Multiphase Gas in Intermediate Redshift Galaxies

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\textbf{Abstract.} We present 40 quasar absorption line systems at intermediate redshifts ($z \sim 1$), with focus on one of the most kinematically complex known, as examples of how the unique capabilities of space–based and ground–based facilities can be combined to glean much broader insights into astrophysical systems.

1. Hubble and the More Complete Picture

Within the field of quasar absorption lines, one long–standing question is how the halos and ISM of earlier epoch galaxies compare or relate, in an evolutionary sense, to those of the present epoch. The look–back time to $z = 1$ covers well more than half the age of the universe. Furthermore, spectral and morphological properties of absorbing galaxies are accessible with present day ground–based and spaced–based observatories (Steidel, Dickinson, & Persson 1994; Steidel 1998). Thus, absorption line studies at intermediate redshifts provide an opportunity to examine the gaseous evolution of galaxies.

The ISM and halos of local galaxies are comprised of many ionization phases, including diffused ionized gas, extended coronae, and denser low ionization regions often located in front of shock fronts (e.g. Dahlem 1998). In absorption, simultaneous study of both the low and high ionization phases in our Galaxy have been required to constrain the ionization mechanisms, chemical abundance variations, and the dust properties (e.g. Savage & Sembach 1996).

A significant obstacle in the face of rapid progress with studies employing absorption lines, however, is that the strongest transitions of the cosmologically most abundant elements lie in the far to near ultraviolet (UV) portion of the electromagnetic spectrum. Fortunately, at $z \sim 1$, the near UV transitions, which are most often associated with neutral and low ionization ions\textsuperscript{1}, are redshifted into the visible. Thus, they can be observed from the ground with large aperture telescopes. However, the far UV transitions, associated with moderate and high ionization ions\textsuperscript{2} are redshifted to the near UV; a study of the high ionization component requires a spaced–based telescope, i.e. HST. The HST archive is rich with $R = 1300$ FOS spectra of quasars, the majority due to the QSO Absorption Line Key Project (Bahcall et al. 1993).

\footnote{\textsuperscript{1}Meaning ions with ionization potentials in the range of a few to $\sim 30$ eV.}

\footnote{\textsuperscript{2}Meaning those with ionization potentials ranging between $\sim 30$ and $\sim 50$ eV and between $\sim 50$ and 140 eV, respectively.}
2. The CIV–MgII Kinematics Connection: Multiphase Gas

We used HIRES/Keck spectra \((R \sim 6 \text{ km s}^{-1})\) and archival FOS/HST spectra \((R \sim 230 \text{ km s}^{-1})\) to place constraints on the ionization and multiphase distribution of absorbing gas at \(z = 0.4\) to \(z = 1\). In Figure 1, we present MgII \(\lambda 2796\) and the CIV \(\lambda \lambda 1548, 1550\) doublet for each of 40 systems (note that the velocity scale for MgII is 500 km s\(^{-1}\) and for CIV is 3000 km s\(^{-1}\)). Ticks above the HIRES spectra give the velocities of the Voigt profile MgII sub–components and ticks above the FOS data give the expected location of these components for the CIV doublet. The labels “D”, “L”, and “Bl” denote detection, limit, and blend, respectively. The systems are presented in order of increasing MgII kinematic spread from the upper left to lower right.

Based upon a highly significant correlation between the CIV equivalent widths and the MgII kinematics, it is inferred that most intermediate redshift galaxies have multiphase gaseous structures (Churchill et al. 1999, 2000). The low ionization gas is in multiple, narrow components, \(\langle b \rangle \approx 5 \text{ km s}^{-1}\), and the high ionization gas is kinematically spread out with \(\langle b \rangle \approx 70 \text{ km s}^{-1}\) (using the
PG 1206+459, $z_{\text{em}}=1.15$

($z_{\text{obs}}=0.9254, 0.9277, 0.9343$)

Figure 2. (top) The HIRES/Keck spectra of the Mg\textsc{ii} $\lambda\lambda 2796, 2803$ doublet and Fe\textsc{ii} $\lambda 2600$ transition. — (middle and lower) The FOS/HST spectrum from the Key Project database. See text for details.
doublet ratio method). This is an effective velocity dispersion, for the FOS spectra are of too low resolution to resolve velocity splittings below \( \sim 500 \, \text{km s}^{-1} \).

3. Case Study; The Complex Triple System at \( z=0.93 \)

The three systems at \( z = 0.9254, 0.9276, \) and 0.9343 along the line of sight to PG 1206 + 459 exhibit complex Mg\( \text{II} \) kinematics and exceptionally strong C\( \text{IV}, \text{N} \text{V}, \) and O\( \text{VI} \) absorption. We investigated the ionization and spatial distribution of these systems using detailed photoionization models (Cloudy; Ferland 1996).

In the top panels of Figure 2, the HIRES/Keck spectra of the Fe\( \text{II} \lambda 2600 \) transition and of the Mg\( \text{II} \lambda\lambda 2796, 2803 \) doublet are shown with a Voigt profile model spectrum superimposed; the ticks give the component centers. The systemic redshifts of the three systems, A, B, and C, are labeled. The lower two panels show the normalized FOS/HST spectrum (histogram) with tuned model predictions (not fits) superimposed (see Churchill & Charton 1999). The dotted–line is a single–phase model, assuming all absorption arises due to ionization balance in the Mg\( \text{II} \) clouds; a single phase of gas fails to account for the high ionization absorption strengths. The solid spectrum is a two–phase model, which allows the higher ionization gas to reside in a separate phase.

Based upon the photoionization modeling, a highly ionized phase, not seen in Mg\( \text{II} \), is required to account for the observed C\( \text{IV}, \text{N} \text{V}, \) and O\( \text{VI} \) absorption. An “effective” Doppler width of \( 50 \leq b \leq 100 \, \text{km s}^{-1} \) is consistent with the complex, blended C\( \text{IV} \) data. The physical size of the high ionization component is less than 30 kpc, with the best values between 10 and 20 kpc.

Based upon the sizes and effective Doppler widths, we infer that the highly ionized material is analogous to the Galactic coronae (Savage et al. 1997), material stirred up by energetic mechanical processes, such as galactic fountains. In this scenario, the gas is concentrated around the individual galaxies which presumably provide a source of support, heating, and chemical enrichment.

It seems promising that the answer to the posed question (§ 1) may be forthcoming when HST resolves the FOS profiles with STIS and COS.

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