The Lyman Alpha Forest of the High-z Quasar 0000-263

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N93-26890

ABSTRACT. Medium-resolution (δv=45 km s^{-1}) optical spectra of the bright, high-redshift (z=4.1) quasar 0000-263 taken at the ESO 3.5-m NTT telescope were analyzed to determine the distribution of column densities, velocities and line widths of the Lyman-α forest absorption components. The values of N_H, b and z were determined by fitting Voigt profiles to the lines, and convolving with a Gaussian instrumental response function. Over 350 components with log $N_H > 13.2$ were identified. An analysis of the dependence of the number of components with z reveals that the number evolution of components obeys the power law $dN/dz \propto (1+z)^{\gamma}$, where $\gamma = 0.5 \pm 0.4$ for the sample of 182 lines with log $N_H > 14.0$. The distribution of component strengths is found to obey $f(N_H) \propto N_H^{-\beta}$, where $\beta = -1.55$ for components with $\log(N_H) > 14.7$, and $\beta = -0.68$ for the components with $\log(N_H) > 13.5$. A distinct break in the $f(N_H)$ histogram is also observed, at $\log(N_H) \sim 14.7$. The results are briefly considered in the context of theoretical models of quasar Lyman alpha clouds and their evolution.

OBSERVATIONS. Optical spectroscopic observations of the quasar 0000-263 were obtained during two nights at the ESO 3.5-m NTT telescope at Cerro La Silla, Chile. Coadded CCD images of the echelle spectra were flat fielded, cosmic rays were removed, and spectra were extracted and wavelength calibrated. The average FWHM resolution of the spectrograph was 45 km s^{-1}, and the spectrum was sampled at 0.3 Å Intervals. The S/N for the coadded spectrum is estimated to be 10, based on analysis of the line-free region redward of the QSO emission line at 6200 Å. Line-free points of the spectrum blueward of 6200 Å were selected and a 4th degree spline was fitted to remove the continuum. The spectrum, and the continuum fit used are shown in Figure 1. The Lyman-α forest was then analyzed by fitting Voigt profiles convolved with the instrumental response of the spectrograph to the absorption components. The fit chosen was based on the minimization of the residual between observed data and modelled profile, after iterating the parameters N_H,b, and v for each component from an initial component model which was determined interactively. 356 components were found, of which 182 had log(N) > 14.0. The sample should be complete for components with log(N) > 14.0, which is a conservative completeness limit corresponding to an equivalent width threshold of $W_{\lambda} \sim 700$ mÅ. The components were analyzed to determine if there were statistically significant correlations in the column densities N and Doppler parameter b, and to determine evolutionary trends in dN/dz and in the distribution function of component strengths, $f(N_H)$.

RESULTS. The correlation between N and b values yields a correlation coefficient of R=0.47. The correlation is statistically significant but may be affected by systematic effects intrinsic to line profile modelling of spectra which have many blended components, such as those described by Rauch, et al (1992). After excluding components with $W_{\lambda} < 0.65$ Å, and b > 90 km s^{-1}, the correlation coefficient was found to decrease to R=0.25. This suggests that the excluded components were responsible for much of the appearance of correlation, although a correlation between b and N for weak components has been predicted from theoretical models of differential ionization of Lyman alpha clouds (Donahue and Shull, 1992).

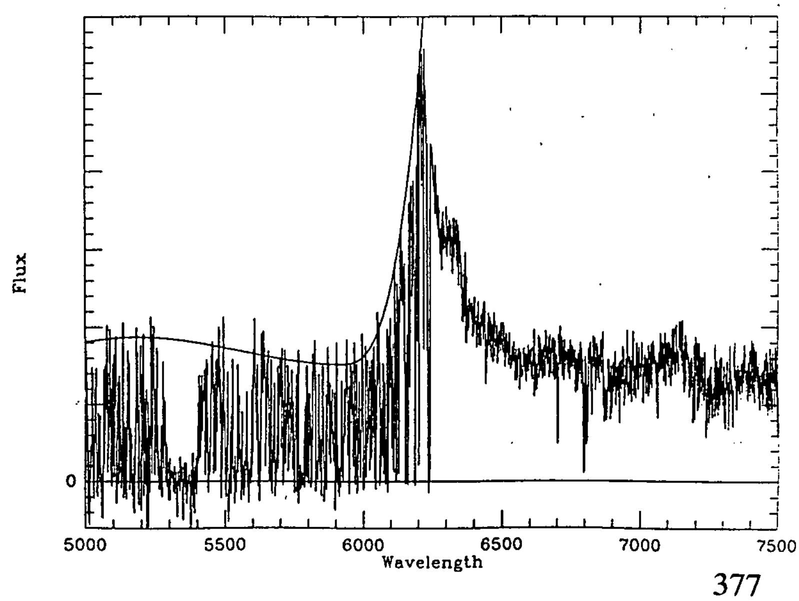

Figure 1: The coadded spectrum of QSO 0000-263, with the continuum fit superimposed. Lyman α components were fit from the wavelengths 5400Å to 6200Å, using modelled Voigt profiles which were convolved with a Gaussian instrumental resolution function, which had a FWHM of δv=45 km s^{-1}.

The distribution function of the component column densities $f(N_H)$ was examined, and the values of $f(N_H)$ for $\log(N_H) > 13.75$ are presented in Figure 2. The function $f(N_H)$ is usually described in terms of a power law $f(N_H) \propto N_H^{-\beta}$, and for the current work we find a value of $\beta = 1.55$ for the strongest components with $\log(N_H) > 14.7$, and a lesser slope of $\beta = 0.7$ for the entire sample. The value of β reported here for the stronger components is consistent with other Lyman α systems, where β is typically 1.5-1.7, (Charlton, et al 1992). While the break in the power law has been predicted by theoretical models to result from changing ionization state of the Lyman α clouds, it may also be due to the weaker lines being incompletely detected due to S/N limitations.

To study the evolution of the number of Hydrogen components N_{comps} with redshift z, we considered redshift intervals of $\delta z = 0.05$ and examined the number of components in each interval. A plot of N vs. (1+z) is shown in Figure 3, for the components with $\log(N_H) > 14.0$. A power law fit was applied to the data, and it was found that $dN/dz \propto (1+z)^{\gamma}$, where $\gamma = 0.5 \pm 0.4$. The fit is shown on Figure 3 with the dashed line. The value of γ derived here is much less than the average value of $\gamma = 2.36 \pm 0.4$ from Bajtlik, Duncan and Ostriker (1988), based on several quasar spectra at the lower redshift redshift range $3.7 > z > 1.7$. The value of $\gamma = 0.5 \pm 0.4$ is however consistent with Lyman limit systems, for which $\gamma = 1.1 \pm 0.4$ for systems with redshifts ranging from $4 > z > 0.4$ (Charlton, et al 1992). It is also worthwhile to note that the value of $\gamma = 0.5$ is consistent with the cosmological model of a constant number of components per unit comoving volume (Sargent, et al 1980; Charlton, et al 1992) where $dN/dz \propto (1+z)/(1+\Omega_0 z)^{1/2}$. For $\Omega_0=1$, and assuming pressure and ionization rates constant over the redshift interval considered, the model reduces to $dN/dz \propto (1+z)^{0.5}$, consistent with our observed result. Further observations at higher S/N and at higher spectral resolution are needed to determine if the apparent low value of γ for QSO 0000-263 is indeed real, and whether it does indicate a change in the number evolution of Lyman alpha clouds at high redshift.

References:

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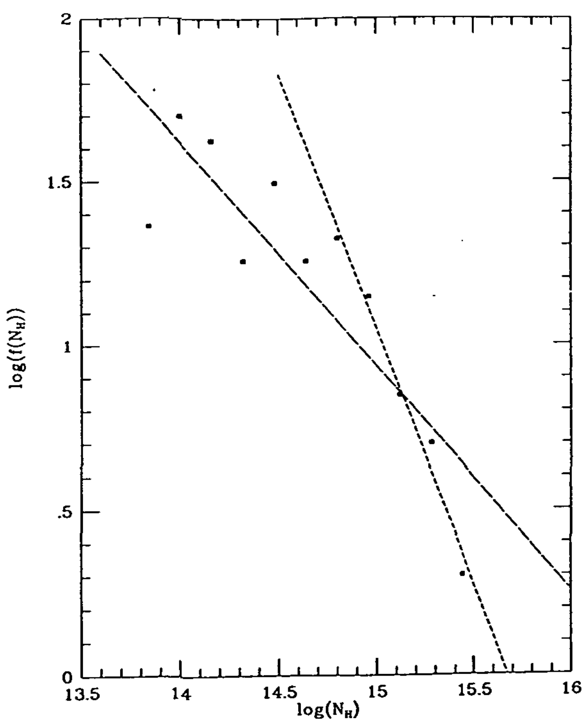

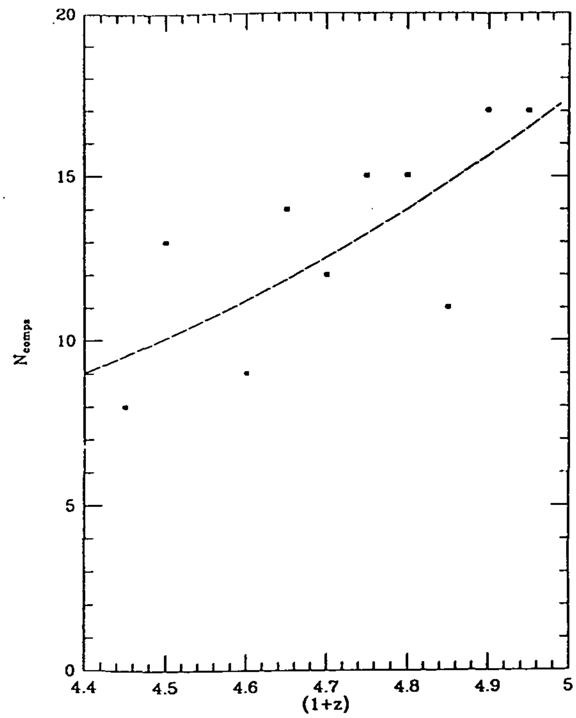

Figure 2: (left) Plot of the histogram function log(f(NH)) with power law fits $f(N_H) \propto N_H^{-\beta}$, with b=1.55 and 0.66.
Figure 3: (right) Plot of the number of components N_{comps} against (1+z), with the best fit $dN_{comps}/dz \propto (1+z)^{0.5}$.