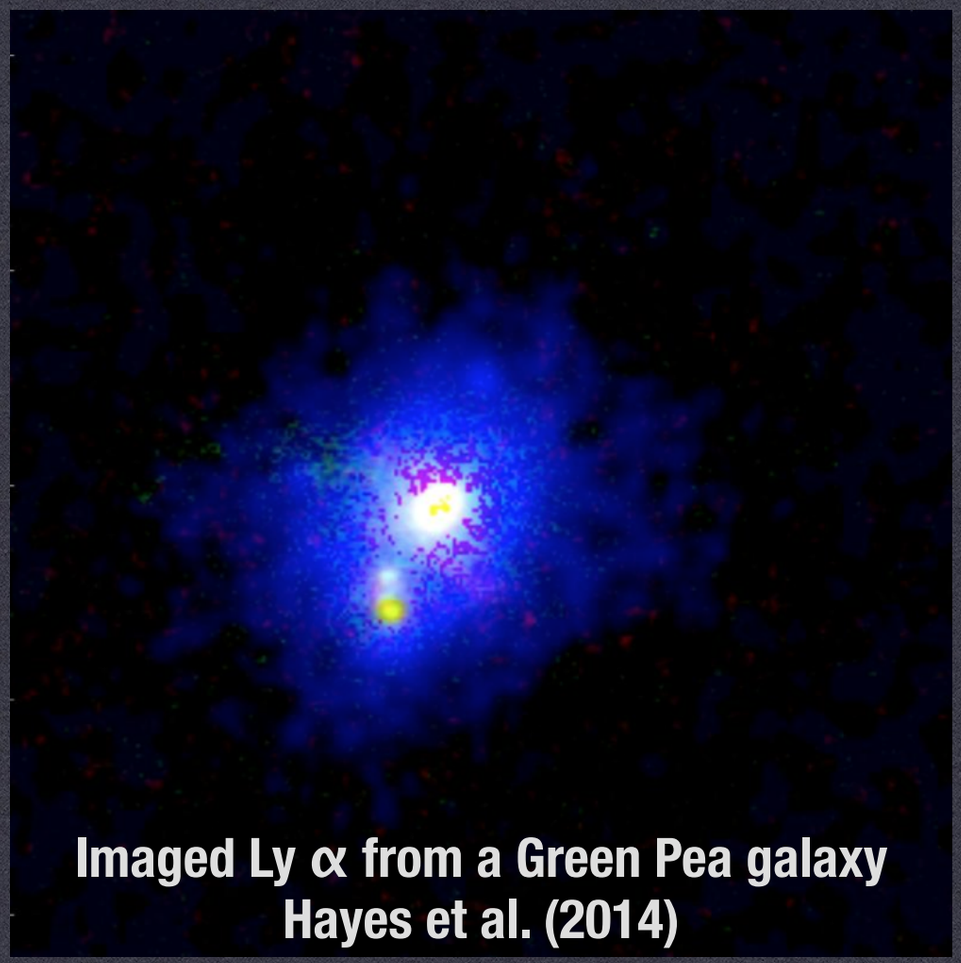
Lyman α Emission from Green Peas:

Circumgalactic gas density, covering, and kinematics



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

Alaina Henry

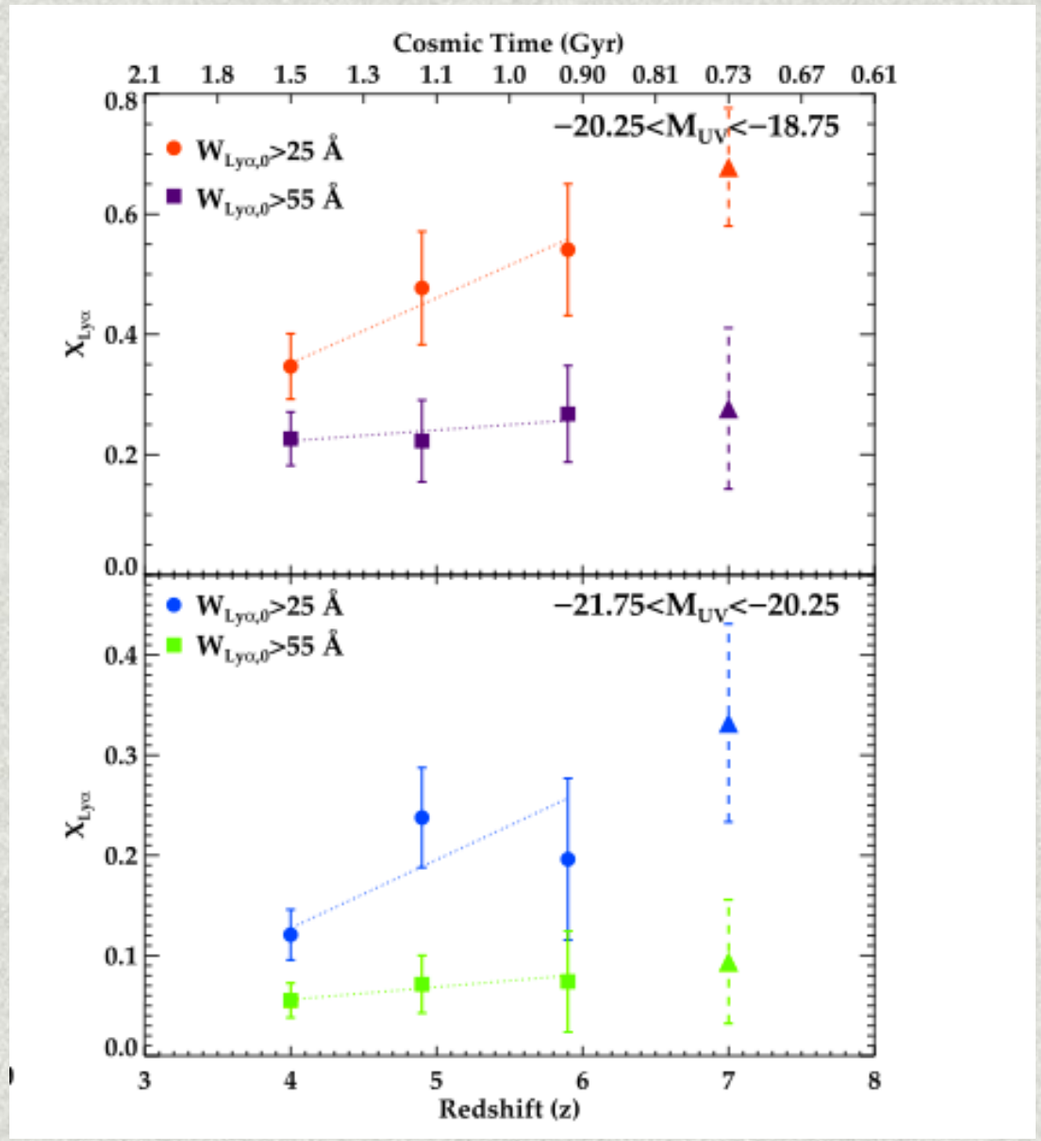
(NASA Postdoctoral Program Fellow, GSFC)

Claudia Scarlata (U Minnesota)
Dawn Erb (UW Milwaukee)
Crystal Martin (UCSB)

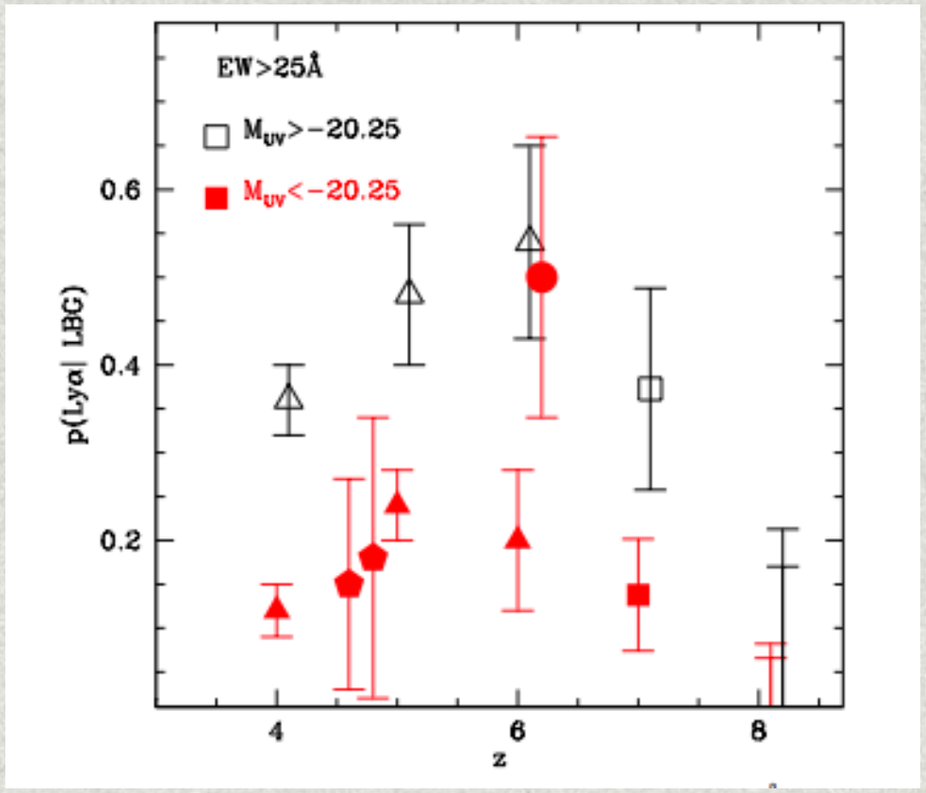
Why do we care about Ly**α** emission from galaxies?

- Ease of Observing:
  - can be the strongest line in the spectrum
  - Favorable rest-UV wavelengths (== ground observable with TMT to very high-z)
- Contains a wealth of information about galaxies, ISM, CGM, IGM gas!
- Even in the era of JWST/NIRSPEC (i.e. Hα obs), *Lyα is still going to be useful*

Wealth of Information from Lyα #1: IGM neutral fraction?



Stark et al. (2011)

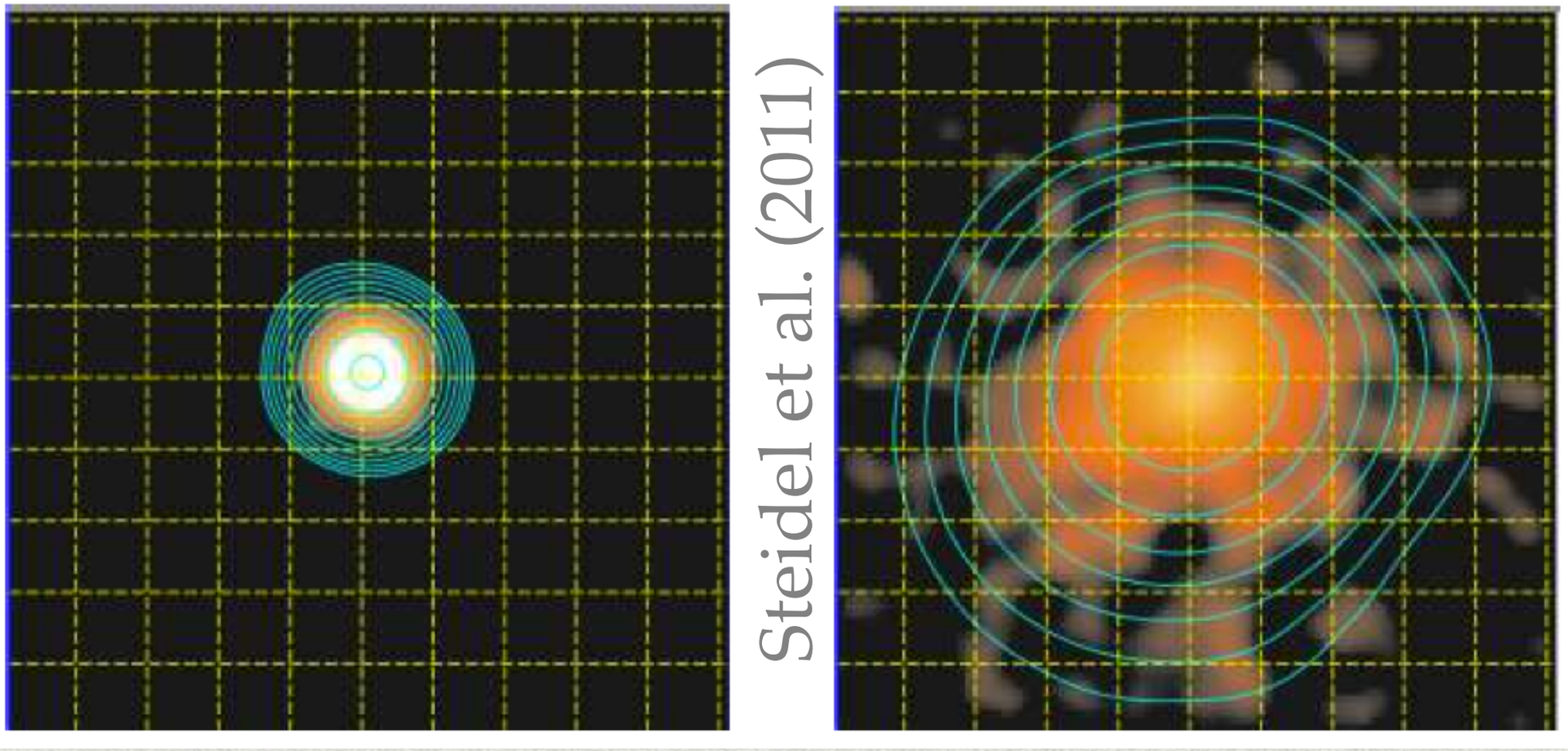


Treu et al. (2013)

Lyα deficit at z>6 suggests partially neutral IGM. **But what is the fiducial for measuring a deficit?**

Wealth of Information from Lyα #2: Illuminates HI in the CGM…

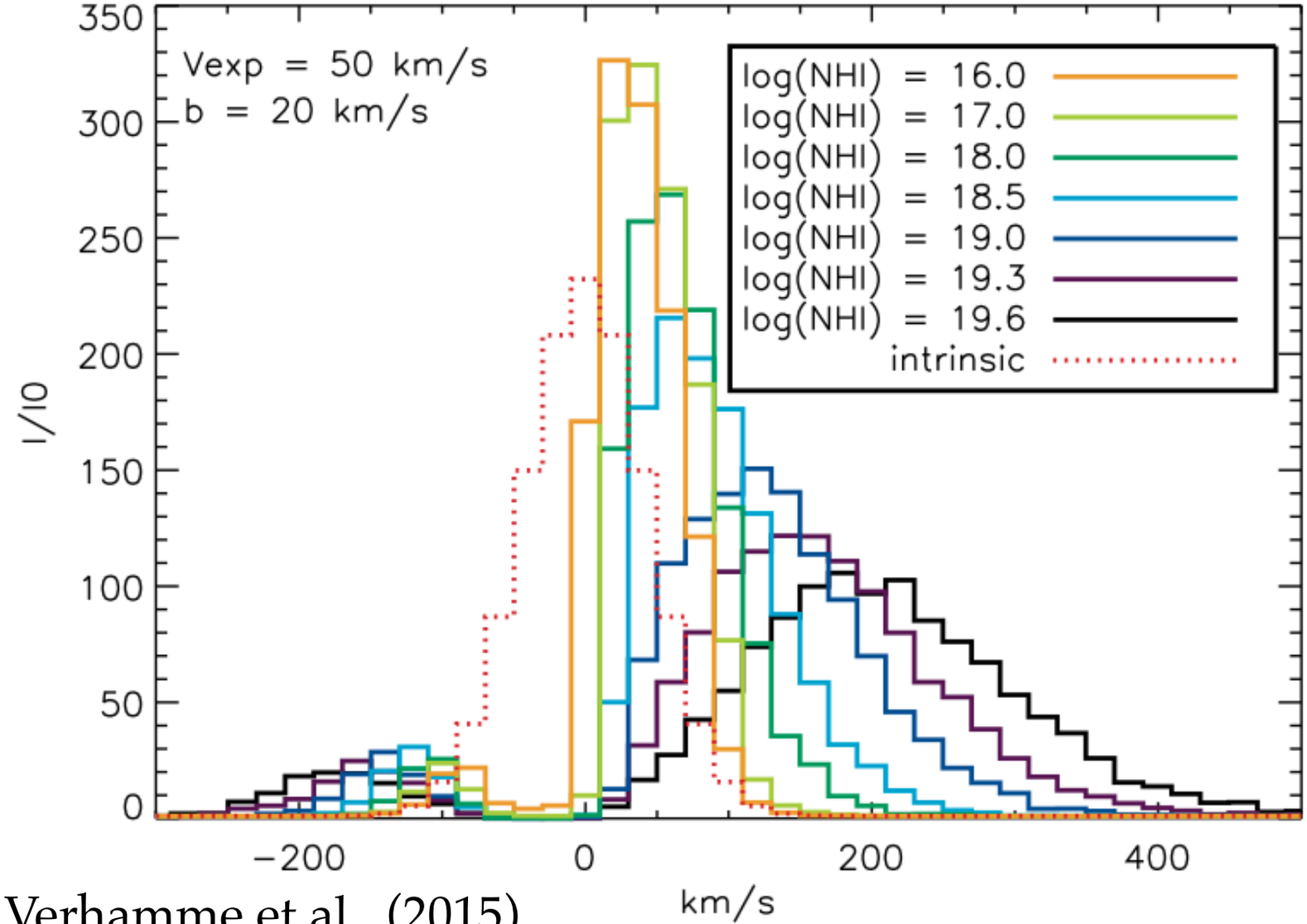
~100 kpc



Stellar Continuum

Lyα

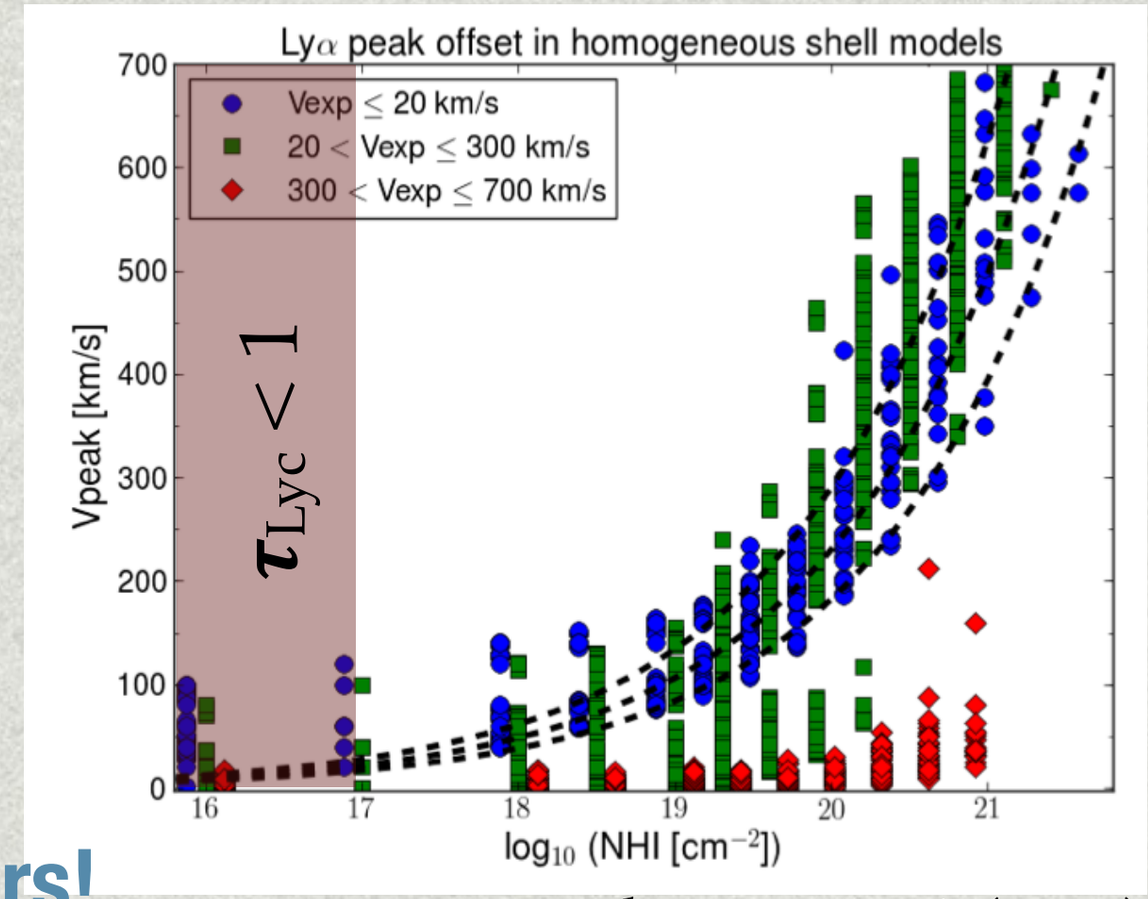
Wealth of Information from Lyα #2: Illuminates HI in the CGM…



Verhamme et al. (2015)

… plus constrains CGM properties

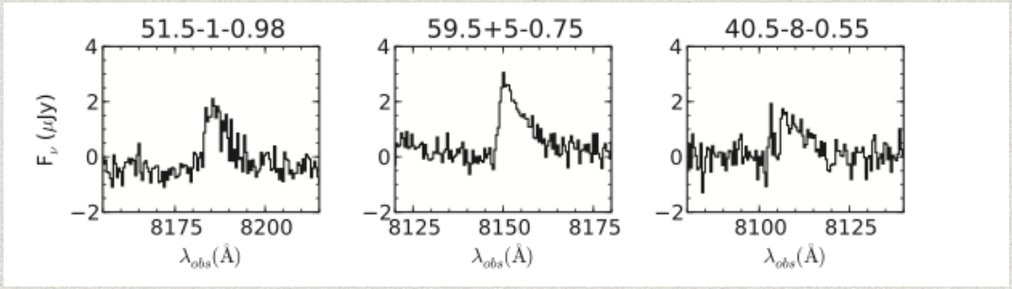
Wealth of Information from Lyα #2: Illuminates HI in the CGM…



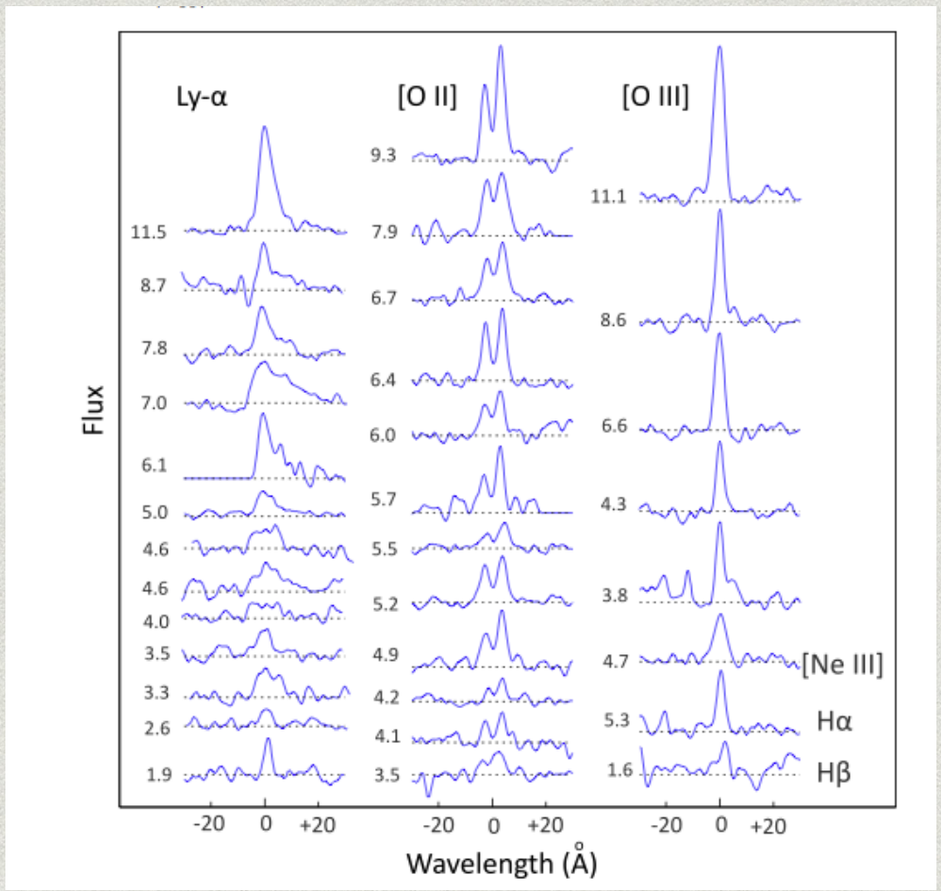
Verhamme et al. (2015)

…and may identify LyC leakers!

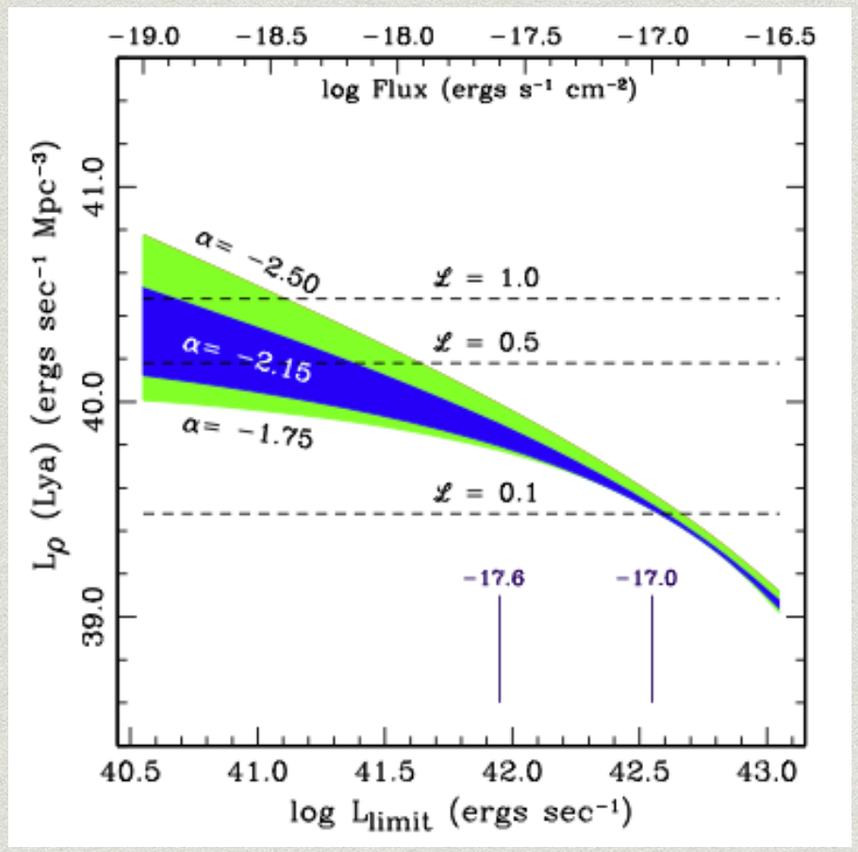
But Lyα at high-redshifts is *difficult!*



Henry et al. (2012)



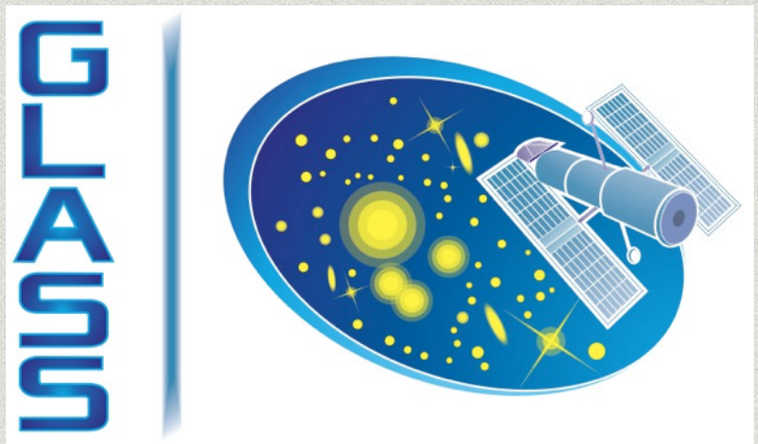
Dressler et al. (2015)



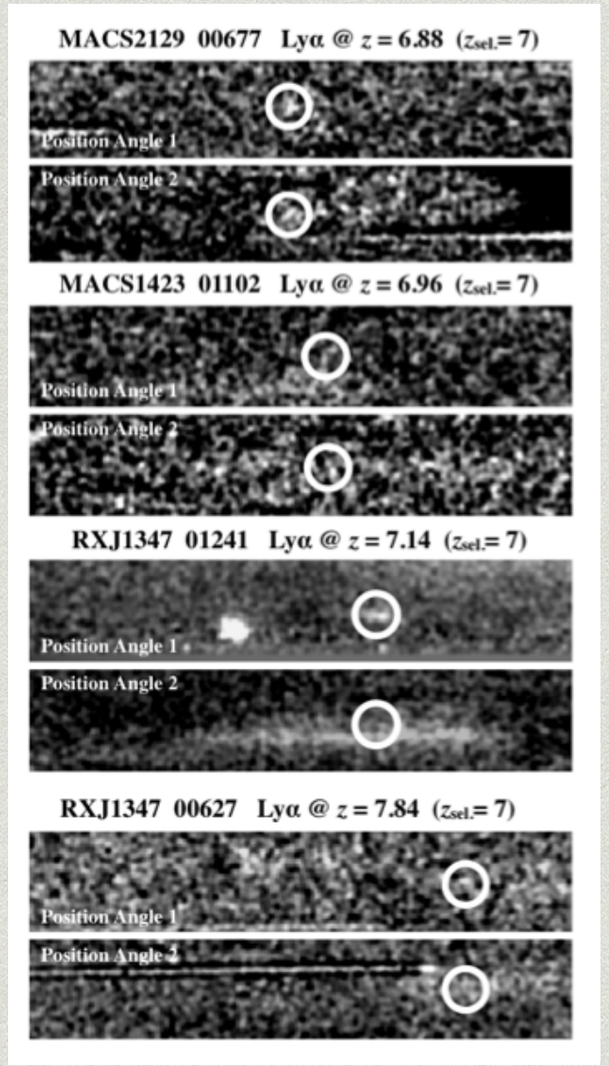
Dressler et al. (2015)

Several years and around 20 LAEs later… we've now measured the faint-end slope of the Lyα LF at the end of reionization.

And Lyα detections during reionization (z~7-8)?



HST grism survey of 10 strong lensing clusters (from CLASH + Frontier Fields)



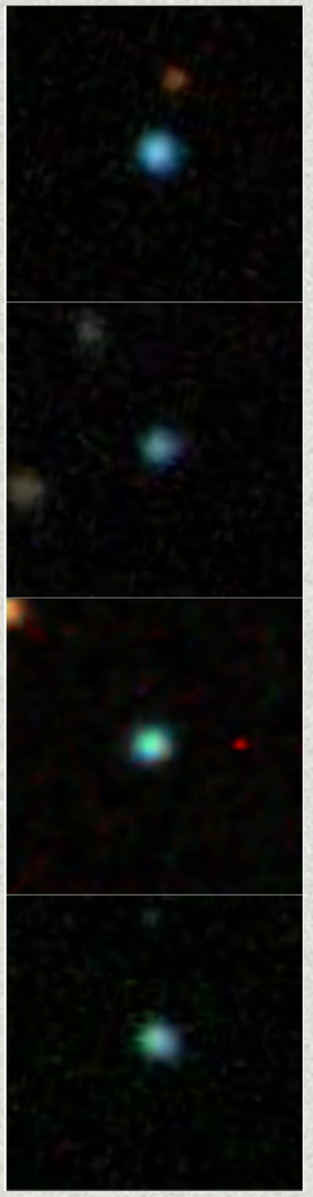
Schmidt et al. (incl AH, TBS)

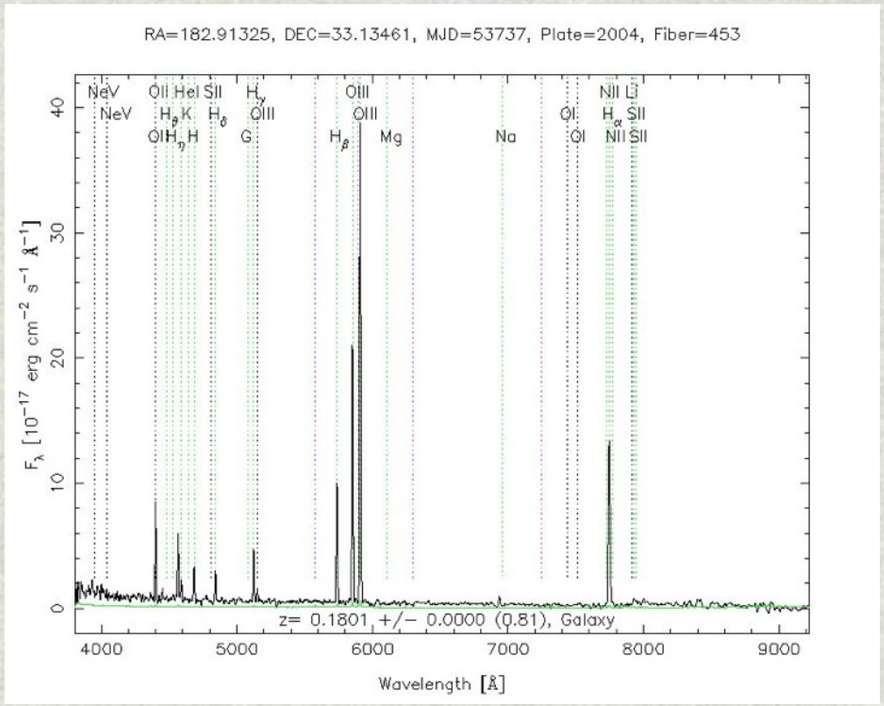
The data are going to get better with TMT and JWST….
but we have to get smarter about Lyα

Addressing Lyα output using local laboratories

“Green Peas” are great local analogs!

Lower metallicity, higher EWs and sSFR than most other nearby samples

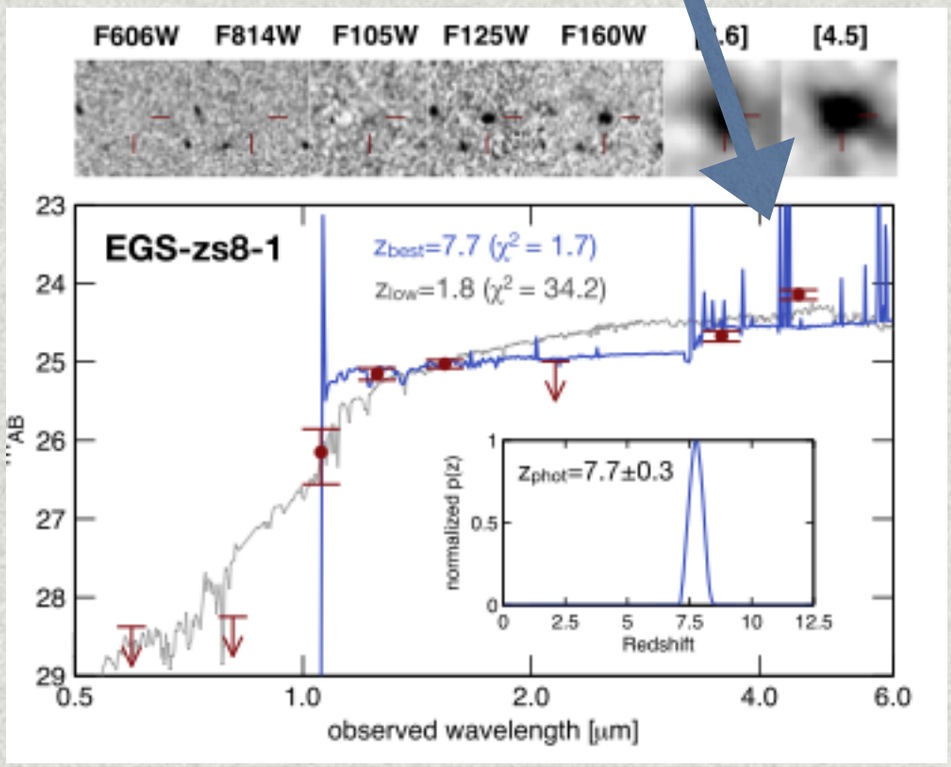




z~0.2

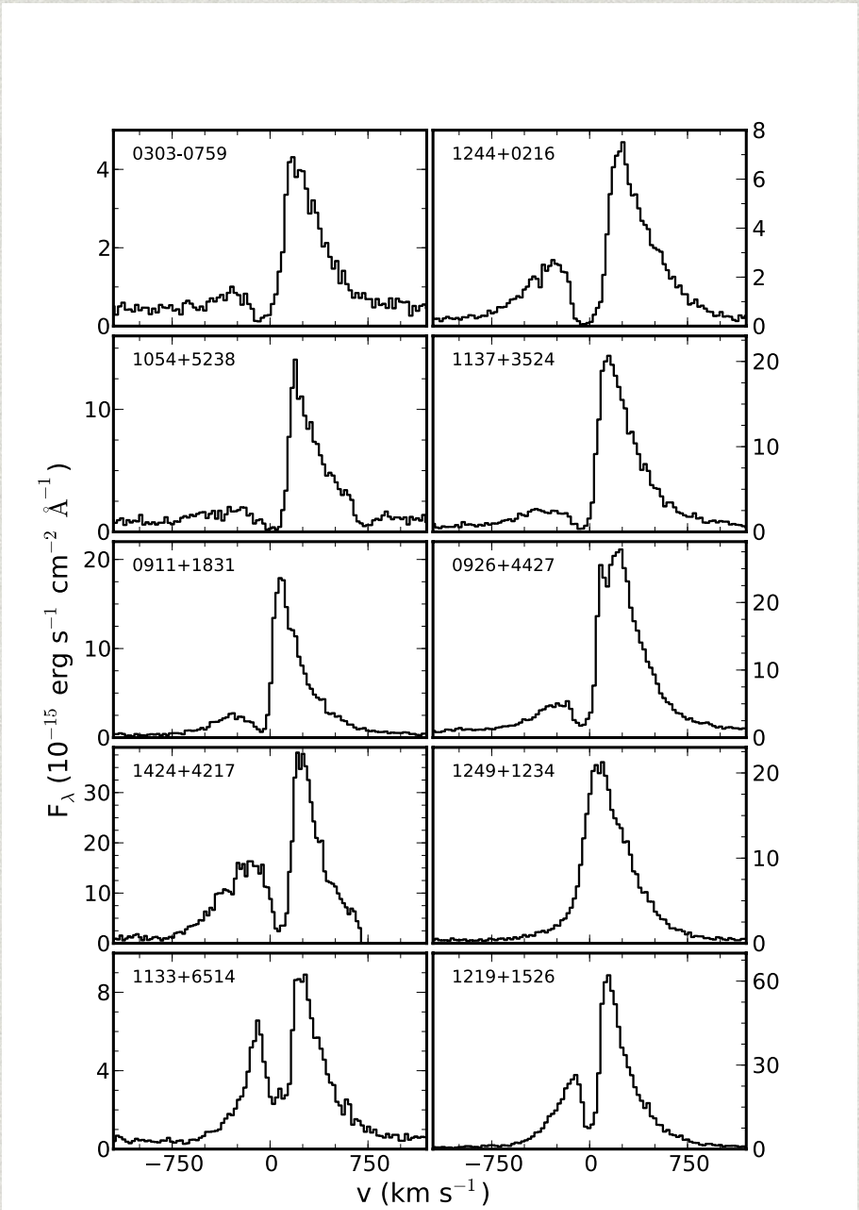
note: SDSS at low-z still much better than MOSFIRE at intermediate-z

strong lines!
W([OIII]+Hb)~700 A



z~8 (Oesch et al. 2015)

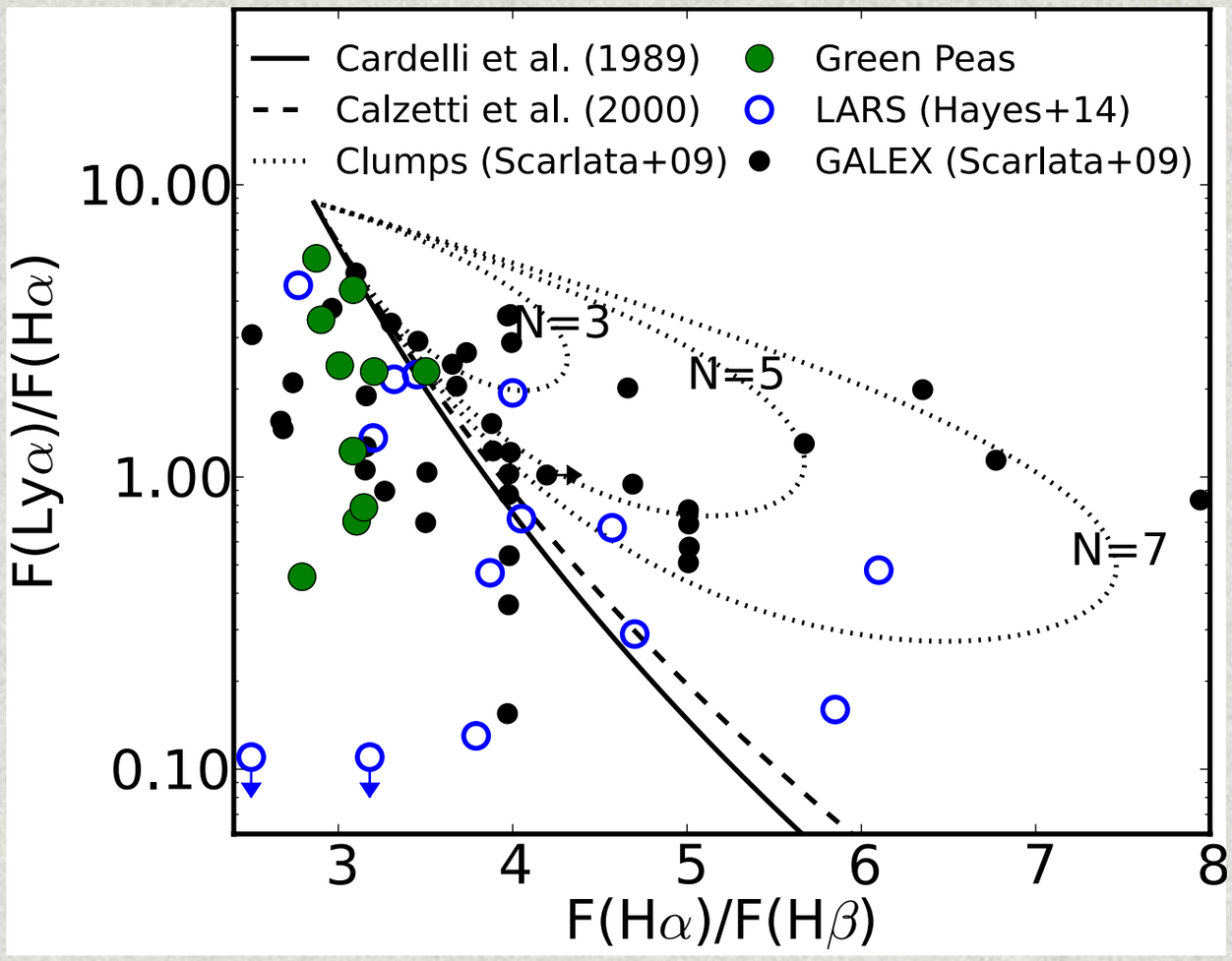
COS Lyα Spectra of Green Peas



- 9/10 double peaked when we observe with high spectral resolution
- Lyα has higher EW, luminosity than other nearby galaxies
- more comparable to LAEs at z >~3

Henry et al. (2015, in press)

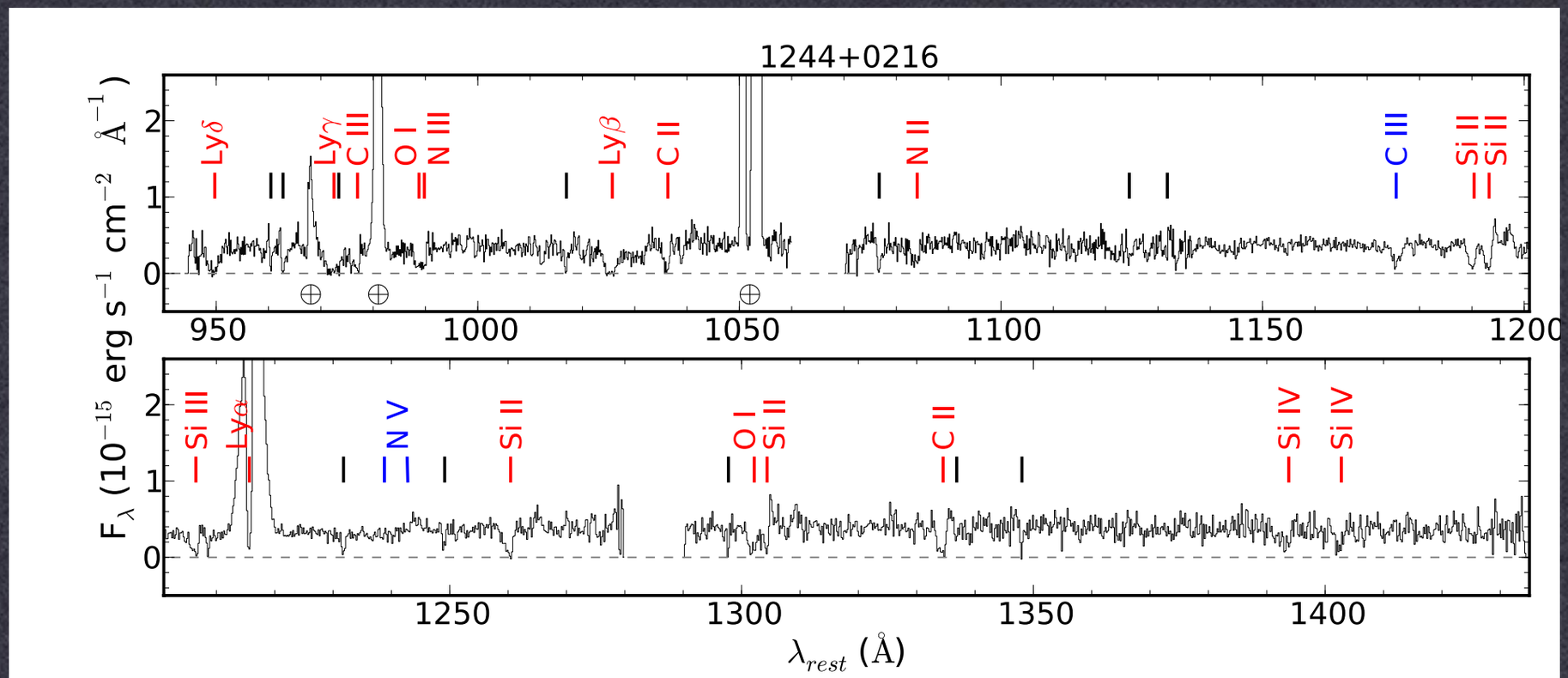
Still, only a fraction of the Lyα photons are escaping



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

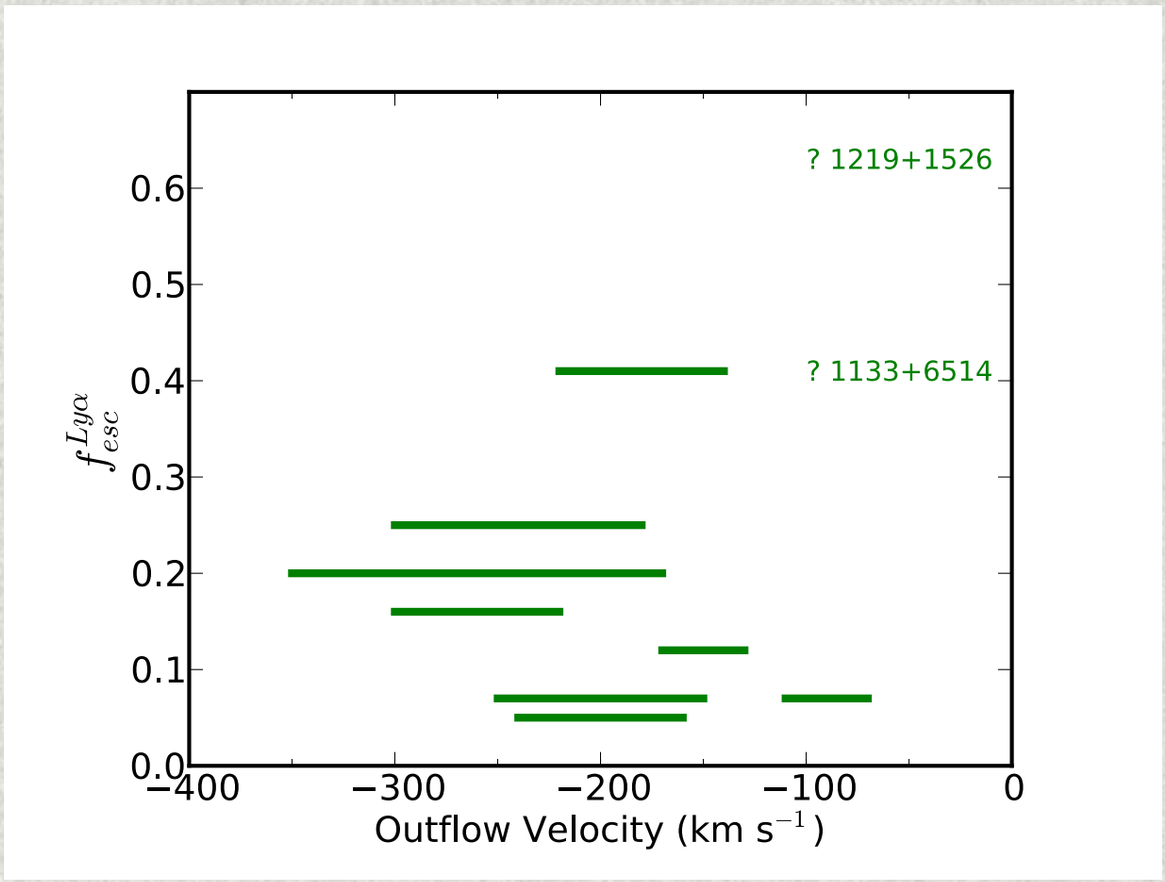
Henry et al. (in press)

What is causing the variation in Ly α in these galaxies?



Maybe the UV absorption lines can help us….

Do outflows help Lyα escape?

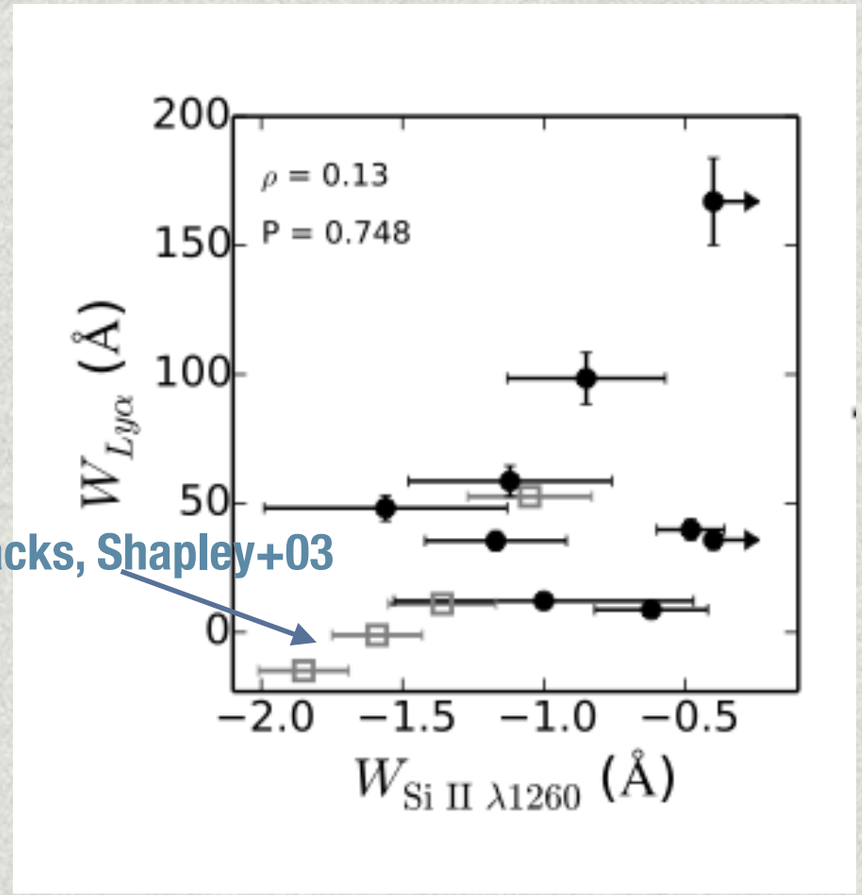


Henry et al. (2015, in press)

- *Hypothesis*: Lyα escapes by scattering in outflowing HI gas, shifting out of resonance with the ISM (e.g Kunth et al. 1998).
- *Result:* While the Green Peas all show Lyα and outflows, there is no correlation between the two.

Does Lyα get out through holes?

- *Hypothesis*: Lyα escapes through sight-lines that are empty of neutral gas



Henry et al. (in press)

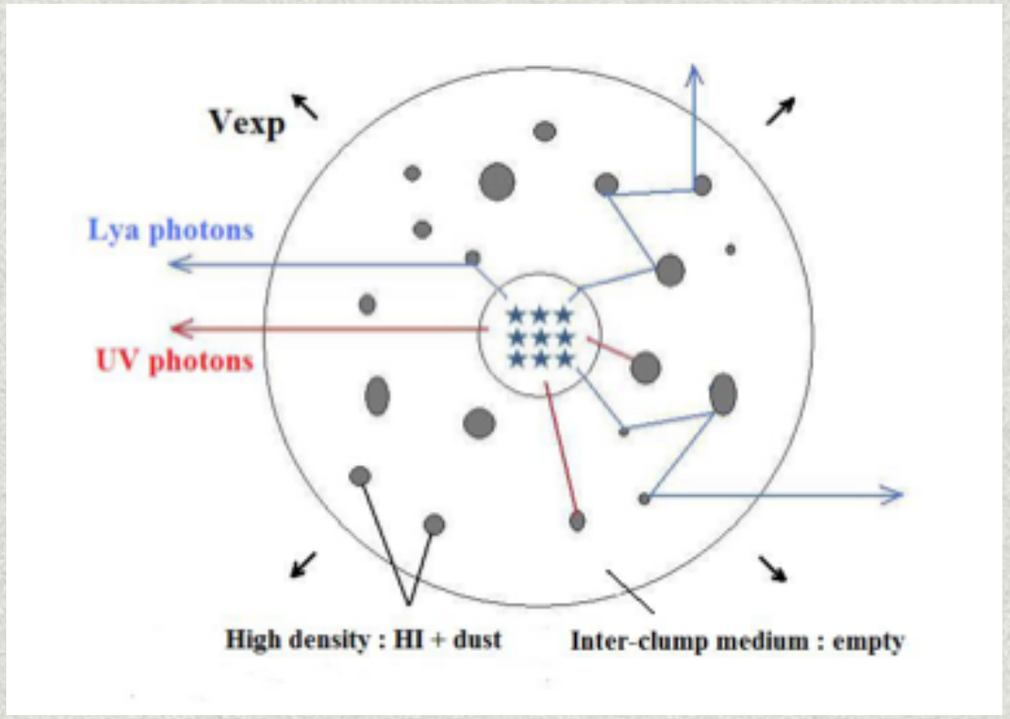
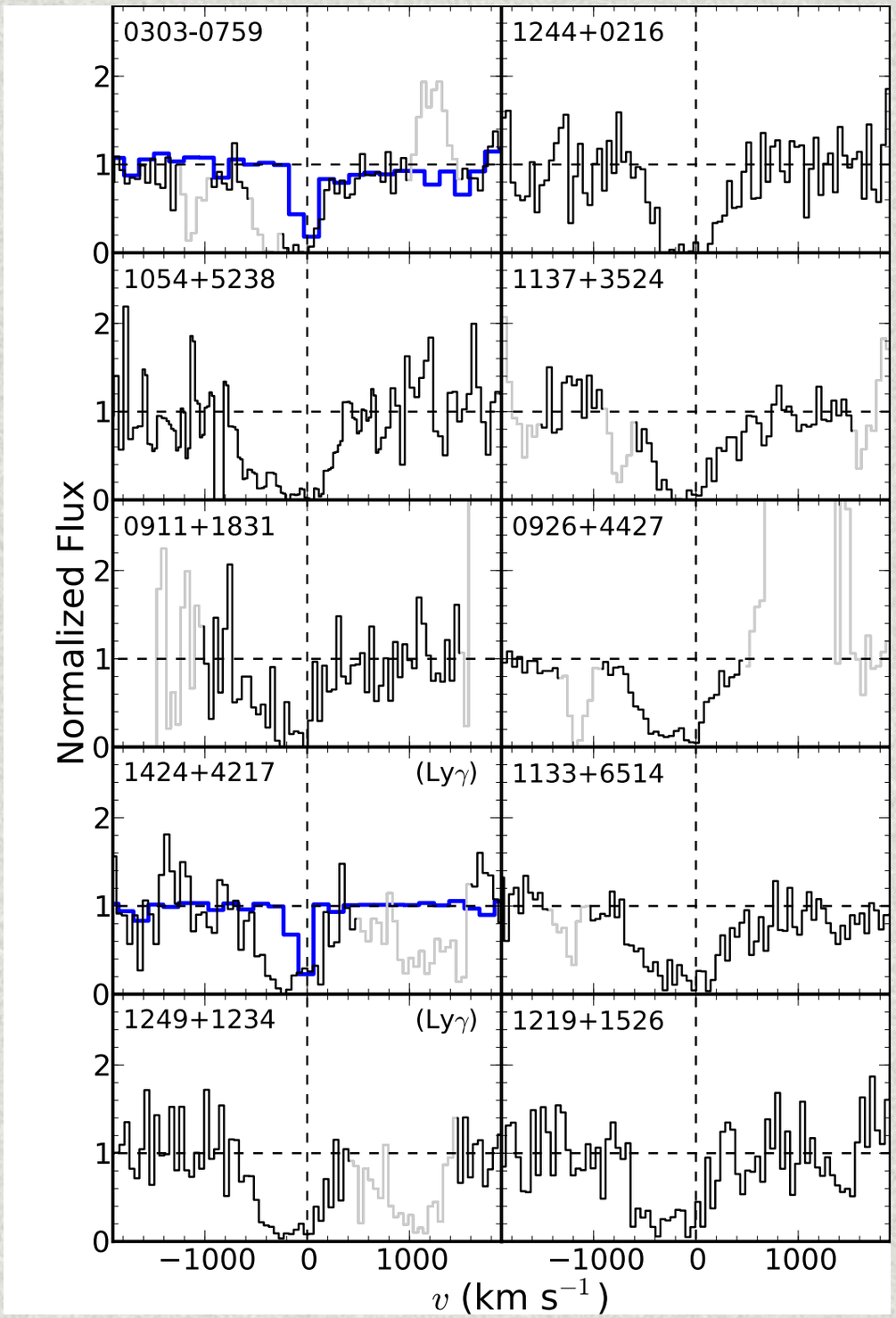


Fig from: Duval et al. (2014)

- *Supported:* By correlation between EW of saturated low ionization absorption and Lyα emission

Does Lyα get out through holes?



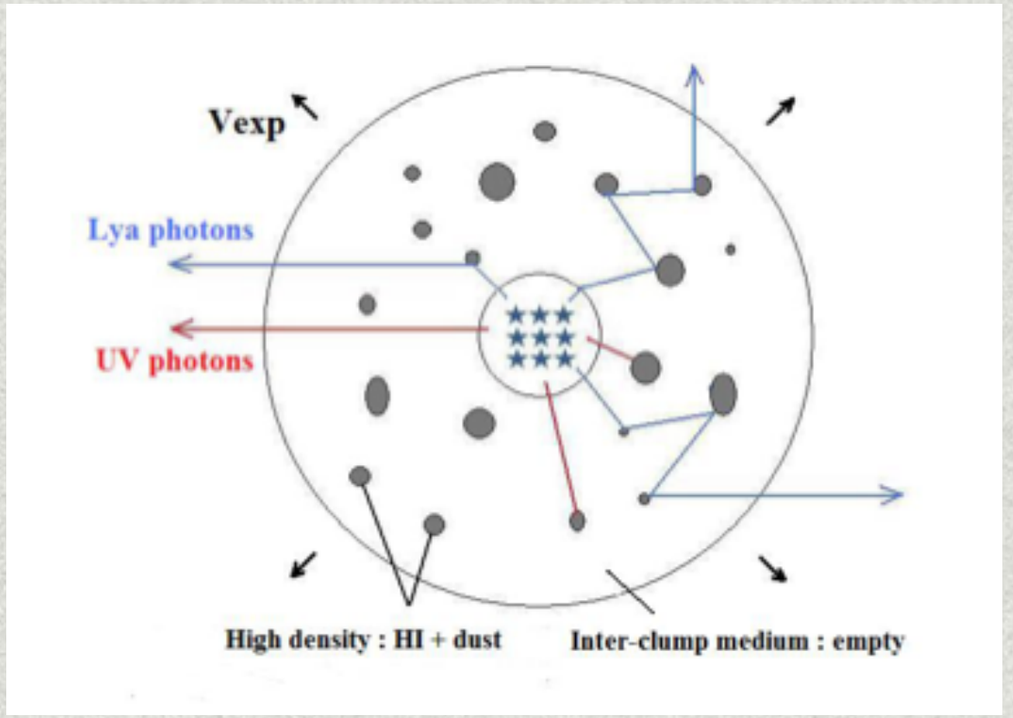
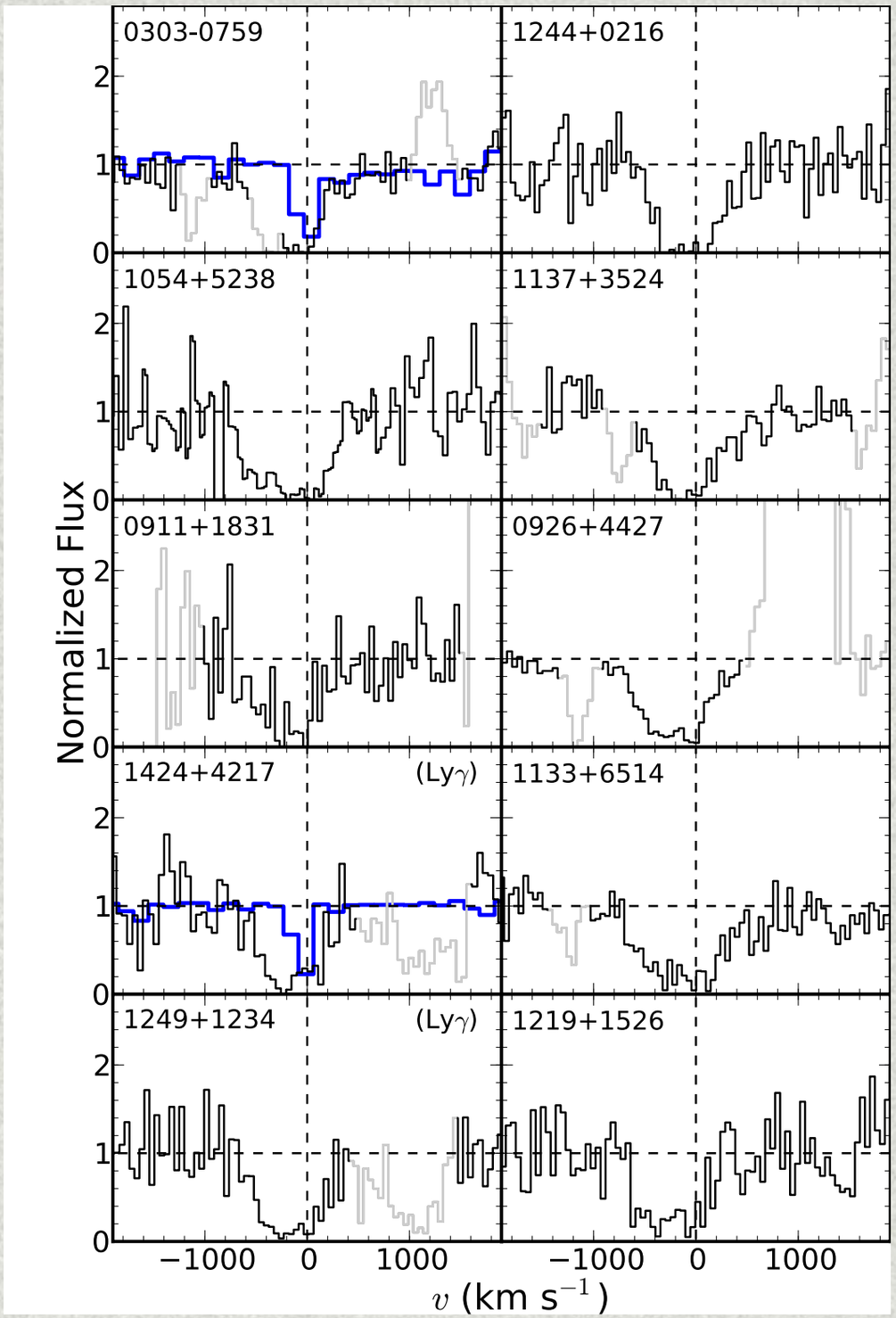


Fig from: Duval et al. (2014)

- *But:* COS spectra show Lyman series absorption is opaque—> covering near unity

Does Lyα get out through holes?



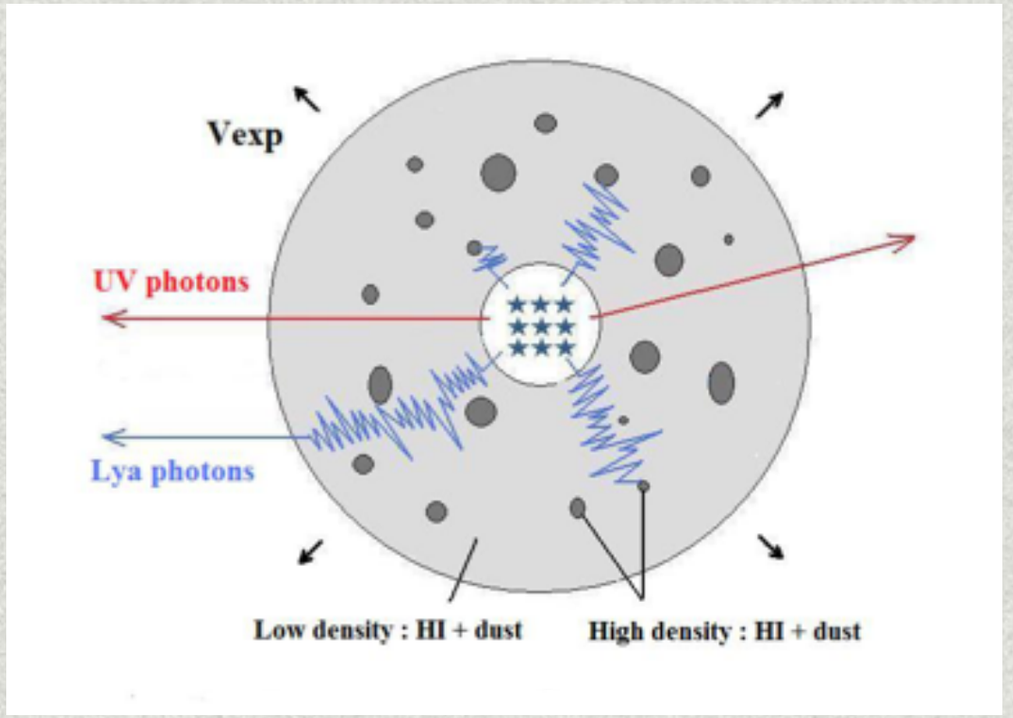
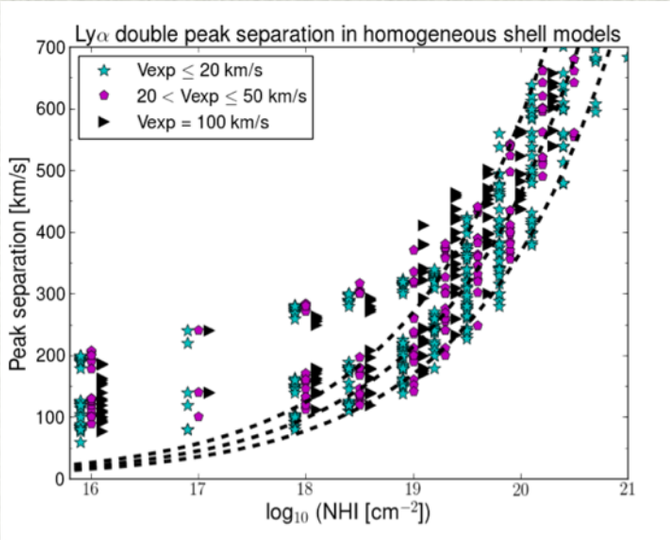


Fig from: Duval et al. (2014)

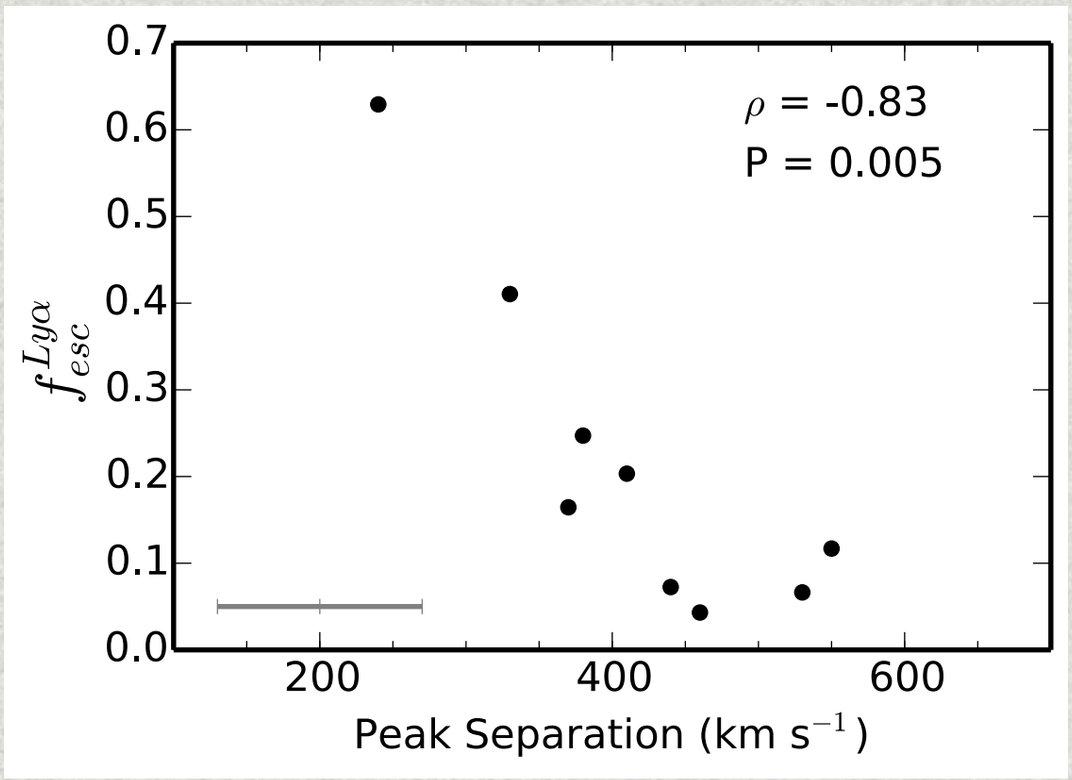
- *But:* COS spectra show Lyman series absorption is opaque—> covering near unity

What about HI gas density?



Verhamme et al. (2015)

- *Hypothesis*: Lyα escapes by more easily when lower HI column density reduces the scattering.



Henry et al. (2015, in press)

- *Result*: Lyα peak velocity separation, which is a signature of HI density correlates with the Lyα escape fraction.

  —This trend is driven by the blue peak velocity.

Conclusions

- Local Analogs are really valuable! Green Peas have taught us a lot about Lyα escape. Such as…
  - Lyα escape is **not explained by varying outflows and does not escape through holes in the ISM/CGM.**
  - HI column density seems to play the dominant role.
- Direct application/comparison to reionization epoch samples (from TMT/JWST) remains a challenge to be addressed.
  - Better moderate to high-z data (both rest UV and optical).
  - Find a way to work around Lyα forest impacted diagnostics, which were really useful in the Green Peas.