DYNAMICAL HISTORY OF Ly α CLOUDS

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ABSTRACT

The clustering properties of Ly α lines are analysed using an intermediate resolution ($\sim 1\mathring{A}$) spectra of 67 QSOs compiled from the literature. The pair velocity correlation function indicates a weak excess in the velocity intervals up to $\Delta v = 600$ km s^{-1}. The z-integrated probability distribution of interline spacings also confirms the excess in the low velocity intervals. The dependence of pair velocity correlation on redshift and equivalent width are investigated. The cross-correlation properties of Ly α clouds with metal line redshifts are analysed. We do not find any tendency of Ly α lines to cluster around metal line systems. Depedence of the cross-correlation on redshift and equivalent widths of Ly α clouds are investigated. Various implications of the results are discussed.

Subject headings: QSO: Ly α absorption lines- clustering

1. INTRODUCTION

Ly α absorption lines seen in the spectra of QSOs, being the most abundant objects at higher redshifts, can provide us valuable information regarding the intergalactic medium at the earlier epochs. Though the properties of these lines have been studied for the past two decades, we are still not in a position to understand the origin of these lines. Since these lines do not show appreciable amount of metallicity and clustering they are considered to be primordial intergalactic material. Sargent et al.(1980) proposed the pressure confined model for these lines. Though this model explains the observed properties of Ly α lines the origin of the clouds is not well defined. The dynamical evolution of Ly α lines in this model will be mainly due to environmental effects.

Rees (1986), Ikeuchi (1986) and Bond, Szalay, and Silk (1988), proposed the gravitationally induced formation scenarios for the origin of Ly α clouds. Ostriker & Ikeuchi (1983) and Chernomordik & Ozernoy (1983) proposed shocked shell models in which the clouds originate in the fragmenting shells, which is a natural extension of the theory of how some stars form in the interstellar medium. Last two models have physical origin for the formation of the Ly α lines and can predict their spatial distribution and its evolution with redshift. Studying the correlation properties and their evolution can allow one to understand the dynamical history of the Ly α clouds and discriminate between various models.

Webb(1987) showed, in the case of Ly α absorption lines obtained using high resolution spectroscopy, that there is an excess in the pair velocity correlation for scales ~ 300 km s^{-1}. Ostriker, Bajtlik and Duncan (1988; OBD here after) showed that the line interval distribution function is the better tool for studying the clustering properties than the pair velocity correlation and showed a significant excess in the lower velocity scales in their low resolution sample. Recently we (Srianand & Khare 1994) also confirmed the excess in these velocity scales using high resolution observations of 8 QSOs. However the distribution of lines, both in the case of low as well as high resolution samples, seems to be uniform beyond

300 km s^{-1}.

Tytler (1987) based on the single powerlaw neutral hydrogen column density distribution, seen over six orders of magnitude in column density, proposed the same origin for metal line systems as well as Ly α clouds. There are indications, from the HST observations, that at least few % of Ly α clouds at very low z may be associated with galaxies (Lanzetta et al. 1994). Deep imaging studies at low redshifts indicate the association between metal line systems and luminous galaxies (Bergeron (1988); Steidel (1993)). Thus studying the cross-correlation between the metal line systems and Ly α lines and its evolution with redshift can provide us some useful information. Barcons and Webb (1990) studied the cross-correlation properties and did not find any significant excess on any velocity scale.

In this paper the clustering properties of the Ly α clouds among themselves and with metal line systems are reanalysed in detail with an extended intermediate resolution sample compiled from the literature. The details of the data used in the analysis are given in section 2. The results of the auto-correlation analysis and the dependence of auto-correlation on equivalent width and redshift are presented in section 3. The results of cross-correlation analysis between Ly α lines and metal line systems and the dependence of cross-correlation on equivalent width and redshift are presented in section 4. Discussion and results are presented in section 5 and 6 respectively.

2. DATA SAMPLE

Most of the earlier studies of correlation properties of Ly α clouds were performed with small samples obtained with varied resolution, S/N and line selection techniques. In order to get any significant result one requires a data sample compiled with large number of spectra obtained with similar resolution and S/N. Such a sample was compiled recently by us from the literature for analysing the properties of Ly α clouds in the vicinity of QSOs

(Srianand and Khare 1995). Our data sample is obtained, by considering the QSO spectra observed with spectral resolution resolution $\leq$ 100 km s^{-1}, from the literature. In total there are 67 QSO spectra covering a redshift range between 1.7 and 4.0. The necessary details of the data with references are given in Table 1.

z_{max} is the smaller of observed maximum and emission redshift of the QSOs and z_{min} is the larger of the observed minimum and the redshift corresponding to the Ly β emission. E is the minimum detectable equivalent width of a line of 5σ level in each spectra. In most of the cases these values are taken as given by the authors of the parent references. Whenever these values are not given E is taken to be five times the largest observable error in the equivalent width of any line in the relevant redshift range. z_{abs} is the redshift of known metal line system in the observable range of Ly α absorption. In order to avoid any ambiguity introduced by the different selection criteria used by various authors the metal line systems are graded as A, B and C, which are also provided in the table 1. The criteria used are discussed in section 4. The gaps in the spectra, the metal lines and the Ly α due to metal line systems are considered as the excluded regions for the Ly α observations. Since the presence of metal line systems can cause a spurious signal in the correlation function even very doubtful systems are excluded from the Ly α sample. Very strong Ly α lines, W $>$ 5Å, are also considered to be excluded regions as they may well belong to the damped Lyman alpha systems.

3. PAIR VELOCITY CORRELATION FUNCTION

The pair velocity correlation between Ly α clouds along the line of sight has been one of the tools commonly used to study the clustering properties of Ly α clouds (Sargent et al. 1980). It is customary to define the pair velocity correlation at any velocity interval v, ξ(v) the excess probability over the expectation based on randomly distributed absorbers, as

$$\xi(v) = \frac{n_{obs}(v)}{n_{exp}(v)} - 1. \quad (1)$$

where $n_{obs}(v)$ is the number of observed pairs with velocity 'v' and $n_{exp}(v)$ is the expected number of pairs obtained assuming the cloud distribution to be random. n_{exp} is calculated taking into account the redshift evolution of number density of Ly α lines, obtained from the sample used here(Srianand & Khare 1995). Sargent et al. (1980) used a ramp-shaped function to account for the limited redshift coverage of each spectra. Instead of taking any correction function, for each Ly α line the expected number of lines in various velocity bins are calculated taking into account the observable range in the particular spectrum. The errors in the correlation functions are calculated using the analytic relations given by Mo, Jing and Borner(1992). These relations provide a realistic estimation of errors for ξ, in the case of weak clustering (i.e. $\xi < 1$). The observed number of pairs in each velocity bin with expected number and their 2σ errors are plotted in figure 1. (for equivalent width cutoff $W_{min} = 0.3$Å). Only lines which are 8 Mpc away from the QSOs are considered in order to avoid the complications due to proximity effect of QSOs.

The excess in the low velocity bins is evident from the figure 1. For the relative velocities between 200 and 400 km s^{-1} the observed value of ξ is 0.316 ± 0.104, a clear 3σ excess. The excess seems to extend up to 600 km s^{-1} with $\xi = 0.23 \pm 0.08$. Note that the deficit seen in the first bin may be an artifact of the blending and actual clustering may be much stronger than the one seen here. Also if the Ly α clouds have small peculiar velocities on top of Hubble flow then the real spatial correlation may be much stronger than the one implied by the velocity correlation. In order to confirm this excess the distribution of interline spacing described by OBD is analysed.

3.1. Distribution of interline spacing

Considering the z-integrated probability distribution of size intervals between adjacent absorption lines, OBD showed a weak excess in the scales 200-600 km s^{-1}. If the line

distribution is locally Poisson, then the expected distribution of line intervals is

$$P(x) = \exp^{-x}. \tag{2}$$

Where $x = \Delta z/\overline{\Delta z}$, is the line interval scaled to the local mean. One can approximate in any given redshift range,

$$\frac{1}{\overline{\Delta z}} = N_o(1+z)^{\gamma} \tag{3}$$

where N_o and γ are constants obtained from fitting the observations. Following OBD, the effect of blending is modeled by assuming the number of low Δz intervals is reduced by a factor,

$$1 - \exp\Big[-\Big(\frac{\Delta z}{\delta_b}\Big)\Big] \tag{4}$$

relative to Poisson, where Gaussian blending scale δ_b is

$$\delta_b = \zeta \frac{W_{min}(z)}{\lambda_\alpha}(1+z) \tag{5}$$

The redshift density of line intervals and z-integrated probability distribution for line interval sizes are derived, using the equations given by Babul(1991), taking into account the excluded regions in the spectra. Both the distributions are fitted simultaneously to get the best fit values of ζ, γ and N_o. The values obtained for $w_{min} = 0.3$Å are 1.0, 2.3 and 3.80 respectively. The line interval distribution and the expected distribution for the best fitted truncated Poisson model are given in fig 2. Kolmogorov-Smirnoff test shows, see fig(3), the probability that the maximum deviation between the observed and the predicted cumulative distributions to occur by chance is 0.0001, and the maximum deviation occurs at the interval separation 0.23. Thus the distribution of interline spacing also confirms the excess correlation in the low velocity intervals.

3.2. Dependence of clustering on rest equivalent width

At least 32% of the very low redshift Ly α lines seem to be associated with luminous galaxies (Lanzetta; 1994). It may be possible that among the Ly α clouds a fraction may be associated with galaxy kind of objects or their progenitors (say metal line systems at higher redshifts), and rest of them are due to intergalactic clouds. In such a scenario one would expect to see strong lines to cluster more than weak lines as the lines associated with galaxies are expected to be stronger.

Models involving biasing for the formation of structure in the universe predict that the objects formed at the sights associated with the stronger potential wells should be more strongly clustered. If Ly α clouds are in some way associated with primordial density fluctuations, and the rest equivalent width is related to cloud mass, then we might expect the strong absorption lines to show clustering which is stronger than their weak counterparts.

The pair velocity correlation analysis is performed for different values of equivalent width cutoff. The calculated values of ξ for various low velocity bins are given in Table 2. A glance at the table reveals that in all cases there is more than 2σ excess in the velocity interval 200-400 km s^{-1} . Also there seems to be a moderate increase in clustering amplitude with equivalent width cutoff. Note that Crotts(1989) also found that the stronger lines tend to cluster more readily compared to weak lines. In the case of metal lines also Steidel and Sargent (1992) showed strong Mg II lines clustered more readily than the weaker ones. Recently Cristiani et al (1995) showed the correlation function to depend on column density for the lines in the spectra of QSO 0055-269.

However the increase in ξ is marginal and within 2σ errors. Thus our results do not show any statistically significant increase in ξ with equivalent width cutoff. And even if the increase is real it is not to the extent that is expected if most of the high equivalent width Ly α lines are similar to the nonLLS C IV systems. Thus it seems strong Ly α lines

at earlier epochs are not associated with the regions similar to the present day galaxies.

3.3 Redshift dependence of pair velocity correlation

Structures formed due to gravitational instabilities and explosions are predicted to show spatial clustering. However the two scenarios predict different evolutionary pattern for clustering with time. The sample used here is divided into two subsamples at z =2.9 (mean redshift of the sample) and analysed to see any possible change in the pair velocity correlation function. The expected and observed number of pairs for various velocity bins together with 2σ errors are shown in figure 4a and figure 4b for low and high z respectively (with $W_{min} = 0.3$Å). While the correlation excess for low z subsample extend up to 800 km s^{-1} with $\xi = 0.263 \pm 0.119$ the high z subsample show weaker correlation strength in the same velocity interval ($\xi = 0.155 \pm 0.106$). The increase is moderate and is with in 1σ errors in ξ. The velocity width of 800 km s^{-1} at z=2.4 (average z of low z subsample), for $q_o = 0.5$ and $H_o = 100$ km s^{-1}, corresponds to a distance scale of 0.5 Mpc. For z = 3.4 the same distance corresponds to a velocity width of 1600 km s^{-1}.

The results for high equivalent width lines (with $W_{min} = 0.6$Å) are shown in figures 4c and 4d. A glance at the figures reveals a moderate evolution in the correlation function. While $\xi = 0.700 \pm 0.342$ for velocity interval 200-800 km s^{-1} for $z < 2.9$ the higher redshift samples show $\xi = 0.080 \pm 0.200$. Also in the lower redshift subsample the excess seems to extend up to 2500 km s^{-1}. This velocity scale corresponds to a distance of ~ 4.0 Mpc (for $q_o = 0.5$ and $H_o = 100$ km s^{-1} Mpc^{-1}), which is roughly the clustering scale of the present day luminous galaxies. It seems for the high equivalent width lines either the spatial correlation strength has increased with time and/or the systemic velocity of the clouds increased with time. However, one can see (in figure 4.) a large positive and negative deviations which are more than 2 σ errors in the higher velocity intervals. Since the number of QSO spectra used in the sub-samples are small these deviations may very well be noise. This prevent us from making any firm conclusions about the clustering scales. In any case one would expect to find more correlation power in the pair velocity correlation for the local

Ly α clouds (Ly α lines observed with HST).

Bahcall et al. (1993) showed, based on HST observations, that there is no excess in the calculated two point correlation function for absorption lines in 13 QSO spectra. They noted that with the available data, the observed Ly α correlation function is not inconsistent with the hypothesis that Ly α lines are correlated as strongly as are galaxies. In order to test this hypothesis at higher significance level one may require data set that is 3 to 4 times bigger than that is available in the literature.

A strong prediction of any model of structure formation based on gravitational instability is that the correlation function should increase substantially with time. Such a picture also predicts that the systemic velocities associated with gravitationally bound systems would also increase with time as they reach virial equilibrium. However the explotionary theories of structure formation (Vishniac, Ostriker and Bertschinger 1985; Weinberg,Ostriker and Dekel 1989) suggest either unchanging or weakening of pair velocity correlation with time. If the increase in ξ shown by the high equivalent width lines are real, and confirmed with higher significance it will favour gravitationally induced structure formation models over the explosion models. Also difference in clustering strength of metal lines and Ly α lines requires some sort of biasing in the usual CDM models (Salmon and Hogan, 1986).

4. Ly α - METAL LINE SYSTEM CROSS CORRELATION

Morris et al (1993) showed, based on very low z observations, an excess in cross-correlation between Ly α and the luminous galaxies, though not as strong as the Galaxy-Galaxy autocorrelation, in the lower velocity scales. Studying the cross correlation function at different epochs will enable us to understand the origin and evolution of Ly α clouds. There are evidences for most of the heavy element absorption systems seen in the spectra of QSOs to be associated with luminous galaxies (Bergeron, 1988; Steidel,

1993). Strong two point velocity correlation also confirms the metal line systems to be the possible sights of present day luminous galaxies. Barcons and Webb (1990) studied the cross-correlation between heavy element systems and the Ly α lines. They considered 18 QSO spectra and 42 metal line systems and Ly α lines with rest equivalent width $> 0.36\AA$ for their analysis and did not find any signal beyond 300 km s^{-1}.

Since number of QSOs considered here is roughly 4 time more than that used by Barcons and Webb (1990), and have uniform signal to noise ratio and resolution, it will be a worthwhile pursuit to reexamine the cross-correlation properties. The metal line systems used for the analysis are given in table 1. Though the Ly α line list is fairly homogeneous the metal line systems are inhomogeneous as they were identified by various groups with spectra of varied resolution and line selection criteria. In order to have a uniformity a grade is assigned to each system using the criteria prescribed by York et al. (1991). If C IV or Mg II doublet was observed with the correct doublet ratio, the system was assigned a grade 'B'. If in addition, plausible lines of another species (besides Ly α) were identified and supported this doublet, the grade is assigned as 'A'. If doublet ratio was inverted, or only one member of a doublet was identified, or, if a spectrum was pictured in the reference and the lines did not appear at all convincing, or the data was especially of poor resolution or of poor signal-to-noise, then the grade assigned was 'C'. Some of the systems show broad and diffuse absorption lines of highly ionized elements without strong Ly α absorption lines. It is possible that these lines are not produced by the intervening clouds rather they are due to ejected materials from the QSOs. These systems are rated as 'C' as the redshift of these systems need not reflect the actual distances. There are Lyman Limit systems in some of the spectra used here which do not show any metal lines. Since it is not clear whether they are very low metallicity metal line systems or high column density Ly α clouds these systems are not considered for the analysis. Thus in a way the possible uncertainties that may be introduced in the cross-correlation because of metal line system selection criteria are avoided.

Only Ly α lines and the metal line systems which are 8 Mpc away from the QSOs are considered to avoid any uncertainty due to proximity effect. Following Barcons and Webb (1990) in the case of multiple system objects, the spectra is splitted at the mid-point (in Ly α redshift) between heavy element systems, and each spectral segment is treated as the independent region of space. The cross-correlation function $\xi_{\rm ML}(v)$ at different velocity separations are calculated. The expected number in each bin is calculated as described for pair-velocity correlation. Since the Ly α line associated with metal line system obscures a significant region of the adjacent Ly α forest, the interval $\lambda_{\rm obs} - W_{\rm obs}/2$, $\lambda_{\rm obs} + W_{\rm obs}/2$ centered on this observed Ly α line is excluded from the analysis.

The observed and expected number of Ly α lines in different velocity bins are presented in figures 5a 5b and 5c, for $w_{\rm min} = 0.3$Å for differently graded metal line systems. A glance at the figure reveals that there is no excess in the lower velocity scales, rather there seems to be a deficit of lines. This deficit seems to be more that 1σ level in the velocity interval 200-400 km s^{-1} and consistent with the expected number within 1σ for other velocity bins. The deficit seems to be roughly 2σ when only systems graded as A are considered. As per our expectations the difference between observed and expected number decreases as the doubtful systems are also included in the analysis. Consistent with the results of Barcons and Webb (1990), we are not finding strong clustering signal in the lower velocity scales. Thus it seems that the Ly α clouds distribution, with equivalent width > 0.3Å, are fairly insensitive to the presence of metal line systems beyond 200 km s^{-1}. Such a thing is expected in a biased CDM model of structure formation, where the Ly α cloud distribution do not follow the mass distribution.

4.1. Dependence of cross-correlation on the rest equivalent width

In the biased gravitationaly induced structure formation models, or if the small fraction of Ly α clouds associate with metal line systems one would expect to see the cross-correlation function to depend on rest equivalent widths. Here we examine the

possible dependence of cross-correlation on the rest equivalent width of the Ly α lines. We performed the analysis for W_{min} = 0.15, 0.30, 0.60 $\AA$ for differently graded metal line systems and the obtained values of $\xi_{ML}(v)$ are given in table 3. A glance at the table 3 reveals no tendency of ξ_{ML} to depend on the rest equivalent width of the Ly α clouds. Thus our results indicate the distribution of strong as well as weak lines are fairly uniform and not affected by the presence of metal line absorbers beyond 200 km s^{-1} at higher redshifts.

4.2. Dependence of cross correlation on redshift

Recent HST observations presented by Bahcall et al. (1995) show the clumps of Ly α lines cluster around the metal line systems. Lanzetta et al (1995) show at least 32% of the Ly α clouds are associated with luminous galaxies at the very low redshifts. simple extrapolation of these results demand the cross-correlation to increase with time. If the Ly α clouds are formed via gravitational instability in a biased scenario, the cross-correlation function is expected to decrease with decreasing redshift due to the environmental dependent cloud evolution. Here we investigate the possible dependence of the cross-correlation on redshift . The metal line systems with grade A and B alone are considered for this analysis. The sample is divided into two at redshift z = 2.8, the expected and observed number of pairs in various velocity bins are calculated for different values of W_{min}. The results are shown in figures 6a, 6b, 6c and 6d.

The observed correlation in the low velocity intervals are given in table 4. In almost all cases we see a slight increase in ξ_{ML} for high z subsample. However the values are with in 1σ errors and fairly consistent with no correlation. Note Barcons and Webb(1990) also got similar trent($\xi_{ML} = -0.01 \pm 0.25$ for low and 0.57 ± 0.42 for high redshift sub-samples). However as noted by them one requires more data to make any firmer statement on the evolution of ξ_{ML}. If this trend is confirmed it will provide a good means to probe the dynamical history of the Ly α clouds.

5. DISCUSSION

Our analysis confirms the existence of clustering in the low velocity scales in the case of Ly α clouds. The redshift dependence of the correlation function can discriminate between various models of Ly α clouds. Though tentative results obtained in our analysis indicate the increase of clustering with time, the data is noisy to make any significant statement.

Sample used in this analysis is obtained with intermediate resolution spectroscopic observations, and thus the lines observed are actually blends of few lines. Barcons and Webb (1991) showed that blending of randomly distributed lines alone cannot produce the observed equivalent width distribution of the low resolution samples from the column density distribution obtained using high resolution samples. They need an enhanced blending due to clustering among Ly α clouds to explain the observed results consistently. Thus our correlation analysis will under predict the correlation amplitude in the smaller scales ≤ 200 km s^{-1}. The velocity interval considered in this analysis, 200 - 600 km s^{-1}, will not be affected by blending. Travese, Giallongo & Camurani(1992) showed that, using the simulated spectra, the blending of lines can artificially increase the number of high equivalent width lines more than the number of low equivalent width lines and produce an apparent differential evolution in number density. If the blending is severe in the sample used here then the enhanced evolution in two point correlation shown by the high redshift strong lines may be just an artifact of blending and the real redshift evolution need not be the function of equivalent width. Only very large sample compiled with high resolution spectra can give a better answer.

One can ascribe the lack of cross-correlation of Ly α lines with metal line systems, as seen in our analysis, as the effect of photoionization due to radiation from the metal line systems. Which implies very high UV flux and hence very high star formation rate (SFR) in the metal line absorbers. However the necessary SFR to shield the cross-correlation excess can be ruled out based on the blank sky Ly α emission searches (Srianand & Khare 1995a). Another possibility may be the merger of Ly α lines into the metal line systems. In

this case one would like to see some time dependent evolution of cross-correlation function. Thus getting a statistically significant estimate of redshift dependence of cross-correlation function will enable us to understand the evolutionary scenarios.

If results obtained here are true then based on simple extrapolation one should not find the clustering of Ly α lines with luminous galaxies at very low redshifts. However Lanzetta et al(1994) showed at least 30 % of the Ly α clouds seem to associate with luminous galaxies. Thus these systems do not represent the population of Ly α lines seen at higher redshifts if the metal line systems seen at earlier epoch are progenitors of the present day galaxies. Mo and Morris (1994) showed that the very low redshift Ly α population can be a combination of mini halo population and the absorbers associated with galaxies themselves. Lanzetta et al(1994) also showed the distribution of relative velocity between the Ly α systems and the luminous galaxies are consistent with the coincidence galaxies being responsible for the absorption systems. Thus these systems may be due to clouds in the extended halos around the galaxies or due to extended disks (Maloney 1992) or tidel tails (Morris and Van den Bergh; (1994)) produced due to interactions among the galaxies. In such a scenario the observations with very high S/N should show some associated metal lines in these systems.

6. RESULTS

An intermediate resolution, 60 $-$ 100 km s^{-1}, sample of Ly α absorption lines in the spectra of 67 QSOs is compiled from the literature. The clustering properties of the Ly α clouds and their evolution with time are analysed. The main results of our analysis are

(1) Pair velocity correlation analysis between Ly α lines shows a slight excess in the two point correlation function in the velocity interval 200-600 km s^{-1}. The value of two point correlation function ξ obtained for $W_{min} = 0.3$Å in the velocity interval 200-400 km s^{-1} is 0.316 ± 0.104.

(2) Analysis of z-integrated probability distribution of size intervals between adjacent absorbers taking into account the effect of blending also confirms the excess in the lower velocity scales. The K-S test shows that, probability that the maximum deviation between the observed distribution to occur by chance is 0.0001.

(3) Dependence of pair velocity correlation on equivalent width is investigated. While $\xi = 0.224 \pm 0.088$ for $w_{min} = 0.16$Å the values obtained for $w_{min} = 0.60$Å are $\xi = 0.458 \pm 0.259$. Thus the change in ξ is within 2σ and seems to be independent of equivalent width cutoff.

(4) The dependence of pair velocity correlation on redshift is investigated. While the correlation excess for $z \leq 2.9$ extend up to 800 km s^{-1} ($\xi = 0.263 \pm 0.119$) the $z > 2.8$ lines show weaker correlation strength in the same velocity interval ($\xi = 0.155 \pm 0.106$) in the case of $W_{min} = 0.3$Å. When only lines with equivalent width greater than 0.6Å are considered the corresponding values are 0.700±0.342 and 0.080±0.200. Thus the correlation seems to increase with decreasing redshift for high equivalent width lines. Confirming this dependence with very high significance will clearly favour the gravitationally induced formation models for Ly α clouds.

(5) The cross-correlation analysis between the metal line redshifts and the Ly α redshifts is performed. The observed distribution for $W_{min} = 0.3$Å beyond 200 km s^{-1} seems to be consistent with the predicted random distribution.

(6) The possible dependence of the cross-correlation on the equivalent widths of the Ly α lines are analysed. while $\xi_{ML} = -0.016 \pm 0.178$ in the case of $w_{min} = 0.16$Å the value for $w_{min} = 0.60$Å is $\xi_{ML} = 0.298 \pm 0.284$ in the velocity interval 200-600 km s^{-1} when we consider the metal line systems graded as A and B. When we consider only the A graded systems then the corresponding values are $\xi_{ML} = -0.108 \pm 0.236$ and $\xi_{ML} = 0.565 \pm 0.417$. Thus there seems to be a little increase in cross-correlation function with rest equivalent width. However the changes are within 2σ uncertainity.

(7) Evolution of cross-correlation function with redshift is investigated. The values obtained for ξ_{ML} for $z \leq 2.8$ and $z > 2.8$ for $W_{min} = 0.3$Å in the velocity bin 200-600 km s^{-1} are -0.504 ± 0.2491 and 0.143 ± 0.228 respectively. The corresponding values for $W_{min} = 0.6$Å are -0.072 ± 0.431 and 0.587 ± 0.380. Thus there seems to be a slight decrease in the cross-correlation with decreasing redshift. However the changes are within 2σ uncertainity.

Thus in order to get a statistically significant results which can be used to understand the dynamical evolution of Ly α lines one has to compile a much larger data set than one used in this analysis. However results of our analysis with the other observed evolutions such as the number density evolution and the evolution in velocity dispersion (Carswell (1994)) and the recent measurement of sizes (Dinshaw et al. (1994)) can be used to construct and constrain the models for the Ly α clouds.

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Figure captions

Figure 1. Histogram showing the observed number of pairs of Ly α lines as a function of relative velocity, for $W_{min} = 0.3$Å. The dotted lines show the expected number and the 2σ errors in each velocity bin.

Figure 2. The histogram showing distribution of line intervals scaled to the local mean, for $W_{min} = 0.3$Å. The curves show the expected distribution for the best fitted blended poisson models.

Figure 3. The cumulative distribution of intervals, S(x). A pure unblended Poisson distribution would be a line of slope 1 on this graph. The dashed curve represent the blended Poisson distribution with the best fitted blending parameters(see text).

Figure 4 (a-d) Histogram showing the observed number of pairs of Ly α lines as a function of relative velocity. The dotted lines shows the expected number with 2σ errors. The results are presented for different values of W_{min} and redshift intervals.

Figure 5 (a-c) The histogram showing the observed number of Ly α lines, with $W_{min} = 0.3$Å at different velocity interval from the metal line systems. The dotted lines show the expected number and the 2σ errors in each velocity bin. Results obtained considering the metal line systems of different grades are presented.

Figure 6 (a-d) Histogram showing the observed number of pairs of Ly α lines at different relative velocity interval from the metal lines systems (only grade A and B are considered). The dotted lines shows the expected number with 2σ errors. The results are presented for different values of W_{min} and redshift intervals.

Table 1: Data sample

QSO	z_{max}	z_{min}	E Å	z_{abs}	grade	ref.
0000-263	4.114	3.303	0.15	3.389	A	9
				3.536	C	
0001+087	3.241	3.035	0.14	2.999	A	1
				3.007	A	
0002+051	1.900	1.764	0.16	1.744	B	2
0002-422	2.767	2.175	0.30	2.302	B	3,4
				2.464	A	
0014+813	3.387	2.743	0.15	2.798	A	1
				2.800	A	
				3.227	A	
0029+073	3.262	2.869	0.14	3.049	A	1
				3.120	C	
				3.194	C	
				3.198	C	
0042-264	3.300	3.192	0.15	3.147	B	9
				3.237	B	
				3.292	B	
0055-269	3.663	3.347	0.15	3.602	B	9
				3.676	C	
0058+019	1.961	1.789	0.13	....	..	5
0114+089	3.163	2.685	0.08	3.106	A	1

QSO	z_{max}	z_{min}	E Å	z_{abs}	grade	ref.
0142-100	2.728	2.142	0.13	2.325	B	5
				2.356	A	
0149+336	2.432	2.174	0.15	2.204	C	12
				2.224	C	
0201+365	2.611	2.298	0.15	2.326	B	11
				2.424	B	
				2.460	B	
				2.554	B	
0237-233	2.225	1.756	0.13	2.042	C	5
				2.203	A	
0256-000	3.377	2.685	0.18	3.018	C	1
				3.082	B	
				3.092	C	
				3.198	B	
0301-005	3.212	2.759	0.12	2.941	A	1
				2.957	C	
0302-003	3.290	2.685	0.17	2.689	C	1,8
				2.964	C	
				3.219	C	
0334+204	3.312	3.043	0.06	3.043	B	1
				3.092	B	1
0347-383	3.230	3.146	0.15	....	..	9
0421+019	2.055	1.772	0.16	1.999	A	2

QSO	z_{max}	z_{min}	E Å	z_{abs}	grade	ref.
0424-131	2.168	1.906	0.12	1.789	C	5
				2.133	B	
				2.173	B	
0428-136	3.244	3.162	0.20	....	..	9
0453-423	2.656	2.209	0.32	2.277	A	3,4
				2.397	B	
0636+680	3.178	3.043	0.13	....	..	1
0731+653	3.038	2.677	0.30	2.887	B	1
0831+128	2.737	2.156	0.29	....	..	1
0837-109	3.329	2.989	0.10	3.1430	B	5
0848+163	1.926	1.764	0.07	1.916	A	5
				1.918	A	
0905+151	3.175	3.043	0.07	....	..	1
0913+072	2.786	2.193	0.19	2.394	C	1
				2.566	C	
				2.619	A	
				2.761	B	
0938+119	3.194	3.043	0.12	....	..	1
0953+549	2.574	2.018	0.15	3.106	A	10
0956-122	3.306	2.964	0.15	3.105	A	8
				3.114	A	
				3.154	A	
				3.223	A	

QSO	z_{max}	z_{min}	E Å	z_{abs}	grade	ref.
1017+280	1.929	1.632	0.10	1.767	B	5
				1.798	A	
				1.834	B	
1017-106	3.158	2.855	0.15	2.940	A	8
				2.972	C	
				2.997	C	
				3.009	B	
				3.054	C	
				3.077	C	
				3.111	C	
1033+137 ·	3.094	3.043	0.05	....	..	1
1115+080	1.728	1.682	0.16	1.699	B	2
				1.732	B	
				1.735	B	
1151+068	2.764	2.173	0.30	....	..	7
1159+124	3.504	2.795	0.20	3.226	C	5
				3.261	C	
				3.526	A	
1206+119	3.110	2.784	0.09	2.987	C	1
				3.022	A	
1208+101	3.825	3.400	0.11	3.537	C	1
				3.544	C	
1215+330	2.617	2.043	0.16	2.166	B	1

QSO	z_{max}	z_{min}	E Å	z_{abs}	grade	ref.
1225+317	2.210	1.698	0.16	1.795	A	4
				1.796	A	
				1.797	B	
				1.886	B	
				1.887	B	
				1.897	B	
1244+349	2.502	2.180	0.15	....	..	12
1247+267	2.042	1.680	0.08	1.959	B	5
1334+005	2.783	2.242	0.07	....	..	1
1400+114	3.179	3.043	0.13	....	..	1
1402+044	3.211	3.032	0.30	....	..	1
1409+093	2.838	2.236	0.30	2.456	A	11
				2.667	B	
				2.727	B	
1410+096	3.316	3.032	0.09	....	..	1
1442+101	3.535	2.872	0.09	3.047	C	1
				3.110	B	
				3.353	B	
1451+123	3.257	3.032	0.20	3.171	A	1
1512+132	3.122	2.872	0.25	2.986	C	1
1548+092	2.749	2.455	0.29	2.491	B	1
				2.609	C	
1601+182	3.229	3.032	0.22	3.218	B	1

QSO	z_{max}	z_{min}	E Å	z_{abs}	grade	ref.
1602+178	2.991	2.749	0.40	2.823	C	1
					B	
1614+051	3.217	3.032	0.25	3.097	C	1
1623+269	2.527	1.973	0.15	1.973	B	5
				2.050	A	
				2.053	A	
				2.162	B	
				2.402	C	
				2.523	B	
1738+350	3.240	3.032	0.32	....	..	1
2000-330	3.783	3.113	0.14	3.173	A	9
				3.187	B	
				3.191	A	
				3.333	A	
				3.338	B	
				3.548	B	
				3.550	B	
				3.552	B	
				3.555	B	
				3.558	B	

QSO	z_{max}	z_{min}	E Å	z_{abs}	grade	ref.
2126-158	3.267	2.608	0.32	2.638	A	4
				2.679	B	
				2.728	B	
				2.769	A	
				2.819	B	
				2.907	A	
2204-408	3.171	3.129	0.15	3.158	B	6
				3.159	B	
2233+131	3.295	3.032	0.14	3.152	B	1
2233+136	3.216	2.869	0.09	2.889	A	1
				2.942	C	
				2.999	B	
				3.063	B	
2239-386	3.511	3.442	0.30	....	..	9
2311-036	3.048	2.750	0.37	2.769	C	1
2359-022	2.810	2.473	0.15	....	..	12

ref: (1) Bechtold (1994), (2) Young, Sargent & Boksenberg (1982), (3) Sargent et al.(1979), (4) Sargent et al. (1980), (5) Sargent, Boksenberg & Steidel (1988), (6) Willinger et al. (1989), (7) Turnshek et al. (1989), (8) Steidel (1990b), (9) Steidel (1990a), (10) Levshakov (1992), (11) Lu et al. (1993), (12) Wolfe et al. (1993).

Table 2: Dependence of clustering on equivalent width

W_{min}	ξ		
	v = 200-400 km s^{-1}	v = 200-600 km s^{-1}	v = 200-800 km s^{-1}
0.15	0.224±0.088	0.184±0.077	0.134±0.070
0.25	0.258±0.099	0.202±0.084	0.154±0.077
0.30	0.316±0.104	0.230±0.085	0.190±0.078
0.45	0.276±0.114	0.214±0.088	0.169±0.092
0.60	0.458±0.259	0.279±0.196	0.243±0.169

Table 3: Dependence of cross-correlation on Ly α equivalent width

W_{min}	grade	ξ_{ML}		
		v = 200-400 km s^{-1}	v = 200-600 km s^{-1}	v = 200-800 km s^{-1}
0.15	A	-0.259±0.351	-0.108±0.236	-0.105±0.189
	A,B	+0.003±0.259	-0.016±0.178	-0.080±0.143
	A,B,C	-0.108±0.197	-0.097±0.137	-0.065±0.112
0.30	A	-0.600±0.365	-0.203±0.248	-0.190±0.201
	A,B	-0.288±0.244	-0.152±0.168	-0.156±0.136
	A,B,C	-0.219±0.188	-0.092±0.131	-0.062±0.106
0.60	A	+0.128±0.577	+0.565±0.417	+0.374±0.353
	A,B	+0.019±0.413	+0.299±0.285	+0.099±0.229
	A,B,C	-0.195±0.317	+0.064±0.220	+0.018±0.178

Table 4: Dependence of cross-correlation on Ly α equivalent width

W_{min}	z range	ξ_{ML}		
		v = 200-400 km s^{-1}	v = 200-600 km s^{-1}	v = 200-800 km s^{-1}
0.15	$\leq$ 2.8	-0.085±0.428	-0.349±0.304	-0.243±0.251
	> 2.8	+0.054±0.325	+0.156±0.220	-0.033±0.174
0.30	$\leq$ 2.8	-0.369±0.355	-0.504±0.249	-0.300±0.203
	> 2.8	-0.216±0.336	+0.143±0.228	+0.105±0.195
0.60	$\leq$ 2.8	-0.243±0.614	-0.072±0.431	-0.017±0.351
	> 2.8	+0.243±0.557	+0.588±0.379	+0.278±0.302

Figure 1

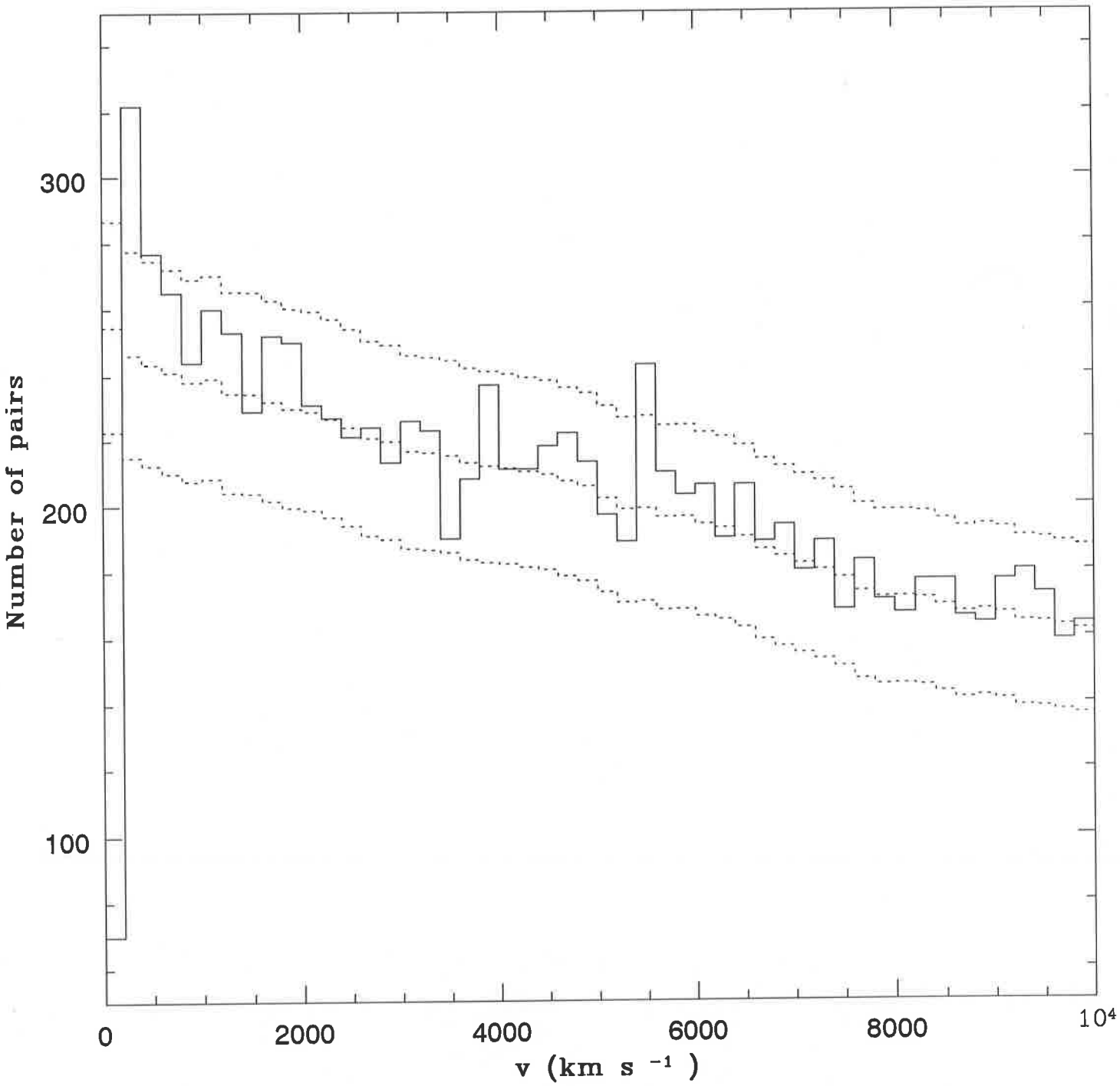

Figure 2

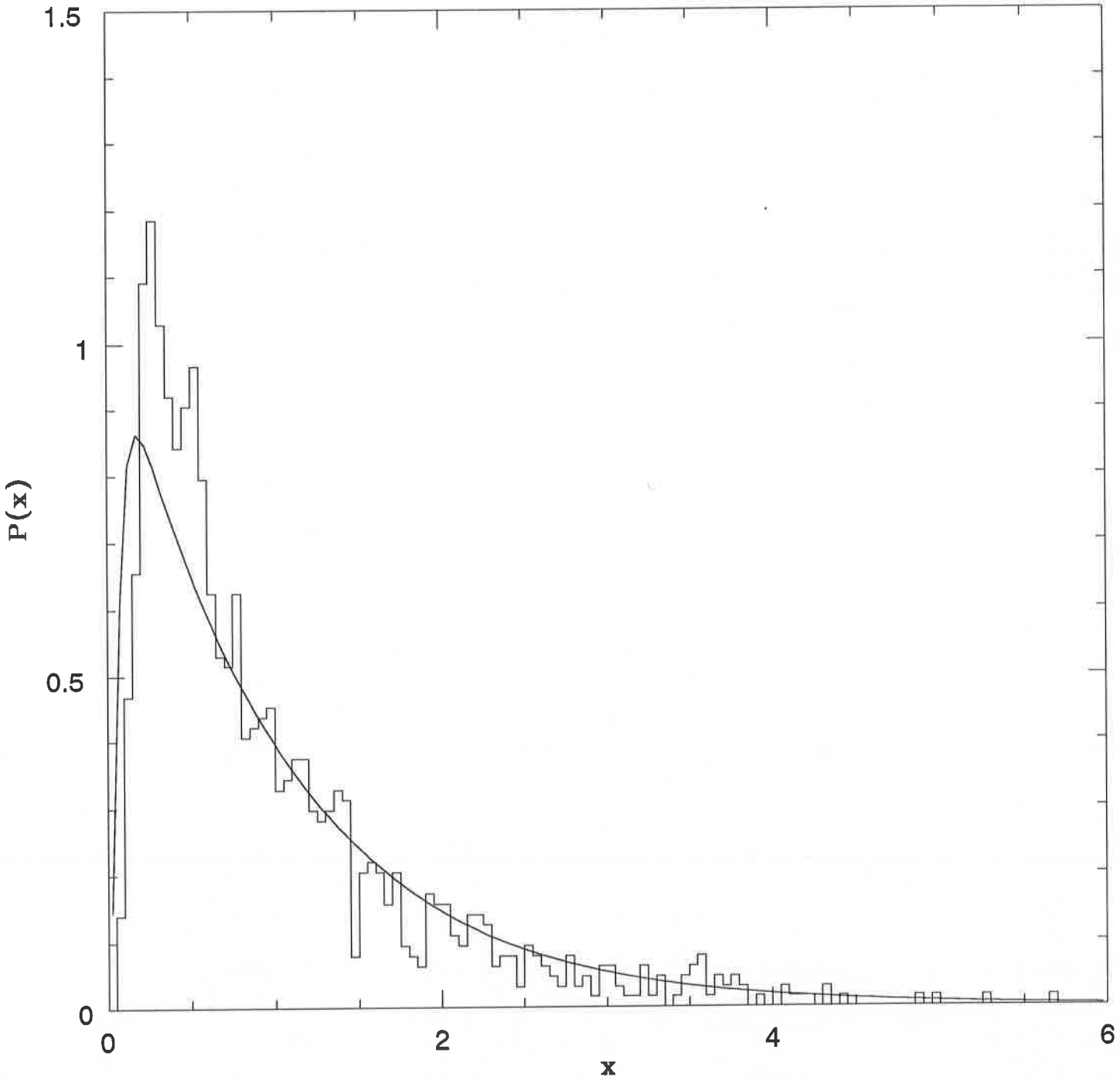

Figure 3

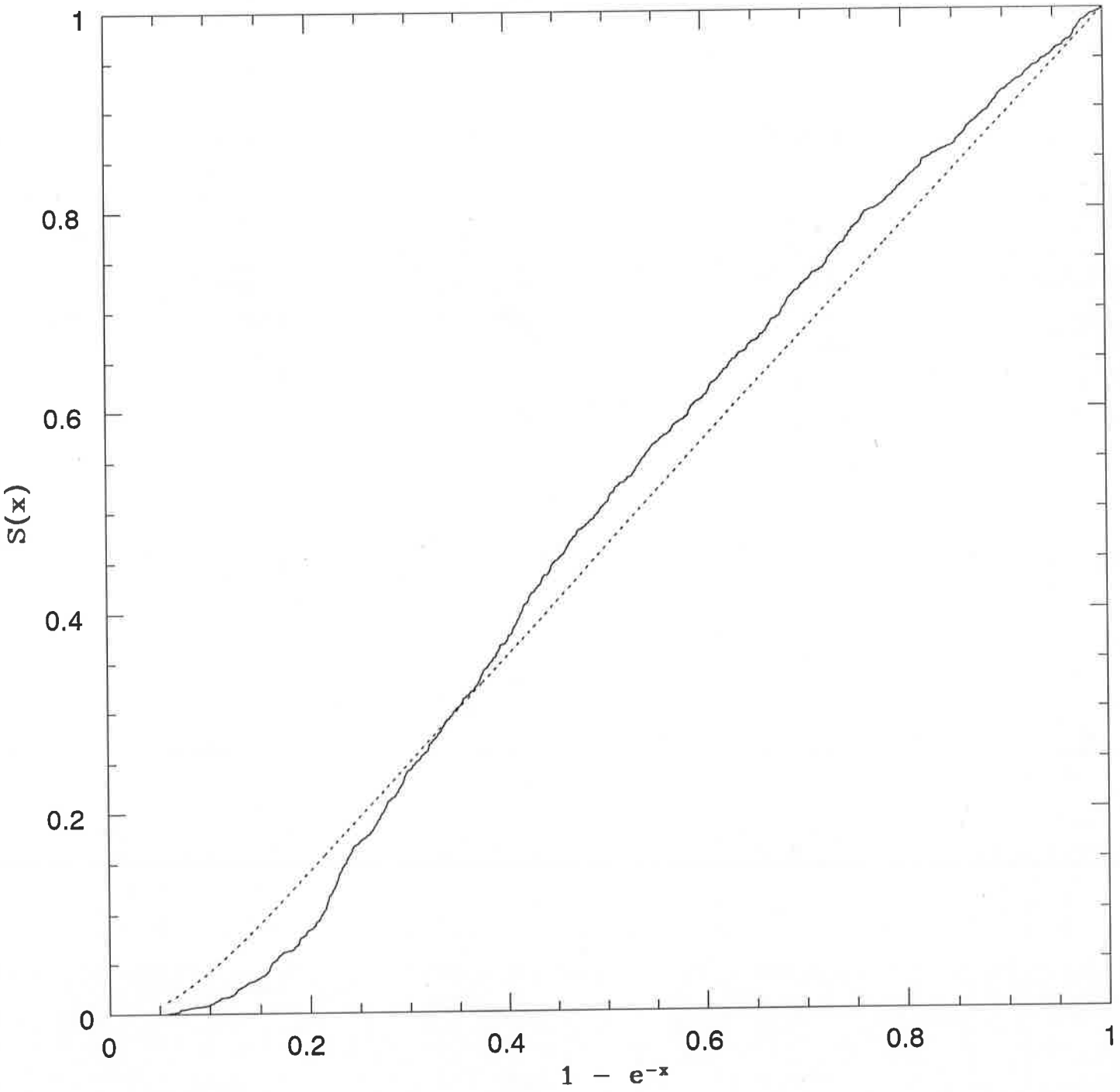

Figure 4a

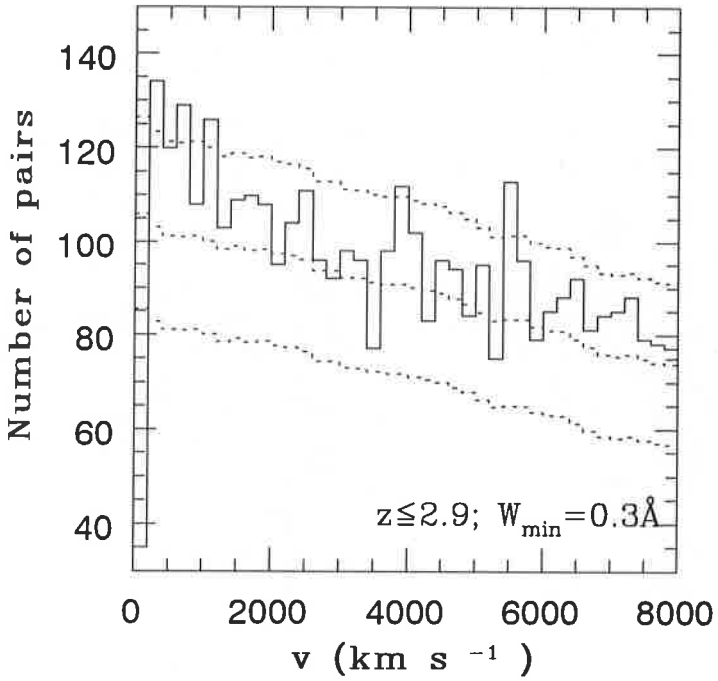

Figure 4c

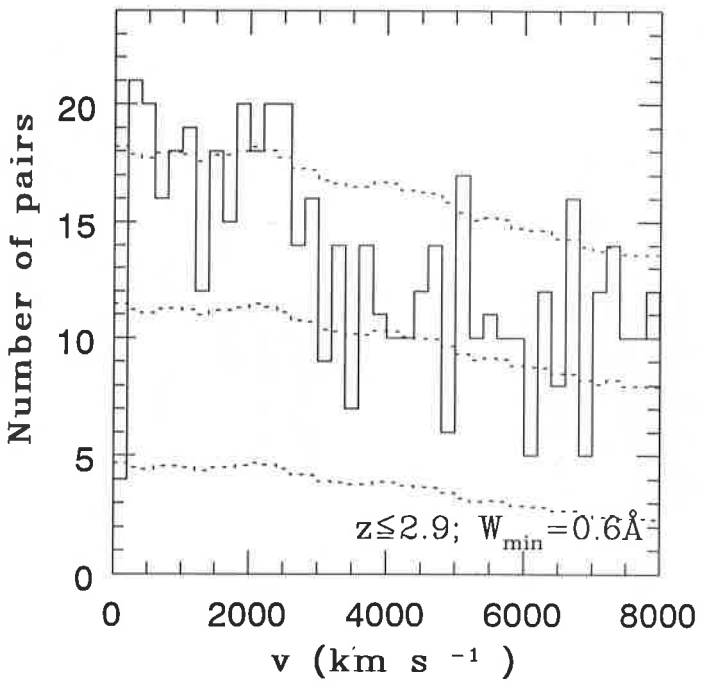

Figure 4b

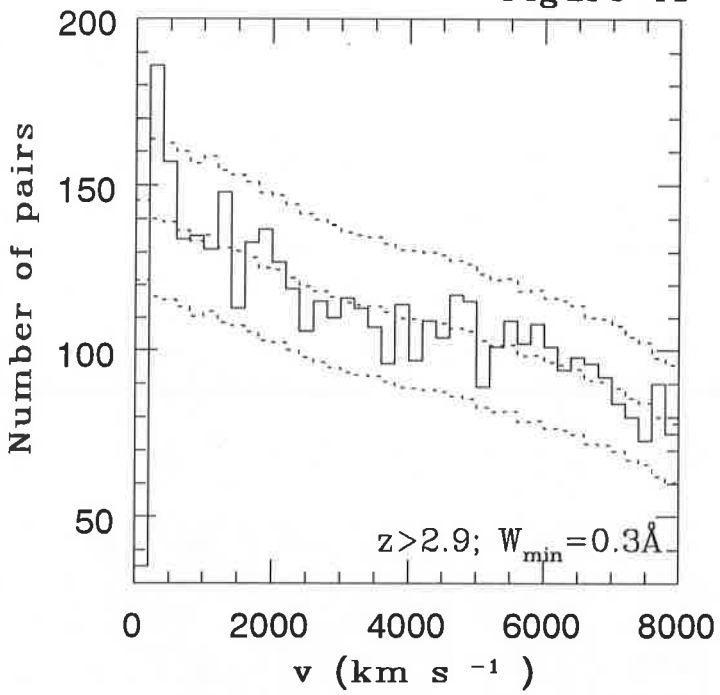

Figure 4d

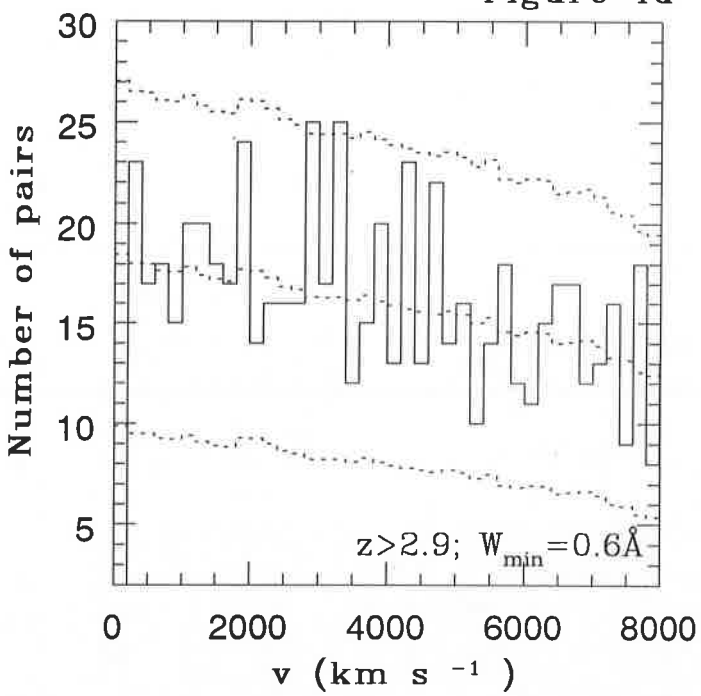

Figure 5a

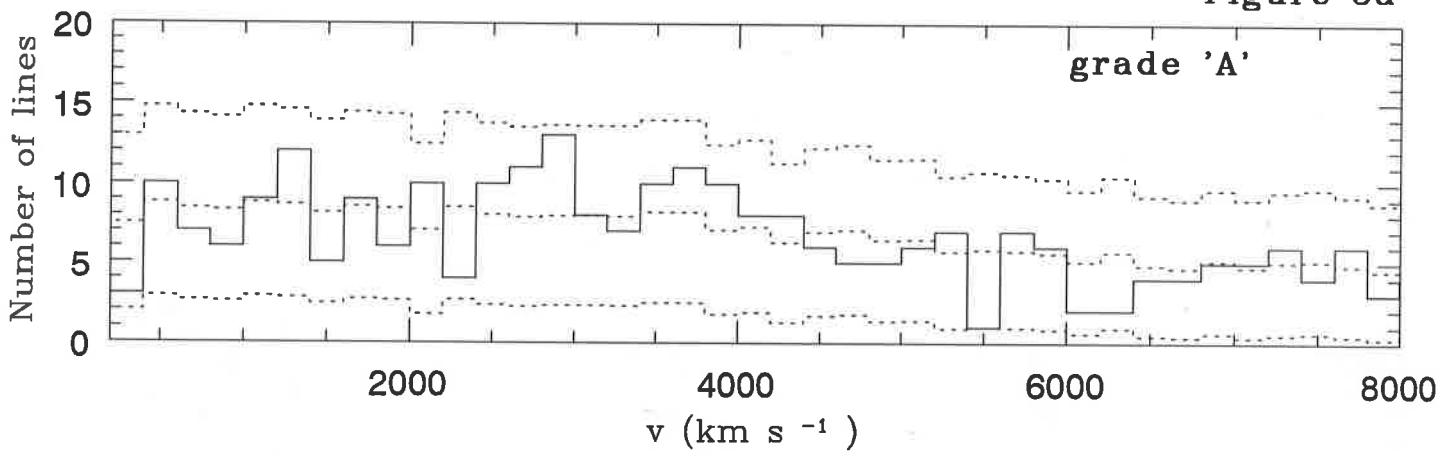

Figure 5b

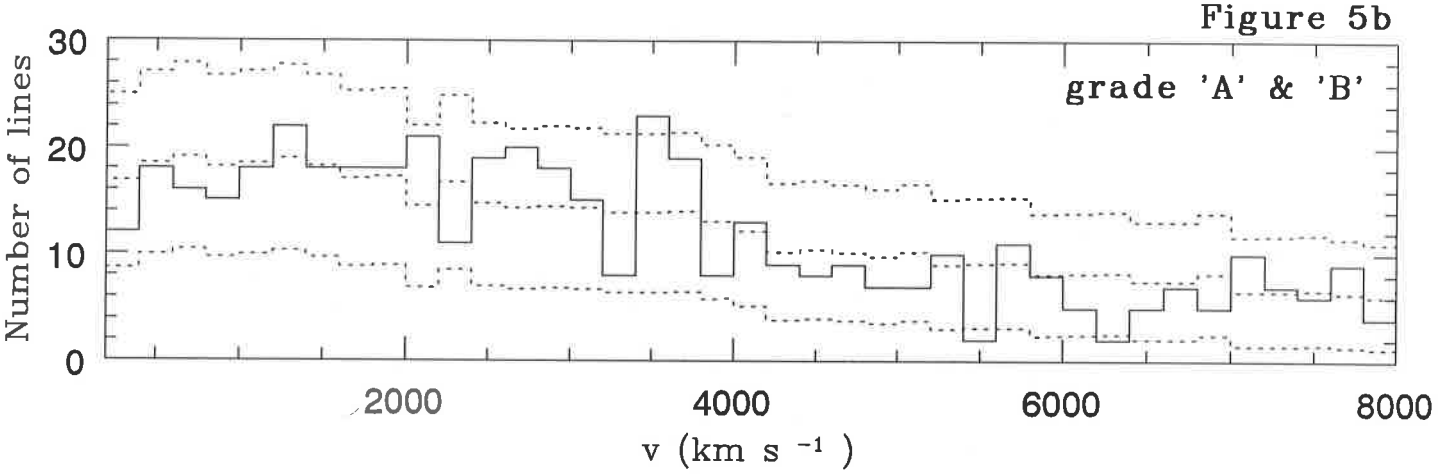

Figure 5c

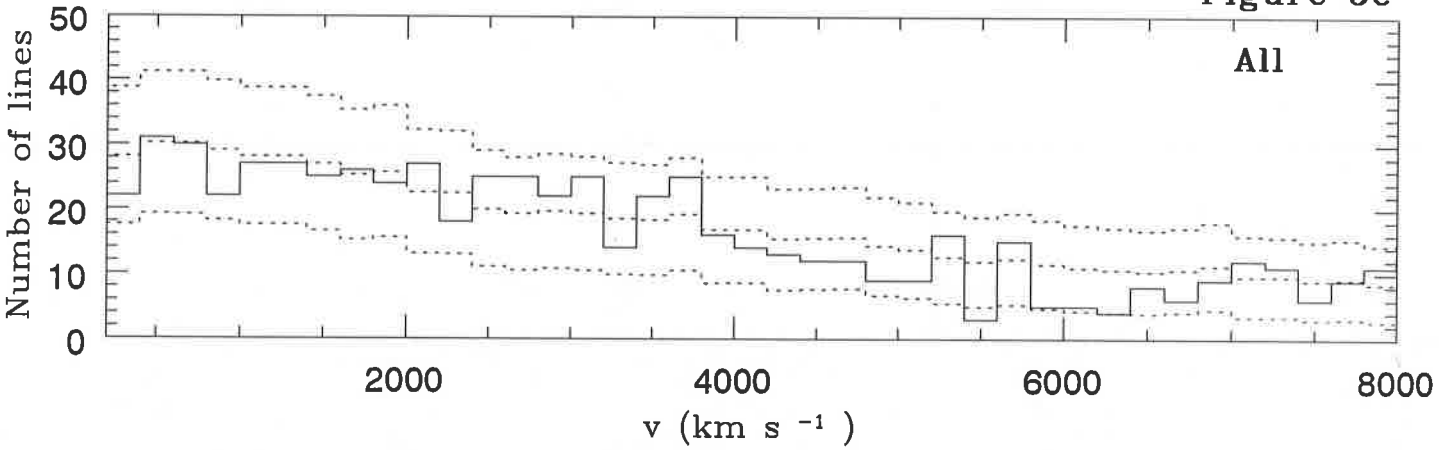

Figure 6a

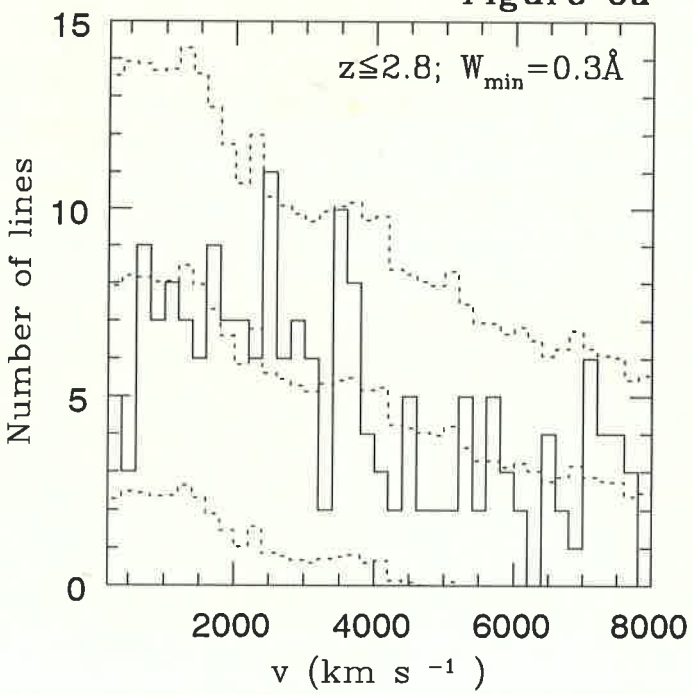

Figure 6c

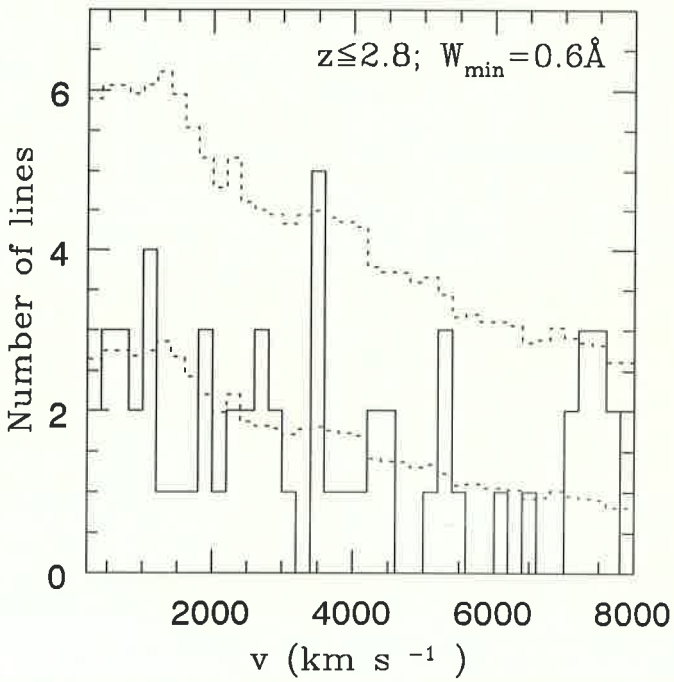

Figure 6b

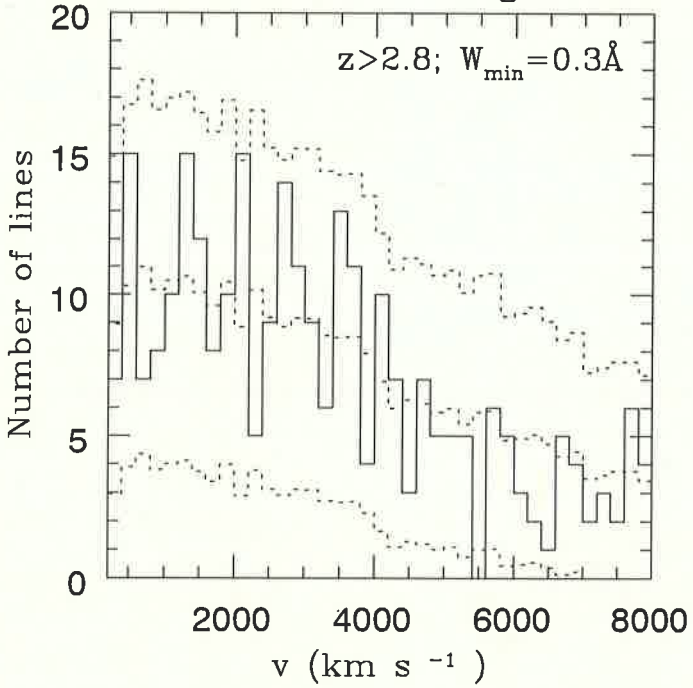

Figure 6d

