Subaru Users Meeting FY2020 Online on Mar 3-5, 2021

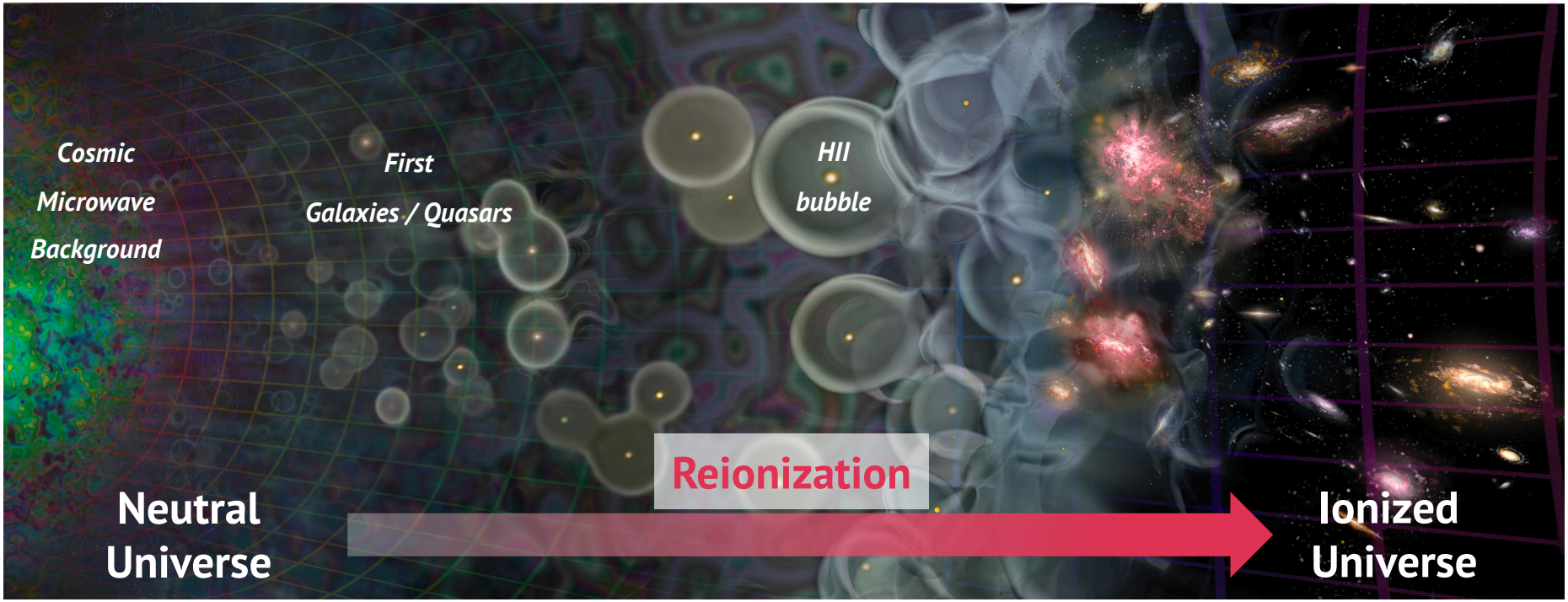
The Lyman Continuum Escape Survey: Ionizing Radiation from Lyman Alpha Emitting Galaxies

Kimihiko Nakajima
(NAOJ)

In collaboration with

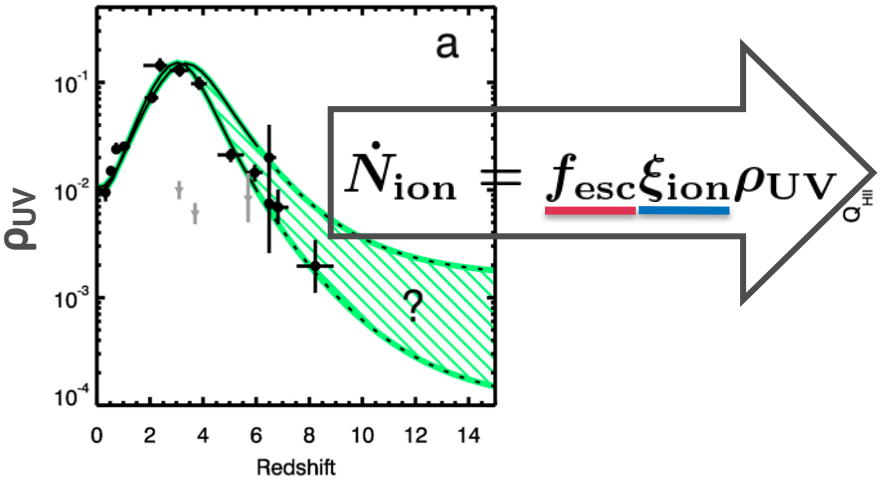
R. S. Ellis (UCL), T. Fletcher (UCL), I. Iwata (NAOJ), A. K. Inoue (Waseda),
B. E. Robertson (UCSC), M. Tang (Univ. Arizona), D. P. Stark (Univ. Arizona)

When and How Cosmic Reionization occurred?



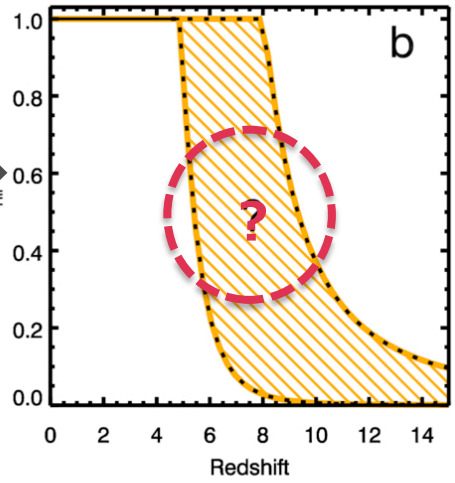
Galaxies governed Reionization process?

History of cosmic star-formation

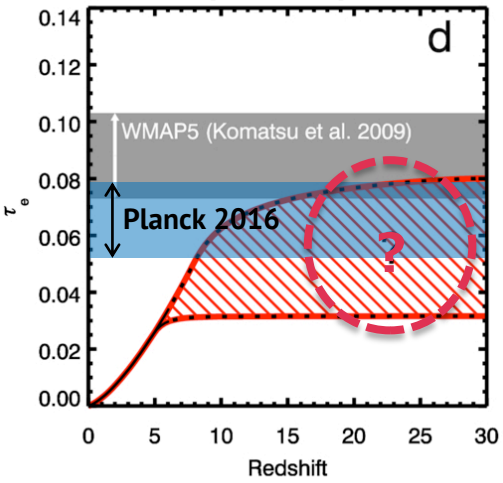


$$\dot{N}_{\rm ion} = f_{\rm esc}\xi_{\rm ion}\rho_{\rm UV}$$

Fraction of ionized hydrogen



Electron scattering Optical depth



Robertson et al. 2010, Nature 468, 55

See also: Robertson+2015, Finkelstein+2019, Naidu+2020

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

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

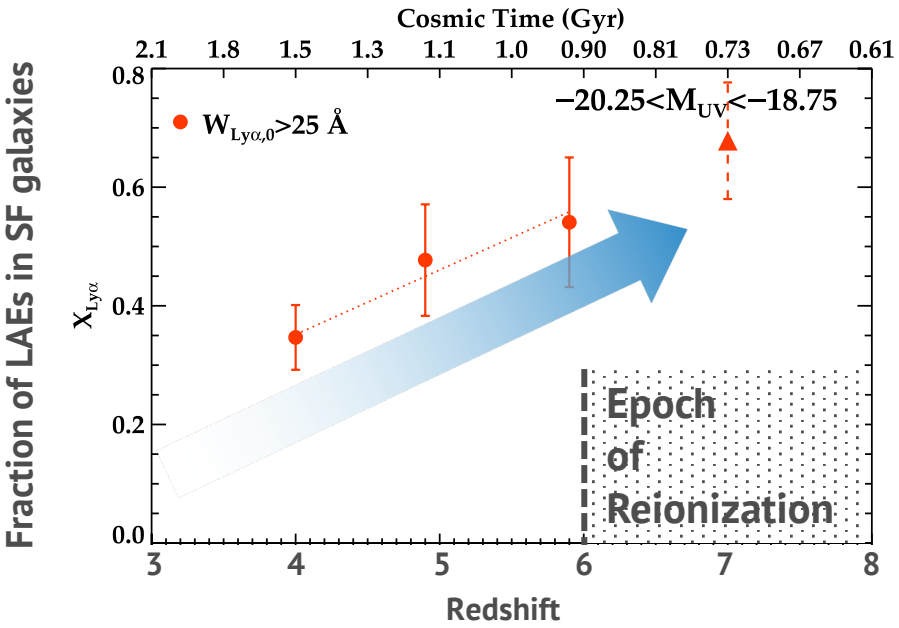
$$f_{\rm esc} = \dot{n}_{\rm ion,esc}/\dot{n}_{\rm ion}$$

Fraction of ionizing photons that escape into IGM

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

Efficiency of ionizing photon production

Lyα emitters (LAEs) as Probes of Early Galaxies



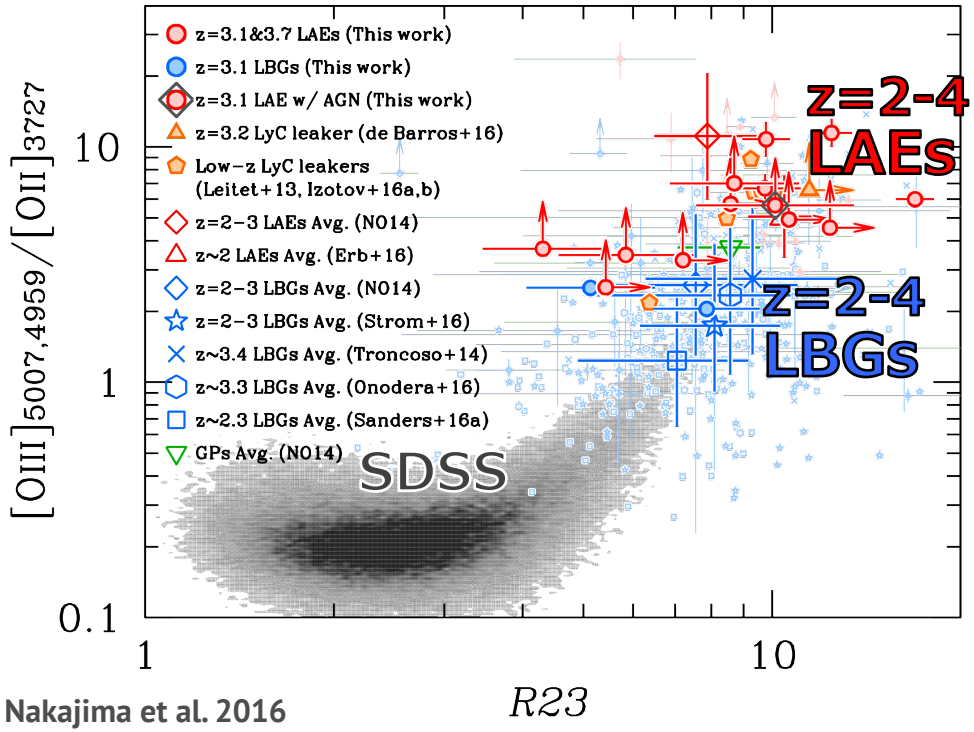
Stark et al. 2011, ApJL, 728, L2

See also: Kusakabe+2020

Low-mass, metal-poor star-forming galaxies

Typical in early universe

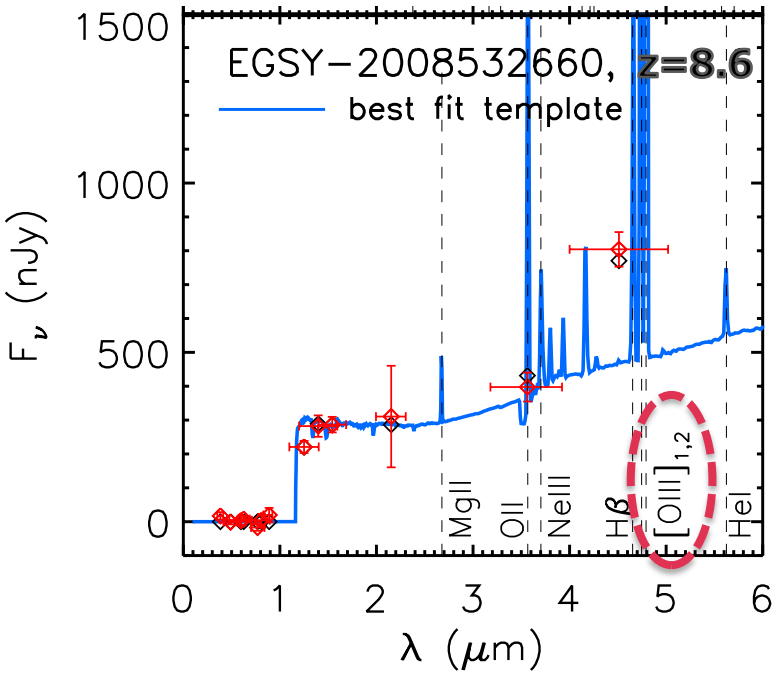
Lyα emitters (LAEs) as Probes of Early Galaxies



Nakajima et al. 2016

See also: Nakajima & Ouchi 2014, Erb+2016

Roberts-Borsani et al. 2016



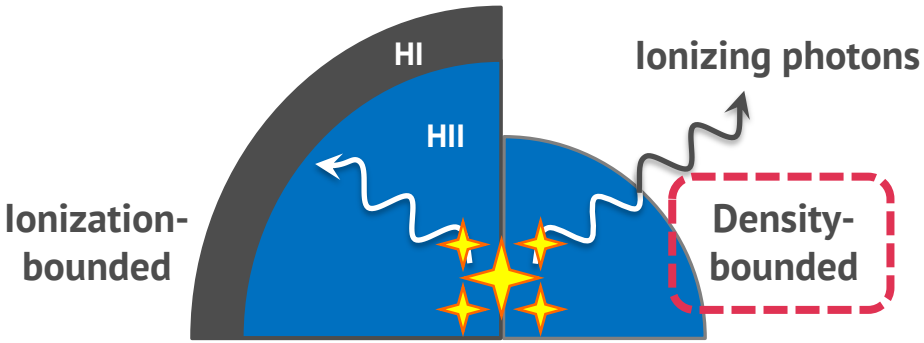
See also: Smit+2014, Inoue+2016, Harikane+2018

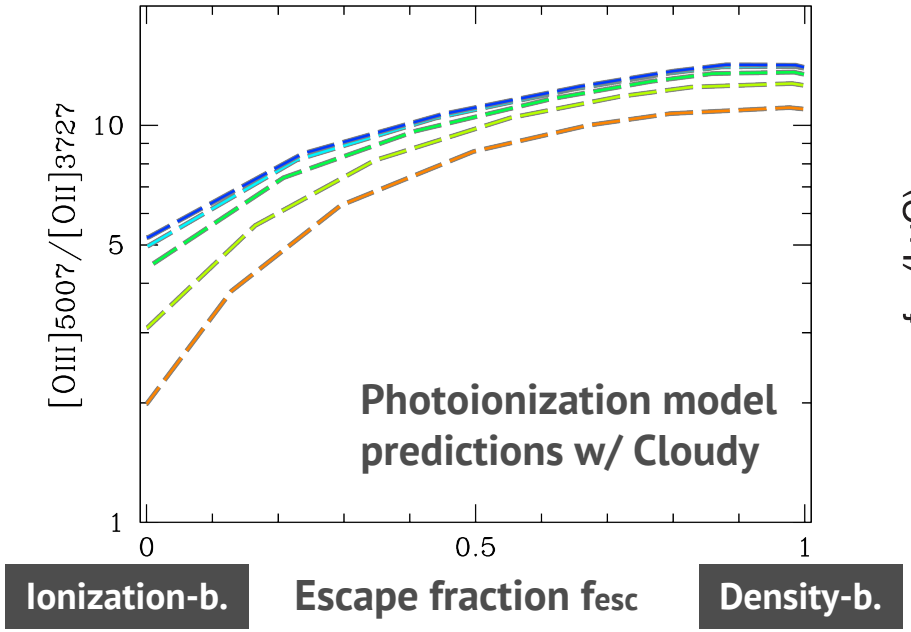
Low-mass, metal-poor star-forming galaxies

Typical in early universe

Intense emission lines as represented by [OIII]5007,4959

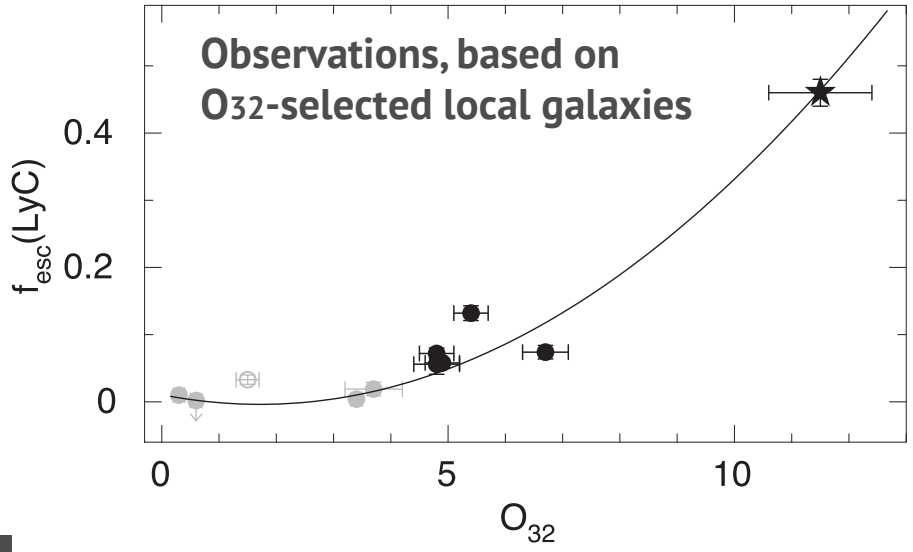
Inter-dependence of fesc and [OIII]/[OII]





Nakajima & Ouchi 2014, MNRAS, 442, 900

See also: Zackrisson+2013, Jaskot+2014

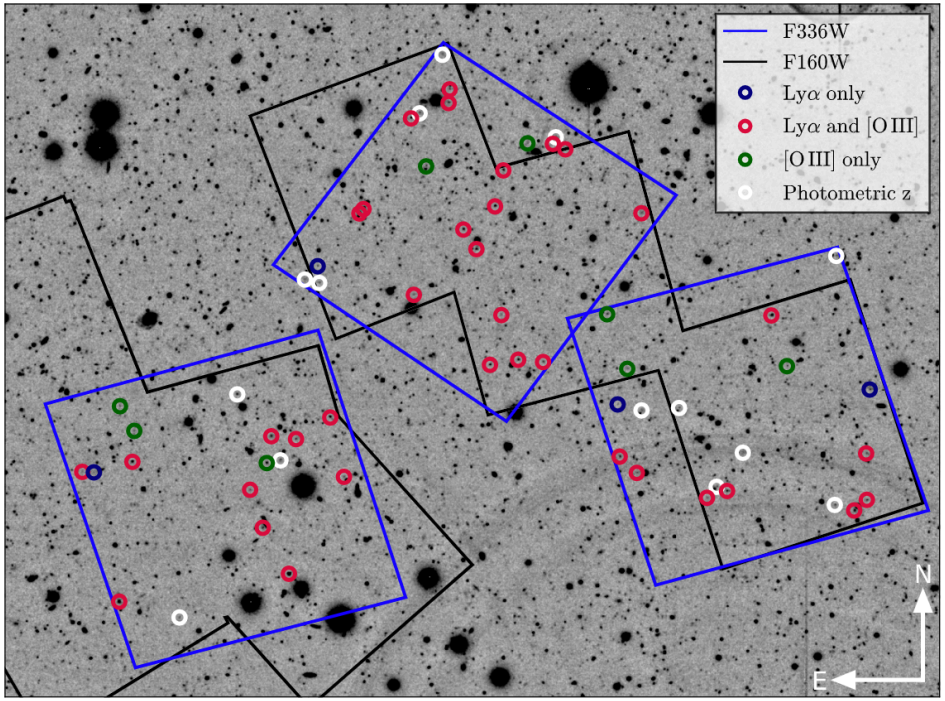


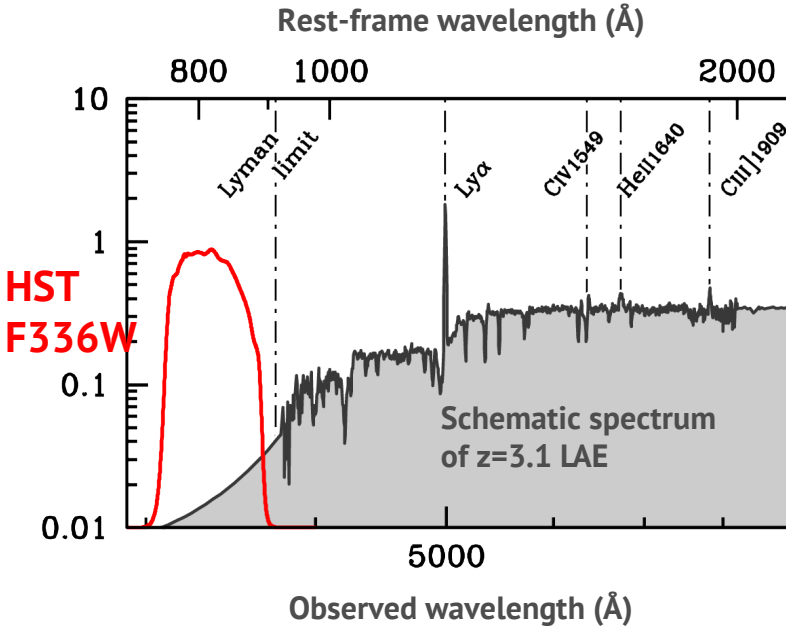
Izotov et al. 2018 MNRAS, 474, 4514

See also: Izotov+2016, Nature, Faisst 2016

LymAn Continuum Escape Survey (LACES): Ionizing photon escape f_{esc} from z=3 LAEs

Deep (60orbits) HST/F336W imaging of 54 z=3 LAEs





Fletcher, KN et al. 2019, ApJ 878, 87; Nakajima's talk in Subaru UM in 2019

See also: Iwata+2009, Siana+2015, Vanzella+2016

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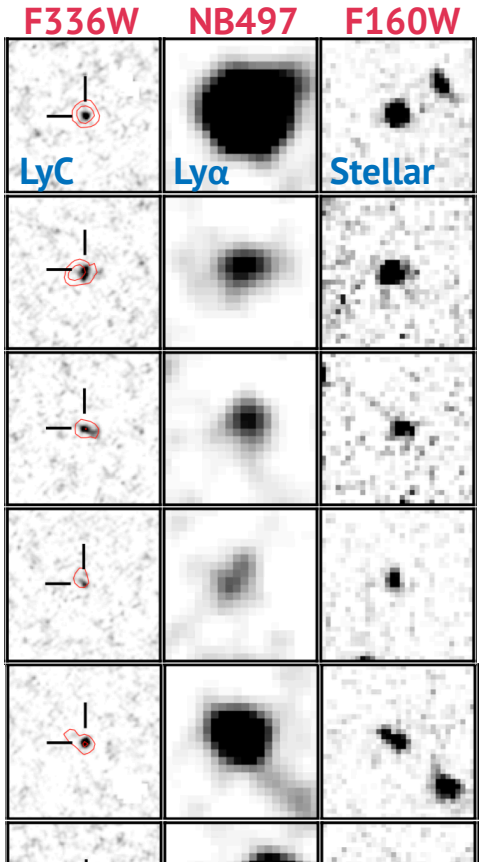
High fraction of LAEs (~20%) presenting high escape fraction (f_{esc}~20-30%)



Fletcher, KN et al. 2019, ApJ 878, 87; Nakajima's talk in Subaru UM in 2019

See also: Iwata+09, Nestor+2011,2013, Mostardi+2013,2015, Micheva+2015
Marchi+2017, Steidel+2018

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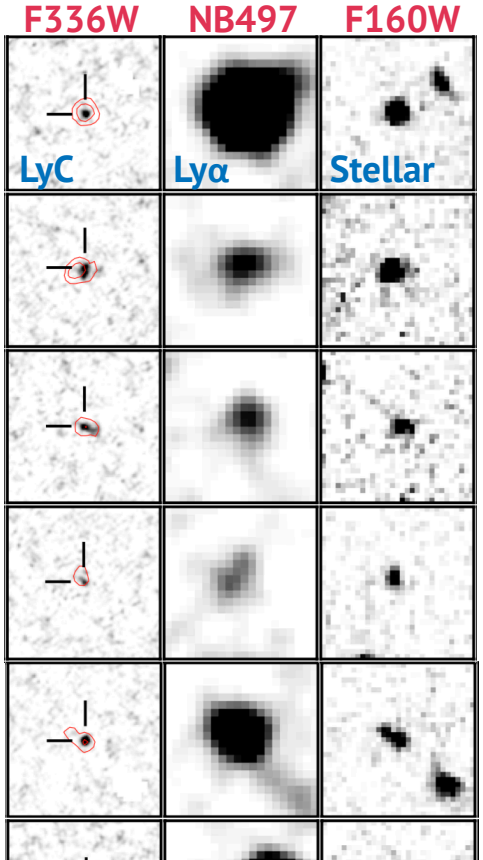
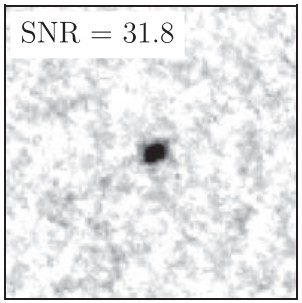
Non-detected LAEs, even when stacked, reveal **no signal** at all (f_{esc}~0)



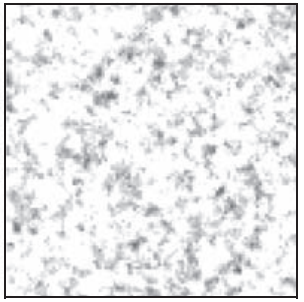
Stacked F336W (LyC) images

LyC **detected** LAEs (12/54)



f_{esc} ~ 20-30%

LyC **non-detected** LAEs (42/54)



f_{esc} < 0.5%

Bimodal nature of ionizing photon escape

Fletcher, KN e… 2019

See also: Iwat… +2015

Marchi+2017, Steidel+2018

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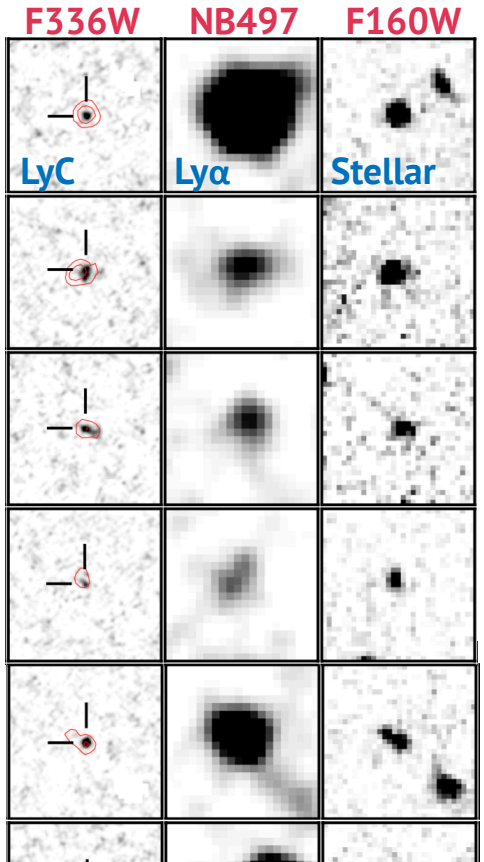
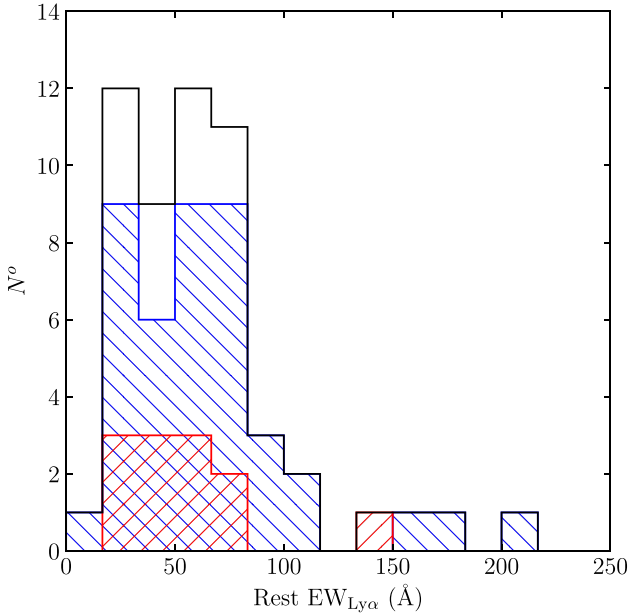
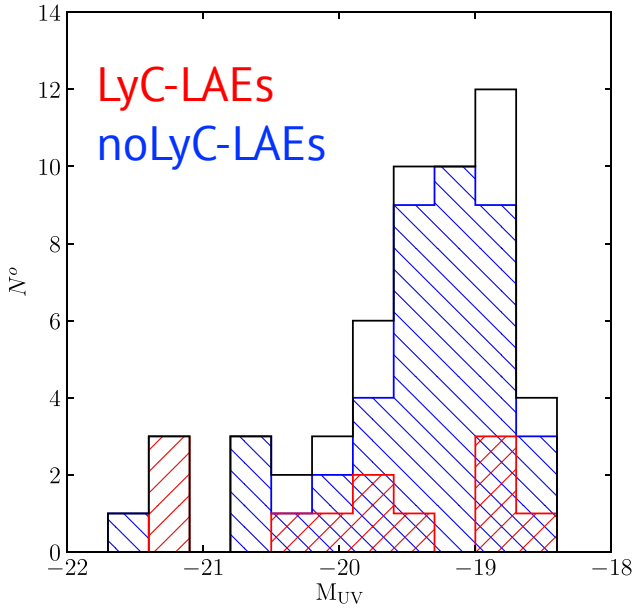






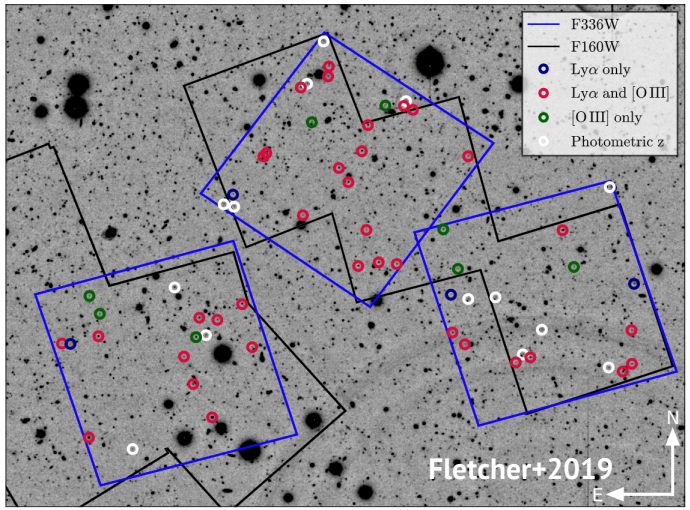
Fletcher, KN e … 2019

See also: Iwat… +2015

Marchi+2017, Steidel+2018

Bimodal nature of ionizing photon escape

Keck/MOSFIRE spectroscopic campaign of LACES sample



4.5 Keck nights through Time Exchange

2.0-6.0 hrs in K ([OIII], Hβ, etc.)

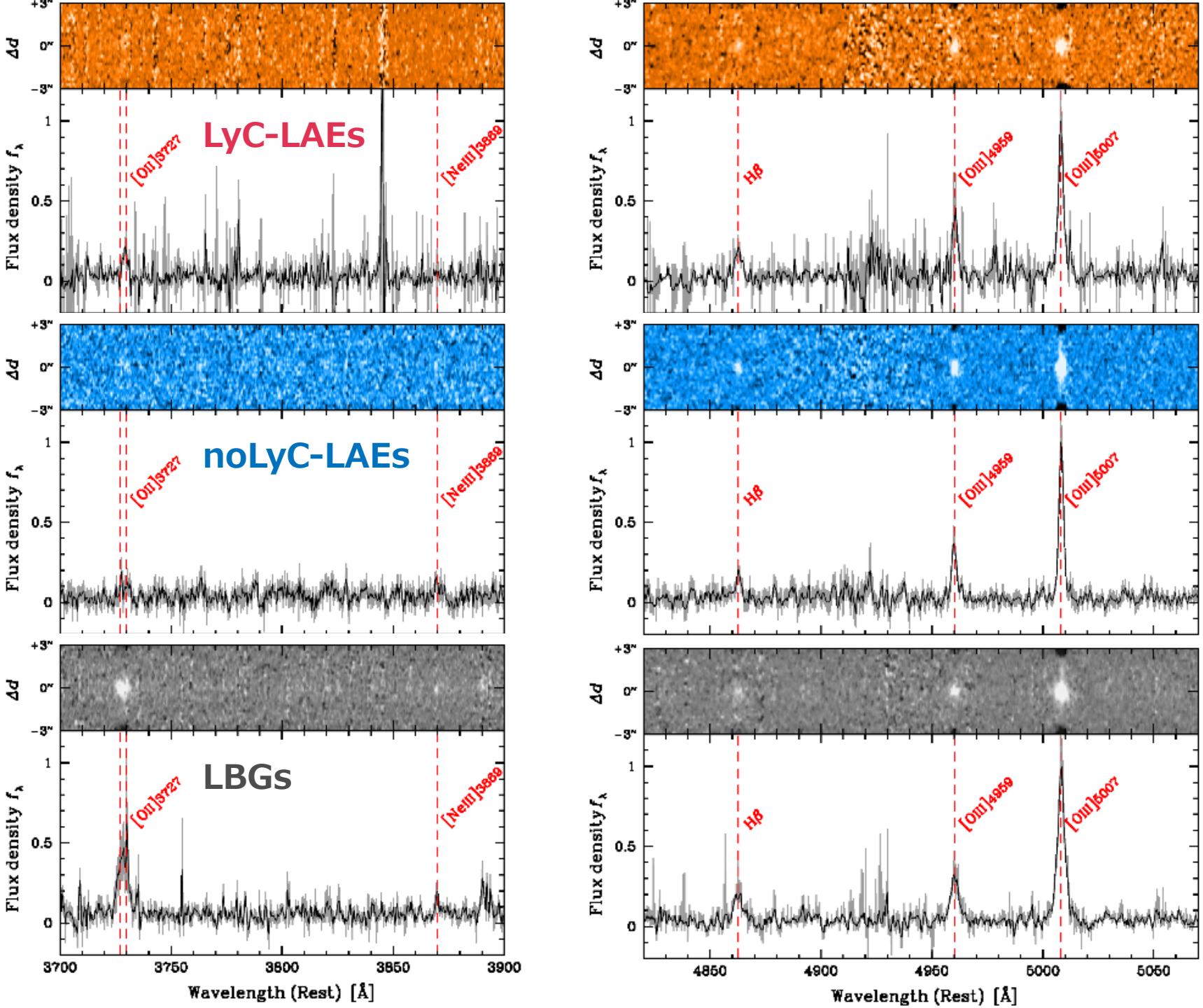
2.5-10.2 hrs in H ([OII], etc.)

in LACES field

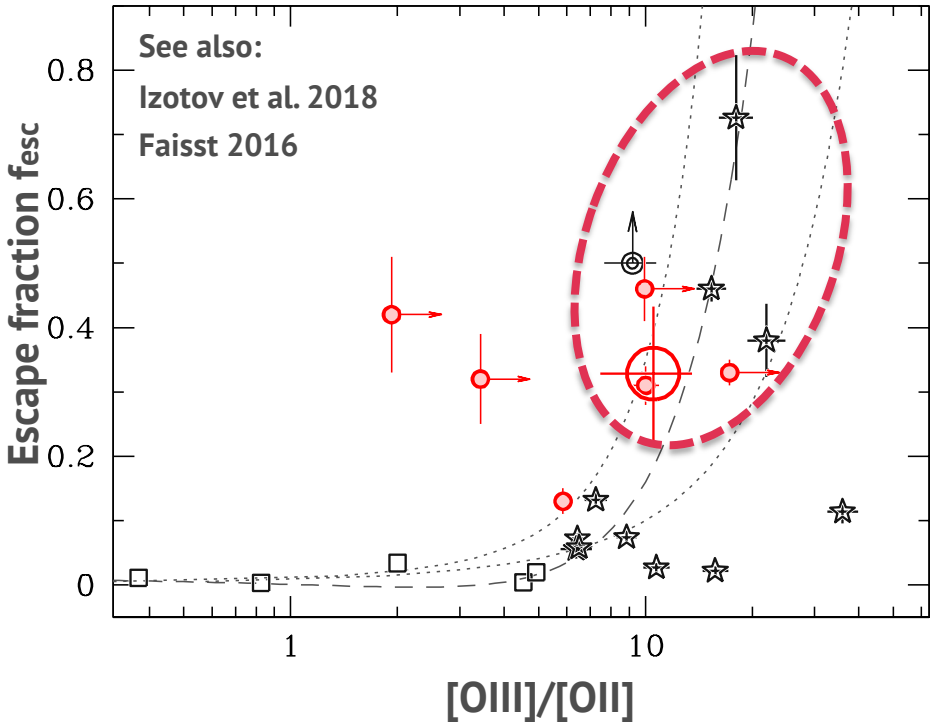
Nakajima et al. 2020, ApJ 889, 161
(see also: Nakajima+2016)

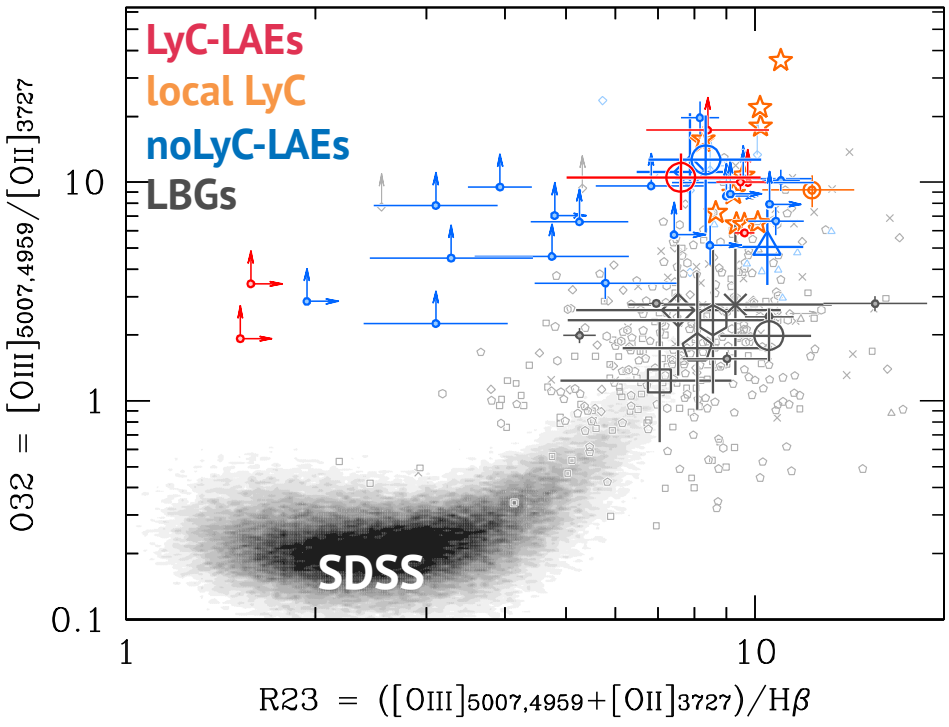
[OIII]+ identified in 43 LACES sources

- **8 LyC-LAEs**
- **29 noLyC-LAEs**
- **6 LBGs (none present LyC signal)**


LyC-LAEs
noLyC-LAEs
LBGs
[OII]3727
[NeIII]3869
Hβ
[OIII]4959
[OIII]5007
Δd
Flux density f_λ
Wavelength (Rest) [Å]

Inter-dependence of fesc and [OIII]/[OII]: Revisited





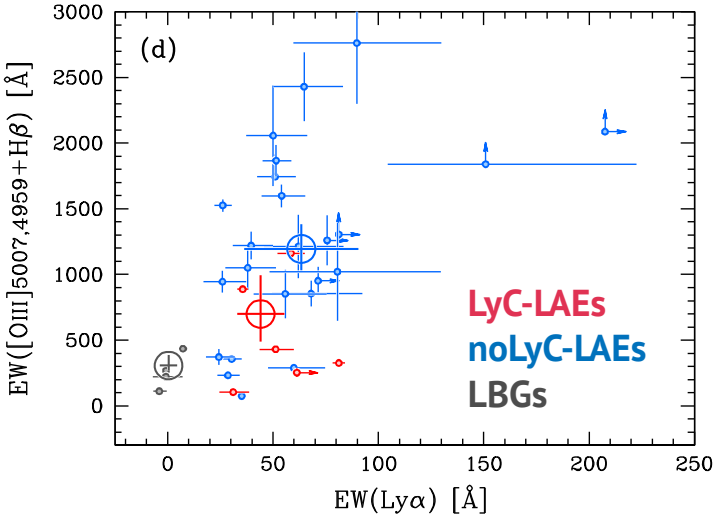
Large [OIII]/[OII] is necessary condition for ionizing photon leakage

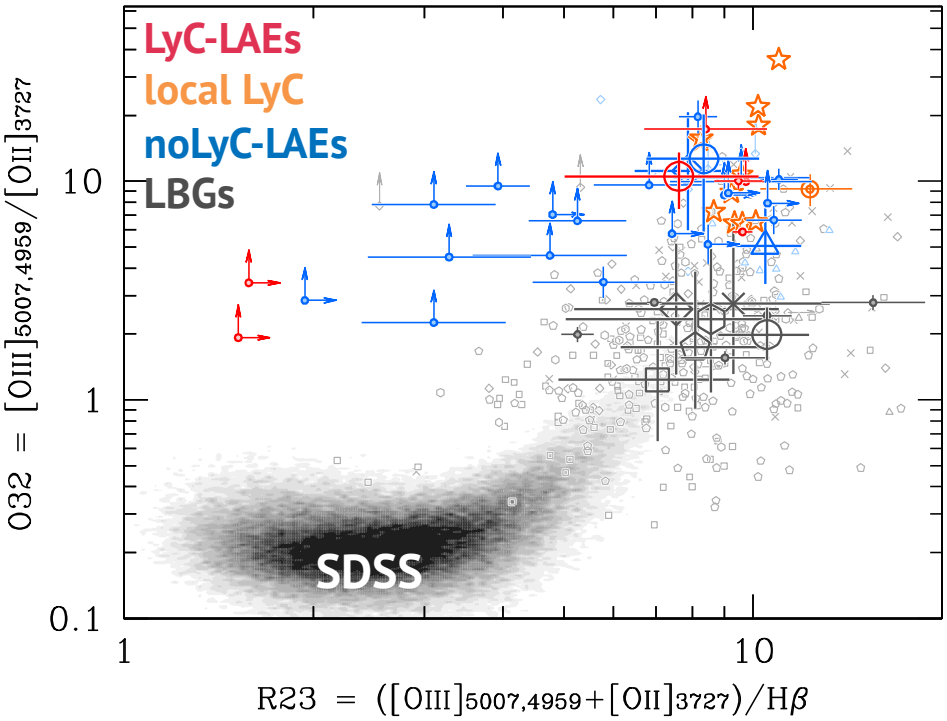
Not all LAEs with large [OIII]/[OII] are LyC leakers

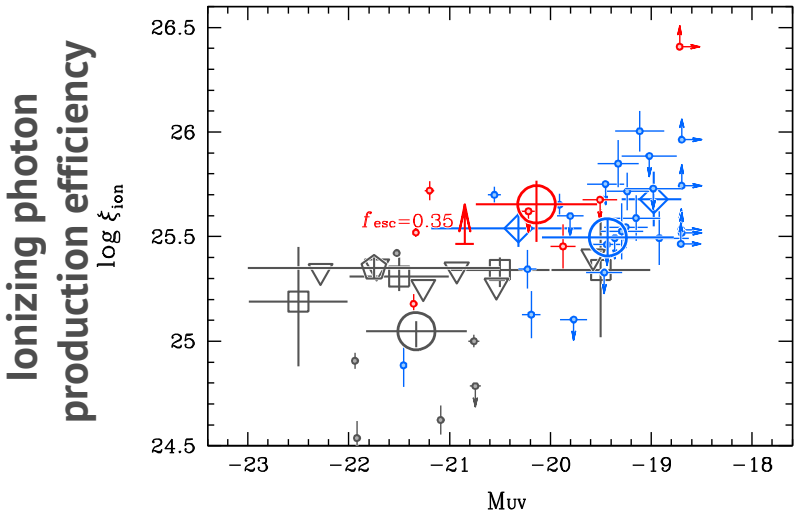
Nakajima et al. 2020, ApJ 889, 161

See also: Bassett+2019

Bimodal nature of ionizing photon escape: Revisited with spectral diagnostics







No fundamental distinction
Between LAE leakers and non-leakers

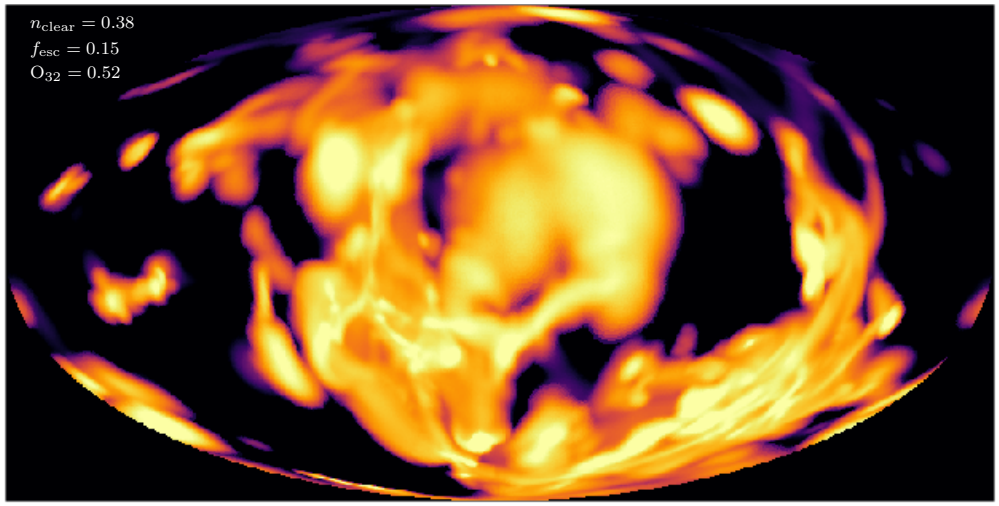
→ Anisotropic LyC leakage

Nakajima et al. 2020, ApJ 889, 161

Anisotropic LyC leakage in cosmological hydro simulation

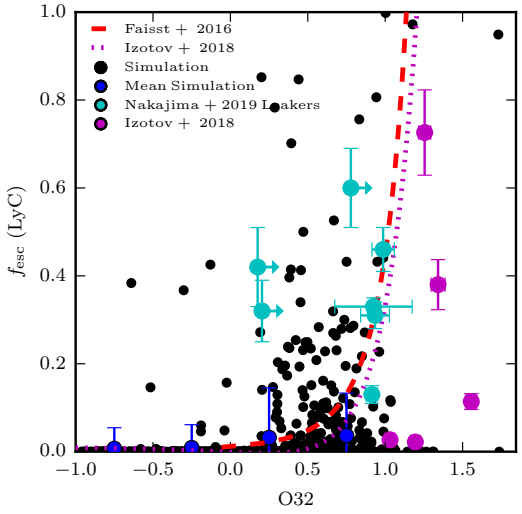
Katz et al. 2020, MNRAS

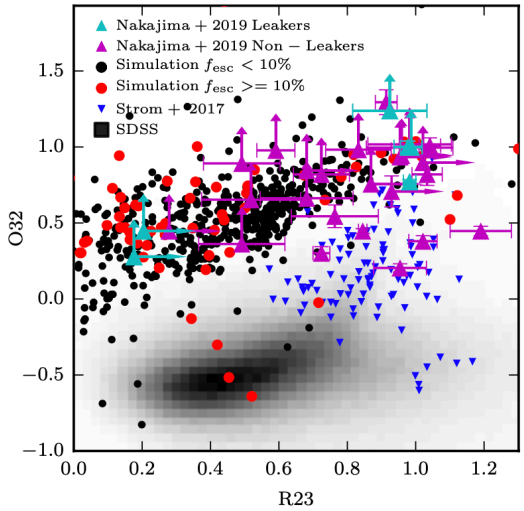
see also:
Wise+2014,
Paardekooper+2015
Trebitsch+2017



Optically thin (high fesc)

Optically thick (low fesc)





HI and dust content varies along individual line-of-sight which impact fesc (but not O32)

LACES LAEs are likely analogs of reionization epoch systems

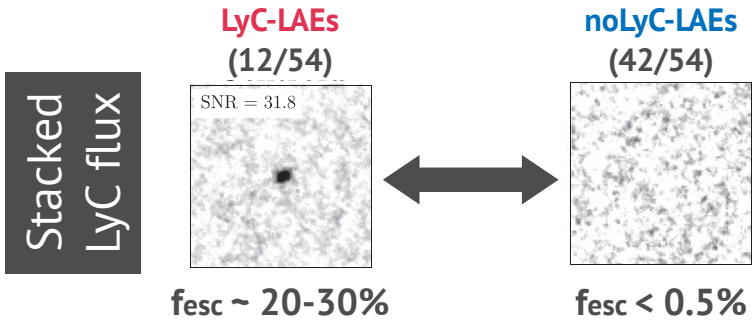
Summary

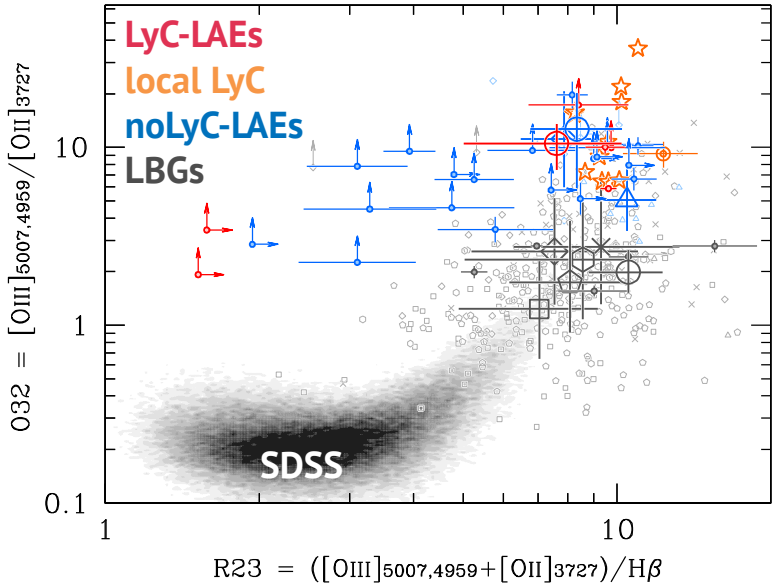
Bimodal nature of LyC leakage

No distinction between leakers and non-leakers

Large [OIII]/[OII] is necessary, but not sufficient

Anisotropic LyC leakage





High fraction of LAEs presenting high fesc *as compared to LBGs*

Low covering fraction of HI

- Large [OIII]/[OII]
- Efficient production of ionizing photons

→ Young galaxies like LAEs as important reionization sources