Galaxies In Absorption: A Study Of Chemical And Kinematic Properties Of Sub-Damped Lyman-α Quasar Absorbers

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Abstract

Study of the chemical composition of the interstellar medium (ISM) in galaxies over cosmic time is essential for a coherent understanding of galaxy formation and evolution. Absorption lines in the spectra of quasars can be used as powerful, luminosity-independent probes of the properties of gas in and around galaxies and have been used extensively to study galaxies, the circumgalactic medium (CGM) and the intergalactic medium (IGM). The Damped Lyman-α systems (DLAs), with neutral hydrogen column densities of log $N_{\text{HI}} \gtrsim 20.3$, and sub-Damped Lyman-α systems (sub-DLAs) with $19.0 \lesssim \log N_{\text{HI}} < 20.3$ are the highest $N_{\text{HI}}$ quasar absorbers and contain the most of the neutral gas available for star formation in the high-redshift Universe. These systems are believed to trace the progenitors of present-day galaxies and accurately probe chemical abundances in the ISM over $\sim 90\%$ of the cosmic history. The DLAs, in contradiction with the cosmic chemical evolution models which predict the mean metallicity of galaxies to rise from low metallicities at high-$z$ to a near-solar level at $z \sim 0$, the DLAs are typically found to be metal-poor at all redshifts, showing little or no evolution. Interestingly, past work showed that the sub-DLAs at $0.6 \lesssim z \lesssim 1.5$ are more metal-rich on average than DLAs, and evolve consistently with the chemical evolution models in this redshift range. This suggests that the DLAs and sub-DLAs may be tracing the progenitors of different populations of present-day galaxies. However, chemical evolution of sub-DLAs is poorly constrained outside of the redshift range $0.6 < z < 1.5$ which hinders a better understanding of galaxy evolution traced by DLAs and sub-DLAs.

This dissertation presents chemical abundance measurements of sub-DLA quasar absorbers at $z < 0.6$ and $z > 1.5$. The low-$z$ absorbers were studied using medium-resolution UV spectra from the Cosmic Origins Spectrograph on board the Hubble Space Telescope.
and high-resolution optical echelle spectra from the High Dispersion Spectrograph at the Subaru Telescope. The systems at $z > 1.5$ were observed with the Magellan Inamori Kyocera Echelle spectrograph at the Magellan-Clay Telescope. Lines of various elements in several ionization stages, present in these spectra, were measured to determine the respective column densities. The metallicity of the absorbing gas was inferred from the nearly undepleted elements Zn or S, and several of the absorbers were found to be near-solar or super-solar in metallicity. We have also investigated the effect of ionization on the observed abundances using photoionization modelling. We find that some of the sub-DLAs have significant amounts of ionized gas, but the ionization corrections to metallicity for all of our sub-DLAs are relatively modest ($\lesssim 0.2$ dex). Combining our data with other sub-DLA and DLA data from the literature, we report the most complete existing determination of the metallicity vs. redshift relation for sub-DLAs and DLAs. This work confirms, over a larger redshift baseline, the suggestion from previous investigations that sub-DLAs are, on average, more metal-rich than DLAs and evolve marginally faster. We also find evidence for metallicity being anti-correlated with H I column density in DLAs and sub-DLAs. The relative abundances and abundance ratios seen in these absorbers are discussed in the context of the overall trends seen in quasar absorbers. We have explored the kinematic properties of DLAs and sub-DLAs determined via velocity width measurements of unsaturated absorption lines. We also present initial evidence for higher interstellar cooling rates in metal-rich sub-DLAs than those seen in DLAs. Our findings suggest that DLAs and sub-DLAs may trace different galaxy populations with sub-DLAs being the progenitors of more massive galaxies.