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Kinematics of log N(H I)$\simeq$17 cm^{-2}, Metal–Rich Gas Extended Around Intermediate Redshift Galaxies

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Abstract. The kinematics of metal–enriched, low–ionization gas at large galactocentric distances are compared to the host galaxy properties and are discussed in the context of global galaxy evolution.

1. Galaxies Selected by Mg II Absorption

Like H I studies, the goal of quasar absorption line studies is to develop an understanding of the role of gas in the formation and evolution of galaxies. Whereas an advantage of H I studies is that both the spatial and line–of–sight velocity distribution of neutral gas can be studied in the context of the galaxy environment, quasar absorption lines offer a complementary approach using an *extremely sensitive* "pencil beam" probe through many galaxies over a wide range of cosmic epochs; independent of redshift, absorption lines can sample H I down to $\log N(\mathrm{H\,I}) \simeq 12$ [cm^{-2}] (e.g. Tytler 1995).

Using the resonant Mg II $\lambda\lambda 2796, 2803$ doublet , H I can be probed in galactic environments with $15 \leq \log N(\mathrm{H\,I}) \leq 21$ [cm^{-2}] (Churchill et al. 1999; Churchill & Charlton 1999; Churchill et al. 2000), making Mg II an ideal tracer for studies of global galaxy–gas evolution (kinematic, chemical, and ionization). The statistical properties of "strongish" Mg II systems are thoroughly documented to $z = 2.2$ (e.g. Lanzetta, Turnshek, & Wolfe 1987; Steidel & Sargent 1992) and are well established to be "associated" with bright, normal galaxies of almost all morphological types to $z = 1$ (e.g. Steidel, Dickinson, & Persson 1994; Steidel et al. 1997; Steidel 1998). Therefore, once the requisite observational survey work is undertaken, it is expected that Mg II absorption can be used as a tracer of extended gas around galaxies to the highest redshifts where stars first formed.

2. Galaxies and Absorption Kinematics

Because the H I column densities of the gas probed in Mg II absorption are several orders of magnitude below those observed with 21–cm emission, the regions and physical conditions studied are quite different, yet complementary, to H I studies. The actual Mg II equivalent width measured from a parcel of gas is dependent upon ionization condition, metallicity, H I column density, and velocity dispersion. For a metallicity of 0.1 solar, low ionization gas with $\log N(\mathrm{H\,I}) \simeq 17$ [cm^{-2}] and a line–of–sight velocity dispersion of ~ 20 km s^{-1} would produce a rest–frame equivalent width of $W_r(2796) \simeq 0.3$ Å. This value is well within the detection capabilities of 4–meter telescopes. However, dispersing the absorption at high resolution, to reveal the component to component velocity splittings, requires a 10–meter class telescope.

In Figure 1, WFPC2/*HST* images of 10 Mg II absorption–selected galaxies (Steidel 1998) are shown with corresponding absorption line profiles of the Mg II λ2796 transition (Churchill & Vogt 2000), obtained with HIRES/Keck I. The galaxies are presented in increasing impact parameter order from left to right (the sky–projected separation between the galaxy center and the quasar line of sight). The images are $2'' \times 2''$; the galaxy impact parameters are given in the upper portion of the panels and the redshifts in the lower portion. The absorbing gas is shown in the galaxy rest–frame velocity from -220 to 220 km s^{-1}. Ticks above the profiles give the numbers and velocities of subcomponents, based upon χ^2 Voigt profile fitting.

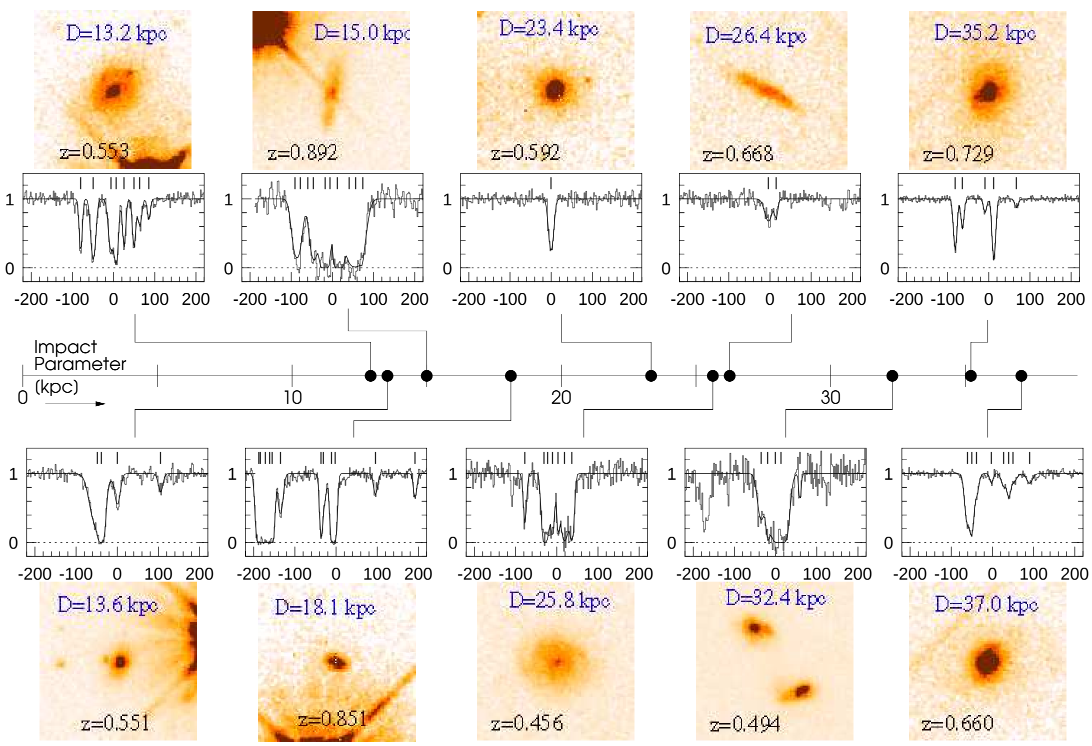

Figure 1. Galaxy morphology and Mg II λ2796 line–of–sight kinematics in increasing impact parameter order (see text for details).

These pencil beam probes reveal a wide range of kinematic complexity, with velocity spreads of $\sim$ 150 km s^{-1}, at various impact parameters. In small samples, including the one shown here, there are no statistically significant ($> 3\ \sigma$) correlations between the spatial and kinematic distributions of the metal–enriched, N(H I) gas and the galaxy properties (Churchill, Steidel, & Vogt 1996). However, the stochastic behavior in the gas properties yield general trends, including decreasing equivalent width (Steidel 1995), and increasing ionization with decreasing optical thickness with impact parameter (Churchill et al. 2000).

The absorption line results are consistent with H I 21–cm kinematic and spatial distributions, which extend to several tens of kiloparsecs, often in a flattened geometry (e.g. Irwin 1995; also see Charlton & Churchill 1996, 1998). The main difference is that the H I column densities sampled by the two techniques differ by as much as three orders of magnitude. Within a ~ 40 kpc region around galaxies, the covering factor of H I gas with $\log N(\mathrm{H\,I}) \geq 19$ [cm^{-2}] is often patchy and highly structured spatially (see many contributions throughout this volume), whereas the $\log N(\mathrm{H\,I}) = 17$ [cm^{-2}] gas has a covering factor very near unity (Steidel et al. 1994). Regardless of the processes that gives rise to the gas, it is evident that the filling factor (i.e. spatial structure "patchiness") decreases as the H I column density increases.

An additional important point, that can be gleaned from Figure 1, is that what may appear as a "normal" galaxy in an optical image may be far from normal in its spatial and kinematic distribution of metal–enriched gas. An example is the $z = 0.851$ very blue, compact galaxy at impact parameter 18.1 kpc that has velocity splittings as large as 400 km s^{-1} with complex variations in component strengths.

3. Absorption Lines and Global Galaxy Evolution

Strong metal–line absorption systems are excellent candidates for placing powerful constraints on global galactic evolution models. Metals are produced in stars, and stars are produced in galaxies; an α–group element is best suited since it is a tracer of the earliest stages of stellar evolution (i.e. Type II supernovae). Also, the absorption lines should be accessible for study over a large range of redshift (from $z \sim 0$ to $z \sim 5$) so that gas can be studied from its first enrichment by stars. This requires a near–UV transition so that confusion with Lyα forest lines can be avoided. The Mg II $\lambda\lambda 2796, 2803$ doublet meets all these criteria.

Figure 2 is a schematic of global galaxy evolution based upon the models of Pei, Fall, & Hauser (1999). Three basic epochs are shown: "Growth" ($z > 3$), "Working" ($1 < z \leq 3$), and "Retirement" ($z \leq 1$), with the respective percent of cosmic time in parenthesis. As shown with grey shading, Mg II surveys have been conducted with detection limits of 0.3 Å from $0.3 \leq z \leq 2.2$ (Lanzetta et al. 1987; Steidel & Sargent 1992) and of 0.02 Å (with high resolution) from $0.4 \leq z \leq 1.4$ (Churchill et al. 1999; Churchill & Vogt 2000).

There is strong differential evolution in the Mg II equivalent width distribution from $z \sim 2$ to $z \sim 0.5$ in that the strongest systems evolve away from "Working" epoch to the "Retirment" epoch. Observationally, this is due to differential evolution in the complexity of the Mg II kinematics with equivalent width (Churchill & Vogt 2000). Physically, it is likely due to strong metallicity and stellar evolution until $z = 1$. An additional clue to the Mg II kinematics evolution is a strong correlation of a separate "C IV phase" with the Mg II kinematics (Churchill et al. 2000). This suggests a direct connection between mechanisms that give rise to extended, multiphase halos, e.g. star formation (Dahlem 1998), and Mg II kinematics.

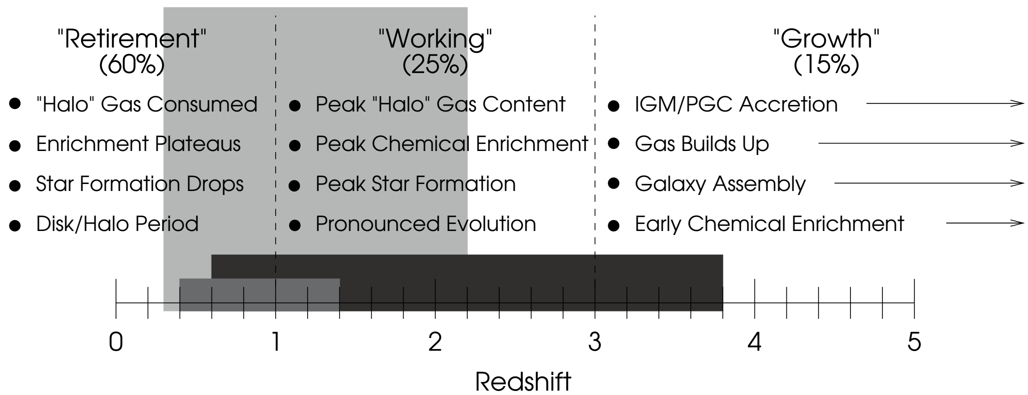

Figure 2. Schematic of the Pei, Fall, & Hauser (1999) scenario of global galaxy evolution and how it compares to observed MgII redshift and sensitivity coverage (greys) and proposed future coverage (black).

It is expected that the properties of MgII systems will evolve even more dramatically from $z = 4$, which includes the “Growth” phase (observations require high resolution infrared spectroscopy on large aperture telescopes).

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