Tokyo Spring Cosmic Lyman-Alpha Workshop:

The Mean Ultraviolet Spectrum of a Representative Sample of Faint z~3 Lyman Alpha Emitters

Kimihiko Nakajima (ESO/UCL)

In collaboration with

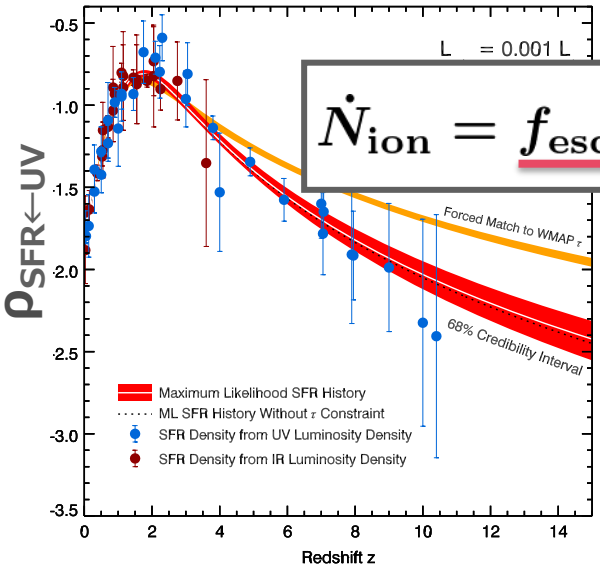
R. Ellis (ESO/UCL), T. Fletcher (UCL), B. Robertson (UCSC),

I. Iwata (Subaru), A. Inoue (Osaka Sangyo U.)

Background

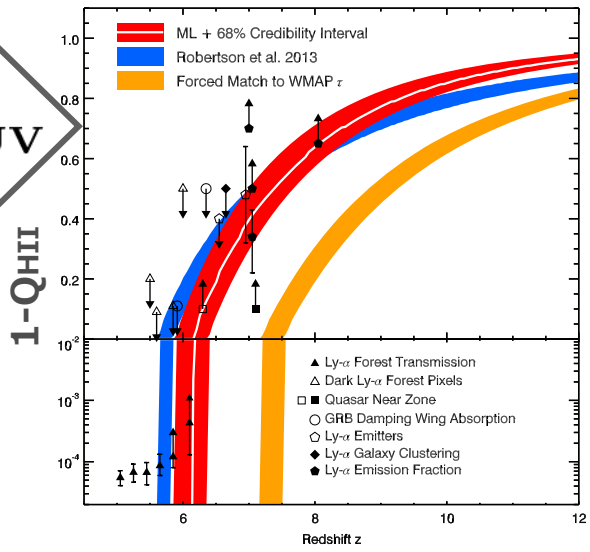
Galaxies governed Reionization process?

History of cosmic star-formation

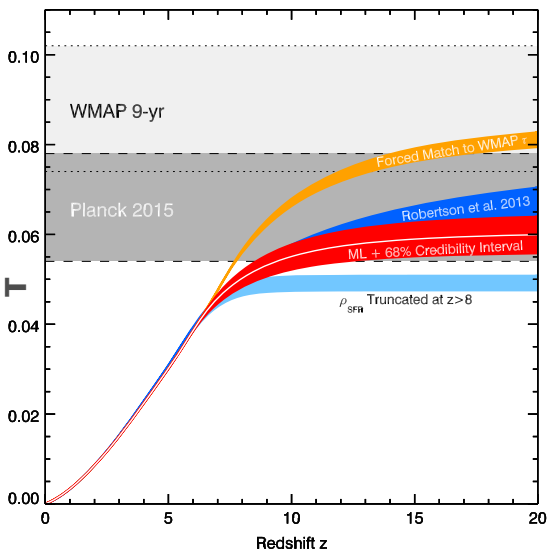


$$\dot{N}_{\rm ion} = f_{\rm esc}\xi_{\rm ion}\rho_{\rm UV}$$

Neutral fraction of IGM



Electron scattering Optical depth



$$\dot{Q}_{\rm HII} = \frac{\dot{N}_{\rm ion}}{\langle n_{\rm H}\rangle} - \frac{Q_{\rm HII}}{t_{\rm rec}}$$

$$\tau_{el}(z) = \int_0^z c\,dt\,n_e(z)\,\sigma_T$$

Robertson et al. 2015

See also Faisst 2016, Talks on Wednesday

$$f_{\rm esc} = \dot{n}_{\rm ion,esc}/\dot{n}_{\rm ion}$$

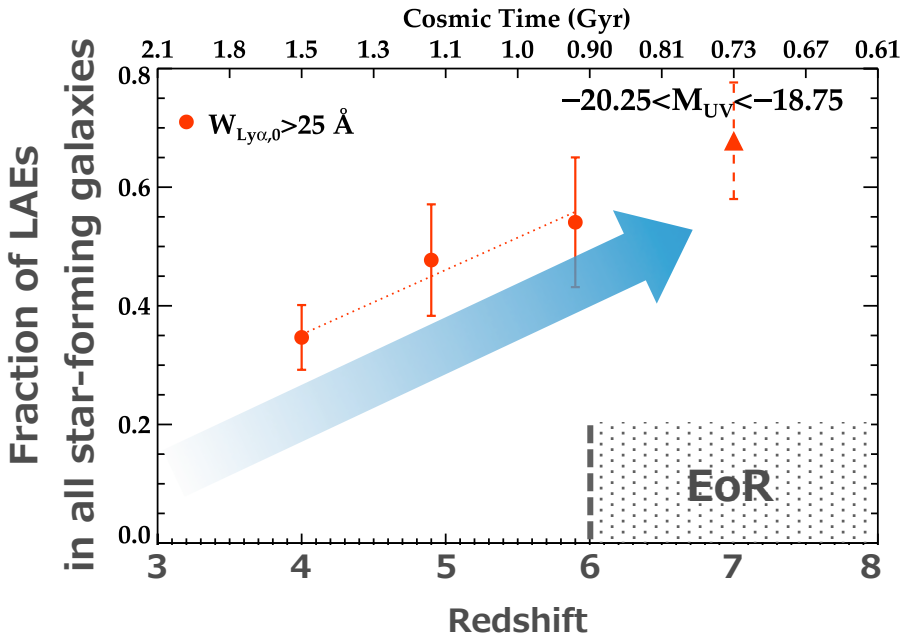
Fraction of ionizing photons that escape into IGM

$$\xi_{\rm ion} = \dot{n}_{\rm ion}/L_{\rm UV}$$

Efficiency of ionizing photon production

Background

Lyα emitters (LAEs) as Probes of Early galaxies



Stark et al. 2011, ApJL, 728, L2

- Low-mass, metal-poor, young star-forming galaxies
- Typical in early universe

Background

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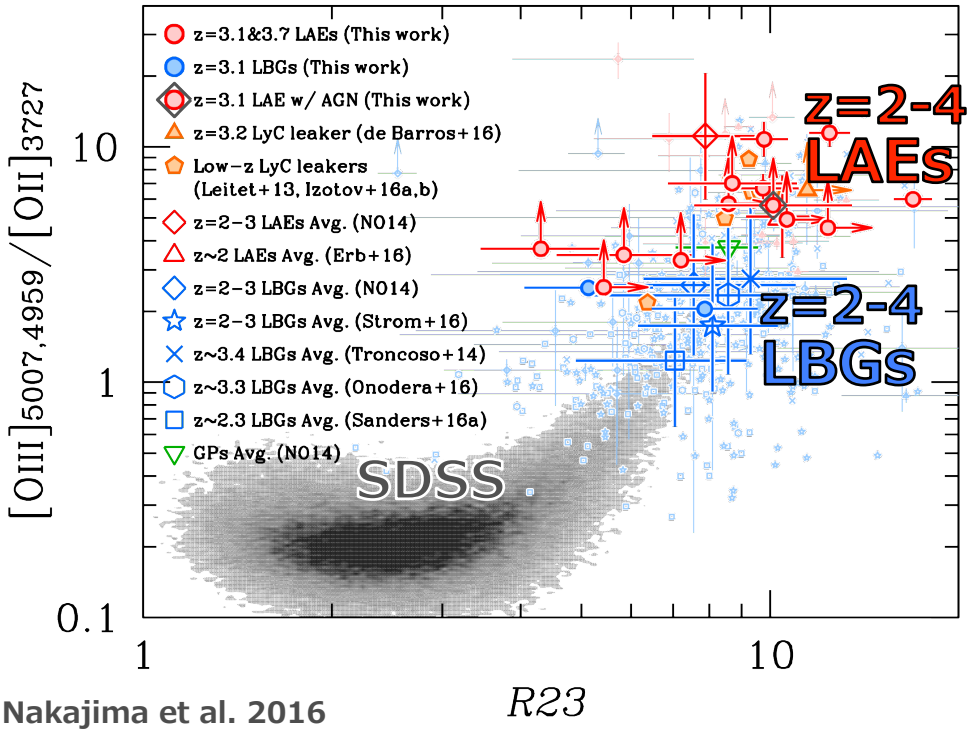
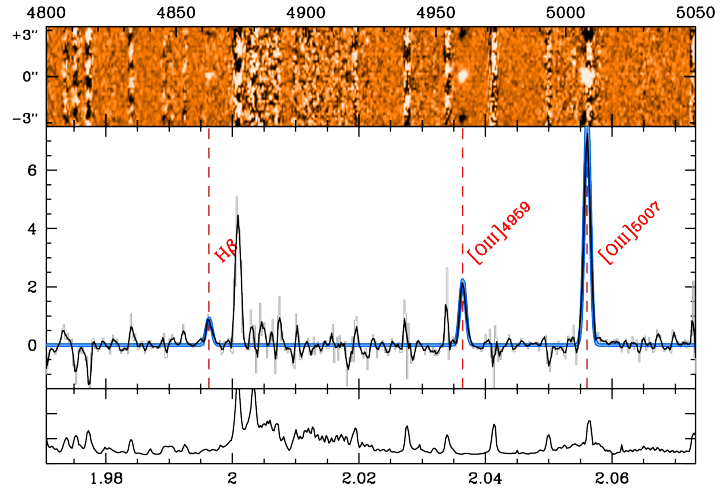


Nakajima et al. 2016

z=3.1 LAE's MOSFIRE K spectrum



See also Nakajima&Ouchi 2014, Erb+2016, Kojima+2017, Talk by D. Erb

- Low-mass, metal-poor, young star-forming galaxies
- Typical in early universe
- Intense nebular lines, e.g. [OIII]5007,4959

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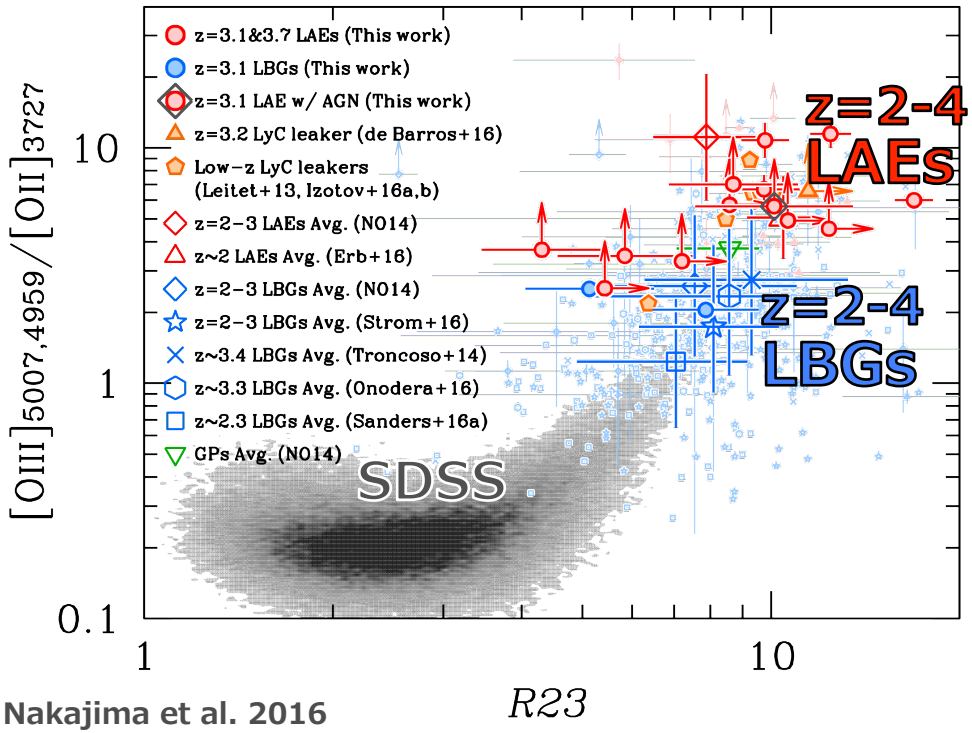
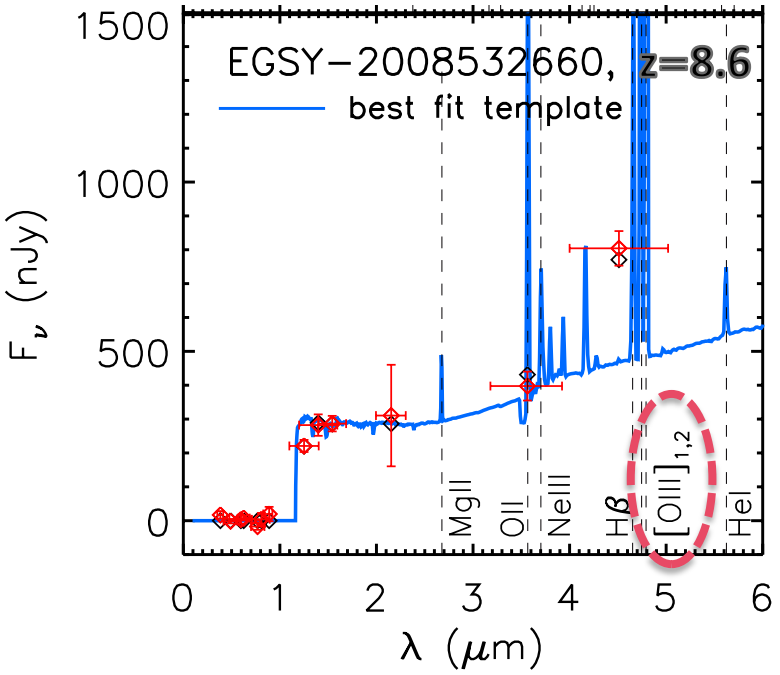


Nakajima et al. 2016

Roberts-Borsani et al. 2016



See also Smit+2014,2015

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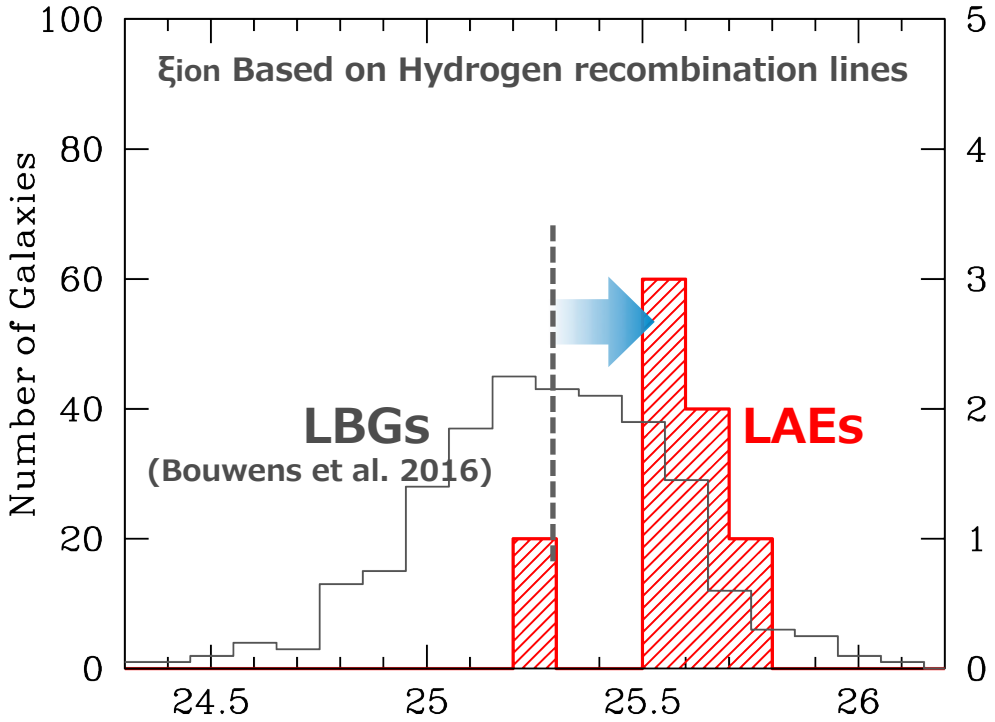
Background

LAEs present Hard Ionizing Spectrum



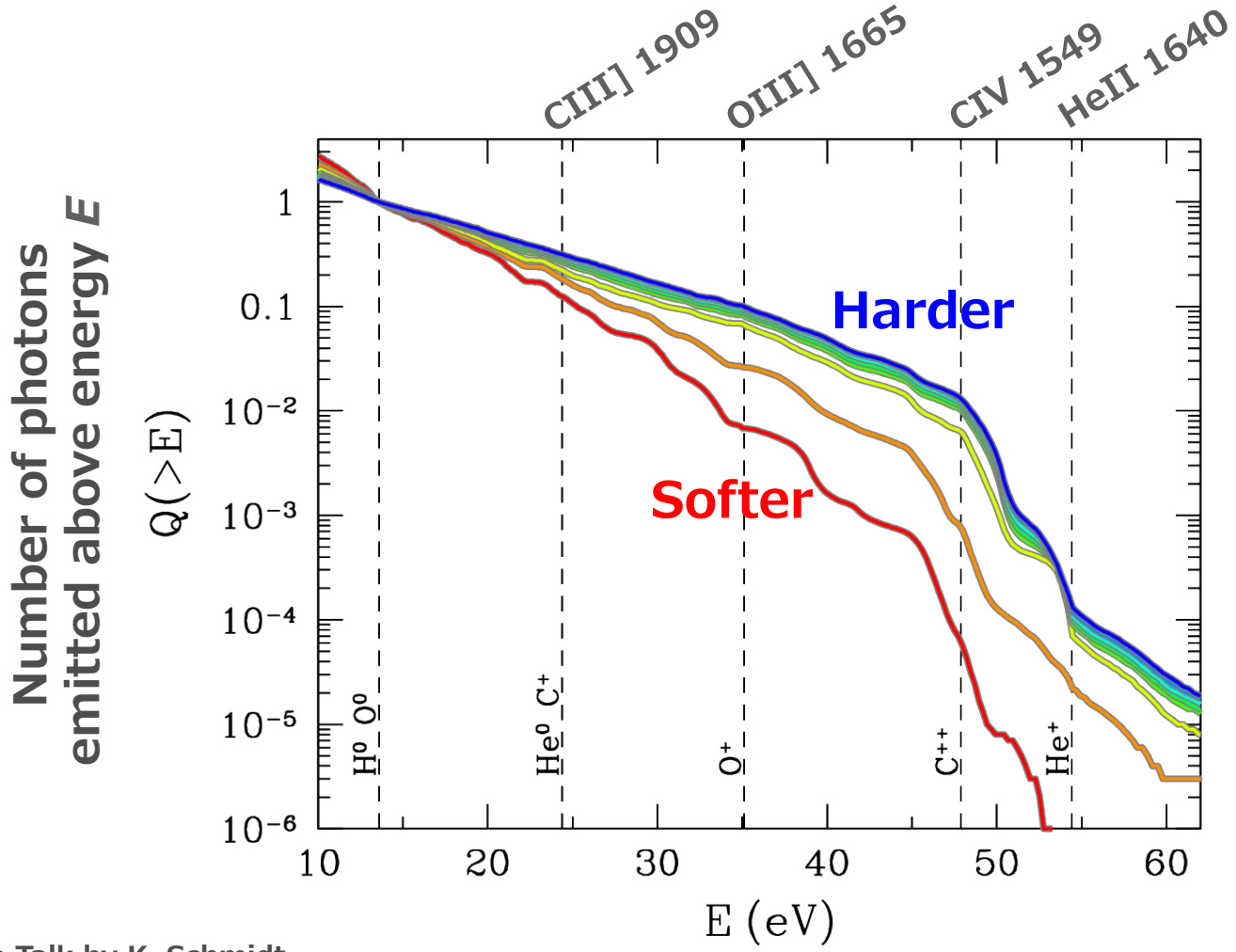
Nakajima et al. 2016

More efficient production of ionizing photons

Typical Characteristics of LAEs ?

Our Work

Nature of Ionizing Spectrum Examined by UV spectrum

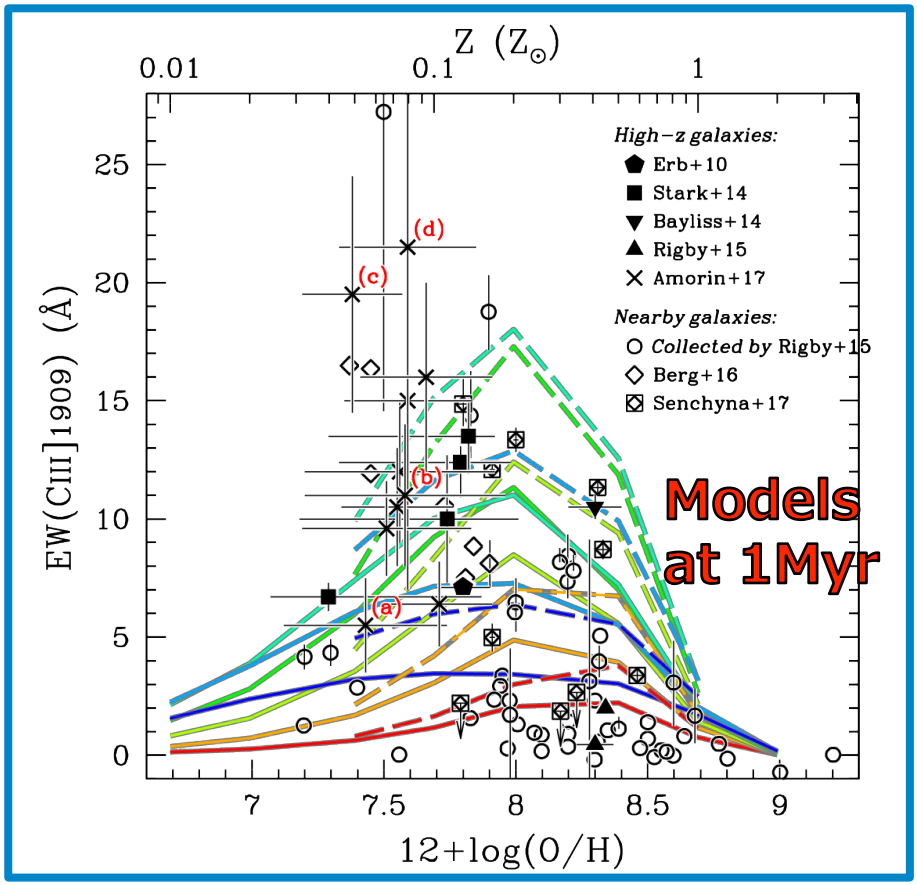


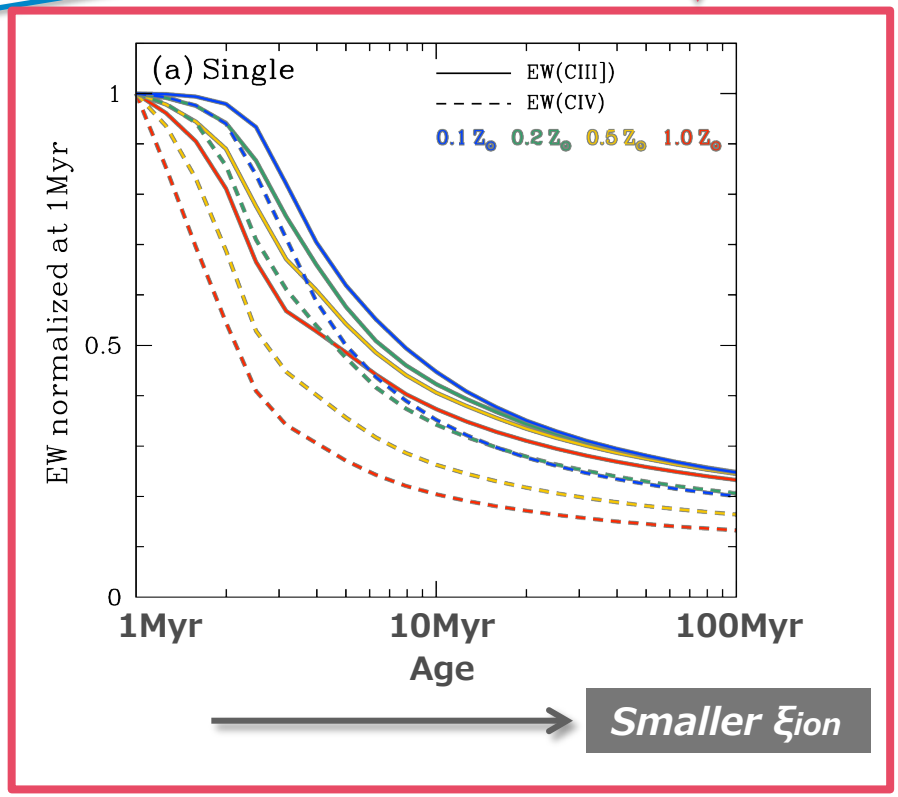
Refer also to Talk by K. Schmidt

Our Work

UV line diagnostics of ξion

$$EW(CIII]) = \frac{Flux(CIII])}{f_{\lambda,1909}} \propto \frac{N_{ion}(>24.4eV)}{L_{UV}} = f(Z,U,\xi_{ion}(age))$$

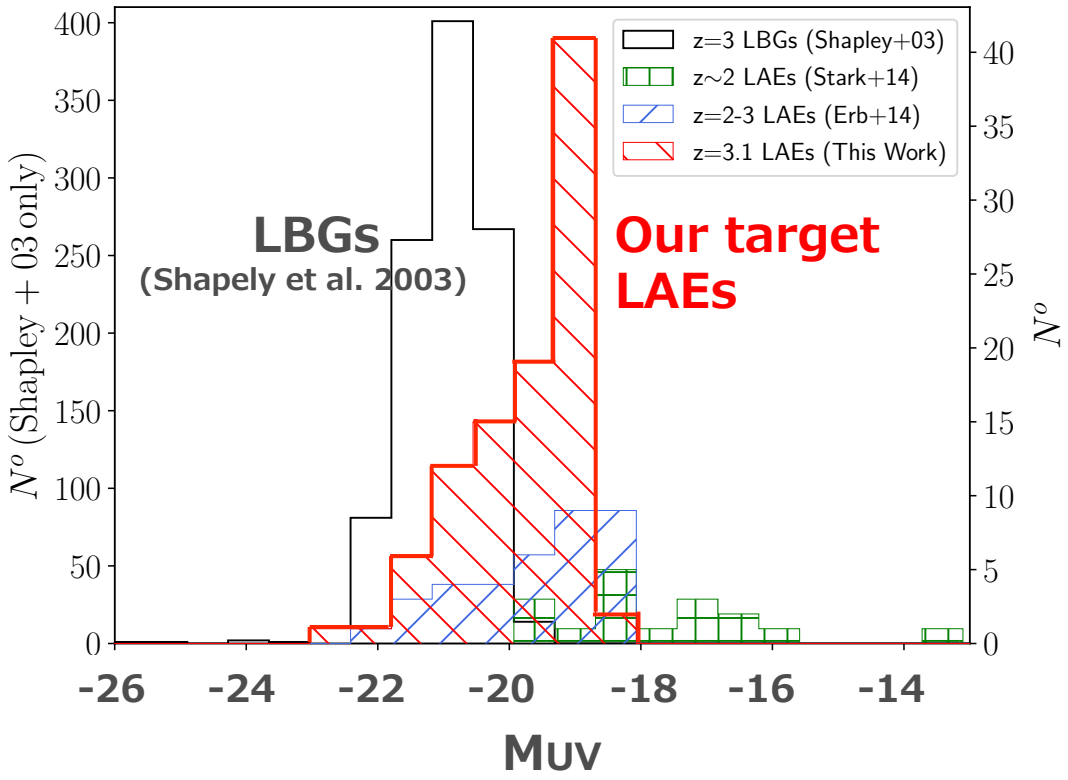




Nakajima et al. 2017 *in collaboration with VUDS*
(A&A in press, arXiv:1709.03990)
See also Stark+2014, Gutkin+2016

Our Work

VLT/VIMOS (11hrs) Observation Identifying Lyα from ~70 Faint z=3 LAEs



Nakajima et al. 2018, MNRAS in press
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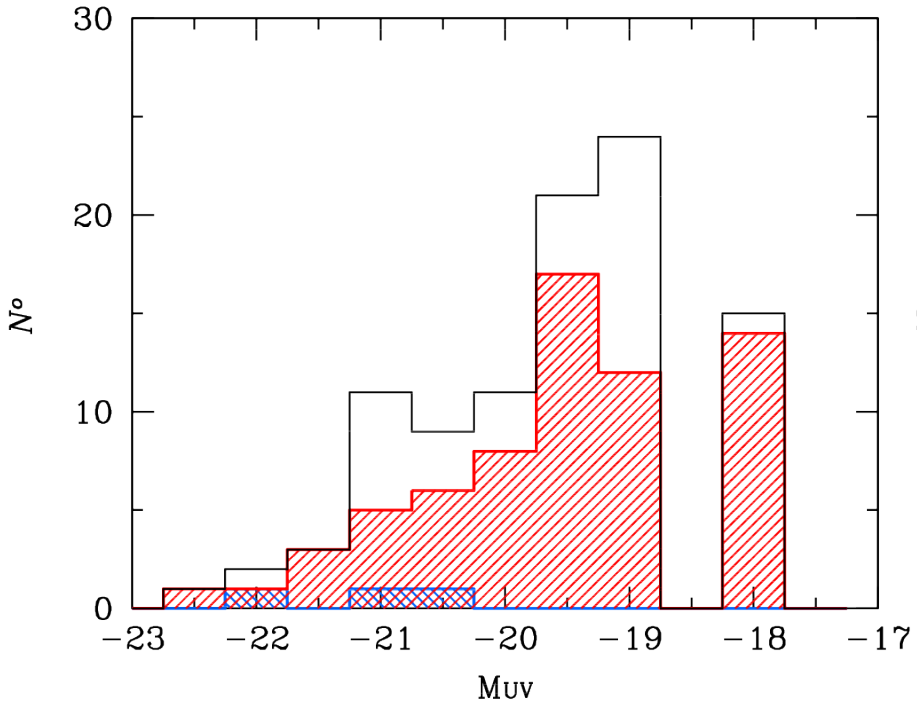

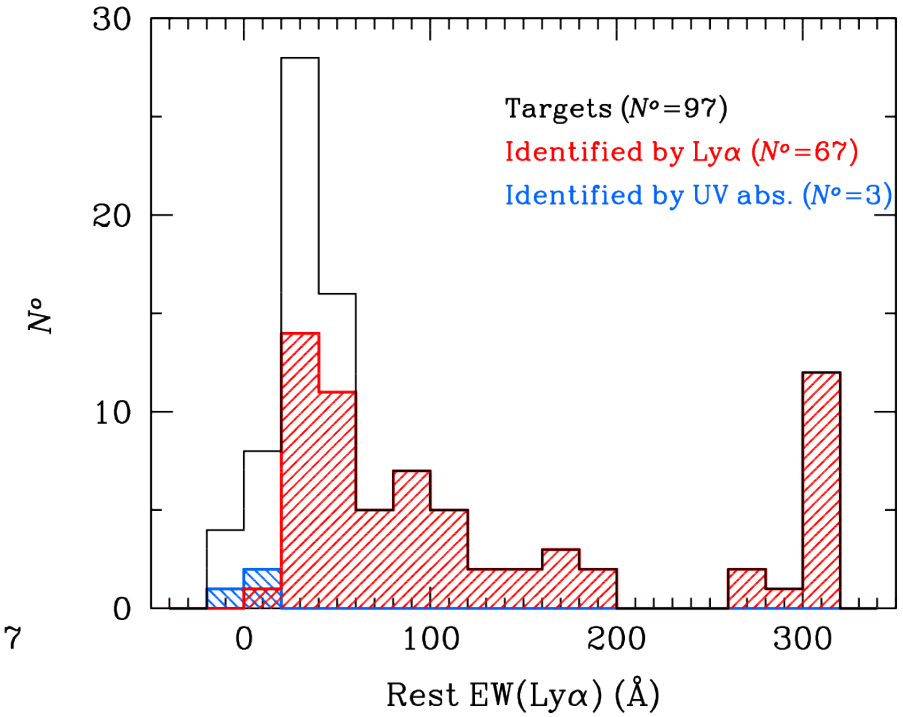

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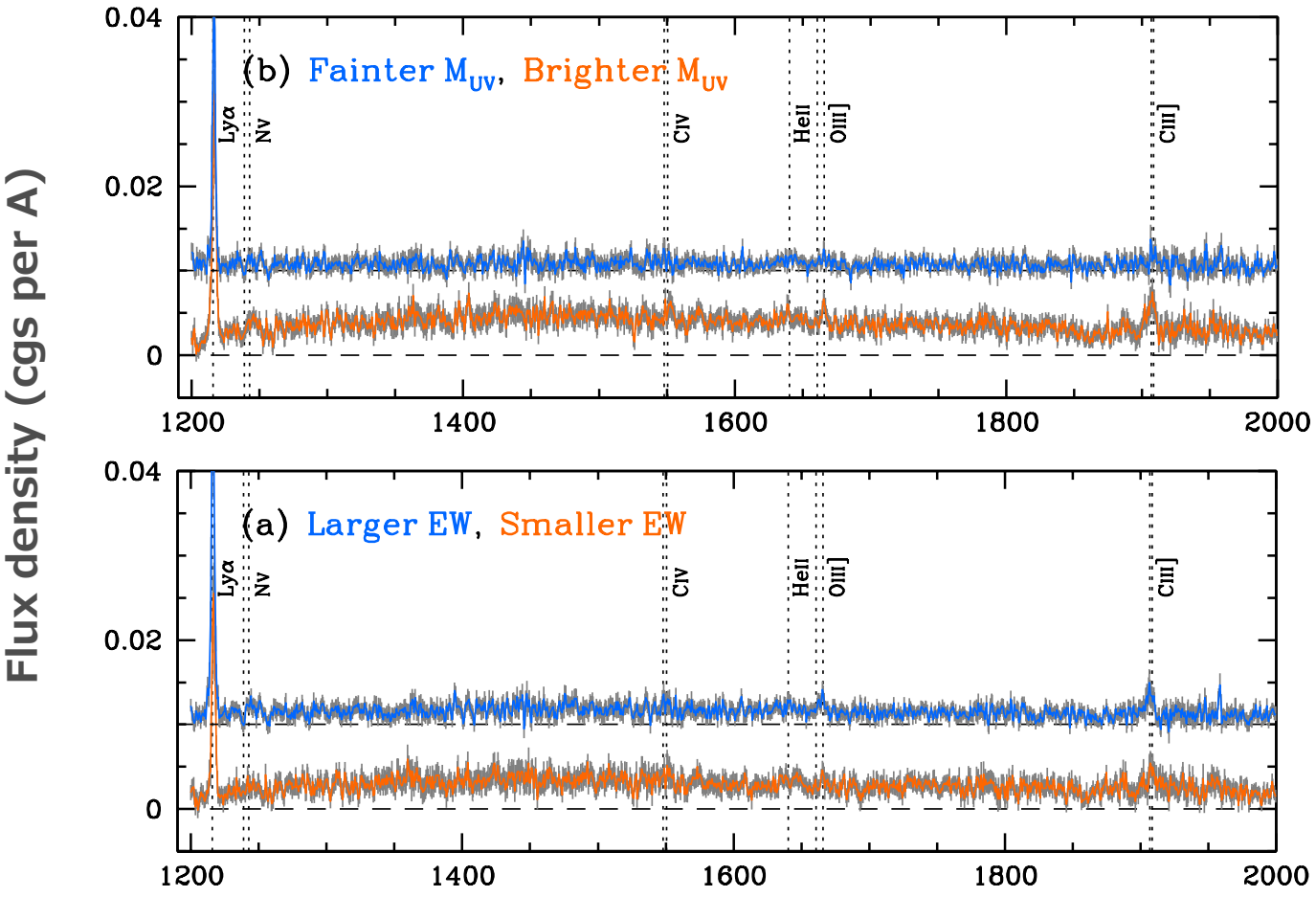
Our Work

VLT/VIMOS (11hrs) Observation
Identifying rest UV lines in Stacks of 70 z=3 LAEs



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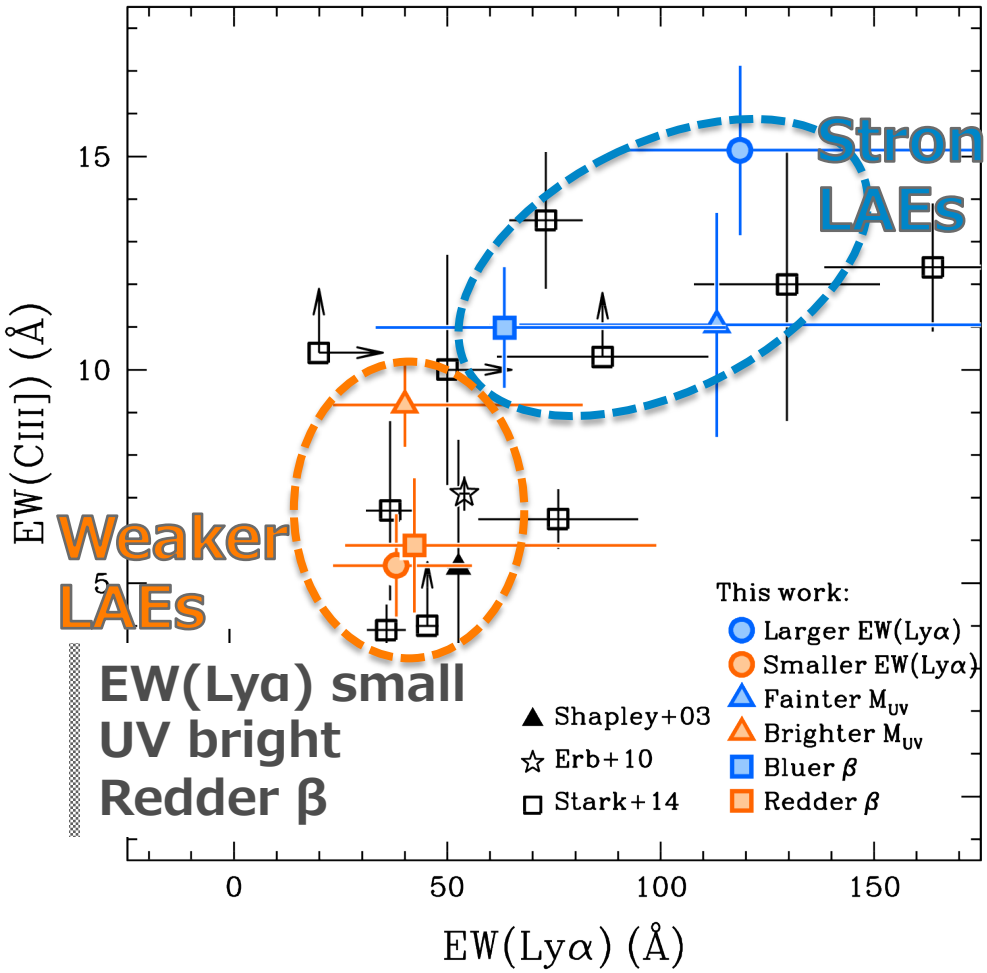
Results

Strong CIII] Associated with Strong Lyα



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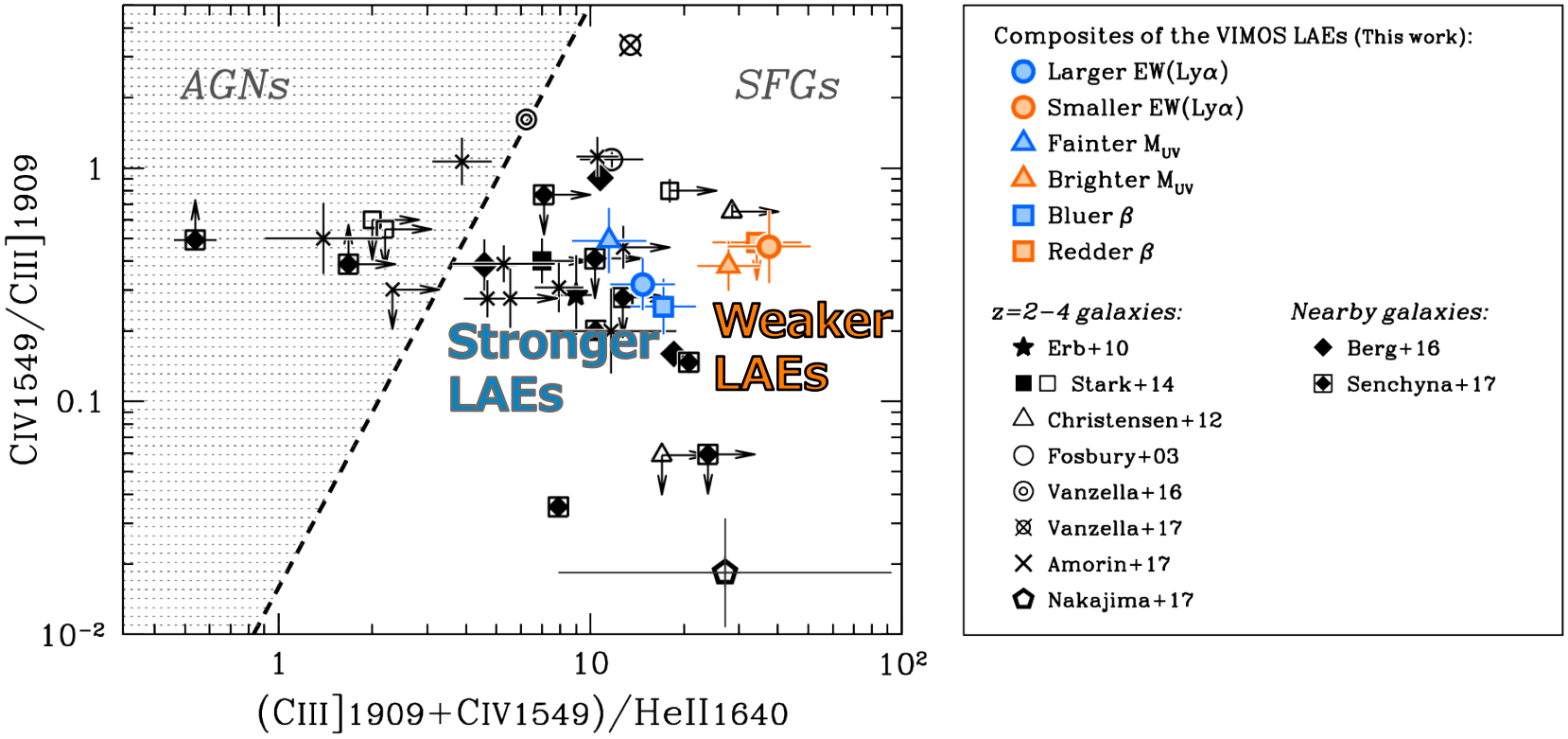
Results

Stronger LAEs are less chemically enriched galaxies



Nakajima et al. 2018

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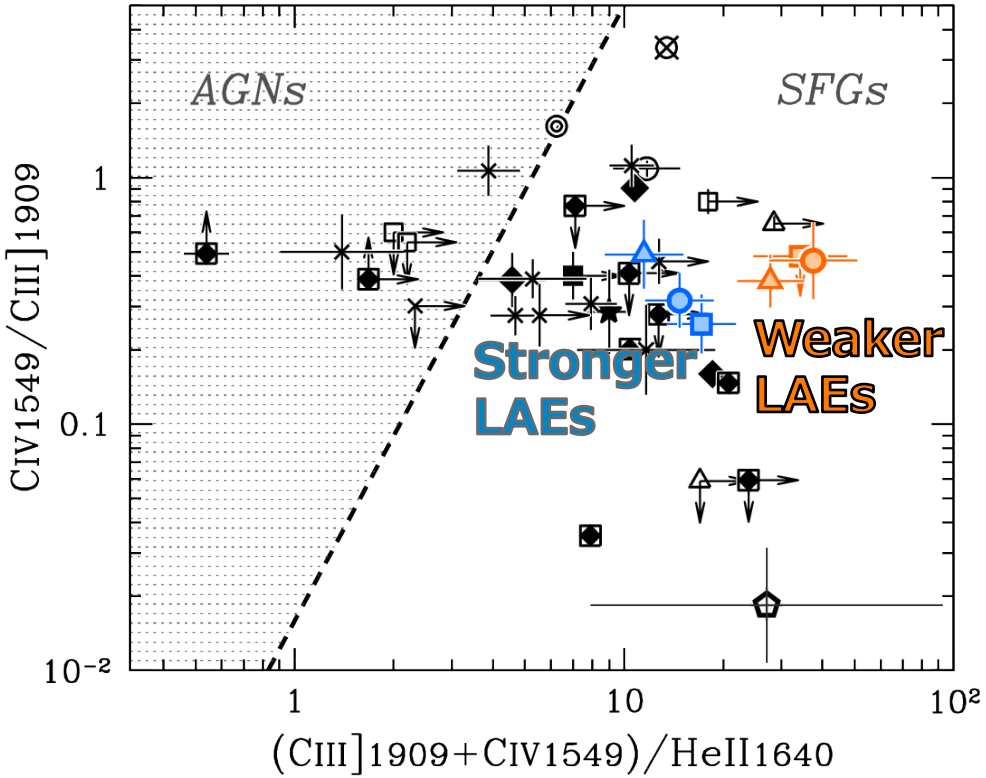
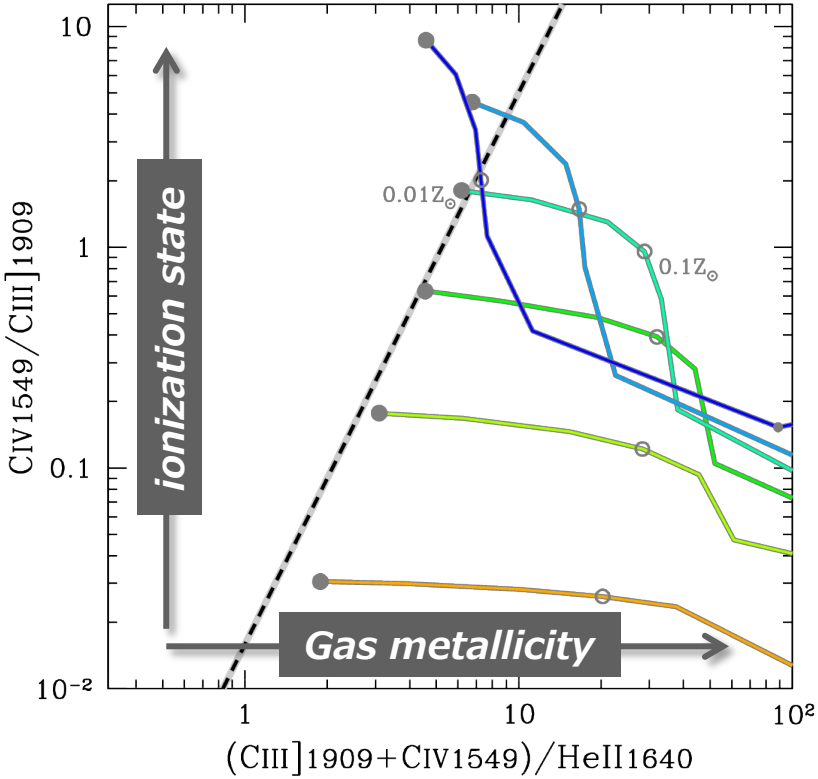


Nakajima et al. 2018



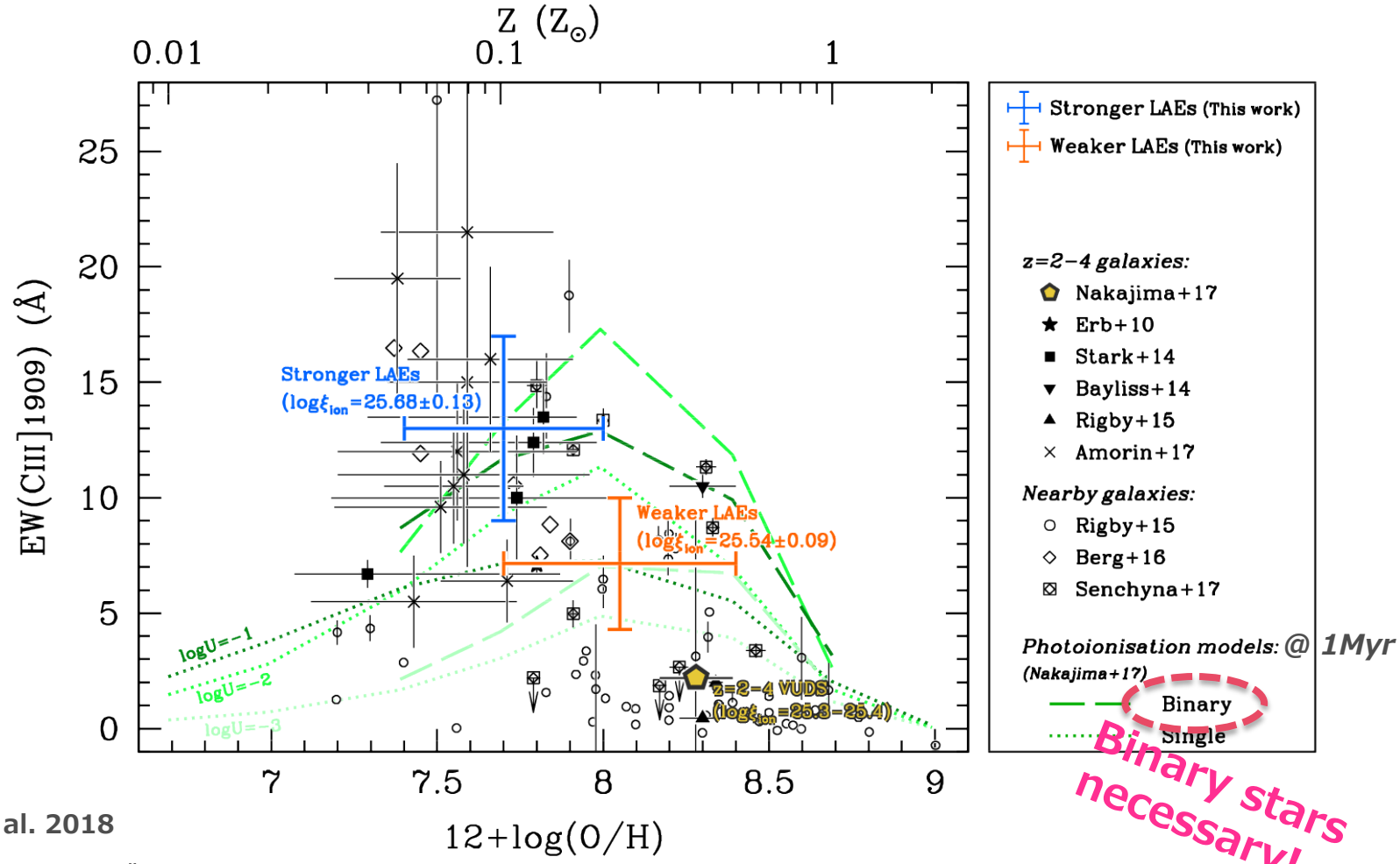
Nakajima et al. 2017

Stronger LAEs: Z = 0.05 – 0.2 Z_{sun}

Weaker LAEs: Z = 0.1 – 0.5 Z_{sun}

Results

LAEs' Hard ξ_{ion} is confirmed with UV line analysis



Nakajima et al. 2018

Stronger LAEs: log ξ_{ion} = 25.68±0.13

Weaker LAEs: log ξ_{ion} = 25.54±0.09

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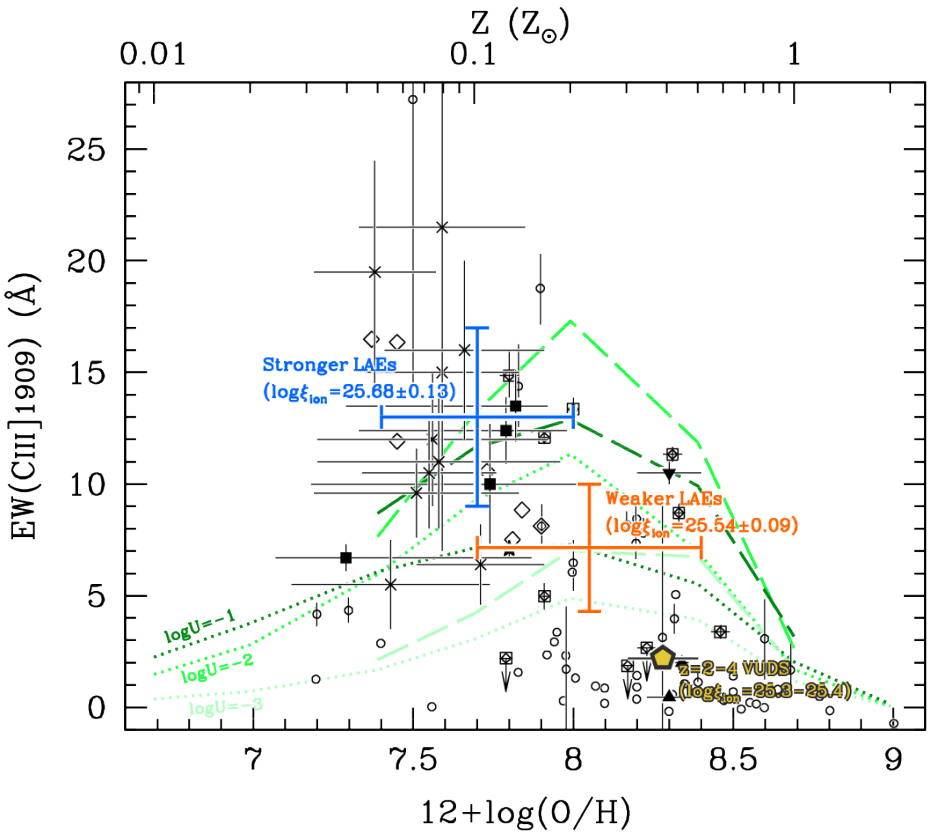

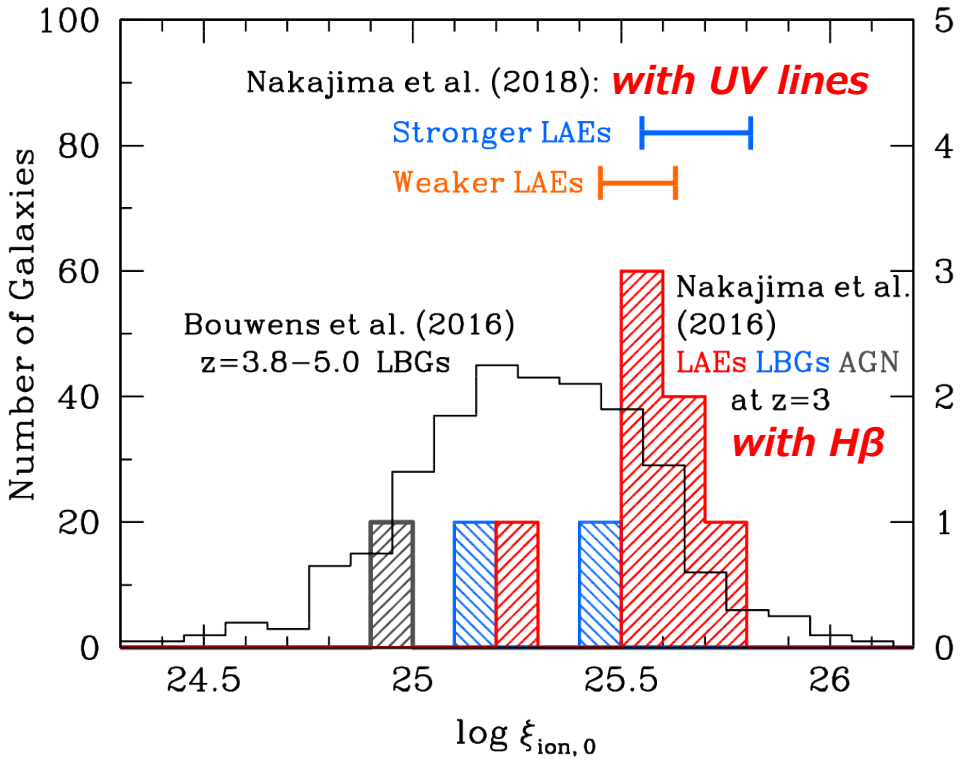

Nakajima et al. 2018

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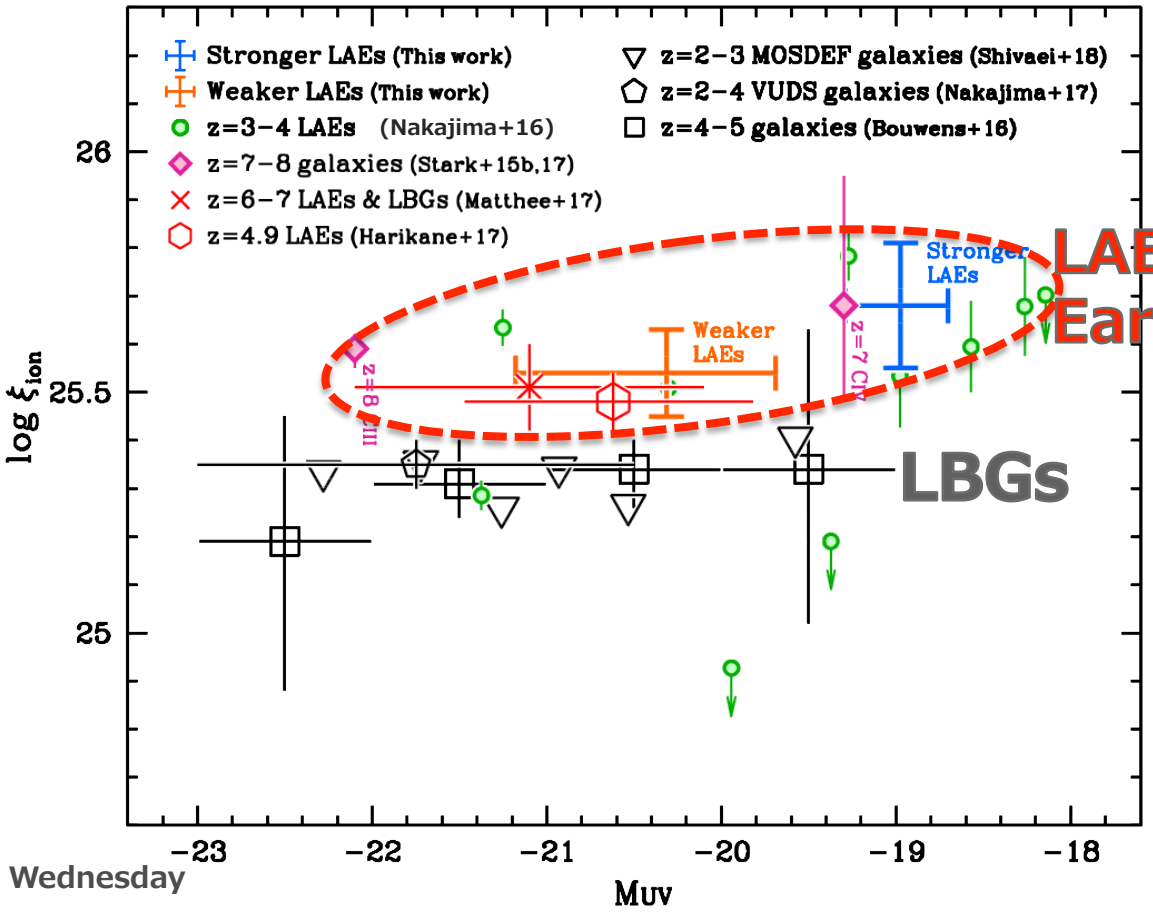
Discussion

ξion as functions of UV luminosity, redshift and Lyα



Nakajima et al. 2018

Refer also to Talks on Wednesday

LBGs: Uniform ξion (~25.2--25.4), independent of MUV, *z*

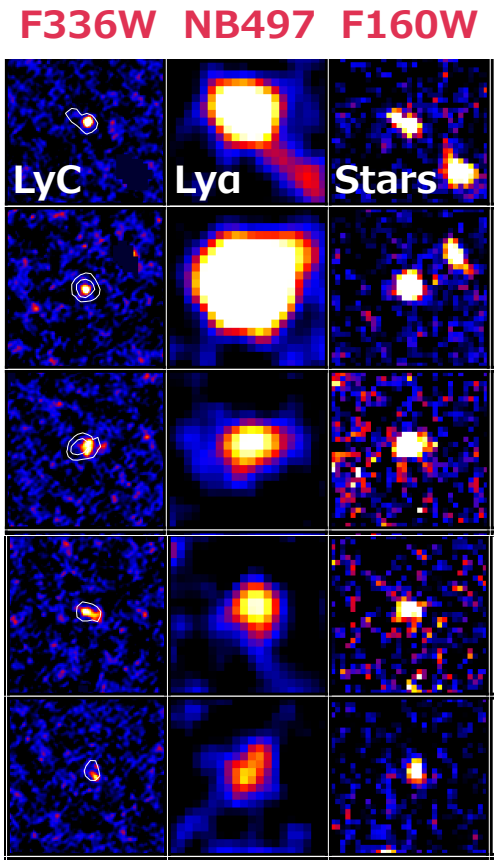
LAEs: Larger ξion (~25.5--25.7), particularly for faintest LAEs

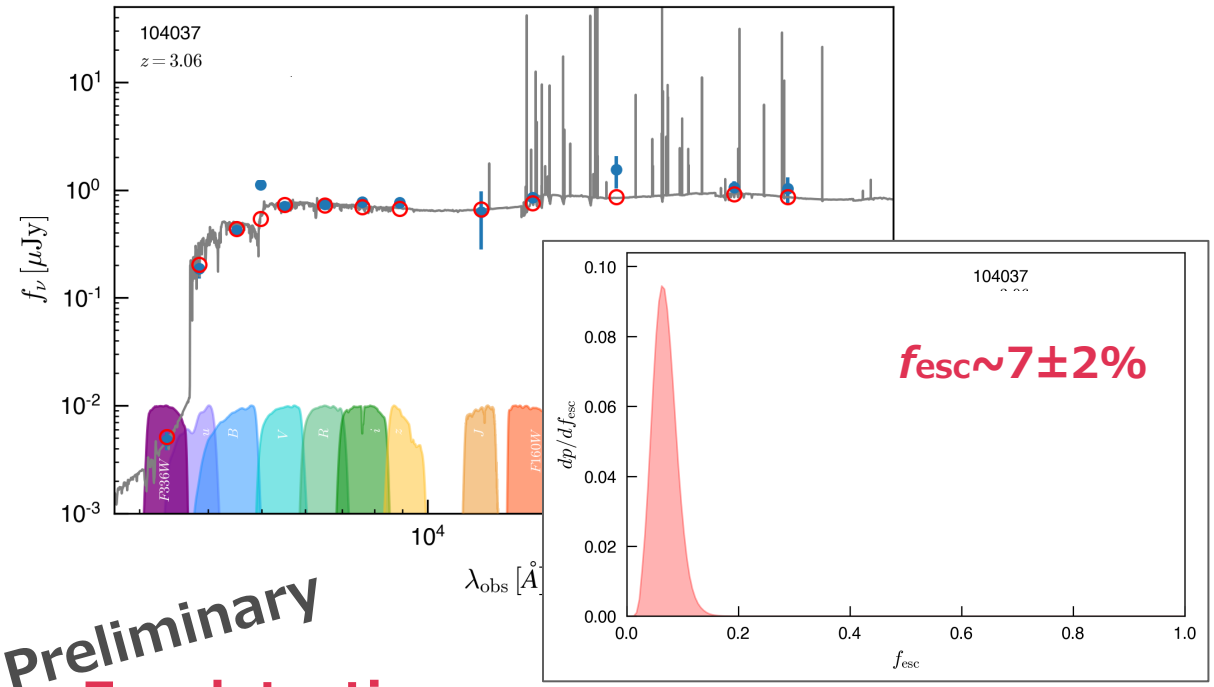
→ Analogous to Galaxies in EoR

Work on-going

LymAn Continuum Escape Survey (LACES): UV Imaging of z=3 LAEs

- Deep (20orbits x3) HST/F336W imaging of 51 z=3 LAEs
- High success rate in securing significant F336W detections (~30%)
- HST localization suggests minimal (<2%) foreground contamination





Preliminary

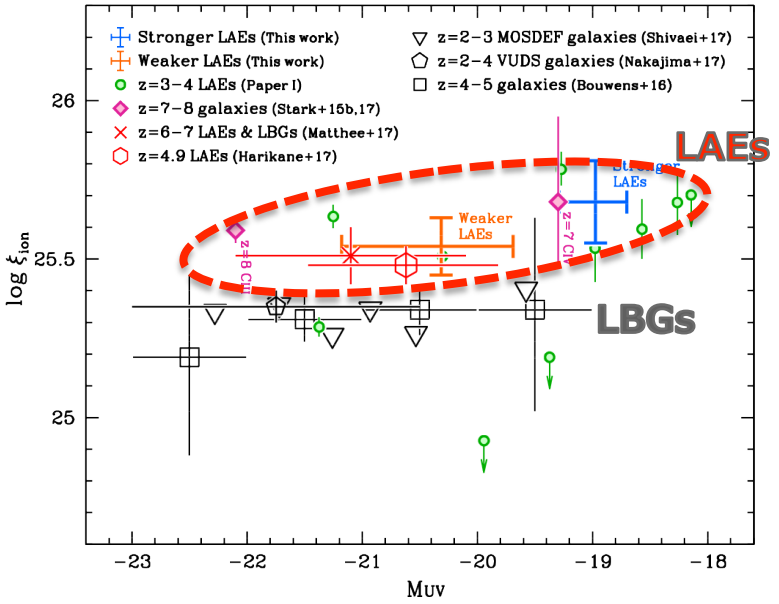
For detections:

Individual *f*esc ranges from 4-60%

Summary

LAEs are ideal analogs of sources in Reionization era

- Low-mass, Low-metallicity, Young
- Intense [OIII]5007,4959
- **Hard Ionizing Spectrum**



Galaxies like LAEs could dominate Reionization process

- Hard Ionizing Spectrum
- **High Escape Fraction?**
- → *To be examined with LACES*