Ultra-dense Broad-line Region Scale Outflow in Highly Reddened Quasar SDSS J145057.28+530007.6

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Abstract

We report the discovery of highly reddening and hydrogen Balmer and metastable helium broad absorption lines in the quasar SDSS J145057.28+530007.6, based on the optical and near-infrared spectra taken from the SDSS-III/BOSS and the TripleSpec observations. The nuclear continuum, Balmer decrement, and absorption-line depth analyses suggest that (1) the accretion disk is completely obscured and the covering factor of the broad-line region (BLR) is only $0.39 \pm 0.03$, (2) the power-law continuum is reddened by the SMC extinction law of $E(B-V) = 0.72 \pm 0.01$ mag and the dusty materials are mainly associated with Ca II H and K rather than the Balmer and He I absorption-line system, (3) the unsaturated Balmer (Hβ, Hγ, and Hδ) and He I$^*$ absorption-line systems have the same two-Gaussian profiles as the shifts of $-931 \pm 33$ and $-499 \pm 39$ km s$^{-1}$ and the widths of $121 \pm 28$ and $196 \pm 37$ km s$^{-1}$, respectively. Constrained mutually by the Balmer, He I$^*$ absorption-line systems and undetected Fe II$^*$ λ5169 in the photoionization simulations, the physical properties of the outflow gases are derived as follows: ionization parameter $10^{-1.1} \lesssim U \lesssim 10^{-0.9}$, density $10^{19.2} \pm 0.4 \lesssim n_H \lesssim 10^{19.0} \pm 0.4$ cm$^{-3}$, and column density $10^{22.0} \pm 0.2 \lesssim N_H \lesssim 10^{22.2} \pm 0.3$ cm$^{-2}$. We propose that the ultra-dense BLR outflow gases appear in the vicinity of the surface of the BLR or are located at most $3.12$ pc away from the engine. That probably implies that the outflow originates from the BLR, and this kind of ultra-dense BLR scale outflow gases can effectively test the physical properties of the outer gases of the BLR.

Key words: galaxies: active – quasars: absorption lines – quasars: individual (SDSS J145057.28+530007.6)

1. Introduction

Early in the twentieth century, astronomers confirmed that our Milky Way galaxy is in reality just one of hundreds of billions of galaxies in the universe. Now we know that each massive galaxy consists of billions of stars, myriad clouds of gas and dust, and a supermassive black hole (SMBH) at its center. There are still some challenges remaining to be solved, such as “How do black holes grow, radiate, and influence their surroundings?” and “How do baryons cycle in and out of galaxies, and what do they do while they are there?” which are closely related to the topics of the SMBHs and host galaxies coevolution (e.g., Granato et al. 2004; Scannapieco & Oh 2004; Hopkins et al. 2008), and the properties of the gas clouds in the structures of active galactic nuclei (AGNs; e.g., Ferland & Osterbrock 1986; Peterson 1993; Netzer & Peterson 1997; Wang et al. 2013).

The blueshifted emission lines and blueshifted/redshifted intrinsic absorption lines are once believed to be a useful approach to diagnosing properties of outflowing (feedback to the host; e.g., Gaskell 1982; Weymann et al. 1991) or infalling (SMBH accretion; Shi et al. 2016b) gases at different scales. However, the blueshifted emission lines are generally mixed with the normal emission lines (e.g., Komossa et al. 2008; Wang et al. 2011; Zhang et al. 2011; Marziani et al. 2013; Liu et al. 2016), with three exceptions in which the blueshifted emission lines dominate the emission profiles (IRAS 13224–3809 and 1H 0707–495, Leighly & Moore 2004; SDSS J000610.67+121501.2, Zhang et al. 2017a). Meanwhile, the ubiquitous broad absorption lines (e.g., C IV and Mg II BALs) are commonly blended and saturated (e.g., Hall et al. 2002; Trump et al. 2006; Gibson et al. 2009; Zhang et al. 2010; Allen et al. 2011), and their variations can only assess the kinetic properties (e.g., Hall et al. 2011; Zhang et al. 2015b; RAFee et al. 2016) or whether variations of the ionization of gas (e.g., Hamann et al. 2008; Filiz Ak et al. 2013; Trevese et al. 2013; Wang et al. 2015; He et al. 2017). Thus, they are difficult to use to accurately study the physical condition and geometry of the gas winds.

The detection of absorption lines from hydrogen Balmer and metastable helium in NGC 4151 (Anderson 1974) rekindled the hope for the quantitative study of AGN absorption lines. (1) Both ions have multiple upward transitions in a wide wavelength span from the ultraviolet (UV) to the near-infrared (NIR), which are easy to observe. (2) There is no blending problem since the transitions are widely separated. (3) Multiple lines from the same lower level are very helpful in jointly determining the column density and covering factor of the lines (e.g., Arav et al. 2005). Meanwhile, H(n = 2) is sensitive to the gas density, while He I$^*$ is sensitive to the ionization state of the absorption gases (e.g., Arav et al. 2001; Ji et al. 2015). Thus, the absorptions of hydrogen Balmer and He I$^*$ can provide us abundant information about the absorption gases, such as velocity distribution, (column) density, ionization state, and, furthermore, distance from the ionization source and even kinetic energy and mass-flow rate. For that reason, samples of He I$^*$ BALs (Liu et al. 2015), He I$^*$ NALs (T. Ji et al. in preparation), and hydrogen Balmer absorption lines (X.-H. Shi et al. 2018, in preparation) have been explored in the Sloan Digital Sky Survey (SDSS; York et al. 2000) -I/II and -III quasar’s
spectral databases (Schneider et al. 2010; Pärk & Zhan et al. 2017) as well as in detailed studies by a few individuals (e.g., Aoki et al. 2006; Hall et al. 2007; Arav et al. 2008; Aoki 2010; Leighly et al. 2011, 2014, 2015; Zhang et al. 2015, 2017a; Shi et al. 2016a, 2016b, 2017; Sun et al. 2017).

In this work, we report on a quasar (SDSS J145057.28 +530007.6, hereafter SDSS J1450+5300) with an emission redshift of $z_{\text{em}} = 0.9166 \pm 0.0001$. SDSS J1450+5300 shows the broad absorption troughs of hydrogen Balmer (from H$\alpha$ to H$\delta$) and metastable helium (He I $\lambda\lambda3889, 10830$) with the width of $\sim 1200$ km s$^{-1}$, suggesting the ultra-dense broad-line region (BLR) scales outflow materials in the nuclear region. SDSS J1450+5300 is also the fifth Balmer BLR quasar after SDSS J125942.80 $+$121321.6 (Hall 2007; Shi et al. 2016a), LBQS 1206$+$1052 (Ji et al. 2012), SDSS J220245.59 $+$010931.2 (Ji et al. 2013), and SDSS J152350.42 $+$391405.2 (Zhang et al. 2015). The data we used will be described in Section 2. We will analyze the reddened continuum and absorption lines in Section 3 and will discuss the properties and possible origins of outflows in Section 4. A summary of our results will be given in Section 5. Throughout this paper, we adopt the cold dark matter “concordance” cosmology with $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_m = 0.3$, and $\Omega_{\Lambda} = 0.7$.

2. Observations

SDSS J1450+5300 is an infrared-luminous dust-reddened quasar. The broadband spectral energy distributions (SEDs) from the ultraviolet out to the infrared are presented by the photometric images taken with the SDSS at the $u, g, r, i$, and $z$ bands; the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) at the $J$, $H$, and $K_s$ bands, and the Wide-field Infrared Survey Explorer (WISE; Wright et al. 2010) at the W1, W2, W3, and W4 bands. The optical–NIR color–color diagram represents that SDSS J1450+5300 just meets the selection criteria of the FIRST-2MASS red quasar in Glikman et al. (2007). The multiband magnitudes are summarized in Table 1.

The optical spectrum of SDSS J1450+5300 was taken with the SDSS 2.5 m telescope on 2013 April 8, in the SDSS-III Baryon Oscillation Spectroscopic Survey (BOSS; Dawson et al. 2013) and published in the SDSS Twelfth Data Release (DR12; Alam et al. 2015). The BOSS spectrum has a wider wavelength range covering 361–1014 nm with a resolution of 1300 at the blue side and 2600 at the red side. There are strong broad/narrow emission lines of H$\beta$, H$\gamma$, [O III] and [O II] doublets, and Mg II, etc., and abundant remarkable absorption lines of the hydrogen Balmer series, He II $\lambda\lambda3889, 3850$ and Ca II H and K, in the “not-high” signal-to-noise ratio (S/N) spectrum.

Two years later, the NIR spectrum of SDSS J1450+5300 was performed with the TripleSpec spectrograph of the Hale 200 inch telescope (P200) at Palomar Observatory on 2015 May 26. Four exposures of 300 s each are taken in an A-B-A-B dithering model. TripleSpec (Wilson et al. 2004) provides simultaneous wavelength coverage from 0.9 to 2.46 $\mu$m at a resolution of 1.4–2.9 $\AA$ with two gaps at approximately 1.35 and 1.85 $\mu$m owing to the telluric absorption bands. The raw data were processed using IDL-based Spextool software (Vacca et al. 2003; Cushing et al. 2004). The H$\alpha$ emission/absorption lines and He II $\lambda\lambda$10830 absorption line are detected with the TripleSpec at the J and $K_s$ bands, respectively.

3. Data Analysis

3.1. Reddened Nuclear Continuum

In Figure 1, we plotted the broadband SED of SDSS J1450+5300 with brown squares in log-space. The multiband magnitudes are first corrected for the Galactic reddening of $E(B-V) = 0.017$ mag (Schlegel et al. 1998) and then transformed to the quasar’s rest frame. Meanwhile, the optical and NIR spectroscopic data are scaled to match the SDSS and UKIDSS photometry and are overplotted in the figure with black curves. The arch structure from $\sim$3000 A to 2 $\mu$m implies that the nuclear continuum is extremely reddened. As discussed in Zhang et al. (2017b), variability of the continuum strength and shape could be an issue in SDSS J1450+5300 because of the large time interval (8.8 years in the rest frame) between the observations. However, the perfect matching of the optical/NIR spectra simply multiplied by a factor and the broadband SED rule out the possibility of variability affecting the SED.

Because of the pollution of H$\alpha$ and H$\beta$ broad lines and optical Fe II multiplets we just chose the magnitudes at the $r$, $i$, $H$, $K_s$, and W1 bands without strong emission lines to constrain the continuum. The phenomenological model contains two components: (1) a reddened power-law continuum from the accretion disk using the SMC-type extinction law (Pei 1992), and (2) a hot dust emission from the dusty torus. Based on the above analysis, we can decompose the broadband SED (3000–20000 A in rest-frame wavelength) with the following model:

$$F_{\lambda} = C_{\text{nuclear}} A_{\text{nuclear}} (E(B-V), \lambda) \lambda^\alpha + C_{\text{bb}} B_{\lambda}(T_{\text{dust}}),$$

where $C_{\text{nuclear}}$ and $C_{\text{bb}}$ are the factors for the respective components, $A(E(B-V),\lambda)$ is the dust extinction to the power-law continuum, and $B_{\lambda}(T_{\text{dust}})$ is the Planck function. As the continuum slope and extinction are somehow degenerate, here $\alpha$ is fixed to $-1.7$ (the mean value of the quasar UV/optical continuum slope), which is the common recipe for reddened AGN continua in the literature (see, e.g., Dong et al. 2005, 2012 and Zhou et al. 2006). In addition, $T_{\text{dust}}$ is set to the dust sublimation temperature of $T_s = 1500$ K, which it is as the typical temperature of the hot dust in torus (e.g., Sanders et al. 1989). Thus, there are three free parameters, i.e., $E(B-V)$, $C_{\text{nuclear}}$, and $C_{\text{bb}}$, in the fitting. We perform least-squares minimization using the IDL procedure MPFIT (Markwardt 2009); the value of $E(B-V)$ is $0.72 \pm 0.01$ mag.

### Table 1

| Band | Magnitude | Date of Observation | Facility | References |
|------|-----------|---------------------|----------|------------|
| $u$  | 23.09 ± 0.47 | 2002 Sep 05         | SDSS     | 1, 2       |
| $g$  | 21.11 ± 0.04 | 2002 Sep 05         | SDSS     | 1, 2       |
| $r$  | 20.63 ± 0.04 | 2002 Sep 05         | SDSS     | 1, 2       |
| $i$  | 19.57 ± 0.03 | 2002 Sep 05         | SDSS     | 1, 2       |
| $z$  | 18.77 ± 0.05 | 2002 Sep 05         | SDSS     | 1, 2       |
| $J$  | 16.66 ± 0.14 | 1998 Jun 16         | 2MASS    | 3          |
| $H$  | 16.12 ± 0.21 | 1998 Jun 16         | 2MASS    | 3          |
| $K_s$ | 15.10 ± 0.18 | 1998 Jun 16         | 2MASS    | 4          |
| W1   | 13.53 ± 0.01 | 2010 Jun 24         | WISE     | 4          |
| W2   | 12.18 ± 0.01 | 2010 Jun 24         | WISE     | 4          |
| W3   | 9.36 ± 0.03  | 2010 Jun 24         | WISE     | 4          |
| W4   | 7.15 ± 0.06  | 2010 Jun 24         | WISE     | 4          |

References. (1) York et al. (2000), (2) Alam et al. (2015), (3) Skrutskie et al. (2006), (4) Wright et al. (2010).
In Figure 1, the best-fit model (red curve) is in good agreement with the continuum windows from the optical out to NIR wavelengths. The reddened power-law continuum and hot dust emission are also shown by green and pink curves. It should be noted that the SDSS spectrum has the “continuous” excess fluxes with the wavelength of $\lambda < 3000$ Å. The unusual Fe II emission gives an illusion of absorption troughs in the wavelength ranges of $\sim 2630–2730$ Å and $\sim 2755–2790$ Å. The analysis and discussion about the Fe II multiplets origin will be present in P. Jiang et al. (2018, in preparation), this work will focus on the absorption-line system of hydrogen Balmer and He I*.

### 3.2. Emission Lines

It becomes apparent that the “naked” eye can find the absorption of hydrogen Balmer and He I*. The absorption strength is generally measured by comparing the observed spectrum and the unabsorbed template. For the broad absorption troughs, there are two methods generally used to obtain the unabsorbed template, i.e., the “pair-matching” method (e.g., Zhang et al. 2014; Liu et al. 2015) and the spectral-decomposition method (for C IV, Gibson et al. 2008; for Mg II, Zhang et al. 2010; for H\(\alpha\) and H\(\beta\), Zhang et al. 2015). The pair-matching method is much more effective for the weak and shallow absorption troughs and the seriously mutilated emission-line profiles that are very hard to process with spectral decomposition. However, the weakness of the pair-matching method in all spectral components (continuum, Fe II multiplets, and broad emission lines) must have one unity covering factor; the spectral-decomposition method is more flexible for the absorption-line measurements.

It is essential that the unabsorbed broad-line profiles are determined through the spectral-decomposition method. The train of thought is briefly as follows: (1) The nuclear continuum and hot dust emission adopt the best-fitting result of the broadband SED. (2) The strength, shift, and width of the optical Fe II multiplets will be ascertained in the wavelength range of 4000–5400 Å (H\(\beta\), H\(\gamma\), H\(\delta\), and [O III] doublet are masked), which are also used for the Fe II emission under H\(\alpha\). (3) The multi-Gaussian profile is implied to model the isolated and uncomplicated H\(\alpha\) line. (4) The emission lines of H\(\beta\), H\(\gamma\), and H\(\delta\) are depicted by the scaled H\(\alpha\) profile. (5) The emission lines of He I $\lambda 10830$ and [Ne III] 3868 are directly described by one single-Gaussian curve.

In step (2), we adopt the I Zw 1 Fe II template provided by Véron-Cetty et al. (2004) and convolve it with a Gaussian kernel in velocity space to match the width of Fe II multiplets in the observed spectrum. There are six free parameters, i.e., the strength, shift, and width for broad and narrow Fe II components, respectively. The broadened Fe II template and the nuclear continuum join to form the so-called the “pseudo-continuum.” We subtracted the pseudo-continuum from the observed spectra and obtained the emission-line spectra of H\(\alpha\) and H\(\beta\). In the next steps, we just mask the potential absorption regions in the emission-line fitting. In the panels of Figure 2, we plot the observed optical/NIR fluxes and errors by black and gray curves. The reddened power-law continuum from the broadband SED fitting, broadened optical Fe II template are shown in pink and blue. The green curves represent the Gaussian components of H\(\alpha\), the whole profiles of H\(\beta\), H\(\gamma\), and
Hα, and also the single-Gaussian profiles of He I λ10830 and [Ne III] λ3868. The sum of the pseudo-continuum and emission lines are overplotted by the red curve.

### 3.3. Absorption Lines

After obtaining the emission-line spectrum, we will try to study the situation of gas absorption step by step. Let us first look at the top left panel of Figure 2: the bottom of the He I λ10830 absorption trough has reached the hot dust emission (orange curve), which implies the absorption gases completely obscure the accretion disk—the continuum source. Do the absorption gases completely or partially cover the BLR? The absorption troughs of hydrogen Balmer series can clarify the question.

Based on the fact that the accretion disk is completely obscured, for a given covering factor Cf of the absorption gases to the emission lines (broad emission lines and optical Fe II multiplets), the absorption-line spectrum (the normalized intensities) is

\[ I_\lambda = \frac{F_\lambda - (1 - Cf) F_\lambda^\text{ELine}}{F_\lambda^\text{Conti} + Cf F_\lambda^\text{ELine}}, \]

(2)

where \( F_\lambda \), \( F_\lambda^\text{ELine} \), and \( F_\lambda^\text{Conti} \) are the observed spectrum, the emission-line spectrum, and the nuclear continuum, respectively. Here, the absorption gases are assumed to have a unity covering factor in different velocities. The residual fluxes in the Hα trough are almost two times those in the Hβ trough; the BLR is partially obscured. Meanwhile, the troughs of He I λ10830 and Hα look like a flat-bottom; we guess that they probably are saturated. In this case, the covering factor is \( \text{Cf} = 0.39 \pm 0.03 \). We also traverse the parameter space \( (0.39 \leq \text{Cf} < 1.0) \) to search the available covering factor, which can ensure the absorption depths of the Hα, Hβ, and Hγ troughs match their known oscillator strengths. The attempt confirmed that the absorption of Hα is saturated, rather than the other Balmer lines. We adopted the above covering factor, calculated the normalized fluxes for hydrogen Balmer series and He I λ3889,10830, and presented their absorption troughs in velocity space in Figure 3. Overall, the absorption troughs in SDSS J1450+5300 are BALs (or mini-BALs), for example, the width of the Hα trough, with the observed spectrum falling at least 10% below the unabsorbed model, is 1214 km s\(^{-1}\).

Panels of Figure 3 show that the He I and hydrogen Balmer absorption lines have similar profiles; thus, we assume the He I and hydrogen Balmer absorbers share the same kinematic structure and can fit two Gaussians to the normalized fluxes of these lines. We first started with He I λ3889, since the He I λ3889 trough is clear and neat and has the highest S/N. The velocity shifts with respect to the quasar’s rest frame are \( -393 \pm 33 \text{ km s}^{-1} \) and \( -499 \pm 39 \text{ km s}^{-1} \) for the two components, respectively. The negative value means the absorption
lines are blueshifted. The widths are $121 \pm 28 \text{ km s}^{-1}$ for the high-velocity component and $196 \pm 37 \text{ km s}^{-1}$ for the low-velocity component. One can find that the sum of two Gaussians can reconstruct the transmission of He I $\lambda 3889$ very well. Second, we used two-Gaussian profiles with the same shifts and widths as those of He I $\lambda 3889$ to model the H $\beta$ trough; the depths of the two components are free and are contained by the bottom of the trough. In the panels of He I $\lambda 3889$ and H $\beta$, the Gaussian components and their sum are shown by green and red curves.

The true optical depth ($\tau_v$) as functions of radial velocity for the relevant ion is $\tau_v = -\ln I_v$, and then the column densities on the hydrogen $n = 2$ shell and metastable He$^0 2^3S$ as a function of velocity are calculated using the general expression (e.g., Arav et al. 2001)

$$N(\Delta \nu) = \frac{3.7679 \times 10^{14}}{\lambda_0 f_{ik}} \tau(\Delta \nu) \text{ [cm}^{-2} \text{ (km s}^{-1})^{-1}]$$

where $\lambda_0 = 4862.68$ and $3889.80 \text{ Å}$ are the wavelengths of the H $\beta$ and He I $\lambda 3889$ lines and $f_{ik} = 0.1190$ and 0.0644 are the corresponding oscillator strengths, respectively. We obtain the

Figure 3. Left: the normalized absorption profiles for H $\alpha$, H $\beta$, H $\gamma$, and H $\delta$ from top to bottom. Right: the normalized absorption profiles for He I $\lambda 10830$, He I $\lambda 3889$, and Ca II $\lambda 3933$. The theoretical double-Gaussian absorption troughs for hydrogen Balmer lines and He I $\lambda 3889,10830$ are overplotted in red, and the sky line spectrum (not scaled) is shown as a pink line in the panels.
The bolometric luminosity is estimated from the monochromatic luminosity using the conversion given by Rumrine et al. (2012), so \( L_{\text{bol}} = 0.75 \times 10^{4.39(\pm 0.16)(0.91(\pm 0.04))} \log_{10} L_{5100} = 6.08 \times 10^{46} \text{erg s}^{-1} \). In Zhang et al. (2015), the bootstrap approach showed that the uncertainty of \( L_{\text{bol}} \) is on the order of 10% (also see Dong et al. 2008). The derived Eddington ratio is thus \( \epsilon = L_{\text{bol}}/L_{\text{Edd}} = 0.57 \). Based on the bolometric luminosity, the amount of mass being accreted is estimated as \( M_{\text{acc}} = \frac{L_{\text{bol}}}{\dot{M}_0} \), where we assumed an accretion efficiency \( \eta \) of 0.1 and \( c \) is the speed of light. The radius of BLR, \( R_{\text{BLR}} \), can be estimated using the formula based on the luminosity at 5100 Å, \( R_{\text{BLR}} = \alpha (L_{5100}/10^{44} \text{erg s}^{-1})^{1/2} \) light-days. The parameters \( \alpha \) and \( \beta \) are 30.2 ± 1.4 and 64 ± 0.02 in Greene & Ho (2005) and 20.0 ± 2.2 and 0.67 ± 0.07 in Kaspi et al. (2005), respectively. Thus, the luminosity yields \( R_{\text{BLR}} = 0.54 \pm 0.60 \) pc. Meanwhile, the radius of the inner side of the dusty torus (the dust sublimation radius), \( R_{\text{torus}} \), can also be estimated based on the thermal equilibrium as \( R_{\text{torus}} = \sqrt{\frac{\text{L}_{\text{bol}}}{4\pi\sigma T^4}} \), where \( \sigma \) is the Stefan-Boltzmann constant, \( T \) is the temperature of the inner side of the torus (Barvainis 1987). Then, we get \( R_{\text{torus}} = 8.56 \) pc. Similarly, the extended scales of the torus are on the scale of 10 pc (Kishimoto et al. 2011; Burscher et al. 2013).

To investigate the physical properties for the absorption gases, we use the photoionization synthesis code Cloudy (V16.0; last described by Ferland et al. 1998) simulations and confront these models with the measured column densities of ions to determine the density \( N_{\text{H}} \), the column density \( N_{\text{He}} \), and the ionization parameter \( U \). We consider a gas slab illuminated by a continuum source in the extensive parameter space. The absorption gases are assumed to have unity density and a homogeneous chemical composition of solar values and be free of dust. The incident SED applied is a typical AGN multicomponent continuum described as a combination of a blackbody “Big Bump” and power laws. We calculated a series of photoionization models with different ionization parameters, electron densities, and hydrogen column densities. The ranges of parameters are \(-2 \leq \log_{10} U \leq 0\), \( 0 \leq \log_{10} N_{\text{H}} \leq 13 \), and \( 20 \leq \log_{10} N_{\text{He}} \leq 24 \) with a step of 0.1 dex.

We extract the resultant column densities on the hydrogen \( n = 2 \) shell and metastable He\(^{2+}\)S from the Cloudy simulations and show them by the red and green lines in Figure 4. The red and green areas show the observed 1σ uncertainty ranges of \( N_{\text{H}(n=2)} \) and \( N_{\text{He}^{1+}} \), so the overlapping region is the possible parameter space \( U > 10^{-1.4} \), \( n_{\text{He}} \sim 10^{-6} \text{cm}^{-3} \), \( N_{\text{H}} > 10^{21.8} \text{cm}^{-2} \) for the absorption gases of SDSS J1450 +5300. Shi et al. (2016a) used the isolated optical Fe\( ^{II} \) lines further to narrow the possible parameter space. The undetected Fe\( ^{II} \) λ5169 gave the upper limit of the column density as \( 3.37 \times 10^{14} \text{cm}^{-2} \) for the Fe\( ^{II} \) λ6364 S/\( \gamma = 2 \) level (yellow area in Figure 4); otherwise, the Fe\( ^{II} \) λ5169 absorption trough will be detected at the 2σ level. We find that the addition of Fe\( ^{II} \) λ5169 largely compresses the parameter space of the (column) density in the range of \( U \sim 10^{-1.4} \), however, it is no help to constrain the ionization parameter \( U \). The only valid limit for the ionization parameter is still \( U > 10^{-1.4} \). If we adopted \( 0.3 \leq U \leq 10 \) as the ionization parameter range of the BLR (Netzer 1993), the upper limit of the absorption gases should be less than 0.3. In fact, the ionization parameter cannot reach such a high value. Based on the distance estimation of the absorption gases in the next paragraph, the gas winds have been located on the surface of the BLR (\( R \sim 0.54 - 0.6 \) pc) with the ionization parameter of \( U \sim 10^{-0.8} \). Thus, the value of \( U \sim 10^{-0.8} \) is used as the upper limit of the ionization parameter of the absorption gases. For the lowest ionization parameter of \( U = 10^{-1.4} \), the (column) densities are \( n_{\text{He}} = 10^{8.2(\pm 0.4)} \text{cm}^{-3} \) and \( N_{\text{H}} = 10^{22.0(\pm 0.2)} \text{cm}^{-2} \), and they will be \( n_{\text{He}} = 10^{9.0(\pm 0.4)} \text{cm}^{-3} \) and \( N_{\text{H}} = 10^{22.2-22.3} \text{cm}^{-2} \) when the ionization parameter is equal to the highest value of \( U = 10^{-0.8} \).

Based on \( U \) and \( n_{\text{He}} \) determined by Cloudy, we estimate the distance (\( R \)) of the absorption gases away from the central source. \( U \) depends on \( R \) and the rate of hydrogen-ionizing photons emitted by the central source \( Q \), as follows, \( U = Q/4\pi R^2 n_{\text{H}} c \), in which \( c \) is the speed of light. To determine the \( Q \), we scale the AGN multicomponent continuum to the extinction-corrected flux of SDSS J1450+5300 at 5100 Å and then integrate over the energy range \( hv \geq 13.6 \text{eV} \). This yields \( Q = 2.16 \times 10^{26} \text{photons s}^{-1} \). Using this \( Q \) value together with the derived lower limit of the ionization parameter \( U = 10^{-1.4} \) and the density of \( n_{\text{H}} = 10^{8.2(\pm 0.4)} \text{cm}^{-3} \), the upper limit of \( R \) can be derived to as \( \sim 3.1 \) pc. With the increase in the ionization parameter, the absorption gases will gradually close (reach) to the surface of the BLR. However, if the spectral S/\( \gamma / N \) of the Fe\( ^{II} \) λ5169 regime are increased by 10 times in the possible future observation with more exposure time, the upper limit of \( N_{\text{Fe}^{II}} \) will be lowered, and the ionization parameter will be limited to \( U \geq 10^{-1.2} \). Thus, we are more inclined to believe that the absorption gases in SDSS J1450+5300 attach to the BLR or appear in the vicinity of the surface of the BLR. Among cases with Balmer and/or H\( ^{I} \) absorbers, the absorber in SDSS J1450+5300 is the second nearest from the central engine, except SDSS J152350.42+391405.2 (Zhang et al. 2015), whose absorption gases are located at a distance of \( \sim 0.2 \) pc (slightly farther than that of the BLR). Other cases are spread about on the scale from several parsecs (Shi et al. 2016a, 2016b; low-velocity component, Sun et al. 2017), dozens of parsecs (Zhang et al. 2017a) to even hundreds of
Figure 4. Predicted ionic column densities from the photoionization simulations by Cloudy with $U$ from $10^{0.0}$ to $10^{1.5}$ as functions of $n_H$ and $N_{H}$. The attached numbers are logarithms of ionic column densities. The red, green, and yellow contours show the ions of $\text{H}_2^+$, $\text{He}^+2\text{S}$, and $\text{Fe}^+\text{S}_{6/2}$, and their measured column densities are overplotted by the corresponding colored areas.

parsec (Leighly et al. 2014; Ji et al. 2015) or kiloparsecs (high-velocity component; Sun et al. 2017). Meanwhile, the high density of $n_H \approx 10^5$ cm$^{-3}$ in SDSS J1450+5300 is also present in SDSS J152530.42+391405.2 (Zhang et al. 2015), SDSS J125942.80+121312.6 (Shi et al. 2016a), SDSS J112526.12+002901.3 (Shi et al. 2016b), and LBQS 1206+1052 (low-velocity component; Sun et al. 2017). Interestingly, Kaastra et al. (2014) reported a fast long-lived outflow in NGC 5548. The clumpy stream of ionized gas blocks 90% of the soft X-ray emission and causes deep BAL broad troughs and it is at a distance of only a few light days from the nucleus (likely originating from the accretion disk). We also notice the similar properties (highly reddened and the small distance between the absorber and the nucleus) in SDSS J1450+5300; the absorber in SDSS J1450+5300 may be another case. Possible high-resolution X-ray and UV observations in the future would tell the similarities and differences between them.

Assuming that the absorption materials can be described as a thin partially filled shell, the average mass-flow rate ($\dot{M}$) and kinetic luminosity ($\dot{L}_k$) can be derived as $\dot{M} = 4\pi R \Omega \mu m_p N_H v$ and $\dot{L}_k = 2\pi R \Omega \mu m_p N_H v^3$ (Borguet et al. 2012), where $R$ is the distance of the outflows from the central source, $\Omega$ is the global covering fraction of the outflows, $\mu = 1.4$ is the mean atomic mass per proton, $m_p$ is the mass of proton, $N_H$ is the total hydrogen column density directly derived from the photoionization modeling of the outflow gases, and $v$ is the flux weighted-averaged velocity of the absorption gases. Here, we adopted $R \approx 0.6$–3.1 pc, $\Omega(\equiv \chi) = 0.39$, $N_H = 10^{21.8}$–22.3 cm$^{-2}$, and $v \approx 600$ km s$^{-1}$, then the kinetic luminosity and mass-loss rate are calculated as $\dot{L}_k = (0.4–2.3) \times 10^{41}$ erg s$^{-1}$ and $\dot{M} = 0.7$–11.6 $M_\odot$ yr$^{-1}$. The kinetic luminosity of SDSS J1450+5300 is just able to meet the reported lower limit on the kinetic luminosity ($\dot{L}_k \sim 10^{45}$ erg s$^{-1}$; e.g., Scannapieco & Oh 2004; Di Matteo et al. 2005; Hopkins & Elvis 2010) to efficiently drive AGN feedback.

From the spectral decomposition, we know that the Balmer decrement is $\text{H}_\alpha/\text{H}/3 = 5.16 \pm 0.15$; however, the intrinsic value of $\text{H}_\alpha/\text{H}/3$ of the BLR is 3.06 with a standard deviation of 0.03 dex (Dong et al. 2008). The observed Balmer decrement suggests that the BLR is reddened by $E(B-V) = 0.57 \pm 0.03$ mag using the SMC-type extinction law, which is smaller than the extinction obtained from the nuclear continuum. This inference is consistent with the fact that the absorption gases partially obscure the BLR. That is why we use the $M_{\text{BLR}} - L_{5100}$ formalism rather than the $M_{\text{BLR}} - L_{160}$ formalism in the estimation of the black hole mass. Meanwhile, one can clearly find the absorption troughs of Ca II H and K in the optical spectrum of SDSS J1450+5300. In the third panel of
the column of Figure 3, we also show the normalized absorption fluxes of Ca II H, which are easily described by a single-Gaussian profile with a blueshifted velocity of 309 ± 33 km s⁻¹ and a width of 232 ± 39 km s⁻¹. Obviously, Ca II H and K absorption lines have different velocity structures from those of hydrogen Balmer and He I. The above results raise the question: “Which absorption system is the dust completely (or partly) associated with?” Two factors of $E_{\text{nuclear}}^{-}(B-V)$ and $E_{\text{host}}^{-}(B-V)$ are set to represent the extinction associated with the absorption of hydrogen Balmer and He I (the gases in the nuclear region) or Ca II H and K (the gases in the host galaxy), which will meet the following conditions:

$$E_{\text{nuclear}}^{-}(B-V) + E_{\text{host}}^{-}(B-V) = 0.72 ± 0.01 \text{ mag},$$

Then the extinction in the nuclear region is $E_{\text{nuclear}}^{-}(B-V) = 0.21 ± 0.04 \text{ mag}$. The dusty materials are mainly associated with Ca II H and K absorption lines and exist in the host galaxy. That implies that the dust-free model we adopted in the Cloudy simulation is approximately reasonable to a certain extent.

5. Summary

In this paper, we present a detailed analysis of the SDSS-III/BOSS optical spectrum and the newly obtained P200 TripleSpec NIR spectrum for SDSS J1450+5300. The object is highly dust reddened with an extinction of $E(B-V) = 0.72 ± 0.01 \text{ mag}$ under the SMC extinction law, which is dominated by the dusty materials associated with Ca II H and K rather than the hydrogen Balmer and metastable helium absorption system. SDSS J1450+5300 is classified as the fifth Balmer BAL quasar based on the widths of Balmer (Hα, Hβ, Hγ, and Hδ) absorption troughs. Indeed, the troughs of Hα and He Iλλ3889 are saturated, and the other unsaturated Balmer and He Iλλ3889 absorption lines are modeled by the two-Gaussian profiles with the center velocity shifts of $−931 ± 33$ and $−499 ± 39 \text{ km s}^{-1}$ and the widths of 121 ± 28 and 196 ± 37 km s⁻¹, respectively. The advantage of multiple lines of hydrogen Balmer and He Iλλ3889 absorption lines is sensitive to the ionization state of the absorption gases. The depths of hydrogen Balmer and He Iλλ3889 absorption troughs suggest that the accretion disk is completely obscured by the outflow gases and the covering factor of the BLR is only 0.39 ± 0.03. The total column densities are $N_{\text{H}}(n=2) = (4.89 ± 1.07) \times 10^{14} \text{ cm}^{-2}$ and $N_{\text{He}^{1+}} = (1.01 ± 0.19) \times 10^{13} \text{ cm}^{-2}$ when integrating the true optical depth. Extensive photoionization models are calculated using Cloudy. Together with the undetected Fe II, the physical parameters of the absorption gases are constrained to be $10^{−1.4} < U < 10^{−0.8}$, $10^{(2.5±0.4)} < N_{\text{H}} < 10^{(0.0±0.4)} \text{ cm}^{-3}$, and $10^{2.5±0.5} < N_{\text{He}^{1+}} < 10^{2.5±0.5} \text{ cm}^{-2}$. The absorption gases are estimated to be in the vicinity of the surface of the BLR or, at most, 3.12 pc away from the central engine.

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