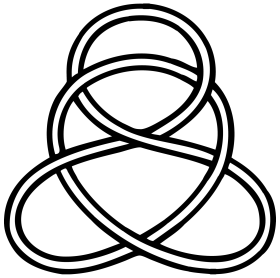
the Production and Transmission of Lyman photons in faint LAEs at z = 2-3



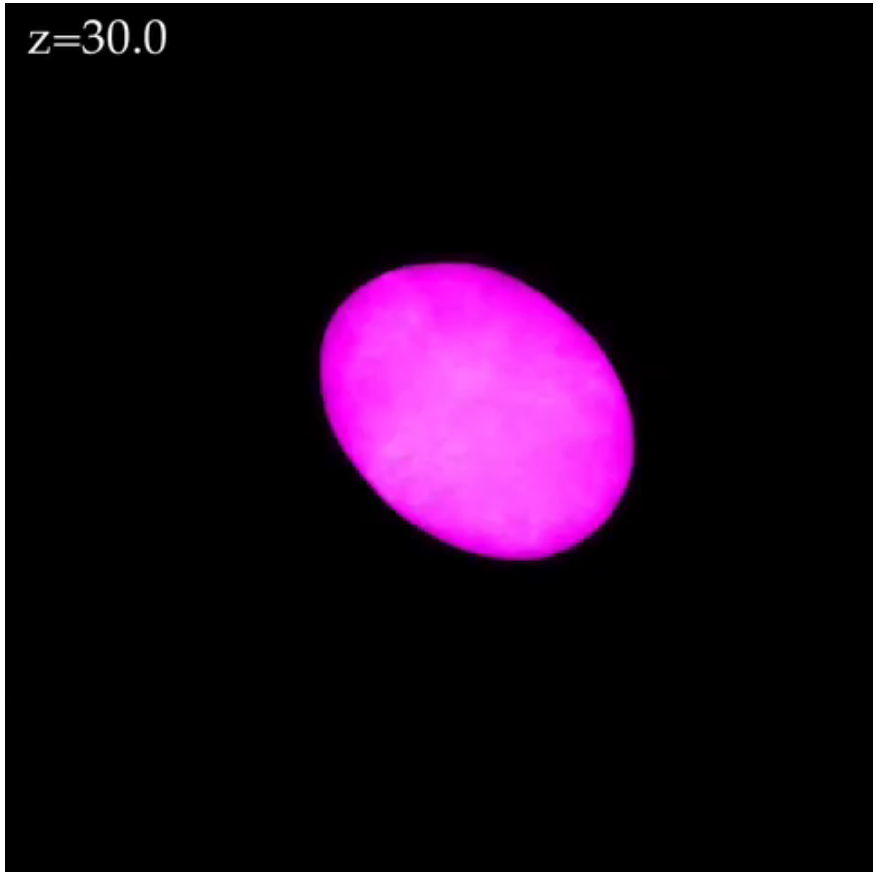
Ryan Trainor (Berkeley/Miller Institute)
with Charles Steidel, Eliot Quataert, Mariska Kriek, Gwen Rudie, Allison Strom, Shanon Oden, Anna de Graaff

outline

1. Stellar feedback in faint galaxies
2. KBSS-Lyα survey description
3. Measurements of:
   a. Gas kinematics and covering fraction
   b. Lyα (and LyC) escape fraction
   c. Properties of star-forming regions

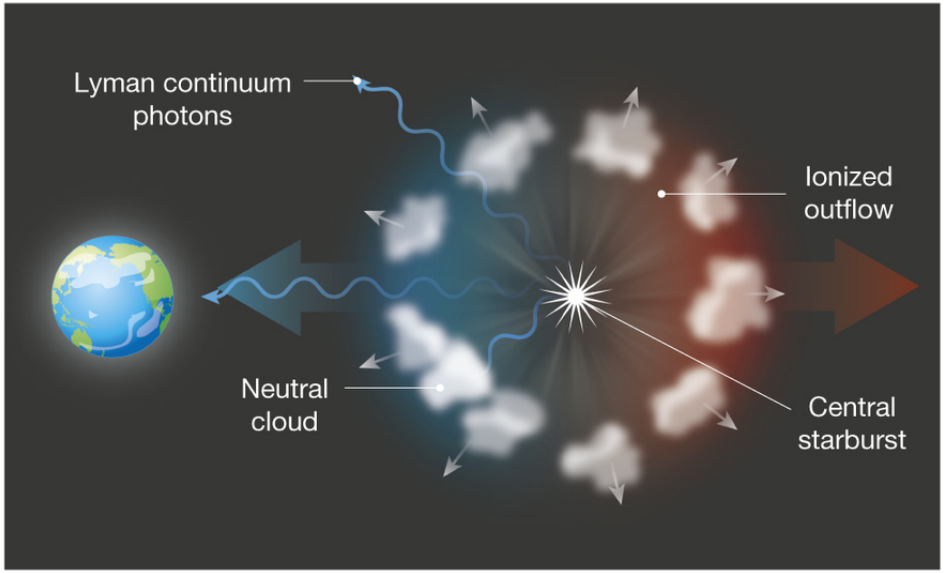
stellar feedback shapes galaxies …and their emission

Phil Hopkins & FIRE



HOT WARM COLD

Erb 2015 (Nature)

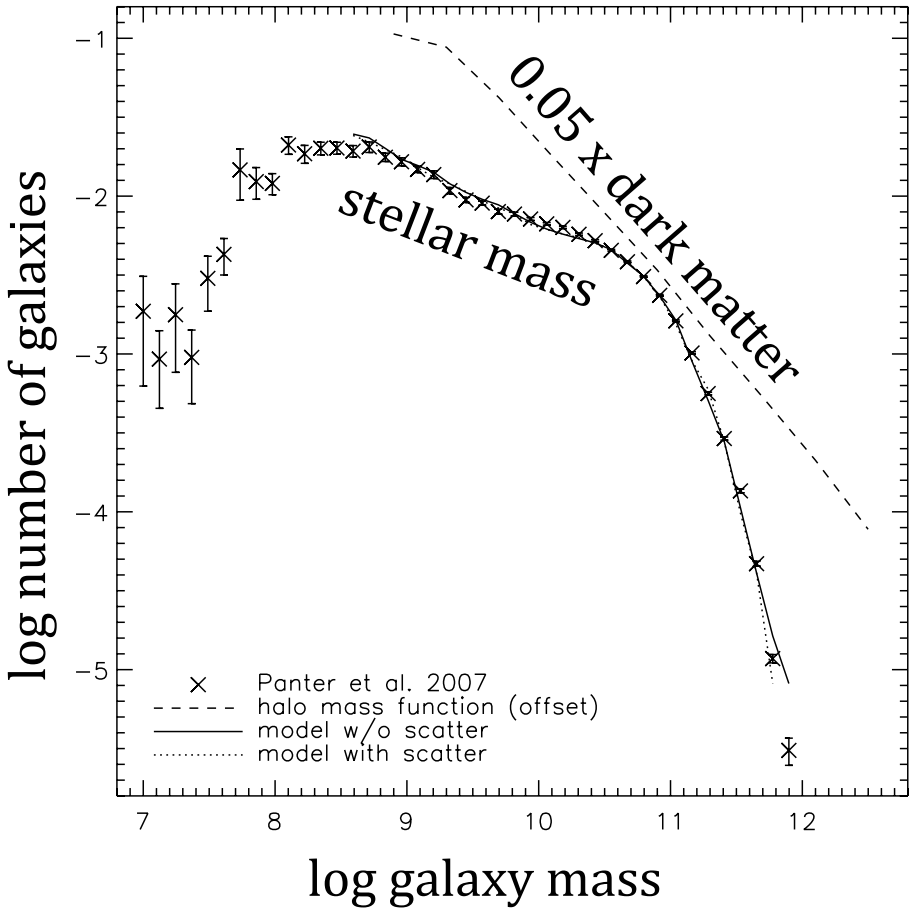


Lyman emission of galaxies depends on:

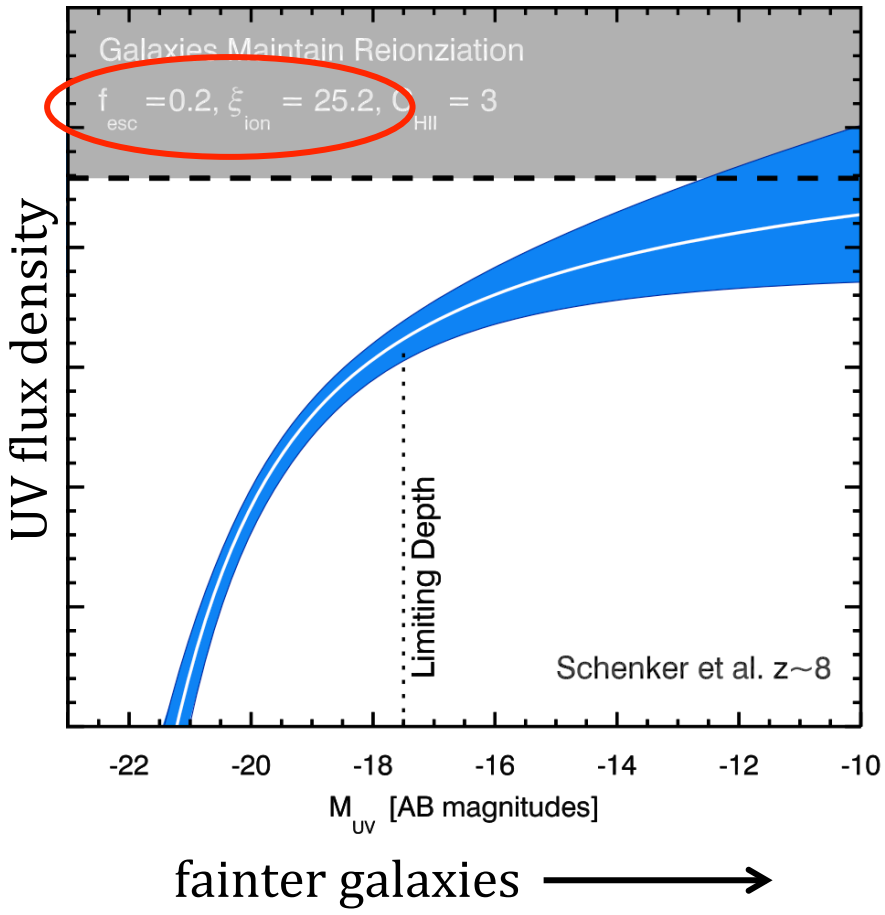
1. Photon production
2. Escape fraction

low mass galaxies are the key?

Moster+2010

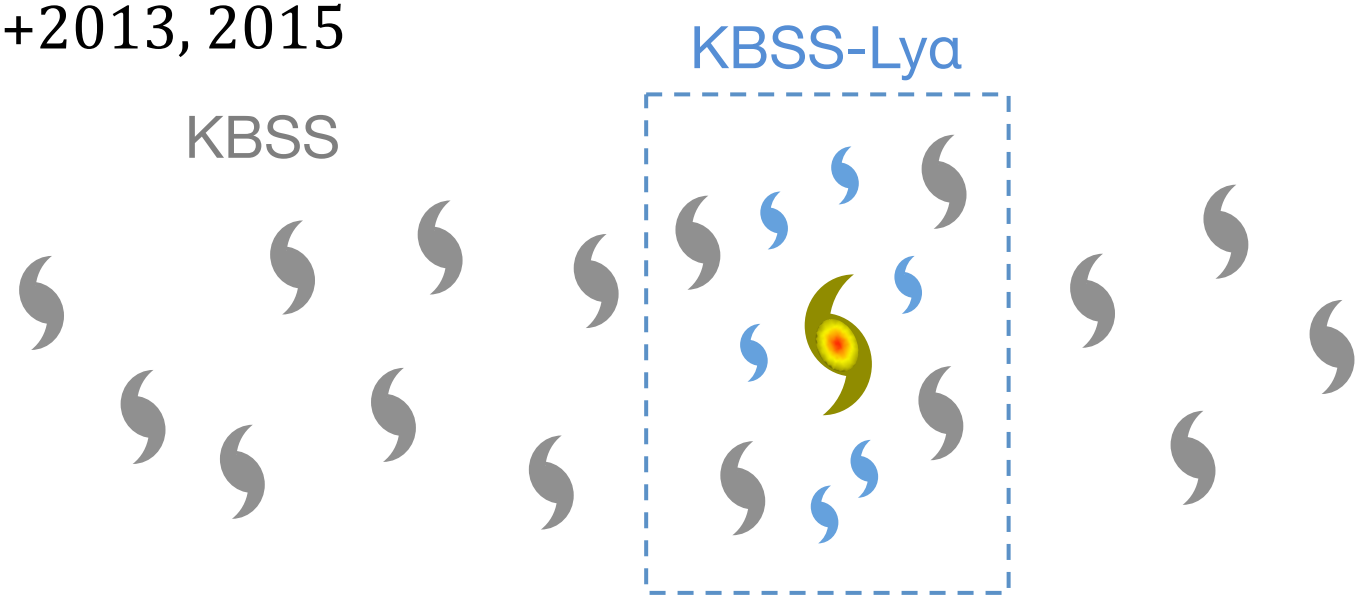


Robertson+2013



Keck Baryonic Structure Survey

- **KBSS** includes 1000+ LBGs in QSO fields at z ≈ 2-3
  - $L \approx L_*$ galaxies, log $M_* \approx 9.5$–11.5
  - Rudie+2012; Trainor+2012; Steidel+2014; Strom+ in prep.
- **KBSS-Lyα** includes ~1000 LAEs, 318 with spectra
  - $L \approx 0.1\ L_*$ galaxies, log $M_* \approx 8$–9.5
  - Trainor+2013, 2015

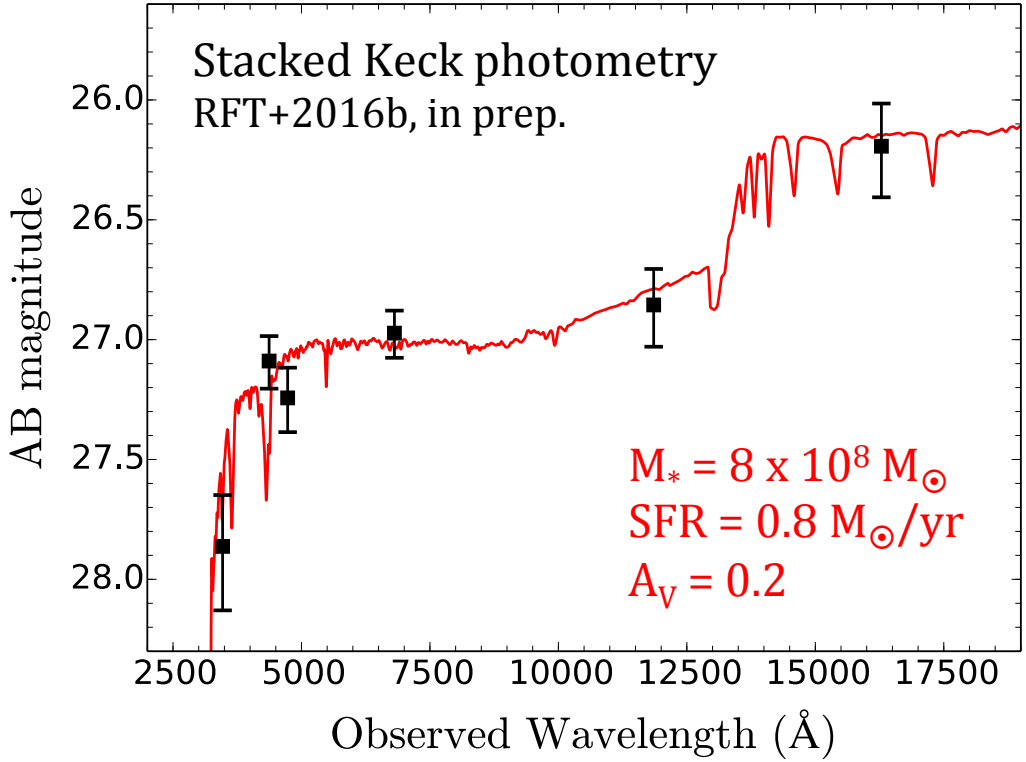


three-tiered KBSS-Lyα samples

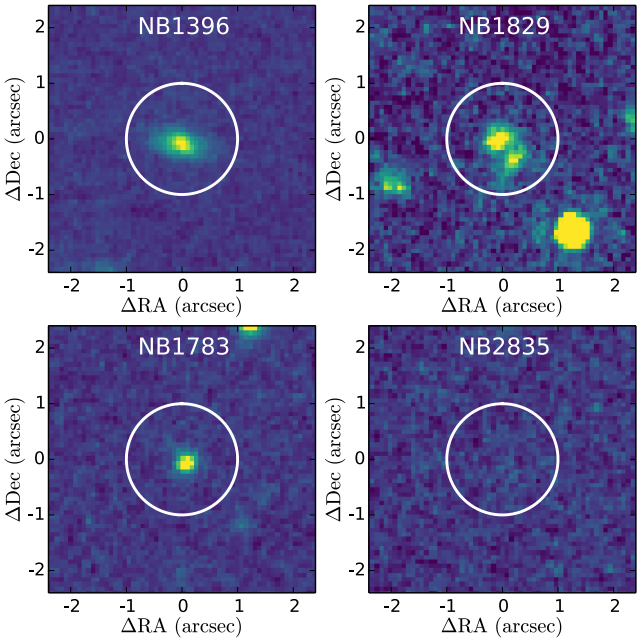
1000 photometrically-selected LAEs

$W_{Ly\alpha}$, $L_{Ly\alpha}$, L_{UV} [M_*]

Anna de Graaff



HST F160W images



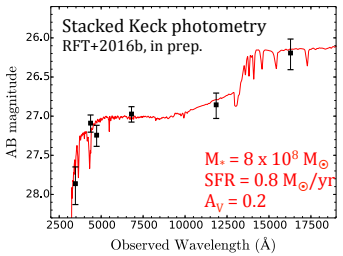
three-tiered KBSS-Lyα samples

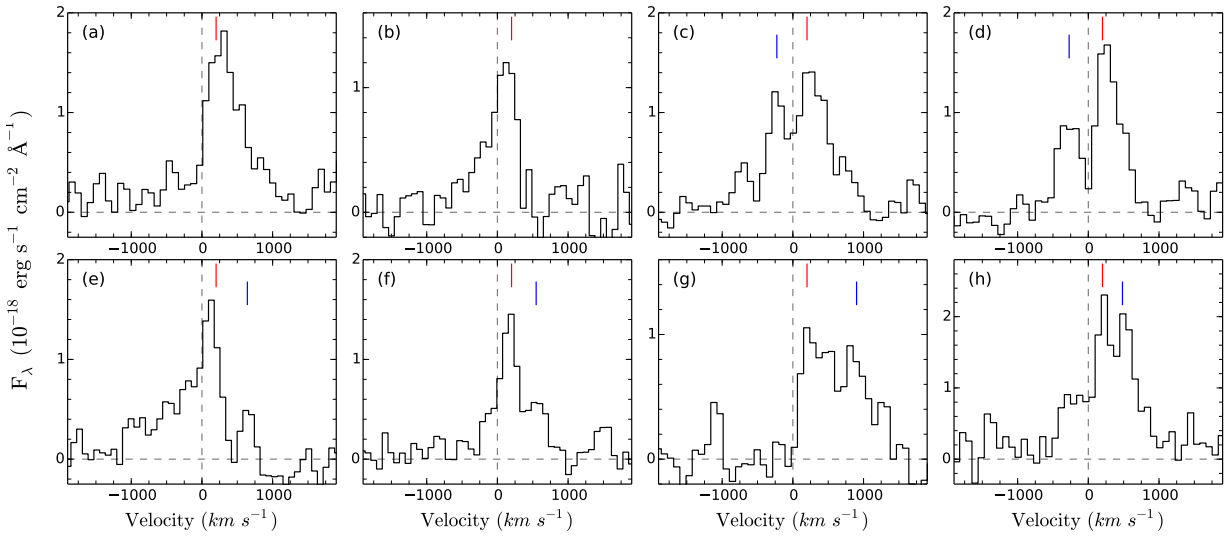
1000 photometrically-selected LAEs

$W_{\mathrm{Ly}\alpha}$, $L_{\mathrm{Ly}\alpha}$, L_{UV} [M*]

318 LAEs with rest-UV spectra

$z_{\mathrm{Ly}\alpha}$, $\sigma_{\mathrm{Ly}\alpha}$, $\Delta v_{\mathrm{peaks}}$ $[v_{\mathrm{abs}}, f_{\mathrm{cov}}]$





Shanon Oden

Keck/LRIS Lyα spectra
RFT+2015

three-tiered KBSS-Lyα samples

1000 photometrically-selected LAEs

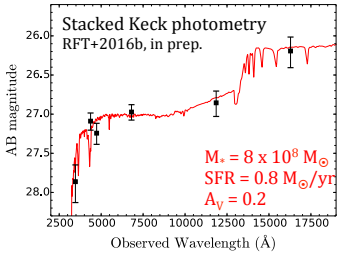
$W_{\mathrm{Ly}\alpha}$, $L_{\mathrm{Ly}\alpha}$, L_{UV} [M$_*$]

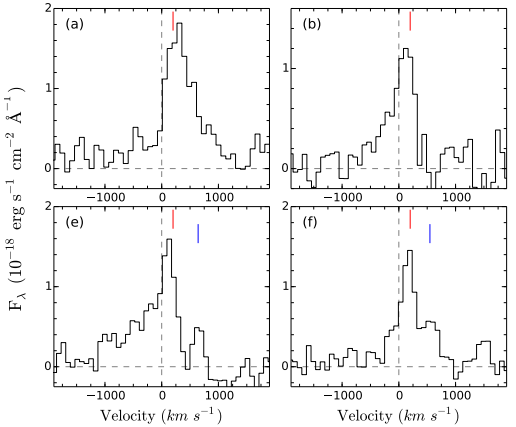
318 LAEs with rest-UV spectra

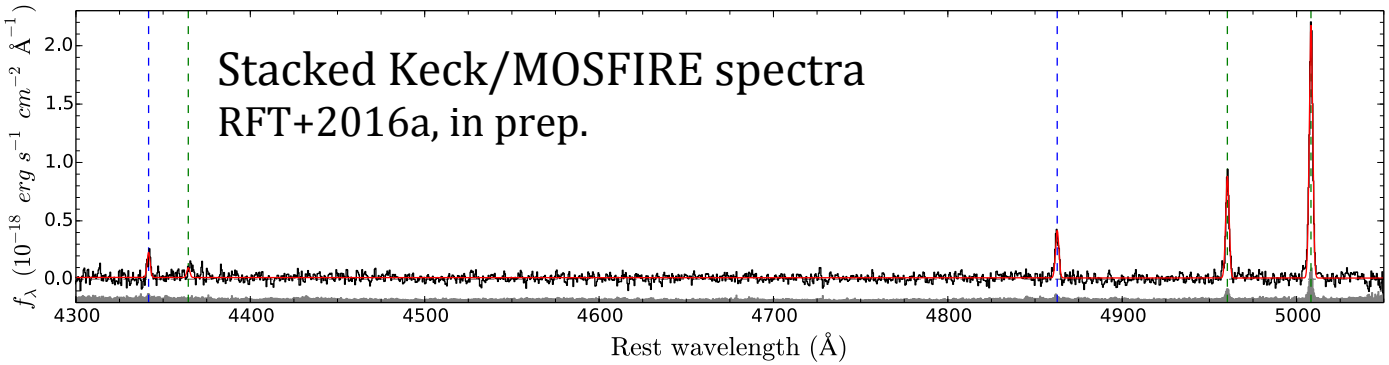
$z_{\mathrm{Ly}\alpha}$, $\sigma_{\mathrm{Ly}\alpha}$, $\Delta v_{\mathrm{peaks}}$ [v_{abs}, f_{cov}]

55 with rest-optical spectra

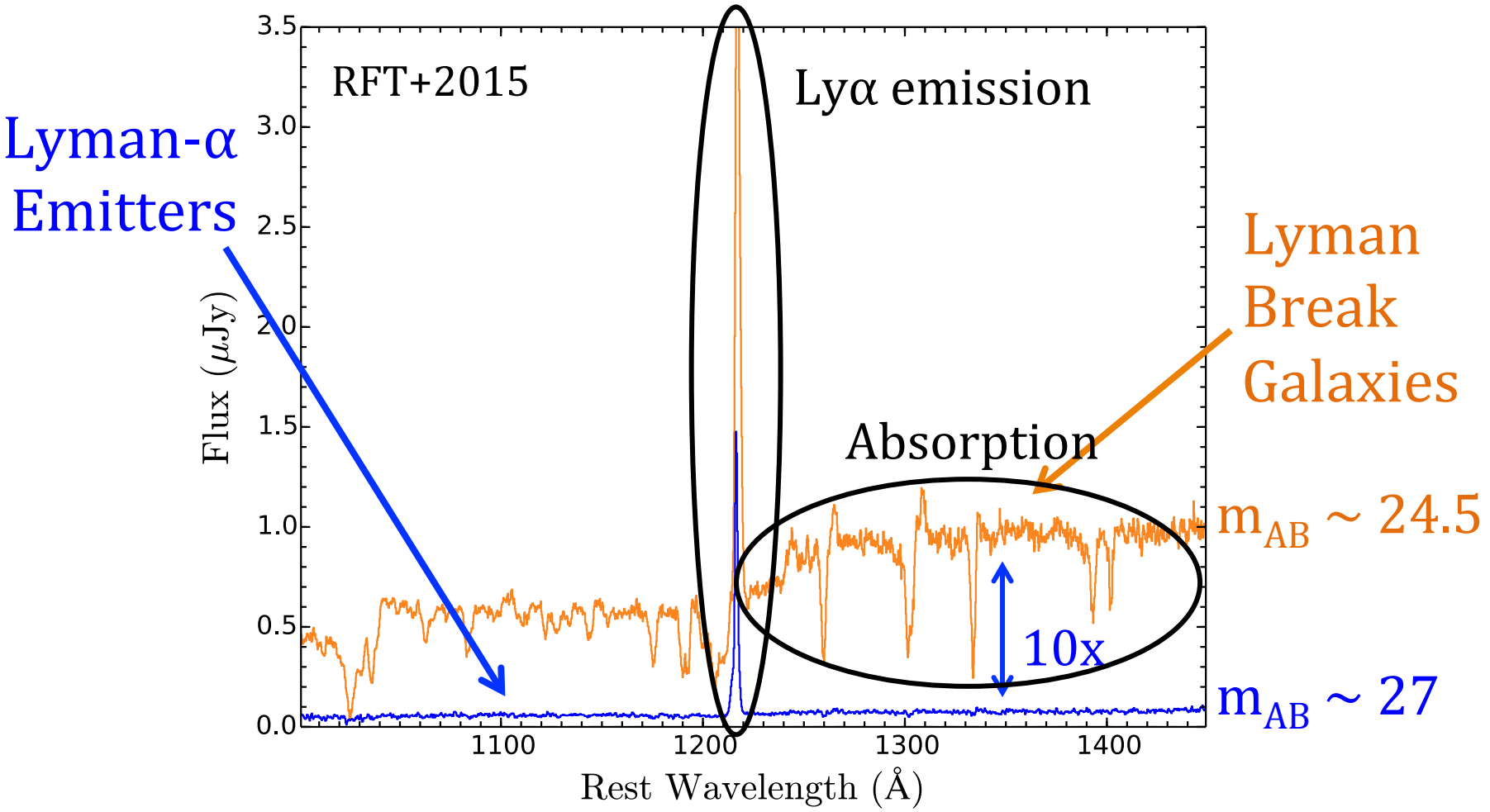
z_{sys}, σ_{neb}, $v_{\mathrm{Ly}\alpha}$, f_{esc}, E(B-V), SFR [Z, T_{e}]





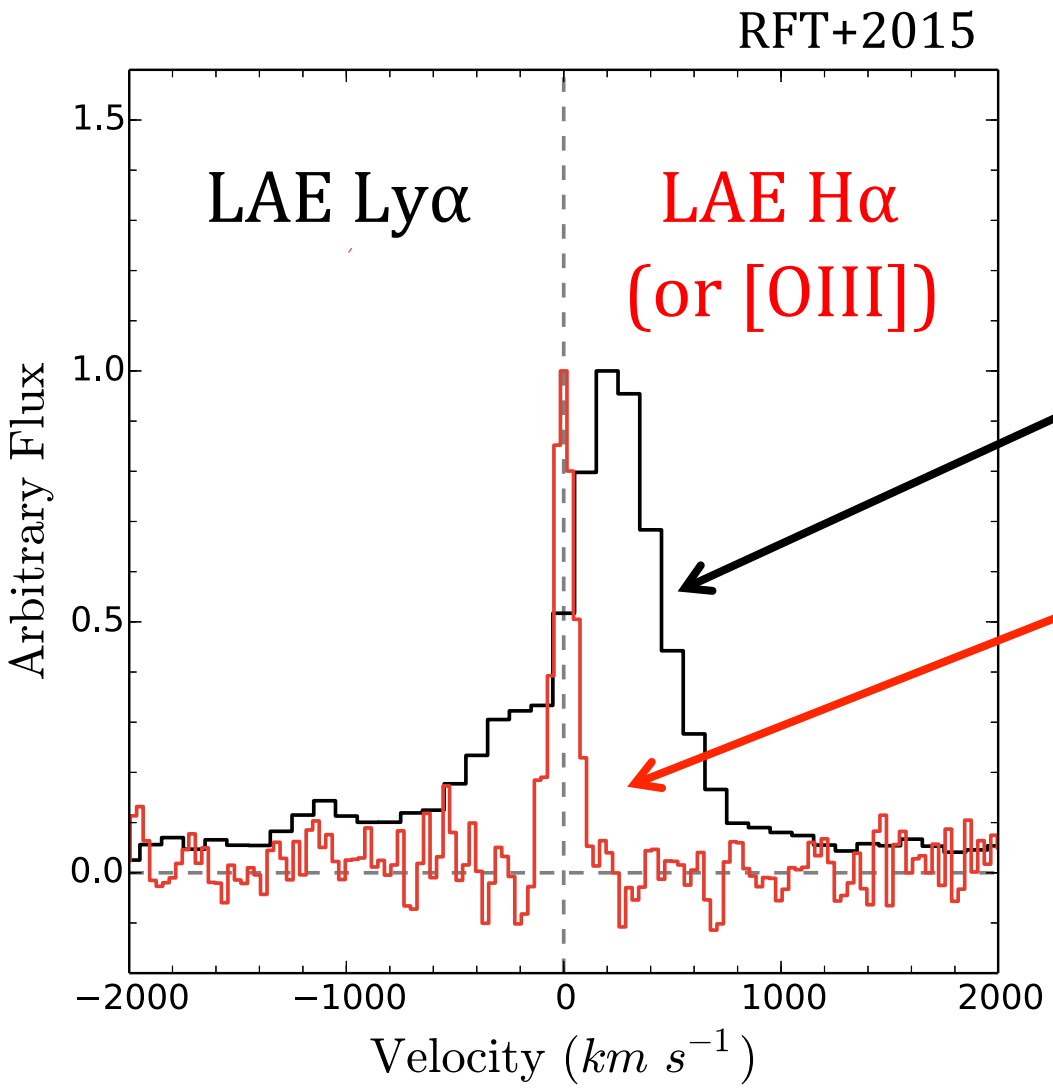


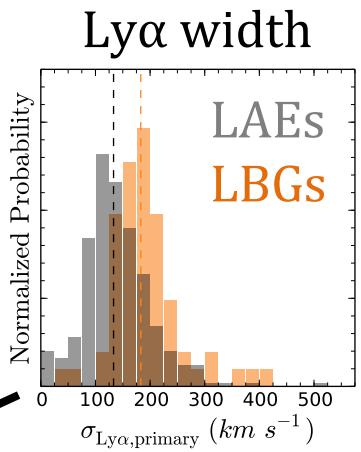
feedback physics in the UV line profiles

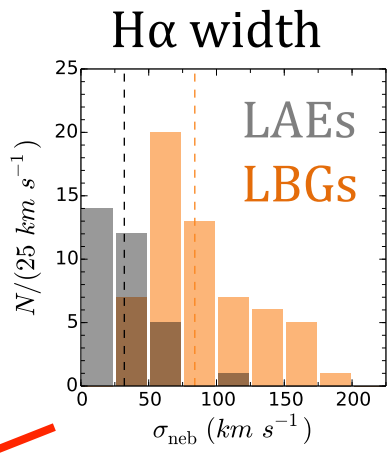


*675 hour Keck/*LRIS *composite spectrum*

gas kinematics in line emission







gas velocity & optical depth grow with galaxy mass/luminosity, drops with $W_{\mathrm{Ly\alpha}}$

see Erb+2014, RFT+2015

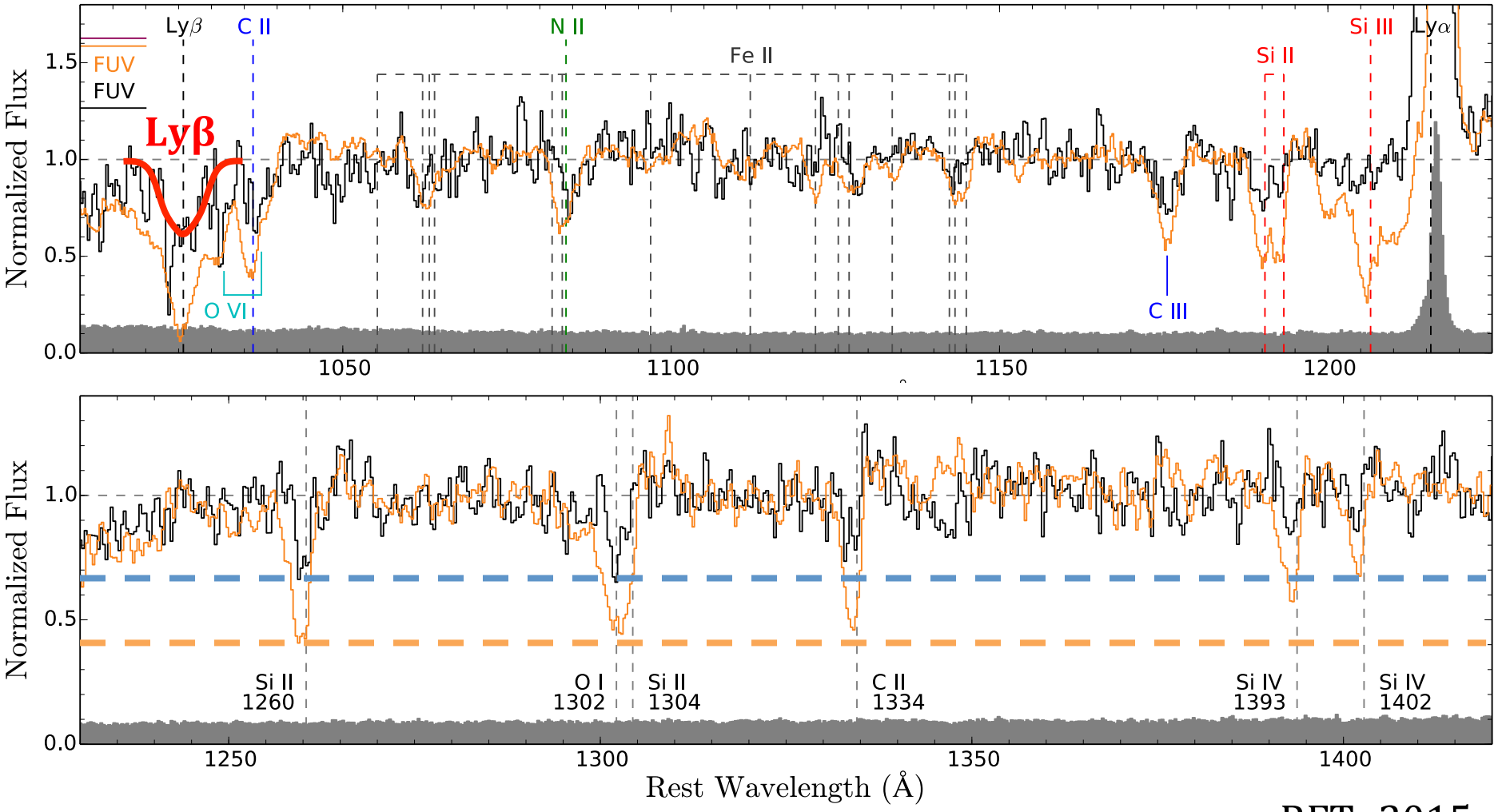
$f_{esc}(\mathrm{Ly\alpha}) \approx (\mathrm{Ly\alpha}/\mathrm{H\alpha})/8.3$

≈ 5% for LBGs

≈ 25% for LAEs

LAE composite
LBG composite

metal-enriched outflows

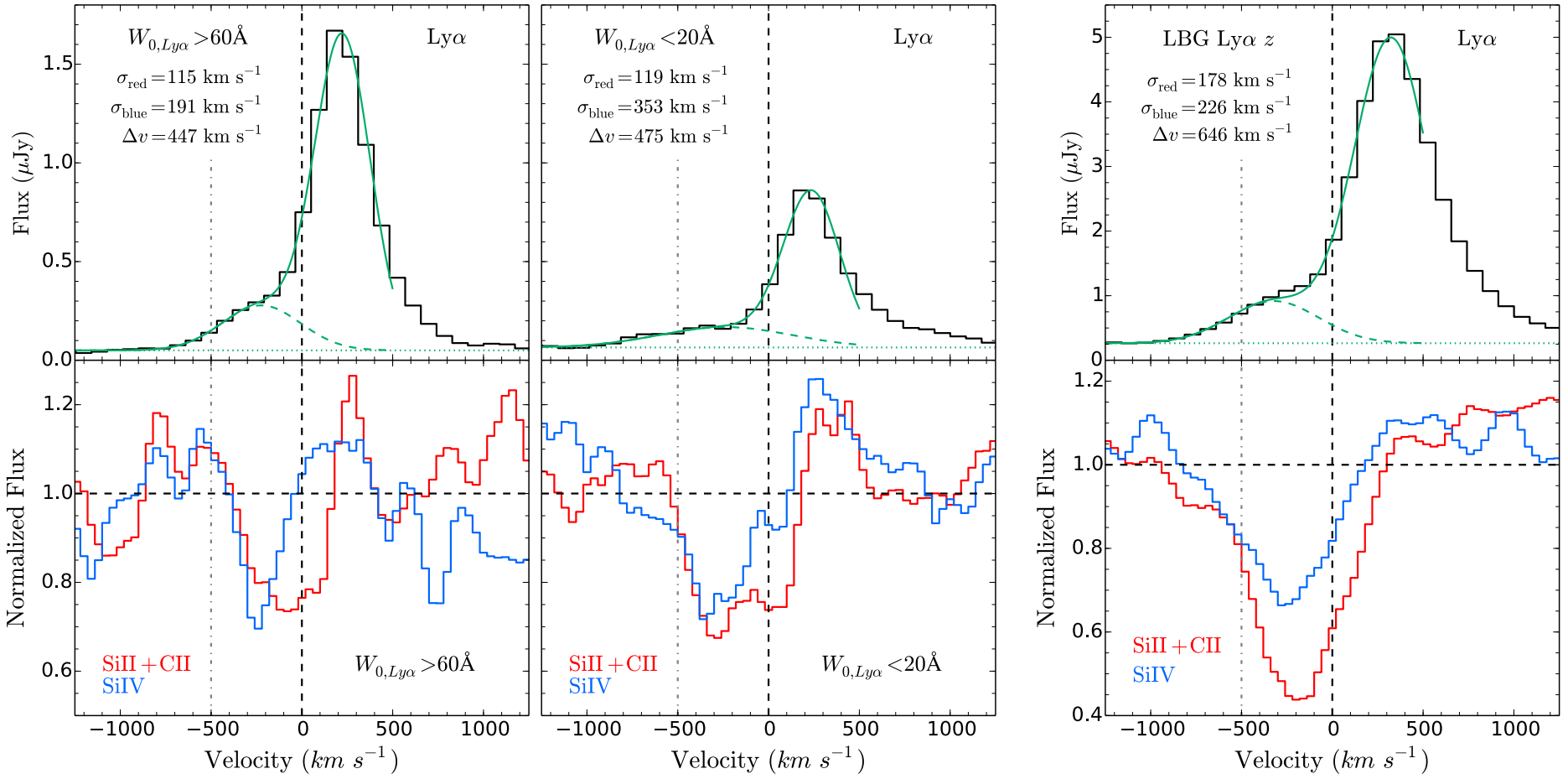


RFT+2015

see also Henry+2015, Rivera-Thorsen+2015 for local analogs

correlated absorption and emission

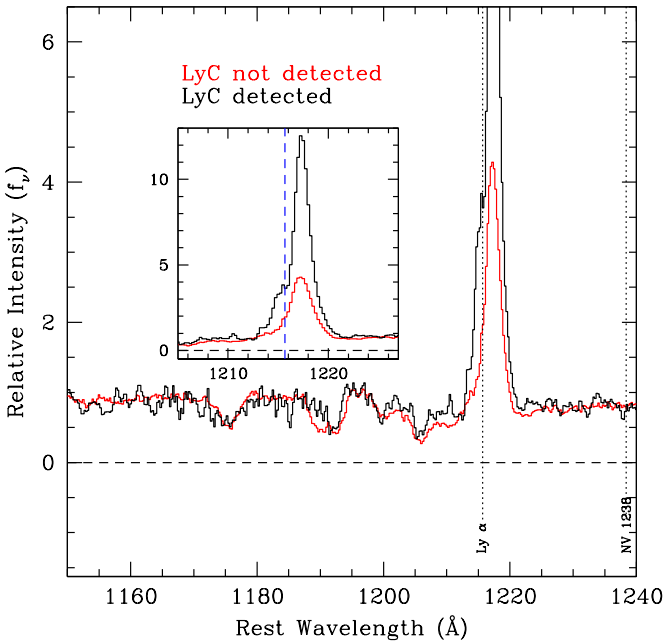
As Lyα EqW increases (or luminosity decreases), outflow velocity decreases



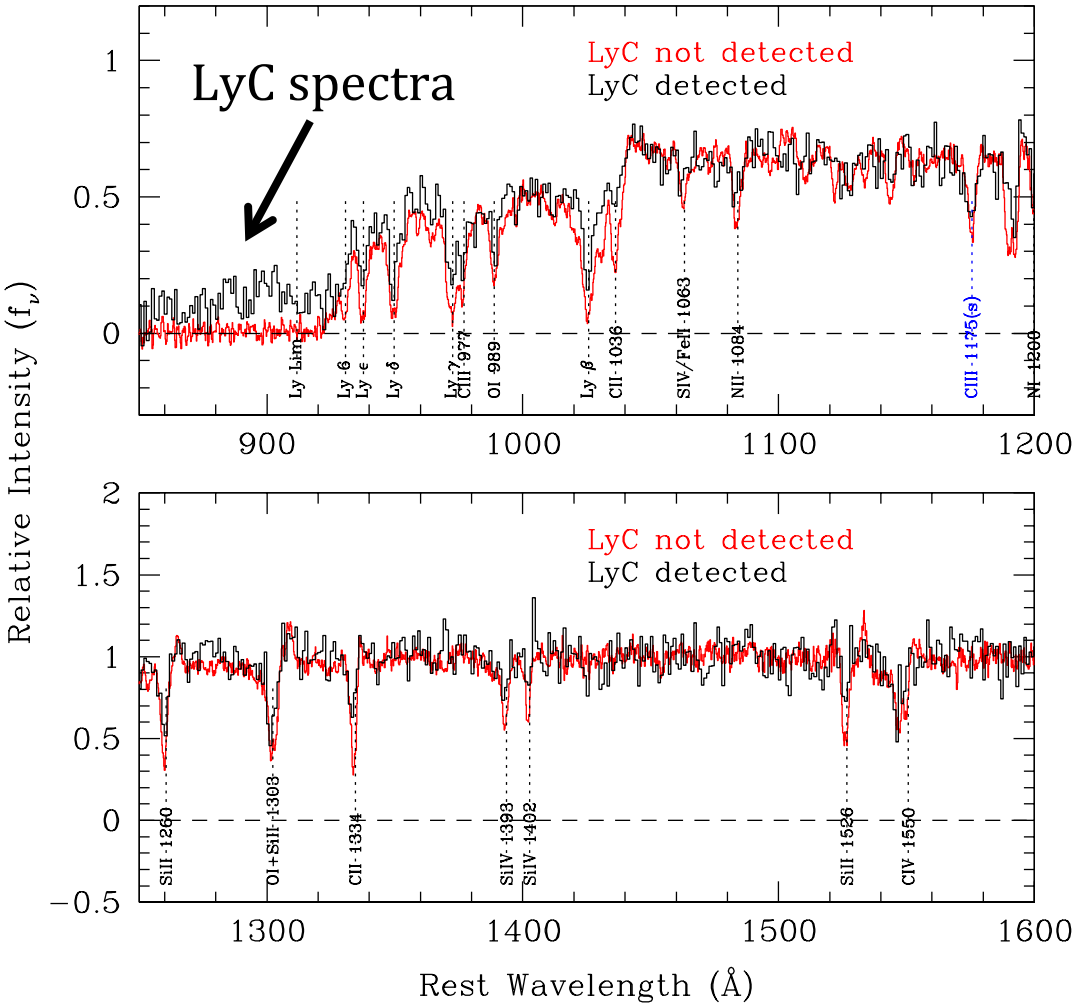
RFT+2015

LyC and Lyα escape

KLCSS: Deep LyC observations of LBGs and bright LAEs (Steidel+, in prep.)



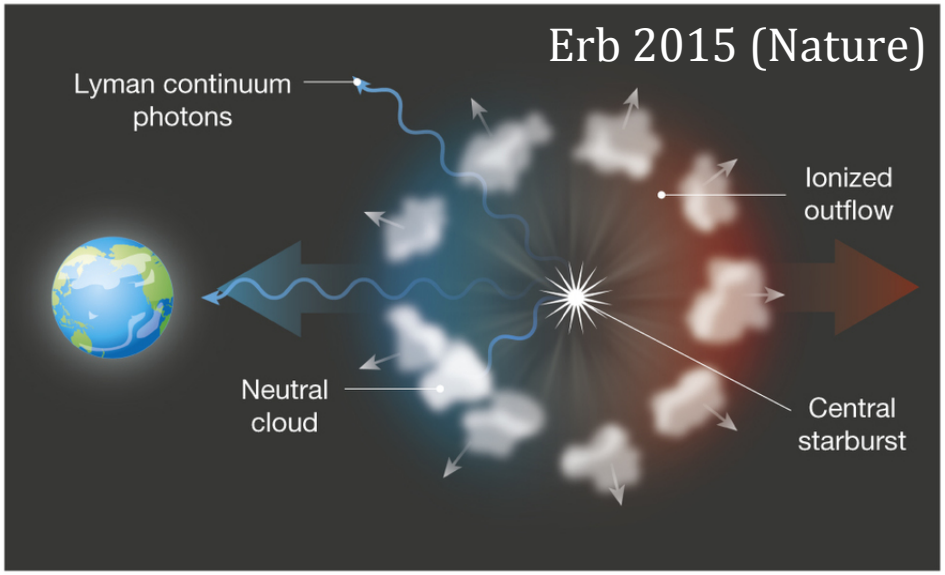
f_{900}/f_{1500}=15%



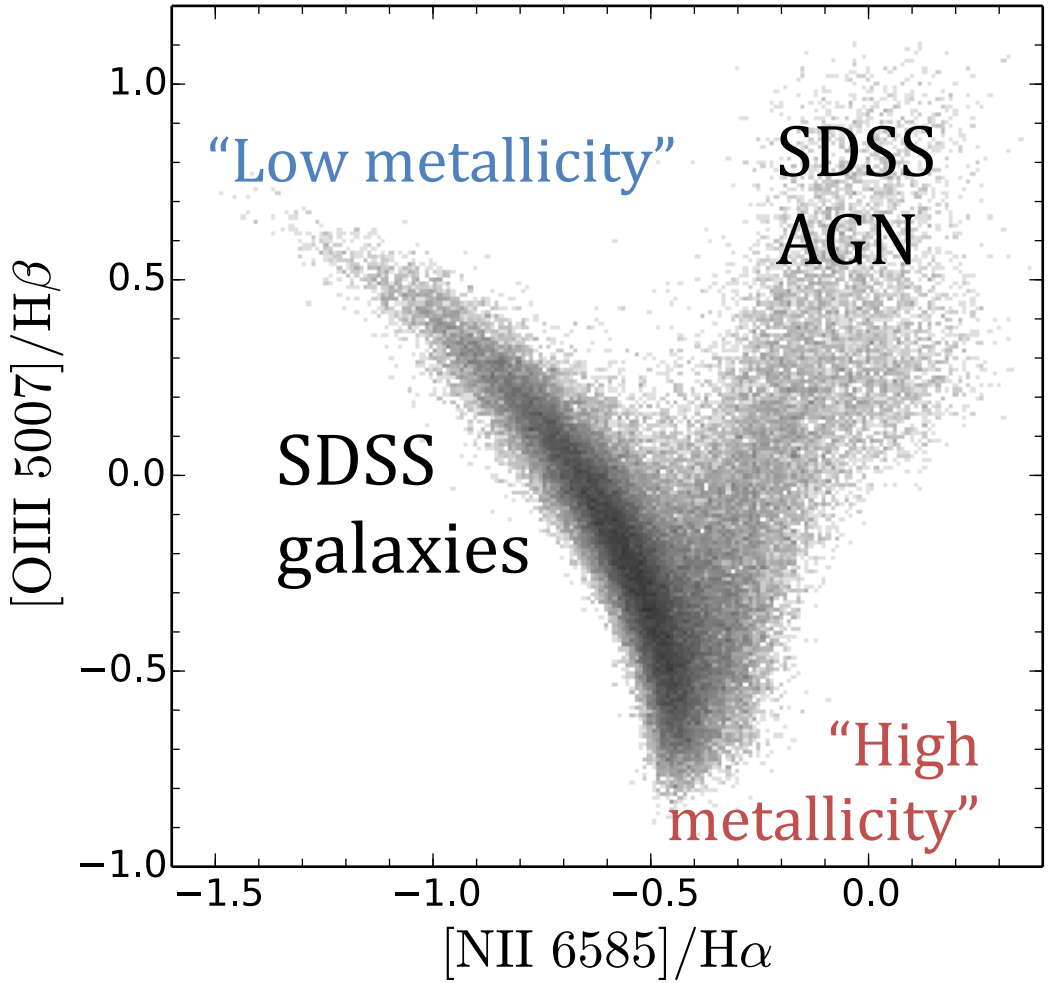
what about the stars?

As we heard from Sally Oey:

Lyman photons and kinetic stellar feedback originate in the same star-forming regions!

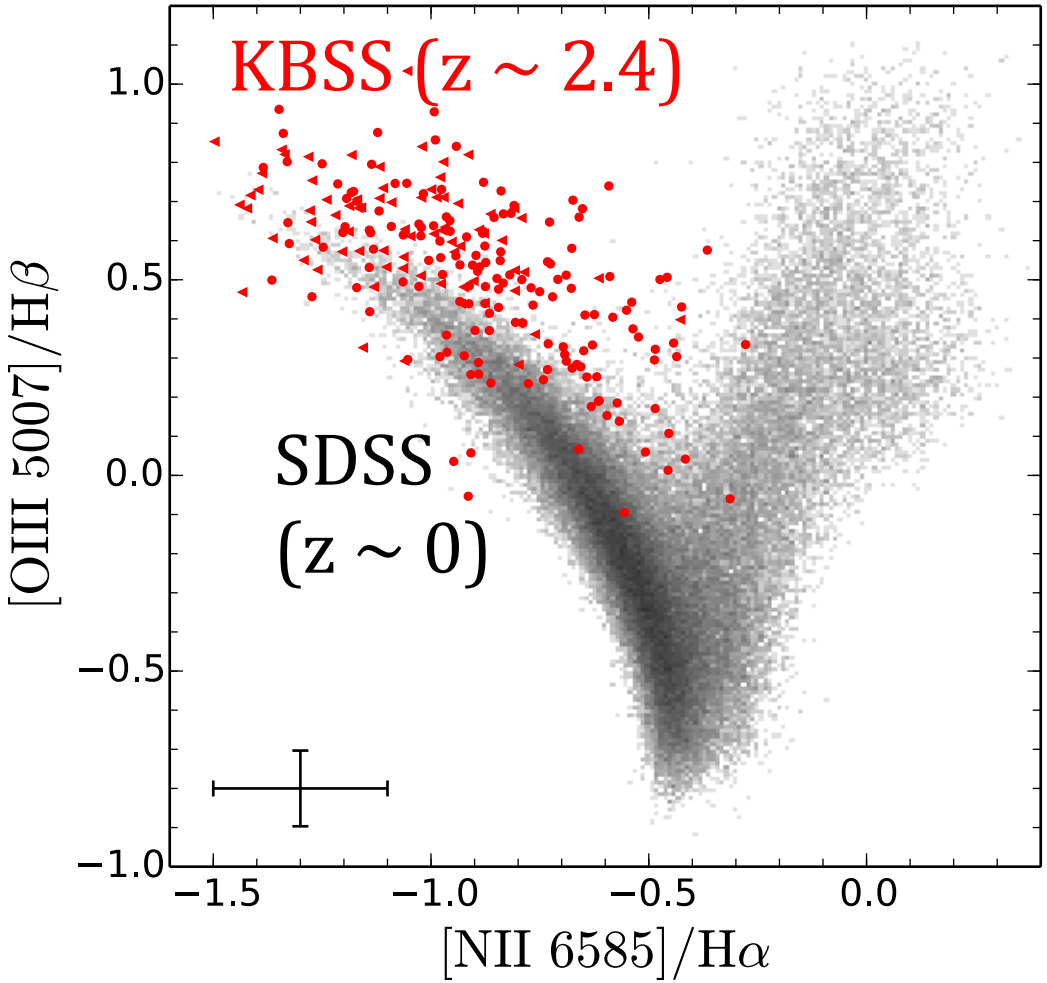


engines of feedback



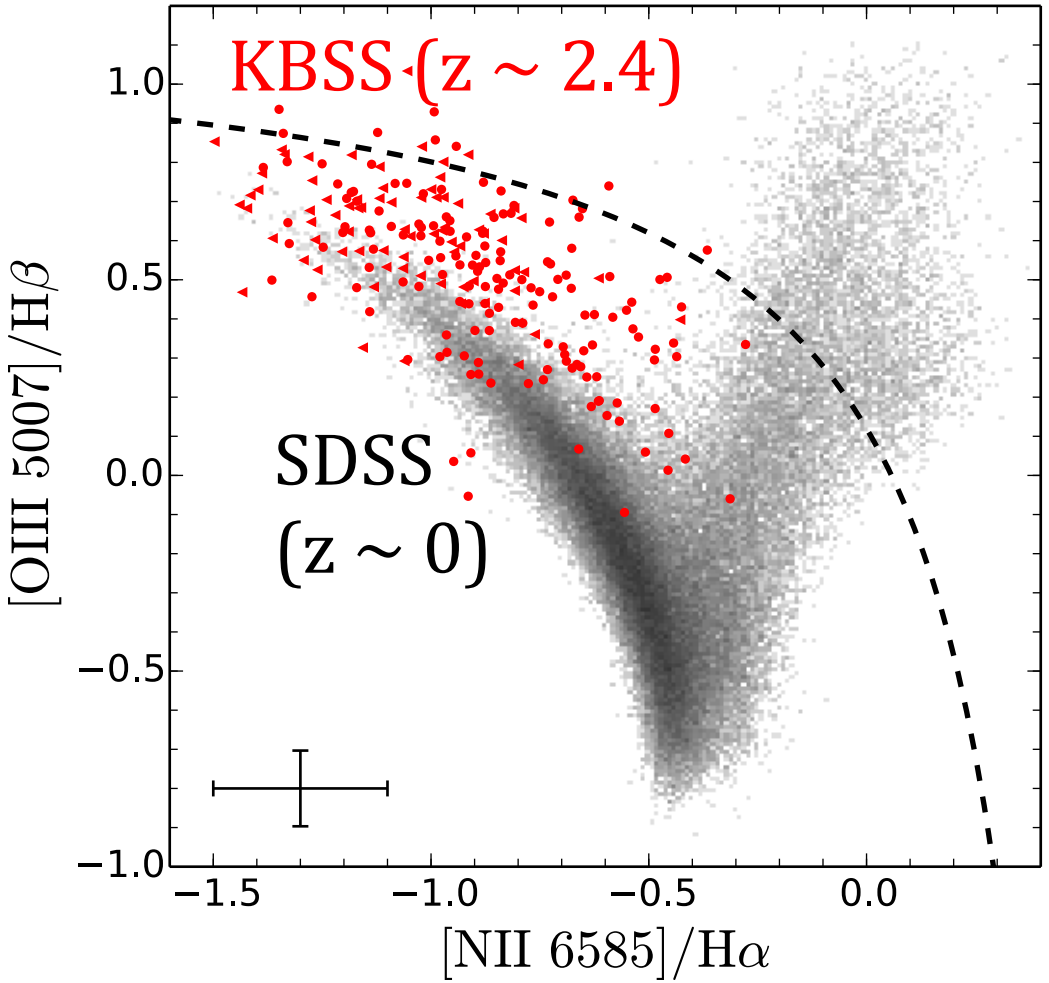
- BPT (NII) diagram
  - Star-formation vs. AGN
  - Gas-phase metallicity (and ionization/excitation)

z ~ 2–3 stellar engines



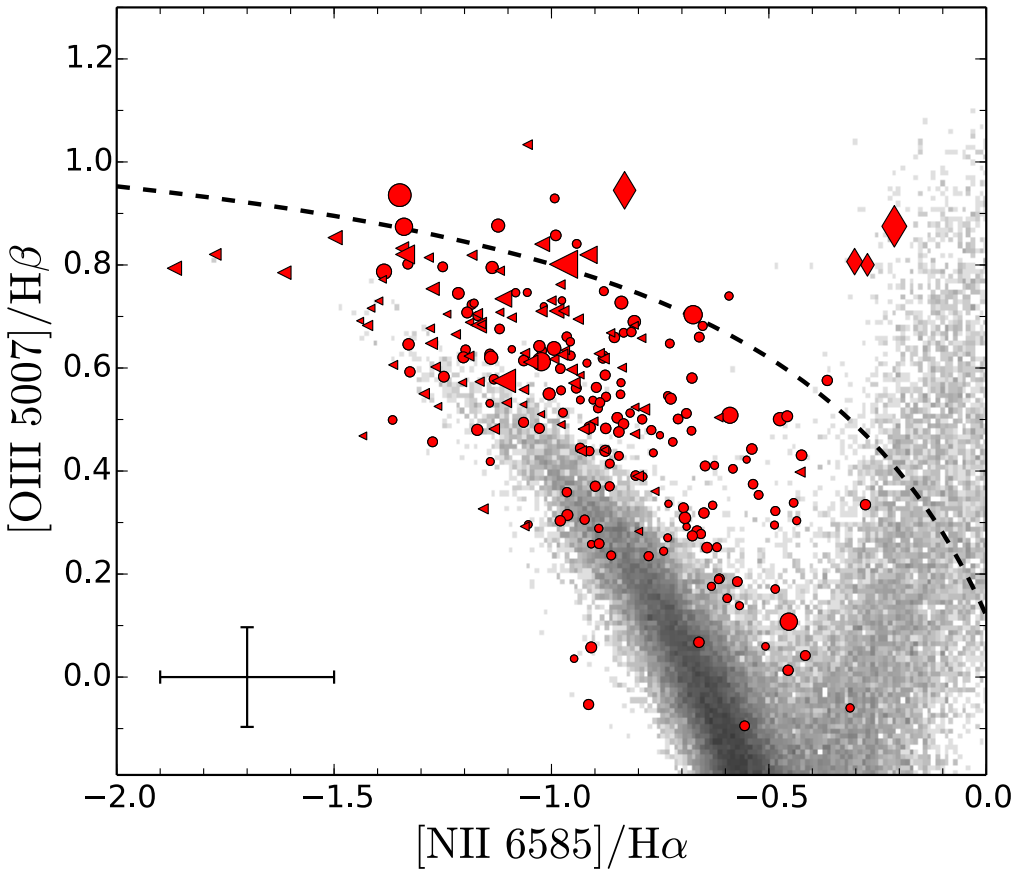
- BPT (NII) diagram
  - Star-formation vs. AGN
  - Gas-phase metallicity (and ionization/excitation)
- High-z galaxies are offset from low-z locus

z ~ 2–3 stellar engines



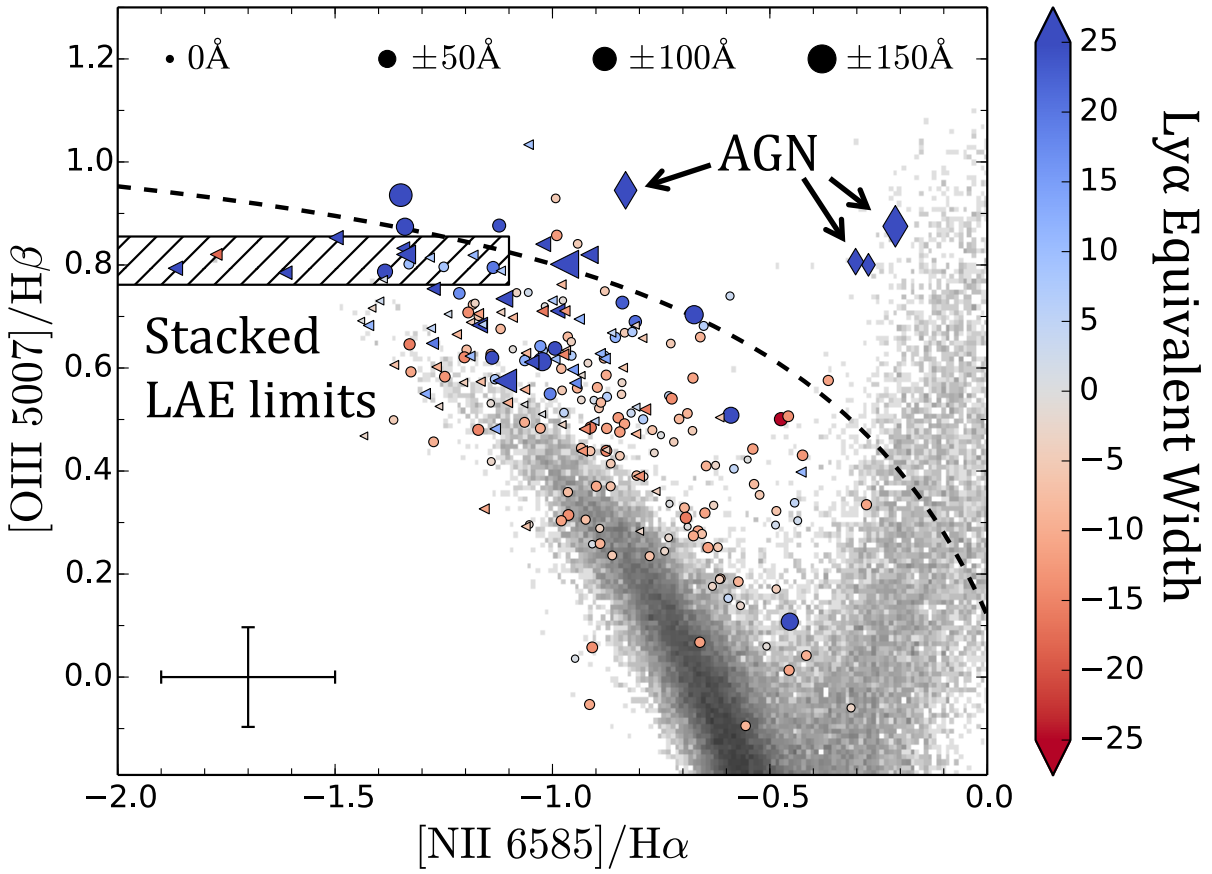
- BPT (NII) diagram
  - Star-formation vs. AGN
  - Gas-phase metallicity (and ionization/excitation)
- High-z galaxies are offset from low-z locus
- Approach Kewley+2001 "maximum starburst" limit
- See Steidel+2014; Shapley+2015; Sanders +2016; Strom+2016 in prep.

BPT-Lyα relation (LBGs)



RFT+2016a, in prep.

BPT-Lyα relation (LBGs)



RFT+2016a, in prep.

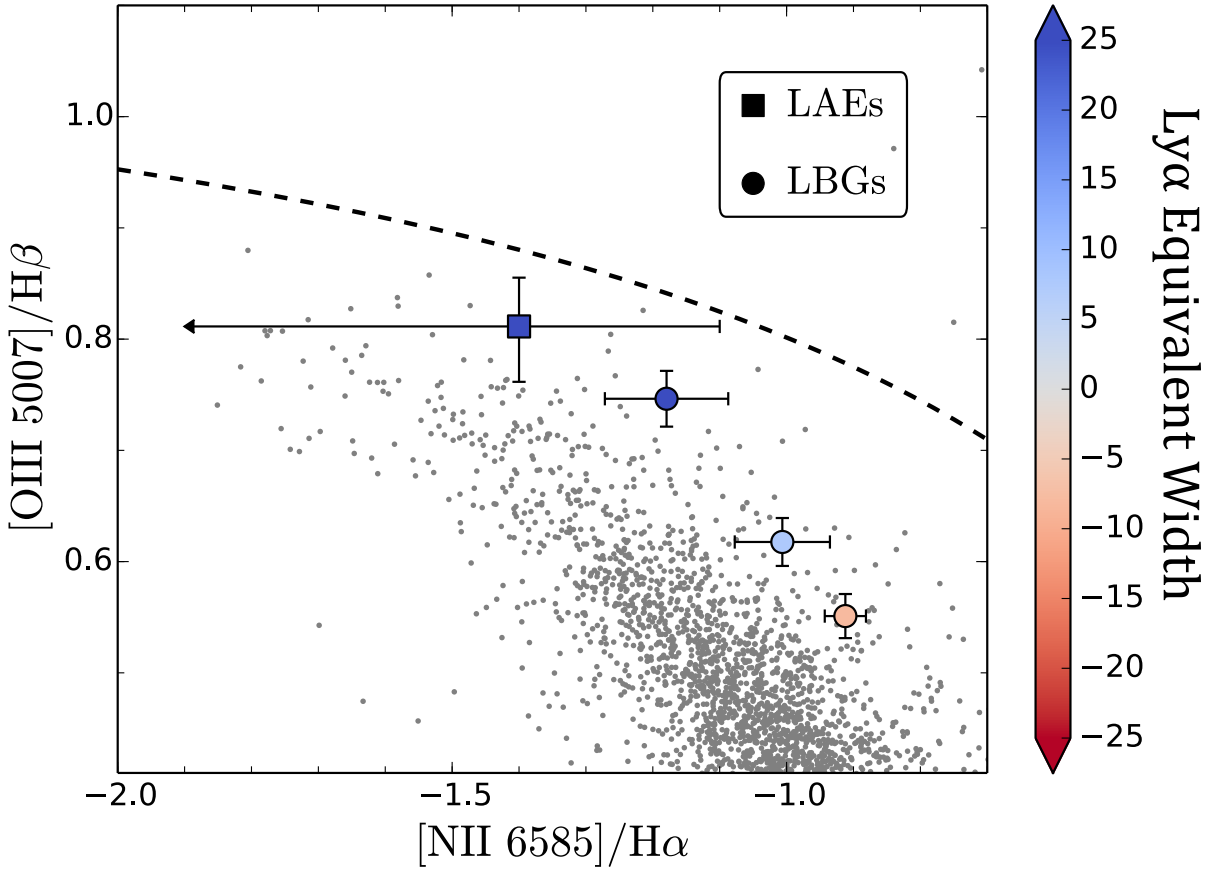
See also: Hagen+2016, Nakajima+2013

KBSS LBGs show a gradient in $W_{\mathrm{Ly}\alpha}$

- Emitters have high ionization, low metallicity
- Absorbers have low ionization, high metallicity

Average faint LAEs consistent with highest-ionization LBGs

BPT-Lyα relation (LBGs+LAEs)



RFT+2016a, in prep.

See also: Hagen+2016, Nakajima+2013

LBGs:

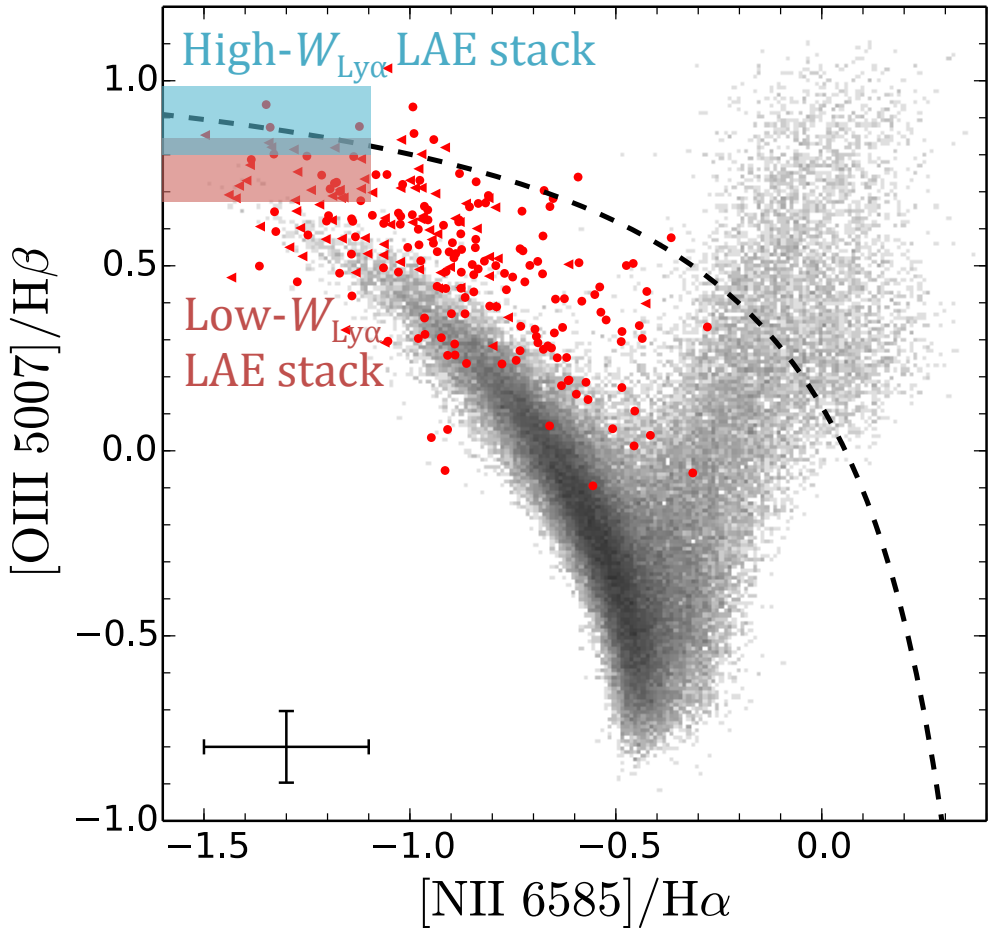
- $W_{Ly\alpha} < 0$
  Average: −8Å
- $0 < W_{Ly\alpha} < 20$Å
  Average: 7Å
- $W_{Ly\alpha} > 20$Å
  Average: 40Å

LAEs:

- $W_{Ly\alpha} > 20$Å
  Average: 56Å

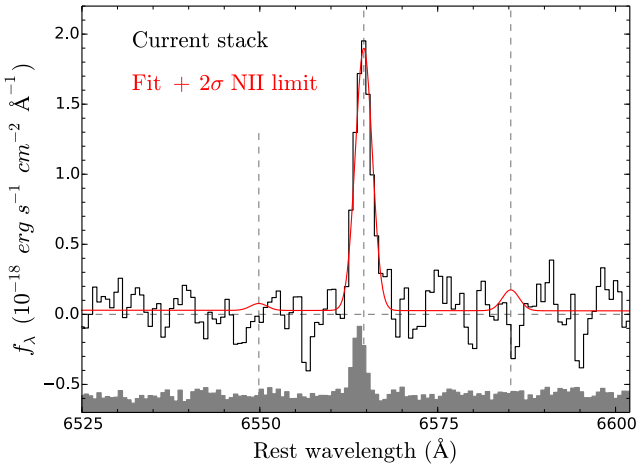
LAE sub-populations continue trend

RFT+2016a, in prep.



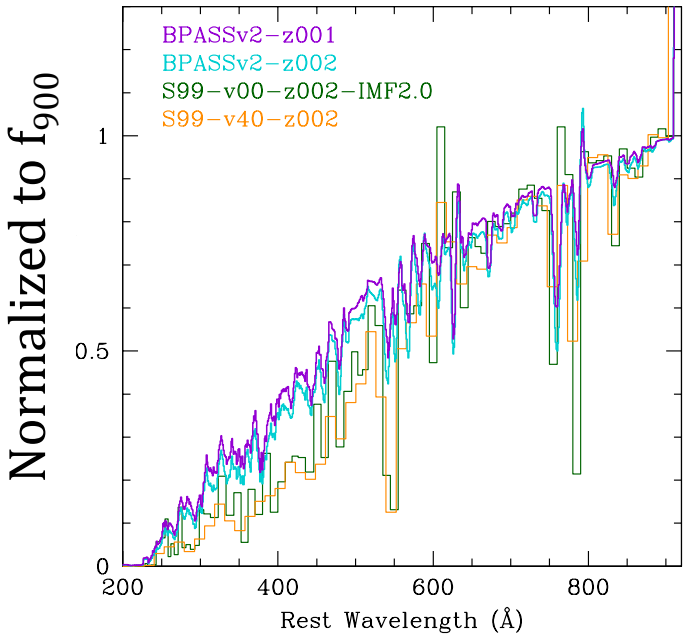
Highest $W_{Ly\alpha}$ sample puts pressure on max starburst line

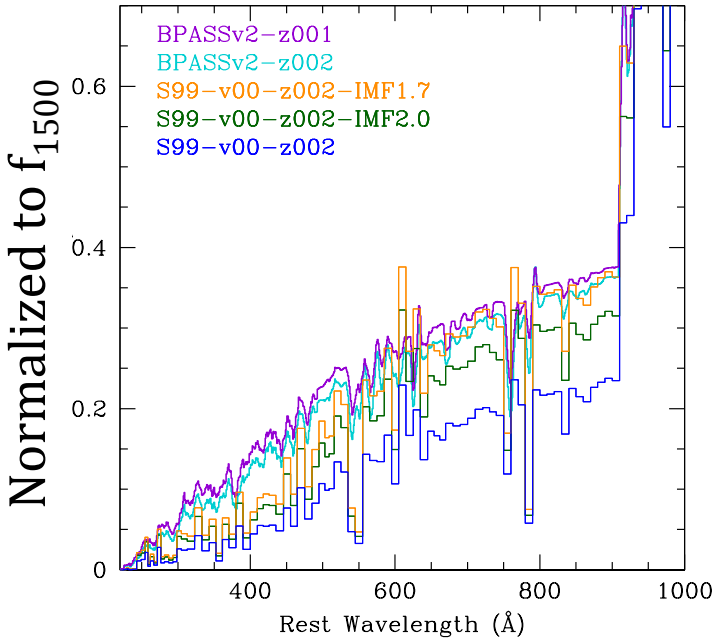
Deep [NII], Hα measurements proposed

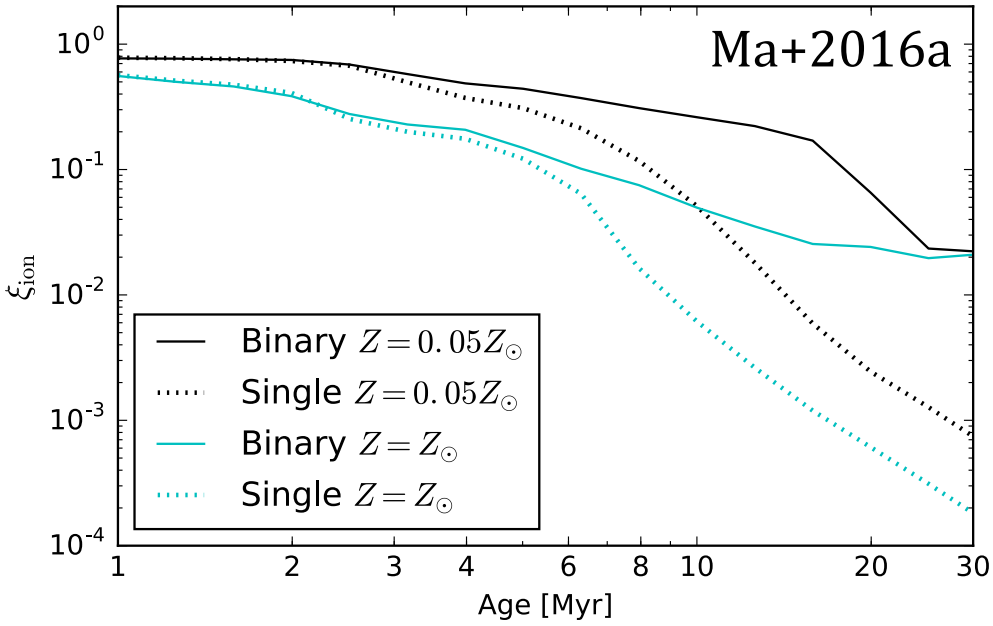


Stellar pops. determine ionizing emissivity

- ξ_{ion} is harder, higher, and more sustained
- Effects estimates and requirements for f_{esc}







summary

- The production and transmission of Lyman photons are linked by stellar feedback
- Outflow velocity and gas covering fraction scale with galaxy mass (and luminosity, SFR, etc.)
- Stellar populations and radiation field vary with galaxy mass (and metallicity, etc.)
- Therefore, photon escape varies strongly with these properties
- Low-mass galaxies (faint LAEs) are key probes