The nature of the metagalactic ionizing radiation field from the Lyman-α forest opacity

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Introduction

The low density hydrogen and helium in the IGM probed by QSO absorption lines is sensitive to the amplitude and spectral shape of the metagalactic UV background. The ratio of He II to H I Lyα column densities, $\eta = N_{\rm HeII}/N_{\rm HI}$, provides a constraint on the spectrum of the UV background (UVB) between 1 and 4 Ryd. Measurements of η indicate a wide spread of values, from $\eta < 1$ to $\eta > 1000$, implying that the metagalactic radiation field exhibits inhomogeneities at the scale of $\simeq 1$ Mpc (Shull *et al.*, Zheng *et al.*, 2004). We use realistic H I and He II Lyα forest spectra, constructed from state-of-the-art hydrodynamical simulations of a ΛCDM Universe, to test the reliability of using line profile fitting techniques to infer the spectral shape of the UVB. We also explore the possible origin of the observed fluctuations in η and discuss the implications for the nature of the ionizing sources.

Simulated H I and He II Lyman-α forest spectra and line fitting

We have rescaled the H I and He II optical depths in each pixel of our simulated spectra to match the respective observed effective optical depths. The optical depths scale inversely with the H I and He II ionization rates; the metagalactic H I and He II ionization rates can thus be determined in this way (*e.g.* Rauch *et al.* 1997, Bolton *et al.* 2005). The ratio of these rates, known as the softness parameter, $S = \Gamma_{\rm HI}/\Gamma_{\rm HeII}$, gives a direct measure of the spectral shape of the UVB between 1 and 4 Ryd. We also use an automated line fitting procedure (VPFIT, Carswell *et al.*) to fit Voigt profiles to our mock spectra and measure the column density ratio, where $S \simeq 2.4\eta$. For the range of values under consideration ($100 < S < 350$), we find line fitting recovers S extremely well compared to the value inferred by rescaling the effective optical depths of the H I and He II spectra. The median appears to provide the better measure of S (see figure 1).

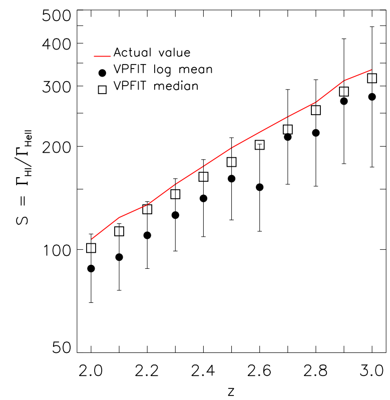

Fig. 1: Comparison of the softness parameter, S, obtained by rescaling the artificial spectra to match the observed H I and He II effective optical depths (solid line) with the value determined by fitting Voigt profiles to the absorption features.

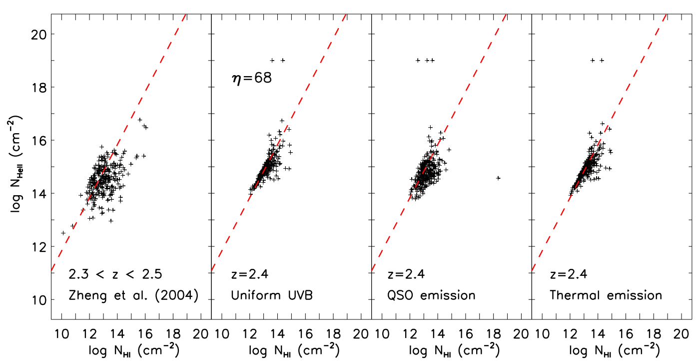

Fig. 2: Scatter plots of the column density ratio η measured by Zheng *et al.* (2004) (left column), from artificial spectra constructed with a uniform UVB at the He II photoelectric edge (second column), a fluctuating UVB due to QSOs (third column) and a UVB dominated by emission from hot gas in collapsing haloes (right column). The redshift ranges are indicated on each panel. The dashed line shows the median column density ratio of the artificial spectra produced with a uniform UVB, shown in the second column. To facilitate comparison, the same line is repeated in the other panels. The scatter is best reproduced by the QSO model.

The origin of the UV background

The scatter in η we measure from our mock spectra is minimal if we assume a spatially uniform UVB at the He II photoelectric edge (see figure 2). We develop two simple models for a spatially inhomogeneous UVB at the He II photoelectric edge, based on the emission from QSOs and hot gas in collapsed structures respectively. The large spatial variations observed in η (Shull *et al.*, Zheng *et al.*, 2004) can be explained with a model where the H I ionization rate is spatially uniform and dominated by the combined UV emission from galaxies and QSOs (Bolton *et al.* 2005) and the He II ionization rate is dominated by emission from QSOs only. The fluctuations in η are due to the small number of QSOs expected to contribute at any given point to the He II ionization rate. A significant contribution to UV emission at the He II photoelectric edge from hot gas in galaxies and galaxy groups (*e.g.* Miniati *et al.* 2004) would decrease the expected fluctuations in the column density ratio. Figure 3 shows our determination of the average S, with the uncertainty shown by the yellow region. Our results for the spatially uniform UVB model agree very well with the softness parameter of the updated Madau *et al.* (1999) model with contributions from QSOs and galaxies.

Summary

- The softness parameter of the UVB can be accurately inferred from the column density ratio of He II and H I absorption lines obtained by applying standard Voigt profile fitting routines.

- A model where the He II ionization rate fluctuates due to variation in the number, luminosity and spectral shape of a small number of QSOs reproduces the observed spatial variations of the He II and H I column reasonably well.

- The large fluctuations observed in the He II and H I column density ratio argue strongly against a significant contribution of emission by hot gas to the He II ionization rate at $2 < z < 3$.

Full references are provided in Bolton et al., astro-ph/0508201

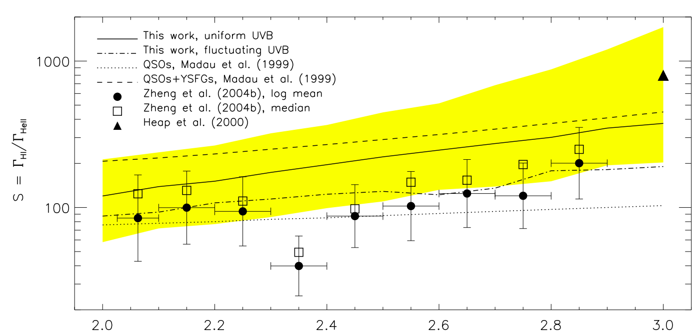

Fig. 3: Our determination of the average softness parameter S, a direct probe of the spectral shape of the UVB, compared to other observational estimates. The yellow region shows the uncertainty in our estimate of S assuming a spatially uniform UVB at the He II photoelectric edge.