

Discovery of a damped Ly α galaxy at $z \sim 3$ towards the quasar SDSS J011852 + 040644

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ABSTRACT

We report the detection of the host galaxy of a damped Ly α system (DLA) with $\log N(\text{H I}) [\text{cm}^{-2}] = 21.0 \pm 0.10$ at $z \approx 3.0091$ towards the background quasar SDSS J011852 + 040644 using the Palomar Cosmic Web Imager (PCWI) at the Hale (P200) telescope. We detect Ly α emission in the dark core of the DLA trough at a 3.3σ confidence level, with Ly α luminosity of $L_{\text{Ly}\alpha} = (3.8 \pm 0.8) \times 10^{42} \text{ erg s}^{-1}$, corresponding to a star formation rate of $\gtrsim 2 M_{\odot} \text{ yr}^{-1}$ (considering a lower limit on Ly α escape fraction $f_{\text{esc}}^{\text{Ly}\alpha} \sim 2\%$) as typical for Lyman break galaxies at these redshifts. The Ly α emission is blueshifted with respect to the systemic redshift derived from metal absorption lines by $281 \pm 43 \text{ km s}^{-1}$. The associated galaxy is at very small impact parameter of $\lesssim 12 \text{ kpc}$ from the background quasar, which is in line with the observed anticorrelation between column density and impact parameter in spectroscopic searches tracing the large-scale environments of DLA host galaxies.

Keywords: quasars: absorption lines – galaxies: high-redshift – galaxies:ISM – galaxies: star formation

1. INTRODUCTION

The evolution of galaxies is significantly influenced by the physical state of gas in and around the central star-forming regions. Observations of local galaxies indicate that the atomic and molecular hydrogen, which make up most of the mass in the interstellar medium (ISM) of galaxies, closely trace the star-formation rate and are the key elements that participate in inflows and outflows (Bigiel et al. 2008; Genzel et al. 2010; Cortese et al. 2011; Janowiecki et al. 2017).

Unfortunately, mapping neutral hydrogen (H I) gas in emission from galaxies is difficult at even moderate redshifts (Kanevar et al. 2016). This low density gas imprints, however, absorption lines on the spectra of an unrelated bright background sources, which offers a powerful tool to study the physical and chemical properties of the intervening gas in a luminosity independent manner (see Wolfe et al. 2005, for a review). At high redshift, most of our knowledge of H I gas primarily comes from a particular class of absorption line systems, the damped Ly α absorbers (DLAs) seen in quasar spectra. With an H I column density of $\geq 2 \times 10^{20} \text{ cm}^{-2}$, DLAs account for the bulk ($> 80\%$) of the neutral hydrogen in the early Universe (Péroux et al. 2003; Prochaska & Wolfe 2009; Noterdaeme et al. 2009, 2012).

Moreover, DLAs appear to be linked to star-forming regions, as evidenced by the metallicity evolution of DLAs with redshift (Rafelski et al. 2012, 2014; Jorgenson et al. 2013) and the velocity spread of low-ion absorption lines (see Wolfe et al. 2005). The average properties of Ly α emission from DLAs, inferred from the stacking experiment of hundreds of DLAs from the Sloan Digital Sky Survey (SDSS), further indicate a connection between star formation activity and outflows in DLA host galaxies (see also, Rahmani et al. 2010; Noterdaeme et al. 2014; Joshi et al. 2017). Therefore, establishing a direct association of the H I gas seen in absorption with emission from galaxies is a useful way to probe the link between the H I gas and star formation at high redshift.

Earlier efforts to detect DLA host galaxies either in continuum emission or nebular line emission have been moderately successful in completely blind surveys, with a detection rate of $\sim 10\%$ (Möller et al. 2004), with several studies mostly resulting in non-detections (Kulkarni et al. 2000; Christensen et al. 2009; Fumagalli et al. 2015). Leveraging the observed correlation between luminosity and metallicity in galaxies (Tremonti et al. 2004; Ledoux et al. 2006; Møller et al. 2013; Christensen et al. 2014), recent campaigns have focused instead on metal-rich DLAs, resulting in a far higher detection rate of $\approx 65\%$ (Fynbo et al. 2010, 2011; Krogager et al. 2017; Ranjan et al. 2020).

In spite of these numerous attempts, however, only ≈ 20 DLAs at redshift $\gtrsim 2$ have been associated directly to counterparts in emission (see Krogager et al. 2017). This low detection rate could be attributed either to the faint nature of DLA galaxies (which become difficult to image at close separation from bright background quasars), or to their dusty nature, or to high H I column density, or yet again to the fact that only a fraction of the DLA population is directly connected to active star-formation.

More recently, interferometers such as the Atacama Large Millimeter/submillimeter Array (ALMA) have overcome the dust bias, with the detection of ~ 10 molecular gas-rich systems using CO rotational transitions and the atomic [CII] line (Neeleman et al. 2016, 2018; Fynbo et al. 2018; Klitsch et al. 2019). So far, these studies have focused on tracing relatively high-metallicity systems, finding the DLA hosts at relatively large impact parameters, $\sim 16 - 45$ kpc, and with high molecular gas masses of $10^{10} - 10^{11} M_{\odot}$. Following these successes, efforts to detect more representative DLAs are ongoing.

Furthermore, the use of integral field spectrographs (IFSSs) at 8-10m class telescopes has proven to be a very efficient tool for searching DLA galaxies and for

characterizing their environment out to several hundreds of kiloparsecs (Péroux et al. 2011, 2012; Fumagalli et al. 2017; Mackenzie et al. 2019). For example, using the MUSE IFS at the VLT telescope, Fumagalli et al. (2017) have detected a tantalizing example of extended Ly α emission tracing gas in a region of about 50 kpc near a $z \approx 3$ DLA. This region hosts multiple galaxies, possibly in a filament, with Ly α emission induced by *in-situ* star formation likely triggered by interactions.

Moreover, in a recent MUSE survey of 6 DLAs at $z \sim 3$, Mackenzie et al. (2019) have obtained a high detection rate of galaxies up to $\approx 80\%$ within 1000 km s $^{-1}$ of the DLAs, with impact parameters ranging between 25 and 280 kpc. Notably, in contrast to previous searches, the blind survey of Mackenzie et al. (2019) has yielded detections of multiple galaxies also for low metallicity systems (see their figure 9), including a galaxy group associated with a metal poor DLA ($Z/Z_{\odot} \approx -2.33$). With a small but representative sample, using cosmological simulations, these authors have been able to place constraints on the typical mass of halos that host DLAs in the range $10^{11} - 10^{12} M_{\odot}$.

To further understand the link between H I gas and star formation near the peak of the cosmic star-formation activity, we have started a survey to search for high-redshift ($z \gtrsim 3$) DLA host galaxy counterparts in Ly α emission using the Palomar Cosmic Web Imager (PCWI). In this article, we present results from a pilot observation that traces the large scale environment of a strong intervening DLA with $\log N(\text{H I}) [\text{cm}^{-2}] = 21.0 \pm 0.10$ at $z_{\text{abs}} \approx 3.0091$ out to 80 kpc. Our observations lead to the discovery of the host galaxy, revealing a direct association of the absorbing gas with star-formation, with no other counterpart within the field of view $20'' \times 40''$. This paper is organized as follows. Section 2 describes the sample selection. In Section 3, we present the observations and data reduction. In Section 4, we present results of our analysis, followed by a discussion and conclusion in Section 5. Throughout, we have assumed a flat Universe with $H_0 = 70$ km s $^{-1}$ Mpc $^{-1}$, $\Omega_m = 0.3$ and $\Omega_{\Lambda} = 0.7$.

2. SAMPLE SELECTION

Using the compilation of thousands of DLAs from SDSS (Noterdaeme et al. 2012), we have selected a subset having high H I column density, with $\log N(\text{H I}) [\text{cm}^{-2}] \geq 21$, which provides the favorable environment for star formation and thus is likely to trace regions in close proximity to star-forming galaxies (Krogager et al. 2012; Altay & Theuns 2013). Moreover, at these high column densities, the Ly α absorption has a dark (optically thick) core, which spreads over at

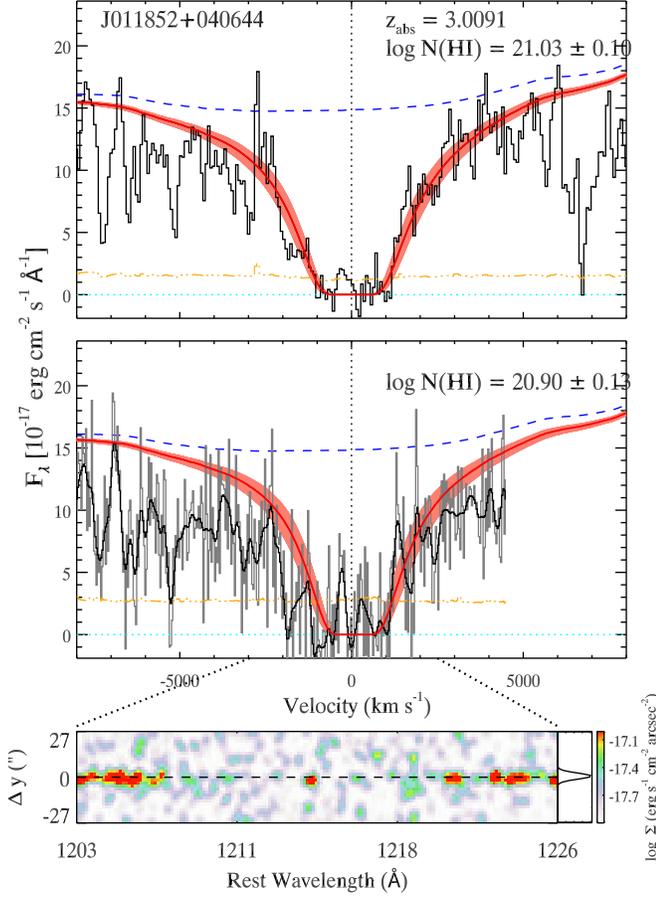


Figure 1. *Top panel:* The $\text{Ly}\alpha$ absorption profile in the SDSS spectrum (black histogram) in the velocity scale with respect to $z_{\text{abs}} \sim 3.0091$. The estimated unabsorbed quasar continuum is shown as blue dashed curve along with the error spectrum using the dot-dashed curve. The continuum template modified by the damped $\text{Ly}\alpha$ absorption is shown with a red solid line, marking the profile uncertainty corresponding to 1σ error in column density with a red shaded region. *Middle panel:* 1D quasar spectrum from the original PCWI data (gray histogram) and following resampling at the SDSS resolution of 2.5\AA (black histogram). A new model fit derived on PCWI data, which is consistent with the SDSS estimate, is also shown. *Bottom panel:* 2D quasar spectrum constructed from PCWI data cube. The trace of the quasar is shown as dashed line.

least 7 times the average full-width at half-maximum (FWHM, $\approx 160 \text{ km s}^{-1}$) of the instrumental profile of the SDSS spectrograph. This makes it possible to search for $\text{Ly}\alpha$ emission lines within the spectrum.

We consider only the DLAs detected in SDSS spectra with a median continuum-to-noise ratio > 3 which ensure an accurate determination of the H I column density. In addition, we avoid DLAs that are proximate to the quasars by considering only systems with velocity offsets of $> 5000 \text{ km s}^{-1}$ with respect to the quasar

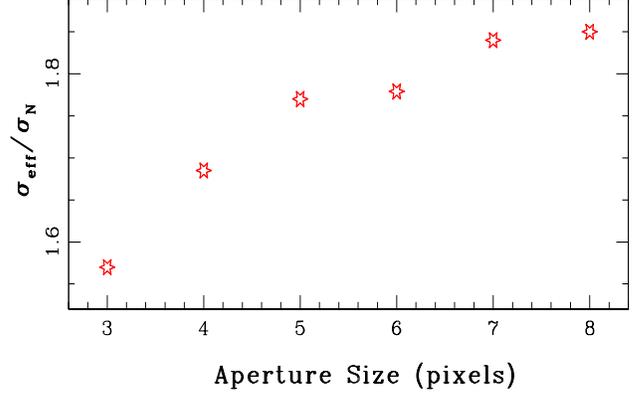


Figure 2. Ratio between the flux dispersion in apertures of varying size (σ_{eff}) and the error computed propagating the pixel standard deviation (σ_{N}), which is useful to assess the impact of correlated noise within the PCWI data cube.

emission redshift. We also exclude sightlines showing broad absorption lines from quasar outflows. To avoid introducing a metallicity bias, we do not preselect targets based on metal lines (e.g., Si II, Fe II, C II).

In order to maximise the detection rate of $\text{Ly}\alpha$ emission, we further search the spectra to identify systems with tentative $\text{Ly}\alpha$ emission (non-zero flux) within the absorption trough where the quasar continuum goes to zero (i.e., the dark core). For this, we avoid the regions with bright sky emission to exclude the false positives due to residuals of the sky subtraction. Due to the finite fiber size of SDSS, this step introduces a selection effect, that is detections are expected to primarily occur at small impact parameters of $\lesssim 15 \text{ kpc}$ (see below). An example of system selected in this way, which is also the target of our pilot observations, is shown in the upper panel of Figure 1.

Following visual inspection to remove systems with clear sky residuals or artifacts, this selection resulted in a unique set of 13 DLAs (out of 608) with absorption redshifts $z \geq 2.9$. Among them, 10 systems lie at declinations that Hale (P200) can reach and are suitable for P200 observations. As a further verification of the presence of possible $\text{Ly}\alpha$ emission, we have also examined the multi-epoch observations from SDSS, which exists for 3 DLAs in our sample. Reassuringly, all 3 systems shows $\text{Ly}\alpha$ emission in spectra at different epochs, albeit with low signal-to-noise. In order to be able to detect the minimum $\text{Ly}\alpha$ emission flux of $\sim 2 \times 10^{-17} \text{ erg s}^{-1} \text{ cm}^{-2}$ found in our sample, an integration of $\sim 1 \text{ hr}$ on source and $\sim 1 \text{ hr}$ on sky would allow us to detect the emission feature at more than $\sim 5\sigma$ level. In what follows, we present the results for the first target successfully observed so far.

3. OBSERVATIONS AND DATA REDUCTION

We have performed observations of the quasar SDSS J011852+040644 ($z_{\text{em}} \approx 3.226$) with an intervening DLA system from our selection above ($z_{\text{abs}} \approx 3.0091$ and $\log N(\text{H I})[\text{cm}^{-2}] = 21.0 \pm 0.1$) using the Palomar Cosmic Web Imager (PCWI) instrument mounted on the Hale 5 meter telescope on Mt. Palomar. PCWI uses a $40'' \times 60''$ reflective image slicer with 24 slices of dimension $40'' \times 2.5''$ each. The observations have been conducted on the night UT 20180816 with a clear sky and with airmass ranging between 1 to 2. We have used the Richardson (MedRez) gratings with a slit-limited spectral resolution of $\Delta\lambda \sim 1\text{\AA}$.

The individual exposures were acquired using the standard PCWI nod-and-shuffle technique, where the central 1/3 of the CCD is used for recording the spectrum while masking the outer 2/3 of the CCD, restricting the spectral bandpass to $\sim 150\text{\AA}$ (see, [Martin et al. 2014](#)). Note that our DLA sample is preselected based on the likely presence of Ly α emission within the 2 or 3 arcsec SDSS-III or SDSS-II fibre spectra. Thus, it is expected that the DLA host galaxy lies at small impact parameters (i.e., ~ 8 to 12 kpc). However, to trace the large scale environment around the quasar, while performing nod-and-shuffle, we offset the frame by 25 arcsec so that the quasar remains within the frame at all time. We acquired a series of 1200s exposures, totalling 1.6 h with the quasar at the center, and 1.6 h after the offset. Combined, this technique doubles the total integration time for the object, to 3.3 h. This strategy resulted in an effective field of view of $20'' \times 40''$ with the quasar at the center which allow us to search for the DLA host galaxy and trace its large scale environment out to ≈ 80 kpc (≈ 10 arcsec at $z \sim 3$).

The data are reduced with the standard PCWI pipeline ([Martin et al. 2014](#)). The flux calibration was performed using the standard star BD+28D4211, observed on the same night, and the final datacube is combined by weighting individual exposures according to their inverse variance. In addition, the wavelengths are converted into their values in vacuum. The final cube has a pixel size of ~ 1.5 arcsec in the spatial direction, and 0.55\AA in the wavelength direction. In addition, the spatial resolution of PCWI cube is seeing limited along the slices in the short direction, which at the time of observations was 1.4 arcsec, and slit limited (~ 2.5 arcsec) in the long direction.

4. RESULTS

With the final PCWI datacube in hand, we first extract the quasar spectrum in an aperture with radius of 3 arcsec which is twice the FWHM and encompasses

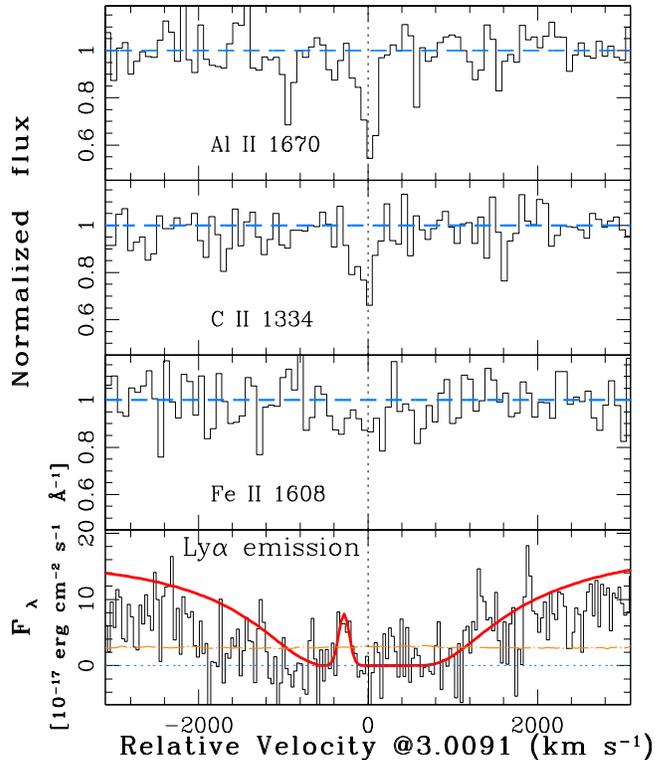


Figure 3. Velocity plots of absorption lines and the Ly α emission from DLA host galaxy. The zero velocity is defined with respect to the DLA redshift at $z_{\text{abs}} = 3.0091 \pm 0.0001$. The bottom panel shows the Ly α emission extracted in an aperture radius of 2 arcsec together with the best fitting Gaussian model. In the top panels, we plot absorption line profiles of Al II, C II, and Fe II detected in SDSS spectrum.

the total quasar emission. In Fig. 1, we compare the DLA absorption profile in the flux-calibrated 1D quasar spectrum from our moderate-resolution ($R \sim 5000$) PCWI data (middle panel) with the lower-resolution ($R \sim 2000$) SDSS fiber spectrum (top panel). The best fit continuum is shown with a dashed (blue) curve, which is modelled with a quasar composite template from [Harris et al. \(2016\)](#) by adjusting the continuum power-law slope and normalisation to fit the quasar continuum over the Ly α forest. It is clear that the DLA absorption profile and quasar continuum level agree well in both spectra. Next, we measure the H I column densities by fitting Voigt profiles to the Ly α lines in the flux-calibrated SDSS and PCWI spectra, as shown in Fig.1. The modelled absorption profile touches the unabsorbed region of the spectrum, but also due to the low resolution, there are regions that are absorbed by the forest. The derived $N(\text{H I})$ from the lower-resolution SDSS spectrum is $\log N(\text{H I})[\text{cm}^{-2}] = 21.03 \pm 0.10$, while our PCWI data result in $\log N(\text{H I})[\text{cm}^{-2}] = 20.90 \pm 0.13$. Both

measurements are consistent with each other and with the measurement of $\log N(\text{H I})[\text{cm}^{-2}] = 21.0 \pm 0.10$ presented in [Noterdaeme et al. \(2012\)](#).

In line with the pre-selection from SDSS, we clearly see an emission line signature in the DLA core at the expected position based on the SDSS spectrum. This is also evident from the reconstructed 2D spectrum from the PCWI datacube (see lower panel of Fig 1). To quantifying the detection significance of the $\text{Ly}\alpha$ emission, we first need to account for any correlated noise introduced by the resampling of individual pixels in the final data cube. Such correlated noise typically results in an underestimate of the effective noise inside an aperture and, thus in an overestimate of the real S/N of a source ([Gawiser et al. 2006](#); [Fumagalli et al. 2014](#)).

To model the noise variation as a function of aperture size, we compute the effective noise σ_{eff} as the standard deviation of fluxes by considering only the regions free from the continuum detected sources across the PCWI data cube over a cubic apertures of 4 spectral pixels ($\sim 4 \text{ \AA}$) and a variable aperture size in the spatial direction. Fig. 2 shows the ratio between this effective noise (σ_{eff}) and the error computed by propagating the variance (σ_N) as a function of apertures size. Ratios above unity indicate that the pipeline noise is underestimated by a factor of $\sim 50\%$ for an aperture of ~ 3 arcsec. We account for this effect throughout our analysis.

Focusing on the properties of the emission line next, a single component Gaussian fit to the $\text{Ly}\alpha$ line gives an intrinsic FWHM (i.e. deconvolved from instrumental effects) of $\approx 131 \text{ km s}^{-1}$ and a velocity dispersion of $\sigma \approx 56 \text{ km s}^{-1}$. The $\text{Ly}\alpha$ emission is found to be blueshifted from the systemic redshift of $z_{abs} \approx 3.0091$ derived from metal absorption lines (see upper three panels of Fig. 3) by $281 \pm 43 \text{ km s}^{-1}$. The flux of the $\text{Ly}\alpha$ line is found to be $f_{\text{Ly}\alpha} = (4.9 \pm 0.9) \times 10^{-17} \text{ erg s}^{-1} \text{ cm}^{-2}$ detected at 5.3σ level which reduces to 3.9σ level after accounting for the correlated noise (see Fig 2). This corresponds to a $\text{Ly}\alpha$ luminosity of $L_{\text{Ly}\alpha} = (3.8 \pm 0.7) \times 10^{42} \text{ erg s}^{-1}$ at the DLA redshift. Although the detection significance is marginal from a statistical point of view, the presence of emission feature exactly at the expected location from the SDSS spectrum further strengthen the case for real detection.

In order to identify the location of the galaxy responsible for $\text{Ly}\alpha$ emission, we generate a $\text{Ly}\alpha$ emission map integrated over a velocity window from $v = -450 \text{ km s}^{-1}$ to $v = -187 \text{ km s}^{-1}$, comprising the $\text{Ly}\alpha$ emission feature. The left panel of Fig. 4 shows the $\text{Ly}\alpha$ emission map, revealing the location of the DLA host galaxy. Given the poor spatial resolution of PCWI, we could only place an upper limit on the extent of the $\text{Ly}\alpha$ emis-

sion to be $< 30 \text{ kpc}$, at a surface brightness limit of $\Sigma_{\text{Ly}\alpha} > 10^{-17.5} \text{ erg s}^{-1} \text{ cm}^{-2} \text{ arcsec}^{-2}$. The right panel of Fig. 4 shows instead the quasar image in the continuum after collapsing the cube. The overlaid contours mark the $\text{Ly}\alpha$ emission map at the flux levels of 0.35, 0.45, $0.55 \times 10^{-17} \text{ erg s}^{-1} \text{ cm}^{-2}$.

It is clear from the figure that the peak flux of the $\text{Ly}\alpha$ emission (marked as cross symbol) is off centered from quasar (marked as diamond). More quantitatively, we have calculated the separation between quasar and DLA host galaxy based on light-weighted center, finding 0.6 arcsec with a corresponding projected distance of 5 kpc . Given that the offset is less than the pixel scale we consider this as a lower limit. In addition, constrained by the pixel size we measure an upper limit on impact parameter of 12 kpc (see also, Fig.5).

5. DISCUSSION AND CONCLUSION

We report the detection of $\text{Ly}\alpha$ emission from the host galaxy of a DLA with $\log N(\text{H I})[\text{cm}^{-2}] = 21.0 \pm 0.10$ at $z_{abs} = 3.0091$ toward the background quasar SDSS J011852 + 040644 at $z_{em} = 3.226$. The DLA host is detected, by selection, at a small impact parameter of $\lesssim 12 \text{ kpc}$ with $\text{Ly}\alpha$ luminosity of $L_{\text{Ly}\alpha} = (3.8 \pm 0.7) \times 10^{42} \text{ erg s}^{-1}$, which is typical of the characteristic luminosity ($\log L_{\star}[\text{erg s}^{-1}] = 42.66$) of the $\text{Ly}\alpha$ emitter galaxies at $z \sim 3$ ([Herenz et al. 2019](#)).

Given the resonant scattering nature of the $\text{Ly}\alpha$ line, the emergent profile is modified and suppressed by many physical effects, e.g. H I content, gas geometry and kinematics, and the dust content and distribution. For instance, in an optically-thick static medium $\text{Ly}\alpha$ escapes through successive resonance scattering leading to a double-humped profile, with the position of the peaks determined by column density, temperature, and kinematics of the medium ([Neufeld 1990](#); [Dijkstra 2014](#)). In addition, scattering through an inflowing (outflowing) medium leads to an overall blueshift (redshift) of the $\text{Ly}\alpha$ profile with enhanced blue (red) peak and suppressed red (blue) peak ([Dijkstra et al. 2006](#), , see below). In a pure static medium, the expected velocity offset of the $\text{Ly}\alpha$ emission is $\sim 344 \text{ km s}^{-1}$ if we assume H I gas temperatures of 10^4 K ([Dijkstra 2014](#), see their eq. 21). For a column density of 10^{21} cm^{-2} , consistent with this DLA, a velocity of $\approx 300 \text{ km s}^{-1}$ is expected, in line with our observations ($\approx 281 \text{ km s}^{-1}$ with respect to the systemic redshift derived from metal absorption lines).

However, a static configuration is perhaps unlikely in real systems, and the blue offset seen for this DLA host may arise because of an inflowing gas geometry (e.g., [Rauch et al. 2008, 2011](#)). [Dijkstra et al. \(2006\)](#) have

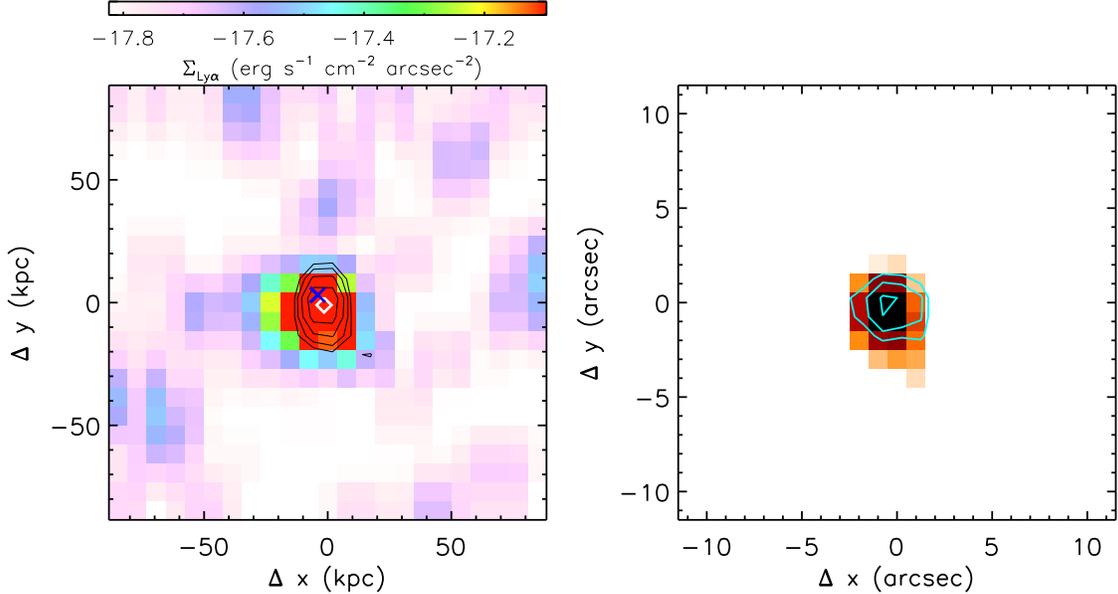


Figure 4. *Left Panel:* The Ly α emission map integrated over a velocity window from $v = -450 \text{ km s}^{-1}$ to $v = -187 \text{ km s}^{-1}$, comprising the Ly α emission feature, reveal the presence of DLA host galaxy at an impact parameter of $\lesssim 12 \text{ kpc}$. The black contours mark the continuum detected source (i.e. the quasar). The quasar and the DLA host galaxy centers are marked with a diamond and a cross, respectively. *Right Panel:* The white-light image reconstructed from the PCWI data cube showing the quasar at the center. The cyan contours mark the Ly α emission map at the flux levels of $0.35, 0.45, 0.55 \times 10^{-17} \text{ erg s}^{-1} \text{ cm}^{-2}$.

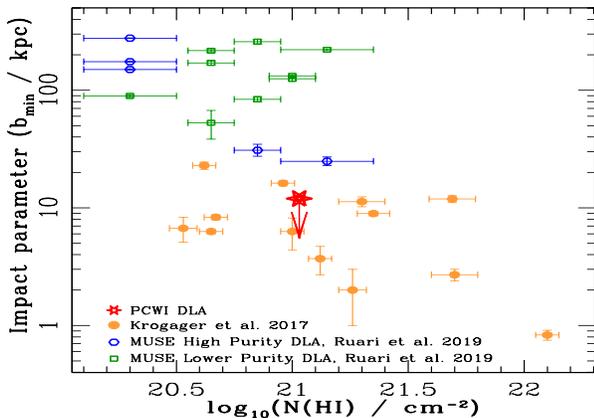


Figure 5. H I Column density versus impact parameter relation for DLA host galaxies at $z > 1.5$. The filled circles show the DLAs identified over 25 year in long-slit based spectroscopic searches, compiled by Krogager et al. (2017) as well as 3 extremely strong ($\log N(\text{H I}) [\text{cm}^{-2}] \geq 21.7$) DLAs from Ranjan et al. (2020). The open diamonds show the galaxy population near DLAs from the recent MUSE survey by Mackenzie et al. (2019). The red star shows our PCWI DLA host galaxy detected at an impact parameter of $\lesssim 12 \text{ kpc}$.

modelled the spectra and surface brightness distributions for the Ly α radiation from collapsing protogalaxies. They demonstrate that due to transfer of energy from the collapsing gas to the Ly α photons, together with a reduced escape probability for photons in there wing, causes the blue peak to be significantly enhanced, which results in an effective blueshift of the Ly α line. Furthermore, employing a three-dimensional Ly α radiative transfer code, Laursen & Sommer-Larsen (2007) have investigated the properties of young Ly α emitting galaxies at high redshift ($z \sim 3$) from a cosmological galaxy formation simulation and found the dominant blue peak showing the signature of infalling gas (see also, Laursen et al. 2009). Such Ly α emission profiles with prominent blue peaks and suppressed red peaks, with typical offset of a few hundred km s^{-1} as seen here, have been observed in several Ly α blobs (Bower et al. 2004; Wilman et al. 2005), LAEs (Bunker et al. 2003) as well as one high confidence DLA by Mackenzie et al. (2019) in VLT-MUSE observations.

Absorption lines from C II 1334Å, Fe II 1608Å, and Al II 1670Å ions are detected in the SDSS spectrum with an equivalent width of $0.36 \pm 0.04 \text{ \AA}$, $0.25 \pm 0.08 \text{ \AA}$, and $0.59 \pm 0.09 \text{ \AA}$, respectively. Based on the strong correlation seen between the rest-frame equivalent width of Si II λ 1526 line and metallicity, we derive an upper limit on the metallicity of $\log Z/Z_{\odot} < -1.58$ from the observed 3σ upper limit of 0.34 \AA on Si II λ 1526 equiva-

lent width (Prochaska et al. 2008; Jorgenson et al. 2013; Neeleman et al. 2013). In addition, we also derive a metallicity of $\simeq -2.13$ based on C II λ 1334 line using the apparent optical depth method. This limit also places the DLA just below the average metallicity of the population at this redshift (Rafelski et al. 2012), and well below the typical metallicity of DLAs chosen for targeted searches towards enriched systems, which typically select DLAs with $\log Z/Z_{\odot} > -1.0$ (see, Krogager et al. 2017). To date, only one other DLA host at this low metallicity, namely J2358+0149 with $\log Z/Z_{\odot} \simeq -1.7$ derived based on Si II absorption, is detected at small impact parameter of < 15 kpc (Srianand et al. 2016).

Besides the detection of emission coincident with the DLA position, our PCWI search has allowed us to trace the environment of this DLA out to 80 kpc. However, apart from the detection of a fairly bright DLA host, no other galaxies are seen in the field, to a luminosity limit of $5.3 \times 10^{41} \text{erg s}^{-1}$. This is a somewhat rare occurrence compared to previous studies that have examined the large-scale environment of DLAs. For instance, efforts to directly image the DLA host galaxies show a very small probability of DLAs being associated with bright Lyman-break galaxies at distances $< 10 - 20$ kpc. These studies favour instead associations with either faint, possibly isolated, star-forming galaxies or dwarf galaxies which are clustered with more massive LBGs (see, Fumagalli et al. 2015). Moreover, in a recent MUSE survey of 6 high redshift ($z > 3$) quasar sightlines with H I column density ranging between $20.3 \leq \log N(\text{H I})[\text{cm}^{-2}] \leq 21.15$ Mackenzie et al. (2019) have traced the environment of DLA host galaxies out to 250 kpc, detecting 5 high-confidence $\text{Ly}\alpha$ emitting galaxies associated with three DLAs and 9 lower-significance $\text{Ly}\alpha$ emission objects in five sightlines. The MUSE detections are typically found at relatively large impact parameters of > 50 kpc, implying that DLAs generally trace the neutral gas in a wide variety of rich environments, including overdense structures with multiple members.

In Fig.5, we explore in more detail the known anticorrelation between the impact parameters versus $N(\text{H I})$. Considering only the high-confidence DLA associations from the literature and the IFU-based searches probing large scale environments, a clear trend seems to emerge, although with large scatter. Indeed, high $N(\text{H I})$ systems are observed at preferentially small impact parameters, with a Pearson's correlation coefficient of -0.544 and a p value of 0.029 (Zwaan et al. 2005; Péroux et al. 2011; Rubin et al. 2015; Krogager et al. 2017). It should however be noted that some of these detections rely on long-slit spectroscopic measurements, for which only

small impact parameters are accessible. Larger samples studied with large format IFUs are needed to confirm the significance of this relation.

As a final point, we infer a value for the *in-situ* star formation rate (SFR, (\dot{M}_{SF})) of this DLA host, by assuming that the $\text{Ly}\alpha$ photons mainly originate from H II regions around massive stars embedded in the DLAs. Assuming case-B recombination (Osterbrock & Ferland 2006),

$$L_{\text{Ly}\alpha} = 0.68h\nu_{\alpha}(1 - f_{\text{esc}})N_{\gamma}\dot{M}_{\text{SF}}, \quad (1)$$

where $h\nu_{\alpha}=10.2$ eV [erg s^{-1}] is the energy of the $\text{Ly}\alpha$ photons, f_{esc} is the fraction of ionising photons that escape before giving rise to ionisation and N_{γ} represents the number of ionising photons released per baryon of star-formation.

At the redshift of interest of this work, the escape fraction of Lyman continuum photons is found to vary over a range of $0 \lesssim f_{\text{esc}} \lesssim 0.29$ with an average value of $f_{\text{esc}} \sim 0.09$, as inferred by the Keck Lyman Continuum Spectroscopic Survey of star-forming galaxies at $z \sim 3$ (Steidel et al. 2018). We further assume $N_{\gamma} = 9870$, corresponding to the average metallicity, i.e. $\log Z/Z_{\odot} = -1.5$, of high redshift DLA absorbers and a Salpeter initial mass function with $\alpha = 2.35$, as given in Rahmani et al. (2010, and references therein). The observed $\text{Ly}\alpha$ luminosity also depends on the escape fraction ($f_{\text{esc}}^{\text{Ly}\alpha}$) of $\text{Ly}\alpha$ photons, and it is related to the emitted $\text{Ly}\alpha$ luminosity ($L_{\text{Ly}\alpha}$) as $L_{\text{Ly}\alpha}^{\text{obs}} = f_{\text{esc}}^{\text{Ly}\alpha} L_{\text{Ly}\alpha}$. The $\text{Ly}\alpha$ escape fraction increases smoothly and monotonically out to $z \sim 6$ and strongly depends on the dust content (Hayes et al. 2011). At the redshift of our interest the $f_{\text{esc}}^{\text{Ly}\alpha} \approx 5 \pm 3\%$, as is estimated for the high-redshift ($z \sim 3$) star forming galaxies by Hayes et al. (2010, 2011, see their table 1).

Following this method, we infer that the DLA host galaxy is forming stars at $\dot{M}_{\text{SF}} \approx 21M_{\odot} \text{ yr}^{-1}$ for an average $f_{\text{esc}} \approx 9\%$ and $f_{\text{esc}}^{\text{Ly}\alpha} \approx 5\%$. However, this value is highly uncertain and ranges between $2 \leq \dot{M}_{\text{SF}} \leq 53$ [$M_{\odot} \text{ yr}^{-1}$] if we account for the large uncertainty in the $\text{Ly}\alpha$ escape fraction from 70% to 2%, respectively (see also, Kimm et al. 2019). A similar SFR of $\sim 2M_{\odot} \text{ yr}^{-1}$ is also inferred from the star formation rate calibration for $H\alpha$ luminosity [i.e. $L_{H\alpha}[\text{erg/s}] = 10^{41.27} * \text{SFR } M_{\odot} \text{ yr}^{-1}$] from Kennicutt & Evans (2012) and the intrinsic $\text{Ly}\alpha/H\alpha$ ratio of 8-10. This is comparable with the typical SFR of Lyman break galaxies at the similar redshifts (Kornei et al. 2010).

In conclusion, our search for DLA hosts of high column density ($\log N(\text{H I}) \geq 21$) systems, with no metallicity pre-selection but identified on the basis of likely presence of $\text{Ly}\alpha$ emission in the SDSS fiber, appears to be

effective in uncovering the gas-galaxy connection in an interesting region of parameter space, where we expect a direct link between gas in absorption and star formation in emission (Rafelski et al. 2012, 2016). Therefore, future IFU observations (e.g., PCWI, MUSE, KCWI) of our sample are likely to yield additional bright DLA host galaxies at small impact parameters, with which we can start to investigate more systematically both the galaxy population on large scales, and how neutral gas relates directly to star formation on smaller scales.

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