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Abstract. The metal absorption lines found in association with Lyα absorbers of moderate to high HI column density contain valuable information about the metallicity and ionization conditions within the absorbers and offer a stronger test of models of the intergalactic medium at $z \sim 3$ than HI absorption lines alone.

We have developed a method to predict the strengths of metal absorption lines within the framework of cosmological models for the Lyα forest. The method consists of evaluating a quantity, the *Line Observability Index*, for a database of hundreds of candidate metal lines, allowing a comprehensive identification of the lines the model predicts to be detectable associated with a Lyα absorber of a given HI column density and metallicity.

Applying this technique to a particular class of models at $z \sim 2-4$, we predict that the OVI(1032 Å, 1038 Å) doublet is the only practical probe of the metallicity of low column density absorbers ($N_{\rm HI} \lesssim 10^{14.5}\,{\rm cm}^{-2}$), that CIV (1548 Å) is the strongest line with rest wavelength $\lambda_r > 1216$ Å regardless of $N_{\rm HI}$, and that the strongest metal lines should be CIII(977 Å) and SiIII(1206.5 Å), which peak at $N_{\rm HI} \sim 10^{17}\,{\rm cm}^{-2}$.

1 Introduction

The prevailing interpretation of the Lyα forest is that it arises naturally from absorption by trace amounts of neutral hydrogen in a photo-ionized, inhomogenous intergalactic medium (IGM). To model the Lyα forest within this picture no speculative assumptions about the physical properties of individual Lyα absorbers have to be made. One merely considers a cosmological simulation of structure formation, including dark matter and a baryonic component as well as a photo-ionizing background radiation field, and evaluates the absorption properties along lines of sight through the simulation box at desired redshifts. During the past few years it has been realized that the artificial absorption spectra resulting from this approach bear close resemblance to the Lyα forest seen in QSO absorption spectra, and these cosmological models of the Lyα forest have been able to quantitatively account for the observed distribution functions in HI column density and b-parameters to a reasonable accuracy ([4] [20] [16] [12]; for related semianalytic modeling see, e.g., [1] [2] [13]).

Within recent years, observations have demonstrated that strong Lyα forest absorbers generally show associated metal line absorption ([15] [5] [21] [19]). Selected metal absorption lines can be readily incorporated into cosmological models of the Lyα forest from a knowledge of densities, temperature, and UV radiation field along the lines of sight, if a metal enrichment pattern of the baryonic IGM is specified. Such models account fairly well for the observed properties of the CIV(1548 Å, 1550 Å) doublet and a handful of other lines, for an IGM metallicity $Z \sim 10^{-2.5} Z_{\odot}$, if a scatter of about an order of magnitude is assumed ([9] [18] [10]).

Instead of making an a priori selection of a few metal lines to include in a model, it is useful to make the models *predict* which metal lines, out of hundreds of candidates, should be observable (in spectra of a given resolution and S/N) associated with Lyα absorbers of given metallicities and HI column densities. Such an approach allows a comprehensive screening for lines that deserve a more detailed treatment, dependent on the specific purpose of the modeling, and allows for the sharpest possible test of the models. We describe the results from an implementation of such a technique in the following.

2 Line Observability Index for 199 candidate metal lines

Let us denote a metal absorption line produced by an element Z in ionization stage i with rest transition wavelength λ and oscillator strength f as $Z^i_{\lambda,f}$. For such a line associated with with a Lyα absorber of neutral hydrogen column density $N_{\rm HI}$ and metallicity $[Z/H] \equiv \log{(n_Z/n_H)} - \log{(n_Z/n_H)_{\odot}}$ we can define the following *line observability index* :

$$\begin{aligned} {\rm LOX}(Z^i_{\lambda,f}, [{\rm Z/H}], N_{\rm HI}) \quad \equiv \quad & -17.05 + \log N_{\rm HI} + [{\rm Z/H}] + \log{(f\,\lambda^2)} \\ & + \log{(n_Z/n_{\rm H})_{\odot}} + \log{(x^i_Z/x^0_H)} \end{aligned} \qquad (1)$$

(see [11] for more details). This expression assumes units of cm^{-2} for $N_{\rm HI}$ and Å for λ. The choice of additive constant then implies ${\rm LOX} = \log(W_{r\lambda}/1m\text{Å})$, where $W_{r\lambda}$ is the rest equivalent width, for weak lines. Hence, this quantity can be used to rank metal lines in terms of strength, and it can be compared to detection limits in spectra of a given quality. The model-dependent ionization corrections are contained in the last term, the ratio of ionization fractions of Z^i and H^0 within the absorber.

As a specific application of the LOX technique we use the standard CDM, $\sigma_{8h^{-1}} = 0.7, h = 0.5$, $\Omega_b = 0.05$ simulation described in [14] and [6]. We assume a Haardt & Madau background radiation spectrum of slope -1.8 at the high-energy end [8] normalized to match the observed mean flux decrement D_A [17], and we focus on redshifts $z \sim 3$. The simulations exhibit rather tight correlations between $N_{\rm HI}$ of an absorbing region and the typical temperature and total gas density within the region, so the ionization correction term is essentially a function only of $N_{\rm HI}$, and we calculate this term using the photoionization code CLOUDY 90 [7].

The LOX has been evaluated for 199 metal lines from the database contained in the Voigt profile fitting software VPFIT [3]. Figure 1 shows the

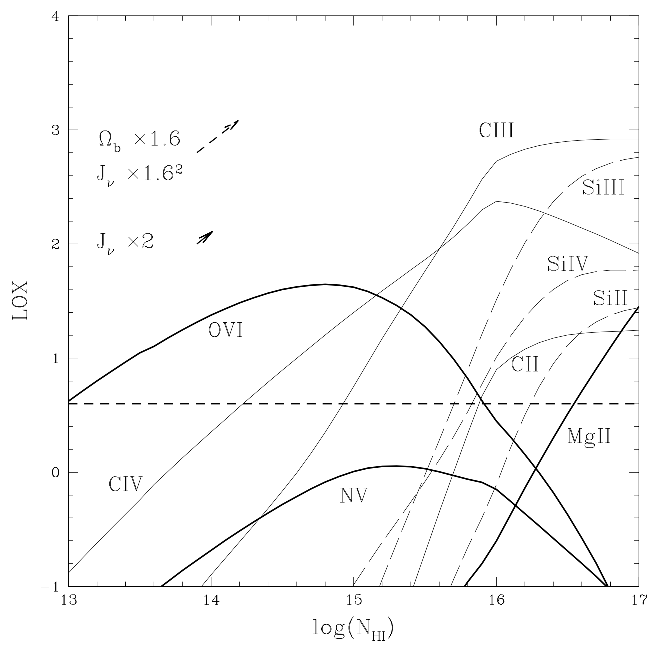

Figure 1: LOX as a function of HI column density for 9 selected absorption lines from carbon (CIV(1548), CIII(977), CII(1335), thin solid lines), silicon (SiIV(1394), SiIII(1206), SiII(1260), dashed lines), and OVI(1032), NV(1243), and MgII(2796) (bold solid lines). The solid arrow indicates the direction and magnitude of changes to the curves if J_ν is doubled, keeping everything else constant, while the dashed arrow indicates the effect of changing the baryonic density while adjusting J_ν to keep the mean flux decrement of the spectrum constant (see [11]). The horizontal dashed line indicates LOX=0.6, roughly corresponding to the detection limit in the best available spectra.

results as a function on $N_{\rm HI}$ for nine of the strongest lines, assuming a carbon abundance of [C/H]=-2.5 and a relative abundance pattern similar to that observed in population II stars. A more exhaustive list of lines is presented in [11], which also discusses the dependence of the LOX on z, Ω_b, and the normalization of the radiation field J_ν. This dependence is weak, and the following predictions are believed to hold rather generally in cosmological models of the Lyα forest:

- The CIV(1548 Å, 1550 Å) doublet is the strongest line with rest wavelength $\lambda_r > 1216$Å regardless of the HI column density of the absorber.
- OVI(1032 Å, 1038 Å) is the only detectable line in low column density ($\log N_{\rm HI} \lesssim 14.5$) absorbers, and hence the best probe of metallicity in

the low density IGM.

- The CIII(977 Å) and SiIII(1206 Å) lines are the potentially strongest metal lines, but they are only expected to be seen in the relatively uncommon absorbers with $N_{\rm HI} \gtrsim 10^{16}{\rm cm}^{-2}$.

The first prediction is easily verifiable from available data and is found to hold. The other predictions, featuring lines that are embedded in the Lyα forest, remain to be verified. If few or no OVI lines are found at $z \sim 3$ in real spectra then the metallicity of the low-density regions of the IGM may actually be less than -2.5, or alternatively there may be a problem with this picture of the Lyα forest. In absorbers with higher values of $N_{\rm HI}$, the higher number of observable metal lines makes a more thorough comparison between model and observations possible. We are currently initiating a detailed systematic study of the distributions and relative strenghts of metal lines associated with such systems.

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