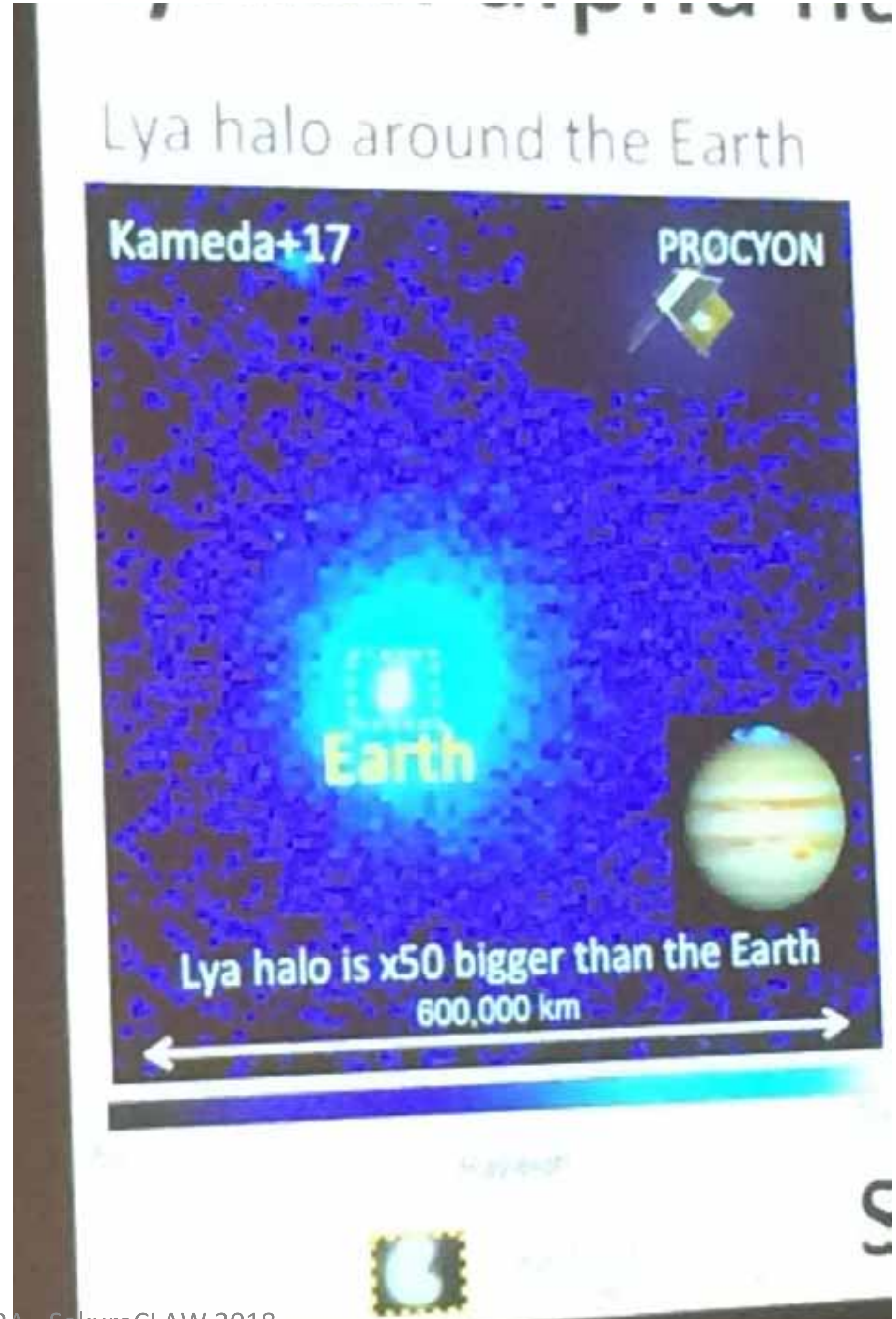
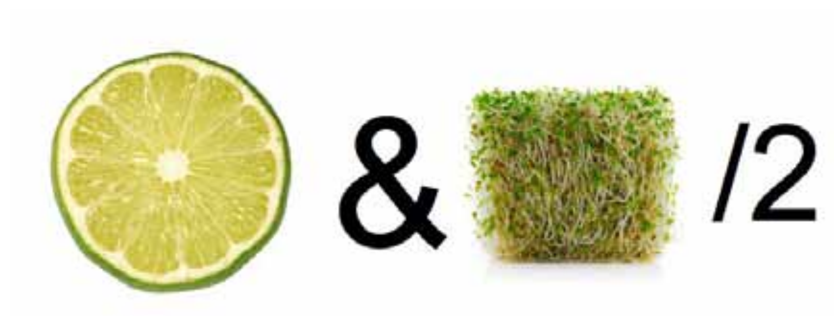
- It is hard to get high EW LyA in galaxies - A. Ferrara
- LyA is everywhere --- aMUSEd observers

- Scattering begins at home – W. Keel.



Are Green Peas local analogs of Lyman-alpha galaxies?

==



YES!!

How can local analogs help us understand Lyman-alpha galaxies?
(JWST on the cheap?)

SANGEETA MALHOTRA - SakuraCLAW 2018

What *is a* Lyman-α galaxy?

A galaxy that makes Ly-α photons?

NO! *All* star forming galaxy do that.

A Lyman-α galaxy is one where the Lyman-α photons *escape* so that we can observe them.

So… *how much* of the Lyman-α escapes?

How does it escape?

What other properties of these galaxies are distinctive?

(typical) Ly-α galaxies (circa 2009)

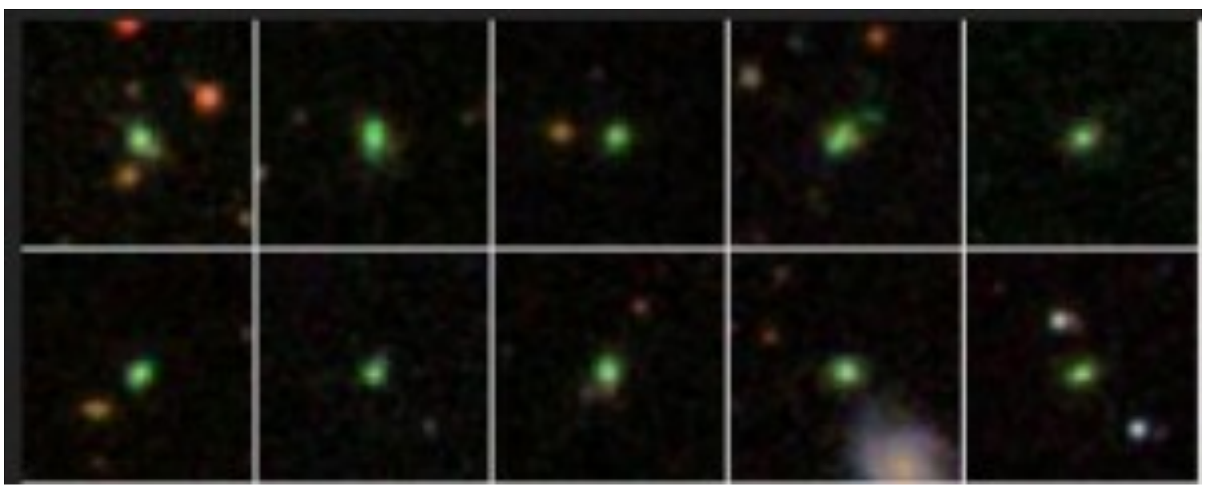
- have **low star-formation rates** ~1-10 M_{sun}/year (Gronwall + 2007)
- are **young**: ~ 10^7 years (Pirzkal et al. 07, Finkelstein et al. 08; Nilsson et al. ….)
- are **not massive**: 10^7-10^9 M_{sun} (Pirzkal et al. 2007, Finkelstein et al. 2008, Gawiser et al. 2007)
- have modest amounts of dust or **not much dust, low metallicity**
- have halo masses ~ 10^{11} M_{sun} (Kovac et al 2007; Gawiser et al 07; Ouchi et al 07)
- Only **~ 10% duty cycle** (Kovac et al 2007).
- **Small physical sizes**, which stays constant between z=2-6.5 (Malhotra+ 2012).

High EW of [OIII] lines (McLinden+ 2011) & low metallicities (Song+ 2014)

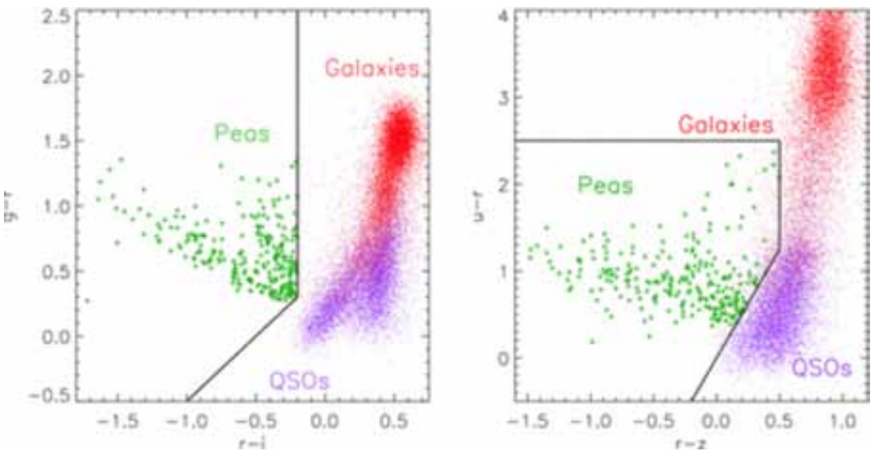
What are Green Peas?

Green Peas Galaxies selected by citizen scientists – (peas corps volunteers) (Cardamone+ 2009)

1. They appear green because of strong [OIII] (5007) line
2. Peas because round and unresolved – compact
3. High ionization, low metallicities

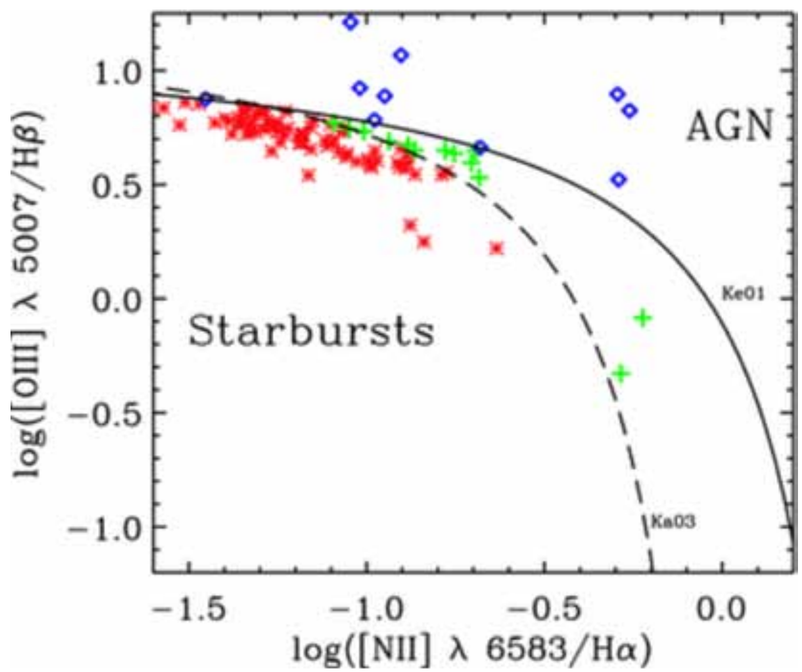


What are Green Peas?

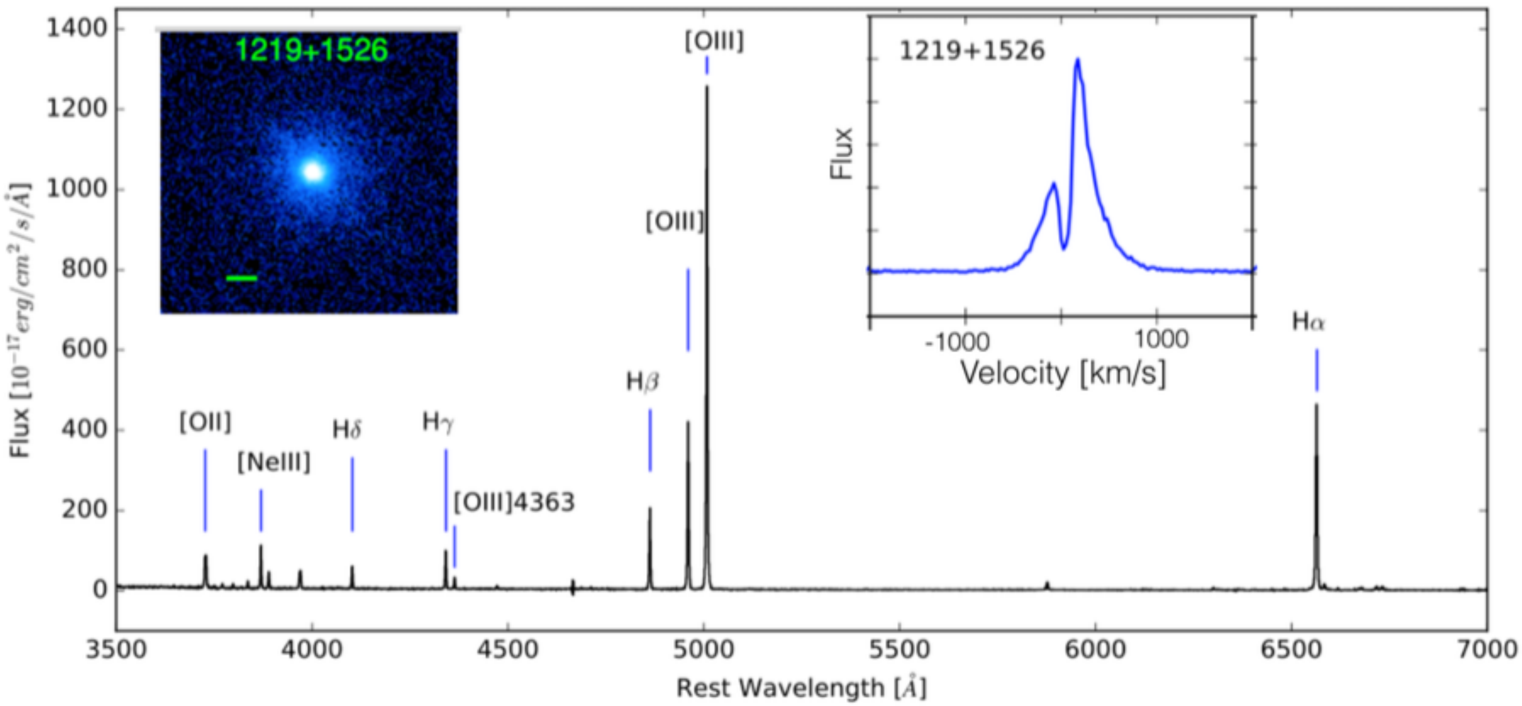


Emission lines are strong enough to give peculiar colors.

2/3rd show non-AGN colors in the BPT diagram (more on this later).

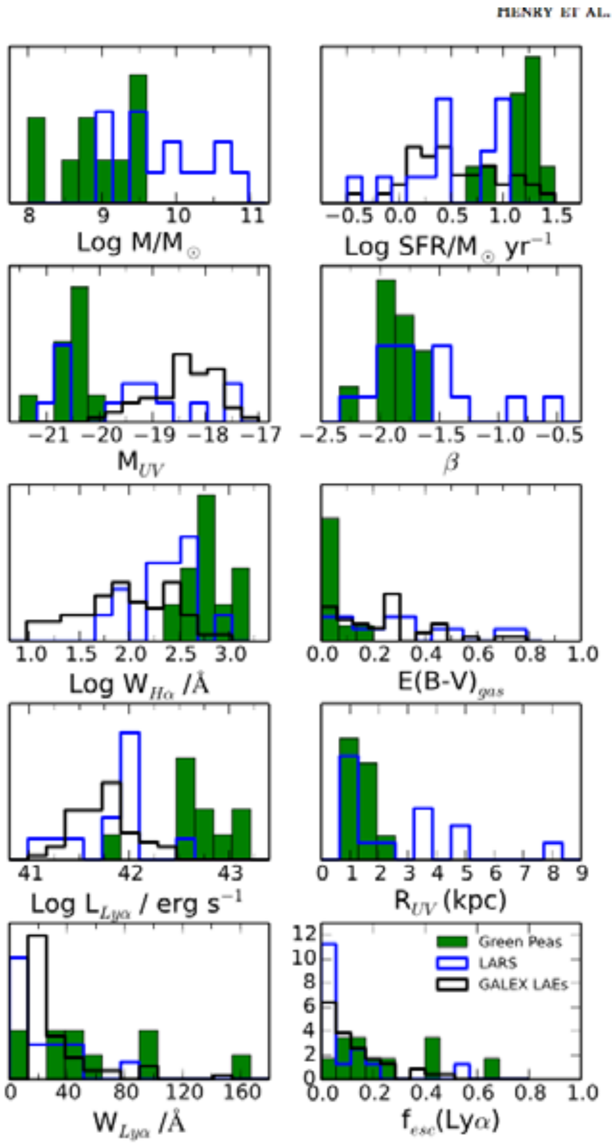


Green Peas in one plot

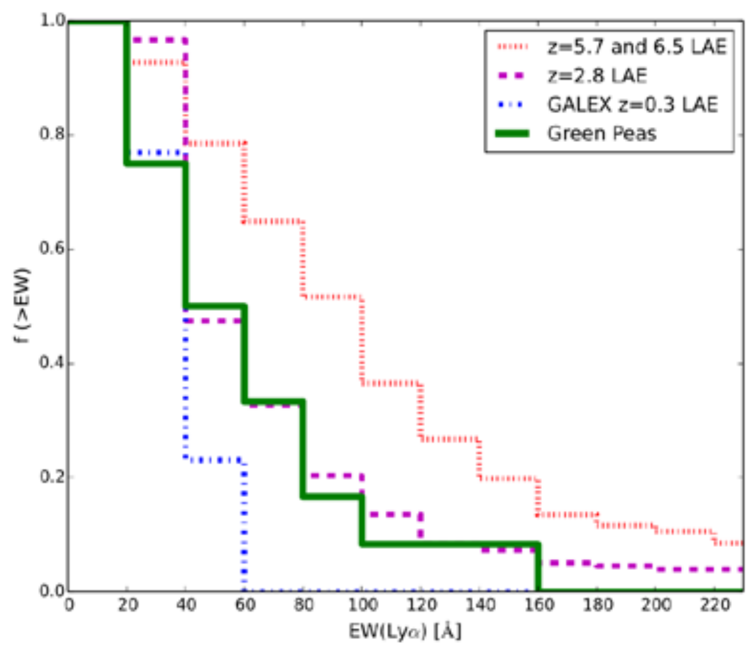


Optical Spectrum from SDSS is line dominated
NUV image with COS (half-light radius=0.33Kpc)
Lyman-alpha spectrum with COS centered on H-alpha redshift.

Henry et al. 2015

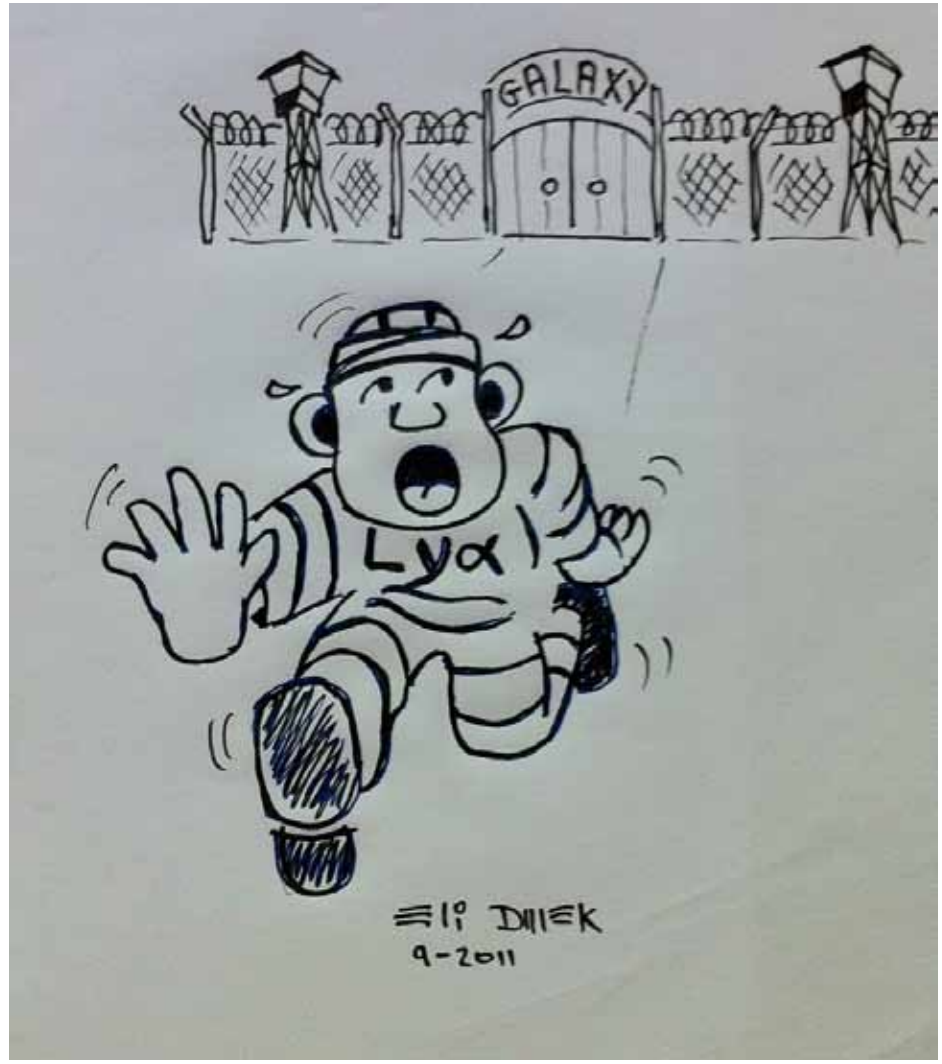


Yang+ 2016



What enables Ly-α to escape?

- Kinematics of gas
- (relative) lack of dust
- Youth
- size (radius)
- Random line of sight



Lyman-α escape

1. Used as diagnostics for reionization
   – NB samples (Malhotra & Rhoads 2004)
   – LBGs (Stark+, Pentericci+, Tilvi+, Treu+)

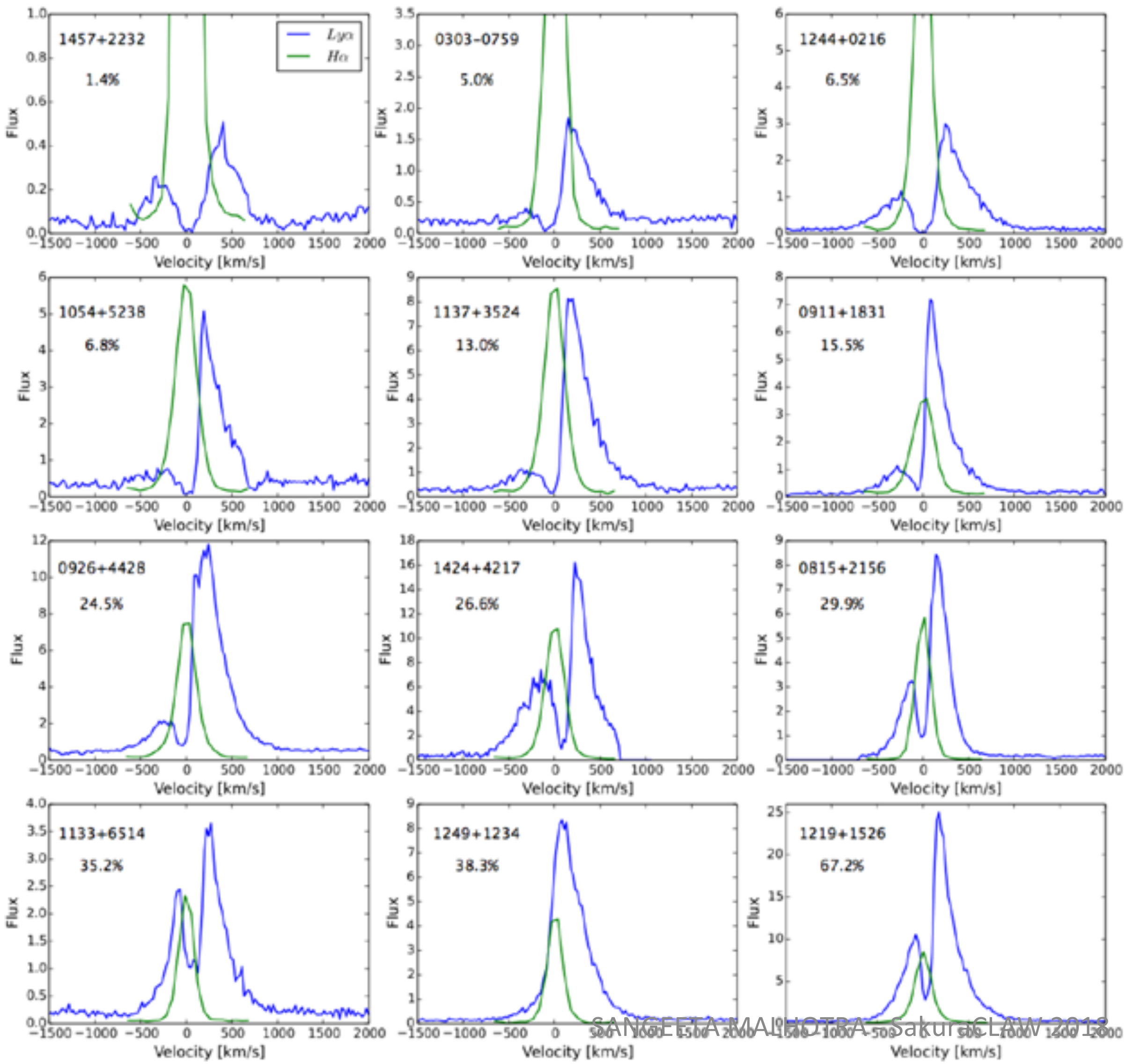
   Requires us to understand the physics of Lyα escape.
2. Also good sources of ionizing radiation …

   escape of ionizing radiation is an unsolved problem

   that resembles the problem of Lya escape.

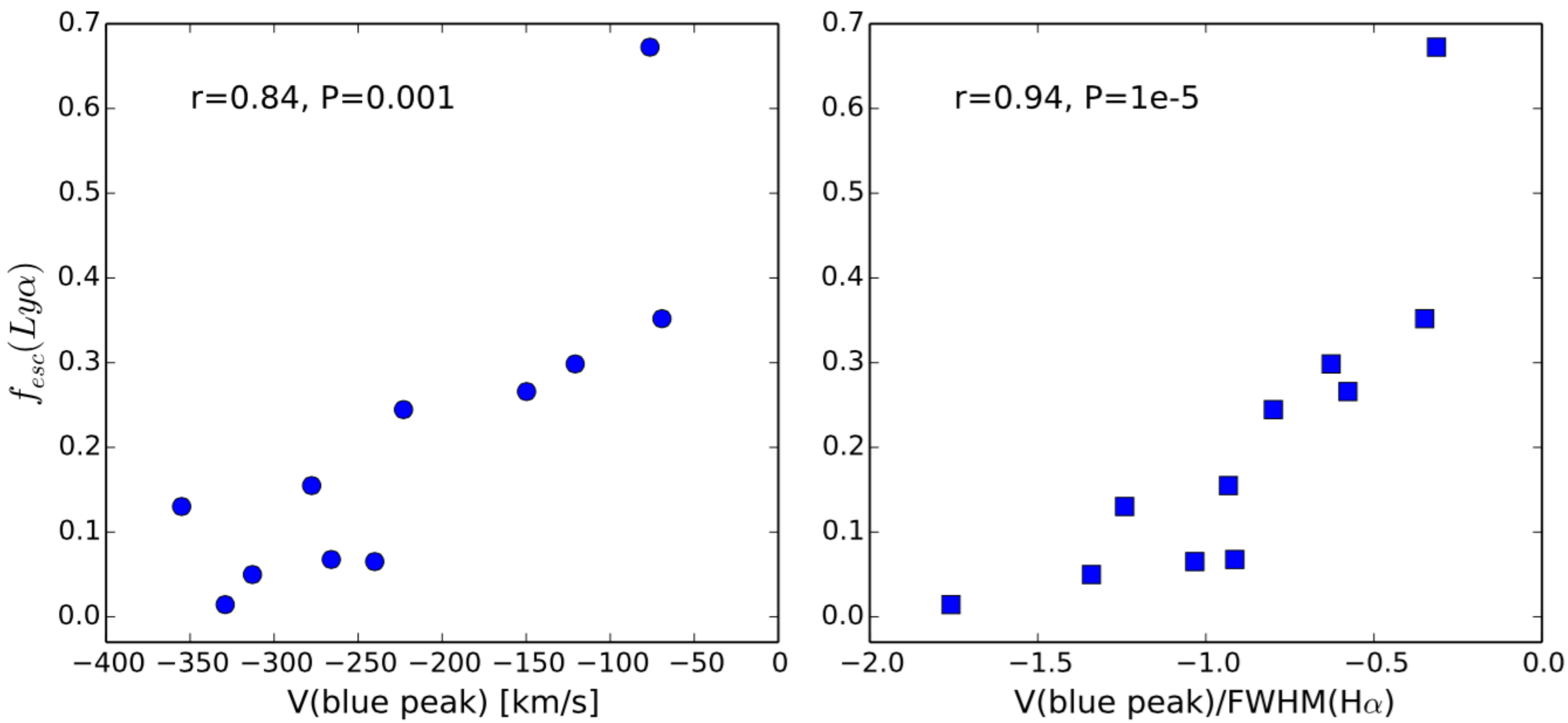
Similar physical conditions promote both escapes.

Compare with H-alpha.



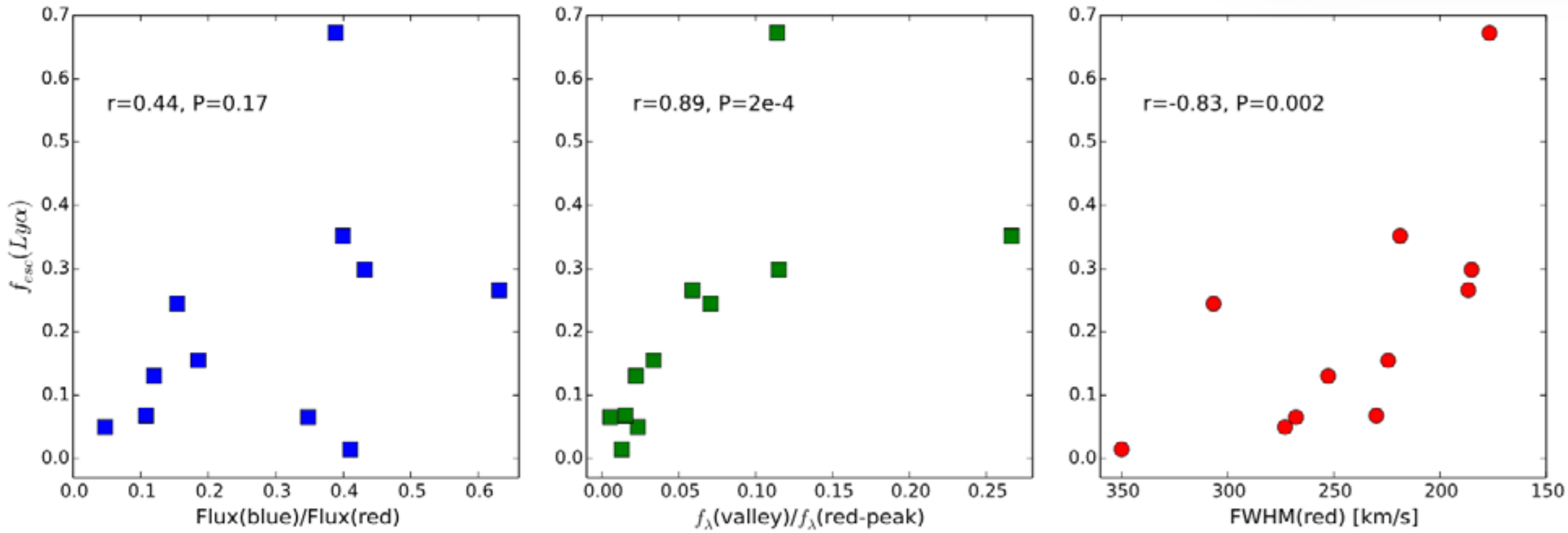
Yang, Gronke et al. 2016

Kinematics: Yang+ 2016



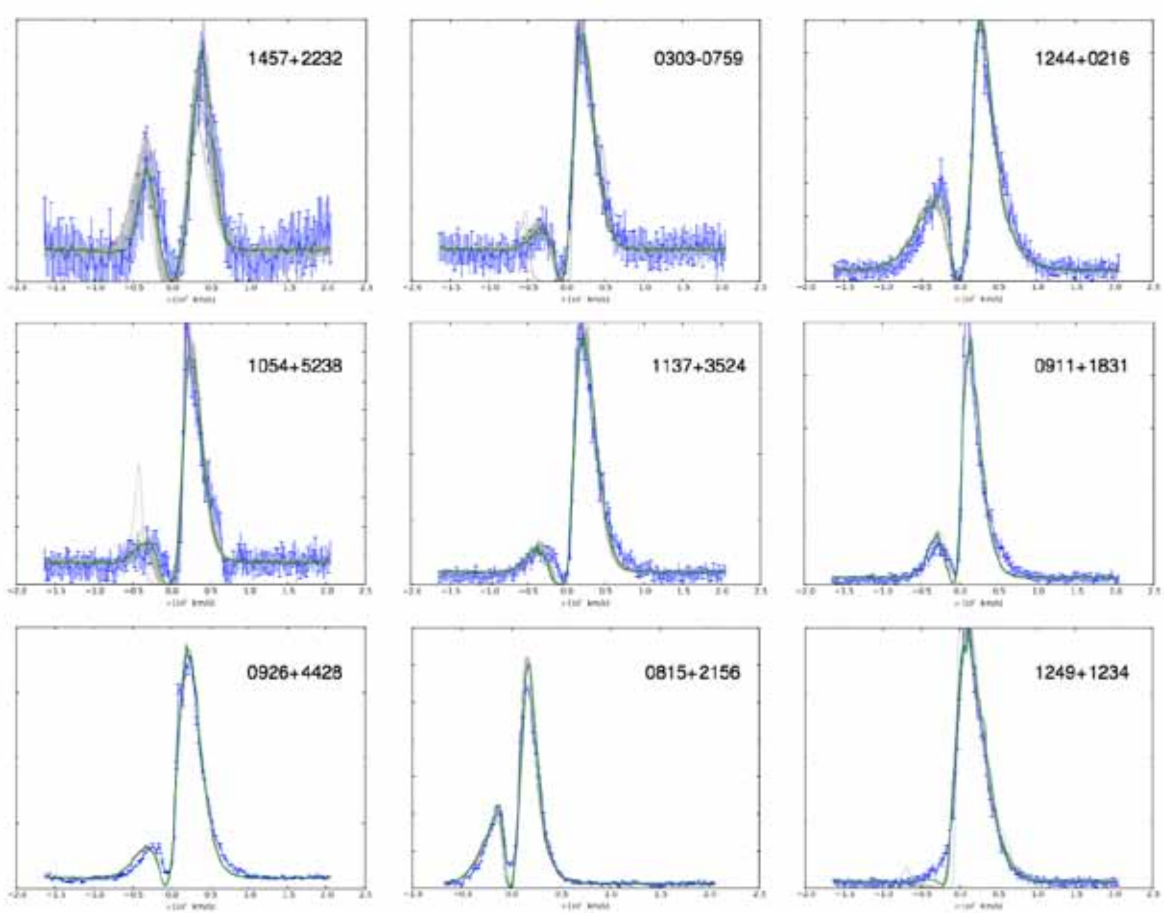
Kinematics II

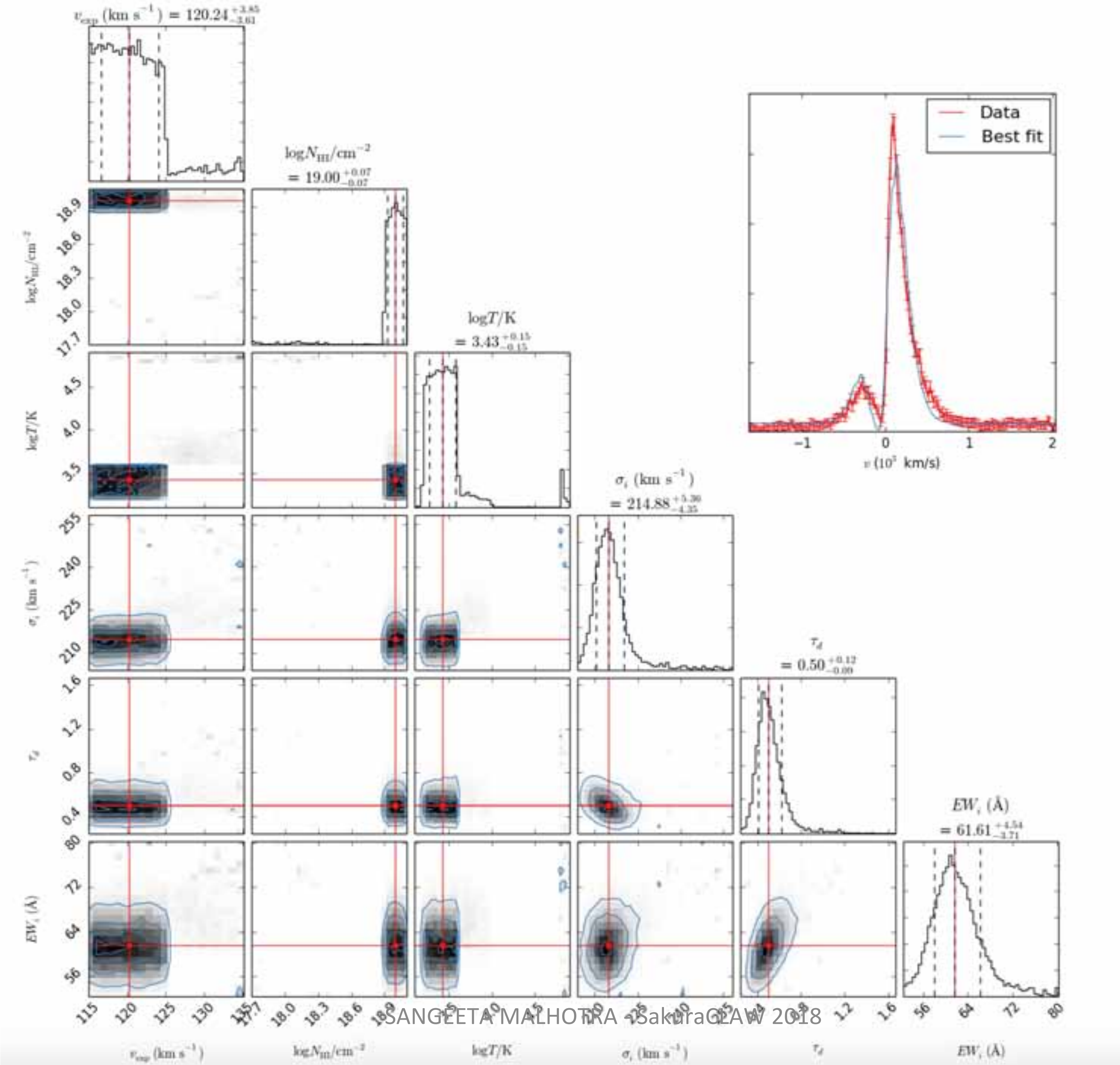
Yang+ 2016



Fitting models
(Gronke, Dijkstra+ 2015)

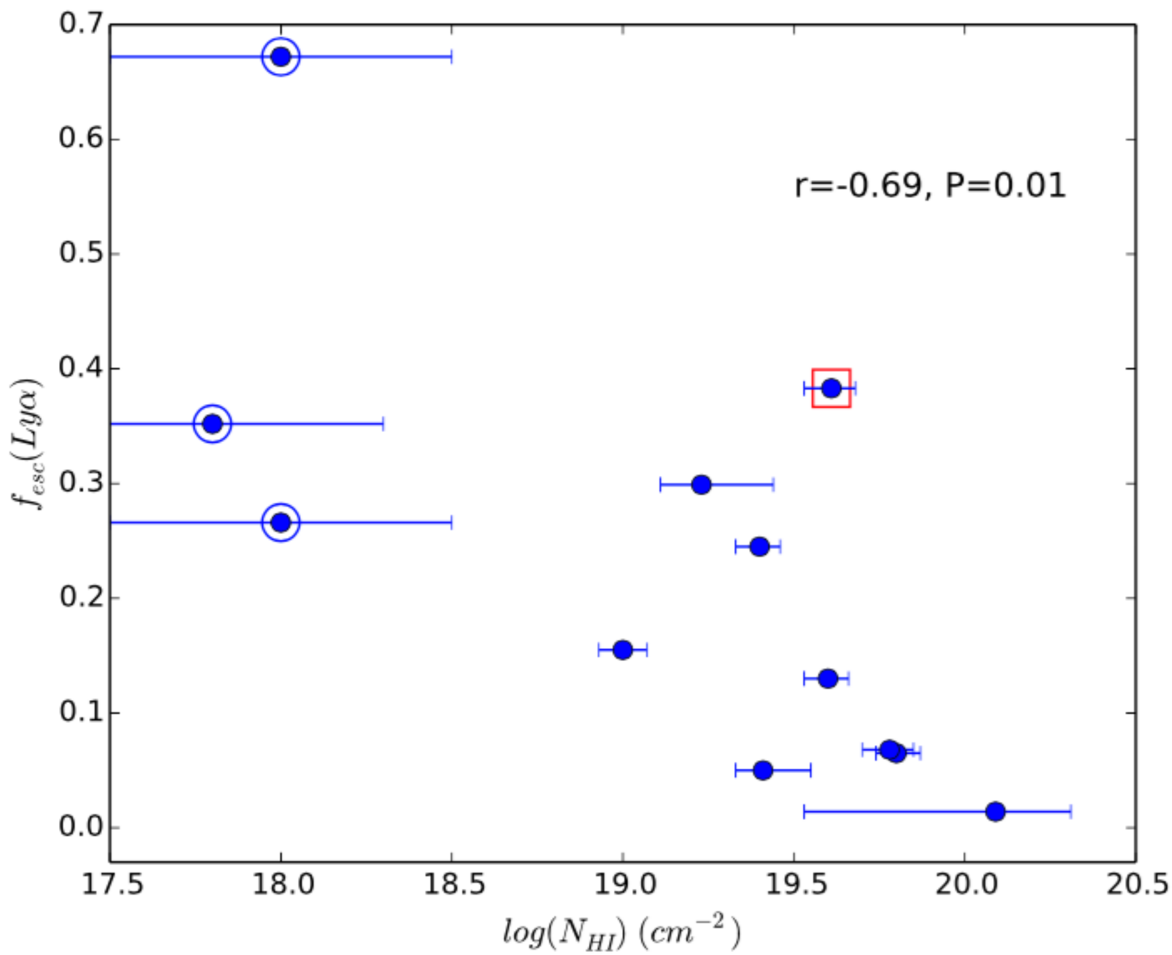
Yang+ 2016



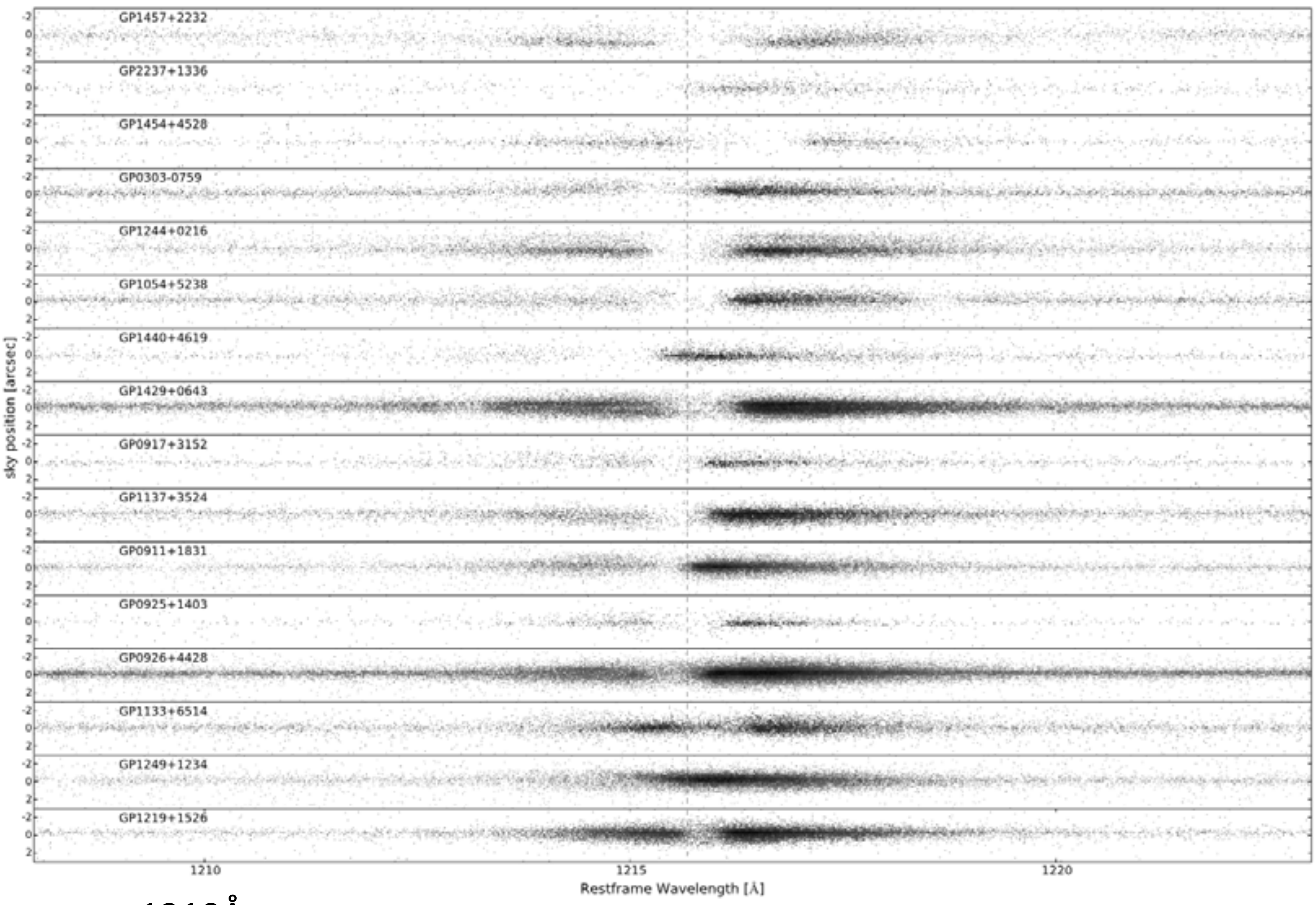

v_{exp} (km s^{-1}) = $120.24^{+3.85}_{-3.61}$
$\log N_{HI}$/cm^{-2} = $19.00^{+0.07}_{-0.07}$
$\log T$/K = $3.43^{+0.15}_{-0.15}$
σ_i (km s^{-1}) = $214.88^{+5.36}_{-4.35}$
τ_d = $0.50^{+0.12}_{-0.09}$
EW_i (Å) = $61.61^{+4.54}_{-3.71}$
Data
Best fit
v (10^3 km/s)
v_{exp} (km s^{-1})
$\log N_{HI}$/cm^{-2}
$\log T$/K
σ_i (km s^{-1})
τ_d
EW_i (Å)

Perhaps its the average column density of neutral gas.

Yang+ 2016

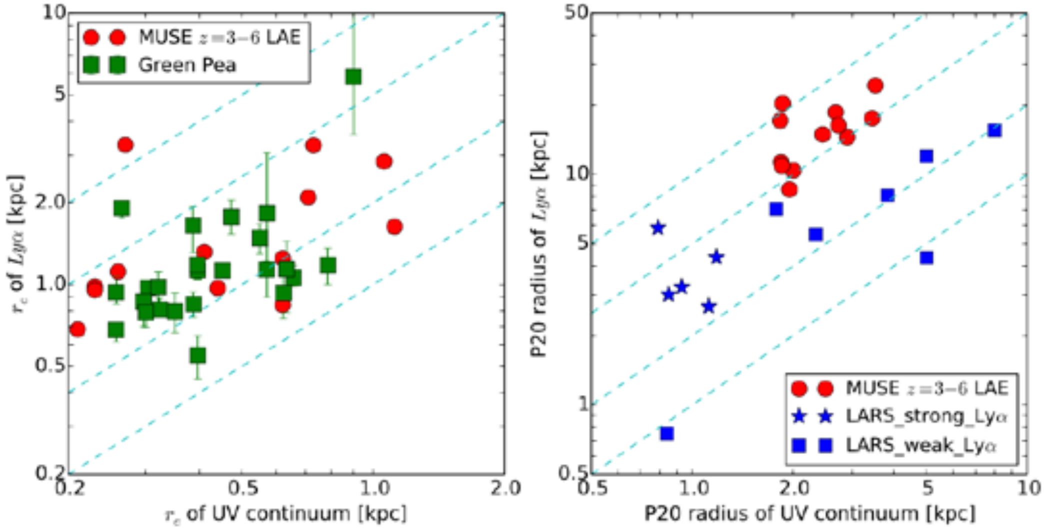


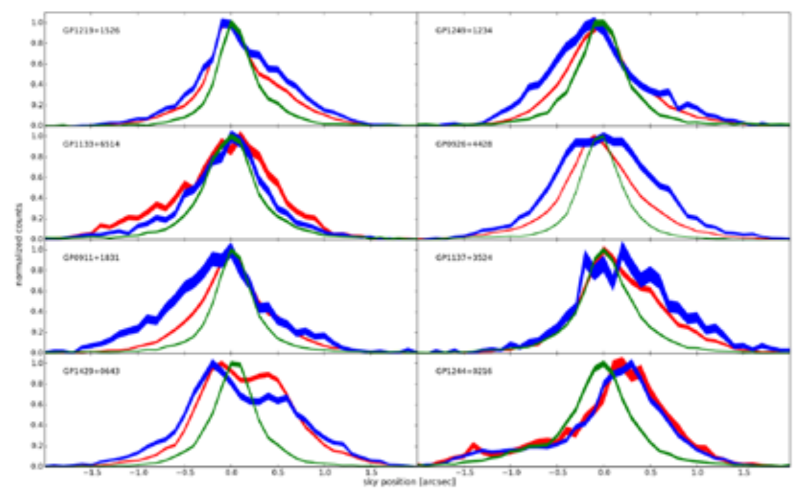
Sizes of Green Peas (Yang et al 2017a)



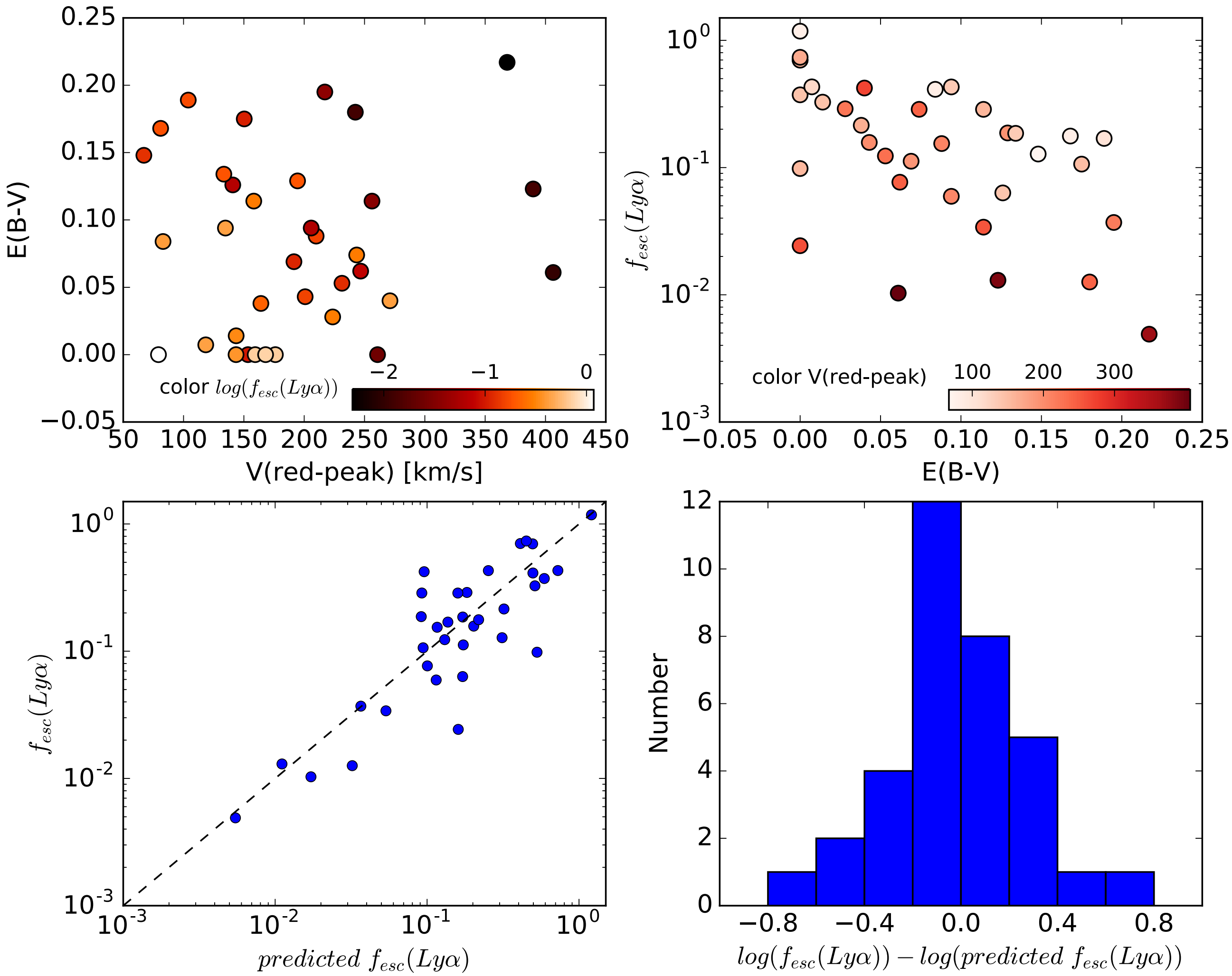
1210Å 1220Å

Yang et al 2017a (arXiv:1610.05767)





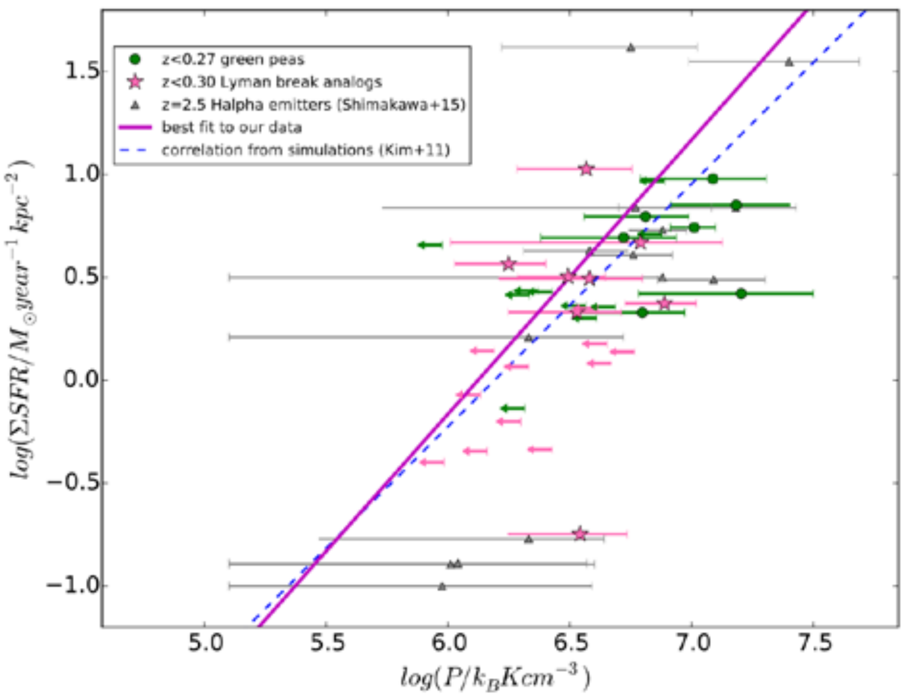
Predicting Ly-α Escape (Yang et al 2017b)



a relation between LyA escape fraction, nebular line dust extinction, and red peak velocity offset.

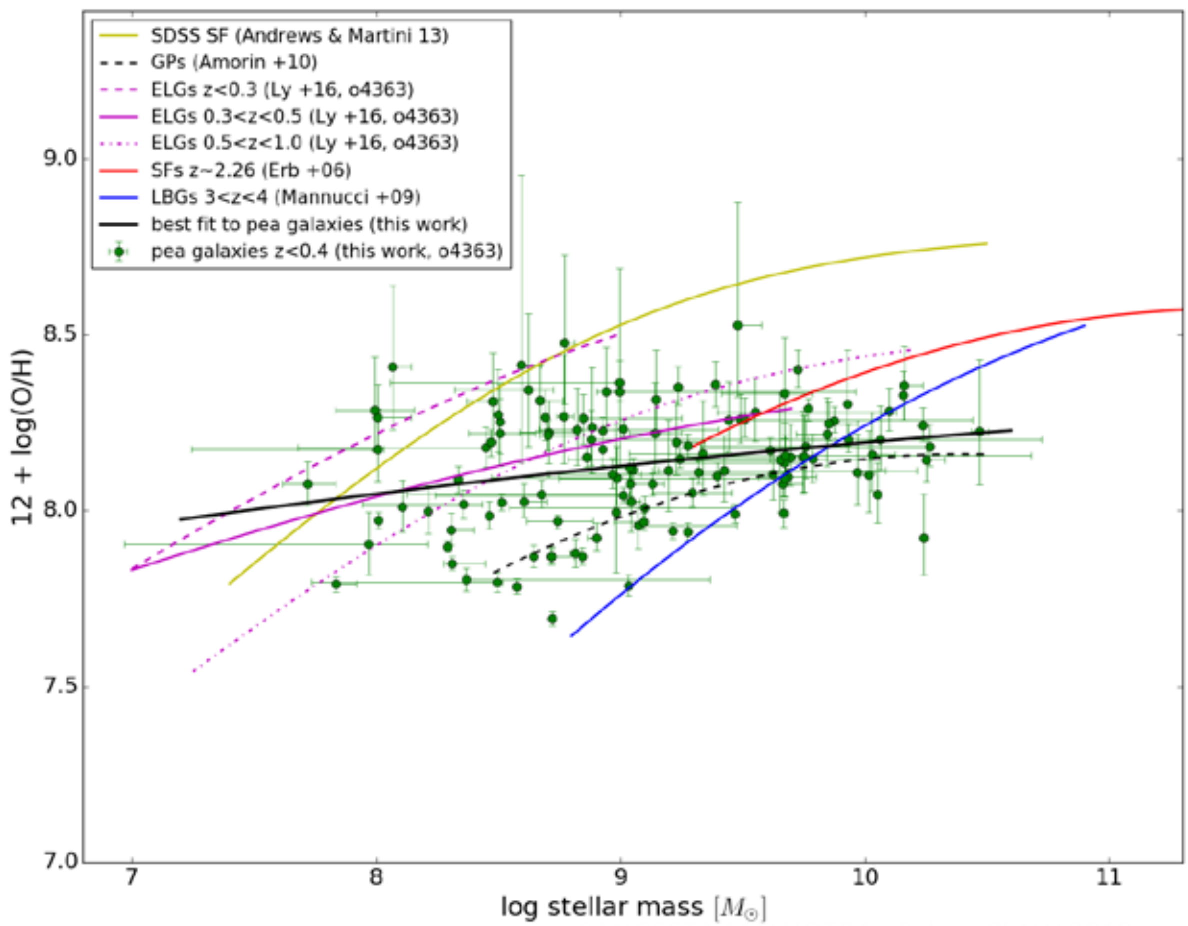
The scatter is a factor of 2. If the same relation holds for

Treating GPs as interesting galaxies:



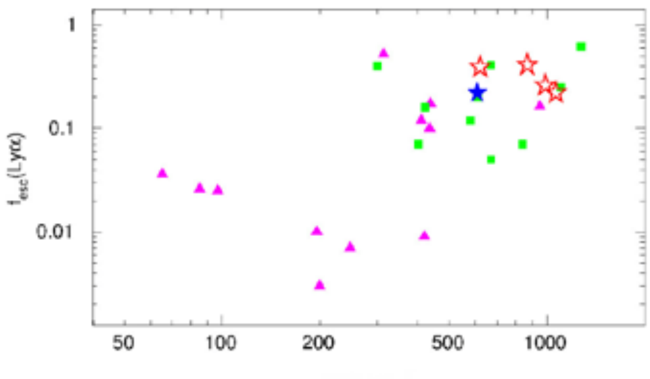
GPs show high Star-formation intensities, high thermal pressures in the HII regions, similar to, or higher than z~2-3 galaxies and Lyman-Break analogs (Jiang et al. 2018)

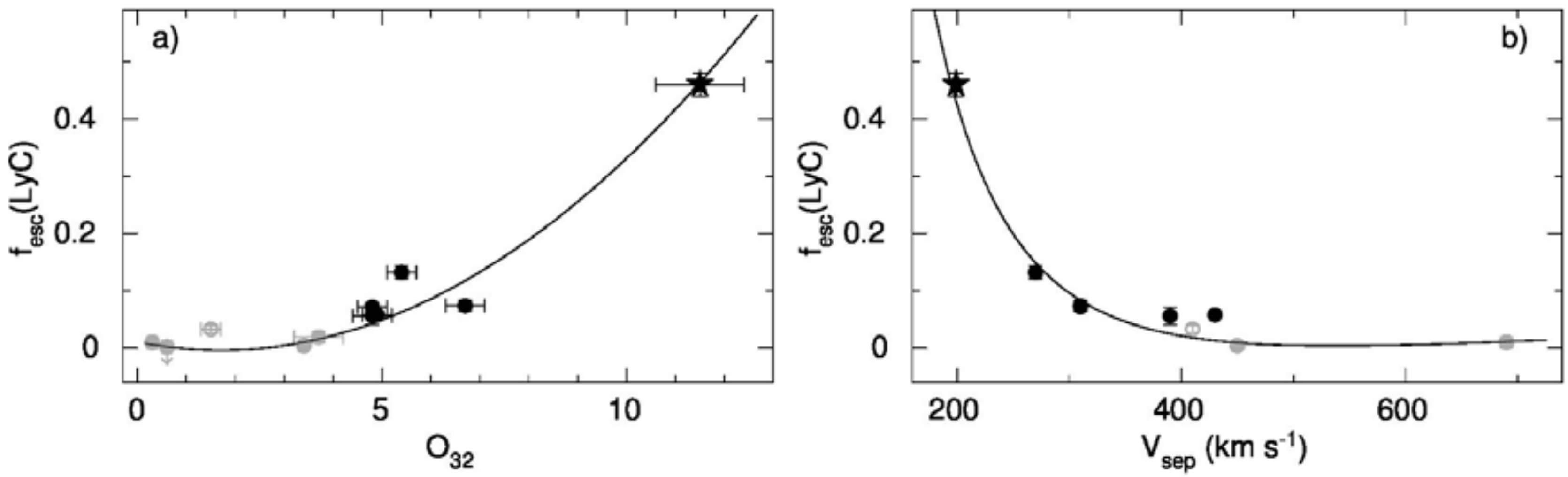
Treating GPs as interesting galaxies: mass-metallicity relations (Jiang thesis 2018)



Lyman-continuum escape

(Izotov et al. 2016, 2018)





It is hard to get high EW LyA in galaxies
A. Ferrara

Lets try something else…

Mon. Not. R. Astron. Soc. **336,** L33–L37 (2002)

Did globular clusters reionize the Universe?

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Accepted 2002 August 16. Received 2002 August 2; in original form 2002 April 24

The Astrophysical Journal, 757:9 (7pp), 2012 September 20 doi:10.1088/0004-637X/757/1/9

FORMATION OF METAL-POOR GLOBULAR CLUSTERS IN Lyα EMITTING GALAXIES IN THE EARLY UNIVERSE

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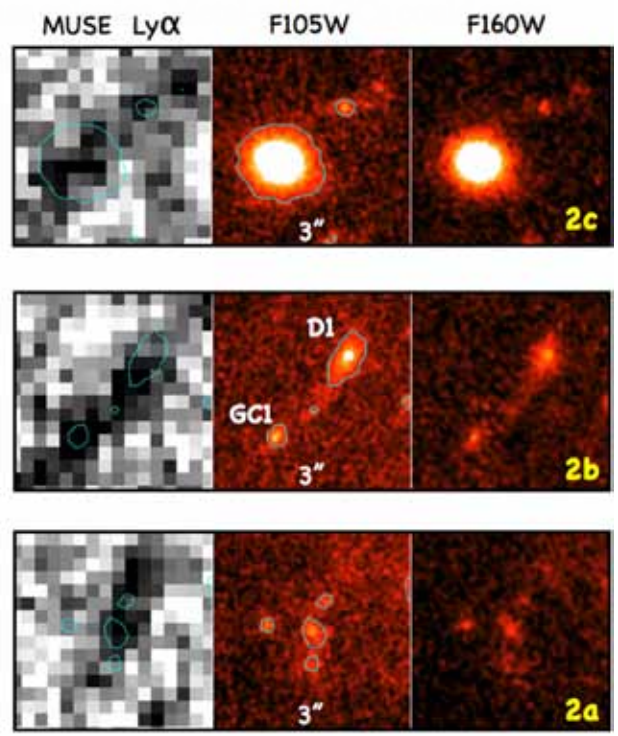
Received 2012 May 13; accepted 2012 July 18; published 2012 August 28

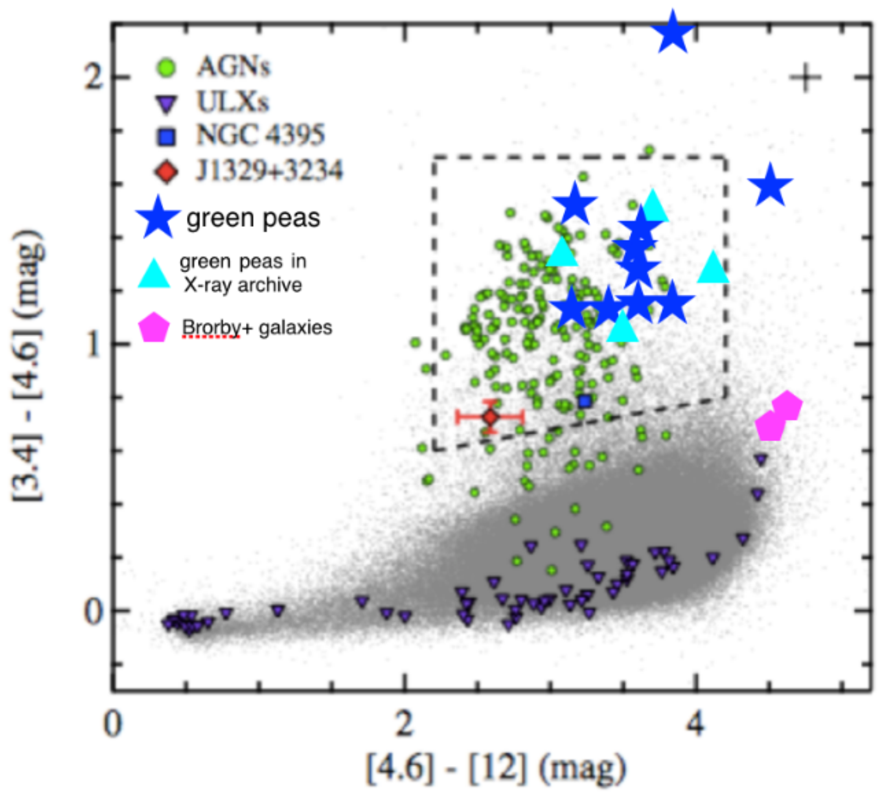
ABSTRACT

The size, mass, luminosity, and space density of Lyα emitting (LAE) galaxies observed at intermediate to high redshift agree with expectations for the properties of galaxies that formed metal-poor halo globular clusters (GCs). The low metallicity of these clusters is the result of their formation in low-
spiral galaxies along with their dwarf galaxy hosts, unlike metal-rich G



Vanzella et al. 2017

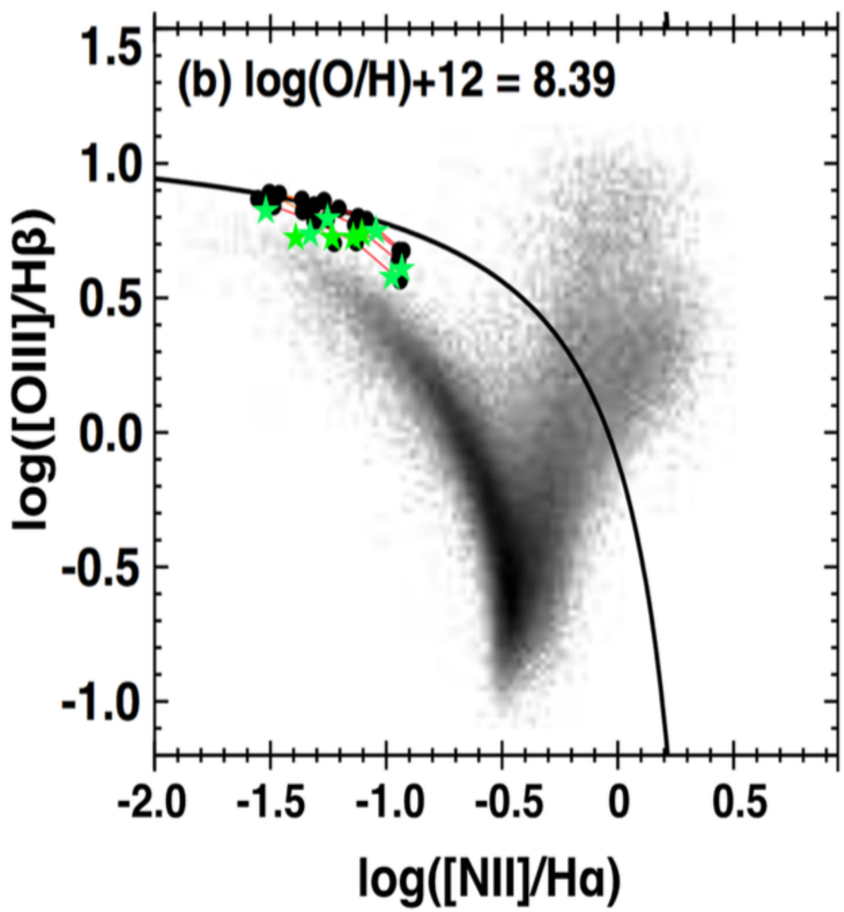
Black Holes in Green Peas?



About 30% of z=0.3 GALEX sample is AGN (Finkelstein et al. 2009)

About 20% of GPs sample shows mid-IR (WISE) colors of AGN (Malhotra et al. 2018). This is only the sample selected to be SF from BPT diagram.

What about BPT diagram at low metallicities?



Kewley+ 2013, Groves+ 2008

Conclusions (for now)

- Green peas (Blueberries) are good analogs of Lyman-alpha galaxies and have high escape fractions for Lyman-alpha.
- Low metallicity, compact sizes, low dust extinction, young stellar population ages, low stellar masses, high gas pressures, all common with high-z.
- They also have high escape fraction for ionizing radiation – the kind of galaxies responsible for reionization.
- Can use full properties to understand Lya escape and predict Lya for individual galaxies to sharpen reionization test.
- AGN involvement ruled out? Stay tuned!
- ***Many thanks to collaborators – Huan Yang, Max Gronke, TianXing Jiang, and Rosie Peillu.***