COLLECTIVE PROPERTIES OF QUASAR NARROW ASSOCIATED ABSORPTION LINES

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ABSTRACT

This paper statistically investigates the properties of C IV and Mg II narrow absorption lines (NALs) to look for velocity cuts that can well constrain quasar-associated NALs. The coverage fraction (f_c) is defined as the ratio between the number of quasars exhibiting at least one detected absorber and the total number of quasars that can be used to detect absorptions with given criteria. We find that, for both C IV and Mg II absorbers, both the number density of absorbers in given velocity intervals (dn/dz) and the f_c show very significant excess at the low-velocity offset from the quasars, relative to the random occurrence that is expected for cosmologically intervening absorbers. These relative excess extensions for Mg II absorptions are not only evidently related to absorption strength but also to quasar luminosity, while they are mainly constrained within 2000 km s^{-1} no matter what quasar luminosity and absorption strength are. In addition, we find that the redshift number density (dn/dz) evolution of Mg II absorbers with v_{abs} < 2000 km s^{-1} evidently differs from that with v_{abs} > 2000 km s^{-1}. Turning to C IV absorptions, the relative excess extensions of both dn/dz and f_c are mainly limited within v_{abs} < 4000 km s^{-1}, and depend neither on absorption strength nor on quasar luminosity. And also, the absorbers with v_{abs} < 4000 km s^{-1} show obviously different redshift number evolution from those with v_{abs} > 4000 km s^{-1}. We suggest velocity cuts of 4000 km s^{-1} and 2000 km s^{-1} to define quasar C IV and Mg II associated NALs, respectively.

Subject headings: Galaxies:active—quasars: general—quasars: absorption lines

1. INTRODUCTION

A widely accepted event is that supermassive black holes (SMBHs) reside at the central region of all massive galaxies, mostly in the form of active galactic nuclei (AGNs) (e.g., Kormendy & Ho 2013), and the mass of the SMBH (M_{BH}) can reach up to 10^{10} M_{\odot} (e.g., Wu et al. 2015). The evolution behavior of star formation rate density within galaxies is similar to that of the black hole accretion rate density (e.g., Aird et al. 2010; Madau & Dickinson 2014). The black hole mass tightly is related with the stellar mass (e.g., Kormendy & Ho 2013; Bell et al. 2017) or stellar velocity dispersion (e.g., Gu et al. 2009; Kormendy & Ho 2013; Bennert et al. 2015; Batiste et al. 2017) of the host galaxy bulge. These signatures reveal a connection between the AGN activity and global properties of host galaxies, which is widely researched and debated in the last decades (e.g., Ferrarese & Merritt 2000; Di Matteo et al. 2005; Bundy et al. 2008; Bongomo et al. 2012; Kormendy & Ho 2013; McAlpine et al. 2017; Wang et al. 2017; Biernacki et al. 2017). However, the underlying physics is still controversial. For example, why, when and how the SMBHs and their host galaxies affect and/or regulate one another, which hampers us from completely comprehending the cosmic evolutions of SMBHs and galaxies.

SMBHs’ accretion of surrounding gas is a foundational process in their lifetimes. The disk gas of AGNs accelerated by radiation pressure (e.g., Murray & Chiang 1995; Chelouche & Netzer 2001; Proga 2007), thermal pressure (e.g., Krollik & Kriss 2001; Owen et al. 2012), magnetocentrifugal forces (e.g., Everett 2005; Fukumura et al. 2015; Chajet & Hall 2017), cosmic ray pressure (e.g., Breitschwerdt et al. 1991; Booth et al. 2013), and/or a combination of them, then leaves off the central region in form of outflow/wind. The gas accretion and outflow are two important hands to regulate the global properties of SMBH and host galaxy. AGN outflows are proven to be an efficient process to halt the gas infall infinitely into both the galaxies and central SMBHs. These outflows are also a good transport tool that carries away the energy, matter and momentum, which could be injected into broad emission line region, narrow emission line region, host galaxy, circumgalactic medium (CGM), and intergalactic medium (IGM). These injections, fashionably called feedback, could quench star formation rate by removing gas off its location or heating gas up to very high temperature (e.g., Cano-Díaz et al. 2012; Zubovas & King 2012; Cresci et al. 2015; Carniani et al. 2016; Zubovas & Bourne 2017), and on the other hand, are also usually invoked to explain the enhancement of star formation rate through compressing gas clouds (e.g., Ishibashi & Fabian 2012; Cresci et al. 2015; Bieri et al. 2016; Zubovas & Bourne 2017).

AGN outflows can be observed via blueshifted emission and absorption features against continuum emissions of central compact regions. Therein absorptions are more fashionable tool to probe global properties of outflows. Quasar absorptions often exhibit complex features, which can be roughly classified into broad absorption lines (BALs), mini-BALs and narrow absorption lines (NALs) based on line widths of their profiles, and can be also divided into associated and intervening absorptions in term of whether they are physically related to the quasar system or not. Complex features indicate that different type of absorption lines would reflect absorbers with different characteristics. BALs display smooth absorption troughs with line widths being larger than a few thousands km s^{-1} at depths > 10% below the continuum, and are believed to be undoubtedly associated with quasars. NALs generally show sharp profiles with full width at half maximum (FWHM) being less than
a few hundreds kms$^{-1}$ and can be formed in a wide variety of medium, no matter what the relationship between the medium and quasar is. When compared to the detected BALs and NALs, the detected mini-BALs that have line widths between BALs and NALs are much rarer. Hence, the mini-BALs lack in-depth research and are poorly understood (e.g., Misawa et al. 2007; Gibson et al. 2009; Wu et al. 2010; Giustini et al. 2011; Rodríguez Hidalgo et al. 2013; Horiuchi et al. 2016; Muzahid et al. 2016; Moravec et al. 2017).

BALs and mini-BALs are usually blended and we find that it difficult to understand the properties of absorbers in greater detail. Resolved NALs, in contrast, are often observed in spectra even at a middle or low resolution. For example, unblended C IV λ1548,1551 and Mg II λλ2796,2803 doublets (e.g., Chen et al. 2015, 2016) are often imprinted on quasar spectra of the Sloan Digital Sky Survey (York et al. 2000), which have a resolution of $R = 1300 \sim 2500$ (Alam et al. 2015). Resolved NALs could lead us to realize the absorber’s ionization level, gas density, metallicity, dynamical process, and so on. Therefore, NALs would be an important tool for investigating the physical conditions and environments of quasars.

Unlike BALs, it is not easy to diagnose which NALs are truly associated with quasars, since NALs with similar profiles can be formed in environments no matter whether or not they are related to quasars. The frequently used methods that infer quasar-associated NALs, mainly include: (1) line variability with time; (2) line profiles that are obviously smoother and broader than those mainly dominated by thermal motion; (3) partial coverage fraction of absorber to background emission source; (4) absorptions requiring strong radiation field or high gas density; (5) significantly statistical excess of absorbers compared to cosmologically intervening ones.

Quasar host galaxy, host galaxy CGM, outflow, and nearby galaxies within the same one cluster/group are able to produce associated absorptions, so one often expects a cluster distribution of NALs around quasars. However, due to distance galaxies that absorb the background, quasar photons randomly distribute in the foreground space of quasars, cosmologically intervening in the absorptions of quasars, and thus would not exhibit obvious excess relative to the random distribution. Thus, statistical analysis of absorber distributions is a practical tool to distinguish associated absorptions from intervening ones.

Large sky surveys are beneficial because they statistically limit the fraction of quasar-associated absorptions, especially the quasar spectroscopy of the Sloan Digital Sky Survey (York et al. 2000) which has obtained more than 0.4 million unique quasar spectra (e.g., Schneider et al. 2010; Pâris et al. 2017). In this work, we will use the largest known quasar narrow-line absorption catalogs that contain both associated and intervening Mg II λλ2796,2803 or C IV λλ1548,1551 doublets to statistically look for empirical evidence that separates quasar-associated absorptions from intervening ones.

We describe the data sample in Section 2 present the statistical properties of absorptions and discussions in Section 3. The conclusions and summary are presented in Section 4. In this paper, we adopt the ΛCDM cosmology with $\Omega_M = 0.3$, $\Omega_{\Lambda} = 0.7$, and $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$.

### 2. DATA SAMPLE

The Sloan Digital Sky Survey (SDSS; York et al. 2000) is one of the most ambitious projects in astronomy, and uses a dedicated wide-field 2.5 telescope (York et al. 2000), located at Apache Point Observatory, New Mexico to map the universe. The SDSS obtained the first light in May 1998, and have collected more than 3 million spectra at a resolution of $R \approx 2000$ from the regular survey operation in 2000. The Baryon Oscillation Spectroscopic Survey (BOSS; Dawson et al. 2013) is an important mapping of the third phase of the SDSS (SDSS-III), which utilized the original SDSS 2.5m telescope with updated multi-object fiber fed optical spectrographs (Smee et al. 2013) to gather data in the main dark time from 2008 July to 2014 June and produce spectra in the range of 3600 Å $< \lambda < 10400$ Å at a resolution of $R = 1300 \sim 2500$ (Alam et al. 2015).

Quasar spectra of the SDSS have been widely used to detect cold gas absorption features, such as Mg II λλ2796,2803, C IV λλ1548,1551 doublets. These absorbing gases might be constrained by the quasars or a part of the quasars (associated absorptions), and might also be well beyond the gravitational bound (intervening absorptions). Most of the absorption line groups (e.g., Nestor et al. 2005; Quider et al. 2011; Cooksey et al. 2013; Seyffert et al. 2013; Zhu & Ménard 2013; Raghunathan et al. 2016) mainly focused on intervening absorptions in their programs that systematically searched for metal absorptions on quasar spectra. Using the first data release of the BOSS (the ninth data release of the SDSS), which includes 87 822 unique quasar spectra (DR9Q; Pâris et al. 2012), a series works of our absorption line group (e.g., Chen et al. 2014a, 2015b, 2016b) were designed to search for metal absorptions on quasar spectra, and have produced, up to today, the largest absorption catalogs that contain not only associated but also intervening Mg II or C IV NALs. This provides us an excellent data set to statistically analyze the properties of quasar-associated NALs.

Chen et al. (2015, 2016) searched for Mg II or C IV absorptions with strengths no smaller than 0.2 Å at rest-frame and significance level larger than 2σ in the quasar spectra data redward of Ly α emissions until red wings of Mg II λ2798 or C IV λλ1549 emissions. In this work, we directly pick out data, including quasar and absorption system samples, from Chen et al. (2015, 2016) to complete our statistical analysis. Our selected criteria are as follows:

1. The BAL (broad absorption line) flag (Pâris et al. 2012) equals to 0, which indicates that the quasar spectra is not imprinted a BAL feature. The quasar with a ZWARNING $> 0$ is also excluded, which flags bad fits in the redshift-fitting code (Pâris et al. 2012).

2. Quasar redshifts that are determined by broad emission lines, especially by the asymmetric and/or possibly blueshifted C IV emission lines, often exhibit a large uncertainty from 100 km s$^{-1}$ to 3000 km s$^{-1}$ with respect to those measured from narrow emission lines (e.g., Hewett & Wild 2010; Shen et al. 2011). Shen (2016) recently uncovered that, after accounting for measurement errors, quasar redshifts measured by broad Mg II emission lines would show an uncertainty of $\sim 200$ km s$^{-1}$ when compared to the redshifts calculated by [O III] λ5007 narrow emission lines. We limit quasars (here after Mg II quasar sample) with $0.4 < z_{em} < 1.1$ for the investigations of Mg II absorptions, so that both narrow [O III] λ5007 and Mg II associated absorptions can be available by the BOSS spectra. Turning to the studies of C IV absorptions, we only consider quasars (here after C IV quasar sample) with $1.4 < z_{em} < 2.4$
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3. STATISTICAL ANALYSIS AND DISCUSSIONS

3.1. Velocity offset distributions

Assuming the difference between absorption and emission redshifts is originated from the relative motion of absorbers with respect to quasars, the velocity offset of absorbers relative to the quasar system can be derived via

\[
\beta = \frac{v_{\text{abs}}}{c} = \frac{(1+z_{\text{em}})^2 - (1+z_{\text{abs}})^2}{(1+z_{\text{em}})^2 + (1+z_{\text{abs}})^2},
\]

where \(c\) is the speed of light, \(z_{\text{em}}\) is the quasar redshift, and \(z_{\text{abs}}\) is the absorber redshift. The absorptions of quasar local environments are expected to exhibit an evidently inequable \(\beta\) distribution at \(\beta \approx 0\) when compared to the distribution of intervening absorptions (\(\beta \gg 0\)). This is confirmed by many early works that obviously excessive numbers of absorbers with \(\beta \approx 0\) are over a random distribution (e.g., Weymann et al. 1979; Foltz et al. 1986; Vestergaard 2003; Nestor et al. 2008; Wild et al. 2008; Perrotta et al. 2010). The statistically significant excess of absorbers around quasars provides convenient cuts to distinguish associated absorptions from intervening ones. In the last two decades, we often use the conventional boundaries of 3000 km s\(^{-1}\) to assemble \(\text{Mg} \ II\) associated \((v_{\text{abs}} < 3000 \text{ km s}^{-1}\); e.g., York et al. 2006; Vanden Berk et al. 2008; Shen & Ménard 2012; Khare et al. 2014) and intervening \((v_{\text{abs}} > 3000 \text{ km s}^{-1}\); e.g., Nestor et al. 2008) absorptions, and 5000 km s\(^{-1}\) to construct \(\text{C IV}\) associated \((v_{\text{abs}} < 5000 \text{ km s}^{-1})\) and intervening \((v_{\text{abs}} > 5000 \text{ km s}^{-1})\) absorption samples.

The number density of absorbers \((dn/d\beta \equiv cdn/d\upsilon)\) is defined as the number of absorbers per unit of velocity interval. The redshift range of the quasar sample and the wavelength coverage range of spectra may play a role to the distribution of the \(dn/d\beta \equiv cdn/d\upsilon\), since some spectra of low-redshift quasars cannot be used to detect absorptions with high velocity offsets from quasars. The redshift distributions of the quasars included in our samples are shown in Figure 1. The BOSS quasar spectra wavelength range is from 3600 Å to 10400 Å. We find that there are > 99% of the spectra of \(\text{Mg} \ II\) quasar sample can be used to detected \(\text{Mg} \ II\) absorption with \(v_{\text{abs}} > 30000 \text{ km s}^{-1}\), and > 95% of the spectra of \(\text{C IV}\) quasar sample can be used to detected \(\text{C IV}\) absorption with \(v_{\text{abs}} > 30000 \text{ km s}^{-1}\).

Starting from \(v_{\text{abs}} = -3000 \text{ km s}^{-1}\) and using a bin size of 2000 km s\(^{-1}\) for the absorptions with \(v_{\text{abs}} > 0\), we calculate the \(dn/d\beta\) and display them as a function of velocity offset in Figure 2. These distributions are complex. No matter what the lowest absorption strength limit is, a significantly excessive \(dn/d\beta\) at small \(v_{\text{abs}}\) range is clearly over-plotted on an approximately constant distribution. These distributions tell us that our absorber sample contain absorptions originated in (1) cosmologically intervening structures which are expected to produce uniform \(dn/d\beta\); (2) quasar environments including quasar host galaxy, CGM and IGM within the same one cluster/group; (3) quasar outflow/wind. The second contributions are expected to show a normal \(dn/d\beta\) distribution that is located at \(\beta \approx 0\) and significantly higher than a random distribution, and the third contributions would cause an asymmetrically extended blue tail and destroy the normal distribution.

In order to assess the significance level of the \(dn/d\beta\) excess at small velocity offsets and make comparisons, we calculate the mean value of \(dn/d\beta\) at \(v_{\text{abs}} > 20000 \text{ km s}^{-1}\) and corresponding Poisson error. The absorbers with so large \(v_{\text{abs}}\) are generally regarded as intervening absorptions, though there are some variable NALs with very large velocity separation from the quasar emission redshift (e.g., Narayanan et al. 2004; Hacker et al. 2013; Hamann et al. 2011; Chen et al.)
The very strong Mg II absorptions with \( v_{\text{abs}} \geq 2000 \) km s\(^{-1}\) are very remarkable for all of the weak (\( \beta < 2796 \) Å), moderate (\( \beta \geq 2796 \) and \( \beta < 3000 \) Å), and strong (\( \beta \geq 3000 \) Å) Mg II absorptions. Measuring the pseudo-continuum fitting of the quasar spectra (e.g., Chen et al. 2013, 2016). The results are displayed in Figure 3. In Figure 3, the fittings of Gaussian function are over-plotted with red dash curves, the centers (\( L_{\text{center}} \)) of the Gaussian fittings are marked with vertical blue dash lines, and \( \pm 1\sigma \) deviations from the centers are labeled with vertical green dash lines, where the \( \sigma \) is the standard deviation returned by the Gaussian fitting. Here we construct low- and high-luminosity quasar samples with \( L_{3000} < L_{\text{center}} - \sigma \) and \( L_{3000} > L_{\text{center}} + \sigma \), respectively. For Mg II absorptions, low- and high-luminosity quasars have \( L_{3000} < 10^{44.05} \) erg s\(^{-1}\) and \( L_{3000} > 10^{44.58} \) erg s\(^{-1}\), respectively. For C IV absorptions, low- and high-luminosity quasars have \( L_{3000} < 10^{44.87} \) erg s\(^{-1}\) and \( L_{3000} > 10^{45.44} \) erg s\(^{-1}\), respectively. For the low- and high-luminosity quasar samples, the number densities of absorbers are displayed in Figure 3 and the significance levels of excessive \( dn/d\beta \) are provided in Table 3 (Mg II) and Table 4 (C IV).

We note from Figure 4 and Table 3 that the excessive \( dn/d\beta \) of Mg II absorptions with \( W_r^{12796} \geq 0.3 \) Å of high-luminosity quasars could be extended up to 8000 km s\(^{-1}\), while that of low-luminosity quasars is mainly limited within 2000 km s\(^{-1}\). These results are similar to those of Pan & Chen (2013). That is, the luminous quasars exhibits a longer extension of excessive \( dn/d\beta \) when compared to the faint quasars. Turning to the C IV absorptions with \( W_r^{1548} \geq 0.3 \) Å, no obvious differences were found.
The number density of absorbers ($dn/d\beta$) in given velocity interval as a function of velocity offset from the quasars, whose unit is number of absorbers per km s$^{-1}$. The starting $v_{abs}$ is -3000 km s$^{-1}$, and the bin size is 2000 km s$^{-1}$ for the absorptions with $v_{abs} > 0$. The horizontal solid-lines illustrate average values for absorbers far away from the quasars, and the horizontal dash-lines are corresponding $\pm 1\sigma$ from Poisson statistics. Left figure is for Mg II absorptions, and right one is for C IV absorptions.

Continuum luminosities of quasars at rest-frame 3000 Å. Red dash-curves represent the Gaussian fittings. Blue dash-lines label the centers of Gaussian fittings ($L_{\text{center}}$), and green dash-lines illustrate the positions deviated from the Gaussian centers $\pm \sigma$, where $\sigma$ are the standard deviations produced by the Gaussian fittings.

We note that the luminous quasars on average have higher continuum signal-to-noise ratio than the faint quasars, hence will have more detectable absorbers. We explore the possibility that luminosity dependence of the $dn/d\beta$ is due to the detection probability of absorbers. Figure 5 shows the equivalent widths at rest-frame for the absorptions with low and high velocity offsets from the quasars. The Kolmogorov-Smirnov (KS) test suggests that Mg II absorptions with low velocity offset have an equivalent width distribution similar to that of intervening Mg II absorptions, which indicates that both the associated and intervening Mg II absorptions would have similar detection probability. In addition, Figure 4 and Table 4 clearly show that the Mg II absorptions with $W_{\lambda 2796} \geq 1$ Å also exhibit a different extension of excessive $dn/d\beta$ for the low- and high-luminosity quasars. The detection of stronger absorptions are expected to be less affected by the different quasar luminosity. Therefore, there is no obvious correlation between the incidence of Mg II absorbers and the absorber detection probability. And thus, the difference of the Mg II $dn/d\beta$ distributions between low- and high-luminosity quasars is not originated from absorber detection probability.

Turning to the C IV absorptions, the KS test suggests that the equivalent width distribution of the C IV absorptions with low velocity offset is different from that of the intervening ones. The C IV absorptions with low velocity offset on average have a larger equivalent width than the intervening ones, which suggests that C IV absorptions with low velocity offset would have a slightly high detection probability relative to the intervening ones. While, the $dn/d\beta$ and $f_c$ (see Sec-
3.2. Coverage fraction and absorption strength

We define the coverage fraction of absorptions, \( f_c \), as the ratio of the number of quasars with at least one detected absorber to the total number of quasars that can be used to detect corresponding absorptions, within a given bin of velocity offset from the quasar system. The error of \( f_c \) can be estimated from Poisson statistics. One would expect that the \( f_c \) is related to absorption strength. Hence, here we measure the \( f_c \) in several ranges of absorption strengths as a function of velocity offset from the quasar system. The measurements are provided in Figure 7. For both \( \text{C}\ IV \) and \( \text{Mg}\ II \) absorptions, no matter what the lowest limit of absorption strength is, we can observe an approximately constant \( f_c \) at large velocity offset, which is expected for the cosmologically intervening absorptions. For comparisons, we calculate the mean value of \( f_c \) at \( v_{\text{abs}} > 20000 \text{ km s}^{-1} \) and corresponding Poisson error. The results are illustrated with green horizontal lines in Figure 7 and the significant levels of excessive \( f_c \) with respect to the random occurrence of intervening absorptions are listed in Table 5 (\( \text{Mg}\ II \)) and Table 6 (\( \text{C}\ IV \)).

The distribution behaviors of the \( f_c \) are similar to those of the \( dn/d\beta \) (see Figure 2). The excessive \( f_c \) at small \( v_{\text{abs}} \) are very obvious relative to the constant \( f_c \). No matter what the \( \text{C}\ IV \) absorption strength is, the obvious excess is extended to \( 6000 \text{ km s}^{-1} \) at a high significance level of \( > 4 \sigma \) and could be sustained beyond \( 10000 \text{ km s}^{-1} \). This is consistent with the results of Perrotta et al. (2016). The excessive \( f_c \) extensions of \( \text{Mg}\ II \) absorptions are seemingly related to absorption strengths. The \( f_c \) excess of the very strong \( \text{Mg}\ II \) absorptions with \( W_{\lambda 2796} > 2 \text{ Å} \) is constrained within \( 2000 \text{ km s}^{-1} \), whereas the weak \( \text{Mg}\ II \) absorptions with \( W_{\lambda 2796} > 0.3 \text{ Å} \) could hold excessive \( f_c \) beyond \( 8000 \text{ km s}^{-1} \). In addition, in the same velocity offset bin, the weaker \( \text{Mg}\ II \) absorptions exhibit the more significant excess.

Figure 7 and Tables 5 and 6 clearly indicate that the high excesses of the \( f_c \) within \( 2000 \text{ km s}^{-1} \) for \( \text{Mg}\ II \) absorptions...
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5. Distributions of equivalent widths at rest-frame. Left panel is for Mg\textsc{ii} absorptions, and right one is for C\textsc{iv} absorptions. Black lines represent the associated absorptions, and red lines represent the intervening ones. Y-axis indicates the number of absorbers that have been normalized by the total number of absorbers within each subsample.

6. Fraction of C\textsc{iv} (Mg\textsc{ii}) absorbers that have a Mg\textsc{ii} (C\textsc{iv}) absorption counterparts as a function of absorber velocity offset from the quasar. The black circles are for C\textsc{iv} absorbers and the red stars are for Mg\textsc{ii} absorbers. The ±1\textsigma errors of the fractions are from Poisson statistics.

Table 6

| Velocity km s\(^{-1}\) | Significant level | [Å] | W\textsc{ii} | W\textsc{ii} | W\textsc{ii} |
|------------------------|-------------------|------|--------------|--------------|--------------|
| -3000<v\textsubscript{abs}<0 | 56.3 | 78.3 | 59.3 |
| 0<v\textsubscript{abs}<2000 | 47.7 | 48.4 | 30.3 |
| 2000<v\textsubscript{abs}<4000 | 30.4 | 36.6 | 25.9 |
| 4000<v\textsubscript{abs}<6000 | 6.5 | 7.9 | 4.1 |
| 6000<v\textsubscript{abs}<8000 | 1.9 | 3.1 | 2.5 |
| 8000<v\textsubscript{abs}<10000 | 1.5 | 3.9 | 3.0 |
| 10000<v\textsubscript{abs}<12000 | -0.6 | -0.5 | -1.6 |

Note — Significant levels of excess relative to the random occurrence of intervening absorptions.

or within 4000 km s\(^{-1}\) for C\textsc{iv} absorptions dramatically decline to much lower values at higher velocity offsets. The quasar environment absorptions of the host galaxies, CGMs, and IGM within the quasar host galaxy cluster/group, and the low velocity quasar outflow/wind absorptions would dominate the significantly excessive \(f_c\) within 2000 km s\(^{-1}\) or 4000 km s\(^{-1}\). The high velocity outflow absorptions would be the principal contributions for the evidently excessive \(f_c\) beyond 2000 km s\(^{-1}\) for Mg\textsc{ii} absorptions and 4000 km s\(^{-1}\) for C\textsc{iv} absorptions.

Figure 7 clearly shows that the excessive tail of C\textsc{iv} absorptions could be extended beyond 10000 km s\(^{-1}\), which is much farther than that of Mg\textsc{ii} absorptions. This implies that the maximum velocity of C\textsc{iv} outflows is much larger than that of Mg\textsc{ii} outflows. In addition, Tables 5 and 6 definitely tell us that the excess of Mg\textsc{ii} absorptions is much less significant than that of C\textsc{iv} absorptions, especially for the excess beyond 2000 km s\(^{-1}\). These different behaviors between C\textsc{iv} and Mg\textsc{ii} absorptions are possibly related to quasar radiation and ionization potentials of Mg\textsuperscript{+} and C\textsuperscript{3+} ionized gas. The Mg\textsuperscript{+} and C\textsuperscript{3+} ions have ionization potentials of 15.035 eV and 64.49 eV, respectively, which indicate that the C\textsc{iv} absorbing clouds can be remained but the Mg\textsc{ii} ones would have been destroyed when the energy of the incident photons is up to 64.49 eV. One generally expects that quasar outflow hosts very strong radiation field and highly ionizes gas within it. Therefore, quasar outflow would be a greenhouse for C\textsc{iv} absorbing gas but fatal for Mg\textsc{ii} one. This would be an important reason why the quasars with C\textsc{iv} BALs, which are generally believed to be formed in outflows, are much more than those with Mg\textsc{ii} BALs. Central gravitation, radiation pressure, thermal pressure, and magnetocentrifugal forces would be the most important mechanisms that drive the quasar outflow. One expects that quasar outflow has been accelerated until the central gravitation is more significant than a combination of another three mechanisms. In addition, we expect that radiation field of quasar outflow in accelerated phase would be much stronger than that in decelerated phase. In this case, intense quasar radiation would result in most of Mg\textsc{ii} outflows that are in decelerated phase. Therefore, very few Mg\textsc{ii} outflows exhibit high velocity and most of them host low velocity. In addition, gas clouds with low ionization potential and high column density would be partly ionized by intense quasar radiation and then become the low column den-
horizonal dash-lines are corresponding ± bin size is 2000 km s$^{-}\text{s}$-sity ones, so that stronger Mg II intervening absorptions.

Note — Significance levels of excess relative to the random occurrence of quasars can be used to search for corresponding absorptions in given bins of velocity offset from quasar redshifts. The starting $v_{\text{abs}}$ is -3000 km s$^{-}\text{s}$, and the bin size is 2000 km s$^{-}\text{s}$ for the absorptions with $v_{\text{abs}} > 0$. The horizontal solid-lines illustrate average fractions for absorbers far away from the quasars, and the horizontal dash-lines are corresponding ±1$\sigma$ from Poisson statistics. Left figure is for Mg II absorptions, and right one is for C IV absorptions.

### Table 7

| Velocity km s$^{-}\text{s}$ | Significance level |
|-----------------------------|--------------------|
| $L_{3000} < 10^{44.05}$ erg s$^{-}\text{s}$ | $L_{3000} > 10^{44.58}$ erg s$^{-}\text{s}$ |
| $\lambda 2796 \geq 3\pm 1$ Å | $\lambda 2796 \geq 1\pm 1$ Å |
| $\lambda 2796 \geq 3\pm 1$ Å | $\lambda 2796 \geq 1\pm 1$ Å |
| $\lambda 2796 \geq 3\pm 1$ Å | $\lambda 2796 \geq 1\pm 1$ Å |

Note — Significance levels of excess relative to the random occurrence of intervening absorptions.

### Table 8

| Velocity km s$^{-}\text{s}$ | Significance level |
|-----------------------------|--------------------|
| $L_{3000} < 10^{44.87}$ erg s$^{-}\text{s}$ | $L_{3000} > 10^{45.44}$ erg s$^{-}\text{s}$ |
| $\lambda 1548 \geq 3\pm 1$ Å | $\lambda 1548 \geq 1\pm 1$ Å |
| $\lambda 1548 \geq 3\pm 1$ Å | $\lambda 1548 \geq 1\pm 1$ Å |
| $\lambda 1548 \geq 3\pm 1$ Å | $\lambda 1548 \geq 1\pm 1$ Å |

Note — Significance levels of excess relative to the random occurrence of intervening absorptions.

3.3. Coverage fraction and quasar luminosity

Quasar radiation could be an important mechanism driving outflow, and plays a significant role in the influence of environments. Thus, it is possible that the coverage fraction of absorbers is connected to quasar radiation. In this section, we investigate whether or not the coverage fraction of absorptions depends on quasar continuum luminosity. Here, the low- and high-luminosity quasar samples are the same as those used in Section 5.1. The results are exhibited in Figure 8. We also estimate the significance level of the excessive $f_c$ with respect to the random occurrences of intervening absorptions, which are offered in Tables 7 and 8.

Figure 8 and Table 7 clearly illustrate that the extensions of the excessive $f_c$ of Mg II absorptions are evidently related to quasar luminosity. For high-luminosity quasars, the excessive $f_c$ of Mg II absorptions with $W_{\lambda 2796} \geq 0.3$ Å could be extended up to 8000 km s$^{-}\text{s}$, and beyond 10000 km s$^{-}\text{s}$ for those with $W_{\lambda 2796} \geq 1$ Å. While the excessive $f_c$ is mainly limited within 2000 km s$^{-}\text{s}$ for low-luminosity quasars. We note in Section 5.1 that both associated and intervening Mg II absorptions would have similar detection probability. In addition, the detection probability of strong absorptions is expected to be less affected by quasar luminosity or signal-to-noise ratio of quasar spectra. Therefore, the very different luminosity dependences of the $f_c$ excess extensions can not be ascribed to signal-to-noise ratio of quasar spectra. The significantly different behaviors of $f_c$ between low-luminosity and high-luminosity quasars can be interpreted by more luminous quasars driving outflows to a higher velocity.

Turning to C IV absorptions, we find that there is no evident correlation between the extension of the excessive $f_c$ and quasar luminosity. The analysis shown in Section 5.1 indicates that the associated C IV absorptions are expected to have a slightly higher detection probability relative to the intervening ones. This could explain the slight difference of the $f_c$ excess extensions between low- and high-luminosity quasars.
3.4. Redshift number density of absorbers

The environments of quasar-associated absorptions are expected to be different from those of intervening absorptions. Therefore, the redshift number density evolution of associated absorptions is possibly different from that of intervening absorptions. In order to further assess the excessive coverage fraction and number density (dn/dz) of absorptions, we investigate the redshift number density evolution of absorbers (dn/dz) for several subsamples of absorptions.

The redshift number density of absorbers (dn/dz) is defined as the ratio between the number of absorbers and total redshift path, where the absorbers have equivalent width $W_\lambda^{2796} \geq 0.3$ Å (or $W_\lambda^{1548} \geq 0.3$ Å) and are located within a given velocity offset range from the quasar redshifts. The error of dn/dz can be estimated from Poisson statistics. The total redshift path covered by quasars is calculated by

$$Z(W_\lambda) = \int_{z_{\text{min}}}^{z_{\text{max}}} \sum_i g_i(W_\lambda, z) dz,$$

where $z_{\text{min}}$ and $z_{\text{max}}$ are determined by the given velocity offset range or the limits of spectra data, $g_i(W_\lambda, z) = 1$ if the detection threshold $W_{\lambda}^{\text{lim}} \leq W_\lambda$, otherwise $g_i(W_\lambda, z) = 0$, and the sum is over all quasars.

We investigate the evolution of dn/dz for Mg II absorbers in velocity offset ranges of: (1) $v_{\text{abs}} < 2000$ km s$^{-1}$, (2) $2000 \leq v_{\text{abs}} < 4000$ km s$^{-1}$, (3) $4000 \leq v_{\text{abs}} < 6000$ km s$^{-1}$, (4) $6000 \leq v_{\text{abs}} < 10000$ km s$^{-1}$, and (5) $v_{\text{abs}} \geq 10000$ km s$^{-1}$; and for C IV absorbers in velocity offset ranges of: (1) $v_{\text{abs}} < 2000$ km s$^{-1}$, (2) $2000 \leq v_{\text{abs}} < 4000$ km s$^{-1}$, (3) $4000 \leq v_{\text{abs}} < 6000$ km s$^{-1}$, (4) $6000 \leq v_{\text{abs}} < 10000$ km s$^{-1}$, (5) $10000 \leq v_{\text{abs}} < 20000$ km s$^{-1}$, and (6) $v_{\text{abs}} \geq 20000$ km s$^{-1}$. The results are presented in Figure 9. Figures 7 and 8 clearly show that the excessive $f_e$ of absorbers within 2000 km s$^{-1}$ is very significant, which is possibly dominated by quasar associated absorptions. While the approximately constant $f_e$ with large velocity offset from quasars is the expectation of cosmologically intervening absorptions. We note from Figure 9 that the dn/dz of Mg II absorbers with $v_{\text{abs}} < 2000$ km s$^{-1}$ evidently differs from that of Mg II absorbers with $v_{\text{abs}} > 4000$ km s$^{-1}$, and the dn/dz of C IV absorbers with $v_{\text{abs}} < 4000$ km s$^{-1}$ obviously differs from that of C IV absorbers with $v_{\text{abs}} > 10000$ km s$^{-1}$. The violent activity and strong radiation within quasar cen-
investigate absorber properties in three ways: (1) the distribution of both associated and intervening components, we mainly investigate absorber properties in three ways: (1) the distribution of the number density of absorbers per velocity offset from quasar redshifts ($z_{\text{abs}}$); (2) the redshift number density evolution of absorbers. The main results are as follows.

(1) Both $dn/dz$ and $f_c$ distributions of Mg II absorptions are related to absorption strength and quasar continuum luminosity. Both the significantly excessive $dn/dz$ and $f_c$ relative to the random occurrence of intervening absorptions are limited within 2000 km s$^{-1}$ when quasar continuum luminosity is $L_{3000} < 10^{44.05}$ erg s$^{-1}$ or absorption strength is $W_{12796} < 2$ Å. While, the evident excesses can be extended to 4000 km s$^{-1}$ for the middle strength absorptions with $W_{12796} > 1$ Å, and beyond 8000 km s$^{-1}$ for the weak absorptions with $W_{12796} > 0.3$ Å and for the luminous quasars with $L_{3000} > 10^{44.58}$ erg s$^{-1}$. The excessive tails for the luminous quasars and for the weak absorptions are much farther than 3000 km s$^{-1}$, which is the traditional cut to divide associated and intervening Mg II absorptions. However, the significant level of the excesses beyond 2000 km s$^{-1}$ is much less than that within 2000 km s$^{-1}$. In addition, we find that the redshift number density evolution of Mg II absorbers with $v_{abs} < 2000$ km s$^{-1}$ evidently differs from that with $v_{abs} > 2000$ km s$^{-1}$ though there is a slight cross in velocity offset range of 2000 $-$ 4000 km s$^{-1}$. The weak excess of both the $dn/dz$ and $f_c$ beyond 2000 km s$^{-1}$, and the slight cross of the $dn/dz$ evolution in 2000 $<$ $v_{abs} < 4000$ km s$^{-1}$ could be mainly originated from a few Mg II outflows with high velocity, which would not evidently contribute to the fraction of quasar associated absorptions. Therefore, we suggest a velocity offset cut of 2000 km s$^{-1}$ to define quasar associated systems of Mg II narrow absorption lines.

(2) Both the relative excess $dn/d\beta$ and $f_c$ of C IV absorptions is neither related to absorption strength nor to quasar continuum luminosity. The relative excesses can be extended up to 10000 km s$^{-1}$. We note that...
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