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A broad absorption line outflow associated with the broad emission line region in the quasar SDSS J075133.35+134548.3

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Abstract We report on the discovery of unusual broad absorption lines (BALs) in the bright quasar SDSS J075133.35+134548.3 at $z \sim 1$, using archival and newly obtained optical and NIR spectroscopic data. The BALs are detected reliably in He I* λ 3889, He I* λ 10830 and tentatively in Al III, Mg II. These BALs show complex velocity structures consisting of two major components: a high-velocity component (HV), with a blueshifted velocity range of $\Delta v_{\rm HV} \sim -9300 - -3500 \,\rm km \, s^{-1}$, which can be reliably detected in He I* $\lambda 10830$, and tentatively in Al III and Mg II, whereas it is undetectable in He I* $\lambda 3889$; and a low-velocity component (LV), with $\Delta v_{\rm LV} \sim -3500 - -1800 \,\rm km \ s^{-1}$, is only detected in He I* λ 3889 and He I* λ 10830. With the BALs from different ions, the HV outflowing gas can be constrained to have a density of $n_{\rm H} \sim 10^{10.3} - 10^{11.4}$ cm⁻³, a column density of $N_{\rm H} \sim 10^{21}$ cm⁻² and an ionization parameter of $U \sim 10^{-1.83}$ -10^{-1.72}; inferring a distance of $R_{\rm HV} \sim 0.5$ pc from the central continuum source with a monochromatic luminosity $\lambda L_{\lambda}(5100)=7.0\times10^{45}$ erg s⁻¹ at 5100 Å. This distance is remarkably similar to that of the normal broad line region (BLR) estimated from reverberation experiments, suggesting association of the BLR and the HV BAL outflowing gas. Interestingly, a blueshifted component is also detected in Al III and Mg II broad emission lines (BELs), and the Al III/Mg II of such a BEL component can be reproduced by the physical parameters inferred from the HV BAL gas. The LV BAL gas likely has a larger column density, a higher ionization level and hence a smaller distance than the HV BAL gas. Further spectroscopy with a high S/N ratio and broader wavelength coverage is needed to confirm this to shed new light on the possible connection between BALs and BELs.

Key words: quasars: emission lines — quasars: broad absorption line — quasars: individual (SDSS J075133.35+134548.3)

1 INTRODUCTION

As a regulator of the growth of central supermassive black holes (BHs) in active galactic nuclei (AGNs), outflows carry away the angular momentum of inflowing gas to sustain mass accretion. (Sulentic et al. 2000; Richards et al. 2011; Wang et al. 2011). Previous studies (e.g. Silk & Rees 1998) suggested that outflows in AGNs can change the gas distribution and hence influence star formation rates in the host galaxies. Blueshifted broad emission lines (BELs; Gaskell 1982) and broad absorption lines (BALs; Weymann et al. 1991) in the quasar spectra are the prominent imprints of outflows, from which the physical conditions of AGNs and their surrounding can be studied in detail.

Traditional BALs defined by balnicity index (BI)¹ (Weymann et al. 1991) in quasar spectra are often blueshifted at high speeds (up to about 0.2c) and significantly broadened ($\geq 2000 \text{ km s}^{-1}$). These BALs are from high ionization ions, such as NV, CIV and Si IV, and low ionization ions, such as Al III and Mg II (Hall et al. 2002; Hewett & Foltz 2003; Trump et al. 2006;

 $^{^{1}}BI = \int_{3000}^{25000} [1 - f(-v)/0.9]Cdv$, where the f(-v) is the normalized spectrum, and the velocity v is in the unit of km s⁻¹ with respect to the quasar emission lines (negative value indicates blueshifted). When the observed spectrum falls at least 10% below the model of continuum plus emission lines in a contiguous velocity interval of at least 2000 km s⁻¹, the weight C is set to 1, otherwise, C = 0.

Zhang et al. 2010, 2014; Zhang et al. 2017). Because of their prominent features, most BALs are easily detected and measured. Making use of BALs from different ions, we can set constraints on the physical conditions of the outflows. However, the global geometry, for example the covering factor, cannot be determined through the BALs, due to only a single line of sight. Conversely, the global covering fraction of the outflows can be constrained by blueshifted BELs. Unfortunately, the blueshifted BELs are often not isolated and their decomposition from the the normal BELs of the broad line region (BLR) is challenging. In fact, the existence of blueshifted BELs is usually identified through their different profiles, such as asymmetry, peak and/or line centroid, compared to normal BELs (e.g., Gaskell 1982; Crenshaw 1986; Marziani et al. 1996; Richards et al. 2002; Boroson 2005; Crenshaw et al. 2010; Rafiee et al. 2016; Zhang et al. 2017; Liu et al. 2019).

The co-existence of both blueshifted BELs and BALs has been reported in several guasars and their physical connections have been inferred. Liu et al. (2016) presented a detailed study of BEL and BAL outflows in a quasar, namely SDSS J163459.82+204936.0 (hereafter J1634) and found that their physical parameters extracted from the photoionization code CLOUDY are similar, strongly suggesting that the observed blueshifted BELs are emitted from the BAL outflowing gas. More recently, Liu et al. (2019) reported another quasar, SDSS J163345.22+512748.4 (hereafter J1633), in which both blueshifted BELs and BALs were detected. The inferred physical conditions are also similar, except for the column density, indicating that the blueshifted BEL outflow and BAL outflow may be associated. If the blueshifted BELs and BALs are indeed from the same outflowing gas, the joint analysis of BELs and BALs could provide complementary or additional constraints on the general physical properties of outflows in quasars.

In this paper, we present a detailed analysis of the BAL and BEL outflows of the quasar SDSS J075133.35+134548.3 (hereafter SDSS J0751+1345). By combining BALs of the He I* λ 10830, Mg IIand Al III, the properties of the BAL outflow can be well determined. In particular, two BAL components with different outflowing velocities are revealed. In Al III and Mg II BELs, we also detect the presence of the blueshifted BEL components. Although the characteristics of the outflow gas, from which the blueshifted BELs originate, are not as well constrained as those of the BAL outflow gas, our analysis suggests that they are not isolated. We describe the observation data in Section 2 and the data are further analyzed in Sections 3 to 6. Our discussion on the results are presented in Section 7. In this paper, the cosmological parameters are adopted as $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_M = 0.3$ and $\Omega_{\Lambda} = 0.7$.

2 OBSERVATION AND DATA REDUCTION

The optical photometric data of SDSS J0751+1345 were taken by the Sloan Digital Sky Survey (SDSS) on 2004 December 13. The point-spread function magnitudes are 19.16 ± 0.02 , 18.42 ± 0.01 , 18.00 ± 0.01 , 17.85 ± 0.01 and 17.50 ± 0.02 in the SDSS *ugriz* bands respectively. The optical spectrum of SDSS J0751+1345 was observed by the Baryon Oscillation Spectroscopic Survey (BOSS; Dawson et al. 2013) of SDSS-III (Eisenstein et al. 2011) on 2011 January 8. The spectrum we examined was extracted from the BOSS Data Release 10 (DR10; Ahn et al. 2014) and its wavelength coverage is from 3600 Å to 10 500 Å.

SDSS J0751+1345 was also observed with the Very Large Telescope (VLT)/X-Shooter (Vernet et al. 2011) on 2014 Dec 6 under the ESO program 094.A-0087(A)². For the three arms, UVB, VIS and NIR, the exposure times are 2820 s, 2520 s and 2400 s, respectively. The slit widths of the UVB, VIS and NIR arms are 1.6", 1.5" and 1.2", leading to spectral resolution ($R = \lambda/\delta\lambda$) of 1900, 3200 and 3900, respectively. Reduced 1-D spectra for the three arms are retrieved from ESO Phase 3 Data Release, and concatenated to form a single spectrum covering 3200 Å– 2.5 µm. Finally, telluric absorption features are corrected using Molecfit (Smette et al. 2015) and the final spectrum (hereafter the VLT spectrum) is displayed in Figure 1.

Besides the optical band, SDSS J0751+1345 was also detected in the surveys of the Two Micron All-Sky Survey (2MASS; Skrutskie et al. 2006) and the Widefield Infrared Survey Explorer (WISE; Wright et al. 2010). All the photometric data of SDSS J0751+1345 are listed in Table 1. On 2017 January 10, using the TripleSpec (Wilson et al. 2004) on the 200 inch Hale telescope at Palomar Observatory, we obtained its near-infrared (NIR) spectrum (hereafter P200 spectrum) in an A-B-B-A dithering mode. Four exposures of 150s each were taken with the primary configuration of the instrument. To match the seeing during the observation, we chose the width of the slit as 1". The corresponding spectral resolution was about 2700 and the wavelength coverage was about 0.95–2.46 µm. For the flux calibration, we also observed two telluric standard stars quasi-simultaneously. Two gaps caused by atmosphere transmissivity exist around 1.35 and 1.85 µm in the NIR spectrum. According to the observed results displayed in Figure 1, SDSS J0751+1345 displays no obvious variability between the different spectrographic

 $^{^2\,}$ PI: Petitjean, Title: large XSHOOTER follow-up of peculiar BOSS quasars



Fig. 1 UV to mid-infrared spectra and SED of SDSS J0751+1345 in the quasar's rest-frame. The BOSS, P200, and VLT spectra are presented by red, blue and black curves, respectively. The photometric data are signified with green diamonds. The consistency between the spectral and photometric data indicates that the variability between the observations can be ignored and we can combine the spectra for the following analysis. The upper inset displays the detections of the He I* λ 10830 BAL in *K*-band of P200 and VLT spectra. The lower inset features the BOSS and VLT spectral details between 1400 and 3200 Å.

Wavelength Band/Range	Mag.	Survey	MJD
и	19.16 ± 0.02	SDSS	53352
g	18.42 ± 0.01	SDSS	53352
r	18.00 ± 0.01	SDSS	53352
i	17.85 ± 0.01	SDSS	53352
z	17.50 ± 0.02	SDSS	53352
J	16.31 ± 0.13	2MASS	50752
Н	15.62 ± 0.15	2MASS	50752
K_s	14.95 ± 0.14	2MASS	50752
W1	13.35 ± 0.02	WISE	55489
W2	12.03 ± 0.03	WISE	55489

 9.02 ± 0.03

 6.85 ± 0.09

WISE

WISE

55489

55489

 Table 1
 Photometric Observations of SDSS J0751+1345

observations. Besides the global spectral feature, an HeI* 10830 BAL was also detected in *K*-band in both the P200 and VLT spectra and the profiles in the two spectra were similar to each other. Thus, to increase the spectral signal to noise ratio (S/N), we created a new spectrum from ultraviolet (UV) to NIR by combining the three spectra after masking the pixels which were bad or polluted seriously by skylines

3 SYSTEMATIC REDSHIFT

W3

W4

Before the spectral analysis, we first attempted to derive the systematic redshift of SDSS J0751+1345. For quasars, one of the main approaches to obtain their redshifts is to compare the observed wavelengths of individual emission lines and their rest wavelengths (e.g., Pâris et al. 2012). For SDSS J0751+1345, a broad H β is detected in the spectrum and the peak of multi-Gaussian BEL can be employed to obtain the systematic redshift (Bonning et al. 2007; Shen et al. 2011)

The redshift of SDSS J0751+1345 was first set as z=1.10052, which was derived from the BOSS DR10 catalog (Pâris et al. 2014). Adopting this redshift, we made a detailed spectral fitting around H β and found that the peak of the H β BEL was shifted by about 650 km s⁻¹. According to previous study of H β in a large sample of quasars (Shen et al. 2011), the mean peak offset of the H β broad line is $150 \pm 200 \text{ km s}^{-1}$ and the measurement result of SDSS J0751+1345 is beyond the 2σ range. Thus, the redshift for SDSS J0751+1345 from the BOSS release may be slightly offset due to the complexity of line profiles, and we revised the redshift of SDSS J0751+1345 from the peak of the broad H β as 1.10512 ± 0.00032 .

The profile of the H β BEL is derived as follows: first, a single power law continuum and optical Fe II multiples derived from I Zw1 (Véron-Cetty et al. 2004) are used to fit the spectrum in the wavelength range of 4000–5500Å. The fitting procedure is the same as that described in



Fig.2 Spectra of H β for SDSS J0751+1345. The horizontal axis is the rest-frame wavelength or relative velocity with redshift derived from the peak of broad H β . The black line indicates the original continuum-subtracted spectrum, while the red dashed line signifies the model including all emission-line components. The blue line shows the total profile for the H β emission and the cyan lines refer to individual Gaussian fittings. The green lines represent optical Fe II and the gold lines are the contributions associated with the narrow line region (H β NEL, [O III] 4959,5007). The red dotted line marks the zero-velocity according the redshift extracted from the BOSS DR10 catalog and it is about 650 km s⁻¹ blueshifted.

Dong et al. (2008). After subtracting the continuum and optical Fe II, we can derive the blend of the H β and [O III] emission lines. The H β BEL is modeled with one to four Gaussians. The fits are accepted when it cannot be improved significantly by adding one more Gaussian (up to 4) with a chance probability of less than 0.05 according to the F-test. The fitting results indicate that, for SDSS J0751+1345, two Gaussians are good enough to fit the H β BEL. The [O III] doublet is fitted with the same profile and the line ratio [O III] 5007/[O III] 4959 is fixed at 3. Each of them is modeled with two Gaussians for a core and a blueshifted component, respectively (e.g. Komossa et al. 2008; Zhang et al. 2011). The H β NEL is assumed to share the same profile as the [OIII] core. The fitting results of the emission lines, converted to the revised redshift, are displayed in Figure 2. Also, based on the profile of the broad H β , we derived the mass of the central BH to be $\log M_{\rm BH}/M_{\odot} = 8.57 \pm 0.37.$

Besides the H β BEL, previous studies suggested that the optical Fe II multiples have no obvious offset with respect to the intrinsic redshift (Sameshima et al. 2011). For SDSS J0751+1345, we also attempted to examine its optical Fe II to verify the redshift revision. As featured in the top panel of Figure 3, after converting to the quasar's rest-frame with the revised redshift, the spectrum of SDSS



Fig. 3 *Top*: Normalized spectrum of SDSS J0751+1345 (*red*) in the wavelength range of 4200–5500 Å according to the revised redshift determined by broad H β . The normalized spectrum of J1633 (*black*) is also displayed for comparison. The spectral regions of 4450–4700 Å and 5100–5350 Å, which are employed in the cross-correlation to verify the redshift revision, are marked in gray. *Bottom*: Cross correlation between the the spectrum of SDSS J0751+1345 and the corresponding region of J1633. The redshifts of SDSS J0751+1345 obtained from the DR10 catalog and broad H β are marked with blue and red dashed lines respectively. The peak of the curve indicates that the revised redshift derived from broad H β is reliable.

J0751+1345 is normalized with the continuum and plotted in red. For comparison, the normalized spectrum of J1633 is displayed in red. We scaled the normalized J1633 spectrum with a constant to make sure the total flux of the J1633 optical Fe II is comparable with that of SDSS J0751+1345. J1633 is employed in the comparison owing to its strong and narrow optical Fe II emission lines. Also, the offset of the optical Fe II multiple in J1633 can be ignored (Liu et al. 2019). To verify the redshift revision, we selected the spectral region of SDSS J0751+1345 in 4450–4700 Å and 5100–5350 Å to cross-correlate with the spectrum of J1633. This spectral region contains the major part of the optical Fe II multiple and is marked in gray. The cross-correlation result is plotted in the bottom panel



Fig. 4 Pair-matching results of He I* λ 10830, He I* λ 3889, Mg II and Al III. In the corresponding panels, the absorption free spectrum is traced by a red solid line and the uncertainty is displayed by green shade.

of Figure 3. The redshifts derived from the catalog and the H β BEL are marked with blue and red dashed lines, respectively. Compared to the redshift of the catalog, the redshift revised with the H β BEL is remarkably close to the peak of the cross-correlation function (CCF) ratio curve, which indicates that the revised redshift of H β is reliable. Thus, in the following analysis, we consider *z*=1.10512 as the systemic redshift of SDSS J0751+1345.

4 BROAD ABSORPTION LINES

4.1 Absorption-free Spectrum

As displayed in the inset of Figure 1, in the velocity space with respect to the He I* $\lambda 10830$ line, we find a prominent BAL trough located at about $-10\,000$ to $-2000 \,\mathrm{km} \,\mathrm{s}^{-1}$, which can be identified with the He I* $\lambda 10830$ BAL. As another absorption line caused by the same ion, the He I* $\lambda 3889$ BAL is expected to be detectable in the spectrum. Moreover, we find indications for the Mg II and Al III BALs. Thus, in this section, we will analyze these BALs and attempt to constrain the properties of the corresponding BAL outflow gas. For these absorption lines in SDSS J0751+1345, we apply the pair-match method (Liu et al. 2015; Sun et al. 2017) to check their existence and derive their absorption-free spectra. In the case of the He I* $\lambda 10830$ BAL, the spectral region of 1.02–1.10 µm is selected and the possible BAL range of –

10000 to $-2000 \,\mathrm{km \ s^{-1}}$ with respect to He I* $\lambda 10830$ is masked. For the non-BAL quasar templates please refer to Pan et al. (2019). These templates are a composite of the infrared quasar spectral atlases (Glikman et al. 2006, Riffel et al. 2006, Landt et al. 2008). The spectral fits of three quasars in the templates are considered acceptable (reduced $\chi^2 < 1.5$, Liu et al. (2015)). The mean spectrum of the three fitted spectra can be regarded as the absorptionfree spectrum of He I* λ 10830 in SDSS J0751+1345 and the variance can be considered as the template uncertainty (Shi et al. 2016; Pan et al. 2019). The pair-match analyses for He I* λ 3889, Mg II and Al III are similar to that of He I* λ 10830. For the He I* λ 3889 BAL, the selected spectral region is 3600 to 4000 Å and the spectral velocity range of $-10\,000$ to -2000 km s⁻¹ with respect to He I* λ 3889 is masked. The 21 quasars in the non-BAL quasar templates are considered acceptable. For the Mg II and Al III BALs, non-BAL templates are selected from the SDSS Data Release 12 (DR12) quasar sample (Pâris et al. 2012) with spectral S/N >15 pixel⁻¹. These templates are required to cover the wavelengths of CIV, Al III and Mg II and show no obvious C IV BAL. The selected spectral region for Mg II is 2400 to 3200 Å. Besides the spectral range of - $10\,000$ to $-2000\,\mathrm{km}\,\mathrm{s}^{-1}$ in the velocity space of Mg II, the spectral wavelength range of 2675 to 2690 Å in the spectrum of J0751+1345 is also masked due to possible Mg II absorption of a foreground galaxy. Seven quasars



Fig. 5 *Left:* Pair matching results and normalized spectra of Al III, Mg II, He I* λ 3889 and He I* λ 10830. The pair matching results are decomposed into the continuum (*blue dashed line*) and the BEL (*blue dotted line*). Based on the assumption that the accretion disk is partially obscured by the BAL gas, the continuum is considered as the absorption-free spectrum. *Right:* The BALs after subtracting the absorption-free spectrum in velocity space. The BALs can be divided into two components: high-velocity component (HV, *yellow region*) and low-velocity component (LV, *red region*). The Al III and Mg II BALs are mainly contributed by the HV component and the He I* λ 3889 is mainly contributed by the LV component. The He I* λ 10830 BAL contains both HV and LV components.



Fig. 6 Comparison of the He I* $\lambda 10830$ BAL profiles between the P200 spectrum (*blue*) and the VLT spectrum (green). This indicates that the deepest absorption structure near -4500 km s^{-1} is reliable and the constant C_f of the HV component can be derived from this absorption structure. To further constrain the estimate of C_f , we rebin the composite spectrum to the resolution of R=1000, which is displayed in red. The lower limit of C_f can be obtained from the deepest pixel near -4500 km s^{-1} which is ~ 0.46 and marked by the horizontal dotted line.



Fig. 7 Estimation of the column density on He I*, Mg⁺ and Al²⁺ through the He I* $\lambda 10830$, Mg II and Al III HV BAL. These BAL profiles are all rebinned to the resolution of R=1000 and displayed in red. C_f is assumed as constant in the velocity range of the HV component. The lower limit of C_f , 0.46, is marked with dotted lines and its upper limit is chosen as 1.

in the templates are chosen to obtain the absorption-free spectrum of Mg II. In the case of Al III, the selected spectral region is 1700 to 1950 Å and the corresponding spectral velocity range of -10000 to -2000 km s⁻¹ is masked. Twelve quasars in the templates meet the criteria to be selected to derive the absorption-free spectrum. The pairmatching results of He I* λ 10830, He I* λ 3889, Mg II and Al III are plotted in Figure 4. Based on these absorption-free spectra, the corresponding equivalent widths (EWs) of He I* λ 10830, He I* λ 3889, Mg II and Al III are 55.4±12.1, 0.83±0.15, 10.8±4.8 and 6.0 ± 2.2 Å, respectively. The uncertainties are at the 1 σ level and include the random fluctuation in flux and the pair-matching template

uncertainty. For He I* $\lambda 10830$ and He I* $\lambda 3889$, their EWs are beyond the 5σ significance and the existence of their BALs can be considered reliable. For Mg II and Al III, their EWs are between 2 and 3σ and we can consider the existence of their BALs to be only tentative.

(1) He I* $\lambda 10830$ regime: As plotted in Figure 5, the He I* $\lambda 10830$ BAL is blended with the HeI 10830 & Pa γ BELs and the velocity range of the BAL trough is from -9500 to $-1800 \,\mathrm{km \ s^{-1}}$. In the spectrum, the absorption features of Ca II K and Na I D, which can effectively constrain the starlight level, are not detected. Thus, the starlight from the host galaxy can be ignored. Also the flux from the dust torus in the wavelength range of the



Fig. 8 Allowed parameter intervals of Mg⁺ (*blue*), Al²⁺ (*orange*) and He I* (*green*) of HV BALs on the plane of density $n_{\rm H}$ versus ionization parameter U as calculated by CLOUDY simulations for the column density $N_{\rm H} = 10^{20.5} - 10^{23}$ cm⁻², solar abundance and MF87 SED. The excluded areas of H⁰_{n=2} 3 σ upper limits are marked with magenta lines. It can be seen that, at $N_{\rm H} = 10^{21}$ cm⁻², all the allowed parameter intervals overlap.

absorption trough is very weak. Therefore, the recovered absorption-free flux, which is shown as the solid green line in the corresponding panel, is mostly contributed by the He I* $\lambda 10830$ & Pa γ BELs and the featureless continuum. A single power law is employed to describe the local continuum and for decomposition of these two components. The continuum and the BELs are displayed in the left column with blue dashed and light green dotted curves, respectively.

(2) He I* λ 3889 regime: Besides the local continuum, the absorption-free flux also contains complex BELs (e.g. FeII 29 3872, FeII] 3884, [Ne III]). A power law, traced by the blue dashed line, is also used to model the local continuum. Different from the He I* λ 10830 BAL, only a narrow absorption trough is clearly observed in the spectrum. In the similar velocity range, this narrow absorption structure can be also detected in the He I* λ 10830 BAL trough, which indicates that this narrow absorption trough is reliable.

(3) Mg II and Al III regime: For both of these two BALs, the absorption free spectra are contributed by two components: the continuum originating from the accretion disk, which can be fitted by a power law, and the Mg II & Fe II BELs or the Al III & Fe II BELs. The velocity ranges of these two BAL troughs are from -9500 to -3500 km s⁻¹. In this velocity range, the absorption of He I* $\lambda 10830$ is obviously detected while the narrow He I* $\lambda 3889$ absorption trough is not.

4.2 Measurements of N_{col} for the Absorption Lines

A comparison of the above mentioned four BALs implies that the BAL outflow gas can be decomposed into two components. One corresponds to the low velocity range (hereafter the LV component), which is about -3500 to -1800 km s⁻¹. For this BAL gas, the N_{col} of HeI* is thick enough to produce absorption features (e.g. HeI* $\lambda 10830$ and HeI* $\lambda 3889$), but the N_{col} of Mg⁺ and Al²⁺ in the outflow gas is so thin that their BAL troughs cannot be detected in the spectrum of SDSS J0751+1345. The other component corresponds to the high velocity range (hereafter the HV component) from -9500 to -3500 km s⁻¹. The BAL gas in this outflow component is thick enough for Mg⁺ and Al²⁺ to generate the Mg II



Fig. 9 As in Fig. 8, the detailed contours of Mg⁺ (*blue*), Al²⁺ (*orange*) and He I^{*} (*green*) of the HV BALs on the plane of $n_{\rm H} - U$. The areas marked by magenta lines are excluded by the upper limit of H⁰_{n=2} column density. The distance to the central engine is also contoured with dotted lines. The overlap region corresponds to 0.5 pc, which is consistent with the size of the BLR.



Fig. 10 Fitting result of UV Fe II multiples. The continuum is plotted by the green dotted line. The Fe II components are displayed by the blue curve and the sum in red.

and Al III absorption troughs. The He I* in this outflow component is sufficient to produce the He I* $\lambda 10830$ BAL trough. However, due to the absorption strength ratio (gf_{*ik*} λ) of He I* $\lambda 3889$ to He I* $\lambda 10830$ being as small

as 0.043 (e.g., Leighly et al. 2011), this He I* is not thick enough to generate a detectable He I* λ 3889 BAL trough.

According to the absorption line theory, for a specified BAL, whose covering factor $C_f(v)$ and true optical depth



Fig. 11 *Left*: Decompositions of Al III and Mg II. The BLR components are fitted with two Gaussians and displayed by pink curves. The profiles of the blueshifted components in the two lines are tied and described by one Gaussian and displayed by blue curves. The line ratio Al III/Mg II for the blueshifted component is obtained as 0.56 ± 0.02 . *Right*: Estimation of the lower and upper limits of Al III and Mg II BELs from the outflow. For each of Al III and Mg II, the flux in the wavelength range between -3000 and -1000 km s^{-1} comprises the emission from the BLR and hence sets an upper limit on the intensity of the blueshifted component. Similarly, the mirrored symmetric flux from -3000 to -1000 km s^{-1} (*green region*) contains the redshifted component of the BEL, and hence the subtraction of total flux (*yellow region*) gives the lower limit of the intensity for the blueshifted component.

is $\tau(v)$ as a function of radial velocity, its normalized intensity can be expressed as

$$I(v) = [1 - C_f(v)] + C_f(v)e^{-\tau(v)}.$$
 (1)

 $\tau(v)$ is proportional to $f\lambda N_{\rm col}$, where f and λ are the oscillator strength and rest wavelength of the BAL, respectively, and $N_{\rm col}$ is the column density of the corresponding absorption ion. From this equation, one can derive the C_f and $N_{\rm col}$ of the BAL gas if at least two BALs originating from the same corresponding ion are available.

For the LV component, as shown in the normalized spectrum in Figure 4, there is still a residual flux of around 80% even at the deepest part of the He I* λ 3889 BAL trough. As mentioned above, the absorption strength ratio of He I* λ 10830 to He I* λ 3889 is about 23.3. Also, in the He I* λ 10830 trough, we detected significant residuals

after removal of He I* $\lambda 10830$ & Pa γ BELs. These facts imply that this BAL component only partially covers the accretion disk. We rely on the He I* $\lambda 3889$ and He I* $\lambda 10830$ absorption lines that transition from the same energy level of He I* to derive C_f and $N_{\rm col}$. The $N_{\rm col}$ of He I* is derived as $3.5 \pm 0.5 \times 10^{14}$ cm⁻². The Mg II and Al III BALs in this component are undetected. With the C_f of He I* we derive the 3σ upper limit on the column density for the two ions, 7×10^{13} cm⁻² and 8×10^{13} cm⁻², for Mg⁺ and Al²⁺, respectively.

For the HV component, according to Figure 5, the residuals of He I* λ 10830, Mg II and Al III BALs are obvious after removal of the BELs in their BAL velocity ranges. This indicates that these ions in the BAL gas are optically thin or the BAL gas partially obscures the accretion disk. We first assume that the BAL gas partially



Fig. 12 Like Fig. 9, the $n_{\rm H} - U$ contours for the corresponding line ratio of Al III/Mg II (*navy blue line*) cover the allowed $n_{\rm H} - U$ parameter ranges derived from the HV BAL. This figure implies that the outflow from which the blueshifted Al III and Mg II BELs originate and that producing the HV BALs are not isolated.

obscures the accretion disk. Thus, the BELs in the velocity ranges of the BALs should be removed from the absorption free spectra and the absorption profiles of He I* $\lambda 10830$, Mg II and Al III are displayed in Figure 5 (right). In order to measure the $N_{\rm col}$ of these ions in the HV component, we first assume the C_f is constant in the velocity range of the HV component. As the two lines are produced by transitions from the same energy level, He I* $\lambda 10830$ and He I* λ 3889 are employed to constrain C_f . Different from the case of the LV component, the He I* λ 3889 BAL in the HV component is undetected. Thus, these two lines can be used to provide only a lower limit of C_f . As mentioned above, the absorption strength ratio $(gf_{ik}\lambda)$ of He I* $\lambda 10830$ to He I* $\lambda 3889$ is as large as 23.3. For the unsaturated pixels in the He I* $\lambda 10830$ HV BAL velocity range, the absorption at the corresponding pixels of He I* λ 3889 is undetectable, as can be seen in the observed spectrum. Therefore, to obtain the lower limit of C_f , we can decrease C_f from 1 to where some pixels start to be saturated in the He I* λ 10830 HV BAL velocity range.

It should be noted that, through this method, the lower limit of C_f is determined by the deepest pixels in the He I* $\lambda 10830$ HV component and these pixels may be affected by the imperfect spectral observations and reductions. We used two methods to examine the reliability of the measurements. First, there are two spectroscopic observations (P200 and VLT spectra) in the NIR band where the He I* $\lambda 10830$ HV BAL is located. By comparing the two spectra, the effect of observations and reductions at the deepest pixels can be investigated. As displayed in Figure 6, the He I* $\lambda 10830$ BALs extracted from the VLT spectrum and P200 spectrum are shown in green and blue, respectively. It can been seen that the deepest pixels of the BAL are located at about $-4500 \,\mathrm{km} \,\mathrm{s}^{-1}$ and the absorption structures are nearly the same. This indicates that this absorption structure is reliable. Second, to further investigate the observational effect and to estimate more conservatively the lower limit of C_f , we produce a composite spectrum and rebin it to a lower resolution of R=1000 as depicted in Figure 6 (red curve). This composite spectrum is employed to obtain the lower limit of C_f . We find that when C_f decreases to 0.46, the pixels of the He I* $\lambda 10830$ BAL at about $-4500 \, \rm km \ s^{-1}$ start to become saturated³ and hence $C_f = 0.46$ can be considered as its lower limit. We also rebin the Mg II and Al III BALs to R=1000 as featured in Figure 7. Compared to the lower limit of C_f , both the Mg II and Al III BALs are unsaturated. Thus, we can obtain the $N_{\rm col}$ upper limits of He I*, Mg^+ and Al^{2+} . Besides, the lower limits of $N_{\rm col}$ on HeI*, Mg⁺ and Al²⁺ can be derived assuming $C_f=1$. Based on the range of C_f , we can derive the $N_{\rm col}$

³ According to Eq. (1), when the normalized residual flux I(v) of a pixel is equal to C_f , the absorption of this pixel is saturated and τ is not measurable. We can rely on Eq. (1) to estimate τ of the pixels in the BAL, and identify the criterion for saturation as $I(v)+\sigma(v) = C_f$, where $\sigma(v)$ is the error of I(v) at the corresponding velocity.

ranges of He I*, Mg⁺ and Al²⁺ to be 0.8–1.6 × 10¹⁴, 2.1– 3.6 × 10¹⁴ and 2.8–5.5 × 10¹⁴ cm⁻², respectively. Note that in the above analysis, we assumed that the different BALs share the same covering factor as the accretion disk. However, according to the disk model, the size of the disk, where the photons of the corresponding wavelength of He I* λ 10830 are emitted, is about 4 times larger than that of the photons of the covering factors of the Al III and Mg II. Therefore, the covering factors of the Al III and Mg II BALs should be larger than that of the He I* λ 10830 BAL. Thus, our assumption on the lower limits of Al III and Mg II covering factors of 0.46 can be considered conservative and the calculation based on this assumption is available.

5 IONIZATION MODEL FOR THE BALS

For the BAL outflow of SDSS J0751+1345, we can make a natural assumption that there are two absorbers, which is consistent with the different velocity ranges of HV and LV components. One of the absorbers corresponds to the LV BAL components. This absorber has slower velocity and smaller column density of Mg⁺ and Al²⁺ but larger column density of He I* than the other. Another absorber is faster, with thicker Mg⁺ and Al²⁺ but thinner He I* than the former. Based on N_{col} of different ions, we attempt to constrain the characteristics of these two absorbers with the help of the photoionization model.

We employ the software package CLOUDY (c13.03; Ferland et al. 1998) to construct the photoionization model of the BALs in SDSS J0751+1345. In photoionization simulations, the absorbed gas is assumed to be slabshaped, dust-free and have solar elemental abundance. For simplicity of computation, the density, metallicity and abundance in the gas-slab are assumed to be uniform. It should be noted that He I*, Mg⁺ and Al²⁺ have different ionization potentials. The ionization potential ranges of He I*, Al^{2+} and Mg⁺ are 24.4 to 54.4 eV, 18.8 to 28.4 eV and 7.6 to 15.0 eV, respectively. The ionization potential range of Mg⁺ has no overlap with those of He I* and Al^{2+} . Also, with a gas slab, the main ionization zone of Mg⁺ is beyond the ionization front where the HeI* and Al²⁺ are ionized. Nonetheless, for simplicity, we assume the same density, metallicity and abundance for the absorbers of HeI*, Al2+ and Mg+. This medium is ionized by continuum originating from the the central engine, whose spectral energy distribution (SED) is in the form that is defined by Mathews & Ferland (1987). The simulation results are compared with the N_{col} of the ions in LV or HV BAL components.

For the HV component, with our measurement for the N_{col} of HeI*, and an assumption on the upper limit for the density ratio of HeI* to He⁺ (Arav et al. 2001; Ji et al. 2015) the lower limit for the He⁺ column density in the outflow can be obtained as $\sim 3 \times 10^{19}$ cm⁻². Assuming solar abundance, the lower limit for the H II column density, as well as the minimal hydrogen column density $(N_{\rm H})$ of the HV absorber, can be estimated as $\sim 3 \times 10^{20} {\rm ~cm^{-2}}$. Thus, in the simulations, we set an array of $N_{\rm H}$ from $10^{20.5}$ to 10^{23} cm⁻² with a step size of 0.5 dex. For each value of $N_{\rm H}$, we run over the grids of simulations with different ionization parameters and hydrogen densities. The range of ionization parameter is $-2.4 \le \log U \le 1$ and the hydrogen density is $8 \le \log n_{\rm H}$ \leq 12. The steps for both of these two parameters are 0.2 dex. The allowed $n_{\rm H}$ and U intervals on the $n_{\rm H}$ -U plane at specific $N_{\rm H}$ can be derived through the comparison between column densities of He I*, Mg⁺ and Al²⁺ and those simulated by CLOUDY. As shown in Figure 8, for constant log $N_{\rm H}$, the corresponding areas in the $n_{\rm H}$ -U plane of He I*, Mg⁺ and Al²⁺ are marked in green, blue and orange, respectively. Besides the measured He I*, Mg⁺ and Al²⁺ column densities in the HV absorber, the nondetection of Balmer BALs can be used to constrain the allowed parameter intervals. With the lower limit of the covering factor to the accretion disk $C_f = 0.46$, we can derive the 3σ upper limit of H_{n-2}^0 column density as 2.8 $\times 10^{14} \text{ cm}^{-2}$. The parameter area with magenta solid line is excluded from the 3σ upper limit of the $H_{n=2}^0$ column density in Figure 8. Only in the case of log $N_{\rm H}$ (cm⁻²) = 21 do the four allowed parameter areas overlap. In summary, the simulation results suggest the physical parameters of $\log n_{\rm H}$ (cm⁻³) are from 10.3 to 11.4, the log U from -1.83 to -1.72 and log $N_{\rm H}$ (cm⁻²) ~ 21 for the HV outflow gas.

With the constrained parameter intervals, we can place a limit on the distance between the HV absorber and the central engine. According to the definition of U, we can express the distance between the absorbing medium and the central engine as $R_{\rm abs} = (Q(H)/(4\pi c U n_e))^{0.5}$, where Q(H), the number of ionizing photons, can be derived as $Q(H) = \int_{\nu}^{\infty} L_{\nu} / h\nu d\nu$. For our source, the monochromatic luminosity at 5100 Å($\lambda L_{\lambda}(5100 \text{ Å})$) can be obtained through the spectrum as $\sim 7.0 \times 10^{45} \text{ erg s}^{-1}$. Based on the MF 87 SED, we derived Q(H) $\approx 5.9 \times$ 10^{56} photon s⁻¹. Thus, $R_{\rm abs}$ can be calculated, which is represented by gray dashed lines on the $n_{\rm H}$ -U plane (Fig. 9). Compared with the contoured lines of $R_{\rm abs}$, the location of the HV BAL absorber is about 0.5 pc away from the central engine. Furthermore, through the $\lambda L_{\lambda}(5100 \text{ Å})$ of our source, we can also estimate the radius of BLR, $R_{\rm BLR}$, according to the equation

$$R_{\rm BLR} = 32.9^{+2.0}_{-1.9} \left[\frac{\lambda L_{\lambda}(5100 \,\text{Å})}{10^{44} \,\text{erg s}^{-1}} \right] \text{ light days,} \quad (2)$$

which is fitted with the reverberation mapping results in Kaspi et al. (2000). Thus, for our source, $R_{\rm BLR}$ is calculated as about 0.5 pc, which is very similar to the distance of the HV BAL absorber.

Assuming solar abundances and the maximum He I*He⁺ abundance ratio, we obtained a minimal column density of the LV absorber, $N_{\rm H}>10^{21}~{\rm cm}^{-2},$ which is larger than that of the HV absorber. For a gas slab with increasing thickness illuminated by a quasar ionization continuum radiation, we expect to detect absorption in the sequence of He I* λ 10830, Al III and Mg II, which have similar oscillator strengths and decreasing ionization potentials (e.g. Ji et al. 2015; Liu et al. 2016). For the LV component, the HeI* λ 3889,10830 BALs are significantly detected but neither Al III nor Mg II is detectable. This indicates that the column density of LV BAL gas is large enough for the development of the He⁺ zone, and yet not enough for the Al²⁺ zone (let alone the Mg⁺ zone), and therefore has a higher ionization level than the HV absorber with a significant detection of the Al III and Mg II lines. This, incorporating the fact that the LV absober gas has a higher column density than the HV absorber, indicates that either the LV absorber has a much lower density than the HV absorber, or the LV absorber is located much closer than the HV absorber to the central engine, since both the LV and HV absorbers are illuminated by the same continuum source. It is hard to imagine, if not impossible, that, for two absorption gas clouds in the nuclear region of the same quasar, a higher column density (LV) absorber has a lower density while a lower column density (HV) absorber has a higher density. Hence the low density scenario for the LV absorber is highly disfavored. Conservatively assuming that both LV and HV absorbers have the same density, we derive a maximal distance of the LV absorber $R_{\rm LV} < 0.5$ pc. The actual value should be much smaller than this, since both the density and column density of the LV absorber may be larger than that of the HV absorber. In this scenario, the LV absorber could be naturally taken as the headstream of the HV absorber (Hall et al. 2011) and the outflow is accelerated. Further high quality spectroscopy is needed to confirm such a speculation, by imposing more stringent constraints on Al III and Mg II BALs and detecting more absorption lines from other ions.

6 BLUESHIFTED COMPONENT IN BELS

Besides the BALs, blueshifted BELs are also a significant feature of the outflow. For SDSS J0751+1345, the main relatively independent BELs expected are Al III, Mg II, H β , He I* 10830 and Pa γ . The blue edge of He I* 10830 and Pa γ is polluted by the LV BAL of He I* λ 10830 and the existence of any blueshifted BEL component is difficult to be determined. The model-fitting to the H β in Section 2 revealed no evidence of the blueshifted component. In this section, we mainly focus on the Al III and Mg II to determine whether the blueshifted BEL components are present.

For AlIII, due to the effect of the AlIII BAL, the local continuum is difficult to determine directly from the spectrum. However, in Section 4.2, we have obtained the local continuum of the Al III absorption free spectrum. Thus, we can regard this continuum as the local continuum of Al III in SDSS J0751+1345 and subtract this continuum from the observed spectrum to obtain the Al III BEL. To derive the Mg II BEL, a power law and a Gaussian-kerneled UV Fe II template (Tsuzuki et al. 2006) are employed to fit the continuum and the UV Fe II multiples around Mg II in SDSS J0751+1345. The Fe II template (Tsuzuki et al. 2006) broadened with a Gaussian-kernel is used to fit the Fe II multiples around Mg II in SDSS J0751+1345. The fitting results are displayed in Figure 10. As suggested by Wang et al. (2011), the parameter BAI is a good indicator for the existence of a blueshifted component in the BEL. A value of BAI>0.5 would suggest the existence of a blueshifted BEL component. For the MgII doublet, in light of the line core of IZW1, we set its rest-frame wavelength to 2999.4 Å. The rest-frame wavelength of the Al III doublet is chosen as 1859.4 Å, corresponding to the line ratio of Al III 1857 / Al III 1863=1.25. The BAI values of Mg II and Al III are calculated to be 0.60 ± 0.01 and 0.67 ± 0.01 , respectively. Note that if possible existence of NELs in the two lines is considered, these values of BAI would be even be larger. This indicates that the blueshifted components are detected in the Mg II and Al III BELs.

We first try to decompose the Al III and Mg II BELs into two components: one is blueshifted and emitted from the outflow, and the other is in the quasar's rest-frame from the normal BLR. The blueshifted component is modeled with one Gaussian, while the component from the normal BLR is fitted with two Gaussians. The profiles and intensities of the BLR Gaussians are free except that their peak offsets are limited in the range of -150 to 150 km s⁻¹, due to the uncertainties of wavelength calibration and redshift determination. The blueshifted Gaussians in Al III and Mg II share the same profile. The fitting results are shown in the left panels of Figure 11. The blueshifted line ratio of Al III/Mg II can be derived as 0.56±0.02. However, the blueshifted component and the BLR component in specific emission lines are heavily blended, especially in Mg II, implying that these decompositions are model dependent.

Thus, we attempt to constrain the corresponding upper and lower limits of the blueshifted line ratio of Al III/Mg II without line decomposition. For each of Al III and Mg II, we first use three Gaussians to describe its emission profile and plot the results in Figure 11 as red solid curves. The velocity range of -3000 to -1000 km s⁻¹ is chosen to calculate the blueshifted line emission ratio of Al III/Mg II. The lower limit of $-3000 \,\mathrm{km} \,\mathrm{s}^{-1}$ is set because it is near the blue ends of Mg II and Al III BELs and the upper limit of $-1000 \,\mathrm{km} \,\mathrm{s}^{-1}$ is set to minimize contamination from the narrow component of the emission line. In this velocity range, the emission of AlIII and Mg II contains the blueshifted component and the normal BEL, and hence their total intensities can be considered as the upper limits of the Al III and Mg II blueshifted components, respectively. Under the assumption that the normal BELs in the BELs arise from the BLR for which the predominant motion is either Keplerian or virial (see Gaskell 2009 for a review), the Al III and Mg II normal BELs are expected to be symmetric with respect to the line centroid at the rest-frame wavelength. The lower limit on blueshifted Al III and Mg II BEL can be estimated by subtracting the blue-side symmetric flux from the total (yellow shaded region in the right panel of Fig. 11). Thus, to be conservative, we estimate the upper limit of the line ratio of Al III to Mg II through the upper limit of the Al III blueshifted component divided by the lower limit of the Mg II blueshifted component. Similarly, the lower limit of the Al III blueshifted component divided by the upper limit of the Mg II blueshifted component gives the lower limit of the Al III/Mg II ratio. The lower and upper limits of the line ratio of the blueshifted Al III to Mg II BEL are calculated to be 0.25 and 0.93, respectively.

Although the BEL outflow is only detected in Al III and Mg II in SDSS J0751+1345, we investigate whether the parameters constrained by the BALs can reconcile with the line ratio of Al III/Mg II via CLOUDY simulations. As the parameters of LV BALs cannot be fully determined, we attempt to reproduce the Al III/Mg II ratio with the parameters of HV BALs. The simulation settings are the same as those of HV BALs except for $N_{\rm H}$ that is fixed to be 10^{21} cm⁻² (corresponding to the derived $N_{\rm H}$ for HV BALs). The parameter intervals on the $n_{\rm H}$ -U plane allowed by the Al III/Mg II ratio are delineated by the navy blue solid lines in Figure 12 and they include the overlapped area derived from HV BALs. This implies that the HV BAL outflow and the blueshifted BEL outflow may not be independent. In fact, with $N_{\rm H} = 10^{21} \text{ cm}^{-2}$, $\log U = -1.77$ and log $n_{\rm H}$ (cm⁻³) = 10.8, the best physical parameters inferred for the HV BAL, we can derive the EWs of Mg II and Al III from CLOUDY simulations, which are about 15 Å and 4 Å respectively. According to the analysis above, the lower limits of the observed EWs of the Mg II and Al III blueshifted component can be estimated as 8 and 2Å, respectively, which are consistent with the values of the simulations, suggesting again that the BAL and BEL outflows may be associated.

7 SUMMARY AND DISCUSSION

We make a detailed analysis of the characteristics of BAL and BEL outflows of SDSS J0751+1345. With the broad $H\beta$ and [O II] NEL, we revise the systematic redshift to be z=1.10512. The Al III, Mg II, He I* λ 3889 and He I* $\lambda 10830$ BALs are detected in the spectrum, suggestive of AGN BAL outflows. The analysis of the velocity ranges of the BALs indicates that there are two BAL components co-exiting in SDSS J0751+1345, namely an HV and an LV component. The HV BAL component is detected in He I* λ 10830, Mg II and Al III and its velocity range is from -9300 to $3500 \,\mathrm{km \ s^{-1}}$. The covering factor of the HV component can be constrained in the range of 0.46 to 1, and the $N_{\rm col}$ of He I*, Mg⁺ and Al²⁺ can be derived as 0.8–1.6 \times 10¹⁴, 2.1–3.6 \times 10¹⁴ and 2.8–5.5 \times 10¹⁴ cm⁻², respectively. By comparing the observations with the photoionization simulations, $n_{\rm H}$, U and $N_{\rm H}$ for the HV BAL component are constrained to be $10^{10.3} \leq n_{\rm H}$ $\leq 10^{11.4} \text{ cm}^{-3}, -1.87 \leq \log U_E \leq -1.73 \text{ and } N_{\rm H} \sim 10^{21}$ cm^{-2} . Here, it must be mentioned that these parameter ranges are derived only from three absorption lines. Due to the lack of a high-quality UV spectrum, we cannot rule out other possible solutions. With the ionization parameter, we constrain the radius of the HV BAL gas to be $r \sim$ 0.5 pc, comparable to the distance of the normal BLR. The LV component corresponds to -3500 to -1000 km s⁻¹ and is only detected in He I* $\lambda 10830$ and He I* $\lambda 3889$. The observations for this component are not sufficient to constrain the characteristic of the corresponding BAL outflow. Nevertheless, a qualitative analysis indicates that the LV BAL gas seems to have a larger U and column density than the HV BAL gas. Also, the distance from the LV BAL gas to the central engine is smaller than that of the HV BAL gas. In addition, the analysis of the BELs of SDSS J0751+1345 indicates that the blueshifted emission components are detected in Al III and Mg II and the corresponding line ratio of Al III/Mg II can be constrained in the range of 0.23-0.95. This line ratio can be reproduced by the outflow with the physical conditions of the HV BAL outflow, which implies that the BAL and BEL outflows may be connected in SDSS J0751+1345.

7.1 Energetic Properties of the Outflow

According to the discussion in Borguet et al. (2012), for a thin $(\Delta R/R \ll 1)$ outflow shell, with a radius to the central source R, a radial velocity v, a column density $N_{\rm H}$ and a global covering fraction Ω , its mass-flow rate (\dot{M}) and kinetic luminosity (\dot{E}_k) can be derived through the equations

$$\dot{M} = 4\pi R \Omega \mu m_p N_{\rm H} v, \tag{3}$$

$$\dot{E}_k = 2\pi R \Omega \mu m_p N_{\rm H} v^3. \tag{4}$$

In the two equations, m_p is the mass of a proton and μ , the mean atomic mass per proton, is equal to 1.4. Usually, Ω of the BAL outflow gas is replaced by the fraction of BAL quasars. In optically-selected quasars, the fraction is about 10%–20% (e.g., Trump et al. 2006; Liu et al. 2016; Zhang et al. 2017). For the HV BAL outflow, with R = 0.5pc, $N_{\rm H} = 10^{21}$ cm⁻², radial velocity $v \sim 6000$ km s⁻¹ and $\Omega \sim 0.15$, we can estimate its \dot{M} and \dot{E}_k as $\dot{M} =$ $0.04 M_{\odot}$ yr⁻¹ and $\dot{E}_k = 7.8 \times 10^{41}$ erg s⁻¹, respectively. Compared to the Eddington luminosity ($L_{\rm EDD}$), which is about 5 × 10⁴⁶ erg s⁻¹, \dot{E}_k of the HV BAL outflow is less than 10⁻⁴ $L_{\rm EDD}$.

According to the previous studies, for an HV AGN outflow that has efficient feedback to the host galaxy, its ratio of $\dot{E}_k/L_{\rm EDD}$ should be as large as a few percent (e.g. Scannapieco & Oh 2004; Hopkins & Elvis 2010; Zhang et al. 2017). For the HV outflow in our source, the ratio $\dot{E}_k/L_{\rm EDD}$ is too low to drive the feedback efficiently. However, it should be noted that the \dot{E}_k of the HV BAL outflow is only a lower limit on the \dot{E}_k of the outflows in SDSS J0751+1345 because the LV BAL outflow and the BEL outflow are not considered in the estimation above.

7.2 Other Quasars with both BAL and BEL Outflows

Blueshifted BALs and BELs provide unique diagnostics of the physical conditions of outflow gas in quasars. In some studies, the quasars with both blueshifted CIV BEL and BAL detected simultaneously have led researchers to suggest that there may be a relationship between the blueshifted BEL and BAL outflows. Richards et al. (2011) found that, compared to normal quasars, the CIV BEL in BAL quasars tends to have larger blueshifted velocities. Rankine et al. (2020) found that for the quasars with a fixed C IV luminosity, with the increase of the C IV blueshifted velocity, a larger fraction of quasars are detected with CIV BAL. However, these studies mainly focus on the blueshifted BELs and BALS of high-ionization lines. In quasars with high-ionization BALs, only 15% show low-ionization BALs. Also, compared to the ubiquitous blueshifted CIV BEL (e.g. Wang et al. 2011; Shin et al. 2017), the low-ionization lines, for example Mg II, are often considered to have no blueshift (Marziani et al. 2013, Popović et al. 2019) and are often used to derive the systematic redshift of quasars (Bonning et al. 2007; Shen et al. 2011).

Besides the C IV blueshfited BEL and BAL, the quasar J1634, which is reported in Liu et al. (2016), is observed with the blueshifted BELs and BALs likely originating from the same outflow. Different from SDSS J0751+1345, the density of the outflow material $n_{\rm H}$ is about 10⁵ cm⁻³ and the distance to the central BH is about 50 pc, which

indicate that the outflow is located at the scale of the narrow line region of quasars.

Liu et al. (2019) reported a quasar, J1633, in whose spectra both low-ionization blueshifted BEL and BAL outflows are detected. The density of the blueshifted BEL outflow is $n_{\rm H} \sim 10^{10.6}$ - $10^{11.3}$ cm⁻³, column density $N_{\rm H} \ge 10^{23} \,{\rm cm}^{-2}$ and ionization parameter $U \sim 10^{-2.1}$ – $10^{-1.5}$. The distance from the central source is similar to the size of the normal BLR. The BAL outflow shares the same physical parameters with the BEL outflow except for the column density which is in the range of $10^{21} \leq$ $\log(N_{\rm H}) \le 10^{21.4}$ cm⁻², about two orders of magnitude less than that derived for the BEL outflow. Assuming that the BAL and BEL outflows come from the same gas, to explain this $N_{\rm H}$ diffusion, we proposed a multicolumn density model for the outflow gas having an increasing global covering fraction with a decreasing column density. In this model, the sight line along which the BALs are produced will have a high probability to peer through the outflow gas with a higher global covering fraction, which means this outflow gas has a lower column density. Conversely, the blueshifted BELs originate more likely from the higher column density outflow gas. In SDSS J0751+1345, we find that the physical parameters for the BAL outflow, such as $n_{\rm H}$ and the ionization parameter U, are very close to those of the BEL outflow in J1633. The $N_{\rm H}$ of the BAL outflow in our source is about two orders of magnitude less than that of the BEL outflow in J1633 but similar to that of the value derived from the BAL in J1633. Furthermore, the distance from the BAL outflow to the central engine in SDSS J0751+1345 is also similar to the BEL outflow of J1633, both located at the scale of the normal BLR. The similarity of the physical properties of the outflow gas in SDSS J0751+1345 and J1633 may suggest the common origin and geometrical distribution of the outflows. Future simultaneous observations of blueshifted BELs and BALs in the spectra of more quasars will be crucial for testing the universality of the production of the outflows.

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