Quasar absorption lines as a cosmological probe: exploring the Lyman forest with VLT/UVES

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1 Observations and Data Reduction

The remarkable efficiency of the Ultra-Violet Echelle Spectrograph (UVES) at the VLT has made it possible to push high-resolution, high-S/N ground observations of the Lyα forest down to $z \sim 1.5$, gaining new insight into the physical state of the intergalactic medium (IGM) and its evolution over more than 90% of the cosmic time. The results presented here are based on recent UVES observations of eight QSOs spectra, covering the Lyα forest at $1.5 < z_{\mathrm{Ly}\alpha} < 3.6$ with S/N $\sim$ 40–50 and resolution $R \sim 45\,000$ [1,2]. The absorption lines of the normalized spectra were fit to the Voigt profiles to derive the three line parameters: absorption redshift, z, the HI column density, N_{HI} in cm^{-2}, and the Doppler parameters, b in km s^{-1}).

2 The Number Density Evolution of the Lyα forest

Fig. 1 shows the evolution of the line number density per unit redshift, dn/dz, in the interval $N_{HI} = 10^{13.6-17}$ cm^{-2}. The maximum-likelihood fit to the $z > 1.5$ data is $dn/dz = 6.1\,(1+z)^{2.5\pm0.2}$ (dashed line). The evolution of the Lyα forest with z is mainly governed by two physical processes: the Hubble expansion and the ionizing ultraviolet background flux (UVB,[3]). At higher z, the Hubble expansion and the non-decreasing UVB cause a rapid evolution of dn/dz. At lower z, HST observations have shown a slow-down in dn/dz (solid line in Fig. 1,[4]), which can be explained with a decrease of the UVB flux in the local universe. The UVES observations imply that the turn-off in the evolution occurs at $z \sim 1$. The evolution and the redshift of the turn-off are consistent with an UVB to which galaxies contribute as much as QSOs or more, as long as a fraction $f_{\mathrm{esc}} \geq 0.05$ of the UV flux can escape the internal absorption in a galaxy [5].

3 The cosmic baryon density

A lower-bound to the cosmic baryon density can be derived from the distribution of the Lyα optical depths [6]. For a UVB with a contribution from galaxies ($f_{\mathrm{esc}} = 0.1$), the effective optical depths measured in the UVES spectra at $1.5 < z < 4$ implies $\Omega_b h^{1.5} > 0.028$ (assuming IGM temperature $T = 2 \cdot 10^4$K, $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$). This value is consistent with the BBN value for a low D/H

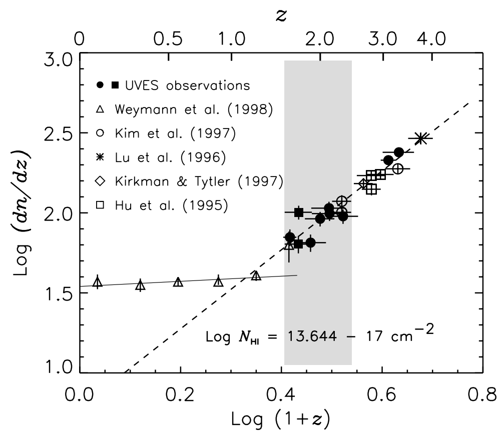

Fig. 1. The number density evolution of the Lyα forest

primordial abundance. Most of the baryons reside in the Lyman forest at $1.5 < z < 4$ with little change in the contribution to Ω as a function of z. Conversely, given the observed opacity, a higher UVB requires a higher Ω_b. As pointed out by Haehnelt et al. [7], values of $f_{\rm esc}$ as large as 0.4 [8], would result in too large Ω_b values.

4 The Temperature of the IGM

Absorption lines in the Lyα forest are broadened by gas thermal motion and other processes, therefore the minimum b value can provide an upper limit on the temperature. The minimum b is found to increase as z decreases [9]. When the column densities are converted into over-densities, this implies that the temperature at the mean ISM density decreases with z. The large fluctuations in the minimum b value and in its dependence on N_{HI}, even at a similar redshift, suggest that the temperature of the intergalactic medium might fluctuate. A large fluctuation seen at $z \sim 3.1$ is probably due to the HeII reionization [10,9].

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