

Probing the He II re-Ionization E_{ra} via Absorbing C IV Historical Yield (HIERACHY) IV: A complex redshifted absorption system intrinsic to quasar

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ABSTRACT

High-resolution spectra provide a powerful tool in studying the associated absorption lines (AALs) in quasars. We present a case study of the quasar J014741-030247 at $z \sim 4.75$, which hosts complex intrinsic absorption lines revealed by the high-resolution Magellan/MIKE spectrum obtained from the HIERACHY program. We focus on one of the strongest absorption systems ($z \sim 4.7804$) and determine the column densities of multiple ionization species. We find that the Apparent Optical Depth method may significantly underestimate the column densities of high ions. Decomposing the absorption into multiple components yields a better fit and reveals clear evidence of partial coverage. The variation in covering fractions among different ions suggests that high ions are distributed more extensively in this system. We estimate electron densities of different components ($630 - 4070 \text{ cm}^{-3}$), these are based on the column densities of Si II* and C II*. By combining these with the hydrogen number density and ionization parameter derived from photoionization modeling, we infer that the different components are located at distances of 2.3 to 9.5 kpc from the quasar. The derived $N_{\text{H}}/n_{\text{e}}$ and the partial coverage observed in low ions all require cloud sizes smaller than 1 pc, even down to 0.01 pc. Finally, the low kinetic luminosity of the gas ($< 0.5\% L_{\text{bol}}$) indicates that it is insufficient to drive significant AGN feedback and may only suppress star formation via ‘multistage’ mechanism.

Keywords: Quasar absorption line spectroscopy; Metal line absorbers; Galaxy kinematics

1. INTRODUCTION

Associated absorption lines (AALs) in quasars are defined as absorption features with redshifts within several thousand km s^{-1} of the quasar’s emission lines (e.g., Vanden Berk et al. 2008; Hamann et al. 2011; Shen & Ménard 2012; Chen et al. 2018). These features are commonly used to probe quasar inflows and/or outflows. However, their origins can be diverse, potentially arising not only from AGN-driven gas flows but also from interstellar medium (ISM) of the host galaxy or the circumgalactic medium (CGM) on larger scales (e.g., Foltz et al. 1986; Tripp et al. 1998).

If the absorbing gas is physically associated with the quasar or its host galaxy rather than arising from unrelated intervening material along the line of sight, we consider the AALs to be intrinsic. Determining whether an AAL is intrinsic requires specific criteria, including: (1) high gas densities inferred from the ratio of excited-state to ground-state lines of the same ion; (2) detectable vari-

ability in the absorption lines over time (e.g., Hamann et al. 1997; Narayanan et al. 2004); (3) partial covering of the background source, which suggests the presence of very small absorbing clouds (e.g., Ganguly et al. 1999; Arav et al. 2008); and (4) significantly broader absorption lines than those expected from thermal or dynamical broadening in the CGM (e.g., Misawa et al. 2007). These characteristics, often found together, strongly indicate an intrinsic origin.

Mass flux and kinetic luminosity quantify how much mass and energy AGN-driven outflows transport, enabling assessments of their potential to drive feedback in galaxy evolution. Both the mass flux ($\dot{M}$) and kinetic luminosity ($\dot{E}_{\text{k}}$) of the gas flow scale linearly with the total hydrogen column density (N_{H}) and the distance of the gas cloud (R) from the central engine. Observationally, N_{H} and R can be using multiple ions, which are used to solve photoionization models and determine the ionization parameter U . Additionally, absorption

lines produced by the excited and metastable levels of the same ion provide a density diagnostic, as their ratios are sensitive to the electron density n_e . The gas flow distance R can then be derived from the ionization parameter U and the electron density n_e . This method has been successfully applied in a series of studies (e.g., Arav et al. 2005, 2008; Dunn et al. 2010; Arav et al. 2013; Xu et al. 2018)

In low-resolution spectra, absorption troughs are typically unresolved and treated as single components using the apparent optical depth (AOD) method, which can introduce biases in the derived physical parameters of the gas flow (e.g., Miller et al. 2018; Xu et al. 2018; Xu et al. 2020; Byun et al. 2022). High-resolution rest-frame UV spectra are therefore essential for decomposing broad AALs into individual components and accurately determining their column densities and other parameters.

The “Probing the **He II re-Ionization ERa** via **Absorbing C IV Historical Yield (HIERACHY)**” program is designed to investigate He II reionization and related processes at $z \sim 3 - 5$ using spectra against bright background quasars obtained with the 6.5m Magellan telescope (Li et al. 2025). The first release of the C IV absorber catalog, based on high-resolution ($R \gtrsim 30,000$) spectra of 26 quasars at $z \sim 3.9 - 5.2$ observed with the Magellan Inamori Kyocera Echelle (MIKE) spectrograph, is published in Yu et al. (2025). Pronounced AALs are detected in about one-third of the spectra, providing an optimal dataset for studying quasar outflows and inflows during a critical epoch of cosmic reionization.

Here, we report an intriguing case of three strong AALs in the spectrum of the quasar J014741-030247 ($z_{\text{QSO}} \sim 4.75$), all exhibiting velocity shifts of $|\Delta v| < 5000 \text{ km s}^{-1}$. We focus on one of the absorption systems (S1, $z \sim 4.7804$) due to its high electron density, evident partial covering, and unusually broad line width. This case provides an excellent laboratory for a comprehensive study of the properties of AALs.

This paper is organized as follows: In §2, we describe the Magellan/MIKE observations and data reduction procedures. In §3, we employ various methods to fit the AALs, measuring column densities, covering fractions, and other key properties. Using these measurements, we determine gas densities and photoionization conditions with the **CLOUDY** code. In §4, we also estimate the absorber’s distance from the quasar and compare the results obtained from the AOD method and component decomposition techniques. We finally summarize our key results in §5. All reported uncertainties correspond to 1σ (68%) confidence levels unless otherwise stated.

2. MAGELLAN/MIKE OBSERVATIONS

J014741-030247 (R.A. = 01h 47m 41.53s, Dec. = 03° 02′ 47.88”) was observed with Magellan/MIKE for ≈ 2.8 hours ($5 \times 1800 \text{ s} + 1 \times 1000 \text{ s}$) on November 14, 2020, as part of the HIERACHY program (Yu et al. 2025). The red channel of its global spectrum has been published in Yu et al. (2025) and is also presented in Fig. 1. The redshift, $z \sim 4.75$, was estimated by fitting its optical spectrum taken with a smaller telescope with the SDSS quasar template using the ASERA toolkit (Wang et al. 2016).

Detailed observation setup and data reduction procedures, including continuum determination and metal absorption line identification, are described in ?. In summary, we used a $0''.7 \times 5''.0$ entrance slit and applied a 2×2 binning to the detector. The spectral resolution is $R \sim 32,000$ in the red channel (4800-9400 Å) and $R \sim 41,000$ in the blue channel (3500-5000 Å). In this paper, we only use data from the red channel, which covers the Ly α emission line of the quasar and the red-der portions of the spectrum that are not blended by the Ly α forest. The signal-to-noise ratio (S/N) of the continuum is ~ 18 near 7100 Å, approximately at the Ly α emission line. (Fig. 1).

In this paper, we focus on absorption systems produced by quasar outflows or inflows, which are selected based on having velocity offsets of $|\Delta v| \leq 5000 \text{ km s}^{-1}$ from the quasar’s redshift. Three such absorption systems are identified and labeled as S1-S3. In the first system (S1), at $v \sim +1600 \text{ km s}^{-1}$ (redshifted relative to the quasar’s systemic redshift determined in Wang et al. 2016), we detect absorption lines from multiple ions, including O VI $\lambda\lambda 1031, 1037$, N V $\lambda\lambda 1238, 1242$, Si IV $\lambda\lambda 1393, 1402$, C IV $\lambda\lambda 1548, 1550$, as well as both ground and excited-state (denoted with *) absorption lines of C II and Si II (Figs. 2 and 3). In contrast, for S2 at $v \sim +4000 \text{ km s}^{-1}$ and S3 at $v \sim +4400 \text{ km s}^{-1}$, we only detect C IV, Si IV, Ly α , and Ly β absorption lines (Fig. 4).

3. DATA ANALYSIS

3.1. Ionic Column Density

Here we try three commonly used methods to measure the column density, and ultimately adopted the results from the apparent optical depth (AOD) method and Voigt profile methods.

3.1.1. AOD method

For high ions such as C IV, N V, and O VI, many of the absorption troughs are either saturated or blended with the Ly α forest, complicating accurate component fitting. A straightforward method to constrain the lower limit of

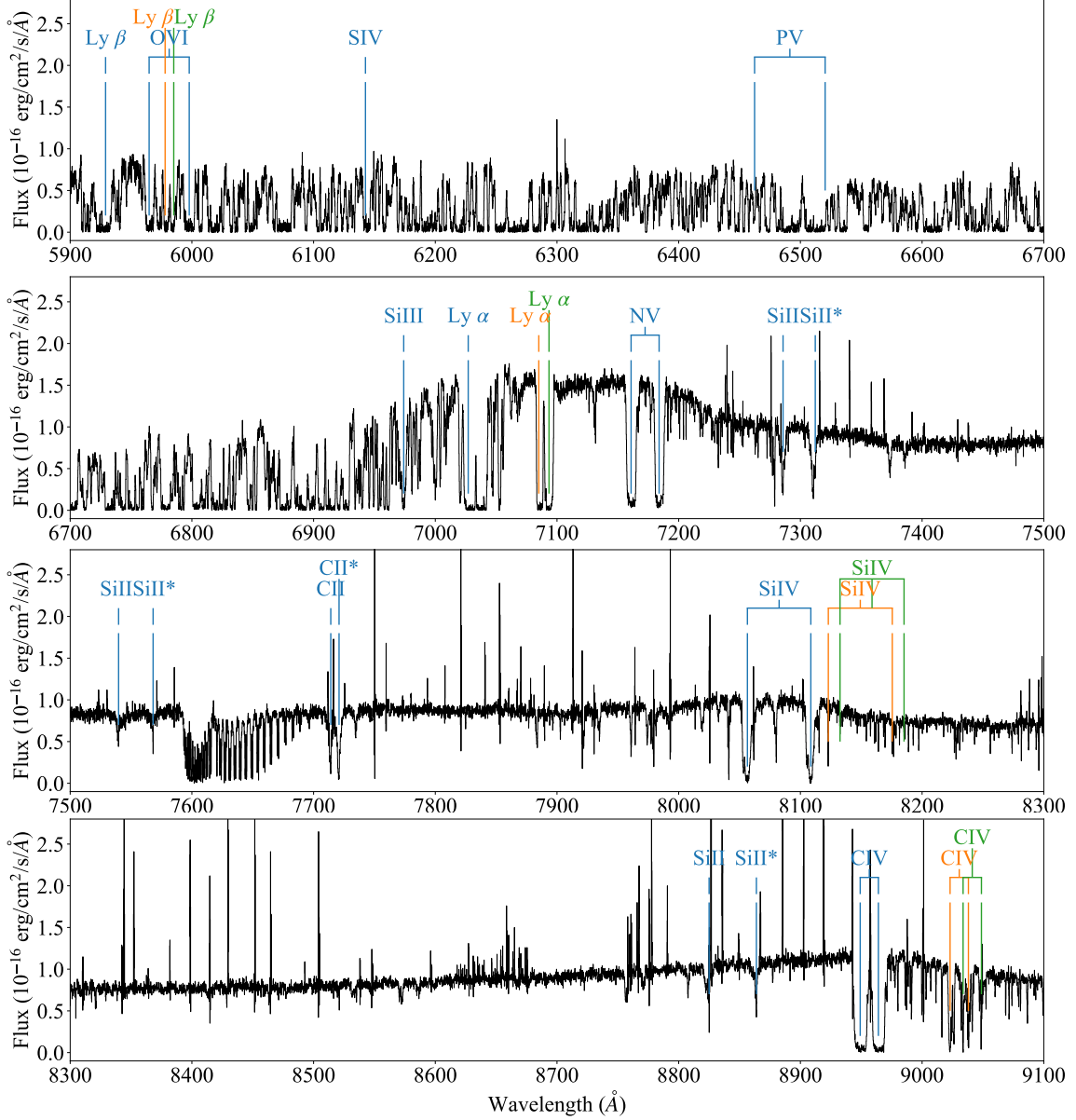


Figure 1. Magellan/MIKE red channel spectrum of quasar J014741-030247 at $z \sim 4.75$. Absorption troughs of different ions are labeled with colored bars. Individual absorption lines associated with systems S1, S2, and S3 are labeled in blue, orange, and green, respectively. It is worth noting that in S2 and S3, only C IV, Si IV, Ly α , and Ly β lines are detected.

their column densities is AOD technique (e.g., [Savage & Sembach 1991](#)). The optical depth $\tau(\lambda)$ is defined in the following form (e.g., Equation (1) of [Savage & Sembach 1991](#)):

$$I(\lambda) = I_0(\lambda)e^{-\tau(\lambda)}, \quad (1)$$

where $I(\lambda)$ is the observed intensity of an absorption line, while $I_0(\lambda)$ is the intensity of the neighbouring continuum, or the intrinsic intensity before absorption. When the optical depth is expressed as a function of velocity, it relates to the column density, $N(v)$, in the following form (e.g., Equation (8) of [Savage & Sembach](#)

1991):

$$\tau(v) = \frac{\pi e^2}{m_e c} f \lambda N(v), \quad (2)$$

where m_e is the electron mass, e is the elementary charge, f is the oscillator strength, and λ is the rest-frame wavelength of the transition. Integrating $N(v)$ over the relevant velocity range yields the total column density. Because this method does not account for saturation or partial covering, it provides only a lower limit.

Using this approach, we estimate the total column densities for the strongest absorption troughs in each

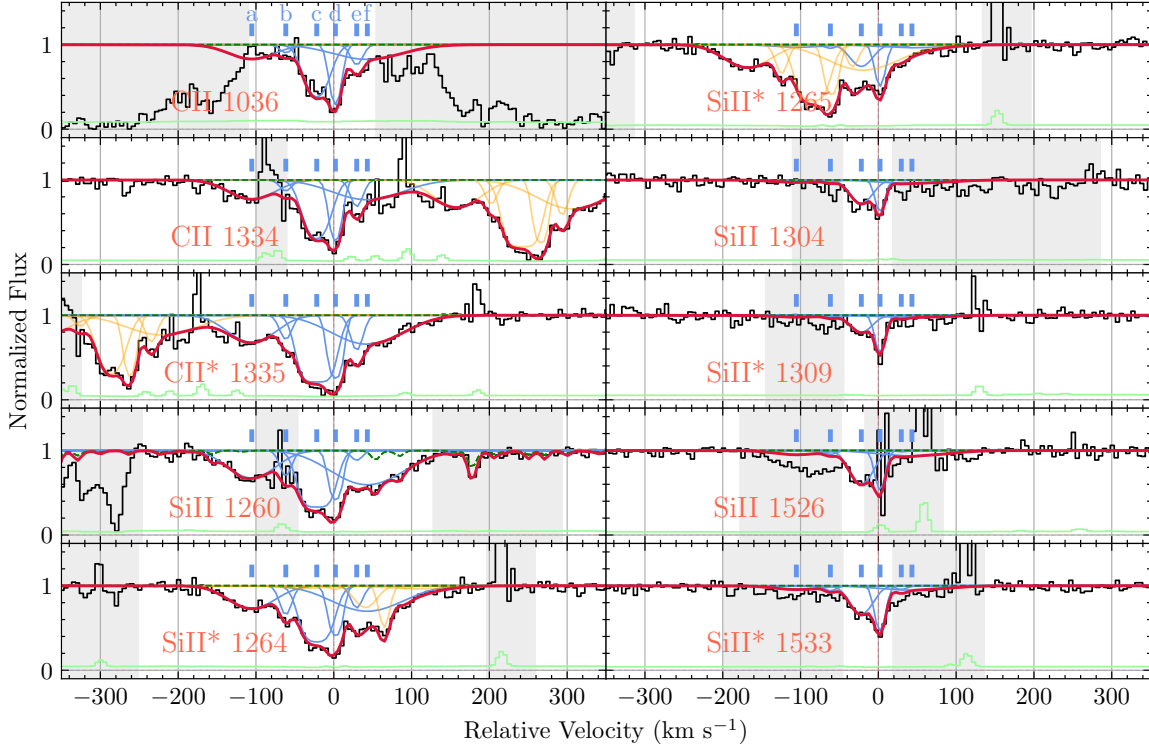


Figure 2. Normalized spectrum shows the absorption of C II, C II*, Si II and Si II* belonging to the system S1 at the redshift of 4.7804. Six components are marked with a bar in blue, and absorption from other lines is in yellow. The absorption from the atmosphere is plotted in a dashed green line. Unrecognized absorptions and emission lines are masked with grey regions. The error of the normalized flux is plotted at the bottom of each figure in green.

system. For the S1 system, we integrate over the velocity range 1400–1750 km s^{−1}. For S2 and S3, the integration ranges are 4000–4200 km s^{−1} and 4360–4550 km s^{−1}, respectively. The resulting column densities and associated 1 σ uncertainties are presented in Table 1 and Table 2.

3.1.2. Partial covering

The AOD method provides a reliable estimate of the column density only when the optical depth is small ($\tau \ll 1$). However, the column densities inferred from the two lines of an ionic doublet are often inconsistent. This mismatch can be explained by the partial homogeneous covering model, in which the absorbing gas only partially covers the background source. Furthermore, although the absorption features of high ions are often nearly saturated, the residual intensity in the absorption troughs often remains nonzero (Fig. 3), indicating that complete coverage is not achieved. We therefore adopt the partial covering (PC) method, which incorporates a velocity-dependent covering fraction $C(v)$ (e.g., de Kool et al. 2002; Arav et al. 2005). $C(v)$ is determined by solving the following relation:

$$I_n(v) - [1 - C(v)] = C(v)e^{-\tau_n(v)}, \quad (3)$$

where $I_n(v)$ denotes the normalized intensities of the absorption line, and $\tau_n(v)$ represents the optical depth, as given in Eq. 2, which can subsequently be converted to column density. In real measurement, there are two types of observational case where the covering fraction can be determined, (1). Doublet with such as C IV $\lambda\lambda 1548, 1550$, (2). multiple lines from the same ion. In the first case, $n = 1$ and 2. the ratio of $\tau_1(v)$ to $\tau_2(v)$ is a constant determined by both the wavelengths and oscillator strengths. With two equations, both $C(v)$ and $\tau_1(v)$ (or $\tau_2(v)$) can be solved. In the second case, if n absorption lines are observed, we obtain n values of $I(v)$, and the ratios between the corresponding $\tau_n(v)$ values are constants determined by the wavelengths and oscillator strengths. In this case, the values of $\tau(v)$ and $C(v)$ can be determined numerically by minimizing the χ^2 between the modeled and observed intensities in each velocity bin.

We rebin the spectra to a resolution of 20 km s^{−1} to improve the signal-to-noise ratio. The regions contaminated by other lines and atmospheric absorption lines are masked and excluded from the calculation. The $C(v)$ is calculated for each bin. For the doublet lines identified in the S1 system—C IV $\lambda\lambda 1548, 1550$,

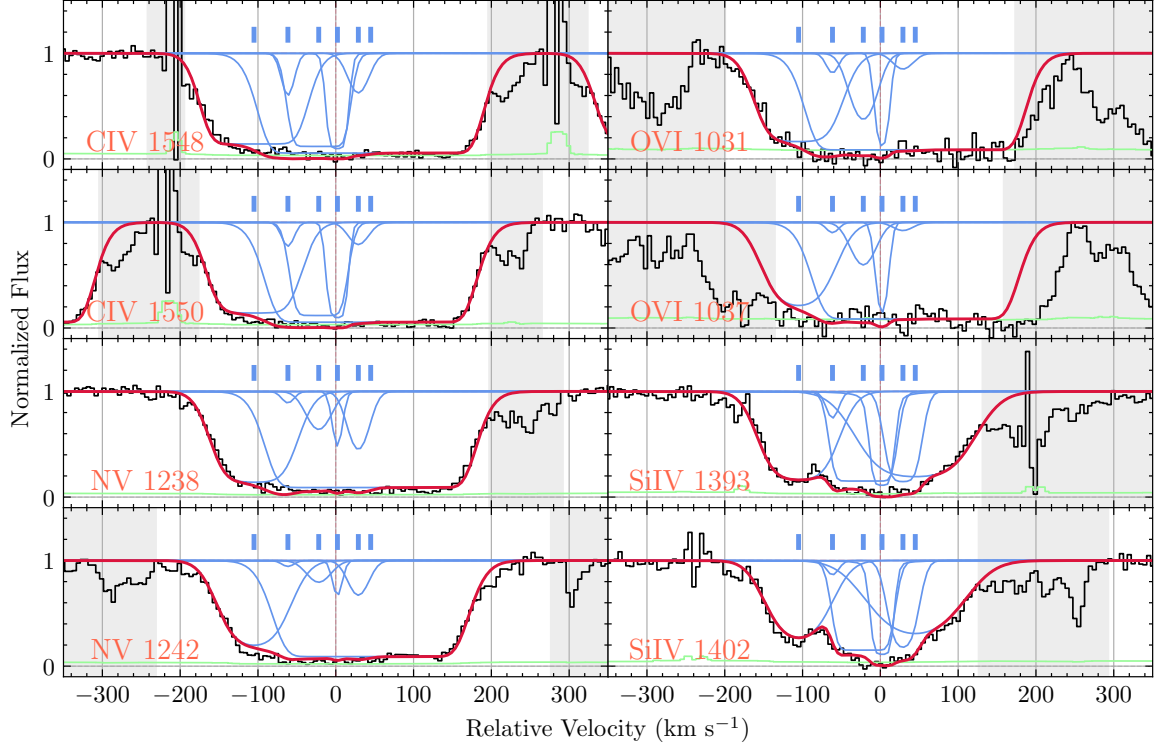


Figure 3. Normalized spectrum shows the absorption of C IV, Si IV, N V and O VI belonging to the system S1 at the redshift of 4.7804. Velocity centroids and nonthermal broadening of six components are fixed to the low ions fitted values.

Si IV $\lambda\lambda 1393, 1402$, N V $\lambda\lambda 1238, 1242$, and O VI $\lambda\lambda 1031, 1037$, these are consistent with the conditions described in the first case. So we can obtain analytical solutions for τ and $C(v)$. The same method is applied to the C II case (C II $\lambda 1036$, C II $\lambda 1334$), which aligns with the second case. For Si II, We have identified numerous lines, which correspond to the third case, meaning we can only obtain a numerical solution. In principle, the covering fractions for different states of the same ion, such as Si II* and Si II, should be consistent. However, the potential difference in column density may cause the ratio between their τ values to not be constant. Therefore, here we calculate $C(v)$ separately for Si II and Si II* (for Si II, Si II $\lambda 1260$, Si II $\lambda 1304$, Si II $\lambda 1526$; for Si II*, Si II* $\lambda 1264$, Si II* $\lambda 1265$, Si II* $\lambda 1309$, and Si II* $\lambda 1533$) to derive the covering fractions. For S2 and S3, atmosphere absorption significantly overlaps with the ionic absorption features (indicated by the dashed green lines in Fig. 4), and the C IV doublets are blended with each other. Minor deviations in the doublet ratio can result in substantial inaccuracies in the determination of both the covering fraction and the column density. Thus PC method is not applied to the S2 and S3 systems.

Fig. 5 shows the covering fraction calculated for each ion. Although the uncertainties are large and it is diffi-

cult to obtain reliable column densities, we can still see from the figure that, within the error range, many bins for each ion exhibit covering fractions significantly less than 1.

3.1.3. Decomposition Fitting

The absorption of low ion clearly calls for multiple components, and their column densities and b factors appear to differ significantly. Therefore, decomposition fitting is necessary. High-resolution MIKE optical spectra allow for the decomposition of each absorption feature into multiple components and enable precise comparison of velocity alignment across different ionic species (e.g., Cooper et al. 2021; Zahedy et al. 2021; Qu et al. 2022). Therefore, we use Voigt profile fitting for multiple components to obtain column densities here. The Voigt profile fitting allows for the inclusion of atmospheric line models, thereby minimizing the impact of telluric absorption features on the results. Our principle for characterizing each complex multi-component system is to use the minimum number of components whenever possible.

We start identifying different components with the most complex S1 system. The lines from high ions (O VI, N V, and C IV) in S1 are strongly saturated, making it difficult to distinguish individual absorption com-

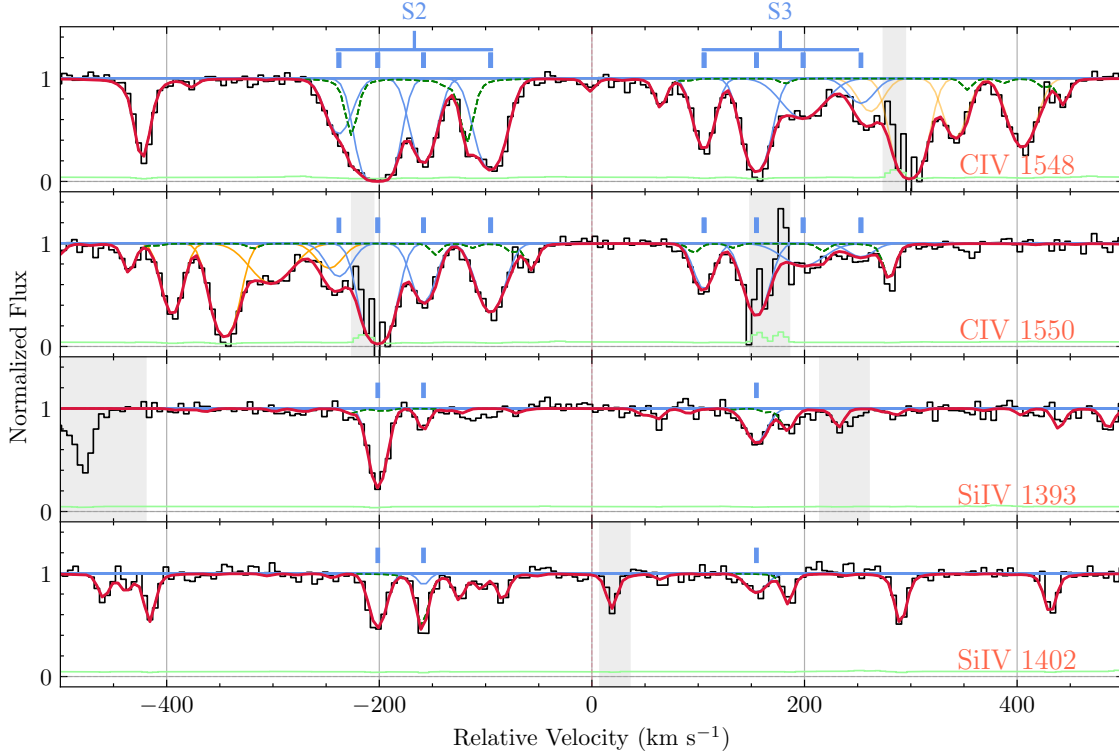


Figure 4. Normalized spectrum shows the absorption of C IV and Si IV belonging to the S2 and S3 systems at the redshift $z = 4.832$. The component is marked with a blue bar while its column density is larger than 10^{12} cm^{-2} . The grey area is the region with contamination that has been masked.

ponents from these transitions alone. Fortunately, several lower-ionization lines—particularly multiple transitions of C II and Si II, including their excited states—are unsaturated and offer better constraints for decomposing the system. Based on these transitions, we identify six distinct absorption components in S1. Among them, components **c** and **d** are the most prominent, with strong absorption signatures consistently detected across all available transitions. Components **a** and **f** appear as broad, shallow troughs in C II $\lambda 1334$, C II* $\lambda 1335$, Si II $\lambda 1260$, and Si II* $\lambda 1264$. Component **b** is relatively weak and is primarily identified through the excited-state transitions C II* $\lambda 1335$ and Si II* $\lambda 1264$. Finally, component **e** is clearly distinguished in most detected lines.

For comparison, the S2 and S3 systems are simpler with less absorption components from various ions. The most prominent absorption lines in S2 and S3 are C IV and Si IV, with the two systems separated by $\sim 400 \text{ km s}^{-1}$ (Fig. 4). We use the stronger C IV $\lambda 1548$ line as the primary tracer for identifying different absorption components. This line is free from contamination by other metal lines, although some telluric features are present in the same wavelength range and are indicated by green dashed curves in Fig. 4. In total, four

distinct absorption components are resolved in S2. For S3, although the C IV $\lambda 1548$ line is blended with the $\lambda 1550$ line from S2, four components can still be clearly identified.

We attempt to simultaneously fit all low ions, with their velocity centroids linked across components. The total normalized intensity can be written as the product of the intensities after absorption of each component:

$$I(v) = \prod \left\{ C_f e^{-\tau(v)} + 1 - C_f \right\}, \quad (4)$$

where C_f and $\tau(v)$ represent the covering fraction and optical depth respectively, and the optical depth can be expressed as:

$$\tau(v | N, b, z) = N \sigma_0 f \Phi(v | b, z), \quad (5)$$

where N, b, z, f, v and σ_0 are the ion column density, Doppler parameter, the redshift of the system, oscillator strength, cross-section of the ion, and the velocity relative to the system. $\Phi(v | b, z)$ is the normalized Voigt profile. In the same system, the velocity centroid of the same component from different ions is linked with each other.

Doppler broadening is caused by thermal and non-thermal motions (e.g., Rauch et al. 1996), $b^2 = b_T^2 +$

b_{NT}^2 . There are currently no other reliable temperature-sensitive indicators available for b_{T} . So we assume a temperature of 10^4 K to fix its value. The typical temperature range in which C II and Si II exist is between 10^4 K and 10^5 K (e.g., Gnat & Sternberg 2007). Within this temperature range, the variation of the b_{T} ($\sqrt{2k_{\text{BT}}/m_i}$) is relatively small (< 8 km/s). Then we link the nonthermal line width b_{NT} of the components from C II with the one from Si II.

For high ions, since the absorption troughs of ions other than Si IV are heavily saturated and do not allow clear separation of different components, we tie the velocity centroids of each component to those derived from the Si II and C II fits. High ions (Si IV, C IV, N V, O VI) typically exist at a temperature of around 10^5 K (e.g., Gnat & Sternberg 2007). Therefore, the thermal broadening between these ions should not differ significantly; instead, the nonthermal broadening, which is the same among these ions, should dominate. Saturation also makes it difficult to determine the precise b_{NT} for each component; therefore, we set the b_{NT} of all components to the same values as the those of Si II and C II, which may underestimate the b_{NT} of high ions. The column densities and covering fractions of different components for various ions are set to be free for fitting.

In Sec. 3.1.2, we find that the covering fraction in S1 is significantly less than 1, so we also take the covering fraction into account in the Voigt profile fitting. We obtain covering fractions of low ions in two cases. For components with sufficiently strong absorption (component **c** and **d**), we treat the covering fraction as a free parameter in the fitting. For the remaining components, we used the covering fractions of high ions as upper limits, they exhibit strong absorption in high ions, allowing their fitted results to be used as upper limits for low ions. We find that components **a** and **f** show nearly identical profiles in the high ions doublets, indicating clear evidence of partial covering. Therefore, we treated the covering fractions of components **a**, **c**, **d**, and **f** as free parameters, while fixing those of components **b** and **e** to 1. Among the four ions (Si IV, C IV, N V, O VI), component **a** of N V has the lowest covering fraction, 0.78, and component **f** of Si IV has the lowest covering fraction, 0.80. We adopt these values as the upper limits for the covering fractions of components **a** and **f** of C II and Si II, respectively. The lower limits of the partial covering are obtained from the lowest normalized flux from the components. The results are presented as a range and shown in Table 3.

From Sec. 3.1.2, we cannot confirm the presence of significant partial covering in S2 and S3; therefore, the covering fractions are fixed to 1. The results of cover-

ing fractions are shown in Table 1. In the subsequent fitting and analysis, we adopt the column densities derived from the upper limits of the covering fractions.

3.1.4. Column density comparison

After deriving the column densities using both the AOD method and the decomposition fitting, we compare the total column density of each ion obtained from the two methods. The results are presented in Fig. 6. The different ions are arranged in order of increasing ionization potential, from low to high. The ratio of measured column densities between these two methods is also shown in the lower panel. The difference between measurements from the two methods is not large in the case of unsaturated lines, even though we identify significant partial covering in the absorption of Si II and C II, the measurements are of the same order. However, the column densities measured by Voigt profile fitting are more than 10 times those measured by AOD method in the case of high ions where the absorptions are nearly saturated. This situation is very common in broad absorption line (BAL) quasars, where absorption troughs from high ions are broad and saturated while the absorptions from low ions are moderate. Our case shows that the column densities of high ions will be significantly underestimated if measured using the AOD method, which may lead to the underestimation of the ionization parameter of the gas.

3.2. Electron Number Density

We can determine the electron number density of each component by measuring the column density ratios between excited and ground states.

$$\frac{N_{\text{excited}}}{N_{\text{ground}}} = \frac{n_e k_{01}}{n_e k_{10} + A_{10}}, \quad (6)$$

Here, k_{01} and k_{10} are the upward and downward collisional rate coefficients, respectively, and A_{10} is the spontaneous decay rate. We then calculated the density using the $N(\text{C II}^*)/N(\text{C II})$ and $N(\text{Si II}^*)/N(\text{Si II})$ ratios following Qu et al. (2019).

The level populations at different temperatures and densities are calculated with the atomic data from CHIANTI 10.0.2 (Dere et al. 1997; Del Zanna et al. 2021). Since both ratios are insensitive to temperature across all density ranges, we adopt a typical temperature of 10^4 K for estimating n_e . As shown in Fig. 7, the ratio of $N(\text{C II}^*)/N(\text{C II})$ have large uncertainties, and the ratio becomes nearly constant when the density exceeds $10^{2.2} \text{ cm}^{-3}$. Therefore, we use $N(\text{Si II}^*)/N(\text{Si II})$ to estimate n_e and find that the n_e of all components are above 10^3 cm^{-3} , consistent with the lower limits inferred from the C II ratio. For component **b**, the Si II

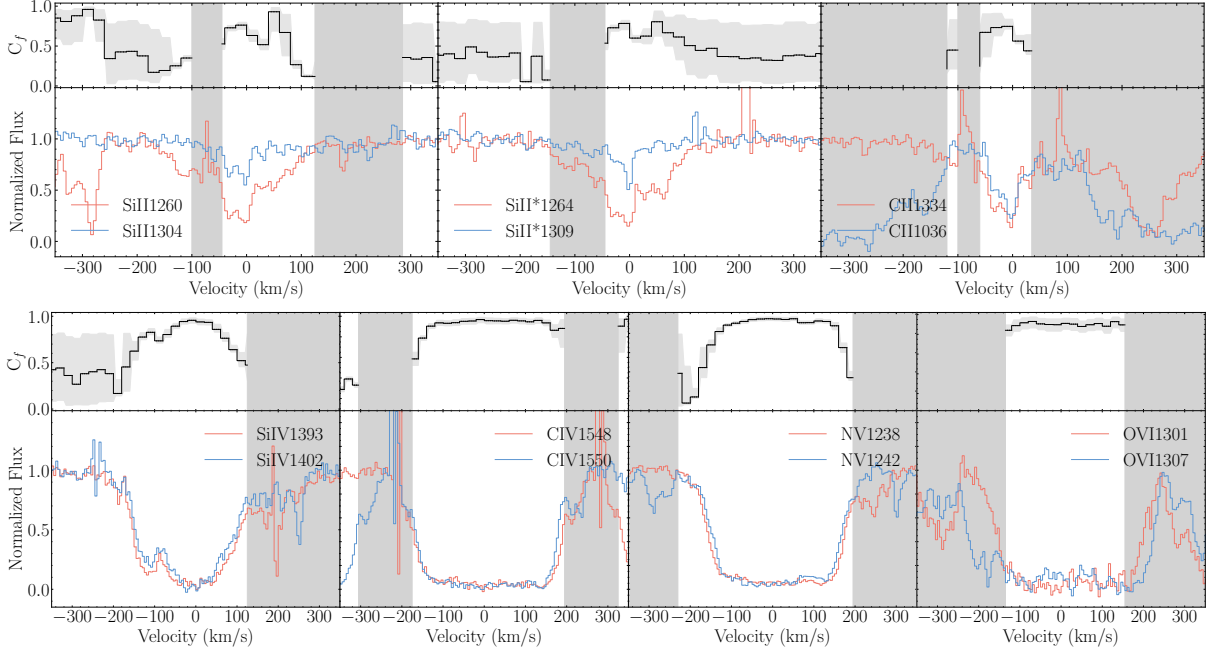


Figure 5. Partial covering fitting results of different ion lines. The covering fraction of each bin is plotted on top of the normalized spectrum. Grey region represents the range of one sigma error. Absorption contaminated is masked by grey rectangles and the covering fractions of these bins are not shown in the figure. Different line profiles of the same ions are plotted in the same velocity space.

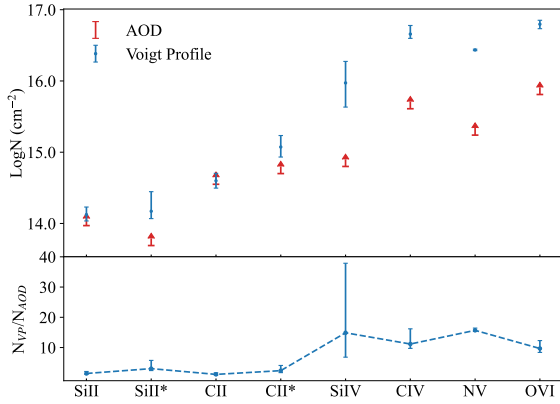


Figure 6. The upper panel is the total column density of each ion measured by AOD and Voigt profile fitting. Blue dots with error bars represent the sum of column densities of six components measured by the Voigt profile and the red one shows the lower limit measured by AOD. The lower panel shows the ratio between the column densities measured by Voigt profile fitting and AOD.

does not have enough unmasked pixels to yield an accurate column density, we adopt the lower limit of n_e derived from the C II ratio, which is $> 2304 \text{ cm}^{-3}$.

We also derive the n_e as a single component using the column density ratios obtained from the AOD method. The results are indicated by black dots in Fig. 7. The electron number density using AOD method derived from the C II ratio is approximately one order of magnitude lower than that derived from Si II. When comparing n_e values derived from C II and Si II individually, those obtained via the AOD method are consistently lower than the results from decomposition fitting.

3.3. Photoionization Analysis

We use the spectral synthesis code **Cloudy** (version c17.01, Ferland et al. 2013, 2017) to determine the hydrogen column density N_H and ionization parameter U_H . Following the approach used in previous studies (Arav et al. 2013; Xu et al. 2018; Xu et al. 2019), we employ **Cloudy** to generate a grid of simulated models corresponding to different values of N_H and U_H , assuming solar metallicity and utilizing the spectral energy distribution (SED) of a radio-quiet quasar HE 0238-1904 (hereafter HE0238; Arav et al. 2013). For the observed data in the 835-1635 Å rest frame, the ratio between the HE0238 SED and the J014741 continuum remains constant within $\pm 10\%$. The electron densities derived in Sec. 3.2 are adopted as input parameters for these simulations. The best-fit total hydrogen column density

Table 1. The fitting results of low ions in S1. The fitting velocity centroid is relative to $z = 4.7804$. For the same component, the velocity centroid and b_{NT} are set to be identical for different ions, so the errors are only shown in C II columns. The covering fraction of the same component for the same ion is assumed to be identical. The upper limits and lower limits of covering fractions for component **a** and **f** are obtained from high ions and normalized flux seperately.

Ion	logN (cm ⁻²)	logN (cm ⁻²) (AOD)	b_{NT} (km s ⁻¹)	velocity centroid (km s ⁻¹)	covering fraction
S1					
C II	13.61 ^{+0.07} _{-0.06}	> 14.55±0.03	39.5 ^{+4.4} _{-3.7}	-105.4 ^{+3.7} _{-3.0}	[0.36, 0.78]
	12.76 ^{+0.25} _{-0.63}		8.2 ^{+2.6} _{-2.6}	-61.7 ^{+1.4} _{-1.4}	1.0
	14.20 ^{+0.08} _{-0.08}		17.6 ^{+2.4} _{-2.6}	-21.9 ^{+2.2} _{-2.3}	0.79 ^{+0.04} _{-0.04}
	14.27 ^{+0.43} _{-0.23}		5.2 ^{+1.3} _{-2.3}	2.1 ^{+0.5} _{-0.7}	0.75 ^{+0.09} _{-0.09}
	13.20 ^{+0.10} _{-0.12}		8.1 ^{+2.2} _{-2.0}	29.5 ^{+1.2} _{-1.3}	1.0
	13.79 ^{+0.06} _{-0.06}		59.4 ^{+3.4} _{-3.5}	43.1 ^{+3.6} _{-2.3}	[0.37, 0.80]
	13.83 ^{+0.04} _{-0.04}		39.5	-105.4	[0.36, 0.78]
C II*	13.20 ^{+0.14} _{-0.17}	> 14.70±0.02	8.2	-61.7	1.0
	14.82 ^{+0.13} _{-0.12}		17.6	-21.9	0.79
	14.78 ^{+0.63} _{-0.43}		5.2	2.1	0.75
	13.40 ^{+0.09} _{-0.10}		8.1	29.5	1.0
	14.04 ^{+0.04} _{-0.04}		59.4	43.1	[0.37, 0.80]
	12.84 ^{+0.06} _{-0.05}		39.5	-105.4	[0.37, 0.78]
	12.21 ^{+0.18} _{-0.15}		8.2	-61.7	1.0
Si II	13.74 ^{+0.06} _{-0.07}	> 13.97±0.04	17.6	-21.9	0.67 ^{+0.02} _{-0.02}
	13.70 ^{+0.16} _{-0.14}		5.2	2.1	0.60 ^{+0.07} _{-0.06}
	11.74 ^{+0.24} _{-0.36}		8.1	29.5	1.0
	13.13 ^{+0.03} _{-0.04}		59.4	43.1	[0.52, 0.80]
	12.78 ^{+0.05} _{-0.05}		39.5	-105.4	[0.37, 0.78]
	12.33 ^{+0.10} _{-0.12}		8.2	-61.7	1.0
	13.63 ^{+0.06} _{-0.07}		17.6	-21.9	0.67
Si II*	13.92 ^{+0.23} _{-0.13}	> 13.69±0.01	5.2	2.1	0.60
	12.18 ^{+0.13} _{-0.18}		8.1	29.5	1.0
	13.02 ^{+0.05} _{-0.05}		59.4	43.1	[0.52, 0.80]

N_H and ionization parameter U_H are then obtained by minimizing the χ^2 . All solutions of different components are summerized in Fig. 11.

For each component, we compute a one-phase photoionization solution. For the majority of components, such a one-phase solution can satisfactorily reproduce the observed column densities of different ions. However, in certain cases, such as component **f** (shown in Fig. 8), where absorption is strong across a wide ionization range from C II to O VI, the one-phase solution appears insufficient to account for the measured column densities of low ions like C II and Si II. If additional low ions such as Fe II or O I were detected, this would further support the need for an additional phase, contributing to a solution with a lower U_H . The results for other components are shown in Appendix.

If the absorber is treated as a single component and the column densities of various ions are derived using the AOD method, the resulting one-phase photoionization

solution fails to simultaneously reproduce the observed column densities of all ions. On one hand, the AOD method provides only lower limits to the column densities, often accompanied by significant uncertainties. On the other hand, when the absorption profile is decomposed into individual components, the derived one-phase solutions vary significantly across components, with differences in $\log(U_H)$ reaching to ~ 1.5 dex. When the entire absorption trough is modeled as a single component, the column densities from all sub-components are summed together. As a result, the combined ion column density becomes difficult to reconcile with a single ionization phase, indicating that a one-phase solution cannot adequately reproduce the total observed features.

To study the influence of different SEDs and metallicities on the photoionization solutions, we consider three different SEDs and metallicities following the method of previous work (e.g., Arav et al. 2013; Chamberlain & Arav 2015; Xu et al. 2018). In addition to the SED of

Table 2. The fitting results of high ions in S1-S3. The velocity centroids fitting in S2 and S3 are set to be relative to $z = 4.832$.

Ion	logN (cm ⁻²)	logN (cm ⁻²) (AOD)	b _{NT} (km s ⁻¹)	velocity centroid (km s ⁻¹)	covering fraction
S1					
Si IV	14.32 ^{+0.02} _{-0.02}	> 14.80±0.01	39.5	-105.4	0.80 ^{+0.01} _{-0.01}
	12.41 ^{+0.18} _{-0.16}		8.2	-61.7	1.0
	15.87 ^{+0.16} _{-0.18}		17.6	-21.9	0.80 ^{+0.02} _{-0.02}
	16.14 ^{+0.19} _{-0.36}		5.2	2.1	0.84 ^{+0.05} _{-0.05}
	13.95 ^{+0.25} _{-0.25}		8.1	29.5	1.0
	14.50 ^{+0.02} _{-0.02}		59.4	43.1	0.80 ^{+0.01} _{-0.01}
C IV	15.38 ^{+0.02} _{-0.02}	> 15.61±0.01	39.5	-105.4	0.84 ^{+0.01} _{-0.01}
	13.05 ^{+0.28} _{-0.25}		8.2	-61.7	1.0
	13.89 ^{+0.59} _{-0.37}		17.6	-21.9	0.89 ^{+0.04} _{-0.04}
	14.44 ^{+0.73} _{-0.58}		5.2	2.1	0.89 ^{+0.04} _{-0.03}
	13.27 ^{+0.29} _{-0.27}		8.1	29.5	1.0
	16.74 ^{+0.08} _{-0.12}		59.4	43.1	0.94 ^{+0.01} _{-0.01}
N V	15.07 ^{+0.01} _{-0.01}	> 15.24±0.01	39.5	-105.4	0.78 ^{+0.01} _{-0.01}
	12.56 ^{+0.25} _{-0.22}		8.2	-61.7	1.0
	13.72 ^{+0.19} _{-0.24}		17.6	-21.9	0.83 ^{+0.06} _{-0.05}
	13.55 ^{+0.29} _{-0.30}		5.2	2.1	0.82 ^{+0.06} _{-0.05}
	13.76 ^{+0.13} _{-0.16}		8.1	29.5	1.0
	16.82 ^{+0.01} _{-0.01}		59.4	43.1	0.90 ^{+0.01} _{-0.01}
O VI	15.23 ^{+0.06} _{-0.05}	> 15.81±0.01	39.5	-105.4	0.79 ^{+0.03} _{-0.03}
	13.06 ^{+0.23} _{-0.23}		8.2	-61.7	1.0
	14.08 ^{+0.36} _{-0.24}		17.6	-21.9	0.89 ^{+0.04} _{-0.03}
	14.45 ^{+0.58} _{-0.41}		5.2	2.1	0.89 ^{+0.04} _{-0.04}
	13.14 ^{+0.25} _{-0.25}		8.1	29.5	1.0
	16.92 ^{+0.03} _{-0.04}		59.4	43.1	0.91 ^{+0.01} _{-0.01}
S2					
C IV	13.44 ^{+0.03} _{-0.02}	> 14.43±0.02	14.6 ^{+0.5} _{-0.5}	-238.0 ^{+0.9} _{-0.8}	1.0
	14.44 ^{+0.03} _{-0.03}		14.9 ^{+0.3} _{-0.3}	-201.4 ^{+0.2} _{-0.2}	1.0
	13.74 ^{+0.01} _{-0.01}		12.9 ^{+0.2} _{-0.2}	-158.4 ^{+0.3} _{-0.3}	1.0
	13.91 ^{+0.01} _{-0.01}		15.0 ^{+0.3} _{-0.2}	-95.2 ^{+0.2} _{-0.2}	1.0
Si IV	<12.0	> 13.19±0.02	14.6	-238.0	1.0
	13.17 ^{+0.01} _{-0.01}		14.9	-201.4	1.0
	12.21 ^{+0.04} _{-0.04}		12.9	-158.4	1.0
	<12.0		15.0	-95.2	1.0
S3					
C IV	13.52 ^{+0.01} _{-0.01}	> 14.21±0.02	10.9 ^{+0.3} _{-0.3}	105.5 ^{+0.2} _{-0.3}	1.0
	13.90 ^{+0.02} _{-0.02}		13.4 ^{+0.2} _{-0.2}	154.8 ^{+0.2} _{-0.3}	1.0
	13.46 ^{+0.02} _{-0.02}		25.3 ^{+1.2} _{-1.1}	198.7 ^{+0.9} _{-0.9}	1.0
	13.02 ^{+0.04} _{-0.04}		15.6 ^{+0.6} _{-0.6}	253.1 ^{+1.0} _{-1.1}	1.0
Si IV	<12.0	> 12.80±0.04	10.9	105.5	1.0
	12.70 ^{+0.02} _{-0.02}		13.4	154.8	1.0
	<12.0		25.3	198.7	1.0
	<12.0		15.6	253.1	1.0

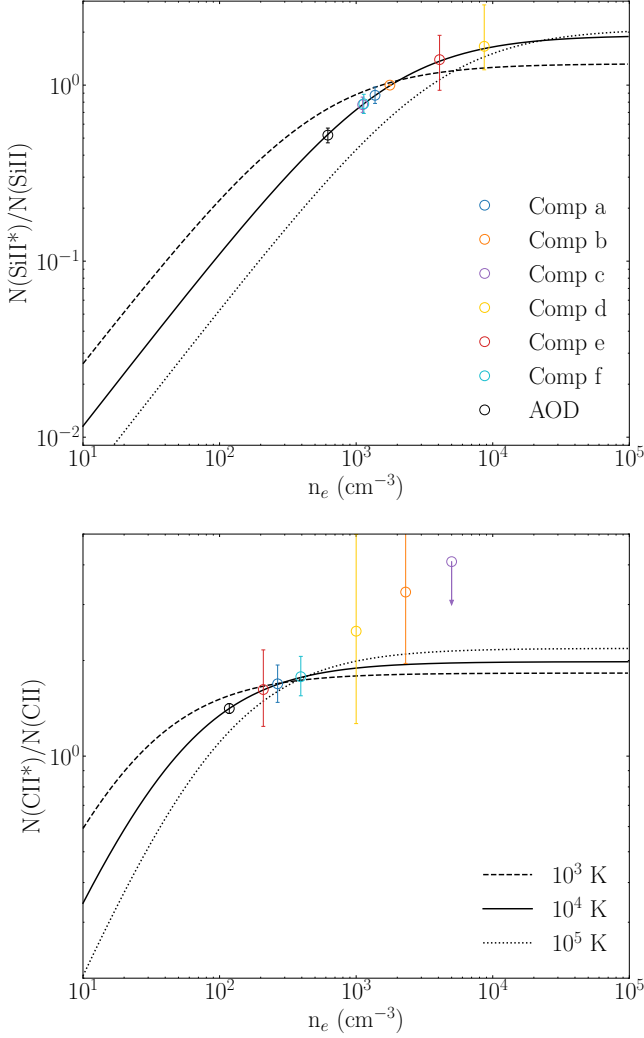


Figure 7. Upper panel: Si II*/Si II column density ratio vs. n_e . The black lines with different line styles represent the same relationships under different temperatures. Colored circles with one sigma error bar represent density solutions from different components. Lower panel: C II*/C II column density ratio vs. n_e , the other are the same as the upper panel.

HE0238, we also test the SED MF87 representative of radio-loud quasars (Mathews & Ferland 1987) and SED UV-soft from ratio-quiet quasars (Dunn et al. 2010). Taking component **f** as an example (shown in Fig. 9), we find that higher metallicity reduces the derived values of $\log N_H$. For instance, increasing the metallicity to four times the solar value, using abundance ratios from (Ballero et al. 2008), results in a total hydrogen column density that is approximately 0.7 dex lower than that obtained under solar metallicity. The choice of different SEDs primarily affects the derived ionization parameters. When the SED is chosen as UV-soft, the $\text{Log}(U_H)$ is approximately 0.4 smaller than when the

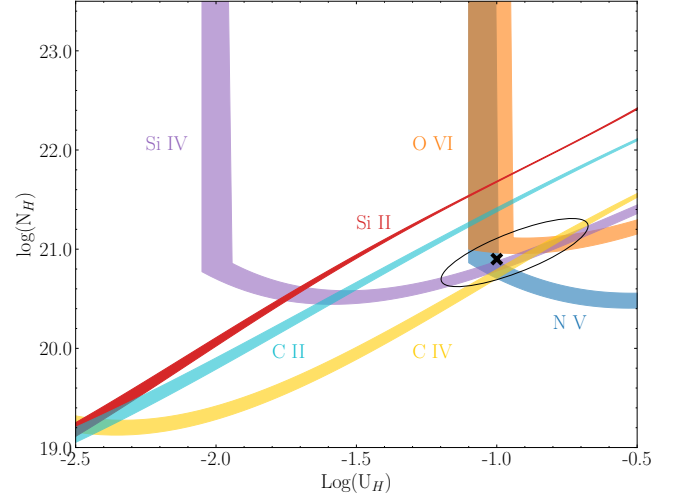


Figure 8. Grid-models showing the photoionization solution of the component **f**, assuming a hydrogen density of 957 cm^{-3} estimated by $N(\text{Si II}^*)/N(\text{Si II})$. The range of possible solutions of different ions is labeled with different colors. The best-fit solution is marked with a black 'X' with a one-sigma contour.

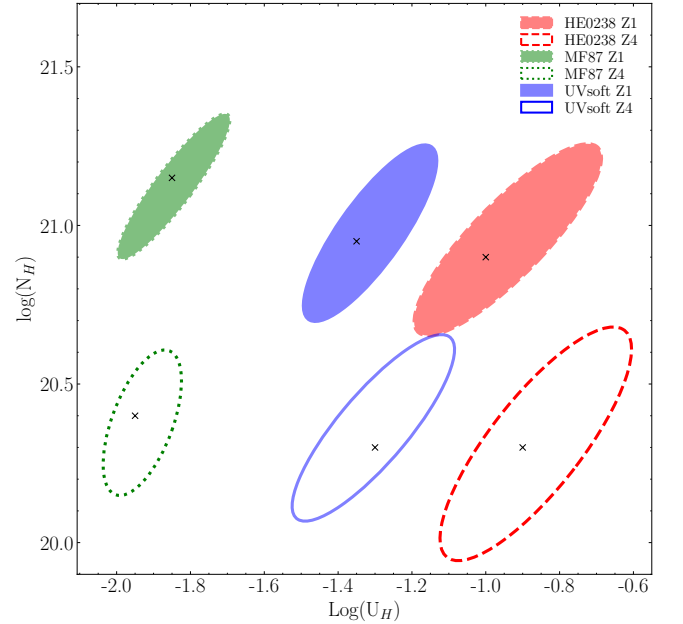


Figure 9. Grid-models displaying the photoionization solutions of component **f** for three SEDs (HE0238, MF87, and UV-soft) and two metallicities: solar metallicity (Z1) and four times solar metallicity (Z4).

SED is HE0238. However, when the SED is MF87, it is about 0.9 smaller than HE0238. While using the other two SED, the estimated distance will be larger, resulting in a larger mass flow rate and kinetic luminosity.

4. DISCUSSION

As mentioned in Sec. 2, the redshift of the quasar was determined based on broad emission lines, which may lead to an underestimation due to their potential blueshifts. We do not detect any narrow emission lines in the near-infrared P200/TripleSpec spectrum of this quasar, making it difficult to determine an accurate redshift¹. If further infrared observations at longer wavelengths detect the H β or [O III] lines, we may be able to determine the redshift with greater precision. Since both the mass flow rate and the kinetic luminosity depend on the velocity, the quasar redshift has a significant impact on the estimation of these two quantities. The absorptions of S2 and S3 are clearly located on the red side of the emission line. Therefore, we adopt the currently measured redshift ($z \sim 4.75$) as a lower limit and the redshift of S3 ($z \sim 4.836$) as the upper limit to estimate the physical properties of the gas.

4.1. Covering Fractions of Different Ions

Although all of the detected lines in S1 are optically thick, none reach zero intensity in our spectra, indicating partial covering by gas that does not fully obscure the background source. In Sec. 3.1.2, we use the PC method to calculate the covering fractions of different ions, and the results are presented in Fig. 5. We mask regions contaminated by airglow emission lines and other ions, which vary among different ions, leading to differences in the number and positions of velocity bins available for calculation. Here we use the PC method to calculate the mean covering fractions between -60 km s^{-1} and 60 km s^{-1} , as most absorption lines remain unmasked in this range. In the decomposition fitting, absorption within this range is primarily contributed by components **c** and **d**. Therefore, we also compare the covering fractions of these two components with the results obtained from the PC method. A comparison of covering fractions among different ions and different methods is shown in Fig. 10.

The C IV and Si IV absorption features lie on top of strong broad emission lines (BELs), suggesting that the absorbers only partially cover the extended BEL region. The typical size of such absorbers could be comparable to that of broad-line region (0.1-1 pc, e.g., Bentz et al. 2013). However, the partial coverage observed in C II and Si II lines implies that the corresponding size of the clouds may be smaller than the continuum source, whose typical size is less than 0.01 pc (Morgan et al. 2010). This conclusion is consistent with the path length size calculated from $N_{\text{H}}/n_{\text{e}}$ in our case, which is from 0.01 pc to 0.1 pc.

¹ Thanks to Jingyi Yang for providing the data and data reduction

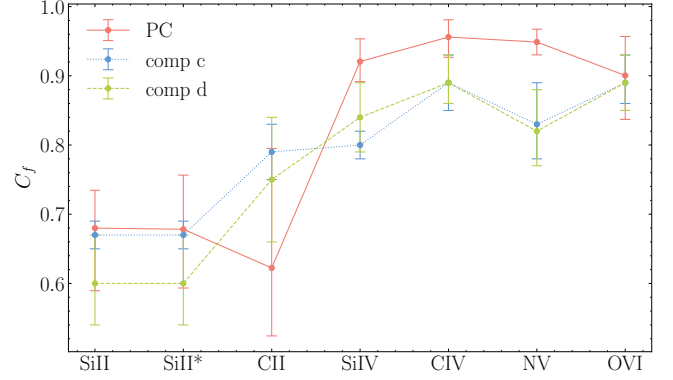


Figure 10. Comparison of covering fractions among different ions. The ions are arranged in order of increasing ionization potential. Red dots represent covering fractions estimated using the Partial Covering method within $|\Delta v| < 60 \text{ km s}^{-1}$ for the S1 system. The blue and green dots represent the covering fractions of components **c** and **d**, respectively, measured via Voigt profile fitting.

The significant variations in covering fractions among different ions provides strong evidence for an inhomogeneous absorbing structure (Hamann et al. 1997; Telfer et al. 1998; Arav et al. 1999; Gabel et al. 2003; Hamann et al. 2019). Despite differences in method, the covering fractions consistently increase with ionization potential, suggesting that high ions are more spatially extended than low ions in our case. For component **c** and **d**, which generate strong absorption in all ions, the result supports a simple geometric model in which a dense core or flow tube of low ions is surrounded by a more diffuse, high ions medium.

4.2. Distance Estimation

The distance of the gas from the quasar could be derived using this relationship. The definition for the ionization parameter is listed below,

$$U_{\text{H}} = \frac{Q_{\text{H}}}{4\pi R^2 n_{\text{H}} c}, \quad (7)$$

Where Q_{H} is the source emission rate of hydrogen ionizing photons, R is the distance of the outflow to the central source, n_{H} is the number density of hydrogen, and c is the speed of light. In high ions, the hydrogen number density n_{H} can be estimated using the relation $n_{\text{e}} \simeq 1.2n_{\text{H}}$. The hydrogen-ionizing photon rate Q_{H} is obtained by integrating the quasar's SED over energies greater than 13.6 eV. We use photometric data from the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) to get the bolometric luminosity for rescaling the SED. This quasar is firmly detected in all bands in 2MASS, at $J_{\text{Vega}} = 16.91 \pm 0.15$, $H_{\text{Vega}} = 16.63 \pm 0.26$, $K_{\text{Vega}} = 15.52 \pm 0.01$, corresponding to rest-frame

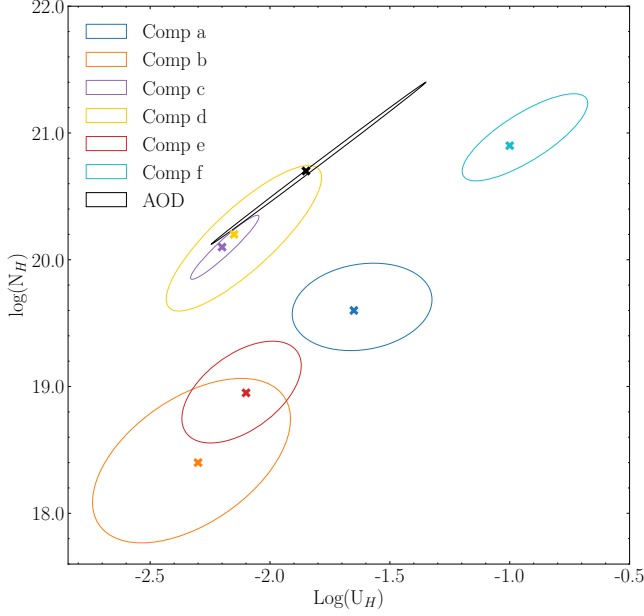


Figure 11. The comparison of photoionization solutions between different components and the AOD method. The ‘X’ markers indicate the solutions found via χ^2 analysis, the ellipses represent the 1σ error.

wavelength between 2150 Å and 3755 Å. Vanden Berk et al. (2001) found that the 1300 Å to 5000 Å continuum roughly has a power-law index $\alpha_v = -0.44 \pm 0.10$. Using this equation, we estimate the optical luminosity at rest-frame 3000 Å to be $(4.77 \pm 0.13) \times 10^{46}$ erg s $^{-1}$. Adopting the empirical factor (Shen et al. 2011) to convert the luminosity at 3000 Å to the bolometric luminosity gives $L_{\text{bol}} = (2.6 \pm 0.7) \times 10^{47}$ erg s $^{-1}$. The emission rate of hydrogen-ionizing photons (Q_H) is $Q_H = (1.9 \pm 0.5) \times 10^{57}$ s $^{-1}$ by scaling the HE0238 SED to match the bolometric luminosity.

The relationship between hydrogen density and distance is plotted in Fig. 12. In general, the distance of the gas from the quasar is on galaxy scales, typically between 1 and 10 kpc. The size of absorbers is smaller than 1 pc even 0.01 pc because of the partial covering of quasar continuum source (Sec. 4.1). While such clouds are rare in the normal circumgalactic medium, they are not unprecedented in distant AAL absorbers. Hamann et al. (2002); Chen et al. (2018) found partial covering of the continuum source in an AAL absorber ~ 28 kpc and ~ 5.7 kpc from the central quasar separately. Chen et al. (2018) inferred that the clouds were more likely created *in situ*, at or near their observed location rather than originated from the central region of the black hole. The sound crossing time for a single cloud is defined as,

$$t_{\text{sc}} = \frac{l}{c_s}, \quad (8)$$

where c_s is the sound speed and l is the characteristic cloud size. If not confined by an external pressure, clouds are expected to dissipate due to instabilities within one to several tens of sound crossing times (e.g., Klein et al. 1994; Li et al. 2020; Gronke et al. 2022). For a nominal temperature of 10^4 K and $l \lesssim 1$ pc for conservation, the cloud survival time is estimated to be $\lesssim 7 \times 10^4$ yr. The mean distance of the components from the quasar is about 5 kpc. If interpreted as outflows ($z_{\text{QSO}} \sim 4.836$), the corresponding flow time is $\sim 1.2 \times 10^6$ yr, which is about 17 times longer than the sound crossing time. In this situation, it is difficult to distinguish whether the gas is produced *in situ* or originates from the vicinity of the quasar. Given the high number density of the cloud, we favor the interpretation that it most likely formed near the quasar.

We find an inverse correlation between the hydrogen density and distance across different components despite their widely varying ionization parameters. The relationship between density and distance generally follows $n(r) \propto r^{-\alpha}$ ($\alpha \sim 1 - 3$) under different scenarios (Contopoulos et al. 2017; Blandford & Payne 1982). The index α is determined by the specific mechanism that drives the outflow, but the relationship consistently follows an inverse trend. Our results show that the densities of different components within the same system may also follow this trend.

4.3. Mass and Kinetic Energy Outflow Rates

With the distance of the outflow determined, we can calculate the mass flow rate of each component (Borguet et al. 2012),

$$\dot{M} = 4\pi\Omega R N_H \mu m_p v, \quad (9)$$

and the kinetic luminosity,

$$\dot{E} \simeq \frac{1}{2} \dot{M} v^2, \quad (10)$$

Where R is the distance of the outflow from the central source, and Ω is the global covering factor for absorbers. $\mu = 1.4$ is the mean atomic mass per proton, m_p is the proton mass, N_H is the absorber’s total hydrogen column density, and v is the radial velocity of the outflow.

There is no way to give a direct measurement of Ω , and the most commonly used method is to use the frequency at which the same type of absorber appears in quasars. Misawa et al. (2007) found that the fraction of intrinsic C IV systems NALs is 11%-19%, which gives a lower limit. So we adopt 0.2 here as the value of Ω .

If calculated using the current redshift (~ 4.75), the gas from S1 would be classified as an inflow. Among the various components, the mass flow rates span three

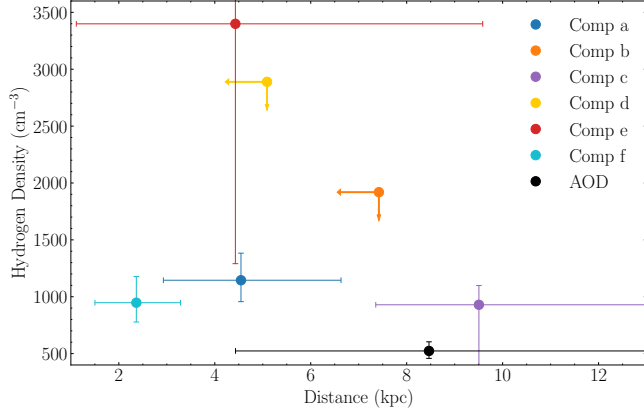


Figure 12. The distance of the gas from the quasar vs. hydrogen density. Results from different components are marked with different colors, and the result from the AOD method is marked with black. The distance of component **b** is calculated with the density lower limit got from $N(\text{C II}^*)/N(\text{C II})$. Since we cannot get the upper limit of the density of component **d**, the distance of this component is also presented in the form of an upper limit.

orders of magnitude (from $0.8 M_{\odot} \text{ yr}^{-1}$ to $88 M_{\odot} \text{ yr}^{-1}$), with component **f** overwhelmingly dominating the total outflow. The mass flow rate estimated from the column density derived using the AOD method is slightly higher than the total mass flow rate summed over the six components.

The highest redshift of detected absorbers in S3 is 4.836. If this redshift is taken as quasar’s redshift, then the absorber would be an outflow. We then recalculate the mass flow rate and derive the kinetic luminosity of the gas to evaluate outflow’s feedback on the host galaxy. Theoretical models and simulations show that outflows carrying $\sim 5\%$ of the quasar’s luminosity can disrupt and sweep up the cold, dense ISM that dominates the total gas mass (Scannapieco & Oh 2004). In the case of ‘multistage’ model, if feedback drives a weak outflow in the hot, diffuse ISM, the resulting instabilities and pressure gradients can cause nearby cold clouds to expand perpendicular to the flow, reducing their density and potentially suppressing star formation (Hopkins & Elvis 2010). Only $0.1\% - 0.5\%$ of the quasar’s luminosity is required as the energy input from the outflowing gas in this scenario. The kinetic luminosity obtained from the AOD method compared to the bolometric luminosity ($\dot{E}_k / L_{\text{bol}}$) is about 0.4% . The most energetic component, component **f**, contributes only 0.15% of L_{bol} , suggesting that only under the ‘multistage’ model can the outflow in our case have sufficient impact on the cold gas to act as a trigger. All physical properties including distances, mass flow rates, and energetic luminosities of different components are listed in Table 3.

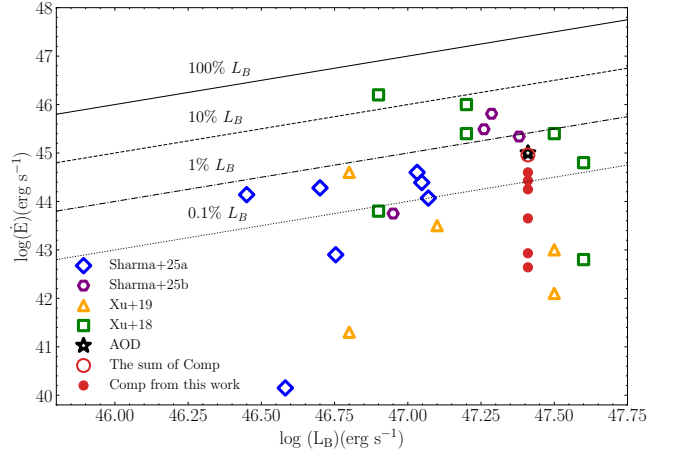


Figure 13. The kinetic luminosity of gas flow from this work and other samples. $\dot{E}$ from other work is also calculated from quasar absorption lines (Xu et al. 2018; Xu et al. 2019; Sharma et al. 2025a,b).

We compare the kinetic luminosity of the outflow with that of luminous quasars ($L_{\text{bol}} > 10^{46.5} \text{ erg/s}$) whose luminosities were derived using the same method. The results are shown in Fig. 13. Overall, outflows from luminous quasars tend to have limited impact on their host galaxies. The total kinetic luminosity of all components, as well as the value derived from the AOD method, does not differ significantly from the those obtained in other cases. Two components exceed the threshold of $0.1\% L_B$, and even the weakest component remains comparable to some weak outflows observed in other cases.

5. SUMMARY

We present a component by component analysis on three absorption systems of a quasar J014741 ($z \sim 4.75$) based on the high-resolution spectrum from Magellan/MIKE. Our main results are as follows:

1. We find three absorption systems (S1-S3) spanning the velocity range from 1600 km s^{-1} to 4500 km s^{-1} ($z_{\text{S1}} \sim 4.780$, $z_{\text{S2}} \sim 4.829$, $z_{\text{S3}} \sim 4.836$). We identify various absorption troughs from both highly and low ions. Then we use the AOD method and decomposition fitting to get the column densities separately. The results show that AOD method underestimates the column densities especially for the high ions.

2. In S1, density-sensitive ratios $N(\text{Si II}^*)/N(\text{Si II})$ and $N(\text{C II}^*)/N(\text{C II})$ determine the electron number density. Both ratios indicate that the gas is dense and that the electron number density is greater than $10^{2.8} \text{ cm}^{-3}$ for all components.

3. With the n_e determined, we use the derived column densities to find the best solution in the $\log(N_{\text{H}}) - \log(U_{\text{H}})$ phase space for each component in the first sys-

Table 3. Physical parameters of different components from S1 assume that $z=4.75$.

Object	$\log(U_H)$ (km s^{-1})	$\log(N_H)$ ($\log(\text{cm}^{-2})$)	$\log(n_e)$ ($\log(\text{cm}^{-3})$)	$\log(R)$ ($\log(\text{pc})$)	$\dot{M}$ ($M_\odot \text{yr}^{-1}$)	$\log \dot{E}_k$ ($\log(\text{erg s}^{-1})$)	$\dot{E}_k/L_{\text{Edd}}^d$ (%)
comp a	$-1.65^{+0.30}_{-0.25}$	$19.60^{+0.35}_{-0.30}$	$3.14^{+0.09}_{-0.08}$	$3.66^{+0.12}_{-0.23}$	$7.7^{+15.3}_{-5.4}$	$42.73^{+0.47}_{-0.53}$	$0.002^{+0.005}_{-0.001}$
comp b	$-2.30^{+0.35}_{-0.40}$	$18.40^{+0.65}_{-0.65}$	>3.36	<3.87	<0.8	<41.78	<0.0002
comp c	$-2.20^{+0.15}_{-0.15}$	$20.10^{+0.25}_{-0.25}$	$3.05^{+0.07}_{-0.69}$	$3.98^{+0.07}_{-0.15}$	$53.8^{+58.6}_{-32.4}$	$43.62^{+0.32}_{-0.40}$	$0.016^{+0.059}_{-0.009}$
comp d	$-2.15^{+0.35}_{-0.30}$	$20.20^{+0.50}_{-0.60}$	>3.54	<3.71	<36.8	<43.47	<0.011
comp e	$-2.10^{+0.20}_{-0.25}$	$18.95^{+0.40}_{-0.40}$	$3.61^{+1.00}_{-0.42}$	$3.65^{+0.30}_{-0.64}$	$1.8^{+7.3}_{-1.7}$	$42.18^{+0.70}_{-1.04}$	$0.001^{+0.003}_{-0.001}$
comp f	$-1.00^{+0.30}_{-0.20}$	$20.90^{+0.40}_{-0.25}$	$3.06^{+0.09}_{-0.09}$	$3.37^{+0.10}_{-0.24}$	$88.0^{+192.7}_{-59.3}$	$43.87^{+0.50}_{-0.49}$	$0.029^{+0.071}_{-0.018}$
AOD	$-1.85^{+0.50}_{-0.40}$	$20.70^{+0.70}_{-0.55}$	$2.80^{+0.06}_{-0.06}$	$3.93^{+0.23}_{-0.32}$	$186.2^{+1396.7}_{-160.8}$	$44.13^{+0.93}_{-0.87}$	$0.053^{+0.398}_{-0.045}$

Table 4. Velocity dependency parameters of different components from S1 assume that $z=4.836$.

Object	$\dot{M}$ ($M_\odot \text{yr}^{-1}$)	$\log \dot{E}_k$ ($\log(\text{erg s}^{-1})$)	$\dot{E}_k/L_{\text{Edd}}^d$ (%)
comp a	$15.6^{+35.5}_{-10.6}$	$43.65^{+0.51}_{-0.49}$	$0.017^{+0.039}_{-0.012}$
comp b	<1.6	<42.64	<0.002
comp c	$100.6^{+368.4}_{-56.8}$	$44.43^{+0.67}_{-0.36}$	$0.105^{+0.385}_{-0.059}$
comp d	<67.2	<44.25	<0.069
comp e	$3.3^{+14.5}_{-2.9}$	$42.93^{+0.74}_{-1.0}$	$0.003^{+0.015}_{-0.006}$
comp f	$154.4^{+384.5}_{-99.2}$	$44.6^{+0.54}_{-0.45}$	$0.154^{+0.385}_{-0.099}$
AOD	$361.8^{+2710.5}_{-308.4}$	$45.0^{+0.93}_{-0.83}$	$0.390^{+2.919}_{-0.332}$

tem. We choose the HE0234 SED and solar metallicity as the input value and test the dependency of the solution on the choice of SED and metallicities. Then we compare the solutions of the AOD method with the decomposing method. The results show that the total hydrogen column density derived from the AOD method is close to the largest component value and its ionization parameter lies in the range of all components.

4. Both the PC method and decomposition fitting for S1 indicate a partial coverage of the gas. This indicates that the absorbers sizes are $\lesssim 1$ pc or even $\lesssim 0.01$ pc (based on C II and Si II that partially cover the quasar continuum source). We also find that ions in higher ionized states tend to have larger covering fractions, which

means that the gas in higher ionized states may have a more extended distribution compared to the gas in lower ionized states.

5. Combining n_e derived from the line ratios, we infer that the gas is located at a distance of 2.3-9.5 kpc from the quasar. The flow time of the gas is about 17 times longer than its sound crossing time, making it difficult to constrain its origin. Nevertheless, the high number density may be more consistent with an origin in the vicinity of the quasar.

6. Since redshifts derived from broad emission lines may underestimate the true redshift of the quasar, we also adopt the redshift of the absorption lines as an upper limit for the quasar redshift. Using both redshift estimates, we separately calculate the gas mass flow rate and kinetic luminosity. In both cases, the kinetic luminosity ($< 0.5\%L_B$) is too low to drive significant AGN feedback and may only suppress star formation through a ‘multistage’ model.

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APPENDIX

A. THE SOLUTION OF EACH COMPONENT

In the main text, the photoionization solutions of all components are summarized in Fig. 11, with a detailed solution for component **f** shown in Fig. 14. For completeness, the full set of solutions for the remaining components is provided in this appendix for reference.

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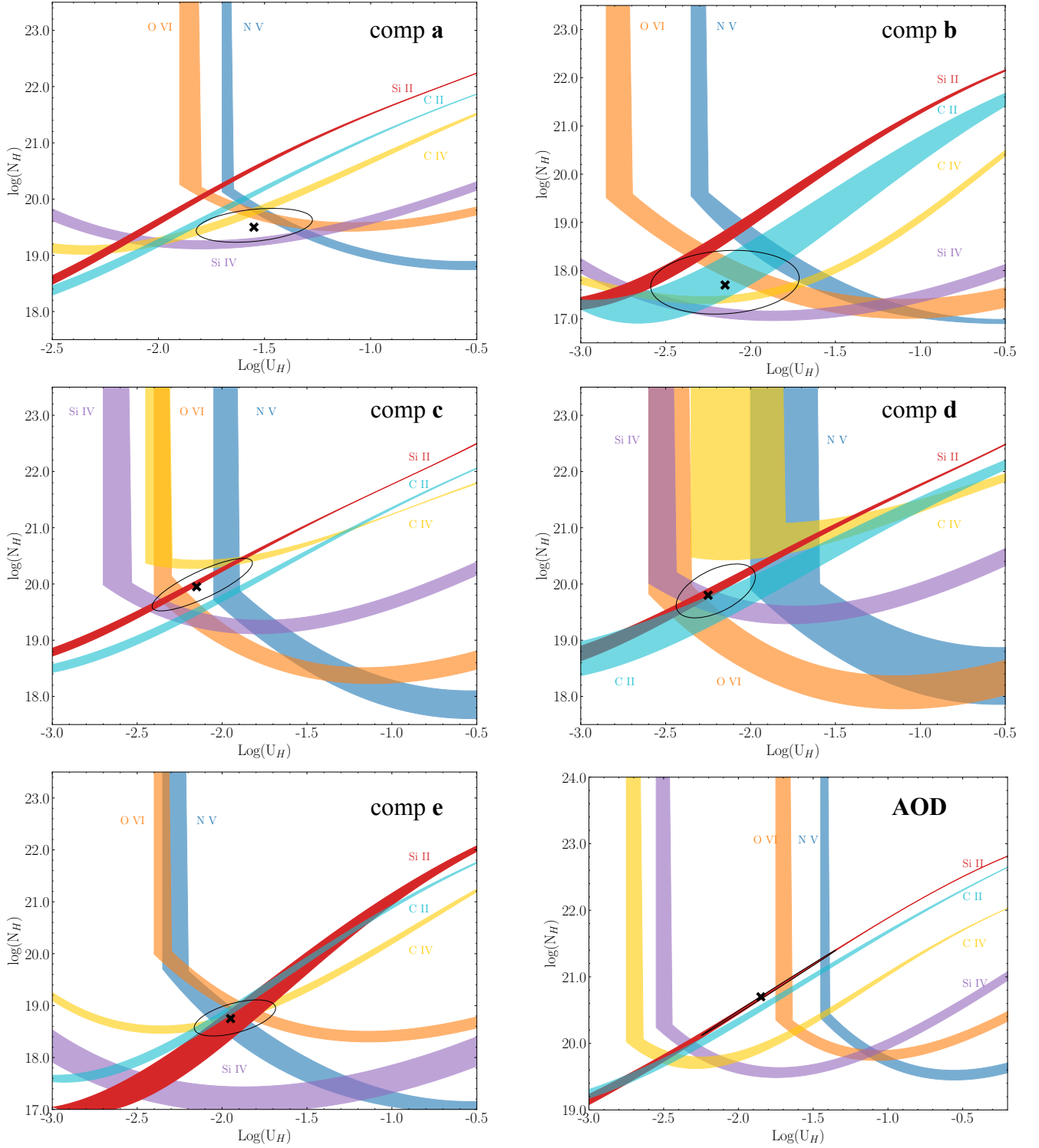


Figure 14. Plots of $\log N_H$ versus $\log U_H$ for different components. This figure presents the detailed solutions for all components, serving as an expanded view of Fig. 11. As in Fig. 14, the colored shaded regions mark the solution ranges constrained by different ions. The black 'X' indicates the best-fit solution and the black ellipse represents the 1σ error.

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