Outflows from young starbursts probed by Lyman-α and UV absorption lines

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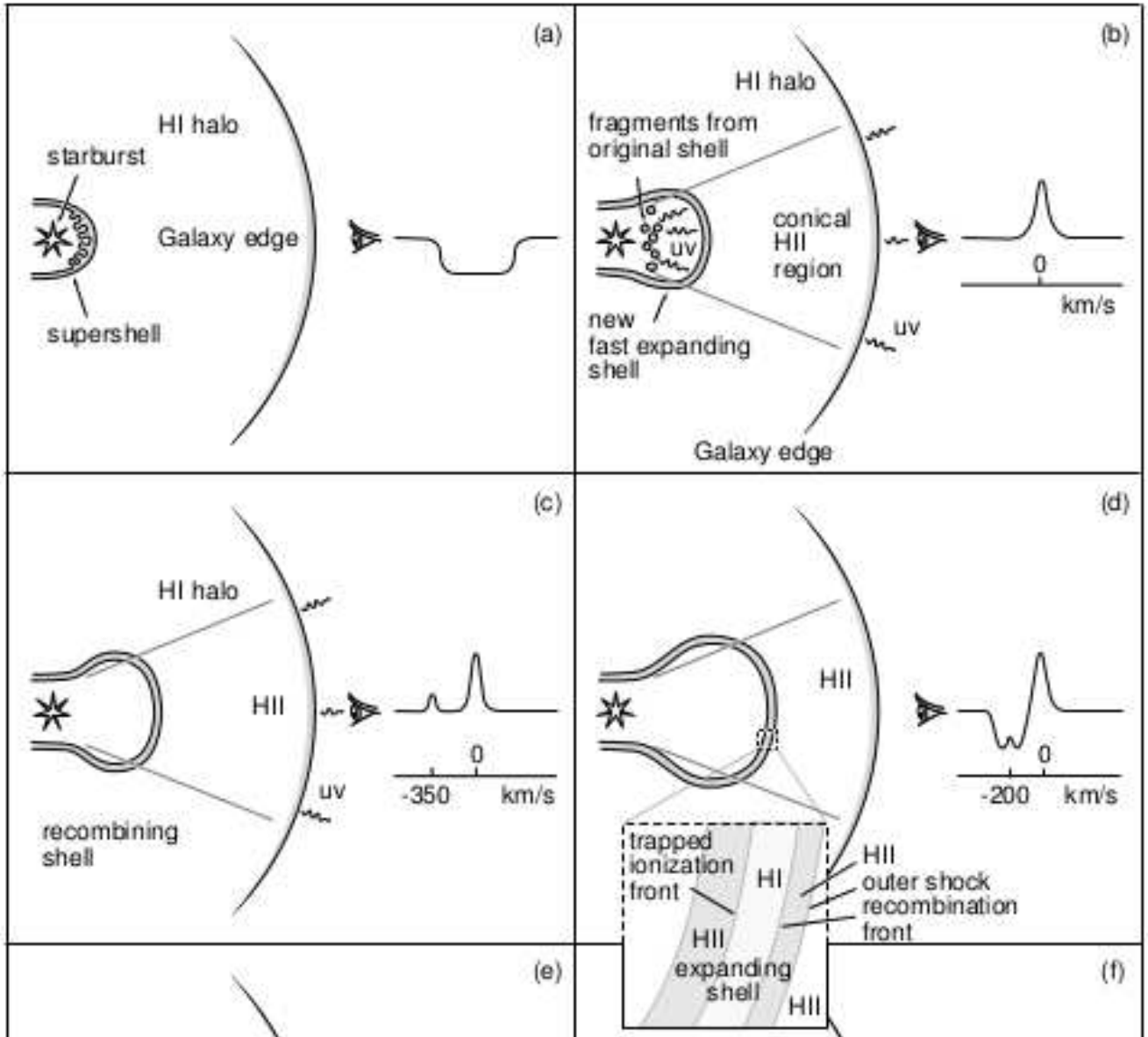
Collaboration:

Anne Verhamme, Daniel Schaerer, Matthew Hayes, Göran Östlin, Alaina Henry, Claudia Scarlata, Sally Oey, Anne Jaskot, John Chisholm, Yuri Izotov, Miguel Mas-Hesse, Daniel Kunth, LARS team ...

EWASS 2017, Prague

Lyα & this symposium

Tenorio-Tagle+99: superbubbles and Lyα in SF galaxies

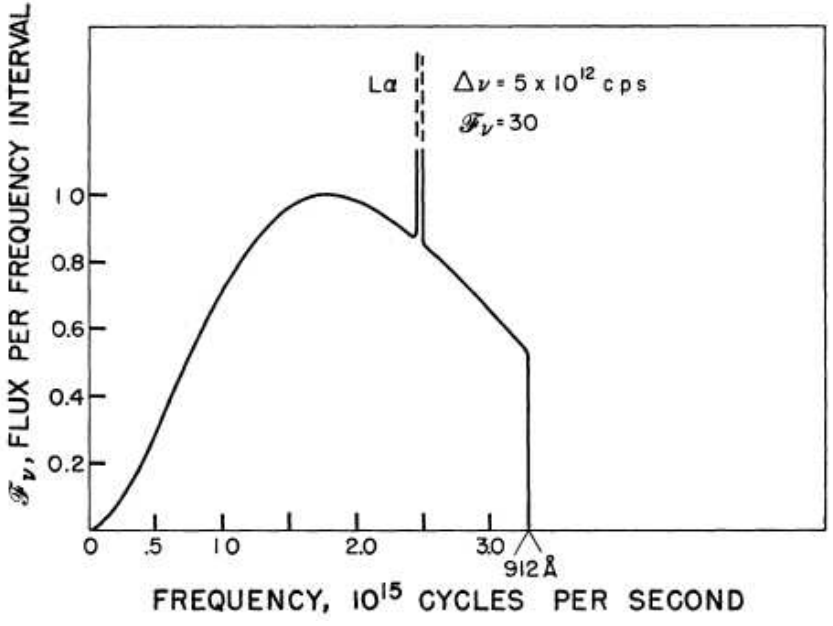


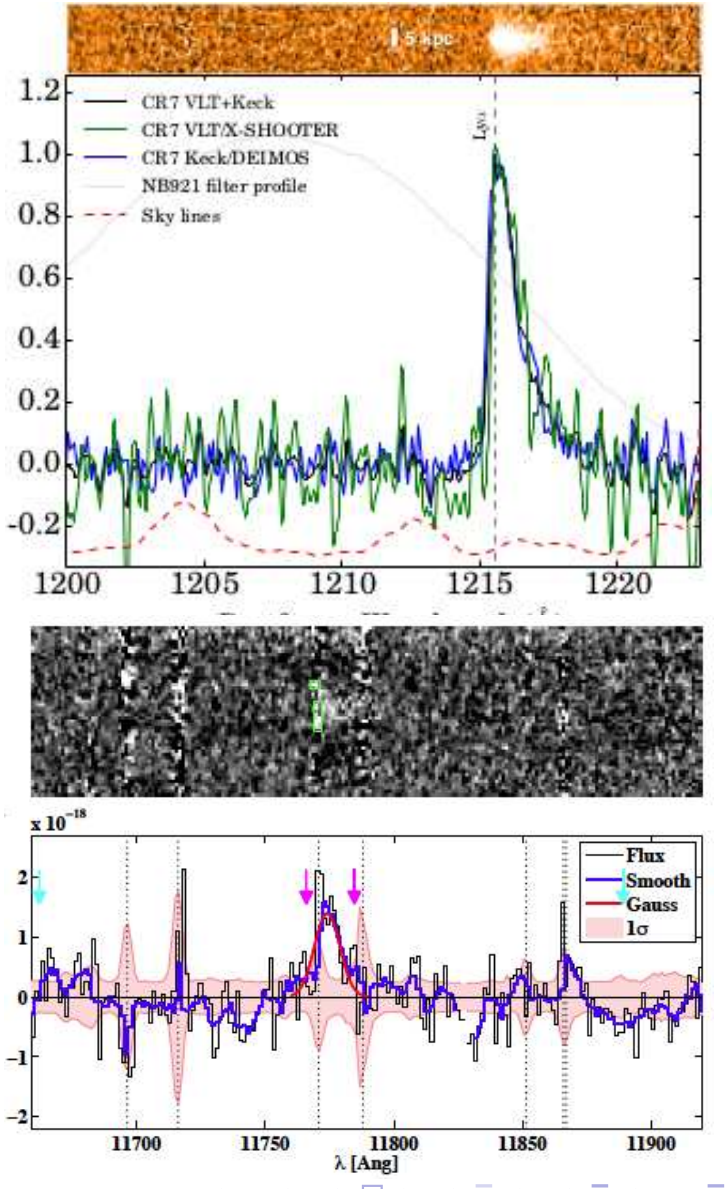
Lyman-alpha as cosmological tool

e.g. Sobral+15, Zitrin+15, $z = 7 - 8$

Prediction 1967

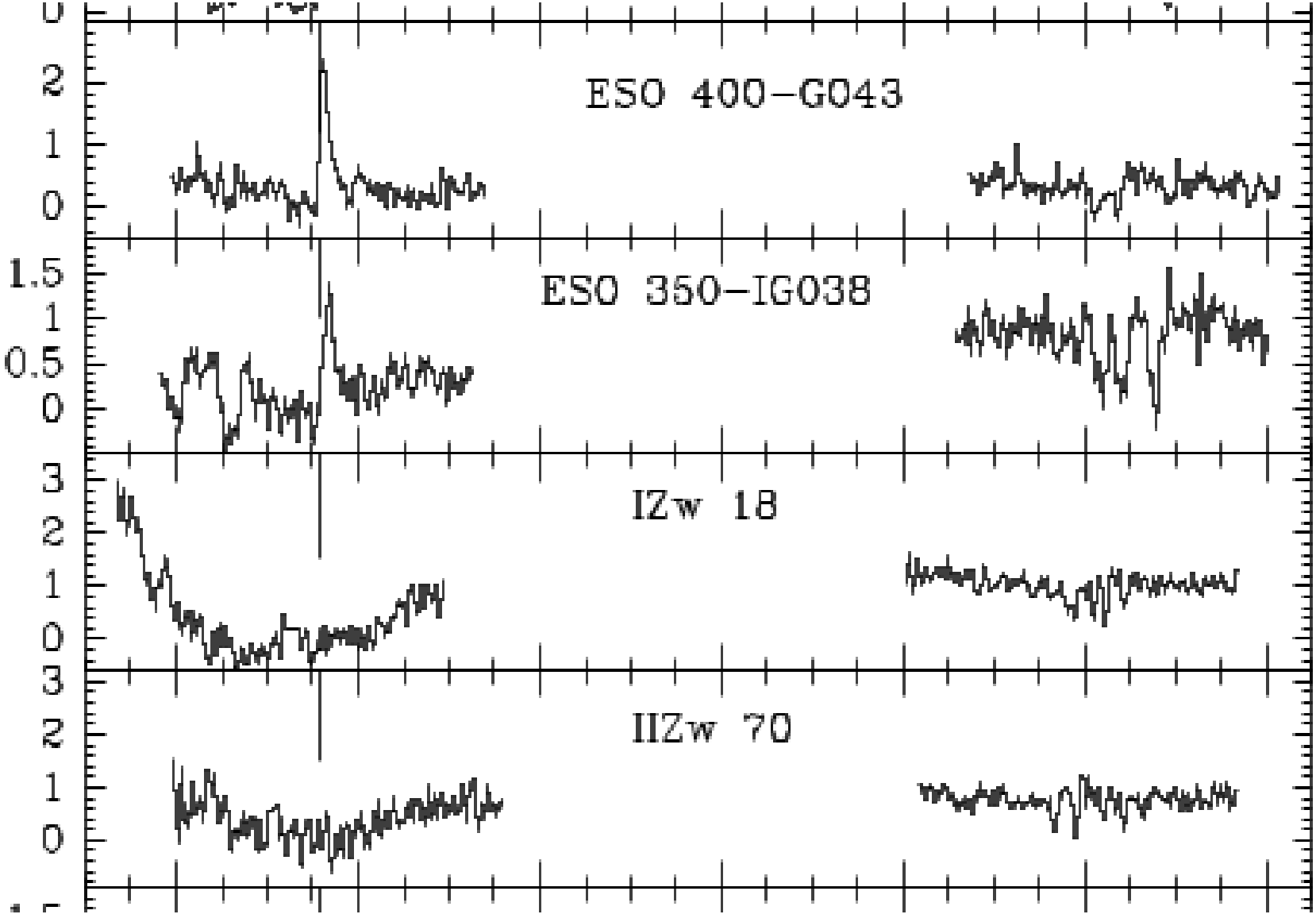
Partridge & Peebles





Lyman-α in nearby galaxies

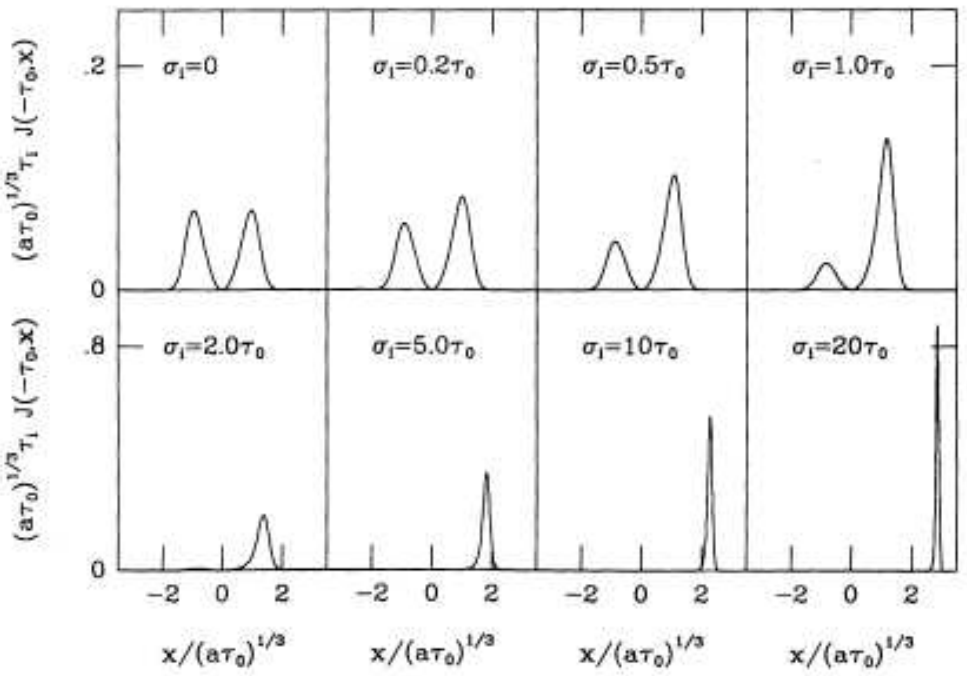
Kunth+98, HST – P Cygni & absorption



Lyman-α

- Recombination line – H II regions
- Optically thick at most galaxies, N(HI) $> 10^{13}\,\mathrm{cm}^{-2}$
- Resonant scattering on H I, destruction by dust

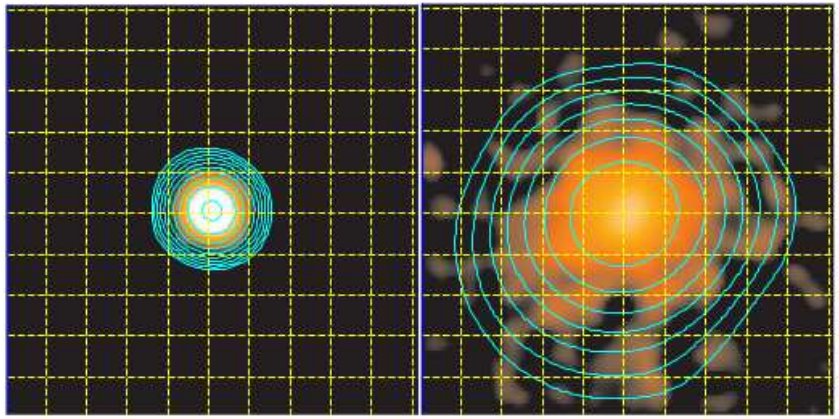
- Analytical models Adams 72, Neufeld 90 – large τ limit
- Monte Carlo - in simple geometries, or HD simulations



How Lyα escapes from galaxies:

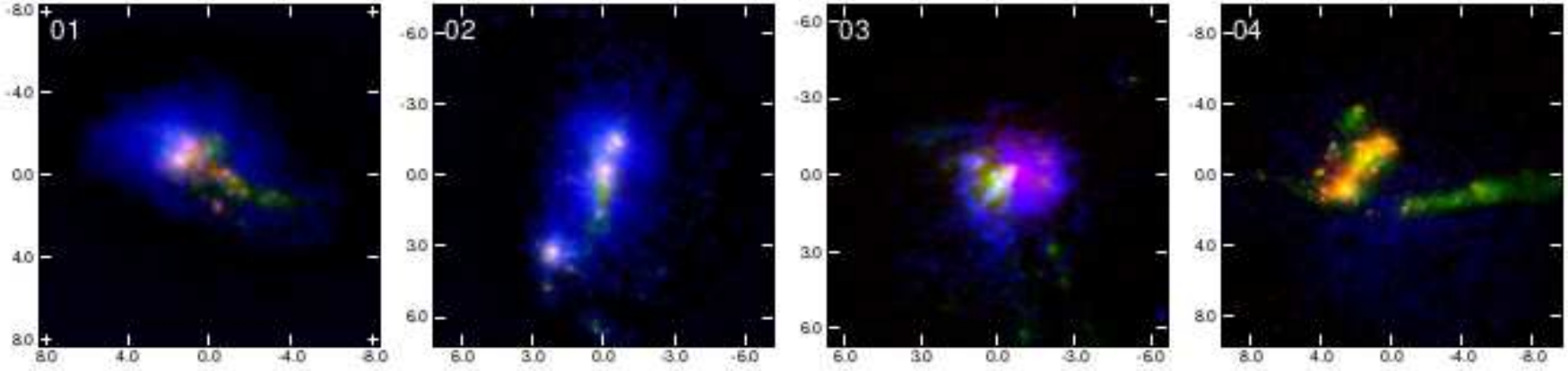
1. Scattering in space

FUV continuum $\longrightarrow$



Lyα "halo" $\longleftarrow$

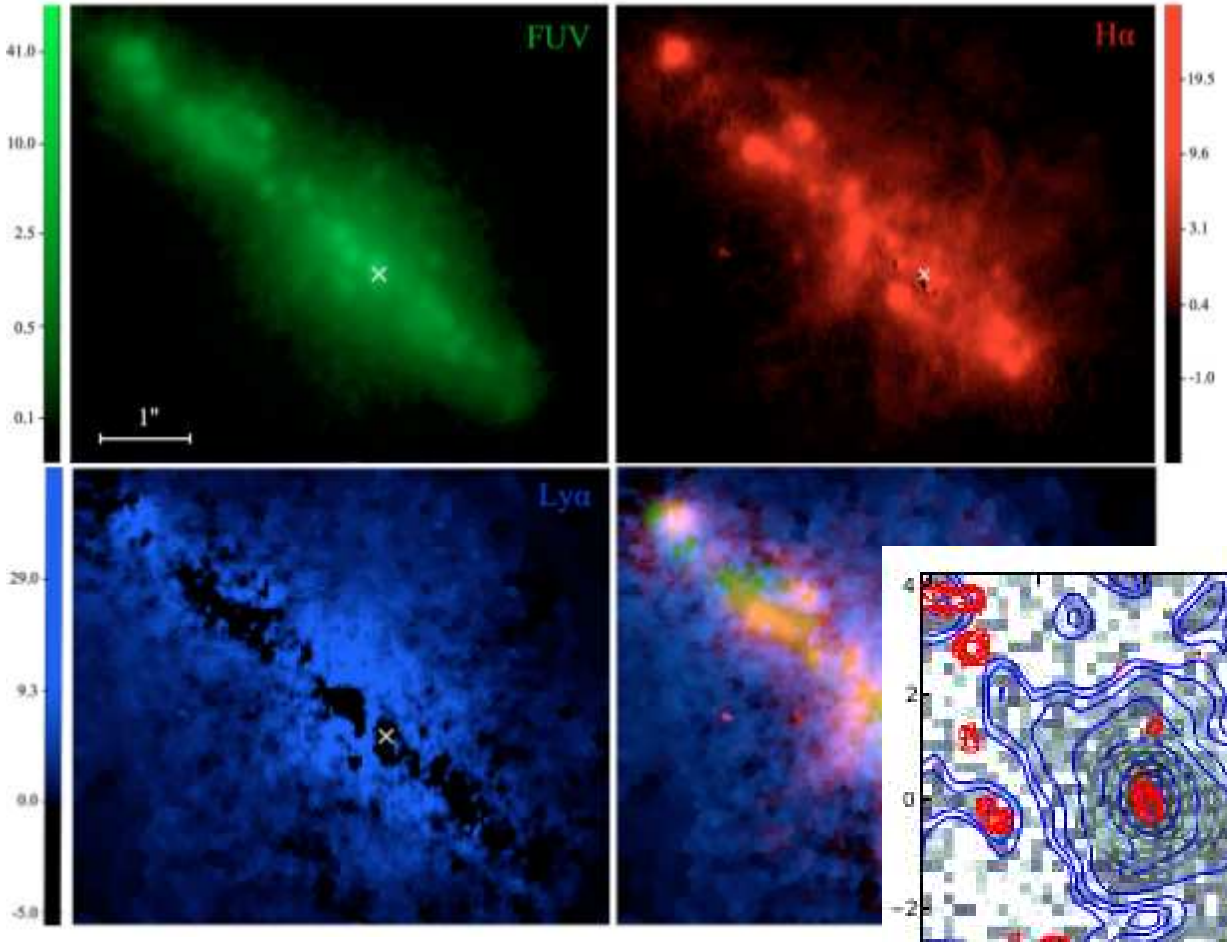
(Steidel+11; $z \sim 2.6$; stack 90 galaxies)



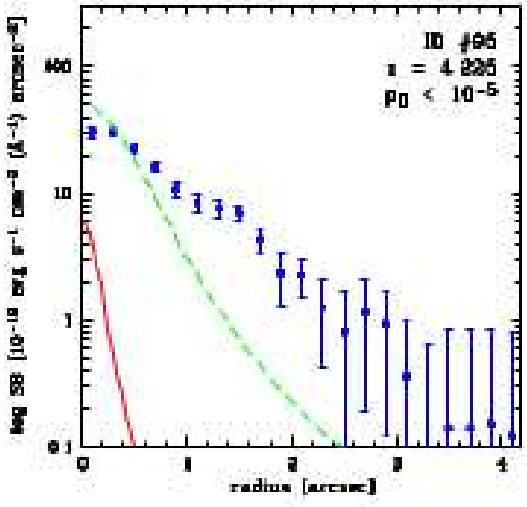
Blue = Lyα (Hayes+13; individual galaxies $z \sim 0.03$)

How Lyα escapes from galaxies:

1. Scattering in space



Duval+16, LARS 5 (HST)

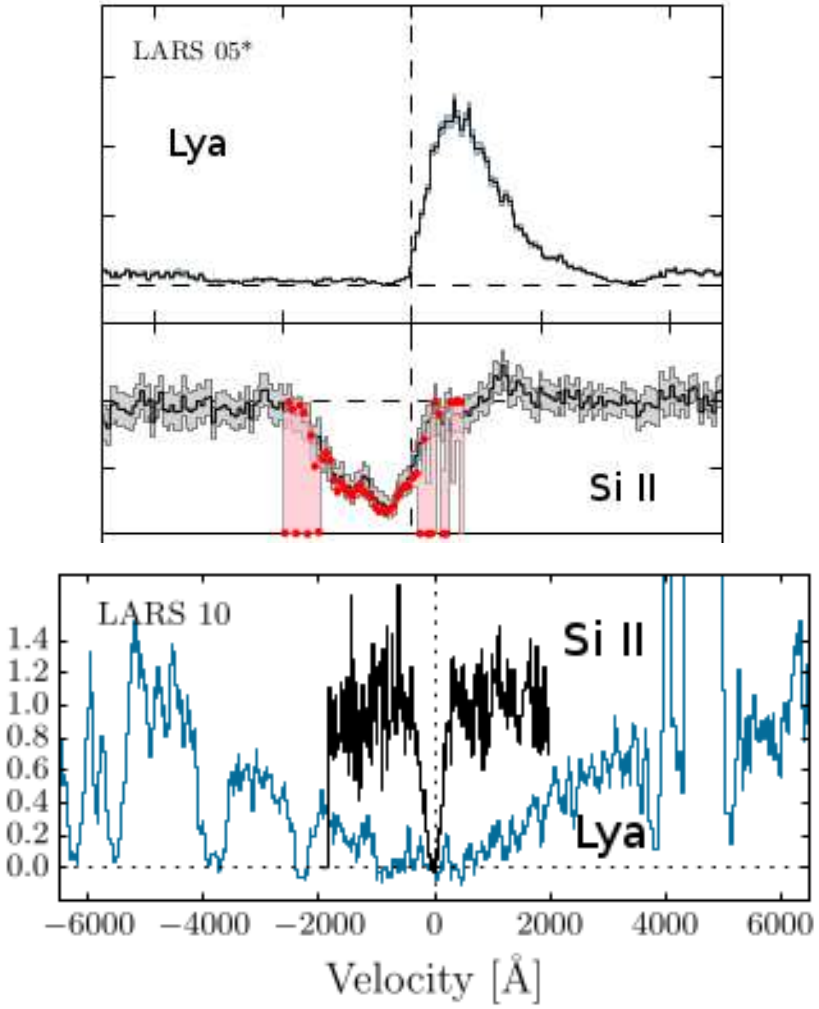


Wisotzki+15 ($z = 4$, MUSE)

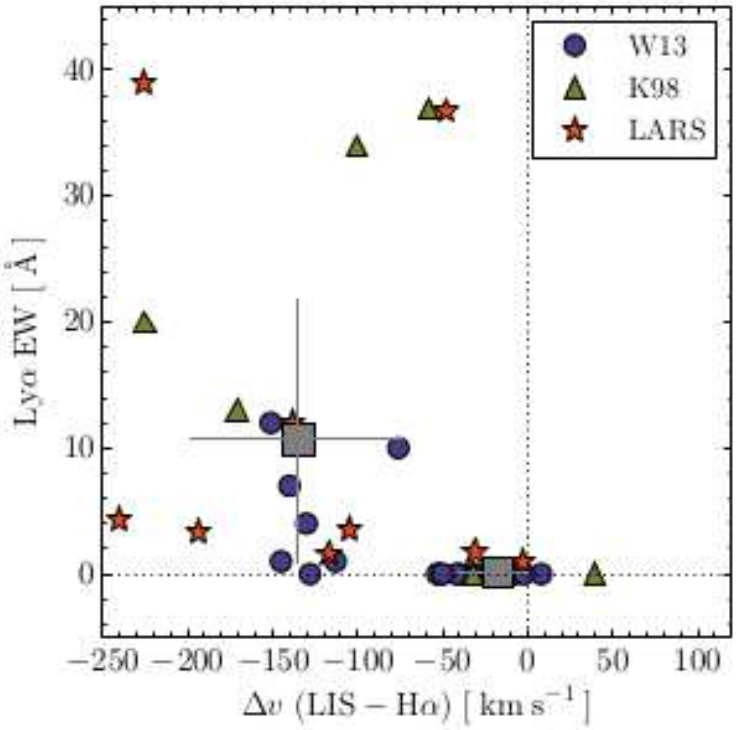
How Lyα escapes from galaxies:

2. Kinematics

Kunth+98; Shapley+03; Wofford+13; Rivera-Thorsen+15; Martin+15



Rivera-Thorsen+15 (LARS)



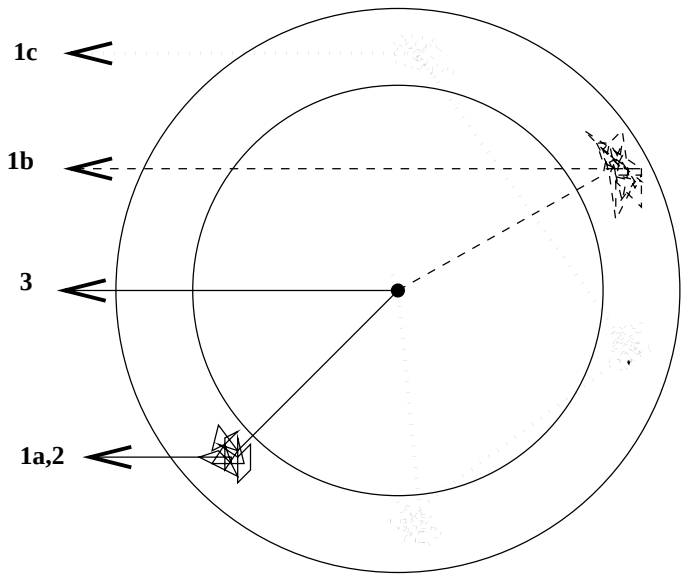
Hayes+15

Radiative transfer in spherical homogeneous H I shells

Use Lyα Monte Carlo code of Verhamme+06

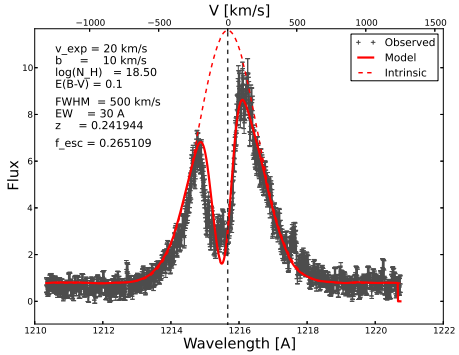
Monte Carlo Lyα photons
H I + dust in spherical shell

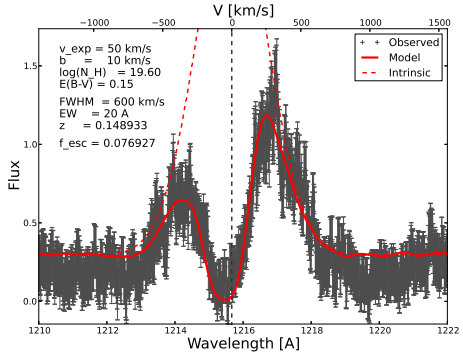
- Shell:
  - $v_{\rm exp}$ ... expansion speed
  - b ... velocity dispersion
  - $N_{\rm HI}$ ... H I column density
  - τ ... dust optical depth
- Lyα source: Gaussian line
  - EW (Lyα^0)
  - FWHM (Lyα^0)
  - z ... redshift

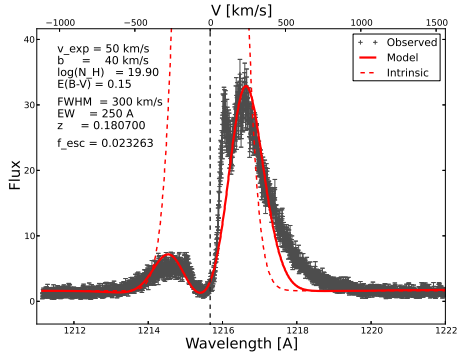


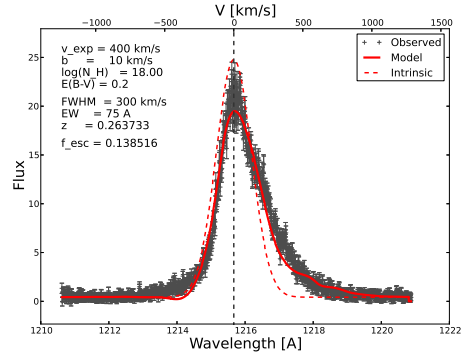
Shell spectra capture reality

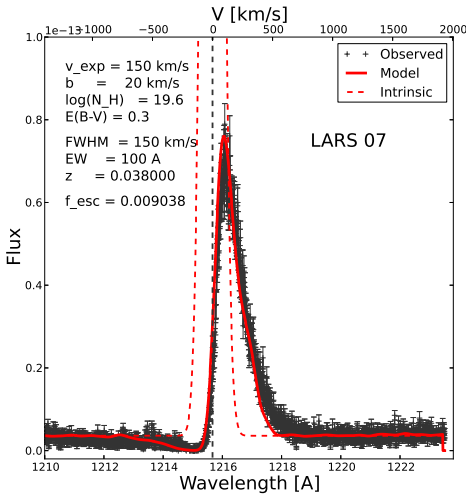
At low computational cost (Verhamme+08, Schaerer+08, Hashimoto+15, Yang+16)

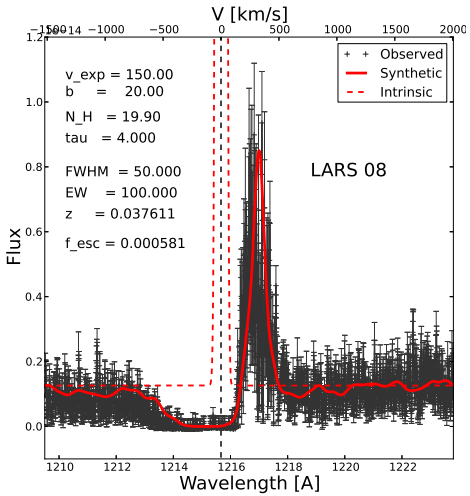


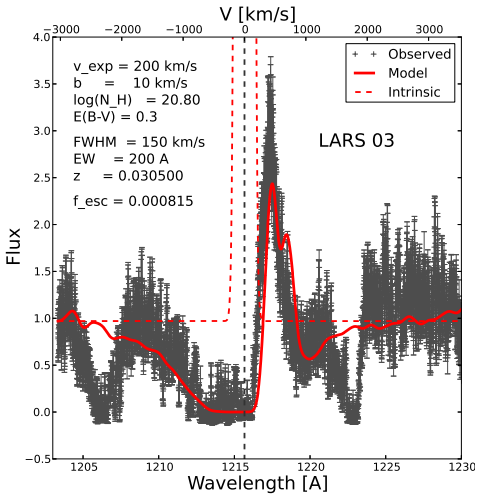


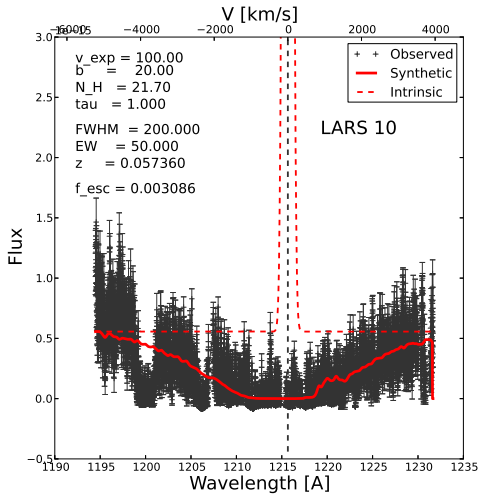










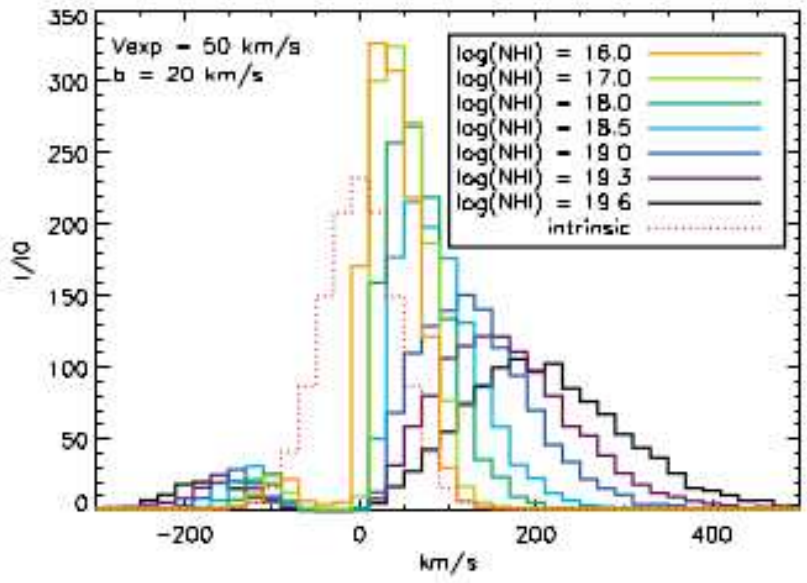


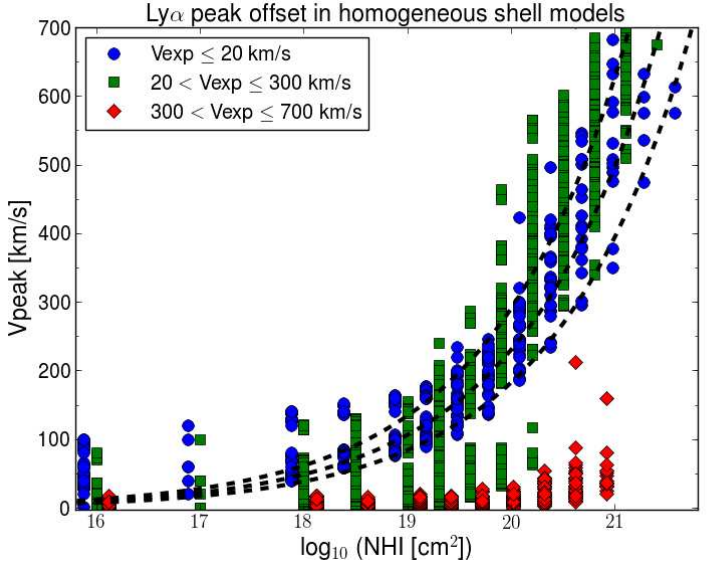
Orlitova+17

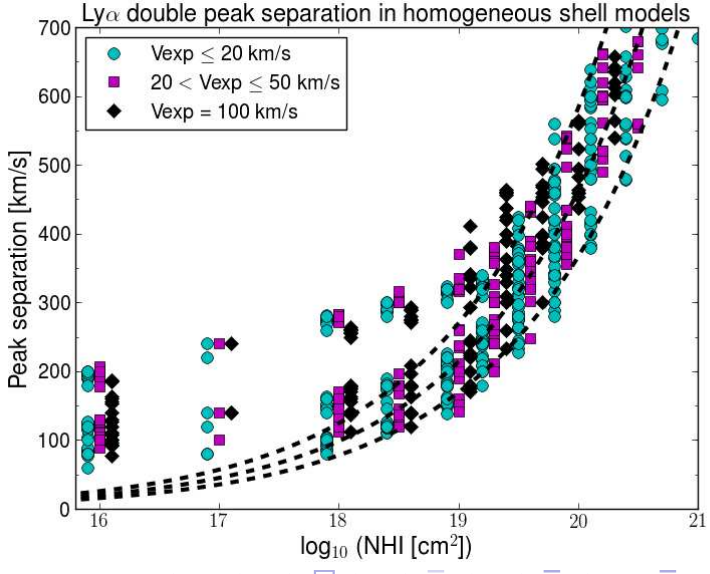
Lyα to predict Lyman continuum escape (LyC)

Theoretical prediction: Verhamme, Orlitova, Schaerer, Hayes (2015)

Peak shift increases with N(HI)







Application:

LyC $\lambda < 912$ Å ionizes H

LyC opt.thick at N(HI)$> 10^{18}$ cm^{-2}

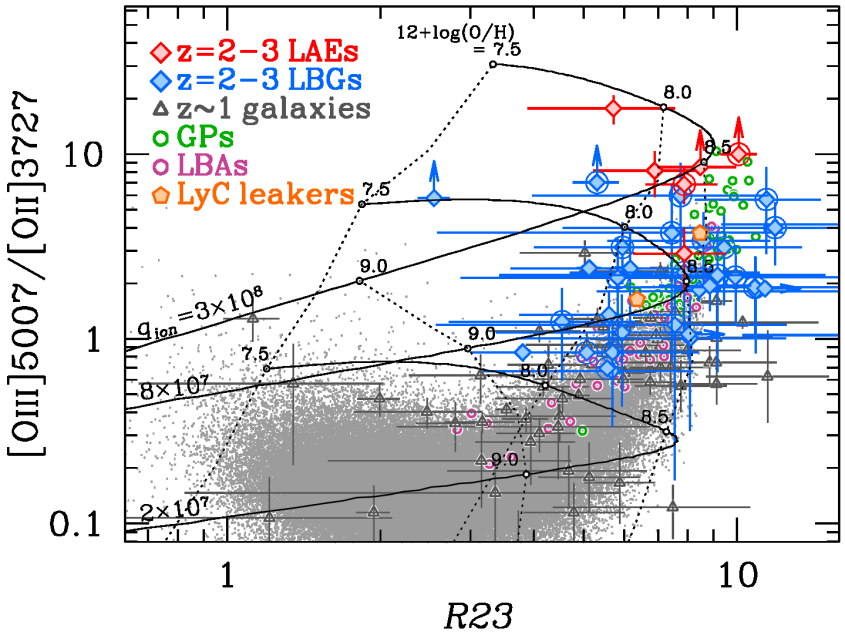
Which sources ionized universe

Lyman continuum (LyC) escape

HST Observation: Izotov, Orlitova, Schaerer, Thuan, Verhamme et al. (Nature 2016)

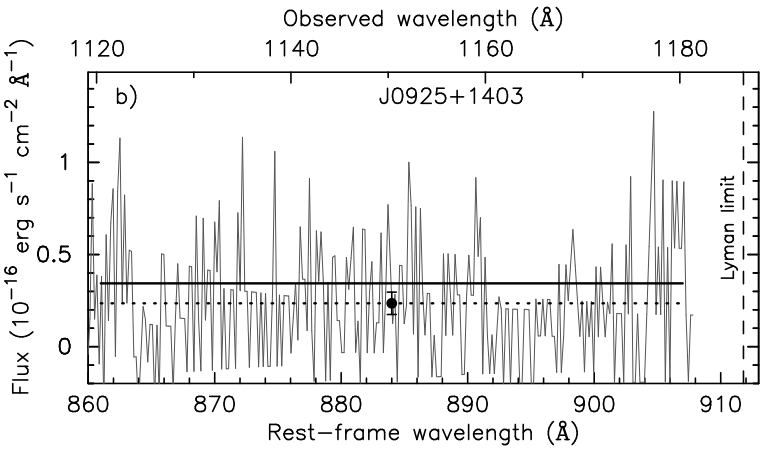
Green Pea galaxies, SDSS (Cardamone+09, Izotov+11)

LyC prediction in GPs by [O III] (Jaskot & Oey 13; Nakajima & Ouchi 14)



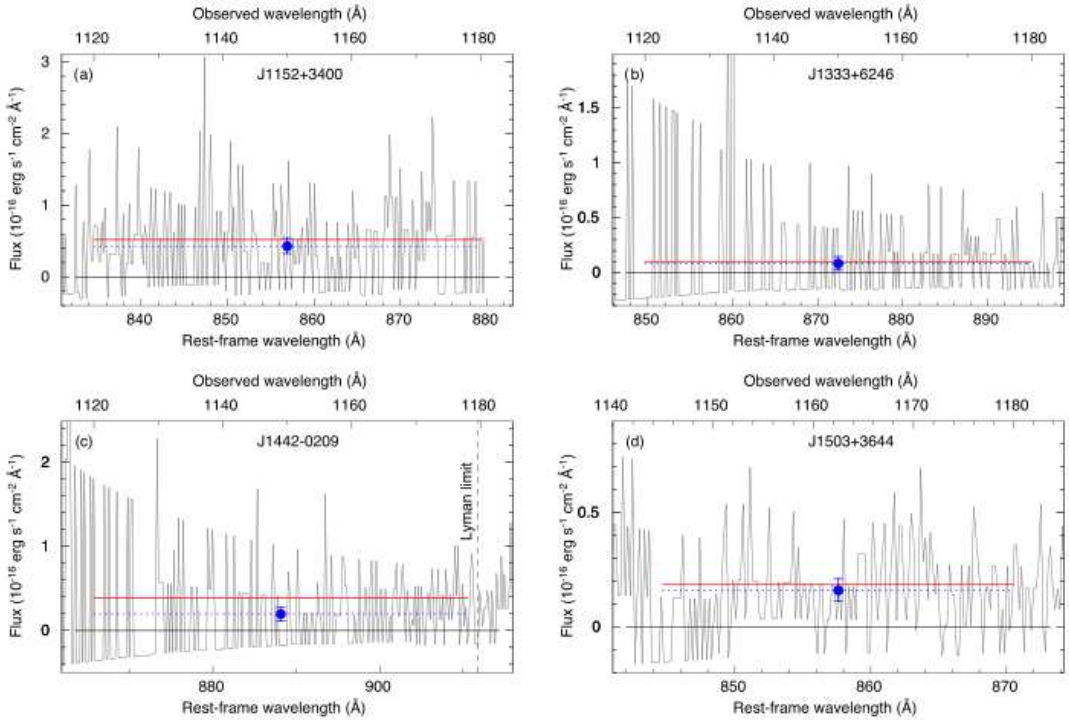
LyC detection in Green Peas (HST)

Izotov, Orlitova, Schaerer, Thuan, Verhamme, Guseva, Worseck (Nature 2016)



HST Cyc 22; 10σ detection

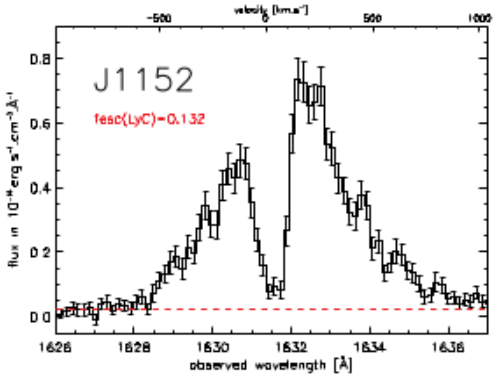
Izotov+16a (Nature)

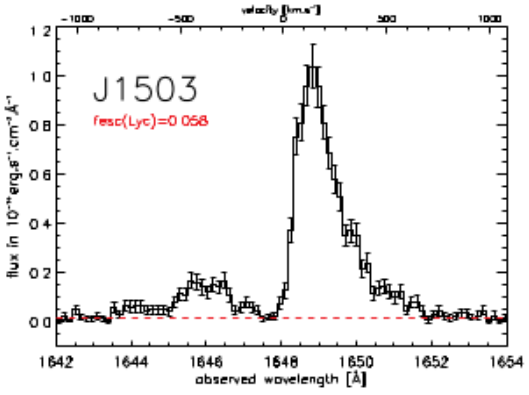


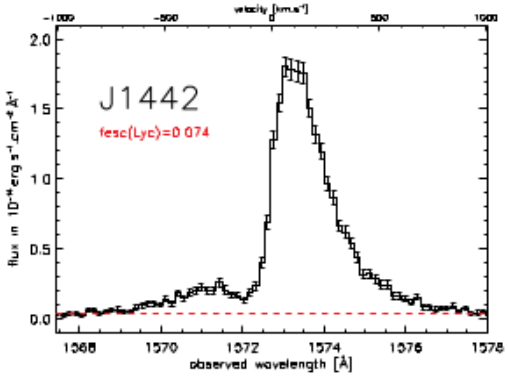
Izotov+16b (MNRAS)

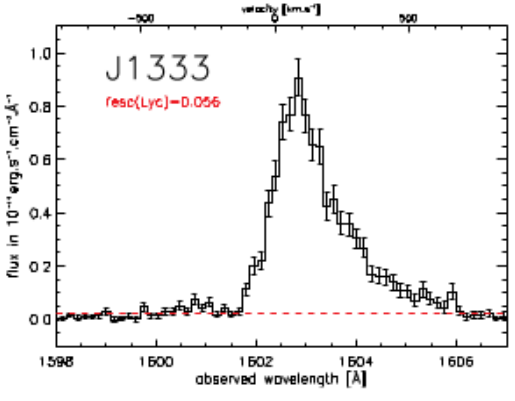
Lyα in Lyman continuum leakers (HST)

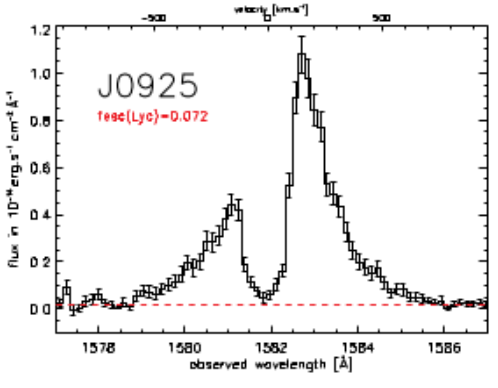
Verhamme, Orlitova, Schaerer, Izotov, Worseck, Thuan, Guseva (A&A 2017)









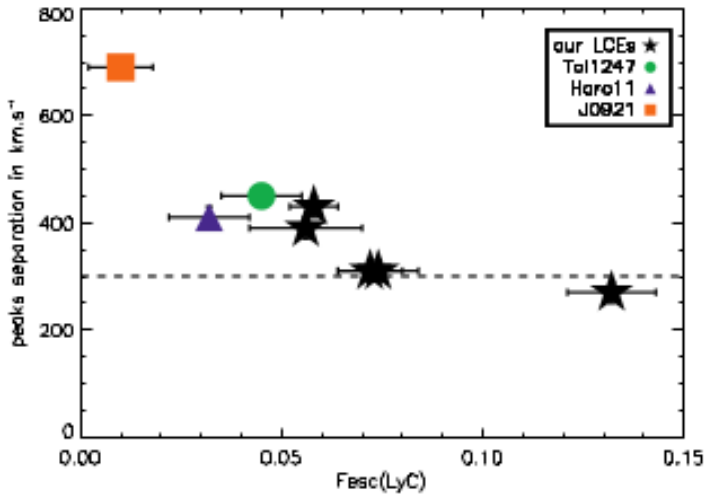


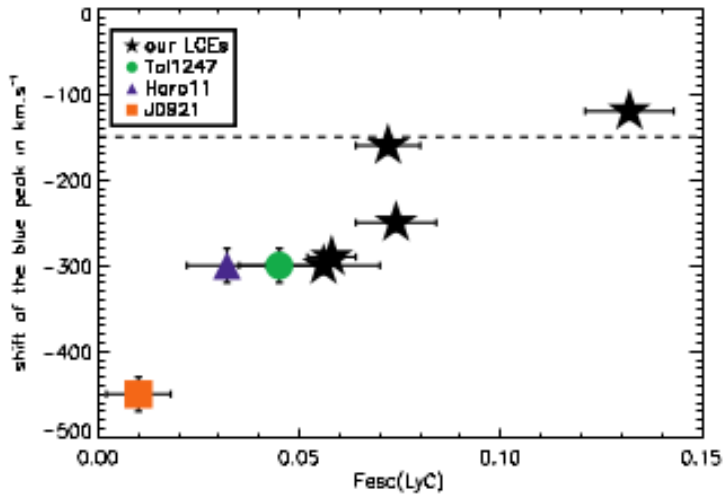
Lyα in Lyman continuum leakers (HST)

Verhamme, Orlitova, Schaerer, Izotov, Worseck, Thuan, Guseva (A&A 2017)

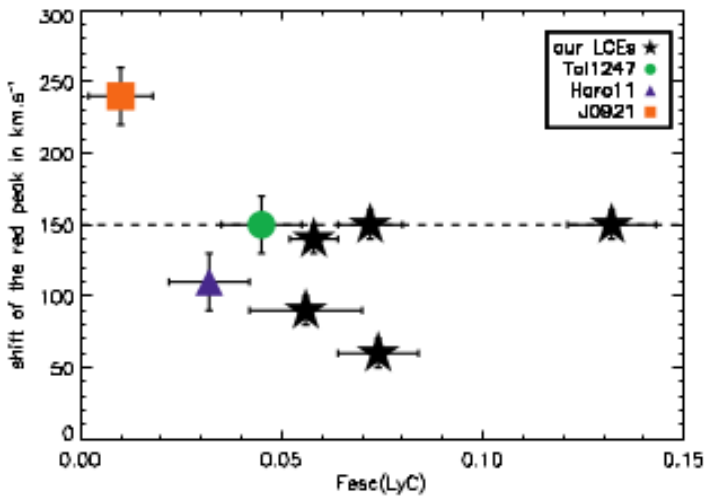
Peak separation

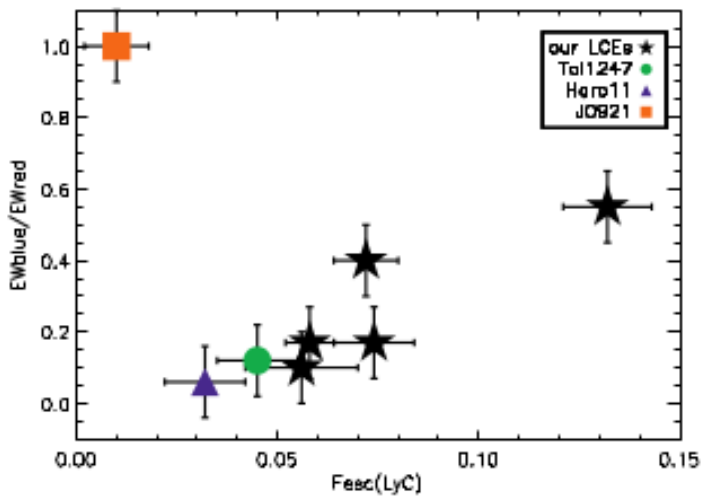
Blue peak





Red peak

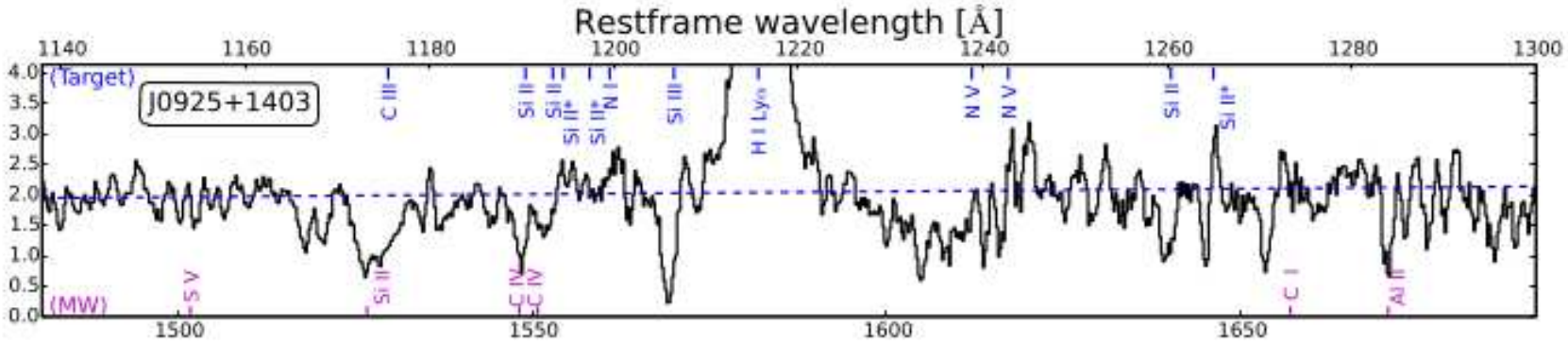


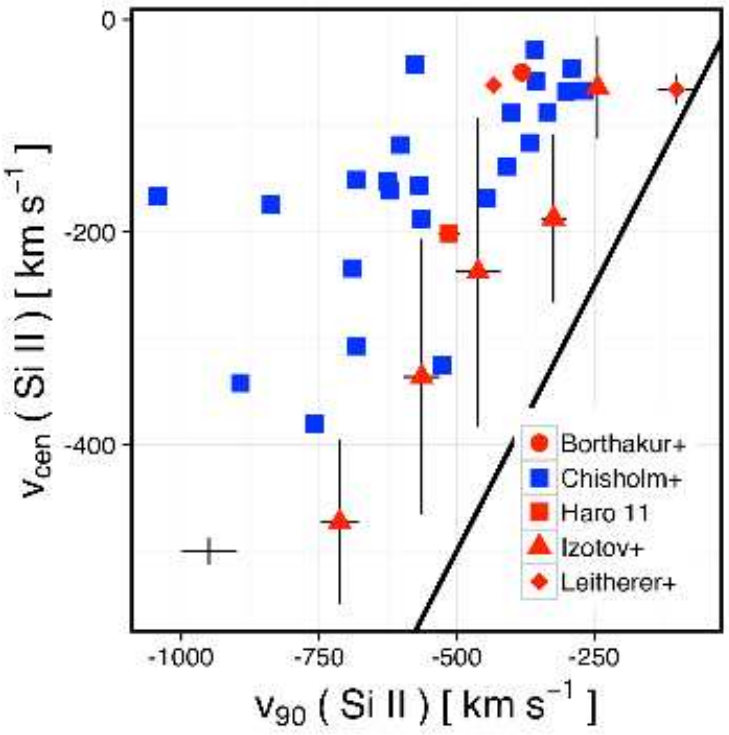


f_{esc} (LyC)

Metal UV lines of LyC leakers (HST)

Chisholm, Orlitova, Schaerer, Verhamme et al. (2017)





Leakers:
No extreme velocities
Different Si II line symmetry

Summary

- Lyα spectra encode ISM conditions – useful high-z, low-z
- Radiative transfer in homogeneous shells capture main features of Lyα spectra
- ISM parameters consistent between models observations
- Parameter inconsistencies in some double-peaks – origin?
- Lyα useful for predicting LyC escape
- LyC detected in 5 Green Peas
- Lyα properties of LyC leakers consistent with models
- Study ISM conditions that allow LyC escape