The Cosmological Evolution of Quasar Damped Lyman-Alpha Systems

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Abstract.

We present results from an efficient, non-traditional survey to discover damped Lyα (DLA) absorption-line systems with neutral hydrogen column densities \( N_{HI} \geq 2 \times 10^{20} \) atoms cm\(^{-2}\) and redshifts \( z < 1.65 \). Contrary to previous studies at higher redshift that showed a decrease in the cosmological mass density of neutral gas in DLA absorbers, \( \Omega_{DLA} \), with time, our results indicate that \( \Omega_{DLA} \) is consistent with remaining constant from redshifts \( z \approx 4 \) to \( z \approx 0.5 \). There is no evidence that \( \Omega_{DLA} \) is approaching the value at \( z = 0 \). Other interesting results from the survey are also presented.

1. Introduction

Quasars, being among the most luminous and distant objects known, are powerful probes of the Universe. Quasar absorption lines reveal the presence of intervening gaseous clouds all the way up to redshift \( z \approx 5 \), back to a time when the Universe was less than 10% of its present age. By studying the properties of intervening absorption-line systems we can answer fundamental questions about the formation and evolution of gaseous structures in the Universe.

Intervening gas clouds (see Figure 1) are found to have neutral hydrogen column densities in the range \( 10^{12} \leq N_{HI} \leq 5 \times 10^{21} \) atoms cm\(^{-2}\) and are thought to be associated with anything from possibly primordial clouds in the intergalactic medium (e.g., the weakest “Lyα forest” systems) to low-luminosity galaxies, interacting systems, low-surface-brightness galaxies, and the evolved gaseous spheroidal and disk components of the most luminous galaxies.

Damped Lyα (DLA) systems, which classically have \( N_{HI} \geq 2 \times 10^{20} \) atoms cm\(^{-2}\), comprise the highest column density systems in the Lyα forest and contain over 90% of the observable HI mass in the Universe. However, these systems are very rare; they are 12 orders of magnitude less abundant than the weakest systems in the forest (e.g., Hu et al. 1995, AJ, 110, 1526). In the past, ground-based surveys for DLA absorption have been used to study the distribution of HI at high redshift (e.g., Wolfe et al. 1995, ApJ, 454, 698). Since the Lyα line falls in the UV for redshifts \( z < 1.65 \), valuable HST time is required to discover DLA systems at low redshift. With \( z < 1.65 \) spanning the most recent 77% of the age of the Universe (\( \Lambda = 0 \) and \( q_0 = 0.5 \)), the determination of the statistics and properties of DLA systems at these redshifts is crucial for understanding the
The Ly$\alpha$ emission line from the QSO is centered at 2930Å. Most of the absorption lines blueward of this emission line are due to Ly$\alpha$ in intervening objects. The strongest line in this “forest” of lines is a “damped Ly$\alpha$” line at 2440Å.

evolution of galaxies. Here, we present results from an efficient, non-traditional survey to discover DLA absorption-line systems at redshifts $z < 1.65$.

2. The Survey

For a detailed description of the survey the reader is referred to Rao & Turnshek (2000, ApJS, in press, astro-ph/9909164). Here, we list some salient points.

1. All DLA systems exhibit low-ionization metal line transitions. Thus, MgII can be used as a tracer for DLA absorption.
2. Since the statistics of low-redshift ($0.1 < z < 2.2$) MgII systems are known (Steidel & Sargent 1992, ApJS, 80, 1), the fraction of DLA systems in a MgII selected sample can be used to derive the DLA incidence, $n_{DLA}(z)$.
3. The measured column densities of the DLA lines give the DLA cosmological mass density, $\Omega_{DLA}(z)$, and their column density distribution, $f(z, N)$.
4. DLA lines can be searched for in over 250 known, $z < 1.65$, MgII systems. In total, from our IUE and HST surveys (Rao, Turnshek, & Briggs 1995, ApJ, 449, 488; Rao & Turnshek 2000), we now have Ly$\alpha$ information on 87 MgII systems with rest equivalent width $W_{\lambda 2796}^{\alpha} \geq 0.3$Å and redshifts $0.11 < z < 1.65$.

3. The Results

We uncovered 14 DLA systems in the survey, more than doubling the number of known low-redshift DLA systems. Again, the reader is referred to Rao & Turnshek (2000) for details on each system. The significant results from the survey are shown in Figures 2, 3, 4, and 5, and are discussed in the figure captions.
Evolution of Damped Ly$\alpha$ Systems

Figure 2. MgII $\lambda 2796$ rest equivalent width, $W_{0}^{\lambda 2796}$, vs. FeII $W_{0}^{\lambda 2600}$. The DLA systems in our sample are marked with open squares. The open circles represent previously known 21 cm absorbers that were excluded from our unbiased MgII sample. Arrows are upper limits. Approximately 50% of the systems with $W_{0}^{\lambda 2796} > 0.5$ Å and $W_{0}^{\lambda 2600} > 0.5$ Å (demarcated by the dashed lines) have DLA absorption. All systems in this regime have $N_{HI} > 10^{19}$ atoms cm$^{-2}$. The two rest equivalent widths are linearly correlated with slope 1.45.

Figure 3. Evolution of the incidence of DLA systems, where $n_{DLA}(z)$ is the number of DLA systems per unit redshift along a line of sight. The high-redshift points are from Wolfe et al. (1995) and the $z = 0$ point is derived from the observed HI distribution in local spiral galaxies (Rao, Turnshek, & Briggs 1995). The lines are power laws of the form $n_{DLA}(z) = n_{0}(1+z)^{\gamma}$. For no intrinsic evolution of the absorbers, $\gamma = 0.5$ for $q_{0} = 0.5$ and $\gamma = 1$ for $q_{0} = 0$. The solid line has $\gamma = 2.5$. The dashed line has $\gamma = 1.5$ and excludes the $z = 0$ data point, but is extrapolated to $z = 0$ (open triangle). Thus, there is strong evidence for evolution in the incidence of DLA systems if the $z = 0$ point is included.
Figure 4. The cosmological mass density of neutral gas in DLA systems, $\Omega_{DLA}$, as a function of redshift ($\Lambda = 0$, $H_0 = 65$ km s$^{-1}$ Mpc$^{-1}$, and $q_0 = 0.5$). Contrary to studies at high redshift (Wolfe et al. 1995; Storrie-Lombardi & Wolfe 2000, astro-ph/0006044) which conclude that $\Omega_{DLA}$ decreases with time for $3.5 > z > 1.5$, our results indicate that $\Omega_{DLA}$ is consistent with remaining constant from redshifts $z \approx 4$ to $z \approx 0.5$. There is no evidence that $\Omega_{DLA}$ is approaching $\Omega_{gas}(z = 0)$. The constant value for $\Omega_{DLA}$ might indicate that DLA absorption lines track a slowly evolving population of objects. This is also consistent with the lack of evolution seen in their metallicities (Pettini et al. 1999, ApJ, 510, 576).

Figure 5. The normalized cumulative column density distribution for the low-redshift DLA sample, the Wolfe et al. (1995) high-redshift DLA sample, and local galaxies (Rao & Briggs 1993, ApJ, 419, 515). The low-redshift DLA sample clearly contains a much larger fraction of high column density systems than either of the other two samples. The $N_{HI}^{-3}$ fall-off in the column density distribution of spiral disks results in the characteristic shape of the solid curve. The low-redshift sample has a distribution that is different at the 99.99% confidence level indicating that low-redshift DLA absorption lines do not arise solely in galactic disks (see also Turnshek et al., these proceedings).