Broad Emission and Absorption Line Outflows in the Quasar SDSS J163345.22 +512748.4

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Abstract

We present a detailed study of the optical and near-infrared (NIR) emission and absorption line spectrum of the quasar SDSS J163345.22+512748.4. We discovered on the newly acquired NIR spectrum a highly metastable neutral helium broad absorption line (BAL) He I $\lambda$ 10830 with a width of $\sim$2000 km s $^{-1}$ and a blueshift of $\sim$7000 km s $^{-1}$ in the velocity space. The BAL system is also significantly detected in Mg II and He I $\lambda$ 3889. We estimate a column density of $(5.0 \pm 1.7) \times 10^{14}$ cm $^{-2}$ for the He I $(2 \, ^{3}S)$ level and infer an ionization parameter of $U_{\lambda} \sim 10^{−1.9}$. For the BAL outflow, assuming that the BAL region is thick enough for a full development of an ionization front. The total column density of the BAL outflow is constrained in the range $N_{HI} \sim 10^{21.1}$–$10^{21.4}$ cm $^{-2}$. We also found that the bulk of both Mg II and UV Fe II, as well as of H $\alpha$ broad emission lines (BELs), are blueshifted with a velocity of $\sim$2200 km s $^{-1}$ with respect to the quasar systemic redshift. We constrain the blueshifted BEL region to have a covering factor $C_{fl} \approx 16\%$, density $n_{HI} \sim 10^{10.6}$–$10^{11.3}$ cm $^{-3}$, column density $N_{HI} \gtrsim 10^{20}$ cm $^{-2}$, and ionization parameter $U_{\lambda} \sim 10^{−2.1}$–$10^{−1.5}$. The outflow gas is located at $\sim$0.1 pc away from the central ionization source, at a scale comparable to the broad-line region. A toy kinetic model has been proposed to reproduce the profile of Mg II BEL well if a partial obscured axisymmetric geometry of the outflow with a radial velocity as observed from the BALs is assumed.

Key words: quasars: absorption lines – quasars: emission lines – quasars: individual (SDSS J163345.22 +512748.4)

1. Introduction

Outflows in active galactic nuclei (AGNs) play an important role in galaxy evolution. Recent studies indicate that the outflow is regulated by the accretion process (Sulentic et al. 2000; Leighly & Moore 2004; Richards et al. 2011; Wang et al. 2011; Marziani & Sulentic 2012). By carrying away angular momentum, the outflowing gas is crucial to maintain the accretion onto the central black hole (BH; Sulentic et al. 2000; Higginbottom et al. 2013; Feruglio et al. 2015; Fontanot et al. 2015), regulating the growth of central supermassive BHs (SMBHs). Moreover, outflows are considered to be able to affect star formation in the host galaxies (Silk & Rees 1998). As one of the important phenomena in quasars, outflows leave prominent imprints on the quasar spectra, such as blueshifted broad absorption lines (BALs; Weymann et al. 1991), as well as broad emission lines (BELs; Gaskell 1982). To date, our study and understanding of the outflows are mainly based on the analysis of BALs and/or BELs.

BALs appear in the spectra of 10%–15% optically selected quasars. These quasars often show absorptions from both high- and low-ionization ions, such as N V, C IV, Si IV, O VI, Al III, and Mg II (Hall et al. 2002; Tolea et al. 2002; Hewett & Foltz 2003; Reichard et al. 2003; Trump et al. 2006; Gibson et al. 2009; Zhang et al. 2010, 2014). Studies of BALs can place constraints on the physical properties of the outflows, which are helpful to understand the connection between the evolution of SMBHs and their host galaxies. However, due to the single line of sight, the covering factor, which is an important parameter of BAL outflows, is difficult to determine for an individual quasar. For most BAL quasars, the covering factor of outflows is usually derived in a statistical way from a sample of sources, resulting in estimates that may not be reliable for other properties.

Blueshifted BELs, another important feature of outflows, were first detected in high-ionization lines (e.g., C IV, Gaskell 1982; Wilkes 1984). Blueshifted BELs are difficult to reconcile with gravitationally bound BELR models, but can be considered as a signature of outflowing gas (Gaskell 1982; Marziani et al. 1996; Leighly 2004; Wang et al. 2011). Recently, blueshifted BELs have also been found in low-ionization lines, such as Mg II, which can be interpreted to be the signature of radiation-driven wind or outflow (Marziani et al. 2011). Different from the BALs, the integral flux of blueshifted BELs can reflect the global properties of outflowing gas. The equivalent widths (EWs) and line ratios can be used to impose strong constraints on the density, ionization state, and geometry of the line-emitting gas (Liu et al. 2016). However, in most quasars with blueshifted BELs, the blueshifted BELs are always blended with the normal BELs emitted from the broad-line region (BLR), and the decomposition between them is a challenging task.

This paper presents a detailed emission line and absorption line analysis of SDSS J163345.22+512748.4 (hereafter SDSS J1633 +5127), a type 1 quasar at redshift of 0.6289 with outflows revealed in both blueshifted BELs and BALs. Because its Mg II emission line is dominated by blueshifted BELs, the uncertainty of decomposing them from normal BELs is small. Aside from Mg II, UV Fe II and H $\alpha$ also show similar blueshifted BEL components. These blueshifted lines can be considered emitted from outflows, the properties for which can be inferred from the EWs and line ratios of BELs. Combined with the properties of BALs, we provide new...
Figure 1. Panel (a): the observed spectra and photometry of SDSS J1633+5127. The BOSS spectrum (MJD 56191) is shown by the black curve. For comparison, we plot the photometry at five SDSS bands (MJD 51948) and the BOSS spectral synthetic magnitude at the g, r, i, and z bands with the black and blue diamonds, respectively. The recalibrated BOSS spectrum is presented in green. Panel (b): the light curve of SDSS J1633+5127 at V band monitored by the Catalina Sky Survey. The red dots represent the mean magnitude for each season. The intrinsic source variability is about 0.06 mag in 6.5 yr in the rest frame, which indicates that the difference between the BOSS spectrum and SDSS photometry is likely due to the spectrophotometric calibration uncertainty. Panel (c): the correction curve between the SDSS photometry and BOSS spectrum. The blue circles present the ratio of the SDSS photometry to the BOSS spectrum in the g, r, i, and z bands. The correction curve (gray) was fitted with a second-order polynomial.

The Catalina Surveys Data Release 24 gives us an opportunity to clarify this issue. SDSS J1633+5127 is monitored for eight observing seasons, beginning in 2005 April 10. Each observing season, spanning from October to April of the next year, contains about 50 photometric observations. Because SDSS J1633+5127 is faint, the individual photometric error is large (about 0.5 mag), and some observed magnitudes have large offsets from their neighboring data, likely due to noise fluctuations. To display the light curve clearly, the photometric data in one observing season, which show very weak long-term variability with large measurement errors, are combined and presented in panel (b) of Figure 1. The intrinsic variability amplitude \( \sigma_v = 0.06 \) mag \((=\sqrt{\sum \sigma_i^2 – \sigma_i^2}; \text{Ai et al. 2010})\) is much smaller than the offset between the SDSS photometry and spectrum. This suggests that the difference between the SDSS photometry and spectrum is more likely to be caused by spectrophotometric calibration uncertainties. Thus, we attempted to use a second-order polynomial to fit the flux ratios between the SDSS photometry and spectral synthetic magnitudes in the g, r, i, and z bands, which are shown in panel (c) of Figure 1. Using the fitted flux ratio at each wavelength bin, we then scaled the spectrum to match the SDSS photometry to obtain a recalibrated spectrum, which is shown in green in Figure 1 (panel (a)).

At the infrared bands, we collected infrared photometric data of SDSS J1633+5137 from the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) and the Wide-field Infrared Survey Explorer (WISE; Wright et al. 2010). We list all the optical and infrared photometric data in Table 1. Meanwhile, we observed the near-infrared (NIR) spectra of SDSS J1633+5137 using TripleSpec (Wilson et al. 2004) on the 200-inch Hale telescope at Palomar Observatory. Four exposures of 300 s each were taken in A–B–B–A dithering mode in the primary configuration of the instrument. A 1′′1 slit was chosen to match the seeing. TripleSpec NIR spectrograph provides simultaneous wavelength coverage from 0.9 to 2.46 \( \mu \text{m} \) at a

- **2. Observation and Data Reduction**

  SDSS J1633+5127 was imaged by SDSS on 2001 February 8. The point-spread function magnitudes measured from the images are 18.59 ± 0.04, 18.04 ± 0.01, 18.23 ± 0.01, 17.80 ± 0.01, and 17.76 ± 0.02 at the u, g, r, i, and z bands, respectively, which are shown by the black diamonds in Figure 1(a). The optical spectrum of SDSS J1633+5137 was observed by the Baryon Oscillation Spectroscopic Survey (BOSS; Dawson et al. 2013) on 2011 October 23, for which spectrographs (Smee et al. 2013) can cover a wavelength range of 3600–10500 Å.

  The spectrum we used was extracted from the BOSS Data Release 10 (DR10; Ahn et al. 2014). After correcting for the Galactic reddening of \( E(B – V) = 0.051 \) (Schlafly & Finkbeiner 2011), the spectrum is presented by the black curve in panel (a) of Figure 1. The comparison with SDSS photometry clearly indicates that the spectrum has a bluer continuum slope and lower flux density than the photometry at longer wavelengths. We also calculate the spectral synthetic magnitudes at the g, r, i, and z bands, which are shown by the blue diamonds. The latter three magnitudes are even ~1 mag lower than the photometry. This difference is possibly due to the BOSS spectrophotometric calibration uncertainty or variability in the 6.5 rest-frame years between the two observations.

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resolution of 1.4–2.9 Å. The raw data were processed using the IDL-based Spextool software (Cushing et al. 2004). There are two gaps in the infrared spectrum around 1.35 and 1.85 μm, due to the effect of atmosphere transmissivity. Fortunately, the redshifted Hα emission line is detected with TripleSpec at the J band.

After masking the bad and seriously polluted skyline pixels, we created a new spectrum by combining the recalibrated optical spectrum with the TripleSpec NIR spectrum for the following analysis. The systemic redshift of z = 0.6289 ± 0.0051 reported in Páris et al. (2014) is consistent with that derived from the narrow [O II] and [O III] lines, and the peak of broad Hβ and Hα lines. However, different from these lines, Mg II shows a blueshifted profile with a blueshifted velocity for the peak emission of about 2000 km s⁻¹. After being converted to the quasar rest frame, the spectrum and spectral energy distribution (SED) from the ultraviolet (UV) to mid-infrared (MIR) from SDSS, 2MASS, and WISE are shown in black curve and green points in the panel (a) of Figure 2. The broadband SED of SDSS J1633+5137 is decomposed into a power law with index −1.3 (cyan) and two blackbodies with temperature of 1232 K and 312 K (red dotted). Compared to the composite quasar spectrum (Zhang et al. 2010), the SED of SDSS J1633+5137 shows clear excess in the NIR bands. As a common feature of BAL quasars, where strong hot dust emission was found (Zhang et al. 2014), this excess may hint at the existence of BALs in the spectrum. Indeed, as shown in the inset panel of Figure 2(a), a BAL trough is present at about 7000 km s⁻¹ with respect to HeⅡ λ10830 in the NIR spectrum.

### 3. Emission Line Analysis

#### 3.1. UV and Optical Fe II Multiples

The Mg II broad emission line, which is dominated by the blueshifted component, is the most remarkable characteristic of SDSS J1633+5137. The blueshift velocity of the Mg II peak is about 2200 km s⁻¹. To precisely obtain the profile of the Mg II emission line, the UV Fe II multiples should be fitted and subtracted first. Interestingly, in the analysis of the UV Fe II multiples, we find that they are also blueshifted and the blueshifted velocity is close to that of Mg II. This is supported by the following three evidence.

First, the valley between the two spikes of the UV Fe II multiples 60 and 61 is an important feature in the UV FeII spectrum and spectral energy distribution (SED) from the ultraviolet (UV) to mid-infrared (MIR) from SDSS, 2MASS, and WISE are shown in black curve and green points in the panel (a) of Figure 2.
optical FeII multiples with the blueshifted velocity more acceptable for the blueshifted velocity Fe II are also displayed. Compared to corresponding reduced normal quasars same as that of SDSS J1633+5137 presented. The variations of corresponding to the peak of the SDSS J1633+5137 wavelength range from 5100 to 5400 Å. The model used to fit the observed spectrum can be described as

\[ \text{Model}_{\text{UVFe II}} = C_1 \chi^2 + C_2 f(v_0, \sigma). \]  

(1)

\( C_1 \chi^2 \) is a power law used to fit the continuum, and \( C_2 f(v_0, \sigma) \) is used to fit the UV FeII multiples. \( v_0 \) and \( \sigma \) represents the shifted velocity and broadened width of UV FeII, respectively. In the fitting process, \( v_0 \) is fixed at a given value; \( C_1, C_2, C_3, \) and \( \sigma \) are free parameters and their best-fit values are searched by minimizing \( \chi^2 \). To distinguish the fitting results between the different \( v_0 \) values given, we select the most remarkable UV FeII multiple, the red shape of UV1, and the gap between UV 60 and UV 61, which are marked in the gray-shaded region in panel (c) of Figure 3, to calculate the reduced \( \chi^2_e \). \( v_0 \) is first fixed to 0, which means UV Fe II has no shift compared to the quasar’s rest frame. The result is displayed in red in panel (c) of Figure 3 with the reduced \( \chi^2_e = 3.03 \). Then, we fixed the \( v_0 \) to \(-2200 \text{ km s}^{-1}\), which means that the UV FeII multiple is blueshifted at the same velocity as Mg II. The results is also displayed in blue with the reduced \( \chi^2_e = 1.27 \), which suggests an obvious improvement compared to \( v_0 = 0 \). To display the variation of reduced \( \chi^2_e \) as a function of \( v_0 \), we run a series of fitting programs where a grid of \( v_0 \) is provided. The \( \chi^2_e \) variation with \( v_0 \) is plotted in the inset panel of Figure 3(c). It can be seen that the reduced \( \chi^2_e \) at \( v_0 = -2200 \text{ km s}^{-1} \) is very close to the minimum value of the reduced \( \chi^2_e \) (1.17), suggesting that the shift velocity of UV Fe II is indeed close to that of Mg II.

Previous studies of the UV FeII and optical FeII have shown that there is no obvious redshift offset between the two components (Sameshima et al. 2011). However, this conclusion is based on quasar samples for which the UV FeII and optical FeII are nearly at the systematic redshift. As mentioned above, the UV FeII multiples of SDSS J1633+5137 are supposed to be blueshifted with a velocity of about 2200 km s\(^{-1}\). It is not clear whether the optical FeII has the same blueshifted velocity in SDSS J1633+5137. Thus, we first compared the optical FeII of SDSS J1633+5137 (black) to the scaled spectrum of IZw1 (cyan) in the wavelength range of 5100–5400 Å, which is shown in the inset panel of Figure 3(d). Different from the UV FeII multiples, the peaks of strong Fe II lines are close to those of IZw1, for which the shift velocity corresponds to the source systematic redshift. Furthermore, the model with a single power-law continuum and optical FeII multiples was also used to fit the spectrum of SDSS J1633+5137 in the wavelength range of 4000–6000 Å. The fitting results with the shift velocity fixed at 0 is plotted in red in Figure 3(d). Consistent with the above empirical analysis, no obvious velocity shift is found.
### 3.2. Narrow Emission Lines

After subtracting the UV and optical continuum and the UV and optical FeII multiples, we are able to obtain the Mg II H/β broad emission line, which is blended with H/β and [O III] narrow lines, and the Hα broad emission line, which is blended with Hα, [N II], and [S II] narrow emission lines. With the help of the individual narrow emission line [O II], we can derive the profiles of other narrow emission lines, which are then used to deblend the H/β and Hα broad lines.

To measure the [O II] emission line, we masked out the spectrum in the velocity range −1500 to 1500 km s⁻¹ and used a third-order spline curve to fit the local continuum of [O II]. The local continuum is shown by the cyan dashed line in the top panel of Figure 5. [O II] includes two narrow emission lines, [O II] 3729 and [O II] 3726. For each narrow emission line, we used one Gaussian to fit its profile. The two Gaussians have the same profile in its own velocity space. The line ratio of [O II] I(3729)/I(3726) is first fixed at 1. The fitting result is given in Table 2. According to Pradhan et al. (2006), the line ratio of [O II] can vary from 0.35 to 1.5. We also try to model with different line ratios, while the width and wavelength shift are constrained to vary less than 30 km s⁻¹. Assuming the width of [O II] is approximately the velocity dispersion of the host bulge, the mass of the central BH log $M_{BH}/M_\odot$ can be estimated to be $8.8 \pm 1.3$ according to Ferrarese & Merritt (2000).

Aside from [O II], we also tried to fit the [O III] 5007 narrow emission line despite it being blended with the H/β broad emission line. As shown in the bottom panel of Figure 5, the intensity of H/β BEL extending to the [O III] wavelength region is about ~1, while the flux of the [O III] NEL is ~10. Thus, we conclude that the influence of the H/β BEL can be ignored in the [O III] fitting. We modeled the [O III] line with one Gaussian, and the results are shown in Table 2. Note that the modeled profile of [O III] is very close to that of [O II].

### 3.3. Broad Emission Lines

Based on the analysis above, we have derived the Mg II, H/β, and Hα BELs in SDSS J1633+5137, and these BELs are displayed in the corresponding velocity space in Figure 6. As in Wang et al. (2011), for a specific emission line, the parameter BAI is defined as the flux ratio of the blue part to the total profile, where the blue part is the portion of the emission line at wavelength less than its laboratory rest-frame wavelength. For the Mg II doublet, the rest-frame wavelength is set to be 2999.4, which is obtained from the Mg II line core of IZw1. Based on this definition, we calculated the BAI of Mg II in our source, and its value is 0.85 ± 0.01. We note that if we consider the possible existence of a Mg II NEL, this value would be larger. It indicates that Mg II is dominated by the blueshifted component. Similar to Mg II, the BAl of H/β and Hα are ~0.56 and 0.54, respectively, suggesting that the blueshifted components of H/β and Hα BELs are also detected.

Thus, we tried to decompose the Mg II, H/β, and Hα BELs into two components: one is blueshifted and emitted from the outflow, the other is in the quasar’s rest frame from the normal BLR. The blueshifted component was modeled with one Gaussian, while the component from the normal BLR was fitted with multiple Gaussians. For the latter, we started from one Gaussian, and inspected visually the resulting $\chi^2$ and
residuals to determine the goodness of fit. When the best possible fit was not achieved, we added another Gaussian with a relative velocity shift less than 100 km s\(^{-1}\). The fit was repeated until the \(\chi^2\) was minimized with no further improvement in statistics. In the fitting process, the intensity of each line is free except for the ratio of Mg II doublets, which was held fixed at 1:1. For SDSS J1633+5137, three Gaussians are good enough to fit the non-blueshifted BEL component. All of these Gaussians were simultaneously fitted through the above iterative \(\chi^2\)-minimization process, and the fitting results are summarized in Table 2. Aside from the BELs, H\(\beta\) and H\(\alpha\) also include the [N II], [Si II], and Balmer NELs. Each NEL was modeled with one Gaussian, for which the velocity shift and width were fixed to the values derived from [O II], assuming that all NELs in the spectrum have a similar profile to [O II].

In the fitting progress, we noted that absorption troughs are present around the Mg II emission lines. To further eliminate the effect of absorption lines, we first fitted the Mg II emission line with one Gaussian, and then masked out those pixels of the absorption features deviating strongly from the model. In addition to the NEL, [O III] always contains a blue outlier (e.g., Komossa et al. 2008; Zhang et al. 2011). For SDSS J1633+5137, however, the F-test suggests that another Gaussian for the blue outlier is not required. Based on the profile of the H\(\beta\) rest component, we derived the mass of the central BH of log \(M_{BH}/M_\odot = 8.37 \pm 0.27\), which is consistent with the mass estimated from [O II].

The intensity ratio of the blueshifted Mg II to H\(\alpha\) is useful to constrain the properties of outflowing gas. However, the decomposition of the blueshifted H\(\alpha\) may be model-dependent, leading to uncertainty in the intensity ratio. We tried to determine its upper and lower limits. For the line ratio of Mg II to H\(\alpha\), the lower limit can be estimated as shown in the left panel of Figure 7. In this figure, the flux of H\(\alpha\) and Mg II is normalized by the peak of H\(\alpha\). The total Mg II emission line (red) is obviously blueshifted, and its red side can reach about 1000 km s\(^{-1}\). Under the assumption that the rest component in the BELs arises from the normal BLR for which the predominant motion is either Keplerian or virial (see Gaskell 2009 for a review), the Mg II rest component is expected to be symmetric. However, the red side of the observed Mg II is affected by the absorption line (Figure 6), and the red side of the modeled total Mg II reaches 3000 km s\(^{-1}\). This gives the blue side of the rest component of \(-3000\) km s\(^{-1}\) as the rest component of Mg II. Thus, we selected the part of Mg II with relative velocity between \(-5000\) and \(-3000\) km s\(^{-1}\) where the Mg II flux is prominent and the influence of Mg II rest component is small. For the H\(\alpha\) in the same relative velocity range, however, the emission line flux includes that of the rest component. Hence, the line ratio of the blueshifted Mg II to H\(\alpha\) in this velocity range can be considered as the lower limit, which is estimated to be 0.46. As shown in the right panel of Figure 7, based on the same assumption that the H\(\alpha\) rest component is symmetric, the lower limit of the blueshifted broad H\(\alpha\) can be estimated by
subtracting the symmetric flux on the blue side from the total. The residual flux at the blue side is shown in green. The line ratio of Mg II to H\(\alpha\) in the velocity range between \(-5000\) and \(-3000\) km s\(^{-1}\) is close to 1, which can be considered as its upper limit.

### 3.4. Ionization Model for Blueshifted Emission Lines

Because the blueshifted velocities of the UV Fe II, Mg II, and Balmer lines are nearly the same, we supposed that these blueshifted components arise from the same outflowing gas. Thus, we can infer the properties of the outflows from these line ratios, using mainly the blueshifted Mg II/H\(\alpha\) and UV Fe II/H\(\alpha\). We did not use H\(\beta\)/H\(\alpha\) as the H\(\beta\) and H\(\alpha\) blueshifted components are relatively weak in the emission lines. The line ratio between them may have large errors and hence not be reliable. For the blueshifted Mg II/H\(\alpha\), as we discussed above, it was estimated to be \(\sim 0.46\)–1. The blueshifted UV Fe II to H\(\alpha\) is equal to the UV Fe II/Mg II times Mg II/H\(\alpha\). Because the blueshifted H\(\alpha\) component is relatively weak compared to the total flux in the emission line, we expect that the error of the H\(\alpha\) blueshifted component is much higher than that of Mg II and UV Fe II. Taking this into account, the error of the blueshifted UV Fe II/H\(\alpha\) mainly comes from the error of Mg II/H\(\alpha\), and the error of UV Fe II/Mg II can be ignored. As shown in Table 2, the value of the blueshifted UV Fe II/Mg II is 0.75. Multiplied by the range of blueshifted Mg II/H\(\alpha\), the blueshifted UV Fe II/H\(\alpha\) can be estimated to be in the range \(\sim 0.35\)–0.75. This is consistent with the Mg II/H\(\alpha\) (0.48) derived from the composite quasar spectrum (Vanden Berk et al. 2001). In spite of the blueshifted UV Fe II/H\(\alpha\) being much larger than that from the composite quasar spectrum (0.01), it is consistent with the line ratio of a typical BLR derived from the photoionization model (Baldwin et al. 2004; Sameshima et al. 2011). Therefore, the UV Fe II blueshifted components can be modeled with a photoionization model, and the physical conditions of outflowing gas are supposed to be similar to the BLR in normal quasars.

The large-scale synthesis code CLOUDY (c13.03; Ferland et al. 1998) is employed to perform the photoionization modeling of the blueshifted broad emission lines. The simulation results are
used to compare with the luminosities and ratios of the blueshifted components measured from the spectrum of SDSS J1633+5137. In photoionization simulations, the solar elemental abundance is adopted and the gas is assumed to be free of dust. To model the Fe II emission lines, we used a 371 level Fe$^+$ model that includes all energy levels up to 11.6 eV, and calculated strengths for 68,000 emission lines (Verner et al. 1999). For simplicity in the computation, the geometry is assumed to be a slab-shaped emission medium with uniform density, metallicity, and abundance. This medium is exposed to the ionizing continuum from the central engine with an SED defined by Mathews & Ferland (1987), hereafter MF87. As shown in Figure 8, an array of hydrogen absorption column densities ($N_H$) was set in the simulations from $10^{21}$ to $10^{24}$ cm$^{-2}$ in 1 dex steps. As we discussed above, the ionization conditions may be nearly the same as those in the BLR. Thus, for each column density, the range of outflow gas electron density ($n_H$) was set to $10^3$ to $10^{14}$ cm$^{-3}$, and a grid of models is calculated by varying the $n_H$ of the emitting gas with a step of 0.5 dex. Finally, the logarithmic ionization parameter (log $U$) was sampled from $-3.5$ to $1.5$ with a step of 0.5 dex.

The calculated results are shown in Figure 8, where we plot the contours of blueshifted Mg II/Hα and UV Fe II/Hα as a function of $n_H$ and $U$. In each panel, the solid lines denote the basic models, and the filled areas represent the observed range with 1σ confidence level. The simulation results indicate that the observed regions of Mg II/Hα and UV Fe II/Hα have no overlap when $N_H \leq 10^{22}$ cm$^{-2}$. The overlap region starts to appear for column density $N_H \geq 10^{23}$ cm$^{-2}$. Hence, we considered $10^{23}$ cm$^{-2}$ to be the lower limit on the column density, which implies that the outflow in SDSS J1633+5137 may be optically thick.

Thus, we provided an ionization boundary model (Ferland et al. 1998) to simulate the emitting gas in the outflow, and the simulation results are plotted in Figure 9.

In this model, the parameters $n_H$ and $U$ of the emitting gas can be constrained as follows: $n_H$ from $10^{10.6}$ to $10^{11.3}$ cm$^{-3}$ and log $U$ from $-2.1$ to $-1.5$. With $n_H$ and $U$, the distance of emitting gas to the central ionizing source was derived to be $R_{em} = (Q(H)/(4\pi U n_H))^{0.5}$, where $Q(H)$ is the number of ionizing photons, $Q(H) = \int_\lambda L_\lambda/\nu d\nu$. Based on the continuum luminosity at 5100 Å ($\lambda L_\lambda (5100 \text{ Å}) = 1.3 \times 10^{45}$ erg s$^{-1}$) and the MF87 SED, we derived $Q(H) \approx 1.1 \times 10^{56}$ photon s$^{-1}$. Thus, we obtained the distance between the emitting gas and central ionizing source to be $\sim 0.1$ pc. Based on the best constrained parameter values by our photoionization modeling, namely, $n_H = 10^{11.1}$ cm$^{-3}$ and log $U = -1.8$, we obtained the simulated EW of Mg II of 257 Å. Because this value is modeled under the assumption of full sky coverage of outflowing gas, the ratio of the observed EW of Mg II to the modeled one can be used to constrain the covering factor $C_{f, em}$ of the emitting gas. The observed EW of Mg II is about 45 Å, suggesting that $C_{f, em}$ is about 0.16.

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**Figure 7.** Estimation of the lower and upper limits of Mg II/Hα. The Mg II and Hα fluxes are both normalized by the peak of Hα. Left: the Hα flux in the wavelength range between $-5000$ and $-3000$ km s$^{-1}$ comprises the photons emitted from the BLR, hence the flux of blueshifted component may be underestimated, providing the lower limit of Mg II/Hα. Right: the estimation for the upper limit of Mg II/Hα. The Hα in $3000$–$5000$ km s$^{-1}$ may include the photons of the blueshifted component. Thus, the rest component of the mirror-symmetric Hα flux from $-5000$ to $-3000$ km s$^{-1}$ may be underestimated, giving the upper limit of Mg II/Hα.
4. Absorption Line Analysis

4.1. Absorption-free Spectrum for the Absorption Lines

As shown in Figure 1, a prominent BAL trough is present in the spectrum at about 7000 km/s blueshifted with respect to He I λ10830. This trough can be identified as the He I λ10830 BAL. Hinted at by the location of the trough, we detected another BAL trough at about 7000 km/s blueshifted with respect to He I λ3889. In addition, at the same location in the respective velocity space, the Mg II BAL was found in the spectrum. With these BALs, we are able to place constrains on the properties of the absorption line outflowing gas.

To measure these BALs, we first used the pair-match method (Zhang et al. 2014; Liu et al. 2015) to recover the absorption-free spectrum of SDSS J1633+5137. The absorption lines of Figure 8. Contours of Mg II/Hα (blue) and UV Fe II/Hα (green) as a function of $n_H$ and $U$ calculated by CLOUDY for the column density $N_H = 10^{21}$–$10^{24}$ cm$^{-2}$, solar abundance, and MFS7 SED. When $N_H > 10^{23}$ cm$^{-2}$, the 1–σ confidence levels of Mg II/Hα and UV Fe II/Hα start to overlap. $N_H = 10^{23}$ cm$^{-2}$ can be considered as the lower limit on the column density of the outflow gas.
interest in the observed spectral regime include He I λ10830, He I λ3889, He I λ3189, and Mg II. For each absorption, the pair-match method was employed to obtain the absorption-free spectrum.

(1) He I λ10830 regime: As can be seen from Figure 10, with a large blueshift of 7000 km s^{-1}, the He I λ10830 BAL is well detached from the corresponding emission line. This spectral regime is largely free of other emission lines (see the composite quasar spectrum displayed in Figure 2; Zhou et al. 2010). The absorption-free flux recovered by the pair-matching method is mostly contributed by the featureless continuum, which is well reproduced by a power-law and blackbody emission. We did not detect starlight from the host galaxy and interpret the power-law component to have originated from the accretion disk of the quasar. The blackbody component is generally believed to be hot dust reradiation of the torus assumed by AGN unification schemes (e.g., Netzer 1995). After removal of the blackbody component, we found that the residual flux is still significant in the BAL trough. (2) He I λ3889 regime: The absorption-free flux around the He I λ3889 BAL is mainly contributed by the power-law continuum radiated by the accretion disk. The absorption depth of the deepest part of the He I λ3889 BAL trough is \sim 20\% on the normalized spectrum (see Figure 10). Because the absorption strength ratio (g_{He}/\lambda) of He I λ10830 to He I λ3889 is as large as 23.3 (e.g., Leighly et al. 2011), this indicates that the BAL region only partially covers the accretion disk, incorporating the fact that there are still significant residuals in the He I λ10830 trough after removal of the host dust contribution. A detailed analysis yielded the covering factor of the absorption gas to the accretion disk is about 0.4 (see Section 4.2).

(3) He I λ3189 and Mg II regime: The emission and absorption characteristics around these two absorption lines are nearly the same. The pair-matching results contain the power-law continuum from the accretion disk and the Mg II and Fe II broad lines from the outflow. Considering that the absorption gas only partially covers the accretion disk, and the emission line gas is of similar size to the normal BLR, the UV Fe II multiples should not be included in the absorption-free spectrum. The normalized absorption spectra of He I λ10830, He I λ3889, He I λ3189, and Mg II are displayed in Figure 10 (right).

### 4.2. Characterizing the Absorption Line Gas

Before investigating the properties of BALs, we first constrain the distance of the BAL outflow gas in a qualitative way. According to the discussion above, the absorption medium partially obscures the accretion disk. Thus, we considered the distance of the absorption medium to be comparable to the size of the accretion disk at 10830 Å. Based on Equation (3.2) in Peterson (1997), the size of the accretion disk at 10830 Å is about 1500rg (rg ≡ GMBH/c^2), or 0.017 pc. A more quantitative constraint on the distance of the absorption gas requires the measurements of the ionization parameter \Upsilon and gas density \nH. The latter can be constrained by comparing photoionization simulations with observed line ratios of multiple ions (e.g., Leighly et al. 2011; Liu et al. 2016). However, only He I and Mg II absorptions are detected in J1633. As we will show below, they are not sufficient to set a useful constraint on the gas density, but useful in determining the ionization parameter and lower limit on the total column density for the BAL gas.

For a BAL, the normalized intensity is

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

where \(C_f(v)\) is the covering factor and \(\tau\) is the true optical depth as a function of radial velocity. For transitions from the ion at a given level, the values of \(\tau(v)\) is proportional to \(fN_{col}\) where \(f\) is the oscillator strength, \(\lambda\) is the rest wavelength of the transition, and \(N_{col}\) is the column density of the ion with the given level. Theoretically, two absorption lines transited from the same ion at a given level are needed to derive the physical conditions of outflowing gas, such as \(C_f\) and \(N_{col}\).

For SDSS J1633+5137, three absorption lines, He I λ3189, He I λ3889, and He I λ10830, are transmitted from the same

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**Figure 9.** Contours of Mg II/Hα (blue) and UV Fe II/Hα (green) as a function of \(n_H\) and \(U\). The calculations are the same as in Figure 8, but assuming an ionization boundary. The overlapping region constrains the parameters of outflow gas to a narrow region of \(n_H\) from \(10^{10.6}\) to \(10^{11.3}\) cm^{-3} and log \(U\) from -2.1 to -1.5.
energy level, He I, and can be used to derive the \( C_f \) and \( N_{\text{col}} \) of this ion. As the He I \( \lambda 3189 \) trough is weak, we used He I \( \lambda 3889 \) and He I \( \lambda 10830 \) to solve Equation (2) to obtain the \( C_f \) and \( \tau(\nu) \) of He I. The He I \( \lambda 3189 \) trough is employed to check for consistency. Because the He I \( \lambda 10830 \) absorption line is seriously affected by the sky lines, the pixels in this region were marked, and the data were interpolated using a third-order spline. As the bottom of He I \( \lambda 10830 \) is about 0.6, we defined that edge of the absorption trough region to be located at the pixels where three continuous pixels are below 0.96, corresponding to a depth of absorption of 4%, or 10% of the depth of the He I \( \lambda 10830 \) BAL. For every pixel in the absorption line regions of He I \( \lambda 3889 \) and He I \( \lambda 10830 \), we derived the \( C_f \) and \( N_{\text{col}} \) of He I, and \( \tau(\nu)_{\lambda 3889} \), which are shown in Figure 11.

The integral \( N_{\text{col}} \) of He I along the absorption trough in the velocity space is found to be \((5.0 \pm 1.7) \times 10^{20} \text{ cm}^{-2}\). With \( C_f \) and \( N_{\text{col}} \), we also simulated the absorption trough of He I \( \lambda 3189 \) and compared it with the observed data in Figure 12. We found that the simulated and observed absorption troughs are consistent with each other, indicating that the derived \( C_f \) and \( N_{\text{col}} \) are reliable. In addition, with the derived \( C_f \) and Mg II absorption troughs, we tried to constrain the \( N_{\text{col}} \) of Mg I. In Figure 13, we show the trough of Mg II in blue and \( 1 - C_f \) in comparison, which indicates the saturation of the Mg II absorption trough at some velocities. Thus, the \( N_{\text{col}} \) of Mg I cannot be obtained directly from Equation (2). However, because of the saturation of Mg II, we can derive \( \log U \) from the \( N_{\text{col}} \) of He I through Equation (3) in Ji et al. (2015), and the value of \( \log U \) is \(-1.9 \pm 0.2\). This value is in the range of \( e \log U \) derived from the blueshifted emission lines.

With our measurement for the total column density seen in the He I metastable lines, we can set a minimum He I column density of \(~1 \times 10^{20} \text{ cm}^{-2}\) in the outflow, taking the maximum density ratio of He I* to He I (Rudy et al. 1985; Arav et al. 2001). Assuming solar abundances, this estimate yields a minimum H II column density \( N_H \sim 1 \times 10^{21} \text{ cm}^{-2}\). On the other hand, we can estimate the H II column density of the BAL gas through the equation \( N_H \approx 23 + \log U \) (Ji et al. 2015), yielding \( N_H \sim 10^{22} \text{ cm}^{-2}\). However, it should be noted that the \( N_{\text{col}} \) of He I* is not a suitable indicator of \( N_H \) for optically thick gas. This is because He I* is a high-ionization line and its column density mainly grows at the very front of the hydrogen ionization front and stops growing behind it (e.g., Arav et al. 2001; Ji et al. 2015). Instead, absorption lines with lower ionization potentials, such as Ca II, Mg II, and Fe II, are useful to probe the total column density of the outflow. Unfortunately, the Ca II and Fe II absorption lines are not detected, and the \( N_{\text{col}} \) of Mg I is difficult to derive, due to the saturation effect. Therefore, we can only set a lower limit for the total H II column density of BAL gas, \( N_H > 1 \times 10^{21} \text{ cm}^{-2}\).

On the other hand, further constraint on the column density of absorbing medium can be placed with the nondetections of the corresponding UV Fe II BALs. This is because given the same ionization parameter, the Mg II and Fe II absorption lines are both sensitive to the total column density. Similar to our analysis of the BEL outflow (Section 3.4), we employ photoionization simulations to evaluate the dependence of
Fe II BALs on the total column density. We assume the geometry of BEL gas to be a slab-shaped medium exposed to the ionizing continuum from the central engine with uniform density. The model setups are the same as those for the BEL simulations except for the ionization parameter, which is \( \log U = -1.9 \) as derived from the HeI \( * \) BALs. Each individual simulation model is customized in terms of the column density (\( N_{\text{H}} \)), which is set to vary in the range \( 21 \leq \log N_{\text{H}} \) (cm\(^{-2}\)) \( \lesssim 22 \) with a step of 0.2 dex. This model can predict the population on various levels of Fe\( ^{+} \) and the strength of the absorption lines that originated from these levels. Figure 14 (upper panel) presents a series of models with the grid of \( \log N_{\text{H}} \).

As can be seen from the simulation results, at \( \log N_{\text{H}} \approx 21.4 \), there are obvious absorption troughs from the iron multiplets raised from the ground state (e.g., Fe II UV2+3 at approximately 2400 Å and Fe II UV1 at approximately 2600 Å. Due to the BALs, they are blueshifted by 7000 km s\(^{-1}\) blueshifted.). Such absorption features are, however, not observed in the spectrum. Thus, the upper limit on the column density of BAL gas can be constrained to be \( \log N_{\text{H}} = 21.4 \). In fact, when compared to the observed spectrum in detail (Figure 14, lower panel), we found a model with column density of \( \log N_{\text{H}} = 21.2 \) matches the data well in the spectral range of 2300–3000 Å. Therefore, in combination with the lower limit on the column density given by the HeI \( * \) BAL, the most probable column density for the BAL gas is \( \log N_{\text{H}} \sim 21.2 \). This suggests that the physical conditions of the BAL and BEL gas are not strictly the same, at least in terms of the total column density.

5. Summary and Discussion

In this paper, we present a detailed study of the emission and absorption line properties of J1633+5137. In the optical and NIR spectra, in addition to the normal emission lines originating from
to be logged observations with photoionization simulations. The physical properties of the outflow gas are obtained by comparing the UV Fe II spectrum for comparison. Components with a common velocity at the BLR and NLR, there are several blueshifted emission lines. The physical parameters for the BEL outflow are constrained to be $10^{19.6} \lesssim n_H \lesssim 10^{11.3} \text{ cm}^{-3}$, $-2.1 \leq \log U \leq -1.5$, and $N_H \gtrsim 10^{21} \text{ cm}^{-2}$. Using the ionization parameter, gas density, and EW of Mg II, we estimated the covering factor and distance of the BEL outflow materials to the central source, which is $C_{\text{emit}} \sim 0.16$ and $r \sim 0.1 \text{ pc}$. In addition, strong BALs from Mg II and He I metastable lines are also detected. Using a simple partial coverage model, we derived the integral column density of He I and the ionization parameter for the BAL gas, which is $(5.0 \pm 1.7) \times 10^{21} \text{ cm}^{-2}$ and $U = -1.9 \pm 0.2$, respectively. The total column density is estimated to be in the range $10^{21} \leq \log (N_H) \leq 10^{21.4} \text{ cm}^{-2}$, which is about two orders of magnitude less than that derived for the BEL gas, suggesting that the physical conditions of the BAL and BEL gas are not strictly the same.

Though the blueshifted BELs are crucial in studying AGN outflows, which can reflect the global properties of outflowing gas, their physical conditions and locations are difficult to investigate, except for a limited number of sources where the spectra from multiple ionic species can be reliably measured. Liu et al. (2016) identified both the BELs and BALs produced by AGN outflows in the quasar SDSS J164509.82+204936.0. The physical parameters determined for the BEL and BAL outflows are very close, with $10^{24.5} \leq n_H \leq 10^{25} \text{ cm}^{-3}$, $-1.3 \leq \log U \leq -1.0$, and $N_H \sim 10^{22.5} \text{ cm}^{-2}$, and the outflow materials are 48–65 pc from the central source, likely exterior to the torus. The similarities of the physical parameters strongly suggest that blueshifted BELs and BALs should be generated in the common outflowing gas. Zhang et al. (2017) reported similar UV and optical emission line outflows in the heavily obscured quasar SDSS J000610.67+121501.2 and inferred a distance at the scale of the dusty torus (and beyond). Conversely, the emission line outflow identified in J1633+5137 has a much higher density ($n_H \sim 10^{24} \text{ cm}^{-3}$) with a distance at the scale of the BLR to the central source, reflecting the diversity of physical conditions for the outflowing gas.

### 5.1. Energetic Properties of the Outflow

Because the physical conditions for the BELs and BALs are not the same, we discuss separately the energetic properties of the BEL and BAL outflows. As discussed in Borghesi et al. (2012), assuming that the outflowing BEL material can be described as a thin ($\Delta R/R \ll 1$), partially filled shell, the mass-outflow rate ($\dot{M}$) and kinetic luminosity ($\dot{E}_k$) are given by

$$\dot{M} = 4\pi R\Omega \mu m_p N_H \nu$$

and

$$\dot{E}_k = 2\pi R\Omega \mu m_p N_H \nu^3,$$

where $R$ is the distance of the outflow from the central source, $\Omega$ is the global covering fraction of the outflow, $\mu = 1.4$ is the mean atomic mass per proton, $m_p$ is the mass of proton, $N_H$ is the total hydrogen column density of the outflowing gas, and $\nu$ is the radial velocity. Based on the physical parameters inferred for the BEL outflow and taking the velocity of the outflow, which is $-2200 \text{ km s}^{-1}$, as the peak of the blueshifted Mg II BEL, the mass-outflow rate and the kinetic luminosity can be derived as $\dot{M} = 0.9 M_\odot \text{ yr}^{-1}$ and $\dot{E}_k = 1.5 \times 10^{42} \text{ erg s}^{-1}$, respectively.

Similar to the BEL outflow, we can also obtain the $\dot{M}$ and $\dot{E}_k$ for the BAL outflow. However, the global covering factor and density of the BAL outflow gas in SDSS J1633+5127 cannot be directly constrained by observations. In the studies of BAL quasars, the global covering fraction of BAL outflow gas is

![Figure 14](image-url)
generally derived from the fraction of BAL quasars. This fraction is about 10%–20% in optically selected quasars (e.g., Trump et al. 2006; Gibson et al. 2009; Zhang et al. 2014). Moreover, we assumed that the BAL outflow is located at the same distance to the central source as the BEL outflow. With the column density of the BAL outflow log $N_{H}$ (cm$^{-2}$) = 21.2 and radial velocity of $\sim$7000 km s$^{-1}$, the $M$ and $E_k$ for the BAL outflow can be estimated as $M = 0.01 M_\odot$ yr$^{-1}$ and $E_k = 2.2 \times 10^{44}$ erg s$^{-1}$, respectively. These values are a factor of 7–9 lower than that obtained for the BEL outflow. Therefore, the mass flux and kinetic luminosity are dominated by the BEL outflow, and the contribution from the BAL outflow is minor.

Previous studies suggest that efficient AGN feedback in the form of high-velocity outflows typically requires kinetic luminosity to be on the order of a few percent of the Eddington luminosity ($L_{\text{edd}}$; e.g., Scannapieco & Oh 2004; Di Matteo et al. 2005; Hopkins & Elvis 2010). For SDSS J1633+5127, the mass of the black hole (log $M_{BH}/M_\odot$) derived from HI is about 8.37 and $L_{\text{edd}}$ is about $3 \times 10^{46}$ erg s$^{-1}$. Taking the calculation results above, the sum of the kinetic luminosities of the BEL and BAL outflows is only $\sim 1.7 \times 10^{42}$ erg s$^{-1}$ ($<10^{-4} L_{\text{edd}}$). This value is apparently far from efficient to drive the AGN feedback. Note that the kinetic luminosity of the total outflow gas can only be considered as a lower limit for the following reasons: (1) the column density of 10$^{23}$ cm$^{-2}$ that we inferred for the BEL outflow is the lower limit; (2) the velocity $v$ for the BEL gas is a sum of the projected velocities of the outflowing gas along different directions, the value of which is only a lower limit on the outflow velocity (Liu et al. 2016; Zhang et al. 2017); and (3) the distance of the BAL outflowing gas may also be a lower limit, as if it were located at much greater distances from the central source.

5.2. Outflow Geometry and the Profile of Outflow Emission Line

As we mentioned above, blueshifted BELs from multiple ionic species are rarely observed in quasars, and both BELs and BALs being observed in the spectrum of the same quasar is even rarer. In Sections 3 and 4, we investigated the physical properties of the BEL and BAL outflows, respectively, and obtained similar ionization parameters for them. Therefore, though the physical conditions are not strictly the same, the BEL and BAL outflows may not be independent. In order to further constrain the outflow geometry, we attempted to reproduce the profile of BELs with the radial velocity of BALs.

The outflows have always been considered to have a biconical structure in previous works (e.g., Elvis 2000), and the emission line profile can be successfully modeled with this structure (Zheng et al. 1990; Marziani et al. 1993; Sulentic et al. 1995). However, the biconical structure is two-dimensional and needs a certain number of free parameters to reproduce the emission line profile in models. For simplicity, we employed a one-dimensional “ring” model to reproduce the emission line outflow profile of SDSS J1633+5137. The cross section of this model is displayed in the left panel of Figure 15.

The ring model for the outflow assumes that the line originates from a ring above the disk to which the axis inclines with an angle $i$ relative to the line of sight. The ring has an angle $\theta_0$ relative to the normal direction of the accretion disk. For SDSS J1633+5137, as the blueshifted BELs and BALs of the outflow are observed at the same time, it is natural to assume our line of sight is penetrating through the outflow, which means the angle $i = \theta_0$. To reproduce the velocity range of BALs, the $v_r$ in this model is constrained at 7000 km s$^{-1}$, which corresponds to the blueshifted velocity of the BALs. The distance from the ring to the black hole is $r$ (expressed in units of the gravitational radius, $r_g$). The distance to the outflow from the central source derived from blueshifted BELs is about 0.1 pc, or about 9000 $r_g$. The outflow velocity along with the radial direction is $v_r$. Aside from the radial velocity, the outflow ring also has a rotation velocity. However, if we assumed our outflow is launched by the disk wind that arises from the accretion disk at about 100 $r_g$, when the outflow arrives at 9000 $r_g$, due to angular momentum conservation, the rotation velocity is about 300 km s$^{-1}$. This rotation velocity is much less than $v_r$. Therefore, in our model, the rotation velocity was ignored. The coordinate of gas in the ring can be expressed as $(r, \theta_0, \phi)$, where the $\phi$ changes from $-\pi$ to $\pi$ and our line of sight corresponds to $\phi = 0$. Assuming the outflowing ring’s rotation increases with the direction of $\phi$, for a certain ring at $r$, $\theta_0$, and $\phi$, the velocity on the line of sight $v_{\text{obs}}$ can be expressed as

$$v_{\text{obs}}(r, \theta_0, \phi) = -(v_r \sin^2(\theta_0) \cos(\phi) + v_r \cos^2(\theta_0)).$$

To compare with the observed profile easily, we defined the direction far away from the central BH as the positive direction of $v_{\text{obs}}$. With this equation, we can derive the emission line profiles of the outflow ring for only one free parameter $\theta_0$ in our model.

In the right panel of Figure 14, we display three model results. For comparison, we also show the fitting result to the Mg II blueshifted BEL (black). All three models are different from the Mg II blueshifted BEL. The model profile is single-peaked when the $\theta_0$ is small, but the blueshifted velocity is higher than Mg II. For the case of larger $\theta_0$, the model profile becomes double-peaked, which is also inconsistent with Mg II even though we found that when $\theta_0 = 40^\circ$, the red part of the model profile appears to match well with the red side of Mg II. If the emission on the blue side is obscured under certain conditions, and only the emission on the red side can be observed, the modeled profile could be consistent with Mg II.

According to Equation (5), for a certain $\theta_0$, a larger blueshifted velocity corresponds to a smaller absolute value of $\phi$. Thus, we proposed another amended toy model. All of the parameters in this model are the same as those of the model above, except we added a free parameter “shadow.” The top view of this model is shown in the left panel of Figure 16. The parameter “shadow” is in the range from 0 to 1. For a given shadow parameter, the outflowing gas in the range $-$shadow $\times \pi$ to $\pi$ in shadow $\times \pi$ is obscured, and only the photons emitted from the rest of the ring can be detected. In the middle panel of Figure 16, we display a modeled profile that can reproduce the profile of Mg II well. The parameters of this best-fit profile are $\theta_0 = 40^\circ$ and shadow $= 0.48$. Note that the free parameter $v_r$, and shadow can be well constrained in our model.

Figure 16 (right panel) shows the 1$\sigma$, 2$\sigma$, and 3$\sigma$ confidence levels of the parameter $\theta_0$ versus shadow. At the 1$\sigma$ confidence level, $\theta_0$ was constrained to be in the range 33$^\circ$–43$^\circ$, while shadow was from 0.33 to 1. In Section 3.4, we estimated that the distance to the BEL gas is $\sim 0.1$ pc, which is much smaller than the distance to the dust torus, typically at $\sim$pc scale (e.g., Barvainis 1987; Kishimoto et al. 2012; Koshida et al. 2014). In addition, previous studies of the dust torus yielded dust covering factors of $\sim$48$^\circ$ (Schmitt et al. 2001) and in the large range of 38$^\circ$–56$^\circ$ (Osterbrock & Martel 1993; Sazonov et al. 2015).
Therefore, it is possible that the shielding of outflowing gas in SDSS J1633+5137 is the dusty torus. Future spectropolarimetry observations will be required to further test this model, and will be helpful to place new constraints on the geometry of the outflowing gas. It should be noted that this model is based on the assumption that the density and column density are uniformly distributed in the outflow gas, which may be oversimplified. Using more complex models, e.g., an inhomogeneous column density distribution, to explain the emission and absorption features observed in SDSS J1633+5127 is beyond the scope of this paper. We present in the Appendix such a multicolumn density modeling of the outflow emission lines, and a detailed investigation will be presented elsewhere.

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Appendix

Multicolumn Density Modeling of the Outflow Emission Line

It should be noted that CLOUDY photoionization simulations in this paper (also in many other works in literature) are based on the assumption that the density and column density are uniformly distributed in the specific outflows. However, this model can be oversimplified. According to the outflow models in Proga et al. (2000) and Higginbottom et al. (2014), the density and column density of the outflow can vary with locations and directions. However, an outflow model with multiple densities and column densities may be too complex to be constrained by the observations of SDSS J1633+5127. If we assume that the BEL and BAL outflows have similar densities, the outflows in SDSS J1633+5127 can be simplified to a slab-shaped medium with multiple column densities and uniform density. In this model, the low-ionization blueshifted BELs, such as Mg II and Fe II, tend to trace the outflow gas with higher column densities. In addition, further assuming that the covering factor of the outflow gas is related to the column density, i.e., the covering factor decreases as the column density increases, the line of sight would have a greater chance of peering through the outflow gas with lower column density. This may explain why the column density derived from the blueshifted BELs is higher than that from BALs. In order to further constrain the outflow properties of SDSS J1633+5127, we attempted to reproduce the Mg II BEL profile with this outflow model. For this model, the Mg II BEL profile can be expressed as

$$\Psi = \int F(N_{\text{H}}) \psi(N_{\text{H}}) C_{\text{f}}(N_{\text{H}}) dN_{\text{H}},$$

where the $F(N_{\text{H}})$ is the intensity of the outflow gas at a given $N_{\text{H}}$, $\psi(N_{\text{H}})$ is the profile of the outflow gas with specific $N_{\text{H}}$ caused by the geometry of the outflow, and $C_{\text{f}}(N_{\text{H}})dN_{\text{H}}$ is the covering factor of the outflow gas in the range of $N_{\text{H}}$ to $N_{\text{H}} + dN_{\text{H}}$, which is assumed to be proportional to $N_{\text{H}}^{-\tau}$.

Using the density and ionization parameter derived for the BEL outflow, log $n_{\text{H}}$ (cm$^{-3}$) = 11 and log $U = -1.9$, we can obtain the Mg II emergent emissivity distribution along with the ionized depth via CLOUDY simulations. The result is
displayed in the left panel of Figure 17. The distribution indicates that the Mg II emission can be ignored when the column density is lower than \(10^{20} \text{ cm}^{-2}\). Therefore, we set \(10^{20} \text{ cm}^{-2}\) as the lower limit for the column density of the multicolumn density outflow model. The upper limit on the column density is set to be \(10^{25} \text{ cm}^{-2}\). We then derived the MgII intensity \((F(N_{\text{H}}))\) as a function of column density, which is shown in the right panel of Figure 17.

While a biconical structure has always been considered as the geometry of outflows in previous works (e.g., Elvis 2000), it is two-dimensional and needs a certain number of free parameters to reproduce the emission line profile. For simplicity, we employed a one-dimensional “ring” model to reproduce the blueshifted Mg II profile of SDSS J1633+5137. The cross section of this model is displayed in the left panel of Figure 18.

The ring model for the outflow assumes that the line originates in a ring above the disk to which axis inclines with an angle \(i\) relative to the line of sight. The ring has an angle \(\theta_r\) relative to the normal direction of the accretion disk. For SDSS J1633+5137, as the blueshifted BELs and BALs of the outflow are observed at the same time, it is natural to assume our line of sight is penetrating through the outflow, which means the angle \(i = \theta_r\). The distance from the ring to the black hole is \(r\) (expressed in units of the gravitational radius, \(r_g\)). The distance to the outflow from the central source derived from the blueshifted BELs is about 0.1 pc (or 9000 \(r_g\)). The outflow velocity along the radial direction is \(v_r\). The coordinates of the gas in the ring can be expressed as \((r, \theta_r, f)\), where \(f\) changes from \(-\pi\) to \(\pi\) and our line of sight corresponds to \(f = 0\).

Assuming the outflowing ring’s rotation increases with the direction of \(\phi\), for a certain ring at \(r, \theta_r\), and \(\phi\), the velocity on the line of sight \(v_{\text{obs}}\) can be expressed as

\[
v_{\text{obs}}(r, \theta_r, \phi) = -(v_r \sin^2(\theta_r) \cos(\phi) + v_r \cos^2(\theta_r)).
\]

To compare with the observed profile easily, we defined the direction far away from the central BH as the positive direction of \(v_{\text{obs}}\). With a specific \(v_r\) and \(\theta_r\), we can derive the emission profile of the ring. According to outflow theory, if an outflow is only regulated by gravitation and ionizing radiation, \(v_r\) can be considered proportional to \(N_{\text{H}}^{-0.5}\) (Netzer & Marziani 2010; Marziani et al. 2013). Assuming the BAL outflow is physically
connected to the BEL, we can use the $v_r$ of the BAL outflow gas ($\sim 7000$ km s$^{-1}$) and the column density ($10^{21.2}$ cm$^{-2}$) to constrain the scaling factor for the above relation. Based on this, we calculated $v_r(N_{\text{HII}})$ for different values of $N_{\text{HII}}$. With this $v_r(N_{\text{HII}})$ and Equation (7), we can derive the emission profile $\psi(N_{\text{HII}})$. This profile includes a free parameter $\theta_r$. In addition to $\psi(N_{\text{HII}})$, the relative $C_f$ value can be obtained through the relationship $C_f(N_{\text{HII}}) \propto N_{\text{HII}}^{-\Gamma}$ by introducing another free parameter $\Gamma$. Thus, together with $F(N_{\text{HII}})$ as determined by photoionization simulations (Figure 17, right), the emission profile of the multicolumn density outflow model can be derived.

In the middle panel of Figure 18, we display a modeled profile that can reproduce the profile of MgII well. The parameters of this best-fit profile are $\theta_r = 30^\circ$ and $\Gamma = 1.5$. Note that the free parameter $\theta_r$ and $\Gamma$ can be well constrained in our model. Figure 18 (right panel) shows the $1\sigma$, $2\sigma$, and $3\sigma$ confidence levels of the parameter $\theta_r$ versus $\Gamma$. At the $1\sigma$ confidence level, $\theta_r$ was constrained to be in the range from 25$^\circ$ to 35$^\circ$, while $\Gamma$ was from 1.4 to 1.65. This multicolumn density outflow model may explain the difference in the column density of the BAL and BEL gas for the source SDSS J1633 +5127 if they are physically connected. The inferred model parameters will also be valuable for the simulations of AGN outflows with multiple column density distributions.

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Figure 18. Left: the cross section of the ring model. The angle relative to the normal line of the accretion disk is $\theta_r$. The angle for the line of sight is $i (=\theta_i)$. Middle: comparisons of the best-fit result ($\theta_r = 30^\circ$, $\Gamma = 1.5$) with the blueshifted observed MgII profile. The modeled MgII $\lambda 2796$ and MgII $\lambda 2803$ are plotted in pink dashed lines, and the total profile of the MgII doublet is displayed in red solid line. The mismatch between the model and observation at about $-7000$ km s$^{-1}$ is due to the MgII BAL, where the observed MgII profile is marked in gray. Right: the $1\sigma$, $2\sigma$, and $3\sigma$ confidence levels for $\theta_r$ vs. the $\Gamma$ parameter. The red star denotes the best-fitted value.
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