Photoionization-driven Absorption-line Variability in Balmer Absorption Line Quasar LBQS 1206+1052

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Abstract

In this paper we present an analysis of absorption-line variability in mini-BAL quasar LBQS 1206+1052. The Sloan Digital Sky Survey spectrum demonstrates that the absorption troughs can be divided into two components of blueshifted velocities of \( \sim 700 \) and \( \sim 1400 \, \text{km s}^{-1} \) relative to the quasar rest frame. The former component shows rare Balmer absorption, which is an indicator of high-density absorbing gas; thus, the quasar is worth follow-up spectroscopic observations. Our follow-up optical and near-infrared spectra using MMT, YFOSC, TSpec, and DBSP reveal that the strengths of the absorption lines vary for both components, while the velocities do not change. We reproduce all of the spectral data by assuming that only the ionization state of the absorbing gas is variable and that all other physical properties are invariant. The variation of ionization is consistent with the variation of optical continuum from the V-band light curve. Additionally, we cannot interpret the data by assuming that the variability is due to a movement of the absorbing gas. Therefore, our analysis strongly indicates that the absorption-line variability in LBQS 1206+1052 is photoionization driven. As shown from photoionization simulations, the absorbing gas with blueshift velocity of \( \sim 700 \, \text{km s}^{-1} \) has a density in the range of \( 10^9 \) to \( 10^{10} \, \text{cm}^{-3} \) and a distance of \( \sim 1 \) pc, and the gas with blueshift velocity of \( \sim 1400 \, \text{km s}^{-1} \) has a density of \( 10^9 \, \text{cm}^{-3} \) and a distance of \( \sim 1 \) kpc.

Key words: galaxies: active – galaxies: evolution

1. Introduction

The spectra of the majority of quasars show absorption lines, which can give us information on the intermediate gas. The absorption lines can be divided into three classes according to the widths of the absorption lines (e.g., Weymann et al. 1991): broad absorption lines (BALs, >2000 km s\(^{-1}\)), narrow absorption lines (NALs, <500 km s\(^{-1}\)), and mini-BALs (500–2000 km s\(^{-1}\)). All BALs and mini-BALs, as well as a part of NALs, are intrinsic absorption lines that are formed by gas associated with the quasar. They are good diagnostic tools for the surrounding environment of quasar nuclei. Most intrinsic absorption lines are blueshifted with respect to the corresponding emission lines, implying that the gas is flowing out of the center. The study of these blueshifted absorption lines can increase our understanding of outflow and quasar feedback, which play a crucial role in the context of galaxy formation and evolution (e.g., Di Matteo et al. 2005).

It has long been known that BAL and mini-BAL systems are variable on timescales from years to months (e.g., Foltz et al. 1987; Smith & Penston 1988; Barlow et al. 1989). Monitoring of BAL samples found that more than 60% of BAL and mini-BAL quasars display variability on timescales of years, and that the fraction of BALs showing variability increases with increasing observing intervals (Capellupo et al. 2011; Filiz Ak et al. 2013). Almost all BALs vary in depth, with only a minor portion of BALs exhibiting a measurable change in velocity and width (Grier et al. 2016), indicating that the BAL variability is mainly caused by either movement of absorbing gas across our line of sight or a change in ionization state. Studies of individual sources show evidence for both origins, with some supporting the scenario of moving absorbing gas (e.g., Capellupo et al. 2014; He et al. 2014; Muzahid et al. 2016) and others supporting the scenario of varying ionization state (e.g., Grier et al. 2015; Saturni et al. 2016; Wildy et al. 2016). However, which of the two dominates among all BAL quasars is still under debate. Capellupo et al. (2013) found variations in only portions of BAL troughs or in lines that are optically thick, suggesting that at least some of the changes are caused by clouds moving across our lines of sight. On the other hand, Filiz Ak et al. (2014) argued that a large fraction of BAL variability was caused by ionization because the variability amplitude of Al \( \text{III} \) is larger than that of C \( \text{IV} \). Wildy et al. (2014) found no strong correlation between the variation and continuum luminosity and then concluded that ionization change is not important. However, Wang et al. (2015) investigated a large sample of Sloan Digital Sky Survey (SDSS) quasars and showed that the equivalent widths of the lines decrease or increase statistically when the continuum brightens or dims, supporting the ionization-driven model. Furthermore, He et al. (2017) used a statistical analysis to demonstrate that at least 80% of the BAL variability is driven by the variation of the ionizing continuum.

The former studies mostly focus on high-ionization BALs (HiBALs) such as C \( \text{I} \) and Si \( \text{IV} \). About 15% of optically selected BAL quasars show low-ionization BALs (LoBALs) besides HiBALs, such as Mg \( \text{II} \) and Al \( \text{III} \), and the fraction may be more in the infrared-selected BAL quasars (e.g., Voit et al. 1993). There is evidence that LoBAL quasars have higher dust reddening (e.g., Zhang et al. 2010) than non-BAL quasars, suggesting that they may be at a transition phase from ultraluminous infrared galaxies to unobscured luminous...
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quasars. Neutral helium absorption lines He $\upnu^* \lambda 10830, 3889, 3189$ (transitions from 2p, 3p, 4p from the metastable 2s level in the He $\upnu$ triplet) provide important information on the absorbing media. The $\lambda 3889$ line was noticed early (e.g., Anderson & Kraft 1969), while the $\lambda 10830$ line was first found in active galactic nuclei (AGNs) by Leighly et al. (2011). Liu et al. (2015, hereafter Liu15) demonstrated that He $\upnu^*$ absorption could be detected in most Mg II LoBAL quasars if the spectral signal-to-noise ratios (S/Ns) are high enough. This means that He $\upnu^*$ absorptions are more common than we thought. Liu15 and Ji et al. (2015) found that the ionization state of an irradiated medium can be solely determined by the column density of He $\upnu^*$ if the medium is thick enough and the ionizing front is well developed. The variability of LoBAL quasars has not yet been substantively examined. Early tests (e.g., Vivek et al. 2014) failed to reach a clear conclusion on the dominating cause of LoBAL variability. We propose that He $\upnu^*$ can distinguish the two possible origins of BAL variability, because it has advantages compared with traditional ions such as Mg II and Al III: (1) He $\upnu^*$ multiplets are well separated and do not suffer from the blending problem; (2) the optical depths of He $\upnu^*$ multiplets cover a large range, such as the optical depth depth of He $\upnu^*$ $\lambda 10830$/He $\upnu^*$ $\lambda 3889 = 23.1$, and thus they are powerful in determining the covering condition of the absorbing gas and the ionic column density at the same time. An example was given in Wildy et al. (2016) and will also be given in this work.

There is a rare population among LoBAL quasars that shows intrinsic hydrogen Balmer absorption lines. It was first noticed in Hutchings et al. (2002), and so far there are only about 10 reported (see Zhang et al. 2015, for a review). The origin of these Balmer absorbers is still a mystery, and former researchers believed that it comes from the high-density medium ($n_H > 10^6$ cm$^{-3}$). Balmer absorption lines are rare but important because they can provide unique information on the high-density gases in the AGN environment, which is difficult to investigate via other approaches. For example, we can obtain the density of the gas from the strength of the Balmer absorption, and hence the distance of the gas to the central ionizing source can be determined using the density and the ionization parameter (e.g., Zhang et al. 2015; Shi et al. 2016b, 2016a). Moreover, the monitoring of Balmer BALs can offer additional information. For example, Shi et al. (2016b) reported the Balmer absorption line variability in SDSS J125942.80+121312.6 due to changes in the covering factor and hence obtained the transverse velocity of the absorbing gas. In this work, we will show that monitoring of a Balmer BAL can help to constrain the density of the absorbing gas and then the distance to the quasar nucleus.

LBQS 1206+1052 was identified during the large bright quasar survey (Hewett et al. 1995) and was classified as a LoBAL quasar (Gibson et al. 2009). The Balmer absorption lines in the quasar were identified by Ji et al. (2012, hereafter Ji12) based on the SDSS spectrum. Ji12 divided the BAL troughs into two components. One component shows an identical profile in Balmer, He $\upnu^*$, and Mg II with its centroid blueshifted by $v \approx -726$ km s$^{-1}$. The other component is detected in He $\upnu^*$ and Mg II with $v \approx -1412$ km s$^{-1}$. Ji12 concluded that Balmer BALs may originate in a partially ionized region via Ly$\alpha$ resonant scattering pumping, and that the gas has a column density $N_H$ in the range of $10^{21}$ to $10^{22}$ cm$^{-2}$ and a density $n_H$ in the range of $10^8$ to $10^9$ cm$^{-3}$.

The high brightness of LBQS 1206+1052 (SDSS $i$-band magnitude of 16.50) makes it an excellent candidate for long-term spectroscopic follow-ups, which are crucial to absorption-line studies. We made follow-up spectrographic observations using the Multiple Mirror Telescope (MMT) red channel and the Yunnan Faint Object Spectrograph and Camera (YFOSC) in 2012 to extend the wavelength coverage to better recover the absorption-free spectrum in H$\alpha$ and Mg II regions. We also took the near-infrared (NIR) spectrum using the P200 Triple Spectrograph (TSpec) in 2013 February to obtain the He $\upnu^*$ $\lambda 10830$ absorption line. Intriguingly, the follow-up observations revealed that the absorption lines have a large amplitude variability. Thus, we made further follow-up observations to study the variability. We analyzed the absorption-line variability in LBQS 1206+1052 by recovering the absorption-free spectra and deriving the absorption troughs (Section 3). We then examined the two possible origins of variability (Section 4).

2. Observation and Data Reduction

LBQS 1206+1052 was observed by the SDSS 2.5 m telescope on 2003 March 24 with an exposure time of 3165 s. The SDSS spectrum was retrieved from the SDSS Data Release 7 database. The wavelength coverage of the SDSS spectrum is 3800–9200 Å, and the spectral resolution is 1500–2500. We obtained follow-up optical spectroscopy of LBQS 1206+1052 with the Red Channel spectrograph of the 6.5 m MMT on 2012 March 01, the YFOSC of the Gaomeigu 2.4 m telescope at the Lijiang station of Yunnan Astronomical Observatories (YNAO) on 2012 May 07 and 2016 January 08, and the Double Spectrograph (DBSP) of the Hale 200-inch telescope at Palomar Observatory on 2014 April 24. For the MMT observation, we used a grating with 1200 lines mm$^{-1}$ that blazed at 1st/7700, and we set the blaze angle to get a wavelength coverage of 8770–9520 Å. The exposure time was 500 s. We used a 1.0 × 180 slit and obtained a spectral resolution of $\lambda/\Delta\lambda \sim 3500$ (FWHM) as measured on the night-sky lines. For the two YFOSC observations, we used the blue-band grism G14, which provided a wavelength coverage from 3500 to 7500 Å. For the 2012 observation, we used a slit with a width of 1′′8. Two exposures of 40 minutes each were taken. For the 2016 observation, we used a slit with a width of 2′′5. The total exposure time was ~43 minutes. The median resolutions are ~500 and ~420 for the 2012 and 2016 observations, respectively. For the DBSP observation, we used a 600/4000 grating for the blue side and a 600/10,000 grating for the red side, and a D68 dichroic was selected. This setting yielded a wavelength coverage of 2977–6027 Å and 7821–11181 Å. We used a 1′′5 slit during the night. The median resolution is ~1200 for the blue side and ~2800 for the red side. The MMT, YFOSC, and DBSP spectroscopic data were reduced following the IRAF standard routine. Wavelength calibration was carried out using an He–Ne–Ar lamp for YFOSC and Fe–Ar and He–Ne–Ar lamps for DBSP, which were taken on the same night during the observations. We used the night-sky lines for the wavelength calibration of the MMT Red Channel. The standard stars were observed for flux calibrations just before or after the observations of LBQS 1206+1052 each night.

We also took NIR spectra using TSpec of the Hale 200-inch telescope on 2013 February 23, 2015 May 26, and 2015 December 28. The observations were carried out in A-B-B-A
dithering mode, and the total exposure time was 12, 20, and 9 minutes for the three observations, respectively. For all three observations, slits with a width of 1" were used, and the spectral resolutions were ∼2200 in H band, where the He I λ10830 line is located. The data were reduced with the specX package. The information for all of the optical and NIR spectrometries of LBQS 1206+1052 is listed in Table 1, and the spectra are plotted in Figure 1 in rest frame according to the equations and synthetic magnitudes in Bessel bands. We converted the magnitude in V-band using SDSS spectra. The SDSS photometric data is plotted in Figure 2. We also plotted the synthetic magnitudes in Bessel V-band using SDSS, YFOSC, and DBSP spectra.

Table 1
Summary of Spectral Observations of LBQS 1206+1052

| Instrument | Obs. Date | Exposure (s) | Rest-frame Wavelength (Å) | S/N* | Resolutions^a |
|------------|-----------|--------------|--------------------------|------|---------------|
| SDSS       | 2003/03/24| 3165         | 2720–6608                | 46   | 2800, 3889    |
| HST/COS    | 2010/05/08| 4840         | 819–923 and 931–1034^b   | ...  | 4862, 6563    |
| MMT/Red Channel | 2012/03/01 | 500         | 6284–6823                | ...  | 10830         |
| Lijiang/YFOSC | 2012/05/07 | 720         | 2410–5540                | 34   |               |
| DBSP       | 2015/05/26| 600          | 2262–4191 and 5616–7673^d| 37   |               |
| TSpec      | 2015/12/28| 1400         | 5616–10760               | 12   |               |
| YFOSC      | 2016/01/08| 2590         | 2410–5540                | 23   |               |

Notes.

^a The signal-to-noise ratio per angstrom, which is measured at ∼3800 Å for SDSS, DBSP, and YFOSC and at ∼12000 Å for TSpec.
^b The spectral resolution R = λ/FWHM. For the eight optical and NIR observations, we listed the resolutions at rest-frame wavelengths of 2800, 3889, 4862, 6563, and 10830 Å, corresponding to Mg II, He I λ3889, Hβ, Hα, and He I λ10830 regions.
^c The wavelength ranges of the two CCD chips.
^d The wavelength ranges of the blue and red sides of DBSP.

Figure 1. Snapshots of the five optical spectra and three NIR spectra of LBQS 1206+1052. The observed wavelengths are converted to rest-frame vacuum wavelengths using z = 0.3953. The instruments and the dates of the observations are labeled.

http://nessi.cacr.caltech.edu/DataRelease/
3. Variability of Quasar Absorption Lines

We compared the observed spectra \( f_{\text{obs}} \) in regions around major absorption lines, including Mg II \( \lambda \lambda 2796, 2803 \), He I \( \lambda \lambda 10830, 3889, 3189, 2946 \), H\(\alpha\), H\(\beta\), and H\(\gamma\), in Figure 3. The variability is notable even without any normalization. The red part of the He I \( \lambda 10830 \) absorption trough became deeper in 2015 relative to 2013. The Mg II absorption trough in the YFOSC 2012 spectrum is shallower than in the SDSS 2003 and DBSP 2014 spectra, indicating a
process of becoming weak and then strong. The variability of Mg II cannot be interpreted as a result of lower spectral resolution of the YFSOC spectrum, because the disparity is still significant after we blurred the SDSS and DBSP spectra, so that all three have the same resolution.

For a further investigation of the absorption lines, we analyzed the spectra via the common procedure, including recovering the absorption-free spectra, decomposing emission components, and generating normalized absorption spectra.

### 3.1. Recovering the Absorption-free Spectra Using the Pair-matching Method

We needed to recover the absorption-free spectra ($f_{\text{AbsFree}}$) to analyze the variability in more detail. A reliable method to obtain the absorption-free spectra is the pair-matching method (e.g., Leighly et al. 2011). This method is based on the similarity of continua and emission-line profiles between quasars with and without absorptions. It is always possible to find enough unabsorbed quasars whose spectra resemble the spectral features surrounding the absorption line of a given absorbed quasar. This method has a big benefit such that the systematic error of the model can be taken into account. Liu15 developed the pair-matching method to analyze MgII and HeI components, and generating normalized absorption spectra. Then the total measurement of BAL parameters, such as centroids, widths, and integrated optical depths. We propose a new method to estimate the uncertainty of BAL parameters in the fitting based on the Monte Carlo algorithm. As with the previous method, we also considered both origins of errors. To account for the random error, we generated fake spectra $f_{\text{fake}}$ using observed flux and error as

$$f_{\text{fake}}(\lambda) = f_{\text{obs}}(\lambda) + R(\lambda) \times \text{error}_{\text{obs}}(\lambda),$$

where $R(\lambda)$ is a series of random numbers in standard normal distribution. To account for the systematic error, we randomly selected one template from the accepted fits for each pair-matching region. The fitting procedure was then done using the fake spectrum and the absorption-free templates by minimizing $\chi^2$, which is expressed as

$$\chi^2 = (f_{\text{obs}}(\lambda) - f_{\text{model}}(\lambda))^2 \times \text{Weight}(\lambda).$$

The computation of Weight(\lambda) considers both origins of errors as

$$\text{Weight}(\lambda) = \frac{1}{\text{error}_{\text{obs}}^2(\lambda) + \text{Stddev}(\lambda)},$$

where Stddev(\lambda) is the standard deviation spectrum of the accepted absorption-free templates for each pixel. We repeated the measurement 500 times to derive distributions of the BAL parameters. We referred to the median value of the distribution as “the best value” of the BAL parameters, and the interval between 5% and 95% ranked values as the “90% confidence interval.”

We examined whether this method can produce good estimations of BAL parameters and their uncertainties by generating fake absorbed spectra using unabsorbed spectra and given profiles, then fitting them using the above method, and then comparing the best-fitting BAL parameters with the given ones. The details are described in Appendix B. From the testing result, we can say that the 90% confidence intervals of BAL parameters obtained from our method are reliable. Throughout this paper, we have measured the BAL parameters using this method.

We can measure the BAL EWs following previous works, and we can also do that using our method. In Appendix B we tested our method and found that the 90% confidence interval of BAL EWs is also reliable. This means that when measuring the BAL EWs, our method is as good as the previous method, and thus we also used our method. In Section 3.3, we attempted to measure the EW ratio between two observations of the same object. We also used our method, though we did not test its behavior in this situation.

### 3.2. Emission Component Decomposition

Quasar UV–optical spectra typically consist of power-law components representing thermal emission from the accretion disk, broad emission lines (BELs), narrow emission lines (NELs), a Balmer continuum component for the blue bump in the wavelength region bluer than 3645 Å, and blended Fe II emission lines. We built a model in which the emission of LBQS 1206+1052 comes from three regions: the accretion disk, the broad emission line region (BELR), and the narrow emission line region (NELR), and the emission components are expressed as $f_{\text{AD}}$, $f_{\text{BELR}}$, and $f_{\text{NELR}}$ hereafter. In the model, the Balmer continuum and Fe II emissions are believed to have
come from the BELR. We modeled the optical spectra of SDSS 2003, YFOSC 2012, DBSP 2014, and YFOSC 2016 by a procedure described in detail in Ji12. We first fit the emission-line-free regions (2855–3010 Å, 3625–3645 Å, 4170–4260 Å, 4430–4770 Å, 5080–5550 Å, 6050–6200 Å) using a “pseudo-continuum” model consisting of a power-law component, a Balmer continuum component, a blended high-order Balmer emission line component, and an Fe II component, by minimization of \( \chi^2 \). The MMT 2012 spectrum does not cover emission-line-free regions; thus, we rescaled the DBSP spectrum to fit the MMT spectrum in the ranges of 6300–6450 Å and 6700–6820 Å and derived the pseudo-continuum model for MMT using the rescaled DBSP model. After subtracting the pseudo-continuum model, we applied a joint fit of the five continuum-subtracted spectra using Gaussians simultaneously by assuming the following: (1) all of the profiles of BELs and NELs are double Gaussian; (2) the profiles of all the BELs in one spectrum are identical; (3) the profiles of each NEL in all five spectra are identical; (4) the profiles of NELs from the same ion are identical; (5) the flux ratios of [N II], [O III], [Ne III], and [Ne V] doublets are fixed at theoretical values. In the windows affected by absorption lines, we used the absorption-free spectra in the fit instead of the observed spectra. The decomposition results of the optical spectra are shown in Figure 5.

For NIR spectra, we are only concerned with the region around the He I* \( \lambda 18380 \) line. The spectra here only contain continua, BELs, and NELs. We fit the continua phenomenologically using power laws in the emission-line-free windows of 10200–10500 Å, 11500–12400 Å, and 14200–15000 Å. The continuum-subtracted spectra around He I* \( \lambda 10830 \) were then fitted by using a model consisting of He I \( \lambda 10830 \) BEL, Pa\( \gamma \)
BEL, and He I $\lambda 10830$ NEL and by assuming that the profile of each is double Gaussian. The decomposition results of the NIR spectra are also shown in Figure 5.

3.3. Normalized Absorption Spectra

In Figure 6, we plotted the normalized absorption spectra $f_{\text{abs}}$. For the optical spectra, $f_{\text{abs}}$ were normalized by assuming that the absorber only covers the accretion disk and does not cover any BELR and NELR emissions. That is,

$$f_{\text{abs}} = 1 + \frac{f_{\text{obs}} - f_{\text{absFree}}}{f_{\text{AD}}}.$$  

(4)

For the NIR spectra, we temporarily treated the power-law component as emission from the accretion disk and also used this equation.

It can be clearly seen that the deepest position in the He I $\lambda 10830$ absorption trough is at a velocity of $v \sim -1400$ km s$^{-1}$ relative to the quasar rest frame for all three observations.\(^6\) The features at this velocity are also seen in Mg II, as the deepest two positions in the Mg II trough in SDSS and DBSP spectra correspond to positions at $v \sim -1400$ km s$^{-1}$ for the Mg II doublet. H$\alpha$ is different because the deepest position is at $v \sim -700$ km s$^{-1}$ and absorption at $v \sim -1400$ km s$^{-1}$ is not detected. We divided the absorption troughs into two components owing to the difference between Balmer and other lines, and we referred to the two components as the V1400 and V700 components for short, according to the blueshift velocity. It can be clearly seen that both components contribute to He I $\lambda\lambda 10830$ and 3889 absorption troughs, while the Mg II trough is more complicated, due to blending of the doublet. Ji12 decomposed the Mg II trough and found that it also consists of the two components, and the V1400 component of Mg II $\lambda 2803$ is blended with the V700 component of Mg II $\lambda 2796$. Thus, we concluded that the V700 component is in Balmer, He I, and

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\(^6\) By ignoring the pixels affected by a strong sky line.
Mg II absorption lines, and the V1400 component is only in He I and Mg II. The absorption troughs in the SDSS 2003 spectrum and in follow-up spectra with time intervals of a decade show similar structures, indicating that the two components remain for over 10 years. By directly comparing the absorption troughs from different observations, we concluded that the velocities of the two components do not vary by time. On the other hand, the variability in strength is notable after normalization. The V700 component of He I \(\lambda 3889\) clearly became weak from 2013 to 2015, while the V1400 component changed little. Although the optical spectra suffer from different spectral resolutions, we can quantify the variations in depths by using EWs because EW is less affected by resolution. We calculated the EW ratios relative to EW in the SDSS spectrum, which shows the deepest absorption, and the results are listed in Table 2. For the Mg II \(\lambda 2796, 2803\) doublet, we converted the wavelengths to velocities for each of the two lines.

**Figure 6.** Normalized spectra assuming that the absorbing gas covers the whole power-law model and no BELR model. The absorption windows and the colors are the same as in Figure 3. For the Mg II \(\lambda 2796, 2803\) doublet, we converted the wavelengths to velocities for each of the two lines.

**Table 2**

| Velocity Range       | Mg II Doublet \(-3000 < v < 0\) (for 2803) | He I \(\lambda 3889\) \(-1000 < v < 0\) | H\(\alpha\) \(-1400 < v < 0\) | H\(\beta\) \(-1400 < v < 0\) |
|----------------------|------------------------------------------|------------------------------------------|-------------------------------|-------------------------------|
| MMT 201203           | ...                                      | 0.16\(^{+0.13}_{-0.12}\)                | 0.19\(^{+0.16}_{-0.16}\)    | ...                           |
| YFOSC 201205         | 0.24\(^{+0.10}_{-0.12}\)                | 0.62\(^{+0.16}_{-0.14}\)                | 0.47\(^{+0.18}_{-0.16}\)    | ...                           |
| DBSP 201404          | 0.89\(^{+0.11}_{-0.15}\)                | 0.62\(^{+0.16}_{-0.14}\)                | 0.69\(^{+0.14}_{-0.14}\)    | 0.61\(^{+0.38}_{-0.41}\)    |
| YFOSC 201601         | 0.83\(^{+0.10}_{-0.13}\)                | 0.54\(^{+0.16}_{-0.20}\)                |                             |                               |

Mg II absorption lines, and the V1400 component is only in He I and Mg II. The absorption troughs in the SDSS 2003 spectrum and in follow-up spectra with time intervals of a decade show similar structures, indicating that the two components remain for over 10 years. By directly comparing the absorption troughs from different observations, we concluded that the velocities of the two components do not vary by time. On the other hand, the variability in strength is notable after normalization. The V700 component of He I \(\lambda 10830\) clearly became weak from 2013 to 2015, while the V1400 component changed little. Although the...
V1400 component also has the same variability pattern as the He I* and Balmer of the V700 component, considering that the Mg II trough is dominated by the V1400 component.

4. The Variability: Change in Ionization State or Movement of the Absorber?

We showed that the velocity of both components did not change significantly over a decade, while the strengths of all of the absorption lines varied. This type of variability may result from either a change in the ionization state or the movement of the absorber. The first can cause a variation in ionic column density, and the second can cause a variation in the covering factor of the absorbing gas. We attempted to distinguish the two possible origins by reproducing the data using two models: one assuming that only the ionization state of the absorbing gas is variable and that all of the other physical properties are invariable, and the other assuming that only the covering factor of the absorbing gas is variable.

4.1. Variable Ionization State Model

If the absorption-line variability is due to variation in ionization state, the variance in strength of the absorption lines should be correlated with variance in continuum flux. We labeled the observation time of the eight spectral observations in the V-band light curve in Figure 2. We found that it is likely that the continuum flux during the SDSS 200303 observation is the lowest among the eight observations according to the Catalina light curve and the synthetic magnitude of the SDSS spectrum. Although not an imaging result, the synthetic magnitude is reliable because the flux calibration of the SDSS data release 7 has good quality, and because the flux is in agreement with the brightening tendency between SDSS photometry in 2002 and Catalina photometry in 2004. At the same time, all of the absorption lines are strongest in the SDSS 2003 spectrum. The highest flux recorded by the Catalina light curve was in 2013, corresponding to the TSpec 2013 spectrum, in which the V700 component of He I* λ10830 is indeed the weakest among the three TSpec spectra. This fact also reveals that the optical depth of He I* λ10830 was not large (<1) in 2013. Thus, the corresponding optical depth of the He I* λ3889 line (23 times less) should be very small. The clear detection of He I* λ3889 in the SDSS, DBSP, and YFOSC 2016 spectrum implies that the V700 component of He I* in 2013 is the weakest among all of the observations. Thus, there is an anticorrelation of the continuum fluxes and absorption depths in 2003 and 2013. We further checked this anticorrelation. The variation in EW of He I*, Balmer, and Mg II shows the same pattern. They became weaker from 2003 to 2012 and became stronger from 2012 to 2014. On the other hand, the strengthening in continuum from 2003 to 2012 can be clearly seen in the light curve. If we adopted the magnitude value from synethetics of the DBSP spectrum, the dimming in continuum can also be found from 2012 to 2014. Though it is not a photometric result, the synthetic magnitude of the DBSP 2014 spectrum has good quality owing to two facts: one is that we observe the standard star just before the observation of LBQS 1206+1052 with close air mass, and the other is that the magnitude agrees with the decreasing tendency in 2013 in the Catalina Sky Survey light curve. In summary, we found an anticorrelation in EW of absorption lines and the continuum flux, supporting the variable ionization state model. For a further examination of this model, we will first model the absorbing troughs and obtain the ionic column densities, and then we check whether the ionic column densities agree with the photoionization model using Cloudy simulations.

4.1.1. Modeling the Absorbing Troughs

The covering conditions of absorbing gases to the central continuum source are essential for measurement of ionic column densities. As can be seen in Figure 6, the V1400 component of the He I λ10830 absorption line has negative flux if normalized using the continuum, indicating that the V1400 absorbing gas covers not only the whole accretion disk but also a part of the BELR. By normalizing using both the continuum and BELs, we concluded that the V1400 absorbing gas covers at least 60% of the BELR, and hence the size is comparable to, or larger than, the BELR. On the other hand, the V700 absorbing gas does not cover as large a fraction of the BELR as the V1400 component does. If it indeed covered 60% or more of the BELR, the Hα optical depth at the deepest position in the SDSS spectrum would be <0.45, while the Hβ optical depth would be >0.1. These two values are inconsistent considering the theoretical ratio of Hα/Hβ = 7.26. The normalized fluxes of Hα and He I* λ10830 at the velocity of ∼700 km s⁻¹ can both reach ∼0.1, indicating that the V700 absorbing gas covers at least 90% of the accretion disk. Assuming that it covers the whole accretion disk and does not cover BELR at all, we computed the optical depth ratio of Hα to Hβ to be 7.0 ± 2.1, which is consistent with the theoretical value. Thus, it is likely that the size of the V700 absorbing gas is comparable to the accretion disk and much smaller than the BELR, and hence the two absorbing gases are different in size. Considering that the V700 component has Balmer absorptions, which are not seen in the V1400 component, the physical conditions of the two absorbing gases are also different. Thus, it is likely that the two absorption gases are physically independent.

We fit the spectral data in absorption regions by assuming the following.

1. For each absorption line in each spectrum, the velocity profile of optical depth is Gaussian for both the V1400 and V700 components.
2. For all of the spectral lines that belong to the same ion for each component, the velocity profiles of optical depths are identical and do not vary by time.
3. The ionic column densities are computed from the optical depth profile by

$$N_{\text{ion}} = \frac{m_e c}{\pi e^2 f \lambda} \int \tau_v dv,$$

where $f$ and $\lambda$ are the oscillator strength and the wavelength of each spectral line, respectively. For ions with two or more lines in the same spectrum, the column densities are fixed.
4. The covering conditions are the same for different ions and do not change by velocity or vary by time, while they are different for the two components. Thus, for each absorption line we have

$$f_{\text{obs}} - f_{\text{AbsFree}} = f_{\text{AD}} \times (1 - f_{\text{resi}}^{\text{AD}}) + f_{\text{BELR}} \times (1 - f_{\text{resi}}^{\text{BELR}}),$$

where $f_{\text{AD}}$ and $f_{\text{BELR}}$ are the covering fractions of the accretion disk and the BELR, respectively. $f_{\text{resi}}^{\text{AD}}$ and $f_{\text{resi}}^{\text{BELR}}$ are the ionization corrections for the accretion disk and the BELR, respectively.
where $f_{\text{resi}}^{\text{AD}}$ and $f_{\text{resi}}^{\text{BELR}}$ are the residual fractions after absorption for the two emission sources, which can be expressed as

$$
\begin{align*}
\frac{f_{\text{resi}}^{\text{AD}}}{f_{\text{resi}}^{\text{BELR}}} &= \left(1 - \left(1 - \frac{f_{\text{resi}}^{\text{AD}}}{f_{\text{resi}}^{\text{AD}}} + \frac{f_{\text{resi}}^{\text{BELR}}}{f_{\text{resi}}^{\text{BELR}}} \right) \cdot e^{-\tau_{\text{V700}}}ight) \\
&\times \left(1 - \left(1 - \frac{f_{\text{resi}}^{\text{AD}}}{f_{\text{resi}}^{\text{AD}}} + \frac{f_{\text{resi}}^{\text{BELR}}}{f_{\text{resi}}^{\text{BELR}}} \right) \cdot e^{-\tau_{\text{V1400}}}ight),
\end{align*}
$$

where $f_{\text{resi}}^{\text{AD}}$ and $f_{\text{resi}}^{\text{BELR}}$ are the covering factors of the V700 and V1400 absorbing gases to the accretion disk and BELR, and $\tau_{\text{V700}}$ and $\tau_{\text{V1400}}$ are the optical depths of the two absorbing gases. We did not consider the situation in which the absorbing gas covers the NERL because the NERL is typically too large to be covered by an absorbing cloud. The V1400 component must cover the whole accretion disk; thus, $f_{\text{resi}}^{\text{AD}} = 1$. The situation for the V700 component is more complicated: it may only cover part of the accretion disk ($f_{\text{resi}}^{\text{AD}} = 0$), or it may cover the whole accretion disk and a small part of the BELR ($f_{\text{resi}}^{\text{AD}} = 1$).

Our model has a total of 46 free parameters, 23 for each absorbing component: line centers and line widths for three ions (Mg II, He I, and H\((n = 2)\)), a total of 16 ionic column densities in eight spectra, and one covering factor. For the V700 component, the only free covering factor is $f_{\text{resi}}^{\text{AD}}$ for the first covering situation and $f_{\text{resi}}^{\text{BELR}}$ for the second covering situation. We simultaneously fit the eight spectra in absorption windows (−2000 to 0 km s\(^{-1}\)) for each line using the method described in Section 3.1. The spectral resolutions are different among different observations and among different wavelengths during the same observation, which are shown in Table 1. We considered the resolution effect by convolving Gaussians to the models. We calculated the probability distributions of all the parameters and listed the best values and 90\% confidence intervals in Table 3.

We first set all the parameters free. Both covering situations yield the same result, that the V700 absorbing gas covers the whole accretion disk and does not cover the BELR ($f_{\text{resi}}^{\text{AD}} = 1$ and $f_{\text{resi}}^{\text{BELR}} = 0$), agreeing with what we had guessed from directly comparing H\(\alpha\) and H\(\beta\) absorption troughs in the SDSS spectrum. This is not surprising because the size of the BELR can be several orders of magnitude larger than the accretion disk. The size of the BELR of LBQS 1206+1052 can be estimated to be $6 \times 10^{17}$ cm using the radius–luminosity relation of Kaspi et al. (2005) as

$$
R_{\text{BELR}} = (22.3 \pm 2.1) \left(\frac{L_{5100}}{10^{44} \text{ erg s}^{-1}}\right)^{0.69 \pm 0.05} \text{ It days},
$$

where $L_{5100} = 3.0 \times 10^{46}$ erg s\(^{-1}\) is the monochromatic luminosity at rest frame 5100 Å. The radius $R_{\lambda}$ at which the disk temperature equals the photon energy, $kT = h\epsilon/\lambda_{\text{rest}}$, is given by Blackburne et al. (2011) as

$$
R_{\lambda} = 9.7 \times 10^{15} \left(\frac{\lambda}{\mu\text{m}}\right)^{4/3} \left(\frac{M_{\text{BH}}}{10^6 M_\odot}\right)^{2/3} \left(\frac{L}{\eta L_{\text{edd}}}\right)^{1/3} \text{ cm},
$$

where $L$ is the bolometric luminosity, $\eta$ is the accretion efficiency (assumed to be 0.1), and $L_{\text{edd}}$ is the Eddington luminosity. For LBQS 1206+1052, the black hole mass can be computed to be $1.9 \times 10^{9} M_\odot$ using the FWHM of the H\(\beta\) BEL (FWHM$_{H\beta}$ ~ 7000 km s\(^{-1}\)) and the continuum luminosity following Greene & Ho (2005) as

$$
M_{\text{BH}} = (4.4 \pm 0.2) \times 10^6 \left(\frac{L_{5100}}{10^{44} \text{ erg s}^{-1}}\right)^{0.64 \pm 0.02} \left(\frac{\text{FWHM}_{H\beta}}{10^3 \text{ km s}^{-1}}\right)^2 M_\odot,
$$

and the bolometric luminosity is $8L_{\beta} \sim 2.4 \times 10^{46}$ erg s\(^{-1}\) using the bolometric correction from Marconi et al. (2004). Then the size of the optical emission region ($\lambda \sim 5000$ Å) can be estimated to be $6 \times 10^{15}$ cm. Considering the two-order-of-magnitude difference between the sizes of the BELR and the accretion disk, the covering condition suggests that the size of
the absorbing gas is larger than the accretion disk and still far smaller than the BELR. The best-fitting CFV1400 is also 1, indicating that the V1400 component covers the whole accretion disk and the whole BELR. As a result, we fixed the covering conditions and redid the fitting. The Gaussian centers and widths of all three ions, which are listed in Table 3, agree with each other for the V700 component, and those of the He 1 and Mg II are also inconsistent for the V1400 component. This indicates that the velocity profiles of different ions are similar; thus, we fixed the profile parameters for a better measurement of ionic column densities. The Balmer absorption of the V1400 component is not detected in all of the spectra, so we obtained an upper limit by assuming that the profile is identical to those of He 1 and Mg II. The resultant ionic column densities are listed in Table 3, and the best-fit model is shown in Figure 7. As can be seen from the figure, the model reproduces the observed spectra well.

We noticed that the He 1 column densities measured from TSpec 201512 and YFOSC 201601 observations differ significantly, especially for the V700 component. Furthermore, the He 1 column densities measured from NIR seem to be systematically lower than when measured from the optical. This may be due to the contribution of the dusty torus to the continuum in the NIR band. The He 1 λ10830 line is at a wavelength where the emission of hot dust reaches its peak; thus, it is natural that a part of the continuum comes from hot dust. The emission region of hot dust has a larger size than the accretion disk and the BELR; thus, it is likely that the hot dust emission is not covered by the two components. Therefore, the optical depths of He 1 λ10830 may be underestimated for both components. By assuming that the He 1 column densities are the same in TSpec 201512 and YFOSC 201601 observations, we estimated that the residual flux of He 1 λ10830 of the V700 component in the TSpec 201512 spectrum would be only ~0.05, and it is impossible to make a precise measurement of He 1 column density in this situation. Thus, we did not adopt the He 1 column density from the TSpec 201512 observation. We also abandoned the value from the TSpec 201505 observation, as the situation is similar.

We plotted the column densities of Mg II, He 1, and H (n = 2) ions as functions of observing time in Figure 8 and compared them with the V-band light curve. For the V700 component, the variations of Mg II and H(n = 2) show the same pattern that the column densities were the highest in 2003, then decreased in 2012, and then recovered in 2014 and 2016. The pattern of He 1 is also consistent if adopting the measurements from optical spectra. For the V1400 component, the pattern of Mg II is similar, while the measurement uncertainties of He 1 are too large. The variability pattern of these ionic column densities is just opposite that of the continuum.

### 4.1.2. Photoionization Model

Figure 13 in Liu15 shows how the column densities of Mg II and He 1 depend on the ionization parameter $U$. Mg II always decreases with increasing $U$. He 1 decreases with increasing $U$ when the absorbing gas is too thin to reach an ionization front, and it increases with increasing $U$ when the gas is thick enough that the ionization front is well developed. The ionic column densities are inversely correlated with the V-band continuum in LBQS 1206+1052 for both components, in accordance with the first situation, indicating that both absorbing gases are optically thin. We noticed that the column densities of He 1 and Mg II are insensitive to H density $n_H$ in a wide range, while $H(n = 2)$ is sensitive to the density of the gas. We first investigate the V700 component with additional information from Balmer absorption lines. We used the photoionization code Cloudy (version 10.00; Ferland et al. 1998) to simulate the ionization process in the V700 absorbing gas. We assumed a slab-shaped geometry, unique density, homogeneous chemical composition of solar values, and a spectral energy distribution (SED) of the commonly used ionizing continuum from Mathews & Ferland (1987; MF87). The undetermined parameters are the ionization parameter $U$, the H density $n_H$, and the total Hydrogen column densities $N_H$. For a quick look at the general situation, we calculated a sparse grid of models with $\log n_H$ varying from 3 to 12, with $\log U$ varying from $-3.5$ to 2.0, and with $\log N_H$ varying from 20 to 24, and the steps of the three are 0.5 dex. The variable ionization state model assumes that only $U$ is variable among the observations and that $n_H$ and $N_H$ are invariant. Thus, we check how the three ionic column densities vary as functions of ionization parameter $\log U$. As can be seen in Figure 9, $N_{He,18}$ has an upper limit for a given $N_H$ value, and therefore we can derive a lower limit for the $N_H$ of $10^{21}$ cm$^{-2}$ using the maximum $N_{He,18}$ measured from the SDSS 200303 observation.

To find the approximate photoionization solutions, we plotted the contours of the column densities of He 1, Mg II, and H(n = 2) according to the levels of observed values in Figure 10. The observed values are selected from SDSS

| Parameter | V700 Absorbing Gas | V1400 Absorbing Gas |
|-----------|-------------------|-------------------|
| $\log N_{He} (\text{cm}^{-2})$ | 21.1 | 21.4 |
| $\log N_{H} (\text{cm}^{-2})$ | 9.32 | 9.52 |
| $\log U$ | SDSS 200303 | -1.9 | -1.41 |
| | HST/COS 2010 | -1.66 | -1.12 |
| | MMT&YFOSC 2012 | -1.47 | -1.25 |
| | DBSP 201404 | -1.77 | -1.25 |
| | YFOSC 201601 | -1.65 | -1.25 |
| $\Delta \log U (2003 \text{ to } 2012)$ | 0.43 | 0.29 | 0.9 | 2800 | 1200 |
| Distance (pc) | 1.7 | 1.3 | 0.9 | 2800 | 1200 |
200303, YFOSC 201205, DBSP 201404, and YFOSC 201601 observations. We abandoned the \( N_{\text{Mg} \, \text{II}} \) values from the two YFOSC observations since the uncertainties are too large. For \( N_{\text{II}} \) in 2012, the value from the MMT 201203 observation was used instead of that from YFOSC 201205 because it has a smaller uncertainty, and because we did not find variation of \( N_{\text{II}} \) between the two epochs, which have a rest-frame time interval of only 50 days. Figure 10(a) shows that the three sets of lines from three ions roughly intersect at a position with \( \log n_{\text{H}} \sim 9 \) for every \( N_{\text{H}} \) value, supporting the results of former works that Balmer absorption lines are only detected when the density is high. For \( \log N_{\text{H}} = 21 \), the red valid line (contour of \( \text{HeI}^* \lambda 10830, \text{HeI}^* \lambda 3889, \text{H}\alpha, \) and the Mg II doublet, overplotted on the observed spectra (black) and the absorption-free spectra (gray).

We then calculated a denser grid of models around the approximate solutions and searched for the photoionization solutions. We assumed that the model has six free parameters, \( n_{\text{H}}, N_{\text{H}}, \) and four \( U \). We compared the difference between spectra predicted by the Cloudy model and the observed spectra, we calculated the \( \chi^2 \) using the difference, and the weights are computed following the method described in Section 3.1. Only Balmer and He I* series were used because they have higher measurement accuracies relative to Mg II for the V700 component and are less influenced by metallicity. The final solution was computed by minimizing \( \chi^2 \). The best-fitting solution has \( \log N_{\text{H}} = 21.25, \log n_{\text{H}} = 9.38, \) and \( U \) varying from \(-1.66\) to \(-1.29\). We cut at \( \Delta \chi^2 = 3 \) and obtained \( 21.1 < \log N_{\text{H}} < 21.4 \) and \( 9.3 < \log n_{\text{H}} < 9.5 \), and the solutions by fixing \( \log N_{\text{H}} \) at 21.1, 21.25, and 21.4 are listed in Table 4 and labeled in Figure 10(b).

4.1.3. Analysis of HST/COS Spectrum

The density of the V1400 component cannot be determined from the optical and NIR spectra because we only detected He I* and Mg II absorption lines, both of which are insensitive to
density (see Figure 9). Fortunately, there is an archival far-UV (FUV) spectrum of LBQS 1206+1052 taken with HST/COS in 2010, which shows abundant absorption lines in rest frame 820–1035 Å. Chamberlain & Arav (2015, hereafter CA15) analyzed the HST/COS spectrum. CA15 noticed that the deepest place in the trough has a blueshifted velocity of \( \sim 1400 \text{ km s}^{-1} \), which coincides with the V1400 component. They also found that the absorption lines exhibit a profile that is skewed toward the red side of the trough. This profile is similar to that of He I at 10830 Å, indicating that both the V1400 and V700 components contribute to the absorption troughs. CA15 measured the density of the absorbing gas using the line ratios of N III/N II and S III/S II. The two components are blended in the N III absorption trough, and meanwhile only V1400 components are detected in the S III absorption trough; thus, the density of the V1400 component can be determined as \( \log n_{H} = 3.0 \pm 0.2 \) using S III following CA15.

CA15 also measured the column densities of H I, N III, O III, O VI, S III, and S VI and obtained \( \log U = -1.82 \) and \( \log N_{H} = 20.46 \) using the Cloudy simulation. Some of the ionic column densities from CA15 are measured by integrating the apparent optical depth (AOD) over the trough, which is mainly contributed by the V1400 component. Thus, we deduced that the ionic column densities and the photoionization solution from CA15 apply to the V1400 component. However, the results may suffer from the contamination by the V700 component. Thus, we need to examine this and measure the physical condition of the V1400 absorbing gas again.

We attempted to predict the FUV absorption spectra for the two components, in order to better understand the HST/COS spectrum. We first predicted the ionic column densities of the two components using the Cloudy simulation, in which the \( n_{H} \), \( N_{H} \), and \( U \) for the V1400 component are from CA15, and those for the V700 component are from our best-fitting solutions of \( \log N_{H} = 21.25 \) and \( \log n_{H} = 9.38 \). The \( V \)-band light curve shows that the quasar luminosity in 2010 is close to that in 2012; therefore, the \( U \) value from the MMT/YFOSC 2012 observation is adopted. The ionic column densities from Cloudy are then converted to optical depths using oscillator strengths, which are obtained from the NIST Atomic Spectra Database. We then generated absorption spectra using Gaussian optical depth profiles obtained in Section 4.1.1. The results for the two components are shown in Figure 11 for two spectral ranges, along with the observed HST/COS spectrum. As can be seen in the figure, most of the absorption troughs can find corresponding features in the predicted absorption spectra.

However, there are contradictions between the observed and the predicted absorption spectra in the Ly\( \beta \) and O VI region (red box in Figure 11). The photons in the range of 1027 Å < \( \lambda < 1032 \) Å are predicted to be fully absorbed by the O VI \( \lambda 1031 \) line of the V700 component, while the observed spectrum shows a strong excess. The excess seems to have a Gaussian shape, and thus we proposed that it may be an O VI emission line. We plotted the observed spectrum in velocity spaces of C III \( \lambda 977 \) and O VI \( \lambda 1031 \) in Figure 12. The red side of the C III emission line is unabsorbed, and we can measure the redder position at half maximum at \( v \sim 600 \text{ km s}^{-1} \), and analyses of profiles of O III and N III emission lines also yield similar results. On the other hand, by assuming that the excess in the O VI absorption trough is the O VI \( \lambda 1031 \) emission line, the bluer position at half-maximum of the emission-line profile is at \( v \sim 400 \text{ km s}^{-1} \). Thus, the FWHM of the UV emission lines is \( \sim 1000 \text{ km s}^{-1} \), far narrower than that of the BELs in the optical (FWHM = \( 6000 \text{ km s}^{-1} \)), and still broader than that of the NELs (FWHM = \( 500 \text{ km s}^{-1} \)). A similar situation was seen in OI 287 (Li et al. 2015), where UV emission lines such as Ly\( \alpha \) and C IV are narrower than Balmer BELs and broader than [O III] NELs. This can be explained by introducing additional intermediate-width emission lines that originate in the inner face of the dusty torus, and by assuming that the UV continuum and UV BELs are suppressed by dust extinction.

We plotted the SED of LBQS 1206+1052 in the UV band in Figure 13. The YFOSC 2012 spectrum was used to generate the SED together with HST/COS spectrum because the light curve shows that the quasar luminosities in the two epochs are close. We found that the continuum in the two spectra can be well fitted by a reddened quasar composite spectrum from Vanden Berk et al. (2001) by an SMC extinction curve with \( E_{B-V} = 0.07 \). This implies that the continuum in the HST/COS spectrum is at a lower normalizaton compared to the continuum as observed at earlier epochs. This is indicated by the FWHM of the UV emission lines. The photons in the range of 1027 Å < \( \lambda < 1032 \) Å are predicted to be fully absorbed by the O VI \( \lambda 1031 \) line of the V700 component, while the observed spectrum shows a strong excess. The excess seems to have a Gaussian shape, and thus we proposed that it may be an O VI emission line. We plotted the observed spectrum in velocity spaces of C III \( \lambda 977 \) and O VI \( \lambda 1031 \) in Figure 12. The red side of the C III emission line is unabsorbed, and we can measure the redder position at half maximum at \( v \sim 600 \text{ km s}^{-1} \), and analyses of profiles of O III and N III emission lines also yield similar results. On the other hand, by assuming that the excess in the O VI absorption trough is the O VI \( \lambda 1031 \) emission line, the bluer position at half-maximum of the emission-line profile is at \( v \sim 400 \text{ km s}^{-1} \). Thus, the FWHM of the UV emission lines is \( \sim 1000 \text{ km s}^{-1} \), far narrower than that of the BELs in the optical (FWHM = \( 6000 \text{ km s}^{-1} \)), and still broader than that of the NELs (FWHM = \( 500 \text{ km s}^{-1} \)). A similar situation was seen in OI 287 (Li et al. 2015), where UV emission lines such as Ly\( \alpha \) and C IV are narrower than Balmer BELs and broader than [O III] NELs. This can be explained by introducing additional intermediate-width emission lines that originate in the inner face of the dusty torus, and by assuming that the UV continuum and UV BELs are suppressed by dust extinction.

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The spectrum is dust extinguished by about one order of magnitude. Therefore, it is likely that the emission lines in the HST/COS spectrum of LBQS 1206+1052 are from intermediate-width emission-line regions, just as in OI 287. CA15 showed their Cloudy simulation results in their Figure 3. They determined the $U$ and $N_{\text{H}}$ using the cross point of the O VI contour and other ions in $U$–$N_{\text{H}}$ space. We argued that the apparent residual flux in the OVI trough is likely to be an emission line; thus, the measured O VI column density may not be real. Then, how should we determine the physical properties of $V_{1400}$ absorbing gas? We noticed that the S VI contour also crosses with other ions. As can be seen in Figure 11 (blue box), the blue side of S VI $\lambda$944 for the V1400 component is not affected by the V700 component. Thus, we measured the S VI column density by integrating the AOD on the blue side and multiplying by 2. Now we can remeasure $U$ and $N_{\text{H}}$ using a Cloudy simulation. The settings of the Cloudy simulation are similar to those for the V700 component, except that $n_{\text{H}}$ is fixed at $10^3$ cm$^{-3}$. The ionic column densities measured by us are listed in Table 5, along with the values from CA15. The absorption troughs of O III, C III, and N III are deep, and the measured column densities may be underestimated, due to unknown flux that is not covered by the absorbing gas, such as scattered light and emission lines. Thus, we did not adopt the column densities of these ions when searching for the photoionization solution. CA15 measured the HI column density from Lyman limit measurements, which are contaminated by the V700 component, and we did not adopt the value either. In addition, we detected weak Ar IV $\lambda\lambda$844, 850 and C II $\lambda$903 absorption lines for the $V_{1400}$ component (purple box in Figure 11), and the column densities of Ar IV and C II are also measured. The Cloudy simulation results are plotted in Figure 14 (a), and the best-fitting solution is labeled with a black star. The ionic column densities predicted by the solution are listed in Table 5. As shown in the table, the observed and predicted column densities of S VI, S III, Ar IV, and C II agree within 0.3 dex.

Relative to CA15’s solution (triangle in Figure 14(a)), our solution has a $U$ 0.22 dex higher and an $N_{\text{H}}$ 0.47 dex higher. As the contours of most ions are in the lower left to upper right direction in $U$–$N_{\text{H}}$ space, ions with higher ionization energies, such as O VI, S VI, and Ar IV, are important to determining the solution because their contours cross with the contours of low-ionization ions. In CA15’s simulation, the cross point of S VI is

![Figure 9](image-url)

*Figure 9. Column density of the Mg II, He I*, and H($\text{n}=2$) ions as functions of ionization parameter $U$ for electron densities from $10^4$ to $10^{10}$ cm$^{-3}$ and gas column densities of $10^{21}$ and $10^{22}$ cm$^{-2}$. The black dashed lines are given by $U = N_{\text{H}} \cdot \beta / e$, where $\beta$ is the H recombination coefficient for $T = 10^4$ K. This means that the ionization front is well developed in the area on the left of the line and is not reached on the right.*
different from the cross point of O VI. If adopting the cross point of SVI in CA15’s simulation, the solution (square in Figure 14(a)) is much closer to ours, and the difference with <0.1 dex is due to applying a different SED. The cross point of Ar IV is close to that of SVI, making the solution of using SVI more reliable.

The HST/COS spectrum shows an additional absorption-line system with a blueshift velocity of \( \sim 200 \text{ km s}^{-1} \) (and hence is referred to as the V200 component hereafter), which is seen in Lyman series, C III \( \lambda 977 \), and N III \( \lambda 989 \), and the corresponding absorption lines are labeled using pink dashed lines in Figure 11.

4.1.4. Consistency between Variations in Continuum and in \( U \)

The variable ionization state model assumes that all of the other parameters are invariable, and thus the variation of \( U \), which is presented as \( U = \frac{Q(n_H)}{4\pi r^2 c n_H} \), is proportional to the variation of the continuum. We showed that the observed ionic column densities are negatively correlated with the optical continuum flux. The photoionization simulation indicates that the ionic column densities of He I*, Mg II, and H(\( n = 2 \)) are all negatively correlated with \( U \). These are consistent. The photoionization simulation presented the change in \( U \) as 0.29–0.43 dex between the SDSS 2003 and YFOSC 2012 observations. The corresponding variability amplitude of the optical continuum is 0.26 mag (\( \sim 0.1 \) dex) in the V band. Considering that quasars are often more variable in UV and X-ray than in the optical, the variation in the flux of the ionization continuum would be larger. By comparing the GALEX photometry in 2004 with the reddened quasar composite that can join the HST/COS 2010 and YFOSC 2012 spectra (Figure 14), we estimated the variability amplitude between 2004 and 2010 to be 0.1 and 0.15 dex in the FUV and NUV bands, respectively. The FUV band is strongly influenced by the Ly\( \alpha \) emission line, whose EW may be different in LBQS 1206+1052 and in the quasar composite; thus, the variability amplitude of NUV was adopted. This finding supports the idea that the variability in the ionization continuum is responsible for the variation in \( U \) in LBQS 1206+1052.

Using the \( U \) and \( n_H \) values from the photoionization simulations, we estimated the distance \( r \) of the absorbing gases to the central source. We obtained \( Q(H^0) \) to be \( 7.4 \times 10^{56} \text{ s}^{-1} \) by integrating the MF87 SED, which is normalized using the observed \( L_{3000} = 4.7 \times 10^{45} \text{ erg s}^{-1} \) in the YFOSC 2012
spectrum. The far-UV continuum luminosity from the HST/COS spectrum was not used, as it is probably under heavy dust extinction. For the V700 absorbing gas, the distance was estimated to be 1.3 ± 0.4 pc using the $U$ value in 2012, which corresponds to the $Q(H^0)$ in 2012, and for the V1400 absorbing gas the inferred distance is $\sim$2.8 kpc.

### 4.2. Variable Covering Factor Model

We found observational evidence against the variable covering factor model. In this model the optical depths of all the absorption lines are invariable, and thus the change in EW is proportional to the change in the covering factor. The EW of HeI* $\lambda$3889 for the V700 component in the YFOSC 201601 observation is $0.54^{+0.16}_{-0.20}$ (90% confidence) times the EW value in the SDSS 200303 observation. Assuming that the V700 absorbing gas covers the whole continuum in the SDSS 200303 observation, we can estimate the upper limit of the covering factor in YFOSC 201601 to be 0.7. On the other hand, another covering factor of HeI* can be obtained from the HeI* $\lambda$10830 absorption trough in the quasi-simultaneous 201512 TSpec observation. It can be seen from Figure 6 that the absorbing gas covers at least 80%–90% of the continuum. This fraction may be higher considering the underneath hot dust emission. Therefore, the covering factors measured from the two observations with only an 8-day interval in rest frame are not consistent if assuming that the ionic column density is invariable. We have estimated the size of the accretion disk to be $\sim$10$^{15}$ cm. This requires a crossing velocity of $\sim$14,000 km s$^{-1}$, which is too large for an absorbing gas with a radial velocity of only 700 km s$^{-1}$. Moreover, if the absorbing...
gas moved across in such a short time, it is difficult to explain how the absorption troughs remained over 10 years.

The variation in absorption lines for the V1400 component is also strange under the assumption of this model. The covering factor of MgII $\lambda 2796$ of the V1400 component to the

![Figure 12](image_url)

**Figure 12.** Observed spectrum in velocity space of CIII $\lambda 977$ and OVI $\lambda 1031$, illustrating the emission-line profile.

![Figure 13](image_url)

**Figure 13.** Comparison between the observed HST/COS 2010 (cyan) and YFOSC 2012 (green) spectra and the reddened composite spectrum (gray) with $E_{B-V} = 0.07$. We also plotted the unreddened quasar composite spectrum for the illustration of the dust extinction of the HST/COS spectrum. The black diamonds show the GALEX photometry in FUV and near-UV (NUV) bands, and the gray stars show the synthetic flux using the reddened composite spectrum in these two bands.

![Table 5](image_url)

**Table 5**

| Ion   | $\log N_{\text{ion}}$ (cm$^{-2}$) | $\log N_{\text{model}}$ (cm$^{-2}$) |
|-------|----------------------------------|------------------------------------|
|       | This Work                        | CA15                               |
|       | Without Shading                  | With Shading                       |
| H I   | 16.90–17.06                      | 17.27                              | 17.04                             |
| C II  | 14.0 ± 0.3                       | 14.35                              | 14.10                             |
| C III | >14.95                           | 16.62                              | 16.80                             |
| N III | 15.68 ± 0.1                      | 16.10                              | 16.22                             |
| O III | 16.26 ± 0.15                     | 17.22                              | 17.76                             |
| O VI  | 15.55 ± 0.1                      | 15.94                              | 14.17                             |
| S III | 15.1 ± 0.2                       | 15.09 ± 0.2                        | 14.84                             |
| S VI  | 15.22 ± 0.1                      | 15.27 ± 0.1                        | 15.24                             |
| Ar IV | 15.19 ± 0.3                      | 15.02                              | 15.40                             |
| He I$^*$ | 13.65 ± 0.3$^c$                | 13.61                              | 14.27                             |
| Mg II | 13.23–13.80$^d$                  | 13.52                              | 13.84                             |

**Notes.**
- $^a$ The sum of the ground and excited levels for each ion.
- $^b$ The column densities predicted by our best-fitting Cloudy model. The results are from two simulations, one not considering the shading effect (using the MF87 SED) and the other considering the shading effect (using the transmitted SED of V700 absorbing gas).
- $^c$ The value is from three TSpec observations.
- $^d$ The upper and lower limits are given using the measurements from SDSS 2003 and YFOSC 2012 spectra.

![Figure 14](image_url)

**Figure 14.** (a) Contours of column densities of CII, N III, S III, S VI, and Ar IV as functions of $N_{HI}$ and $U$ for V1400 absorbing gas. The $n_{eq}$ value is fixed to be $10^7$ cm$^{-3}$ in the Cloudy simulation. The best-fitting solutions by considering and not considering the shading effect are labeled using red and black stars, respectively. We also labeled the solution from CA15 with a triangle and the solution using S VI from the CA15 simulation with a square. (b) Comparison of the MF87 SED (black) and transmitted SED of V700 absorbing gas (red).
continuum increased by about twice between YFOSC 201205 and DBSP 201404, while the covering factor of He I’ λ10830 changed little between 2013 and 2015. One can only explain this by introducing more complicated models, such as adopting different covering factors for He I’ and Mg II. However, the velocity profiles of He I’ and Mg II are nearly identical, indicating that the two ions are located in the same position, and hence it is likely that the covering factors are also the same.

The model is also difficult to understand kinetically. If the weakening of absorption lines from 2003 to 2012 is due to movement of an absorbing gas cloud, the recovery in 2014 is unusual because the cloud would not move back. If the recovery is due to the entering of a new cloud, it is difficult to explain why the velocity profiles of the two clouds show no difference. As we have reproduced all of the data using the variable ionization state model, we concluded that the absorption-line variability in LBQS 1206+1052 is due to a change in ionization state.

5. Discussion

5.1. Robustness on the Parameters of the Two Components

We first discuss the parameters of the V700 component. The lower limit of \( N_{\text{HeI}} (\log N_{\text{HeI}} > 21.1) \) was from the observed \( N_{\text{HeI}} \), which is rather robust. The upper limit of \( \log N_{\text{HeI}} < 21.4 \) was derived by assuming that \( N_{\text{HeI}} \) is invariable among the observations. In the process we only considered the measurement uncertainty, while the systematic errors in the photoionization simulation are not accounted for. Considering the systematic errors, the possible ranges of the parameters would be larger. The influence of uncertain metallicity is little because the BAL parameters are determined using He I’ and He II, both of which are insensitive to metallicity. In addition, the \( N_{\text{MgII}} \) from the best-fit solution and from the observations are consistent by 0.3 dex, suggesting that the chemical composition of the V700 absorbing gas is similar to that of the solar one. On the other hand, the SED of the ionization continuum indeed affects the measurement of the parameters. We tested another SED, which is described in detail in Ji et al. (2015) and has a lower flux in extreme-UV and X-ray than the MF87 SED if normalized at 3000 Å. Using \( N_{\text{HeI}} \), the lower limit of \( \log N_{\text{He}} \) is 21.3, slightly larger than that using MF87 SED. The upper limit is also larger, with \( \log N_{\text{He}} < 22.5 \), and the \( N_{\text{He}} \) range is also wider. The \( n_{\text{He}} \) is in the range of \( 9.4 < \log n_{\text{He}} < 9.9 \), and the inferred distance is in the range of 0.2–0.3 pc using a lower \( Q (H^0) \) of \( 3.3 \times 10^{56} \) s\(^{-1}\). There are no available X-ray data for LBQS 1206+1052, and the UV band suffers from dust reddening; thus, we have no observational limitation to the SED of the ionization continuum. Thus, the uncertainty of parameters due to an uncertain SED should also be considered.

Combining the results by using different SEDs, we concluded that the \( n_{\text{He}} \) is in the range of \( 10^9–10^{10} \) cm\(^{-3}\), and the distance of the absorbing gas to the central source is in the range of 0.2–2 pc.

We then discuss the parameters of the V1400 component. The \( n_{\text{He}} \) is converted from \( n_e \) which is measured using the ratio between the excited and ground states of [S III], [S III] absorption lines are optically thin and hence do not suffer from uncertainty in unknown covering conditions, yet they still have a high enough S/N to ensure an accurate measurement. Thus, the measurement of \( n_{\text{He}} \) is reliable. The \( N_{\text{He}} \) and \( U \) values are from Cloudy simulations. As CA15 showed, the photoionization solution is independent of the metallicity of the gas, and the choice of SED can influence the measurement of \( U \) by up to 0.3 dex.

Since the variability is photoionization driven, the density can also be limited using the recombination timescale \( \tau = (n_e \alpha e)^{-1} \), where \( \alpha_e \) is the recombination rate, which is related to the electron temperature. For a typical ionized gas, \( T \sim 10^4 \) K, and thus the recombination rates are \( 4.2 \times 10^{-13} \), \( 4.6 \times 10^{-13} \), and \( 1.2 \times 10^{-12} \) cm\(^3\) s\(^{-1}\) for H, He I, and Mg II, respectively, which were obtained from Verner & Ferland (1996). For the V700 absorbing gas with \( n_{\text{He}} \sim 10^{9.4} \), the recombination timescales of the three ions are all less than \( 10^4 \) s assuming \( n_e = 1.2 n_{\text{He}} \) for a highly ionized gas. Therefore, the variation of ion column densities can trace the continuum variability immediately for the V700 component. For the 1400 component, we can similarly estimate a recombination timescale to be \( \sim 20 \) yr using \( n_e = 10^{3.0} \) cm\(^{-3}\), too long to match the observation. And by assuming that the recombination timescale is \( < 1 \) yr, the inferred \( n_e > 10^{14} \) cm\(^{-3}\), higher than that measured from S III. We noticed that for the V1400 component, only the response of Mg II to the continuum can be seen, and we did not see the variability of He I’ and other ions. Considering that the ionization energy of Mg II (7.6 eV) is much lower than that of S III (23.3 eV) and other ions, a possible explanation for the contradiction is that Mg II comes from a region with higher density and thus has a shorter recombination timescale. This requires a two-phase medium for the V1400 absorbing gas, and the parameters we obtained may apply to the lower density phase.

The distance of the V1400 absorbing gas is three orders of magnitude larger than the V700 absorbing gas. Though the measurements of distances have uncertainty, we can conclude that the V1400 absorbing gas is located behind the V700 absorbing gas relative to the quasar. Thus, we needed to consider that the ionization continuum of the V1400 absorbing gas is filtered by the V700 absorbing gas. A Cloudy simulation shows that the V700 absorbing gas causes a total decrease in \( Q (H^0) \) of 40% and that the output SED is also different than the input SED, as nearly all of the photons with \( 54.6 \) eV \( < E < 100 \) eV are absorbed (see Figure 14(b)). We refer to this effect as the “shading effect” hereafter. We made another photoionization simulation of the V1400 absorbing gas using the transmitted spectrum of the V700 absorbing gas as the input SED. The shading effect mainly causes a decrease of column densities of high-ionization ions, such as S VI, O VI, and Ar IV, and the low-ionization ions are less affected. The solution is at \( \log U = -1.13 \) and \( \log N_{\text{He}} = 21.09 \) (red star in Figure 15), which moves toward the upper right direction in \( U–N_{\text{He}} \) space relative to the solution without the shading effect. Considering the shading effect, the \( U \) value from the Cloudy simulation is higher and the ionization photons are reduced. Using the effective \( Q (H^0) \) of \( 4.4 \times 10^{50} \) s\(^{-1}\), the best estimation of the distance of the V1400 absorbing gas is about 1.2 kpc.

5.2. The Absorbing Gases and Outflows in LBQS 1206+1052

We showed that there are three absorption-line systems in the spectra of LBQS 1206+1052 with blueshifted velocities of 1420, 700, and 200 km s\(^{-1}\) relative to the quasar rest frame, respectively. The V700 absorbing gas has an \( n_{\text{He}} \) in the range of \( 10^9–10^{10} \) cm\(^{-3}\), and it is located at a distance of \( \sim 1 \) pc from the central source, just outside of the BELR. The virialized velocity
in this distance is $v \sim \sqrt{\frac{GM_{\text{host}}}{r}} = 2000 \text{ km s}^{-1}$, and thus the gas may be restricted in this region.

The V1400 absorbing gas is at a distance of $\sim 1.2 \text{ kpc}$ and with an $n_{\text{H}}$ of $10^{3} \text{ cm}^{-3}$. The blueshifted velocity of $\sim 1400 \text{ km s}^{-1}$ indicates that it is an outflow, as it is in the line of sight of the quasar. We found a strong blue wing in the profiles of NELs of [O III] $\lambda 4959$, 5007 and [Ne III] $\lambda 3869$, which is extended to a velocity of $-2500 \text{ km s}^{-1}$. We measured the luminosity of [O III] $\lambda 5007$ and [Ne III] $\lambda 3869$ in a velocity range from $-2000$ to $-1000 \text{ km s}^{-1}$ to be $6 \times 10^{5} L_{\odot}$ and $6 \times 10^{7} L_{\odot}$, respectively. The distance and density of the V1400 absorbing gas are similar to those of the NELR, where the blue wing of NELs may originate, and the blueshifted velocities of the V1400 absorbing gas and the blue wing are also consistent. These similarities suggest a link between the blue wing of NELs and the V1400 absorbing gas. Thus, we calculated the outflow rate in the kiloparsec scale by assuming that the outflow seen in the blue wing is formed by a layer of gas clouds with similar distances and properties to those of the V1400 absorbing gas. For this purpose we first simulated the emission-line spectrum of the layer by assuming a spherical shell of gas with a radius of 1 kpc, $n_{\text{H}}$ of $10^{3} \text{ cm}^{-3}$, and radial H column density of $10^{21.06} \text{ cm}^{-2}$. We used the MF87 SED instead of the transmitted SED of the V700 absorbing gas. The results show that the layer of outflowing gas can produce enough of the [O III] and [Ne III] emission lines measured above if the global covering factor is $>10^{-3}$, the mass outflow rate is estimated to be $0.3 M_{\odot} \text{ yr}^{-1}$, and the inferred kinetic outflow rate is $1.5 \times 10^{41} \text{ erg s}^{-1}$. The total mass outflow rate in this distance may be several times higher considering those gases with lower or higher velocities, and the possible gases in the opposite direction, which are probably obscured by the dusty torus. The estimation assumes that all of the gases in this region have the same density as the V1400 absorbing gas, and considering the typical density in the NELR of $10^{2} - 10^{4} \text{ cm}^{-2}$, the mass outflow rate may have an uncertainty of 1 dex.

The V200 absorbing component shows too few lines, and we cannot obtain a good estimation on the properties of the absorbing gas. We attempted to set a constraint on its properties using the nondetection of several lines. The nondetection of N III $\lambda 991$ can set an upper limit of the $n_{\text{H}}$ as $10^{7} \text{ cm}^{-3}$. The nondetection of the high-ionization line S VI $\lambda 944$ suggests either a lower $U$ in the V200 absorbing gas than in the V1400 absorbing gas or a further decrease in hard photons due to the shading effect of the V1400 absorbing gas, both of which indicate a larger distance of the V200 absorbing gas relative to the V1400 absorbing gas. The lower blueshift velocity also implies that the V200 absorbing gas is in an outer region.

We found extended emission-line regions (EELRs) around LBQS 1206+1052 from the long-slit optical spectra. The EELRs were found in MMT 201203, YFOSC 201205, DBSP 201404, and YFOSC 201601 spectra with different position angles of 21, 0, 24, and 90°, respectively. [O III] $\lambda 4959$, 5007, H$\alpha$, H$\beta$, [Ne III] $\lambda 3869$, and [O II] $\lambda 3727$ emission lines were seen for the EELRs. The highest flux of the extended emission-line feature was recorded in the YFOSC 2012 spectrum with a long slit in the N–S direction. We plotted the two-dimensional spectral image in Figure 16. The brightest position is at 2.8° (15 kpc in projection) north of the quasar, and the EELR extends for a maximum distance of $\sim 5''$. After subtracting the contribution of the traditional NLR, the measured extended [O III] luminosity is $1.1 \times 10^{43} \text{ erg s}^{-1}$, and the total luminosity is higher considering that this luminosity is only extracted from a slit with $1''.8$ width. This luminosity is very high among the EELRs, e.g., the highest extended [O III] luminosity recorded in Fu & Stockton (2009) is $1.0 \times 10^{43} \text{ erg s}^{-1}$. Assuming that the density of the EELR is similar to those measured by Fu & Stockton (2009), the mass of the gas can be estimated to be $3 \times 10^{5} M_{\odot}$ using H$\beta$ luminosity. The extended [O III] feature shows a radial velocity difference relative to the quasar rest frame on both sides, and we measured a redshift velocity of $\sim 100 \text{ km s}^{-1}$ on the north side. We have seen outflows in the kiloparsec scale with enough mass and a high enough velocity to form a structure with a size of 15 kpc. If the EELR was formed by a similar outflow in the past, the dynamic timescale can be estimated to be $\sim 1.5 \times 10^{8} \text{ yr}$ using the size and an expanding velocity of $\sim 100 \text{ km s}^{-1}$, which is close to the lifetime of AGNs (e.g., Marconi et al. 2004). Therefore, we presented an overall scenario of outflows in LBQS 1206+1052 that the quasar started to drive outflows when it was born $\sim 10^{8} \text{ yr}$ ago, and continuously generated strong outflows until at least $10^{6} \text{ yr}$ ago, which is the dynamic timescale of the V1400 outflow. A detailed analysis of the EELR is beyond the scope of this work. Future integral field spectroscopic observations are needed to better understand the large-scale outflow in LBQS 1206+1052.

5.3. Future Follow-up Observations of He I* and Balmer BAL Quasars

Changes in ionization state and movement of absorbing gas are the two best origins of absorption-line variability. To date, no one can unambiguously say which is more important among BAL quasars. He I* and Balmer multiplets are powerful in directly determining covering conditions and measuring ionic column densities. Therefore, follow-up observations of He I* BAL quasars and Balmer BAL quasars can distinguish the two possible origins in these quasars, and examples are presented in Shi et al. (2016b) and this work. He I* absorption lines exist in

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**Figure 15.** Two-dimensional spectral image from the YFOSC 201205 observation in the [O III] $\lambda 5007$ region, illustrating the EELR.
nearly all LoBAL quasars; thus, follow-up observations of a sample of HeI* BAL quasars can tell us the fraction of those that show variable ionic column densities and those that show variable covering factors. In this way we can make clear the origin of absorption-line variability in LoBAL quasars.

Balmer BAL quasars are rare but important because they trace high-density media. We need to measure the properties of absorbing gases in Balmer BAL quasars to better understand this rare type of BAL and high-density media around quasar nuclei. Typically column densities of three ions are needed to obtain the basic parameters, such as \( n_\text{H} \), \( N_\text{H} \), and \( U \). For example, objects studied by Zhang et al. (2015) and Shi et al. (2016b, 2016a) are iron LoBALs, and they used Balmer, HeI*, and excited states of FeII to calculate all three parameters. We show in this work that by taking follow-up observations, we can limit the parameters using only Balmer and He I*.

Considering that all known Balmer BALs show corresponding HeI*, this means that the density and position of absorption media can be determined for most of the Balmer BAL quasars. Thus, we propose that follow-up observations of Balmer BAL quasars are essential to better understand this rare population, especially those that are not iron LoBALs.

6. Summary

We present the analysis of absorption variability in mini-BAL quasar LBQS 1206+1052. We first recovered the absorption-free spectra using a pair-matching method. After normalization, we found an anticorrelation between the variation in EW of absorption lines and the V-band light curve, suggesting that the variability is photoionization driven. We then attempted to reproduce the data using two models: one assuming that only the ionization state is variable and that all the other physical properties are invariable, and the other assuming that only the covering factor is variable. In the variable ionization state model, the two components are both optically thin, and thus the column densities of HeI*, Mg II, and H\((n = 2)\) all decrease with increasing ionization parameter, demonstrating the anticorrelation between the EW of absorption lines and the continuum flux. The ionic column densities from the best-fit photoionization solution are also in agreement with the measured values, and the variation of \( U \) in the model is also in agreement with the observed variation in the continuum. In this way we present that the variable ionization state model can successfully reproduce the data. On the other hand, the variable covering factor model cannot reproduce the data because of the inconsistency between covering factors of He I* from quasi-simultaneous optical and NIR spectra, the unsynchronized variation between He I* \( \lambda 10830 \) and Mg II during 2012 and 2015, and the behavior of first weakening and then strengthening, which is difficult to understand kinetically. Therefore, we conclude that the absorption-line variability in LBQS 1206+1052 is photoionization driven.

We also obtained the physical properties of the two absorbing gases. The V700 absorbing gas has a size similar to the accretion disk, is at a distance of \( \sim 1 \) pc to the central source, and has a density in the range of \( 10^9-10^{10} \) cm\(^{-3}\). The velocity and position suggest that it is a restricted structure just outside the BELR. The V1400 absorbing gas represents an
outflow with a distance of \( \sim 1 \) kpc and a density of \( 10^3 \) cm\(^{-3} \). We related the outflow to the blue wing of the NELs and estimated a mass outflow rate of \( >0.3 \) \( M_\odot \) yr\(^{-1} \) and a kinetic outflow rate of \( >1.5 \times 10^{41} \text{ erg s}^{-1} \) at this distance. We suggest that the large-scale outflow started \( \sim 10^8 \) yr ago, as we found an EELR, which is worth follow-up investigations.

### Appendix A

#### The Details of the Pair-matching Method

In the main body, we introduced the principle of the pair-matching method. Here we describe in detail the application of this method for LBQS 1206+1052. We divided four ranges containing absorption lines as follows.

The first range is 2500–3300 Å for the MgII doublet and HeI \( \lambda \lambda 2946, 3189 \) lines. Liu15 developed the pair-matching method for this range. We directly used the template library of unabsorbed quasars of Liu15, which contains 1343 quasars from the SDSS DR7 quasar catalog. We noticed that the EW of the MgII emission line varies among the observed spectra of unabsorbed quasars of Liu15, which contains 1343 quasars.

The second range is 3300–3727 Å. The pseudo-continuum and Mg II emission lines for the templates following Wang et al. (2009), and we applied different scaling factors to the two components when fitting different spectra of LBQS 1206+1052. This can be expressed as

\[
f_{\text{obs},i}(\lambda) = f_{i,\text{cont}}(\lambda) \times S_{i,1} + f_{i,\text{Mg II}}(\lambda) \times S_{i,2} + (P_{0,i} + P_{1,i} + P_{2,i} \lambda^2),
\]

where the subscript \( i \) indicates different spectra for LBQS 1206+1052; \( f_{i,\text{cont}} \) and \( f_{i,\text{Mg II}} \) are the pseudo-continuum and Mg II components of the templates; \( S_{i,1} \) and \( S_{i,2} \) are the scaling factors for the two components; and \( P_{0,i} \), \( P_{1,i} \), and \( P_{2,i} \) are coefficients for an additional two-order polynomial. These five parameters are variable for different spectra. Thus, the variations in strength of BEL, strength of FeII emission, and strength and spectral shape of the continuum are all considered. We measured three ranges of 2775–2804 Å, 2930–2945 Å, and 3170–3190 Å in the fitting, which are affected by absorption lines. We noticed that the spectral resolutions in the MgII region, which are listed in Table 1, are not uniform. Thus, we blurred the templates using Gaussians with different widths for different spectra to be accounted for resolutions. We also considered the effect of resolutions for the following two parts in the optical.

The second range is 3800–4000 Å for HeI \( \lambda \lambda 3889 \) lines. Liu15 also developed the pair-matching method for this range. However, the situation in LBQS 1206+1052 is different, as the absorption trough is strongly affected by \( [\text{Ne III}] \lambda 3870 \) emission lines. Thus, we further developed the pair-matching method as follows. We reselected the unabsorbed templates from the DR7 and DR12 quasar catalogs. We required \( z < 1.2 \) for DR7 and \( z < 1.3 \) for DR12 to ensure that HeI \( \lambda 3889 \) is located in the spectral coverage, and we required that a median S/N of \( > 10 \) in 3800–4000 Å. We found variation in the EW of the NEL among spectra of LBQS 1206+1052; thus, we decomposed the template spectra into two components, an NEL component and a continuum+BEL component. In brief, we considered Balmer BELs from H\( \alpha \) to H\( \beta \) and NELs of [O II] \( \lambda 3727 \), [Ne III] \( \lambda \lambda 3869, 3968 \), H\( \beta \), H\( \alpha \), and H\( \delta \); we assumed that the continuum is a two-order polynomial and that all of the BELs and NELs are Gaussian; and we fit the template spectra in 3700–4200 Å. To better recover the shape of [Ne III] \( \lambda 3870 \) emission lines, we only selected those with an S/N of [Ne III] \( > 10 \). We also visually ruled out those with absorption lines and finally selected a library of 576 quasar spectra as templates.

We fit the spectra of LBQS 1206+1052 using the following formula:

\[
f_{\text{obs},i}(\lambda) = f_{i,\text{cont}}(\lambda) \times S_{i,1} + f_{i,\text{NEL}}(\lambda) \times S_{i,2} + (P_{0,i} + P_{1,i} + P_{2,i} \lambda^2),
\]

which is similar to that used for the MgII region. In the fitting we raised the weight in a region of 3840–3869 Å, where the blue side of the [Ne III] \( \lambda 3869 \) NEL is, because it is the key region to recover the whole shape of the NEL. The region of 3869–3890 Å, corresponding to \( -1500–0 \) \( \text{km s}^{-1} \) for HeI \( \lambda 3889 \), was masked in the fitting, and the velocity range was determined using the HeI \( \lambda 3889 \) trough.

The third range is for H\( \beta \) and H\( \alpha \) absorption troughs. The unabsorbed templates are also selected from the DR7 and DR12 quasar catalogs, and \( z < 0.4 \) was required for DR7 and \( z < 0.5 \) for DR12 to ensure that both lines lie in the spectral coverage. To recover the absorption-free spectra, the main features that we need to consider are H\( \alpha \), H\( \beta \), and [N II] \( \lambda \lambda 6548 \) NELs and H\( \alpha \) and H\( \beta \) BELs. Therefore, we selected a large range containing these features at first. The two parts are treated as a whole because the profiles of H\( \alpha \) and H\( \beta \) emission lines are strongly correlated. After a test, we found that there are too few templates that can fit the entire emission-line profile consisting of NELs and BELs at the same time. Thus, we narrowed down the wavelength range to 4825–4892 Å and 6510–6610 Å in the pair-matching process because only the top part of the BEL profile is essential for recovering the absorption-free spectrum. We required that the median S/N in the two ranges are both \( >25 \), and after this 1496 unabsorbed quasars remain. The variation in continuum and BELs can be expressed approximately as a two-order polynomial for both H\( \beta \) and H\( \alpha \). Thus, we have

\[
\begin{align*}
\text{f}_{\text{obs},i}(\lambda) &= f_i(\lambda) \times S_{i,1} + (P_{0,i} + P_{1,i} + P_{2,i} \lambda^2), \\
&\quad 4825 < \lambda < 4892, \\
\text{f}_{\text{obs},i}(\lambda) &= f_i(\lambda) \times S_{i,2} + (Q_{0,i} + Q_{1,i} + Q_{2,i} \lambda^2), \\
&\quad 6510 < \lambda < 6610.
\end{align*}
\]

We masked the regions affected by absorption lines using a velocity range of \( -1100 < v < -100 \) for both H\( \beta \) and H\( \alpha \), and the velocity range was set according to the absorption parameter from Ji12.

The last range was for the HeI \( \lambda 10830 \) trough. The wavelength range was selected to be 10550–11150 Å, which contains emission-line-free regions for both the blue and red sides. We collected NIR quasar spectra from Gilman et al. (2006), Riffel et al. (2006), and Landt et al. (2008) and added some quasar spectra we observed in the past using TSpec. We selected unabsorbed templates by three criteria as follows. First, the HeI \( \lambda 10830 \) does not exceed the wavelength coverage, or fall in the gap between \( J \) and \( H \) or in the gap between \( H \) and \( K \). Second, a BEL can be clearly seen, which means that the spectrum does not show only HeI \( \lambda 10830 \) NELs (FWHM < 2000 \( \text{km s}^{-1} \)), and that the emission line has S/N > 15. Third, there are no HeI \( \lambda 10830 \) absorption lines by visual check. After the selection, 51 quasar spectra remained.
and were used as templates. We also decomposed the spectro

t templates considering the variation in continuum and BEL. The

to fit the templates consists of a two-order polynomial as

two Gaussians for He I $\lambda$10830 and Pa y BELs, and two Gaussians for the two NELs. And the spectra of LBQS 1206+1052 were fit using

$$f_{\text{obs},i}(\lambda) = f_{s,\text{cont}}(\lambda) \times S_{\text{cont},i} + f_{s,BEL}(\lambda) \times S_{\text{BEL},i} + f_{s,NEL}(\lambda) \times S_{\text{NEL},i} + (P_{0,i} + P_{1,i} \lambda),$$

while we masked a wavelength range of 10741–10831 Å, which was determined visually. For He I $\lambda$10830, we only used a one-order polynomial for the deviation in continuum because we found that a one-order polynomial is enough.

**Appendix B**

**Testing the Fitting Procedure**

We examined the robustness of the fitting procedure to obtain the BAL parameters and their uncertainties. We made the test in the Mg ii region. We randomly selected 100 unabsorbed quasar spectra from the library, with a total of 1343 quasars. We generated fake absorbed spectra as

$$f_{\text{fake}}(\lambda) = f_{\text{unabs}}(\lambda) \times e^{-\tau(\lambda)},$$

where $\tau(\lambda)$ is the same for all 100 spectra and has a Gaussian profile with the following three parameters: centroid $\nu = -1400 \text{ km s}^{-1}$, $\sigma = 250 \text{ km s}^{-1}$, and integrated optical depth of Mg ii $\lambda$2803 $\tau_{2803} = 4$. We fit the fake absorbed spectra using the method described in Section 3.1. The results are plotted in Figure 16. For all three parameters, the best values are close to the true value. For 92 of the 100 unabsorbed quasars, the true value of the centroid falls into the 90% confidence interval, and the corresponding numbers for $\sigma$ and $\tau_{2803}$ are 88 and 84, respectively. The mean fraction of 88% is close to 90%; thus, the method yields a reliable confidence interval.

We also examined our method for directly measuring BAL EWs. We also measured from the 100 fake absorbed spectra and plotted the results in Figure 16. The best values are close to the true value of 4.89 Å, and for 88 of 100 the true value is in the 90% confidence interval. Thus, the method is also robust when measuring BAL EWs. This work is supported by the National Basic Research Program of China (the 973 Program 2013CB834905) and the National Natural Science Foundation of China (NSFC-11421303 and 11473025). T. Ji is supported by NSFC-11503022 and Natural Science Foundation of Shanghai (No. 15ZR1444200). S. Zhang is supported by NSFC-11573024. This research uses data obtained through the Telescope Access Program (TAP), which has been funded by the Strategic Priority Research Program, the Emergence of Cosmological Structures (Grant No. XDB09000000), the National Astronomical Observatories, the Chinese Academy of Sciences, and the Special Fund for Astronomy from the Ministry of Finance. This research also uses data obtained from the MAST. We acknowledge the support of the staff of the Lijiang 2.4m telescope. Funding for the telescope has been provided by CAS and the People's Government of Yunnan Province.

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