A DUSTY Mg II ABSORBER ASSOCIATED WITH THE QUASAR SDSS J003545.13+011441.2*

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ABSTRACT

We report on a dusty Mg $\text{II}$ absorber associated with the quasar SDSS J003545.13+011441.2 (hereafter J0035+0114) at $z = 1.5501$, the strongest of the three Mg $\text{II}$ absorbers along the sight line of the quasar. The two low-redshift intervening absorbers are at $z = 0.7436$ and 0.5436. Based on the photometric and spectroscopic data of the Sloan Digital Sky Survey (SDSS), we infer that the rest-frame color excess $E(B - V)$ due to the associated dust is more than 0.07 by assuming a Small Magellanic Cloud (SMC) type extinction curve. Our follow-up moderate resolution spectroscopic observation with the ESI spectrometer at the 10 m Keck telescope enables us to reliably identify most of the important metal elements, such as Zn, Fe, Mn, Mg, Al, Si, Cr, and Ni, in the associated system. We measure the column density of each species and detect significant dust depletion. In addition, we develop a simulation technique to gauge the significance of a 2175 Å dust absorption bump in the SDSS quasar spectra. By using this technique, we analyze the SDSS spectrum of J0035+0114 for the presence of an associated 2175 Å extinction feature and report a tentative detection at a $\sim 2\sigma$ significant level.

Key words: dust, extinction – galaxies: abundances – galaxies: active – quasars: absorption lines – quasars: individual (SDSS J003545.13+011441.2)

Online-only material: color figures

1. INTRODUCTION

Absorption lines in the spectra of quasars have been detected since shortly after the discovery of quasars (e.g., Burbidge et al. 1966; Schmidt 1966). They provide us with a powerful tool to probe the abundances, physical conditions, and kinematics of gas in a wide variety of environments. The absorption systems could be divided into two populations by the difference between the redshift of the absorption lines ($z_{\text{abs}}$) and the redshift of the quasar emission lines ($z_{\text{em}}$). If $z_{\text{abs}}$ and $z_{\text{em}}$ are almost the same ($z_{\text{abs}} - z_{\text{em}} < 5000 \text{ km s}^{-1}$ in the quasar rest frame), the absorption system is taken to be associated with the quasar. Otherwise, the absorption system is usually intervening (Weymann et al. 1979; Foltz et al. 1986), although some associated C IV absorbers may be found at relative velocities of as much as 75,000 km s$^{-1}$ with respect to the quasar (Richards et al. 1999).

The presence of dust grains associated with different absorbers could be constrained by measuring the relative abundances of volatile and refractory elements in order to infer a dust depletion level. The depletion of Cr with respect to Zn in a high dust depletion level, $[\text{Zn}/\text{Fe}] > 0.8$, has a high molecular hydrogen detection rate (e.g., Ge & Bechtold 1997; Ge et al. 2001; Cui et al. 2005; Noterdaeme et al. 2008). Dust in an absorber could also be inferred by measuring its reddening and extinction effects on background objects.

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York et al. (2006) studied the extinction of 809 intervening Mg $\text{II}$ absorption systems from the Sloan Digital Sky Survey (SDSS) in a statistical way at $1 \leq z_{\text{abs}} < 2$. Their extracted average extinction curves were similar to the SMC curve with $E(B - V) \leq 0.08$, and indicated a tentative correlation between $E(B - V)$ and the Mg $\text{II}$ equivalent width in the rest frame $W_{\lambda}^{0}$. Recently, Ménard et al. (2008) composed a much larger sample with almost 7000 strong Mg $\text{II}$ absorption systems at $0.4 < z_{\text{abs}} < 2.2$ and confirmed the correlation between $E(B - V)$ and $W_{\lambda}^{0}$.

The prominent difference between the extinction curves of the Milky Way (MW) and that of the SMC is the presence of a 2175 Å dust absorption bump (Savage & Mathis 1979; Fitzpatrick 1989). Reliable detections of the 2175 Å feature in individual intervening absorption systems are rare. Cohen et al. (1999) detected the 2175 Å feature in a damped Ly$\alpha$ absorber at a redshift of $z = 0.524$ toward the BL Lac object AO 0235+164 (later updated by Junkkarinen et al. 2004). Wang et al. (2004) identified three intervening Mg $\text{II}$ absorption systems at $1.4 < z < 1.5$ with the 2175 Å dust absorption feature in quasar spectra from SDSS. Srianand et al. (2008) found a 2175 Å extinction feature in two Mg $\text{II}$ systems at $z \sim 1.3$ and detected 21 cm absorption, which usually traces the cold dense gas content, in both of them. Recently, Noterdaeme et al. (2009) presented a detection of carbon monoxide molecules (CO) at $z = 1.6408$ toward a red quasar and a pronounced 2175 Å bump at the redshift of the CO absorber. In the past several years, analysis of gamma-ray burst (GRB) afterglow spectra has also revealed several positive detections from intervening absorbers and from gas in the GRB host galaxies (e.g., Ellison et al. 2006; Elfasdoitir et al. 2009; Prochaska et al. 2009).

In this paper, we report on a dusty Mg $\text{II}$ absorber associated with the quasar SDSS J0035+0114 at $z = 1.5501$. In the next section, we will describe the observation data, including the
SDSS spectrum and our follow-up spectroscopic observation with the ESI spectrometer on the 10 m Keck telescope. In Section 3, we infer the color excess $E(B - V)$ of the dust extinction with photometric and spectroscopic SDSS data. In Section 4, we measure the column densities of important metal ions with high accuracy on the Keck spectrum and explore the dust depletion patterns in the absorber. The possible detection of a 2175 Å absorption bump will be discussed in Section 5. Our main results will be summarized in the last section, together with a discussion.

2. OBSERVATIONS

The SDSS images of J0035+0114 were acquired on UT 2001 October 15. The point-spread function magnitudes measured from the images are $19.997 \pm 0.040$, $19.293 \pm 0.010$, $18.972 \pm 0.010$, $18.493 \pm 0.012$, and $18.344 \pm 0.048$ in $u$, $g$, $r$, $i$, and $z$, respectively. The SDSS spectrum was obtained on UT 2000 September 6 and covered $\approx 3800$–9200 Å with a spectral resolution $R \approx 2000$ and a median signal-to-noise ratio $(S/N) \approx 7$ (Stoughton et al. 2002). The SDSS spectrum is relatively remarkable for its red color and the strong associated absorption lines imposed on it. Because our initial inspection suggested a very dusty system, we performed follow-up spectroscopic observations of the quasar at a higher spectral resolution. On UT 2004 September 11, we acquired two 1200 s exposures of J0035+0114 with the ESI spectrometer (Sheinis et al. 2002) on the 10 m Keck II telescope. We employed the 0.5 slit providing an FWHM $\approx 37$ km s$^{-1}$ resolution and a wavelength coverage $\lambda = 4000$–10000 Å. The spectral images were reduced and calibrated using the XIDL software package ESIRedux (v1.0). The optimally extracted one-dimensional spectra were converted to vacuum wavelengths and to the heliocentric frame (v1.0). The optimally extracted one-dimensional spectra were converted to vacuum wavelengths and to the heliocentric frame and then flux calibrated using a spectrophotometric standard acquired on the same night. The data were normalized by fitting a series of polynomials to absorption-free regions of the quasar spectrum. The emission redshift of $z = 1.5501$ is measured.

3. COLOR AND REDDENING

The color of quasars is redshift dependent, since the broad emission features on the underlying continuum move in/out of the photometric passbands at different redshifts (Richards et al. 2001). Richards et al. (2003) introduced relative color to determine the underlying continuum color of quasars by subtracting the median colors of quasars at the redshift of each quasar from the measured colors of each quasar. The relative color $\Delta(g - i)$ can be used to distinguish between reddened quasars and optically steep quasars. The distribution of relative colors should be a Gaussian, assuming a Gaussian distribution of the power-law spectral indices of quasars. However, $\Delta(g - i)$ shows a significant asymmetric tail at the red end. The objects in this tail are reddened by dust.

The relative color $\Delta(g - i)$ of J0035+0114 is $0.40 \pm 0.02$. The $\Delta(g - i)$'s of all quasars with redshift between 1.525 and 1.575 in SDSS Data Release 7 (Abazajian et al. 2009) are extracted to compose the relative color distribution at the redshift of J0035+0114 ($z = 1.5501$). All the colors in this analysis are dereddened by using the dust map of Schlegel et al. (1998). In Figure 1, it is clear that J0035+0114 is in the red tail of the composed color distribution. By assuming that the intrinsic spectral index of J0035+0114 is flat ($\Delta(g - i) = 0$), we infer that it could be reddened by an SMC type extinction curve with $E(B - V) \approx 0.09$ in the rest frame of quasar emissions at $z = 1.5501$ (Richards et al. 2003).

On the Keck spectrum of J0035+0114, three absorption line systems can be readily identified, with redshifts of $z = 1.5501$, 0.7436, and 0.5436, respectively (hereafter systems A, B, and C). The Mg $\equiv \lambda\lambda2796,2803$ doublet has been detected in all of the three systems. The Mg $\equiv \lambda2796$ absorption line in system A is the strongest with a rest equivalent width $W_{\lambda2796} = 1.986 \pm 0.022$ ($W_{\lambda2796} = 1.622 \pm 0.186$ in system B; $W_{\lambda2796} = 0.923 \pm 0.182$ in system C). To examine the dust reddening on the SDSS spectrum of J0035+0114, we fit it with two reddened composite SDSS quasar spectrum models. First, we assume that the dust reddening is solely due to system A, which is the strongest one. The composite SDSS spectrum (Vanden Berk et al. 2001) is reddened by the SMC type extinction curve (Pei 1992), in which $E(B - V)$ is a free parameter and $R_V = 2.93$ is fixed at $z = 1.5501$. To focus on the fitting continuum of the quasar spectrum, the regions with strong emission lines and known strong absorption lines are masked. The best-fit $E(B - V)$ is 0.15, with $\chi^2_r = 1.28$ (see Figure 2(a)). Second, we fit the SDSS spectrum with a three-absorber model. We assume that three SMC extinction curves with the same $E(B - V)$ at the redshifts of 1.5501, 0.7436, and 0.5436 contribute the total dust reddening. The best-fit $E(B - V)$ is 0.07, with $\chi^2_r = 1.28$ (see Figure 2(b)). Since system A is the strongest absorber, we infer that its rest frame $E(B - V)$ would be greater than 0.07, which is the average reddening of the three absorbers, by assuming that $E(B - V)$ scales with $W_{\lambda2796}$ in strong quasar Mg $\equiv$ absorption systems (Ménard et al. 2008).

4. COLUMN DENSITY AND DUST DEPLETION

Most of the important heavy elements are reliably identified in system A (see Figure 3). Column densities of all elemental ions except Zn$^+$ were first estimated by measuring the apparent optical depth (AOD; Savage & Sembach 1991). Zn $\equiv \lambda\lambda2026,2062$ are heavily blended with Mg $\equiv \lambda2026$ and

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8 http://www.ucolick.org/~xavier/IDL
7 http://www2.keck.hawaii.edu/inst/esi/ESIRedux/index.html

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The SDSS spectrum has been corrected for the Galactic reddening of $E(B - V) = 0.022$ before fitting the procedure.
The equivalent width and column density measured from ionized lines are presented in Table 1. We also measure the column densities of strong Mg\textsc{i} and Fe\textsc{ii} absorption lines of the associated absorber in this work are in the high detection rate region for DLAs. Thus, the column density of neutral hydrogen \( N(\text{H}^0) \) cannot be measured. Since there are no lines of high ions detected in the Keck spectrum (except for Al\textsc{iii}), we assume that hydrogen gas is mostly neutral and other heavy elements are singly ionized in this Mg\textsc{i} absorption system while the absorber is very likely to be a DLA system containing substantial dust. However, it is at low redshift \( z<1 \) and the Ly\( \alpha \) transition cannot be observed in the optical band with ground instruments. Thus, the column density of neutral hydrogen \( N(\text{H}^0) \) cannot be measured.

The presence of dust grains could be constrained by measuring the relative abundances of volatile and refractory elements in order to infer a depletion level of metals in gas phase. As zinc is a relatively undepleted element due to its low condensation temperature, the ratios of other heavy elements to zinc are usually used to measure the dust depletion (Meyer & Roth 1990; Pettini et al. 1994). The depletion factors, \([X/Zn] = \log(N(X)/N(Zn))−\log(N(X)/N(Zn))_{⊙}\), are listed in Table 3. It is clear that the absorber associated with J0035+0114 has significant depletion factors,\(^9\) which indicates that this system contains substantial dust grains. Figure 5 plots the dust depletion patterns compared with the “warm” and “cold” Galactic interstellar medium (ISM) and SMC ISM. It seems that the depletion pattern in this absorber is similar to those found in sight lines through the “warm” gas of MW.

5. POSSIBLE 2175 Å ABSORPTION BUMP

Initially, the quasar absorption line system in J0035+0114 at \( z = 1.5501 \) is a candidate in our ongoing project of searching for quasar absorption line systems with the 2175 Å absorption bump feature (Zhou et al. 2010). It was selected because of the suppressed flux of the quasar around 2200 Å in the rest frame of the associated Mg\textsc{i} absorber. However, the depression can be caused by the variation in the strength of Fe\textsc{ii} emissions, too (Pitman et al. 2000). Hence, we develop a simulation technique to gauge the significance of the 2175 Å dust absorption bump in the SDSS quasar spectra.

J0035+0114 is taken as an example to introduce our simulation procedures below. First, all the SDSS spectra of the quasar with emission redshift in the range of \( z_{\text{J0035}}−0.05 \) and \( z_{\text{J0035}}+0.05 \) with median \( S/N>6 \) are chosen to compose a control sample and then are corrected for Galactic reddening. We basically fit each of them by reddening the composite quasar spectrum (Vanden Berk et al. 2001) with a parameterized extinction curve at the redshift of the absorber of interest. The

\(^9\) Zn\textsc{ii} λ2026,2062 of systems B and C are not covered by the Keck spectrum. Thus, the dust depletion patterns in those systems are not obtainable.
extinction curve is defined in a similar formula with the prescription of Fitzpatrick & Massa (1990) as

\[ A(\lambda) = c_1 + c_2 x + c_3 D(x, x_0, \gamma) \]  

where \( x = \lambda^{-1} \), and \( D(x, x_0, \gamma) \) is a Lorentzian profile, which is expressed as

\[ D(x, x_0, \gamma) = \frac{x^2}{(x^2 - x_0^2)^2 + x^2\gamma^2}, \]

where \( x_0 \) and \( \gamma \) are the peak position and FWHM of the Lorentzian profile, respectively. Our aim is to unveil the 2175 Å absorption feature associated with absorption line systems in the quasar spectra. We do not try to derive the absolute extinction curve and our derived one is a relative extinction curve without normalization. We cannot measure the conventional extinction parameters \( A_V \), \( E(B - V) \), and \( R_V \) from it, but all the features of the 2175 Å absorption bump are preserved. The linear component in the extinction curve accounts for the variation of the quasar spectral index. Thus, the parameter \( c_2 \) could be negative if a quasar spectrum is steeper than the composite spectrum. The Lorentzian profile is used to model the absorption bump. The strength of the bump is measured by the area of the bump \( A_{\text{bump}} = \pi c_3/(2\gamma)^2 \). However, this strength is not necessarily zero even if the spectrum does not have any absorption bump feature. In the absence of a bump, the distribution of the best-fit strengths is expected to be Gaussian by assuming the random fluctuation of Fe\textsc{ii} emission on each spectrum and photon noise. During the fitting procedure, \( x_0 \) is fixed at 4.59 \( \mu m^{-1} \) in the rest frame of the absorber of interest and the width \( \gamma \) is fixed at 0.89 \( \mu m^{-1} \) in the same frame. The three free parameters are \( c_1 \), \( c_2 \), and \( c_3 \). To focus on the fitting continuum of the quasar spectrum, the regions with strong emission lines \( (\text{Mg}\textsc{ii} \lambda 2796, \text{C}\textsc{ii} \lambda 1334, \text{Si}\textsc{iv} \lambda 1400) \) and known strong absorption lines are masked.

The SDSS spectrum of J0035+0114 is modeled by a composite quasar spectrum reddened using the parameterized extinction curve at its same redshift. Although J0035+0114 could be reddened by three dusty absorbers simultaneously, the two low-redshift absorbers (systems B and C) cannot contribute to the possible 2175 Å extinction bump. In addition, we think that

\[ A_{\text{bump}} = \pi c_3/(2\gamma)^2. \]

10 The area of the bump defined in this work is different from that in Fitzpatrick & Massa (2007, hereafter FM07). \( A_{\text{bump}} = E(B - V) \times A_{\text{bump}}^* \), where \( A_{\text{bump}}^* \) is the area defined in FM07. \( A_{\text{bump}} \) can be interpreted as rescaling the integrated AOD of bump absorption \( (A_b = 2.5 \times A_{\text{bump}}^*) \).

11 The most likely values of peak and width for the Galaxy 2175 Å absorption bump are 4.59 \( \mu m^{-1} \) and 0.89 \( \mu m^{-1} \) (Fitzpatrick & Massa 2007).
Intervening Strong Absorption Lines and Column Density Measured by the Apparent Optical Depth

| λ_vacuum (Å) | Ion | f  | λ* (Å) | EW* (Å) | N_X^0 (log(cm^{-2}) | N_X^0 (log(cm^{-2}) |
|--------------|-----|----|--------|---------|---------------------|---------------------|
| 1608.451     | Fe II | 0.0580 | 1608.437 | 0.516 ± 0.043 | 14.98 ± 0.02 | ... |
| 1670.7874    | Al II | 1.3800 | 1670.822 | 0.883 ± 0.046 | 13.71 ± 0.01 | ... |
| 1709.6042    | Ni II | 0.0324 | 1709.558 | 0.103 ± 0.022 | 14.18 ± 0.06 | ... |
| 1741.5531    | Ni II | 0.0427 | 1741.591 | 0.124 ± 0.022 | 14.11 ± 0.07 | ... |
| 1808.0130    | Si II | 0.0022 | 1808.035 | 0.278 ± 0.026 | 15.84 ± 0.03 | ... |
| 1854.7164    | Al II | 0.5390 | 1854.704 | 0.520 ± 0.035 | 13.80 ± 0.02 | ... |
| 1862.7895    | Al II | 0.2680 | 1862.805 | 0.401 ± 0.036 | 13.86 ± 0.03 | ... |
| 2026.136     | Zn II | 0.4890 | 2026.277 | 0.286 ± 0.022 | 13.30 ± 0.03 | 13.21 ± 0.03 |
| 2026.4678    | Mg I  | 0.1120 | 2026.277 | 0.286 ± 0.022 | 13.95 ± 0.05 | ... |
| 2056.2539    | Cr II | 0.1050 | 2056.236 | 0.123 ± 0.017 | 13.57 ± 0.06 | ... |
| 2062.234     | Cr II | 0.0780 | 2062.563 | 0.242 ± 0.029 | 13.98 ± 0.05 | ... |
| 2062.664     | Zn II | 0.2560 | 2062.556 | 0.224 ± 0.031 | 13.47 ± 0.05 | 13.21 ± 0.03 |
| 2066.116     | Cr II | 0.0515 | 2066.282 | 0.053 ± 0.022 | 13.46 ± 0.13 | ... |
| 2249.8768    | Fe II | 0.0018 | 2249.905 | 0.106 ± 0.025 | 15.17 ± 0.09 | 15.20 ± 0.04 |
| 2260.7805    | Fe II | 0.0024 | 2260.781 | 0.154 ± 0.022 | 15.22 ± 0.05 | 15.20 ± 0.04 |
| 2344.2140    | Fe II | 0.1140 | 2344.265 | 1.003 ± 0.043 | 14.62 ± 0.03 | 14.88 ± 0.03 |
| 2374.4612    | Fe II | 0.0313 | 2374.482 | 0.731 ± 0.031 | 15.00 ± 0.03 | 14.88 ± 0.03 |
| 2382.7650    | Fe II | 0.3200 | 2382.779 | 1.295 ± 0.034 | 14.33 ± 0.03 | 14.88 ± 0.03 |
| 2576.8770    | Mn II | 0.3508 | 2576.927 | 0.240 ± 0.023 | 13.14 ± 0.04 | ... |
| 2586.6500    | Fe II | 0.0691 | 2586.659 | 0.977 ± 0.034 | 14.73 ± 0.01 | ... |
| 2594.4990    | Mn II | 0.2710 | 2594.506 | 0.176 ± 0.022 | 13.09 ± 0.04 | ... |
| 2600.1729    | Fe II | 0.2390 | 2600.233 | 1.328 ± 0.031 | 14.42 ± 0.04 | ... |
| 2606.4620    | Mn II | 0.1927 | 2606.470 | 0.168 ± 0.020 | 13.20 ± 0.04 | ... |
| 2796.3520    | Mg II | 0.6123 | 2796.563 | 1.986 ± 0.022 | 14.22 ± 0.03 | ... |
| 2803.5310    | Mg II | 0.3054 | 2803.964 | 1.896 ± 0.022 | 14.49 ± 0.04 | ... |
| 2852.9652    | Mg I  | 1.8100 | 2853.018 | 0.534 ± 0.022 | 12.81 ± 0.01 | ... |

Notes. Equivalent width is measured in the absorber rest frame at the redshift of 1.5501. Vacuum wavelengths and oscillator strength f are adopted from the Atomic Data collected by J. X. Prochaska (http://www.astro.ufl.edu/~jpaty/qal.lst). All statistical uncertainties reported are 1σ confidence. However, the systematic error of column densities can exceed 0.05 dex due to continuum fitting and line saturation with ESI data.

| Ion | Redshift | EW (Å) | N_X (log(cm^{-2}) |
|-----|----------|--------|-------------------|
| Fe II | 0.7436 | 0.652 ± 0.200 | 14.49 ± 0.06 |
| Fe II | 0.829 ± 0.210 | 14.12 ± 0.06 |
| Fe II | 0.920 ± 0.211 | 14.32 ± 0.08 |
| Mg II | 1.622 ± 0.186 | 14.06 ± 0.04 |
| Mg II | 1.408 ± 0.207 | 14.03 ± 0.04 |
| Mg II | 0.879 ± 0.418 | 14.13 ± 0.21 |
| Mg II | 0.923 ± 0.182 | 13.81 ± 0.50 |
| Mg II | 0.976 ± 0.155 | 14.15 ± 0.20 |

Notes. Equivalent width is measured in the rest frame of the absorber of interest. See the note to Table 1 for the oscillator strengths and systematic errors.

their reddening effects can be well modeled by the linear component of the parameterized extinction curve. The fitting results are presented in Figure 6: panel (a) shows the best model compared with observation data and panel (b) shows the best-fitting

| Ion | Redshift | EW (Å) | N_X (log(cm^{-2}) |
|-----|----------|--------|-------------------|
| Fe II | 0.7436 | 0.652 ± 0.200 | 14.49 ± 0.06 |
| Fe II | 0.829 ± 0.210 | 14.12 ± 0.06 |
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| Mg II | 1.622 ± 0.186 | 14.06 ± 0.04 |
| Mg II | 1.408 ± 0.207 | 14.03 ± 0.04 |
| Mg II | 0.879 ± 0.418 | 14.13 ± 0.21 |
| Mg II | 0.923 ± 0.182 | 13.81 ± 0.50 |
| Mg II | 0.976 ± 0.155 | 14.15 ± 0.20 |
Figure 4. Normalized spectrum of J0035+0114 taken with the ESI spectrometer at the 10 m Keck telescope. Panel (a) shows the strong absorption lines detected in the intervening absorber at $z = 0.7436$; Panel (b) shows the strong absorption lines detected in the intervening absorber at $z = 0.5436$. The dashed lines indicate $v = 0 \text{ km s}^{-1}$ in the rest frame of the interested absorber.

(A color version of this figure is available in the online journal.)

Figure 5. Relative abundances are measured in J0035+0114 and compared with other known dusty clouds. Values for “warm” and “cold” Galactic ISM and SMC ISM were adopted from Jenkins et al. (1986), Welty et al. (1999), and Welty et al. (2001).

6. DISCUSSION AND SUMMARY

The strongest Mg$\text{\textsc{ii}}$ absorption system presented in this work is probably associated with the quasar, since it has $(z_{\text{em}} - z_{\text{abs}}) \sim 30 \text{ km s}^{-1}$ in the quasar rest frame. It is very possible that the corresponding cold gas rises from the host galaxy of the quasar. However, we cannot rule out a nearby foreground galaxy absorption scenario.

Interstellar dust grains play an important role in the evolution of galaxies, star formation, and planet formation. The dust content in the physical environment of the quasar has not been well studied (Li 2007 and reference therein). Increased detections of the associated dusty absorption system will aid us in understanding the nature of this dust and provide more...
Figure 6. In panel (a), the best-fit model is plotted with the observed data in the frame of the observer. The red arrow indicates the center of the fitted 2175 Å absorption bump and the blue arrow indicates the Mg $\text{ii}$ absorption lines. In panel (b), the solid line is the best-fit extinction curve in the rest frame of the absorber. Its linear component is plotted with the dashed line.

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Figure 7. Histogram of strength of bumps extracted in the simulation (black line). The dashed blue line is the best-fit Gaussian. The red arrow indicates the strength of the bump in J0035+0114.

(A color version of this figure is available in the online journal.)

Figure 8. Histogram of the strength of the 2175 Å absorption bumps measured in 328 Galactic extinction curves (Fitzpatrick & Massa 2007). The dashed lines are the 3$\sigma$ and 5$\sigma$ thresholds suggested by the simulation. Blue arrows indicate the bump strength measured in sight lines of the SMC bar and the red arrow indicates the bump strength measured in the sight line of the SMC wing (Gordon et al. 2003).

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clues on the evolution of galaxies and quasars. Furthermore, the population of dust-reddened quasars is a possible contributor to the X-ray background (e.g., Shanks et al. 1991; Mushotzky et al. 2000; Brandt et al. 2000; Dong et al. 2005). Its contribution is independent of the contribution of type 2 quasars with completely obscured broad emission line regions (Antonucci 1993).

On the basis of Keck spectroscopic observations, the dust depletion factor, [Fe/Zn] $\sim -0.86$, represents the high depletion population in high-redshift DLAs reported in Noterdaeme et al. (2008). All of the previous DLAs showing high dust depletion factor, [Fe/Zn] $< -0.8$, have high molecular hydrogen abundance. Thus, this system is very likely to have high molecular hydrogen content. Unfortunately, the molecular hydrogen absorption bands associated with this system are in the UV region beyond the atmospheric transmission window.

Figure 8 plots the histogram of the strength of the 2175 Å absorption bump measured in 328 Galactic extinction curves (Fitzpatrick & Massa 2007). The dashed lines are the 3$\sigma$ and 5$\sigma$ thresholds suggested by the simulation. Blue arrows indicate the bump strength measured in sight lines of the SMC bar and the red arrow indicates the bump strength measured in the sight line of the SMC wing (Gordon et al. 2003).

(A color version of this figure is available in the online journal.)

sorption bands associated with this system are in the UV region beyond the atmospheric transmission window.
The strength of the bumps measured in SMC (Gordon et al. 2003) is also plotted in Figure 8. The extinction curve measured in the sight line of the SMC wing exhibits a significant 2175 Å absorption bump.

In summary, we identify three Mg II absorption line systems along the sight line of the quasar J0035+0114. The strongest one is most likely associated with the quasar. The dust content in this associated system is firmly detected by either reddening or the dust depletion patterns of the elements. The extinction curve of this system is more likely to be of SMC type with $E(B-V) > 0.07$. However, we detect a tentative 2175 Å extinction bump at the $\sim \sigma$ significant level with our parameterized extinction curve technique. The high dust content suggests that this system is likely to be a DLA with molecular hydrogen content.

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**Table 4** Parameters of Optical/UV Extinction Curves

| Reddened Object | $E(B-V)$ | $C_1$ | $C_2$ | $E_0$ | $\gamma$ | $\lambda_{bump}$ | $x_0^2$ | Reference |
|-----------------|---------|------|------|-------|--------|-------------|-------|----------|
| J003545.13+01441.2 | 1.5501 | −2.17 ± 0.01 | 0.28 ± 0.01 | 0.08 ± 0.01 | 4.59b | 0.89b | 0.15 ± 0.02 | 1.21 | 1 |
| J012147.73+002718.7 | 1.3947 | −0.65 ± 0.02 | 0.06 ± 0.01 | 0.48 ± 0.04 | 4.64 ± 0.01 | 0.80 ± 0.04 | 0.93 ± 0.03 | 1.08 | 2.3 |
| J005042.21+515911.7 | 1.3265 | −2.70 ± 0.02 | 0.41 ± 0.01 | 0.61 ± 0.07 | 4.54 ± 0.01 | 1.21 ± 0.06 | 0.79 ± 0.05 | 1.14 | 4 |
| J005244.74+343540.4 | 1.3095 | −2.98 ± 0.02 | 0.47 ± 0.01 | 0.47 ± 0.05 | 4.55 ± 0.01 | 0.84 ± 0.05 | 0.88 ± 0.04 | 1.40 | 4 |
| J100713.68+283448.4 | 0.8839 | −3.85 ± 0.05 | 0.65 ± 0.03 | 6.45 ± 2.38 | 4.91 ± 0.15 | 1.78 ± 0.19 | 5.69 ± 1.49 | 1.10 | 5 |
| J145907.19+002401.2 | 1.3888 | −2.17 ± 0.02 | 0.08 ± 0.01 | 9.22 ± 0.71 | 4.56 ± 0.02 | 2.68 ± 0.07 | 5.40 ± 0.27 | 2.19 | 2.3 |
| J160457.50+220300.5 | 1.6405 | −2.09 ± 0.01 | 0.28 ± 0.01 | 0.46 ± 0.03 | 4.58 ± 0.01 | 0.93 ± 0.03 | 0.75 ± 0.03 | 1.37 | 6 |

**Notes.** Best-fit parameters of optical/UV extinction curves for SDSS 2175 Å absorbers.

a Redshift of the absorber of interest.

b These values are fixed during spectrum fitting.

**References.** (1) This work; (2) Wang et al. 2004; (3) Jiang et al. 2010; (4) Srianand et al. 2008; (5) Zhou et al. 2010; (6) Noterdaeme et al. 2009.
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