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Connecting the Interstellar Gas and Dust Properties in Distant Galaxies Using Quasar Absorption Systems

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Abstract. Gas and dust grains are fundamental components of the interstellar medium and significantly impact many of the physical processes driving galaxy evolution, such as star-formation, and the heating, cooling, and ionization of the interstellar material. Quasar absorption systems (QASs), which trace intervening galaxies along the sightlines to luminous quasars, provide a valuable tool to directly study the properties of the interstellar gas and dust in distant, normal galaxies. We have established the presence of silicate dust grains in at least some gas-rich QASs, and find that they exist at higher optical depths than expected for diffuse gas in the Milky Way. Differences in the absorption feature shapes additionally suggest variations in the silicate dust grain properties, such as in the level of grain crystallinity, from system-to-system. We present results from a study of the gas and dust properties of QASs with adequate archival IR data to probe the silicate dust grain properties. We discuss our measurements of the strengths of the 10 and 18 μm silicate dust absorption features in the QASs, and constraints on the grain properties (e.g., composition, shape, crystallinity) based on fitted silicate profile templates. We investigate correlations between silicate dust abundance, reddening, and gas metallicity, which will yield valuable insights into the history of star formation and chemical enrichment in galaxies.

Keywords. (galaxies:) intergalactic medium, (galaxies:) quasars: absorption lines, galaxies: ISM, (ISM:) dust, extinction, ISM: abundances

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1. Silicate Dust in Gas-Rich QASs

QSO absorption systems (QASs) probe the gas and dust properties in galaxies along the sightlines to background quasars. Evidence for dust in gas-rich QASs includes refractory element depletions and background quasar reddening. In the Milky Way $\sim$66% of the core mass of interstellar dust is found in silicate grains (e.g., Zubko *et al.* 2004). Our finding of 9.7 μm silicate dust absorption in five $0.4 \leqslant z \leqslant 1.4$ dusty QASs (Kulkarni *et al.* 2011), using the Spitzer Infrared Spectrograph (IRS), led us to obtain IRS spectra covering the 9.7 μm (and for some 18 μm) absorption feature(s) for 8 more dusty, gas-rich $0.1 \leqslant z \leqslant 1.4$ QASs. We use these data in combination with archival optical spectra covering gas-phase metal lines to explore the correlations between gas and dust properties in QASs.

We find differences in the 10 μm silicate dust absorption feature substructure between QASs, which suggests dust grain property variations. This is illustrated by comparing the absorption spectrum for the z=0.886 QAS toward PKS 1830-211 with that for the

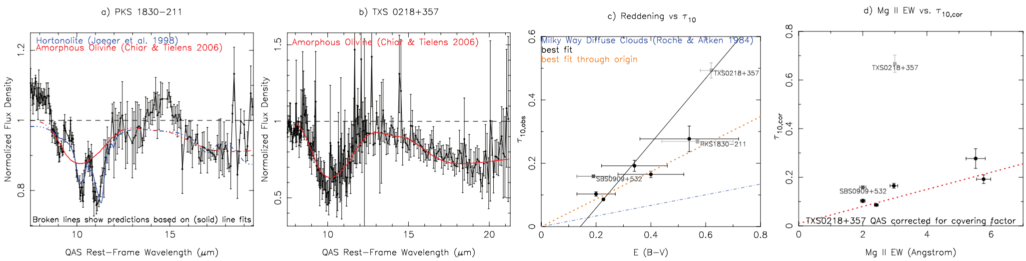

Figure 1. Template profile fits to silicate dust absorption features for (a) the z=0.886 QAS toward PKS 1830-211 and (b) the z=0.685 QAS toward TXS 0218+357 illustrating the range in spectral substructure. Adapted from Aller *et al.* 2012; Aller *et al.* 2014. (c) Possible correlation between the measured τ_{10} and the reddening, E(B-V). If corrected for the covering factor, the lensed QASs (labeled squares) will be further offset from the diffuse Milky Way clouds relationship (see Aller *et al.* 2014). (d) Suggestion of a trend between the Mg II λ2796 rest-frame EW and τ_{10}. Values in c-d for the z=0.83 QAS toward SBS 0909+532 are preliminary.

z=0.685 QAS toward TXS 0218+357 (Fig. 1, a-b). In both lensed systems the QAS is hosted by a molecule-rich (e.g., CO, HCO+, H_2O, and NH_3) face-on spiral galaxy. While the TXS 0218+357 QAS 10 μm absorption feature is well-fit by an amorphous olivine template profile, this profile does not well-reproduce the peak wavelength, breadth, and substructure of the 10 μm feature in the PKS 1830-211 QAS. Profile fits indicate that the 10 μm absorption feature properties can instead be reproduced by crystalline olivine ($Mg_{2x}Fe_{2-2x}SiO_4$) silicate templates, suggesting that the ISM silicate dust in this QAS may be more crystalline than that in the predominately amorphous Galactic ISM.

2. Silicate Dust Trends and Correlations

We investigate correlations between the 10 μm peak optical depth (τ_{10}) and both the reddening and the Mg II λ2796 rest-frame equivalent width (EW). The τ_{10}-reddening correlation is 3-6 times steeper than that found for Milky Way diffuse ISM clouds (Fig. 1, c). This may suggest differences in the silicate grains (e.g., larger grains yielding a lower UV extinction) or stellar population differences (e.g., a higher fraction of O-rich stars could increase the amount of silicate dust). We find a weak trend between the τ_{10} and the Mg II λ2796 EW (Fig. 1, d). Since the Mg II line is saturated in most systems, it may be a proxy for the velocity spread, in which case the suggested trend may indicate that silicate-dust-rich QASs are on average more massive or have stronger outflows.

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