Simulating Lunar Eclipse in the Lab: Key to Understanding the Epiregoith

Benjamin Greenhagen
Johns Hopkins Applied Physics Laboratory

Neil Bowles (Univ. Oxford)
Kerri Donaldson Hanna (Univ. Oxford)
Paul Hayne (JPL/Caltech)
Paul Lucey (Univ. Hawaii)
David Paige (UCLA)

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What is the epiregolith?

- The epiregolith (Mendell and Noble, 2010) is the surface layer of lunar regolith that interacts with the space environment.
  - The sensing depth for optical remote sensing techniques.
- Epiregolith thermal gradients greatly affect mid-infrared spectroscopy (e.g. CF position and intensity, RB contrast).
  - Induces a wavelength dependent temperature effect.
  - Effects for UV, visible, near-infrared, and far-infrared are unknown.

Figures after Donaldson Hanna et al., 2012
Why simulated lunar eclipses?

- Thermal wave penetration depth is related to the duration of the thermal pulse
  - Diurnal (29 days) = few 10s cm
  - Eclipse (hours) = few cm

- Pre-dawn and deep eclipse temperatures combined with thermal models can constrain thermal inertia

- The lunar surface is typically at radiative equilibrium with temperatures changing slowly

- Eclipse cooling and warming is much more abrupt affecting the upper mm
  - Multi-spectral observations may elucidate insolation deposition / thermal emission as a function of depth
Motivation: Diviner Eclipse Observations

- LRO Diviner Lunar Radiometer observed wavelength dependent heating immediately following a lunar eclipse (Greenhagen et al., 2015 – LPSC)

- Diviner has nine spectral channels than span the visible to far infrared

Channel 8: 50-100µm
250 K (blue) to 350 K (red)
Surface cools rapidly, indicating a highly insulating layer (Hayne et al.)

During warm-up, chs 6 & 7 warm up much more quickly than chs 3, 4, 5, 8, & 9
Post-eclipse heating 9 and 50 µm dominates anisothermality.

C3 - C6 (13-23µm)
C3 - C8 (50-100µm)
Simulated Eclipse Environment

- Specifically designed thermal-vacuum chamber to simulate conditions on the lunar surface [Thomas et al., 2012]
  - Pressure: <10^{-4} \text{ mbar}
  - Cold Shroud: <125 \text{K}
  - Sample Heating: typically 350-410 \text{K}
  - Illumination: Solar-like quartz-halogen with variable intensity
  - Spectrometer: Bruker IFS-66v FTIR configured for measurements from 5 – 25 \mu m
Methodology

- Two Apollo Soils: 15071 (mare) and 61141 (highlands)
- Two sample cup temperatures: 283K and 353K
- Each sample run included cool-down and warm-up

**Typical sample run**
- Heat sample (using lamp and heater) to radiative equilibrium
- Collect baseline spectrum
- Turn lamp off
- Collect data for 20 minutes (30 second increments)
- Collect baseline spectrum
- Turn lamp on
- Collect data for 20 minutes (30 second increments)

- Also, new calibration measurements and pipeline
  - Some issues reducing the 61141 data
Results: Temperature, 283K Sample Cup

- **Rapid initial temperature change (>100K / 3 min)**
  - Consistent with a highly insulating regolith
- **Generally consistent with Diviner observations**
  - Still cooling >1K / min at end of cooling experiment
Results: Spectral (I)

- **Cooling run**
  - CF shifts shortward
  - CF intensity increases
  - RB contrast decreases

- **Warming run**
  - CF shifts first longward, then shortward
  - CF intensity first decreases then increases
  - RB intensity increases


- Preferential cooling and heating in Reststrahlen Bands is generally consistent with Diviner observations.
Results: Environmental Conditions

- Sample cup temperature effects are \( \sim 10K \) for this 20 minute experiment

- Future experiments will expand parameter space
  - Colder sample cup heater
  - Longer time baseline
Future Work

- **Next round(s) of laboratory experiments**
  - Shorter and longer (more eclipse-like) thermal pulses
  - Variable heating (lamp and sample cup) and sampling packing (i.e. Donaldson Hanna et al., NESF2014)
  - Effects of composition and maturity

- **Incorporate thermophysical models**
  - Cool-down is dominated by thermal inertia and established thermophysical models can constrain the thermal inertia of the epiregolith of our laboratory samples
  - Led by Hayne (JPL), based on Diviner-derived thermal model

- **Incorporate spectral models**
  - Warm-up is dominated by wavelength-dependent insolation deposition
  - Led by Bowles (Oxford), based on Millan et al., 2011 spectral model

- **Incorporate relevant Diviner eclipse data**
Relevant Diviner Eclipse Observations

- Diviner has observed two total lunar eclipses with adequate illumination geometry
- There is one more total eclipse during ESM2

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- LRO will propose additional eclipse observations for ESM3
Conclusions

- Short thermal pulses contain information regarding the thermophysics of the upper mm of regolith
- Cooling observations imply a highly insulating epieregolith
  - Rapid cooling
- Warming observations can provide insights into insolation deposition as a function of depth
  - Reststrahlen bands initially enhanced as surface warms more quickly than near-surface
  - Christiansen feature is initially subdued
- Simulated environment laboratory work coupled with Diviner observations serve as key inputs into necessary thermophysical and spectral thermal modeling

- Incorporate findings into VORTICES multi-body thermal model (SHERMAN)
  - Aid interpretation of NIR and MIR thermophysical and compositional datasets of Moon, NEAs, and moons of Mars