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

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JOHNS HOPKINS
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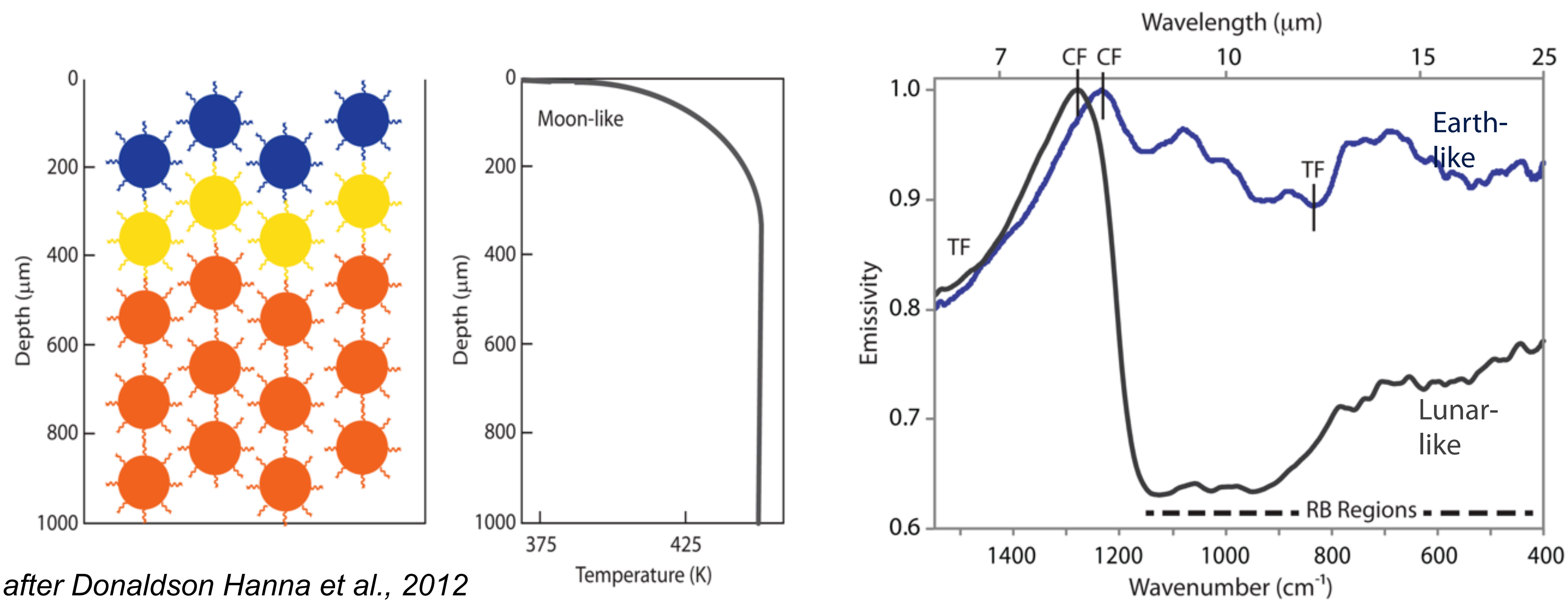
What is the epiregolith?

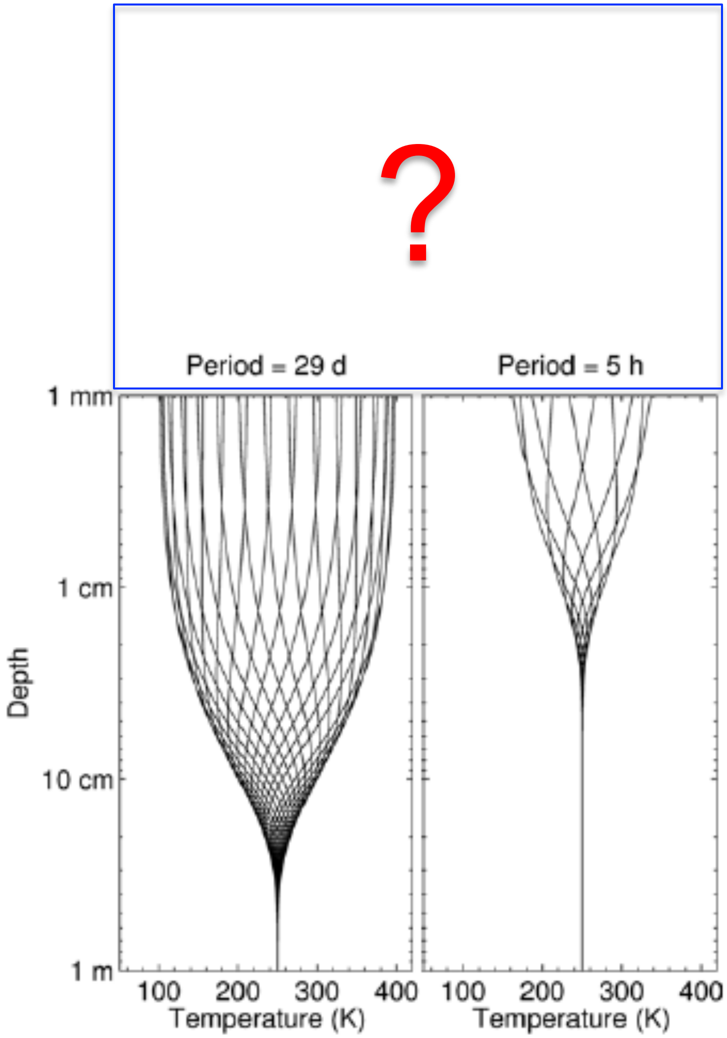
- **The epiregolith (Mendell and Noble, 2010) is the surface layer of lunar regolith that interacts with the space environment**
  - **The sensing depth for optical remote sensing techniques**
- **Epiregolith thermal gradients greatly affect mid-infrared spectrscopy (e.g. CF position and intensity, RB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



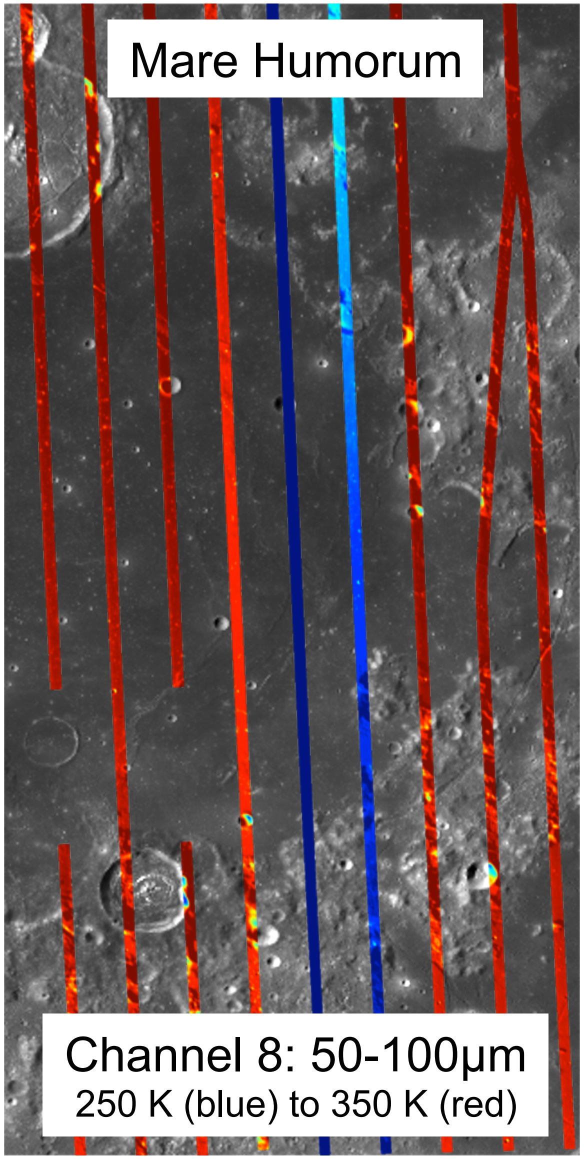
Figures after Donaldson Hanna et al., 2012

Why simulated lunar eclipses?

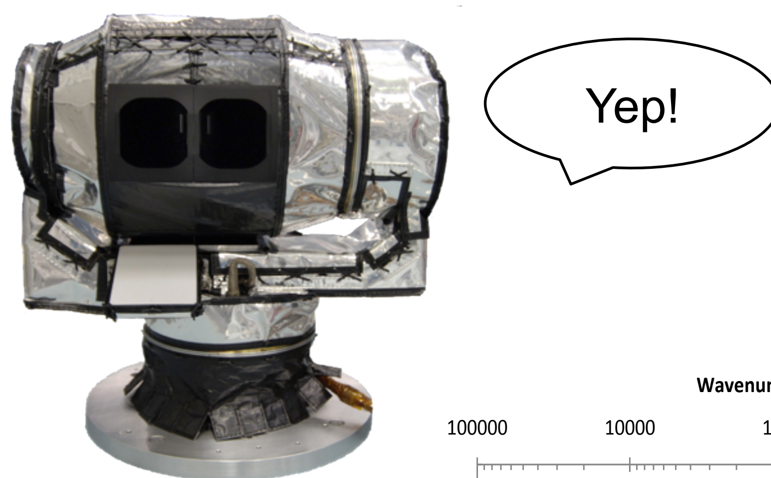
- **Thermal wave penetration depth is related to the duration of the thermal pulse**
  - **Diurnal (29 days) = few 10s cm**
  - **Eclipse (hours) = few cm**
- **Pre-dawn and deep eclipse temperatures combined with thermal models can constrain thermal inertia**
- **The lunar surface is typically at radiative 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**



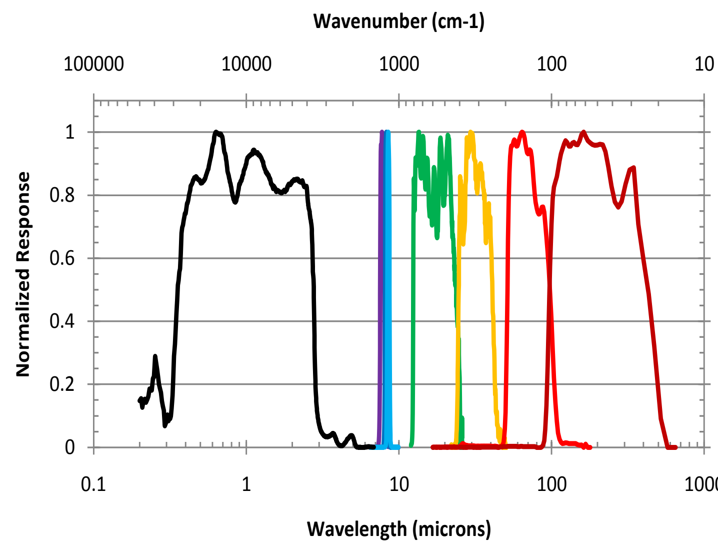
Motivation: Diviner Eclipse Observations



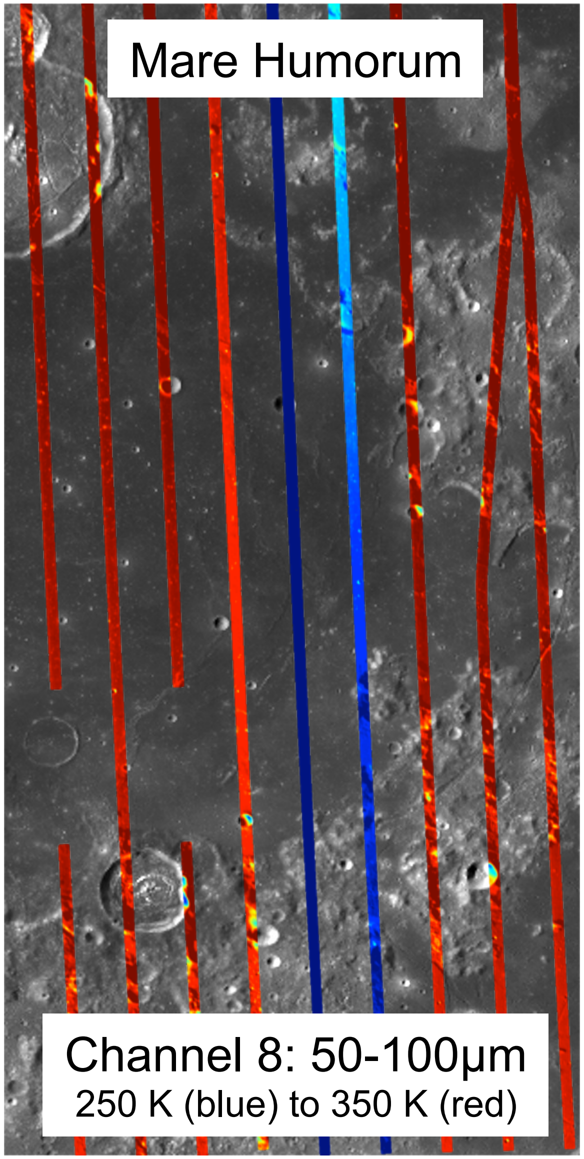
- **LRO Diviner Lunar Radiometer observed wavelength dependent heating immediately following a lunar eclipse** **(Greenhagen et al., 2015 – LPSC)**

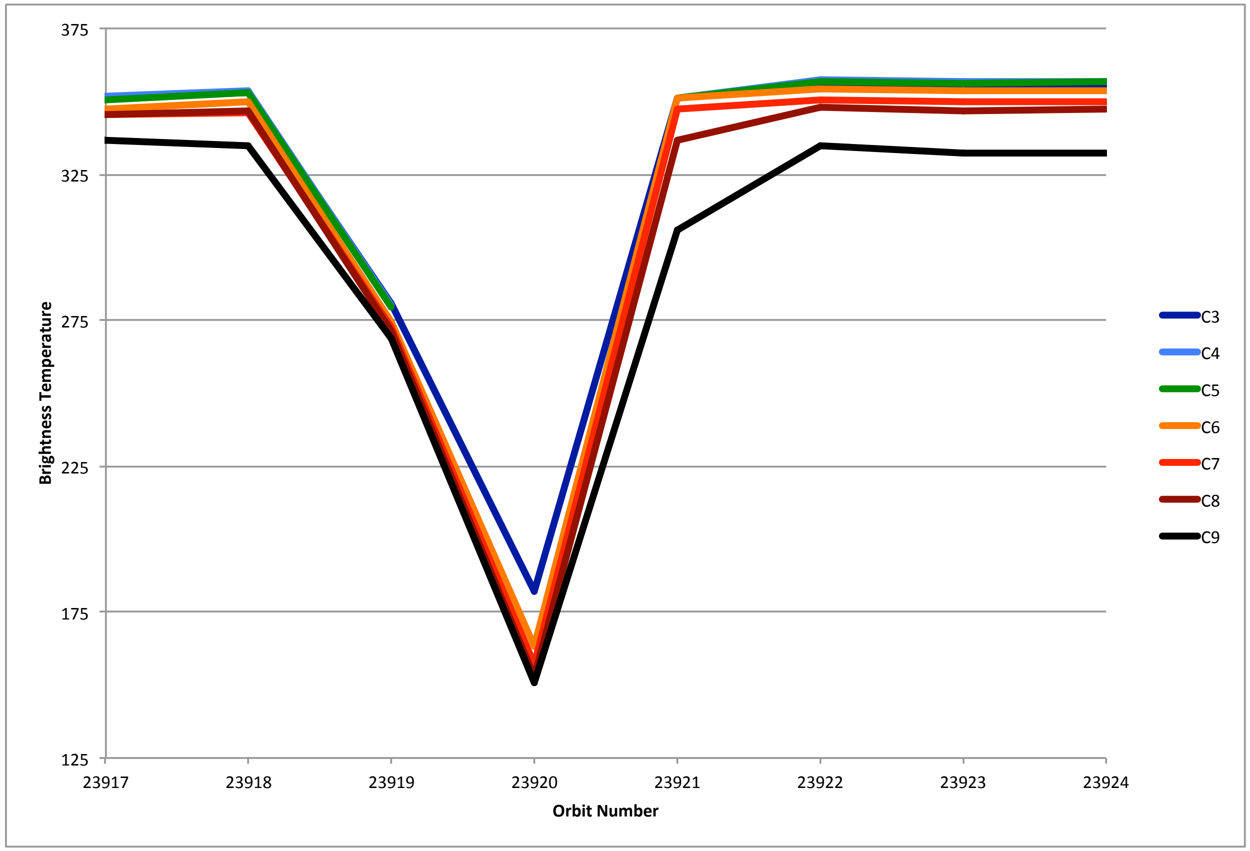


- **Diviner has nine spectral channels than span the visible to far infrared**



Diviner Eclipse Observations (II)

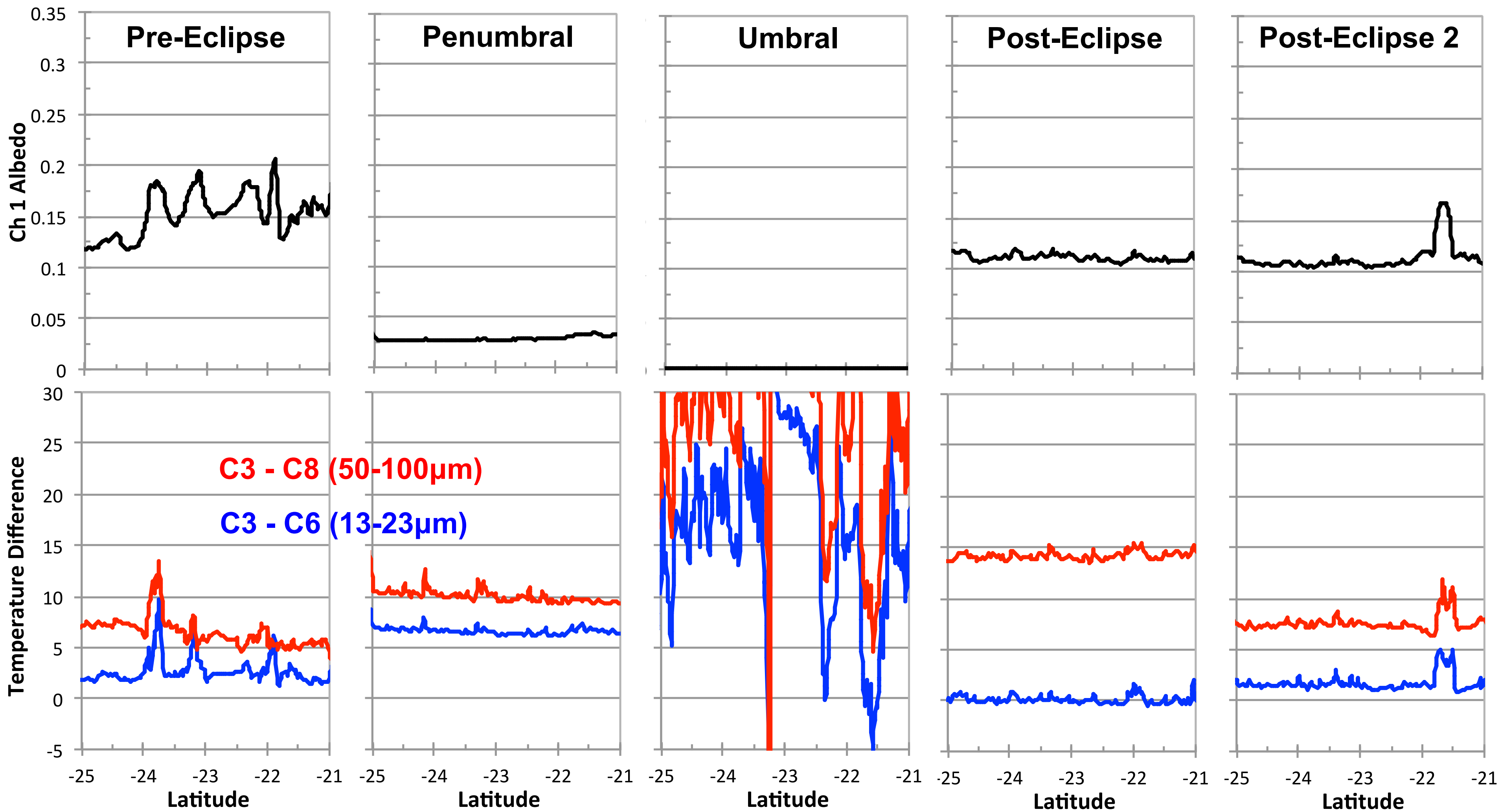




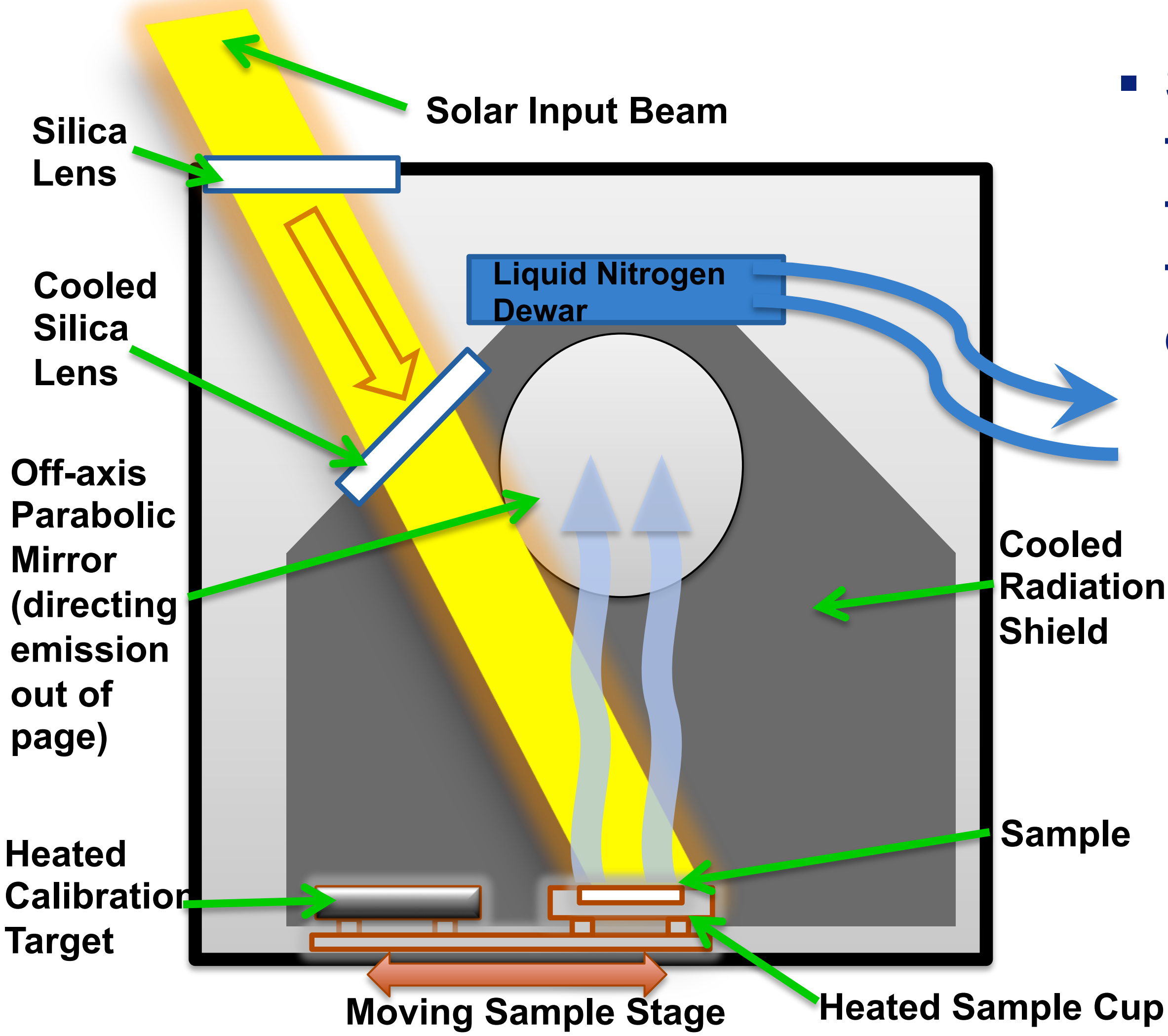
- **Surface cools rapidly, indicating a highly insulating layer (Hayne et al.)**
- **During warm-up, chs 6 & 7 warm up much more quickly than chs 3, 4, 5, 8, & 9**

Diviner Eclipse Observations (III)

- **Post-eclipse heating 9 and 50 µm dominates anisothermality**



Simulated Eclipse Environment



Simulated Lunar Environment Chamber (SLEC)
University of Oxford Planetary Spectroscopy Facility

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

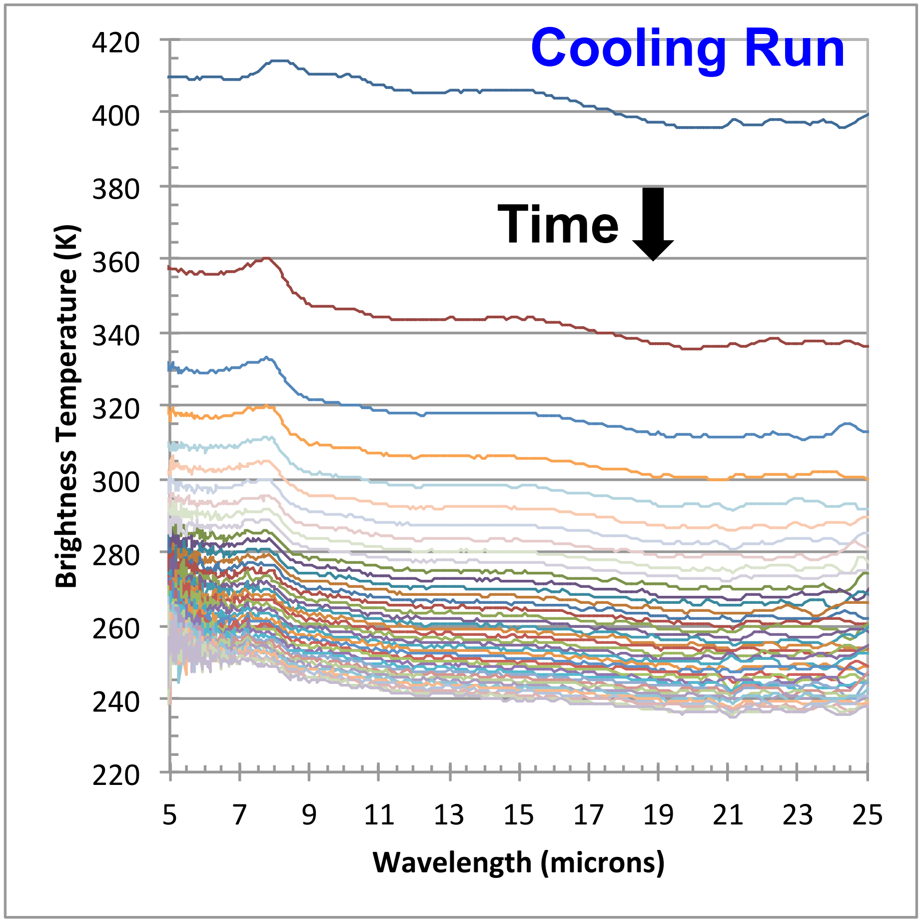
Methodology

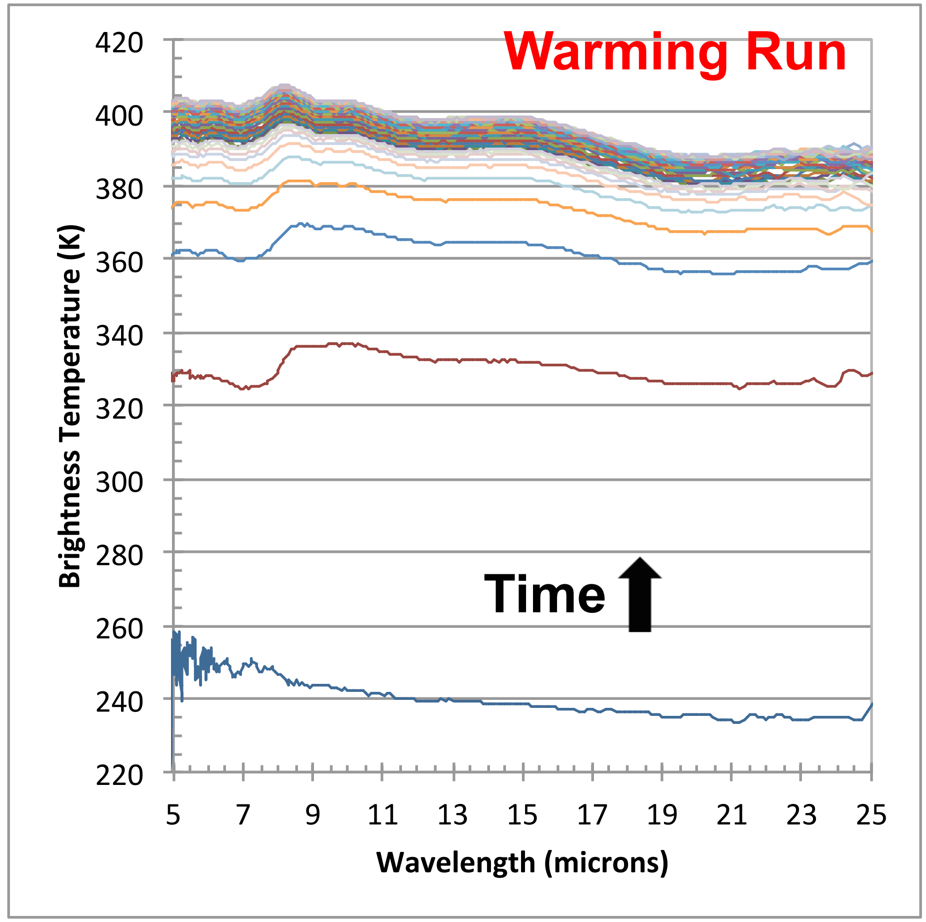
- Two Apollo Soils: 15071 (mare) and 61141 (highlands)
- Two sample cup temperatures: 283K and 353K
- Each sample run included cool-down and warm-up

- Typical sample run
  - Heat sample (using lamp and heater) to radiative equalibrium
  - 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

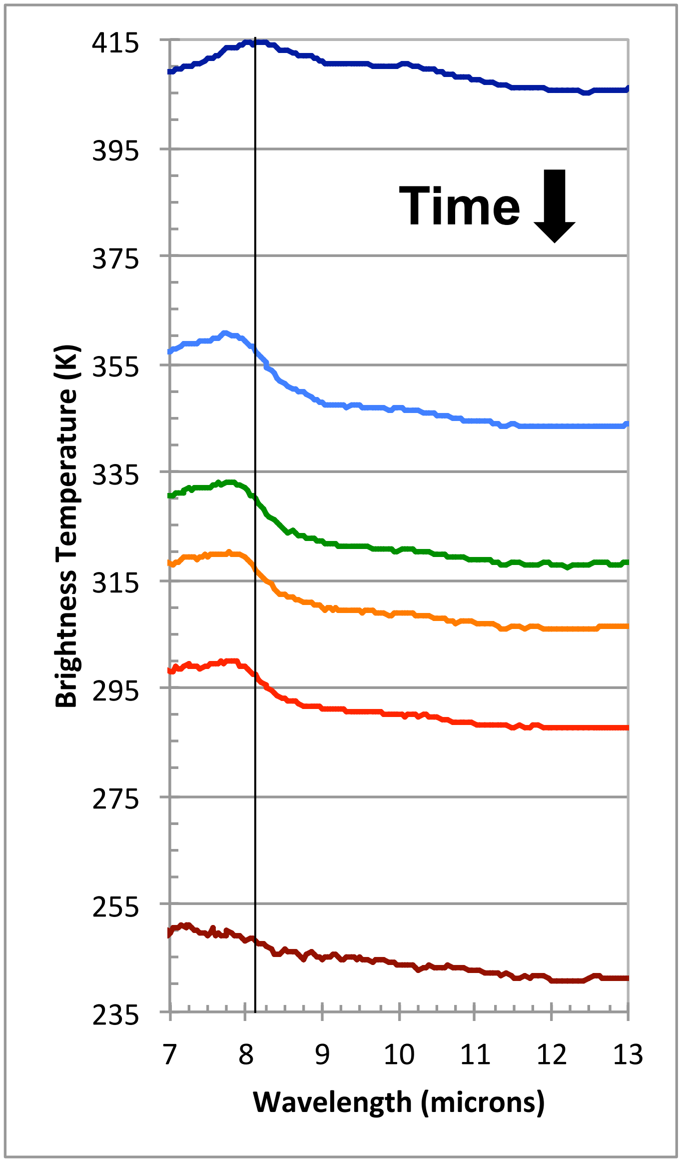
Results: Temperature, 283K Sample Cup



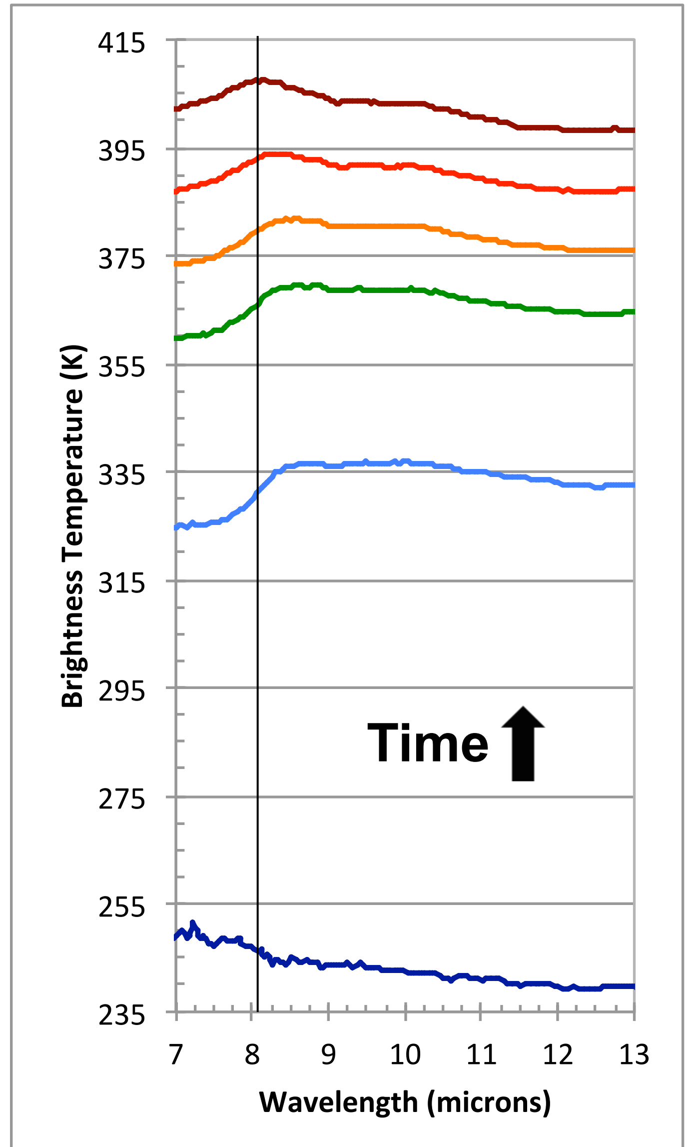


- **Rapid initial temperature change (>100K / 3 min)**
  - **Consistent with a highly insolating regolith**
- **Generally consistent with Diviner observations**
  - **Still cooling >1K / min at end of cooling experiment**

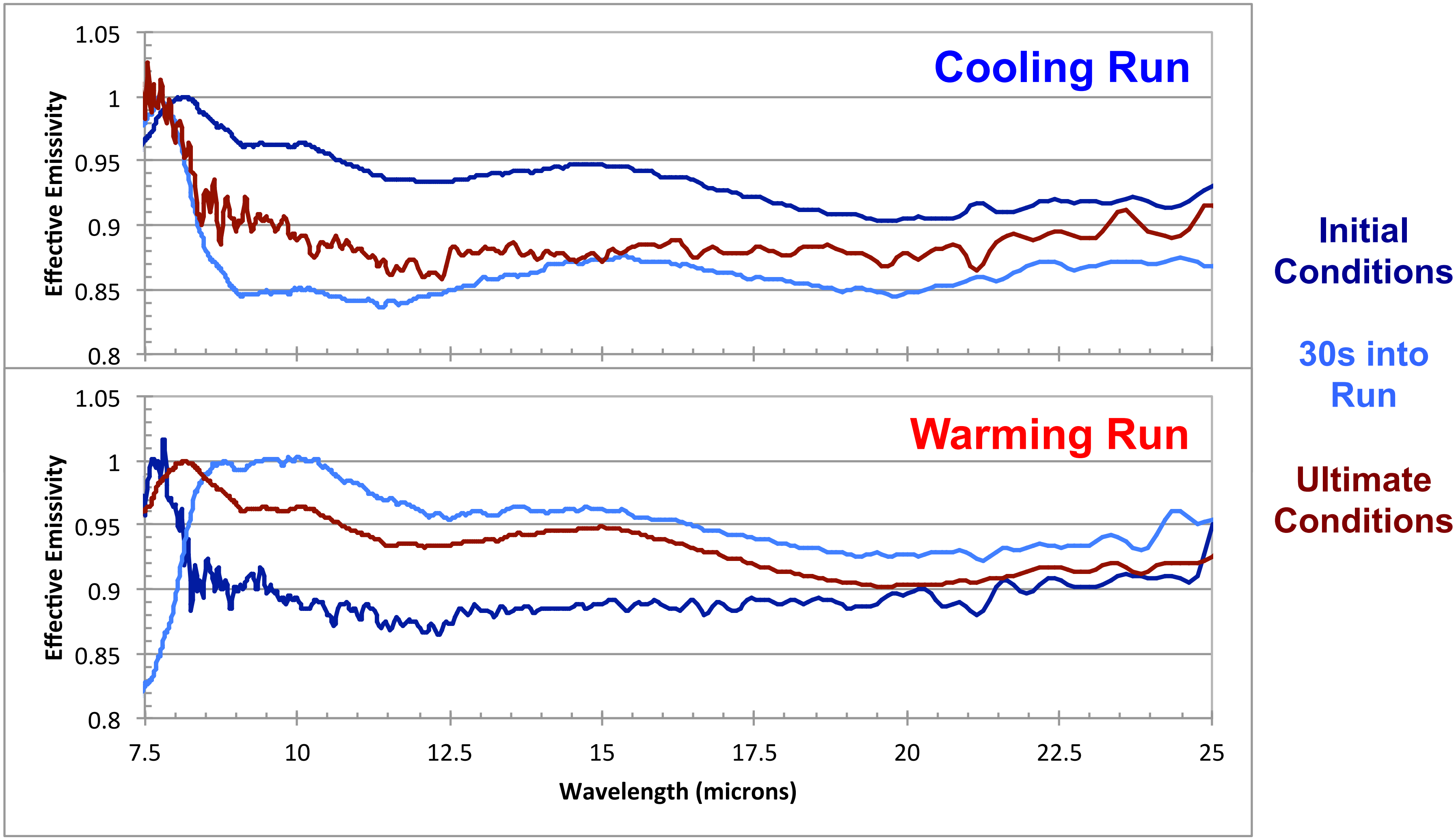
Results: Spectral (I)



- **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**

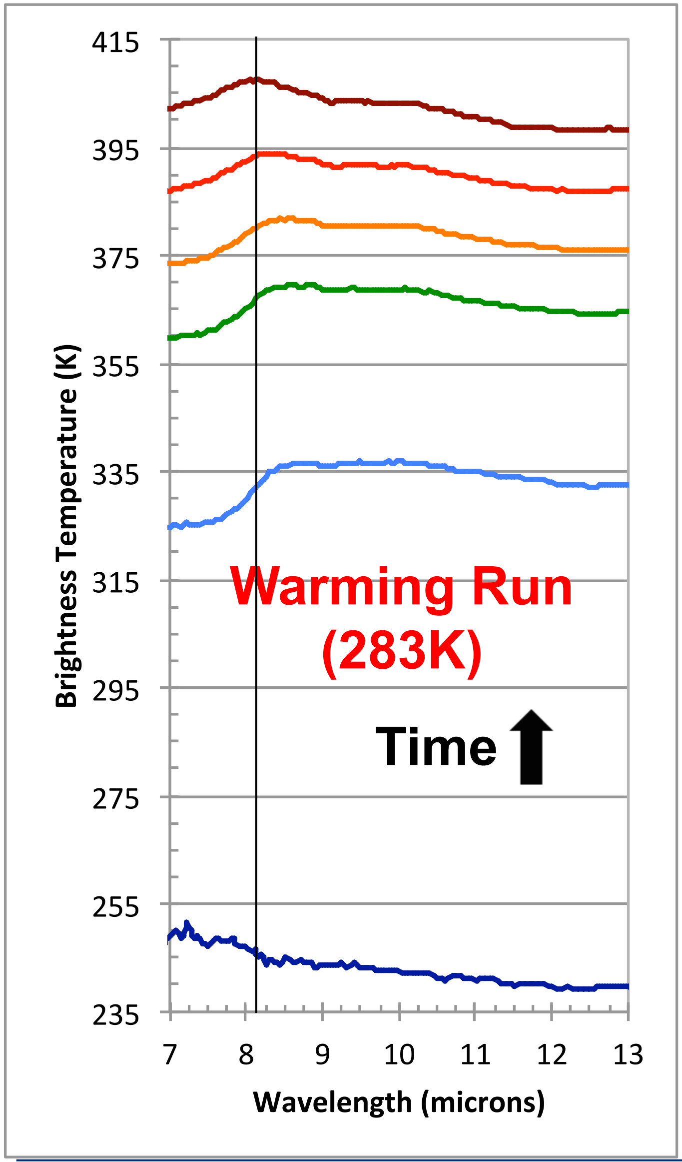


Results: Spectral (II)

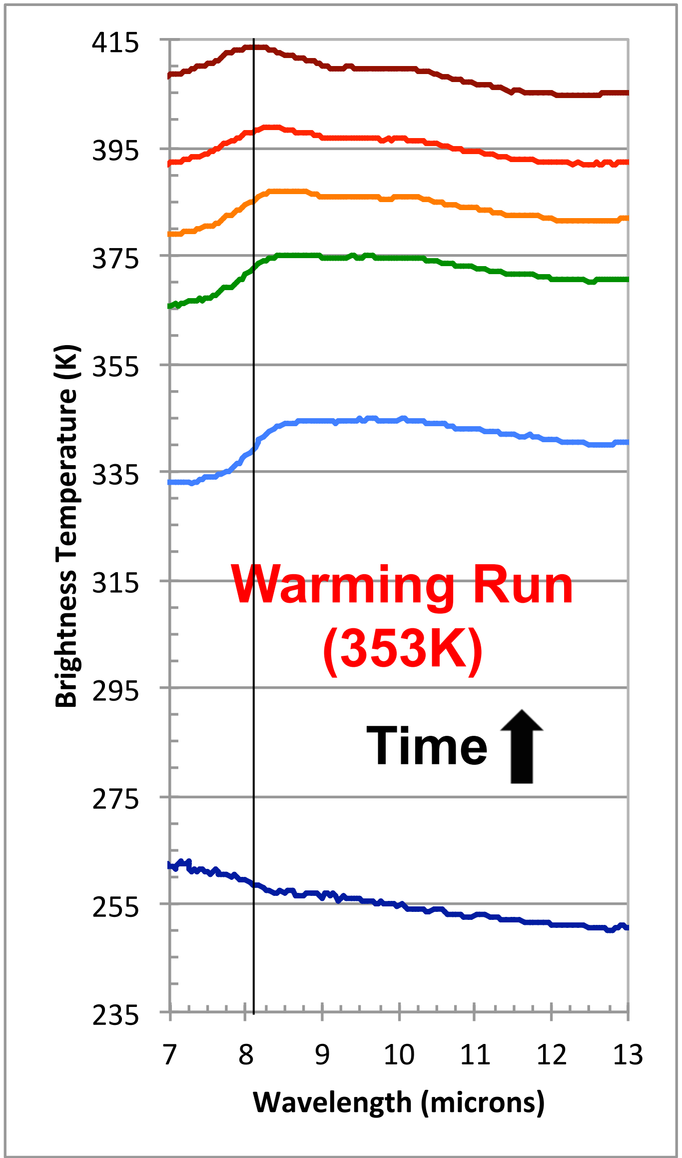


- **Preferential cooling and heating in Reststrahlen Bands is generally consistent with Diviner observations**

Results: Environmental Conditions



- Sample cup temperature effects are ~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 a., 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**

Date	LRO Mission	Diviner Status	SC Lon	Local Time
12/21/10	Science	Turned Off	N/A	N/A
6/15/11	Science	Operational	-77.1	06:50
12/10/11	Science	Operational	-81.5	06:34
4/15/14	ESM1	Turned Off	N/A	N/A
10/8/14	ESM2	Operational	-35.9	09:37
4/4/15	ESM2	Operational	-48.4	08:46
9/28/15	ESM2	Planned	~ 30	~ 14:00

- **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 epiregolith
  - 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

Questions?