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LOW REDSHIFT LYα FOREST AND THE COLUMN DENSITY DISTRIBUTION FUNCTION

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Abstract. Recent discovery that most of the low-redshift Lyα forest absorption systems in QSO spectra are located in well-defined extended gaseous haloes around normal luminous galaxies has several interesting consequences. In this paper, we apply the simple argument advanced originally for the minihalo model column density distribution to the case of galactic ("normal") haloes. The exponent of the column density distribution function obtained in this manner is in suprisingly good agreement with the value obtained directly from large samples of (mainly high-redshift) Lyα lines.

1. INTRODUCTION

One of the principal aims of any model for the origin of Lyα absorption systems in QSO spectra is to reproduce the column density distribution function (CDDF). As noted by Rauch (1998) in QSO absorption studies, the CDDF occupies the same elevated position as the luminosity function in investigation of galaxy systems and distribution. It is usually assumed that it is expressed as the *differential* distribution function, i.e. the number of Lyα absorbing systems per unit redshift path per unit neutral hydrogen column density as a function of the neutral column density $N_{\rm HI}$.

The CDDF is traditionally given in the form (Carswell *et al.* 1984; Milgrom 1988; Hu *et al.* 1995)

$$f(N_{\rm HI}) = BN_{\rm HI}^{-\beta}, \tag{1}$$

where B and β are positive constants to be fixed by observations in each particular column density and redshift range. The original result of Carswell *et al.* (1984) was that $B = 1.058 \times 10^{11}$ and $\beta = 1.68 \pm 0.10$ in the column density interval $13 < \log N_{\rm HI} < 15$ cm^{-2}. Newer measurements of the spectra taken with the Keck HIRES suggest the values for high-redshift parameters of Eq. (1) of (Hu *et al.* 1995; Kim *et al.* 1997)

$$B = 4.9 \times 10^{7}, \tag{2}$$

and

$$\beta = 1.46^{+0.05}_{-0.09}. \tag{3}$$

This result is shown in Fig. 1. (obtained courtesy of E. M. Hu). The solid line represents the single power law of Eq. (3) and points are those obtained in studies of Petitjean *et al.* (1993; diamonds) and Hu *et al.* (1995; circles), with 1σ uncertainties.

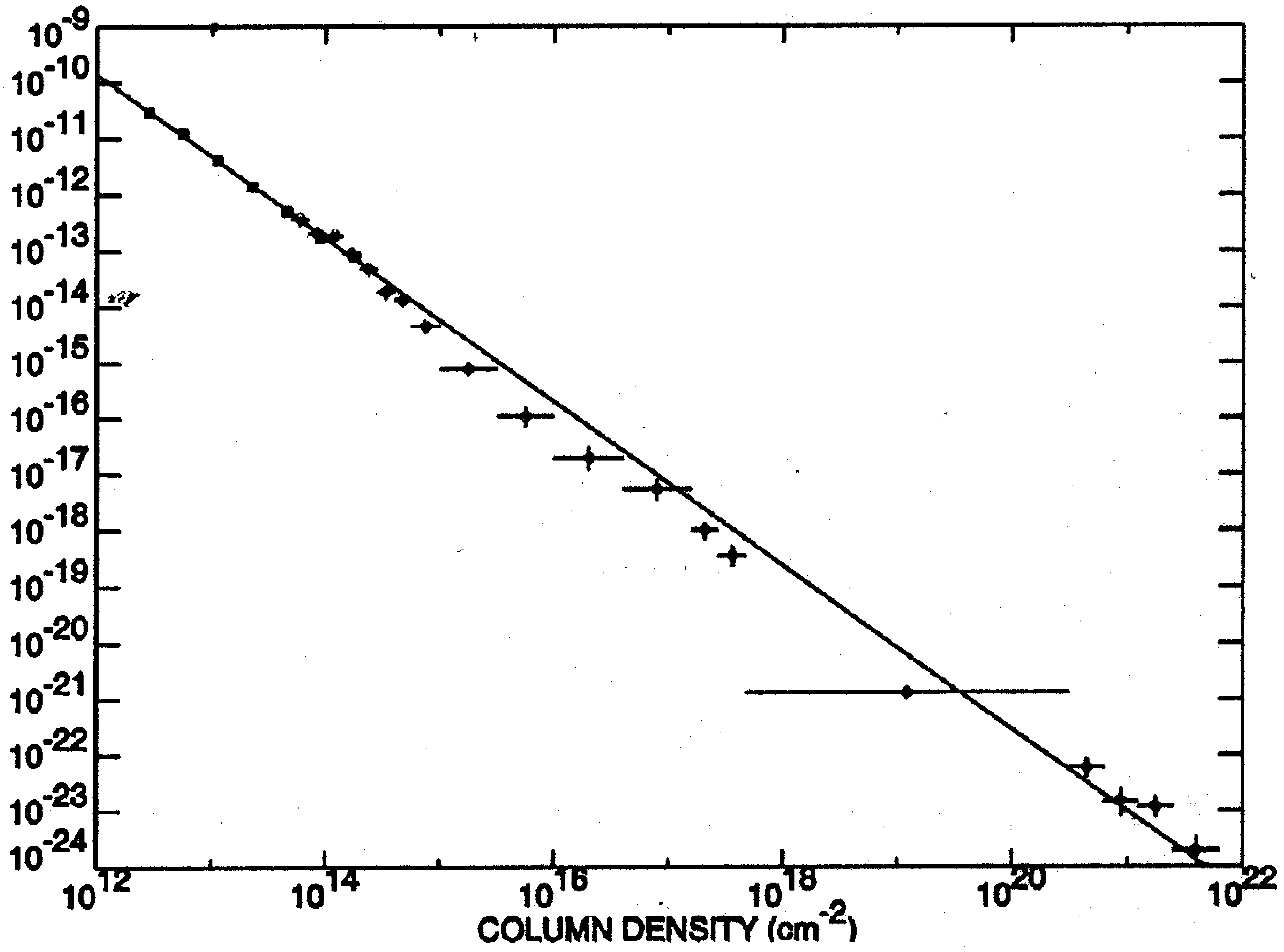

Fig. 1. The column density distribution of the Lyα clouds at $z \sim 3$; reproduced with permission by Hu (1997).

Similar results have been obtained by other investigators. For instance, in an excellently performed and a particularly well-written study, Press & Rybicki (1993) obtain the best-fit result for the index of the CDDF

$$\beta = 1.43 \pm 0.04. \tag{4}$$

These results, it should be noted, are obtained by statistical analysis of ***high-redshift*** samples of the Lyα forest.

2. COLUMN DENSITY PROFILE OF GALACTIC HALOES

With the advent of *HST*, low-redshift Lyα forest has become available for detailed investigation, and several observational surveys (Spinrad *et al.* 1993; Lanzetta *et al.* 1995; Chen *et al.* 1998) showed that a significant fraction of these absorption lines arose in extended gaseous haloes of normal luminous galaxies. This confirmed old galactic halo model of Lyα clouds, first put forward by Bahcall & Spitzer (1969). Moreover, some detailed information on the distribution of neutral gas in such huge galactic haloes of characteristic size $\sim 174\,h^{-1}$ kpc has been obtained. The spatial column density distribution of neutral hydrogen around galaxies in low-redshift absorption-selected sample of Chen *et al.* (1998) as a function of galaxy impact parameter can be written as

$$\log\left(\frac{N_{\rm HI}}{10^{20}\ {\rm cm}^{-2}}\right) = -\alpha_1 \log\left(\frac{\rho}{10\ {\rm kpc}}\right) + \alpha_2 \log\left(\frac{L_B}{L_{B*}}\right) + \alpha_3, \tag{5}$$

where ρ is the absorbing galaxy impact parameter, L_B is its B-band luminosity, and α_1, α_2 and α_3 are constants, (with 1σ uncertainties), $\alpha_1 = 5.33\pm0.50, \alpha_2 = 2.19\pm0.55$, and $\alpha_3 = 1.09\pm0.90$. This is in agreement with earlier results of Lanzetta *et al.* (1995), who obtained for the constant α_1 a value of 5.3 (no errors quoted).

3. INFERRED CDDF, INDEX

For the huge galactic haloes, we can apply the same approach as for minihaloes (Rees 1988; Milgrom 1988) in an attempt to infer the CDDF of a statistically significant sample of absorption systems. When the impact parameter is between ρ and $\rho + d\rho$, the probability for the column density to be observed between $N_{\rm HI}$ and $N_{\rm HI} + dN_{\rm HI}$ can be written as

$$P(N_{\rm HI})\, dN_{\rm HI} \propto \rho\, d\rho. \tag{6}$$

It is natural to assume that the observed column density distribution is proportional to this probability (Murakami & Ikeuchi 1990). Therefore, we have

$$\frac{dn}{dN_{\rm HI}} \propto P(N_{\rm HI}) \propto \rho \left(\frac{dN_{\rm HI}}{d\rho}\right)^{-1}. \tag{7}$$

In this manner, one can establish connection between the column density-impact parameter relation and the CDDF index. This is well-known argument, which has been used by Rees (1988), Milgrom (1988) and Murakami & Ikeuchi (1994) to show the plausibility of the minihalo model for the origin of the Lyα forest lines. For the general case with the isothermal distribution of optically thin gas, the minihalo model predicts decrease of the physical H I density with "minihalo-centric" radius as $n_{\rm HI} \propto r^{-4}$. Resulting theoretical CDDF will exhibit index of $\beta_{mh} = 1.5$ (Milgrom 1988), which is in rather good agreement with the empirical values in Eqs. (3) and (4).

However, there is no reason not to apply the same argument to the normal galactic haloes as well. It has been used in this manner by Lanzetta & Bowen (1990) for the Mg II-selected sample of absorbing galaxies, but the predicted value of the index of the Mg II column density distribution (or, in their case, equivalent width distribution) function has been in violation of the observational data, being ~ 1.5 times larger than observed. Consequently, they have not attached much significance to it. Probable reason for this is that the variation of column densities of classical metal-line absorption systems with galactocentric radius is necessarily much shallower than for Lyα lines

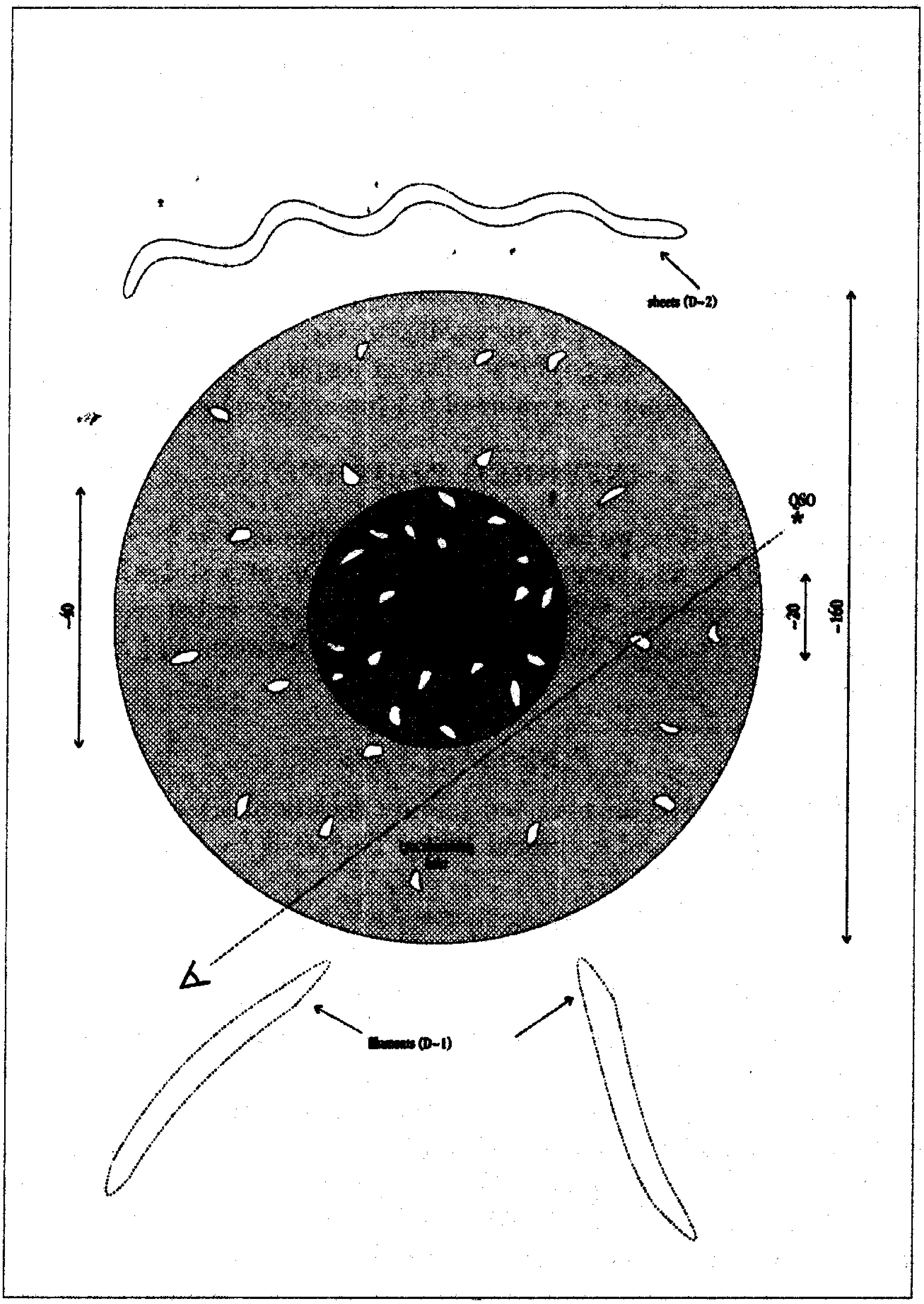

Fig. 2. A schematic representation of galactic halo absorption system population. If it is assumed, as usual, that damped Lyα and metal absorbers arise in the denser regions of galactic haloes, this picture could be generalized to include the Lyα forest absorbers, in accordance with the low-redshift findings of Chen *et al.* (1998). Intergalactic absorbers of higher fractal dimension are also shown. Approximate sizes are given in units of h^{-1} kpc.

originating in the same population of clouds, due to effects of metallicity gradients (cf. Srianand & Khare 1993). On the other hand, after Chen *et al.* (1998) have established the relationship between H I column density and galaxy impact parameter, as expressed in Eq. (5), there is no reason not to compare this piece of observational information specific to galactic gaseous haloes with statistical CDDF in large Lyα forest line samples. Thus, from Eqs. (1), (5) and (7), we infer that the exponent of the power-law CDDF can be written as

$$\beta = \frac{\alpha_1 + 2}{\alpha_1} = 1.38 \pm 0.04, \qquad (8)$$

which is in remarkably good agreement with the results in Eqs. (3) and (4).

4. DISCUSSION

The similarity between the results in Eqs. (3) and (8) has to be interpreted as a coincidence if we believe that normal galaxies do not constitute a significant fraction of the total absorption cross-section of the universe. Conversely, it is conceivable that subpopulation of galactic halo absorption systems retains the same CDDF over a large redshift range. Galactic halo absorbers would have a complicated structure like the one shown in Fig. 2. (not drawn to scale).

The fact that galactic halo theory seems to be able to account for global behavior of the column density distribution function can be regarded as another piece of evidence that a significant part of the entire Lyα absorbing population is truly of galactic origin. This is in agreement with the mixed population theories, such as developed recently by Chiba & Nath (1997), which invoke absorption in both galactic haloes and minihaloes. This view is strongly supported by results on the redshift evolution of the Lyα forest, suggesting a slow transition between two distinct populations occured at redshifts $z \sim 1.7$ (Bahcall *et al.* 1996; Weymann *et al.* 1998; see the discussion in Rauch 1998). It may be indicative that minihalo models predict systematically higher CDDF index than the one the observations suggest for galactic haloes; thus, any mixture of populations would tend to give intermediate values, as is really the case. This may also be the explanation for the break in the CDDF power-law detected in some studies (Petitjean *et al.* 1993; Rauch 1998, and references therein).

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