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Measurements of Narrow Mg II Associated Absorption Doublets with Two Observations

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Abstract. The measurement of the variations of absorption lines over time is a good method to study the physical conditions of absorbers. In this paper, we measure the variations of the line strength of 36 narrow Mg II$\lambda\lambda$2796, 2803 associated absorption doublets, which are imprinted on 31 quasar spectra with two observations of the Sloan Digital Sky Survey (SDSS). The timescales of these quasar span 1.1–5.5 years at the quasar rest-frame. On these timescales, we find that these narrow Mg II associated absorption doublets are stable, with no one λ2796 line showing strength variation beyond 2 times error (2σ).

Key words. Quasars: general—quasars: absorption lines—methods: statistical.

1. Introduction

The intervening absorption systems are often believed to be associated with the galaxies which are distant from the quasar (e.g., Bergeron 1986; Bond *et al*. 2001) and beyond the gravitational well of the quasar host galaxy ($z_{\rm abs} \ll z_e$). In contrast, the associated absorption systems are often believed to be physically related with the quasar ($z_{\rm abs} \approx z_e$). A note is that, in principle, the associated absorption systems need not be intrinsic to the corresponding quasar. The intrinsic absorption systems are caused by the gas which is likely to be ejected from the quasar central regions or within the quasar host galaxies (e.g., Murray *et al*. 1995; Elvis 2000). However, some associated absorption systems originate in the clouds within the galaxy cluster that contains the quasar, which would still be affected by the quasar environment but would not be the gas ejected from the quasar. The associated absorption systems can provide a wealth of information on the kinematics and energetics near the central black hole, dust content, ionization structure, star formation in massive/young galaxies, and so on.

Up to now, it is still poorly understood how the quasar outflows are launched and driven, but many models suggest that the quasar outflows be physically related to the gas lifted off the accretion disk, which would be driven by the radiation pressure or *magnetic fore* (Arav *et al*. 1994; de Kool & Begelman 1995; Murray & Chiang 1997; Proga *et al*. 2000; Everett 2005), where the radiation pressure seems to play a dominant role (Laor & Brandt 2002). The quasar outflows are detected most conspicuously via intrinsic absorption lines. The broad absorption lines (BALs), with the absorption troughs being broader than 2000 km s^{-1} at depths $>10\%$ below the continuum (Weymann *et al*. 1991), are undoubtedly intrinsic to the corresponding quasar. Therefore, the BALs are the most popular absorption lines to investigate the properties of the quasar outflows (Lundgren *et al*. 2007; Ganguly & Brotherton 2008; Ak *et al*. 2012). Although it is difficult to identify the narrow absorption lines (NALs), with widths being less than a few hundred km s^{-1}, to be intrinsic to the quasars, the intrinsic NALs are very important for the study of quasar outflows (e.g., Wise *et al*. 2004; Hamann *et al*. 2011; Chen *et al*. 2013). It is generally agreed upon that both the BALs and the intrinsic NALs are physically related to the quasar outflows, but we still poorly understand the physical relationship between the BAL and NAL outflows. It is possible that both the BALs and NALs arise in the same quasar outflows but are viewed at different angles. In the model of Murray *et al*. (1995), the outflow, with many dense filaments, is launched from the entire surface of the accretion disk. In this scenario, the BALs are formed in the main body of the outflow near the accretion disk plane and would be imprinted on the quasar spectra when the sightline is near to the accretion disk plane, while the intrinsic NALs are formed in the dense filaments at higher latitudes above the accretion disk plane and would be detected on the quasar spectra if the sightline passes through a dense filament (Ganguly *et al*. 2001; Misawa *et al*. 2008; Chartas *et al*. 2009).

One of the most popular methods to identify the intrinsic absorption lines is the time variations of absorption profiles (e.g., Ganguly *et al*. 1999; Lundgren *et al*. 2007; Hamann *et al*. 2011; Chen *et al*. 2013). Although the extreme events, namely the absorption trough disappearances (e.g., Hall *et al*. 2011; Vivek *et al*. 2012) or emergences (e.g., Krongold *et al*. 2010; Rodríguez *et al*. 2011) from the spectra are rare, the variations of the intrinsic absorption lines seem to be common, which can be detected on the timescales of months to years at quasar rest-frame (e.g., Hall *et al*. 2002, 2011; Narayanan *et al*. 2004). Barlow & Sargent (1997) estimated that about 30% intrinsic NALs are variable to some unspecified level. Although the origins of time variations of intrinsic absorption lines are unclear, the proper motions of absorbers across the sightline and the changes in the ionization state of the absorbing gas would be two mechanisms of them (e.g., Misawa *et al*. 2005; Hamann *et al*. 2011). The proper motion of the intervening absorbers might also be common, but the intervening absorption lines are found to be very stable: no intervening absorption lines with obvious variability have ever been reported. Therefore, the measurement of the variabilities of the absorption lines over time would be a good diagnostic to determine whether the absorption lines are really intrinsic to the quasars.

The Baryon Oscillation Spectroscopic Survey (BOSS), part of the Sloan Digital Sky Survey-III (SDSS-III; Eisenstein *et al*. 2011), aims to obtain spectra of over 150,000 quasars at $z > 2.2$ (Ross *et al*. 2012). The SDSS Data Release 9 is the first release of BOSS spectroscopy to the public, which contains $\sim$87, 000 quasars detected over 3,275 deg^2 (Pâris *et al*. 2012). About 8,000 quasars obtained by SDSS-I/II (York *et al*. 2000; Abazajian *et al*. 2009; Schneider *et al*. 2010) are reobserved during the first two years of BOSS.

Shen & Ménard (2012) have searched all the quasar spectra of SDSS DR7 (SDSS-I/II, Schneider *et al*. 2010) with Mg II emission line coverage for narrow Mg II$\lambda\lambda$2796, 2803 associated absorption doublets on both sides of the Mg II emission line. Adopting the method of Shen *et al*. (2011) and limiting the fit within 2200–3090 Å in the quasar rest-frame, the authors fitted a pseudo-continua with a power-law function plus a UV iron template provided by Vestergaard & Wilkes (2001), and fitted Mg II emission lines with multi-Gaussian functions. They detected Mg II absorption doublets on the spectra that has been subtracted by the pseudo-continua and emission lines, and invoked a pair of Gaussian functions to measure the equivalent width of absorption lines. Only the absorption doublets that were detected at $> 3\sigma$ for each Gaussian component and with velocity offset $\upsilon_r < 3000$ km s^{-1} to the quasar emission redshift (which were calculated with the emission redshifts based on the broad Mg II centroid), were selected. They finally arrived at 1937 Mg II associated absorption doublets from 1833 quasar spectra.

The quasars reobserved by SDSS-III provide a good chance to investigate the time variations of associated absorption lines. We find that there are 31 quasars (36 narrow Mg II associated absorption doublets), which are included by the sample of Shen & Ménard (2012) and reobserved during the two first years of BOSS. In this paper, we measure the variations of narrow Mg II associated absorption doublets of these 31 quasars. In section 2 we describe the spectral analysis, and in section 3 we discuss the time variations of line strengthes.

2. Spectral analysis

As noted in the above section that 31 out of the 1833 quasars included by the sample of Shen & Ménard (2012), which contain 36 Mg II absorption doublets, were reobserved during the two first years of the BOSS. We download the 31 quasar spectra, obtained by SDSS-I/II and SDSS-III respectively, from the SDSS database. The corrections of galactic extinction are done with the reddening map of Schlegel *et al*. (1998). For each spectra, we fit a pseudo-continua adopting a combination of cubic splines (for underlying continuum) and Gaussians (for emission features). The pseudo-continua is used to normalize the spectral fluxes and flux uncertainties. We measure the rest-frame equivalent widths (W_r) of each Mg II absorption doublet with a pair of Gaussian functions on the pseudo-continua normalized spectra, and the uncertainties of the rest-frame equivalent widths (σ) are estimated from the Gaussian fits. In the fitting processes, we assign the absorption redshifts of Shen & Ménard as the initial values of the central values of Gaussian functions. However, for consistency, in this paper we do not directly adopt the fitting results of absorption lines provided by Shen & Ménard. We compute the difference in equivalent widths of the same absorption line imprinted respectively on the SDSS-III and SDSS-I/II spectra using $\Delta W_r = W_r$(SDSS-III) $- W_r$(SDSS-I/II), and also normalize this difference with the corresponding combined error (σ'), $\Delta W_r/\sigma'$. The combined error was computed by adding all the relevant errors in quadrature, $\sigma'^2 \equiv \sigma^2$ (SDSS-III) $+ \sigma^2$ (SDSS-I/II). We present the fitting results in Fig. 1 and Table 1.

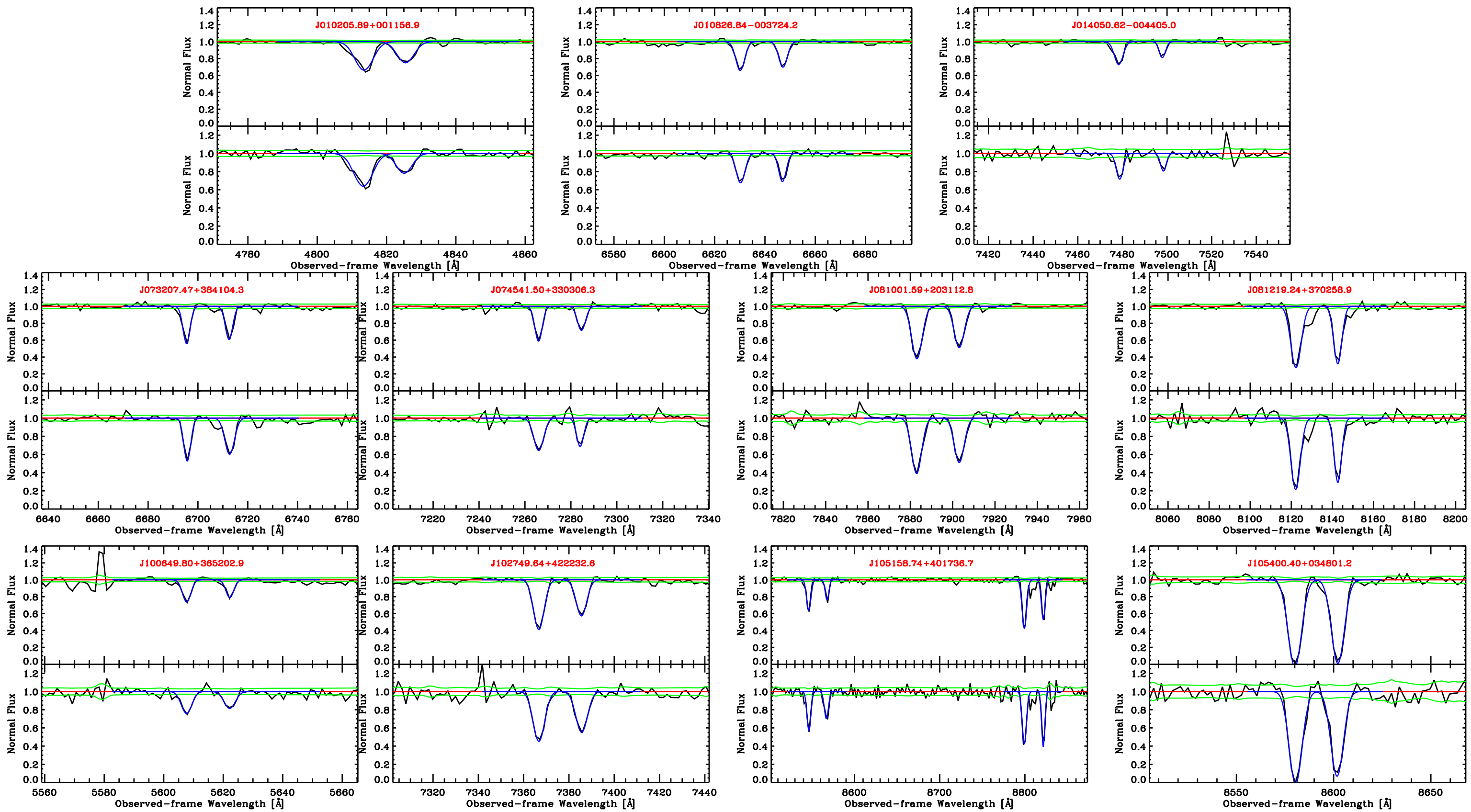

Figure 1. The pseudo-continua normalized spectra with the measured Mg II absorption doublets. The lower panel was observed by SDSS-I/II and the upper panel was reobserved by SDSS-III for each quasar spectra. The green lines represent the flux uncertainty levels which have been normalized by the corresponding pseudo-continuum, the blue curves are the Gaussian fittings.

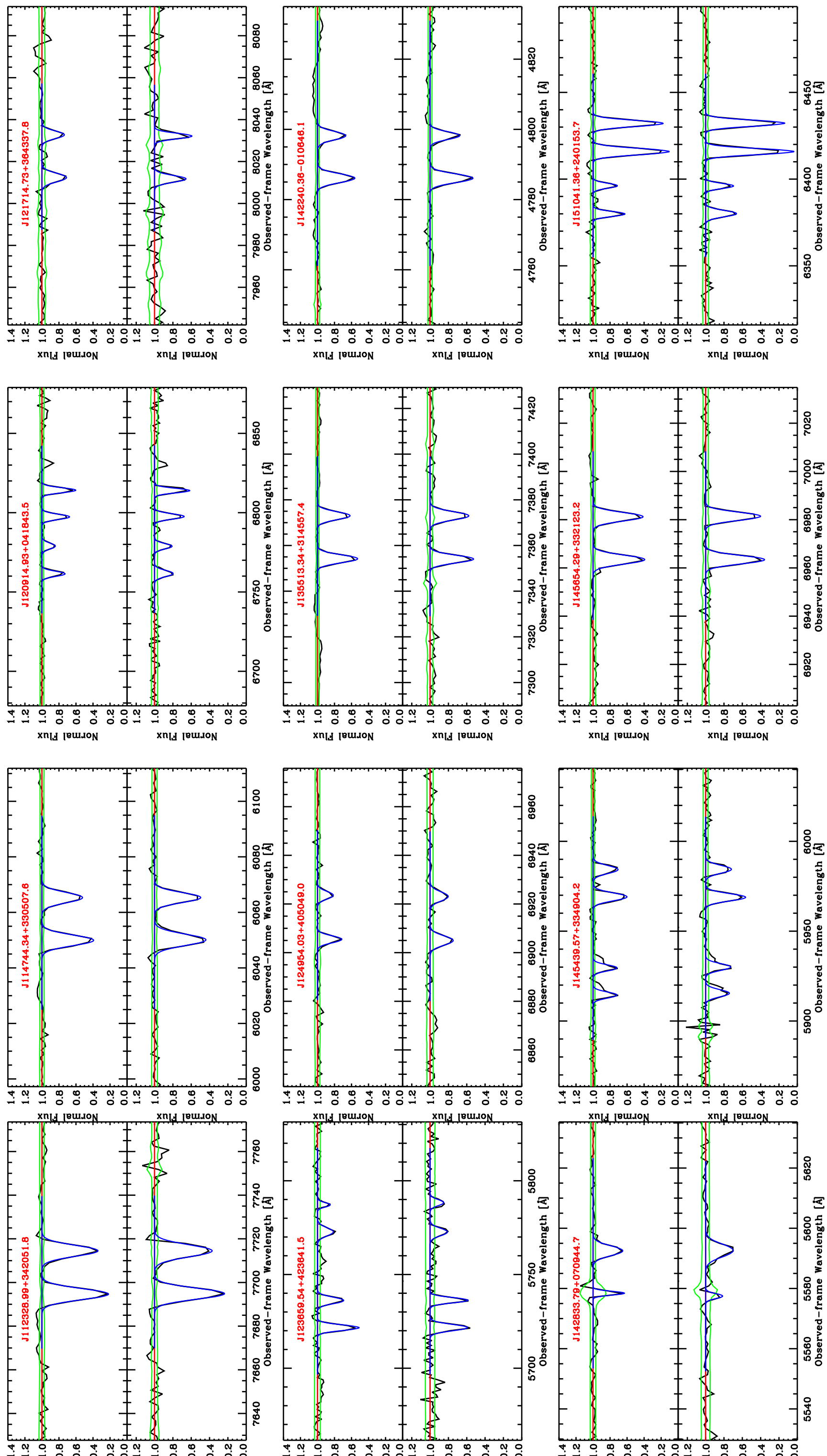

Figure 1. (*Continued*).

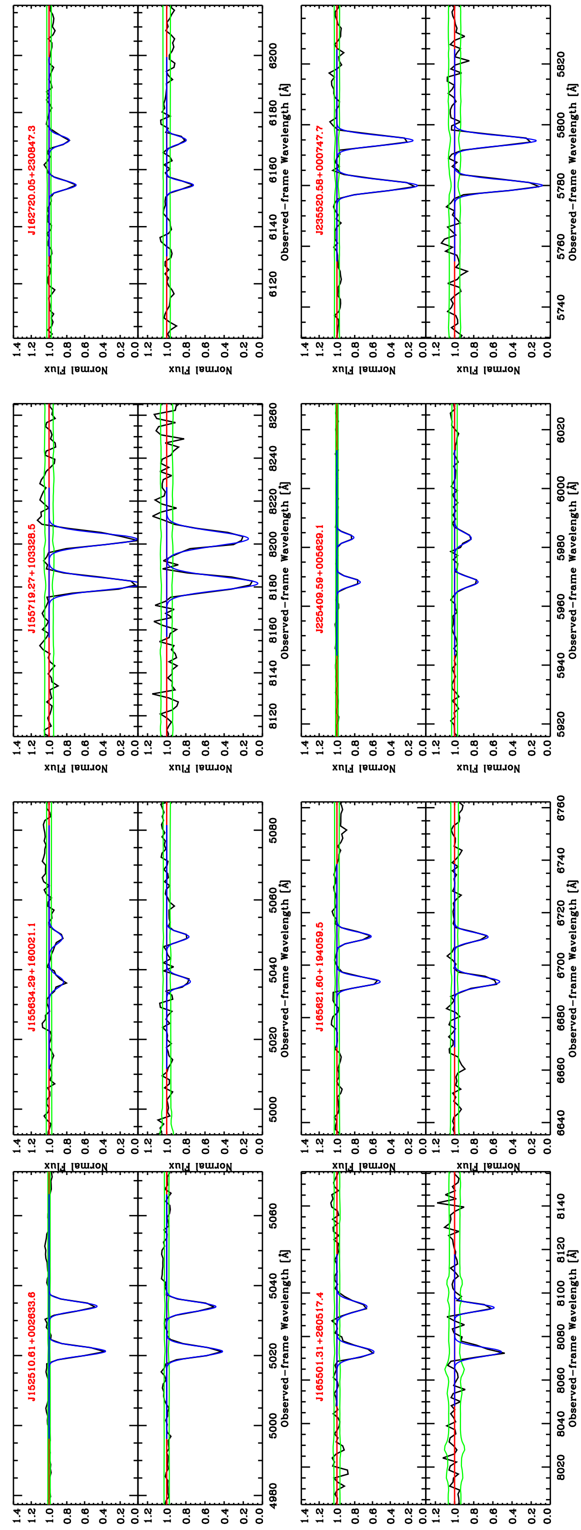

Figure 1. *(Continued).*

Table 1. Parameters of the 36 Mg II absorption doublets.

	Observed date			Measured from the SDSS-III spectra					Measured from the SDSS-I/II spectra					
SDSS name	SDSS-I/II	SDSS-III	z_e	$W_r\,\lambda2796$ (Å)	$\sigma_{\lambda2796}$ (Å)	$W_r\,\lambda2803$ (Å)	$\sigma_{\lambda2803}$ (Å)	$z_{\rm abs}$	$W_r\,\lambda2796$ (Å)	$\sigma_{\lambda2796}$ (Å)	$W_r\,\lambda2803$ (Å)	$\sigma_{\lambda2803}$ (Å)	$\frac{\Delta W_r}{\sigma'_{\lambda2796}}$	$\frac{\Delta W_r}{\sigma'_{\lambda2803}}$
010205.89+001156.9	2003-10-02	2010-09-13	0.7260	1.29	0.06	0.90	0.05	0.7214	1.44	0.11	0.74	0.10	−1.2	1.5
010826.84-003724.2	2000-09-07	2010-09-17	1.3756	0.64	0.03	0.54	0.03	1.3710	0.60	0.05	0.49	0.04	0.7	1.0
014050.62-004405.0	2000-09-01	2009-12-18	1.6565	0.50	0.03	0.25	0.02	1.6743	0.42	0.06	0.24	0.05	1.2	0.2
073207.47+384104.3	2004-02-12	2010-02-17	1.3788	0.66	0.04	0.61	0.04	1.3944	0.70	0.04	0.81	0.06	−0.7	−3.0
074541.50+330306.3	2001-11-22	2010-12-09	1.5867	0.64	0.03	0.49	0.04	1.5984	0.75	0.07	0.47	0.05	−1.5	0.3
081001.59+203112.8	2004-11-21	2011-03-09	1.8345	1.38	0.04	1.03	0.04	1.8191	1.29	0.07	1.02	0.07	1.1	0.1
081219.24+370258.9	2002-11-11	2010-03-12	1.8796	1.59	0.05	1.17	0.04	1.9046	1.57	0.06	1.11	0.05	0.3	1.0
100649.80+365202.9	2003-12-20	2011-02-24	1.0060	0.47	0.03	0.35	0.03	1.0054	0.54	0.07	0.44	0.07	−1.0	−1.2
102749.64+422232.6	2003-12-23	2011-01-27	1.6221	1.32	0.05	0.95	0.05	1.6344	1.34	0.09	1.10	0.09	−0.2	−1.5
105158.74+401736.7	2003-12-21	2011-03-10	2.1465	0.75	0.04	0.43	0.04	2.0563	0.82	0.07	0.59	0.07	−0.9	−2.1
				1.24	0.04	0.86	0.04	2.1468	1.14	0.09	0.92	0.07	1.0	−0.8
105400.40+034801.2	2002-03-05	2011-04-06	2.1017	2.89	0.08	2.69	0.07	2.0683	2.74	0.18	2.46	0.17	0.8	1.2
112328.99+342051.8	2005-04-07	2011-03-01	1.7259	1.81	0.05	1.50	0.05	1.7517	1.77	0.06	1.58	0.07	0.5	−1.0
114744.34+330507.6	2005-05-01	2011-02-12	1.1749	1.35	0.04	1.03	0.04	1.1635	1.33	0.06	1.05	0.05	0.3	−0.3
120914.93+041843.5	2002-04-12	2011-03-13	1.4249	0.45	0.03	0.31	0.04	1.4180	0.41	0.06	0.34	0.05	0.6	−0.5
				0.56	0.03	0.65	0.03	1.4308	0.57	0.05	0.58	0.04	−0.2	1.4
121714.73+364337.8	2005-03-13	2011-01-30	1.8704	0.52	0.06	0.42	0.05	1.8653	0.49	0.08	0.48	0.06	0.3	−0.7
123659.54+423641.5	2004-03-26	2011-05-24	1.0724	0.90	0.06	0.66	0.06	1.0461	0.85	0.09	0.72	0.08	0.5	−0.6
				0.50	0.08	0.22	0.04	1.0644	0.46	0.11	0.29	0.09	0.3	−0.7
124954.03+405049.0	2005-03-02	2011-02-25	1.4785	0.42	0.04	0.30	0.04	1.4695	0.50	0.06	0.38	0.06	−1.1	−1.1
135513.34+314557.4	2007-01-15	2010-03-19	1.6089	0.78	0.03	0.64	0.03	1.6299	0.77	0.05	0.74	0.05	0.2	−1.7
142240.36-010646.1	2002-05-01	2010-05-17	0.7183	0.81	0.04	0.59	0.04	0.7116	0.85	0.03	0.52	0.03	−0.8	1.5
142833.79+070944.7	2006-03-01	2011-05-08	1.0102	0.30	0.05	0.72	0.12	0.9949	0.19	0.05	0.81	0.14	1.5	−0.5
145439.57+334904.2	2005-06-10	2010-03-18	1.1373	0.57	0.04	0.57	0.04	1.1151	0.61	0.07	0.61	0.07	−0.5	−0.5
				1.03	0.05	0.76	0.05	1.1346	1.06	0.06	0.72	0.06	−0.4	0.5

Table 1. (*Continued*).

	Observed date			Measured from the SDSS-III spectra					Measured from the SDSS-I/II spectra					
SDSS name	SDSS-I/II	SDSS-III	z_e	$W_r\,\lambda2796$ (Å)	$\sigma_{\lambda2796}$ (Å)	$W_r\,\lambda2803$ (Å)	$\sigma_{\lambda2803}$ (Å)	$z_{\rm abs}$	$W_r\,\lambda2796$ (Å)	$\sigma_{\lambda2796}$ (Å)	$W_r\,\lambda2803$ (Å)	$\sigma_{\lambda2803}$ (Å)	$\frac{\Delta W_r}{\sigma'_{\lambda2796}}$	$\frac{\Delta W_r}{\sigma'_{\lambda2803}}$
145654.29+332123.2	2005-06-10	2010-03-18	1.5057	1.14	0.04	1.06	0.04	1.4902	1.14	0.05	1.03	0.05	0.0	0.5
151041.36+240153.7	2006-05-17	2011-04-03	1.3233	0.60	0.04	0.46	0.04	1.2815	0.69	0.06	0.49	0.05	−1.3	−0.5
				1.83	0.05	1.62	0.05	1.2944	1.83	0.05	1.66	0.05	0.0	−0.5
152510.61+002633.6	2000-05-09	2010-05-07	0.8033	1.14	0.02	0.96	0.02	0.7956	1.13	0.04	0.95	0.04	0.2	0.2
155634.29+160021.1	2008-03-12	2010-05-10	0.8106	0.39	0.06	0.36	0.06	0.8011	0.50	0.07	0.40	0.06	−1.1	−0.5
155719.27+103328.5	2008-04-16	2011-06-08	1.9301	2.46	0.11	2.30	0.10	1.9257	2.51	0.15	2.46	0.17	−0.3	−0.8
162720.05+230847.3	2004-08-09	2010-09-11	1.1990	0.53	0.04	0.41	0.04	1.2009	0.42	0.05	0.33	0.06	1.7	1.2
165501.31+260517.4	2005-04-12	2011-04-13	1.9043	0.86	0.06	0.71	0.06	1.8870	0.91	0.11	0.59	0.09	−0.4	1.1
165621.60+194059.5	2004-06-13	2011-04-29	1.3974	0.89	0.04	0.69	0.04	1.3937	0.96	0.07	0.61	0.06	−0.9	1.1
225409.59+005629.1	2000-09-02	2010-10-02	1.1572	0.44	0.02	0.28	0.02	1.1343	0.46	0.05	0.37	0.05	−0.4	−1.6
235520.58+000747.7	2000-09-01	2010-10-01	1.0625	1.93	0.05	1.62	0.04	1.0670	1.88	0.11	1.61	0.10	0.4	0.1

3. Discussions and conclusions

Time variations of intrinsic absorption lines seems to be common (e.g., Wise *et al*. 2004; Narayanan *et al*. 2004; Hall *et al*. 2011; Hamann *et al*. 2011) on the timescales of months to years at the quasar rest-frame. The line variations would mainly arise from the scenarios: the absorber owns an appreciable motion transverse to the sightline; or/and the physical conditions of the absorbing gas change with time. The bulk motion of the absorbing gas transverse to the sightline would give rise to a change in the coverage fraction of the discrete absorbing clouds that only partially blocks the background emission sources, which results in a change in the total column density of the absorber. This model is supported by some recent studies on the BAL variability (Gibson *et al*. 2008; Capellupo *et al*. 2011; Ak *et al*. 2012). Whether one can detect an obvious variability of the absorption line, is determined by the time interval of observations and the physical conditions of the absorber in this model, such as the size, velocity transverse to the sightline.

The variabilities in the background emission sources could induce a global change in the ionization structure of the absorber. This scenario is a reasonable explanation to the coordinated variations of five absorption systems measured by Hamann *et al*. (2011). Due to the distances between the background emission sources and absorber and the finite recombination time of the absorbing gas, the absorption trough should show a delayed reaction to the variabilities in the background emissions. Therefore, in this model, the significant line variation would be tightly related to the absorber location and the monitoring timescale.

Ak *et al*. (2012) found that 21 C IV broad absorption troughs imprinted in the SDSS-I/II spectra disappear from the SDSS-III spectra. These disappearance events are the extreme variabilities of the intrinsic absorption lines. In this work, we measure 36 narrow Mg II associated absorption doublets with SDSS two observations, some of which might be really intrinsic to the quasars. However, it can be clearly seen from Fig. 1 that there is no event of the absorption line disappearance. In order to investigate the variations of the line strengths of the 36 narrow Mg II associated absorption doublets, we compare the equivalent widths of absorption lines at the epochs of the SDSS two observations in Figures 2 and 3. The normalized differences of W_r, $\Delta W_r/\sigma'$, are defined in the previous section and tabulated in the two last columns of Table 1. We can find from Figures 2 and 3 that the absorption strengths are stable. Most of the W_r are consistent within 1 σ error. Not one absorption of the $\lambda 2796$ line shows $\Delta W_r/\sigma' > 3$.

The time variation of the line strength is one of the most effective ways to identify intrinsic absorption lines. In the model of Murray *et al*. (1995), the BALs are formed in the absorbing gas near the accretion disk plane, while the intrinsic NALs originate in the absorbing gas at the higher latitude above the accretion disk plane. The timescales of the 21 extreme examples of the C IV broad absorption trough disappearance analysed by Ak *et al*. (2012) span 1.1–3.9 years at quasar rest-frame. And these are 1.1–5.5 years for the 31 quasars analysed in this work, which are similar or longer to the timescales of the 19 quasars used by Ak *et al*. (2012). If the narrow Mg II associated absorption doublets analysed in the work are really intrinsic to the quasars, the stability of these absorption lines might imply that these absorbers would be far away from the background emission sources. And therefore, a longer timescale is required to give rise to a change in the ionization structure of the

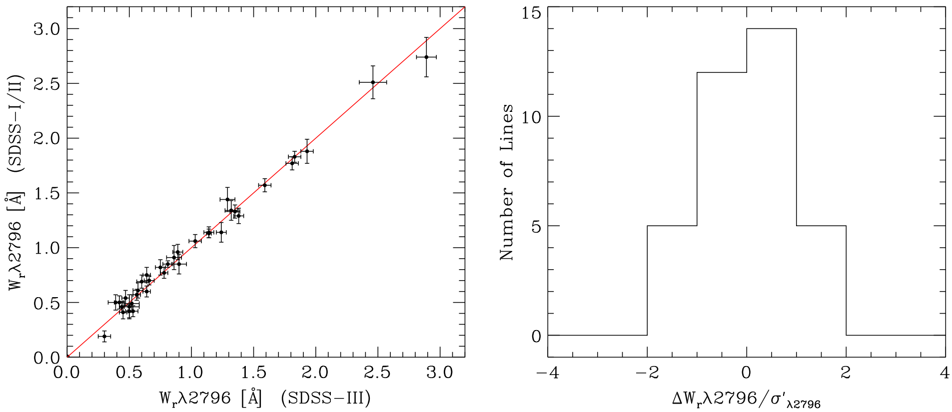

Figure 2. *Left panel*: Comparison of the $W_r\lambda2796$, which are measured from the SDSS-III and SDSS-I/II spectra, respectively. The red solid line represents the identical line. *Right panel*: The normalized difference of $W_r\lambda2796$ between the SDSS two observations, namely, $\Delta W_r\lambda2796/\sigma'_{\lambda2796} \equiv (W_r\lambda2796(\mathrm{SDSS\text{-}III}) - W_r\lambda2796(\mathrm{SDSS\text{-}I/II}))/\sqrt{\sigma'^2_{\lambda2796}(\mathrm{SDSS\text{-}I/II}) + \sigma'^2_{\lambda2796}(\mathrm{SDSS\text{-}III})}$. Note that there is no absorption line with the discrepancy of $W_r\lambda2796$ beyond $2\sigma'_{\lambda2796}$.

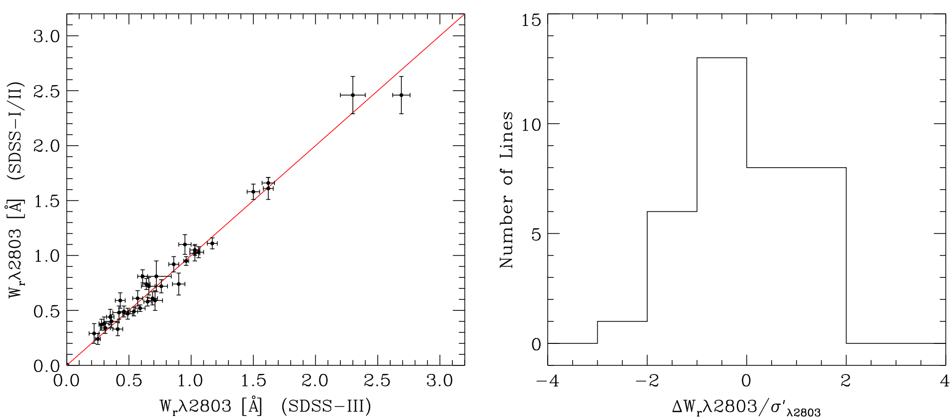

Figure 3. The meanings of the symbols are the same as those of Fig. 2 but for the $\lambda2803$ line. Note that there is no absorption line with the discrepancy of $W_r\lambda2803$ beyond $3\sigma'_{\lambda2803}$.

absorbing gas, or/and a change in the coverage fraction of the absorber to the background emission sources.

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