Ly$\alpha$ forest and the total absorption cross-section of galaxies – an example of the NTT SUSI Deep Field

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Abstract. By extrapolating the accumulated low-redshift data on the absorption radius of galaxies and its luminosity scaling, it is possible to predict the total absorption cross-section of the gas associated with collapsed structures in the universe at any given epoch. This prediction can be verified observationally through comparison with the well-known spatial distribution of the QSO absorption systems. In this way, it is shown that HDF, NTT SUSI Deep Field and other such data give further evidence for the plausibility of origin of the significant fraction of the Ly$\alpha$ forest in haloes of normal galaxies.

1. Introduction

Deep images like the Hubble Deep Field (HDF), fields of the QSO BR1202-0725 (Giallongo et al. 1998) and NTT SUSI Deep Field (NDF) (Arnouts et al. 1998), offer an unprecedented opportunity to study global properties of galaxies at all epochs. One of the crucial such property with relevance to several fields of astrophysical research is the absorption cross-section of normal luminous galaxies. From coincidence studies of metal and Ly$\alpha$ absorption lines seen in QSO spectra, it was recently established that significant fraction (possibly all) of the low-redshift ($z < 1$) absorbers are associated with galaxies, with known luminosity scaling (Steidel, Dickinson & Persson 1994; Lanzetta et al. 1995; Chen et al. 1998). It is only natural to ask whether the same situation persists when we look to higher redshifts and what is appropriate total absorption cross-section of the universe due to galactic haloes.

2. Comparison of deep fields

A crude way to estimate the total absorption cross-section and to predict the number of narrow Ly$\alpha$ absorption lines to be observed in spectrum of a source located at arbitrary $z$ is to use the galaxy surface densities obtained from very deep images and extrapolate the results of low-redshift analysis up to redshifts of $z \sim 4$, at which redshifts are easily accessible today through photometric techniques (e.g. Lanzetta, Yahil & Fernandez-Soto 1996).

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Figure 1. Left: The number of predicted absorption lines $N$ with 1σ error bars (for the HDF data) as a function of redshift, without luminosity scaling, in comparison with the empirical data derived from absorption statistics (dotted curve). Points in the field of BR1202-0725 are shown as filled circles. Right: The same as in the left panel, with luminosity scaling according to the data by Chen et al. (1998).

In the “zeroth” approximation, we have assumed identical sizes of absorbing galaxies, and compared the predictions for the total number of absorption lines obtained in this manner in the HDF and in the field of the QSO BR1202-0725, as well as both of them with the empirical data on the spatial distribution of the Lyα forest. These results are shown in the Fig. 1. Calculations were done within context of Einstein-de Sitter universe, and are independent on the value of $H_0$. The covering factor here and elsewhere is assumed to be unity (Čirković et al. 1997).

Next natural step is to use recently established luminosity scaling of the absorbing material associated with galaxies with galactic B-band luminosity. Convolution of the local luminosity function (Schechter 1976; Willmer 1997) with available photometric surface densities acts, as expected, to reduce the predicted number of absorption lines and brings it into better agreement with the empirical data, as shown in the right panel of Figure 1. In the simplest (Einstein-de Sitter) case, the total number of absorption lines seen out to redshift $z$ is given as

$$N = \frac{\kappa \pi R_0^2 H_0^2}{c^2} \left( \frac{10800}{\pi} \right)^2 \int_0^z n(z) \left( \frac{1+z}{\sqrt{1+z}-1} \right)^2 \times$$

$$\times \left[ \frac{\phi_*}{L_*} \int_{L_{\min}}^{L_{\max}} \left( \frac{L}{L_*} \right)^{2\alpha-\gamma} \exp \left( -\frac{L}{L_*} \right) dL \right] dz; \quad (1)$$

where $\gamma$ and $\phi_*$ are the parameters of the luminosity function, $n(z)$ is the galaxy surface density at $z$ in (arc min)$^{-2}$, and $\alpha$ is the index of Holmberg-type scaling of the absorption radius (Chen et al. 1998). Only luminosities corresponding to magnitudes $-21.5 <$
$M < -14$ are considered (Willmer 1997), and standard Schechter luminosity is taken to correspond to absolute magnitude $M^* = -19.1$.

The agreement of predicted and observed spatial distribution of absorption lines at low and intermediate redshift is obvious, especially in the case of the HDF. Unfortunately, the errors in surface densities for the field of BR1202-0725 are still not available, but it is probable that agreement at lower redshifts is achieved here too. Empirical power law for the spatial distribution of Ly$\alpha$ forest was used with the values of Kim et al. (1997). Our results are in agreement with those of Fernandez-Soto et al. (1997), although we do not find a single power law capable of reproducing data points at low $z$ with any statistical significance. We notice that these results suggest the existence of a critical redshift $z_c$ above which it is impossible to explain observed absorption with the material exclusively associated with galaxies. This is expected, in view of several other circumstantial arguments, such as behavior of the Ly$\alpha$ forest autocorrelation function (e.g. Cristiani et al. 1997), as well as the results of numerical simulations of the structure formation. The theoretical significance of that result as one further discriminator between various gasdynamical histories will be discussed in a subsequent work.

In order to investigate whether the ground-based deep fields like that of BR1202-0725 are representative of the high-redshift galaxy population, we have performed several other tests, including analysis of the angular size distribution of sources in the NDF. Due to spatial limitations, we do not present results here, but emphasize the strong impression that, within uncertainties due to large pixel size, the field is fairly representative sample of galaxy populations, at least up to redshifts of $\sim 3$, which are interesting from our current point of view.

Other issues to be aware of are dependence of angular size on the cosmological model (models with $\Lambda$-term are interesting in this respect), and changes in the comoving flux in the selected band due to effects of secular galactic evolution. At this point, the problem of the total absorption cross-section of galaxies comes again into close contact with the general problem of star-formation history of the universe. Further problems to be addressed in the subsequent work are various effects connected with non-conservation of the phase-space density of galaxies. This arises for fundamentally two reasons: late ($z < 3$) galaxy formation, predicted in many models of structure formation, and mergers of galaxies. Both effects have been only slightly discussed in a quantitative way so far.

Work currently in progress includes analysis of NDF photometric redshifts, and their incorporation in the general pattern, as well as more precise and accurate analysis of errors and uncertainties, apart from the points mentioned above. Further significance stems from the prospects of incoming deep images, like Southern Deep Field, to be taken in very near future. It is our modest hope that these results will, together with all others resulting from the current revolution in observational techniques, contribute to our understanding of the structure and evolution of the deep universe.

3. Technical remarks and some results

We used the SExtractor program (Bertin and Arnouts 1996) in order to analyze the NTT SUSI Deep Field images. In the Figure 2 (left panel) we present the plot of the “stellarity index” that ranges between 0.0 (galaxy) and 1.0 (star) for the B band; we included all extracted objects regardless on the $S/G$ ratio and flag parameter. We also present some preliminary results concerning angular diameter of the galaxies in the NTT SUSI Deep Field for the B band (Figure 2, right). We note that the “holes” in the distribution are artifacts due to the rather large size of the pixel (1 pixel corresponds to 0.129 arcsec). This result can be compared to other estimates (e.g. Shanks et al. 1998). Further analysis is to be performed after obtaining the redshift estimates for the galaxies in the field in order to test the effects of non-zero cosmological constant, $\Lambda$. Figure 3 (left panel) shows the histogram of the number of galaxies according to their angular radius. A comparison with the corresponding data obtained from the
Figure 2. Left: Stellarity index as a function of magnitude. Right: Angular radius as a function of magnitude for the B band.

Figure 3. Left: Histogram of semi-major axes of NDF galaxies up to AB ∼ 27. Right: The same as in the left panel for HDF (from Yahil et al. 1998) with correction for incompleteness at AB > 28 (shaded region).
HDF analysis (Yahil, Lanzetta and Fernandez-Soto 1998), presented in Figure 3 (right panel), shows obvious similarities. We exclude the galaxies with S/G ≥ 0.5 (cf. Arnouts et al. 1998) and flag ≥ 10; this criterion is quite conservative, as can easily be seen from the Figure 2 (left panel) and in comparison to the quoted references.

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