Investigating Silicate Dust in Galaxies Using Quasar Absorption Systems

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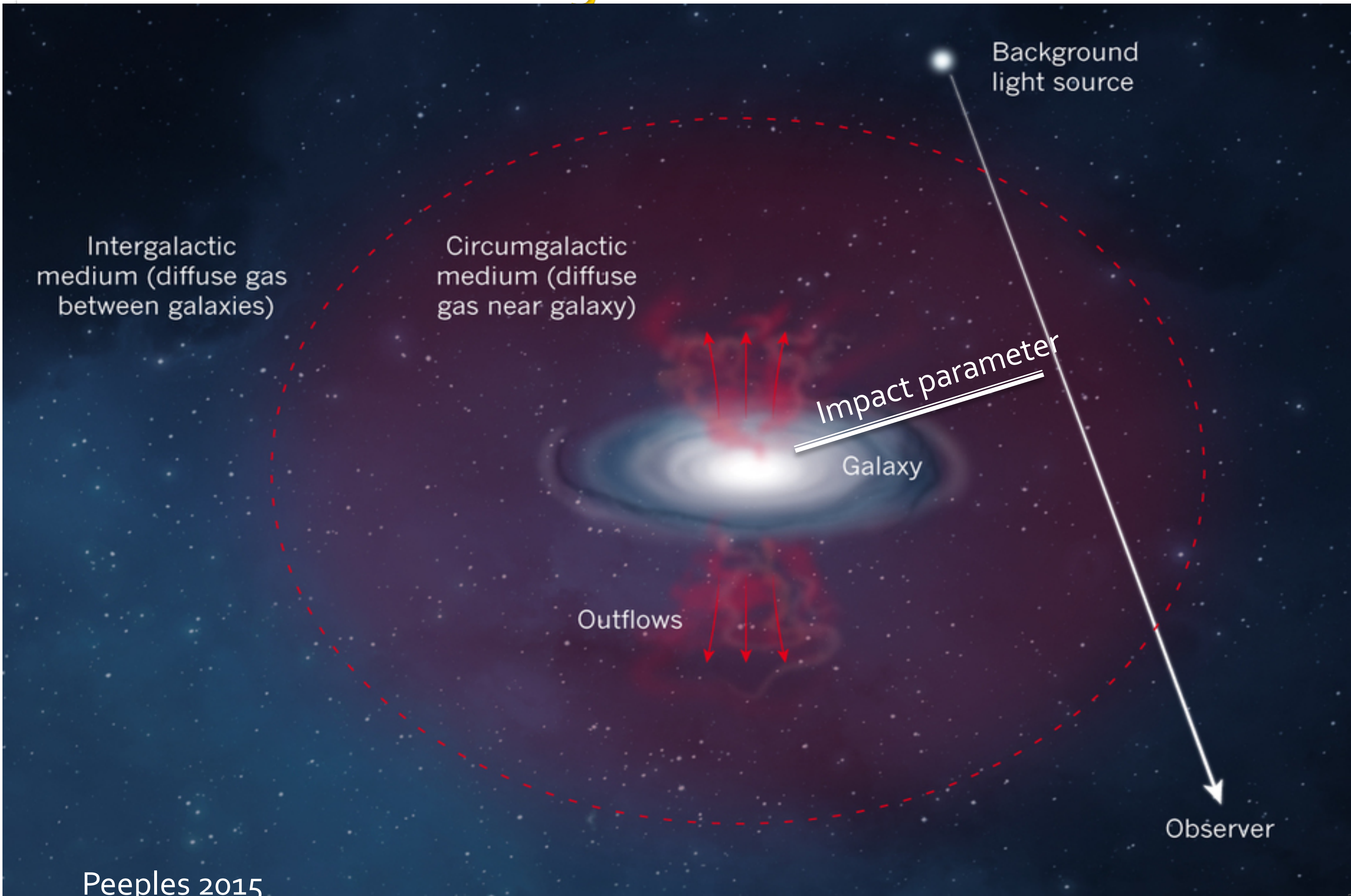
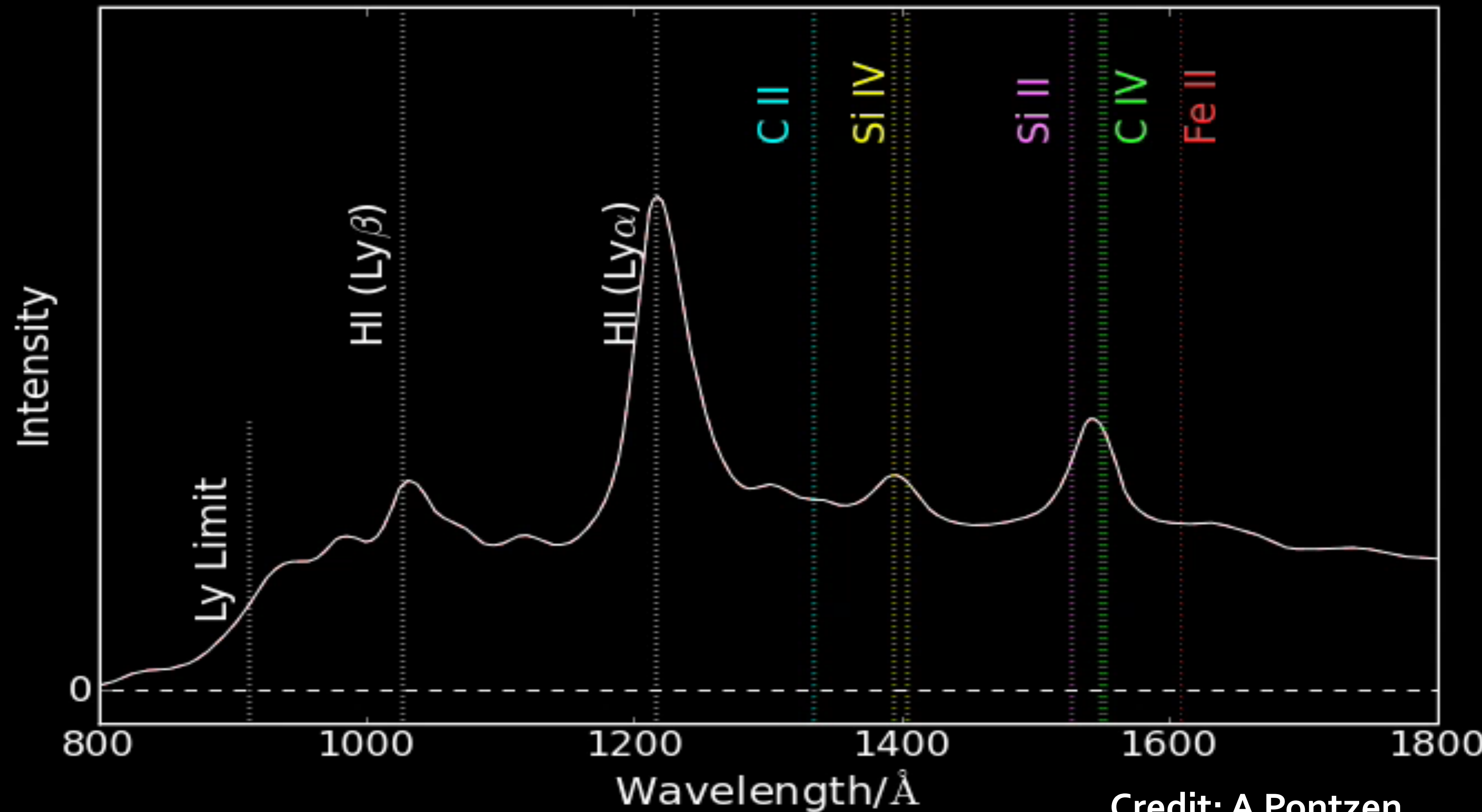
Outline

- 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

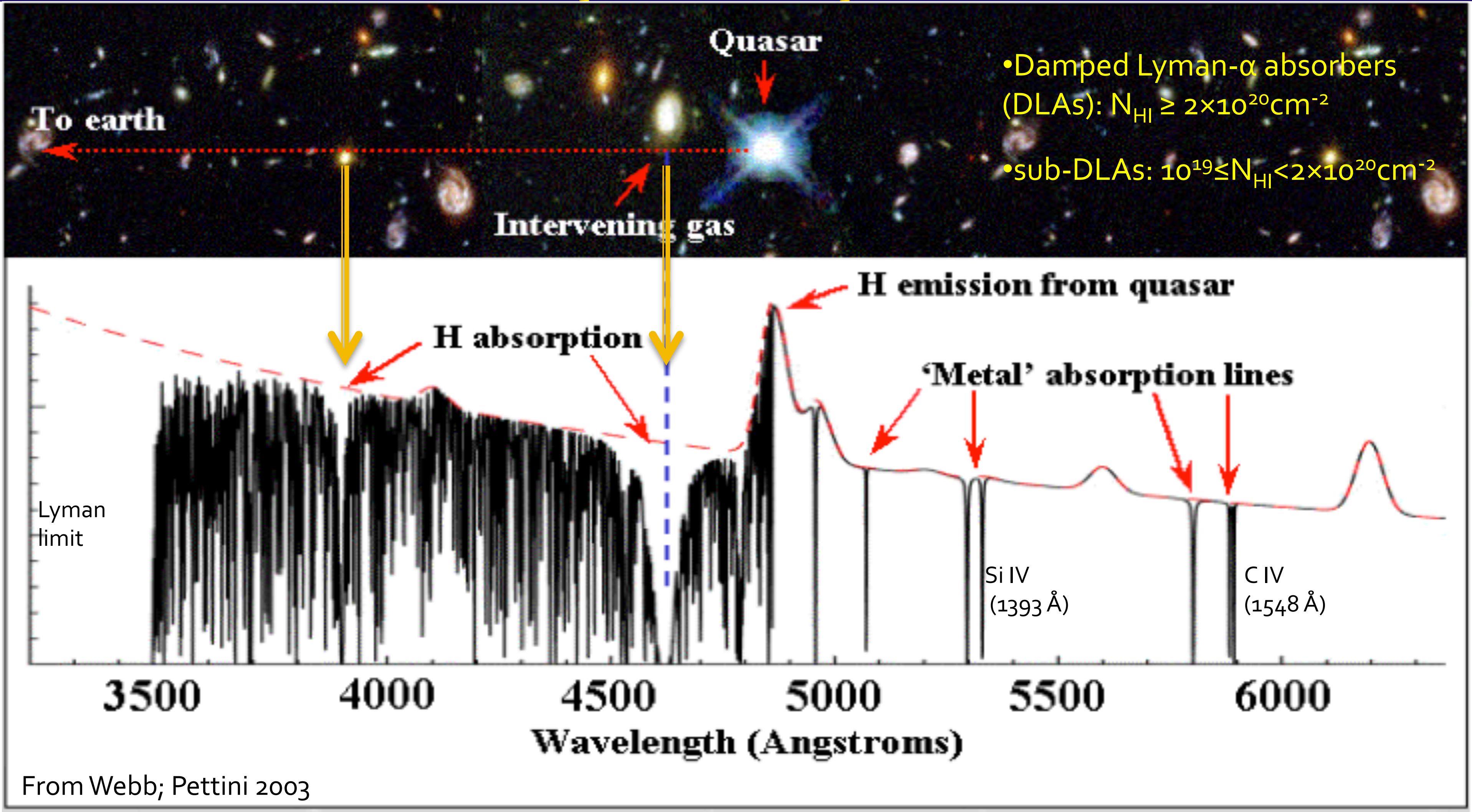
Absorption Features along Line of Sight to Luminous Background Source





Credit: A Pontzen

Quasar Absorption Systems (QASs)



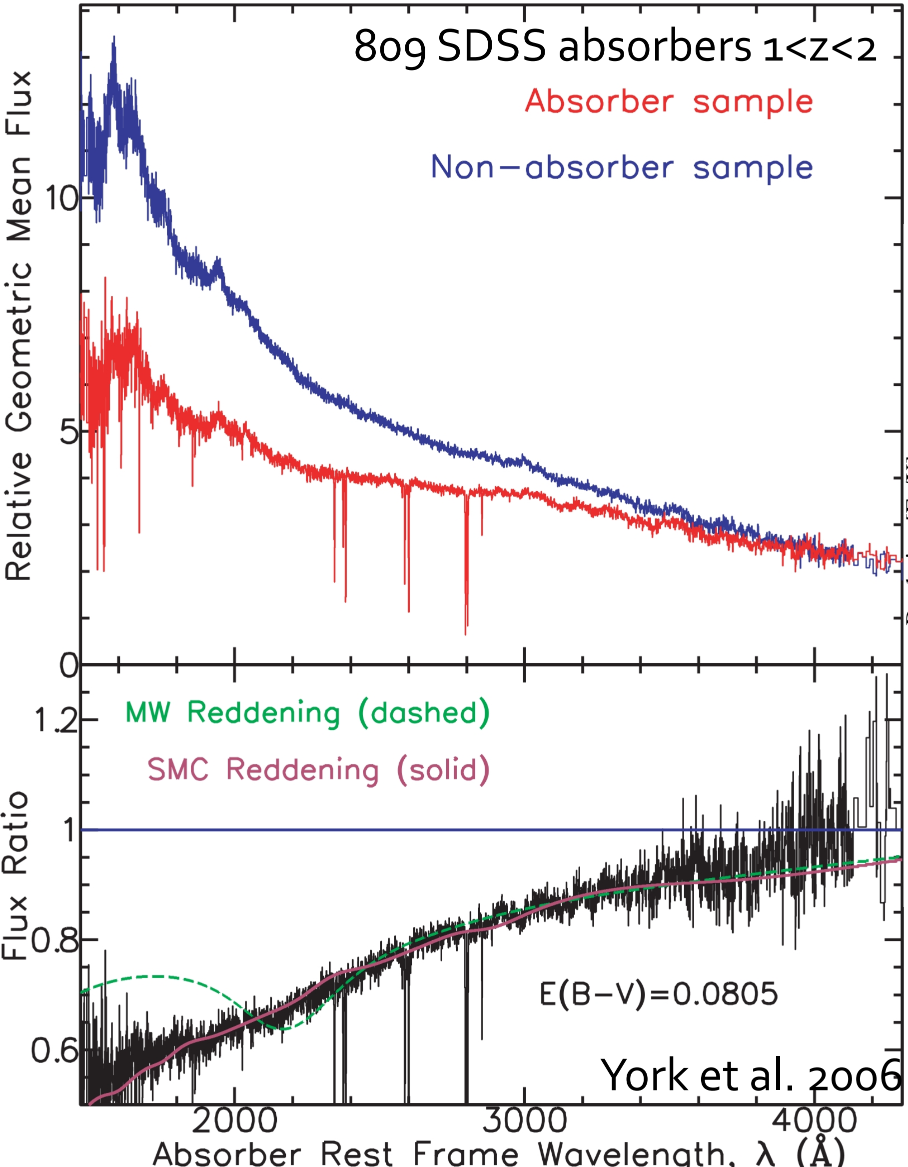
From Webb; Pettini 2003

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

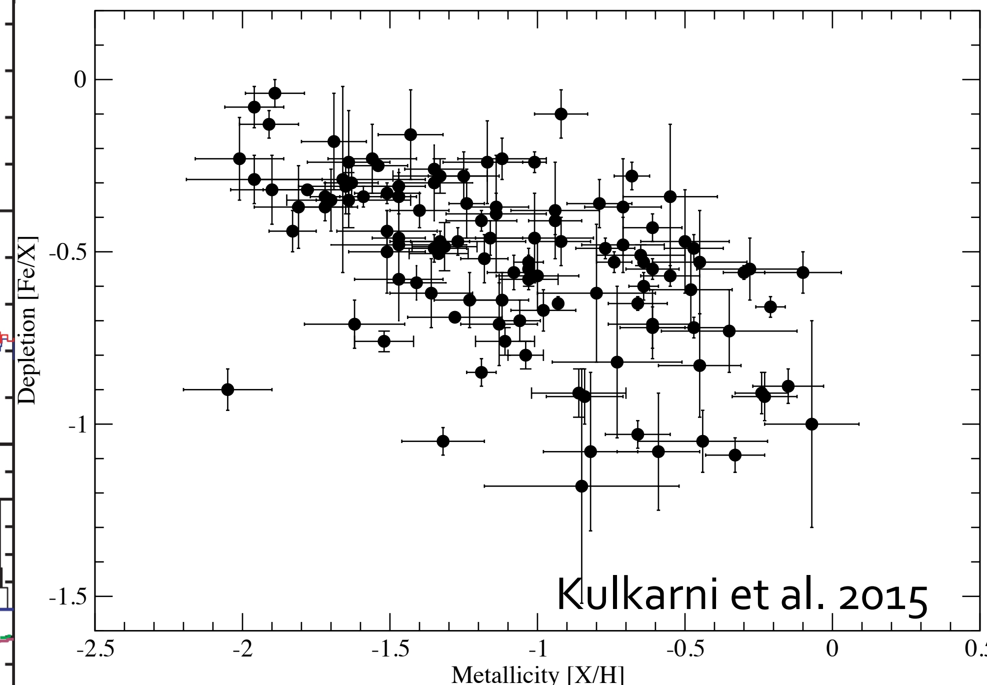
Evidence for Dust in QASs: reddening & depletions

SMC-like reddening for absorbers



More severe depletions with increasing metallicity

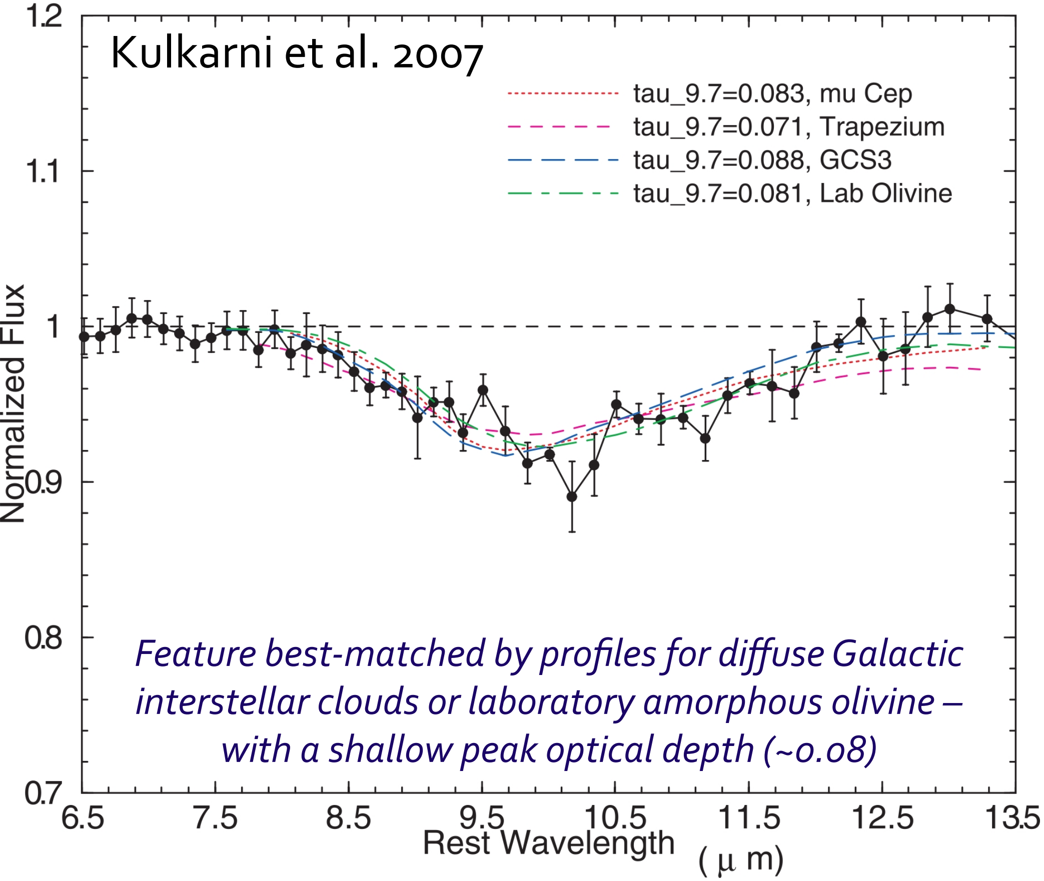
(e.g., Ledoux et al. 2003; Meiring et al. 2006, 2009)



X = Zn or S (if Zn unavailable)

Evidence of Carbonaceous and Silicate Dust in Limited Number of Individual QASs

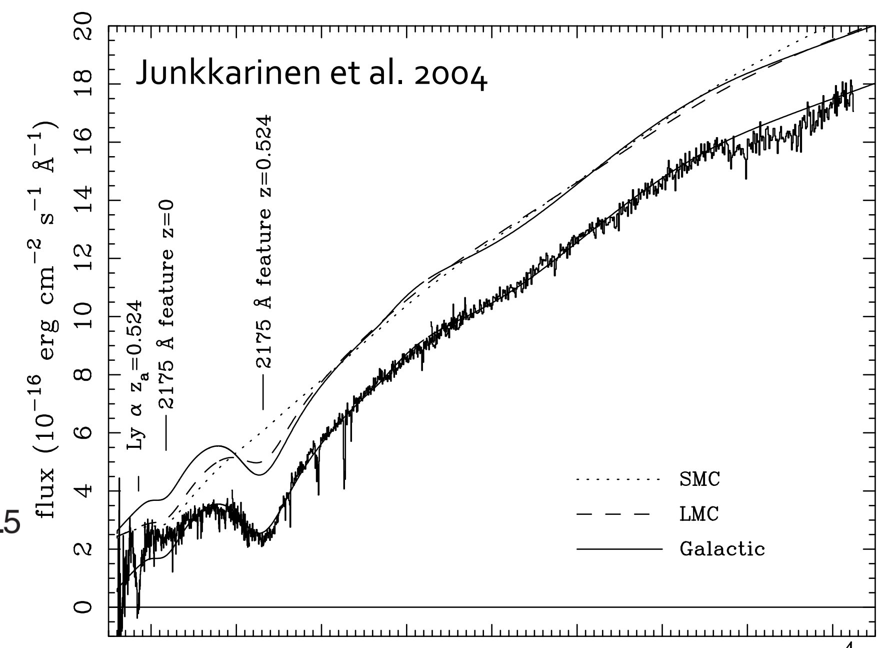
Silicate Dust in z=0.524 QAS toward blazar AO 0235+164



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

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

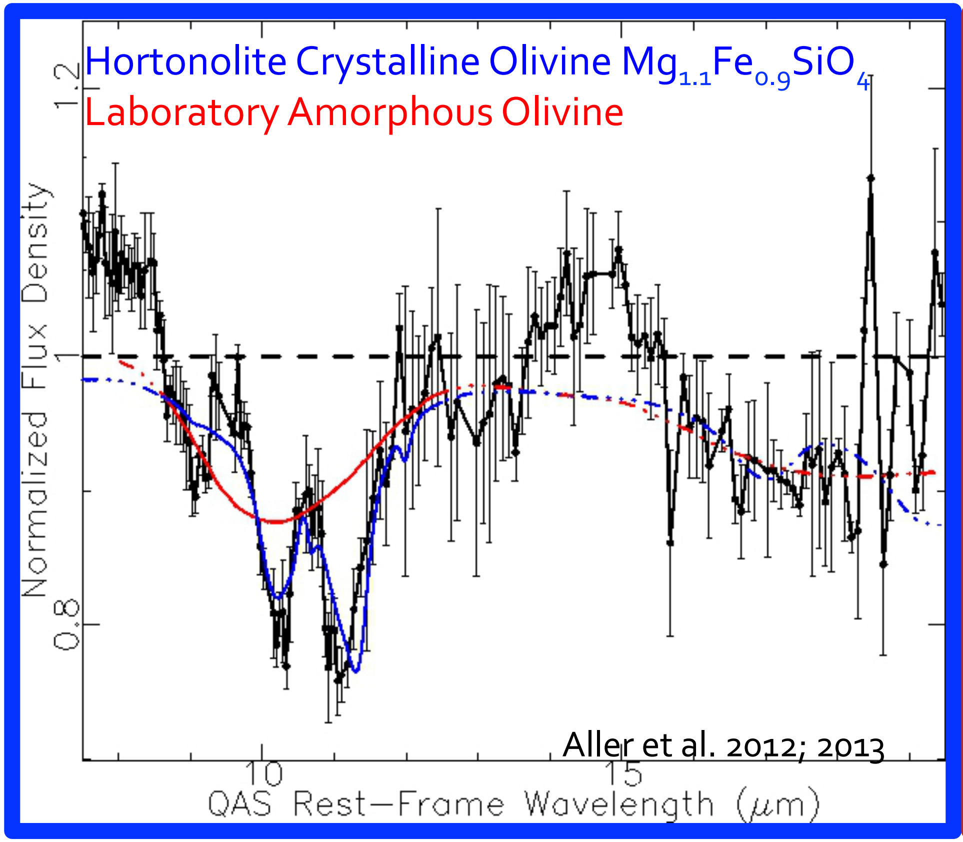
Dust extinction is present based on 2175 Å bump (carbonaceous)



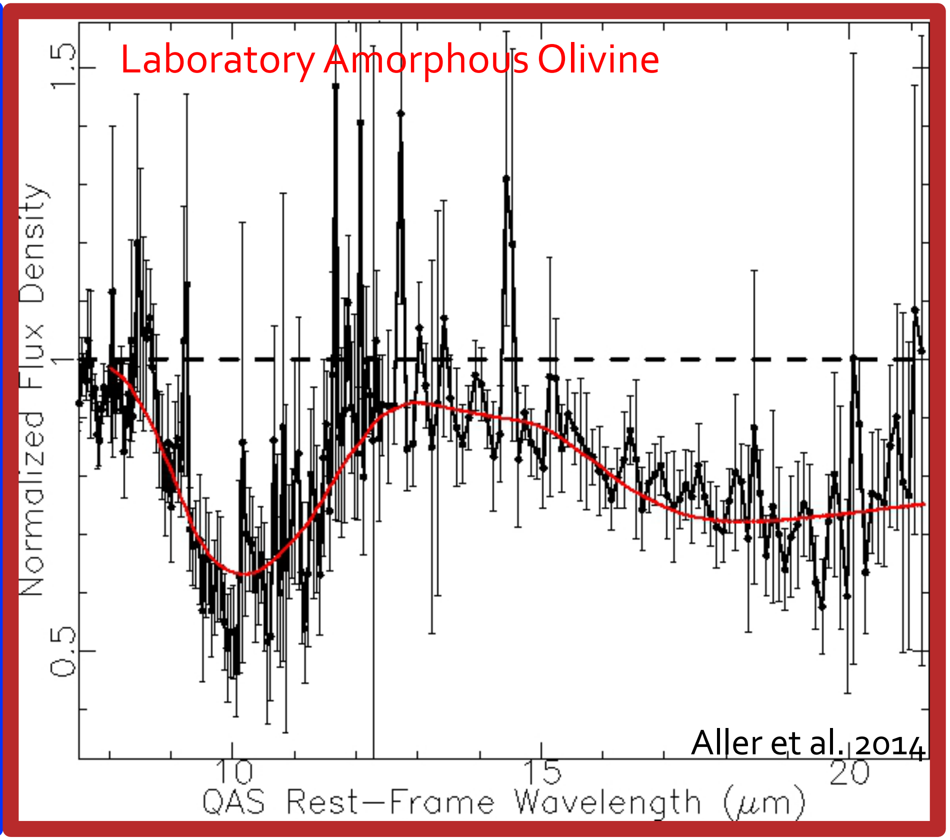
Variations in Silicate Dust in QASs

- z=0.9 QAS (log N_{HI}~21.3-21.5)
- molecules (e.g., CO, HCO^+, HCN, H_2O, 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_2O, NH_3, LiH)
- host galaxy: face-on spiral galaxy
- background QSO: lensed blazar



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

V. P. Kulkarni (PI, *U. South Carolina*); M.C. Aller (co-I/Science-PI; *Ga. Southern U.*); E. Dwek (co-I; *NASA-GSFC*)

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:

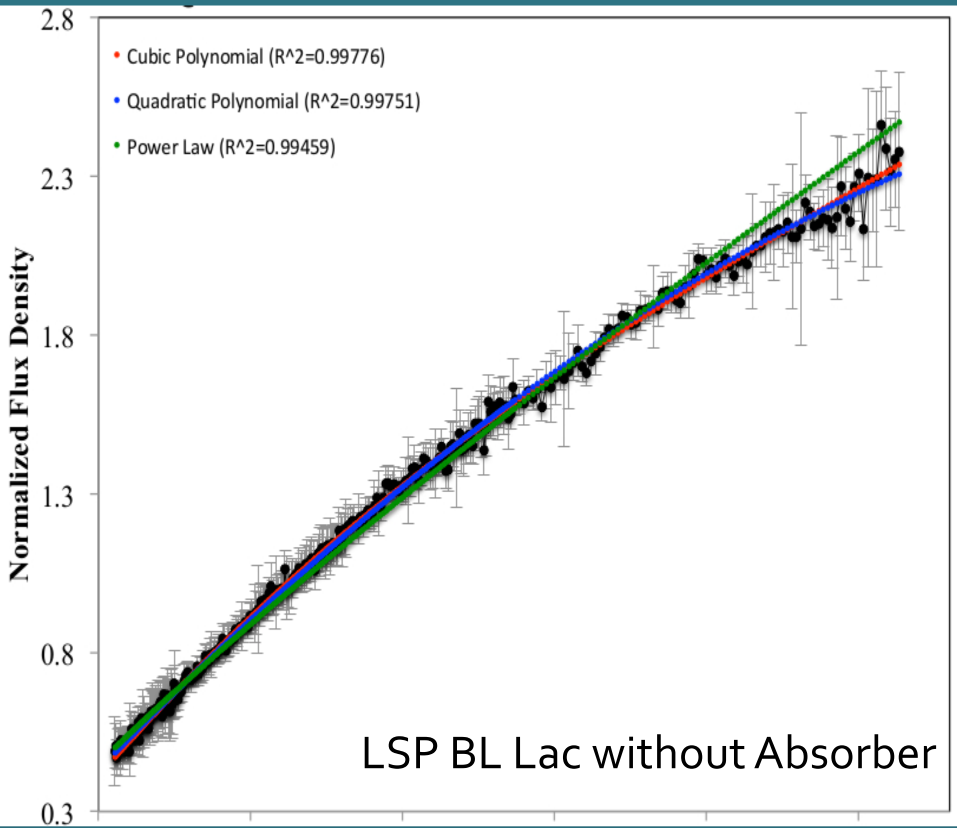
- Gas phase element depletions

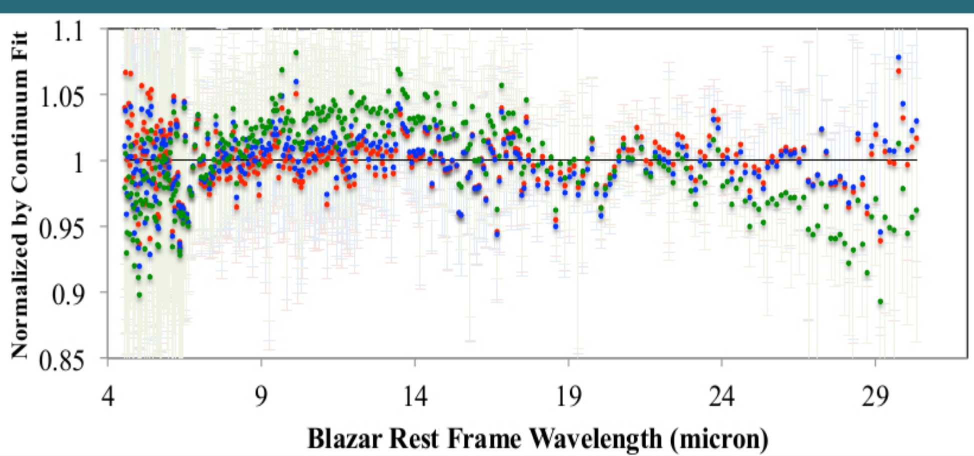
Connections Between Local and Higher Redshift Dust:

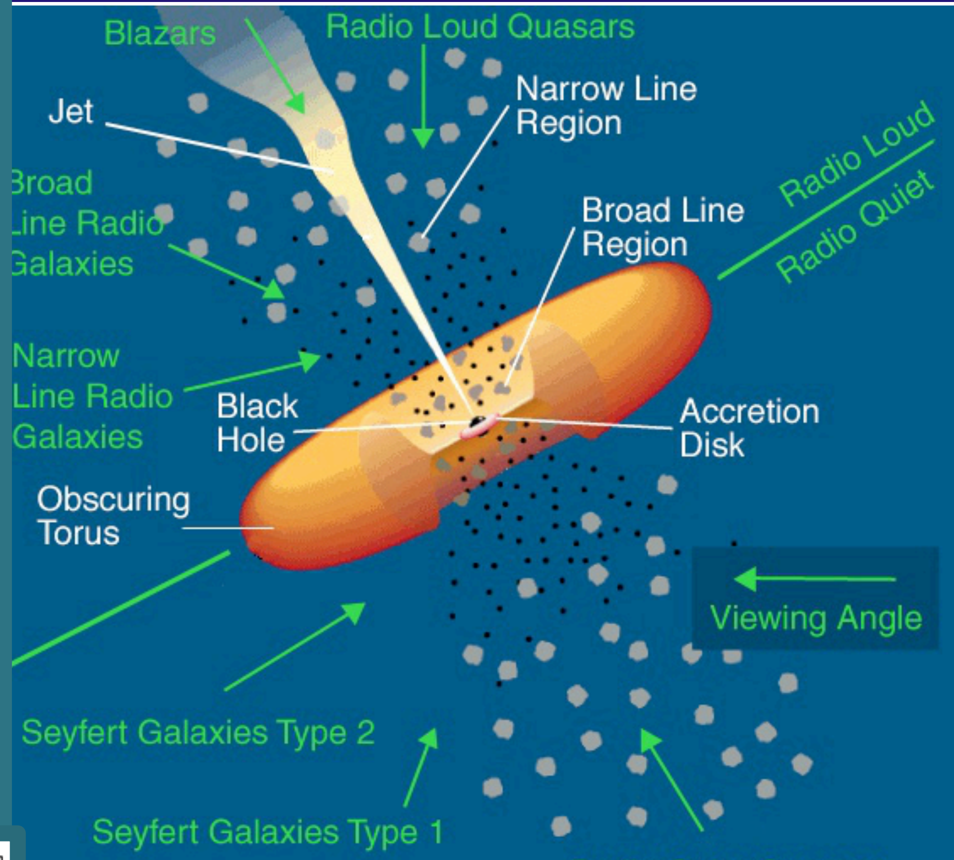
Examine dust properties and correlations at low redshift (<0.1) relative to those in higher redshift study

V. P. Kulkarni (PI, *U. South Carolina*); M.C. Aller (co-I; *Ga. Southern U.*); E. Dwek (co-I; *NASA-GSFC*)

Quasar Continuum Normalization

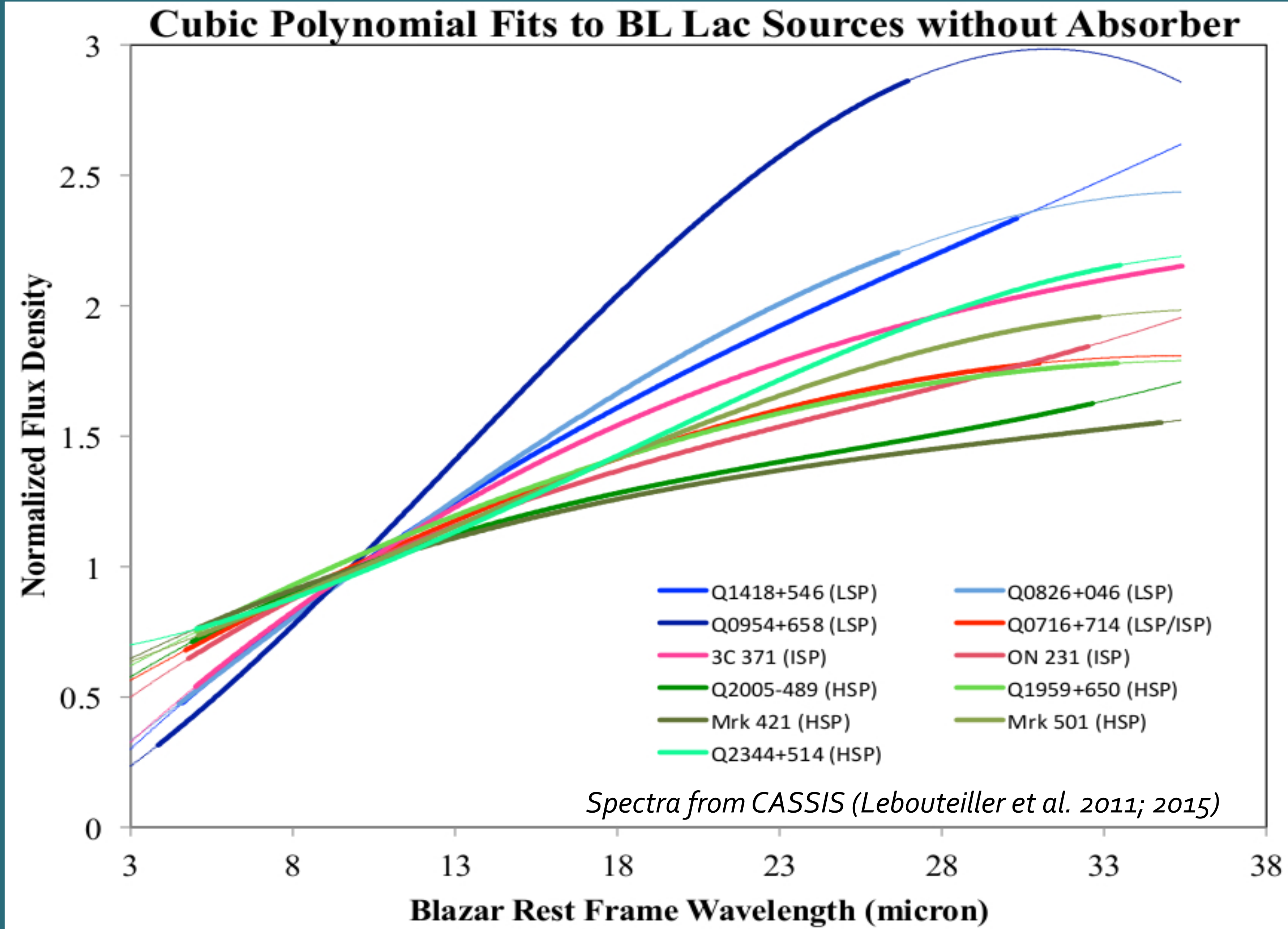




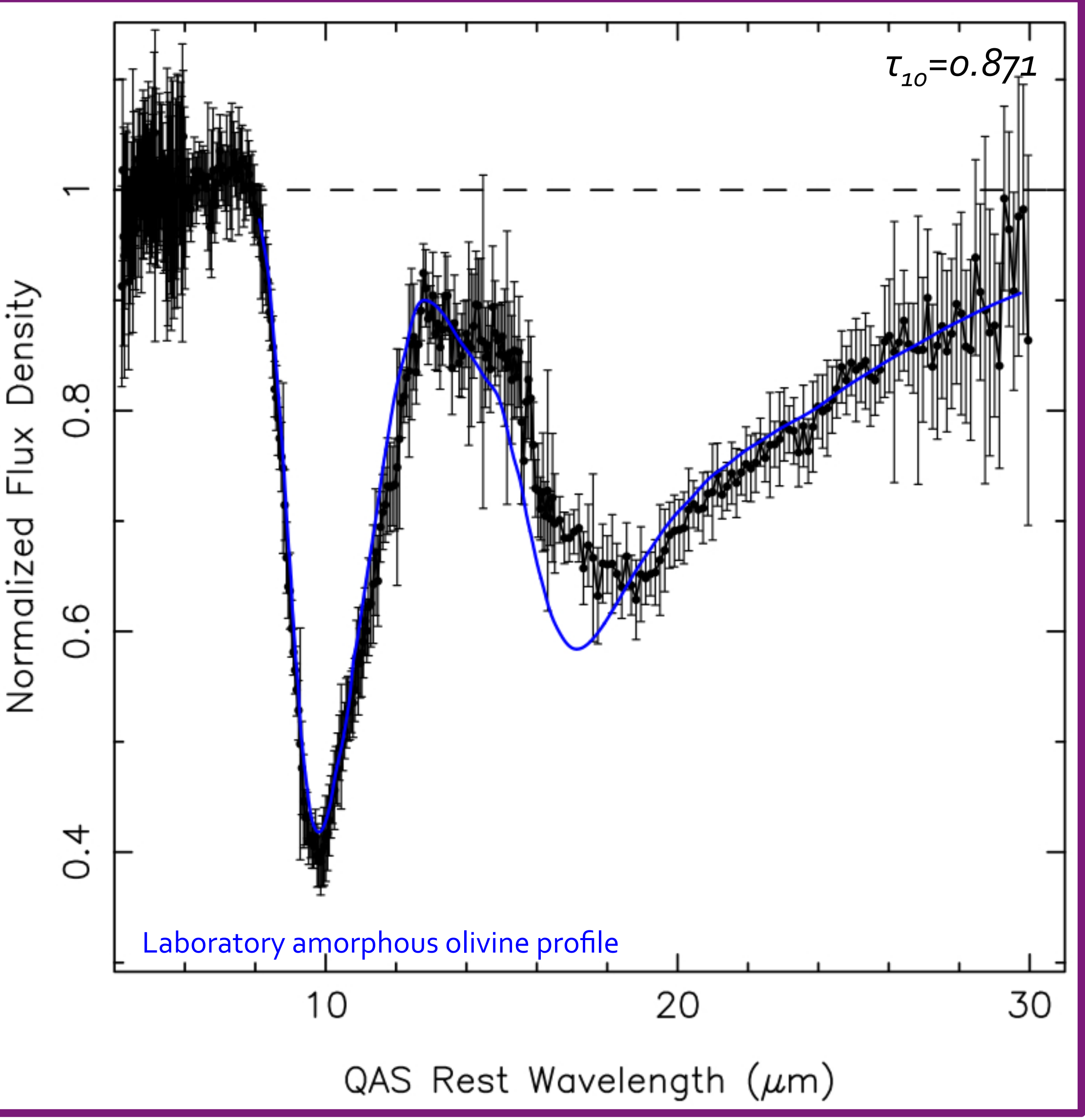


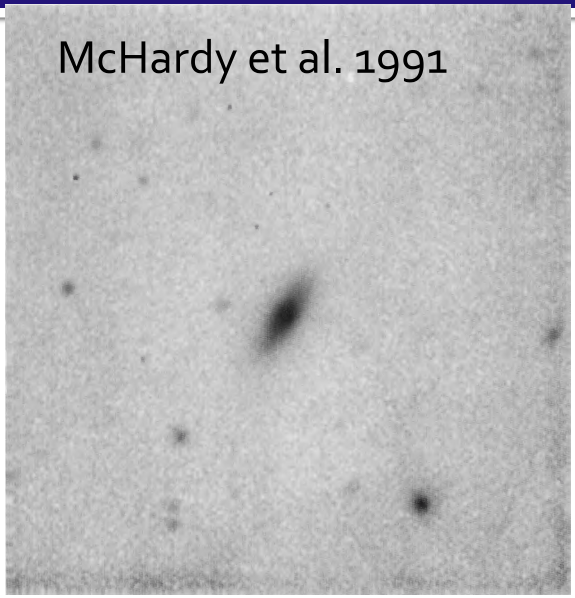
Credit: Pierre Auger Observatory

Quasar Continuum Normalization



z=0.2 DLA (log N_{HI}~22) in a spiral host galaxy



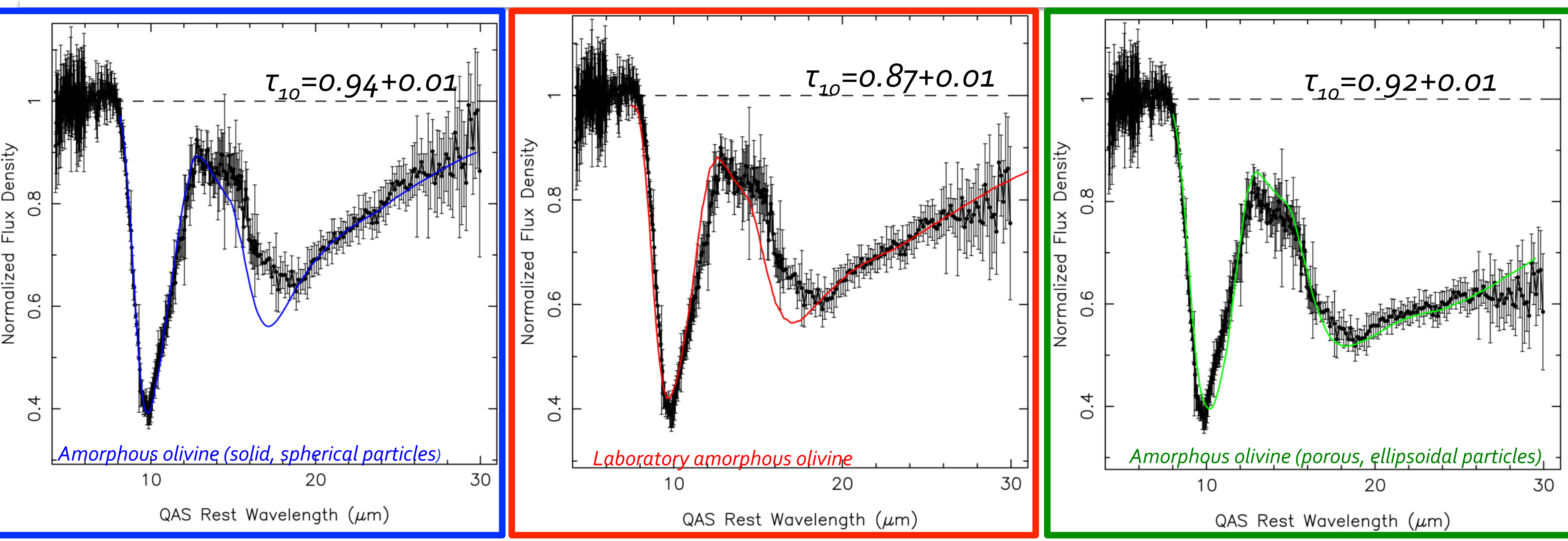


- in blazar host galaxy
- blazar: LSP BL Lac

- rich in molecules (e.g., CO, CN, OH, HCO^+, HCN, HNC)

- exhibits 21-cm absorption

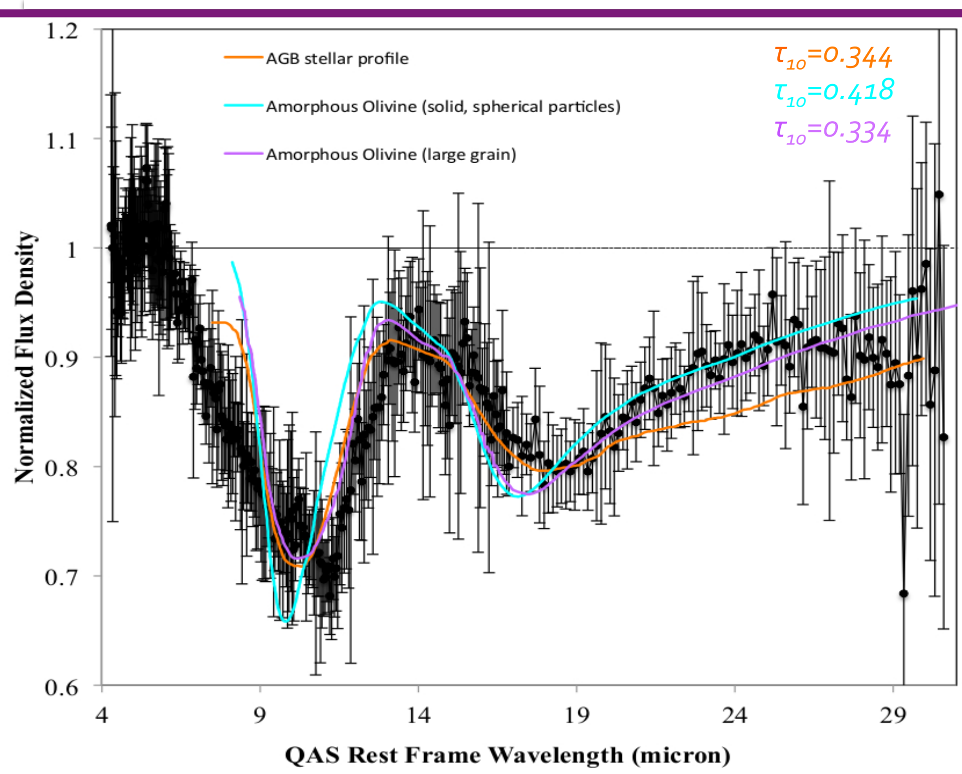
Variations in 10-18 micron ratio with Normalization

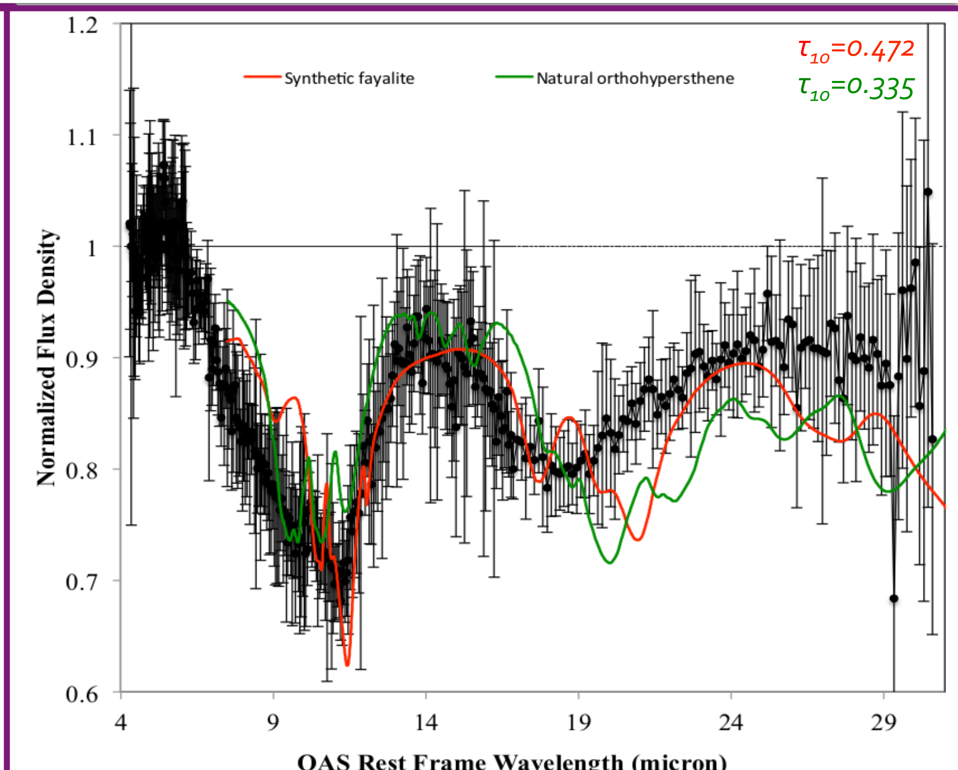


Different quasar continuum normalizations can significantly impact the 10:18 micron ratio

The background blazar is classified as an LSP BL Lac

z=0.2 DLA (log N_{HI}~21) in early-type dwarf galaxy

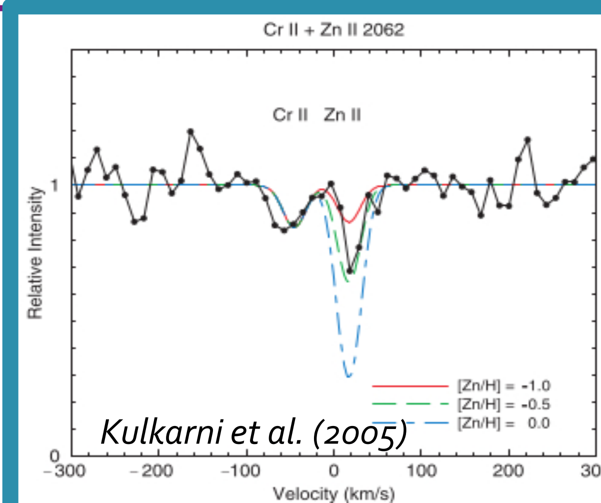




- impact parameter 20 kpc
- LSP FSRQ blazar

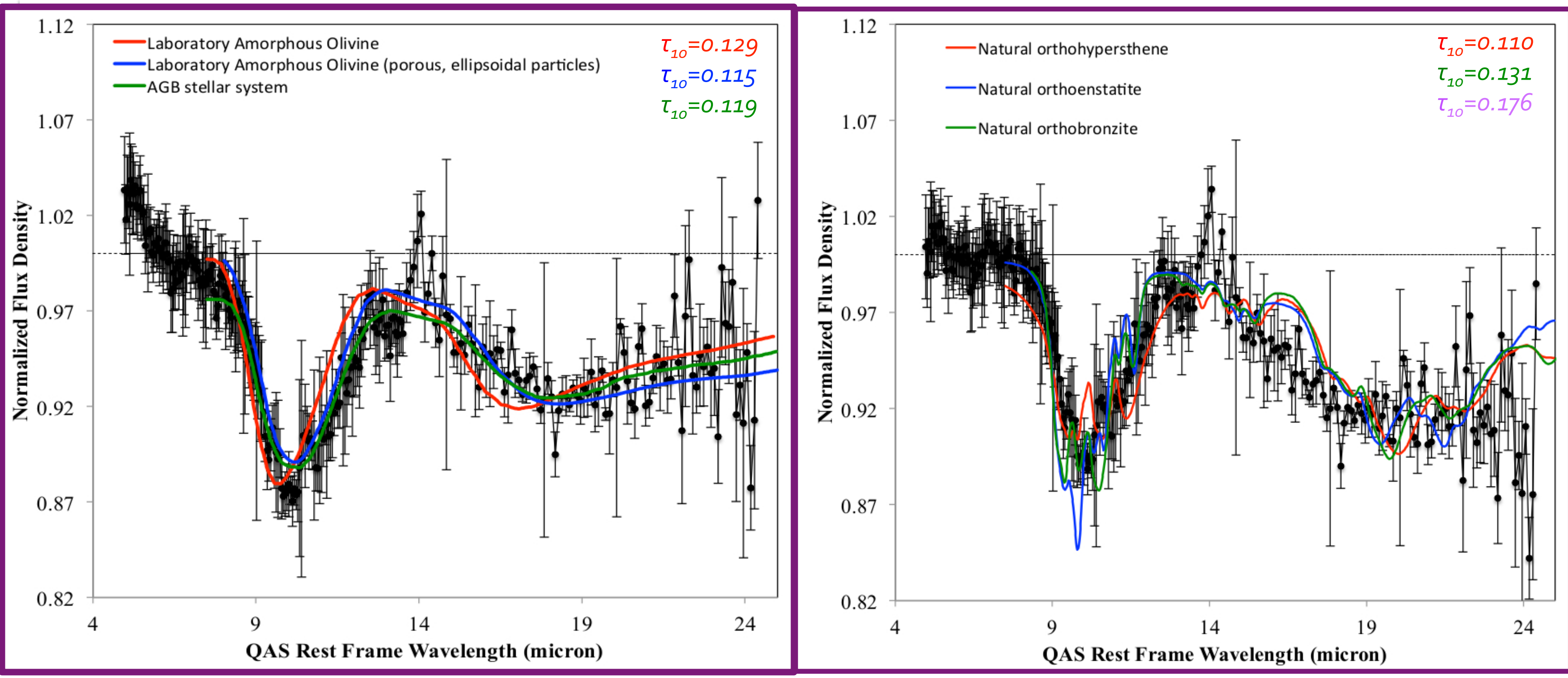
- disk-dominated galaxy, with a B/D ratio of 0.34
- SFR <0.3$M_{\odot}$/yr

- < 20% solar metallicity



Kulkarni et al. (2005)

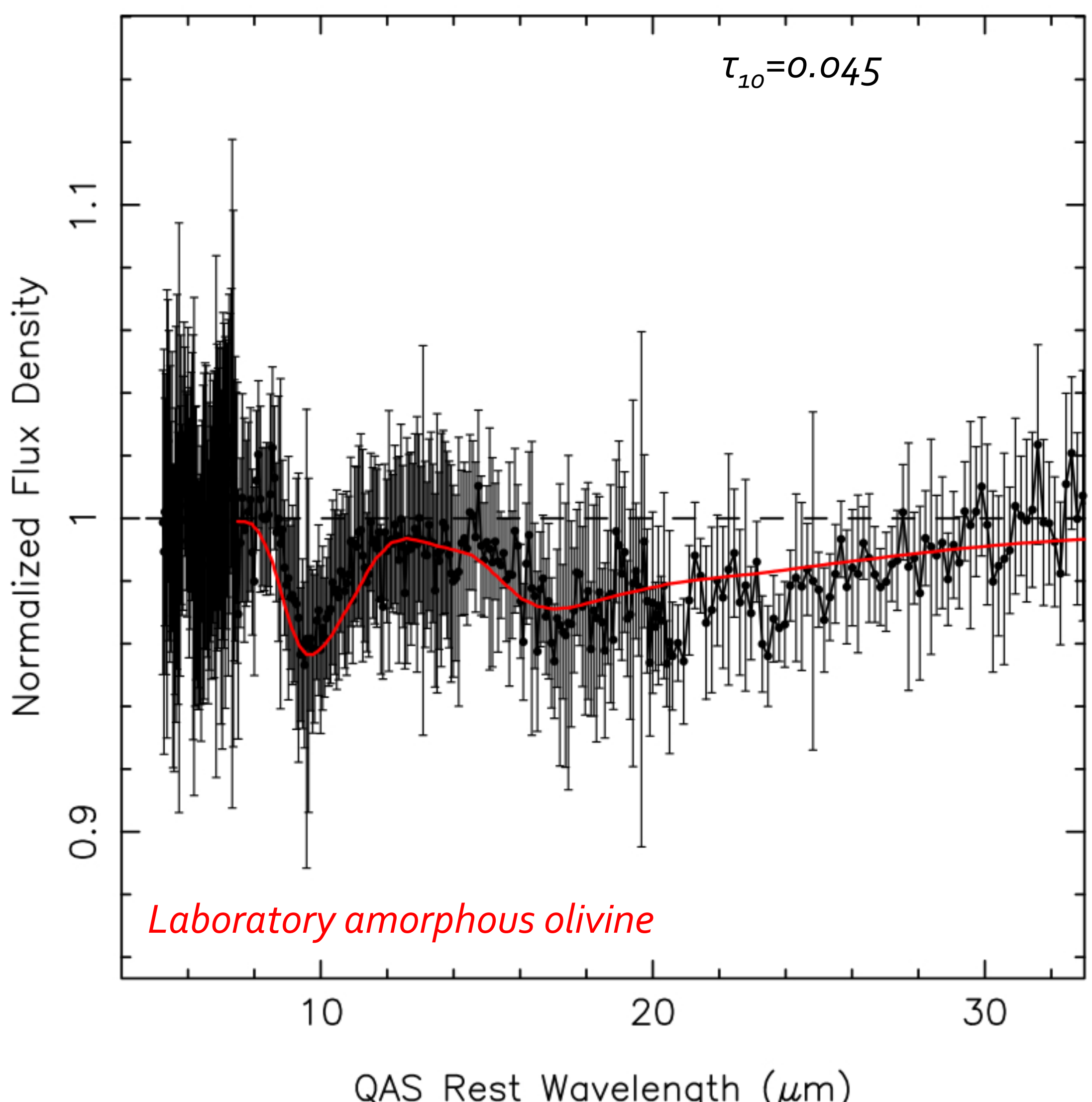
z=0.5 DLA (log N_{HI}=22) to LSP blazar



<u>Absorber Properties:</u>

- 21-cm and X-ray absorption
- metallicity of 0.7 solar
- strong 2175 Å bump
- several diffuse interstellar bands

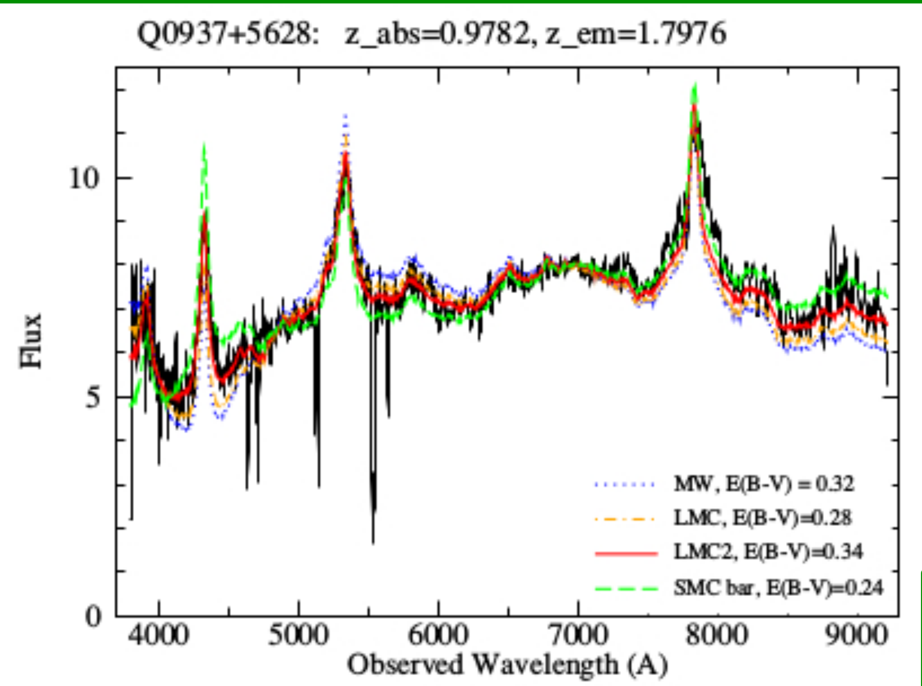
Local Universe: Milky Way Sightline



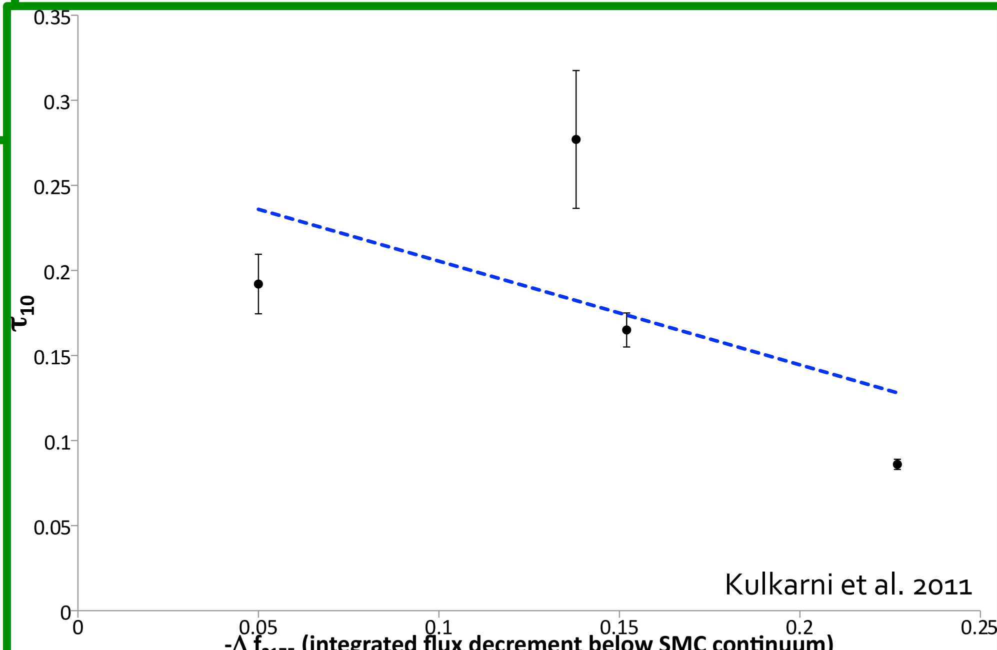
As part of our investigation into the relationship between silicate and carbonaceous dust in the Milky Way galaxy and Local Group galaxies, we are examining all AGN sightlines passing close to the Galactic plane.

This sightline to an LSP BL Lac blazar at a Galactic latitude of -10°.

Extinction Curves & 2175 Å Bump



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



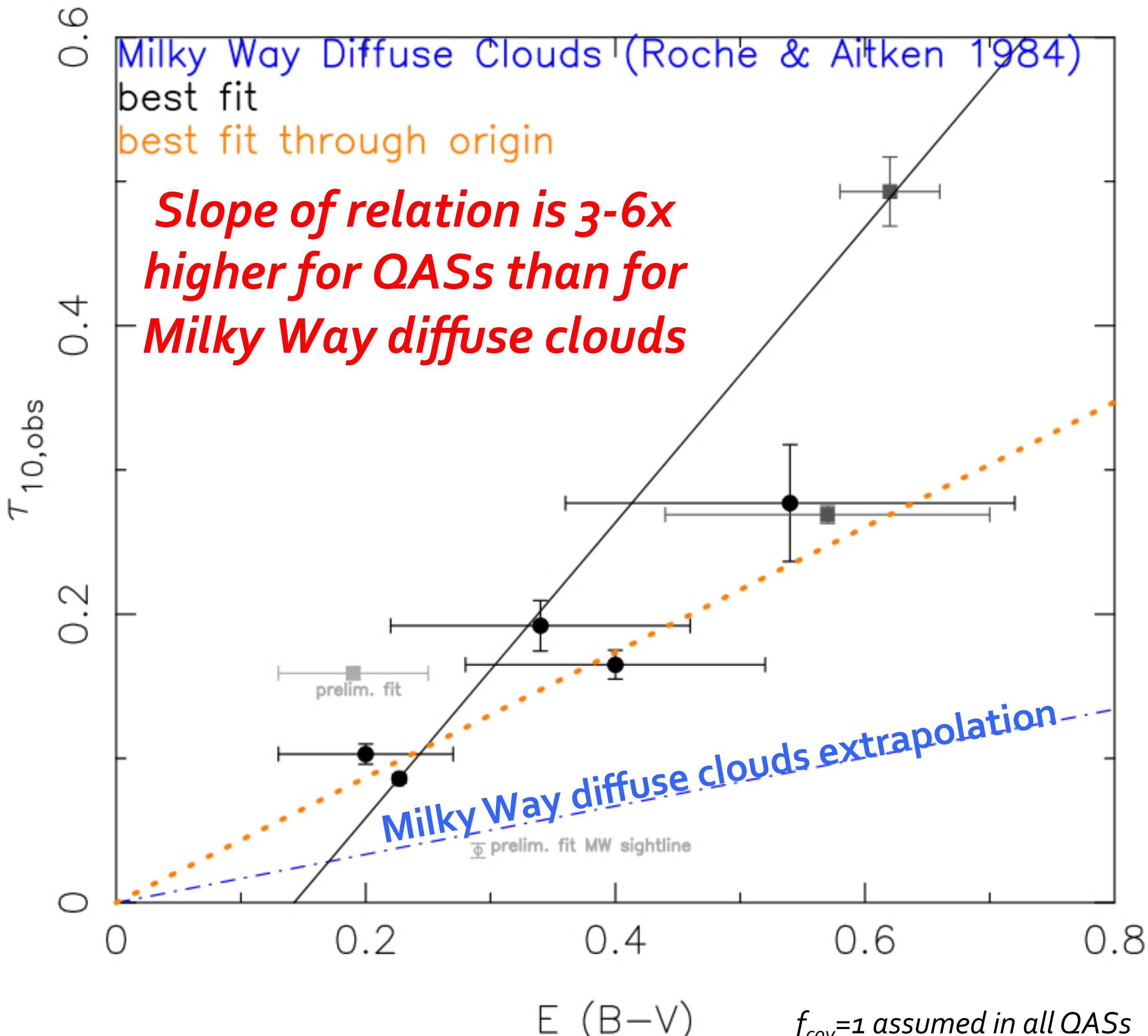
Kulkarni et al. 2011

Silicate Dust vs. Reddening in QASs

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

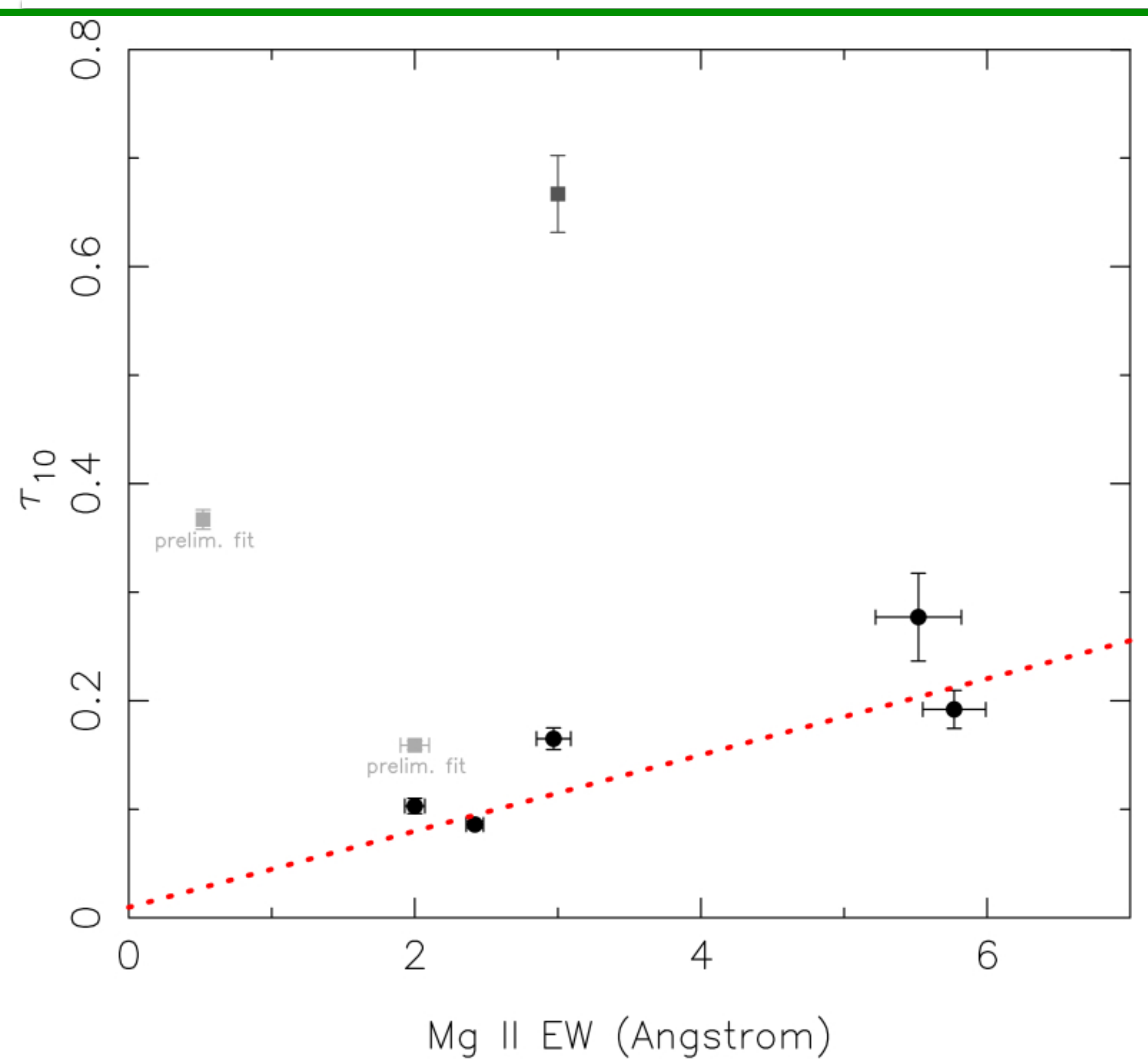
- ***Sampling different dust grain population?***
  e.g. face-on vs. through MW disk

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



f_{cov}=1 assumed in all QASs

Silicate Dust vs Mg II EW in 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 τ_{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

<u>Big Picture Questions Working to Address:</u>

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?*