STRONG ABSORPTION-LINE SYSTEMS AT LOW REDSHIFT: MgII AND DAMPED LY$\alpha$

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Abstract
We detail a powerful indirect method for the study of damped Ly$\alpha$ systems (DLAs) at low redshift. We increase the probability of finding a low-redshift DLA to nearly 50% by targeting QSOs that are known to have strong low-redshift MgII and FeII absorption lines in their spectra. We are using Sloan Digital Sky Survey QSO spectra complemented by a survey we are conducting at the MMT to study the metal-line systems. The Hubble Space Telescope is being used to confirm low-redshift DLAs. In addition, we are imaging low-redshift DLA galaxies with several ground-based telescopes to directly study their environments.

1. Introduction

Damped Ly$\alpha$ systems (DLAs), QSO absorption line systems with column densities $N(HI) \geq 2 \times 10^{20}$ atoms cm$^{-2}$, contain less than 10% of the baryons in the universe. However, since over 95% of the neutral gas content of the universe resides in DLAs, they are extremely important for the study of galaxy formation and evolution. In particular, low-redshift DLAs provide a unique opportunity to study the gaseous and luminous components of galaxies simultaneously.

In order to fully understand the evolution of the neutral gas component, one needs to know how much of it exists and where it exists at every epoch. In the absence of selection effects which recent observations suggest are not important (Ellison et al. 2001), the answer to the former can be found in the statistics of DLAs. The whereabouts of this neutral gas relative to starlight can be studied if the DLA galaxies can be identified. Eventually we hope to understand the evolution of DLAs consistently with other studies of galaxy evolution such as the star formation history of the universe, the evolution of galaxy number counts, and simulations of structure formation and evolution.
There are, however, difficulties inherent to the study of DLAs. Specifically, imaging DLAs is difficult at high redshift (z > 1.65) where the Lyα transition is observed in the optical and the statistics are better understood, while the statistics are poor at low redshift where imaging studies are more practical. Only ≈ 30 low-redshift DLA absorbers are known from UV spectroscopic surveys in comparison to the over 100 high-redshift ones found in optical spectroscopic surveys. Thus, the low-redshift DLA number density, and hence Ω_{DLA}, the cosmological neutral gas mass density in DLAs, are poorly known (see Figure 1). Given that the look-back time associated with redshift 1.65 is ≈ 70% of the age of the universe, this is a serious limitation.

DLA galaxies are sometimes elusive even at low redshift (Steidel et al. 1997, Bouche et al. 2001). Since only a handful of low-redshift DLA galaxies have been identified (Le Brun et al. 1997 and Nestor et al. 2001 describe most of them), a detailed study of DLA environments is not yet possible. In this contribution we describe our efforts to increase the sample of low-redshift DLAs, addressing both the how much and the where of neutral gas in the universe, as well as some recent results.

2. DLAs and Low-Ionization Metal Line Systems

Rao & Turnshek (2000, hereafter RT2000) uncovered an empirical relation between the strengths of the MgIIλ2796 and FeIIλ2600 absorption lines and the occurrence of DLAs (Figure 2). They found that

![Figure 1](image-url)
nearly 50% of systems with $W_0^{\lambda 2796} > 0.5$ Å and $W_0^{\lambda 2600} > 0.5$ Å were DLAs, and the rest were subDLAs with $10^{19} \leq N(\text{HI}) < 2 \times 10^{20}$ atoms cm$^{-2}$. This discovery has two implications for low-z DLA work. First, targeted surveys for DLAs in QSO spectra with known strong low-ionization metal line absorption systems will have a much greater success rate. Second, these metal lines appear in the optical down to much lower redshift (for a spectrograph with coverage down to 3200Å, for example, FeII$\lambda 2600$ can be found down to $z = 0.23$ and MgII$\lambda 2796$ to $z = 0.14$.) Because of the relative ease of acquiring optical QSO spectra, $dn/dz$ for these systems is much better known, thus allowing us to “bootstrap” from $dn/dz$ for the metal-line systems to that of DLAs. We are undertaking targeted surveys with HST to discover $z < 1.65$ DLAs in known strong low-ionization metal line absorption systems. The goals are to provide new systems at low enough redshift for imaging, to better determine the statistical properties of DLAs including $dn/dz$, $\Omega_{\text{DLA}}$, and their column-density distribution, $f(N)$, at $z < 1.65$ as well as to better understand the relationship between FeII absorption, MgII absorption, and the properties of the Ly$\alpha$ line associated with them.

An observationally ideal sample for discovering DLAs would include bright QSOs with strong intervening metal-line absorption systems at redshifts close to that of the QSO. A low value of $z_{\text{em}} - z_{\text{abs}}$ reduces a chance occurrence of an intervening Lyman limit system that might

![Figure 2](image-url)  

Figure 2 $W_0^{\lambda 2796}$ vs. $W_0^{\lambda 2600}$ for low-redshift systems with Ly$\alpha$ information. DLAs are represented by squares around the data point. Circles are DLAs discovered by 21-cm studies. Nearly 50% of systems in the upper right quadrant are DLAs.
result in the absence of continuum flux at the expected wavelength of the DLA line. Thus, the first step is to find large samples of low-redshift metal-line systems from which homogeneous subsets with specific selection criteria can be constructed. The Sloan Digital Sky Survey (SDSS) is an excellent resource for this as it provides over 3800 optical QSO spectra in the Early Data Release (EDR, June 2001) alone.

3. Metal-Line Statistics from the SDSS

We have constructed an unbiased sample of 640 absorption line systems with $W_{\lambda 2796} > 1.0$ Å from the SDSS EDR. The task of analyzing several thousand spectra requires automation and good spectral analysis algorithms. We used our own continuum-fitting and line-finding routines and interactively confirmed or rejected each candidate absorption system. We also checked for blending and the quality of the continuum fit. Initial tests suggest that the 1.0 Å sample is complete, and analysis of the sample with $W_{\lambda 2796} > 0.5$ Å is in progress. Statistical results of the 1.0 Å sample are discussed in Nestor et al. (these proceedings). We find that there is evidence for mild evolution with redshift for both $dn/dz$, especially at $z < 0.6$, and in the slope of the log $W_{\lambda 2796}$ distribution.

The metal-line $dn/dz$ results from the SDSS will greatly reduce the statistical errors in the calculation of the DLA $dn/dz$ and $\Omega_{DLA}$ for $z > 0.4$. Currently, $\approx 50\%$ of the error in $dn/dz$ for the DLAs comes from the error in $dn/dz$ for the MgII systems. We are also conducting a large survey for MgII and FeII absorption at the MMT which will eventually permit improved estimates of $\Omega_{DLA}$ down to $z = 0.14$.

4. DLA Galaxies

The $\approx 14$ low-redshift DLA galaxies that have been imaged thus far reveal a mix of morphologies ranging from compact dwarf galaxies to large spirals (Le Brun et al. 1997, Steidel et al. 1995, Turnshek et al. 2001, Nestor et al. 2001). There also appear to be a higher fraction of low surface brightness galaxies among the DLA galaxies in comparison to the general field. Here, we present imaging results on two of the DLA fields. For details see Rao et al. (2002).

Figure 3 shows UBRK images of the PKS 1629+120 field that has a DLA at $z = 0.532$. The only resolved object within 10″ of the QSO is a spiral galaxy (labeled G1) with an impact parameter of $\approx 17$ kpc. Although the galaxy redshift has not been spectroscopically confirmed, it would be $\approx L^*$ at $z = z_{abs}$. Spectral evolution synthesis model fits to the photometry suggest that if the galaxy was at $z = 0.532$ it would consist of a young stellar population with some dust reddening in addition to
Figure 3 UBRK images of the PKS 1629+120 field ($z_{DLA} = 0.532$). North is up and East is left. The QSO PSF has been subtracted and its position marked with a “+”. G1 is identified as the DLA galaxy.

Figure 4 Smoothed BRJK images of the PKS 0952+179 field ($z_{DLA} = 0.239$). North is up and East is left. The QSO PSF has been subtracted and the residuals masked out. See text for details.
an underlying older population. The UBRK morphologies in Figure 3 are consistent with this interpretation. This sightline also has a subDLA system at $z = 0.901$. G1 would be an unusually luminous, $\approx 4L^*$, galaxy at this redshift and is therefore unlikely to be the $z = 0.901$ galaxy.

The PKS 0952+179 field ($z_{DLA} = 0.239$) shown in Figure 4 is quite different. Faint disk-like structures, labeled 1 and 2, can be seen to the immediate east and southwest of the QSO sightline in the J-band image, which has the best seeing and QSO PSF subtraction of the four. They span $\approx 25$ kpc. PSF subtraction of the light from the QSO leaves residuals that are $\approx 0.02L^*$ at $z = 0.239$. Several additional features within this $20'' \times 20''$ field are visible in at least 2 of the images. The relatively bright object in the K-band image to the west of the QSO sightline, #7, has colors that classify it as an extremely red object (ERO). If it is related to the $z = 0.239$ DLA galaxy it would be the lowest redshift ERO known. The conclusion would be that it is a starbursting region with very strong dust extinction ($A_V \gtrsim 4.8$).

5. Summary

Through both indirect and direct methods, we are making progress in the attempt to understand the low-redshift DLA population. The SDSS and our own MMT survey spectra are enabling us to determine the statistical properties of low-redshift MgII and FeII absorption systems, which can be used to track high $N(\text{HI})$ systems at $z < 1.65$ to a high degree of accuracy. With our ongoing HST surveys we are finding new low-redshift DLAs, improving the low-redshift DLA statistics, and improving our understanding of the empirical relation between low-ionization metal-line systems and DLAs. In addition, we are directly studying the DLA environment with an active imaging campaign.

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