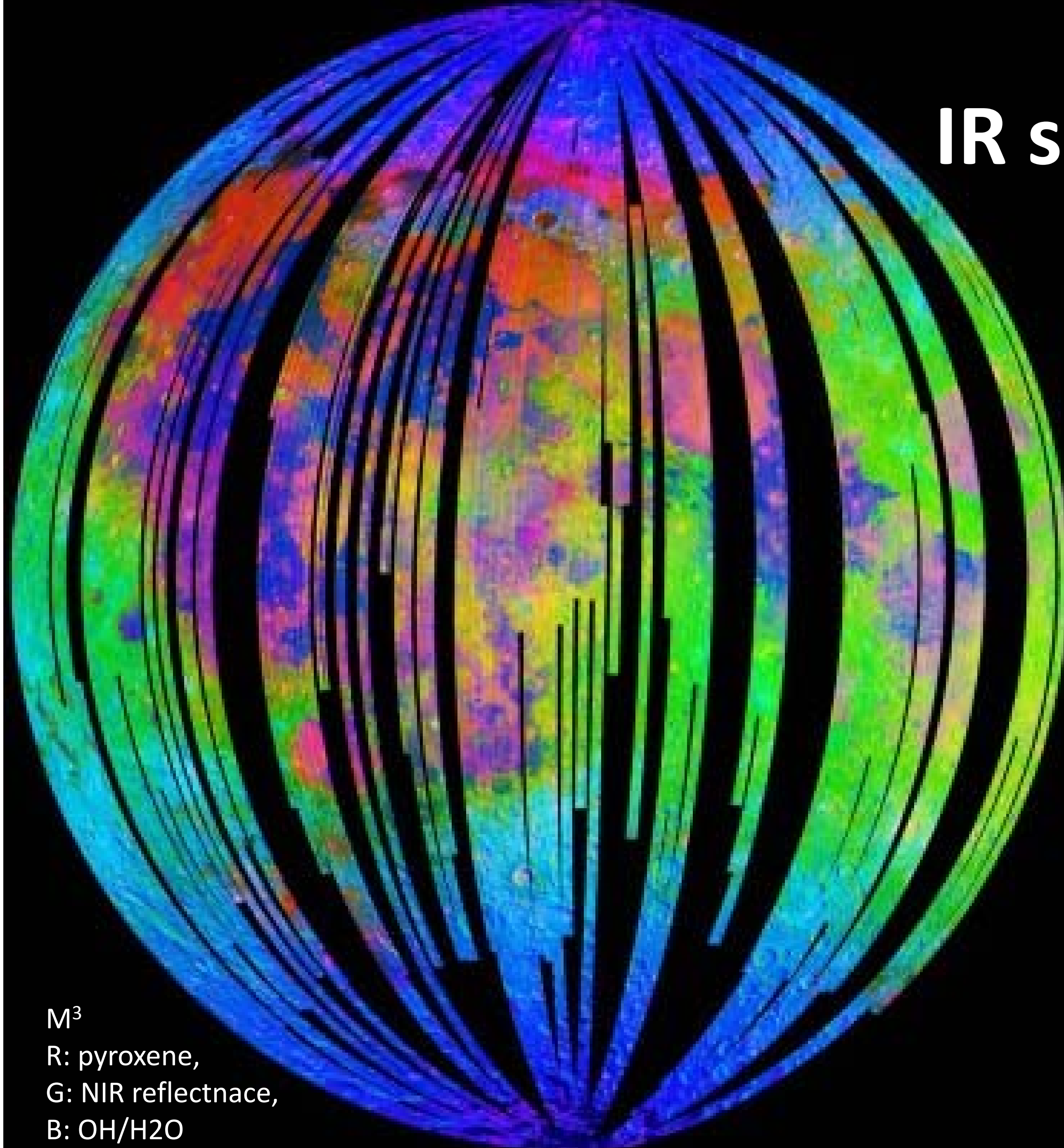
IR spectroscopy of Lunar Volatiles



M³
R: pyroxene,
G: NIR reflectnace,
B: OH/H2O

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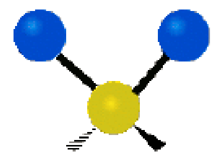
July 23, 2013

What do we want to know?

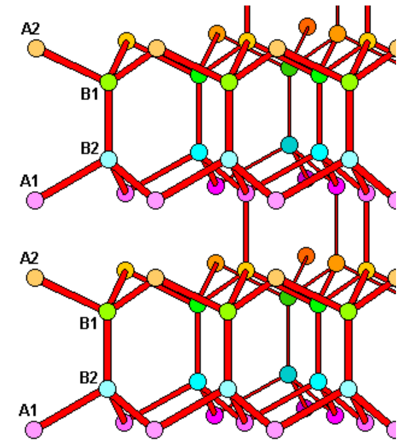
- **Where** is the H_2O(ice,bound)/OH? (Where is each?)
- **How much?** (and how much variation?)
- **What else** is there (regolith, H_2S, NH_3, etc.)?
- **What is the isotopic ratio**?

IR spectroscopy: Quick Review

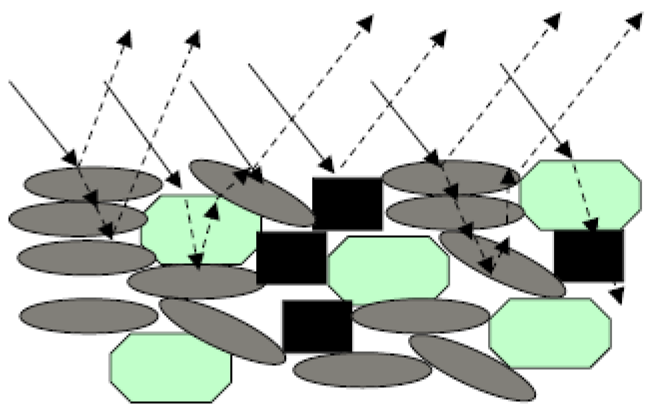
- Bends and stretches related to vibrations of molecules, typically associated with a mineral structure



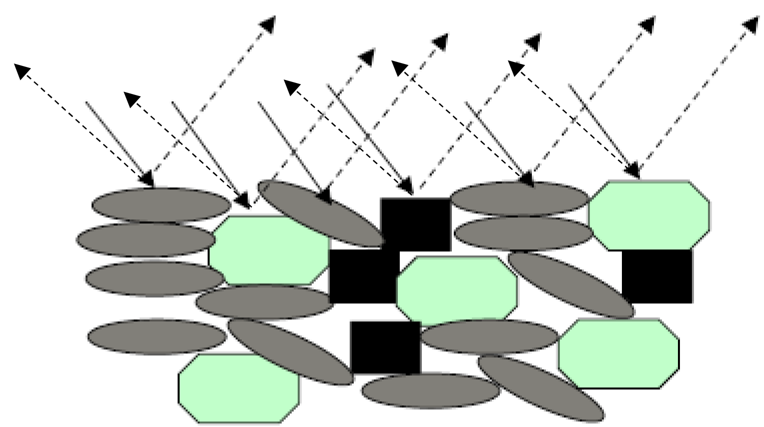
Hexagonal water ice



- Reflected light, f(F,n,k,D)

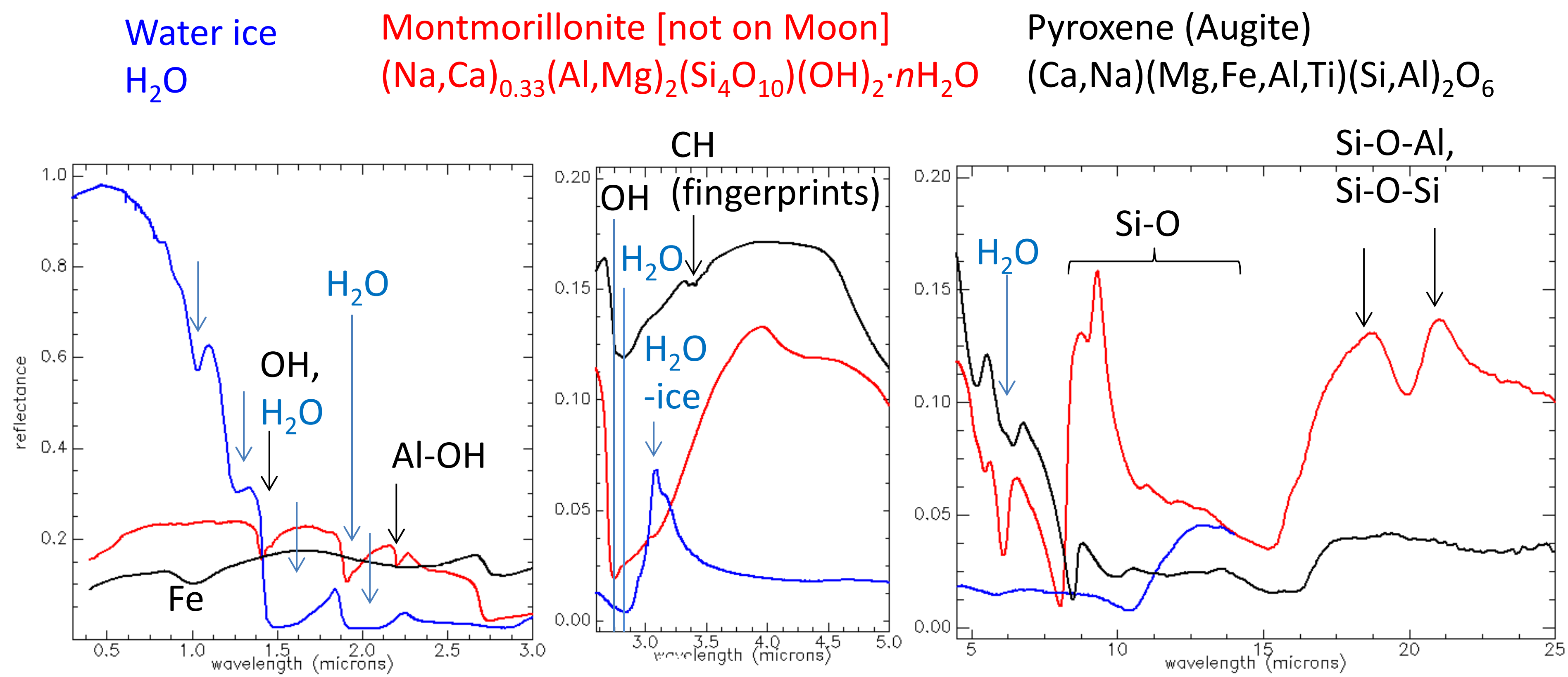


Emitted light f(T, n, k, D)



- On Moon, crossover at 3.1um (for T=250K)

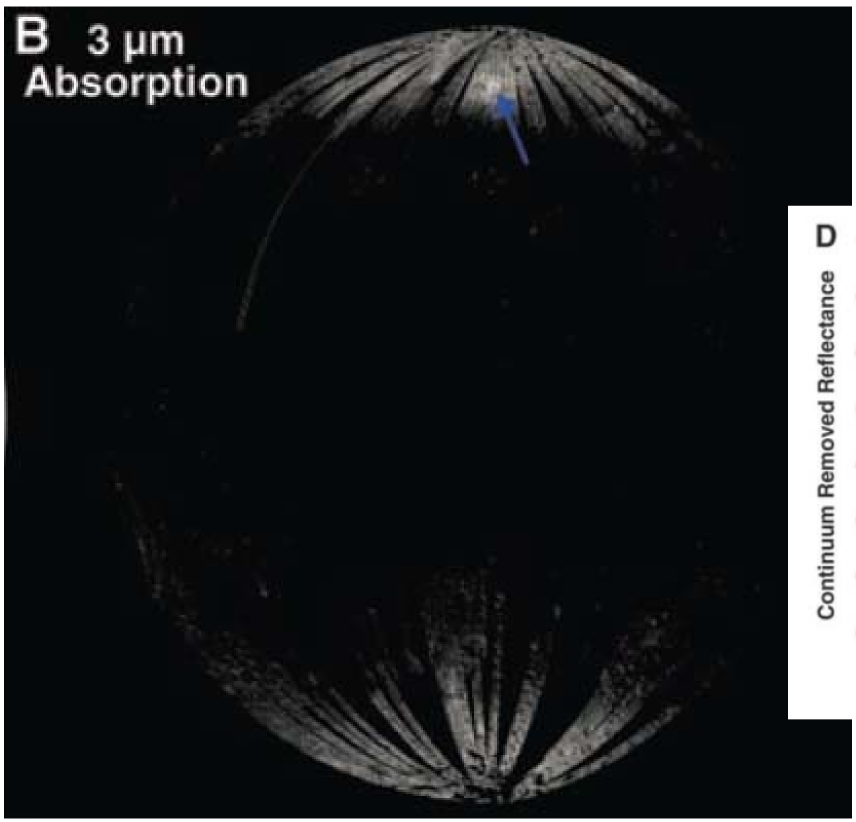
IR spectroscopy H_2O (ice), H_2O (bound), OH (strucutral)



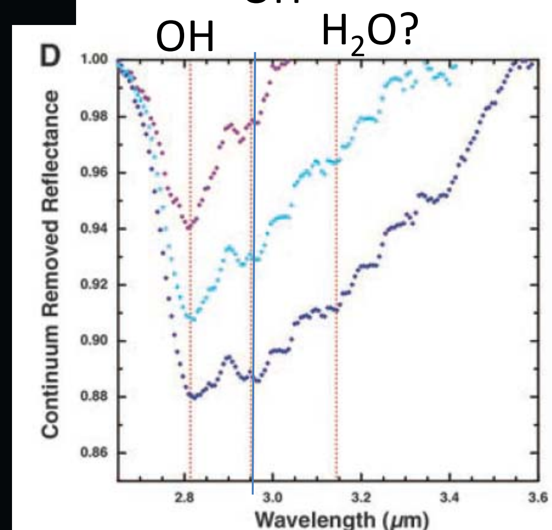
- OH vs. H_2O-bound and H_2O-ice can be discriminated with appropriate spectral sampling and SNR
- Hard to study OH vs. H_2O question on Earth because too much water

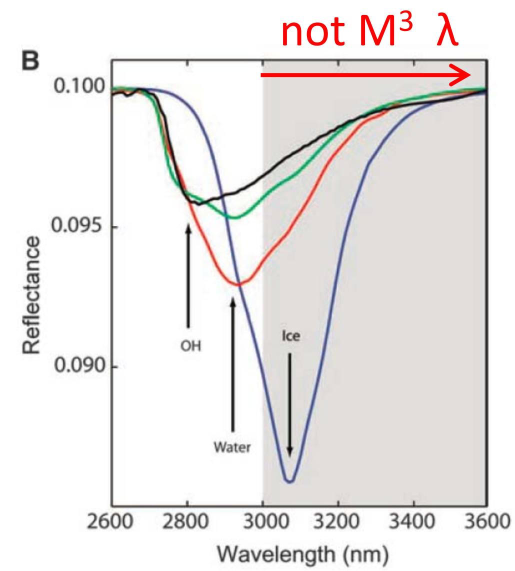
Where is the H_2O(ice,bound)/OH? Where is each?
Recent results: VNIR reflectance

- Three NIR instruments detect 3-µm absorption (M^3, VIMS, HRI-IR)
- Certainly OH, possibly bound H_2O (deleted) (10-1000ppm)
- Possibly diurnal variation (but difficult to calibrate thermal contribution)
- Highest spatial res (M^3) doesn't have wavelength range to verify H_2O-ice



Hydroxylated/hydrated phase: 10-1000ppm and locally higher

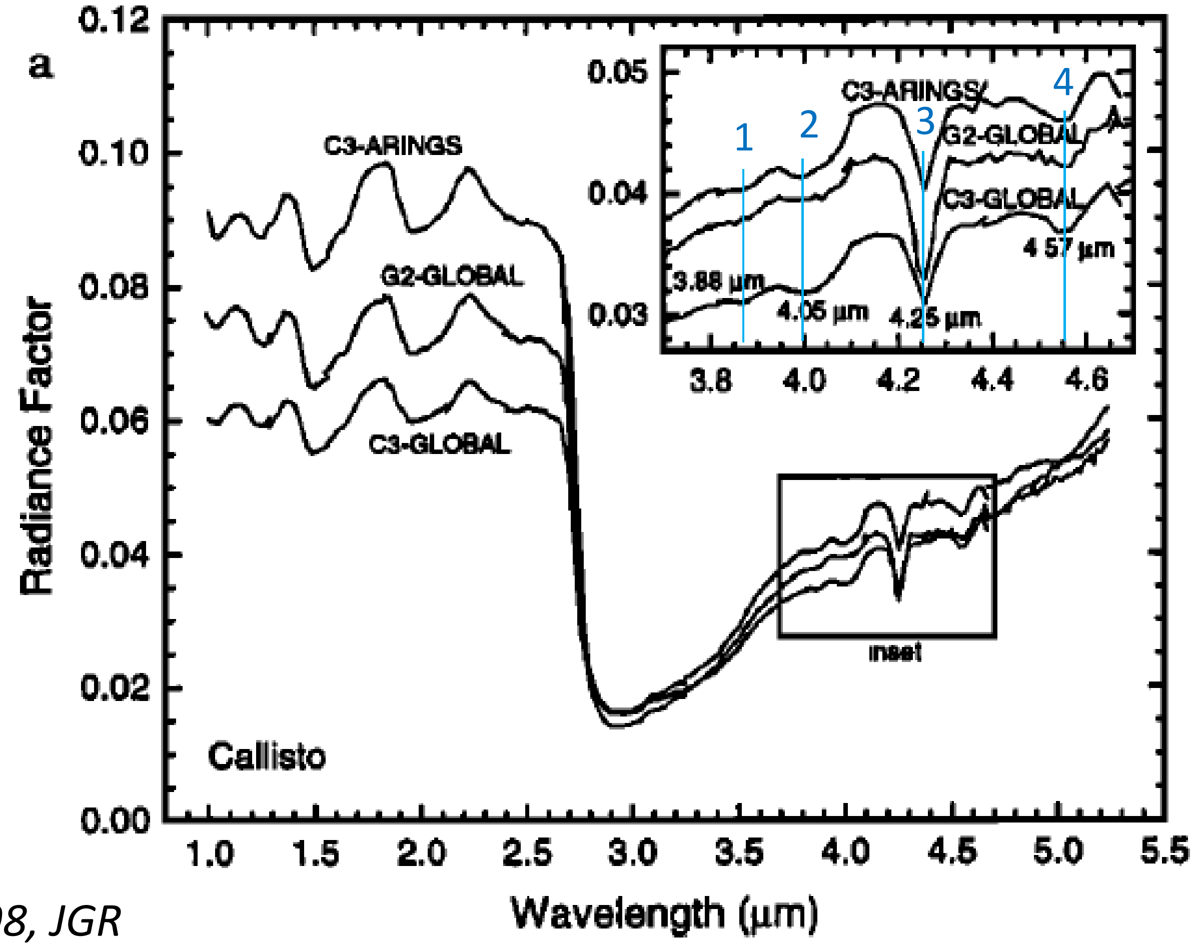




Pieters et al.; Sunshine et al.; Clark et al.; 2009, Science

Detecting Minor Constituents

- Multiple scattering enables low abundance constituents to be discerned, e.g. ices of Jovian satellites



H_2O-ice and

1. S-H
2. SO_2
3. CO_2
4. CN

McCord, 1998, JGR

Next generation NIR reflectance

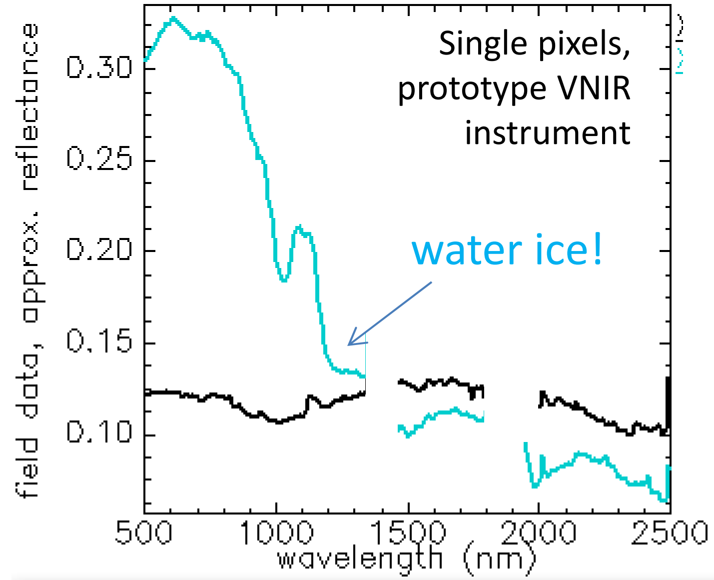
- Enables ice detection (vs. OH, bound H_2O) and modeling of abundance
- Drawback: Will always have low photons in permanently shadowed regions
- **Extend coverage out to at least 4.0-5.0 µm** to enable H_2O-ice discrimination (and better thermal correction)
- Get **high SNR at high spatial res. near poles**
  - ***repeat coverage*** over several orbits and co-add
  - ***highly elliptical orbit*** near craters for better spatial res
  - BYOI: bring your own ***illumination*** (broadband or tunable laser)
  - or ***bring your own solar reflector*** from orbit
- Preserve or improve **spectral sampling** for OH vs. H_2O and minor constitutents
- **Land** and get a closer view

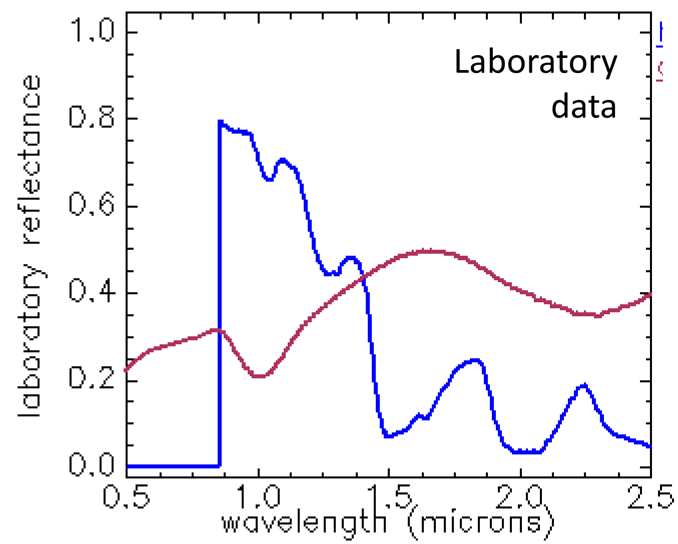
Landed IR instruments

- Improved spatial resolution
- BYOI approach is easier
- Rove and trench to expose materials

VNIR hyperspectral imager tests, JPL Mars yard, July 18, 2013

Sol 23,
Opportunity
trench



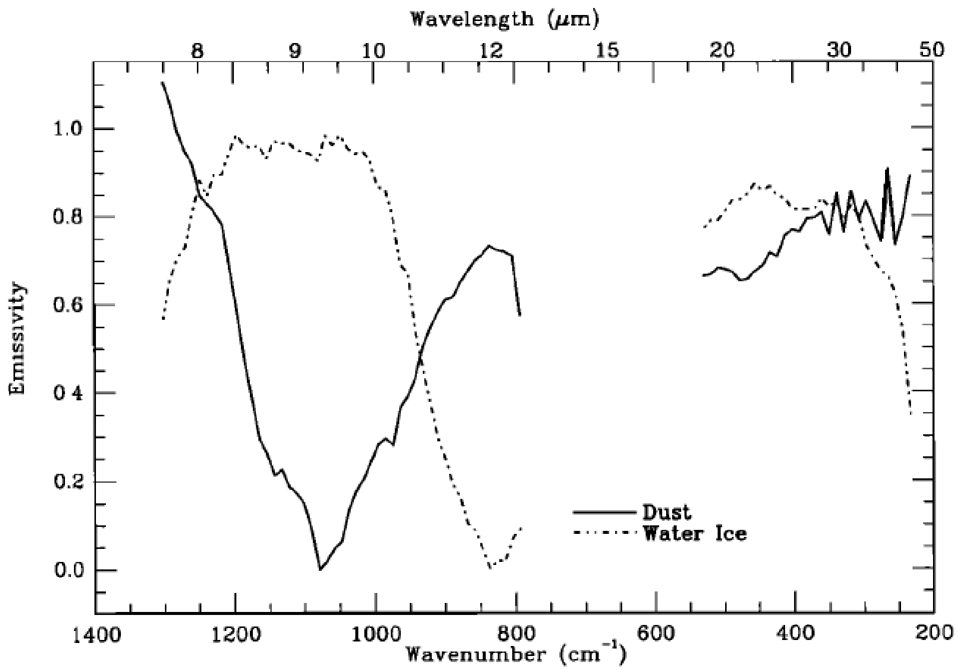


TIR Emission Spectroscopy

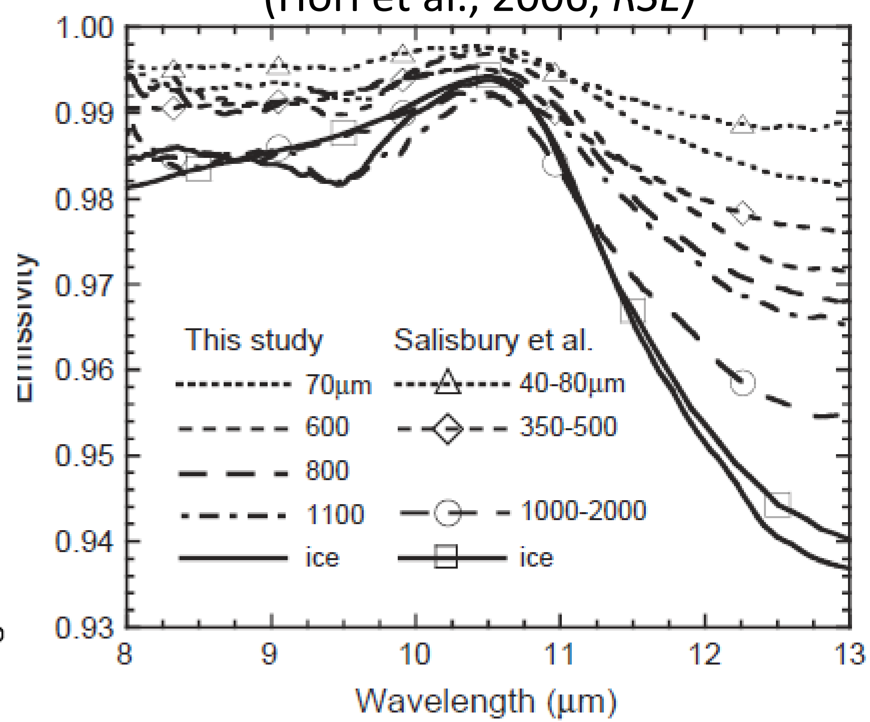
- Silicate and ice emissivity minima are distinct, separable
- Grain size can be established (confounding effects from mixing)

More details…Ben?

Ice vs. Silicate in Atmospheric Dust, Mars (Smith et al. 2000)



Ice Monitoring Earth (Hori et al., 2006, *RSE)*

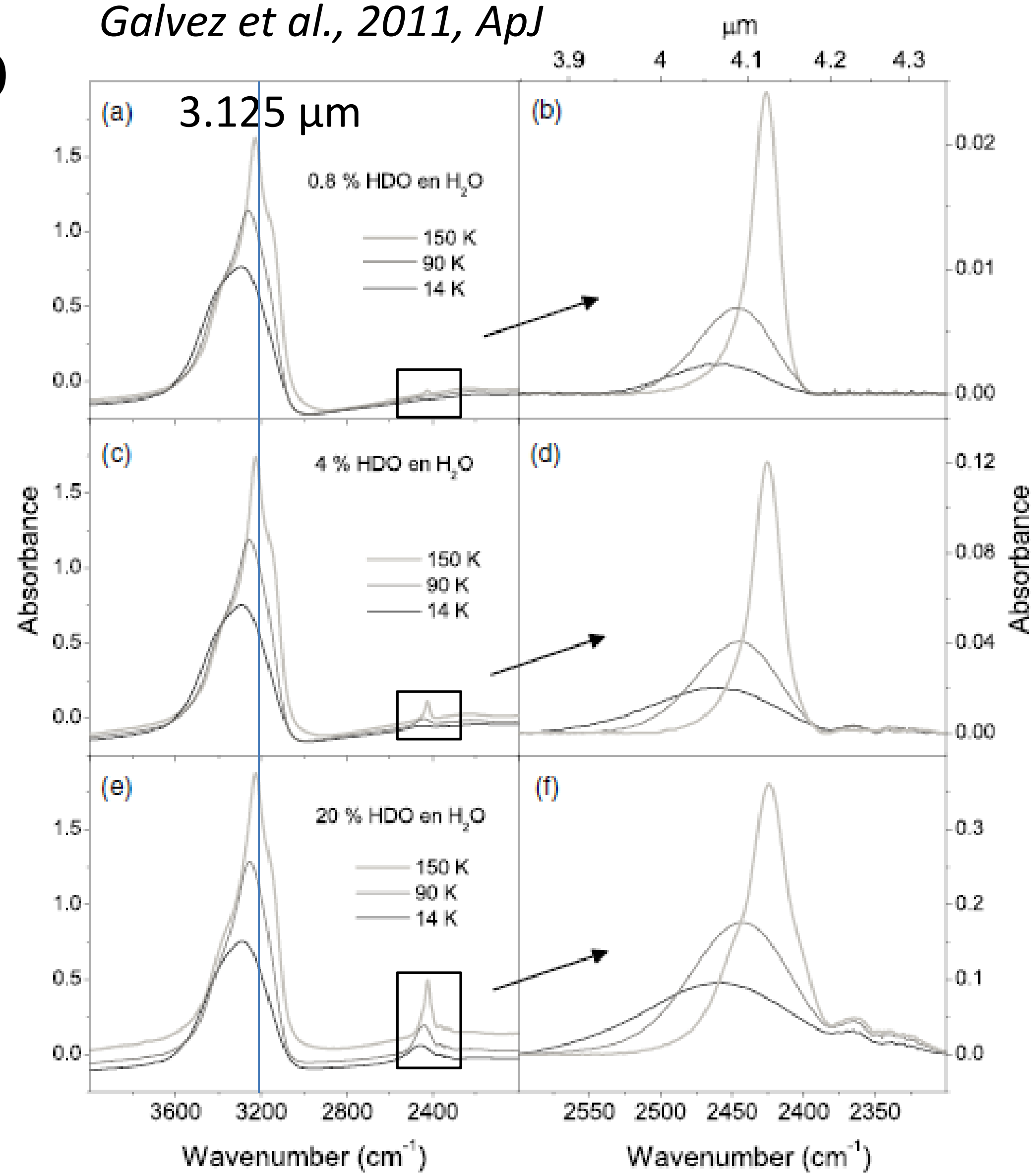


Discriminating Hydrogen and Deuterium

- Detectable HDO/H_2O ratios with range from a few ppt in crystalline ice to a few % for amorphous samples.
- Dependence of the band shape on temperature complicates the interpretation.

More details…other workshoppers?

Galvez et al., 2011, ApJ



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Possible Lunar Volatiles Mission Approaches with IR

- Elliptical orbiter, including NIR reflectance (possibly with own illumination source) + TIR multi-band imager and/or spectrometer
  - Possibily for this to be small, low-cost (passive)
  - Or, more advanced active light source to reduce difficulty with SNR

- Rover to explore spatial distribution and shallow depths, including IR mast- or arm-mounted imager/spectrometer

- Lander to core regolith, including IR mast-mounted imager/spectrometer and onboard laboratory

From Orbit: Active vs. Passive

- Some numbers from Paul and Glenn

Extras

Mixtures

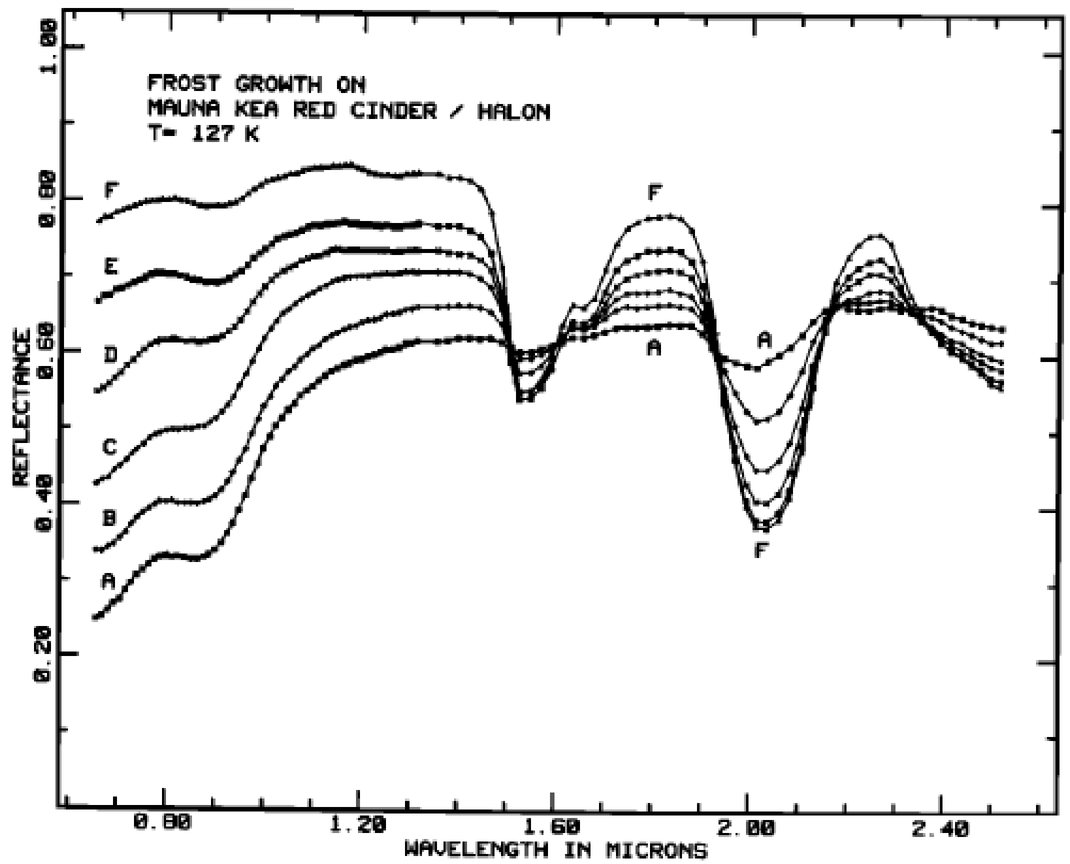

Fig. 16. Spectra of frost growth on Mauna Kea red cinder, showing a decrease at shorter wavelengths even when there is a thick water frost layer and the 1.5- and 2.0-μm frost bands are very prominent. The frost depths are 0.0 (sample A), 0.05 (sample B), 0.1 (sample C), 0.2 (sample D), 0.3 (sample E), and 0.6 mm (sample F). The frost grain size is less than 30 μm, and the red cinder grain size was ≤125 μm.

Clark, 1981, JGR

Water on Surfaces

Anderson & Wickersheim, 1964

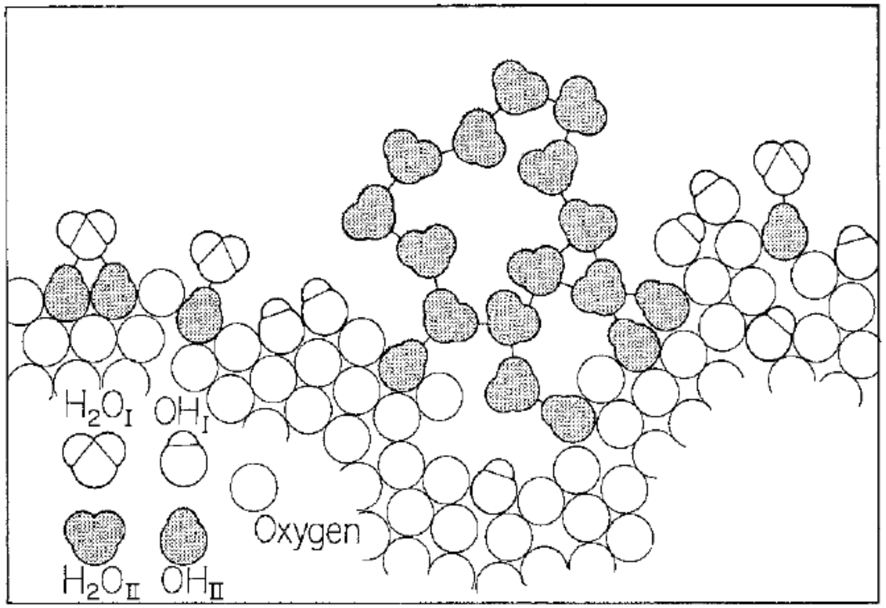

Fig. 3. Schematic picture of a partially hydrated silica surface.