Establishing the Connections Between Galaxies and Mg II Absorbing Gas¹

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ABSTRACT

HIRES/Keck spectra of Mg II $\lambda 2796$ absorption arising in the "halos" of 15 identified 0.4 < z < 0.9 galaxies are presented. Comparison of the galaxy and absorbing gas properties reveal that the spatial distribution of galactic/halo gas does not follow a smooth galactocentric dependence. The kinematics of absorbing gas in $z \sim 1$ galaxies are not suggestive of a single systematic velocity field (i.e. rotation or radial flow) and show little dependence on the QSO–galaxy impact parameter. From the full HIRES dataset of 41 systems (0.4 < z < 1.7), strong redshift evolution in the cloud–cloud velocity dispersion is measured. Direct evidence for turbulent or bulk motion in "high velocity" clouds is found by comparing Fe II and Mg II Doppler parameters.

Introduction

The study of Mg II absorption in QSO spectra provides a powerful tool for studying the evolution of the kinematic and spatial distribution of galactic/halo gas in galaxies from the epoch of the first QSOs. Ultimately, these studies will provide observational constraints on the mechanisms and frequency of events by which galaxies are constructed, which in turn will provide an independent and direct quantification of the development of $10^{12-13}~\rm M_{\odot}$ structure formation in the universe.

It has been a few short years since Petitjean & Bergeron (1990) undertook the first investigation of the kinematic and spatial distribution of Mg II absorbing gas based upon the subcomponent clustering within the absorption profiles. Shortly thereafter, Bergeron & Boissé (1991) were the first to established that Mg II absorption lines in QSO spectra arise in the proximity of apparently normal L^* field galaxies. With the more recent sample of Mg II absorbing galaxies compiled by Steidel, Dickinson, & Persson (1994, hereafter SDP) and the advent of the HIRES spectrograph (Vogt et al. 1994) on the Keck 10-m telescope, one can now undertake a detailed study designed to establish how galaxy and absorption properties correlate. Such a study promises to provide the information necessary for developing a more detailed picture of galaxy/halo gas substructures and their dynamics (Lanzetta & Bowen 1990, 1992; Charlton & Churchill 1996; Charlton & Churchill, this volume).

¹To appear in *IAGUSP Workshop on Young Galaxies and QSO Absorbers*, eds. S.M. Viegas, R. Gruenwald, & R. de Carvalho, (PASP Conference Series)

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This contribution is a partial description of my thesis work and of work that appears elsewhere [Churchill, Steidel, & Vogt 1996 (hereafter CSV); Churchill, Vogt, & Charlton 1996].

The Project

The HIRES sample was selected on the basis that each absorption system was associated with an imaged galaxy that was spectroscopically confirmed to have the same redshift as seen in absorption (SDP). For each galaxy, the rest L_B and L_K luminosities, rest B-K colors, QSO–galaxy impact parameters, D, and redshifts, $z_{\rm gal}$, are measured.

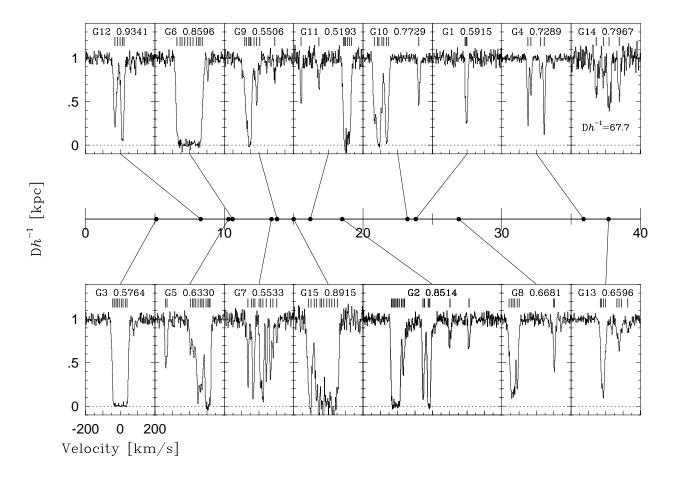


Fig. 1.— The HIRES/Keck absorption profiles of the Mg II ($\lambda 2796$) transition in order of increasing impact parameter, Dh^{-1} kpc (taken from CSV). The redshifts and galaxy IDs, as tabulated in Table 2 of CSV, are given. The vertical ticks above the continuum of each absorption feature mark the subcomponents used in the kinematic analysis. Each panel has a velocity spread of 400 km s⁻¹, except G2, which has an 800 km s⁻¹ spread. Note that $D \sim 70$ kpc for G14.

One motive for the study was to test the paradigm suggested by Lanzetta & Bowen in which intermediate redshift galactic halos are roughly identical, having cloud spatial number density distributions $\propto r_{\rm gal}^{1-2}$ and systematic rotational or radial flow kinematics. The primary test of this scenario is the prediction that the observed differences in the absorption properties from one system to another are predominantly due to the QSO-galaxy impact parameter. In Figure 1, the Mg II ($\lambda 2796$) transitions are shown in order of increasing QSO-galaxy impact parameter ($q_0 = 0.05$ and $h = H_0/100 \text{ km s}^{-1} \text{ Mpc}^{-1}$). The gas properties have been parameterized from the absorption profiles using Voigt profile fitting (cf. Carswell et al. 1991), which yields the number of "clouds" and their individual column densities, Doppler b parameters, and velocities. As described by CSV and given in Table 2 of their work, the gas kinematics of each system have been characterized by (1) the number of clouds, (2) the median absolute deviation of cloud velocities, (3) the number of median absolute deviations of the highest velocity cloud, (4) and the velocity asymmetry. The absorption strengths are measured by the rest equivalent widths and doublet ratios.

Results

Spearman and Kendall non-parametric rank correlation tests were used to ascertain if galaxy properties correlate with the absorption strengths and kinematic indicators. The tests revealed that the null-hypothesis of no correlation is consistent with the data when the criterion of a greater than 97% confidence level is applied. However, trends with large scatter are not ruled out (cf. Steidel 1995, Fig. 3; CSV). Of primary significance is the fact that the QSO-qalaxy impact parameter does not provide the primary distinguishing factor by which absorption properties can be characterized. The implication is that the spatial distribution and kinematics of absorbing gas surrounding intermediate redshift galaxies is not roughly identical from galaxy to galaxy, even if the processes that give rise to the gas are.

In Figure 2, results from profile fitting to the full HIRES dataset are shown, where only 5σ detections have been included. As shown in the left-hand panels, the sample was sub-divided by the median redshift, $\langle z \rangle \sim 0.9$, and the cloud-cloud velocity differences within each system were computed. The histograms are the relative number of cloud-cloud pairs in each 20 km s⁻¹ bin. The solid lines are fitted Gaussians and give the cloud-cloud velocity dispersion of the absorbing gas. The kinematic dispersion is seen to evolve with redshift, such that $\sigma(\Delta v) \sim 140 \text{ km s}^{-1}$ at $\langle z \rangle = 1.2$ decreases to $\sigma(\Delta v) \sim 60 \text{ km s}^{-1}$ at $\langle z \rangle = 0.6$. The number of clouds do not evolve with redshift, so one can conclude that the observed evolution of large equivalent width systems (Steidel & Sargent 1992) is in fact due to a settling of the velocity dispersion.

For all 41 systems, the distribution of Doppler b parameters, b(Mg II), is peaked at $\sim 4.9 \text{ km s}^{-1}$ and is consistent with a Gaussian with $\sigma \sim 1.5 \text{ km s}^{-1}$ that is truncated below 3.0 km s⁻¹. Using the atomic masses of Fe and Mg, the bulk/turbulent b parameter has been computed for unblended clouds assuming that the thermal and turbulent components can both be represented as Gaussians $(b_{\rm tot}^2 = b_{\rm therm}^2 + b_{\rm bulk}^2)$, where $b_{\rm therm}^2 \propto m_{\rm ion}^{-1}$. The typical Fe II and Mg II b parameter uncertainties are $\sigma(b_{\rm tot}) \sim 0.25~{\rm km~s^{-1}}$. As a result of selecting unblended lines, these clouds all happen to have velocities in excess of 100 km s⁻¹ from the profile optical depth weighted velocity zero point. It is apparent that some fraction of these "high velocity" clouds exhibit both a thermal broadening and a turbulent or bulk motion component.

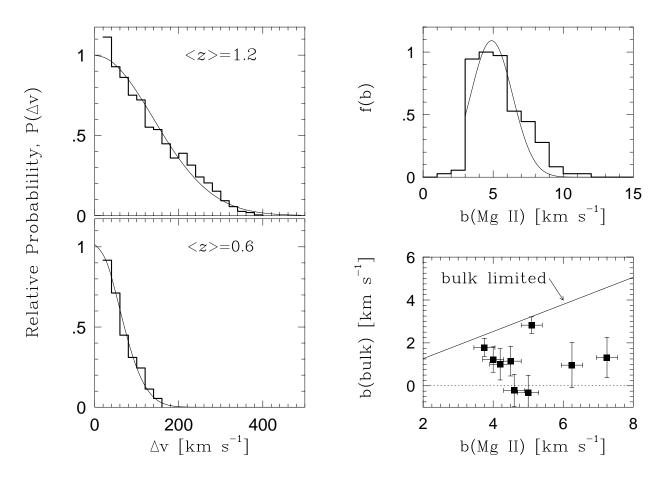


Fig. 2.— Results from profile fitting to the full HIRES dataset. The left panels illustrate the redshift evolution of the gas kinematics. Shown are the normalized probabilities that any two clouds in a given system have a line of sight velocity difference Δv . The upper right panel illustrates the distribution of Doppler b parameters. The lower right panel shows the degree to which unblended "high velocity" clouds exhibit bulk or turbulent internal motions. See the text for details.

Future plans include incorporating the galaxy morphologies and orientations with respect to the QSO light path from Hubble Space Telescope images obtained by Chuck Steidel. The new STIS should be ideal for obtaining the wider range of higher ionization species needed for a more complete picture of the kinematic, chemical, and ionization conditions of early epoch galactic gas. I thank Jane Charlton, Chuck Steidel, and Steven Vogt for their continued support, assistance, and pleasurable collaborations. This work supported in part by the California Space Institute, and NASA (grant NAGW-3571).

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