Velocity shift of Mg II and Al III broad absorption lines in quasar SDSS J134444.33+315007.6

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ABSTRACT
We report, for the first time, a synchronized velocity shift of Mg II and Al III broad absorption lines (BALs) in quasar SDSS J134444.33+315007.6 (hereafter J1344+3150). We found this quasar from a sample of 134 Mg II BAL quasars with multi-epoch observations. This quasar contains three low-ionization BAL systems, the fastest of which at ∼−17,000 km s⁻¹ shows a kinematic shift of ∼−1101 km s⁻¹ and ∼−1170 km s⁻¹ in its Mg II and Al III ions, respectively, during a rest-frame time of about 3.21 yr. Meanwhile, this quasar also shows other various variation characteristics, including an obvious weakening in its continuum, a coordinated enhancement in multiple emission lines (Mg II, C III and Al III), and a coordinated enhancement in three Al III absorption troughs. These variation characteristics convincingly indicate that the BAL outflows of J1344+3150 are under the influence from the background radiation energy. Thus, we infer that the velocity shift displayed in system A in the quasar J1344+3150 may indicate an actual line-of-sight acceleration of an outflow due to the radiation pressure from the central source.

Key words: galaxies : active – quasars : absorption lines – quasars: individual (SDSS J1344+3150).

1 INTRODUCTION
At present, there is a lack of understandings for the velocity shift of absorption lines seen in the ultraviolet (UV) spectra of quasars. This is in sharp contrast with the extensive research on the equivalent width (EW) variability of absorption lines. But we still cannot ignore that an observed velocity shift of an absorption profile can be a signature of potential acceleration/deceleration, which is an important physical property of the outflowing gas in quasars.

On the one hand, the study of velocity shift of absorption lines is limited by the number of its direct detection cases. Recent studies have presented abundant cases or large samples to show the universality of the EW variations of absorption lines in quasars (for broad absorption lines, namely BALs: e.g. Hamann et al. 2008; Grier et al. 2015; McGraw et al. 2017; He et al. 2017, 2019; Yi et al. 2019, and references therein; for narrow absorption lines, namely NALs: e.g. Hamann et al. 2011; Chen et al. 2015; 2018a,b, and references therein). However, only a few studies have shown direct detection of the velocity shift of absorption lines (Vilokovskij & Irwin 2001; Rupke et al. 2002; Gabel et al. 2003; Hall et al. 2007; Joshi et al. 2014; Grier et al. 2016; Joshi et al. 2019; Lu & Lin 2019; Yao et al. 2020; Xu et al. 2020). Most of these studies are based on single quasar objects, with the exception of Grier et al. (2016), who firstly performed the systematic research of velocity shift using a quasar sample. In 140 BAL quasars that were observed at least three epochs by the Sloan Digital Sky Survey (SDSS; York et al. 2000), Grier et al. (2016) found only three quasars existing velocity shifts in the C IV BALs. This means that, to date, there is no further quantitative statistical investigation or common trend analysis of the velocity shift of BALs that based on a large sample. Moreover, these existing studies of the velocity shift of absorption lines mainly focus on high-ionization the C IV ion, sometimes along with the Si iv ion, but there is no case on the velocity shift signatures in low-ionization ions, such as the Mg ii etc.

On the other hand, the research progress on the physical mechanism of the change in velocity of absorption lines has not kept up with EW variation. Though the cause of absorption trough EW variability is still debated in the literature, it is widely suggested that its possible causes include variations in the ionization state (e.g. Hamann et al. 2011; He et al. 2017; Lu et al. 2017; Lu et al. 2018; He et al. 2019) and the transverse motion of the absorption materials across our line of sight (e.g. Hamann et al. 2008). Both these two origins have been supported by observational ev-
Figure 1. Top panel: original spectra of quasar SDSS J1344+3150 that observed on MJD 53,503 (black) and 56,363 (red), together with their power-law continua. The blue vertical dashed lines represent the rest wavelengths of the main emission lines. The y-axis is in unit of $10^{-17}$ erg cm$^{-2}$ s$^{-1}$. The blue horizontal bars at the top are the wavelength regions we used to fit the power-law continua. Middle panel: normalized spectra of quasar J1344+3150 showing three BAL systems (marked by black horizontal solid bars); Bottom panel: snippets from normalized spectra showing the Mg II and Al III BALs of system A. The black (MJD 53,503) and red (MJD 56,363) horizontal dashed lines are the line centers of the absorption troughs.

In this letter, we report, for the first time, a synchronized velocity shift of the Mg II and Al III BALs in quasar SDSS J1344+3150 ($z_{em} = 1.440$, hereafter J1344+3150). We found this special case based on a visually check of a sample of 134 Mg II BAL quasars with multi-epoch observations by the SDSS, which was constructed by Yi et al. (2019).

The rest of this letter is divided into the following two parts. In Section 2 we present the methods and results of the spectra analysis and the measurements of broad absorption troughs. In Section 3 we discuss the implications of our results.

2 SPECTRA ANALYSIS AND ABSORPTION TROUGH DETECTION

We obtained the spectra of quasar J1344+3150 from the SDSS data release 16 (DR16; Ahumada et al. 2020), which were archived on MJD 53,503 and MJD 56,363, respectively. The resolution of them is $R = 2000$. The MJD 53,503 spectrum covers a wavelength range from 3800 to 9200 Å, while the MJD 56,363 spectrum covers a wavelength range from 3600 to 10,000 Å. The median signal-to-noise ratio (S/N) of the MJD 53,503 and MJD 56,363 spectra are 21 and 24, respectively.

By iteratively fitting the continuum within the wavelength regions that are relatively free from strong emission lines and absorption lines, we obtained a power-law continuum of each original spectra (see the top panel of Figure 1). Then we normalized the two original spectra using their corresponding power-law continuum (see the middle panel of Figure 1). In the power-law continuum normalized spectra, we detected three broad absorption systems (systems...
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3 DISCUSSION AND CONCLUSION

As can be seen from Figure 1, the BAL systems mainly exhibit two observational characteristics. One characteristic is the coordinated enhancement of all three Al iii absorption troughs. Besides, although suffering from large uncertainties, all three Mg ii troughs also show faint trends of weakening (see also Table 1). Another characteristic is the synchronized velocity shift displayed in the fastest Mg ii and Al iii BALs (system A).

First, we hold the view that the ionization change is more reasonable (than the transverse-motion scenario) to be the cause of the absorption line variation in J1344+3150, according to the following several reasons. For the first reason, variations in the continuum within our available wavelength coverage possibly indicate the changes in ionizing radiation at bluer wavelengths. For the second reason, significant variability of the broad emission line (BEL) generated in the photoionized broad-line region can be an indicator of a change in the ionizing radiation field, which may result in an ionization change of a BAL outflow. Last but not least, coordinated BAL variability covering a large velocity range (~15,000 km s$^{-1}$ in this source) can be a strong evidence in support of the ionization-change scenario, because this situation is difficult to be interpreted by the transverse-motion scenario, which requires multiple outflowing absorbers to move synchronously (see e.g. Hamann et al. 2011; Grier et al. 2015; McGraw et al. 2017).

Second, we suggest that the observed velocity shift may be related to the radiation pressure from the central source. As mentioned in the introduction, at present, the physical mechanism of the velocity shift of absorption line is still difficult to determine, and there is even no observational case of velocity shift that can be perfectly explained by existing models. For J1344+3150 in this letter, only relying on the data of two observations from the SDSS, we have not been able to determine the physical mechanism of its line velocity shift. However, between the two observations of this source, we detected the coordinated BAL variations cover a large velocity range, and significant fluctuations in the continuum and BELs. These variation characteristics convincingly indicate that the BAL outflow of J1344+3150 is under the influence from the background radiation energy. Thus, we infer that the velocity shift displayed in system A in quasar J1344+3150 may indicate an actual line-of-sight acceleration of an outflow due to radiation pressure from the central source. If the actual acceleration of an outflow is indeed the reason for the BAL velocity shift displayed in J1344+3150, then its BAL measurements may be comparable with those of the J1042+1646 in Xu et al. (2020), which BAL velocity shift is attributed to the same reason. First, both these two sources show a synchronized velocity shift of more than one ions, but the ion ionization states of J1042+1646 (Ne viii, O v and Mg x) are higher than J1344+3150 (Mg ii and Al iii); second, the outflow velocity of J1042+1646 (~20,000 km s$^{-1}$) is faster than J1344+3150 (~17,000 km s$^{-1}$); third, the velocity shift (~1500 km s$^{-1}$) and average acceleration rate (1.52 cm s$^{-2}$) of J1042+1646 are both larger than those of J1344+3150. These compar-

| BAL Specie | Velocity$^a$ (km s$^{-1}$) | FWHM$^b$ (km s$^{-1}$) | EW(A)(MJD: 53,503) | EW(B)(MJD: 56,363) | Fractional EW | Note |
|------------|--------------------------|----------------------|-----------------|-----------------|-------------|-----|
| Mg ii      | -1595 - -1409            | 5435                 | 3.95 ± 0.24     | 3.81 ± 0.25     | -0.04 ± 0.091 | system A |
| Mg ii      | -1392 - -10508           | 2784                 | 0.60 ± 0.19     |                 |             | system B |
| Al iii     | -8738 - -5665            | 3073                 | 1.69 ± 0.17     | 1.35 ± 0.19     | -0.22 ± 0.172 | system C |
| Al iii     | -19493 - -14006          | 5487                 | 3.65 ± 0.30     | 5.17 ± 0.23     | 0.35 ± 0.092  | system A |
| Al iii     | -14066 - -10142          | 3864                 | 1.91 ± 0.26     | 2.65 ± 0.20     | 0.32 ± 0.151  | system B |
| Al iii     | -10142 - -3694           | 6447                 | 7.08 ± 0.31     | 8.66 ± 0.24     | 0.20 ± 0.050  | system C |

$^a$Velocity range of the BAL trough that are calculated with respect to wavelength of the blue component of the absorption doublet.

$^b$Total width calculated from edge-to-edge of the BAL trough.

$^c$Note that Mg ii BAL in system B in the MJD 56,363 spectrum is nearly undetectable.

A, B, and C). We measured the EW and full width at half-maximum (FWHM) of these three broad absorption systems in Al iii and Mg ii ions, following the methods in our previous studies (e.g. equations (2) and (3) in Lu & Lin (2018)). The measurements can be seen in Table 1. Note that system B in Mg ii ion in the MJD 56,363 spectrum is nearly undetectable.

We found that system A exhibited a velocity shift between the two observations in both the Mg ii and Al iii ions. Following Lu & Lin (2019), we determined the line center of a BAL by averaging the EWs of the troughs. In order to more correctly estimate the line centers, we generated 10,000 simulated spectra via adding Gaussian noise to the original spectra according to the corresponding flux density errors, and then used the same procedure to measure the line centers for these simulated spectra. Then, we estimated the line center and the measurement errors according to the median values and the standard deviations of the 10,000 trials, respectively. Finally, we got the centroid radial velocities of the Mg ii BAL of system A for the MJD 53,503 and 56,363 spectra, which are $-16194 \pm 39$ km s$^{-1}$ and $-17295 \pm 61$ km s$^{-1}$, respectively. The difference between their velocities is $-1101 \pm 80$ km s$^{-1}$, which corresponds to an acceleration rate of 1.087 ± 0.079 cm s$^{-2}$. Meanwhile, the centroid radial velocities of the Al iii BAL of system A are $-16814 \pm 77$ km s$^{-1}$ and $-17353 \pm 29$ km s$^{-1}$ for the MJD 53,503 and 56,363 spectra, respectively, and their velocity difference is $-1170 \pm 69$ km s$^{-1}$, corresponding to an acceleration rate of 1.155 ± 0.068 cm s$^{-2}$.

We integrated the wavelength range from 1600 to 3000 Å to obtain the flux of each continuum, and find out that, during a rest-frame time of about 32.1 yr, the continuum of quasar J1344+3150 experienced an obvious weakening with the fraction variation of about –0.423.

Table 1. Measurements of BALs.
ions may infer that more dramatic acceleration can be seen at higher ionization states and/or higher velocities.

In conclusion, we have reported a velocity shift of a low-ionization broad absorption system (including Mg\textsc{ii} and Al\textsc{iii} ions) in quasar SDSS J1344+3150. According to the variation characteristics displayed in its two-epoch SDSS spectra, including an obvious weakening in its continuum, a coordinated enhancement in multiple emission lines (Mg\textsc{ii}, C\textsc{iii} and Al\textsc{iii}), and a coordinated enhancement in three Al\textsc{iii} absorption troughs, we infer that the velocity shift of the absorption lines shown in quasar J1344+3150 may be dominated by radiation pressure.

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DATA AVAILABILITY

The data underlying this article were accessed from the Sloan Digital Sky Survey.

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