The Physical Conditions and Metal Enrichment of Low-Redshift Interstellar and Intergalactic Media: The Benefits of High-Resolution Ultraviolet Spectra

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Abstract. To underscore the value of high spectral resolution for the study of low-$z$ QSO absorption lines, we briefly present Space Telescope Imaging Spectrograph echelle data that demonstrate how increased resolution leads to dramatic improvement in line measurements. We show that even $R = \lambda / \Delta \lambda \approx 20,000$ is insufficient for some measurements. The higher the resolution the better, but $R \approx 50,000$ is adequate for many outstanding questions about the IGM and the ISM of galaxies that can be probed using QSO absorption lines.

1. Introduction

QSO absorption lines provide a sensitive probe of the physical conditions and enrichment of the diffuse intergalactic medium as well as the interstellar media of galaxies. It is well known that at low redshifts, the critical absorption lines are all in the ultraviolet and must be observed from space. However, the need for high spectral resolution is not always fully appreciated. This poster presented several examples, from real data obtained with the Space Telescope Imaging Spectrograph (STIS), of the benefits of high-resolution spectroscopy for the study of QSO absorbers. Some of these examples are reproduced in this short contribution to illustrate the importance of high spectral resolution as we consider options for more powerful telescope/instrument combinations to follow in the footsteps of the Hubble Space Telescope. The data used for these demonstrations were obtained with the echelle modes of STIS, which provide the following resolutions: E140M with $R = 46,000$ (FWHM = 7 km s$^{-1}$); E140H with the “Jenkins Slit” with $R = 200,000$ (FWHM = 1.5 km s$^{-1}$).

Of course, the spectral resolution required depends on the nature of the measurement. For example, due to the lower mass of hydrogen, H I absorption lines are often much broader than their corresponding metal lines (_framework_equation$^{b^2 = 2kT/m}$ for thermal broadening), and consequently the resolution requirements are more stringent for metals than for H I studies. Using E140M STIS data, Davé & Tripp (2001) showed that the majority of low-$z$ H I Ly$\alpha$ lines have $b > 15$ km s$^{-1}$, i.e., well-resolved at E140M resolution. Therefore a resolving power $R = \lambda / \Delta \lambda \approx 20,000$ is probably adequate for most H I measurements. Similarly, highly-ionized species such as O VI are often quite broad (e.g., Tripp et al. 2000; Tripp 2002) and may be sufficiently resolved at this resolution. However,
the lower-ionization lines associated with O VI systems are often narrow and intricate (e.g., Tripp et al. 2000; Simcoe et al. 2002). To study the detailed component structure of metal lines (e.g., column densities and line widths of individual components), resolving power substantially better than 20,000 is often required. It is crucial to examine individual components to properly constrain the conditions of the gas and to study abundance patterns, which sometimes show remarkable variation from component to component (e.g., Ganguly et al. 1998).

2. The ISM of NGC4319

The sight line to the QSO Mrk 205 provides a useful example of the benefits of high resolution. This sightline passes through the interarm region of the foreground spiral galaxy NGC4319 at a projected distance of 2.8 $h_{75}^{-1}$ kpc from the galaxy center (see Bowen et al. 1995 and references therein). Selected absorption lines due to the ISM of this spiral, recorded at the full 7 km s$^{-1}$ E140M resolution, are shown in the left panels of Figure 1. At 7 km s$^{-1}$ resolution, two components are readily apparent in the profiles of C I, O I, and Si II. The high ion (Si IV and C IV) profile components are remarkably similar, but not identical, to those of the low ions. $R = 46,000$ is sufficient to constrain the component parameters for all of the species in Figure 1 except O I, where the two
components are severely blended. Unfortunately, at \( R = 20,000 \), much of this information is lost, as shown in the right panels of Figure 1. At this resolution, the O I line appears to be a single component, and moreover the various species appear to have rather different component structure. Two components are still apparent (albeit badly blended) in Si II and C I. However, attempting to fit two components to the \( R = 20,000 \) Si II data leads to serious errors, as illustrated in Figure 2. The lower resolution is not sufficient to back out the correct parameters of the individual components. It is worth noting that the equivalent widths and total (i.e., integrated) column densities are correctly measured from the lower-resolution data, but the individual components are poorly constrained.

3. C I in Damped Ly\( \alpha \) Absorbers

The component structure in Figures 1 and 2 is relatively simple. Figure 3 shows a more daunting example: Milky Way C I lines in the sight line to HD210839 (\( \lambda \) Cep). Here \( R = 20,000 \) is certainly insufficient, but with \( R = 200,000 \) and coverage of many C I lines (i.e., broad wavelength coverage), the C I profiles can be effectively analyzed (Jenkins & Tripp 2001). The \( E(B - V) \) and \( N(\text{H I}) \) are substantially higher toward \( \lambda \) Cep than in NGC4319, but C I lines have been detected in several damped Ly\( \alpha \) QSO absorbers (e.g., Quast et al. 2002; Petitjean et al. 2002) that do have high H I column densities. For analysis of these systems, very high spectral resolution is paramount.

High resolution is expensive, and it is certain that compromises between resolution and throughput will be required in the design of the HST successor,
Figure 3. (top) STIS E140H echelle spectra of HD210839 (λ Cep) at $R = 200,000$ (from Jenkins & Tripp 2001). (bottom) Same data reduced to $R = 20,000$. The estimated distance to this star is 880 pc in the direction $l = 103.8$, $b = 2.6$; $E(B - V) = 0.57$.

based on the science drivers. In our experience, the resolution provided by the E140M echelle mode of STIS ($R \approx 50,000$) is adequate for a large fraction of the current questions about the IGM and ISM, but STIS can only observe the brightest targets. Ability to go deeper at this resolution would be highly valuable.

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