ABSORPTION LINE SYSTEMS AT $z > 3$ IN THE QSO 2000-330

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1. INTRODUCTION

This paper presents some preliminary results from analysis of our high-resolution (30-35 km/s FWHM) spectra of the Lyman α forest region in the $z = 3.78$ QSO 2000-330. These spectra were obtained at the Anglo-Australian Telescope over several observing seasons and have been analysed by fitting multiple-cloud Voigt profiles to Lyman series and heavy-element absorption lines. Two specific issues are addressed here:

(i) The distribution of column densities, N(H I), and velocity dispersions, b, for hydrogen clouds in the interval $z_{abs} = 3.43$-3.78;

(ii) Heavy-element abundances in a system at $z_{abs} = 3.1723$.

2. PROPERTIES OF THE LYMAN α CLOUDS

It is generally assumed that the Lyman line absorbing clouds seen in QSO spectra constitute an intergalactic population (Sargent *et al.* 1980) which evolves strongly with redshift (Murdoch *et al.* 1986). While statistical studies on samples complete to a given Ly α equivalent width can shed light on the global properties of the so-called Ly α clouds, we need to look in detail at the *intrinsic* cloud properties (N, b), as well as possible spatial correlations, to provide clues to their origin, confinement and ultimate fate.

The most detailed studies of Lyman α clouds to date at high resolution are for the $z = 2.14$ QSO 1101-264 (Carswell *et al.* 1984, hereafter CMSSTW; resolution 20 km/s FWHM) and the $z = 3.12$ QSO 0420-388 (Atwood, Baldwin and Carswell 1985, hereafter ABC; 33 km/s FWHM). In each study the distribution of column densities was fitted to a power law of the form $dn \propto N^{-\beta}\, dN$, with $\beta = 1.68 \pm 0.10$ for 1101-264 ($\log N = 12.8$-15.0) and $\beta = 1.89 \pm 0.14$ for 0420-388 ($\log N = 14.0$-16.7). In the former, Voigt profiles were fitted to Ly α alone in the ranges $z_{abs} = 1.89$-1.98 and 2.04-2.13 while in the latter fitting was restricted to the interval $z_{abs} = 2.72$-3.12 so that at least two Lyman lines were available.

Due to its higher redshift, 2000-330 gives us access to many Lyman lines ; indeed, for $z > 3.65$ the entire Lyman series is available above

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our short wavelength limit of 4240 Å and at z = 3.43 we still have coverage to Ly γ. The setting of continuum levels and the generation of superimposed plots of Lyman series lines followed the procedures given in Hunstead *et al.* (1986a). The plots were invaluable in revealing the presence of structure and blends in the higher-order lines.

Our spectra in the region below Ly β emission have uniformly good signal/noise ratio and this has generally imposed tight constraints on the values of z, b and N for the high-column (log N > 15) clouds. For clouds on the linear part of the curve of growth (log N < 13.6), the parameters are determined chiefly by the fit to Ly α; the signal/noise is therefore crucial in deciding, for example, whether to fit two or more narrow components or a single broad component. At intermediate column densities the reliability of b, N estimates depends on having the low-order Lyman lines free of serious blending. In a later paper we will discuss in detail our treatment of the many problems encountered in attempting to deconvolve the complex profiles in the Lyman forest.

The present line sample is preliminary; we have not attempted here to differentiate between lines with well-determined parameters and those where the parameters are less well defined. We show the column density distribution in Fig. 1(a). The best-fit exponent, β = 1.57±0.05, was determined by maximum likelihood (ML) fit to the 149 lines with log N > 13.25. The binned data in Fig. 1(a) seem to indicate possible structure in the distribution function, although a Kolmogorov test shows a good fit to the assumed power law. The influence of selection effects and incompleteness on this distribution are currently being investigated.

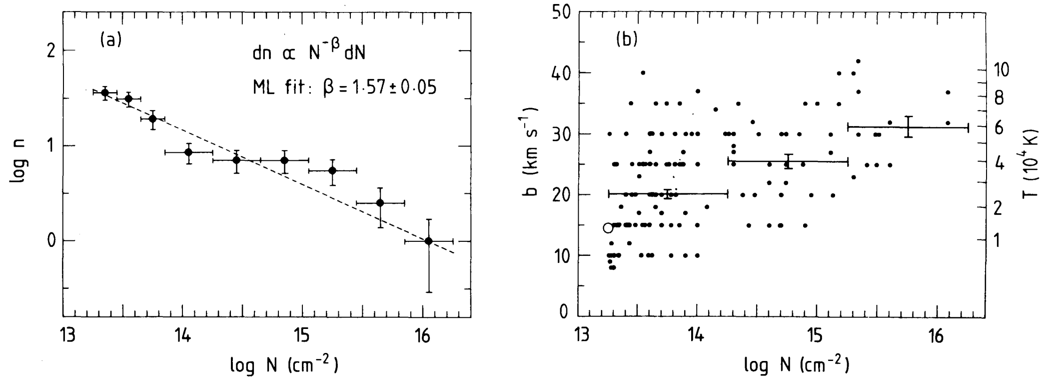

Figure 1. Lyman α clouds in 2000-330 with log N > 13.25 and <z> = 3.6: (a) H I column density distribution; dashed line is the ML fit to the 149 individual clouds; (b) b vs log N for individual clouds together with coarsely-grouped means and standard errors.

A plot of b versus log N is shown in Fig. 1(b). The scatter is large but the lower envelope defines a trend which is supported by that of the coarsely-grouped means. A possible correlation in the same sense was reported by CMSSTW, but ABC comment that this could be a selection effect caused by blending. Our data for 2000-330 suggest that blending is probably important at low N (refer Fig. 1b) but that the dearth of

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low-b, high-N clouds is real; if so, the detection of deuterium in the Lyman forest clouds may well be ruled out (Chaffee *et al.* 1983). The temperature scale shown in Fig. 1(b) assumes that the b values arise solely from thermal motions in a gas at temperature T. Chaffee *et al.* (whose measurement for a Ly α cloud towards PHL 957 is shown as an open circle in Fig. 1b), point out that temperatures as low as $1\text{-}2\times10^4$ K pose serious problems for current models for confinement of the Ly α clouds.

3. HEAVY-ELEMENT ABUNDANCES AT $z_{abs} = 3.1723$

An earlier search for heavy-element absorption systems (Hunstead *et al.* 1986b) turned up four plausible systems, all of which are confirmed by the higher-resolution data. A new system at $z_{abs} = 3.1723$, previously listed as Lyman-only, has been detected on the basis of several neutral and low-ionisation species which were too weak (or too heavily blended) to be recognised in the earlier search. This means that metals have now been found spanning the entire width (∿ 1400 km/s) of the deep trough near 5080 Å (Hunstead *et al.* 1986b, Fig. 5).

Whereas the previously reported systems at $z_{abs} = 3.1881$ and 3.1914 show complex velocity structure, the system at $z_{abs} = 3.1723$ appears single, making the association of heavy-element lines with H I more straightforward. Another important factor is a good determination of N(H I): a radiation-damped Ly α profile at the redshift determined by Ly β gives an excellent fit to the blue wing of the 5080 Å trough. Changes of ±20% in N(H I) produce markedly poorer fits to the data. A final point concerns the ionisation state of the gas: the weakness or absence of high-ionisation species (e.g. Si III weaker than Si II; Si IV not detected) implies that the gas is predominantly neutral, which may indicate an origin in the disk of an intervening galaxy.

The column densities and relative abundances in this system are given in Table I. These measurements imply a more-or-less uniform underabundance in C, N, O and Si of ∿ 2.2 dex relative to solar values, suggesting only modest metal enrichment. If systems with comparable underabundances are found to be common at z ∿ 3, this would provide important constraints for current models of galactic chemical evolution.

TABLE I. Element abundances at $z_{abs} = 3.1723$

Ion	$Ab_{\odot}$	log N(X)	log depletion
H^0	12.00	19.78	...
C^+	8.57	≦13.95*	≦-2.40
N^0	8.06	≦13.65*	≦-2.18
O^0	8.83	14.40	-2.21
Al^+	6.40	<12.1**	<-2.1
Si^+	7.55	13.15	-2.18
Si^{++}	7.55	13.08	...

* Upper limit due to line blending
** Upper limit based on nearby spectral features

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DISCUSSION

SILK: How uncertain are your CNO abundance determinations for the Lyα absorption system at z = 3.1723. How sensitive are they to the assumed ionization state of the gas?

HUNSTEAD: Firstly, H, N and O have similar ionization potentials and little N^o and 0^o can exist in HII regions due to efficient recombination through charge-exchange reactions with H^+. In addition, there seems to be very little HII gas anyway, judging from the relative weakness of Si III with respect to Si II.

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