Lyα and UV Sizes of Green Pea Galaxies

Huan Yang1,2, Sangeeta Malhotra2, James E. Rhoads2, Claus Leitherer1, Aida Wofford1, Tianxing Jiang2, and Junxian Wang1
1 CAS Key Laboratory for Research in Galaxies and Cosmology, Department of Astronomy, University of Science and Technology of China, China; huan.y@asu.edu
2 Arizona State University, School of Earth and Space Exploration, USA
3 Space Telescope Science Institute, 3700 San Martin Dr, Baltimore, MD 21218, USA
4 National Autonomous University of Mexico, Institute of Astronomy, Mexico

Received 2016 October 17; revised 2017 February 23; accepted 2017 February 24; published 2017 March 17

Abstract

Green Peas are nearby analogs of high-redshift Lyα-emitting galaxies (LAEs). To probe their Lyα escape, we study the spatial profiles of Lyα and UV continuum emission of 24 Green Pea galaxies using the Cosmic Origins Spectrograph (COS) on the Hubble Space Telescope. We extract the spatial profiles of Lyα emission from their 2D COS spectra, and of the UV continuum from both 2D spectra and NUV images. The Lyα emission shows more extended spatial profiles than the UV continuum, in most Green Peas. The deconvolved full width at half maximum of the Lyα spatial profile is about 2–4 times that of the UV continuum, in most cases. Because Green Peas are analogs of high z LAEs, our results suggest that most high-z LAEs probably have larger Lyα sizes than UV sizes. We also compare the spatial profiles of Lyα photons at blueshifted and redshifted velocities in eight Green Peas with sufficient data quality, and find that the blue wing of the Lyα line has a larger spatial extent than the red wing in four Green Peas with comparatively weak blue Lyα line wings. We show that Green Peas and MUSE z = 3–6 LAEs have similar Lyα and UV continuum sizes, which probably suggests that starbursts in both low-z and high-z LAEs drive similar gas outflows illuminated by Lyα light. Five Lyman continuum (LyC) leakers in this sample have similar Lyα to UV continuum size ratios (~1.4–4.3) to the other Green Peas, indicating that their LyC emissions escape through ionized holes in the interstellar medium.

Key words: galaxies: dwarf – galaxies: high-redshift – galaxies: starburst – line: formation – radiative transfer – ultraviolet: ISM

1. Introduction

The Lyα emission line is a key tool in discovering and studying high-redshift galaxies (e.g., Dey et al. 1998; Hu et al. 1998; Rhoads et al. 2000; Ouchi et al. 2003; Matthee et al. 2014; Zheng et al. 2016). At z > 6, the Lyα luminosity, Lyα equivalent width (EW), and spatial clustering of Lyα emitting galaxies (LAEs) are important probes of the reionization of universe (e.g., Malhotra & Rhoads 2004; Kashikawa et al. 2011; Treu et al. 2012; Pentericci et al. 2014; Tilvi et al. 2014). To understand LAEs and reionization requires us to understand how Lyα escape from galaxies.

Because Lyα is a resonant line, the Lyα escape depends on the amount of dust, the H I gas column density (NHI), the velocity distribution of H I gas, and the geometric distribution of HI gas and dust (e.g., Neufeld 1990; Charlot & Fall 1993; Dijkstra et al. 2006; Verhamme et al. 2006). One important indicator of Lyα escape processes is the Lyα spatial distribution. The Lyα emission would be confined to H II regions and have similar size to the UV continuum emission, if most Lyα photons escape from ionized holes in the interstellar medium (ISM). However, if most Lyα photons diffuse out of a galaxy through numerous resonant scatterings, the Lyα emission would be more extended than the UV continuum (e.g., Östlin et al. 2009; Zheng et al. 2010; Hayes et al. 2014).

Prior Hubble Space Telescope (HST) studies of Lyα morphology in low-redshift starburst galaxies usually show diffuse Lyα emission in the outer part of galaxy, and sometimes Lyα absorption in the center of galaxy (Kunth et al. 2003; Mas-Hesse et al. 2003; Hayes et al. 2005, 2014; Östlin et al. 2009). But most of those low-redshift starbursts have much lower Lyα EW (EW < 20 Å) and Lyα escape fraction (fesc) than high-z LAEs. Because Lyα photons escape more easily and probably have fewer scatterings in high-z LAEs, it is reasonable to suppose that LAEs with high Lyα EW may have compact Lyα sizes. Due to the faintness of high-z LAEs, there are only two studies of Lyα size with high-resolution HST narrow-band imaging for a few high-z LAEs (Bond et al. 2010; Finkelstein et al. 2011), and they reached contradictory conclusions: Bond et al. (2010) suggested that Lyα sizes are compact and similar to UV continuum emission; but Finkelstein et al. (2011) posited that Lyα appears larger than the UV continuum.

Many ground-based studies of Lyα morphology suggest that a large-scale faint Lyα halo is common in high-z Lyα galaxies, due to the scatterings of Lyα photons by the H I gas in the circum-galactic medium (e.g., Möller & Warren 1998; Swinbank et al. 2007; Rauch et al. 2008; Steidel et al. 2011; Matsuda et al. 2012; Feldmeier et al. 2013; Momose et al. 2014; Wisotzki et al. 2016; Matthee et al. 2016). As the ground-based data has low spatial resolution, however, it is still unclear if the Lyα morphology of LAEs on galactic scales is compact or larger than the UV continuum, or if they show central Lyα absorption.

Green Pea galaxies are compact starburst galaxies with strong [O III]λ5007 emission lines (EW([O III]λ5007) > 300 Å) in the nearby universe (Cardamone et al. 2009). They have strong Lyα emission lines (Jaskot & Oey 2014; Henry et al. 2015; Yang et al. 2016) and their Lyα EW distribution is similar to high-z LAEs (Yang et al. 2016). Five Green Peas in our sample also show Lyman-continuum (LyC) emission (Izotov et al. 2016). In this paper, we study the spatial distribution of Lyα and UV emission of 24 Green Peas with HST-COS spectra, and compare the spatial...
profiles of Lyα photons at blue and red velocities, and discuss the implications to Lyα and LyC escape.

2. Observations and Data Analysis

In Yang et al. (2017), we assemble a sample of 43 Green Peas with HST-COS spectroscopic observations. Comparing to the parent sample of Green Peas in Cardamone et al. (2009), this sample covers the full ranges of properties, such as dust extinction, metallicity, and star-formation rate (Figure 1 in Yang et al. 2017). Thus, it is a representative sample of Green Peas. From this sample, we select 24 Green Peas that have good spatial resolution, i.e., full width at half maximum (FWHM) \( \sim 0.3^\circ \) for the point source, in their 2D spectra. Because the COS FUV channel is not corrected for spherical aberration, the cross-dispersion resolution of COS FUV spectra depends on the chosen grating, the wavelength position (WP) of the grating, and the wavelength (COS ISR2013_07). The grating and WP are chosen based on considerations of wavelength coverage and the gap in FUV detectors, and thus vary mostly with the redshifts. Although this sample only covers a small redshift range (\(-0.1\) to \(0.3\)), a slightly different redshift, and thus a different grating WP, can result in very different spatial resolution in the 2D spectra. Thus, these 24 selected Green Peas are not statistically different from the sample of 43 Green Peas, in obvious ways.

High-resolution NUV acquisition images were taken with the COS acquisition mode ACS/IMAGE for all 24 Green Peas. Their FUV spectra were taken with the 2.5'-diameter Primary Science Aperture and the G160M grating, which has the best spatial resolution of the COS gratings.

The COS FUV grating G160M has five WP—1577, 1589, 1600, 1611, 1623 Å. The WP = 1623 Å has the best spatial resolution, and 15/24 of Green Peas are taken in this WP. The COS spatial resolutions are about \(0.3 - 0.6^\circ\) for point source and stable with wavelength for the WP = 1600, 1611, and 1623 Å, but are larger and vary moderately with wavelength for the WP = 1577 and 1589 Å. We generally avoid using objects with WP = 1577 Å or 1589 Å, except for three cases where their Lyα emission lines are in wavelength ranges with small spatial resolution. The WP of each object is shown in Table 1.

We retrieved COS spectra of these 24 Green Peas from the HST MAST archive after they had been processed through the standard COS pipeline. The calibrated two-dimensional Lyα and FUV spectra are shown in Figure 1. We extract the spatial profiles of Lyα along the sky direction by summing the spectra in a wavelength range about 1211–1220 Å, along the dispersion direction. We extract the spatial profiles of FUV continuum in wide wavelength ranges of a few tens of Angstroms, near Lyα lines in the same spectra segment. We then sum the spatial profiles from spectra taken at different central wavelengths or FP-POS settings for each Green Pea. In Figure 2, we show their normalized spatial profiles of Lyα and FUV continuum light. The pixel scale along the sky direction is \(0.1^\circ\) pixel. Because the COS FUV detector counts photons, we assume the photon counts in each spatial bin follows Poisson statistics, and calculate its statistical error as counts_{stat} = (counts)^{1/2}.

In Figure 2, we also show the instrumental spatial profile of each object, derived from observations of a point source in the
same grating and WP (WD1057+719, CAL/COS 12806, PI: Derck Massa). Because the spatial resolution slightly varies with wavelength, the instrumental profiles are extracted separately for the Ly$\alpha$ and FUV continua in the corresponding wavelength ranges that are used to extract the Ly$\alpha$ and FUV spectra of each object.

The response of COS/FUV detector decreases with usage, a process called gain-sag. To mitigate these gain-sag effects, COS/FUV spectra are moved to pristine locations of the detector, i.e., different lifetime positions (LP), every 2–3 years. Our sample spans all three LPS (LP1, LP2, and LP3). As we only use the data with small spatial resolution, the spatial

Figure 1. The 2D FUV spectra and NUV images of these 24 Green Peas. In the 2D spectra, the x-axis is along the dispersion direction and the y-axis is along the sky direction. The COS aperture is a circle with a diameter of 2.5 arcsec. The dashed vertical line marks the restframe wavelength of Ly$\alpha$. The NUV images (6" × 6") are at the same orientation as the 2D spectra. All NUV images have the same range of color-bar in log-scale. These 24 galaxies are sorted by decreasing f$_{esc}$Ly from top to bottom. The ID of each galaxy is marked in each panel.
profiles are separated from the insensitive detector regions of earlier LPs. The LP of each object is shown in Table 1.

We then measure the Lyα EW and Lyα escape fraction ($f_{esc}^{Ly\alpha}$) of this sample (details in Yang et al. 2017). The $f_{esc}^{Ly\alpha}$ is defined as the ratio of the measured Lyα flux to intrinsic Lyα flux. Assuming case-B recombination, the intrinsic Lyα flux is about 8.7 times the dust-extinction-corrected Hα flux measured from SDSS spectra. Thus, the $f_{esc}^{Ly\alpha}$ is Lyα(observable)/(8.7 × Hα(corrected)). In Table 1, we show their redshifts, Lyα EWs, and Lyα escape fractions.

3. Compare Spatial Profiles of Lyα and UV emission

From the 2D spectra and 1D spatial profiles, we can see that the Lyα emission comes from a larger region than the FUV emission in most of these 24 Green Peas. The spatial profiles of UV are only slightly larger than the instrumental profiles, but the spatial profiles of Lyα are well-resolved and show asymmetric spatial distributions in many cases. In four cases with low $f_{esc}^{Ly\alpha}$ (GP1457+2232, GP0303−0759, GP0752+1638, and GP1244+0216), Lyα light shows a significant offset from the FUV continuum (similar to some high-$z$ LAEs in Mchicha et al. 2015). In GP1429+0643, a large fraction of the Lyα emission in the galactic center is absorbed, resulting in a double-horned spatial profile.

To characterize the size of spatial profile, we measure the FWHM ($FWHM_m$) of each profile. The FWHM is not sensitive to the depth of the observation. To get the error of $FWHM_m$ for each observed spatial profile, we simulate 1000 fake profiles by adding random Gaussian errors to the observed profile. We measure the $FWHM_m$ of each fake profile and calculate the standard deviation of the 1000 fake profiles as the error of $FWHM_m$ for each observed spatial profile. The measured $FWHM_m$ and its errors are shown in Table 2. We can see again that the Lyα emission have significantly larger $FWHM_m$ than the UV continuum emission.

3.1. The Deconvolved Sizes of Lyα and UV Emission

To estimate the deconvolved sizes, we assume that the intrinsic Lyα or UV emission follows an exponential profile with scale radius $r_e$, and convolve the exponential profile with the instrumental profile, so we get a relation between observed FWHM and intrinsic FWHM. Because the throughput begins to decrease when the offset from aperture center is larger than about 0.5”, we multiply the convolved profile with a throughput curve of G160M, retrieved from COS instrumental handbook. In Figure 3, we show an example of the profile convolution and how the FWHM of convolved profile varies with $r_e$ of intrinsic profile. We then calculate the deconvolved size of Lyα emission as the FWHM of the exponential profile that has the same FWHM as the observed Lyα spatial profile. Because the measured $FWHM_m$ of Lyα emission (about 0.6−1.0”) are within the angular ranges with $\gtrsim$80% throughput, the Lyα sizes are not underestimated due to attenuation at large offsets, except in GP1018+4106, which has very large Lyα size.

Because the NUV image has a spatial resolution of about 0.04” (less than two pixels, at a scale of 0.0235/pixel), the NUV emissions of this sample are well-resolved. We estimate the NUV size from the NUV acquisition image shown in
Figure 1 at the same orientation as the 2D spectra. We extract the objects with weaker blue peaks in the Ly$\alpha$—UV spatial profiles show a relation with the Ly$\alpha$ velocity profile. For one object (GP1249+1234) with a single-peaked Ly$\alpha$ velocity profile, we separate the blue and red parts by velocity $= 0$. We then extract the spatial profiles of the blue- and red-part Ly$\alpha$ emissions. Because the blue is usually weaker than the red-part Ly$\alpha$ emission, we show the 8 of 24 Green Peas with the best signal-to-noise ratio in the blue-part Ly$\alpha$ emission. These eight Green Peas also have relatively high $f_{\text{esc}}$. We compare their spatial profiles of blue-part and red-part Ly$\alpha$ emissions in Figure 4.

The spatial profiles of blue-part and red-part Ly$\alpha$ emissions are generally similar. However, in four cases (GP1137+3524, GP1249+1234, GP0911+1831, and GP0926+4428), the blue-part Ly$\alpha$ emissions are more extended than the red-part Ly$\alpha$ emissions. In the other four cases (GP1244+0216, GP1133+6514, GP1429+0643, and GP1219+1526), the blue-part and red-part Ly$\alpha$ emissions are very similar. We also noticed that the Ly$\alpha$ spatial profiles show a relation with the Ly$\alpha$ velocity profiles—the objects with weaker blue peaks in the Ly$\alpha$ velocity profiles (i.e., small flux ratio of blue-part to red-part Ly$\alpha$ emission), such as GP1137+3524, GP0911+1831, and GP0926+4428, also have broader blue-part spatial profiles. On the other hand, Green Peas usually show double-peaked Ly$\alpha$ velocity profiles (Jaskot & Oey 2014; Henry et al. 2015; Yang et al. 2016). The Ly$\alpha$ photons with different velocities are scattered differently by the H$_{\text{II}}$ gas. Because we have the 2D Ly$\alpha$ spectra, we can compare the spatial profiles of Ly$\alpha$ photons at different velocities. We define the blue-part (red-part) as the negative-velocity-side (positive-velocity-side) of the inter-peak dip of the Ly$\alpha$ velocity profile. For one object (GP1249+1234) with a single-peaked Ly$\alpha$ velocity profile, we separate the blue and red parts by velocity $= 0$. We then extract the spatial profiles of the blue- and red-part Ly$\alpha$ emissions. Because the blue is usually weaker than the red-part Ly$\alpha$ emission, we show the 8 of 24 Green Peas with the best signal-to-noise ratio in the blue-part Ly$\alpha$ emission. These eight Green Peas also have relatively high $f_{\text{esc}}$. We compare their spatial profiles of blue-part and red-part Ly$\alpha$ emissions in Figure 4.

The spatial profiles of blue-part and red-part Ly$\alpha$ emissions are generally similar. However, in four cases (GP1137+3524, GP1249+1234, GP0911+1831, and GP0926+4428), the blue-part Ly$\alpha$ emissions are more extended than the red-part Ly$\alpha$ emissions. In the other four cases (GP1244+0216, GP1133+6514, GP1429+0643, and GP1219+1526), the blue-part and red-part Ly$\alpha$ emissions are very similar. We also noticed that the Ly$\alpha$ spatial profiles show a relation with the Ly$\alpha$ velocity profiles—the objects with weaker blue peaks in the Ly$\alpha$ velocity profiles (i.e., small flux ratio of blue-part to red-part Ly$\alpha$ emission), such as GP1137+3524, GP0911+1831, and GP0926+4428, also have broader blue-part spatial profiles. On the other hand, Green Peas usually show double-peaked Ly$\alpha$ velocity profiles (Jaskot & Oey 2014; Henry et al. 2015; Yang et al. 2016). The Ly$\alpha$ photons with different velocities are scattered differently by the H$_{\text{II}}$ gas. Because we have the 2D Ly$\alpha$ spectra, we can compare the spatial profiles of Ly$\alpha$ photons at different velocities. We define the blue-part (red-part) as the negative-velocity-side (positive-velocity-side) of the inter-peak dip of the Ly$\alpha$ velocity profile. For one object (GP1249+1234) with a single-peaked Ly$\alpha$ velocity profile, we separate the blue and red parts by velocity $= 0$. We then extract the spatial profiles of the blue- and red-part Ly$\alpha$ emissions. Because the blue is usually weaker than the red-part Ly$\alpha$ emission, we show the 8 of 24 Green Peas with the best signal-to-noise ratio in the blue-part Ly$\alpha$ emission. These eight Green Peas also have relatively high $f_{\text{esc}}$. We compare their spatial profiles of blue-part and red-part Ly$\alpha$ emissions in Figure 4.
Because the outflowing H I gas presented in many Green Peas has larger optical depth for the blue-part Ly α photons than the red-part Ly α photons, we expect that the escaped blue-part Ly α photons went through more scatterings on average, and were scattered to larger radius. For the Ly α photons at velocities near zero, the optical depth is the largest and their spatial profiles also show the largest sizes.

5. Discussion

5.1. Comparison to Previous Results

Many studies have measured the Ly α morphology of some nearby star-forming galaxies with HST/STIS (Mas-Hesse et al. 2003) and HST/ACS images (e.g., Kunth et al. 2003; Hayes et al. 2005; Östlin et al. 2009, 2014). Mas-Hesse et al. (2003) analyzed the HST/STIS 2D spectra of Ly α and UV emission and showed that both Haro 2 and IRAS 0833+6517 have low Ly α EW (6 and 12 Å) and larger Ly α sizes than UV continuum sizes, and that their Ly α peaks are offset from the peaks of UV continuum emission.

The LARS program studies the Ly α morphology of 14 nearby starburst galaxies (Hayes et al. 2014; Östlin et al. 2014). Nine out of the 14 galaxies have low Ly α EW and escape fraction. They also show Ly α absorption or weak Ly α emission in the central part of galaxy, and diffuse Ly α emission in the outer part of the galaxy. The other five galaxies (LARS01, 02, 05, 07, and 14; LARS14 is galaxy GP0926 +4428 in our sample) are LAEs with relatively high Ly α EW and comparable to most of the Green Peas in our sample. These five galaxies also have [O III]5007 equivalent widths around 200−300 Å in their SDSS spectra. The Ly α emission in LARS01 shows an offset from the UV emission, and is very similar to the four cases with Ly α-UV offsets in our sample. The Ly α emission in LARS05 shows partial central absorption and is very similar to GP1429+0643, the double-horned case in our sample. The 20% Petrosian radii of the Ly α emissions of these five galaxies are 2.3−3.6 times larger than the 20% Petrosian radii of Hα emission (Hayes et al. 2014), which makes them very similar to the Ly α/UV FWHM ratios in our sample.

Two studies measure Ly α sizes of five high-z LAEs with high-resolution HST narrow-band imaging (Bond et al. 2010; Finkelstein et al. 2011). Bond et al. (2010) suggested that Ly α sizes are compact and similar to UV emission, but Finkelstein et al. (2011) posited that the half light radius of Ly α appears ~1.6 times larger than the half light radius of UV continuum. These narrow-band HST images of high-z LAEs are very hard to obtain and have low S/Ns. Thus, the Ly α and UV sizes of low-z LAEs are valuable. Because Green Peas are analogs of high-z LAEs, our results suggest that most high-z LAEs likely have larger Ly α than UV sizes. The extended Ly α emission probably indicates gas outflows around galaxies illuminated by Ly α light.

One interesting question regards the redshift evolution of Ly α sizes of LAEs. Recently, Wisotzki et al. (2016) measured Ly α radial profiles of a sample of LAEs at $z = 3−6$ from VLT/MUSE data. They found that, in 12 LAEs with both Ly α and UV continuum sizes, the Ly α light is considerably more extended than the UV continuum light. Here, we compare the sizes of Green Peas and the MUSE LAEs. Using the Ly α radial profiles in Wisotzki et al. (2016), we measured the deconvolved Ly α scale radius $r_s$, assuming intrinsic exponential
profiles, so that the methods are same when measuring the re of MUSE LAEs and Green Peas. As shown in Figure 5, the Lyα-to-UV scale ratios of Green Peas and MUSE LAEs are very similar. Notice that some MUSE LAEs have extended Lyα halos far beyond the scale radius. For Green Peas, however, we do not have robust data to characterize the Lyα emission beyond a few Kpcs.

In the right panel of Figure 5, we compare the Petrosian 20% radius (RP20) of MUSE LAEs (Table 2 in Wisotzki et al. (2016)) to that of the LARS sample (Table 1 in Hayes et al. 2014). Compared to the five strong Lyα emitters in LARS sample (marked by stars, LARS01, 02, 05, 07, and 14), the MUSE LAEs only have about two times larger ratios of RP20(Lyα) to RP20(UV). One caveat of the comparison is that the Petrosian radius of MUSE sample is measured from the best-fit model of radial profile, instead of the observed data, which is different from the method used in the LARS sample. This might be the reason that the RP20(UV) of MUSE LAEs are about 2–4 kpcs, approximately a factor of three larger than the RP20(UV) of the five LARS Lyα emitters.

Based on our rough comparison of Green Peas and MUSE LAEs, the scale lengths of Lyα and UV continuum have small evolution with redshift. This is not surprising, considering that Green Peas and high-z LAEs have very similar galactic properties, such as stellar mass, star formation rate, and starburst age. The starburst in Green Peas and LAEs can drive gas outflows to the outer part of galaxies, and the gas outflows can scatter the Lyα light and cause the extended Lyα emission.

5.2. Implication for Lyα and LyC Escape

Our results indicate that Lyα have larger sizes than the UV continuum. Because Lyα is a resonant line, our results suggest that most Lyα photons escape out of a galaxy through many resonant scatterings in the low H1 column density gas in Green Peas. If there are fewer scatterings in the Lyα escape process, the Lyα escape fraction would be higher and the Lyα emission would be more compact. Thus, there may be an anti-correlation between fescLyα and the size of Lyα light. In Figure 6, we show the relation between fescLyα and the size ratio of FWHM(Lyα)/FWHM(UV) (column (7) of Table 2). The scatter is large, but it shows a weak trend for objects with fescLyα ≥0.1, indicating that LAEs with higher fescLyα have more compact Lyα morphology, and the size ratio of FWHM(Lyα)/FWHM(UV) tends to have more compact Lyα morphology.

In Figure 6, we also mark the five LyC leakers with blue squares. These LyC leakers have Lyα-to-UV continuum size ratios similar to the other Green Peas. We note that the other Green Peas could be unknown LyC leakers, as their current UV spectra ranges do not cover the LyC emission. The LyC leakers have 1.4–4.3 times larger Lyα sizes than the UV continuum sizes, so most H1 gas, which scatters Lyα emission, is unlikely to be transparent to the LyC emission. Therefore, the LyC emission of these LyC leakers probably escape through ionized holes in the interstellar medium.

6. Conclusion

We have investigated the Lyα and UV sizes of Green Pea galaxies using their HST-COS 2D spectra. Our main results are as follows.

1. We compared Lyα and UV sizes from the 2D spectra and 1D spatial profiles, and found that most Green Peas show more extended Lyα emission than the UV continuum. We also measured the deconvolved FWHM of the spatial profiles as their Lyα and UV sizes. The Lyα sizes in most Green Peas of this sample are about 2–4 times larger than their UV continuum sizes. We also found that the five LyC leakers in our sample have larger Lyα than UV continuum sizes by 1.4–4.3 times.

2. In eight Green Peas, we compared the spatial profiles of Lyα photons at blueshifted and redshifted velocities, and found the blue wing of the Lyα line has a larger spatial extent than the red wing in four Green Peas with comparatively weak blue Lyα line wings.

3. Because Green Peas are analogs of high-z LAEs, our results suggest that most high-z LAEs likely have larger Lyα than UV sizes. We also show that Green Peas and the MUSE z = 3–6 LAEs sample have similar Lyα-to-UV continuum size ratios.

4. We compared the Lyα escape fraction with the size ratio FWHM(Lyα)/FWHM(UV), and found that, for those Green Peas with fescLyα > 10%, objects with higher fescLyα tend to have more compact Lyα morphology.
These imaging and spectroscopy data are based on observations with the NASA / ESA Hubble Space Telescope, (GO11727, GO12928, GO13293, GO13017, GO13744, GO14201), obtained at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy (AURA), Inc., under NASA contract NAS 5-26555. Some of the data presented in this paper were obtained from the Mikulski Archive for Space Telescopes (MAST). STScI is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555. Support for MAST for non-HST data is provided by the NASA Office of Space Science via grant NNX09AF08G, and by other grants and contracts. H.Y. acknowledges support from China Scholarship Council. H.Y. and J.X.W. are grateful for support from NSFC 11421303, CAS Frontier Science Key Research Program (QYZDJ-SSW-SLH006), and the Strategic Priority Research Program “The Emergence of Cosmological Structures” of the Chinese Academy of Sciences (grant No. XDB09000000). Partial support for this work was provided by NSF grant AST-1518057.

References
Alexandroff, R. M., Heckman, T. M., Borthakur, S., Overzier, R., & Leitherer, C. 2015, ApJ, 810, 104
Bond, N. A., Feldmeier, J. J., Matković, A., et al. 2010, ApJL, 716, L200
Cardamone, C., Schawinski, K., Sarzi, M., et al. 2009, MNRAS, 399, 1191
Charlot, S., & Fall, S. M. 1993, ApJ, 415, 580
Dey, A., Spinrad, H., Stern, D., Graham, J. R., & Chaffee, F. H. 1998, ApJL, 498, L93
Dijkstra, M., Haiman, Z., & Spaans, M. 2006, ApJ, 649, 14
Feldmeier, J. J., Hagen, A., Ciardullo, R., et al. 2013, ApJ, 776, 75
Finkelstein, S. L., Cohen, S. H., Windhorst, R. A., et al. 2011, ApJ, 735, 5
Hayes, M., Ostlin, G., Duval, F., et al. 2014, ApJ, 782, 6
Hayes, M., Ostlin, G., Mas-Hesse, J. M., et al. 2005, A&A, 438, 71
Heckman, T. M., Borthakur, S., Overzier, R., et al. 2011, ApJ, 730, 5
Henry, A., Scarlata, C., Martin, C. L., & Erb, D. 2015, ApJ, 809, 19
Hu, E. M., Cowie, L. L., & McMahon, R. G. 1998, ApJL, 502, L99
Izotov, Y. I., Schaerer, D., Thuan, T. X., et al. 2016, MNRAS, 461, 3683
Jaskot, A. E., & Oey, M. S. 2014, ApJ, 791, 19L
Kashikawa, N., Shimasaku, K., Matsuda, Y., et al. 2011, ApJ, 734, 119
Kunth, D., Leitherer, C., Mas-Hesse, J. M., Ostlin, G., & Petrosian, A. 2003, ApJ, 597, 263
Malhotra, S., & Rhoads, J. E. 2004, ApJL, 617, L5
Mas-Hesse, J. M., Kunth, D., Tenorio-Tagle, G., et al. 2003, ApJ, 598, 858
Matsuda, Y., Yamada, T., Hayashino, T., et al. 2012, MNRAS, 425, 878
Matthee, J. J., Sobral, D., Oteo, I., et al. 2016, MNRAS, 458, 449
Matthee, J. J. A., Sobral, D., Swinbank, A. M., et al. 2014, MNRAS, 440, 2375
Micheva, G., Iwata, I., Inoue, A. K., et al. 2015, arXiv:1509.03996
Möller, P., & Warren, S. J. 1998, MNRAS, 299, 661
Momose, R., Ouchi, M., Nakajima, K., et al. 2014, MNRAS, 442, 110
Neufeld, D. A. 1990, ApJ, 350, 216
Ostlin, G., Hayes, M., Duval, F., et al. 2014, ApJ, 797, 11
Ostlin, G., Hayes, M., Kunth, D., et al. 2009, AJ, 138, 923
Ouchi, M., Shimasaku, K., Furusawa, H., et al. 2003, ApJ, 582, 60
Pentericci, L., Vanzella, E., Fontana, A., et al. 2014, ApJ, 793, 113
Rauch, M., Haehnelt, M., Bunker, A., et al. 2008, ApJ, 681, 856
Rhoads, J. E., Malhotra, S., Dey, A., et al. 2000, ApJL, 545, L85
Steidel, C. C., Bogosavljević, M., Shapley, A. E., et al. 2011, ApJ, 736, 160
Swinbank, A. M., Bower, R. G., Smith, G. P., et al. 2007, MNRAS, 376, 479
Tilvi, V., Papovich, C., Finkelstein, S. L., et al. 2014, ApJ, 794, 5
Treu, T., Trenti, M., Stiavelli, M., Auger, M. W., & Bradley, L. D. 2012, ApJ, 747, 27
Verhamme, A., Schaerer, D., & Maselli, A. 2006, A&A, 460, 397
Wisotzki, L., Bacon, R., Blaizot, J., et al. 2016, A&A, 587, A98
Yang, H., Malhotra, S., Gronke, M., et al. 2016, ApJ, 820, 130
Yang, H., Malhotra, S., Gronke, M., et al. 2017, arXiv:1701.01857
Zheng, Z., Cen, R., Trac, H., & Miralda-Escudé, J. 2010, ApJ, 716, 574
Zheng, Z.-Y., Malhotra, S., Rhoads, J. E., et al. 2016, ApJS, 226, 23