What causes the Ly$\alpha$ forest, clouds or large-scale velocity fields?

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If an additional large scale hydrodynamic velocity field is superposed on the general Hubble flow, the peculiar velocities have the effect that spatially separated volume elements along a given line of sight may contribute to the absorption at the same value of $\lambda$. This effect leads to a 'line-like' absorption structure rather than to a smooth GP-depression. From this it follows that at least part of the Ly$\alpha$ forest may be explained without invoking density fluctuations (clouds). Thus, there is no clear observational distinction between intergalactic clouds and the diffuse medium in-between.

We have investigated this effect by means of Monte Carlo simulations [1]. In Fig. 1 we present results based on a model in which we assumed the diffuse intergalactic medium to be (locally) homogeneous having at $z = 3$ the parameters $n$(HI) = $4 \times 10^{-11}$ cm$^{-3}$ and $T_{\text{kin}} = 10^4$K. For the large scale stochastic velocity field we assumed a rms velocity of $\sigma_t = 300$ km s$^{-1}$, and a correlation length $l = 6$ Mpc. In calculating the expansion rate we assumed $q_0 = 0.5$ and $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$. The value of $n$(HI) was estimated from the continuum depression $D_A$ at $z = 3$ observed in low resolution spectra, $T_{\text{kin}}$ corresponds to the width of the narrowest lines in the Ly$\alpha$ forest, $\sigma_t$ is half the value found for the peculiar velocities in the local universe [2], and the value of $l$ corresponds to the expected size of voids at $z = 3$. We performed similar calculations for He II Ly$\alpha$ (Fig. 2).

Assuming a photoionizing rate of $\Gamma_{\text{HI}} = 10^{-12}$ s$^{-1}$ [3] one derives from $n$(HI) a total baryon density of the order of $10^{-5}$ cm$^{-3}$ at $z = 3$ corresponding to $\Omega_{0,\text{IGM}} \approx 0.03$, i.e. it is about 3 per cent of the mass needed to close the Universe. This result indicates that most of the baryonic matter is found in the IGM inbetween clouds.

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References

Figure 1: Monte Carlo simulation of the HI Lyα forest for a given velocity field realization at \( z = 3 \) (S/N = 100, FWHM = 8 km s\(^{-1}\)). The horizontal ‘noisy’ line shows a result for zero correlation coefficient, representing a classical GP-trough (marked by GP\(_{\text{micro}}\)). Commonly the diffuse intergalactic \( n(\text{HI}) \) is estimated by measuring the intensity distribution near the apparent continuum, these regions are labeled by GP\(_{\text{meso}}\).

Figure 2: Monte Carlo simulation of the HI (upper panel) and the corresponding HeII (lower panel) Lyα forest at \( z = 3.2 \) (thin lines) calculated with S/N = 50. Also shown (thick lines) are the same spectra convolved with a spectrograph function of a 0.6 Å width.
H I Lyα \[ \tau_{GP} = 0.37, \quad n(HI) = 5.6 \times 10^{-11} \text{ cm}^{-3} \]

He II Lyα \[ \tau_{GP} = 3, \quad n(HeII) = 3.2 \times 10^{-9} \text{ cm}^{-3} \]