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 resemblance to carbonaceous chondrites.

- However, not all dark asteroids are primitive!

- **Ureilites are differentiated meteorites with very high carbon contents:**

![Graph showing carbon content of various meteorites types.](image1)

![Optical photomicrograph of Ureilite meteorites.](image2)
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)

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**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)

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*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 ureilite samples from Almahata Sitta (2008 fall):

**interior mantle**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS-MU-038</td>
<td>olivine-rich, low-shock, abundant graphite</td>
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</tbody>
</table>

**regolith**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS-MU-022</td>
<td>olivine + orthopyroxene medium-shock, low abundance graphite, metal</td>
</tr>
<tr>
<td>MS-MU-025</td>
<td>very fine-grained highly-shocked, dispersed graphite, metal, sulfide</td>
</tr>
</tbody>
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*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**.
**Comparisons with Asteroid Classes**

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

**Asteroid 2008 TC\textsubscript{3} may not have been significantly space weathered.**

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**SMASS II means:** DeMeo et al. (2009)

**Albedo data:** Mainzer et al. (2011)

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*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 ureilites.

- 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.
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 $\mu$m band!

2.7 $\mu$m 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 TC₃ (shallow regolith)

many impacts

Goodrich et al. (2015)