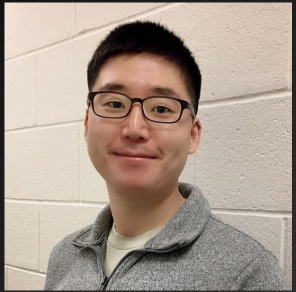
# Characterizing Strongly-Lensed Lyman-Alpha Galaxies at z > 4

Speaker - Alexander Navarre
PhD Advisor - Matthew Bayliss
Email - navarrae@mail.uc.edu

SGAS
Sloan Giant Arcs Survey

**Riley Owens**
-University of Cincinnati
-10:00 tomorrow



**Keunho Kim**
-University of Cincinnati
-12:30 tomorrow

**Emil Rivera-Thorsen**
-Stockholm University
- 2:40 tomorrow

# Table of Contents

1

## Background & Motivation

2

## Sample & Methods

3

## Results

4

## Discussion

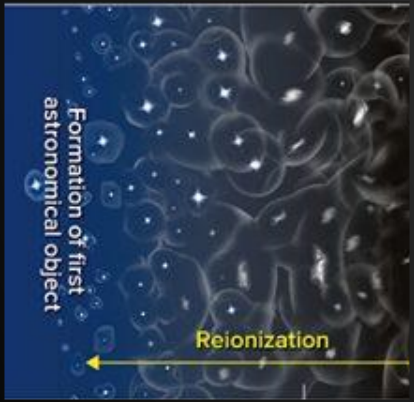
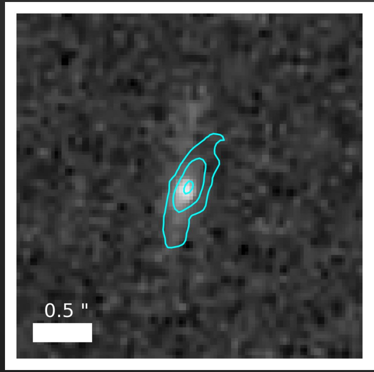
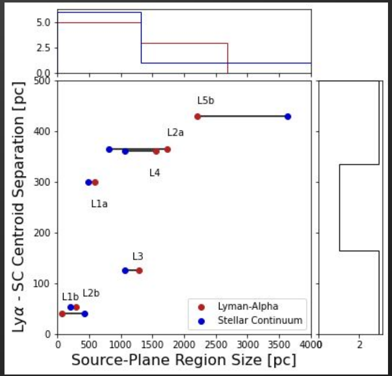
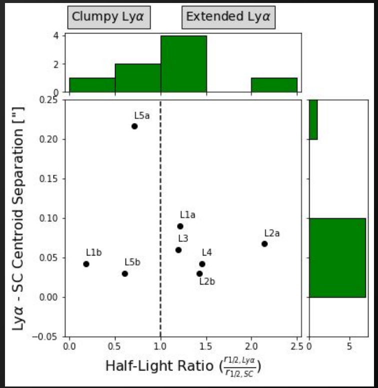



Image Credit: NAOJ



# Background & Motivation

Universe Cools,
Neutral IGM

# Cosmic Reionization

Time Passes,
Ionized IGM

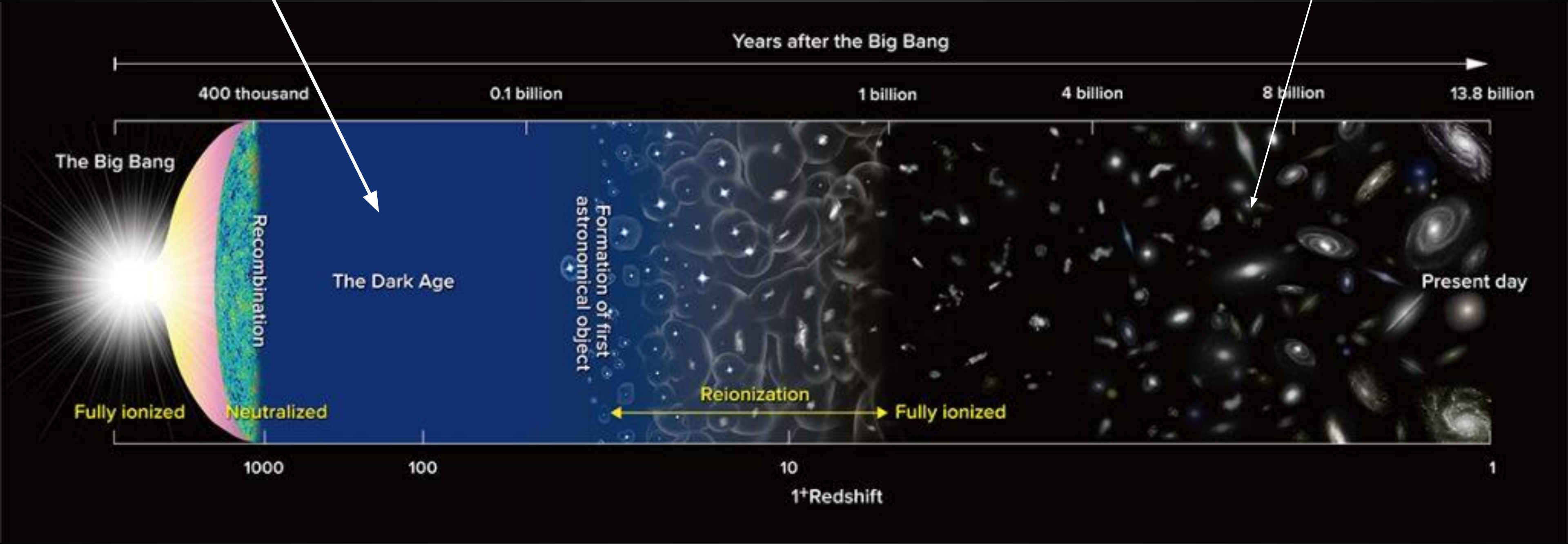



Image Credit: NAOJ

# What Caused Reionization?

ARTWORK: NASA, ESA, Joseph Olmsted (STScI)

## Quasars

Unclear role at $z > 6$

- **<30 %** (Masters 2012, Ricci 2017)
- **Quasar-Dominated** (Madau & Haardt 2015)

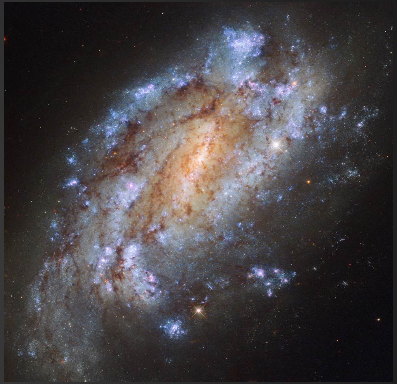


Image Credit: NASA, ESA, Hubble

## Star-Forming Galaxies (SFGs)

Lyman-Continuum (LyC) photons from young stars escape host galaxy

How do they create enough ionizing photons?

# Star-Forming Galaxies And Lyman Radiation

- Problems with observing LyC
  - LyC escape depends on neutral Hydrogen morphology
  - Direct detection difficult above z ~ 4.5
- Lyman-Alpha (Lyα) is bright and resonantly scatters with neutral Hydrogen -> complex radiative transfer

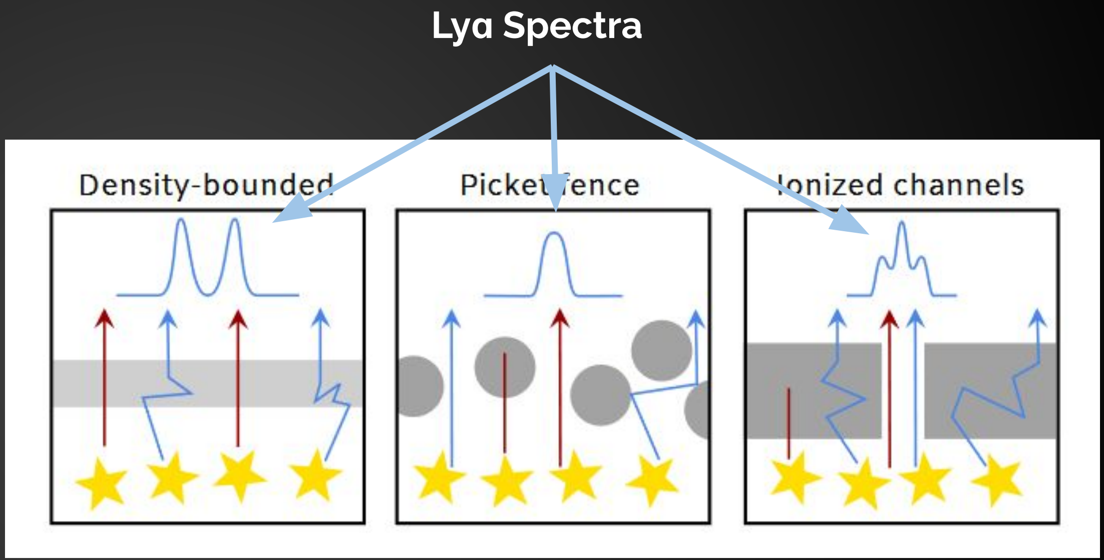



**Figure Credit: M. Gronke; (Rivera-Thorsen et. al 2017)**

Blue - Lyα

Red - LyC

Grey - Neutral Hydrogen

# Lyα Size

Understanding Lyα morphology -> How could LyC photons have escaped at high z.

## LARS

### Lyman-Alpha Reference Survey

**Z = 0**

- $0.6 < r_{1/2} < 12.21$ kpc
- Guaita et. al 2015

**Z = 0**

- $1.03 < r_s < 9.05$ kpc
- Rakesh et. al 2022

**Z = 0**

- $0.2 < r_{p, 20} < 28.0$ kpc
- Melinder et. al 2023

## Compact Emission

**z = 3.1**

- $\lesssim 1.5$ kpc
- Bond et. al 2010

**z = 4.4**

- $\lesssim 2$ kpc
- Finkelstein et. al 2011

**0.1 < z < 0.35**

- $r \sim 0.33$ kpc
- Kim et. al 2021

## Extended Emission

**z = 2.6**

- $\gtrsim 80$ kpc
- Stiedel et. al 2011

**2.9 < z < 6.7 (Lensed LAEs)**

- $1.15 < c_{Lya} < 33.3$
- Claeyssens et. al 2022

# Lyα Size

Understanding Lyα morphology -> How could LyC photons have escaped at high z.

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**0.1 < z < 0.35**

- r ~ 0.33 kpc
- Kim et. al 2021

## Extended Emission

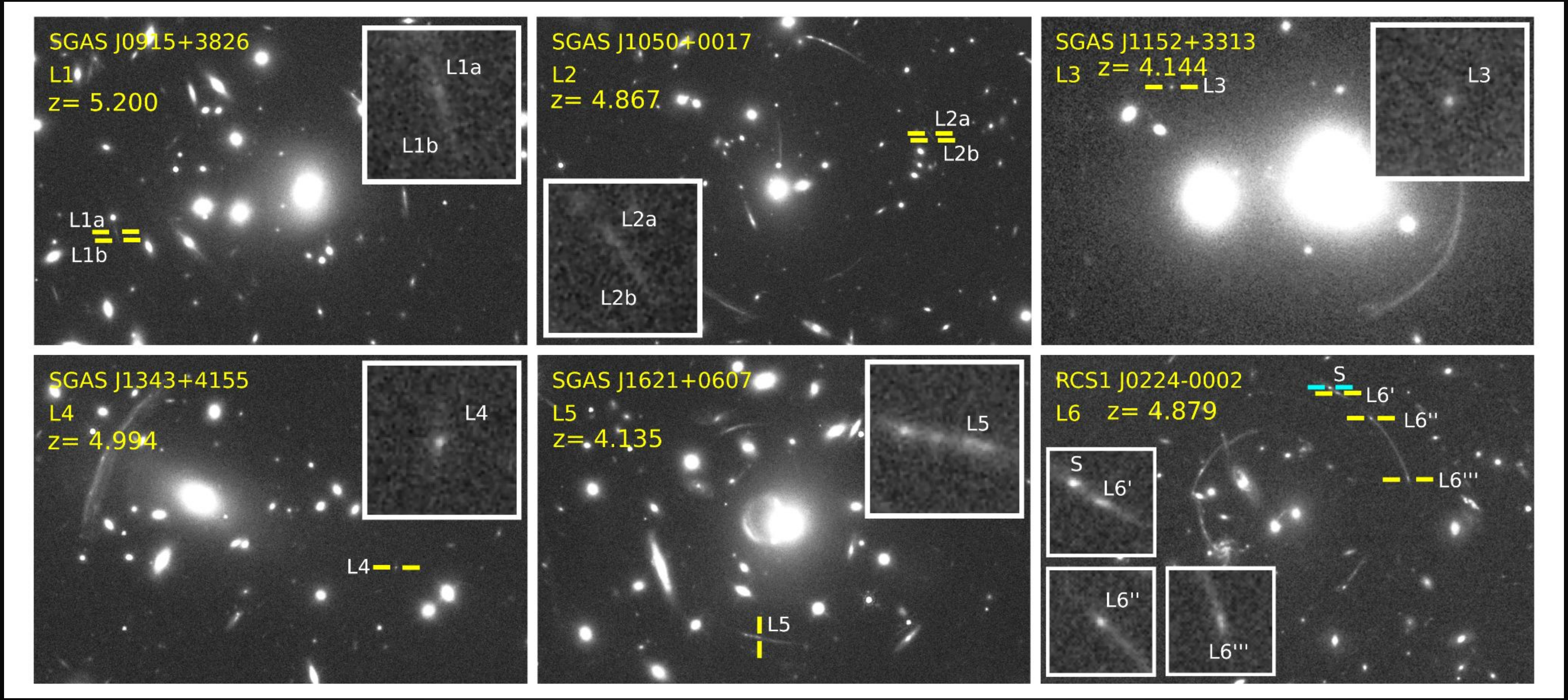
**z = 2.6**

**2.9 < z < 6.7 (Lensed LAEs)**

- $1.15 < c_{Lya} < 33.3$
- Claeyssens et. al 2022

See: Rest of Conference!

# Sample - Lyman-Alpha Emitters (LAEs)

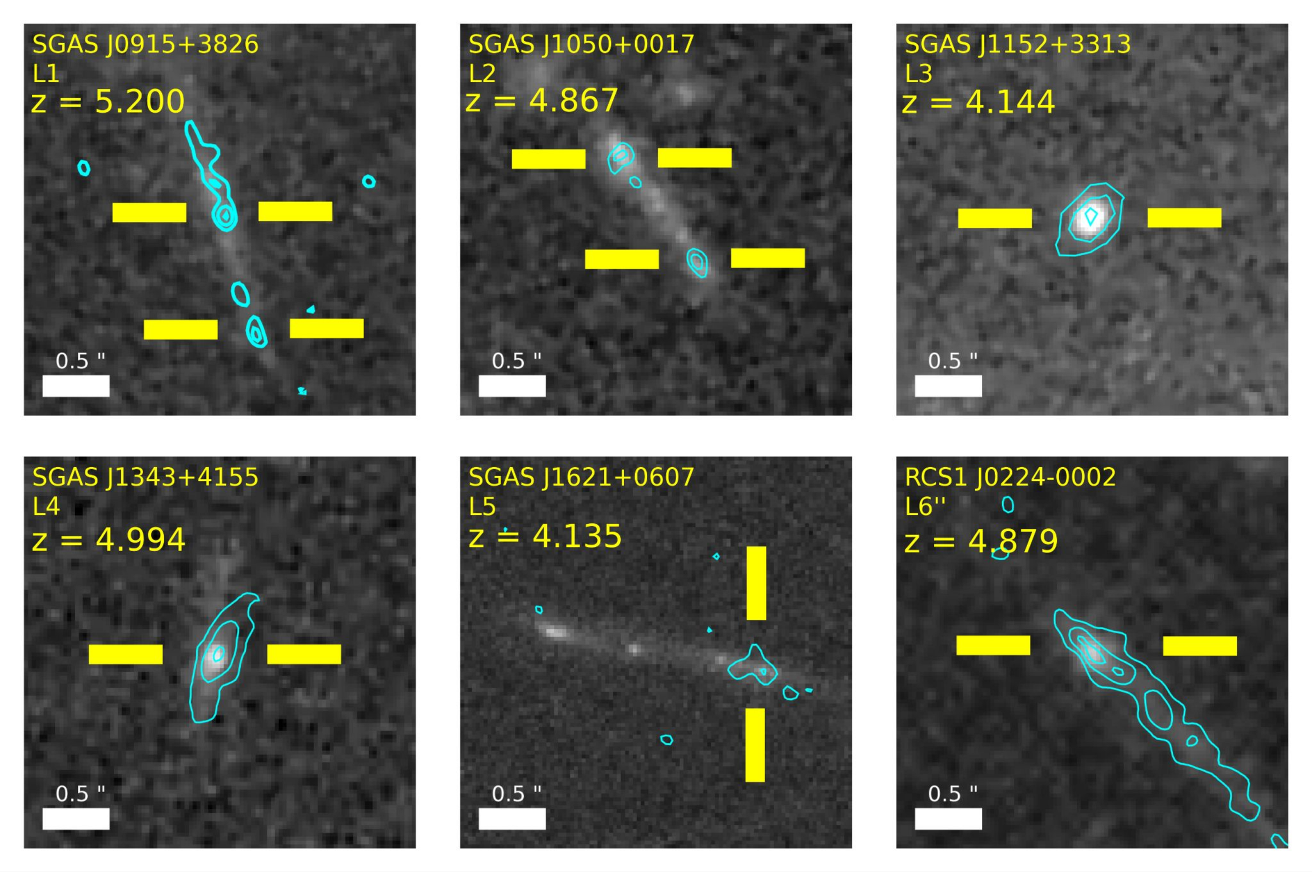


# Motivating Questions

1. What are the physical properties of high-redshift LAEs?
2. Is their Lya distribution smooth or clumpy?
3. Where, and how often, is the Lya emission spatially offset from the UV continuum emission?

# Sample & Methods

# Sample - Lyman-Alpha Emitters (LAEs)



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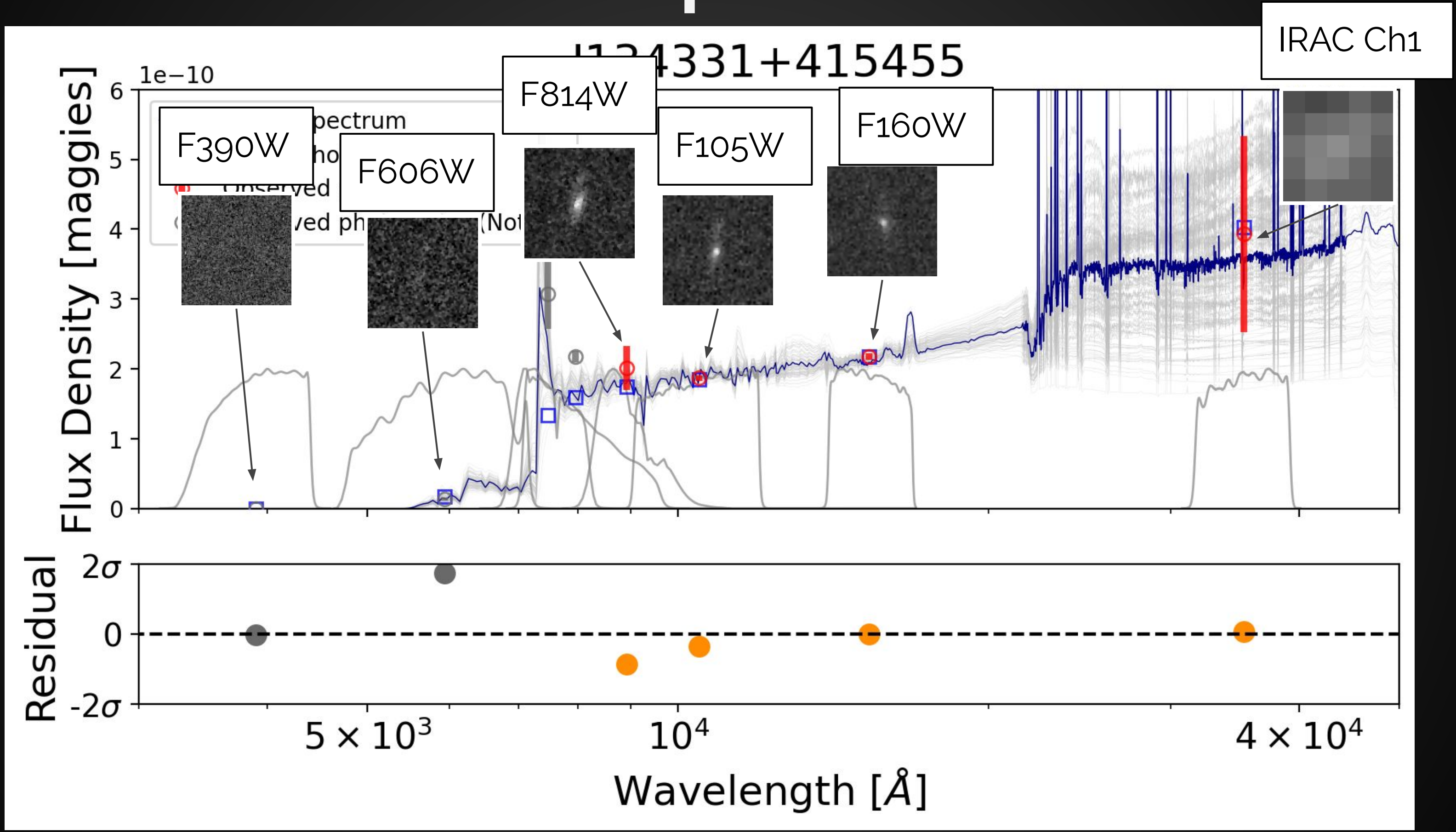
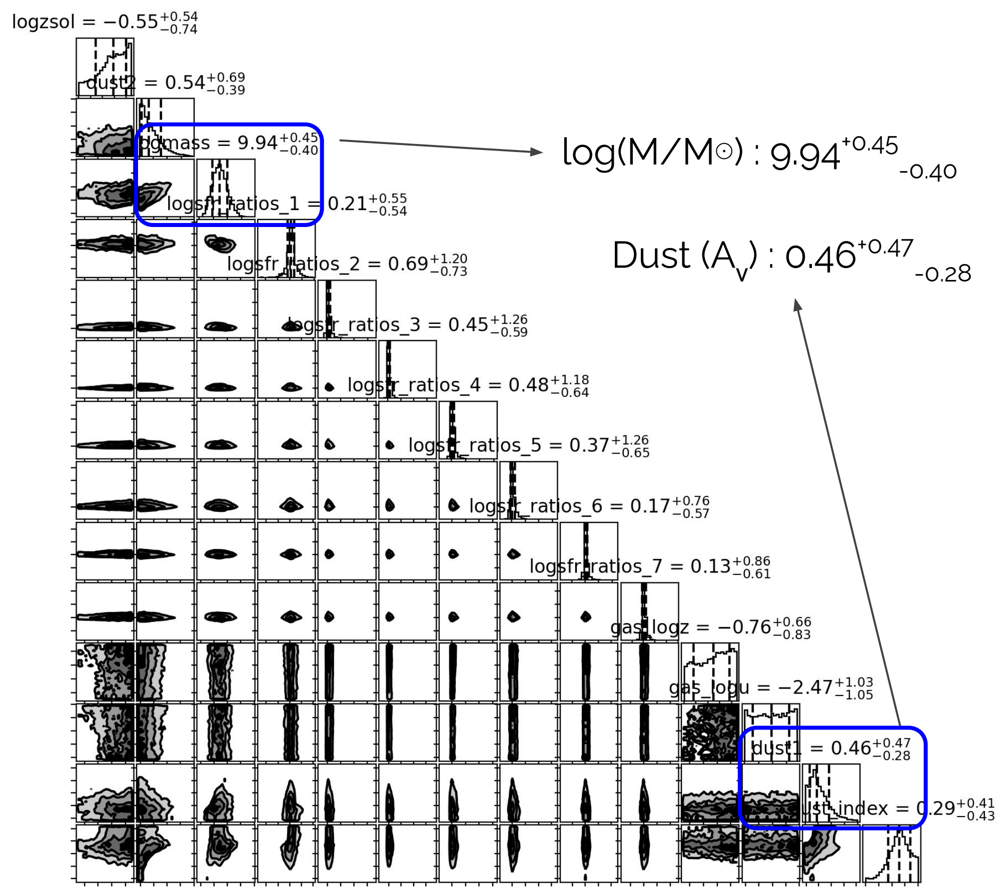
# Prospector

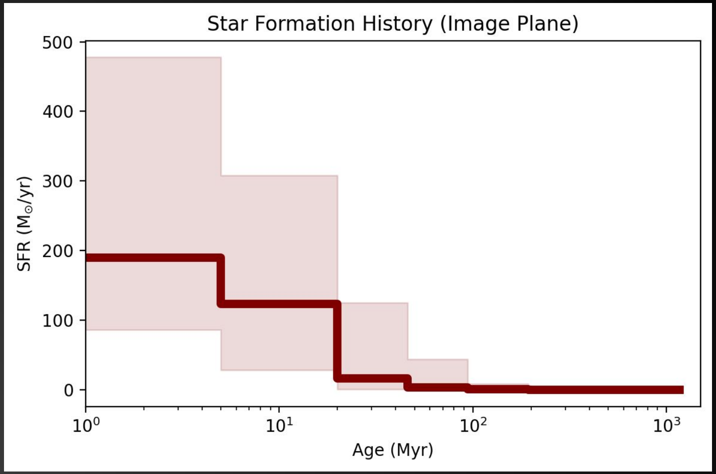

J134331+415455
1e−10
Flux Density [maggies]
pectrum
Observed
ved ph
(Not
F390W
F606W
F814W
F105W
F160W
IRAC Ch1
Residual
2σ
0
-2σ
0
1
2
3
4
5
6
$5 \times 10^3$
$10^4$
$4 \times 10^4$
Wavelength [Å]

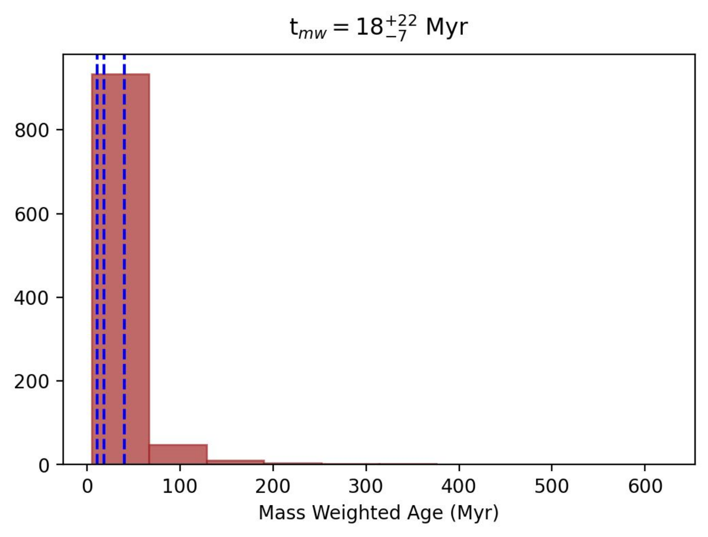
# Prospector




log(M/M⊙) : $9.94^{+0.45}_{-0.40}$

Dust ($A_v$) : $0.46^{+0.47}_{-0.28}$



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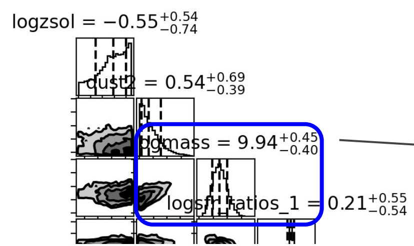


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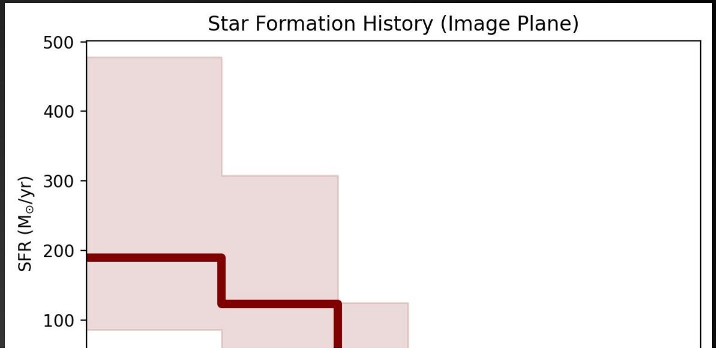
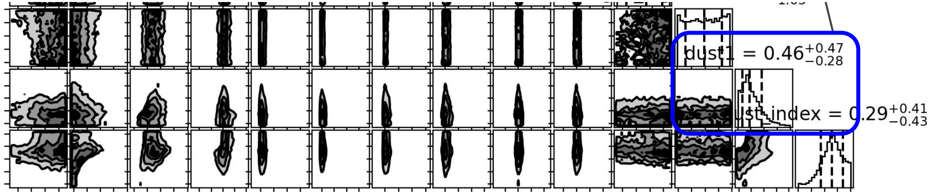
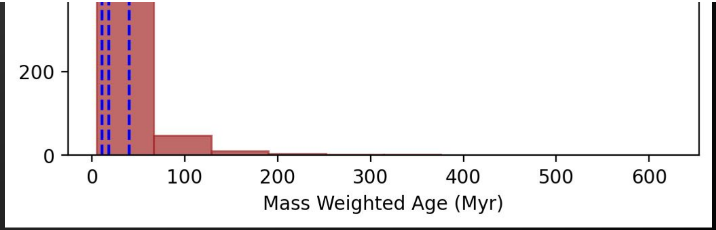



| Identifier | log(Lensed Stellar Mass [$M_\odot$]) | log(Intrinsic Stellar Mass [$M_\odot$]) | Mass-Weighted Age [Myr] | Dust1 [$A_V$] |
|---|---|---|---|---|
| L1 | $9.85^{+0.62}_{-0.48}$ | $8.15^{+0.64}_{-0.51}$ | $17^{+19}_{-8}$ | $0.10^{+0.23}_{-0.08}$ |
| L2 | $9.72^{+0.43}_{-0.61}$ | $8.60^{+0.44}_{-0.61}$ | $8^{+9}_{-3}$ | $0.09^{+0.14}_{-0.07}$ |
| L3 | $9.69^{+0.58}_{-0.68}$ | $7.79^{+0.58}_{-0.68}$ | $33^{+83}_{-20}$ | $0.57^{+0.84}_{-0.43}$ |
| L4 | $9.94^{+0.45}_{-0.40}$ | $8.82^{+0.45}_{-0.40}$ | $20^{+27}_{-9}$ | $0.46^{+0.47}_{-0.28}$ |
| L5 | $10.41^{+0.09}_{-0.08}$ | $8.71^{+0.10}_{-0.10}$ | $7^{+2}_{-1}$ | $0.23^{+0.06}_{-0.06}$ |
| L6 | $10.55^{+0.26}_{-0.26}$ | $9.24^{+0.47}_{-0.37}$ | $16^{+11}_{-06}$ | $0.42^{+0.56}_{-0.31}$ |



# Motivating Questions

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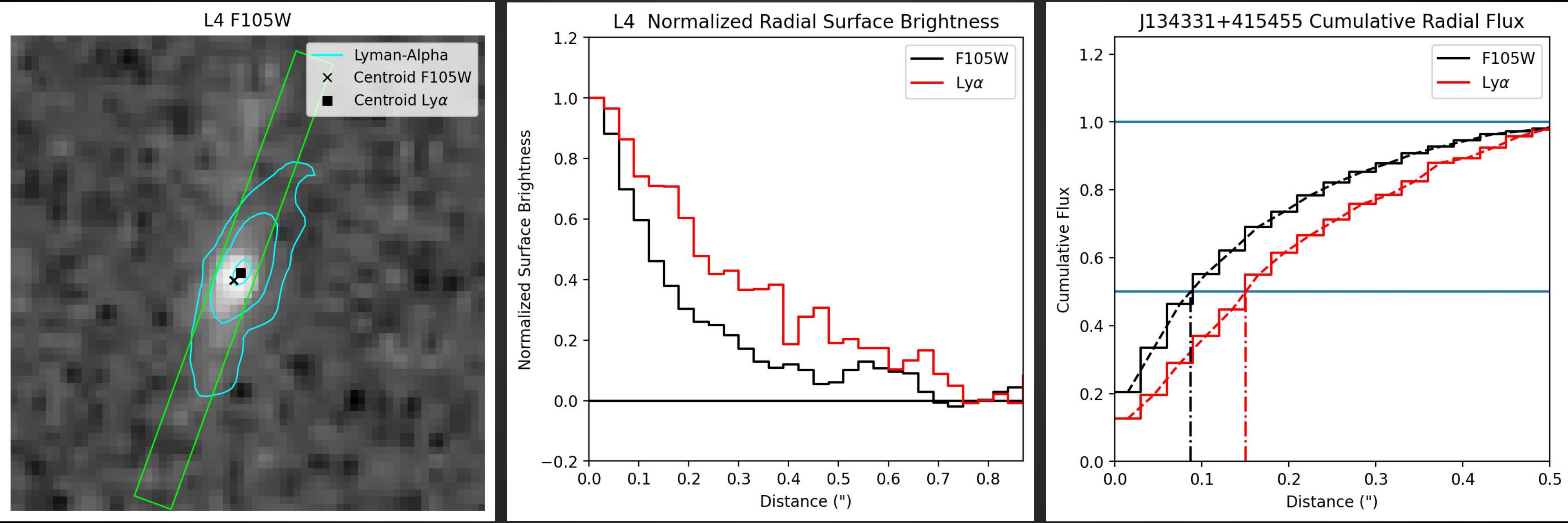
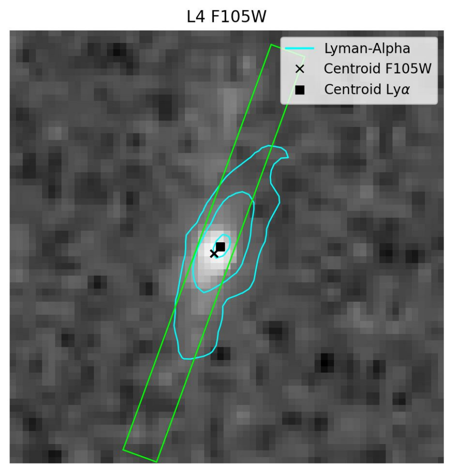
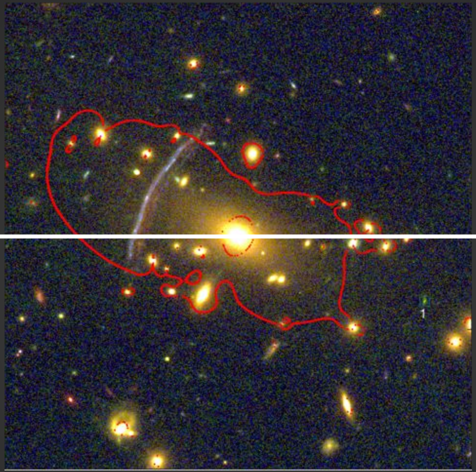
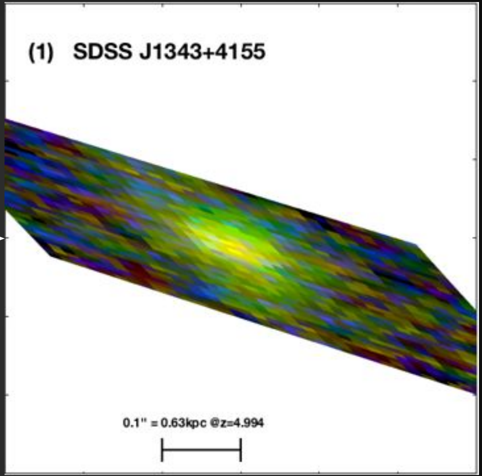
# Angular Sizes



# Angular Size -> Physical Size



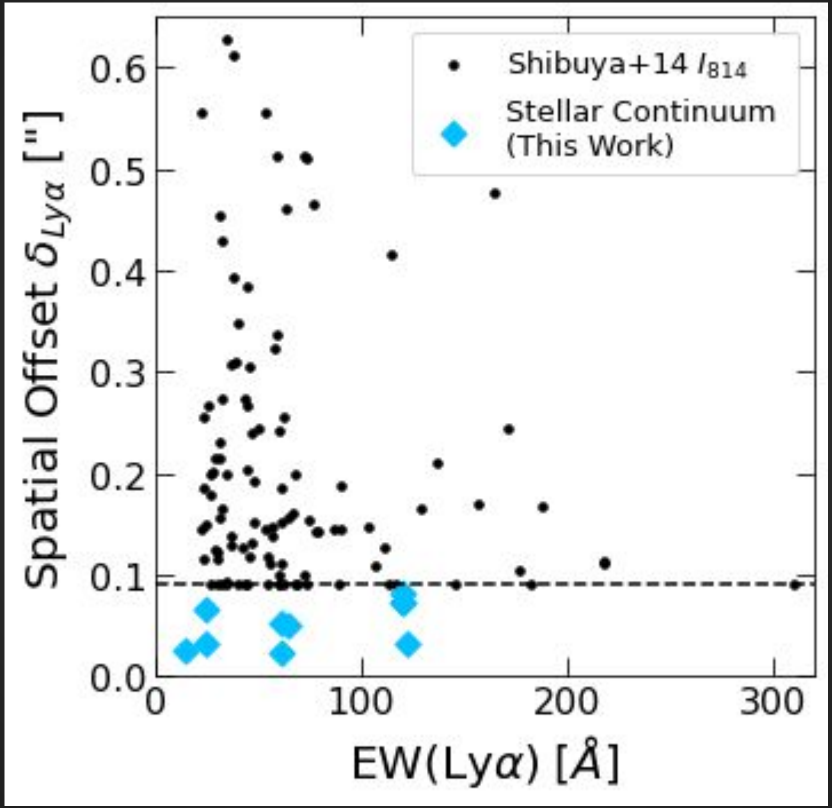



Lens Models from Sharon et. al 2020

- Half-Light Length
  - Lyα : 800 pc
  - Continuum : 500 pc
- Centroid Separation
  - 350 pc

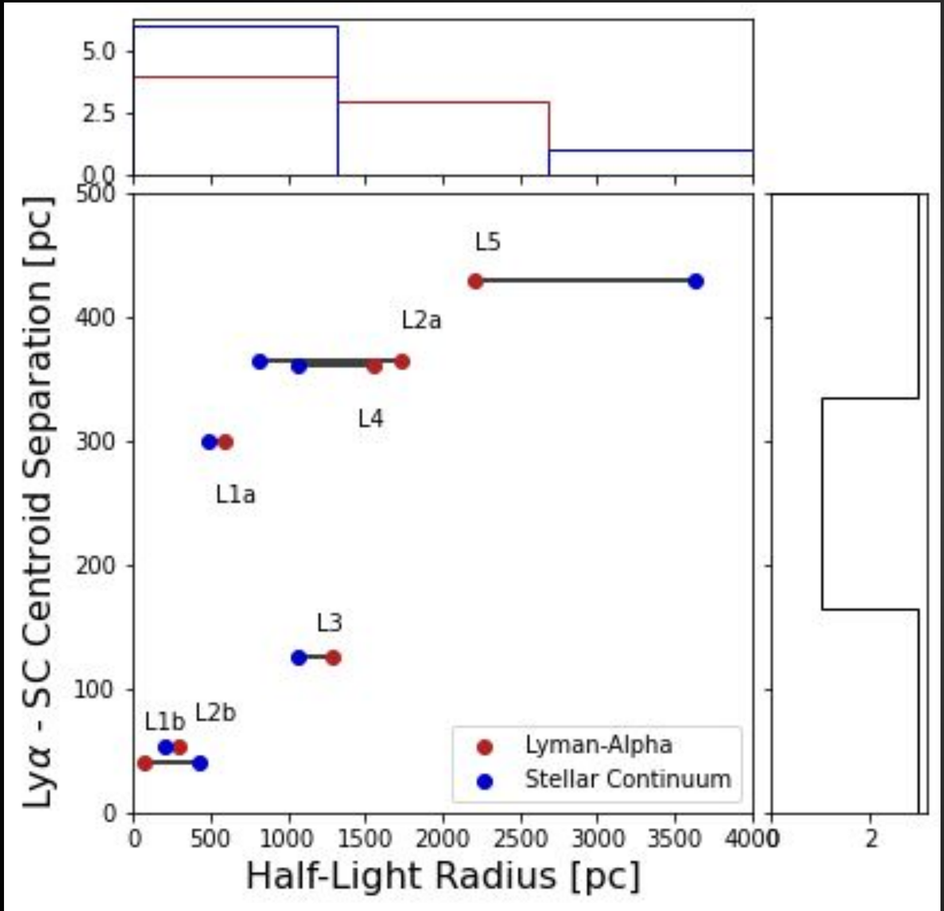
# Results

# Lyman-Alpha Spatial Offsets




Shibuya et. al 2014

# Physical Sizes & Offsets




Pearson Correlation Coefficient

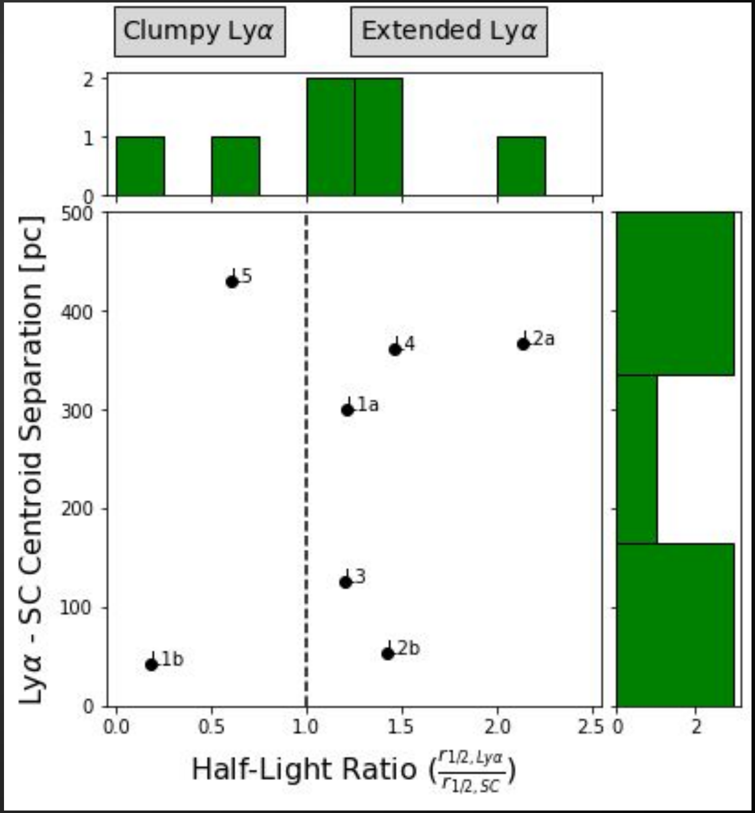
p = 0.83

p = 0.62

# Clumpy vs. Extended

$$\text{Half Light Ratio} = \frac{\text{Half Light Radius}(Ly\alpha)}{\text{Half Light Radius (Stellar Continuum)}}$$

Pearson Correlation Coefficient
p = 0.32



# Discussion

# Motivating Questions

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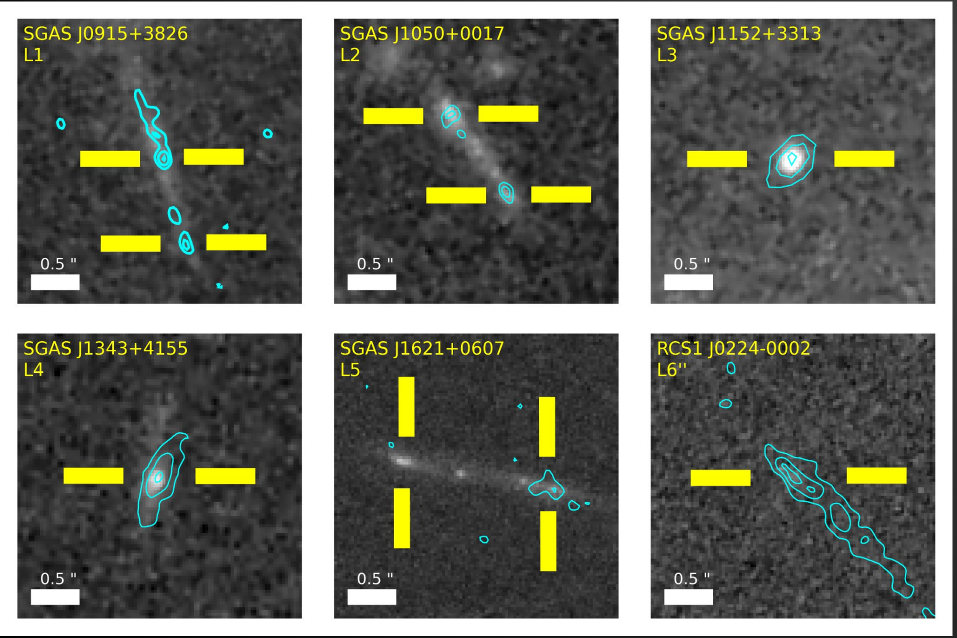
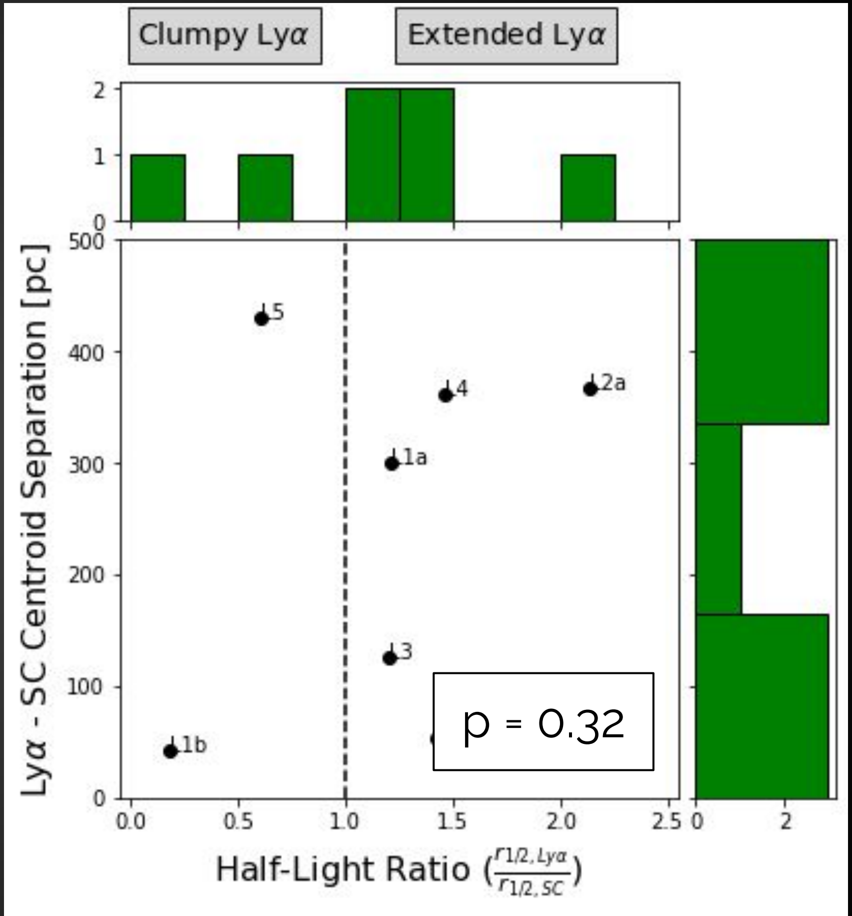
- Stellar mass of 7.5 < log(M) < 9.5
- Age < 50 Myr, consistent with young, massive stars
- Low to moderate dust values

# Is the Lya distribution smooth or clumpy?

- Both!
  - LAEs with multiple, compact, regions.
  - LAEs with one, extended region.



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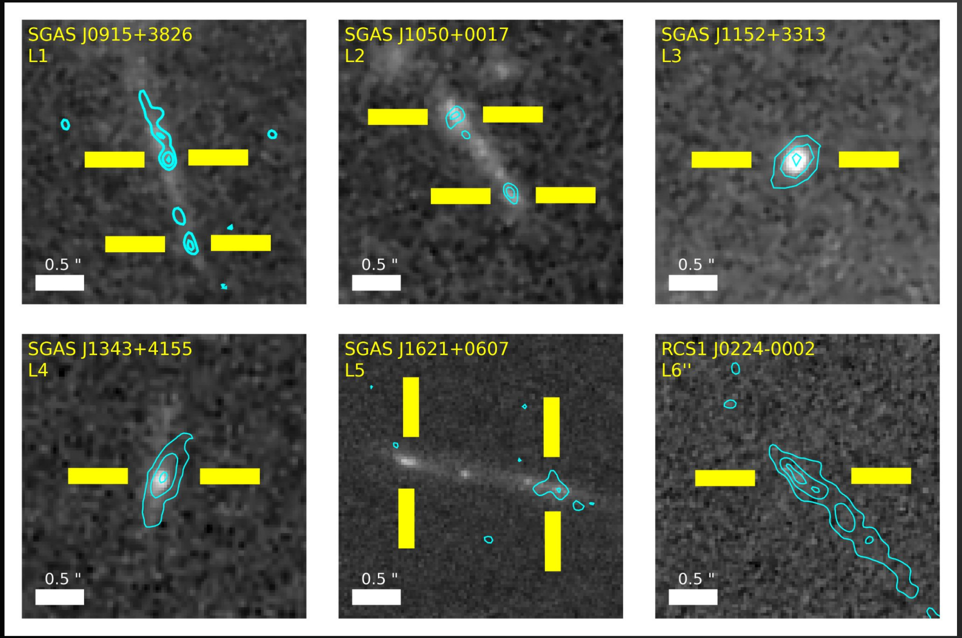


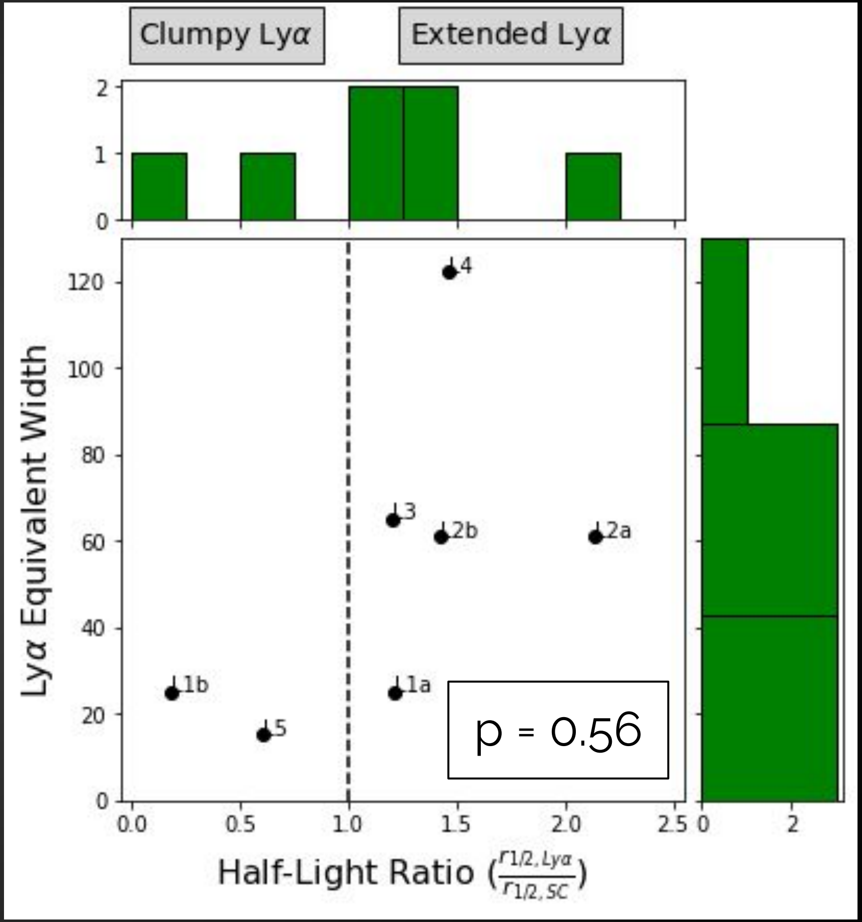

# Questions

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