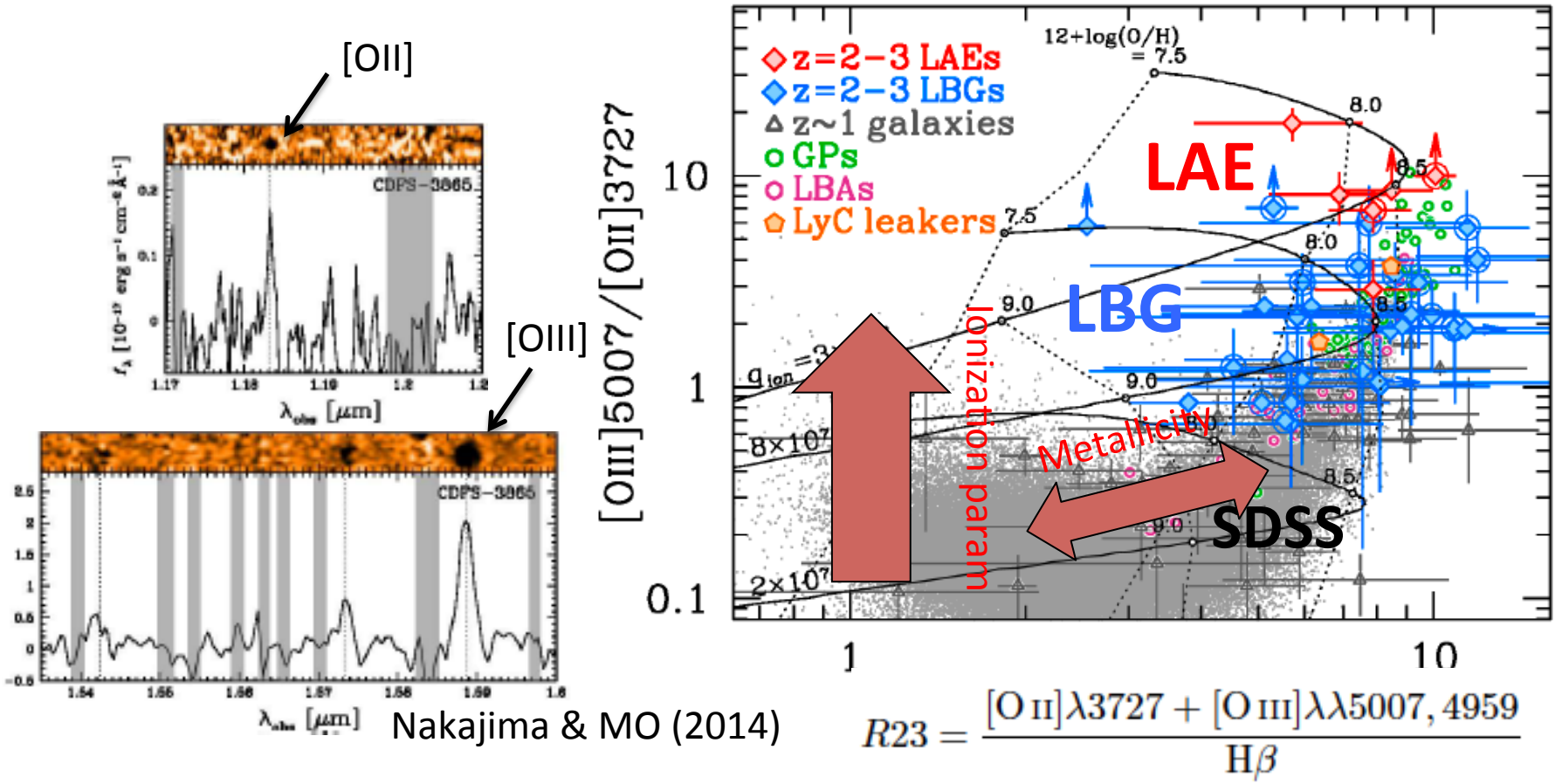
Galaxy Size Evolution



Shibuya, MO, Harikane+15

- Σ_{SFR} increases towards high-z by ~100 times due to the size ev.
- Intensive star-formation in a small vol. -> ISM change.

High Ionization State of ISM



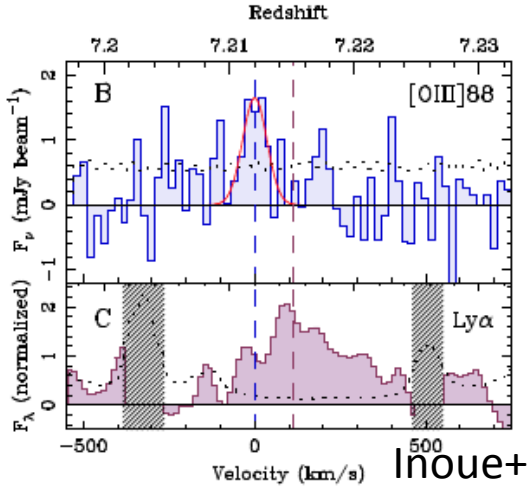
Nakajima & MO (2014)

$$R23 = \frac{[\mathrm{O\,II}]\lambda 3727 + [\mathrm{O\,III}]\lambda\lambda 5007, 4959}{\mathrm{H}\beta}$$

- 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.
  - Average ionization parameter increases towards high-z.
  - Very efficient ionizing photon production: young stellar population+low hydrogen mass. → ISM ionization state different from typical low-z galaxies

High Ionization State of ISM

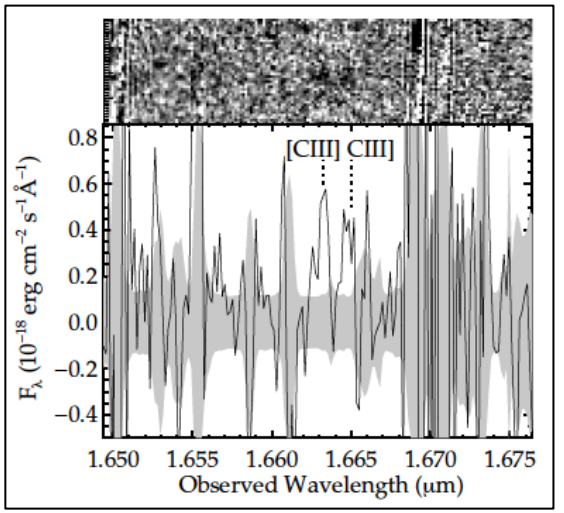
z=7.0

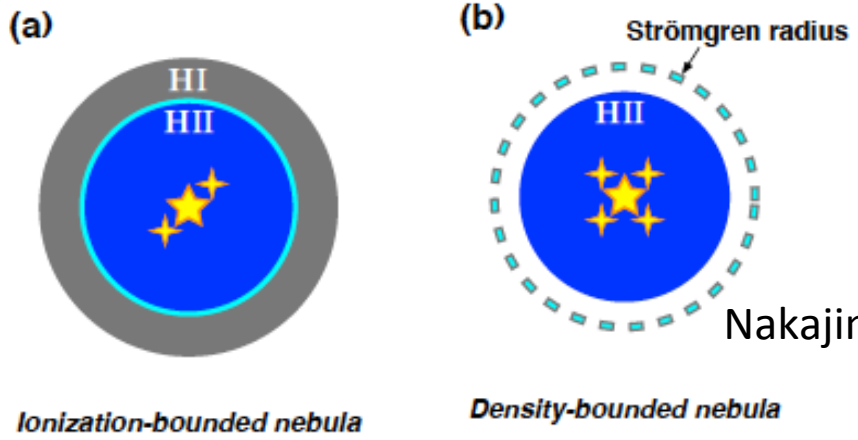


Inoue+16

Stark+15/+16

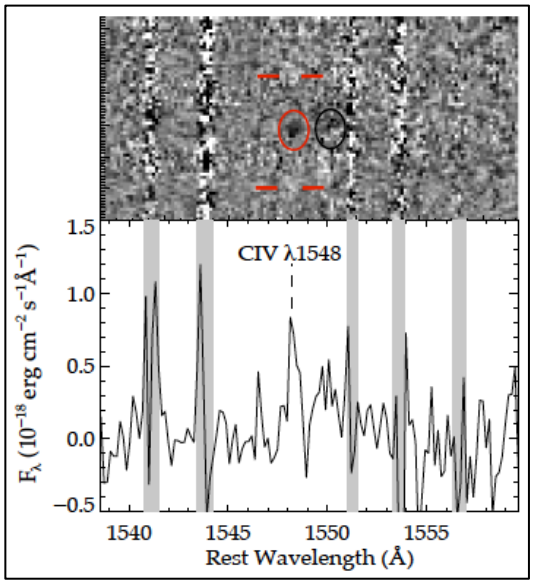
z=7.7





Nakajima & MO 14

z=7.0



For z~7 galaxies,

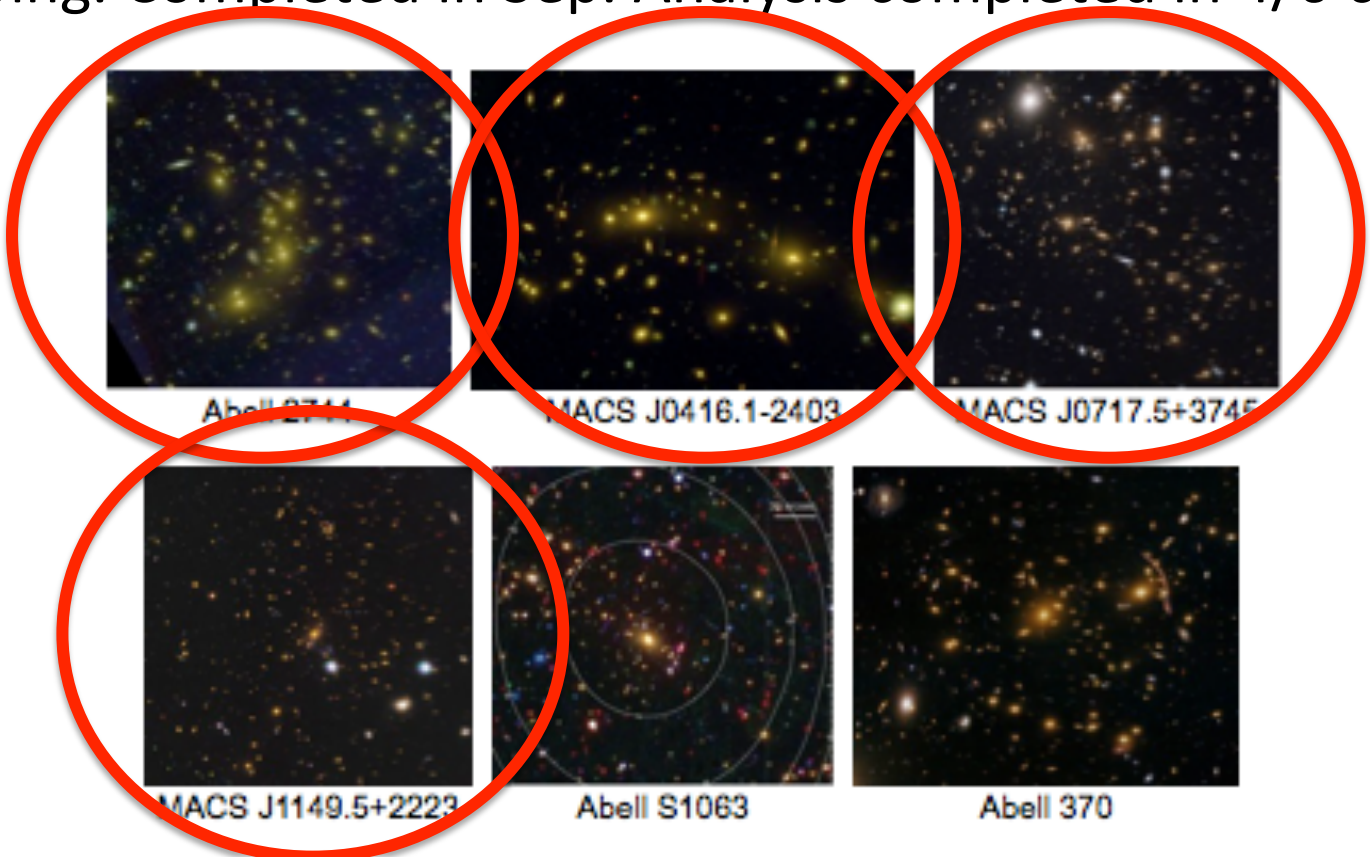
- [OIII]88um detection with no [CII] line (Inoue+16)
- CIII]1909 and CIV1548 detections (Stark+15)
  - Very efficient ionizing photon production: young stellar population → different from typical low-z galaxies
- Low HI galaxies? → Helping ionizing photon escape?

COSMIC REIONIZATION

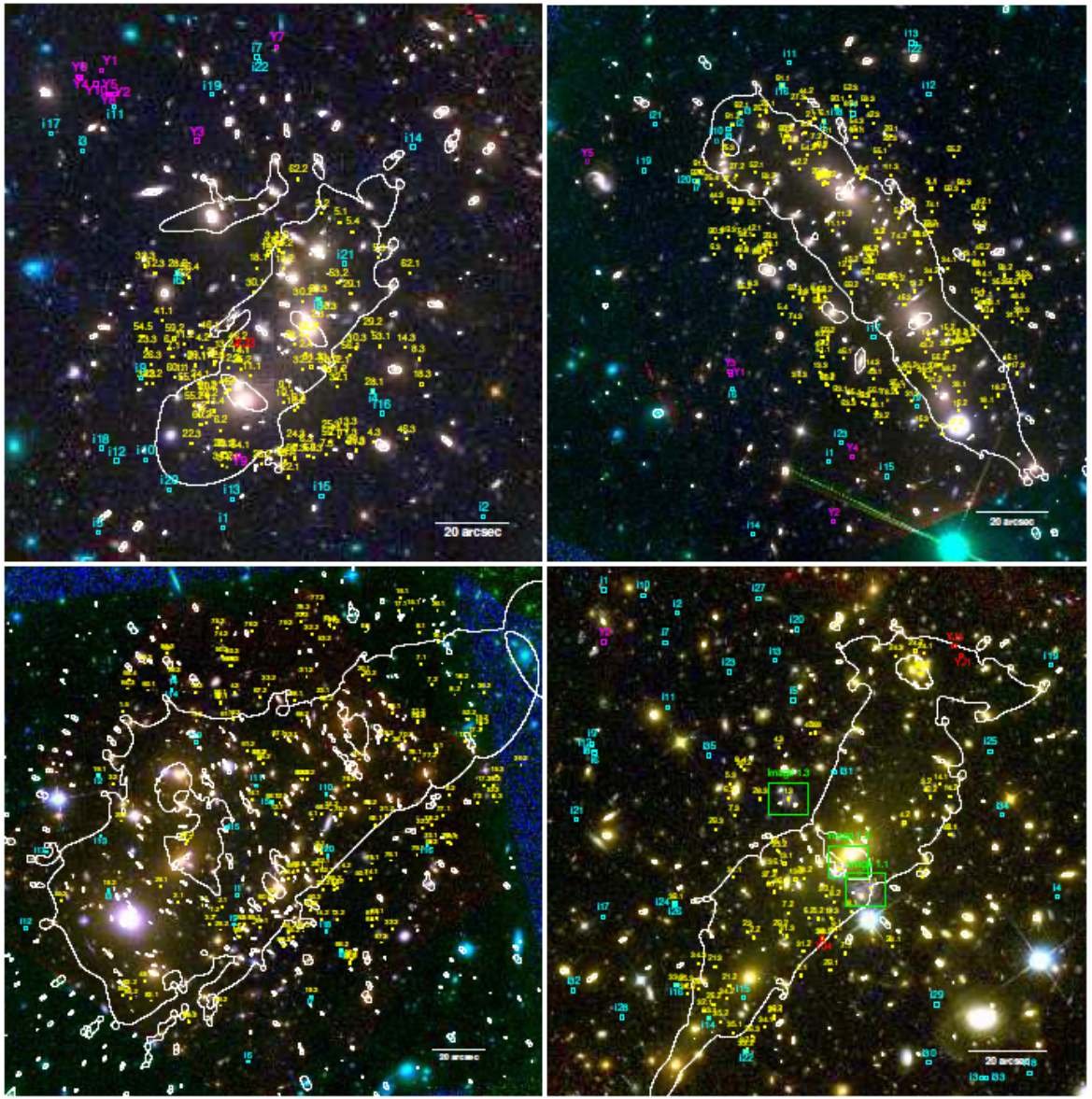
Hubble Frontier Fields (HFF)

- 6 clusters by deep Hubble ACS and WFC3-IR imaging (Lotz+16)
- Lensing magnifications for faint galaxies behind the clusters.

- 3 year program spending 840 orbits. Started from fall 2013.
  (Atek+14,15, Ishigaki+15, Oesch+15,McLeod+15,+16, Livermore+16…)
- On-going. Completed in Sep. Analysis completed in 4/6 clusters



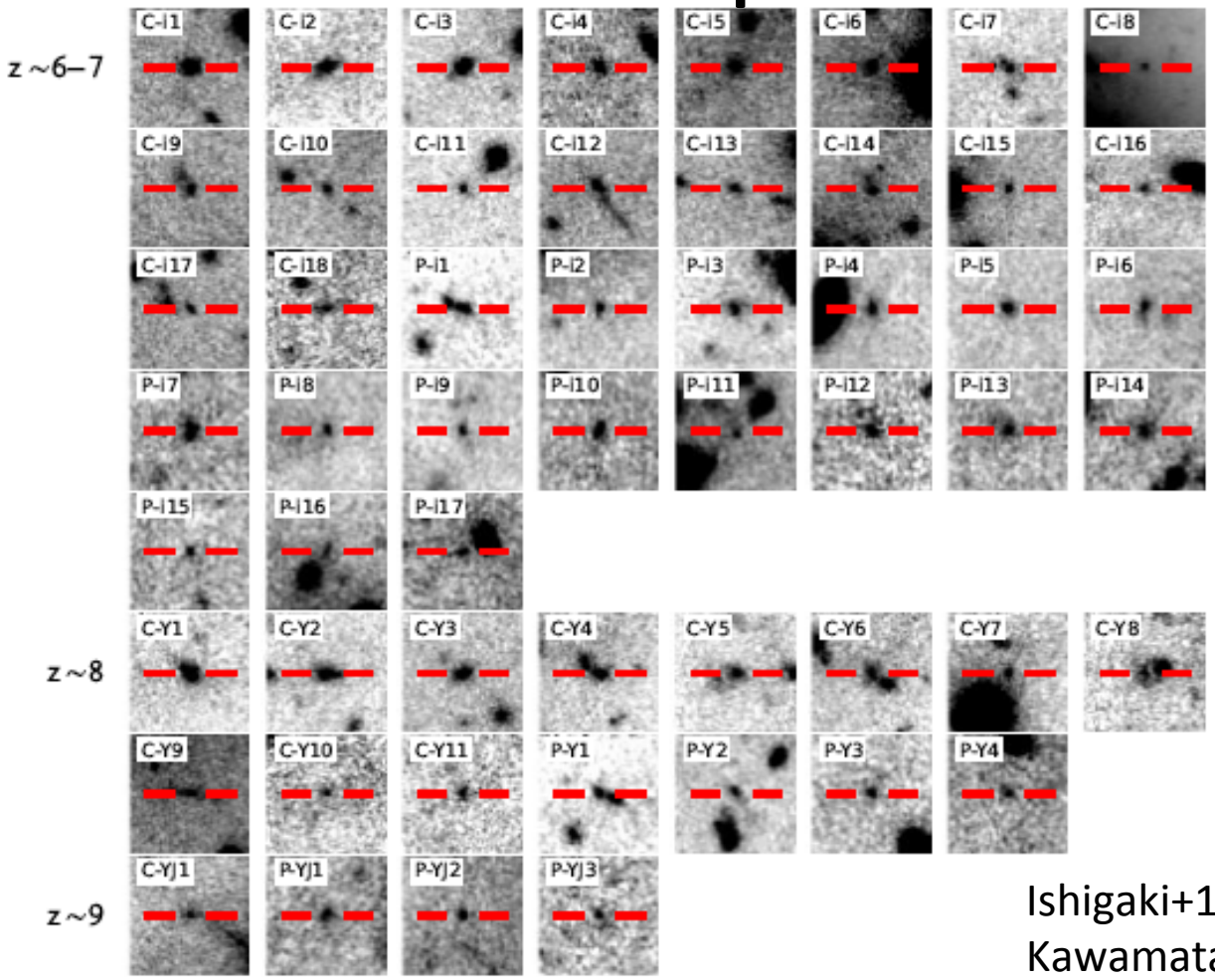
Mass Models



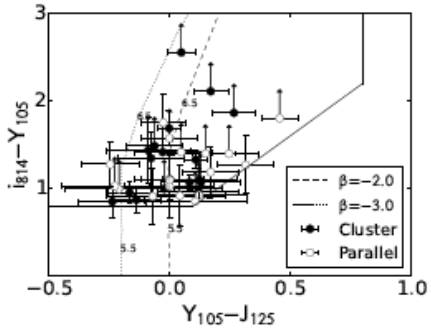
Kawamata+16

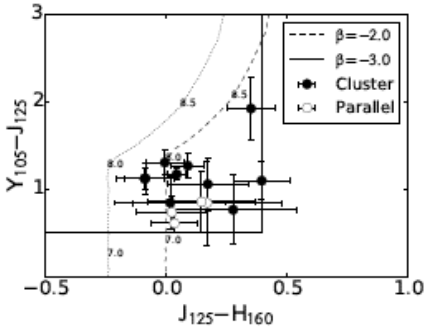
100-200 multiple images for modeling w parametric lensing package (glafic; Oguri+10)

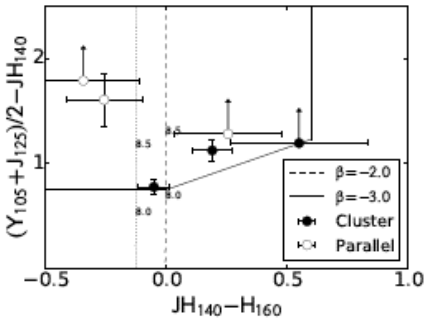
HFF Dropouts at z~6-10



Ishigaki+15,
Kawamata+16



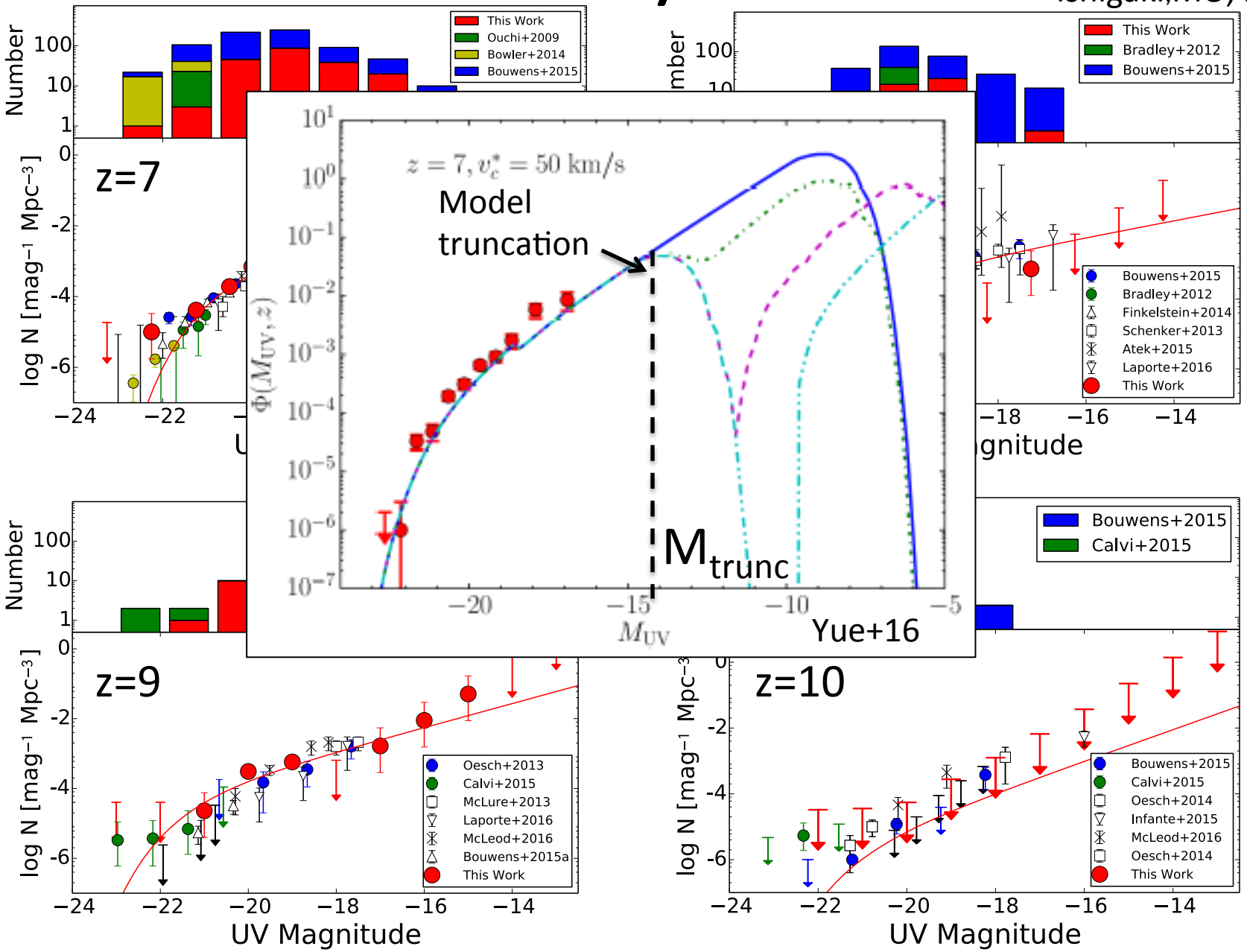




- 127 galaxies at z=6-10 identified by dropout tech.,
  18 out of which have μ>10 (Kawamata+16)

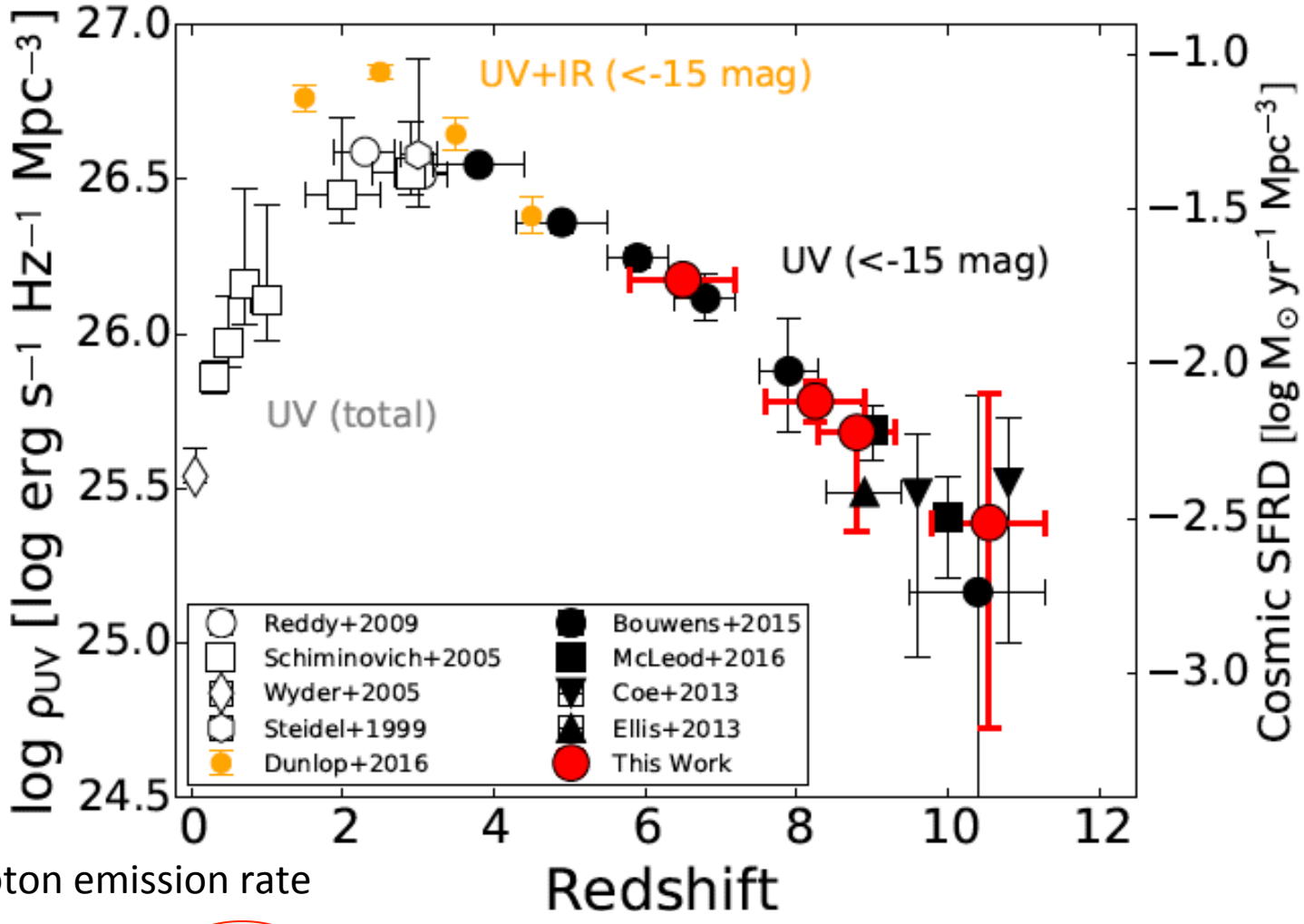
UV Luminosity Functions

Ishigaki,MO, in prep



No flattening or break at the faint-end LF. No sig. of feedback effect down to ~-14mag at z~7.

Evolution of UV Luminosity Density



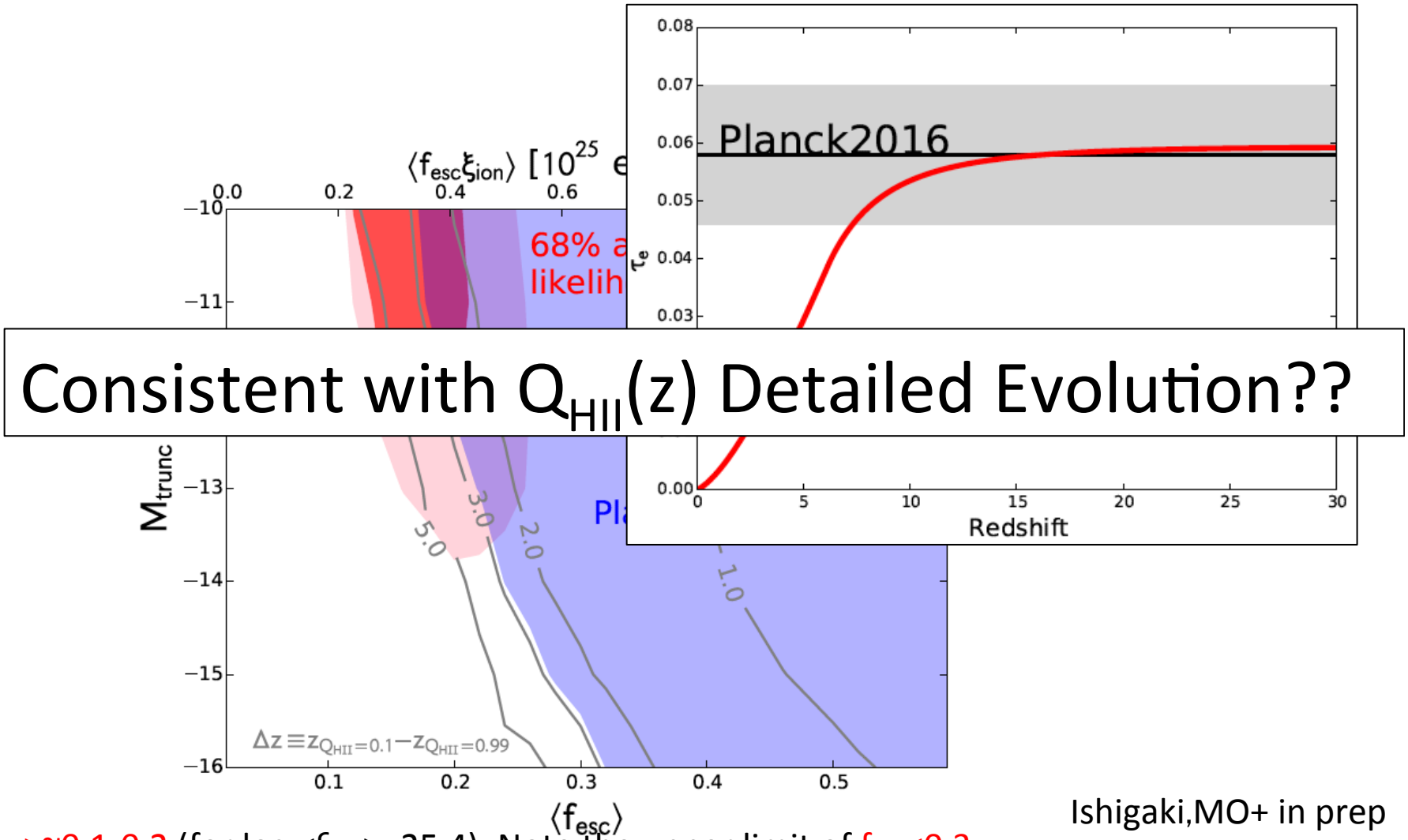
Ionizing photon emission rate

$$\dot{n}_{\rm ion} = \int_{-\infty}^{M_{\rm trunc}} f_{\rm esc}(M_{\rm UV})\,\xi_{\rm ion}(M_{\rm UV})\,\Phi(M_{\rm UV})L(M_{\rm UV})\,dM_{\rm UV}$$

3 free parameters

$\rho_{\rm UV}$

Constraints on f_{esc} and M_{trunc}



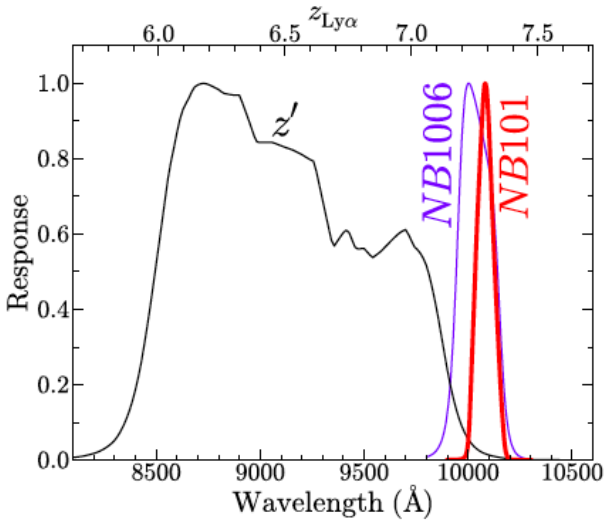
Consistent with $Q_{HII}(z)$ Detailed Evolution??

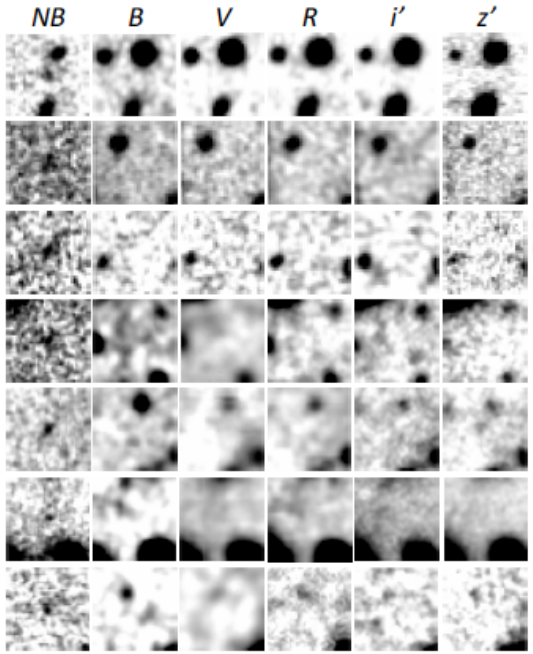
Ishigaki,MO+ in prep

- $\langle f_{esc}\rangle \sim 0.1\text{-}0.2$ (for log $\langle \xi_{ion}\rangle = 25.4$). Note the upper limit of $f_{esc}<0.3$
- $M_{trunc} >\sim -13$
- $\Delta z=3$ (-1/+2) [for Q_{HII}=10%-99%] Consistent w kSZ measurements of Planck2016

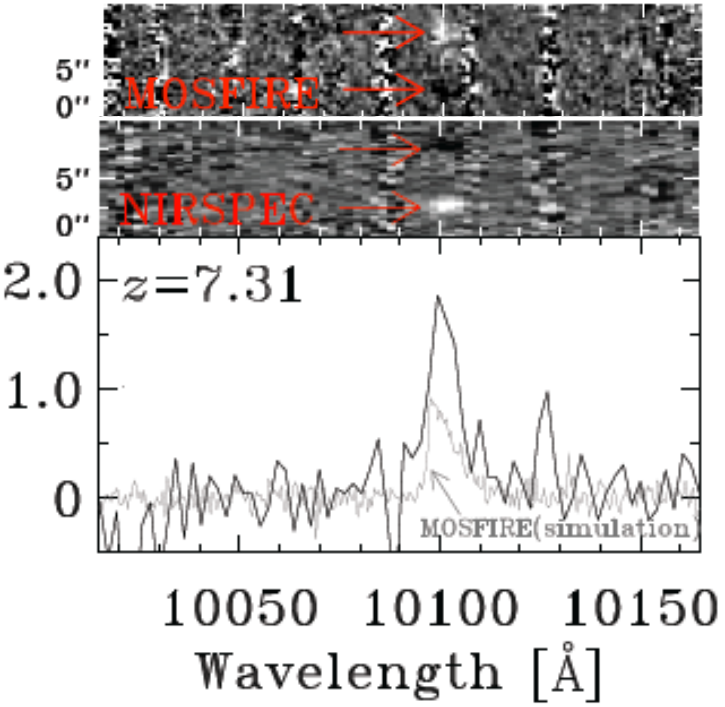
If the other ionizing sources (excpt. galaxies) give negligible contributions to ion phot. prod.

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



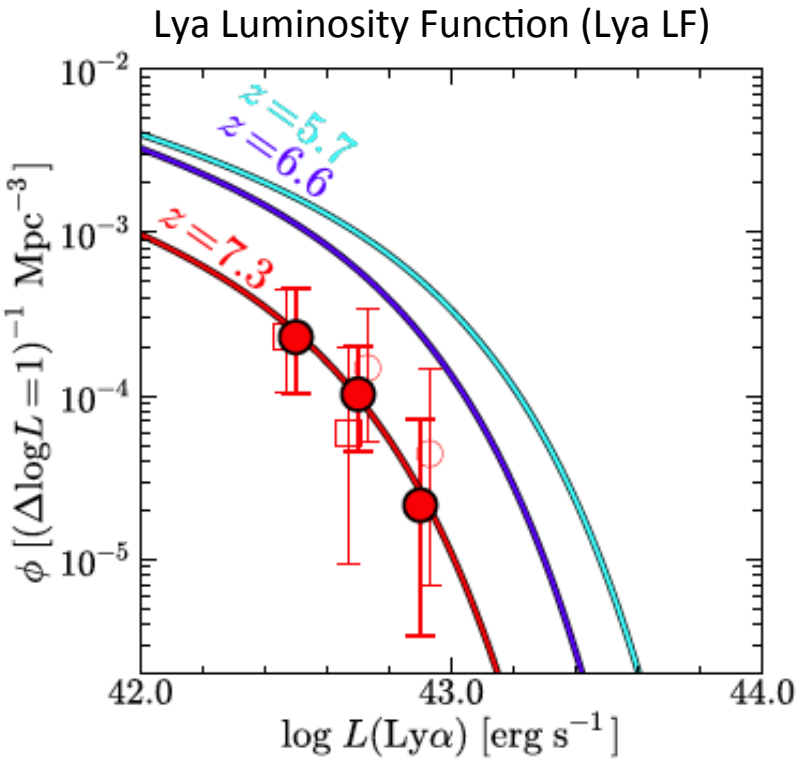


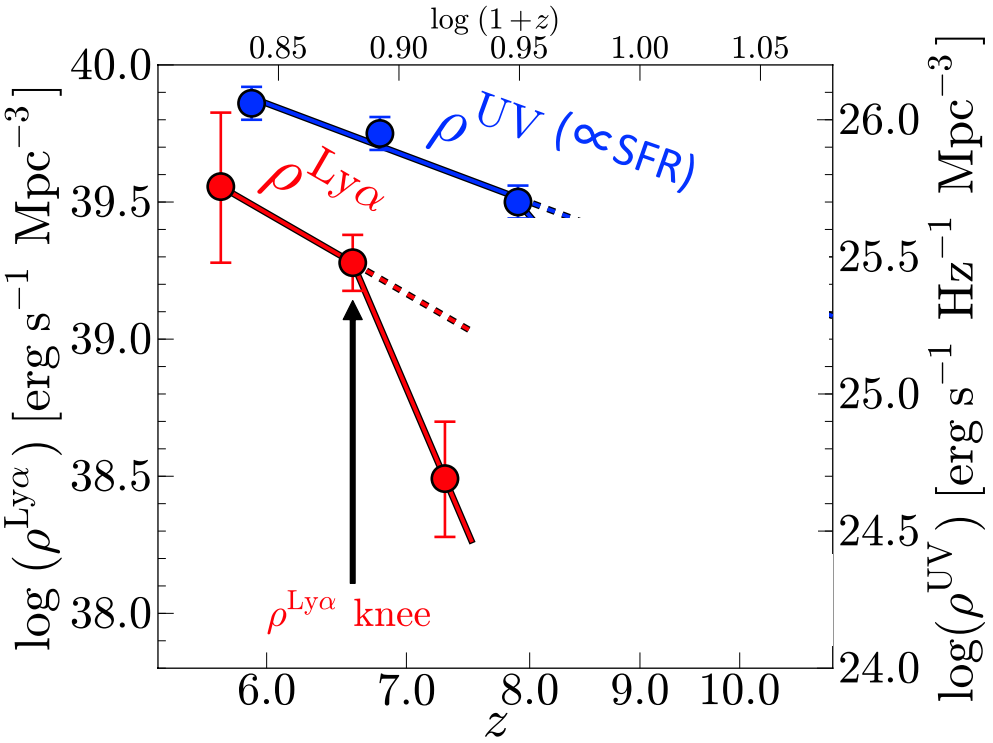
Konno, MO et al. (2014)



- Lya emitter (LAE) sensitive to neutral IGM: Subaru deep (106 hour integ.) large area survey
- At z=7.3, a comparable Lya lum. depth as previous lower-z (z=3-6) survey (Konno+14).
- However, only 7 sources… ~1/10 of the expected number if no evolution from z=6.6.

Accelerated Evolution of Lya Luminosity at z>~7



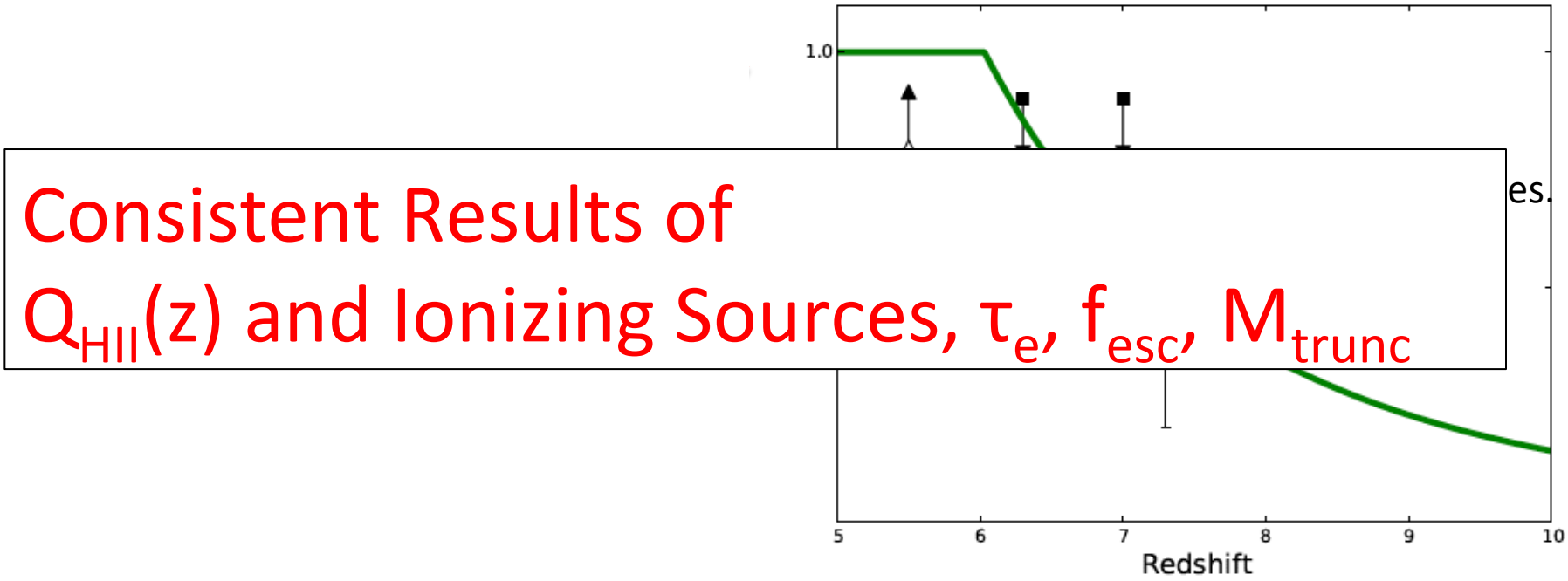


Konno, MO et al. (2014)

- 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
  - Likely by IGM scattering of Lya (cosmic reionization)

  →the evolution of Q_{HII} is rapid at z~7

Reionization History and CMB τ_e

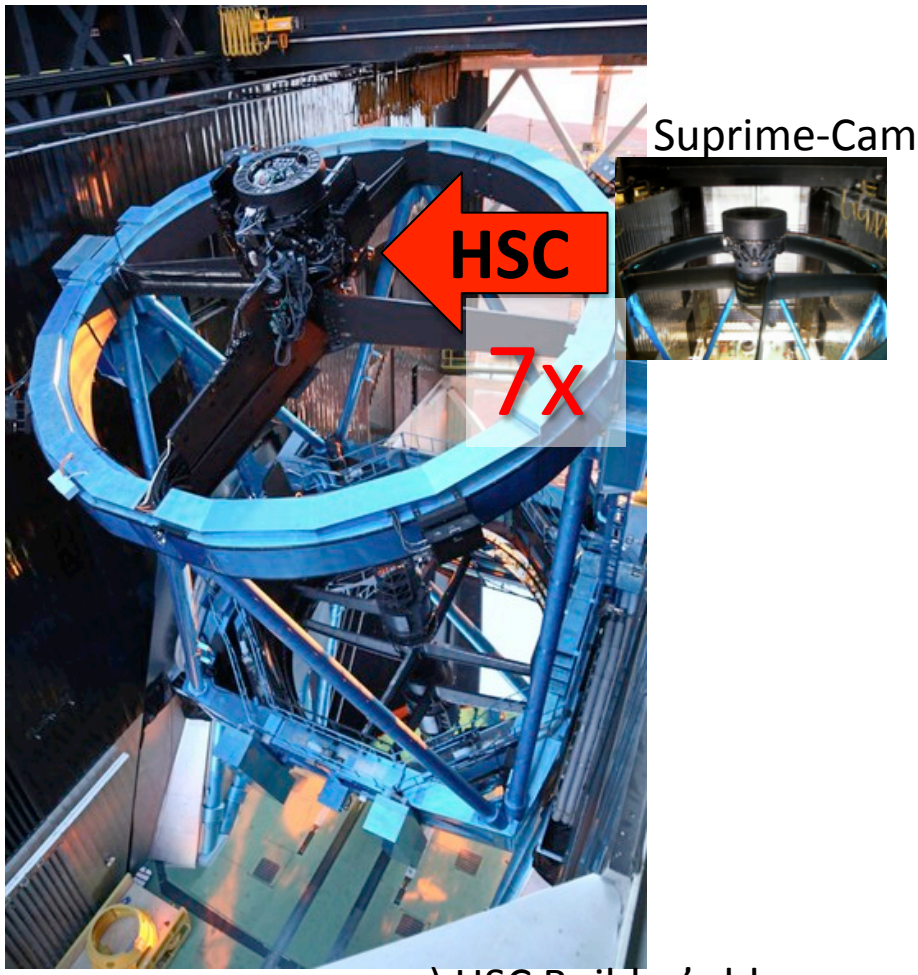


Consistent Results of
$Q_{HII}(z)$ and Ionizing Sources, τ_e, f_{esc}, M_{trunc}

- Q_{HII} estimates from the accelerated Lya evolution.
  - Prefer moderately low Q_{HII} at z~7. Late reionization.

ON GOING AND FUTURE SURVEYS IN 3 YEARS

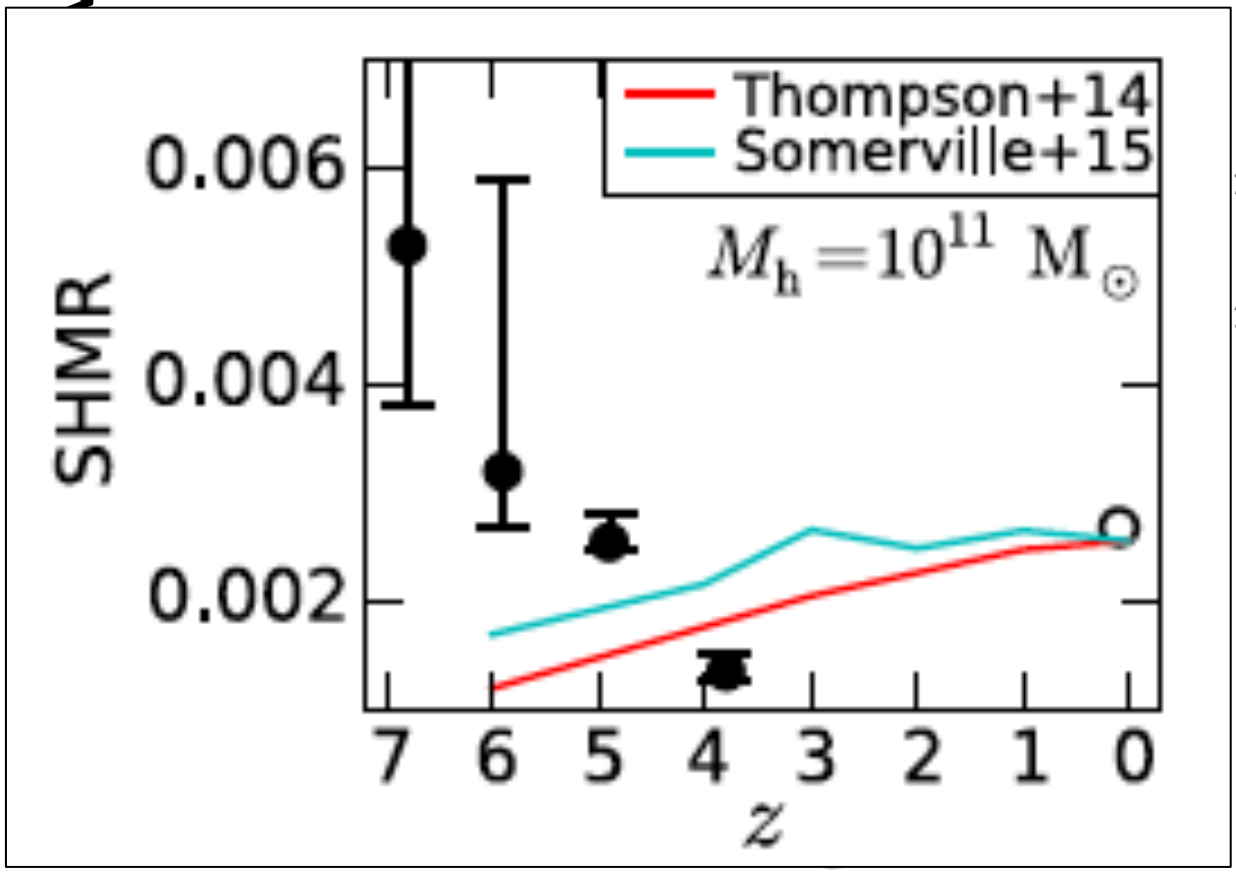
Subaru Hyper Suprime-Cam (HSC) Surevey

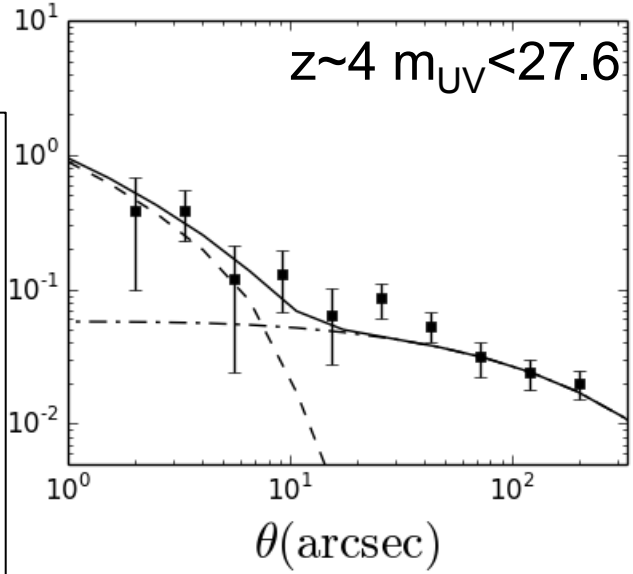


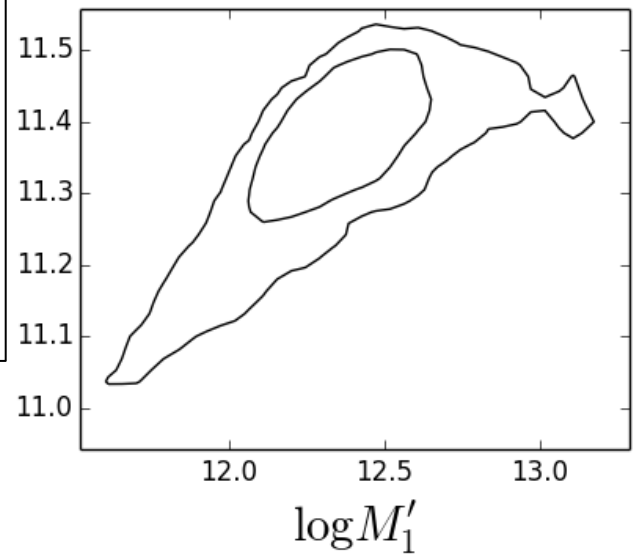
c) HSC Builder's blog

- Subaru optical imager Hyper Suprime-Cam (HSC)
  - Subaru/HSC survey has started since March 24, 2014 under the collaboration of JP/US/TW.
  - ~1/3 of observations are completed.

HSC Survey for High-z Galaxies







Harikane,MO+ ApJ, 2016

- SHMR at 10^{11}Mo decreases

from z=0 to z~4, and increases to z~7

- At z>4, feedback is weaker than those previously thought?

James Webb Space Telescope (JWST)

Figure 1: The data usefully available at each proposal deadline for the nominal 12-month proprietary period is shown (taken from the March 2014 JSTAC letter). This includes 0.2 cycle as the lead-time needed to process the new data after its release, evaluate new results and write proposals. The nominal Cycle timing shown here (April—April) may change depending on the actual mission timing and conclusion of commissioning activities, but this would not change the data availability by Cycle as shown in green. See the March 2014 JSTAC letter for the details.

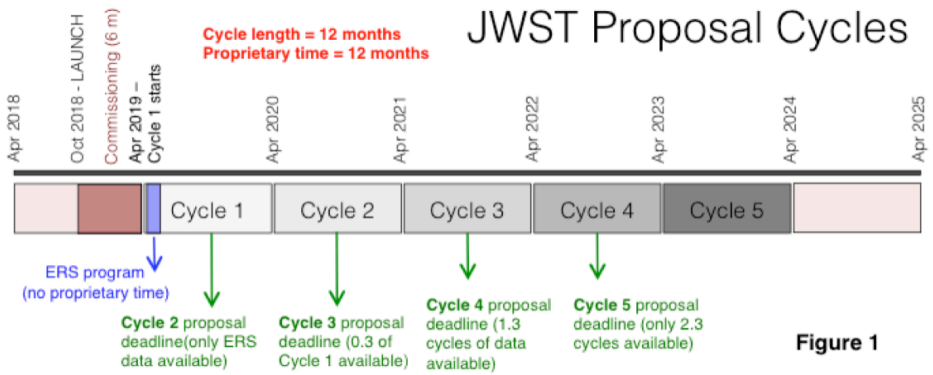
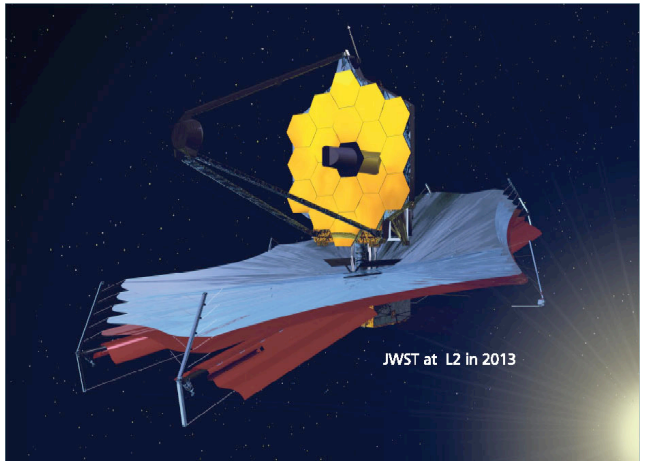
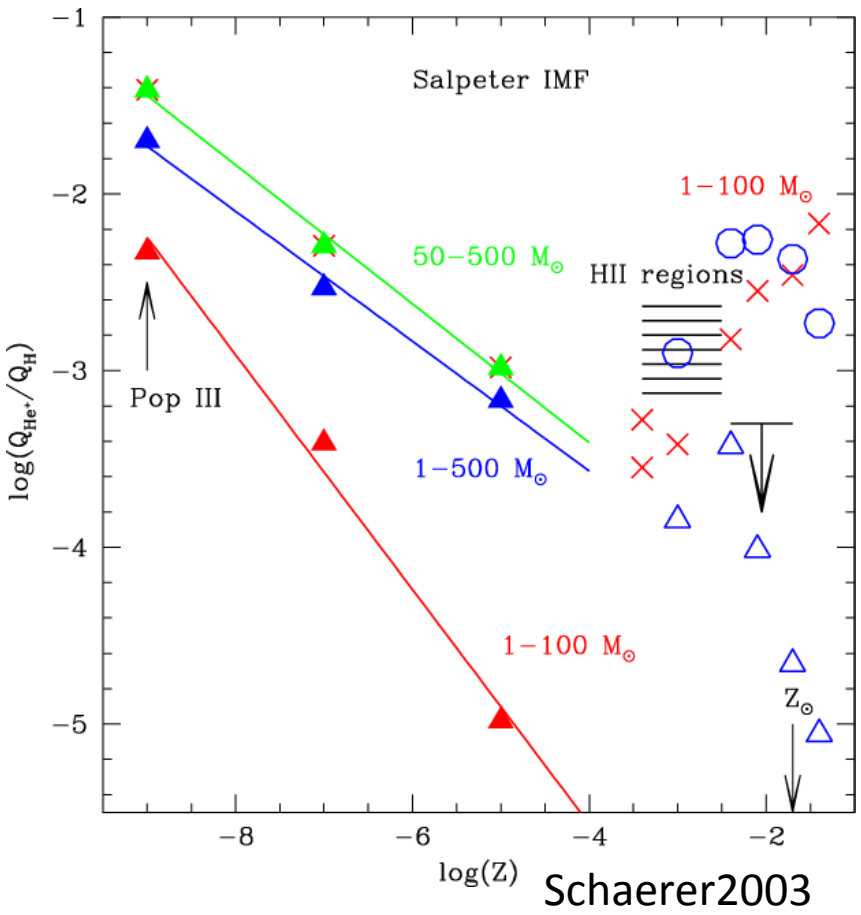


Figure 1



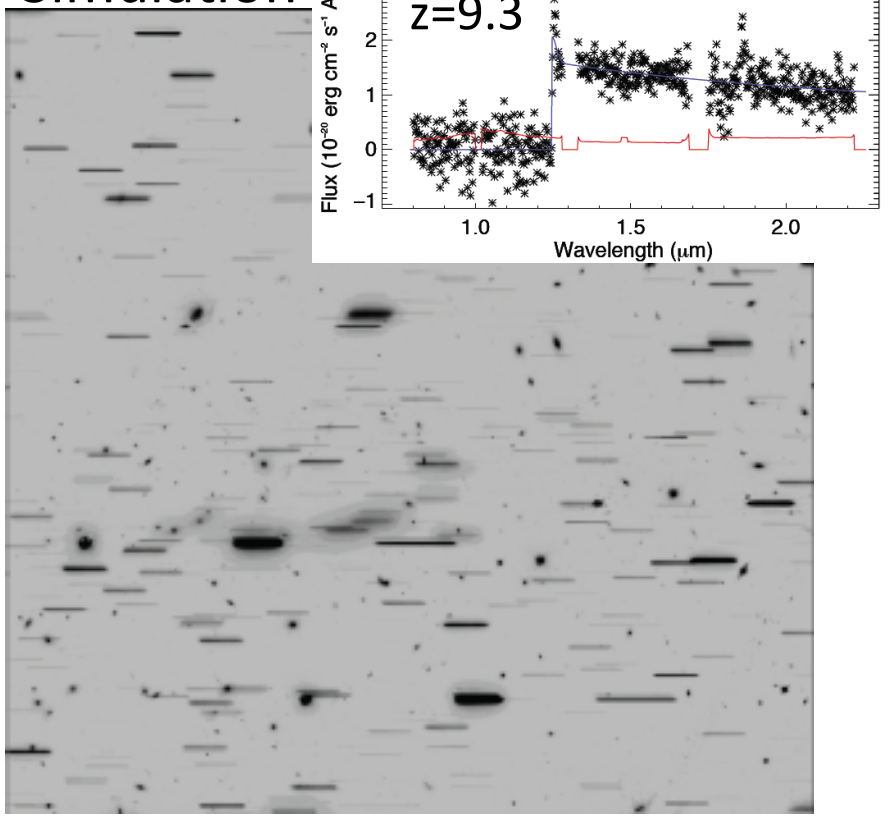
- New window for high-z galaxies
  - Galaxy identifications up to z~20
  - Detailed early galaxy properties up to z~10 (w oxygen lines)
- Schedule
  - 2018 Oct. (Launching)
  - 2019 Apr (Cycle 1 start)

JWST Probes for LAEs



Schaerer2003

Simulation



Dixon & Willott 2014

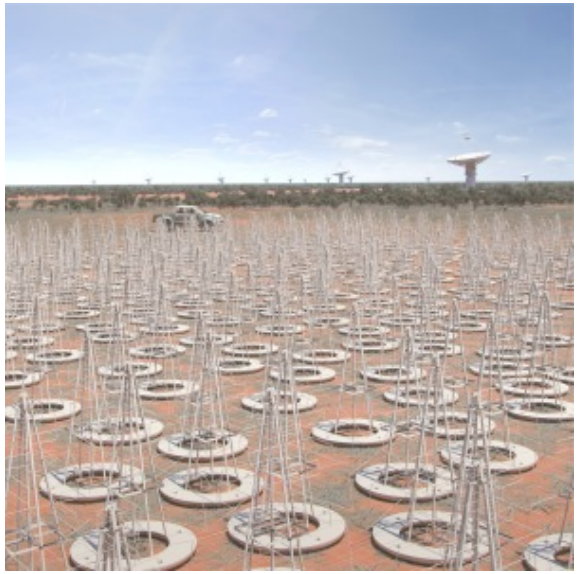
- H Balmer (Ha, Hb) lines at ~2.5-5.0 um
  - Indicator of popIII (HeII/Hb)
- Other nebular lines
  - Early galaxies for chemical/dynamical evolution w e.g. [OIII]5007

- JWST/Near Infrared Imager and Slitless Spectrograph (NIRISS) in guide camera
- WFSS mode: 1-2.5um, R~150, in ~4 arcmin^2
- Simulation for MACS cluster obs in 10hr
  - Identifying 100 LAEs+LBGs at z=5-15

Square Kilometer Array (SKA)

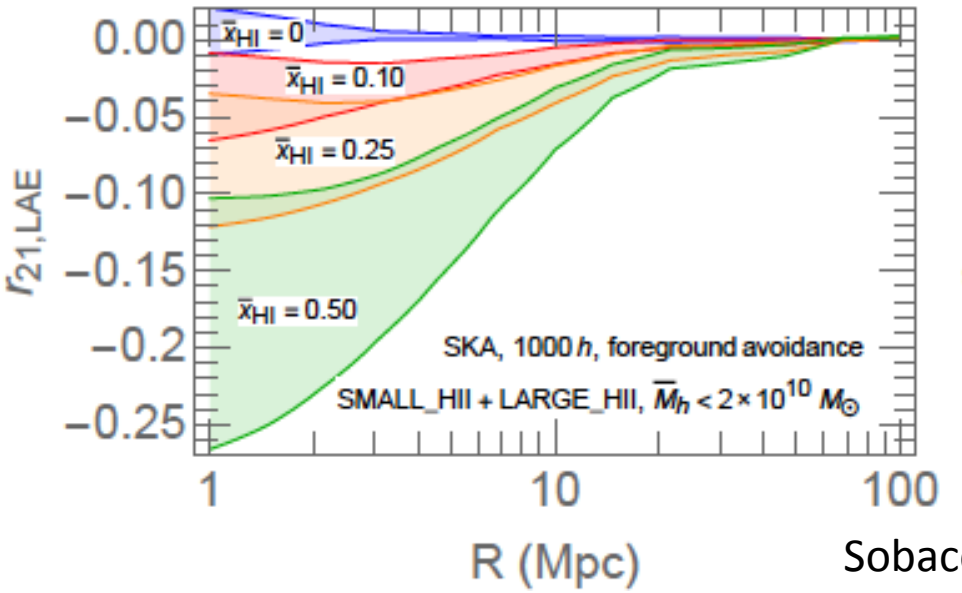
- So far, no reion 21 cm line detections (LOFAR/MWA)

- SKA epoch of reion (EOR) survey (SKA pre. plan; Hasegawa+16)
  - Shallow 10,000 deg^2 (10hr/pt)
  - Medium 1,000 deg^2 (100hr/pt)
  - Deep 100 deg^2 (1000hr/pt)

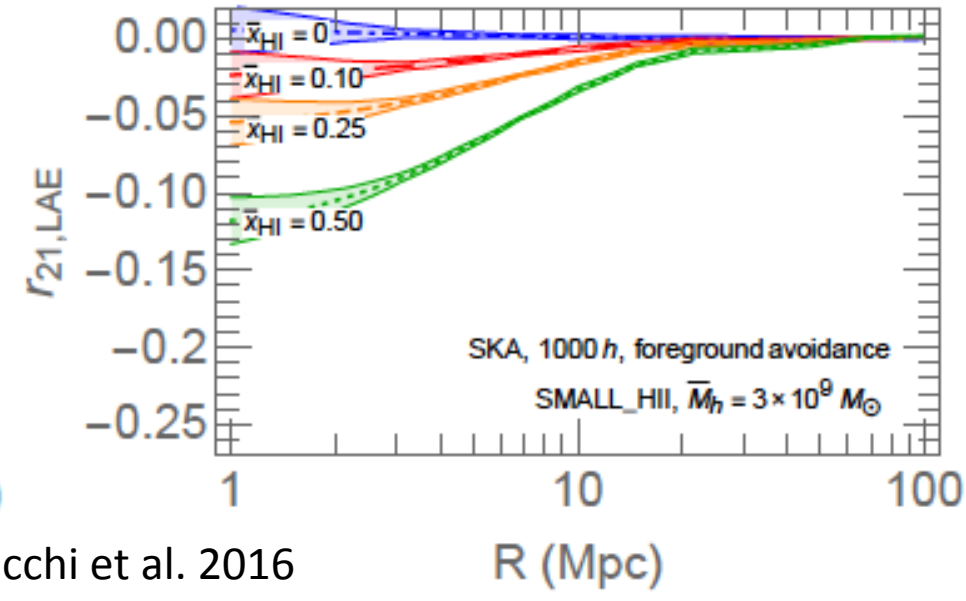


→ Cross-correlation btw. HI 21cm and Subaru galaxies
SKA1: 2018
SKA(full): mid 2020s

SKA1+Subaru



SKA+Subaru



Sobacchi et al. 2016

Summary

- Reviewing recent progresses of high-z galaxy obs.
  - Galaxy formation
    1) SFRD: Smooth SFR density evolution towards z~10
       SFR density negligibly contributed by ALMA (dusty SB) sources at z>4
    2) popIII: [OIII]5007 line found in PopIII cand. CR7 is neither popIII nor DCBH
    3) Morph: More compact galaxies towards high-z: $r_e \propto (1+z)^{-1.1}$
       Clumpy galaxy fraction peaks at z~2, and decreases towards z~8
    4) ISM: High Σ_{SFR}. ALMA [CII]158um deficit and [OIII]88um. Keck CIII], CIV detect.
       Suggestive of high ionization state.
  - Cosmic reionization
    - $<f_{esc}>$~0.1-0.2
    - No truncation found in LFs. The statics also infers $M_{trunc} > -13$
    - $\Delta z=3$ (-1/+2) [for Q_{HII}=10-99%] consistent w Planck2016
    - $Q_{HII}(z)$ of Subaru LAE suggests moderately high HI frac at z~7-8
      → Self-consistent picture of reion history and ionizing photons.
  - On-going and future surveys
    - Early HSC: M_*/M_h ratio upturn(z>~4) Signature of feedback eff. change?
    - JWST observations for z>~10 galaxies (launching in 2018)
    - SKA1 observations for EoR 21 cm (observing from 2018)