Chapter 1

Introduction

1.1 Background

It was first suggested by Bahcall & Spitzer (1969) that absorption lines from metals seen in the spectra of distant quasars (QSOs) arise in the extended halos of intervening galaxies. Demonstrating the veracity of this hypothesis, and deeper probing into the very nature of the absorbing systems themselves, has taken roughly two decades of work by several researchers. The resonant MgII $\lambda\lambda 2976, 2803$ and CIV $\lambda\lambda 1548, 1550$ doublets, which provide sensitive probes of low and high ionization gas, respectively, have been targeted because their strong doublet signatures are easily identified in QSO spectra.

Low resolution spectroscopic surveys of the MgII doublet have yielded insights on the evolution of the product of the number density and the absorption cross section (co–moving density) of the absorbing systems, and on the cosmological clustering of the systems (Tytler et al. 1987; Lanzetta, Turnshek, & Wolfe 1987; Sargent, Steidel & Boksenberg 1988; Steidel & Sargent 1992, hereafter SS92). From these works, it has become generally accepted that the redshift distribution of MgII absorbers is consistent with a population of cosmologically distributed objects, i.e. galaxies. Direct evidence soon followed that, at least in some cases, galaxies are associated with the MgII absorbing systems (Bergeron & Boissé 1991). Soon after, from an imaging and spectroscopic survey of roughly 60 QSO fields, Steidel (1993a), and Steidel, Dickinson, & Persson (1994) presented quite convincing results that a bright galaxy is virtually always associated with a known MgII absorption system. Over this time period, a schematic picture of the relationships between MgII absorbing gas properties and the associated galaxy properties has emerged (Lanzetta & Bowen 1990; Lanzetta & Bowen 1992; Steidel 1993; Bergeron et al. 1994; Steidel 1995; Churchill, Steidel, & Vogt 1996; Steidel et al. 1997). However, the picture in which extended ~ 40 kpc galactic halos, per se, are actually the structures giving rise to absorbing gas has not always been universally accepted (York et al. 1986; Yanny 1992; Charlton & Churchill 1996b; and see discussion in Steidel 1993a).

SS92 presented a uniform and statistically complete survey of MgII absorption systems and provided a comprehensive look at the distributions of the equivalent widths, doublet ratios, and of the redshift evolution and clustering on scales of greater than 500 km s^{-1}. Most notable is their result that the co–moving density is consistent with a

non–evolving population of absorbers when both weak and strong (low and high equivalent width) systems are included (the overall population). However, as the population is restricted to stronger systems, the co–moving evolution becomes significant, suggesting that the strongest systems are evolving away with time but are not necessarily evolving into the weaker systems. It is also seen that the mean rest–frame equivalent width of Mg II λ2796 increases with redshift (decreases with time). The doublet ratio shows no evolution over the range $0.3 \leq z \leq 2.2$, which indicates that the absorbing gas is optically thick on the flat part of the curve of growth.

Petitjean and Bergeron (1990) studied Mg II absorbing systems with a moderate resolution of 30 km s^{-1}. They found substructure in complex absorption profiles, measured the cloud–cloud velocity clustering on the scale of galactic velocity dispersions, and established a correlation between the equivalent width and the number of subcomponents in galaxies [as suggested by York et al. (1986) and Wolfe (1986)].

Nothing is really known about the statistics of the line of sight kinematics, for these systems nor about the basic physical conditions of the gas, such as the degree to which it is in thermally relaxed or undergoing bulk motions. Following two decades of efforts, we have finally achieved both the background knowledge and powerful instrumentation necessary for interpreting and measuring the detailed physical conditions of and within galaxies with intermediate redshifts ($0.4 \lesssim z \lesssim 1.5$).

1.2 Motivations

Ultimately, the goal of studying absorption lines in the spectra of QSOs with high resolution is to learn about the detailed chemical, ionization and kinematic conditions of the absorbing gas. However, these conditions are astrophysically important only through their potential for providing detailed data to be leveraged against fundamental problems in cosmology and astrophysics. Many of the problems include questions on galactic formation and evolution, cosmic chemical evolution, and cosmic evolution of the UV ionizing background. Yet, based upon the inferences drawn from these studies, there is the manifold of implications which branch out and influence subdisciplines from stellar populations to galactic dynamics, from star formation to dwarf–galaxy tidal stripping, or from supernovae frequencies, energetics, and yields to the evolution of AGN.

The study of the low ionization gas known to be associated with the normal population of galaxies is no exception to the above. Some general issues that may ultimately be addressed by the detailed study of Mg II absorption systems include: Are galaxy halos static remnants of formation or dynamic components which are continually replenished and/or recycled? What is the total mass of the gas in the halo "reservoir", or if the gas is recycled, from where does it originate and what is its fate? What implications can be inferred for disk evolution and disk/halo interactions?

More direct questions about the absorbing gas itself can be addressed with this work: What is the source of the ionization in the clouds? Are the clouds supported primarily by thermal internal motions, or do they exhibit turbulence? What type of kinematics is consistent with absorption line profiles? Are certain absorption properties correlated with galaxy luminosities, colors, or the QSO–galactocentric impact of the line

of sight?

Cloud kinematics in galaxies, particularly in extended halos, are important clues to overall gas dynamics and energetics [i.e. galactic fountain disk/halo interaction, satellite galaxy tidal disruption, intergalactic medium accretion, etc.] (Churchill, Vogt, & Steidel 1995). A first step toward understanding detailed kinematics is to discern if MgII absorbing clouds reside primarily within galactic disks or halos or both? It is hoped that the detailed absorption properties measured in the HIRES spectra will provide useful constraints for simple heuristic kinematic models of the absorbing systems. The "geometry question" is a topic of current debate (Charlton & Churchill 1996b; Bowen, Blades, & Pettini 1995; Steidel 1995; Steidel et al. 1997) and is of primary importance, since kinematic models will necessarily build upon the inferred overall geometric distribution of the gas.

1.3 The Data

The cornerstone for a study of the gaseous content of these absorbing galaxies is a large set of high signal to noise ($S/N \geq 30$) high–resolution spectroscopic data, needed to resolve the multiple clouds along the line of sight. For some of the absorption systems, the associated galaxy properties have been measured (Steidel, Dickinson, & Persson 1994). These data have been made available for this study courtesy of C. Steidel.

High resolution spectra are required to determine the number of *individual* clouds and their line of sight velocities within each galaxy. Additionally, high signal to noise is required to measure weaker transition species (i.e. MgI, FeII, CaII, MnII), which allow chemical and ionization conditions to be investigated.

The host galaxy properties needed for correlation studies are their redshifts, spectral features, luminosities, colors, line of sight impacts to the QSO, morphologies, and sky orientations [the latter two require high spatial resolution imaging from the Hubble Space Telescope (HST)].

1.3.1 The HIRES Spectra

The absorbing systems were selected from the spectroscopic surveys of SS92 and SSB, and from the imaging survey of SDP. Primarily, the systems were chosen based upon the criteria that the QSO was observable during the alloted telescope time, had a visible magnitude of $V \lesssim 17.5$ (in order to obtain a high signal to noise ratio in roughly a 3600 second integration), had multiple systems along the line of sight that could be observed with a single setting of the HIRES echelle, and had at least one system with a "large" MgII equivalent width (EW). Large EW systems were selected because the number of subcomponents in a given absorption profile is known to correlate with the equivalent width (Petitjean & Bergeron 1990) and a main goal of this project was to study the nature of the multiple absorbing components in individual system.

1.3.2 SDP Galaxies

The original SDP survey consisted of deep images and follow–up faint spectroscopy of more than 50 QSO fields (and half again as many "control" fields) with known

absorption systems in the redshift range $0.2 \leq z \leq 0.9$. The sample is mainly drawn from the Sargent, Steidel, & Boksenberg (1988) and Steidel & Sargent (1992) surveys, which have limiting $\mathrm{EW_r} \simeq 0.3$ Å. The images were taken over a large range of band passes and the detection levels were targeted to ~ 2 magnitudes fainter than present day L^* for the known absorption redshift. A combination of filters were used in order that the rest–frame B magnitude and the 4000 Å break of the galaxies could be measured. Additionally, K band images were obtained for all fields (K band is sensitive to total stellar content and not to stellar formation rates). Confirmation of any absorbing galaxies identified in the imaging portion of the program required follow–up spectroscopy. Unless a field had several identified candidates, spectra were obtained in a pattern from small angular separation to larger until a match was found for the redshift seen in absorption[1]. The bottom line is that *no identified and confirmed absorption galaxy is proven to actually be the structure giving rise to* Mg II *absorption.* It is argued (Steidel 1995) that the program techniques have indeed singled out the galaxies responsible for the absorption, since (i) in every case a galaxy with the absorption redshift was identified without having to image to extremely faint levels, (ii) statistically significant correlations between absorption line properties and the confirmed galaxy properties have been observed, and (iii) for the most part, there was a clear absence of interloping galaxies within the fields.

1.4 HIRES/Keck Observations

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} ($R = 45,000$). Because of the HIRES format, there are small gaps in the spectra redward of 5100 Å where the free spectral range of the echelle format exceeds the width of the 2048×2048 Tektronix CCD. In the continuum near the observed Mg II features, the spectra have signal to noise ratios ranging from 15 to 50, with the majority being around 30. Both July runs were adversely affected by high patchy cirrus clouds, so these spectra typically have lower signal to noise ratios. The January 1995 spectra were obtained in clear and stable $0.5''$ seeing conditions. Thus, they typically have higher signal to noise ratios.

The journal of observations are listed in Table 1.1. The targeted systems are listed in Table 3.1. Included with these systems, are two absorbers from the spectrum of Q1101 – 264, which was generously donated by Max Pettini. The total number of Mg II systems is 48.

[1] The follow–up in most fields is nearly complete within a $10''$ radius of the QSO.

Table 1.1. Journal of HIRES/Keck Observations

Object	V [mag]	z_{em}	Date [UT][a]	Exp [s][b]	λ Range [Å]	Decker	Blocker
$0002+051$	16.2	1.899	1994 Jul 05	2700	3655.7–6079.0	C1	clear
$0058+019$	17.2	1.959	1996 Jul 18	3000	3766.2–5791.3	C1	clear
$0117+212$	16.1	1.491	1995 Jan 23	5400	4317.7–6775.1	C1	clear
$0420-014$	17.0	0.915	1995 Jan 23	3600	3810.5–6304.9	C1	clear
$0450-132$	17.5	2.253	1995 Jan 24	5400	3986.5–6424.5	C1	kv370
$0454+036$	16.5	1.343	1995 Jan 22	4500	3765.8–6198.9	C1	clear
$0454-220$	15.5	0.534	1995 Jan 22	5400	3765.8–6198.9	C1	clear
$0823-223$	15.7		1995 Jan 24	3600	3977.8–6411.8	C1	kv370
$1148+384$	17.0	1.299	1995 Jan 24	5400	3986.5–6424.5	C1	kv370
$1206+456$	16.1	1.155	1995 Jan 23	3600	3810.5–6304.9	C1	clear
$1213-003$	17.0	2.691	1995 Jan 24	5200	5008.1–7356.7	C2	kv418
$1222+228$	15.5	2.040	1995 Jan 23	3600	3810.5–6304.9	C1	clear
$1225+317$	15.9	2.219	1995 Jan 24	2400	5737.5–8194.7	C2	og530
$1241+174$	15.4	1.282	1995 Jan 22	2400	3765.8–6189.9	C1	clear
$1248+401$	16.3	1.032	1995 Jan 22	4200	3765.8–6189.9	C1	clear
$1254+044$	16.0	1.018	1995 Jan 22	2400	3765.8–6189.9	C1	clear
$1317+274$	16.0	1.014	1995 Jan 23	3600	3810.5–6304.9	C1	clear
$1329+412$	16.3	1.937	1996 Jul 18	6300	3766.2–5791.3	C1	clear
$1354+193$	16.0	0.719	1995 Jan 22	3600	3765.8–6189.9	C1	clear
$1421+331$	16.7	1.906	1995 Jan 23	3600	3818.6–6316.9	C1	clear
$1548+092$	17.5	2.749	1996 Jul 19	3600	3766.2–5791.3	C1	clear
$1622+235$	18.3	0.927	1994 Jul 04	16200	3726.9–6191.0	C1	clear
			1994 Jul 05	3040		C1	clear
$1634+704$	14.9	1.335	1994 Jul 04	2700	3723.3–6185.7	C1	clear
			1994 Jul 05	5400		C1	clear
$2128-123$	15.9	0.501	1996 Jul 19	3900	3766.2–5791.3	C1	clear
$2145+064$	16.3	0.999	1996 Jul 18	4500	3766.2–5791.3	C1	clear

[a]Total exposure time is sum of combined frames

[b]1994 July and 1996 July exposures were severly effected by cloud cover