An Observational Investigation of Interstellar Silicate Dust Grains in Low- and Moderate-Redshift Galaxies Using Quasar Absorption Systems

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Introduction – Quasar Absorption Systems (QASs)
- Using QASs to study local and distant galaxies
- Investigating dust in QASs with multi-wavelength data

Silicate Dust in QASs
- Silicate dust detections in local and moderate redshift galaxies
- Importance of quasar continuum normalizations
- Investigating correlations of silicate dust with other dust and gas properties

Summary & Future Work
Absorption Features along Line of Sight to Luminous Background Source

- Intergalactic medium (diffuse gas between galaxies)
- Circumgalactic medium (diffuse gas near galaxy)
- Outflows

Impact parameter

Background light source

Observer

Peeples 2015
UV/Optical Spectra (gas properties):
- abundances;
- kinematics;
- temperature;
- density;
- ionization parameter

Infrared Spectra (silicate dust):
- grain property constraints from 10 and 18 μm absorption features

From Webb; Pettini 2003
In investigating Dust in Individual QASs

Dust Absorption in z=0.524 QAS toward Blazar AO 0235+164

UV ➔ Carbonaceous Dust

IR ➔ Silicate Dust

multi-wavelength data yields extinction curve from UV to IR
Dust Absorption in z=0.524 QAS toward Blazar AO 0235+164

Varsha Kulkarni’s talk yesterday

multi-wavelength data yields extinction curve from UV to IR
investigated catalogued blazars with archival Spitzer IRS spectra
QASs towards blazars

Credit: Pierre Auger Observatory
Crystalline Silicates?

Hortonolite Crystalline Olivine Mg\textsubscript{1.1}Fe\textsubscript{0.9}SiO\textsubscript{4}
Laboratory Amorphous Olivine

QAS HOST: z=0.9 late-type spiral galaxy
- lensed $\rightarrow$ 2 sightlines separated by 7.6 kpc
- gas-rich QAS $\rightarrow$ log $N_{\text{HI}}$\~21.3-21.5
- molecule-rich (CO, HCO\textsuperscript{+}, HCN, H\textsubscript{2}O, NH\textsubscript{3})

Amorphous Silicates?

Laboratory Amorphous Olivine

QAS HOST: z=0.7 face-on spiral galaxy
- lensed $\rightarrow$ 2 sightlines separated by $\sim$2.4 kpc
- gas-rich QAS $\rightarrow$ log $N_{\text{HI}}$\~21.1
- molecule-rich (CO, HCO\textsuperscript{+}, H\textsubscript{2}O, NH\textsubscript{3}, LiH)
QASs in moderate redshift (z<2) foreground galaxies relative to blazar

QAS HOST: z=0.2 dwarf galaxy
- impact parameter 20 kpc (Chun+2006)
- disk-dominated (bulge:disk ratio of 0.34)
- gas-rich QAS $\rightarrow$ log $N_{\text{HI}}$~21
- < 20% solar metallicity, SFR <0.3M$_{\odot}$/yr
- 21-cm absorption

QAS HOST: z=0.5 spiral galaxy
- impact parameter ~7 kpc (Chun+2006)
- gas-rich QAS $\rightarrow$ log $N_{\text{HI}}$~22
- 0.7 solar metallicity
- 21-cm and X-ray absorption, 2175 Å bump
- several diffuse interstellar bands
QAS in Milky Way

Galactic latitude of -10°

Laboratory amorphous olivine \( \tau_{10} = 0.045 \)

AGN sightlines passing close to the Galactic plane

LSP BL Lac
QAS in blazar host galaxy

Laboratory amorphous olivine profile

\[ \tau_{10} = 0.871 \]

z=0.2 spiral galaxy

HI abs. 25 mas from nucleus

- gas-rich QAS \( \rightarrow \) \( \log N_{\text{HI}} \approx 22 \)
- molecule-rich (CO, CN, OH, HCO\(^+\), HCN, HNC)
- 21 cm absorption: \( \tau_{\text{peak}} = 0.3 \) Curran et al. 2005

LSP BL Lac

McHardy et al. 1991
Variations in 10-18 micron ratio with Normalization

\[ \tau_{10} = 0.94 \pm 0.01 \]

Amorphous olivine (solid, spherical particles)

\[ \tau_{10} = 0.87 \pm 0.01 \]

Laboratory amorphous olivine

\[ \tau_{10} = 0.92 \pm 0.01 \]

Amorphous olivine (porous, ellipsoidal particles)

Different quasar continuum normalizations can significantly impact the 10:18 micron ratio.
**Silicate Dust vs. Reddening in QASs**

- **Grain differences?**
  e.g. larger grains-low UV extinction

- **Sampling different dust grain population?**
  e.g. face-on vs. through MW disk

- **Different stellar populations?**
  e.g. more O-rich

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**Slope of relation is 3-6x higher for QASs than for Milky Way diffuse clouds**

\[ f_{\text{cov}} = 1 \text{ assumed in all QASs} \]
Are silicate-rich QASs more massive? Are silicate-rich QAS poor in carbonaceous dust?
Summary & Future Work

- **Silicate dust absorption in gas-rich QASs**
  - Variation in shape, breadth of absorption feature → grain differences?
  - 10:18 μm feature ratio & derived grain properties depend on continuum normalization
  ➔ Exploring more systems with non-blazar AGN (more structured)

- **Trends of $\tau_{10}$ with other dust and gas properties of QAS**
  - Correlation with E(B-V) – but steeper slope than in MW clouds
  - Possible trends with Mg II EW and carbonaceous dust abs. strength
  ➔ Investigating more diverse sample and new E(B-V) measurements

  **Big Picture Questions Working to Address:**

1. **ISM metallicity vs. depletion?** → enrichment of gas versus solid phase following peak era of SF
2. **Dust composition –distant galaxies dominated by silicate or carbonaceous dust?** → SFH; extinction corrections for distant galaxies
3. **Silicate grain structure** → Crystallinity implies recent SF or weaker ISM processing; grain structures crucial in dust models
4. **Gas-Dust Interrelations: trends between metallicity-silicate dust-galaxy mass-dust abundance** → is dust processing more efficient in high mass or higher SFR galaxies?