Investigating Silicate Dust in Galaxies Using Quasar Absorption Systems

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Outline

Introduction – Quasar Absorption Systems (QASs)
- Using QASs to study distant galaxies
- Evidence for dust in QASs
- Evidence of variations in silicate dust in QASs

Multi-wavelength archival study of dust & gas in QASs
- Silicate dust in QASs
  - Importance of quasar continuum normalizations
  - Silicate dust detections in local and higher redshift galaxies
- Investigation into trends and correlations of dust and gas

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

Galaxy

Observer

Peeples 2015
Quasar Absorption Systems (QASs)

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

- Damped Lyman-α absorbers (DLAs): $N_{\text{HI}} \geq 2 \times 10^{20} \text{cm}^{-2}$
- sub-DLAs: $10^{19} \leq N_{\text{HI}} < 2 \times 10^{20} \text{cm}^{-2}$

Si IV (1393 Å)

C IV (1548 Å)

Lyman limit

H absorption

H emission from quasar

Intervening gas

To earth

From Webb; Pettini 2003
Evidence for Dust in QASs: reddening & depletions

SMC-like reddening for absorbers

More severe depletions with increasing metallicity
(e.g., Ledoux et al. 2003; Meiring et al. 2006, 2009)

$X = \text{Zn or S (if Zn unavailable)}$
Evidence of Carbonaceous and Silicate Dust in Limited Number of Individual QASs

Silicate Dust in $z=0.524$ QAS toward blazar AO 0235+164

Feature best-matched by profiles for diffuse Galactic interstellar clouds or laboratory amorphous olivine – with a shallow peak optical depth (~0.08)

Dust extinction is present based on 2175 Å bump (carbonaceous)

Kulkarni et al. 2007

Junkkarinen et al. 2004

Led to dedicated Spitzer IRS mini-survey of 12 dusty gas-rich $0.2 \leq z_{\text{abs}} \leq 1.4$ QASs to investigate silicate dust
Variations in Silicate Dust in QASs

- z=0.9 QAS (log $N_{HI}$~21.3-21.5)
- molecules (e.g., CO, HCO$^+$, HCN, H$_2$O, NH$_3$)
- host galaxy: late-type spiral galaxy
- background QSO: lensed blazar

- z=0.7 QAS (log $N_{HI}$~21.1)
- molecules (e.g., CO, HCO$^+$, H$_2$O, NH$_3$, LiH)
- host galaxy: face-on spiral galaxy
- background QSO: lensed blazar

Hortonolite Crystalline Olivine $\text{Mg}_{1.1}\text{Fe}_{0.9}\text{SiO}_4$
Laboratory Amorphous Olivine

Crystalline Silicates?
Amorphous Silicates?
NASA-ADAP programs to explore connections between gas and dust properties in QASs using archival space- and ground-based data:

**DISTANT GALAXIES:**
Moderately gas-rich QASs (0.1 < z_{abs} < 2.8)

**DUST MEASUREMENTS IN QASs:**
- Silicate dust 10/18 µm feature in QASs (Spitzer IRS)
- Signatures of silicate crystallinity?
- Shapes of extinction curves for QASs
- Relative abundance of carbon:silicate dust

**GAS MEASUREMENTS IN QASs WITH DUST INFORMATION:**
- Ascertain gas metallicity and depletions
- Estimate gas kinematics (e.g. velocity structure)

**CONNECTIONS BETWEEN DUST/GAS AND MODELS:**
Interrelation between gas and dust properties in connection to dust/ chemical evolution models

**LOCAL GALAXIES:**
Sightlines to background AGN close to Galactic plane or through local galaxies

**DUST MEASUREMENTS:**
- Silicate dust 10/18 µm feature
- Extinction curves along sightlines
- 2175 Å features along *same sightline* to look at carbon:silicate ratio

**GAS MEASUREMENTS:**
- Gas phase element depletions

**CONNECTIONS BETWEEN LOCAL AND HIGHER REDSHIFT DUST:**
Examine dust properties and correlations at low redshift (<0.1) relative to those in higher redshift study

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Quasar Continuum Normalization

LSP BL Lac without Absorber

Credit: Pierre Auger Observatory
Quasar Continuum Normalization

Cubic Polynomial Fits to BL Lac Sources without Absorber

Normalized Flux Density

Blazar Rest Frame Wavelength (micron)

Spectra from CASSIS (Lebouteiller et al. 2011; 2015)
z=0.2 DLA (log $N_{\text{HI}} \sim 22$) in a spiral host galaxy

- in blazar host galaxy
- blazar: LSP BL Lac
- rich in molecules (e.g., CO, CN, OH, HCO$^+$, HCN, HNC)
- exhibits 21-cm absorption

Labatory amorphous olivine profile

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

Amorphous olivine (solid, spherical particles)

Laboratory amorphous olivine

Amorphous olivine (porous, ellipsoidal particles)

Different quasar continuum normalizations can significantly impact the 10:18 micron ratio

The background blazar is classified as an LSP BL Lac
$z=0.2$ DLA ($\log N_{\text{HI}} \sim 21$) in early-type dwarf galaxy

- impact parameter 20 kpc
- LSP FSRQ blazar
- disk-dominated galaxy, with a B/D ratio of 0.34
- SFR $< 0.3 M_{\odot}$/yr
- $< 20\%$ solar metallicity

Kulkarni et al. (2005)
Absorber Properties:
- 21-cm and X-ray absorption
- metallicity of 0.7 solar
- strong 2175 Å bump
- several diffuse interstellar bands
As part of our investigation into the relationship between silicate and carbonaceous dust in the Milky Way galaxy and Local Group galaxies, we are examining all AGN sightlines passing close to the Galactic plane.

This sightline to an LSP BL Lac blazar at a Galactic latitude of -10°.
As part of our investigation into the relationship between silicate and carbonaceous dust in the Milky Way galaxy and Local Group galaxies, we are examining all AGN sightlines passing close to the Galactic plane. This sightline to an LSP BL Lac at a Galactic latitude of -10° has weak absorption features consistent with silicate dust absorption in the Milky Way. The shape of these features are consistent with laboratory amorphous olivine over the 10 and 18 μm features.

Fitting extinction curves to SEDs constructed for sightlines to 72 AGN with known z>0.1 absorption systems & measuring 2175 Å strength.
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

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

\( f_{cov} = 1 \) assumed in all QASs
Suggestion of trend between Mg II EW and silicate 10 µm peak optical depth:

Are silicate-rich QASs more massive?

Mg II saturated in most systems, and is proxy for velocity spread (QAS mass; outflows)
Summary & Future Work

- **Silicate dust in absorption in QASs**
  - 10 µm (and 18 µm) silicate absorption in gas-rich QASs at z<1.4
  - Variation in shape, breadth of absorption feature
  - Ratio of 10:18 µm feature & derived grain properties dependent 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 Trend with Mg II EW – silicate rich are more massive?
  - Suggestion of anti-correlation with carbonaceous dust abs. strength
  ➔ Investigating with larger/more diverse sample

**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?*