Measurements to Understand the Origin & Evolution of H_2O and OH on the Illuminated Moon

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How much, if any, of the ‘water’ observed on the illuminated Moon is H_2O

The Johns Hopkins University
APPLIED PHYSICS LABORATORY

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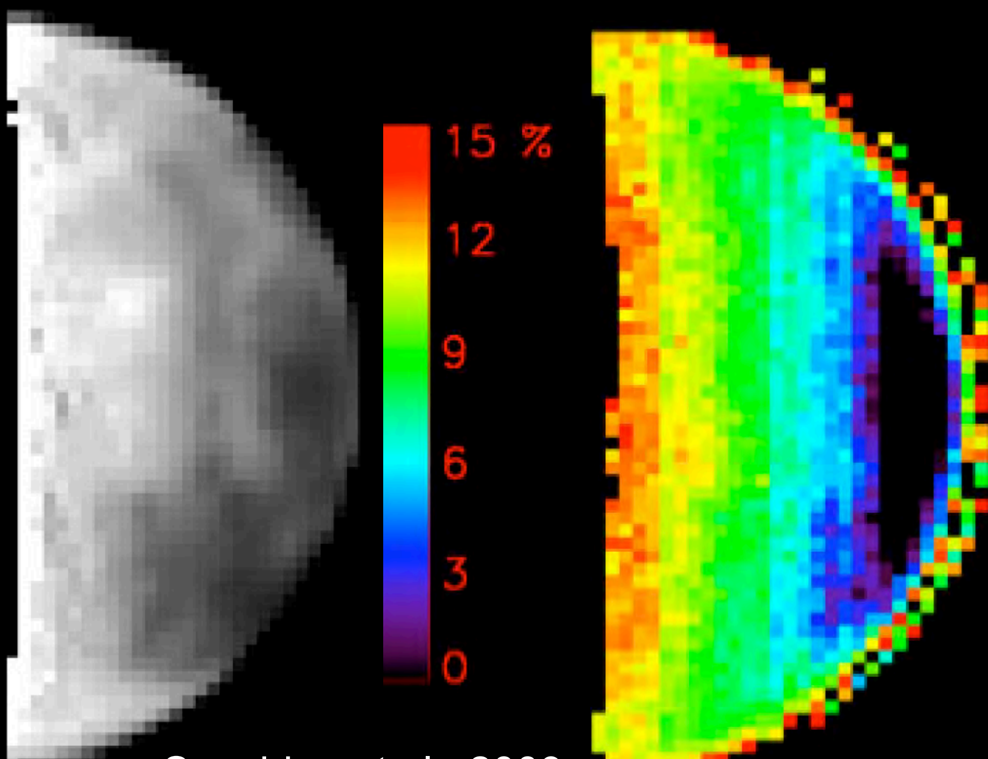
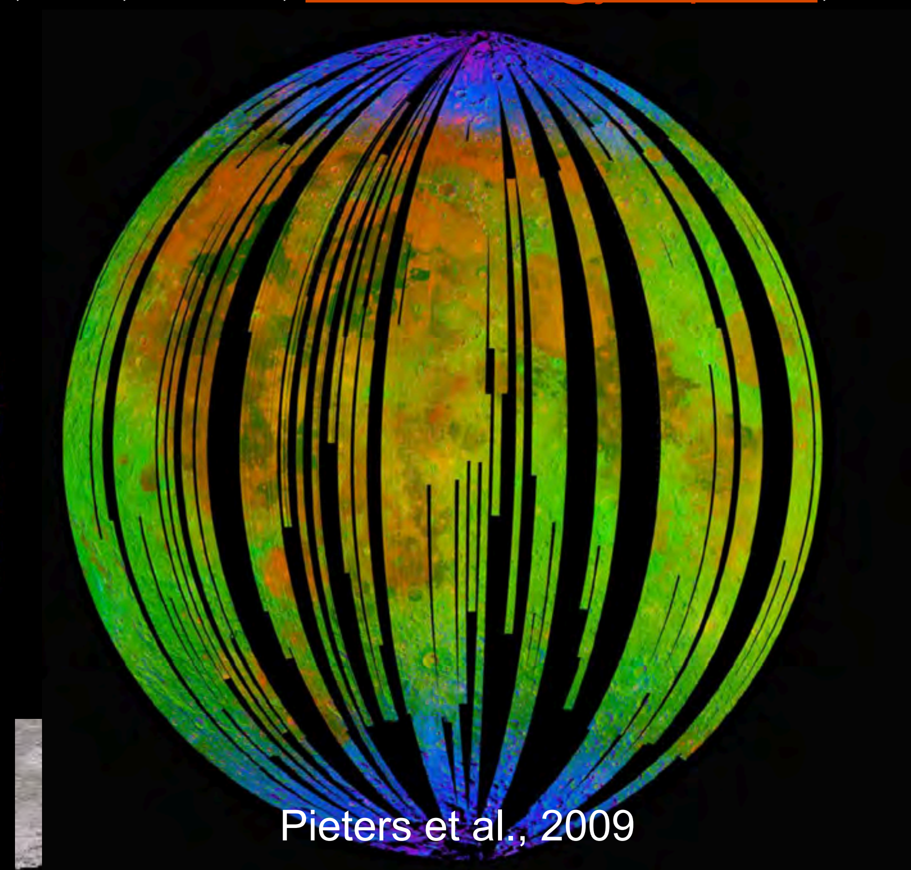
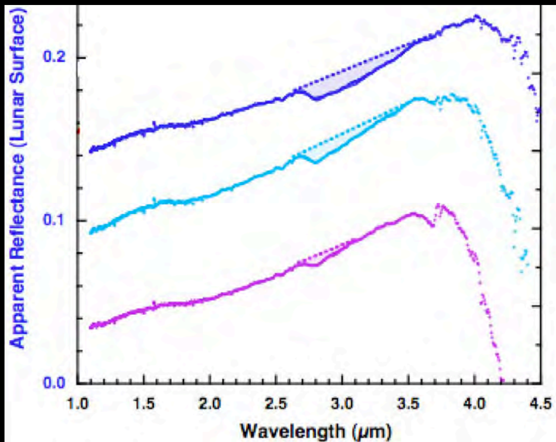


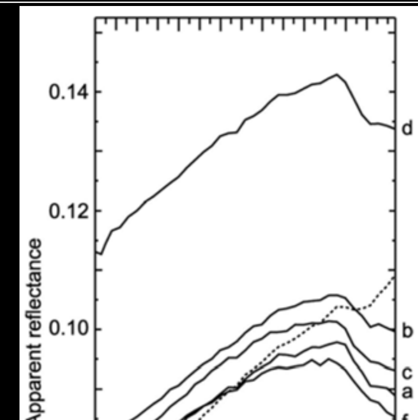
Sunshine et al., 2009

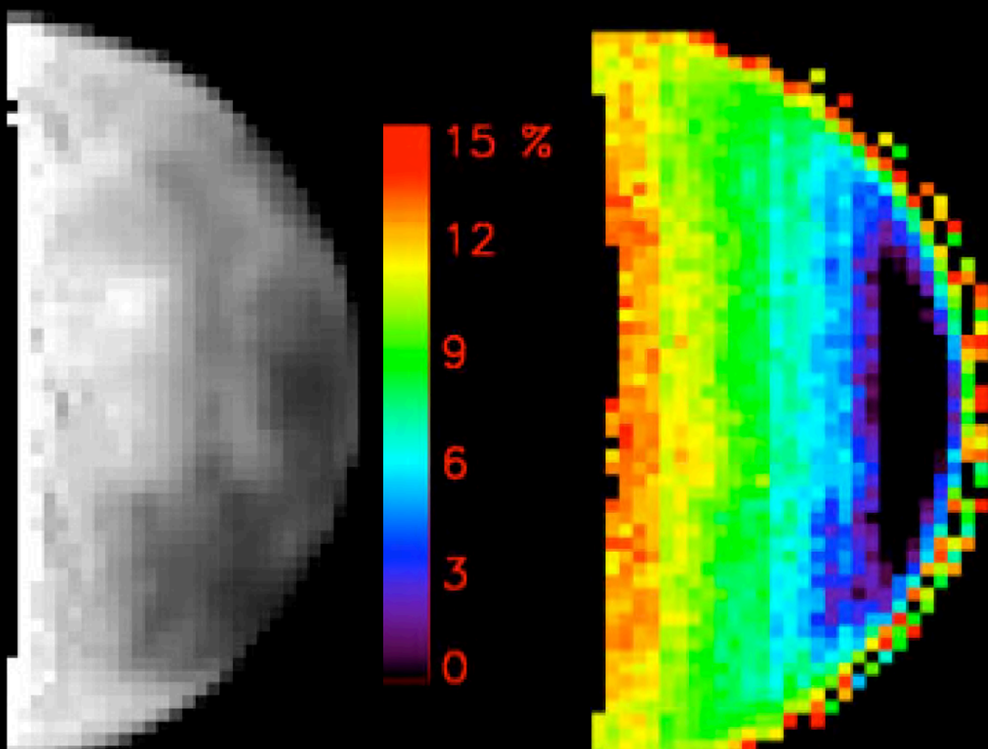


Pieters et al., 2009

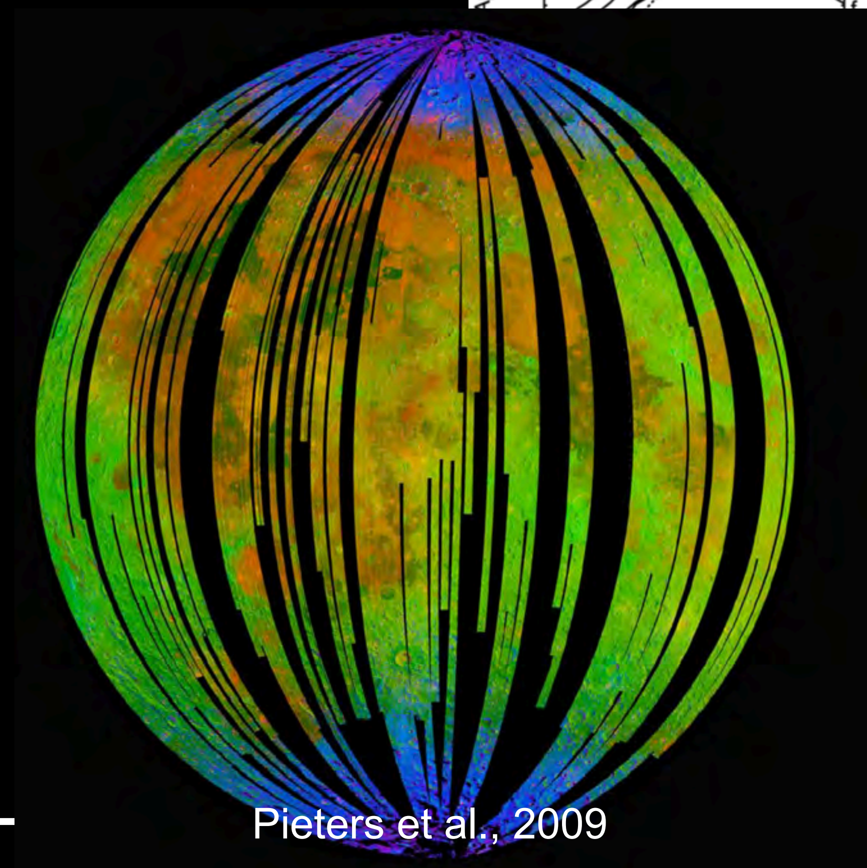
“Water” on the Illuminated Moon







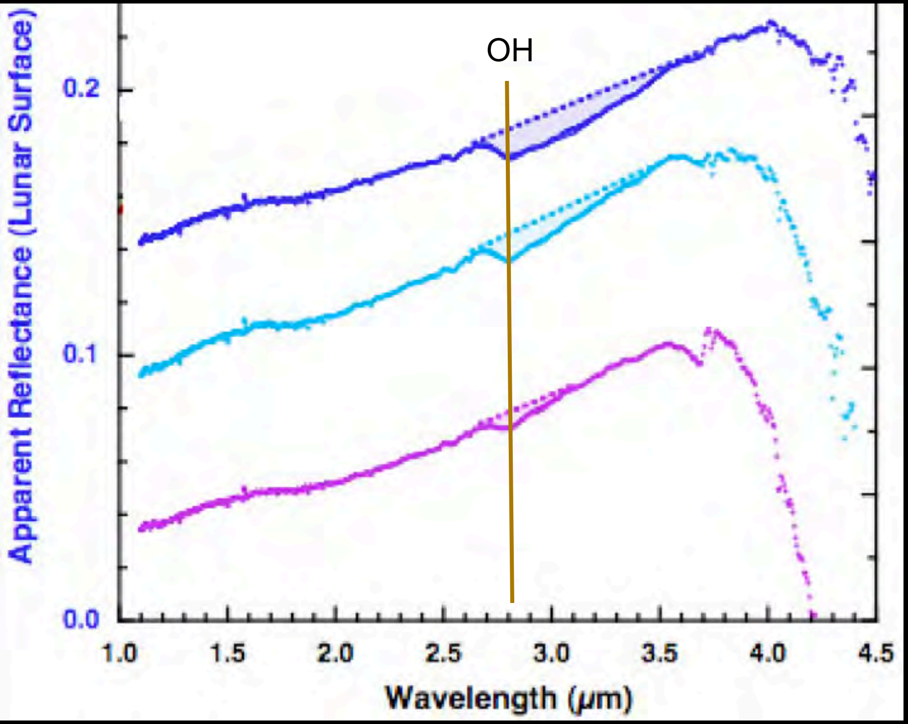
Sunshine et al., 2009



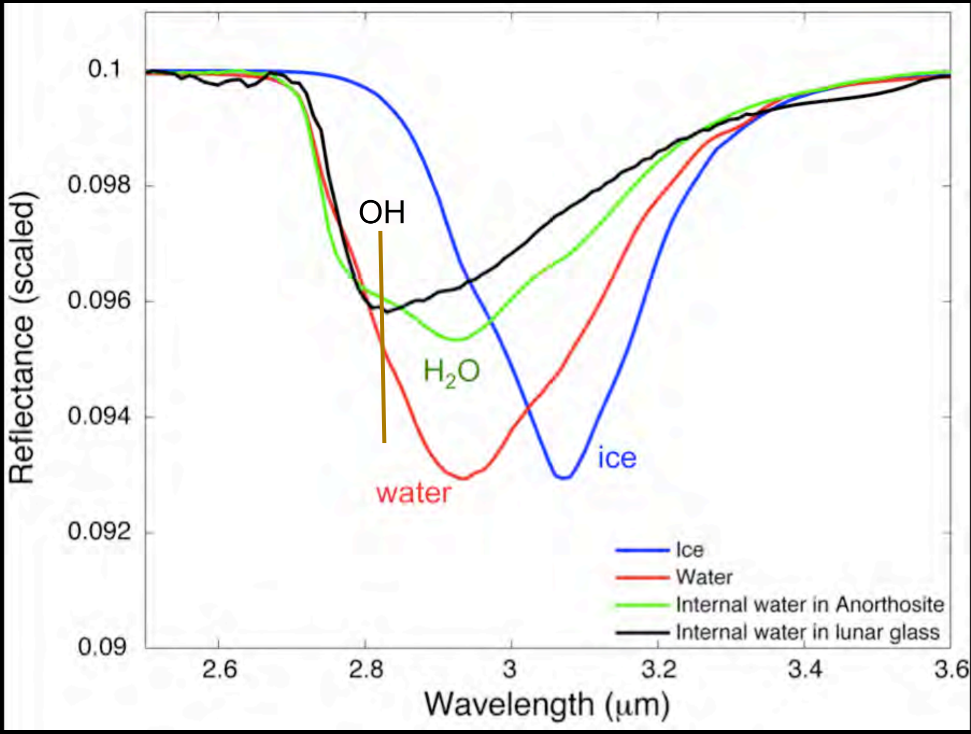
Pieters et al., 2009

Hydroxyl (OH) does exist on the illuminated Moon

EPOXI

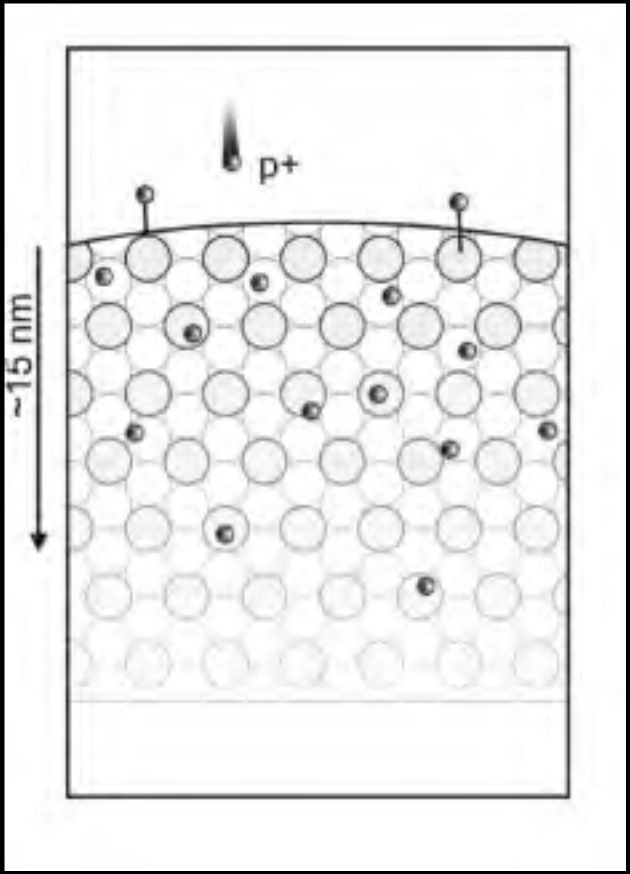


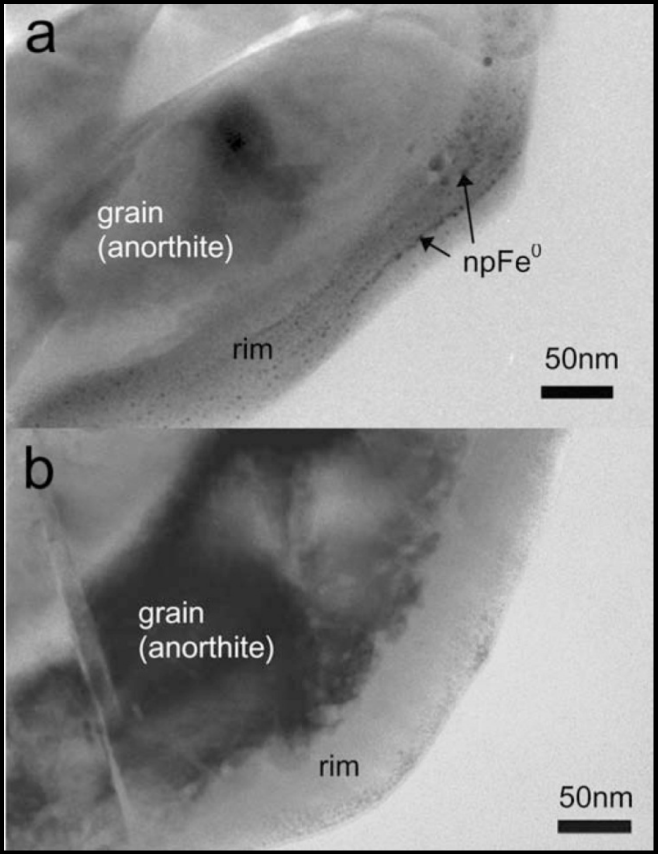
Lab



Possible formation mechanism of ‘water’ on the Illuminated Moon

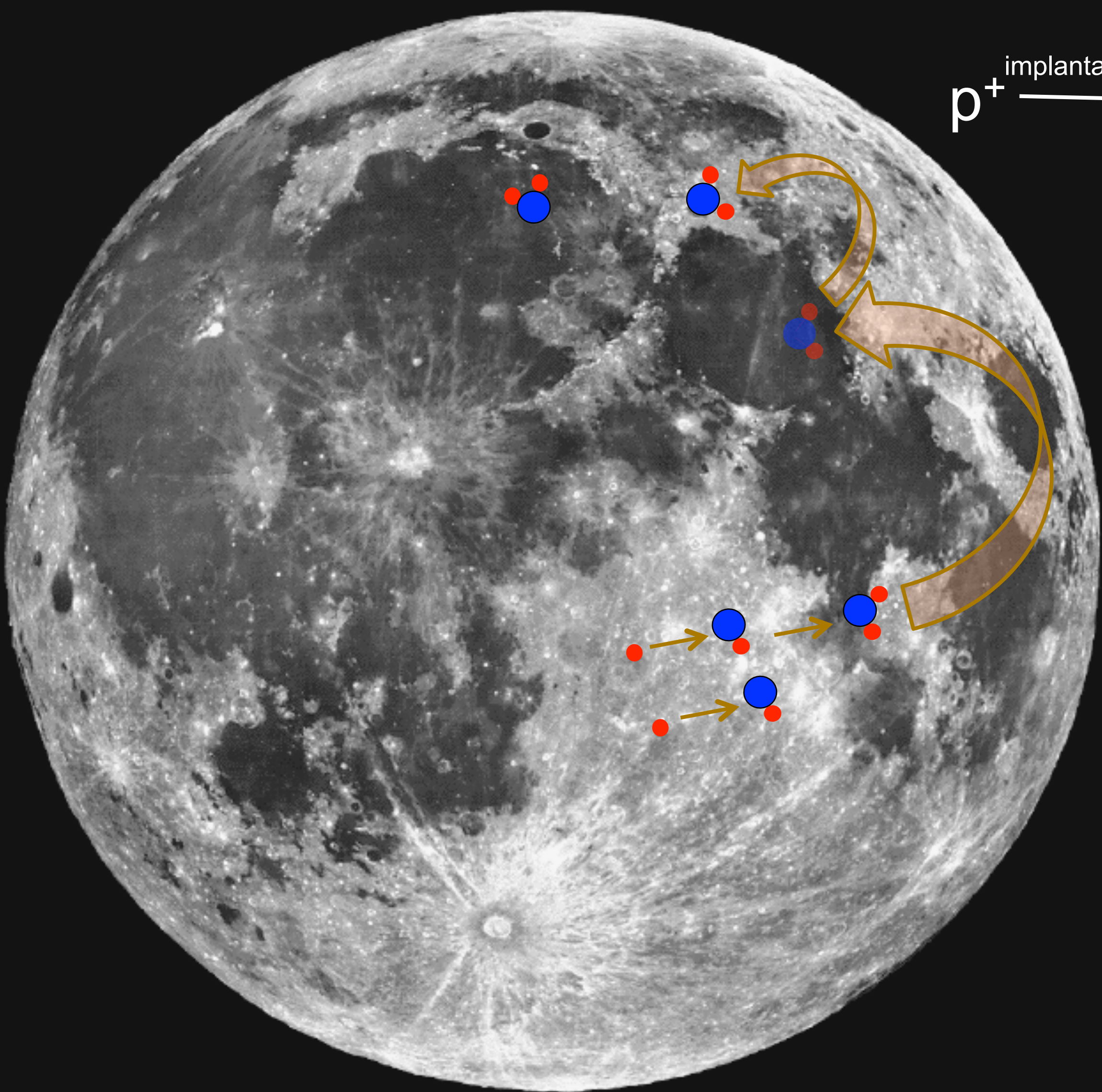
Hydroxyl formation

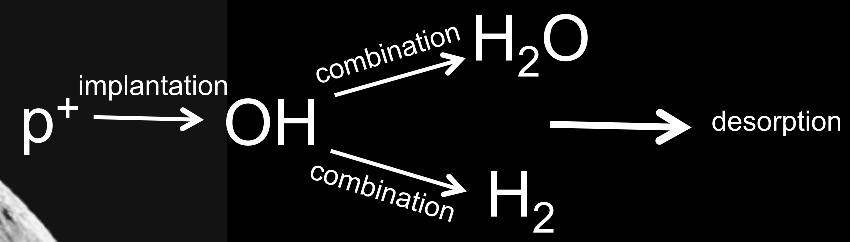


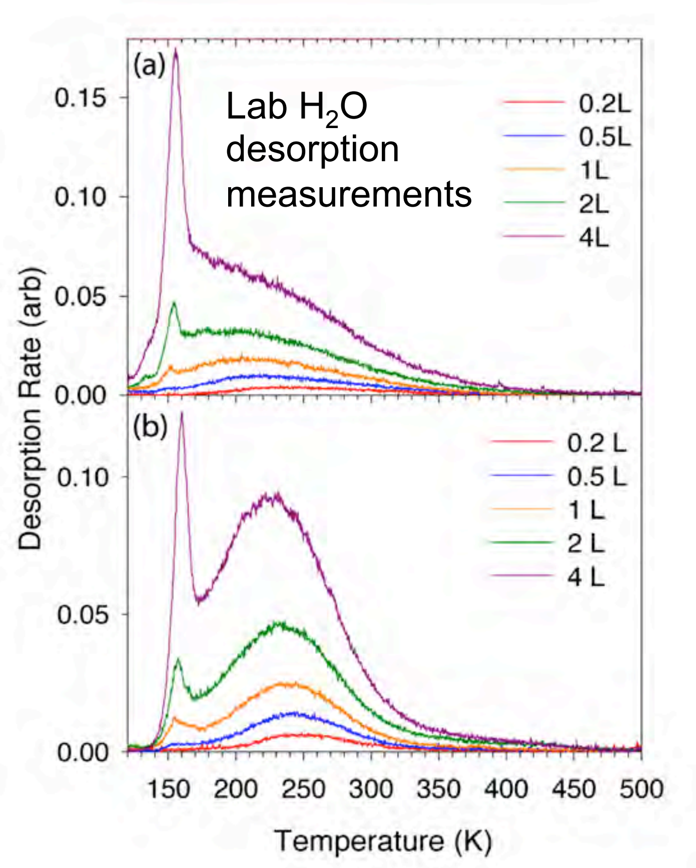


From Noble et al. (2005)

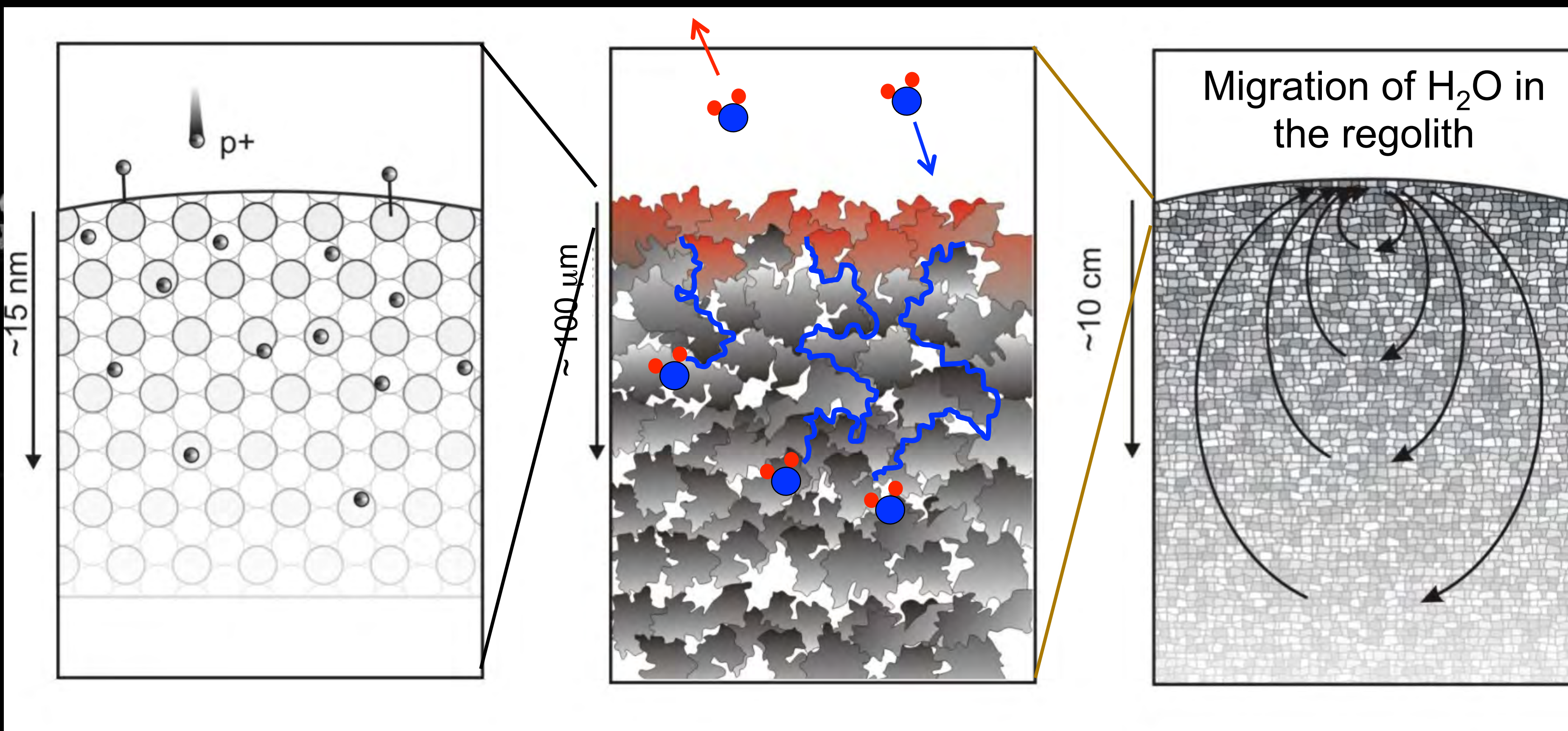
Possible evolution of 'water' on the illuminated Moon



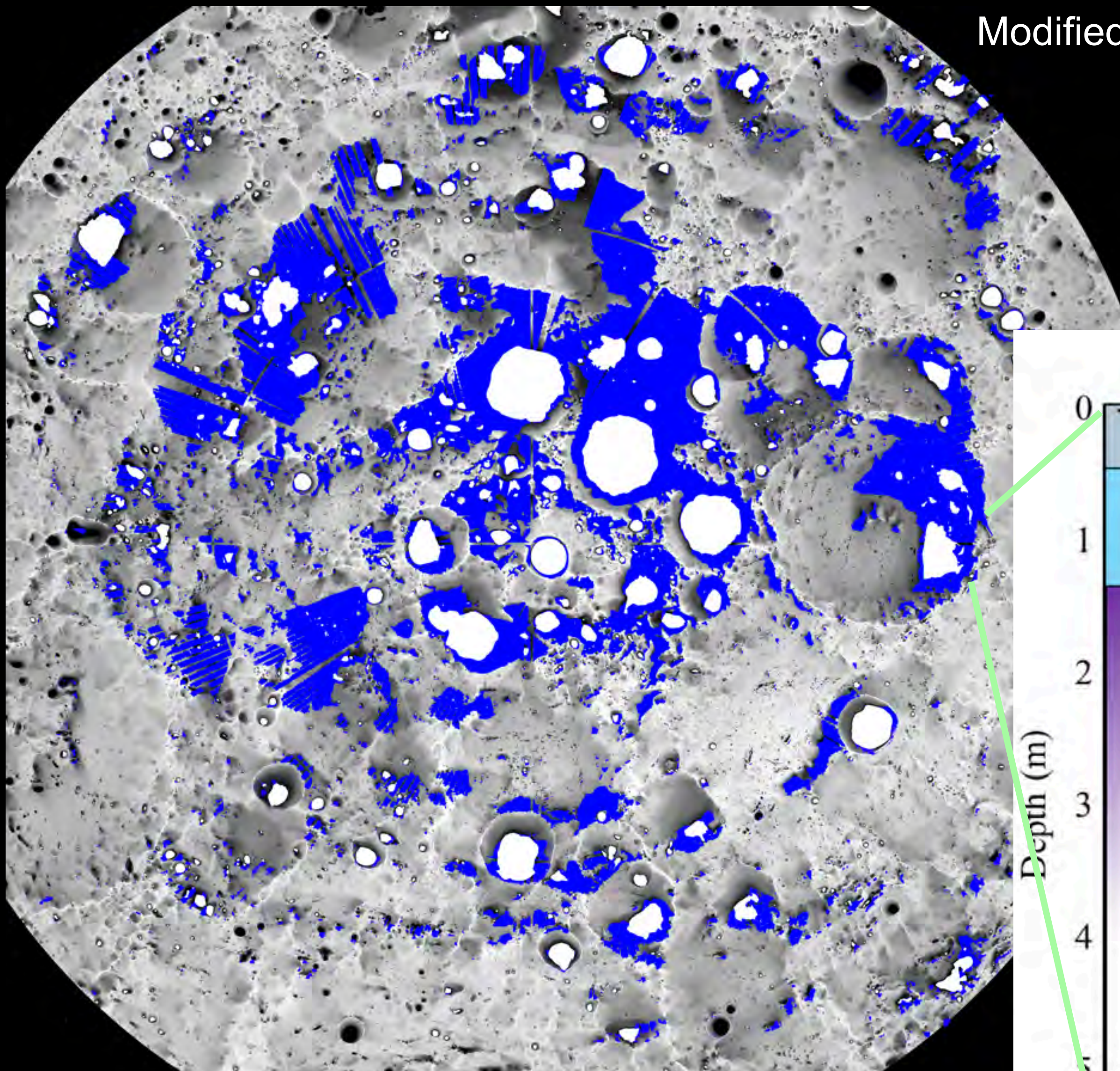




Possible mechanisms for concentrating OH & H_2O in the near surface

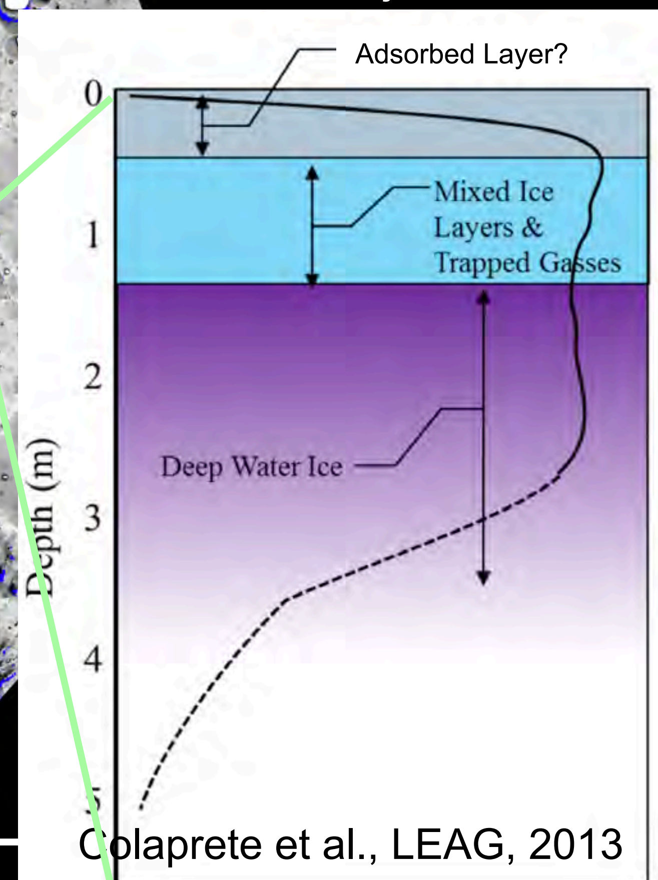


Surface adsorbed water may exist…



Modified from McGovern, 2013

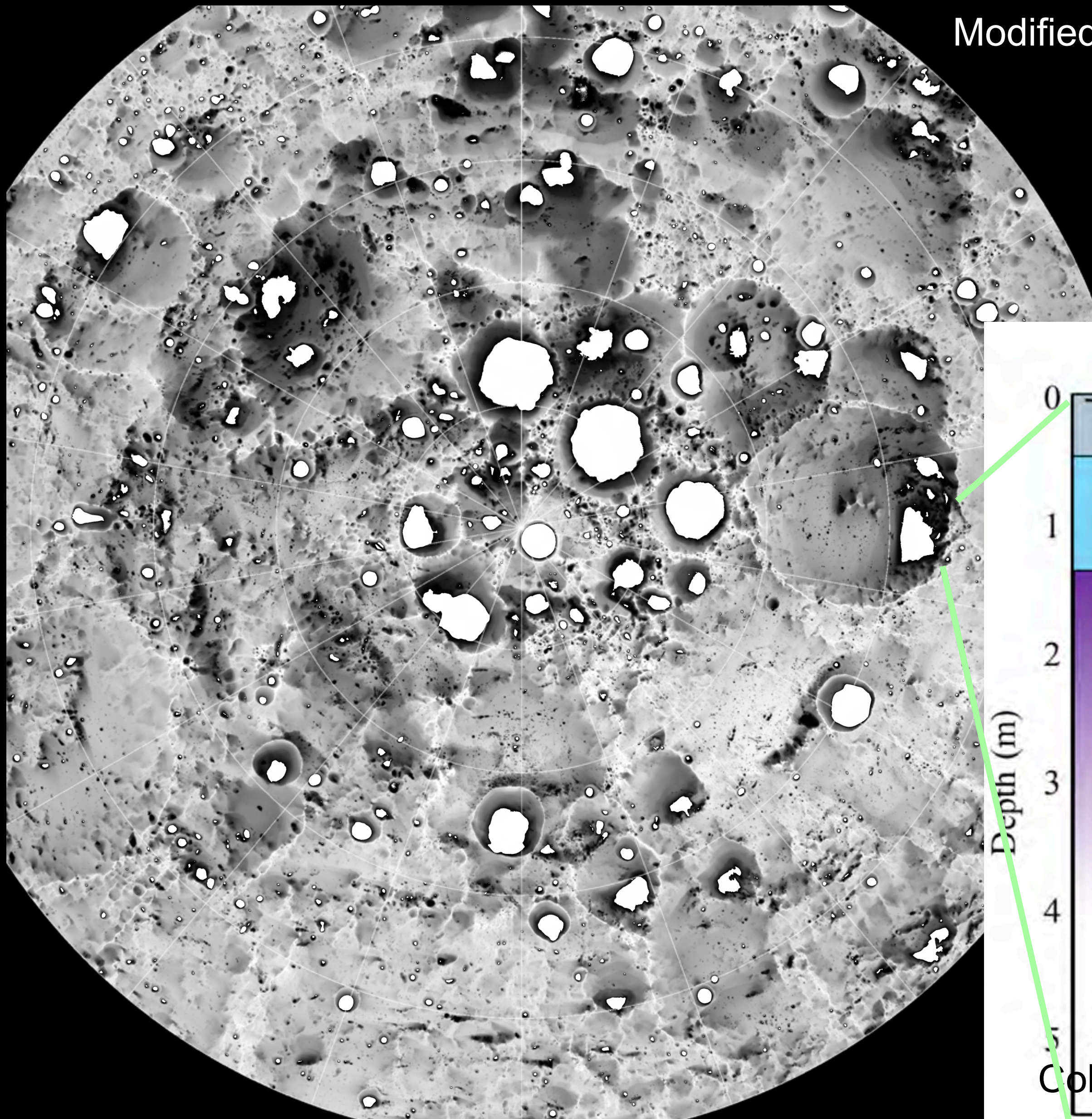
Adjacent to PSR



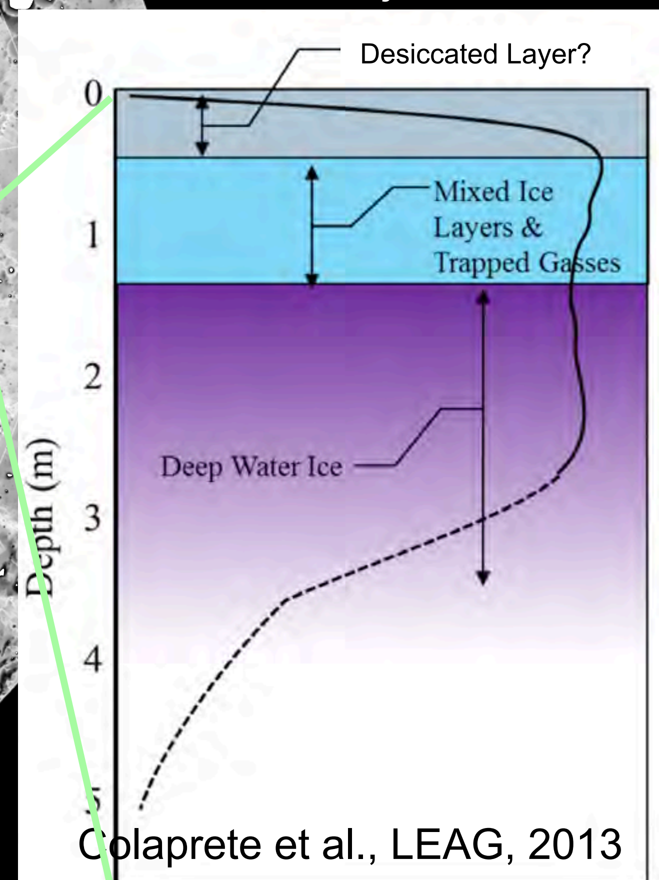
Colaprete et al., LEAG, 2013

Or the upper surface may be bone dry…

Modified from McGovern, 2013



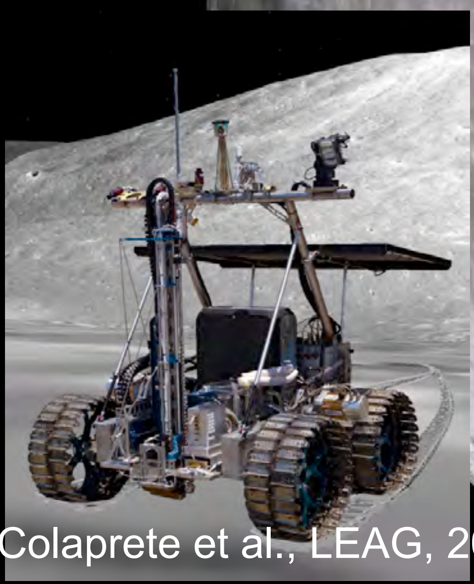
Adjacent to PSR



Colaprete et al., LEAG, 2013

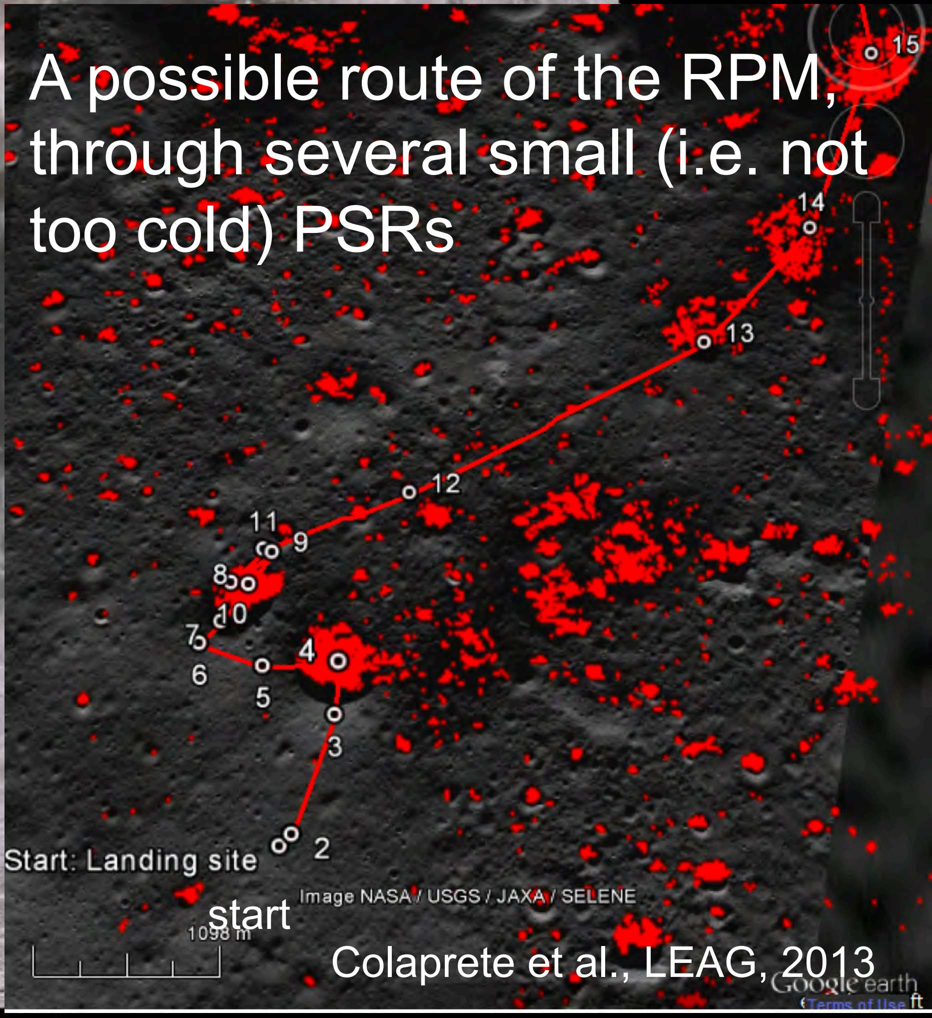
A ground truth mission - RPM

…might not find water ice, but it may find significant adsorbed water



Colaprete et al., LEAG, 2013

A possible route of the RPM, through several small (i.e. not too cold) PSRs



Colaprete et al., LEAG, 2013

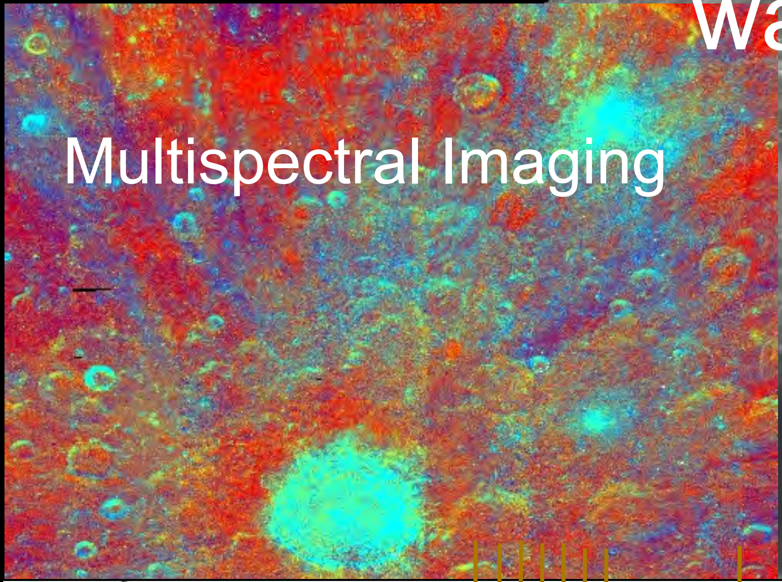
Goals for understanding water on the illuminated Moon

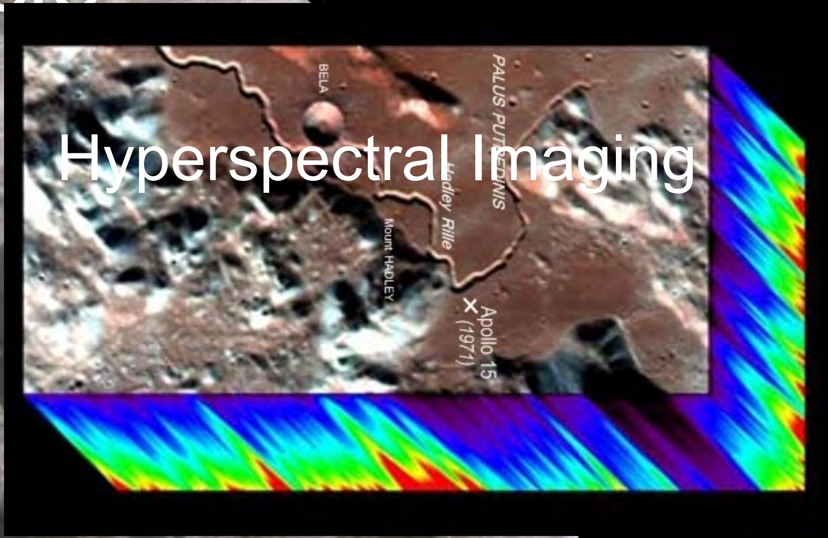
Characterize the amount of, the chemical and physical state of, the distribution of, and evolution of (or life cycle of) water (OH and H_2O) on the Moon.

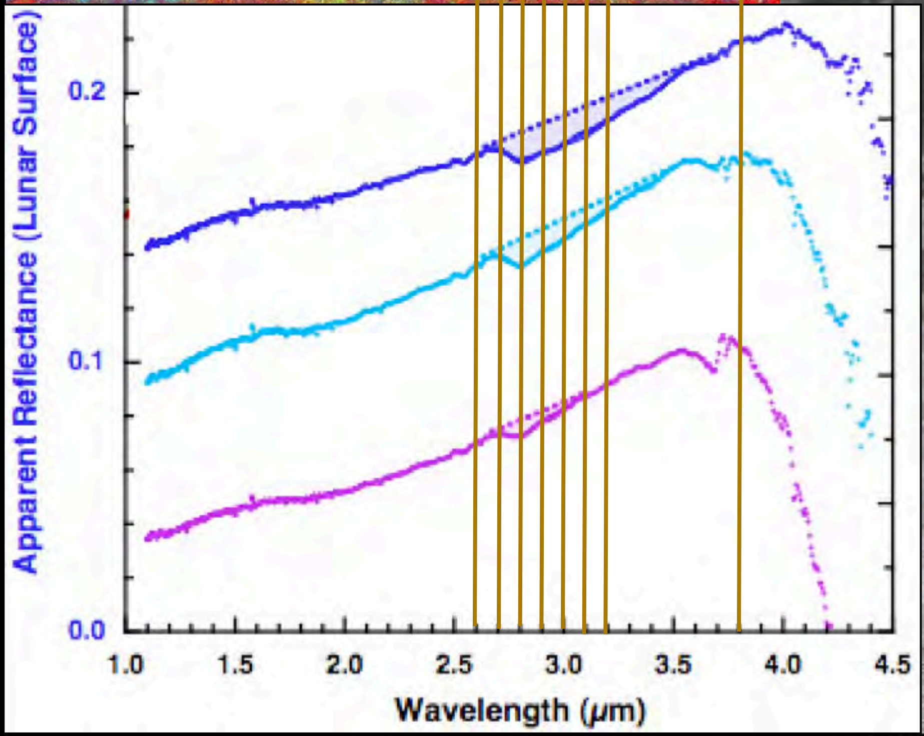
Scientifically interesting – answering these questions will have large implications for 'water' on ALL airless silicate bodies from Mercury to asteroids

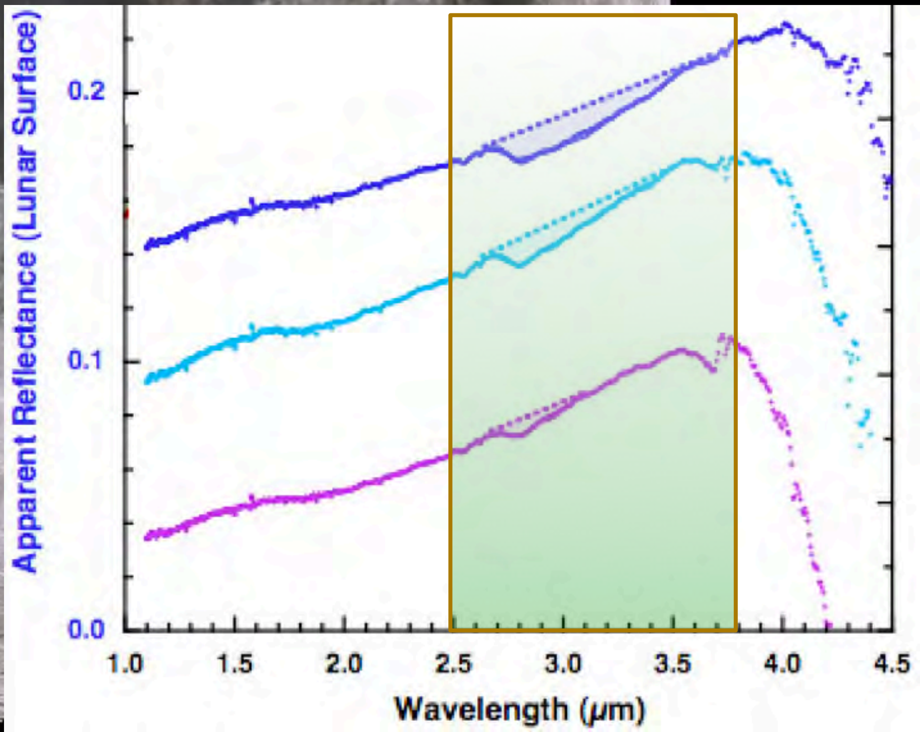
Exploration significance – two endmembers: extractable H_2O or ephemeral OH. Knowing which exists (and relative abundance of each) has significant implication on our understanding of in-situ resources.

Spectral measurements to characterize water cycle









Long-duration stratospheric balloon payloads

- 5000 lb total payload
- instrumented for these measuremnts
- 100K - 120K feet altitude (no telluric)
- ~1” IFOV
- better than 1” stability
- 2wk → 2mo duration
- no data volume limit
- potential 27/7 operations
- balmy summer Antarctic conditions

Extra Slides

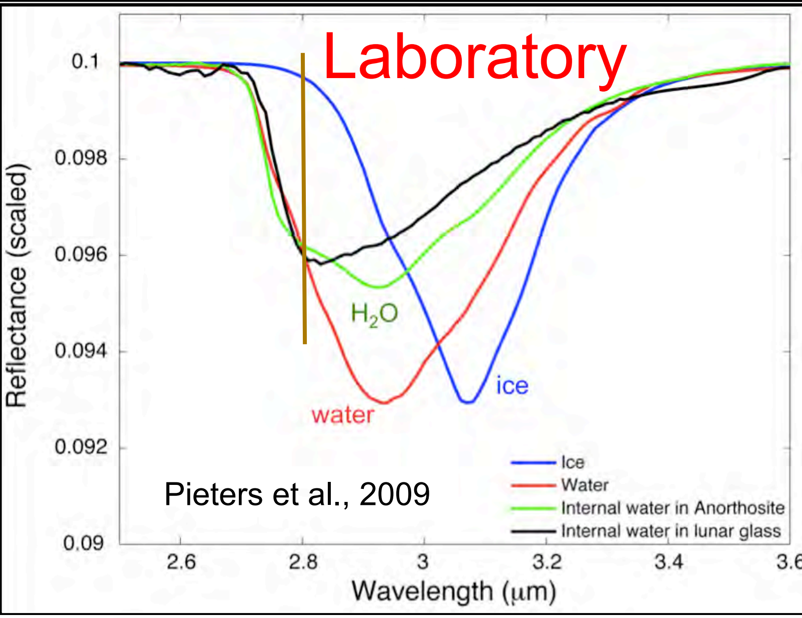
Our understanding of the 'water'

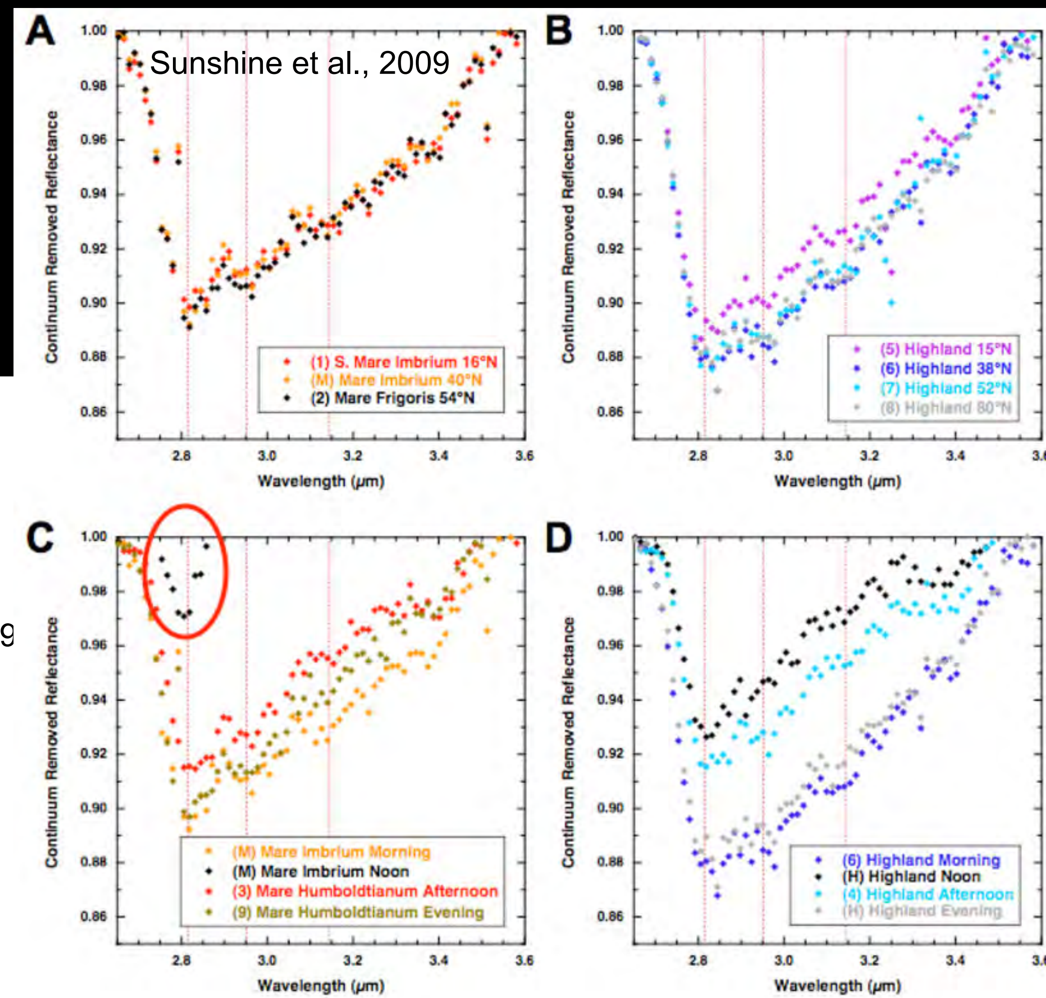
Observation	Inferrence
There is hydroxyl on the illuminated surface of the Moon	It is of solar wind origin
The band changes with time of day	Either the 'hydroxyl' is being lost or it's a photometric effect
Hydroxyl is found in pyroclastic deposits	There is some primordial water in the Moon (few hundred ppm)
Laboratory simulations produce hydroxyl in lunar samples and analogs	Solar wind can result in OH.
The flux of solar wind is 3×10^8 /sec	

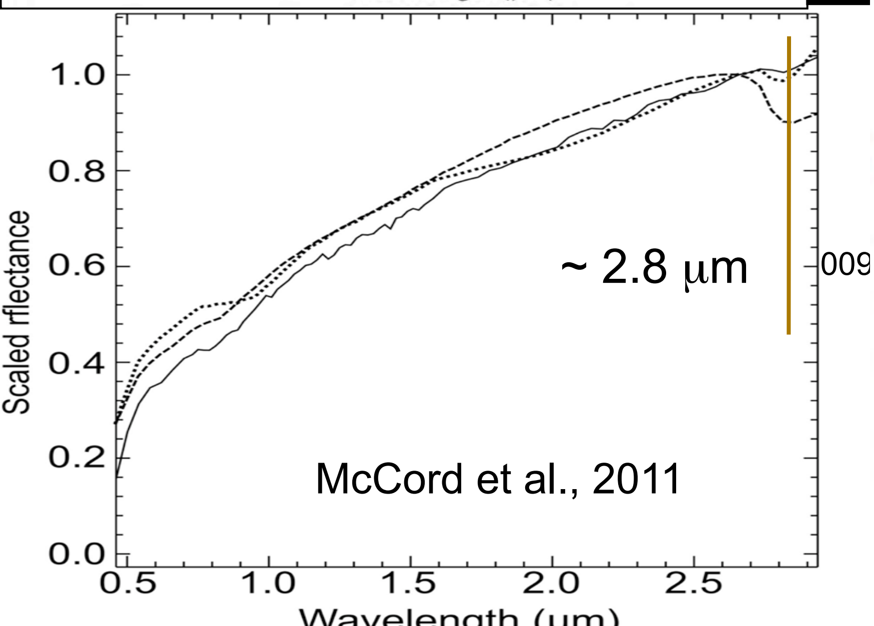
Scientific and exploration relevant questions

Unknown	Implication
Is the ‘water’ on the illuminated Moon due to solar wind implantation?	A potentially renewable resource. May also be ephemeral
Is there molecular H_2O, in addition to OH, on the illuminated Moon (some tantalizing evidence from M3 and EPOXI)?	Potential easily extracted resource.
What is the evolution of the ‘water’? Does its abundance cycle over a lunation? If the abundance decreases, by what mechanism does it devolve?	Evolution by H_2 implies a poor resource. Evolution by H_2O implies a possible accumulation in cold traps.
Is there a concentration of either OH or H_2O at higher latitudes, or are the observations a photometric effect?	If H_2O is present in illuminated high lats., may represent convenient resource, and possibly suggest continual formation of H_2O

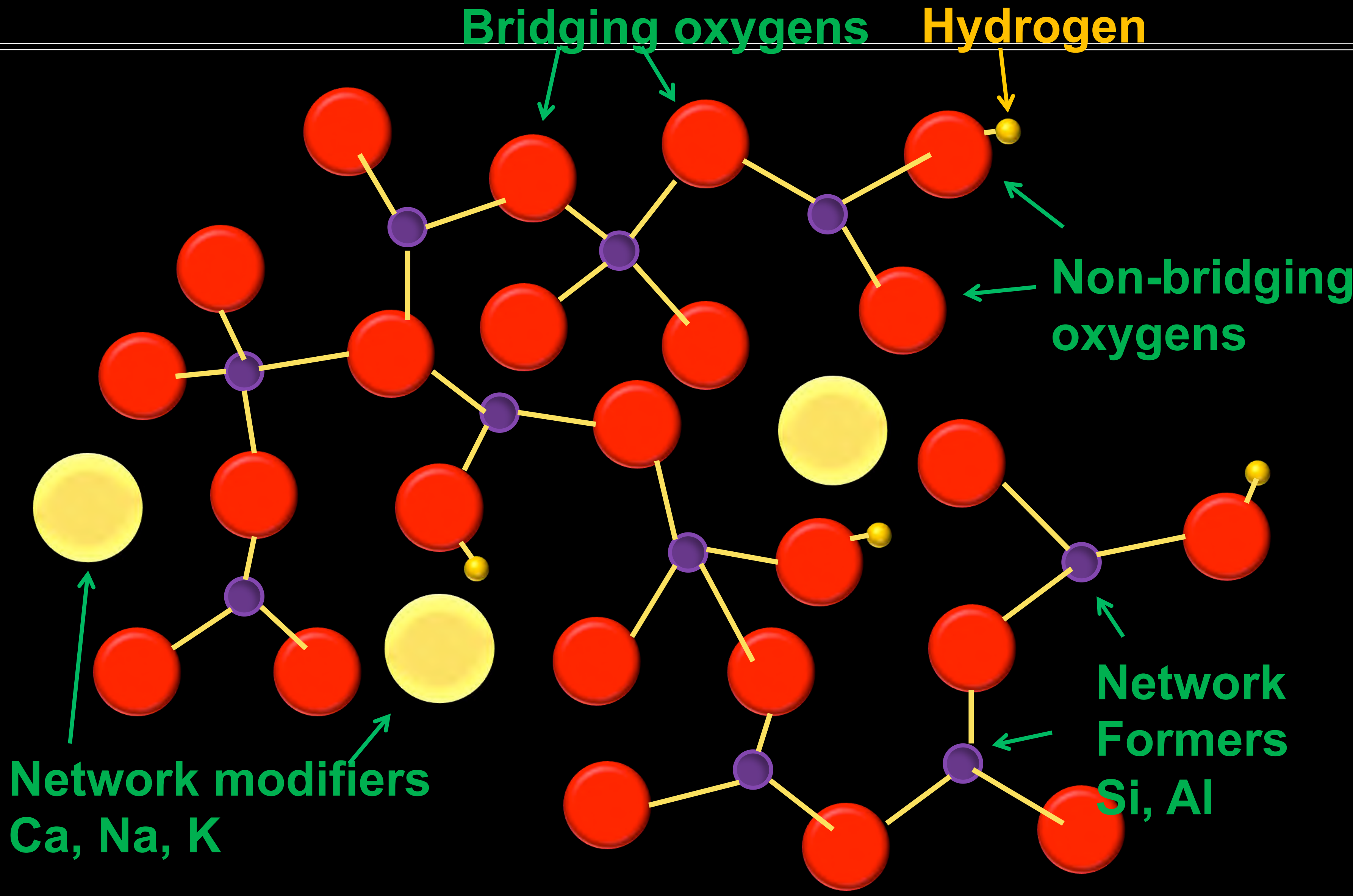
Infrared Observations of Water (or at least OH)







Schematic of a lunar mineral



High alkali contents create non-bonded O where H can bond…more H.
High alkali contents should should imply high H adsorptivity!

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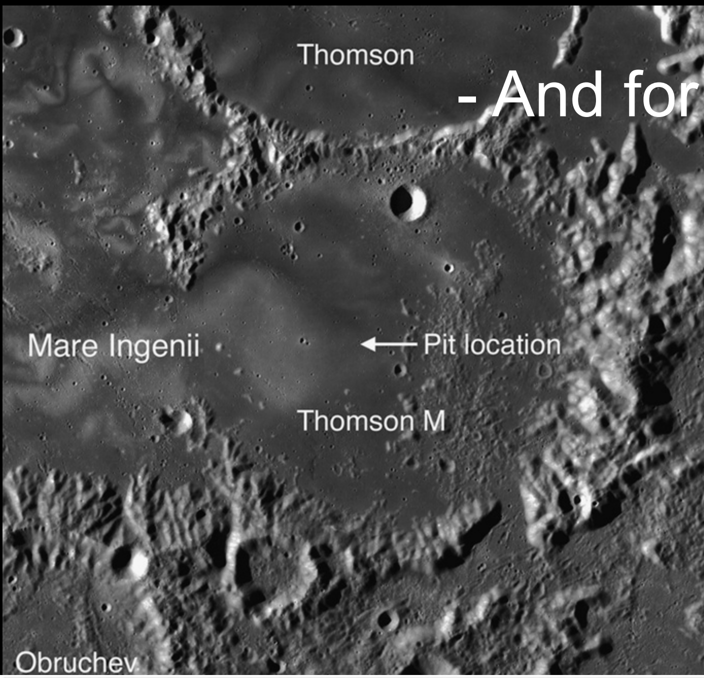
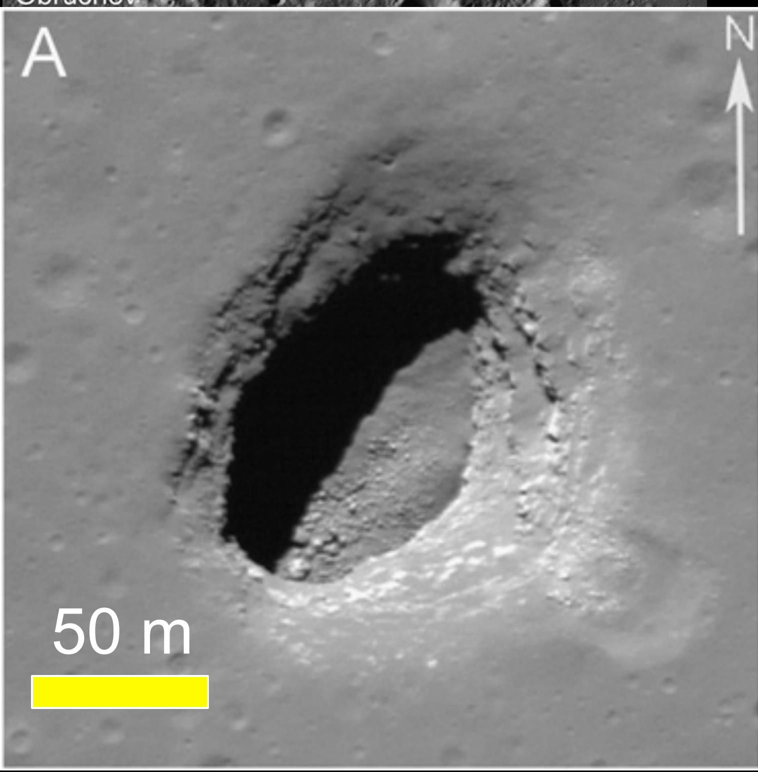
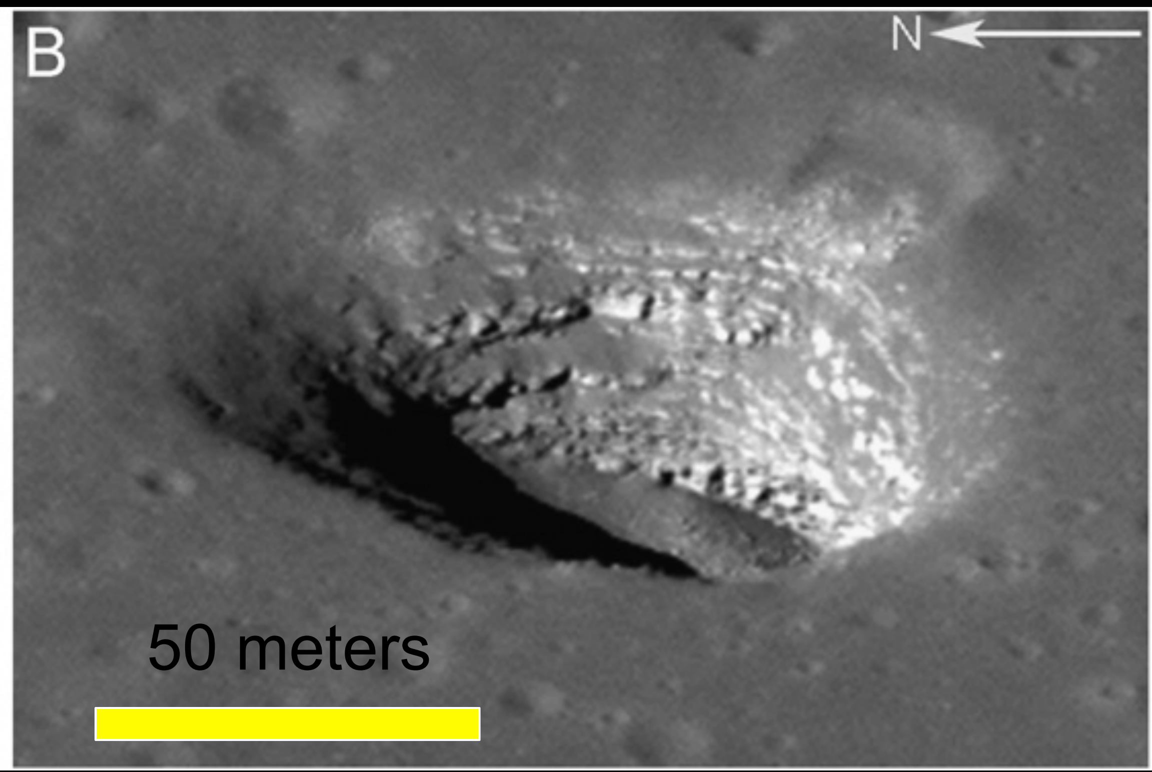
- And for the not too adventurous water molecules



Pit craters may offer a shaded recesses cool enough to allow small amounts of water to accumulate

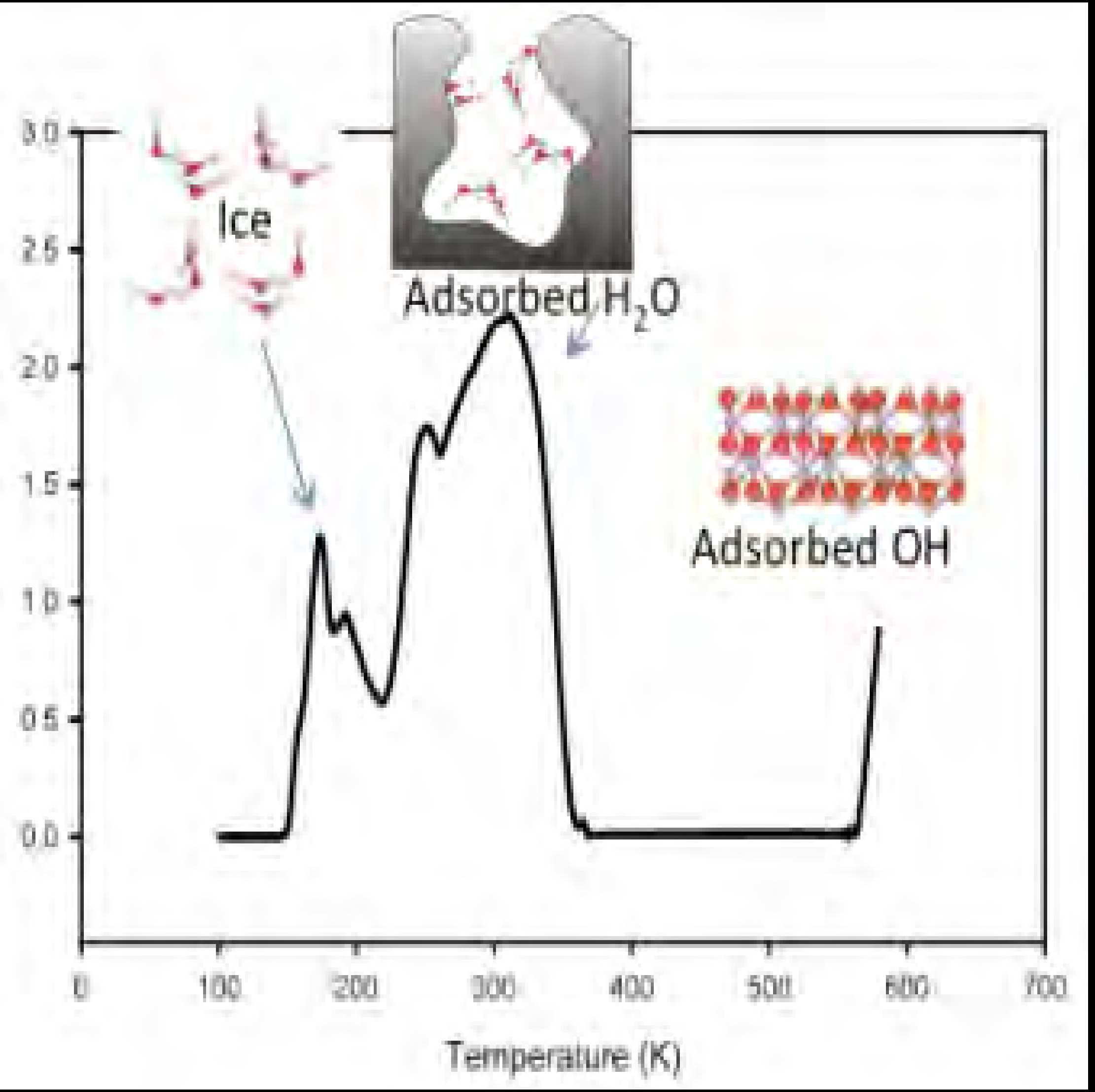
Robinson et al. (2012) *Planetary & Space Science* **69**, 18-27.





In what ways does water stick to soil?

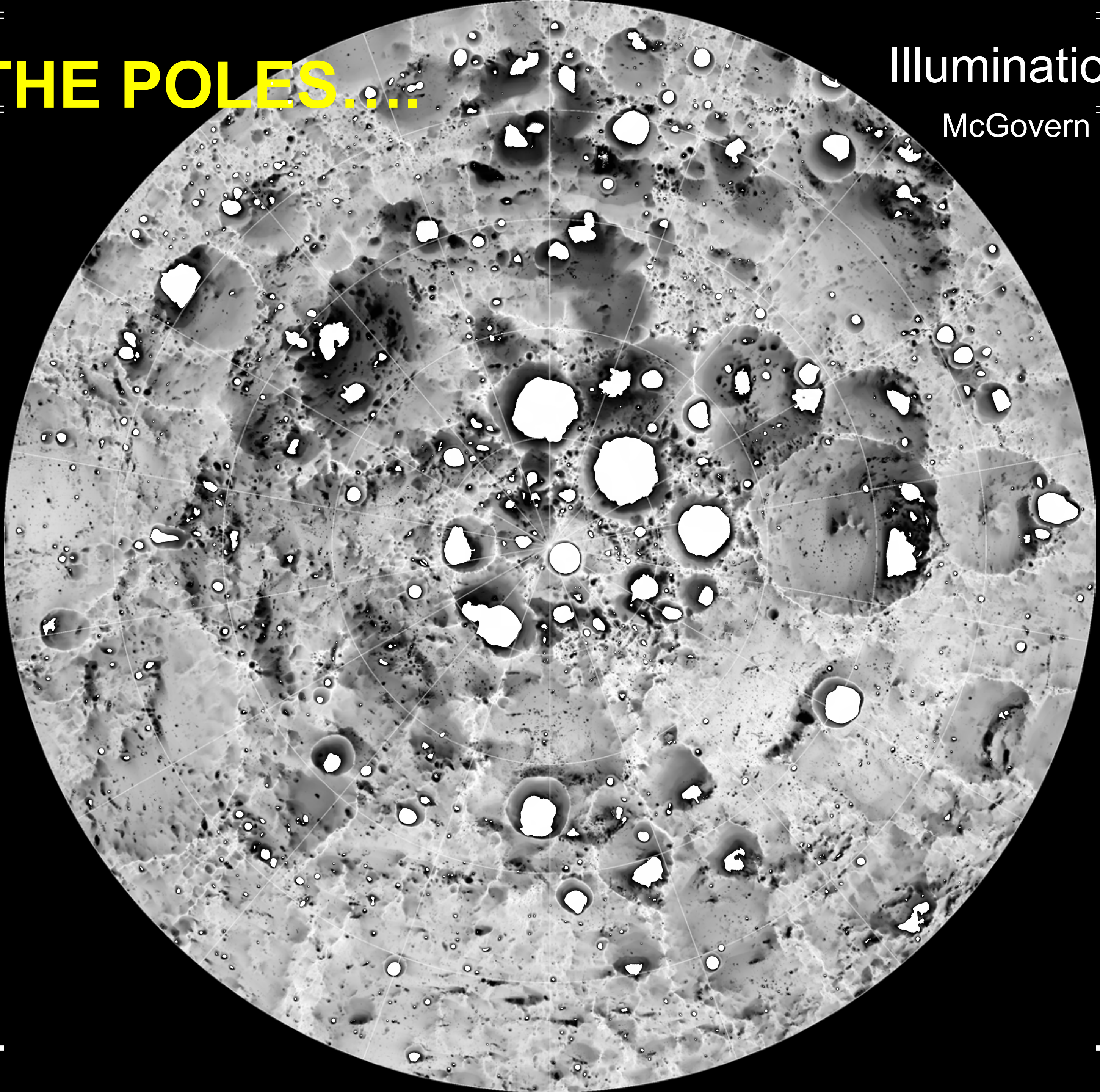
- Bulk physisorption of various phases (~150K).
- Low energy molecular chemisorption (~150 to 250K).
- High energy molecular chemisorption (~250K to 350K).
- Dissociative chemisorption of -OH groups (usually >500K).



AT THE POLES….

Illumination map

McGovern et al., 2012



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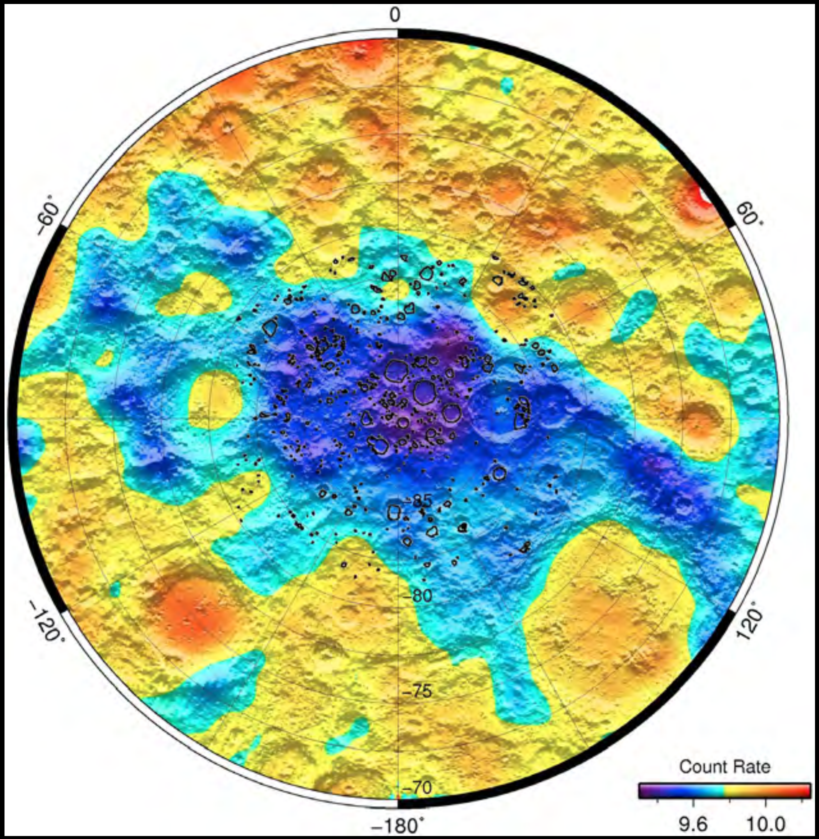
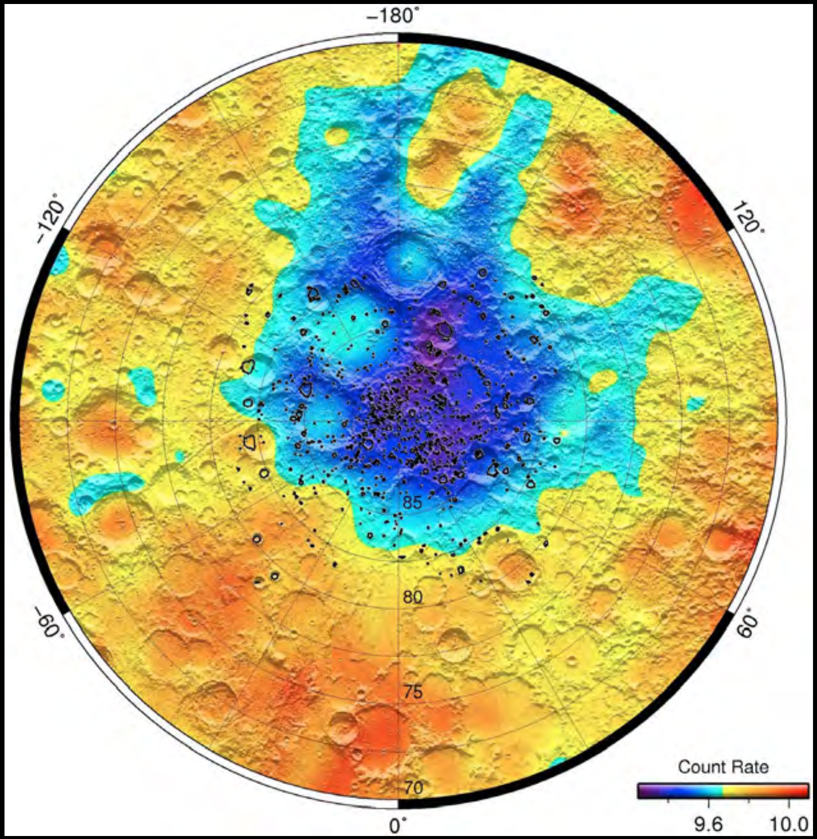
Large Hydrogen concentrations exist even deeper

H-rich areas down to 70° latitude! (up to 1m deep)

South Pole



North Pole



Litvak et al. (2012) *JGR* **117**, E00H22, doi:10.1029/2011JE003949

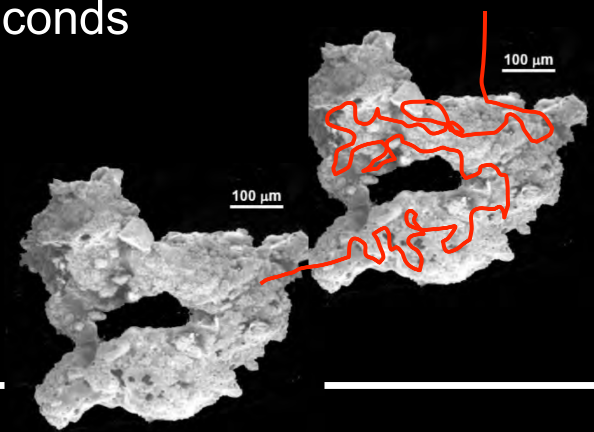
Diffusion and Desorption

Diffusion: 'slow', but happens more easily (at lower temperature). Requires "bridging" contact surface. This limiting area is the reason for the poor thermal conductivity.

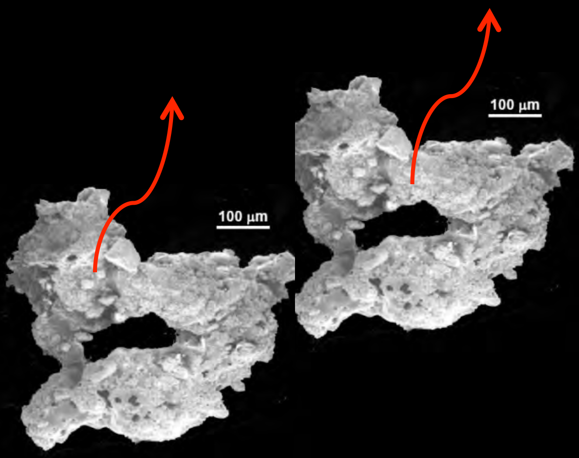
Desorption: 'fast', but requires the ~ 2x the energy.

Diffusion:

1. at 250 K diffusion "lifetime" ~ 10^{-7} s path goes as particle radius^2
2. Site to site hop distance ~3 Angstroms
3. Assuming 100 μm grain (10^{14} A) and assuming non-infinitesimal contact area between grains,
4. Result: can take ~3×10^{18} hops or 10^4 seconds



Desorption: at 250 K desorption lifetime ~0.3 s



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