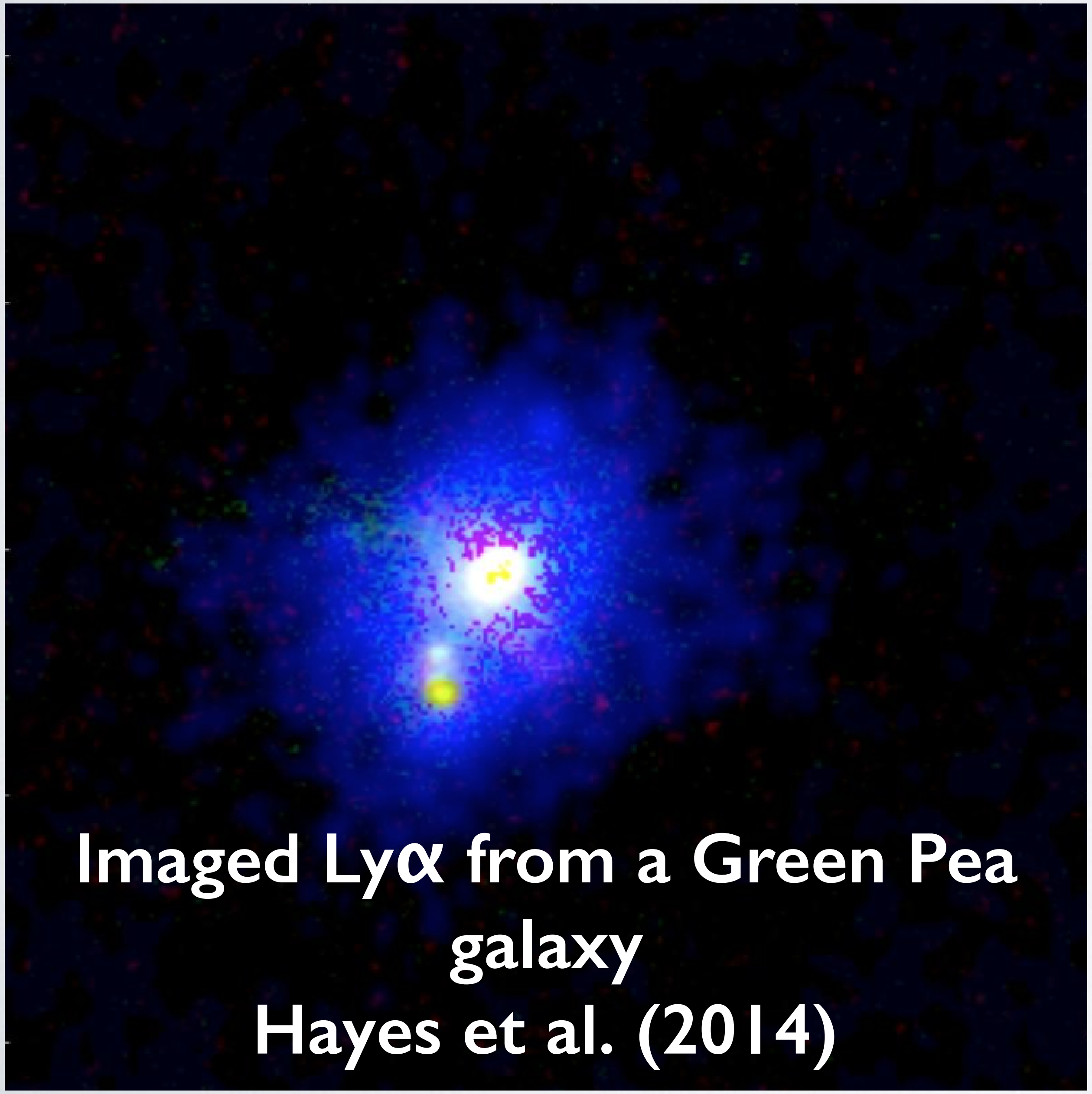
Lyman α emission from Green Peas

The Role of Circumgalactic Gas Density, Covering, and Kinematics

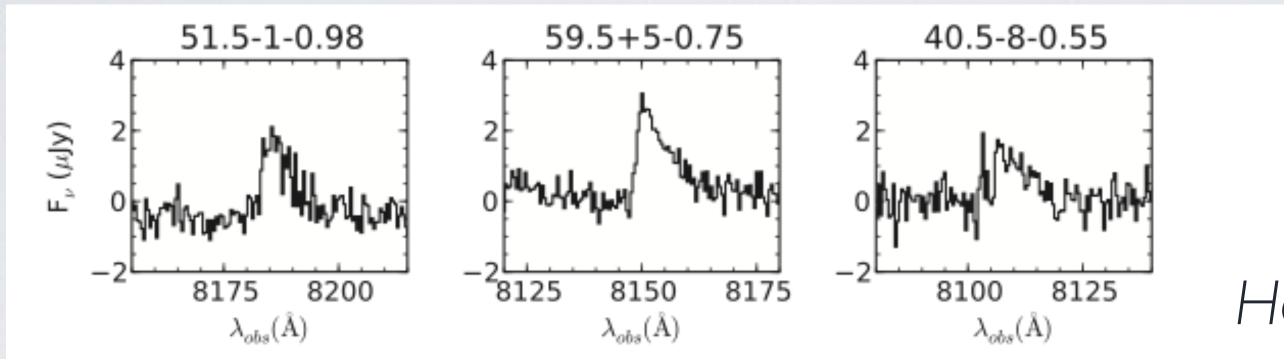


Imaged Lyα from a Green Pea galaxy
Hayes et al. (2014)

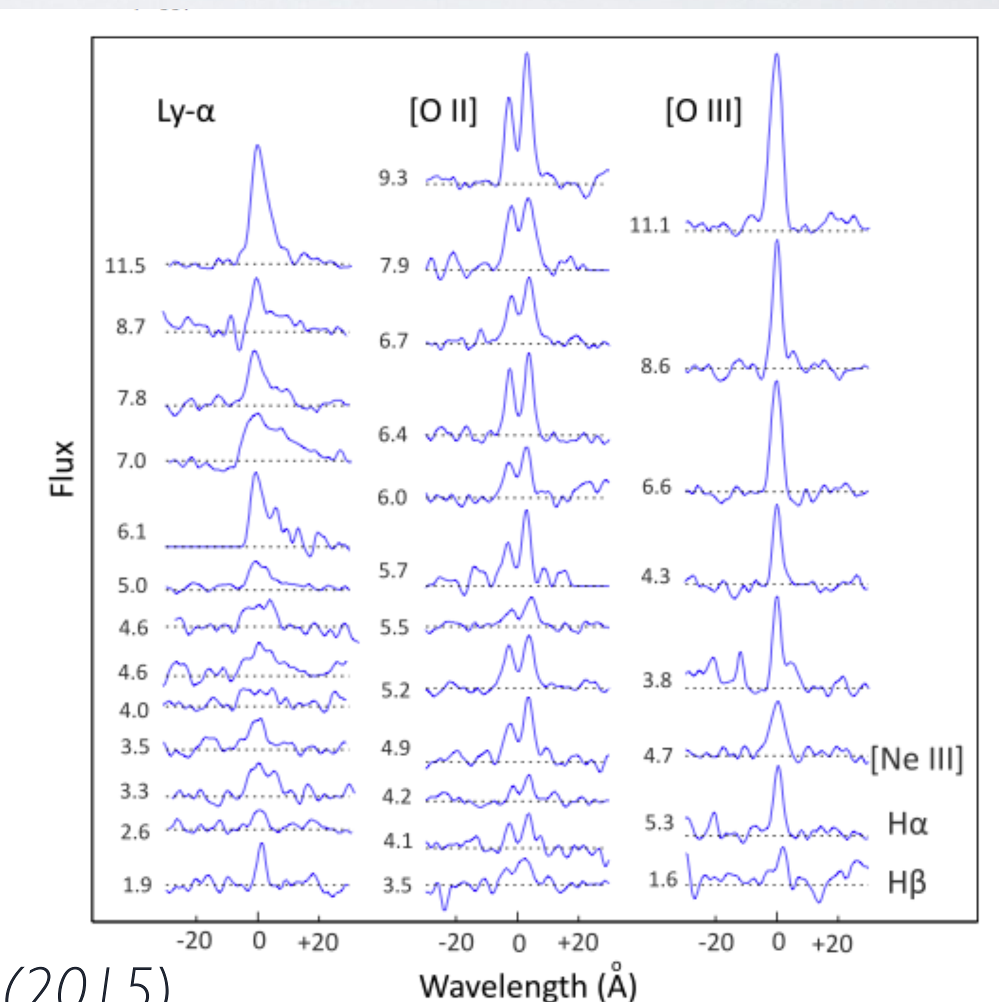
Alaina Henry
Goddard Space Flight Center

Claudia Scarlata
Dawn Erb
Crystal Martin

Lyα can tell us a lot about galaxies and the IGM!



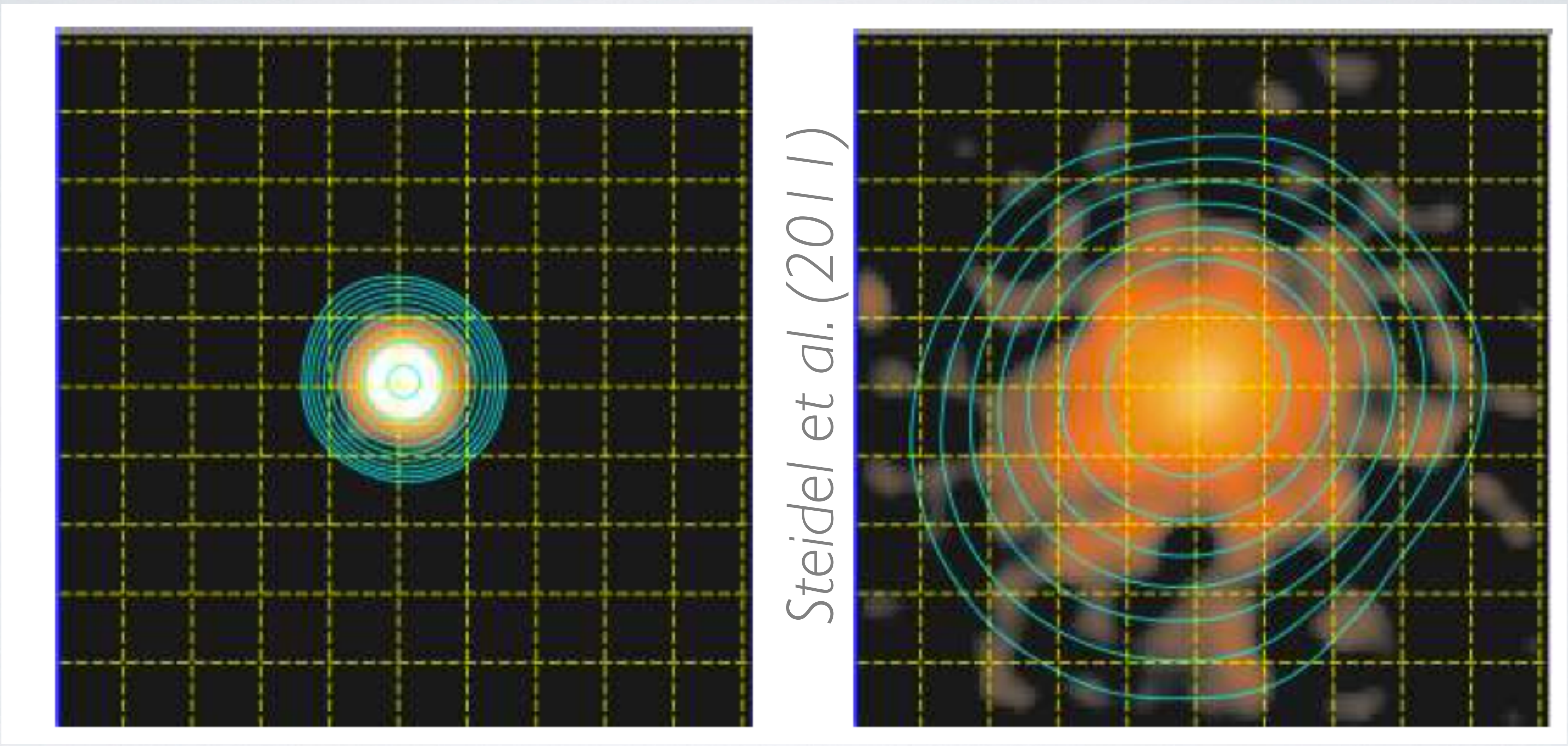
Henry et al. (2012)



Dressler et al. (2015)

Lyα can tell us a lot about galaxies and the IGM!

~100 kpc



Stellar Continuum

Lyα

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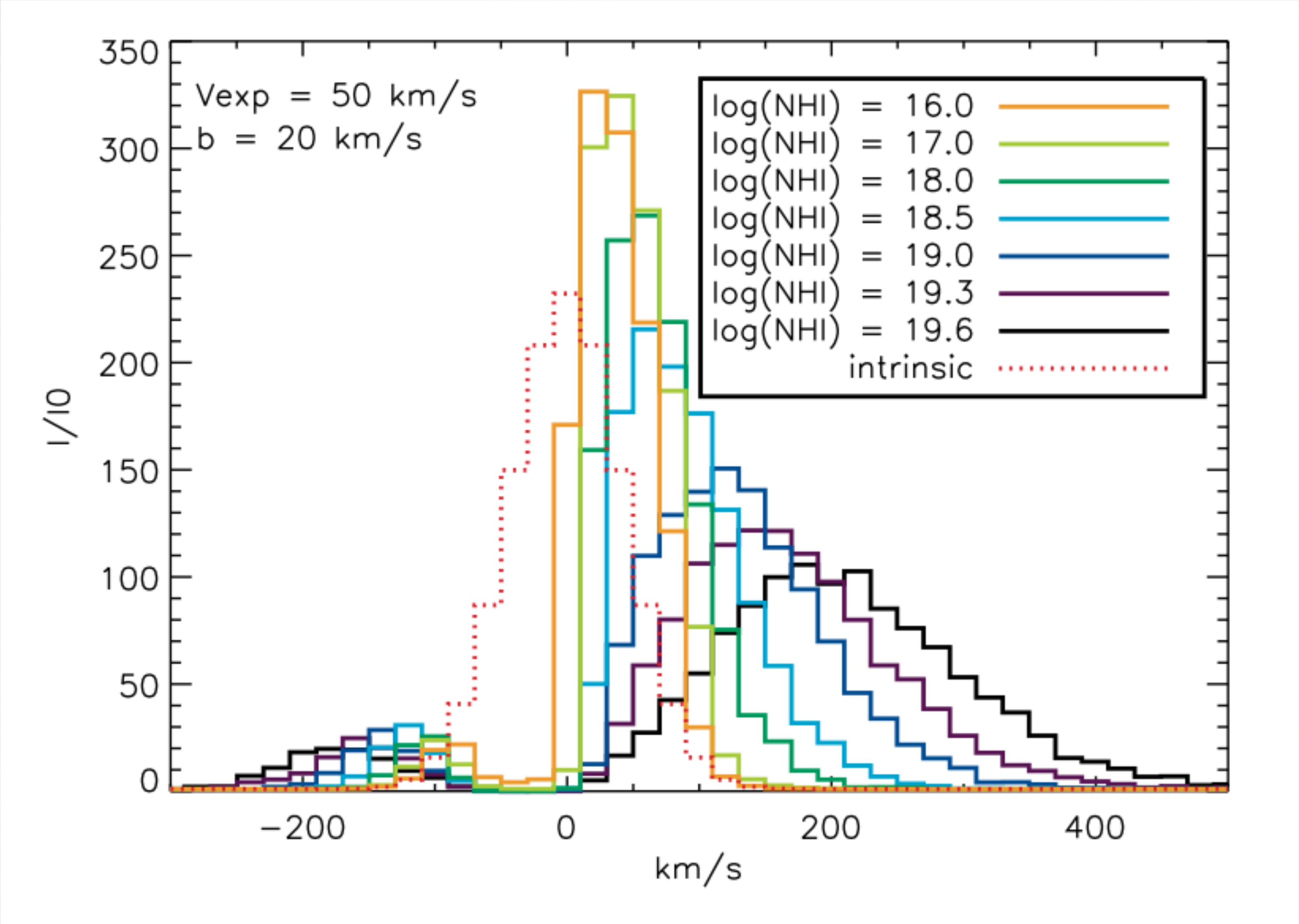
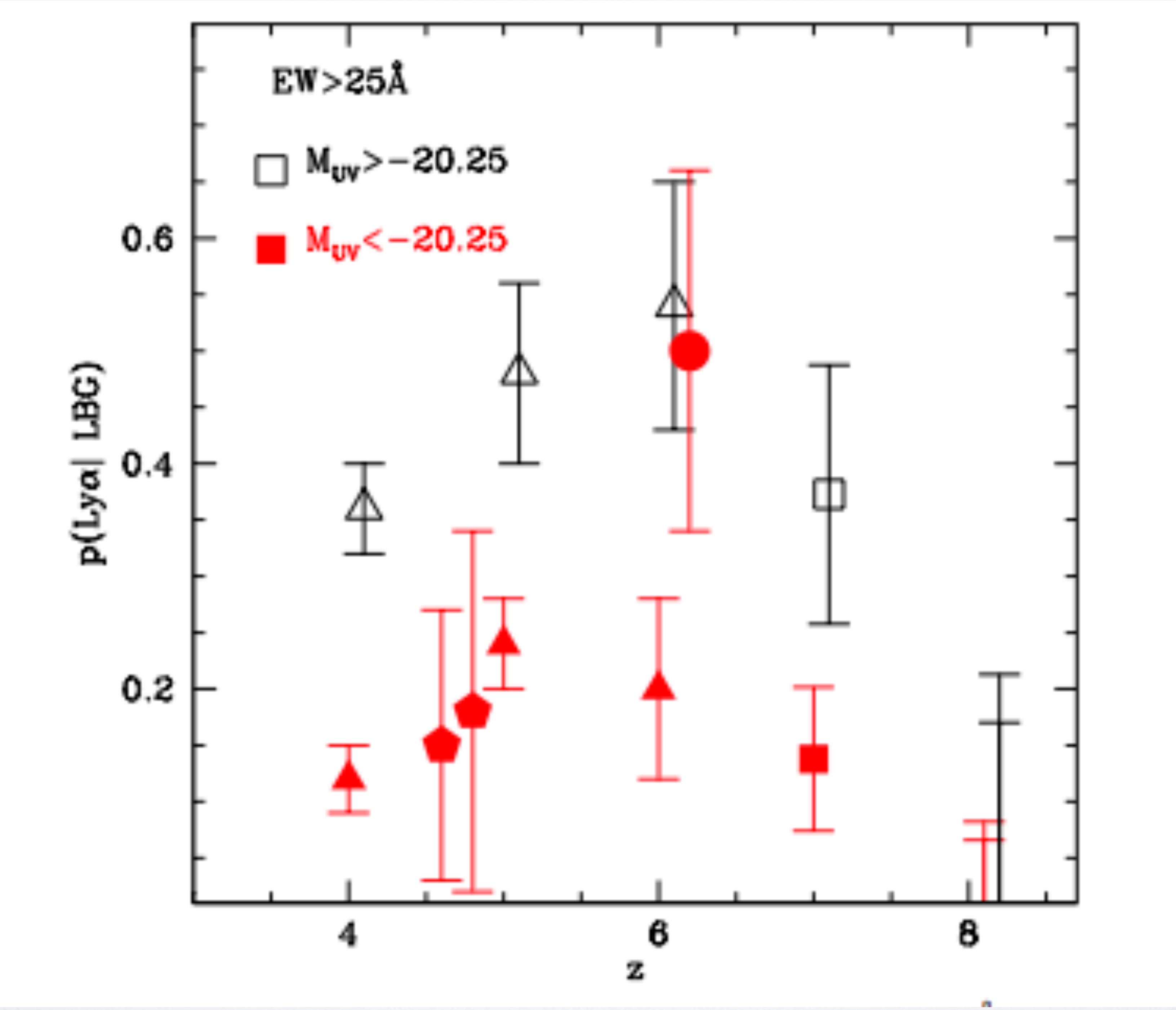


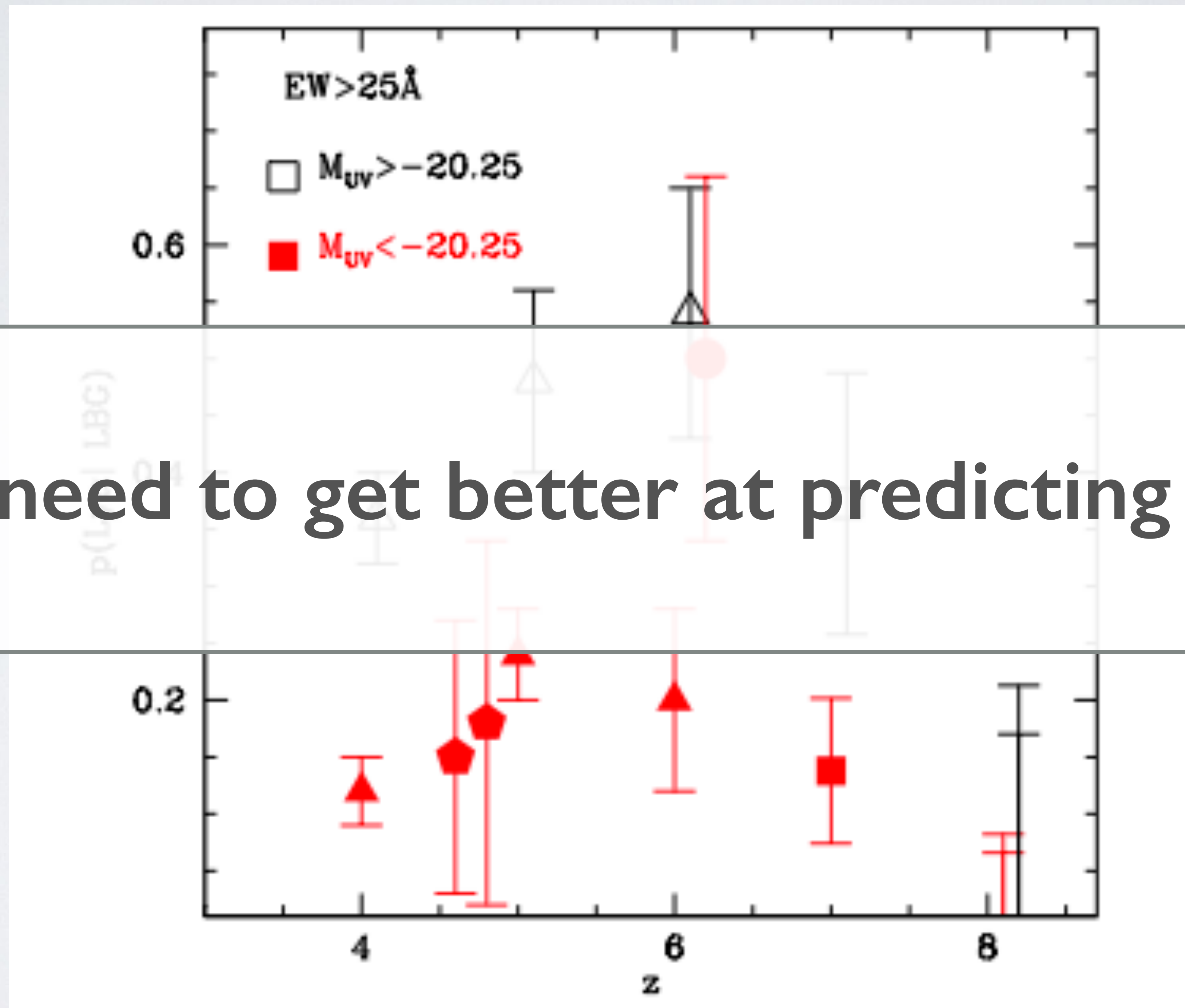
Verhamme et al. (2015)

Lyα can tell us a lot about galaxies and the IGM!



Treu et al. (2013)

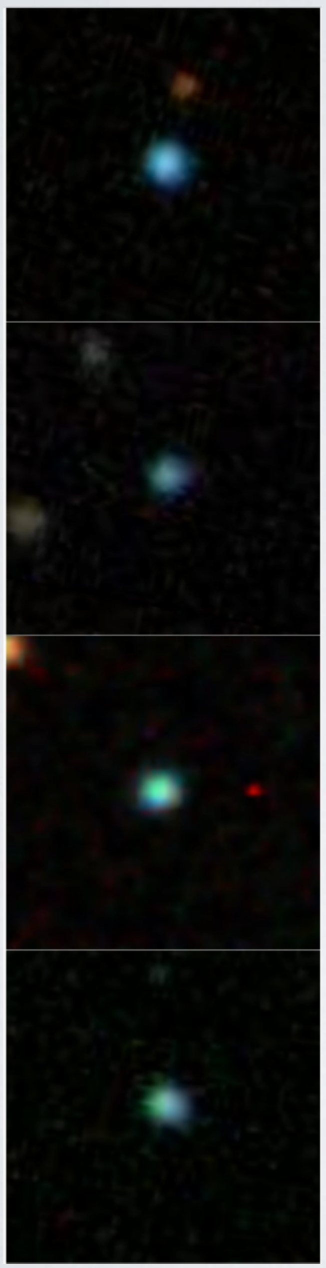
Lyα can tell us a lot about galaxies and the IGM!



We need to get better at predicting Lyα!

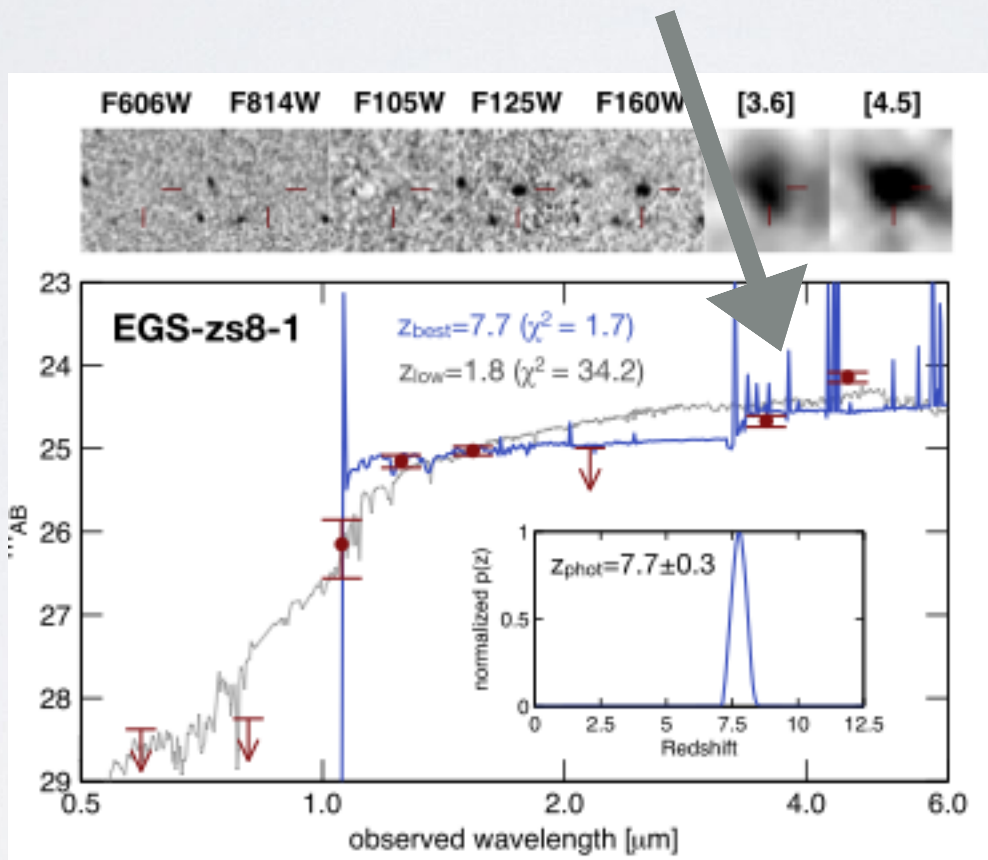
Treu et al. (2013)

“Green Peas” are an important population of high-z analogs



z~0.2 (SDSS)

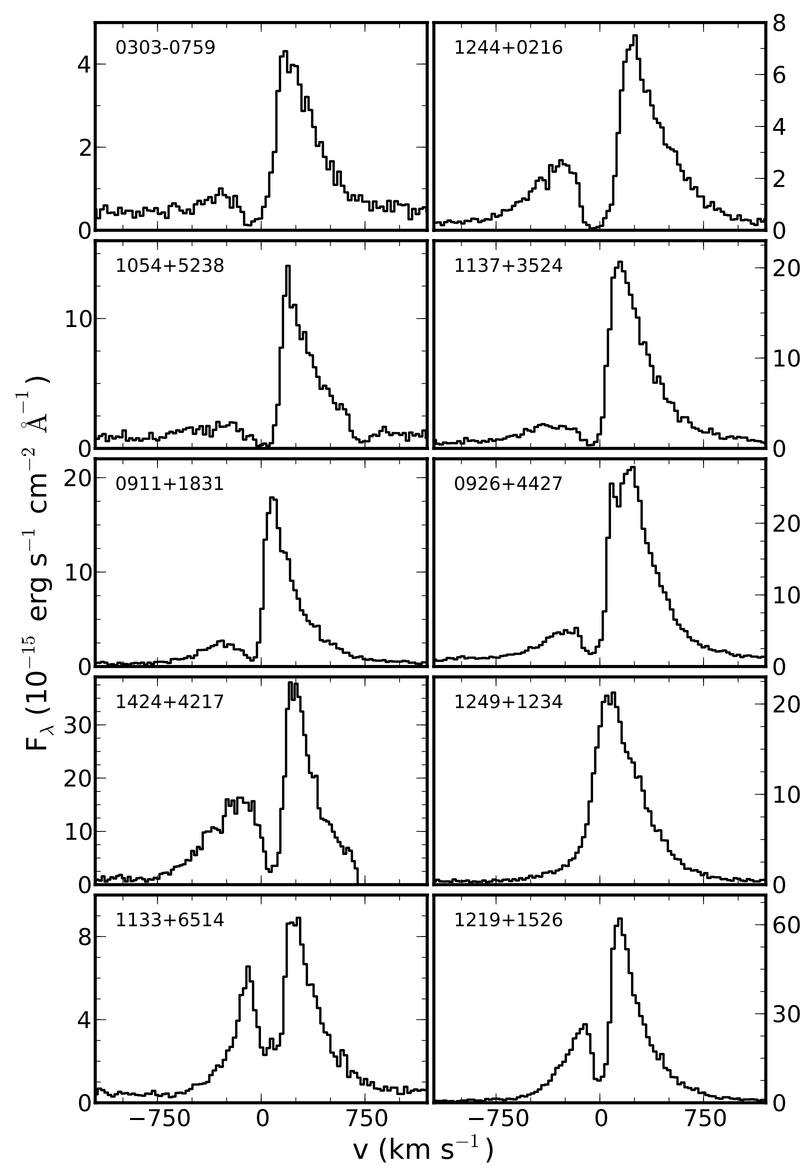
strong lines!
W([OIII]+Hβ)~700 A



z~8 (Oesch et al. 2015)

- Lower metallicity, higher EWs and sSFR than many other nearby samples
- occupy extreme end of BCD population (Izotov et al. 2011)
- more massive, higher SFR than local volume dwarfs
- extreme line ratios (offset on BPT diagram)

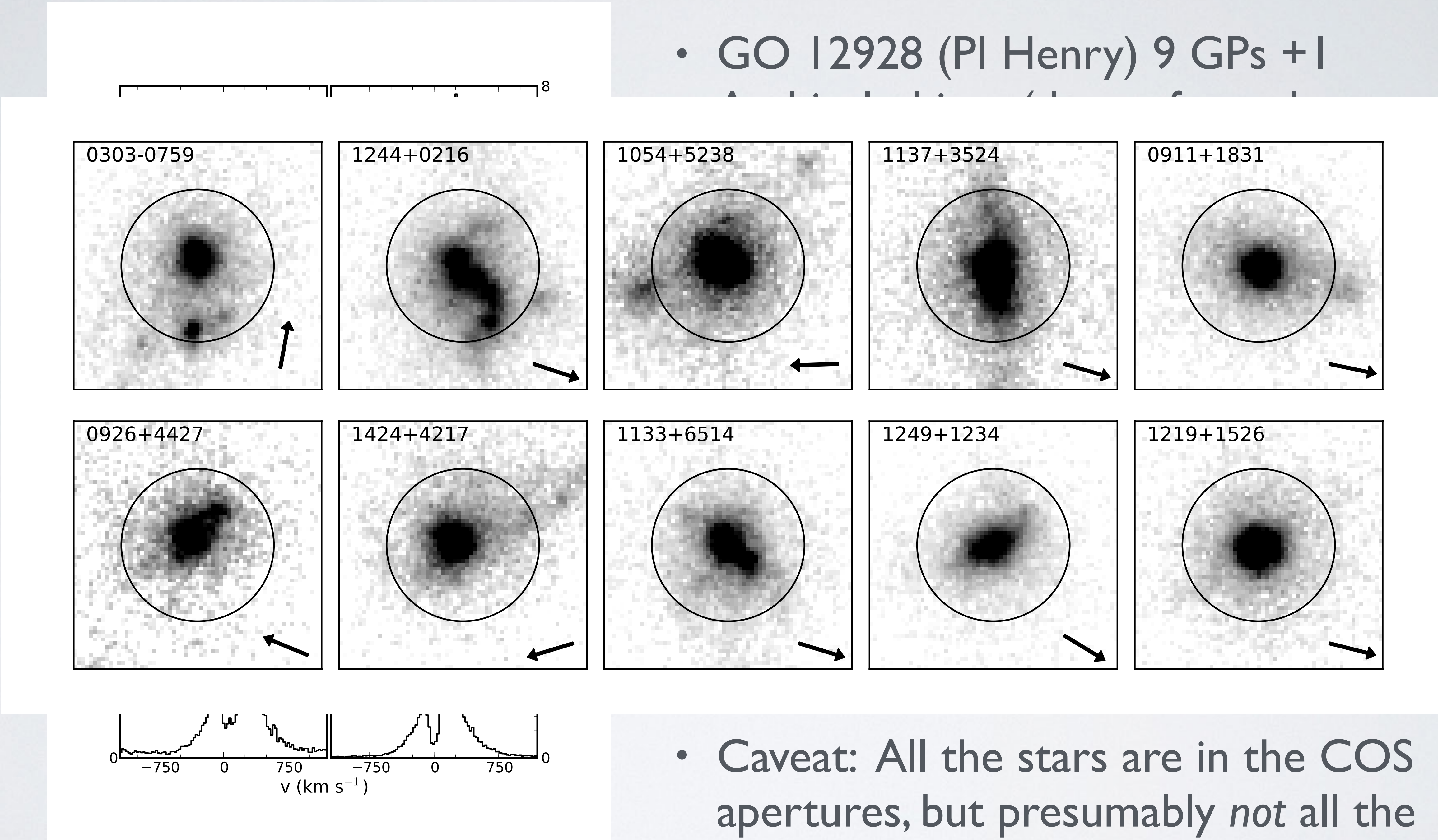
COS Lyα Spectra of Green Peas



Henry et al. (2015)

- GO 12928 (PI Henry) 9 GPs +1 Archival object (drawn from the initial Cardamone+09 sample; z~0.2)
- 9/10 double peaked when we observe with high spectral resolution
- Lyα has higher EW, luminosity than other nearby galaxies
- in terms of luminosity and EW, more comparable to LAEs at z >~3
- Caveat: All the stars are in the COS apertures, but presumably *not* all the Lyα.

COS Lyα Spectra of Green Peas



Henry et al. (2015)

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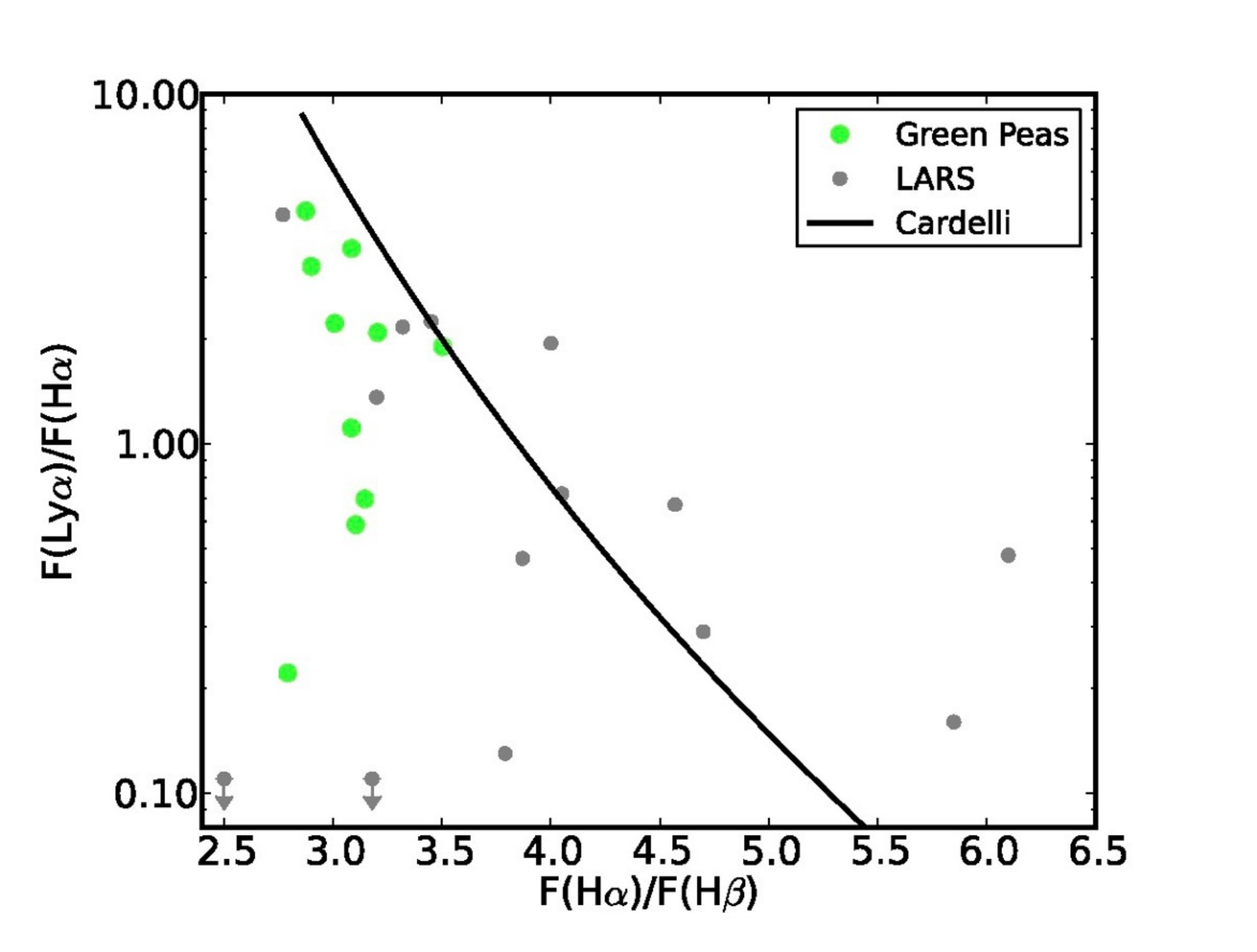
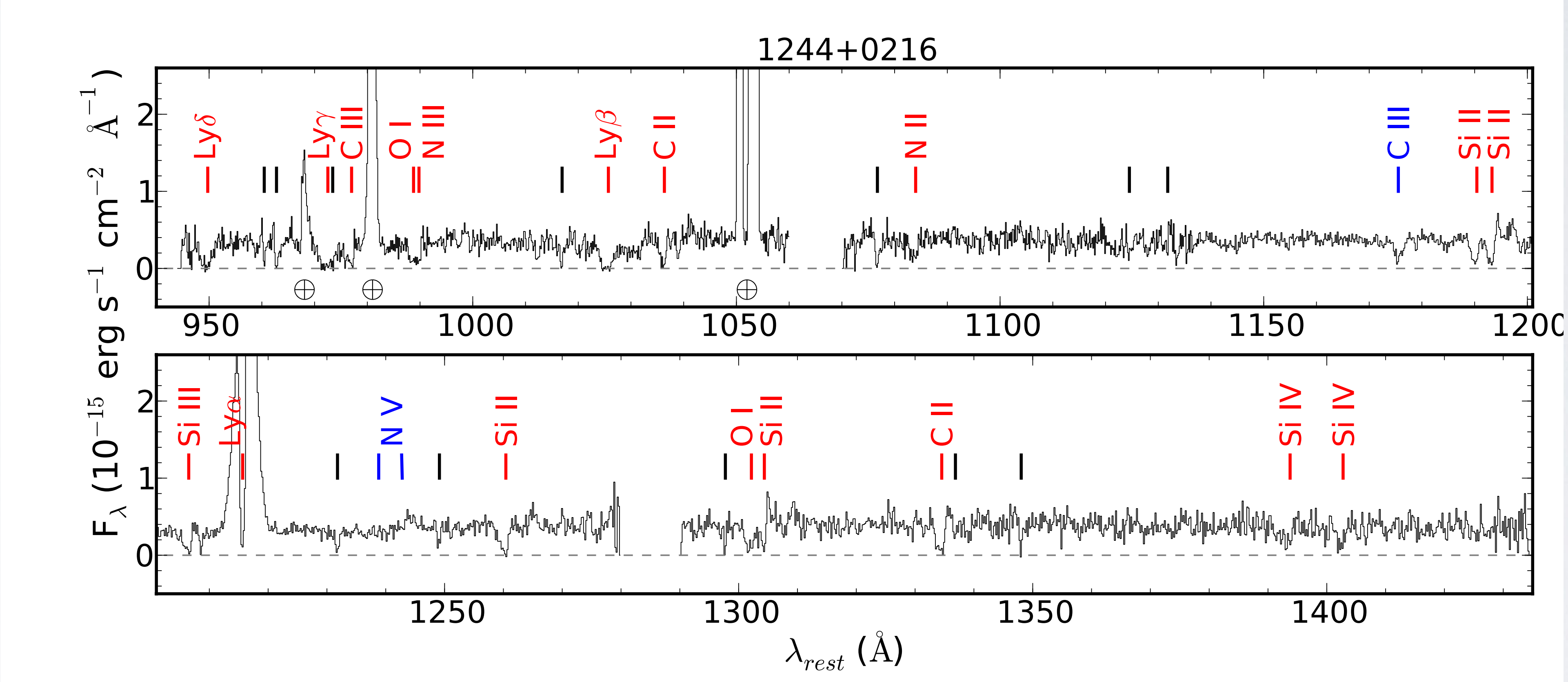
Dust does not explain the range of escaping Lyα



Henry et al. (2015)

The range of Lyα / Hα flux ratios is not explained by extinction alone. $E(B\text{-}V)_{gas}$ is uniformly low.

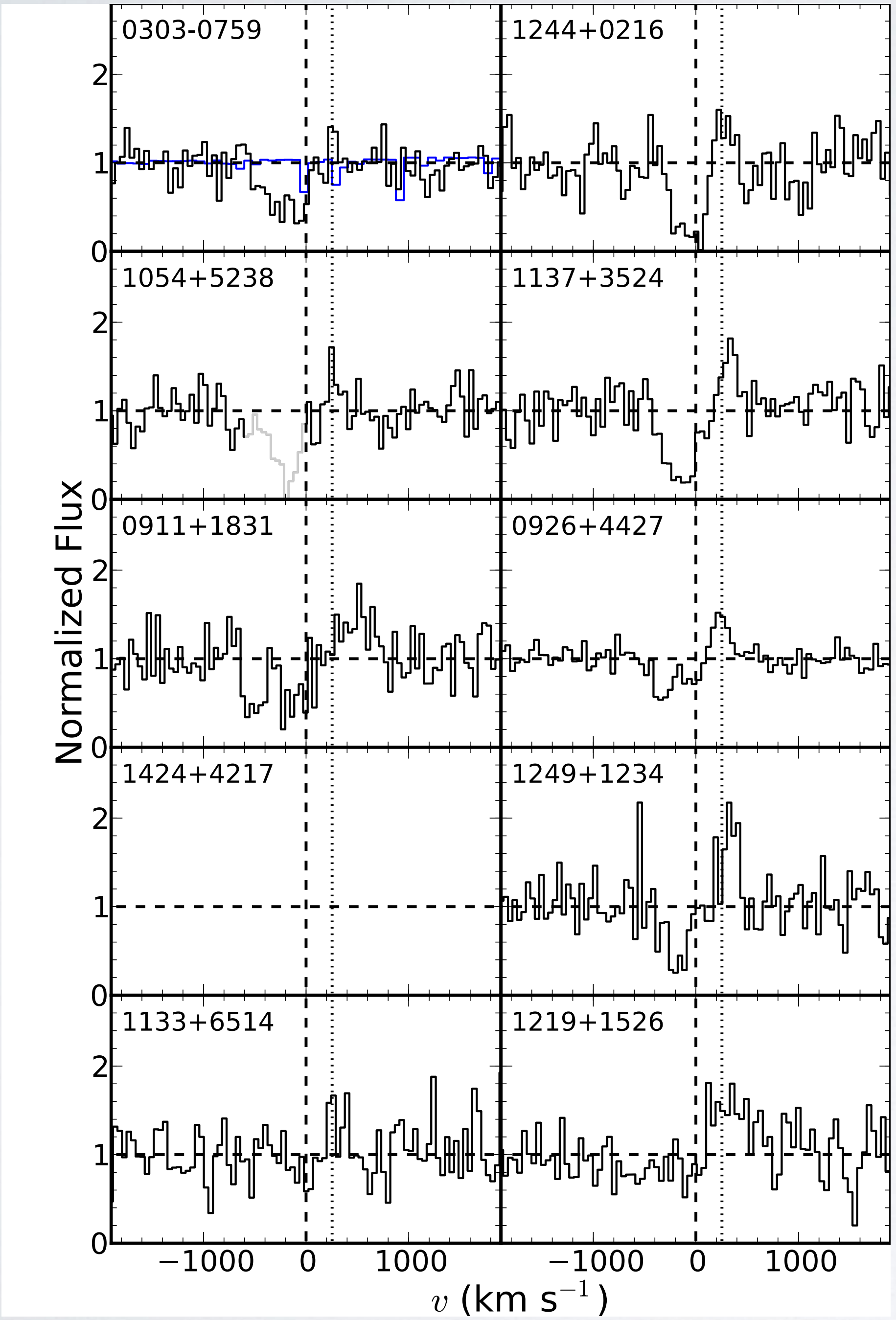
What is causing the variation in Lyα in these galaxies?



Henry et al. (2015)

The UV absorption lines trace gas that scatters Lyα

We cover several low-ionization lines that trace neutral hydrogen

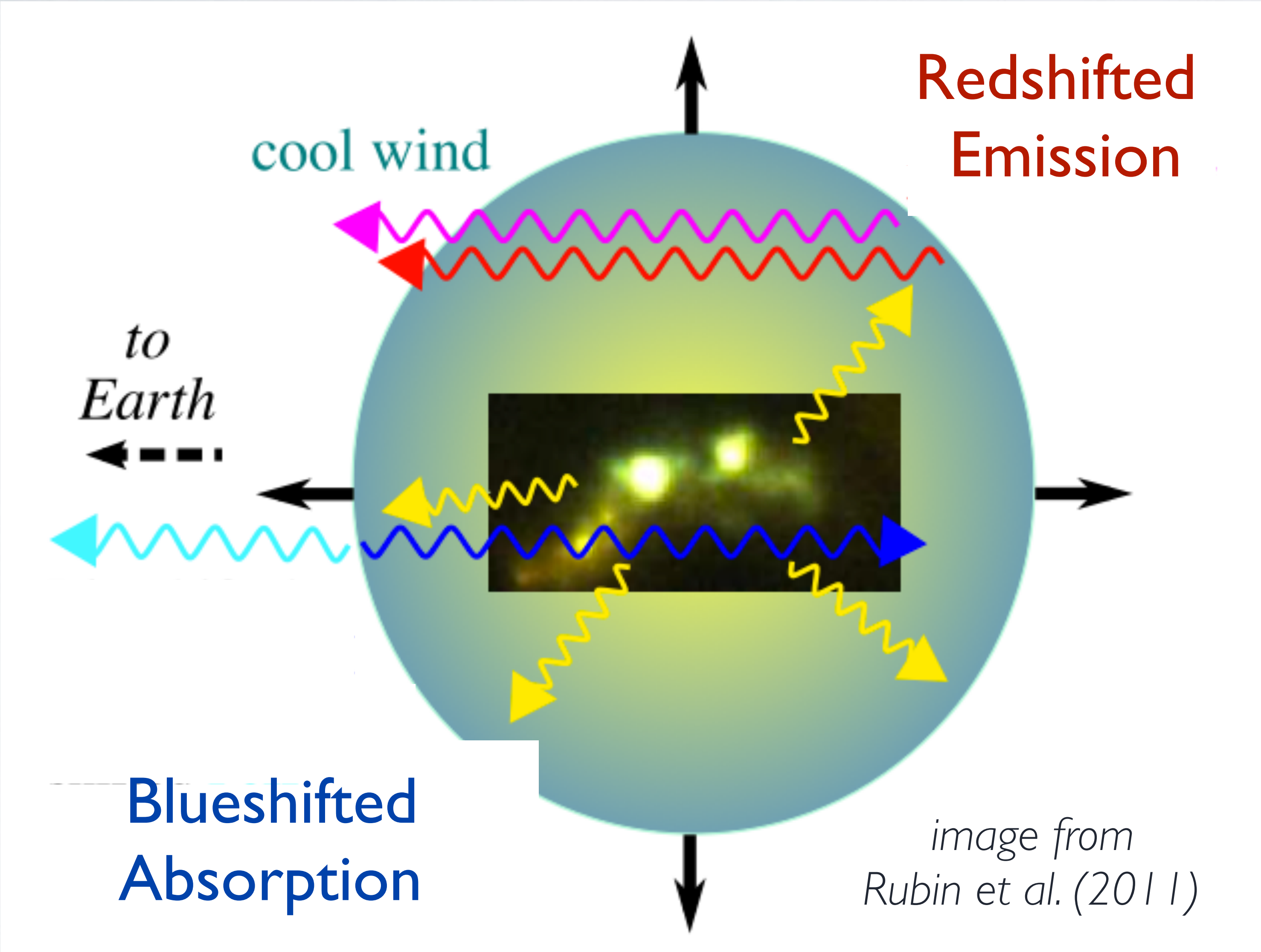


Henry et al. (2015)

e.g. C II 1334
E_{ion} = 11.3 eV
(C I → C II)

Si II 1190, 1193, 1260
E_{ion} = 8.1 eV
(Si I → Si II)

Test 1: Do outflows help Lyα escape?



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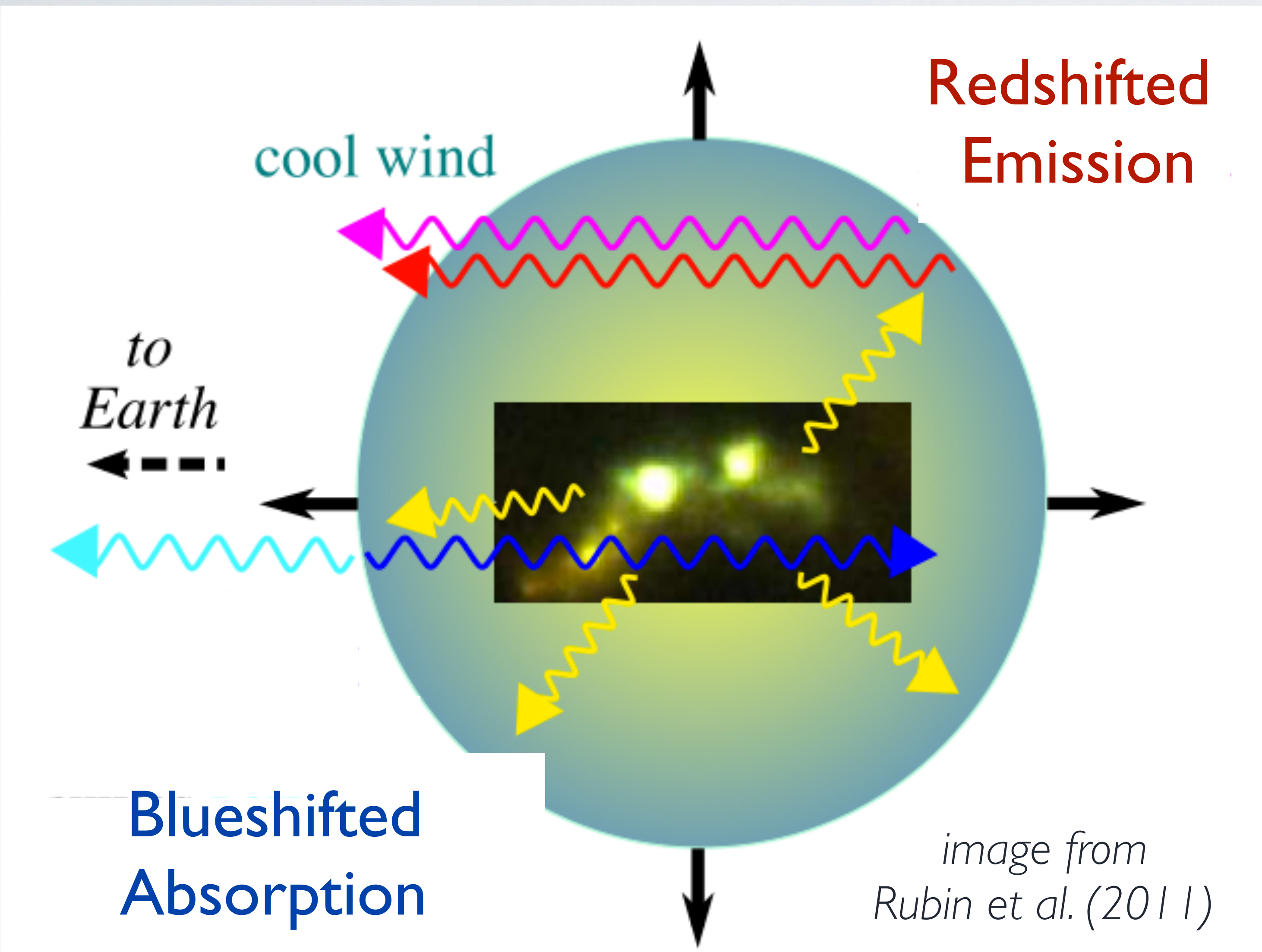

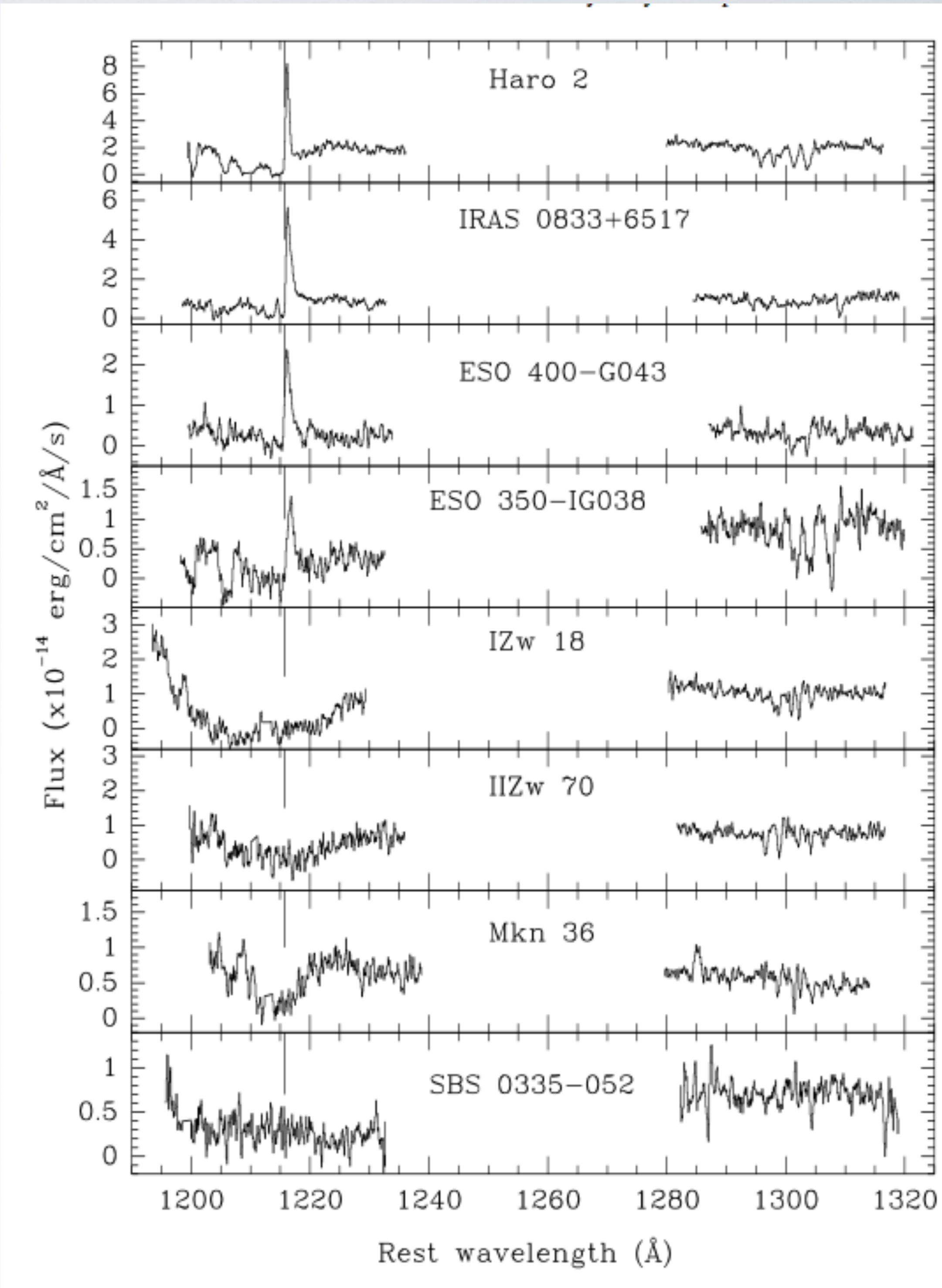

z~0 GHRS: Kunth et al. (1998)

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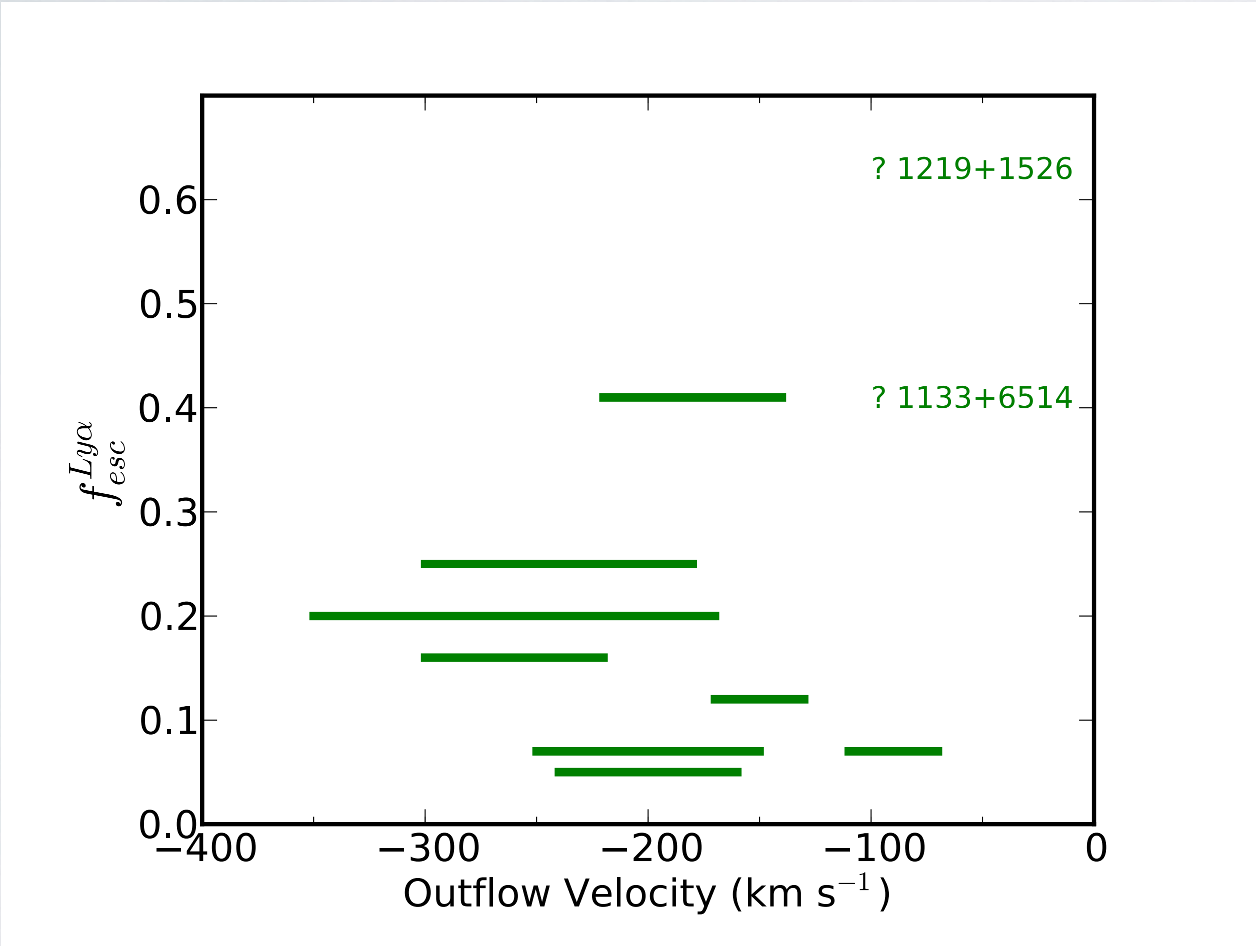

Result: While the Green Peas all show Lyα and outflows, there is no correlation between the two.

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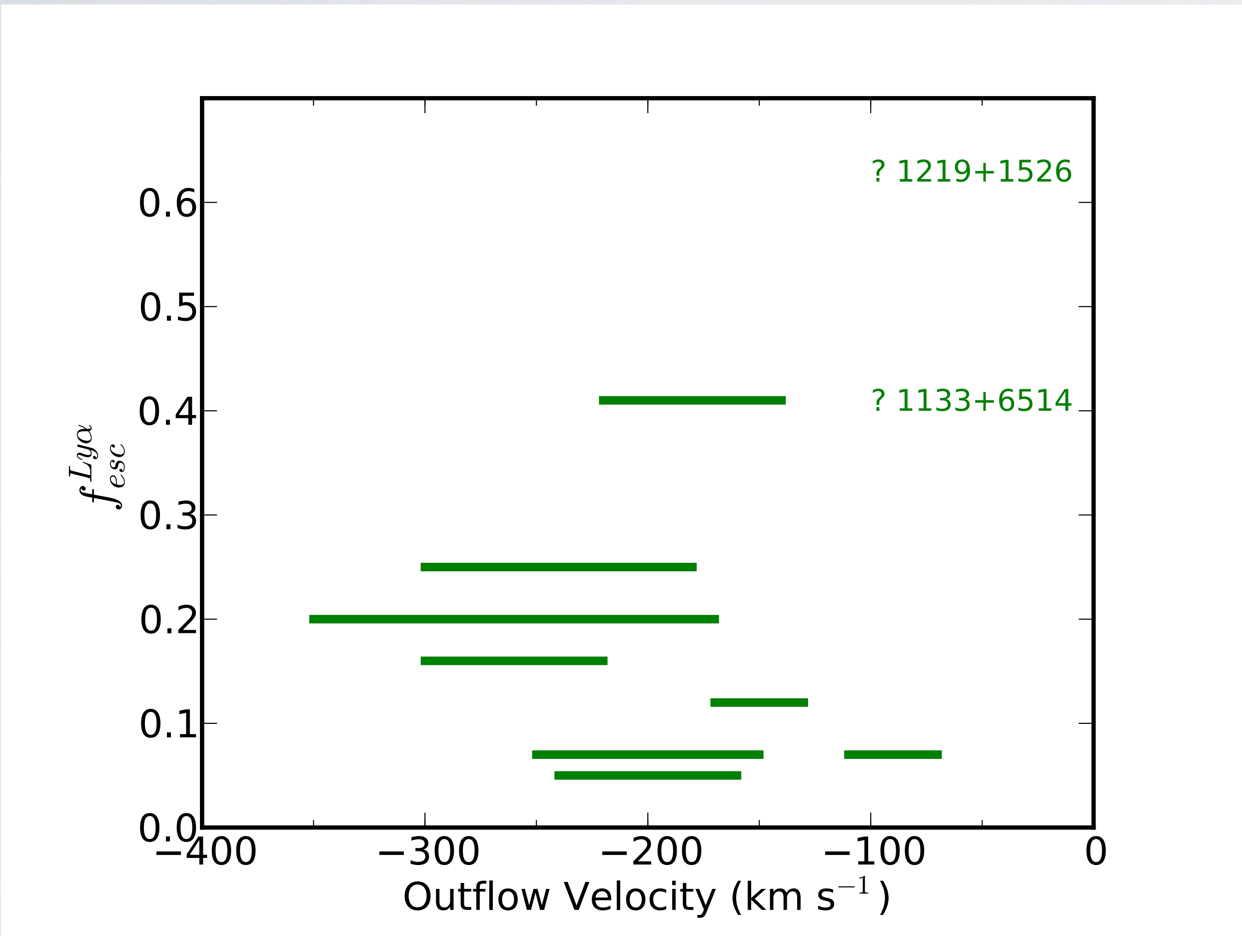


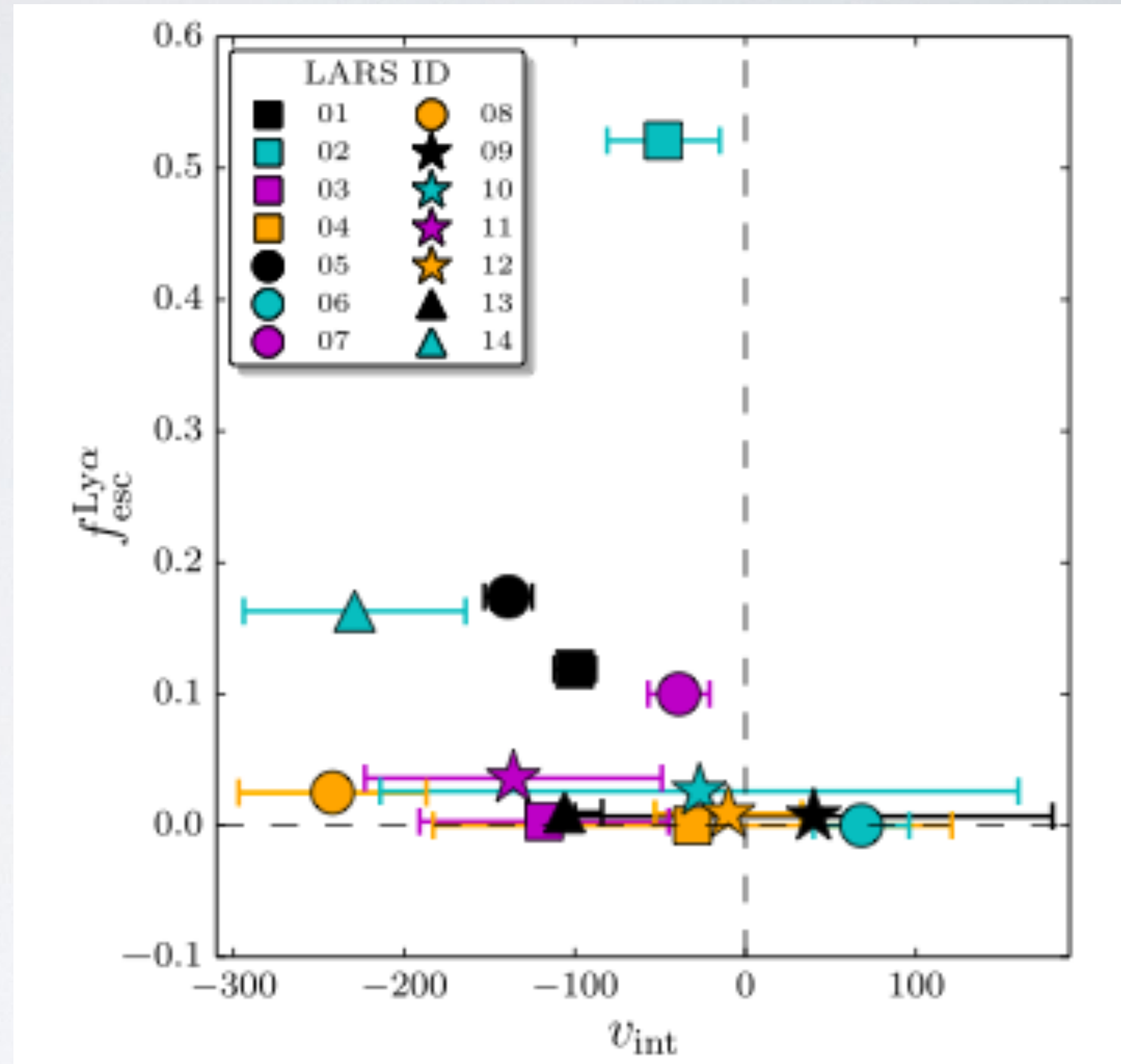


Figure 13. Plot of wind velocity vs. escape fraction $f_{\rm esc}^{\rm Ly\alpha}$ for the LARS sample. Escape fractions are global, imaging-derived values from Hayes et al. (2014).

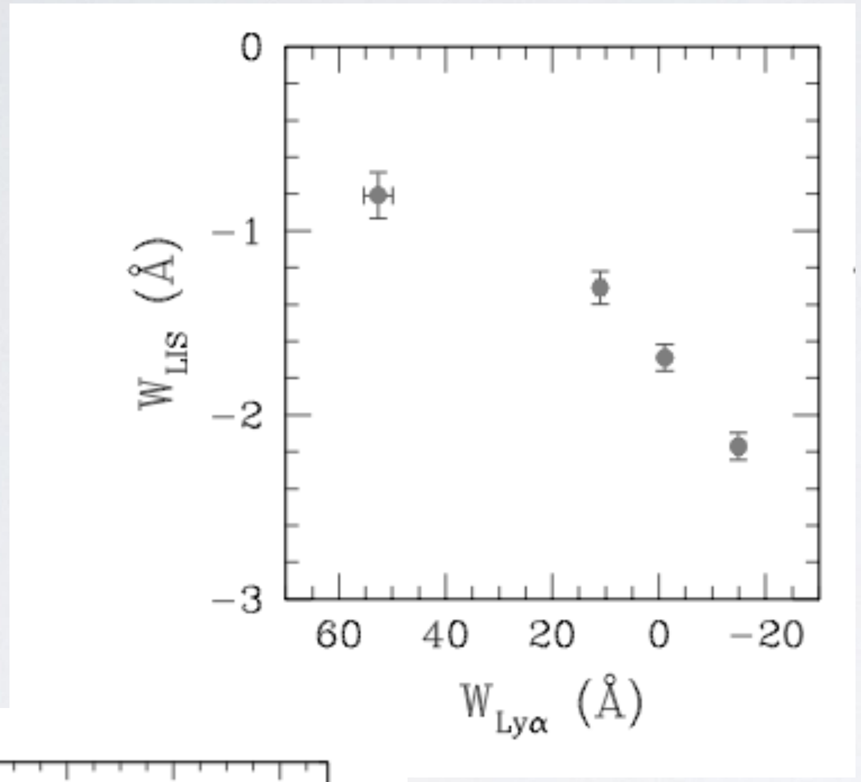
Result: While the Green Peas all show Lyα and outflows, there is no correlation between the two.

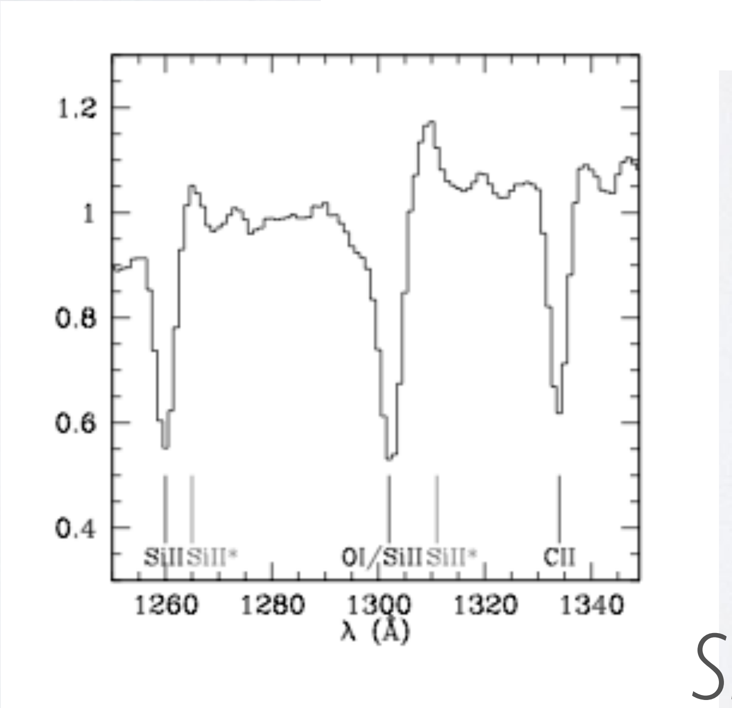
necessary but insufficient?

Rivera-Thorsen et al. (2015)

Test 2: Does Lyα escape through holes in the HI gas? [the picket fence]

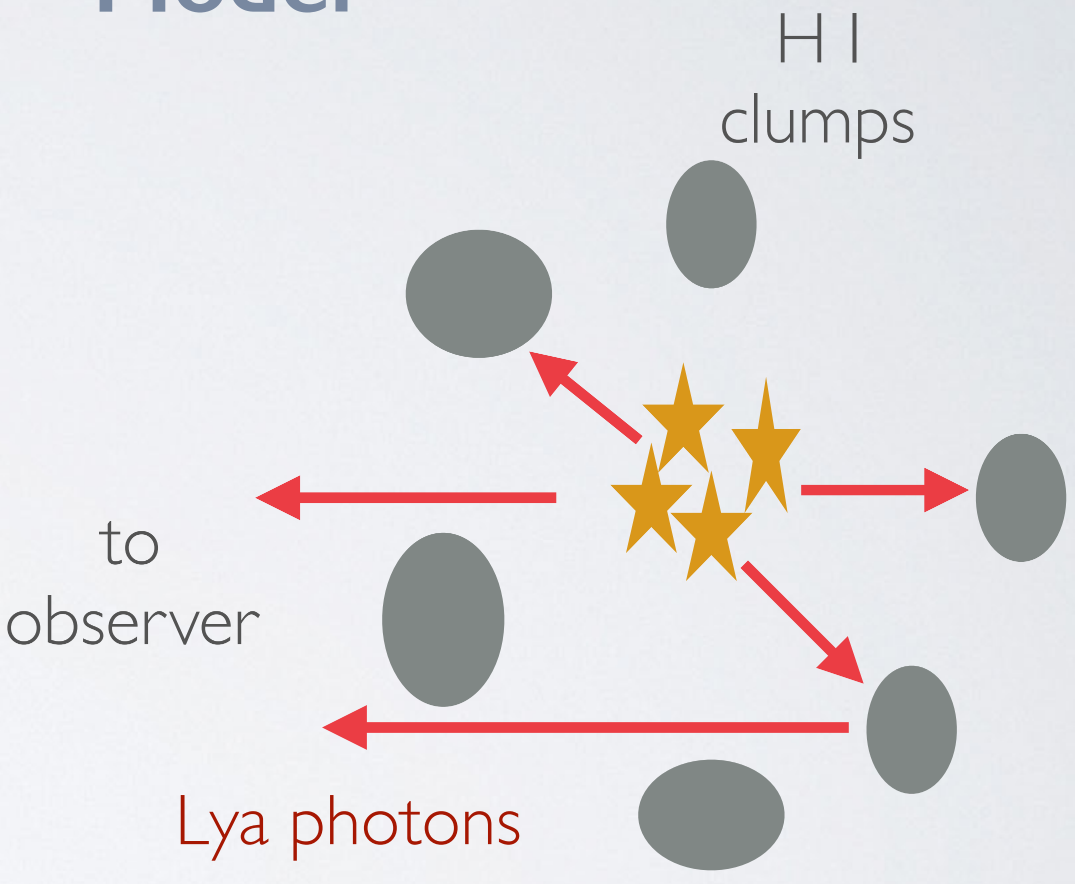
Data (z~3)





Shapley+03

Model



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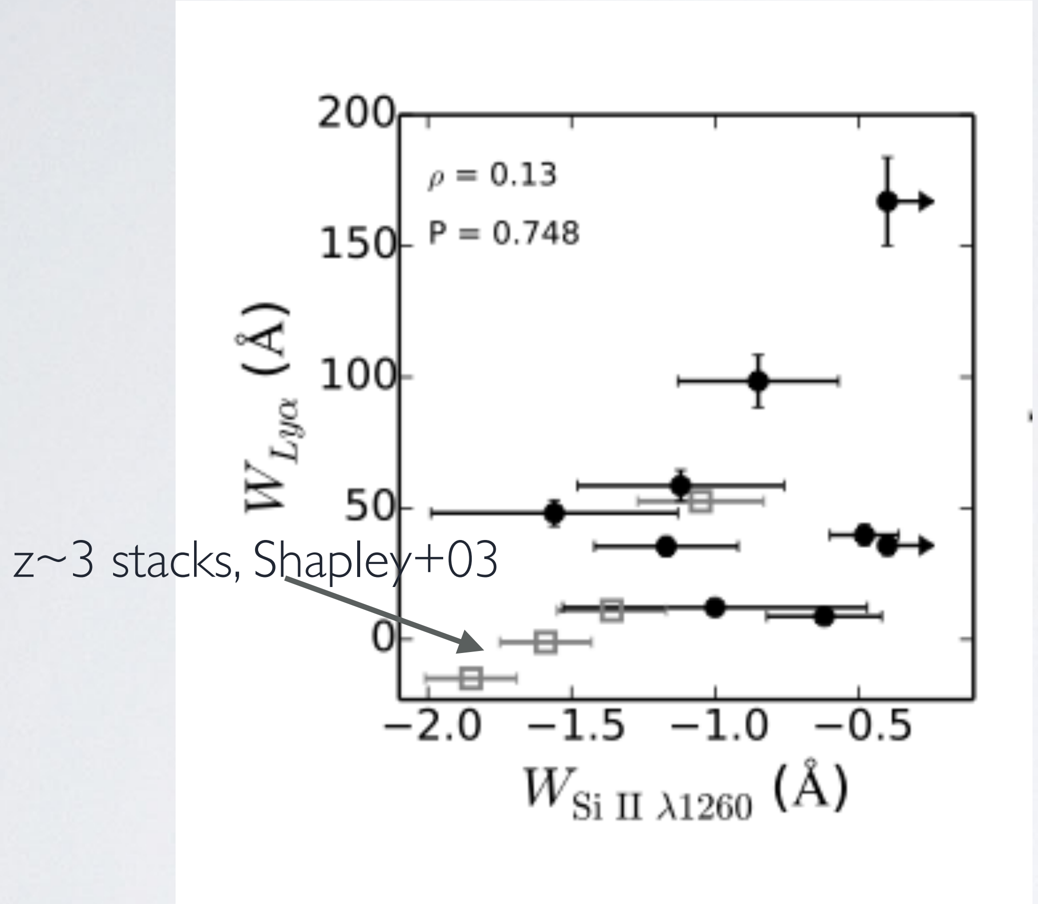

Henry et al. (2015)

- Consistent with high-z equivalent width trend…

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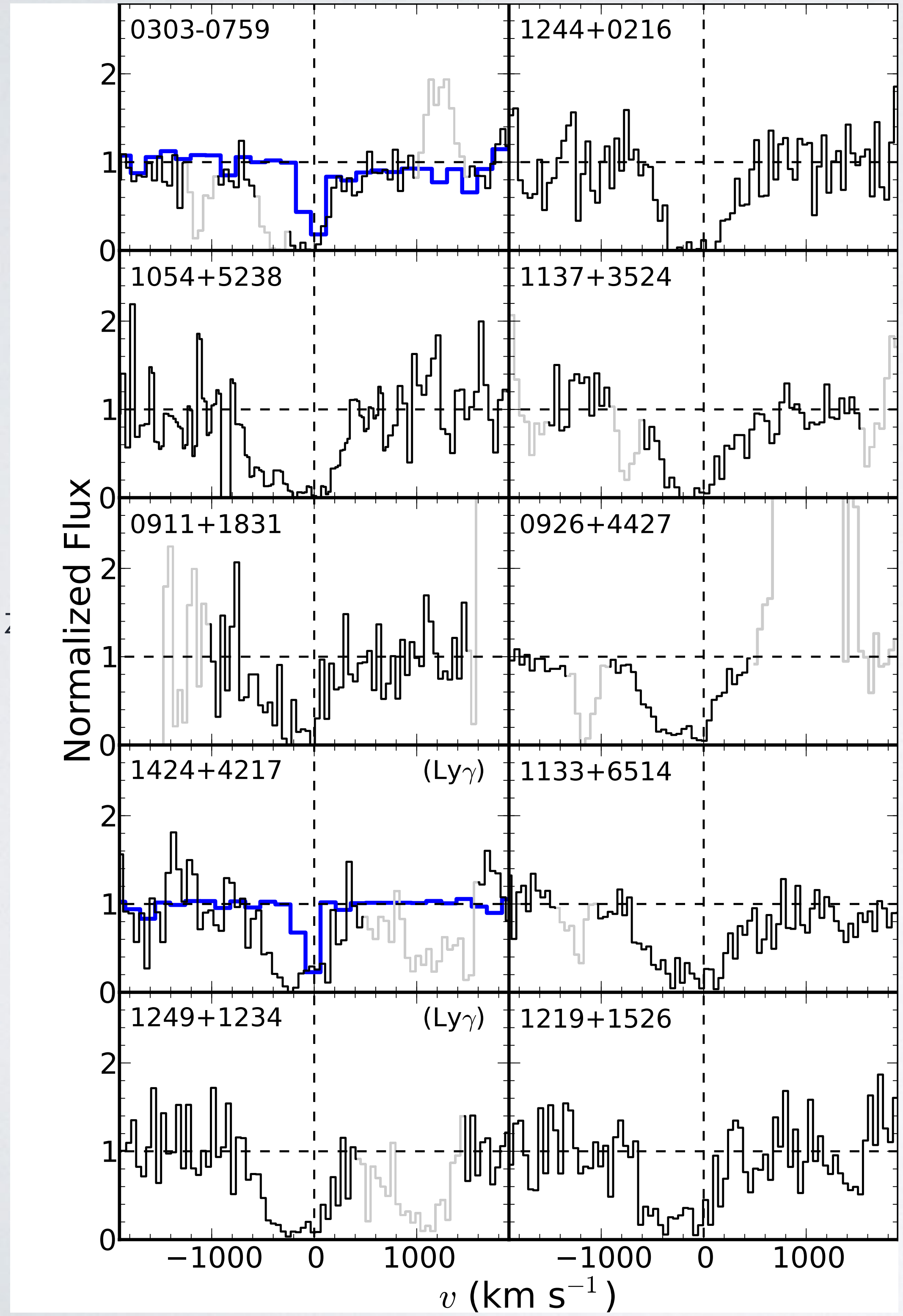
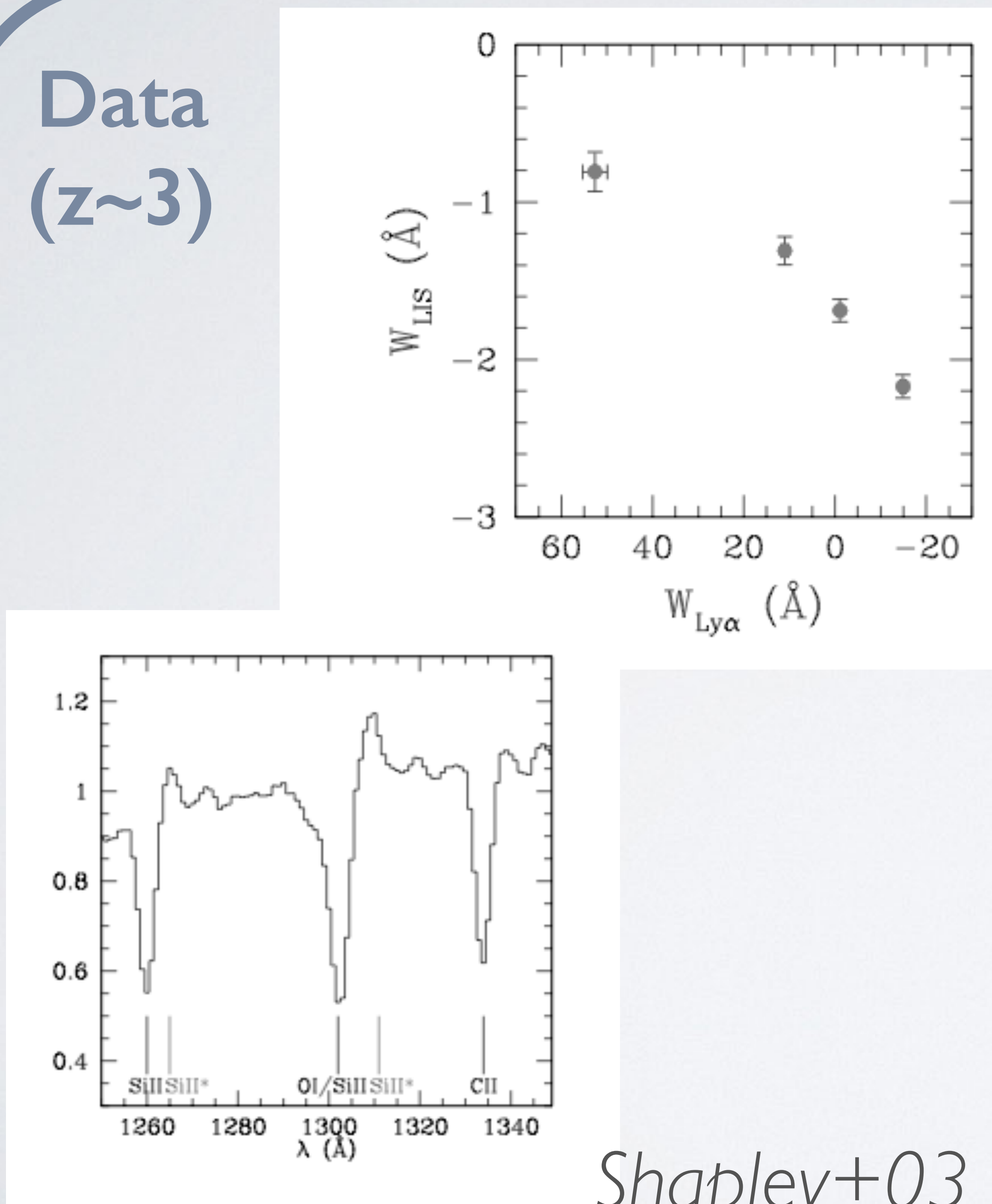


- Consistent with high-z equivalent width trend…
- <u>But</u>: COS spectra show Lyman series absorption is opaque → HI covering near unity

HI gas is everywhere.

Test 2: Does Lyα escape through holes in the HI gas?

Data (z~3)



Shapley+03

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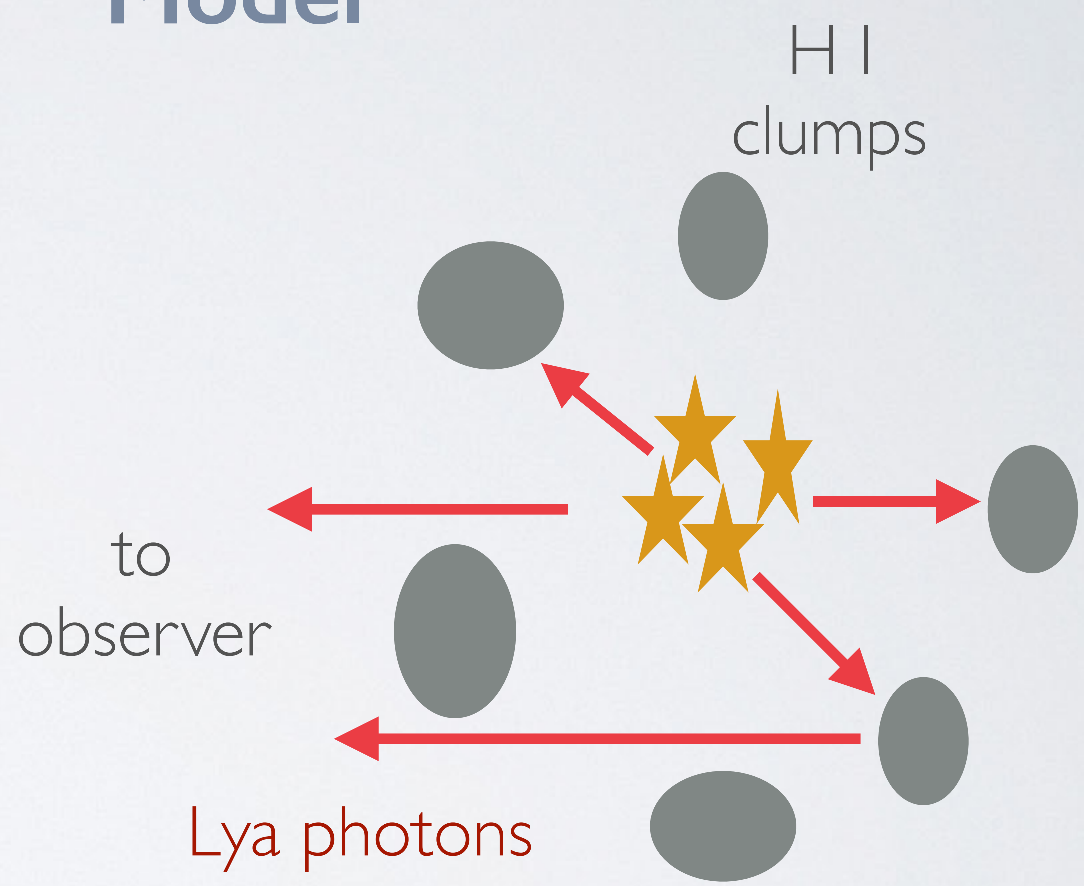

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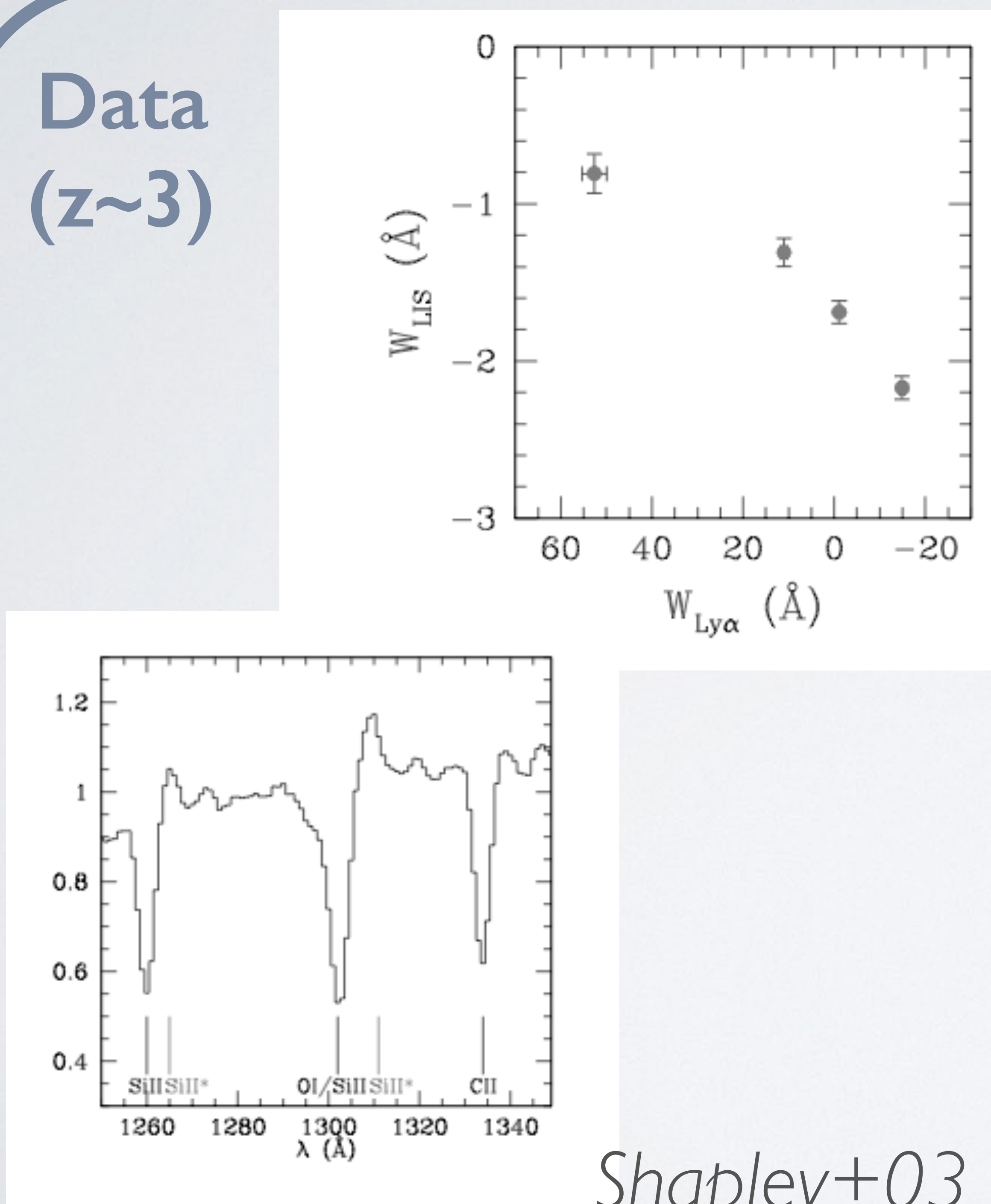

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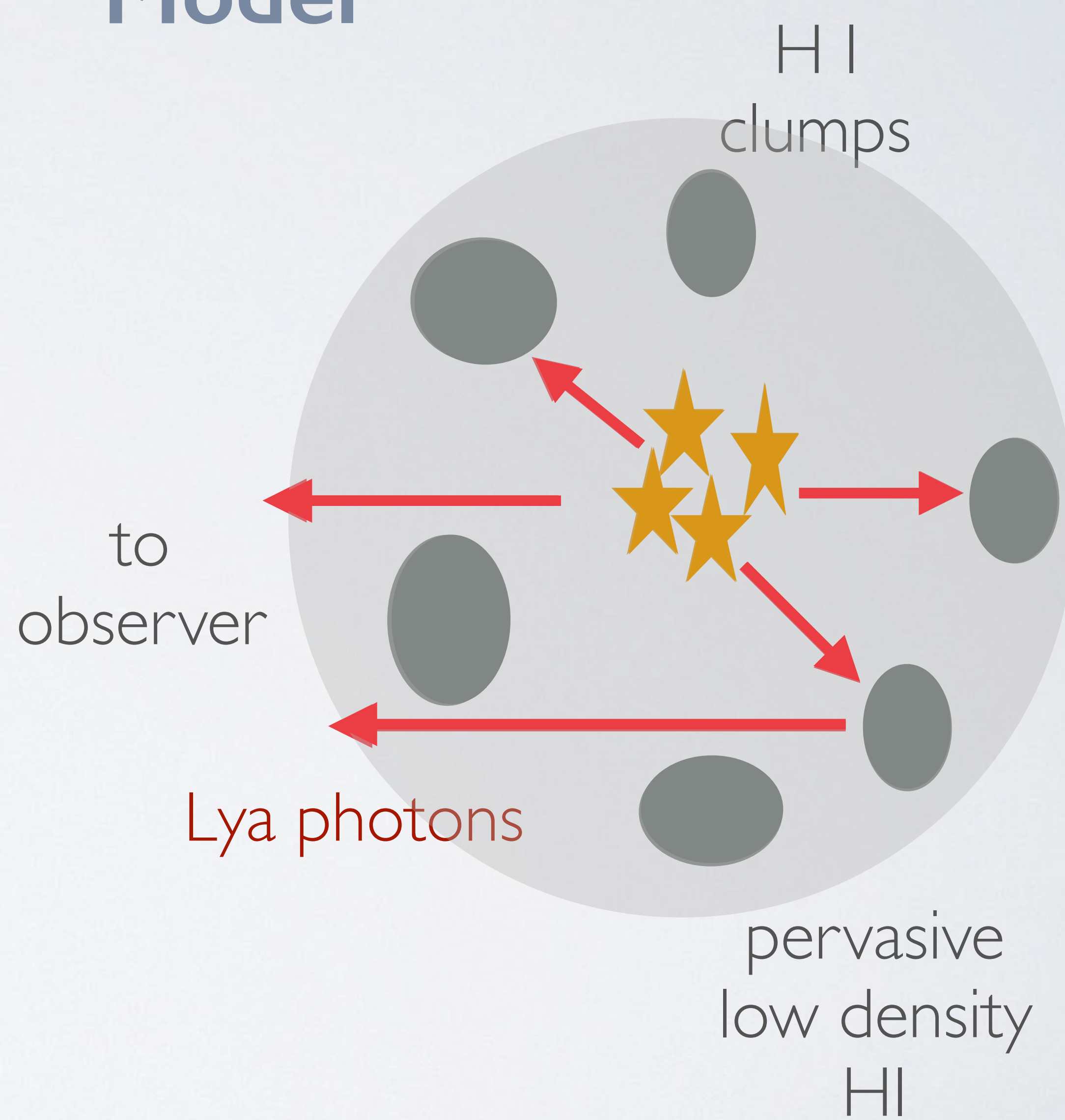

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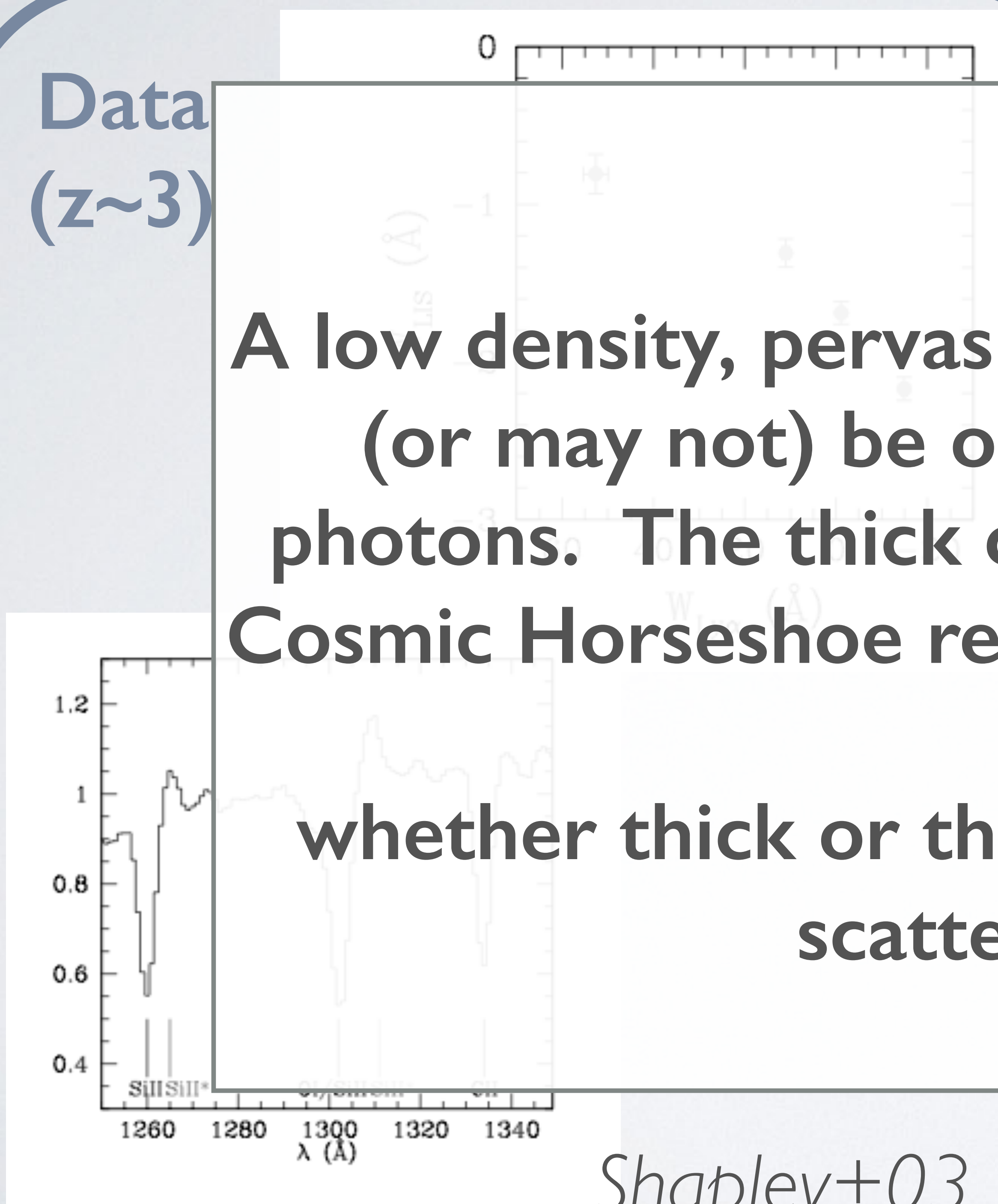

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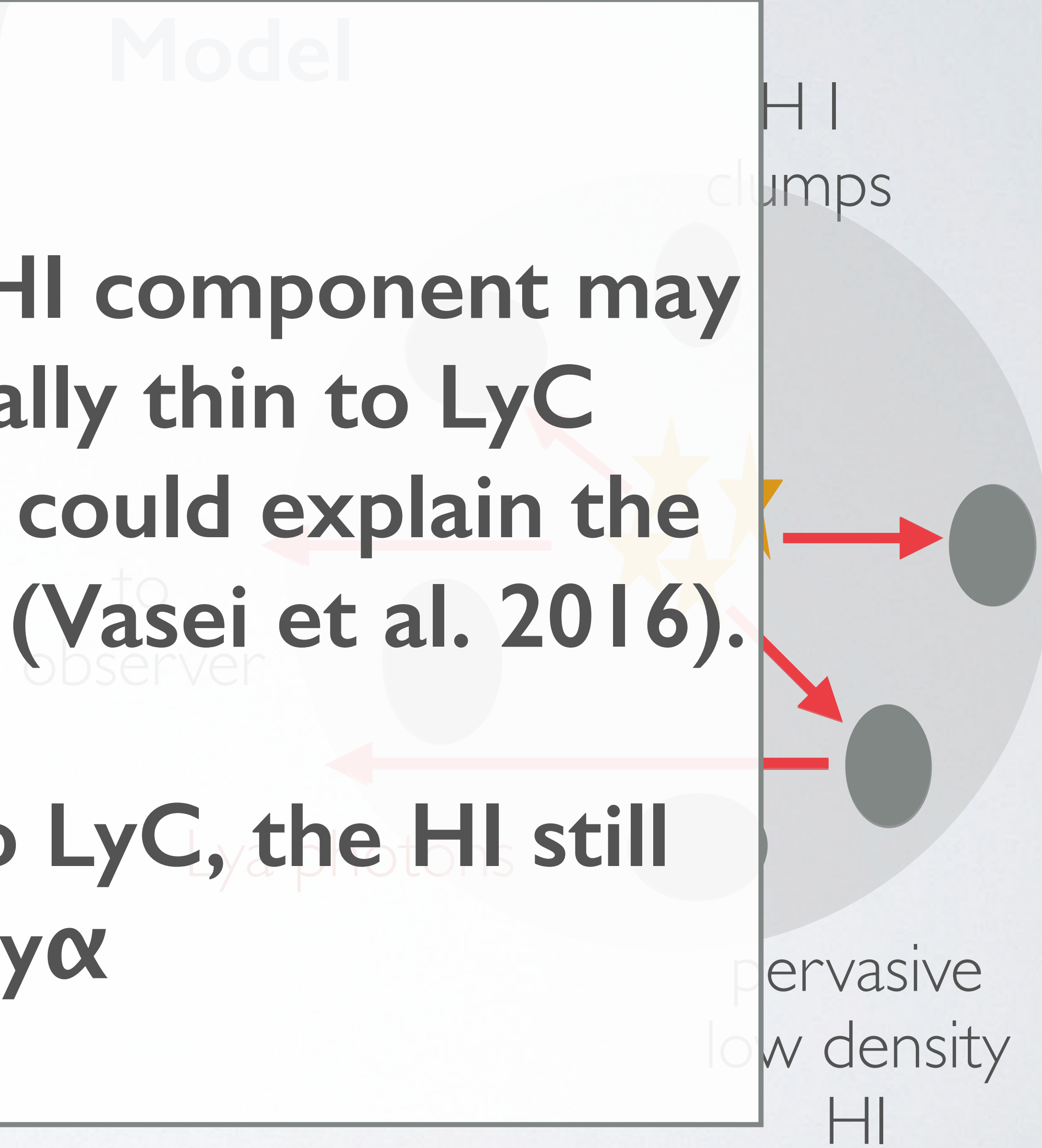


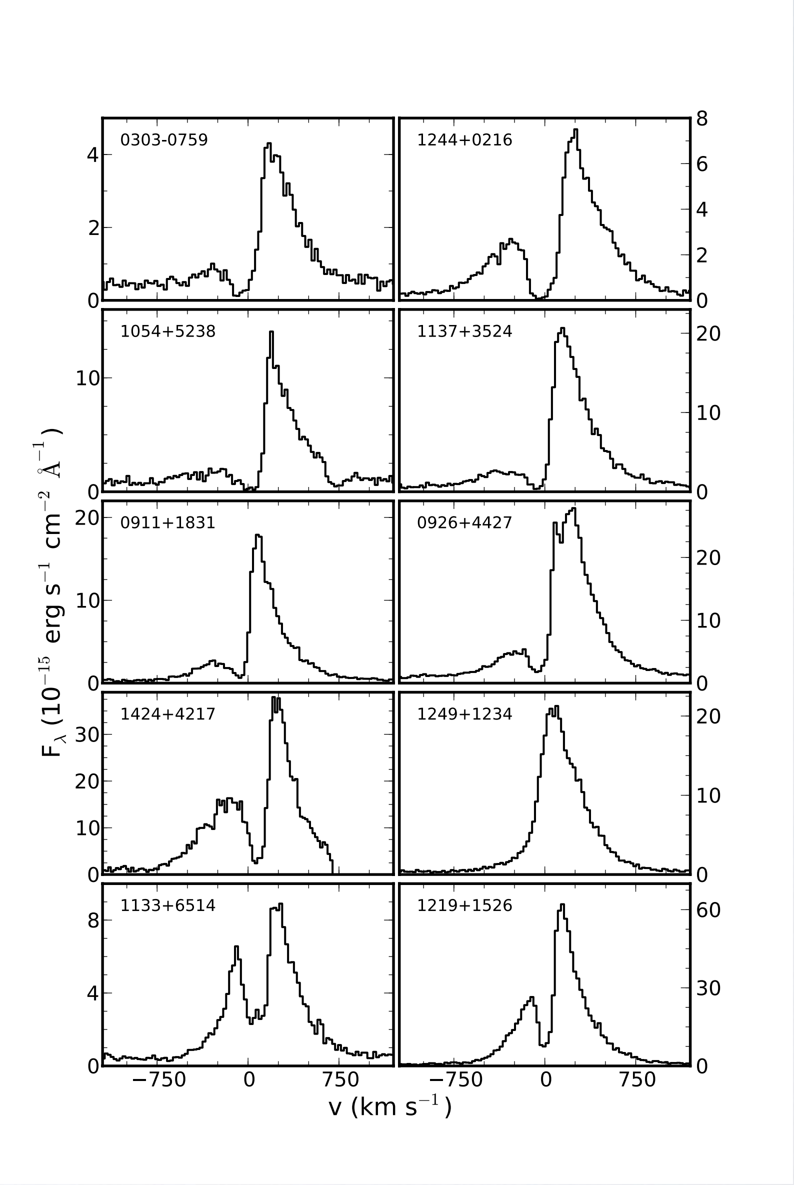
A low density, pervasive HI component may (or may not) be optically thin to LyC photons. The thick case could explain the Cosmic Horseshoe result (Vasei et al. 2016).

whether thick or thin to LyC, the HI still scatters Lyα

Test 3: HI gas density? (yes!)

- *Hypothesis*: Lyα escapes more easily when lower HI column density reduces the scattering. And Lyα can give us the HI column density!

Verhamme et al. (2015)



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Lyα velocity structure tells us about gas density more than outflow velocities.

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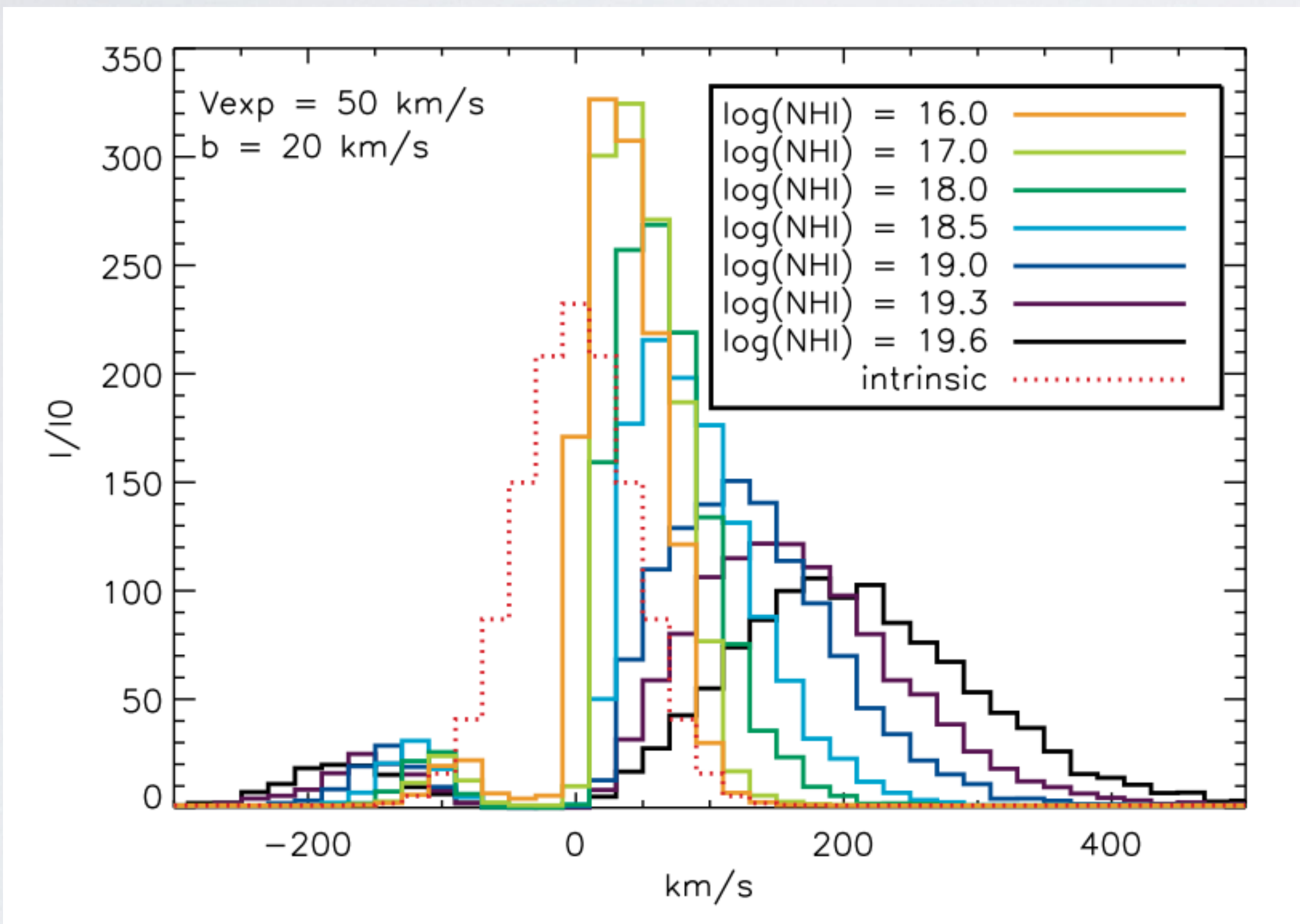

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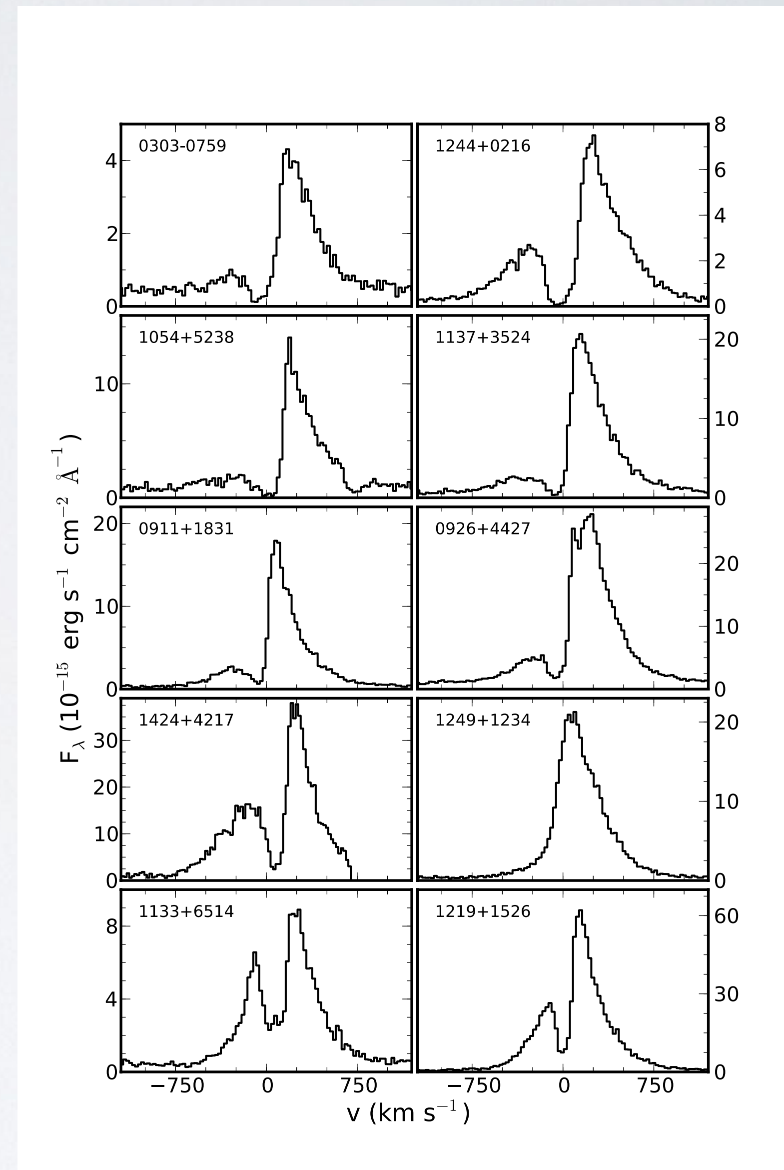

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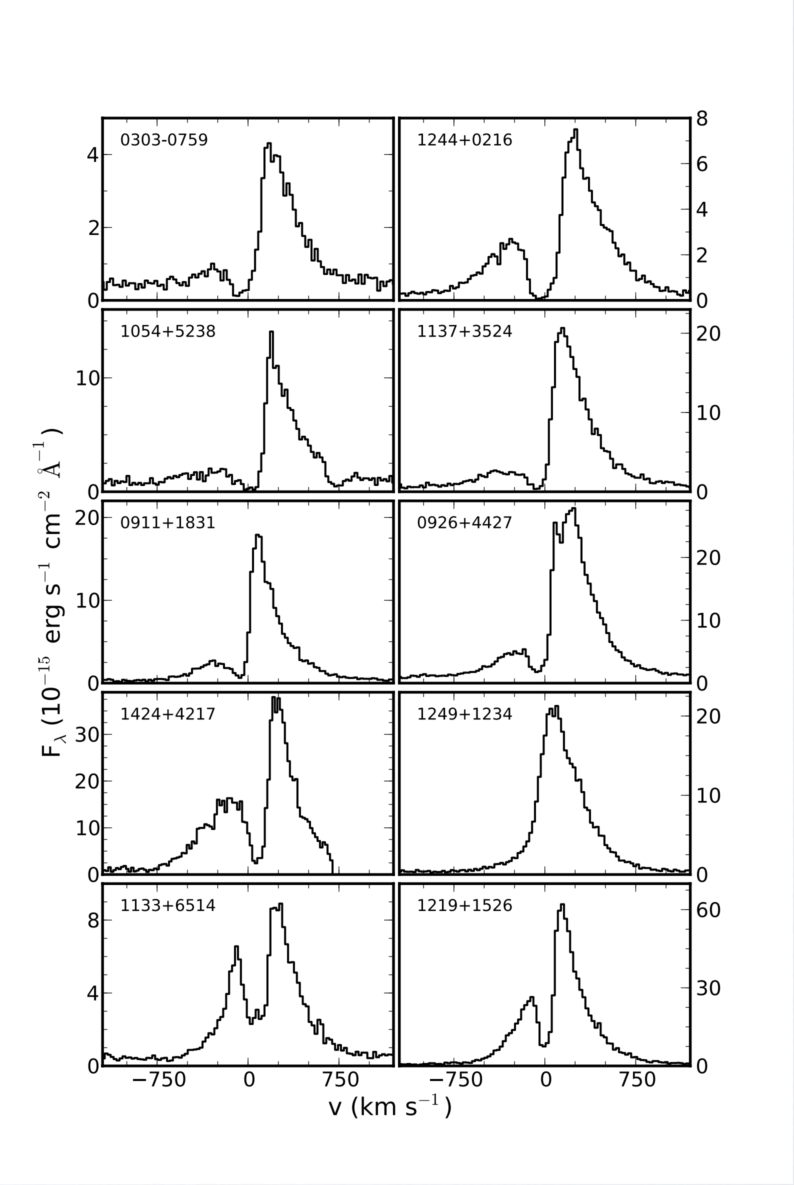

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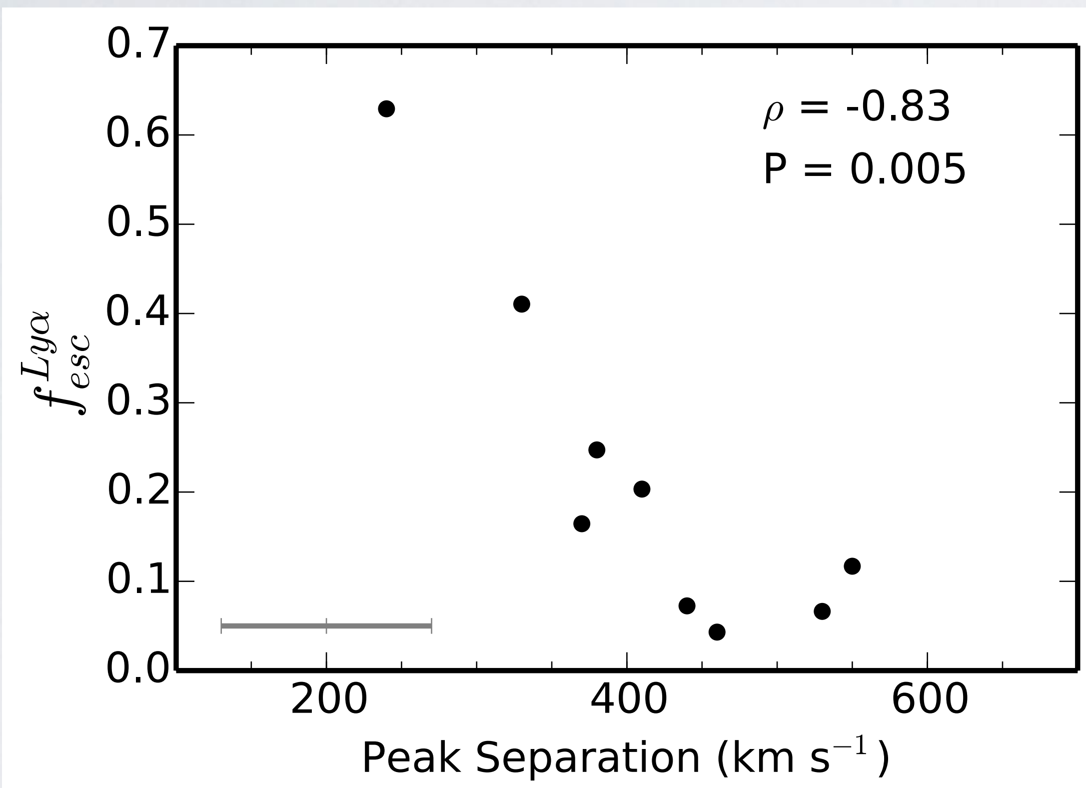
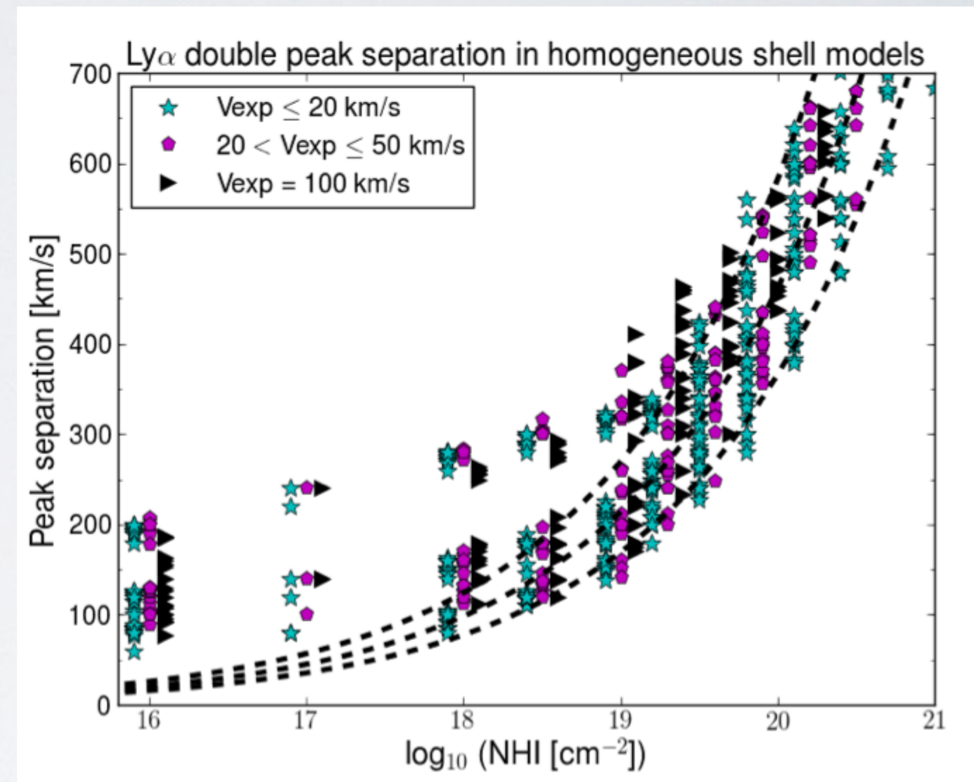


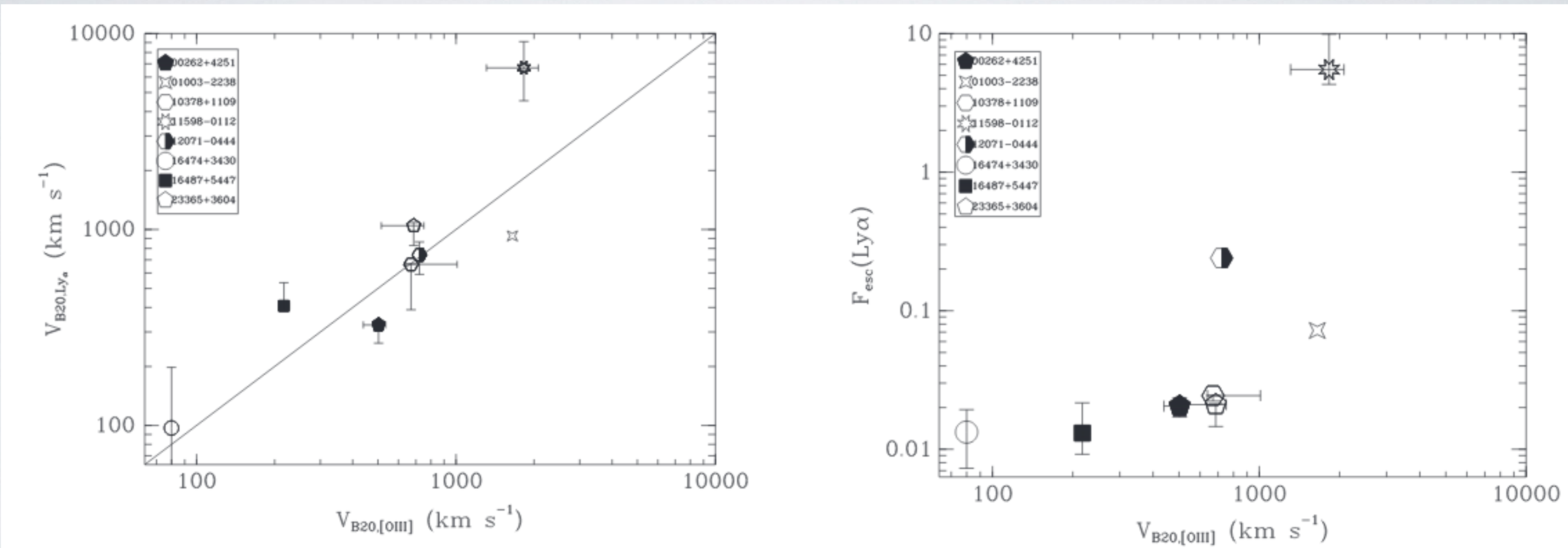
Henry et al. (2015)



Verhamme et al. (2015)

- Lyα peak velocity separation, correlates with the Lyα escape fraction, **implying that HI density determines Lyα escape.** **<u>Driven by blue peak.</u>**
- Also implies strong Lyα may indicate LyC leakage (e.g. Verhamme et al. 2015).

Caution: Ionized Emission at high velocities may also contribute



we already saw evidence of this in ULIRGs!
Martin et al. (2015), w/ AH

Caution: Ionized Emission at high velocities may also contribute

The Astrophysical Journal Letters, 791:L19 (6pp), 2014 August 20

Jaskot & Oey

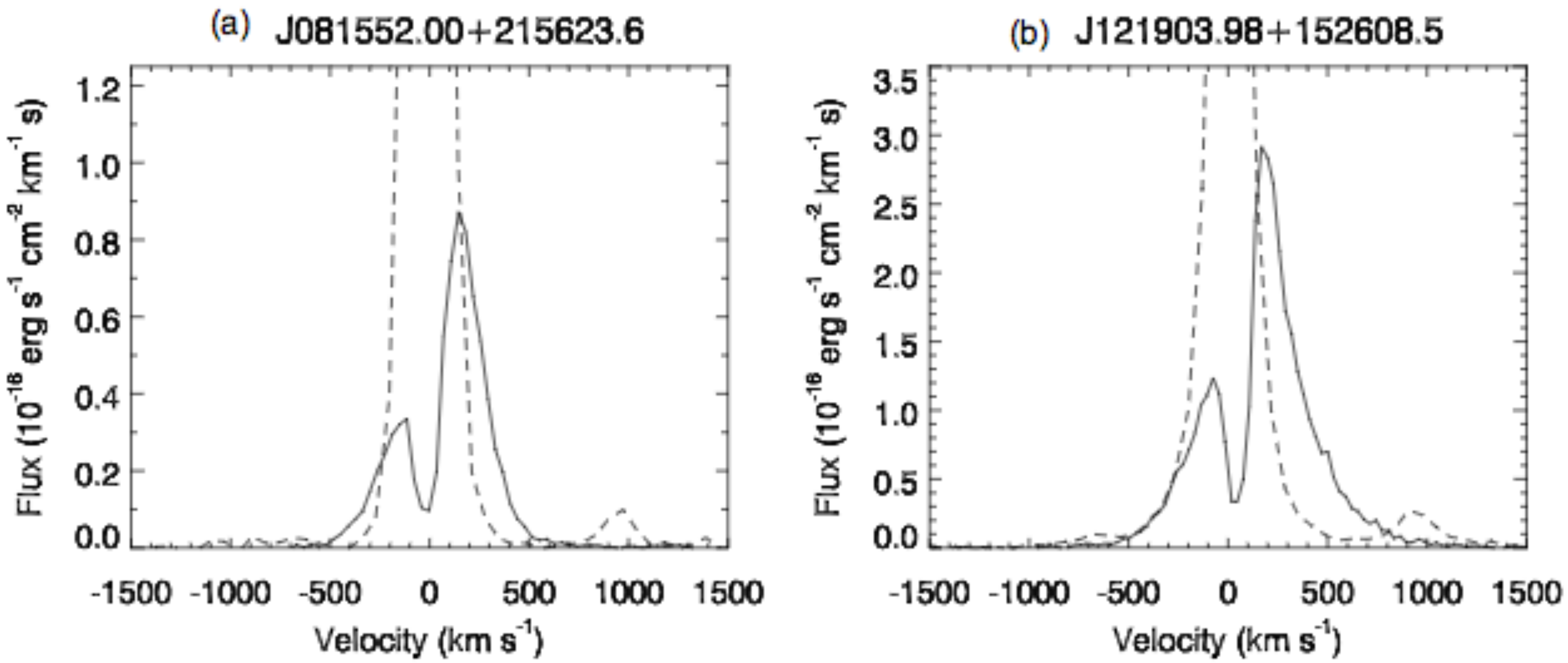


Figure 3. Solid lines show the Lyα emission for J0816+22 and J1219+15. Dashed lines show the Hα profiles from the SDSS spectra, scaled by a factor of 8.7 to approximate the intrinsic Lyα profiles. The [N II] lines appear as bumps near -700 and $+1000$ km s^{-1} .

Conclusions

- Escape regulated by:
  - dust (no)
  - H I covering (no)
  - resonant scattering in outflow (insufficient)
  - H I density (yes)
- H I:
  - everywhere — challenge to picket fence model (e.g. Jones et al. 2013; Heckman et al. 2015; Rivera-Thorsen et al. 2015; Vasei et al. 2016; talks by Oey & Verhamme)
  - low density — Lyα velocity structure can select LyC leakers (e.g Izotov et al. 2016, Nature)
- we have learned:
  - spectral resolution better than 100 km/s is ideal.
  - real variations in the metal lines erased by stacking high-z spectra.
  - significant Si II* and C II* scattered emission implies significant emission filling in absorption lines. Must be accounted for (e.g. Scarlata & Panagia 2015).
  - Observations of HI Lyman series absorption lines are critical.