Ghostly Strong Lyα Absorbers: Tracers of Gas Flows in the Close Vicinity of Quasars?

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Received 2018 August 20; revised 2019 October 2; accepted 2019 November 19; published 2020 January 10

Abstract

We have searched the Sloan Digital Sky Survey Data Release 12 for ghostly strong Lyα (DLA) systems. These systems, located at the redshift of the quasars, show strong absorption from low-ionization atomic species but reveal no H I Lyα absorption. Our search has, for the first time, resulted in a sample of 30 homogeneously selected ghostly absorbers with \( Z_{\text{QSO}} > 2.0 \). Thirteen of the ghostly absorbers exhibit absorption from other H I Lyman series lines. The lack of Lyα absorption in these absorbers is consistent with them being dense and compact with projected sizes smaller than the broad-line region of the background quasar. Although uncertain, the estimated median H I column density of these absorbers is \( \log(N(\text{H} I)) \sim 21.0 \). We compare the properties of ghostly absorbers with those of eclipsing DLAs that are high-column-density absorbers, located within 1500 km s\(^{-1}\) of the quasar emission redshift and showing strong Lyα emission in their DLA trough. We discover an apparent sequence in the observed properties of these DLAs, with ghostly absorbers showing wider H I kinematics, stronger absorptions from high-ionization species, C II and Si II excited states, and a higher level of dust extinction. Since we estimate that all these absorbers have similar metallicities, \( \log(Z/Z_\odot) \sim -1.0 \), we conclude that ghostly absorbers are part of the same population as eclipsing DLAs, except that they are denser and located closer to the central active galactic nuclei.

Unified Astronomy Thesaurus concepts: Interstellar absorption (831); Interstellar line absorption (843); Quasars (1319); Active galactic nuclei (16); Quasar absorption line spectroscopy (1317); Intergalactic medium (813); Interstellar dust extinction (837); Circumgalactic medium (1879); Extragalactic astronomy (506); Galaxy structure (622); Galactic winds (572)

Supporting material: machine-readable table

1. Introduction

The feeding habits of supermassive black holes (SMBHs), residing at the center of distant galaxies, and the subsequent feedback from their active galactic nuclei (AGNs) are among the processes key to understanding how galaxies and their SMBHs coevolve (Audibert et al. 2017; Dutta et al. 2018). Simulations have shown that AGNs are primarily fed by the infall of gas into the gravitational potential well of SMBHs (Martin et al. 2016). The infall of gas occurs preferentially through so-called cold flows along the filaments of the cosmic web (Kereš et al. 2005; Rahmani et al. 2018a). Direct, unambiguous detection of cold accretion flows onto galaxies has proven to be extremely challenging (Rauch et al. 2008; Cresci et al. 2010; Steidel et al. 2010; Giavalisco et al. 2011). Instead, AGN- or supernova-driven outflows are commonly observed as blueshifted absorption lines in the spectra of galaxies and quasars (Srianand et al. 2002; Chisholm et al. 2015; Wood et al. 2015; Schroetter et al. 2016; Sur et al. 2016; Finley et al. 2017; Rahmani et al. 2018b).

It is expected that chemically young infalling gas should be detected as redshifted absorption lines in the spectra of galaxies and quasars (Kimm et al. 2011; Stewart et al. 2011a). However, the intrinsically weak absorption produced by the low-metallicity and low-velocity infalling gas, along with the possible contamination of these weak absorption lines with the strong absorption from the interstellar medium of the galaxy or enriched outflowing gas, makes it difficult to confidently detect absorption signals from the cold flows in the spectra of galaxies and quasars (Stewart et al. 2011a, 2011b; Kimm et al. 2011; Rubin et al. 2012). Simulations show that if a cold flow is exactly aligned with the line of sight, then some signal might
Fathivavsari et al. 2015, 2016, 2018). The Lyα emission would be detected in the DLA absorption core. If the optically thick H I cloud continuously covers the full extent of the Lyα-emitting region, then no emission is seen in the DLA core.

If an eclipsing DLA cloud is located closer to the quasar, then it would have a higher density and smaller dimensions. Such a small DLA cloud would then cover a smaller fraction of the background Lyα-emitting regions (i.e., star-forming regions or NLR). Accordingly, in the quasar spectrum, one would detect stronger, narrow Lyα emission in the DLA trough. In extreme cases where the density of the gas is very high \((n_{\text{HI}} > 1000 \text{ cm}^{-3})\) and the size of the DLA is smaller than that of the BLR, the leaked emission from the BLR would almost fully fill the DLA absorption trough. In this case, we will have a ghostly absorber as no H I absorption is detected in the quasar spectrum (Fathivavsari et al. 2017; Xie et al. 2018). Figure 1 illustrates the DLA−QSO configuration leading to the formation of a ghostly absorber in quasar spectra. As shown in this figure, the continuum from the accretion disk (AD) is fully blocked by the absorber, while only part of the BLR is covered. As a result, the leaked Lyα emission from the regions of the BLR and NLR that are not covered by the cloud would sufficiently elevate the flux level at the bottom of the DLA to form a ghostly absorber.

\[ \text{Figure 1. Illustration of the DLA−QSO configuration that can lead to the formation of ghostly absorbers in quasar spectra. The continuum from the accretion disk (AD) is fully blocked by the DLA absorber, while only part of the BLR is covered. As a result, the leaked Ly}^\alpha \text{ emission from the regions of the BLR and NLR that are not covered by the cloud would sufficiently elevate the flux level at the bottom of the DLA to form a ghostly absorber.} \]

2. Method

2.1. Finding Ghostly Absorbers

Conventional approaches to finding DLAs require absorption with a damping wing to be present in the spectrum or the flux at the bottom of the absorption to be at zero level (Prochaska & Herbert-Fort 2004). However, since the DLA trough in a ghostly absorber is almost fully filled with the leaked emission from the BLR (Fathivavsari et al. 2017), such methods are not well suited for finding these DLAs. We, therefore, use the metal template technique (Herbert-Fort et al. 2006; Fathivavsari et al. 2014) to search for ghostly absorbers in SDSS-BOSS spectra. The metal template technique identifies DLA candidates by cross-correlating the observed spectra with an absorption template made up of several strong metal absorption lines generally detected in DLAs. Detailed descriptions of the technique are presented in Paper I. Below, we briefly explain the outline of the approach.

In our search for ghostly absorbers, we take into account only those quasars that have emission redshift higher than \(z_{\text{em}} = 2.0\), zero balnicity index (Weymann et al. 1991; Páris et al. 2017), and continuum-to-noise ratio above 4.0. Employing these criteria on the BOSS spectra leaves us with 149,378 quasars. This sample of quasars is called the \(S_{\text{QSO}}^1\) sample. For each quasar in the \(S_{\text{QSO}}^1\) sample, we cross-correlate its spectrum with the metal absorption template, and then record systems when their correlation function has a maximum with high significance \(\geq 4\sigma\). Similar to eclipsing DLAs, the search for ghostly absorbers is also performed within 1500 km s\(^{-1}\) of the quasar redshift. Applying this constraint on the \(S_{\text{QSO}}^2\) sample returns 45,040 systems, many of which are false-positive detections. This new sample is called the \(S_{\text{QSO}}^2\) sample.

In order to exclude the spurious systems from the \(S_{\text{QSO}}^2\) sample, we measure the equivalent width (EW) and its corresponding error \((\sigma_{\text{EW}})\) for all metal transitions used in the template. We then exclude those systems that have less than three absorption lines detected above 3\(\sigma\). With this constraint, we are left with 10,224 systems. We call this sample \(S_{\text{QSO}}^3\) sample. In principle, the \(S_{\text{QSO}}^3\) sample comprises Lyman limit systems (LLSs), sub-DLAs (i.e., absorbers with H I column densities, \(\log N(\text{H}^\text{I}) \leq 20.30\)) DLAs, ghostly absorbers, and some false-positive detections. Since ghostly absorbers exhibit no DLA absorption, we first exclude from the \(S_{\text{QSO}}^3\) sample both those spectra in which a DLA absorption is present. For this purpose, we cross-correlate each observed spectrum in the \(S_{\text{QSO}}^3\) sample with a series of synthetic DLA absorption profiles corresponding to \(N(\text{H}^\text{I})\) in the range \(19.0 \leq \log N(\text{H}^\text{I}) \leq 22.50\). If a DLA absorption is present in the spectrum, the correlation coefficient will be larger than 0.7 and the system is rejected. Employing this algorithm on the \(S_{\text{QSO}}^3\) sample returns 6702 systems. This new sample is called the \(S_{\text{QSO}}^4\) sample. We note that a strong \((e.g. \text{C II})\) metal absorption from some intervening systems (occurring at the expected position of the Lyα absorption from a ghostly absorber) could mimic a Lyα absorption with \(\log N(\text{H}^\text{I}) < 19.0\). That is why the synthetic DLA absorptions are constructed for \(\log N(\text{H}^\text{I}) \geq 19.0\).

The \(S_{\text{QSO}}^4\) sample contains LLSs with \(\log N(\text{H}^\text{I}) < 19.0\), ghostly absorbers, and some false-positive detections. To further exclude the false-positive detections from the \(S_{\text{QSO}}^4\) sample, we cross-correlate each spectrum with an absorption template made up of the Si IV and C IV doublet transitions. It is worth
mentioning that we first checked and found that by cross-correlating this absorption template with the spectra of the DLAs from the Paper I sample, the cross-correlation function (CCF) almost always has a peak with $\geq 5\sigma$ significance at the DLA redshift. Therefore, we take into account only those systems from the $S_{QSO}^5$ sample for which the CCF has a maximum with $\geq 5\sigma$ significance. With this constraint on the $S_{QSO}^5$ sample, most false-positive detections are excluded and we are left with 1446 systems. We call this new sample the $S_{QSO}^5$ sample. By visually inspecting all spectra from the $S_{QSO}^5$ sample, we could identify 30 ghostly absorbers (see Table 1). The remaining systems are mostly LLSs (with log(N(H I)) $< 19.0$) for which the Ly$\alpha$ absorption is also observed in the spectra. All S1QSO to S5QSO samples are available in machine-readable format. An extract of the full table is shown in Table 2.

### 2.2. Constraining H I Column Densities

In this section, we present different approaches used to constrain the H I column densities of the ghostly absorbers.
2.2.1. Ghostly Absorbers with Lyman Series Absorption

Although ghostly absorbers reveal almost no Ly$\alpha$ absorption in the spectra, one could still use the absorption from other Lyman series transitions to constrain $N$(H I) provided the redshift of the DLA is high enough that the Lyman series are covered by the SDSS spectrum. We will see higher Lyman series absorption because (1) since we see strong metal absorption lines, the cloud most certainly covers the QSO continuum completely, and (2) the continuum-to-emission line ratio is large for all Lyman series lines except Ly$\alpha$. We note that our best H I column density measurements of ghostly absorbers are achieved through the fitting of the Lyman series absorption lines.

The minimum DLA redshift at which at least one more H I transition other than Ly$\alpha$ falls on the observed spectral window is $z_{\text{abs}} \sim 2.55$ for the BOSS spectra. Thirteen (out of 30) of our ghostly absorbers satisfy this criterion. To constrain $N$(H I) of these DLAs, we simultaneously fit all absorption lines from the H I Lyman series that are available in the spectra. An example of such a fit is shown in Figure 2, and the fits of the remaining systems are presented in the Appendix. The parameters of the fit are listed in Table 1. We show in Figure 3 the H I column density distribution of the ghostly absorbers measured from the fit to the Lyman series absorption lines. As shown in this figure, the majority of the systems with at least one transition other than Ly$\alpha$ available in the spectrum have H I column densities larger than $\log N$(H I) = 21.0.

2.2.2. Multicomponent Fit on Lyman Series Absorption

In this section, we explore the possibility that our ghostly absorbers are not single-component structures and that they are made up of several adjacent LLSs that may reduce the total H I column density. Since the signal-to-noise ratios (S/Ns) of the individual spectra in the Lyman series spectral region are low, we do this exercise on the stacked spectrum, which has a better S/N. Section 3.4 describes how the stacked spectrum is constructed. Our best single-component fit on the Lyman series absorption lines in the stacked spectrum is achieved for $b = 105$ km s$^{-1}$ and $\log N$(H I) = 21.0 (see the upper panel in Figure 4).

We then perform a multicomponent fit with $n$ (= 5, 10, 20, 30) components. The $b$-value of each component is fixed to $b = 10$ km s$^{-1}$, and the components are uniformly distributed over the velocity width of $\Delta V = 250$ km s$^{-1}$. We derive $\Delta V$ by fitting a Gaussian function on the Fe II $\lambda$1608 and Al II $\lambda$1670 absorption lines. For simplicity, we assume similar column densities for all components. The results of our multicomponent fits are shown in Figure 4. As shown in this figure, the fit with five components is clearly ruled out because, except for Ly$\beta$, the model underestimates the optical depth of the absorption from other Lyman series lines.

We found that the lowest number of components for which a rather satisfactory reconstruction of the observation is achieved is $n = 10$. In this case, each component has $\log N$(H I) = 19.60, and the total H I column density is $\log N$(H I) = 20.60. We also tried 20- and 30-component structures, which resulted in almost the same total H I column density of $\log N$(H I) = 20.40. Careful inspection of the Ly$\beta$ absorption lines in Figure 4 shows that the wings of the Ly$\beta$ absorption line are better reproduced with the single-component fit and $\log N$(H I) = 21.0. Although uncertain, the multicomponent fits show that the H I column densities are robustly larger than $\log N$(H I) = 20.40.

2.2.3. Ghostly Absorbers with Shallow Ly$\alpha$ Absorption Dip

As mentioned in Section 2.2.1, when the redshift of the DLA is below $z_{\text{abs}} \sim 2.55$, only the Ly$\alpha$ spectral region falls in the observed spectral window. This is the case for 17 (out of 30) of our ghostly absorbers. In these systems, the absence of absorption from neutral hydrogen makes it almost impossible to measure the H I column density. However, in seven of our ghostly absorbers, a shallow absorption dip is seen at the expected position of the DLA absorption. This shallow absorption dip is actually a ghostly signature of an otherwise strong Ly$\alpha$ absorption. This absorption dip can help us...
constrain the HI column densities, as discussed in detail by Fathivavsari et al. (2017). Below, we briefly explain the technique.

The technique is based on predicting the amount of neutral hydrogen that is needed to reproduce the shape of the shallow dip seen in the Lyα spectral region. To estimate the HI column density, we model the DLA absorption and the broad Lyα and N V emission lines. To this end, a series of models with fixed $N(\text{H I})$ (varying from $\log N(\text{H I}) = 19.0$ to $22.5$) is constructed. In each of these models, the amplitude, the FWHM, and the redshift of the broad Lyα and NV emission line components are set as free parameters. Each of the broad Lyα and N V emission lines is assumed to have two components (Fathivavsari et al. 2017). The covering factor of the narrow component of the Lyα emission is fixed at 0.0, while that of the broad component is set as a free parameter. The redshift of the DLA is also fixed to that obtained from the low-ionization metal absorption lines.

Figure 5 shows an example of a reconstruction of the quasar spectrum around the Lyα spectral region. The broad (narrow) components of the Lyα and N V emission lines are shown as dashed (solid) green and pink curves. The Si II emission line of the quasar is shown as a cyan curve. The purple curve shows the reconstructed quasar spectrum, which is the combination of the quasar continuum (a power-law function) and all green, pink, and cyan dashed and solid curves. We found that the best match between the model and the observation is achieved when the partial coverage of the broad component of the BLR Lyα emission is 30%. The dotted green curve actually shows the corresponding 70% leaked Lyα emission from the BLR. Note that the covering factor of the narrow component of the BLR Lyα emission line is assumed to be 0%. The dashed blue curve is the combination of the quasar continuum, the dashed pink curve plus a DLA absorption profile with $\log N(\text{H I}) = 21.00$. The solid blue curve shows the combination of the dashed blue curve and dotted green curve. The final fit, which is overplotted as a red curve on the observed spectrum, is achieved by adding the solid green curve to the solid blue curve. The SiII emission line (the cyan curve) is also included in the red curve. The right-hand panel in Figure 5 shows the reduced $\chi^2$ values for different HI column densities. The $\chi^2$ map in Figure 5 implies that the hydrogen column density is $\log N(\text{H I}) \sim 21.0$. The fits of the remaining systems are shown in the Appendix. It must be noted that these estimates of HI column densities are highly uncertain compared to the ones measured from the fits to the Lyman series (see Section 2.2.1).

2.2.4. Ghostly Absorbers with No Signature of HI Absorption

Ten (out of 17) of the ghostly absorbers with $z_{\text{abs}} < 2.55$ reveal no signature of the Lyα absorption in the spectra. For these systems, the methods described in the two previous sections are not applicable. However, since at $z_{\text{abs}} < 2.55$ the Mg II doublet falls in the observed spectral window in the BOSS spectra, one could exploit the strength of the Mg II $\lambda 2796$ absorption line to at least infer whether these absorbers are DLAs (Rao et al. 1995, 2006; Ellison et al. 2009; Berg et al. 2017). Rao et al. (2006)
studied 197 Mg II systems with $z_{\text{abs}} < 1.65$ and found that 36% ± 6% of the absorbers with the Mg II λ2796 and Fe II λ2600 rest EWs above 0.5 Å are DLAs. From their Table 1, the median rest EWs of Mg II λ2796 and Fe II λ2600 for the DLAs in their sample are 1.9 Å and 1.3 Å, respectively.

We have measured the rest EWs of Mg II λ2796 and Fe II λ2600 absorption lines for the ghostly absorbers in our sample (see Table 1). In the two (out of 10) systems, the Mg II absorption lines are contaminated by noise. The EWs of the Mg II λ2796 absorption line in the remaining eight systems with clean Mg II absorption are all larger than 2.4 Å, so they are higher than the median rest EW of this absorption line in the Rao et al. (2006) sample (see above). Moreover, the rest EWs of Fe II λ2600 in all but one (toward J090424.08+560205.4) of these eight systems are larger than the median rest EW of the Fe II λ2600 absorption line in the Rao et al. (2006) sample. We plot, in Figure 6, the rest EW distributions of the Mg II λ2796 and Fe II λ2600 absorption lines in our ghostly absorbers (red histograms) and in the intervening DLAs (black histograms) with $z_{\text{abs}} = 2.3 ± 0.2$ and log $N$ (H I) = 20.50 ± 0.20 from Noterdaeme et al. (2012). As shown in this figure, all eight of our Mg II EW measurements are larger than the median of the distribution. These indications imply that these eight systems are highly likely to be DLAs. We also note that the EWs of Mg II λ2796 absorption lines in all our ghostly absorbers with Mg II measurements are much larger than the median of the EW of this absorption line in the intervening LLS (i.e., (EW)$_{\text{LLS}} < 1.0$ Å; Nestor et al. 2006).

In order to assess whether the two remaining systems (with no Mg II λ2796 and Fe II λ2600 measurements available) could also be DLAs, we make a comparison of the rest EWs of Al II λ1670 and Fe II λ2382 in the two systems with those of the intervening DLAs from Noterdaeme et al. (2012). The results are shown in the upper panel of Figure 6. As shown in this figure, the rest EW of Al II λ1670 (Fe II λ2382) is ∼ 2.2 (∼ 1.6) times larger than the median rest EW of Al II λ1670 (Fe II λ2382) of the intervening DLAs. The high EW of these absorption lines hints at the possibility that these absorbers could also be DLAs.

2.3. Lyβ and C IV Absorption in Ghostly Absorbers

Since the DLA absorption troughs in ghostly absorbers are almost fully filled with the leaked Lyα emission from the BLR (and NLR), one would expect the corresponding leaked Lyβ emission from the BLR to also fill the Lyβ absorption trough in the spectra. However, in all ghostly absorber candidates for which the Lyβ spectral region is observed, the Lyβ absorption is clearly visible. Here we demonstrate that this is because, in the spectrum, the ratio of the continuum to the Lyβ emission is larger than the ratio of the continuum to the Lyα emission.

For this, we use the ghostly absorber toward the quasar J0222+0005, which reveals a shallow dip in both the Lyα spectral region (which is a signature of a DLA absorption) and the Lyβ absorption. We first follow the technique described in Section 2.2.3 and determine the H I column density from the Lyα absorption dip. To properly fit the shallow dip, we require the partial coverage of the BLR to be ∼ 0.7. We then assume that the Lyβ/Lyα emission line ratio is ∼ 0.2 (Martin 1988), and consequently we fit the Lyβ absorption by taking into account a partial coverage of 0.7 for the BLR. The result is shown in Figure 7. As shown in this figure, the Lyβ absorption line is only slightly elevated and is clearly visible in the spectrum despite the highly elevated DLA absorption trough.
The low S/N of the spectrum does not allow for accurate measurement of the flux in the Ly$\beta$ absorption trough. High S/N and higher resolution spectra of our ghostly absorbers would be needed to better estimate the flux at the bottom of the Ly$\beta$ absorption line and correspondingly determine more accurately the Ly$\beta$/Ly$\alpha$ ratio.

We also probed the partial coverage of the BLR by the high-ionization phase of the cloud, using the C IV doublet absorption lines. In most of our systems, the C IV absorption lines are very strong, and the two components of the doublet are heavily blended. Nevertheless, seven systems reveal well-separated components to allow for a successful Voigt profile fitting of the doublet. In these systems, we could conduct single-component fitting of the C IV absorption lines without invoking partial coverage. The lack of partial coverage could be easily explained by the fact that the high-ionization phase of the cloud is more extended than the low-ionization or neutral phase of the cloud. However, we could still get a satisfactorily good fit even if we remove a residual flux of up to 15% from the bottom of the C IV absorption lines. This would imply that the observed C IV absorption lines in these systems are not inconsistent with the presence of partial coverage. Higher resolution spectra would be needed to properly tackle this issue.

3. Results

In Paper I, we conjectured that eclipsing DLAs with strong Ly$\alpha$ emission arise in smaller and denser clouds and possibly closer to the AGN. Here, we would like to ascertain this conclusion using ghostly absorbers. In this section, we characterize the ghostly absorber sample and then compare their properties with those of the eclipsing DLAs. We note that in Paper I we defined two kinds of eclipsing DLAs: (1) eclipsing DLAs with weak, narrow Ly$\alpha$ emission (i.e., the integrated flux or IF of the narrow Ly$\alpha$ emission is $<20 \times 10^{-17}$ erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$) in their DLA troughs, and (2) eclipsing DLAs with strong, narrow Ly$\alpha$ emission (i.e., IF $\geq 20 \times 10^{-17}$ erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$). Here, we also consider these two kinds of eclipsing DLAs separately.

3.1. Kinematics

For each quasar in our ghostly absorber sample, we remeasure the emission redshift by conducting Gaussian fits on the He II, C III, and Mg II emission lines. These emission lines are good redshift indicators as their statistical shift with respect to the quasar systemic redshift is small (Hewett & Wild 2010). The redshift distribution of ghostly absorbers is shown in Figure 8 as a blue histogram. For the sake of comparison, the redshift distribution for all DR12 quasars with $z_{QSO} > 2.0$ is also shown as a red dashed histogram.

Figure 8. The blue histogram shows the distribution of the quasar redshifts for the ghostly absorber sample. For the sake of comparison, the redshift distribution for all DR12 quasars with $z_{QSO} > 2.0$ is also shown as a red dashed histogram.
Following the approach described in Ellison et al. (2010), emission leads to smaller values of the spectral index. The presence of dust in a DLA would extinguish the quasar spectrum free from emission and absorption lines. The lowest median value of $\alpha$ belongs to the ghostly absorber sample, implying that eclipsing DLAs with weak emission have a smaller median $\alpha$ compared to what is seen in eclipsing DLAs with strong emission. The lowest median value of $\alpha$ is shown in Figure 10. As can be seen from this, quasars with eclipsing DLAs with strong emission have a smaller median $\alpha$ compared to what is seen in eclipsing DLAs with weak emission. The lowest median value of $\alpha$ belongs to the ghostly absorber sample, implying that quasars behind these DLAs are the reddest.

3.2. Reddening due to Dust

In this section, we employ different techniques to investigate the reddening of the quasar spectra that is due to the presence of dust in our ghostly and eclipsing DLAs.

3.2.1. Reddening Estimates Based on Spectral Index Distributions

By examining the difference in the spectral indices of the spectra of the ghostly and eclipsing DLA quasars, one can probe the reddening of the quasar spectra that is due to dust in these absorbers (Murphy & Liske 2004; Wild & Hewett 2005; Wild et al. 2006; Ellison et al. 2010; Kaplan et al. 2010). The first step in this approach is to determine the spectral index, $\alpha$, defined as $f_\lambda \propto \lambda^{-\alpha}$, by fitting a power law to the regions in the spectrum free from emission and absorption lines. The presence of dust in a DLA would extinguish the quasar emission, leading to smaller values of the spectral index. Following the approach described in Ellison et al. (2010), we fit a power law on the spectra of each of our quasars. The distribution of the spectral indices, $\alpha$, is shown in Figure 10. As can be seen from this, quasars with eclipsing DLAs with strong emission have a smaller median $\alpha$ compared to what is seen in eclipsing DLAs with weak emission. The lowest median value of $\alpha$ belongs to the ghostly absorber sample, implying that quasars behind these DLAs are the reddest.

3.2.2. Reddening Estimates Based on Quasar Colors

We plot in Figure 11 the $\Delta(g-i)$ colors as a function of quasar redshift (left-hand panel) and the $\Delta(g-i)$ color distribution (right-hand panel) for the quasars from the samples of ghostly absorbers (red filled squares and histogram) and eclipsing DLAs with weak (blue filled circles and histogram) and strong (green filled triangles and histogram) narrow Ly$\alpha$ emission in their troughs.

Using the SMC reddening law (Prevot et al. 1984; Khare et al. 2004),

$$A_\lambda = 1.39 \lambda^{1.2} E(B - V),$$

we can determine $E(B - V)_{g-i}$ from the observed $\Delta(g-i)$ values. Taking $\lambda_g$ and $\lambda_i$ to be 4657.98 and 7461.01 Å, respectively, we find

$$E(B - V)_{g-i} = \Delta(g-i)(1 + z_{abs})^{-1.2}/1.506,$$

where $z_{abs}$ is the redshift of the DLA. To convert to an $A_{V(g-i)}$, we use the standard definition $A_V = RV E(B - V)$ with $R_V = 2.74$ (Gordon et al. 2003). Converting the observed $\Delta$
(g−i) to $A^{\text{Vgi}}_{\text{rest}}$, we get median $A^{\text{Vgi}}_{\text{rest}}$ = 0.24, 0.19, and 0.12 for the ghostly and eclipsing DLAs with strong and weak emission, respectively.

3.2.3. Reddening Estimates Based on Geometric Mean Composite Spectra

The geometric mean composite spectra of ghostly (blue spectrum) and eclipsing DLAs with strong (black spectrum) and weak (red spectrum) narrow Lyα emission are shown in the upper panel of Figure 12. These composite spectra are used to estimate the extinction due to dust in these absorbers. We use the geometric mean to create the composite spectra because the geometric mean of a set of quasar spectra preserves the average power-law index of the spectra (York et al. 2006).

We use the template-matching technique to measure the extinction, $A_V$ (Fitzpatrick & Massa 2007; Fynbo et al. 2013; Ranjan et al. 2018). The technique is based on iteratively reddening a template quasar spectrum (Selsing et al. 2016), using the SMC extinction curve (Gordon et al. 2003), until the reddened template best matches the observed spectrum. In this case, the observed spectrum, $f_\lambda$, can be represented as

$$f_\lambda = C_0 F_\lambda \left( \frac{\lambda}{\lambda_0} \right)^{-\Delta \alpha} \exp \left( - \frac{1}{2.5 \log_{10}(e)} k_\lambda A_V \right),$$

(3)

where $F_\lambda$ is the quasar template from Selsing et al. (2016), $\Delta \alpha$ is the power-law slope relative to the intrinsic slope of the quasar template, $k_\lambda$ denotes the SMC reddening curve, $A_V$ is the V-band extinction, and $C_0$ is an arbitrary factor, scaling the quasar intrinsic flux. Using this equation to fit the observed spectra, we found $A_V = 0.19 \pm 0.06, 0.11 \pm 0.07, 0.05 \pm 0.05$ for ghostly and eclipsing DLAs with strong and weak emission, respectively.

For each composite, the uncertainty in $A_V$ is estimated by adopting $\Delta \alpha = \pm 0.2$ (see Krawczyk et al. 2015). Interestingly, these $A_V$ values are consistent with the photometric measurement of extinction from Section 3.2.2. Since intervening absorbers are also present along the line of sight to the quasars used in constructing these composites, the possible presence of dust in these absorbers could in principle affect the shape of the continuum of the composite spectra. However, the consistency found between the spectroscopic and photometric measurements of extinction implies that the effect of dust extinction from intervening absorbers is negligible, and that the extinction predominantly arises in the ghostly and eclipsing DLAs.

Our results show that quasars behind ghostly absorbers are the reddest despite the lower H I column density in these absorbers (see Section 3.4.1).

3.3. Metals

Figure 13 shows the Kolmogorov–Smirnov (K-S) tests, comparing the rest EWs of Si ii λ1526, Fe ii λ1608, and C ii λ1334 in the ghostly absorbers (red lines) and eclipsing DLAs with weak (blue lines) and strong (green lines) narrow Lyα emission in their DLA absorption troughs. As shown in the figure, the EWs are larger in the eclipsing DLAs with strong emission compared to what is observed in the eclipsing DLAs.
with weak emission. Moreover, the largest EWs are observed in the ghostly absorbers. Higher EWs would imply that the absorbers are of higher metallicities or the DLAs are located in more turbulent regions.

As shown in Figure 13, the maximum distance parameter is the largest for C IIλ1334 (D = 0.58). We note that since the C IIλ1334 and C II′λ1335 absorption lines are almost fully blended with each other at the SDSS spectral resolution, the EW of the whole C II+C II′ absorption feature is taken as the EW of C II. Therefore, the stronger difference seen for C II is mainly due to the blending of this absorption line with the C II′λ1335 absorption. If C II′ are stronger in ghostly absorbers, then the K-S test for Si II′ would be illuminating because stronger C II′ absorption could imply stronger absorption from Si II′. Although the low S/N of the spectra does not allow us to perform the K-S test for this species, the Si II′ in the stacked spectra of eclipsing and ghostly absorbers clearly shows that ghostly absorbers have the strongest Si II′ absorption (see Section 3.4).

3.4. Normalized Median Composite Spectrum

In this section, we create a stacked spectrum of ghostly absorbers and then compare its absorption properties with those of the eclipsing DLAs with weak and strong Lyα emission. We also construct median composite spectra of the associated Super Lyman Limit System (SLLSs, quasar absorption line systems with $10^{19} \text{ cm}^{-2} \leq N(\text{H I}) \leq 10^{20.5} \text{ cm}^{-2}$) and intervening DLAs to compare with that of the ghostly absorbers.

3.4.1. Comparison with Eclipsing DLAs

We first create a normalized stacked spectrum using the quasar spectra from our ghostly absorber sample. To create the stacked spectrum, all spectra are first shifted to the rest frame of the DLAs and then normalized. The final stacked spectrum is generated by median-combining these normalized spectra (Ellison et al. 2010; Rahmani et al. 2010). The aim of this section is to statistically look for differences between ghostly and eclipsing DLAs, by comparing the strength of the absorption lines in their stacked spectra. Here, we would like to test the hypothesis that ghostly absorbers are from the same population as eclipsing DLAs but with higher densities and closer distance to the quasars.

Figure 14 shows absorption from the Lyman series transitions for the composite spectra of ghostly absorbers (upper panels) and eclipsing DLAs with weak (lower panels) and strong (middle panels) Lyα emission in their troughs. The Voigt profile fits to the Lyman series absorption lines are overplotted on the observed spectra as red curves. The green curves show the uncertainty of ±0.10 dex on the H I column density. The $b$-value increases from $b = 53 \text{ km s}^{-1}$ in eclipsing DLAs with weak emission to $b = 105 \text{ km s}^{-1}$ in ghostly absorbers. If we ascribe the line widths to turbulence, then higher $b$-values would imply that the cloud is exposed to a more turbulent region and perhaps is located closer to the quasar.

We determined the rest EWs of the absorption lines in the stacked spectrum of the ghostly absorbers using Gaussian fits (Fathivavsari et al. 2013). The results are summarized in Table 3. Figure 15 shows the empirical curve of growth constructed using the Si II absorption lines from the ghostly absorber composite spectrum (Prochaska 2006). The data from Si II′, Fe II, and Al III are also included in Figure 15. The curve of growth analysis gives a metallicity of [Si/H] $\sim$ −1.0 for ghostly absorbers. This is similar to the metallicities estimated for the eclipsing DLAs with weak (log Z/Z⊙ $\sim$ −1.1 ± 0.2) and strong (log Z/Z⊙ $\sim$ −1.0 ± 0.2) Lyα emission. We note that the estimated column densities and metallicities are subject to the assumption of a single-component cloud. The large $b$-value shows that the cloud has a multicomponent structure. We therefore refer to these measurements as tentative estimates (Jenkins 1986).

Figure 16 presents the spectral regions of some important transitions in the stacked spectra of the ghostly and eclipsing DLAs. As shown in this figure, absorptions from the excited states of Si II and C II are detected in all three composites, but with different strengths. These absorption lines are the weakest in the eclipsing DLAs with weak emission (red curves), while they are the strongest in the ghostly absorbers (blue curves). Moreover, the strength of these absorption lines in the eclipsing DLAs with strong emission (black curves) is intermediate.
between what is seen in ghostly absorbers and eclipsing DLAs with weak emission.

Fine structure levels can be populated by collisions, radiative pumping due to a local radiation field, and direct excitation by the cosmic microwave background (CMB) radiation (Silva & Viegas 2002; Wolfe et al. 2003, 2008; Srianand et al. 2005).

However, direct excitation by the CMB radiation is negligible for Si II because the fine structure levels in Si II are so far apart from each other. The pattern seen in the strength of the Si II absorption lines in the three composites (see Figure 16) implies that the gas is progressively getting denser or closer to the quasar as one goes from the eclipsing DLAs.

Table 3. Rest Equivalent Widths for the Three Composites in Milliangstroms

| ID  | \( \lambda_{ab} \) | Composite 1 | Composite 2 | Composite 3 |
|-----|------------------|-------------|-------------|-------------|
| N V | 1238             | 235 ± 16    | 483 ± 15    | 1071 ± 11   |
| N V | 1242             | 120 ± 5     | 446 ± 28    | 667 ± 9     |
| Si IV | 1393            | 585 ± 13    | 953 ± 18    | 1337 ± 41   |
| Si IV | 1402            | 495 ± 15    | 801 ± 18    | 1222 ± 14   |
| C IV | 1548             | 795 ± 22    | 1420 ± 12   | 2278 ± 20   |
| C IV | 1550             | 633 ± 21    | 1189 ± 18   | 1342 ± 20   |
| Al III | 1854          | 321 ± 18    | 465 ± 28    | 856 ± 12    |
| Al III | 1862           | 201 ± 24    | 370 ± 23    | 642 ± 21    |
| Si II | 1260            | 1036 ± 15   | 1156 ± 19   | 1248 ± 10   |
| Si II | 1304            | 524 ± 6     | 683 ± 16    | 771 ± 20    |
| Si II | 1526            | 692 ± 18    | 890 ± 19    | 1045 ± 20   |
| Si II | 1808            | 240 ± 16    | 298 ± 12    | 200 ± 40    |
| Si II* | 1264          | 71 ± 6      | 306 ± 22    | 790 ± 50    |
| Si II* | 1309          | 33 ± 13     | 113 ± 16    | 330 ± 20    |
| Si II* | 1533          | 15 ± 3      | 164 ± 14    | 470 ± 50    |
| Fe II | 1608            | 430 ± 7     | 462 ± 13    | 364 ± 15    |
| Fe II | 2374            | 804 ± 46    | 785 ± 33    | 657 ± 100   |
| Fe II | 2382            | 1051 ± 71   | 1021 ± 25   | 972 ± 200   |
| Al II | 1670            | 709 ± 17    | 844 ± 11    | 815 ± 20    |
| C II | 1334            | 895 ± 10    | 1220 ± 15   | 1464 ± 20   |
| C II* | 1335           | 232 ± 13    | 455 ± 17    | 657 ± 20    |

Notes. First column: ID of the species. Second column: rest wavelengths. Third column: rest EWs for the composite of eclipsing DLAs with weak narrow Ly\( \alpha \) emission. Fourth column: rest EWs for the composite of eclipsing DLAs with strong narrow Ly\( \alpha \) emission. Fifth column: rest EWs for the composite of ghostly absorbers.

Figure 14. Voigt profile fits (red curves) on the Lyman series absorption lines in the composite spectra of the ghostly absorbers (upper panels) and the eclipsing DLAs with weak (lower panels) and strong (middle panels) Ly\( \alpha \) emission in their troughs. The green curves show the ±0.1 dex variations in the H I column density measurements.

Figure 15. Empirical curve of growth constructed using the Si II absorption lines from the ghostly absorber composite spectrum. Column densities are from the weak transitions, and EWs are from Table 3.
with weak emission to ghostly absorbers. Higher resolution spectra of the ghostly and eclipsing DLAs would in principle allow us to disentangle the effects of higher gas density and proximity to the quasar.

As shown in Figure 16, although the OI$^*$ absorption is fully blended with the Si II absorption at the SDSS spectral resolution, the OI$^{**}$ absorption is clearly detected in both the eclipsing DLAs with strong emission and ghostly absorbers. The CI and Mg I absorptions are also detected in all three composites. However, due to the low S/N, the CI detection in the composite of eclipsing DLAs with weak emission is tentative. The detection of the CI and Mg I absorption in ghostly absorbers implies that the density of the gas should be high. While CI is known to be a good tracer of H$_2$ (Noterdaeme et al. 2018), the composite spectrum of ghostly absorbers does not show any signature of H$_2$. However, we found an upper limit of $10^{18}$ cm$^{-2}$ for the column density of H$_2$ in individual systems, which is standard in DLAs.

Similar to the Si II and C II excited state transitions, high-ionization species (i.e., N V, C IV, and Si IV) also exhibit the strongest absorptions in ghostly absorbers and the weakest absorptions in eclipsing DLAs with weak emission. This trend is also seen in the Al III absorption lines. Among the high-ionization species, the N V absorption shows the highest difference in the three composites. For example, the EW of the N V $\lambda 1238$ absorption in ghostly absorbers is a factor of $\sim 4.4$ ($\sim 2.1$) higher than in eclipsing DLAs with weak (strong) emission. Stronger N V absorption could be attributed to higher metallicity (Ellison et al. 2010) or a higher level of ionization (Fox et al. 2009; Perrotta et al. 2016). However, the similar metallicities of the three composites, along with the fact that our ghostly absorbers have smaller H I column densities, hint at the possibility that the stronger N V absorption in ghostly absorbers is mainly due to the higher level of ionization in the external layers of these gas clouds. Since the median luminosities (at 1500 Å) of the quasars in the three samples do not positively correlate with the strength of the high-ionization absorption lines in the composite spectra, the stronger absorption from the N V, Si IV, and C IV doublets could be an indicator of the proximity to the quasars.

### 3.4.2. Comparison with Associated SLLSs and Intervening DLAs

In this section, we create stacked spectra of associated SLLSs and intervening DLAs with log $N$(H I) $= 20.30 \pm 0.20$, $21.00 \pm 0.20$, and $21.50 \pm 0.20$. The SLLSs are chosen from the S$^4$QSO sample, and the intervening DLAs are from Noterdaeme et al. (2012). Our sample of SLLSs and intervening DLAs each contain 164 and 6090 (with 486 DLAs with log $N$(H I) $= 20.30 \pm 0.20$, 1537 DLAs with log $N$(H I) $= 21.00 \pm 0.20$, and 4067 DLAs with log $N$(H I) $= 21.50 \pm 0.20$) spectra, respectively. In this study, we choose only those SLLSs with $10^{19.5}$ cm$^{-2}$ $\lesssim N$(H I) $\lesssim 10^{20}$ cm$^{-2}$. This choice is motivated by the fact that the low-ionization absorption lines in ghostly absorbers (with which the SLLSs are compared) are very strong. To create the stacked spectra, we first randomly choose 30 spectra from each sample and stack them. We repeat this process 100 times. The median of these 100 spectra is taken as the final stacked spectrum, and their standard deviation is taken as the uncertainty spectrum.

Figure 17 presents the spectral regions of some important transitions in the stacked spectra of the ghostly absorbers, SLLSs, and intervening DLAs. As shown in this figure, absorptions from high-ionization species are the strongest in ghostly absorbers. These absorption lines are all stronger in
SLLSs compared to what is seen in intervening DLAs. The Al III absorption, which is also the strongest in ghostly SLLSs compared to what is seen in intervening DLAs. The striking feature in Figure 17 is the presence of strong absorption from fine structure states in ghostly absorbers and the absence of such absorption in other absorbers. From this figure, one can see that the absorption properties of ghostly absorbers are uniquely different from those of the other categories of absorbers. Figures 18 and 19 show the spectra of the ghostly absorbers for which hydrogen column density is estimated.

3.5. Physical Properties of the Absorbers

3.5.1. Constraining the Ionization Parameter and the Gas Temperature

In this section, we construct some photoionization models using the code CLOUDY (Mathews & Ferland 1987) in order to roughly estimate the gas temperature and the ionization parameter. The latter is defined as the ratio of the density of hydrogen-ionizing photons to the hydrogen density. We construct a series of CLOUDY models for a range of ionization parameters, U, varying from log(U) = −3.0 to +1.0. For each ionization parameter, the calculation is stopped when a neutral hydrogen column density of log N(HI) = 21.30 is reached. The relative abundance of elements is assumed to be solar, and the observed silicon abundance, [Si/H] ≈ −1, is taken as the gas metallicity in the model cloud. The adopted spectral energy distribution comprises the standard AGN spectrum of Mathews & Ferland (1987), the Haardt–Madau metagalactic UV spectrum (Haardt & Madau 1996), and the CMB radiation of both at z = 2.50, which is the median redshift of our ghostly absorbers.

Inspection of these photoionization models shows that the N V column density of log(N V) ≈ 14.15, measured from the composite spectrum of eclipsing DLAs with weak emission, is reproduced only when log(U) ≈ −1.0. We also checked that when log(U) ≲ −2.0, the predicted N V column density is log(N V) ≲ 12.0, which is so small that its corresponding absorption lines would be hardly detected, if at all, in the SDSS spectra. So, it is highly likely that the ionization parameter is log (U) ≈ −1.0. This is similar to what Fathivavsari et al. (2015) found for an eclipsing DLA toward the quasar J0823+0529.

For eclipsing DLAs with strong emission and also for ghostly absorbers, we will assume the same ionization parameter (log (U) ≈ −1.0), although the stronger absorption from high-ionization species (especially N V) and the presence of absorption from O I” hint at the possibility that the ionization parameter is higher in these absorbers. Precise measurements of the ionization parameter would be possible by follow-up high-resolution spectroscopy of our eclipsing and ghostly absorbers.

Our CLOUDY models also show that the electron temperature, T_e, in the regions of the cloud where low-ionization species are dominant is ≈ 10,000 K. Moreover, the n_e/n_H and n_p/n_H in these regions are ≈ 0.3 and ≈ 0.25, respectively. We will use these values to constrain the gas density (in Section 3.5.2) and the DLA–QSO distance (in Section 3.5.3).

3.5.2. Constraining the Gas Density

In this section, we will use absorption from the Si II fine structure states to put some constraints on the gas density. Fine structure levels can be populated by collisions, radiative pumping due to a local radiation field, and direct excitation by the CMB radiation (Silva & Viegas 2002; Wolfe et al. 2003, 2008; Srianand et al. 2005). However, direct excitation by the CMB radiation is negligible for Si II because the fine structure levels in Si II are so far apart from each other. If we assume that collisional excitation by atomic hydrogen, protons, and free electrons is the dominant process in populating the Si II fine structure state, then the level population can be given by

$$\frac{N(\text{Si}\text{II}_j=1/2)}{N(\text{Si}\text{II}_j=3/2)} = \frac{1}{2} + \frac{2.5 \times 10^4}{n_H^2}.$$  (4)

To derive this equation, we adopt an electron temperature of T_e = 10,000 K, n_e/n_H = 0.3, and n_p/n_H = 0.25 (see Section 3.5.1). The observed N(Si II)_{1/2}/N(Si II) ratios from the composites of ghostly absorbers and eclipsing DLAs with strong and weak emission are 0.11, 1.3 × 10^−2, and 1.4 × 10^−3, respectively. We can use Equation (4) and derive from these observed ratios the hydrogen density and the characteristic size (i.e., l = N(H I)/n_H) of our ghostly and eclipsing DLA clouds.
The results are summarized in Table 4. The detection of C I absorption seems to be consistent with the high density found for the ghostly absorbers.

As seen in Table 4, the gas is progressively getting denser, and the cloud becomes smaller in size as one goes from the eclipsing DLAs with weak emission to the ghostly absorbers. It could be possible that the gas is compressed by the interaction with outflowing gas, and that denser clouds are located closer to the AGN where outflows are stronger (see next section).

### 3.5.3. Constraining the DLA–QSO Distance

By knowing the ionization parameter, \( U \), and the gas density, \( n_{H\text{I}} \), one can estimate the DLA–QSO distance using the following relation:

\[
r = \sqrt[4]{\frac{Q}{4\pi U n_{H\text{I}} c}},
\]

where \( Q \) is the number of hydrogen-ionizing photons, and \( c \) is the speed of light. To determine \( Q \), we first estimate the flux (and then the quasar luminosity, \( L_{\text{QSO}} \)) at the Lyman limit by extrapolating, with a power law, the continuum observed at 6100 and 8100 Å. We then assume a flat spectrum (i.e., \( L_{\nu} = L_{\text{QSO}} \)) and integrate \( L_{\nu}/\hbar\nu \) over the energy range 1 to 20 Ryd (Fathiavarsi et al. 2015) to estimate the number of hydrogen-ionizing photons. When \( Q \) is known, one can use Equation (5) to get the DLA–QSO distance. The results are summarized in Table 4. As shown in this table, these distances, albeit being rough estimates, are consistent with our proposed scenario in which ghostly absorbers are located closer to the quasars compared to eclipsing DLAs.

### 4. Summary and Conclusion

In this paper, we have presented and studied a sample of 30 ghostly absorbers from SDSS-III BOSS DR12. We compared the properties of the ghostly absorbers with those of the eclipsing DLAs from Paper I. By analyzing the spectra of these DLAs, we found an interesting sequence in the observed properties of ghostly and eclipsing DLAs. The sequence is such that the eclipsing DLAs with strong emission always exhibit properties that are intermediate between what is seen in the ghostly and eclipsing DLAs with weak emission. Below, we summarize these observed sequences:

(i) We found that the \( b \)-values obtained from the single-component curve of growth for the Lyman series absorption lines progressively get larger from the eclipsing DLAs with weak emission to ghostly absorbers. If we attribute the \( b \)-values to the turbulence, then higher \( b \)-values would imply that the absorber is experiencing stronger turbulence, and that the cloud may be located closer to the quasar.

(ii) The strength of the absorption from the excited states of Si II and C II also exhibits a sequence in which ghostly absorbers show the strongest absorption in these transitions. Since fine structure states can be populated by collisional and radiative excitation, stronger absorption from these transitions would imply higher gas density or proximity to the quasar. Higher resolution spectra of these DLAs are required in order to break the degeneracy between the gas density and proximity to the quasar.

(iii) The absorption from high-ionization species (e.g., Si IV, C IV, and N V) is the strongest in the ghostly absorbers and the weakest in the eclipsing DLAs with weak emission. Stronger N V absorption could be attributed to higher ionization and, maybe to the proximity to the quasar.

(iv) We employed three different approaches to estimate the reddening of the background quasar by the dust in the ghostly and eclipsing DLAs. We found that the dust extinction is highest in ghostly absorbers. Using the template-matching technique, we found \( A_V = 0.19 \pm 0.06, 0.11 \pm 0.07 \), and \( 0.05 \pm 0.05 \) for ghostly and eclipsing DLAs with strong and weak emission, respectively.

Taken together, these results are suggestive that the ghostly absorbers are located closer to the quasars and are perhaps of higher densities compared to the eclipsing DLAs. In Paper I, we argued that the eclipsing DLAs with strong Ly\( \alpha \) emission are denser and closer to the quasars, compared to eclipsing DLAs with weak emission. We proposed that eclipsing DLAs could be the product of the collision between infalling and outflowing gas, and that when the Ly\( \alpha \) emission in the DLA trough is stronger, the collision occurs closer to the quasars. This scenario is corroborated by the correlation found between the strength of the Ly\( \alpha \) emission detected in the DLA trough and the strength of the absorption from the fine structure states (indicative of the gas density or proximity to the quasar) and high-ionization species (indicative of the ionization level).

We now extend this scenario and propose that ghostly absorbers are from the same population as eclipsing DLAs, except that they are so dense that the projected size of the DLA is much smaller than that of the BLR. In this case, the leaked
emission from the BLR would fill the DLA absorption trough, and consequently no apparent DLA absorption would be detected in the spectrum. We recall that in eclipsing DLAs (especially those with Ly$\alpha$ emission in their troughs) the gas density is low (high) enough that the projected size of the DLA cloud is larger (smaller) than that of the BLR (NLR or star-forming regions in the host galaxy). That is why, in the spectra of eclipsing DLAs (with or without Ly$\alpha$ emission), the DLA absorption profile is clearly visible.

If eclipsing and ghostly absorbers are the product of the interaction between infalling and outflowing gas, then higher densities in ghostly absorbers would imply that the interaction should have occurred closer to the quasars. Since regions close to quasars are expected to be highly turbulent, the larger widths of the hydrogen absorption lines in ghostly absorbers seem to be consistent with the picture in which ghostly absorbers (compared to eclipsing DLAs) probe regions closer to the quasars. The higher level of ionization along with the higher $N$(Si II$^+)$/N(Si II) ratio in ghostly absorbers is also consistent with this scenario.

Higher resolution spectra of some of our best eclipsing and ghostly absorber systems would allow detailed analysis of the kinematics and ionization state of the gas, which would in turn help confirm the validity of the scenario presented here and in Paper I.

H.F. would like to thank the referee for useful comments and the Iranian National Observatory for their support during this project. H.F. also acknowledges conversations with Narges Jamialahmadi, Habib Khosroshahi, Hadi Rahmani, Ragunathan Srianand, Pasquier Noterdaeme, and Patrick Petitjean during the preparation of this manuscript. Funding for SDSS-III has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, and the U.S. Department of Energy Office of Science. The SDSS-III website is http://www.sdss3.org/.

SDSS-III is managed by the Astrophysical Research Consortium for the Participating Institutions of the SDSS-III Collaboration including the University of Arizona, the Brazilian Participation Group, Brookhaven National Laboratory, Carnegie Mellon University, University of Florida, the French Participation Group, the German Participation Group, Harvard University, the Instituto de Astrofísica de Canarias, the Michigan State/Notre Dame/JINA Participation Group, Johns Hopkins University, Lawrence Berkeley National Laboratory, Max Planck Institute for Astrophysics, Max Planck Institute for Extraterrestrial Physics, New Mexico State University, New York University, Ohio State University, Pennsylvania State University, University of Portsmouth, Princeton University, the Spanish Participation Group, University of Tokyo, University of Utah, Vanderbilt University, University of Virginia, University of Washington, and Yale University.

Appendix A
Some Additional Figures

The Voigt profile fit to the Lyman series absorption lines (Figure 18) and the reconstruction of the quasar spectrum in the Lyman-$\alpha$ spectral region (Figure 19).
Figure 18. Same as Figure 2.
Figure 18. (Continued.)
Figure 19. Same as Figure 5.
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Figure 19. (Continued.)
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