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Tracing Outflows in High-Redshift Quasars

Leah E. Simon and Fred Hamann

Department of Astronomy, University of Florida, 211 Bryant Space Science Center,
Gainesville, FL 32611, USA

Abstract. We present preliminary results from the largest-ever survey of high-resolution associated absorption line (AAL) region metallicities and physical properties in a sample of high redshift ($z > 3$) quasars.

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High-redshift quasars are thought to represent an early stage of galaxy evolution, in which models by, e.g., Di Matteo *et al.* (2008) and Hopkins *et al.* (2008) predict that major mergers trigger violent star formation and the rapid growth of a central supermassive black hole. We investigate the details of this relationship using the largest-ever survey (others include Savaglio *et al.* 1994; Wampler *et al.* 1996) of narrow associated absorption line (AAL, $v_{\rm width} < 500\,{\rm km\,s^{-1}}$, forming within 12,000 $\rm km\,s^{-1}$ of the quasar emission velocity) metallicities and physical properties in a sample of high-redshift ($z > 3$) quasars with Keck high-resolution spectra in a range of near-quasar environments, including quasar outflows and host galaxy halos. We measure C IV and H I optical depths, covering fractions, widths, and column densities. We obtain good ionization constraints and determine well-constrained metallicities for five AAL systems in one $z > 3$ and two $z > 4$ quasars. We determine lower limits for metallicities for AALs in four other $z \sim 4$ quasars.

We distinguish AALs in outflows from AALs with other origins by their broad, smooth profile shapes, covering fractions, and velocity shifts. The outflow fraction for AALs in the $z > 4$ quasars is $30\% < f_{\rm O} < 50\%$, and when combined with the larger $z > 2$ sample is $50\% < f_{\rm O} < 60\%$. Smaller velocity shifts and broader lines are more likely to be associated directly with the quasar as outflows, but we see no strong trend in metallicity with velocity shift or line width. We find a broad range in AAL metallicity, from only ~ 0.01 solar up to ~ 10 times solar, consistent with previous supersolar results (Nagao *et al.* 2006; Dietrich *et al.* 2003). One $z \sim 3.5$ quasar has AALs that are supersolar in seven out of nine systems (see Simon & Hamann 2010). The AALs with covering fraction less than one are more likely to be metal rich. These results are consistent with evolutionary models in which luminous quasars appear in host galaxies after significant star formation.

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