Prospecting for Lunar Water-Ice Using Infrared Reflectance Spectroscopy of the Moon's Surface

Using remotely sensed grain size of surficial water to infer origin as either frost or exposed subsurface ice

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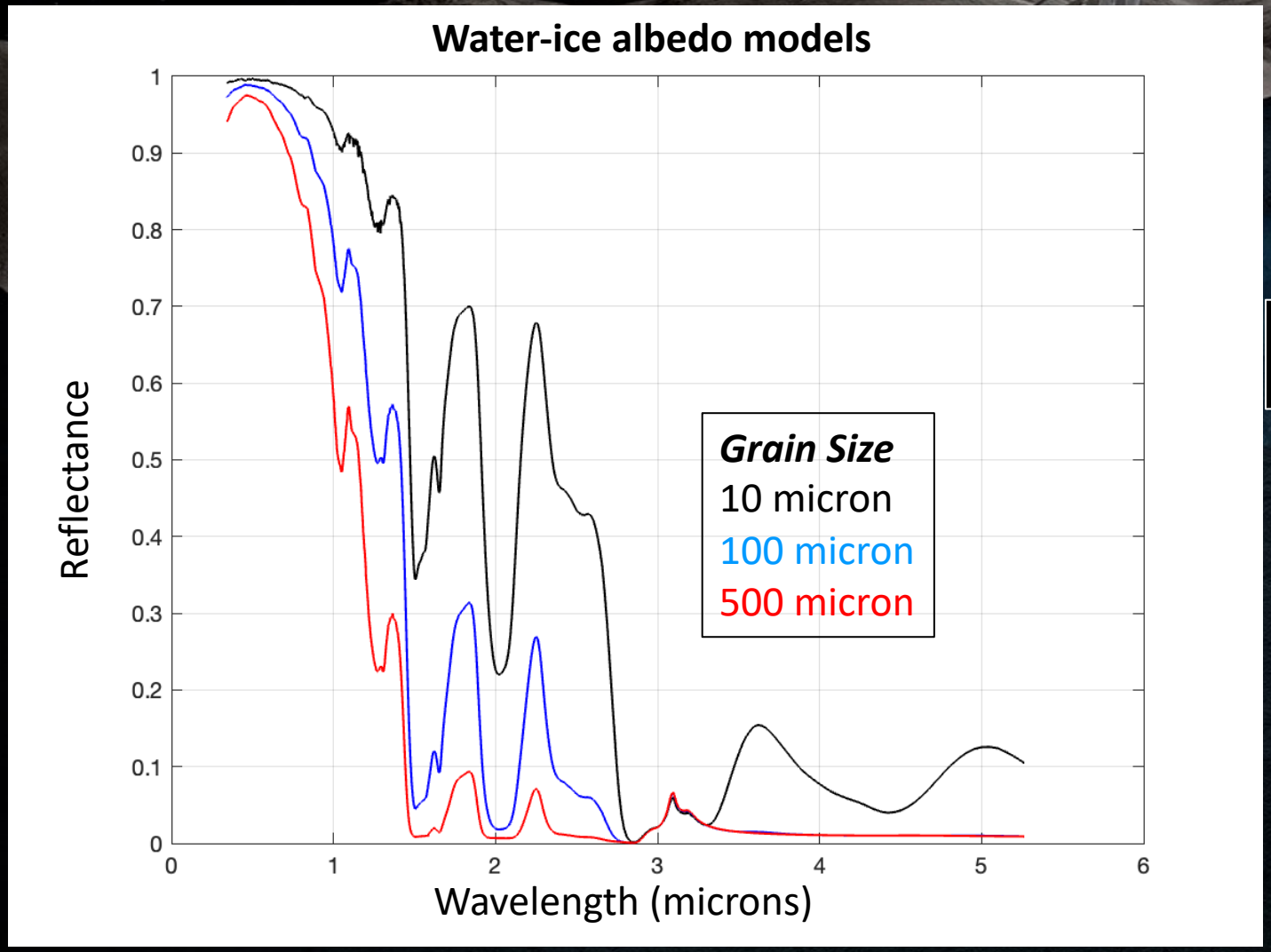
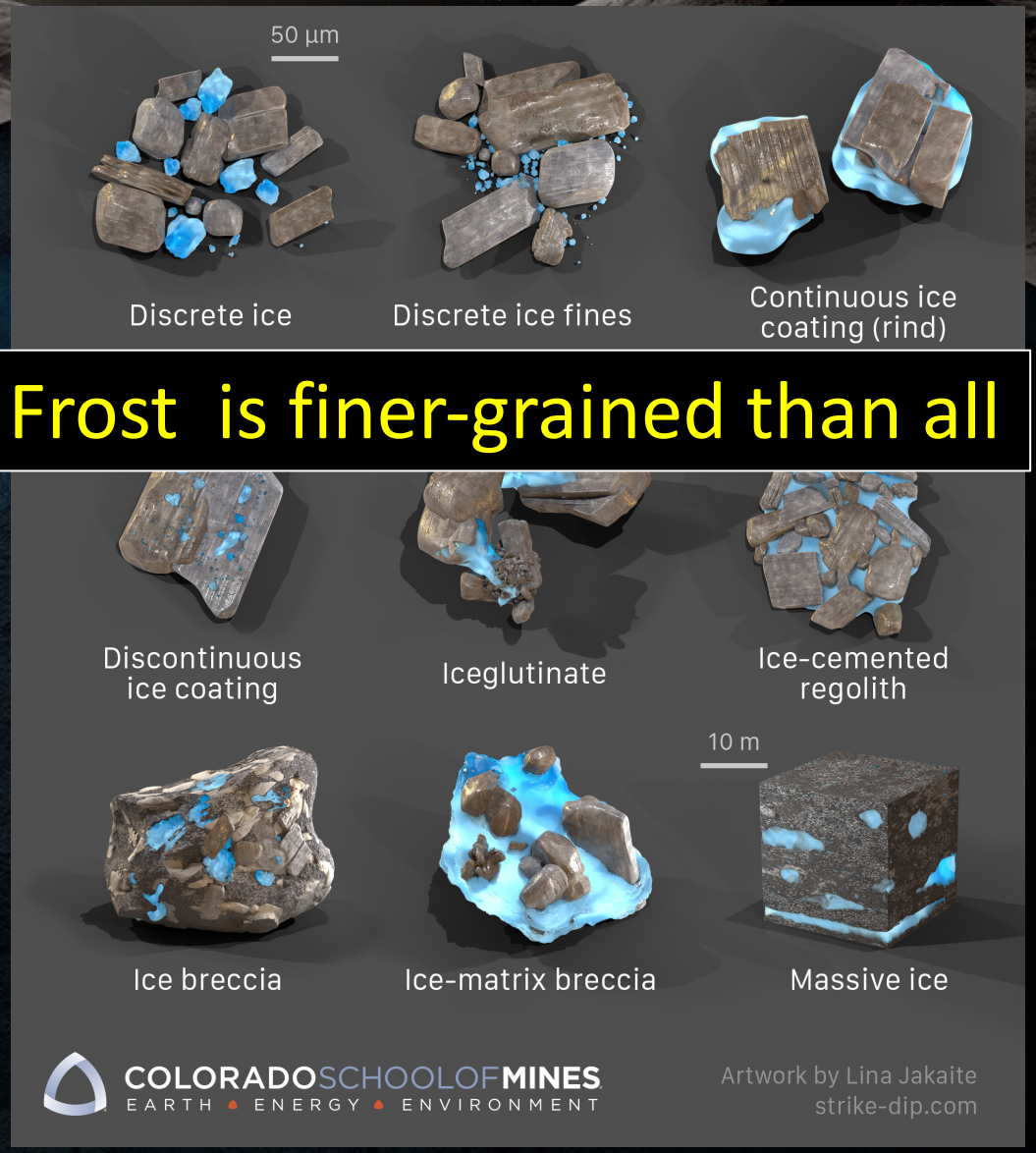
Ice in PSRs and discrimination by grain size

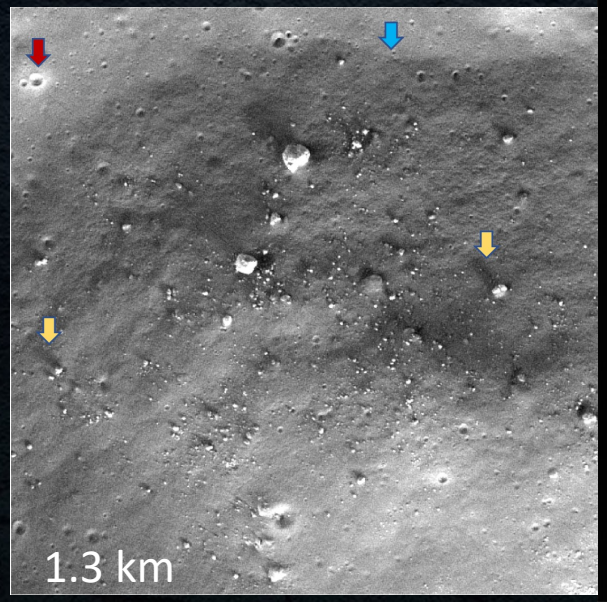




Spectral Detection of Ice in Permanently Shadowed Regions (PSRs)

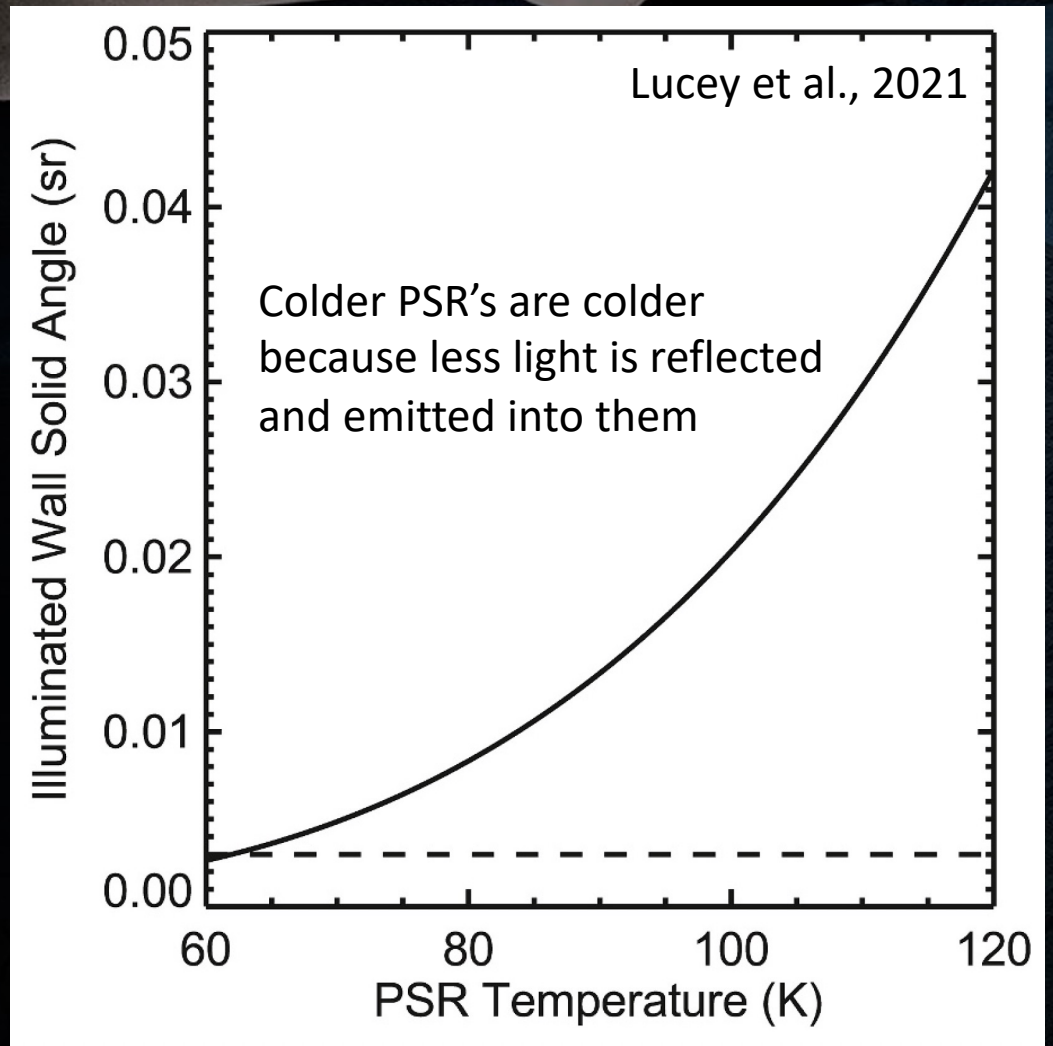
- PSRs can be << 110K. The colder they are, the darker they are.
- They have variable levels of illumination, but still enough
  - Reflected light from illuminated terrain
  - Emitted thermal light from illuminated terrain
  - Earthshine
- Infrared Reflectance spectroscopy possible

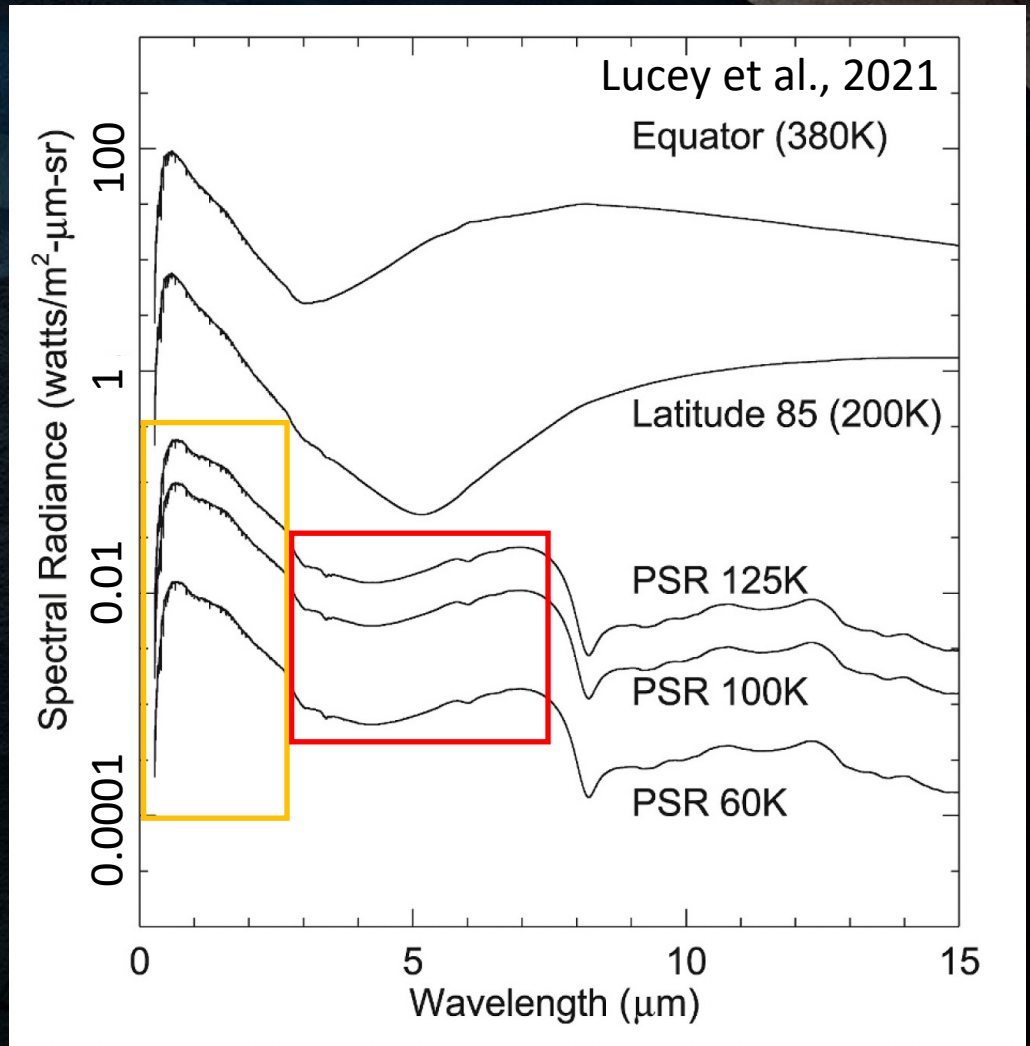
KPLO ShadowCam images of shadowed Shackleton Crater (ASU)



LROC NASA/ASU

Illumination in Permanently Shadowed Regions (PSRs)





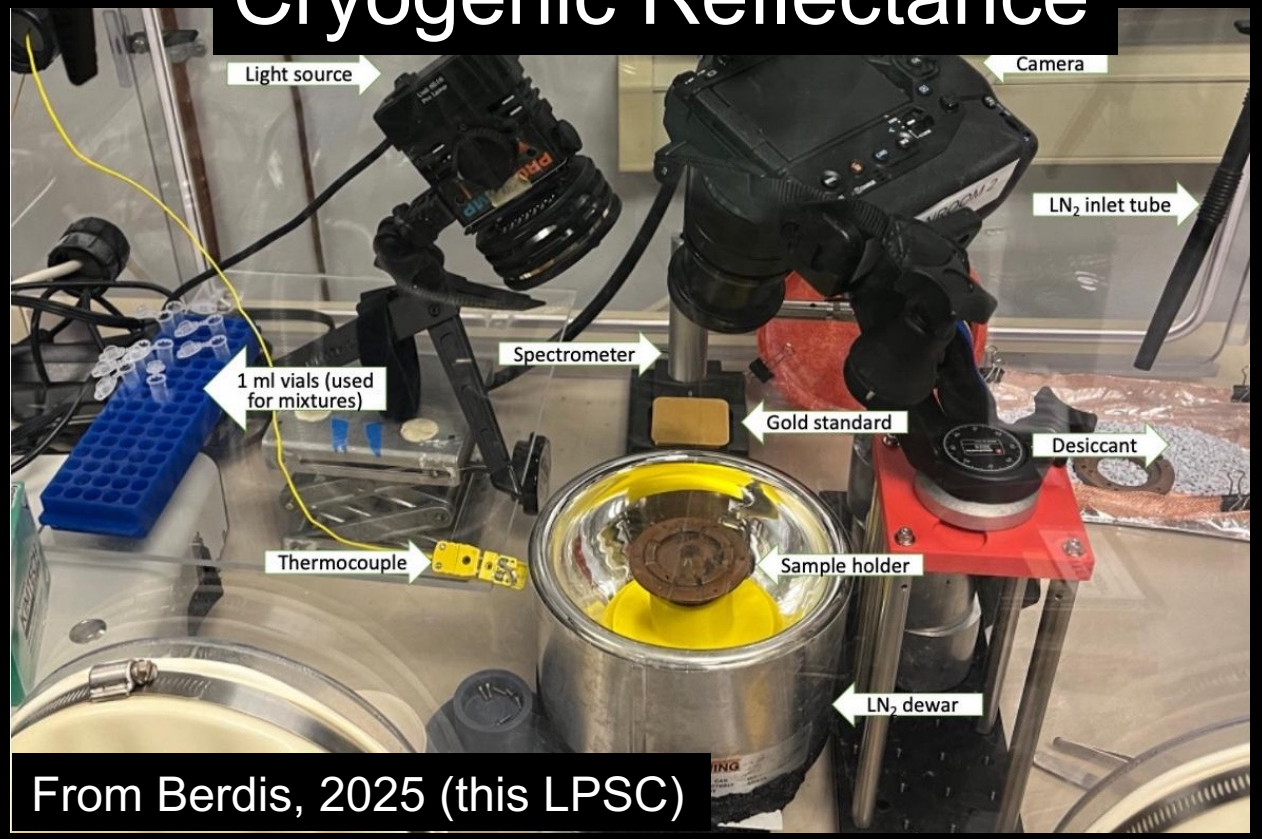
CRONOS facility – Cryogenic Reflectance Observations using Nitrogen-purged Optical Spectroscopy

400 – 2400 nm cryogenic reflectance on powders of lunar simulants and sieved ice

Sample Preparation

Grinding & wet sieving ice (and anorthite and ice mixtures) w/ liquid nitrogen in an N_2-purged box.

Cryogenic Reflectance



Subsequently, taking cryogenic 1 – 2.5 μm reflectance spectra w/ liquid nitrogen in same N_2-purged box.

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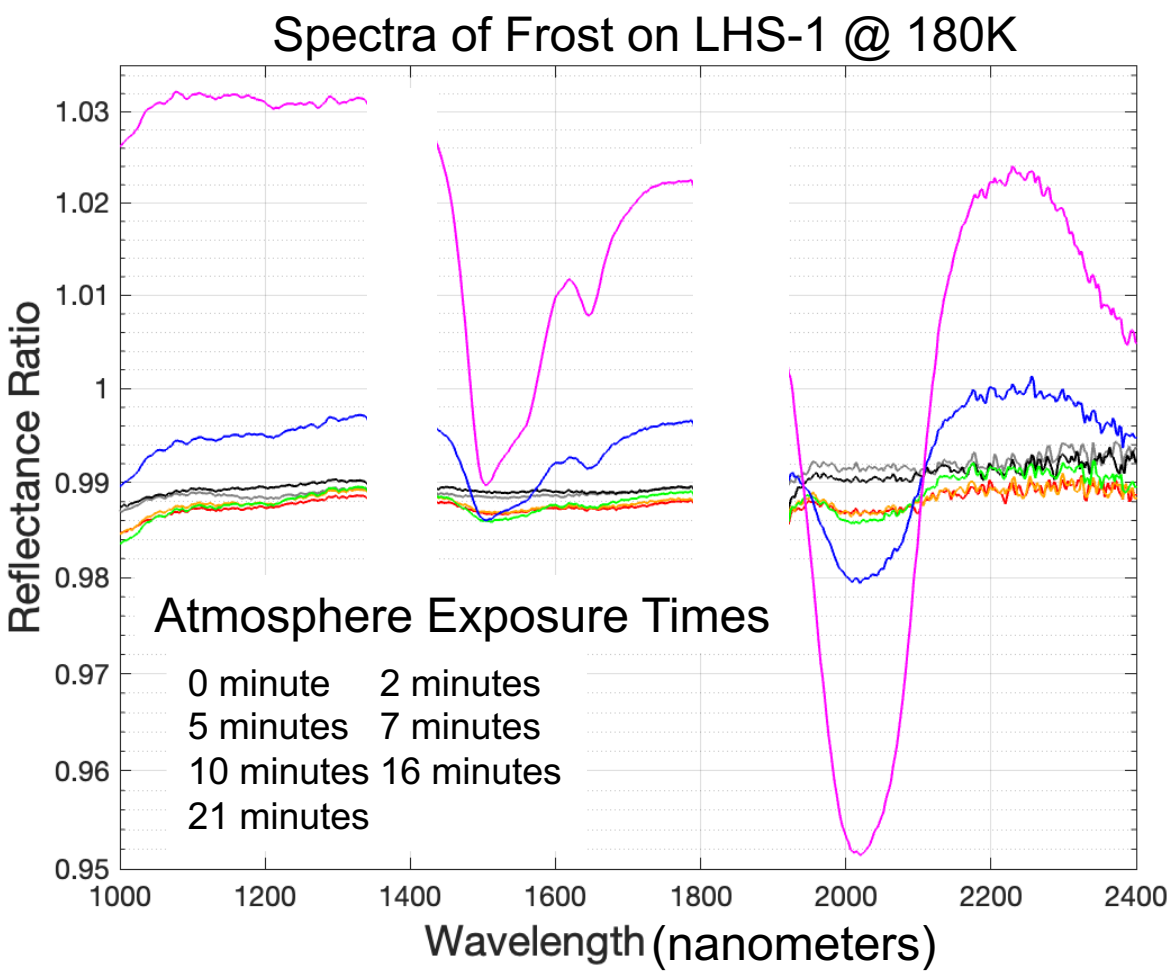
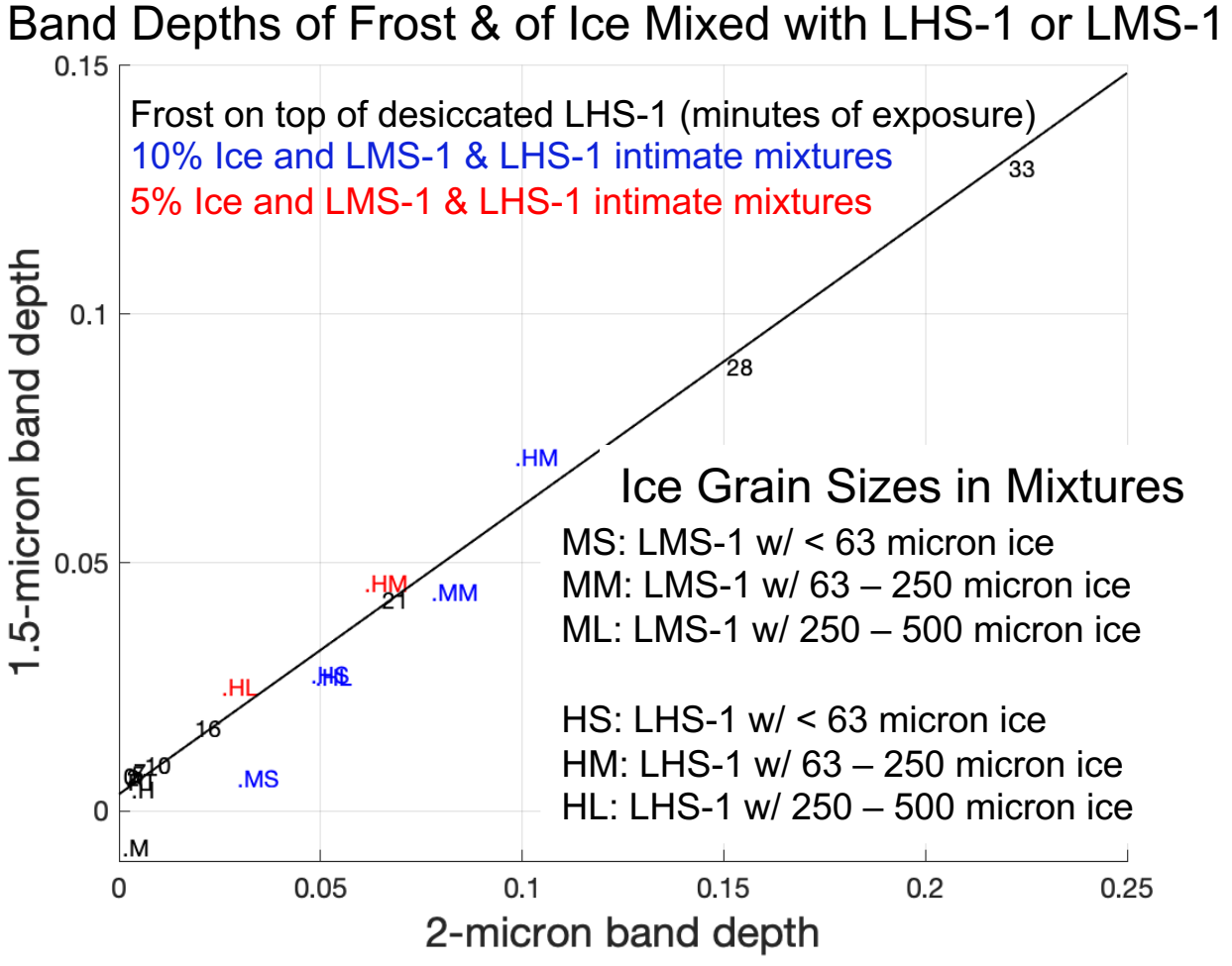
CRONOS facility – Cryogenic Reflectance Observations using Nitrogen-purged Optical Spectroscopy

- The 1.5 and 2-micron bands grow proportionally with increasing ice abundance. $\Delta 1.5/\Delta 2=0.58$
- Trend is independent of fractional abundance of ice, mixture style, and grain size (at these low abundances)





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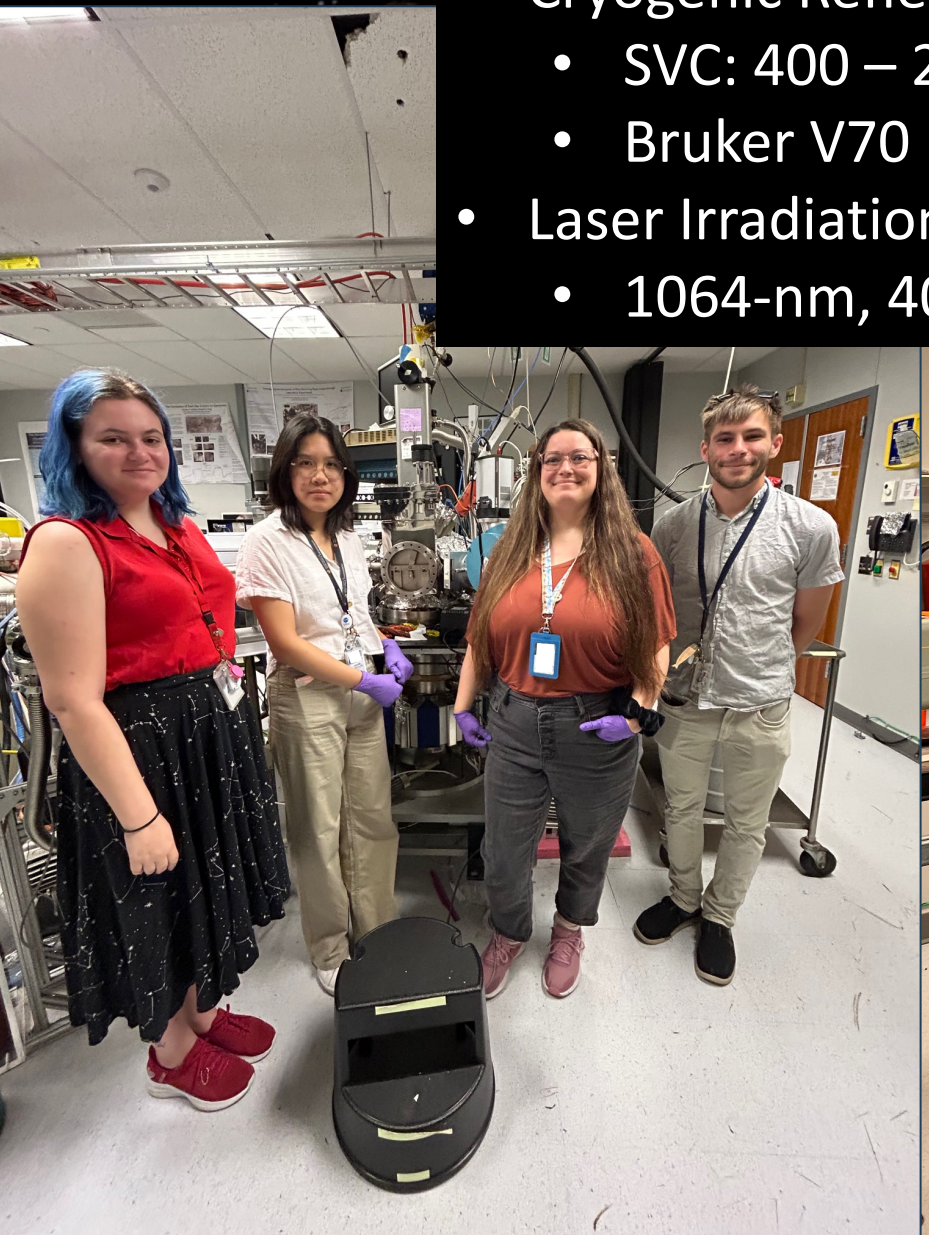
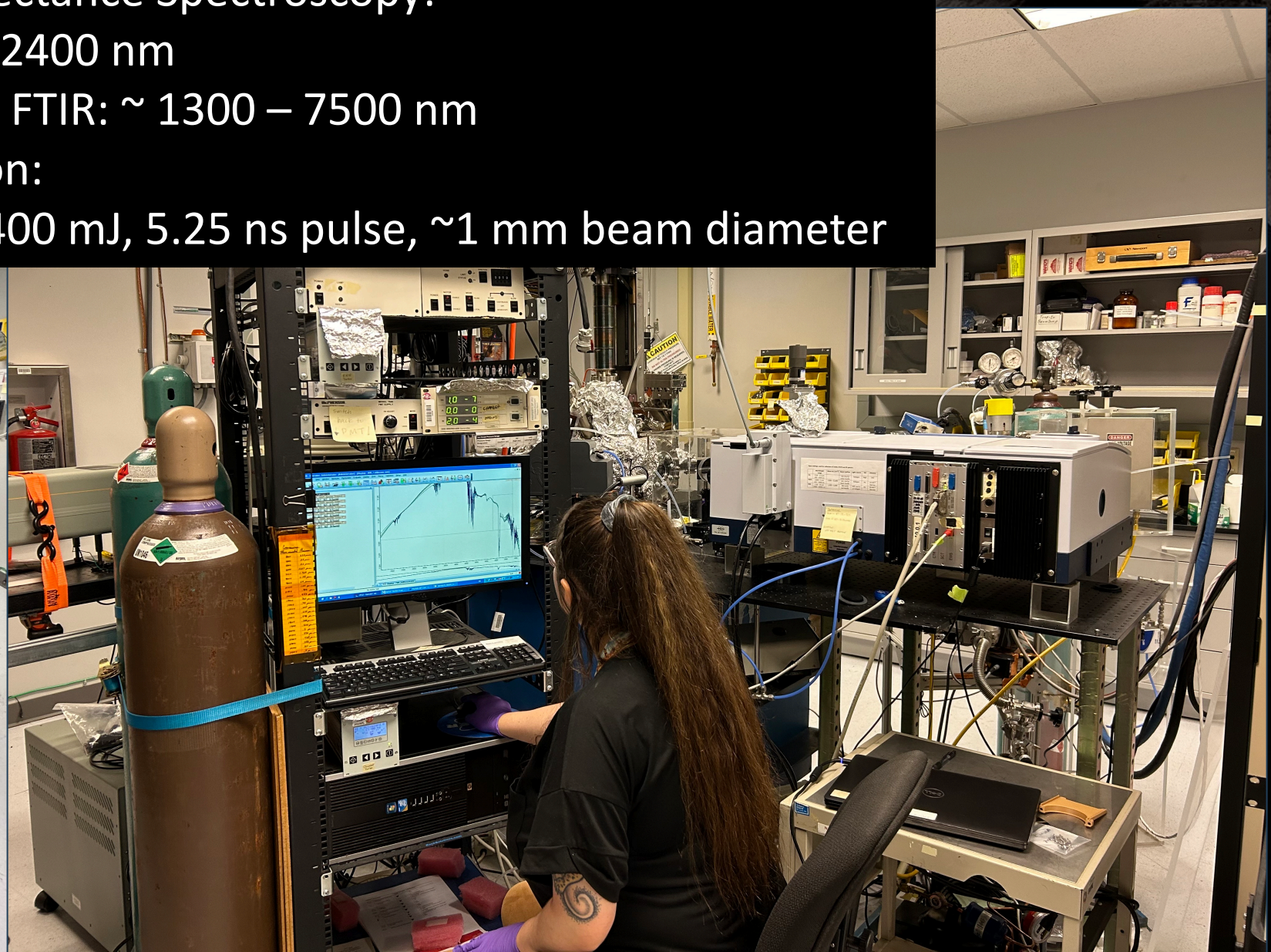
LabSPEC Laboratory for Spectroscopy under Planetary Environmental Conditions

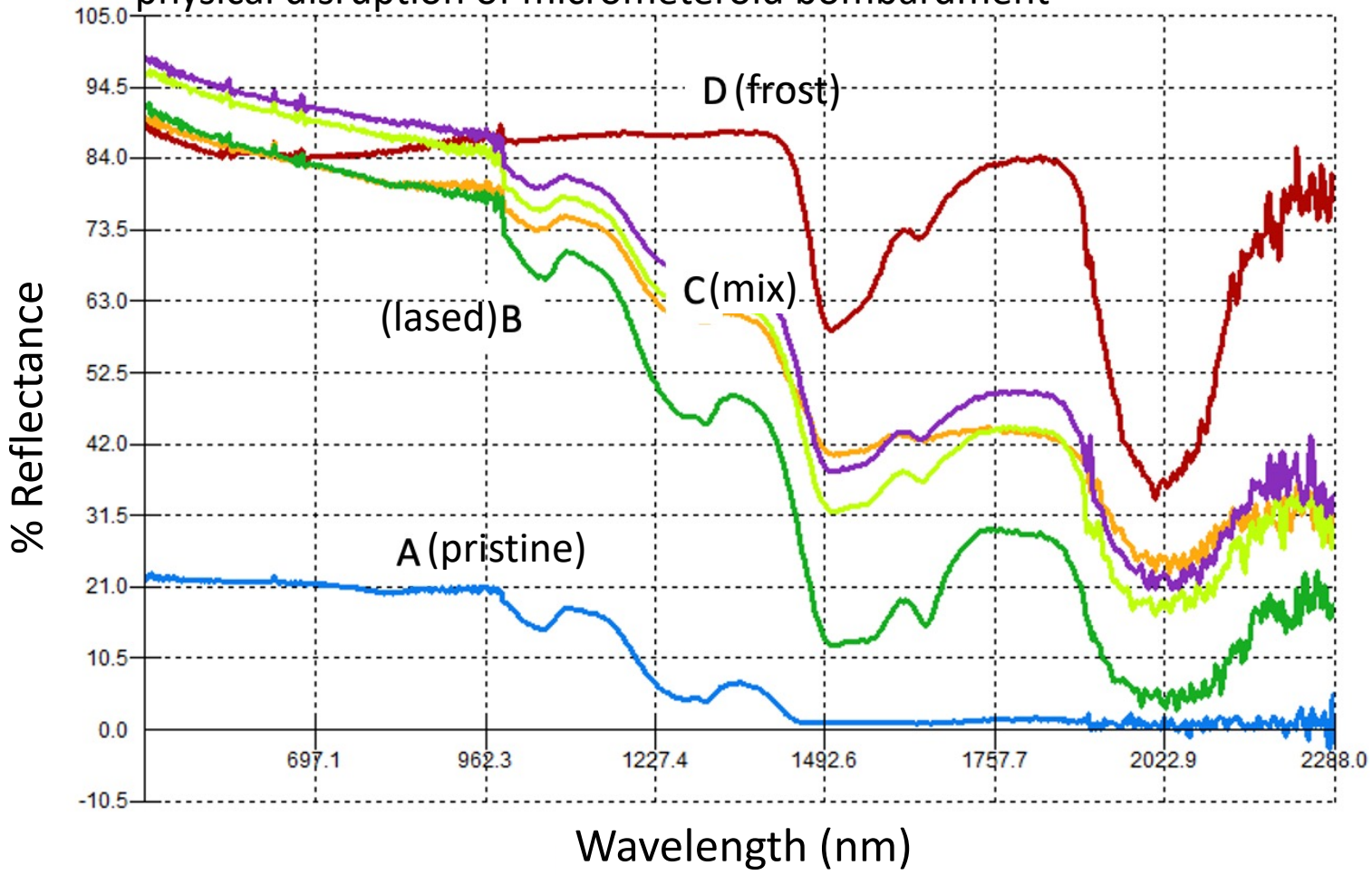
- Cryogenic Reflectance Spectroscopy:
  - SVC: 400 – 2400 nm
  - Bruker V70 FTIR: ~ 1300 – 7500 nm
- Laser Irradiation:
  - 1064-nm, 400 mJ, 5.25 ns pulse, ~1 mm beam diameter

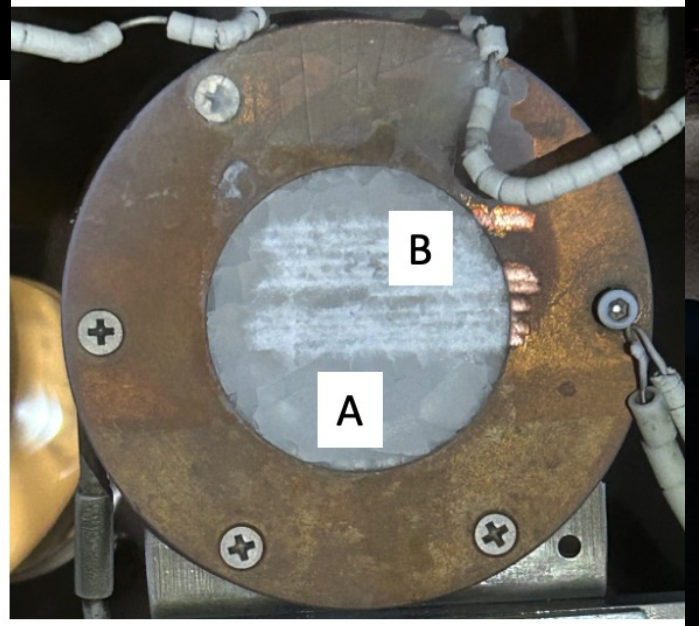


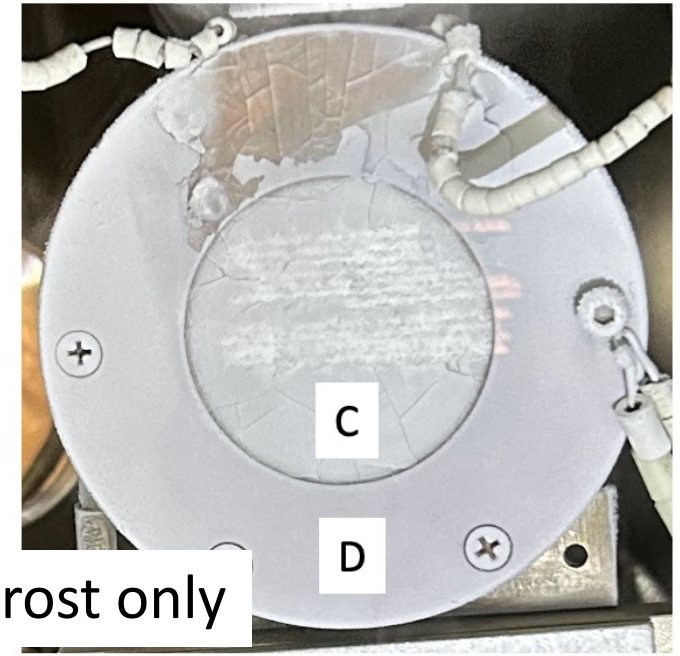


Pure Ice (not realistic)

Spectra of Ice before and after disruption by lasing to simulate the physical disruption of micrometeroid bombardment

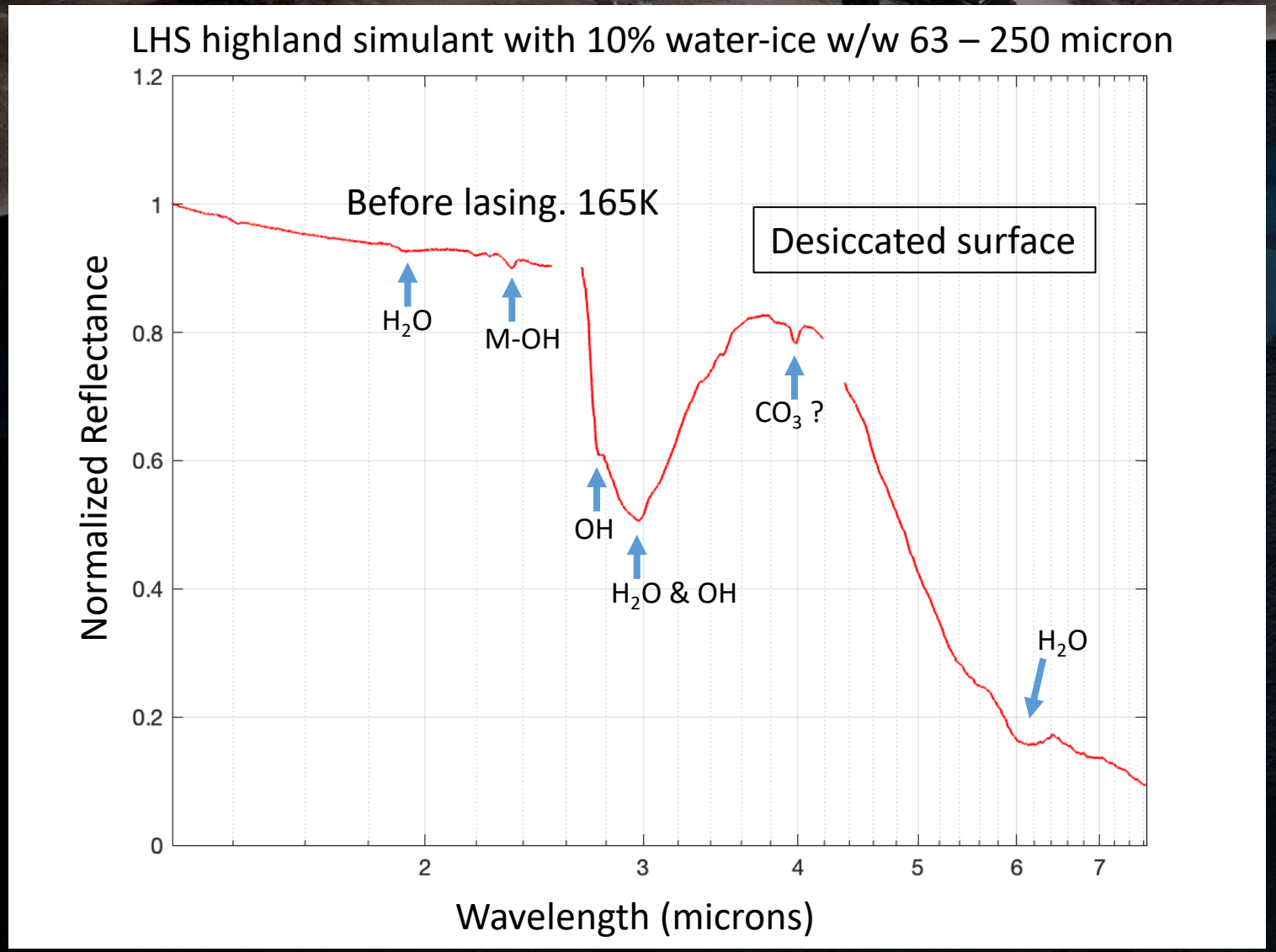






(A) Massive ice; (B) Laser irradiated; (C) Frost on massive ice; (D) Frost only

Comminuted Ice Deposit: Granular Mixtures of Water Ice and Highland Simulant



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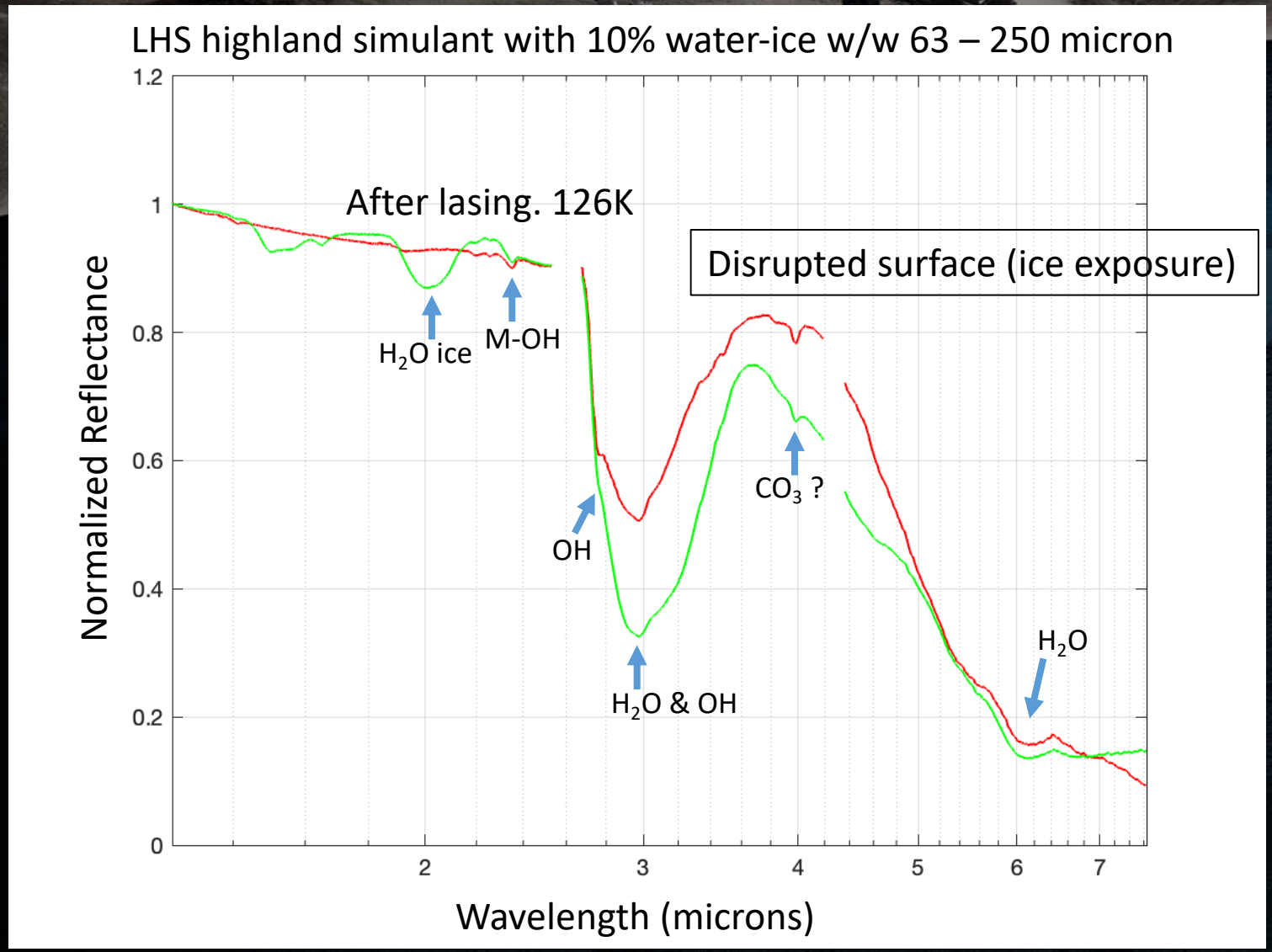

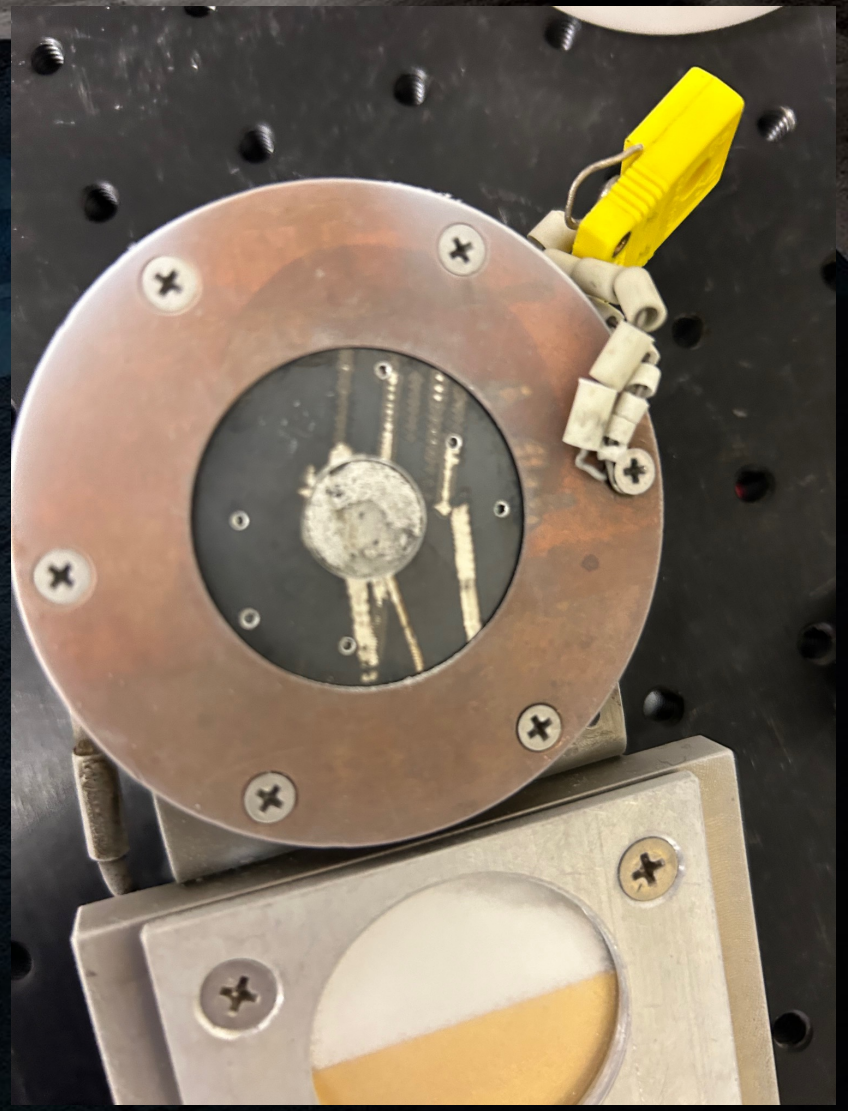

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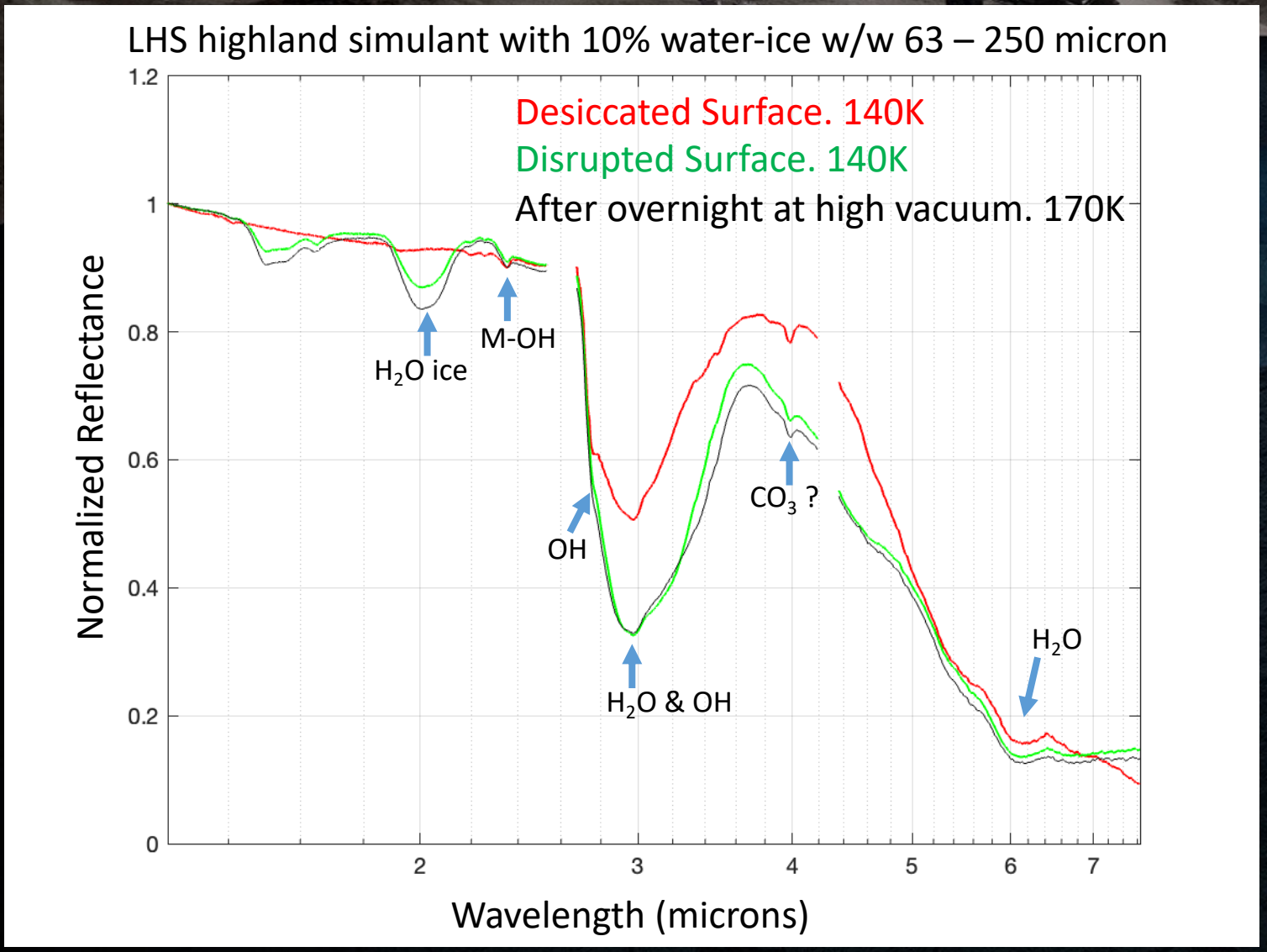

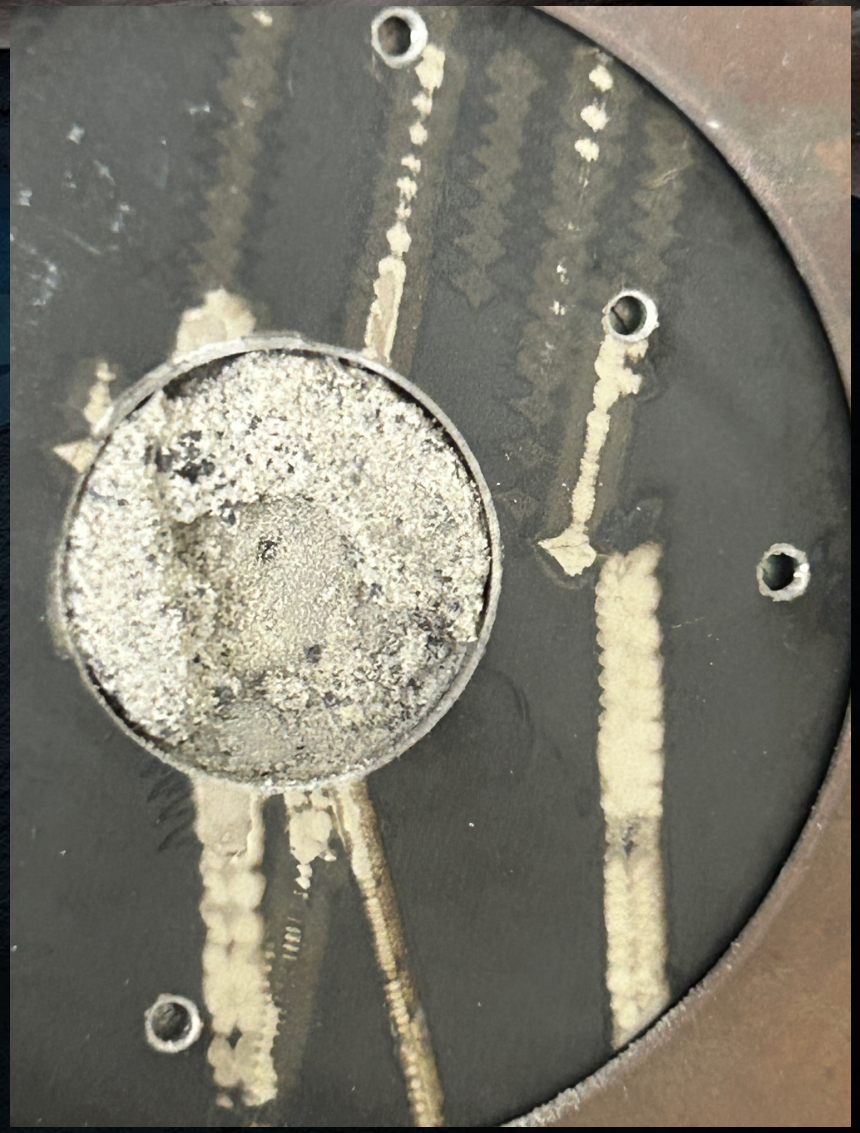

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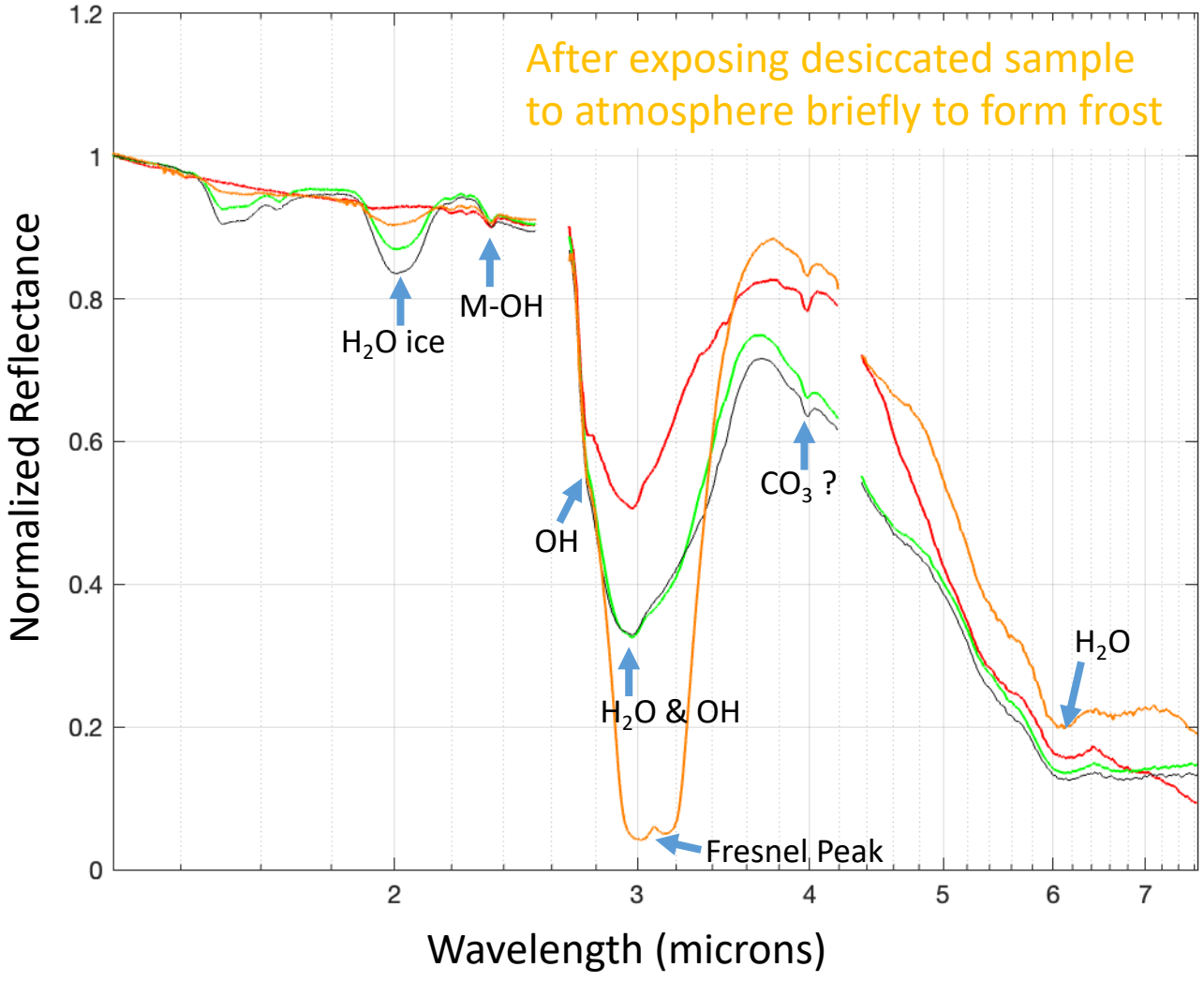
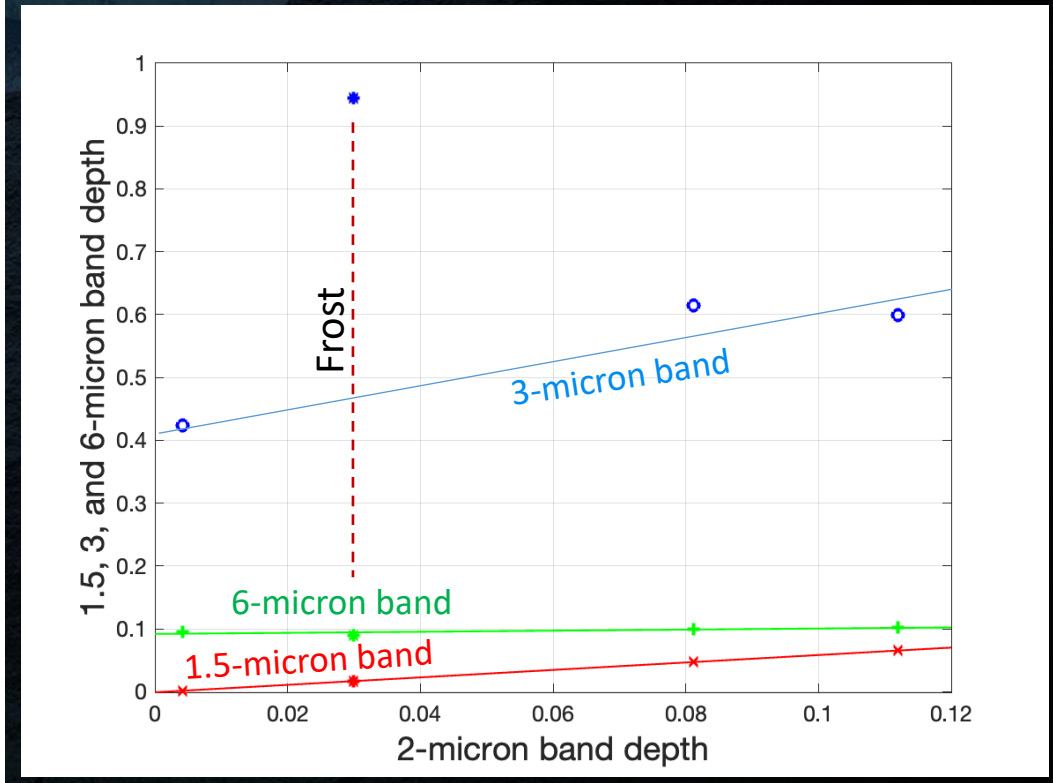
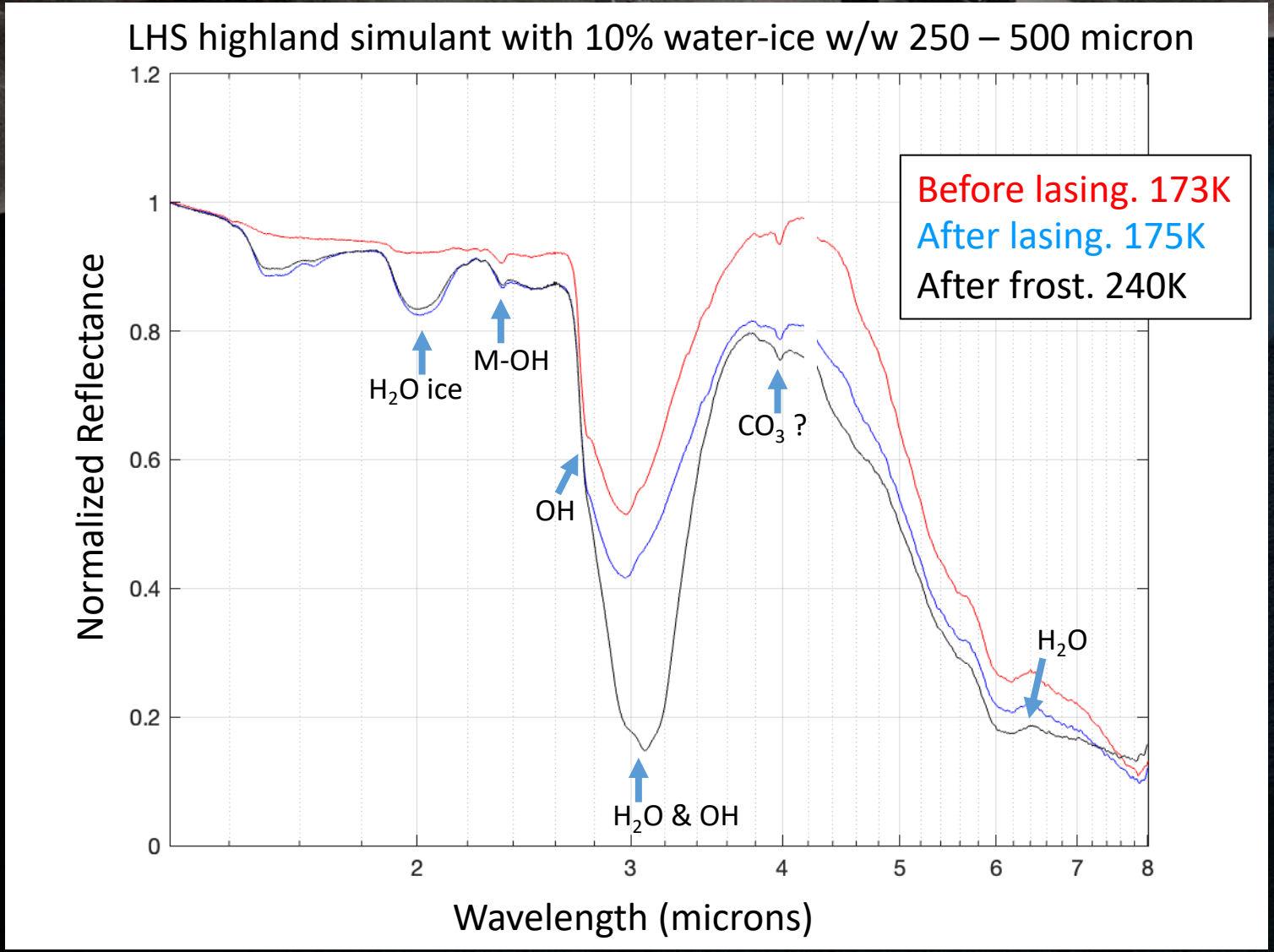


- Frost has relatively large 3-micron band
- The 6-micron band is insensitive to ice
- The 1.5 and 2-micron bands grow proportionally with increasing ice abundance $\Delta 1.5/\Delta 2=0.59$



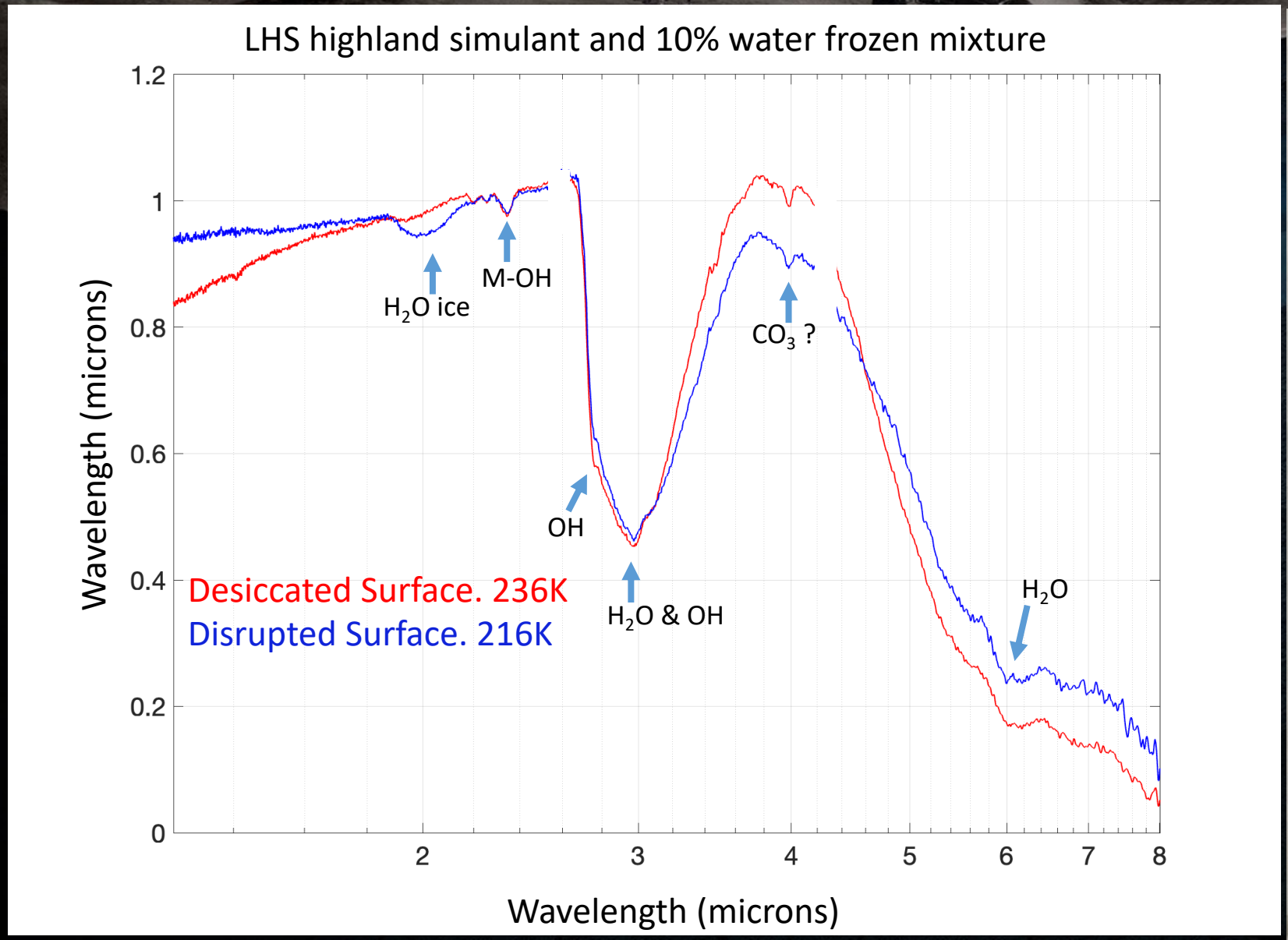
Comminuted Ice Deposit 2: Granular Mixtures of Water Ice and Highland Simulant



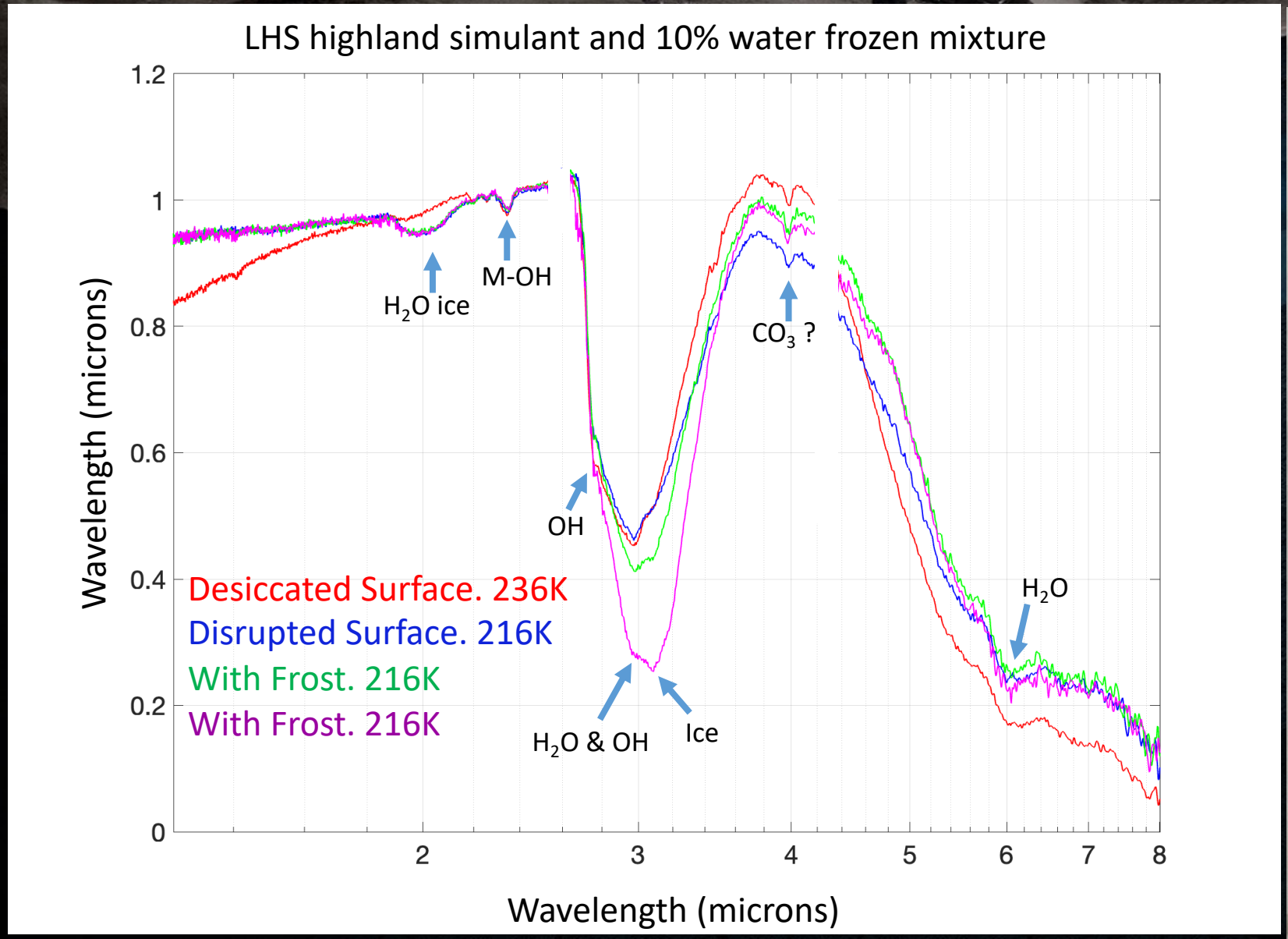
Begins with a desiccated surface
Ice is exposed by lasing
Frost adds to and shifts the 3-um band but doesn't affect the 1.5 and 2-um bands

What does frost on desiccated simulant look like?

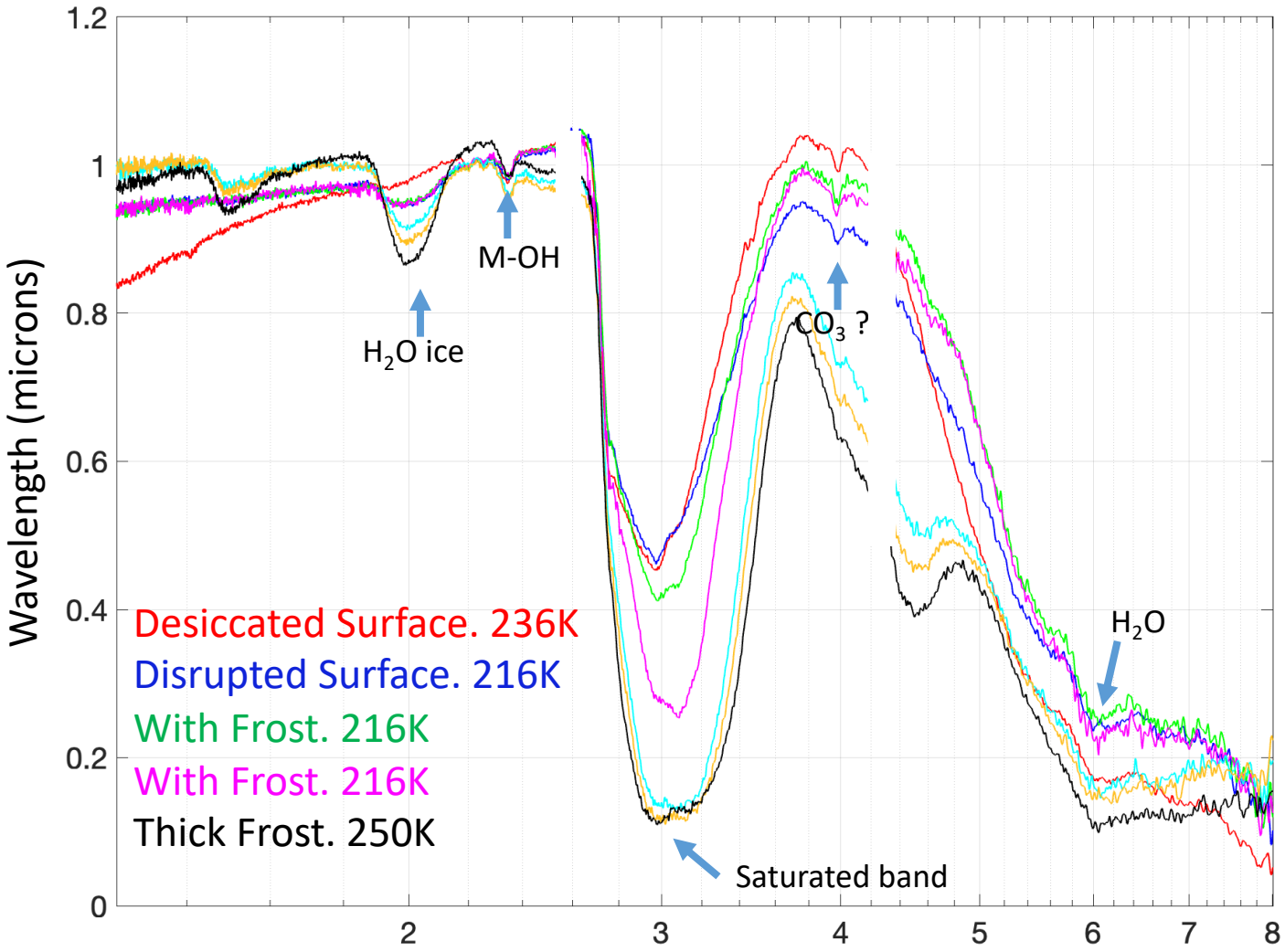
Massive Ice Deposit: Frozen Slurry of Water and Highland Simulant

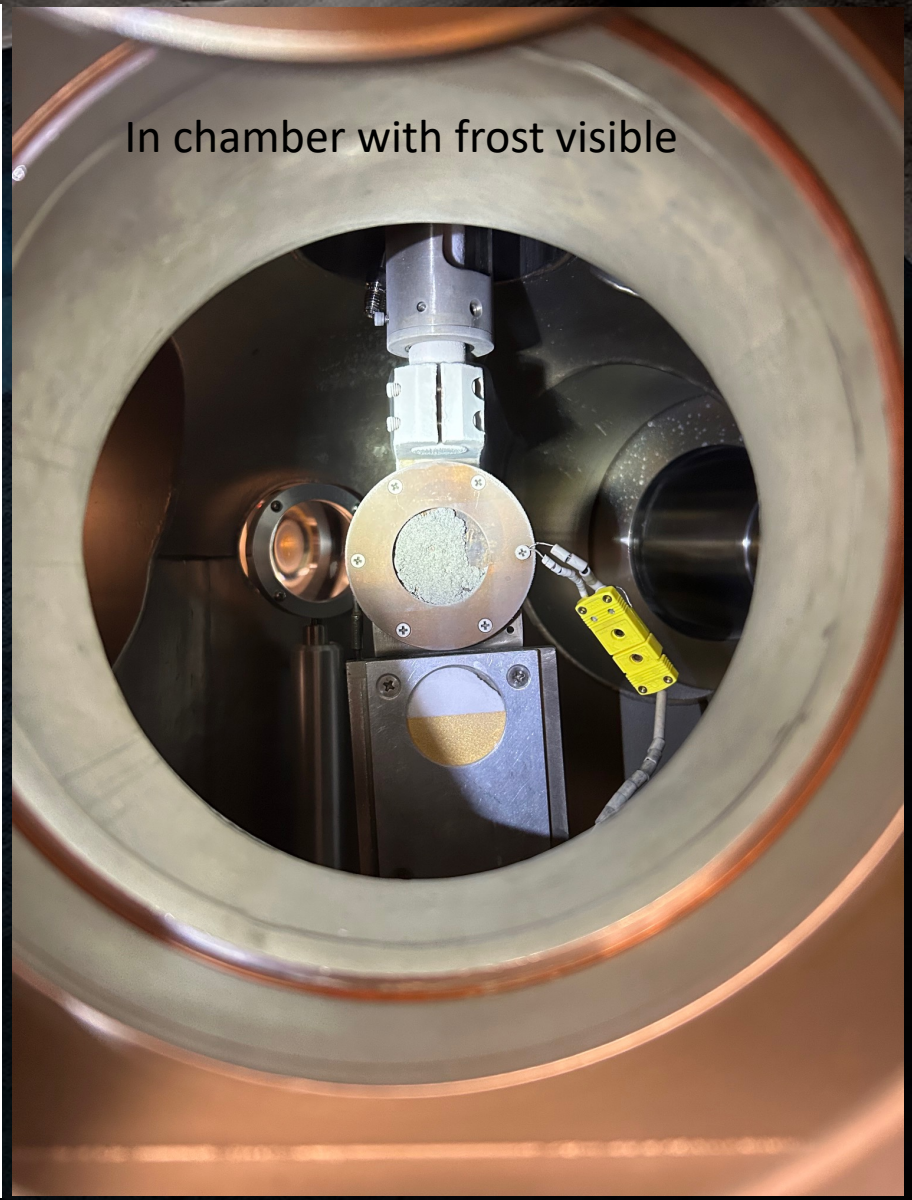


Massive Ice Deposit: Frozen Slurry of Water and Highland Simulant



Vacuum Chamber: Mixtures of Water and Highland Simulant (frozen)





Conclusions

in the infrared spectral characteristic of **water-ice at <10% abundances**

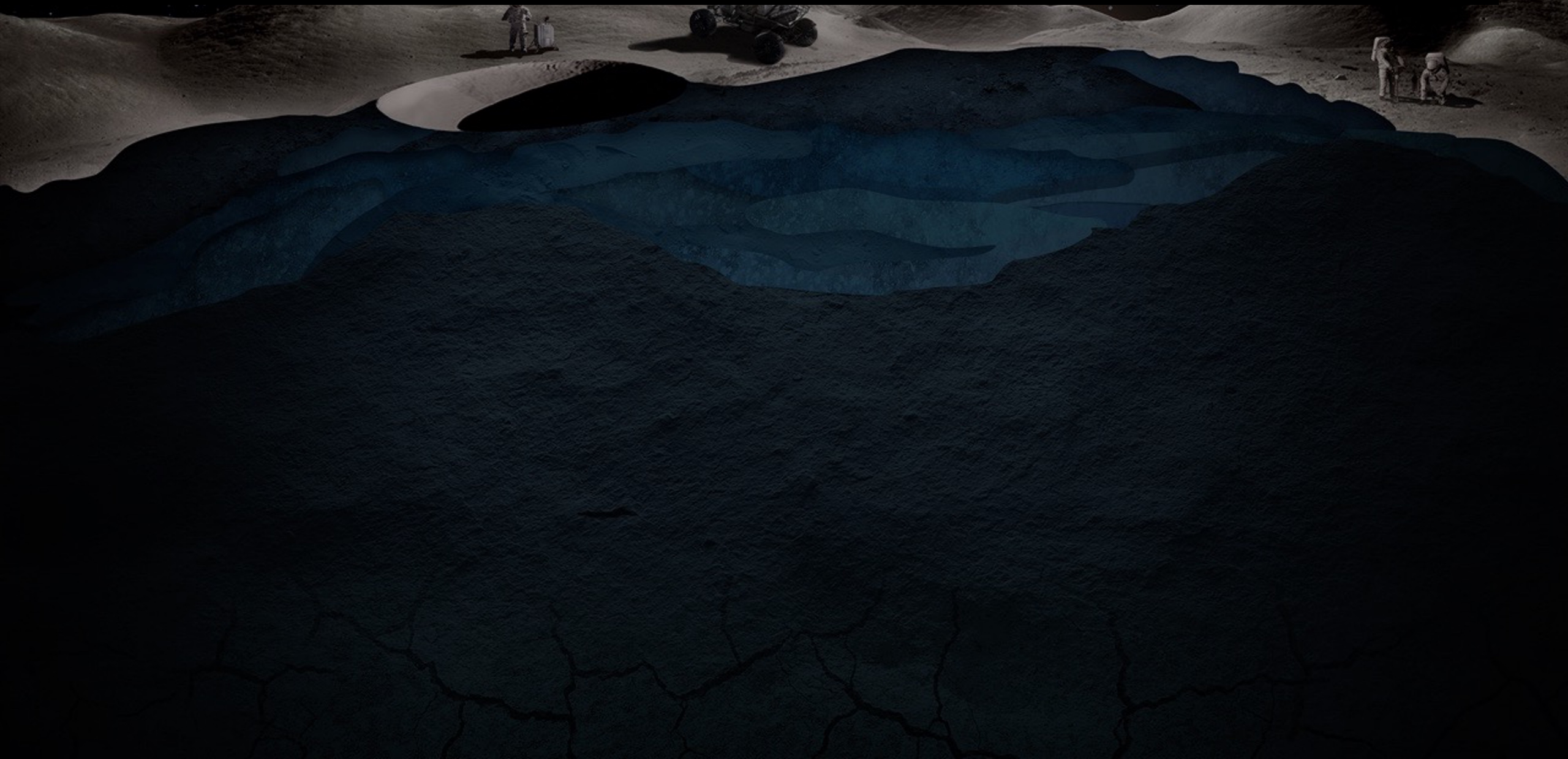
1. The depths of the 1.5- and 2-micron bands vary linearly with a $\Delta 1.5/\Delta 2$ of ~0.6 independent of grain size, albedo of material it is mixed with (at least to some extent), mixing style (so far), and abundance.
   - Not likely possible to only use the SWIR to constrain both grain size and abundance. One has to be known
   - A ~2-micron band only is not necessarily indicative of water ice; it is also present with adsorbed water

2. Including the 3-micron band is enabling to discerning ice grain size at low ice abundance.
   - Surface frost can potentially be distinguished from ice intimately mixed with regolith by a relatively deep 3-micron band compared to the 2-micron band.
   - Thus, it may be possible to discern excavated ice (larger grained) from surface frost

3. The 6-micron band is uniquely capable of detecting molecular H_2O in forms other than ice; water ice does not contribute to the 6-micron absorption.

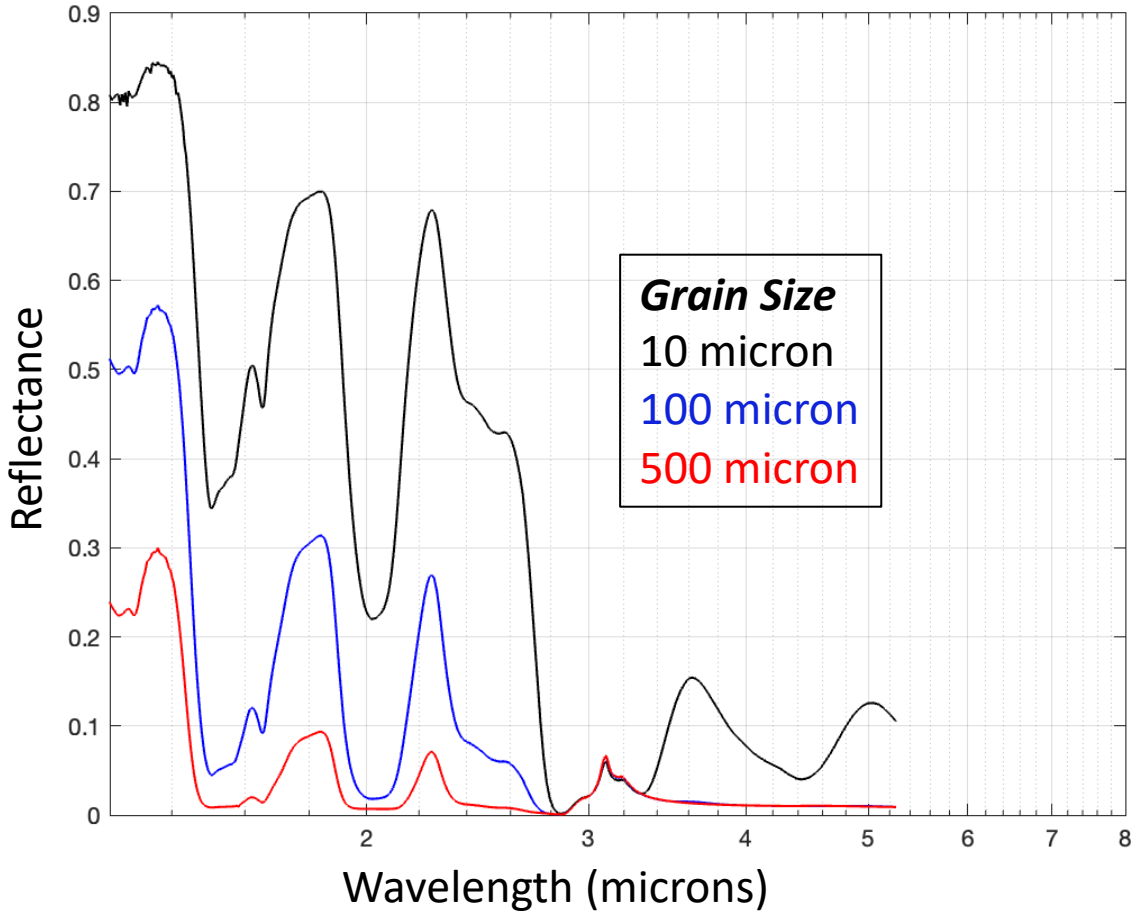
4. Recommendation:
   - Orbital and rover missions would need to leverage both the 2- and 3-micron bands to understand grain size to infer origin and evolution of low abundances of ice on the Moon or other non-icy surfaces. The 1.5-micron band can be too weak at low ice abundances and the 6-micron band is not sensitive to ice.

Extra



Water Ice Sieve Fractions

Albedo models



Laboratory bidirectional reflectance (i=15°, e=45°)