Studying Helium Reionization using Metals

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Introduction

- The reionization of He II, i.e. ionization of He I to He II, marks a major change in the thermal and ionization history of the intergalactic medium. It is believed that quasars, which started becoming more numerous at $z \lesssim 4$, provided the hard ($E > 4$ Ryd) ultraviolet (UV) photons leading to the reionization of He II by $z \sim 3$ (Worseck et al., 2016).
- The reionization process can be probed using ionic column density ratios of metals with ionization potentials close to that of He II. Using the best available model for extragalactic UV background, we perform a suite of photoionization models using the spectral synthesis routine CLOUDY (Ferland et al., 2017) to track the changes to ionic column density ratios of metals as a function of redshift for the physical conditions that prevail in the IGM.
- The column density measurements of these ions at different redshifts can be obtained from the intervening absorption lines observed in high redshift quasars. The sample of 467 quasar spectra from the SQUAD survey (Murphy et al., 2019) was systematically searched for metal lines of C II, C IV, Si II, and Si IV.
- We plan to compare the observed column density ratios of these ions to the predicted variation from CLOUDY models to study the He II reionization.

Using Metals to study He II reionization

- The He II ionizing photons from quasars can ionize the various metals with ionization potentials which are near the ionization potential of He II, i.e. 4 Ryd (54.4 eV). Some of these include, C II – C IV, N II – N V, O II – O VI, Ne II – Ne V, and Si III – Si V.
- The UV background determines the ionization balance of metals in the IGM. The redshift evolution of the UV background can be studied by estimating the variation in the column densities of metals as a function of redshift.

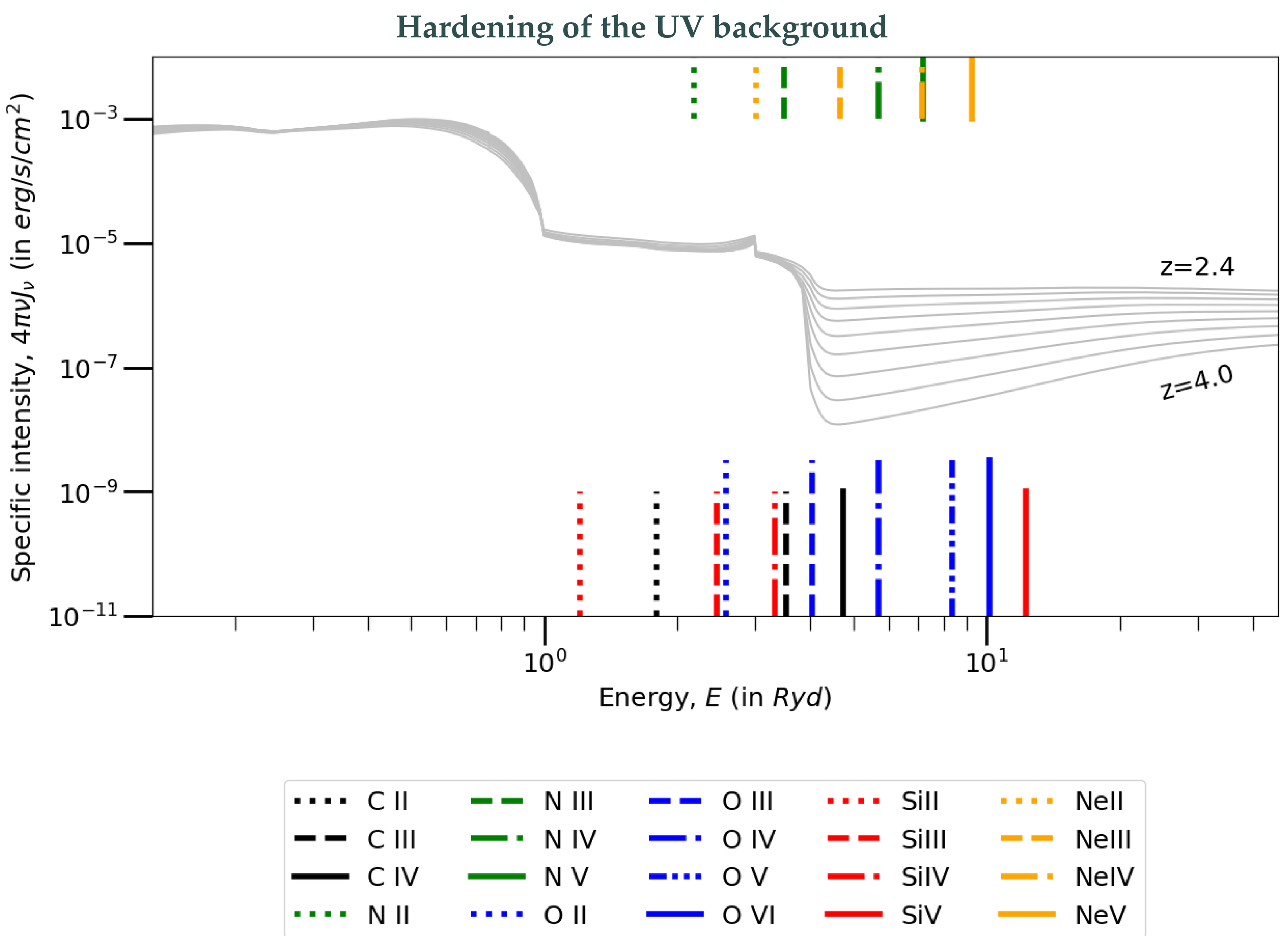

Figure 1: The UV background at various redshifts between $z = 2.4$ and $z = 4$. The specific intensity is in $\mathrm{erg\,s^{-1}\,cm^{-2}}$ and the energy, E is in rydbergs. The ionization edge of H I and He II at 1 and 4 Ryd, respectively is seen. The small kink at $E \sim 3$ Ryd due to the He II Lyα recombination emission is also seen. Also shown are the ionization potentials of various metals near the Helium ionization potential, i.e. 4 Ryd. The metals C, O, and Si are shown at the bottom of the plot, while N and Ne are at the top. (From National Institute of Standards and Technology (NIST))

Identifying sensitive ions using CLOUDY modeling

The column density ratio that shows a considerable redshift evolution will be easier to observe. To find column density ratios with significant redshift variation, we ran CLOUDY models and found the variation in the column density ratios of metals along with redshift.

- Absorbers were placed at $z = 2, 2.1, 2.2, ...4.5$.
- The UV background was set as the KS19 UV background model (Khaire & Srianand (2019))
- The metallicity of the absorbers was set as $Z = 0.1Z_\odot$.
- The total hydrogen number density of the absorbers was set as $n_\mathrm{H} = 10^{-4}\mathrm{cm}^{-3}$.

The column density ratio has no dependence on the value of Z while n_H was taken to be representative of the IGM conditions.

Column density ratios, including N V, show the most significant variation. In contrast, the remaining column density ratios, which include C II, C IV, Si II, and Si IV, show lesser amount of variation.

After selecting column density ratios which show a large variation in $z = 2 - 4.5$, the column densities of the ions need to be estimated using their absorption lines in the high-z ($z > 2$) quasar spectra.

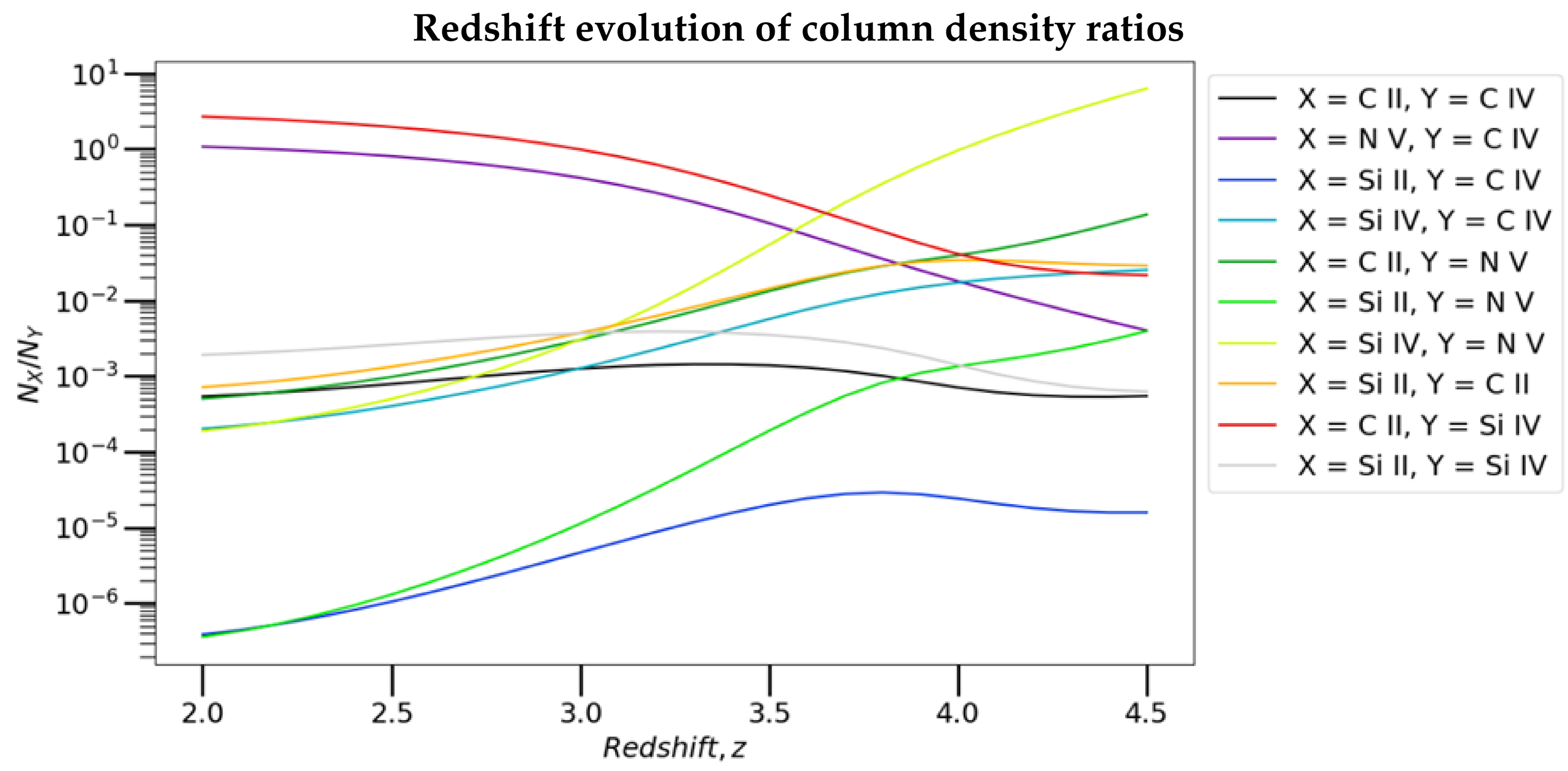

Figure 2: The evolution of ratios of column densities of ions as a function of redshift is shown. The y-axis is the ratio of column densities of X and Y. On the x-axis is the redshift.

Choosing the archival dataset - The SQUAD survey

The Spectral Quasar Absorption Database (SQUAD) DR1 survey was selected for this project.

- The SQUAD survey by the Ultraviolet and Visible Echelle Spectrograph (UVES) on the Very Large Telescope (VLT) includes 475 quasars between redshifts $z = 0 - 5$, out of which 467 have fully-reduced, continuum-fitted spectra.
- The spectral coverage is 3050 Å - 10500 Å at high resolution, $R \sim 50,000$. This survey is the largest database of high-resolution quasar spectra.

Searching for metal ions - Identification of lines

- The column density ratios, which were combinations of C II, C IV, Si II, and Si IV, were found to have a good balance of pathlength and variation in the redshift range, $z \sim 2 - 4.5$. These are good candidates for studying He II reionization.
- Each spectrum was searched for C II 1334, C IV $\lambda\lambda 1548.19, 1550.77$, Si II 1260, Si II 1526, Si II 1304 and Si IV $\lambda\lambda 1393.76, 1402.77$ absorption lines. Since the shape of the absorption features can be very complicated in some cases, the search was carried out manually through each spectrum.

Redshift distribution of absorbers

- 1228 absorption systems were found with 142 of them having C II, 1048 with C IV, 172 with Si II, and 314 with Si IV.
- The redshifts of the absorption systems were calculated using the apparent optical depth velocity centroid method. The redshift distribution of absorbers with C II, C IV, Si II, and Si IV is shown in Figure 3.

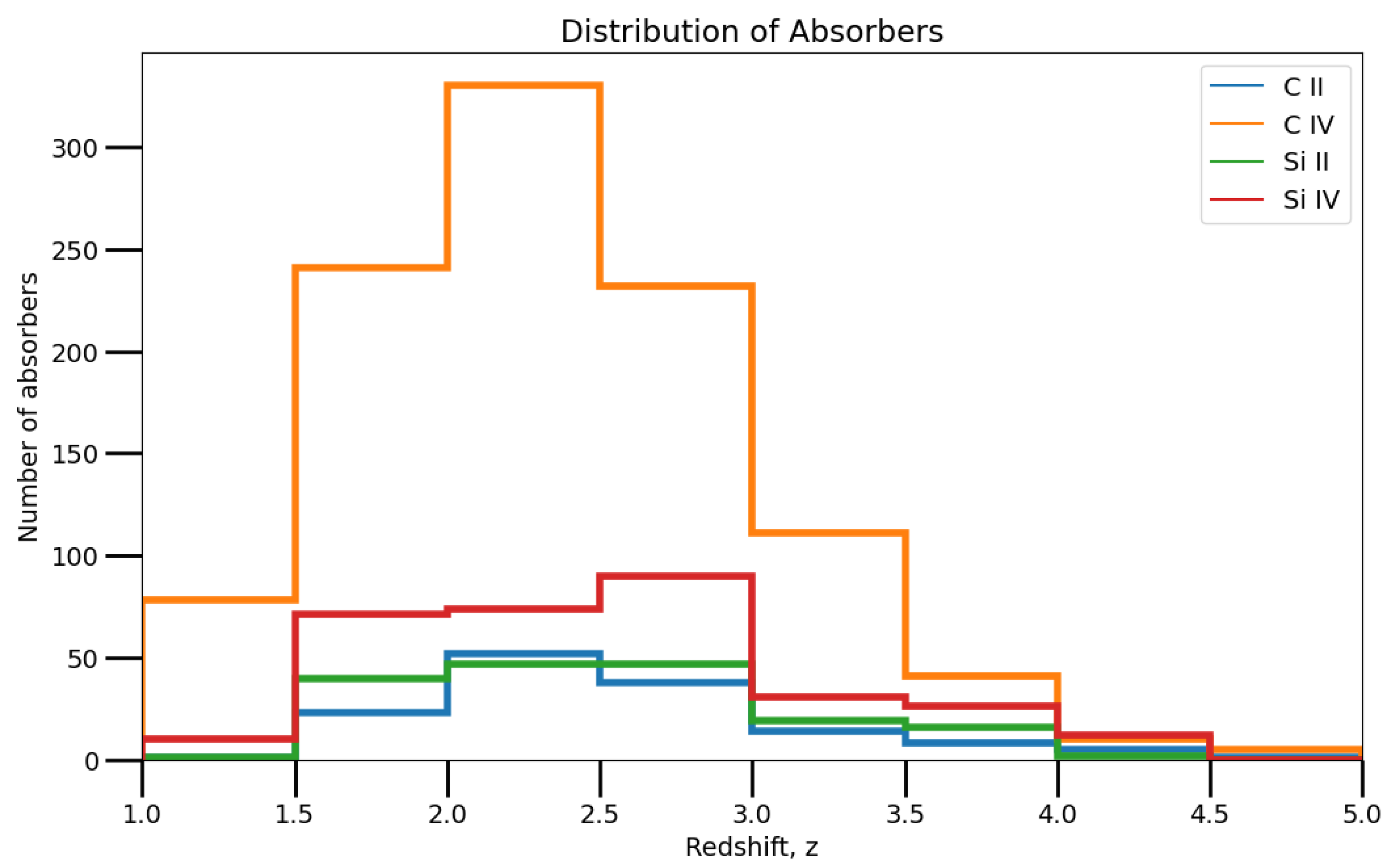

Figure 3: The redshift distribution of absorbers with C II, C IV, Si II, and Si IV is shown.

Forthcoming Research

We aim to compare the observational results with the predicted variation in column density ratios and better constrain the:

- The shape of the He II ionizing UV background,
- The duration of He II reionization

References

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