Chapter 7

Summary

Observations of Mg II absorption line systems in the high resolution spectra of quasars have been presented. A total of 25 QSOs were observed with the HIRES spectrometer (Vogt et al. 1994) on the Keck I telescope on the nights of 4–5 July 1994, 23–25 January 1995, and 19–20 July 1996 UT. The spectral resolution was 6.6 km s^{-1} ($R = 45,000$). The HIRES spectra are presented in Figures 3.15–3.62. Below is a brief description of the analyses employed for this work. Following this description is a list of the main conclusions.

7.1 Overview of Study

A total of 48 Mg II systems have been included in the survey. The redshift distribution of the systems is illustrated in Figure 3.1. There is a bias in the redshift distribution in that $z > 1$ systems are biased toward large equivalent widths. Two samples for study have been defined based upon the $\mathrm{EW_r}$ detection threshold. Sample A includes all 48 systems listed in Table 3.1. Sample B includes only those systems for which the 5σ $\mathrm{EW_r}$ detection limit of the Mg II λ 2796 transition is below 0.02 Å. There is no correlation between 5σ $\mathrm{EW_r}$ detection limit and system redshift for Sample B. Thus, there is no sensitivity bias with redshift in this Sample.

The HIRES data were reduced and calibrated in the standard way using the IRAF `Apextract` package for echelle data (also see Churchill 1995). The spectra were "extracted" using the optimal routines of Horne (1986) and Marsh (1989). All further processing of these calibrated spectra was performed using personalized codes on ASCII format data in the Unix environment and using SunOS Fortran 77. Absorption features in the spectra have been identified using the "aperture" method used by Lanzetta, Turnshek, & Wolfe (1987). In order to study the subsystem properties directly from the profiles, individual subfeatures were also identified in each system. The redshift of each absorbing system was determined by finding the optical depth median of the Mg II λ2796 profiles (or the λ2803 profiles when the former were not available). The absorber redshift sets the velocity zero point for the system. Guided by the methods presented by Sembach & Savage (1992), expressions for several absorption properties were derived. These properties are based upon direct measurements of the flux values in the absorption profiles. They include the equivalent widths, doublet ratios, apparent optical depth (AOD) weighted velocity widths, AOD weighted asymmetries, and AOD column densities. These quantities are presented in Table 3.1 for the overall Mg II profiles and in Table 3.3 for the subfeatures, or subsystems. The rest–frame equivalent widths and adopted AOD column densities and their 1σ uncertainties (or limits) for all observed transition are presented in Tables 3.6–3.54.

The absorption profiles were modeled using Voigt profile (VP) decomposition. Initial VP models for the profiles of most spectra were obtained using an automated VP fitting routine (Davé et al. 1996) that was modified for this work to include convolution with the HIRES instrumental spread function. The VP fitting approach was to tie all velocities of the VP components together, and to allow the Doppler b parameters to vary freely from species to species but tie all transitions of a given species. The purpose of the latter was to allow a deconvolution of the thermal and non–thermal components of the total b parameters. The VP models were refined using a maximum likelihood least squares fitter (LSF), called MINFIT, which was written for this work. The final MINFIT LSFs are illustrated with the HIRES spectra in Figures 3.15–3.62. The VP component parameters are presented in Tables 3.55–3.81.

To quantify the accuracy of the VP parameters, and in order to examine the level at which inferences can be drawn from these parameters, extensive simulations of HIRES spectra were performed. The simulated systems included the Mg II $\lambda\lambda 2976, 2803$ doublet and all five Fe II transitions listed in in Table 2.1. These spectra were analyzed in the exact same way the HIRES data were analyzed. Four single component simulations (Sim–1A, 1B, 1C, and 2) and a single Blending Simulation were carried out. For these simulations, 500–2000 simulated systems, each with a single component VP absorption line, were generated.

- Sim–1A was used to determine the Mg II, Fe II, and Mg I column density detection limits as a function of the HIRES rest–frame equivalent width detection threshold. It was also used to ascertain the distribution of the fitted Mg II column densities as a function of the input column density.

- Sim–1B was used to determine if the automated VP fitting and minimization processing was introducing a systematic bias. For this Sim–1A was duplicated, except that the automated VP fitting was by–passed and instead the column density and b parameter which generated each simulated Mg II doublet was handed to MINFIT as the initial model.

- Sim–1C was used to determine if the probability of recovering an Mg II input column density is dependent upon the simultaneous fitting of the five Fe II transitions.

- Sim–2 was used to determine the degree to which turbulent broadening in single component "absorbing clouds" can be inferred from a sample of HIRES spectra with a well defined rest–frame equivalent width detection limit.

- The Blending Simulations were used to determine how line blending in complex profiles affects the column density detection limit, how the inferred distribution of column densities is influenced with respect to the known input distribution, and how well the distribution of input column densities can be recovered. These simulations were also used to study whether statistical correlations in the VP parameters are artifacts of the fitting procedure.

To further the interpretation of the Mg II, Fe II, and Mg I VP column densities, a grid of photoionization models were constructed using Ferland's CLOUDY (Ferland 1988). Each cloud was defined by its H I column density, metallicity, and ionization parameter. The main question being addressed was whether absorbing clouds are photoionized by stellar continuum from the local galaxy or if the clouds are ionized by the UV meta–galactic background flux. Thus, two UV ionizing continua were chosen to bracket these extreme idealization. The UV background is approximated with a power law of slope $\alpha = -1.5$. The stellar ionizing field is assumed to be a simple blackbody with $T = 30,000$ K. To examine the supposition that some clouds may be collisionally ionized, such as H II regions, a direct comparison of the two extreme photoionization models was made with the collisional excitation model given in Tytler et al. (1987).

Using the database of Mg II absorption selected galaxy properties obtained by Steidel, Dickinson, & Persson (Steidel, private communication), non–parametric rank correlation tests were used to search for correlations of the absorption strengths, saturation, and line–of–sight kinematics with the galaxy redshifts, rest frame B and K luminosities, rest $\langle B - K \rangle$ colors, and impact parameters D. One motive for studying the connections between galaxy properties and absorption properties was to examine the model of $z \leq 1$ galaxy halos suggested by Lanzetta & Bowen (1990, 1992). They suggested that intermediate redshift galactic halos are roughly identical, have absorbing gas spatial number density distributions $\propto r_{\rm gal}^{-2}$, and likely exhibit systematic rotational or radial flow kinematics. The primary test for this picture 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.

Preliminary kinematic models of the absorbing systems were presented based upon the work of Charlton & Churchill (1996b, 1997b). A population of randomly oriented rotating disks, a population of spherical infall halos, and a population of hybrid disk and infall halos have each been studied. The galaxy luminosities have been selected from the Schechter function and the rotation or infall velocities have been computed using the Tully–Fisher relation. Random lines of sight were placed through the galaxies and simulated Mg II and Fe II HIRES absorption line spectra were generated. These spectra were analyzed in the exact same way the HIRES data were analyzed. The main goal of the modeling was to see if the spatial distributions and dynamics input into galactic dynamical models can reproduce both the observed absorption line properties of individual systems and the overall distributions and statistics of the full Sample B.

7.2 Main Results

1. A strong correlation between the number of VP components and the rest–frame equivalent width has been measured. The maximum likelihood constant of proportionality in the relation $N = kW$ is $k = 0.076 \pm 0.004$, which is in good agreement with the value reported by Churchill, Steidel, & Vogt (1996) for a much smaller

sample of HIRES data. The value of k is resolution dependent, based upon a comparison with the significantly larger value obtained by Petitjean & Bergeron (1990) with medium resolution spectra. The value of k may also be redshift dependent. Strong blending is seen to result in an under estimate of the number of VP components comprising a given profile. Based upon the severe blending and saturation of the small sample of $z > 1$ large equivalent width systems, and the observed evolution in the number of strong systems with redshift, it might be that the ratio N/W is systematically smaller as redshift increases.

2. Segregating the overall profiles into distinct absorption subsystems has revealed several observed trends in the subsystem absorption properties, especially with respect to the velocity distribution relative to the median optical depth of the full system. Excluding Q0450 − 132 at $z_{\rm abs} = 1.1746$, Q0823 − 223 at $z_{\rm abs} = 0.91102$, Q1213 − 003 at $z_{\rm abs} = 1.5541$, and Q1225+317 at $z_{\rm abs} = 1.7948$, the maximum width of these subsystems is ~ 45 km s^{-1}. It may be that higher redshift absorbers that are found to have a "central" or "main" subsystem with a velocity width greater then ~ 50 km s^{-1} are the type of systems that are decreasing in numbers by $z \sim 1$. In other words, these large subsystems are splitting into multiple smaller subsystems, as characterized in the absorption profiles. That the Mg II doublet ratio is not seen to evolve with redshift (Steidel & Sargent 1992), and considering that $z < 1$ absorption profiles are almost always characterized by a "main" optically thick subsystem with $\omega_v \leq 45$ km s^{-1}, it appears that some type of an organized underlying absorbing structure is a fundamental component to Mg II absorbers, whereas a significant part of the structure is evolving away. On the other hand, these systems could be "double galaxies", which are more common at higher redshifts.

3. Out of 33 systems, there are 39 subsystems with velocities greater than 20 km s^{-1}. Higher velocity subsystems are quite common, and in fact, on average there is likely to be one or more subsystem with EW$_{\rm r} < 0.2$ Å per absorbing system. Two of 27 systems are seen to have $A(\Delta v) \geq 140$ km s^{-1}. This suggest that less than 10% of all $z < 1$ systems will be observed to have very high velocity kinematic subsystems to a limiting EW$_{\rm r}$ of 0.02 Å. It is still a complete unknown if these are chance alignments of multiple galaxy halos, or if they arise in "active" systems.

4. All subsystems with $v > 40$ km s^{-1} have been culled into a separate sample. Roughly 80% of these subsystems have EW$_{\rm r} \leq 0.1$ Å, are on the linear part of the curve of growth (based upon their DR), and have $\omega_v < 10$ km s^{-1}. These subsystems are characterized almost exclusively by optically thin gas having small column densities and small b parameters. It may be that these subsystems comprise a subpopulation characterized first and foremost by their velocity with respect to the optical depth mean of the overall system. Interestingly, there is no clear evidence for a turnover at small values in the EW$_{\rm r}$ distribution of the $v > 40$ km s^{-1} subsystems down to the detection limit of the sample. Higher signal to noise and/or higher resolution spectra would be required to investigate the lower end cutoff to the EW$_{\rm r}$ distribution of these higher velocity subsystems.

5. It is interesting to know if the VP component velocity dispersion can be inferred from the value of $\mathrm{EW_r}$, which can be measured in low resolution spectra. A maximum likelihood linear fit was obtained to the $A(\Delta v)$ verses $N_{\rm cl}$ data (proportional to $\mathrm{EW_r}$), and a maximum likelihood slope of 6.72 ± 0.76 was obtained. However, as can be seen in Figure 3.4, the data exhibit increased scatter for $A(\Delta v) \geq 40$ and $N_{\rm cl} \geq 10$. The value of $A(\Delta v)$ is sensitive to somewhat "extreme" kinematics that cannot be discerned simply from the number of VP components nor from the equivalent width. Primarily, this is due to saturation/blending on one extreme and due to the chance presence of high velocity subsystems that do not contribute much to the value of $\mathrm{EW_r}$ on the other. Thus, the $\mathrm{EW_r}$ does not provide a robust indicator of the average kinematic dispersion of VP components.

6. The maximum likelihood method was used to obtain the slope and normalization of the column density distributions of Mg II, Fe II, and Mg I, assuming a power–law probability distribution. The measured powers were 1.58, 1.65, and 2.22 for Mg II, Fe II, and Mg I, respectively. However, as discussed in Section 5.1.1, the Fe II distribution may be more in accord with the value of 1.58 measured for the Mg II. This would be consistent with the ratio $\log N(\mathrm{Fe\,II}) - \log N(\mathrm{Mg\,II})$ verses $\log N(\mathrm{Mg\,II})$ result, which once corrected for saturated Mg II components, is consistent with being flat.

7. Based upon CLOUDY photoionization models, it appears that clouds ionized by a power law ionizing continuum are consistent with the data for $\log U \leq -3.0$ with the bulk of the clouds having $17.0 \leq \log N(\mathrm{H\,I}) \leq 18.0$ cm^{-2}. These values are similar to those found from low resolution spectra (Bergeron & Stasińska 1986; Bergeron et al. 1994; Dittmann & Köppen 1995). On the other hand, if the clouds are ionized by a thermal radiation source, then the implied hydrogen neutral column density is $\log N(\mathrm{H\,I}) < 17.0$ cm^{-2} for $\log U \leq -1.0$ This would imply that $\log N(\mathrm{Mg\,II}) = 13.0$ cm^{-2} clouds arise in optically thin hydrogen clouds, which is inconsistent with the association of Mg II systems with Lyman limit systems (Bechtold et al. 1984; Lanzetta 1988). None of the data are clearly consistent with the absorption arising in collisionally excited H II regions.

8. The ratio $\log N(\mathrm{Mg\,I}) - \log N(\mathrm{Mg\,II})$ is strongly correlated with $\log N(\mathrm{Mg\,II})$ to the 4σ level, even after suspect points are removed from the Spearman–Kendall tests. There are a significant number of clouds with $N(\mathrm{Mg\,I}) - \log N(\mathrm{Mg\,II}) \geq -1.6$, which is difficult to explain in view of the photoionization grids. These "clouds" may be experiencing shielding, either due to internal ionization structure (self–induced) or due to nearby optically thick clouds that modify (soften) the ionizing radiation. It is tentatively suggested that the charge transfer reaction between H II and Mg I may have been overestimated in previous photoionization models, since this would tend to reduce the predicted ratio of Mg I to Mg II. In view of this charge exchange process, the anticorrelation of $\log N(\mathrm{Mg\,I}) - \log N(\mathrm{Mg\,II})$ with $\log N(\mathrm{Mg\,II})$, may be indicating that the gas density, and not the line of sight path length, is governing the Mg II strength.

9. The peak values in the Mg II, Fe II, and Mg I Doppler b parameter distributions are ~ 3.5, ~ 5.5, and ~ 4.5 km s^{-1}. The means are 6.2, 5.0, and 8.6 km s^{-1}, respectively. VP components with $b > 11$ km s^{-1} occur, in all cases, within the ≤ 80 km s^{-1} velocity range in broad saturated profiles (see Figure 5.12). Thus, they are not well constrained and may arise because these profiles are not consistent with being a composition of Voigt profiles. The thermal Doppler b has been inferred, and for the 56 thermal b parameters included in the sample, the median is 4.7 km s^{-1} with a standard deviation of 3.5 km s^{-1}, and a mean of 6.1 km s^{-1}. The median and mean values correspond to the cloud temperatures $T = 32,000$ and 54,000 K, respectively. The inferred mean turbulence b parameter was found to be 1.7 ± 10.8 km s^{-1}, which is consistent with zero. The data are not altogether inconsistent with thermal clouds. Indeed, one could infer that the higher velocity optically thick population of clouds are likely to be quiescent, given that their profiles do appear to be well described using VP decomposition. These higher velocity clouds may be drawn from a "population" with substantially different physical conditions than those "embedded" in the broad saturated profiles. Based upon the ratio $b(\text{Mg I})/b(\text{Mg II})$, there is no evidence that Mg I absorption arises in gas where the temperatures or non–thermal conditions are different than those in which Mg II absorption arises.

10. The Fe II column densities and Doppler b parameters show no evidence of a correlation. However, the Mg II data appear to be correlated at the 3σ level. In the case of the Blending Simulations, where the input column densities and b parameters were uncorrelated, only a suggestive correlation resulted following VP decomposition. A 3σ result is not overwhelming. This observed correlation could arise either as an artifact of the VP decomposition, such as the inclusion of small clouds required to obtain a better fit to the spectra, or because the VP decomposition method provides a poor description of gas that is complex and varied in its underlying distributions.

11. The cloud–cloud clustering function (TPCF) in galaxy halos has been measured for Mg II and the best decomposition is a two component Gaussian. For Sample B, the dispersions are $\sigma_1 = 30$ and $\sigma_2 = 150$ km s^{-1}. If a $z \leq 1$ subsample is analyzed, the TPCF shows a slight narrowing in the broader component, $\sigma_2 = 140$ km s^{-1}, but is consistent with no change in the narrower component, $\sigma_1 = 29$ km s^{-1}. The reduced dispersion of the broader component in the TPCF is likely a direct result of removing the four high–redshift large equivalent width systems from the sample. Interestingly, there is an inversion of the amplitudes of the two components, so that the narrower component is dominant in the $z \leq 1$ subsample. A robust measure of how the TPCF evolves, if it does, would require a doubling of the sample size with the goal of observing $1 \leq z \leq 2$ absorbers with an unbiased distribution of EW_r.

12. To the 2.5σ level, no correlations were found between the measured absorption properties and galaxy properties. In particular, no anti–correlation (99.9% confidence level) was found for EW_r with the projected galactocentric distance, D, in 15 systems. Thus, the strong correlation by Lanzetta & Bowen (1990) found in a similar size but different data set is not confirmed. That no dependence of N_c with D was found has implications for predictions from systematic rotational and radial flow

kinematic models. Both models predict that $A(\Delta v)$ decreases with D and sharply cuts off at $D = R$. There is no such anti–correlation in the sample. In fact, the Spearman and Kendall tests are weakly suggestive of a correlation, not the predicted anti–correlation. The implications are that (1) the spatial distribution of absorbing gas surrounding intermediate redshift galaxies is not smoothly varying, and that (2) the velocities of the absorbing gas clouds cannot be described by a *single* systematic kinematic model. These facts suggests investigations to learn the degree to which galaxy morphologies and, in the case of disk galaxies, orientations with respect to the QSO light path play a role in distinguishing between observed absorption properties.

13. Several lessons have been learned by exploring kinematic models of the Mg II absorption systems. One striking result is that a multi–component Gaussian decomposition of the TPCF does not imply that the absorbing clouds are comprised of more than one type of systematic kinematics. Moreover, it is not trivial to recover the observed values of the TPCF Gaussian components. Some combination of extended thick disk plus infall halo provides a promising model in that its simple kinematics yield a TPCF with Gaussian components consistent with those describing the observed TPCF. The distribution of subsystem equivalent widths and velocity widths as a function of velocity provide very strong constraints on the distribution of column densities and Doppler parameters. Using an upper limit to the cloud column density in the infall halo component goes a long way toward reproducing the distribution of equivalent widths and doublet ratios of the $v > 40$ km s^{-1} subsystems. It is also apparent from the models that the "observed" Doppler b parameter distribution that results from the VP decomposition is significantly broadened (see Figure 5.20).

7.3 Concluding Remarks

There is little doubt that the majority of the Mg II systems arise in gas associated with normal field galaxies (SDP). There is also little doubt that the projected galactocentric distance of the absorbing gas often extends to roughly 40 kpc (Steidel 1995) and that the total strength of the absorption is predominantly due to intercepting multiple "clouds" along the line of sight. What issues remain less established are the actual spatial and kinematic distributions of the low ionization gas and the chemical and ionization conditions of the gas. Is the absorbing gas distributed in an extended more or less spherical halo with a near unity covering factor? If so, what can be inferred about the clustering of the gas in the halo and the distribution of the cloud sizes from high resolution absorption spectra? In the case of spiral galaxies, could a significant portion of the absorbing gas be considered to be more associated with the warped outer reaches of neutral gas observed in present day galaxies (see Yun, Ho, & Lo 1994 for a dramatic example). To claim that disks provide only an insignificant contribution to the statistics of the absorption–galaxy relationships ignores the fact that spirals comprise 70% of the galaxy population selected by Mg II absorbing gas cross section (Steidel, private communication) and the fact that the gas cross sections of disk are competitive with the cross sections of spherical halos (Charlton & Churchill 1996b). Answers to these question await a comparison between the HIRES data and the high spatial resolution WFPC2/HST images of the absorbing galaxies obtained by Steidel and collaborators.

It is important to ask questions such as: Could the current or past mergings of dwarf galaxies around the absorbing galaxies be requisite for extended gaseous material in their halos or for the warped diffuse extended disks? If so, perhaps such mergings are commonplace in that each galaxy swallows a reservoir of dwarfs over a Hubble time, but that this reservoir begins to be depleted at a fairly well defined epoch, say $z \sim 1$. Such a scenario would naturally explain the redshift evolution seen in the strongest absorbers. In a sense, this could be called a "halo infall scenario". However, what is sought is an identification of what actually is doing the infalling or what process is giving rise to the infall. If such a process occured from $z \sim 2$ to $z \sim 1$, it would imply that the typical absorbing galaxy has cannabilized 20–30 dwarf companions over a several Gyr time span. If the process began earlier or shut down later, that number would be reduced. Charlton & Churchill (1997a) showed that absorption *by* the gas surrounding the dwarf companions themselves is extremely dependent upon the presence of an LMC/SMC type companion when the line of sight passes near a Milky Way like galaxy *that is bound in a "Local Group" environment of 20 odd dwarfs*. If absorbing gas is spatially organized in the galaxy potential through the process of dwarf merging, then it may be the case that the tidal stripping of gas is what gives rise to the large cross sections, whether in the galactic plane [as with M81 (Yun, Ho, & Lo 1994)] or well out of the plane (for example, the Magellanic Stream).

If the accretion/tidal stripping scenario is the dominant mechanism by which absorbing gas is organized around galaxies then several implications for the formation of present day galaxies can be inferred. If the accretion occurs primarily in an outward–in direction, then a dilution of the metallicity content of the ISM would occur with increasing galactocentric radius. Additionally, the disks in spiral galaxies would "build up" with time and likely would be come extended and diffuse.

If galaxy halos were populated by "Lyman limit" clouds (as inferred by their Mg II column densities and doublet ratios) that produced a near unity covering factor, their spatial distribution would likely be somewhat random and they would likely be balanced by pressure confinement that scales with galactocentric radius (Steidel 1995; Mo & Miralda–Escudé 1996). As such, when viewed in high resolution spectra, it would be expected that often two or three Lyman limit clouds would be seen, provided their relative velocities were on the order of 30–50 km s^{-1}, which is small compared to the *overall* observed velocity spread of Mg II absorbing clouds. As seen in the observed distribution of subsystem equivalent widths and velocity widths, especially as a function of subsystem velocity, such a picture is not suggested by the observations. What is suggested, however, is that the majority of the systems are dominated by what appears to be a single structure of Lyman limit clouds with a small velocity dispersion between these clouds. The small velocity dispersion, in turn, suggests that the kinematics of the clouds is systematic.

The obvious alternative to the accretion and/or infall scenario is the recycling of gas via disk/halo interactions, most likely driven by correlated stellar winds, i.e. OB associations and correlated supernovae explosions. Interestingly, Steidel and collaborators have seen ~ 1000 km s^{-1} outflowing stellar winds in $z \sim 3$ galaxies, as inferred from LRIS/Keck spectra (Steidel, private communication). If such winds are common, a picture of extended gaseous halos, as proposed by Bregman (1980), MacLow & McCray (1988), Norman & Ikeuchi (1989), and Tomisaka, Habe, & Ikeuchi (1981), may apply. The implication is that much of the gas surrounding $1 \leq z \leq 2$ galaxies does not arise by accretion and mergings but by galactic fountains, chimneys, and/or supershells. Churchill, Vogt, & Steidel (1995) have proposed the latter possibility for the complex features observed in the $z \sim 0.74$ absorbing system in the spectrum of Q1331 + 170. In the chimney model, the gas circulation time is $(3-5) \times 10^7$ yrs (Norman & Ikeuchi 1989). The picture is that ≈ 1 kpc superbubbles can be formed if sequential supernovae explosions occur every 10^5 yrs during the 10^7 yr lifetime of a giant molecular cloud (Tomisaka, Habe, and Ikeuchi 1981). The cooling time of the gas is $\approx 10^6$ yrs at densities of 10^{-2} cm^{-3}. From these sequential supernovae explosions, chimneys can form with cool dense walls of neutral gas and central outward flows of hot gas, which cool due to adiabatic losses and then finally by radiative losses as the gas rises to the top of the halo. The chimneys trace the spiral arms, and will be on the order of thousands in number for a given galaxy. The OB star formation regions (knots in spiral arms) should be detectable in HST images. Perhaps there is a correlation between the number of OB associations and the strength of absorption or the detailed kinematic structure inferred from the QSO absorption lines.

If the disk/halo interaction and outflow scenario dominates the mechanism by which absorbing gas is mixed about in galactic halos, then the process is primarily mechanical as opposed to gravitational, as implied by the accretion/infall scenario. Whichever the case, the implications for the evolution of galaxies is quite different between the two pictures. In the disk/halo recycling scenario, the total gas content of a galaxy would remain roughly constant for a several billion year period up to the present epoch. This would imply that the major epoch of galactic structure formation was greater than $z \sim 3$ and that "normal" galaxies were in place much earlier than $z \sim 1.5$.

As such, there would be no *building up* of gaseous disks, per se, though they could conceivably become extended through the gas redistribution processing. Moreover, the variations of metallicity across the disk would reflect the redistribution of metals, presumably from type I supernovae. Thus, the metallicity build up of the disk interstellar medium should reflect type I supernovae yield. It also might be expected that the mixing would become fairly uniform with time, such that any metallicity gradient in a disk would be diluted. That the Galaxy [and apparently M31 and M33 (K. Venn, private communication)] have decreasing metallicity in their disks with increasing galactocentric radius is not supportive of a *global* mechanical redistribution scenario. It does not rule out, however, the possibility that the stirring up of gas well above and below the galactic plane is not common but that much of the material actually escapes the galactic potential (cf. Norman & Ikeuchi 1989). Indeed, the large outflow velocities witnessed by Steidel et al. are suggestive of escape velocities. It would seem that the period in which a galaxy has its maximum extended gaseous "halo" would be within the Gyr following a starburst, which may in fact correspond to the time shortly after the excess blue colors indicative of starbursting had decayed away. If so, there would be no clear correlation between galaxy color and the presence of an extended absorbing gas envelope. Accounting for the fact that extended absorption is seen to persist in galaxies for ~ 10 Gyr would imply multiple star bursts, which decay in frequency to the present epoch. It is not too far fetched to imagine cycles of outflow and infall, accompanied by accretion of dwarf satellites, etc., that help drive these starbursts. In a sense, these cycles could link the penetration of high velocity clouds into disks with the formation of OB associations, small star bursts, and eventual correlated outflowing winds.

As with all things, a single scenario is probably not correct. It is more likely that some combination of these pictures is occuring and that the relative contribution of the mechanisms that give rise to the absorbing gas are linked to environment. Regardless, since large column density systems evolve away with redshift, there should be a steepening in the power law slope with redshift. If the large column density systems evolve into small column density systems, then the steepening would occur over all measured columns. But, the number of small column density systems does not evolve with redshift, and in fact traces the number of Lyman limit systems. One could infer then, that the large systems are a separate population (either due to physical conditions, chance alignments of double galaxies, or alignments along the primary axis of filamentary structure). The upshot is that these extreme structures are evolving away, whereas the galaxies embedded within them are not. This scenario predicts that a steepening in the column distribution should occur predominantly at the highest column densities and that the small column density slope should change very little or not at all. Also, the small column density regime should have a slope consistent with the distribution of hydrogen columns near the Lyman limit. The source of the evolution would not be the dissipation of low ionization filaments due to changing ionization conditions, but due to the kinematic dissipation of the material falling into the high density regions (ie. the galaxies) or the lower frequency of "double galaxy" systems with decreasing redshift.

High resolution observation in the infrared, covering $z \geq 2.2$ would be very interesting for measuring the evolution in the kinematic spreads and the column density distribution with cosmic time.

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