Effects of Space Weathering on Reflectance Spectra of Ureilites: First Studies

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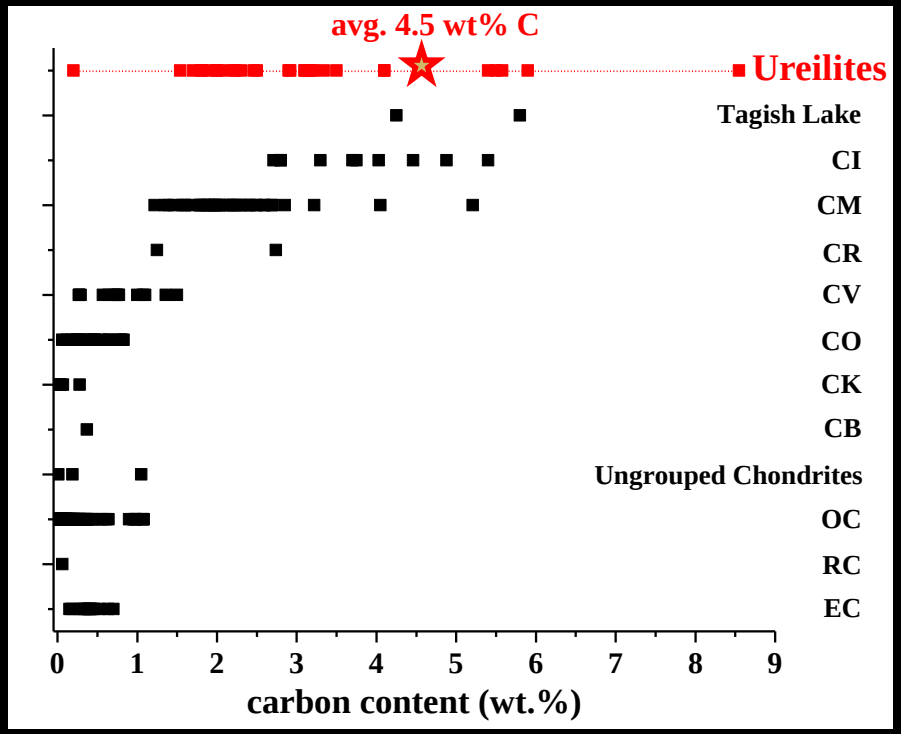
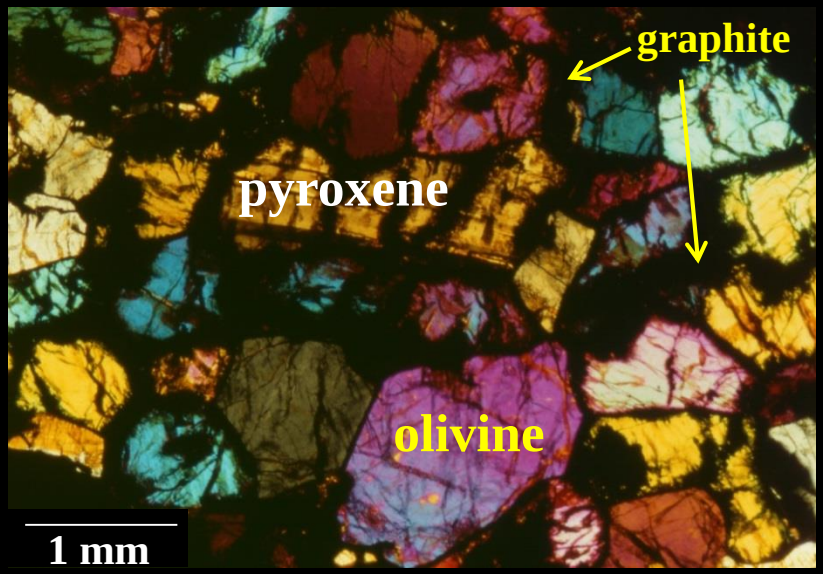
Space Weathering of Ureilite Meteorites: Motivation

- Dark asteroids are of interest as primitive, volatile-rich, based on spectral resemblence to carbonaceous chondrites.

OSIRIS-REx
Hayabusa 2
Lucy

- However, not all dark asteroids are primitive!
- **Ureilites are differentiated meteorites with very high carbon contents:**

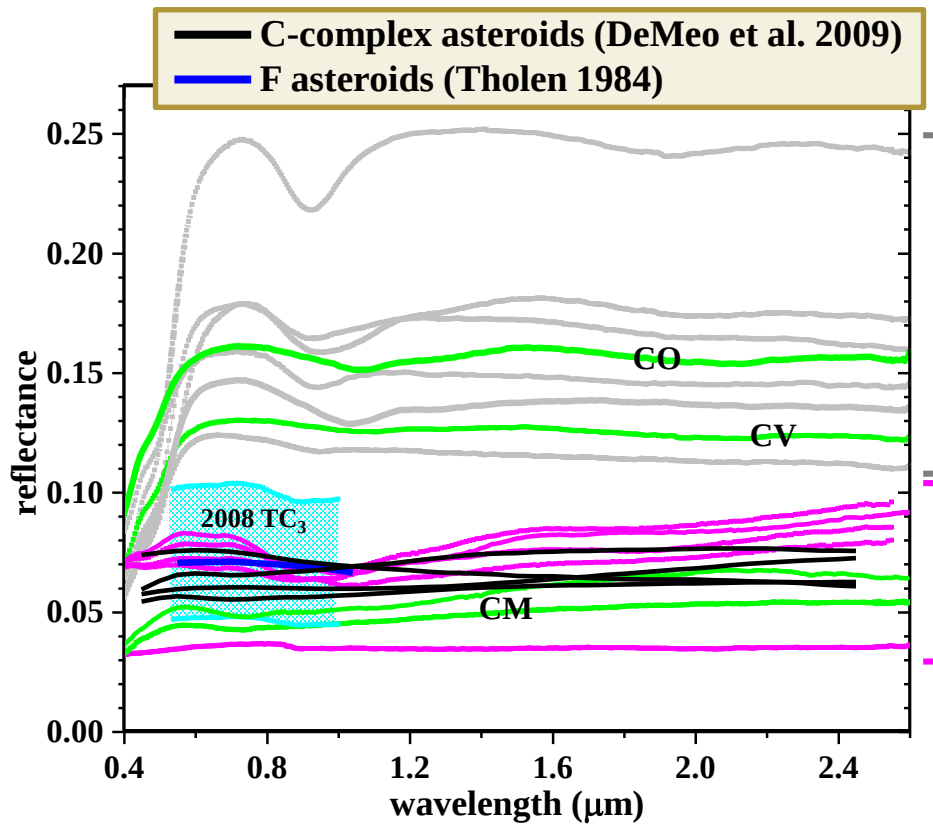




Optical photomicrograph

Space Weathering of Ureilite Meteorites: Motivation

VNIR reflectance spectra of ureilites (some similarities to CC):



Main group ureilites: exhumed mantle rocks

- Mg-rich olivine and pyroxene (various ratios)
- various amounts metal, sulfide, graphite
- various degrees of shock
- spectral similarities to CO, CV

Almahata Sitta (2008 TC_3): ureilitic regolith*

- AhS ureilites = clasts in regolith
- highly shocked, fine-grained, porous
- some have spectral similarities to CM
- spectral similarities to C-complex asteroids
- 2008 TC_3 = F (Tholen)

How to distinguish differentiated dark asteroids from primitive dark asteroids?

Data Sources:
Main group ureilites: Cloutis et al. (2010)
AhS: Hiroi et al. (2010); Goodrich et al. (2018)
CC: Cloutis et al. (2011, 2012a,b)
2008 TC_3: Jenniskens et al. (2009)

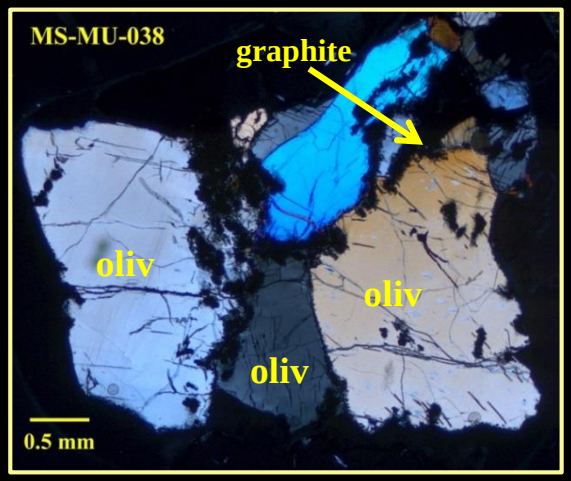
**Herrin et al. (2010); Goodrich et al. (2015)*

Space Weathering of Ureilite Meteorites: First Studies

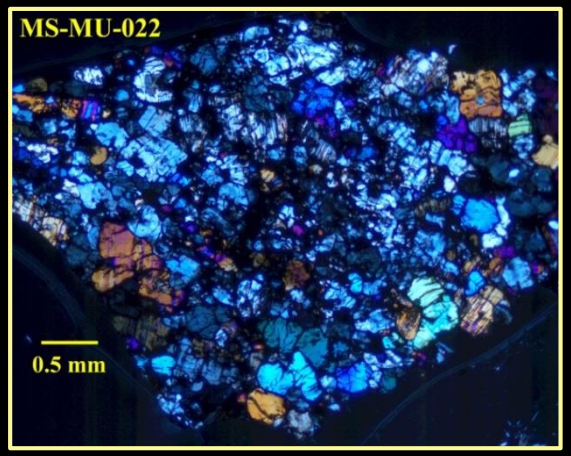
- Space weathering of ureilites has not previously been studied.
- Based on space weathering studies of CC* significant effects expected.

3 ureilitic samples from Almahata Sitta (2008 fall):

interior mantle

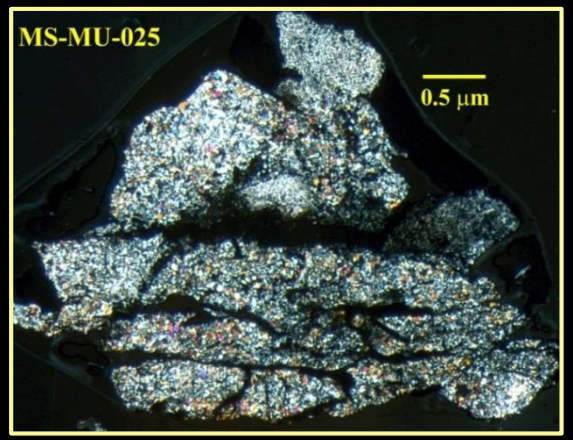


MS-MU-038
olivine-rich,
low-shock,
abundant graphite



MS-MU-022
olivine + orthopyroxene
medium-shock,
low abundance graphite, metal

regolith



MS-MU-025
very fine-grained
highly-shocked,
dispersed graphite, metal, sulfide

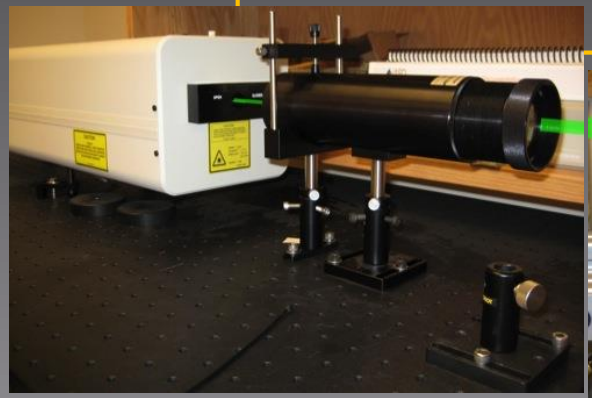
**Hiroi & Pieters (1991); Gillis-Davis et al. (2013, 2015); Keller et al. (2015)*

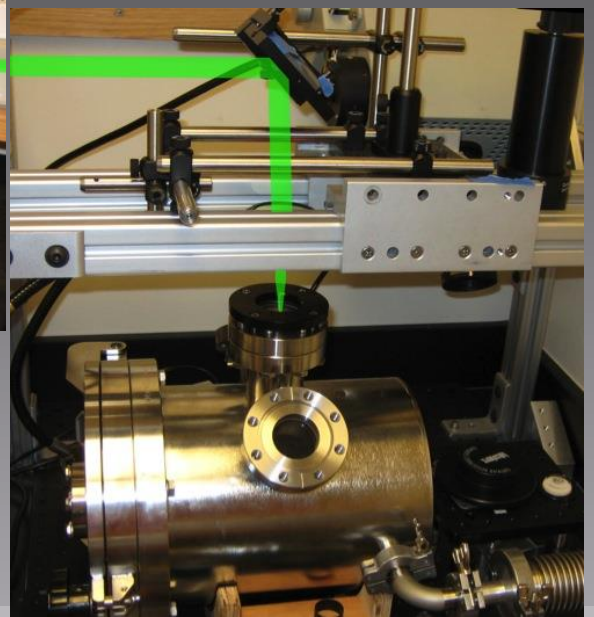
Laser Heating Experiments: (HIGP, U. HI)

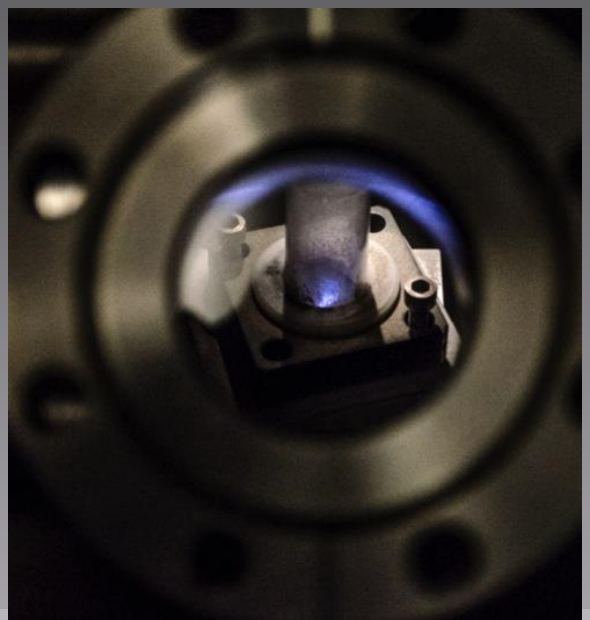
- **Samples powdered and sieved to <75 μm grain size**
- **Micrometeorite bombardment simulated with pulsed laser irradiation**
- **Reflectance spectra measured at 6000 12000, 24000, 36000, 48000 laser shots**

Laser pulse heating, with mass spectrometer

- 1064 nm, 20-Hz, 6 ns pulse, 30 mJ, 0.25 mm spot
- Simulate micrometeorite impacts ~ 20 mm in size
- Vacuum 10e-7 torr, residual gas analyzer 100 amu

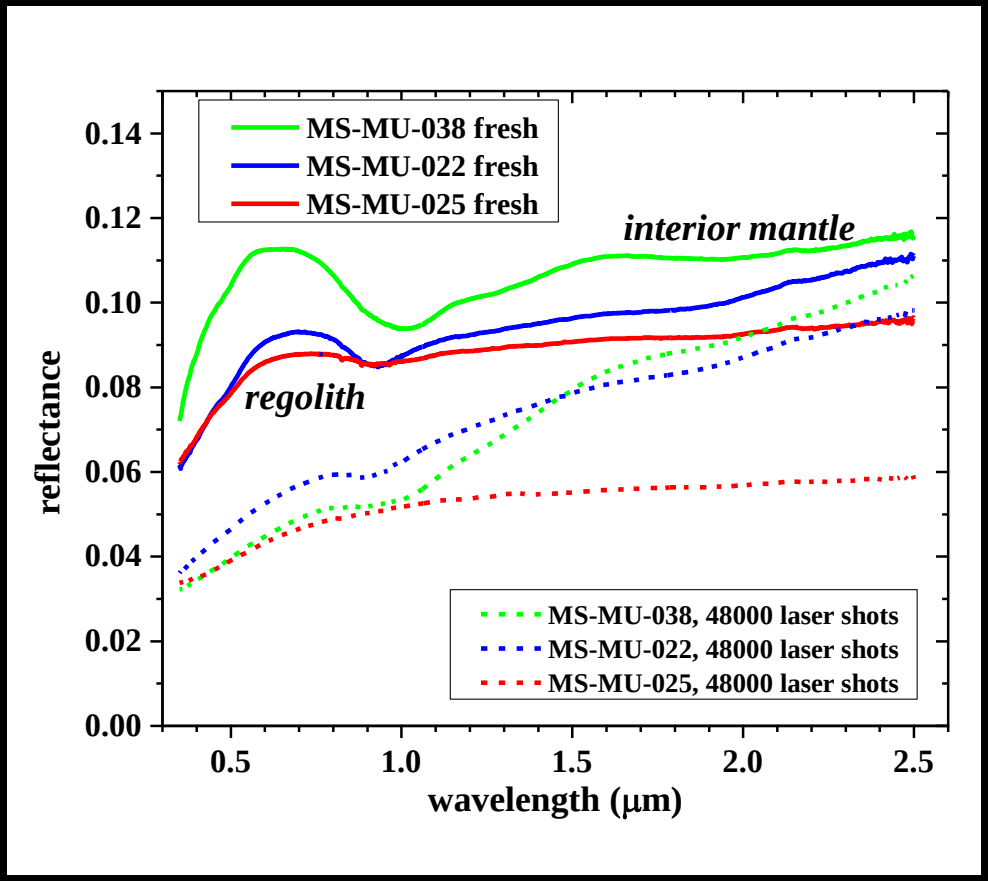


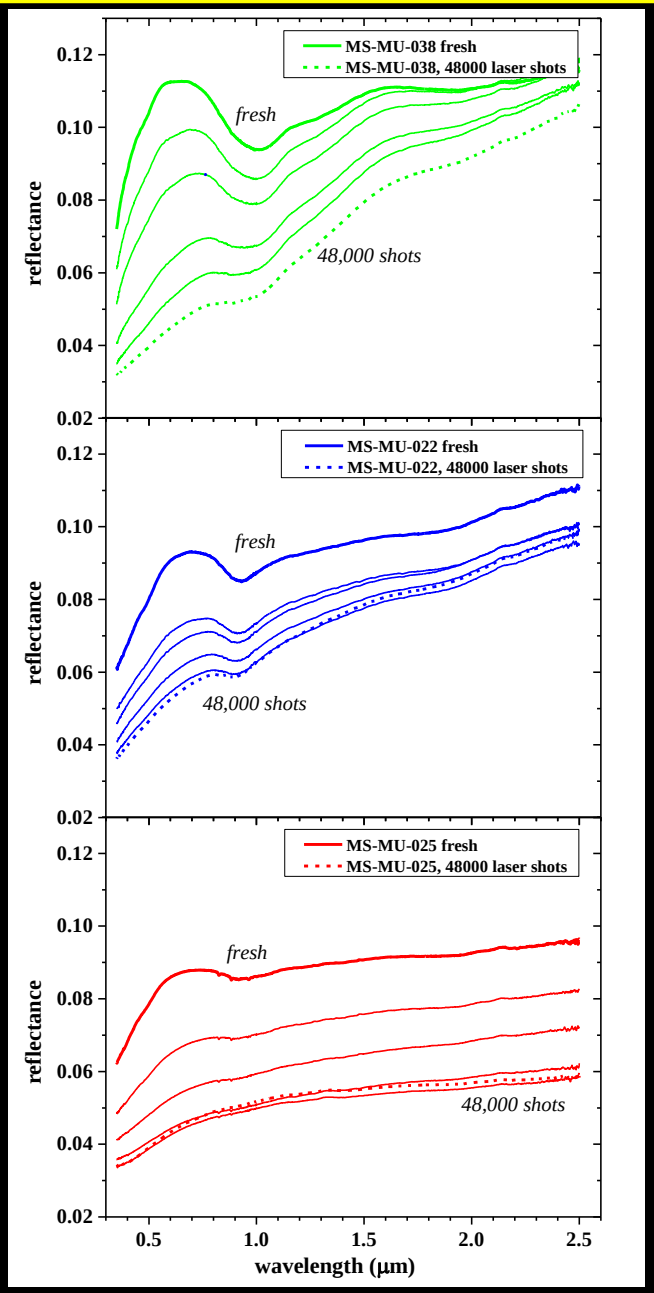




References:
Gillis-Davis et al. (2015, 2017)
Yamada et al. (1999)

Space Weathering of Ureilite Meteorites: Results



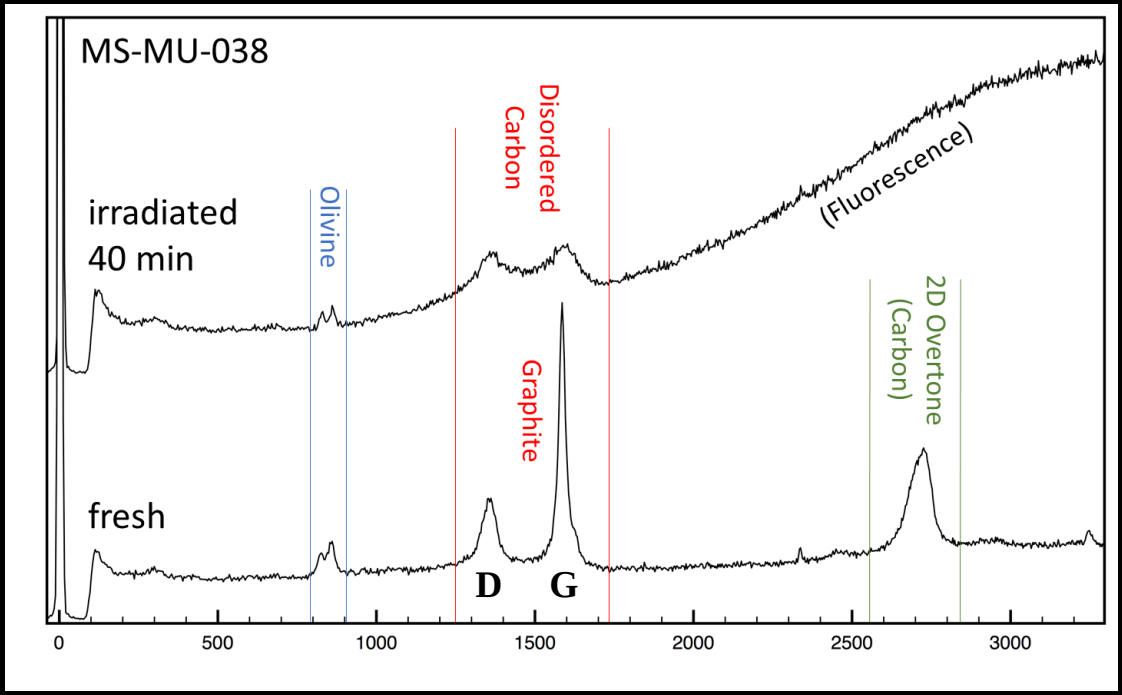


increasing irradiation ⇒

darker, redder, decreased spectral contrast

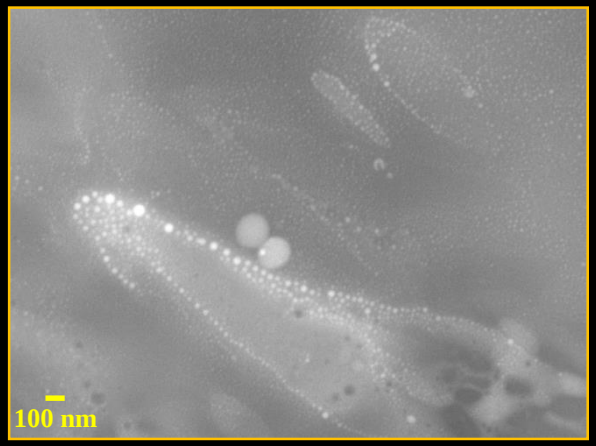
Space Weathering of Ureilite Meteorites: Results

Raman

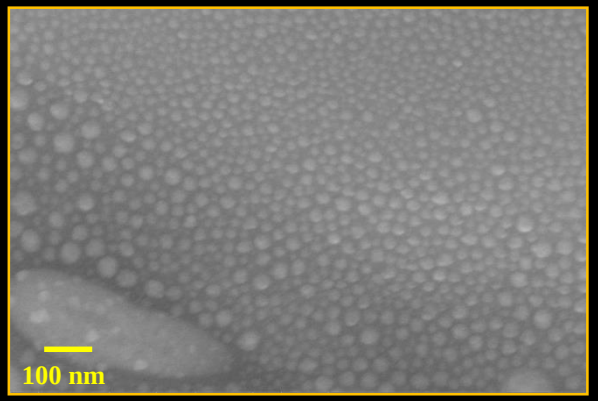


- **Raman** spectrum of fresh -038 shows olivine and highly crystalline graphite.
- **After irradiation** the carbon peaks have broadened and the D band is as intense as the G band, both indicators of disordered carbon.

MS-MU-022

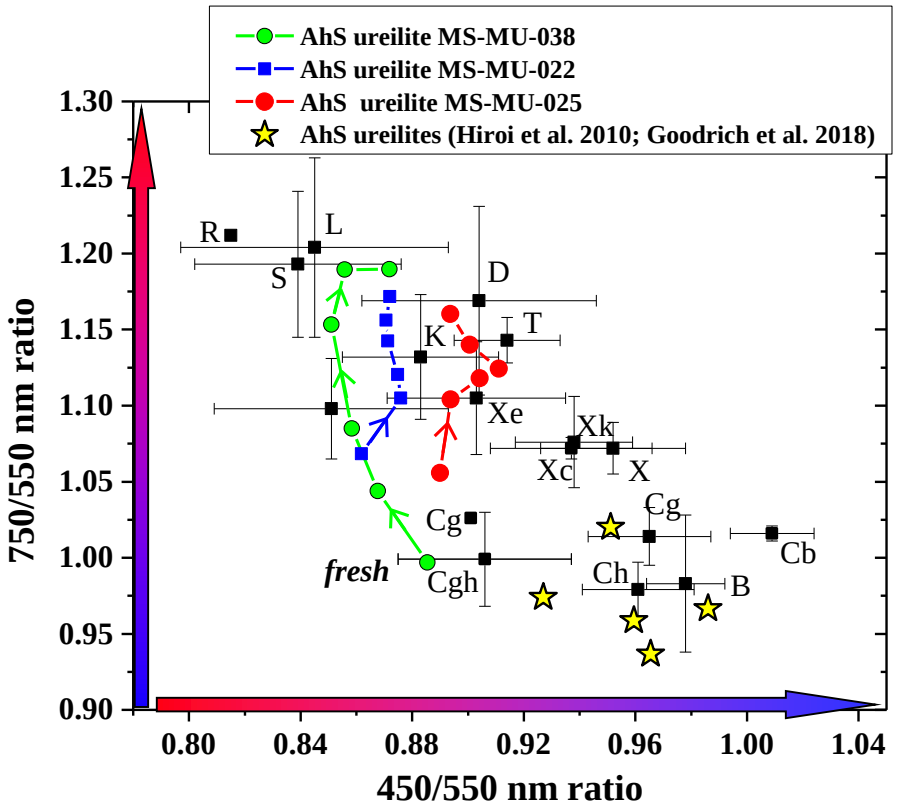


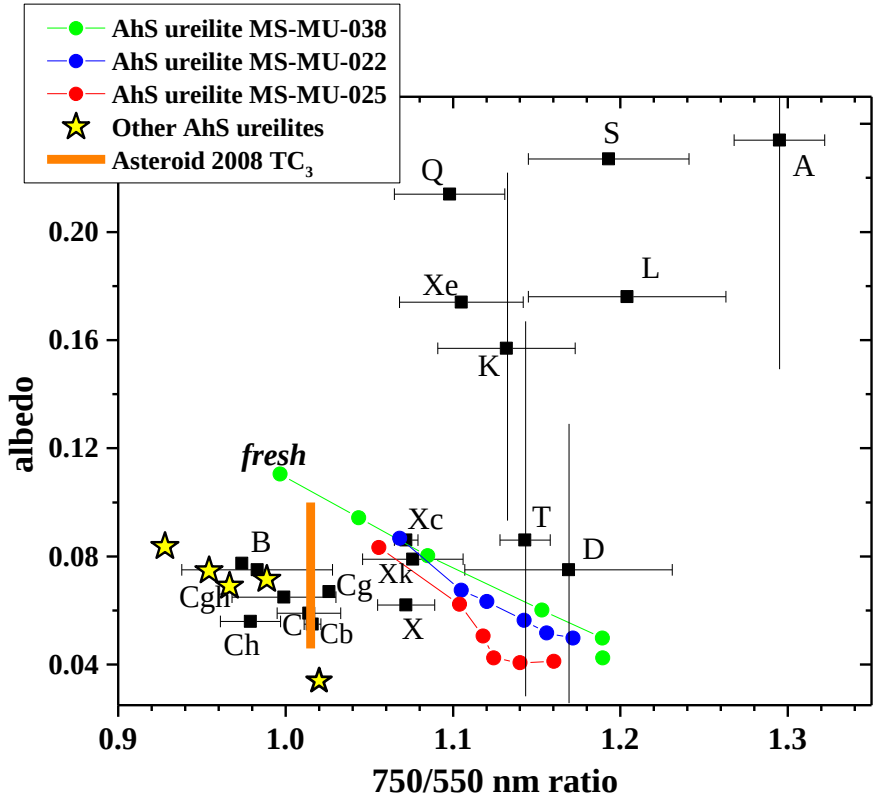
MS-MU-025



SEI

Comparisons with Asteroid Classes





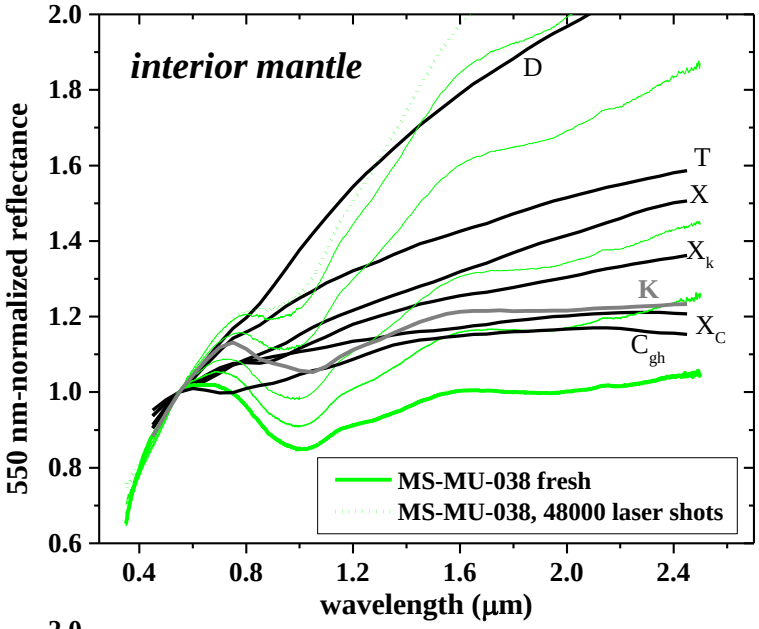
Increasing irradiation ⇒ move away from C-complex, toward D, T, some X.

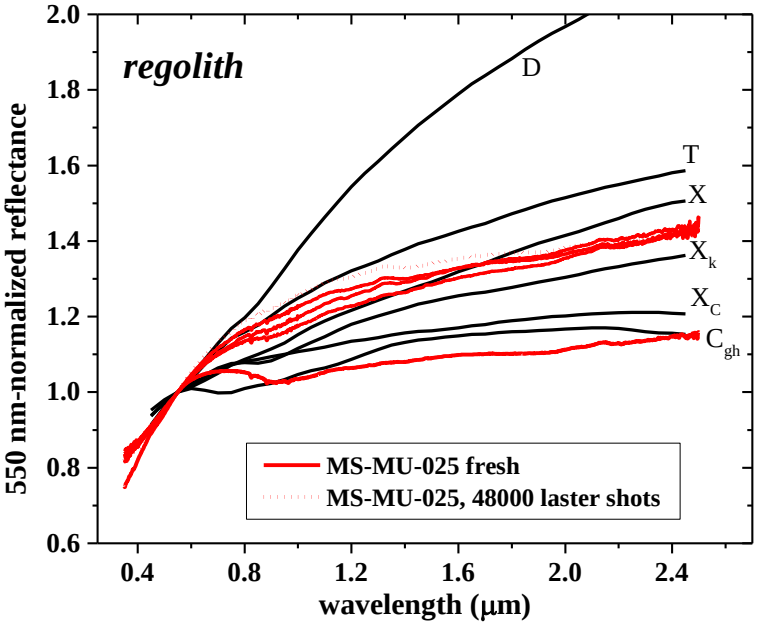
Asteroid 2008 TC_3 may not have been significantly space weathered.*

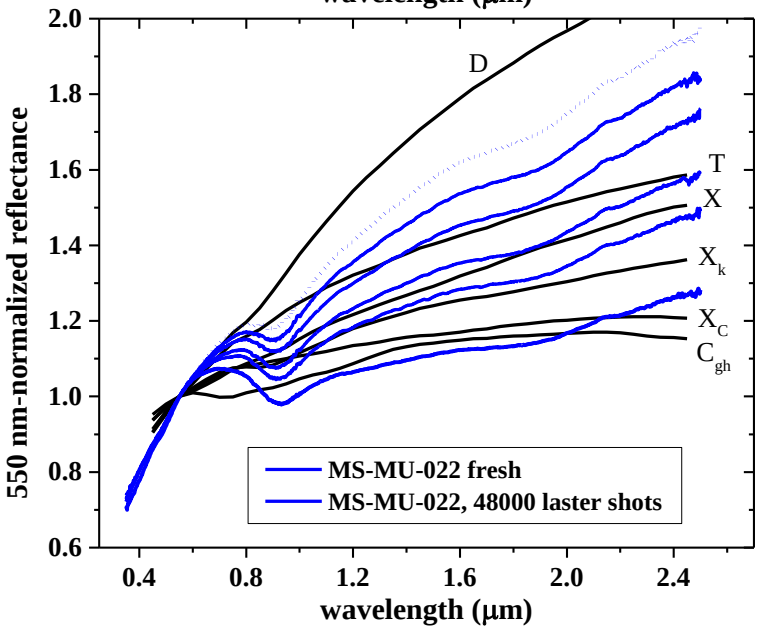
SMASS II means: DeMeo et al. (2009)
Albedo data: Mainzer et al. (2011)

***Consistent with Hiroi et al. (2010) and absence of solar gases in AhS (Ott et al. 2010; Downes et al. 2015; Riebe et al., this meeting).**

Comparisons with Asteroid Classes







No exact spectral matches with asteroid class means for fresh or laser-weathered ureilites

But,
none of these samples individually represents bulk properties of ureilitic regolith.

Conclusions (So Far)

- **Space weathering results in significant changes in the reflectance spectra of ureiltes.**

- **Results *suggest* that non-space weathered ureilitic regolith may resemble C-complex asteroids, whereas space weathered ureilitic material may resemble D, T, or some X type asteroids.**

- **Space weathering experiments on a series of ureilite samples with controlled variations in petrologic properties are essential to understand the range of spectral signatures of ureilitic asteroids.**

- **Especially need to study fine-grained, highly-shocked AhS ureilites most likely to represent the bulk of asteroid 2008 TC_3 (ureilitic regolith).**

Future Work

- **Space weathering experiments on a series of ureilite samples with controlled variations in petrologic properties.**

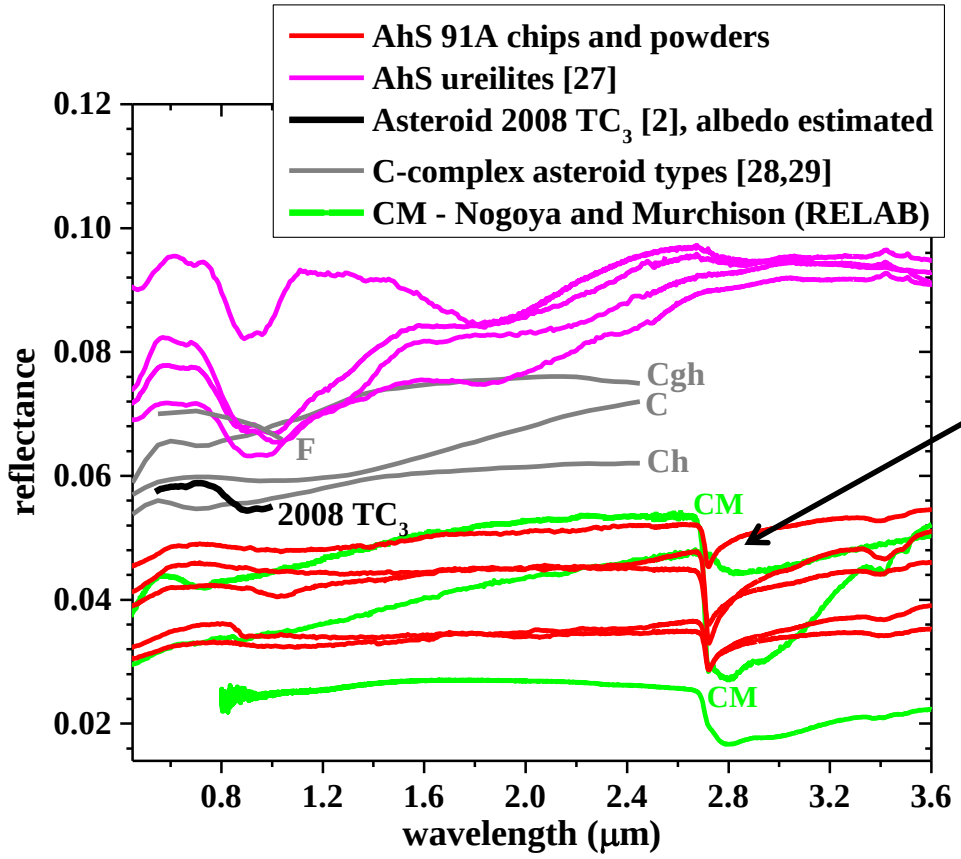
- **Space weathering experiments on fine-grained, highly-shocked Almahata Sitta ureilites most likely to represent the bulk of asteroid 2008 TC_3 (ureilitic regolith).**

- **Include UV (to 140 nm) and Raman, to examine changes in carbon phases.**

- **TEM of space weathered powdered to understand microstructural changes that affect optical properties.**

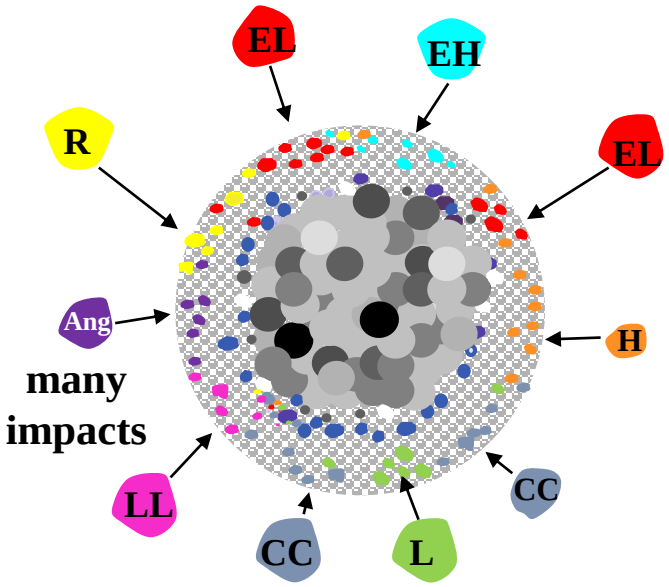
Extra Slide (see Goodrich et al. this meeting)

- Almahata Sitta sample UOK 91A is a friable breccia of hydrated CC material with clasts of ureilitic minerals and other chondrites (OC, EC).
- Suggested to represent significant fraction of the mass of 2008 TC_3.
- Spectra of 91A show 2.7 μm band!



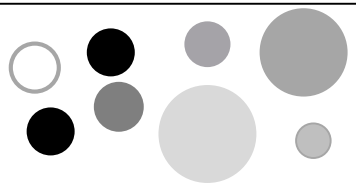
2.7 μm band
water of hydration
on a ureilitic asteroid!

Development of Diverse Regolith on Ureilitic Asteroid



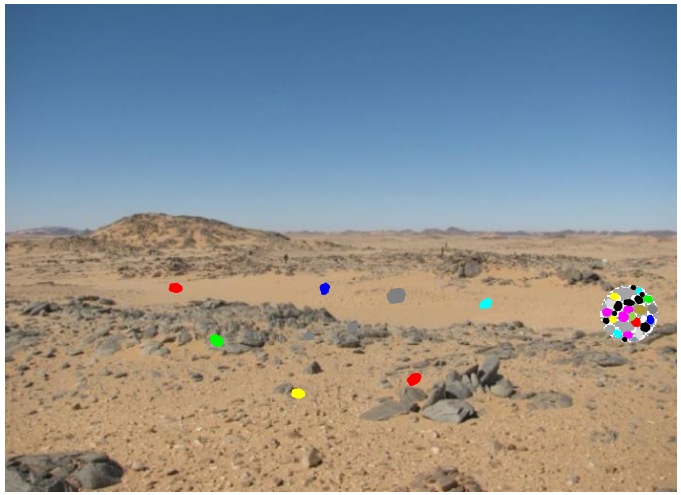
Recent Breakup. Fragments drift into Earth-crossing orbits

Main Group Ureilites



Typical Polymict Ureilites (deep regolith)

2008 TC_3 **(shallow regolith)**



Goodrich et al. (2015)