

Lunar Volatiles Network: A Ring Around the Poles

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Complex Volatile Environment

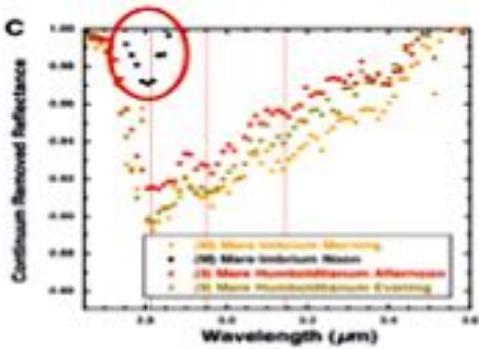
Just beginning to be understood:

- LRO: Observe both deep H reservoirs and surface frost in PSR/polar cold traps; H₂ gas emission from surface
- LCROSS: Observation of impact-released water and possibly complex hydrocarbons like CO₂, C₂H₄ and CH₃OH.
- Chandrayaan-1/EPOXI/Cassini: IR observations of hydroxyl at mid-latitude surface
- Kaguya/Chandrayaan-1: Detection of reflected H⁺ and emitted fast neutral H
- LADEE: Detection of methane at mid-latitudes and possibly CO⁺ and C⁺ also detected in exosphere
- LACE made preliminary detection of exospheric CO and CO₂

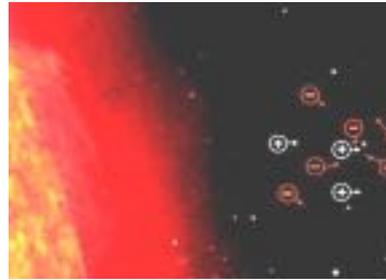
How do you place all of this in context?

How are all of these volatile observations inter-connected?

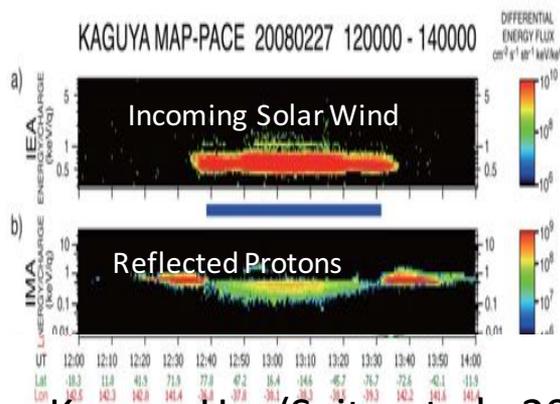
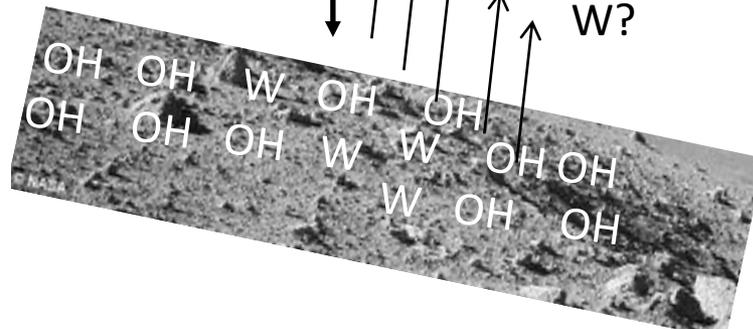
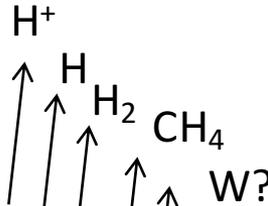
Dynamic Hydrogen Cycle



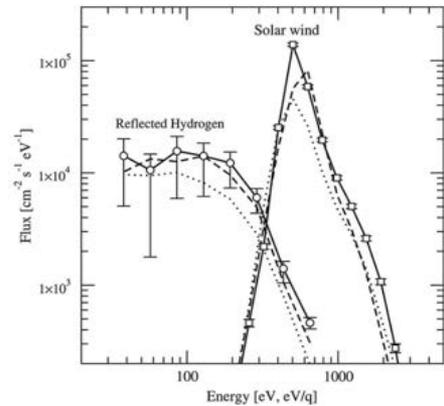
EPOXI OH (Sunshine et al., 2009)



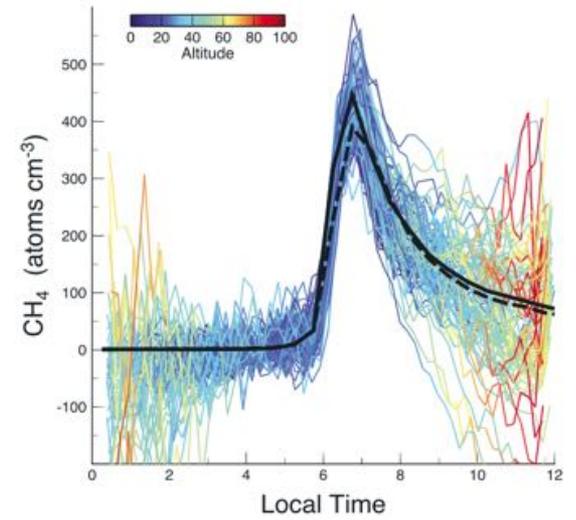
Solar Wind (H⁺)



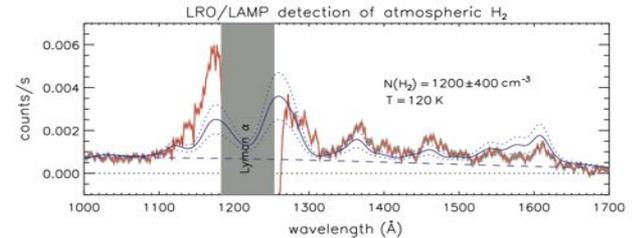
Kaguya H⁺ (Saito et al., 2008)



Chandrayaan-1 Fast H (Wieser et al., 2009)

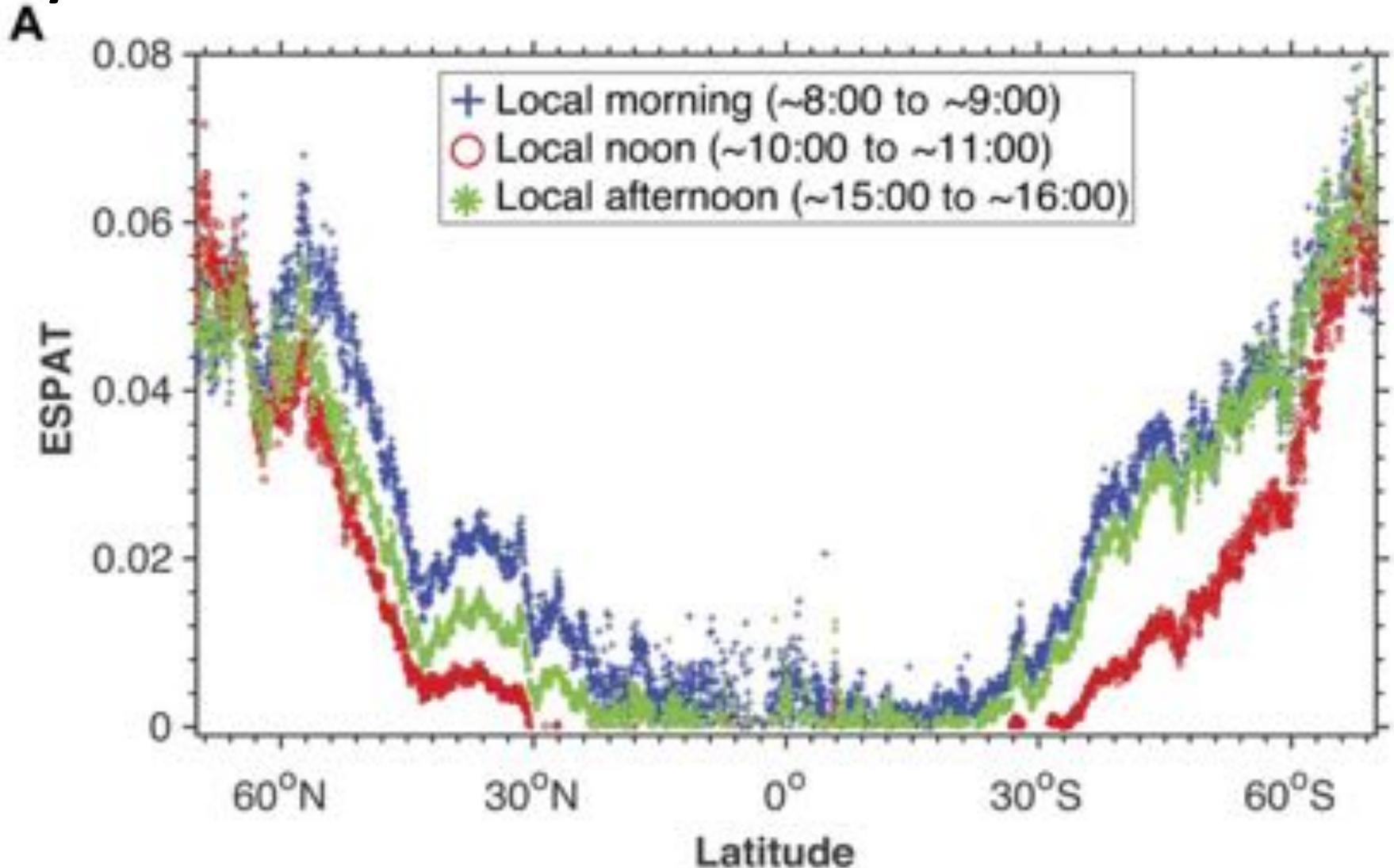


LADEE Methane (Hodges, 2016)



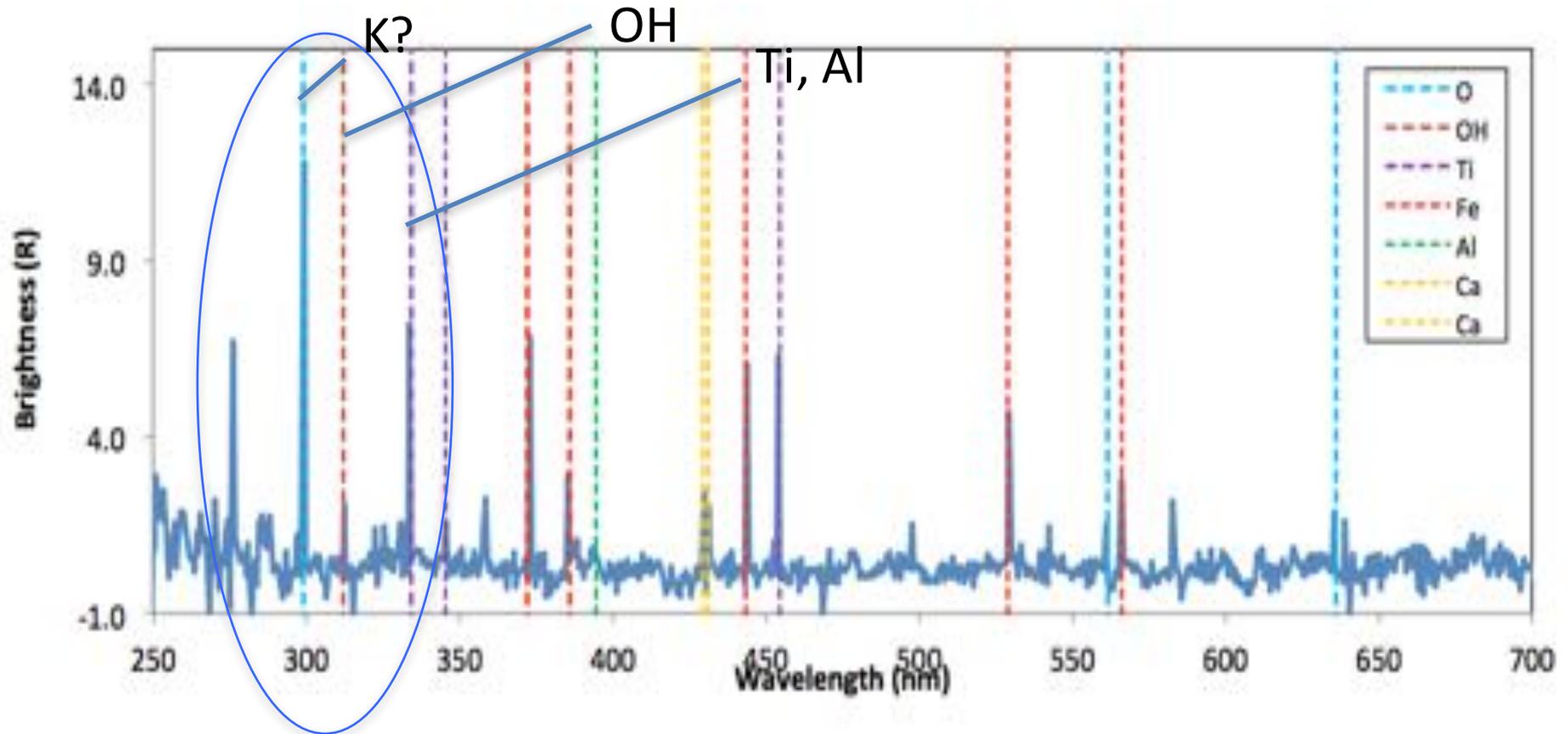
LAMP H₂ (Stern et al., 2013)

Dynamic Diurnal Surface Variation of H



Li and Milliken, 2017 – Effective Single Particle Absorption Thickness, proportional to H content

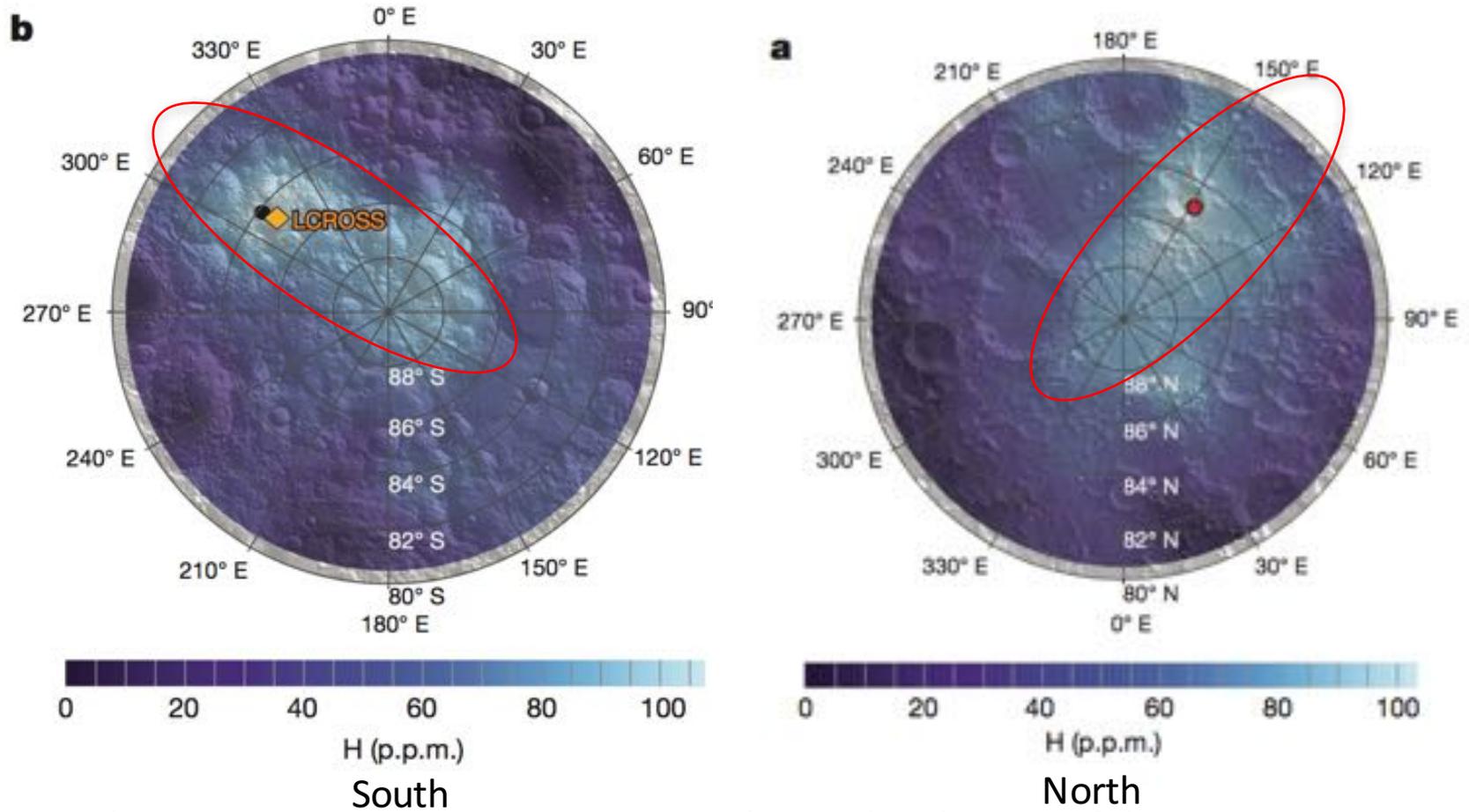
Dynamic Meteoric Effects



Colaprete et al, 2015 ESF talk – LADEE UVS Pre- and Post- Geminids with meteoric release of OH

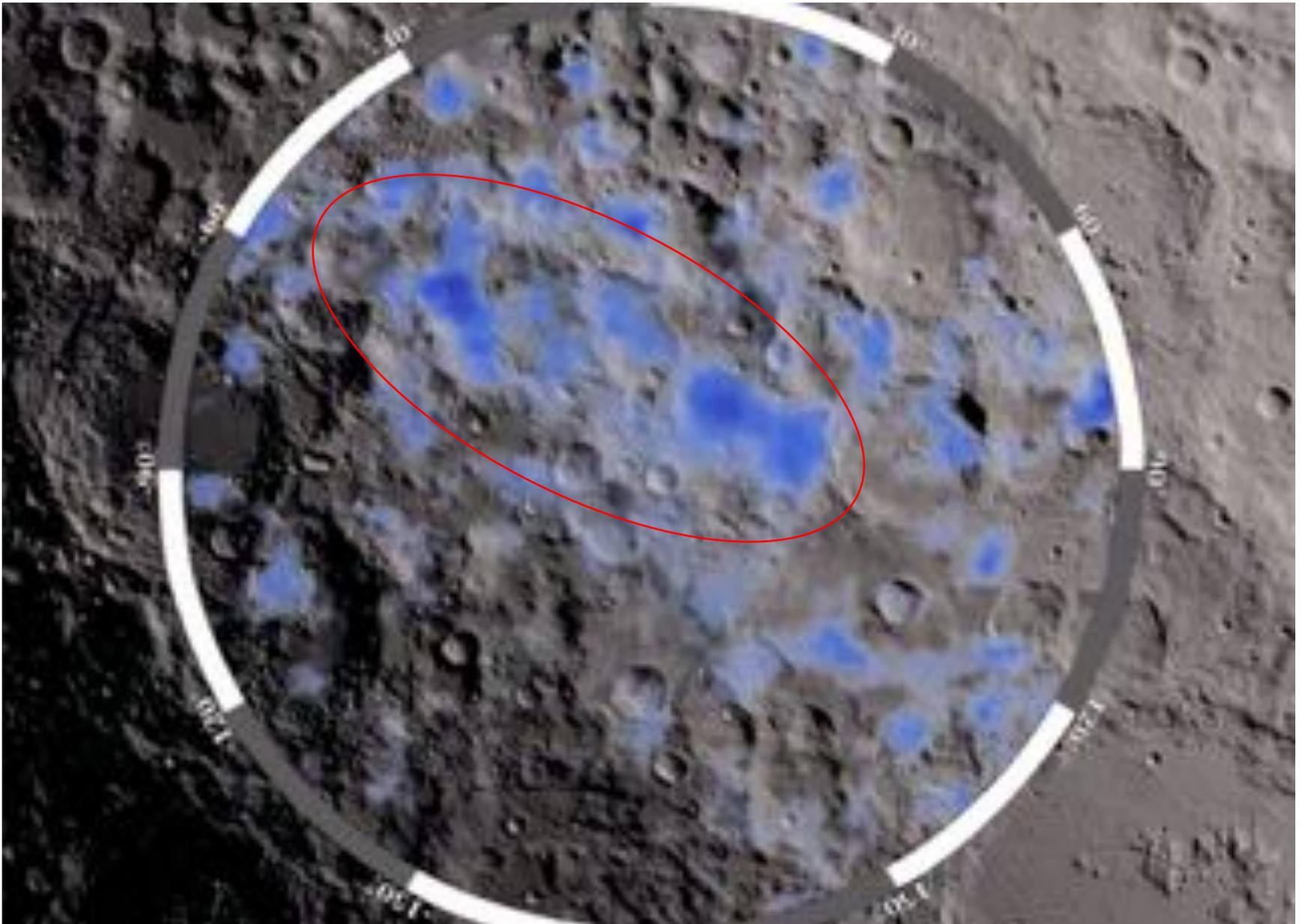
Note:RMK assignment of 300 nm to K; 308.5 to OH; 103 to O (not shown)

Consider the Poles.....

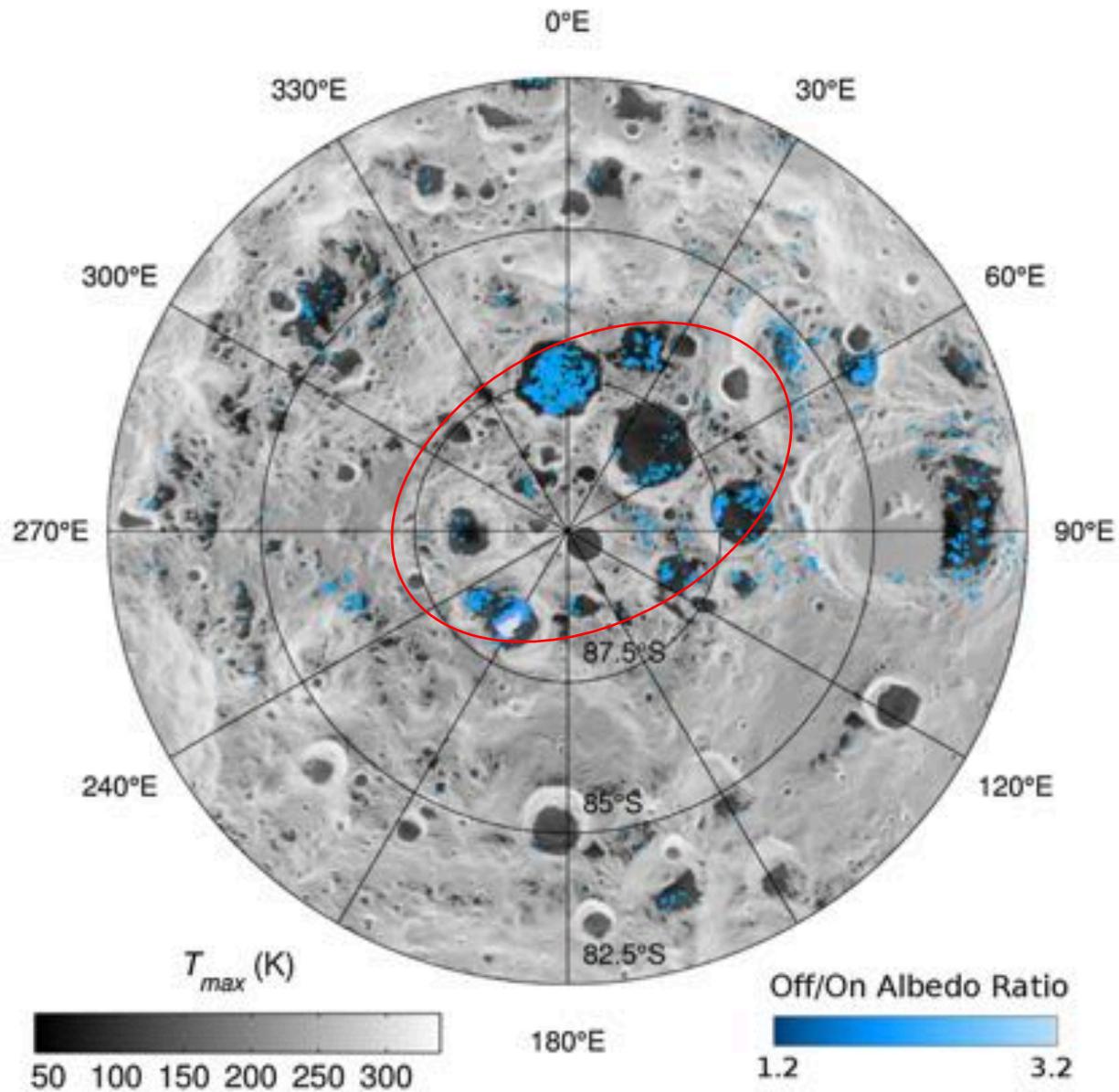


Siegler et al., 2016 – LP Neutron Spectrometer shows distribution of deeper H concentrations, Near-antipodal distribution, not a modern source

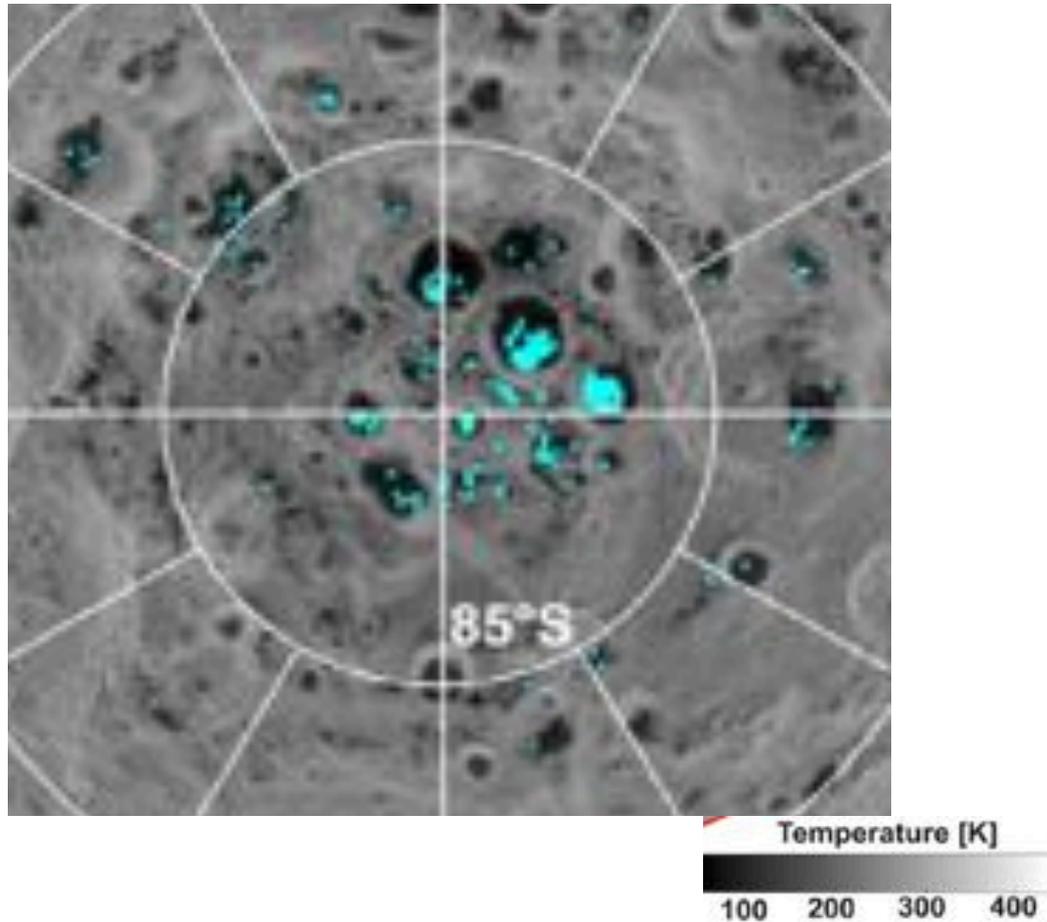
A Cabeus shift



LEND Map – 2012 press release of neutron data also shows the Cabeus shift



Hayne et al 2015- Locations of surface water frost in the UV.
 Cabeus shift not obvious



Fisher et al 2017- LOLA's 1064 nm lidar;
Anomalously bright pixels possibly from water surface frost
Also no Cabaeus shift

Gladstone's 2011 Provocative idea: Polar Crater Water Frost is Locally Generated

surfaces of PSRs than originally thought. At this reduced desorption rate the loss of water from IPM Ly α photolysis is comparable to the steady source of water due to micro-meteoroids and the episodic source due to comets (i.e., $1.9 \times 10^5 \text{ cm}^{-2} \text{ s}^{-1}$ and $3.4 \times 10^5 \text{ cm}^{-2} \text{ s}^{-1}$, respectively, from *Morgan and Shemansky [1991, Table 3]*). The fact that the sources and sinks of water are roughly equal may explain the observed heterogeneity in the FUV albedos of the PSRs, since it would make the retention of frost very dependent on local conditions and their history. Over the billion-year history of the PSRs some frost migration (vertically and horizontally) is expected. At the lowest PSR temperatures measured by Diviner, thermal diffusion is extremely slow [*Schorghofer and Taylor, 2007*]. However, in warmer PSRs, thermal cycling can increase diffusion rates considerably [*Siegler et al., 2011*]. Thus, some heterogeneity may be caused by temperature differences. Even in the coldest regions, impact gardening is expected to substantially redistribute volatiles with depth [e.g., *Crider and Vondrak, 2003*].

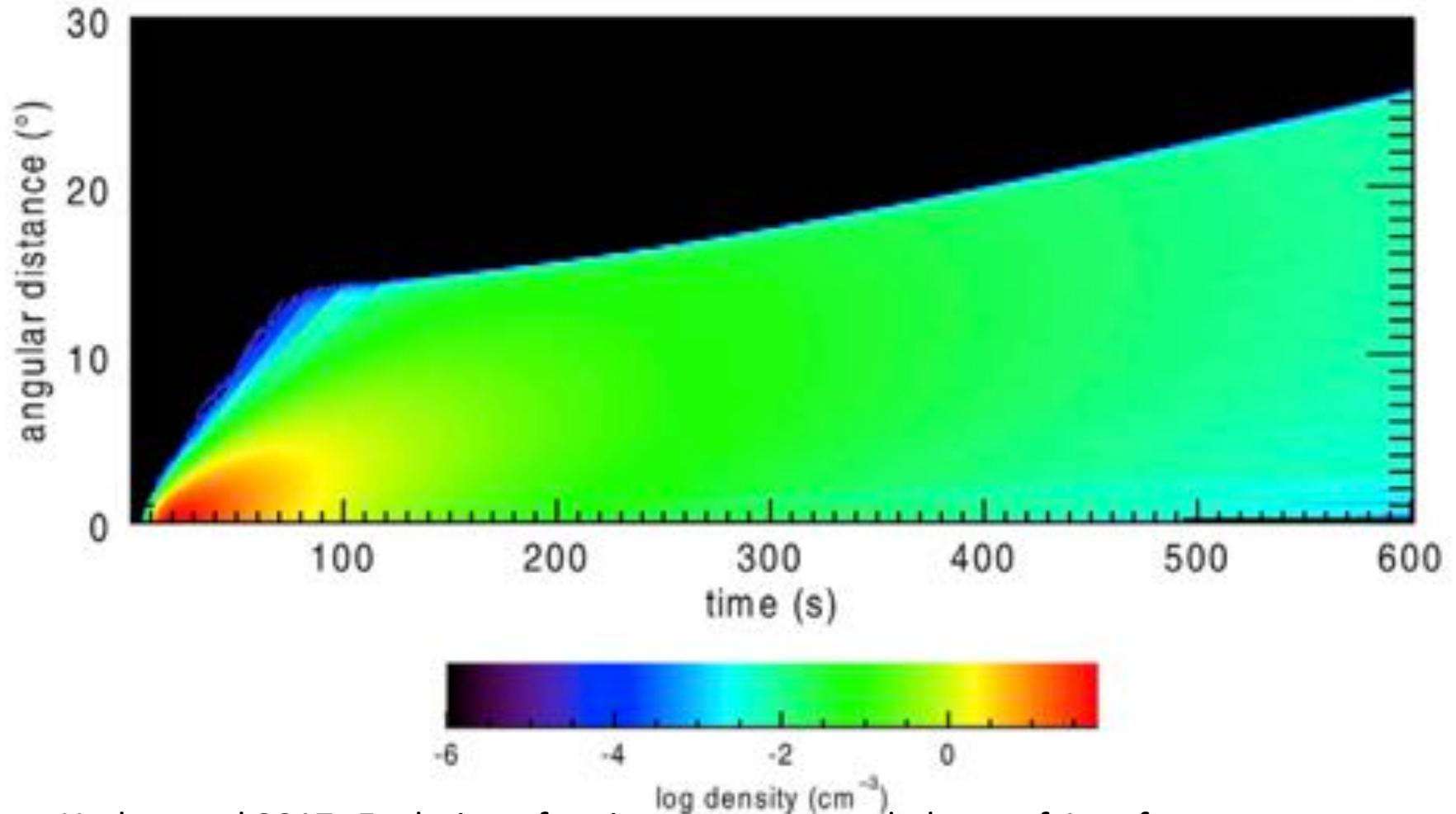
Zimmerman et al., 2014
Hayne et al., 2015

Source: Local delivery of volatiles into PSRs by meteoritic infall
-Prompt Vaporization
-Most of vapor cloud local

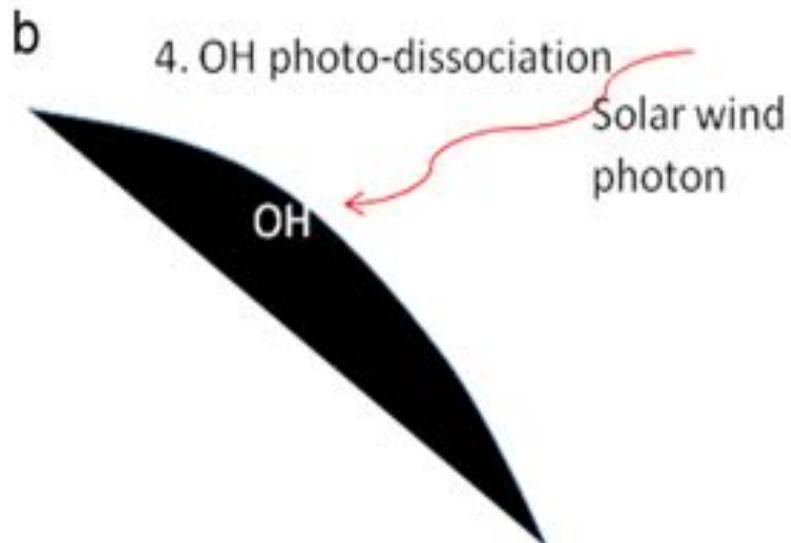
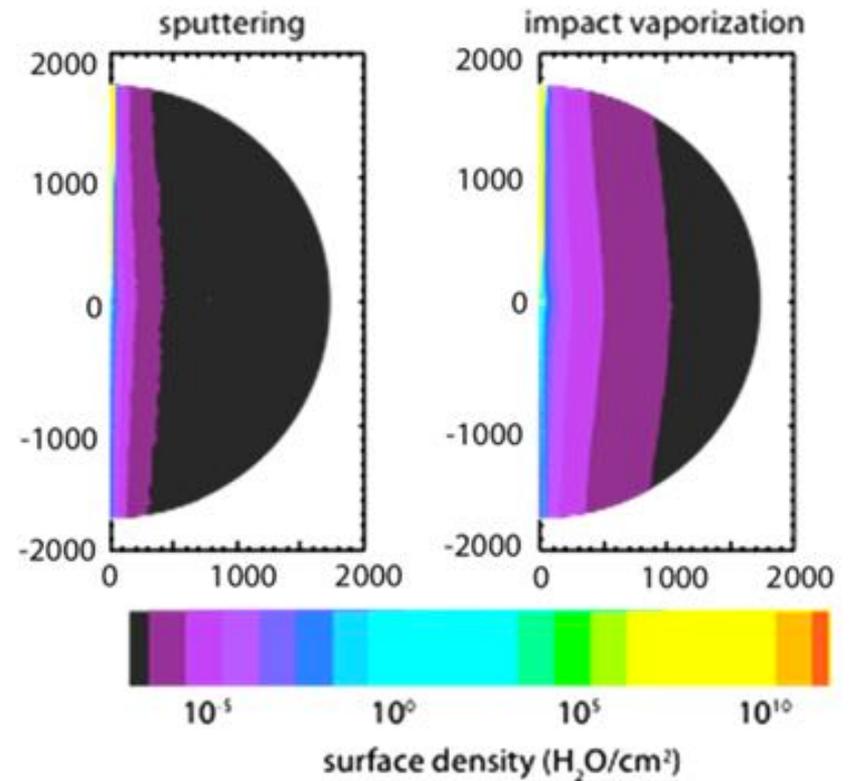
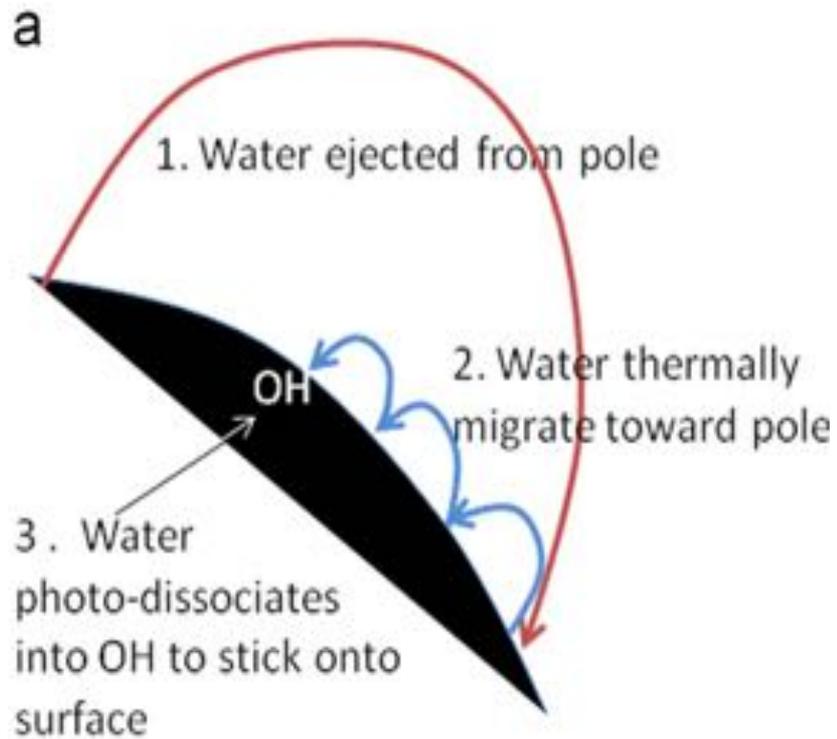
Loss: PSD via Lyman- α , prompt impact vaporization

In dynamic equilibrium - disequilibrium creates the heterogeneity in T and illumination, etc

Don't necessarily need a global migration system



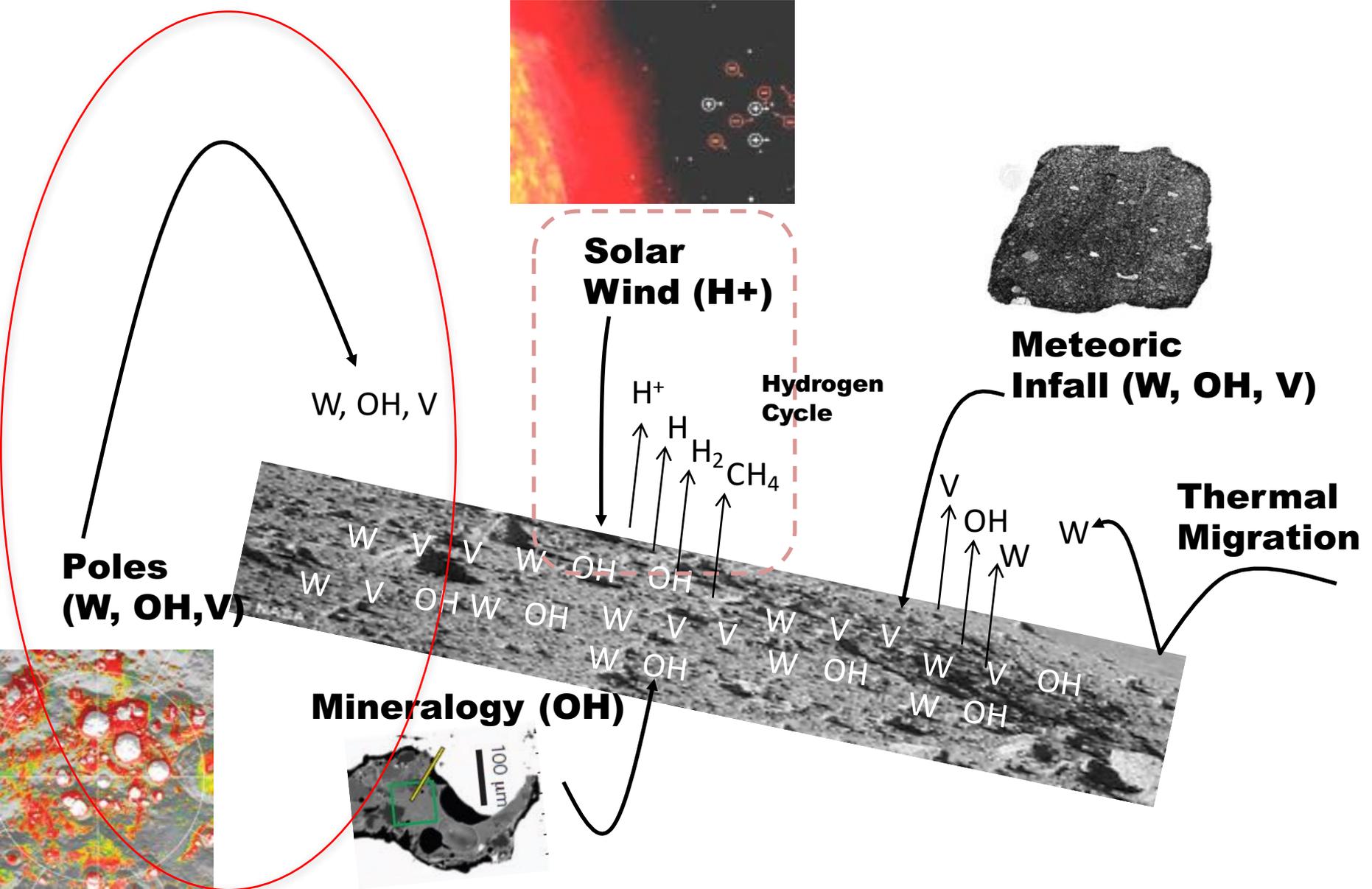
Hurley et al 2017: Evolution of an impact-generated plume of 1 g of water vapor
Prompt vaporization
Most of water stays local – within 2° or ~60 km of source
Energetic tail of water energy distribution spreads 100's of km



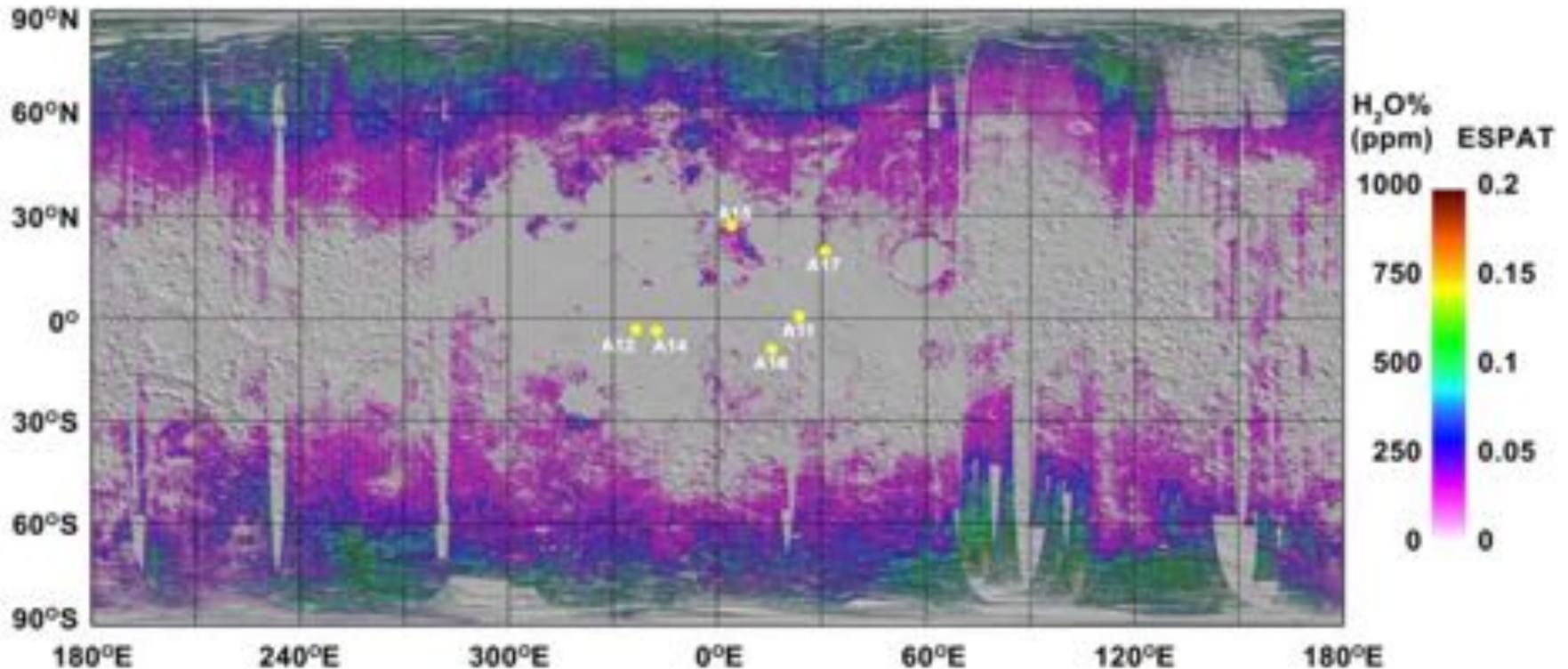
Farrell et al 2013 model of polar crater water emission via impact vaporization and sputtering

Back to Mid-Latitudes.....

Non-Polar Volatiles: Complex Array



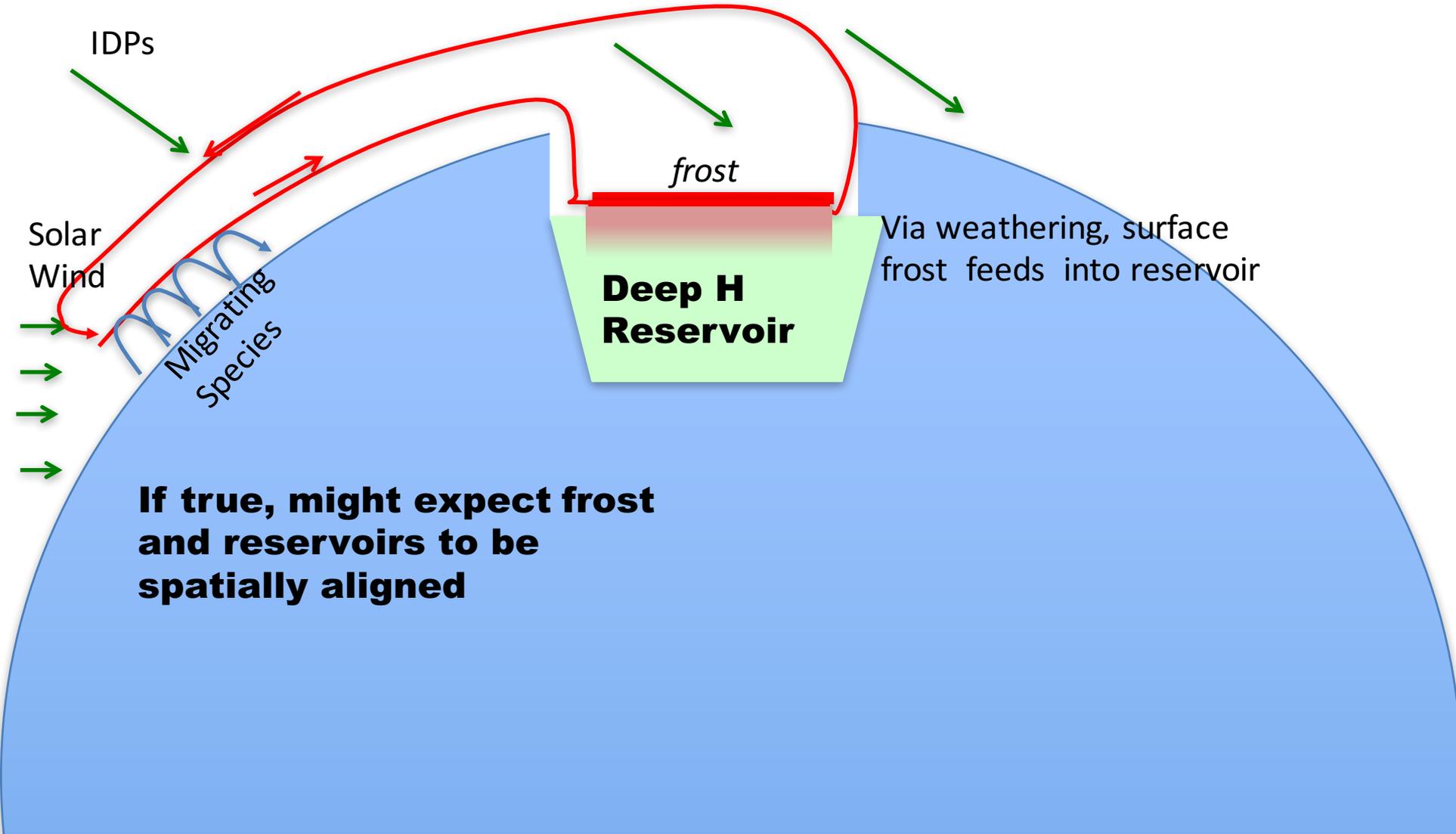
What does it really mean?



- Li and Milliken 2017 – Map of surficial OH in the IR from M³
Phenomenal, very revealing map but still difficult to determine the dynamics
- Is it representative of solar wind hydrogen implantation?
 - Is it residual of photo-dissociated water at equator migrating pole-ward?
 - Is it a signature of water outflowing from poles?

Scenario #1 – Strong Cycle-Reservoir Connection featuring migrating species (hopping volatiles)

Modern Dynamic Volatile Cycle



IDPs

Solar
Wind

Migrating
Species

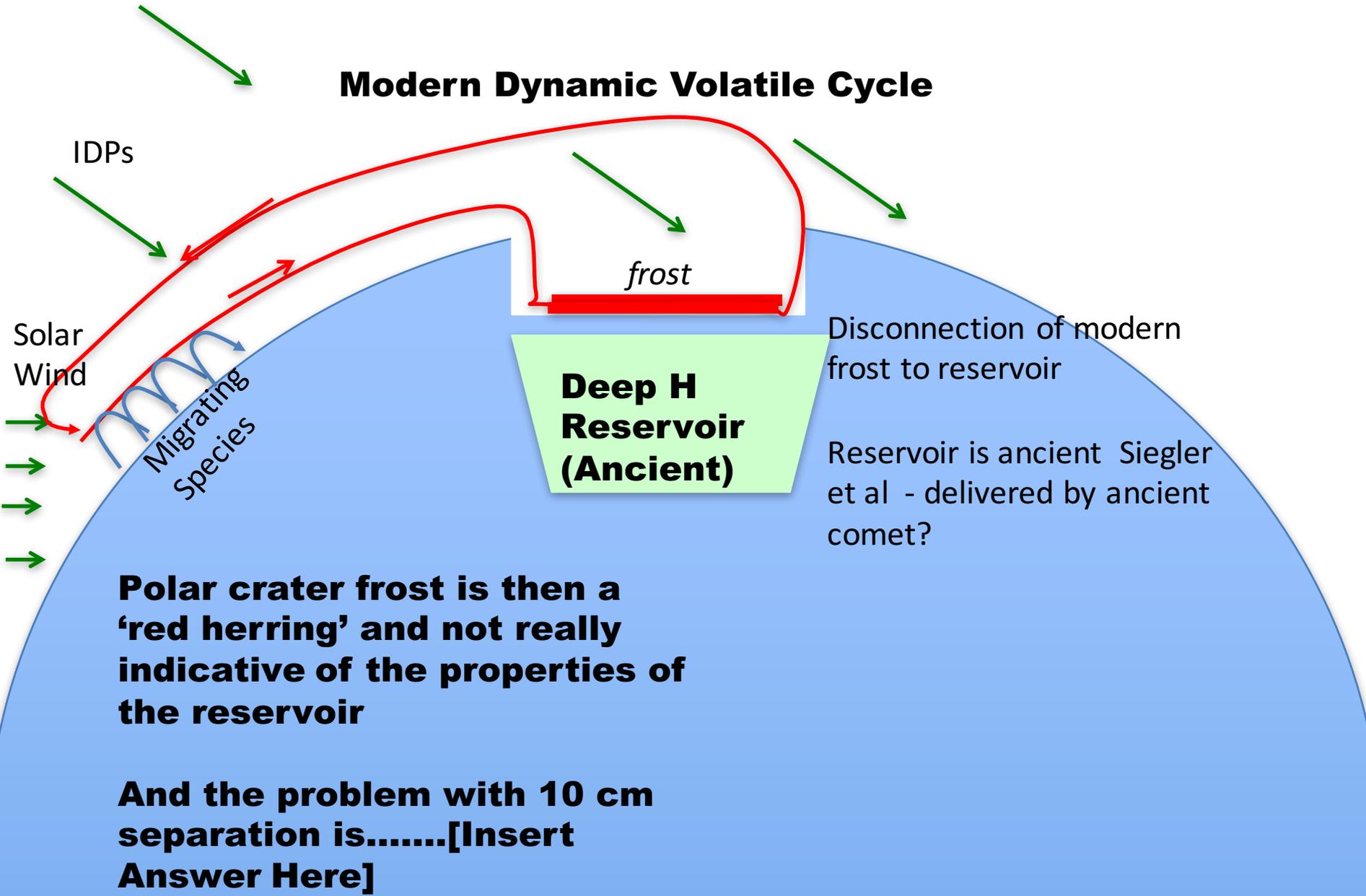
frost

**Deep H
Reservoir**

Via weathering, surface
frost feeds into reservoir

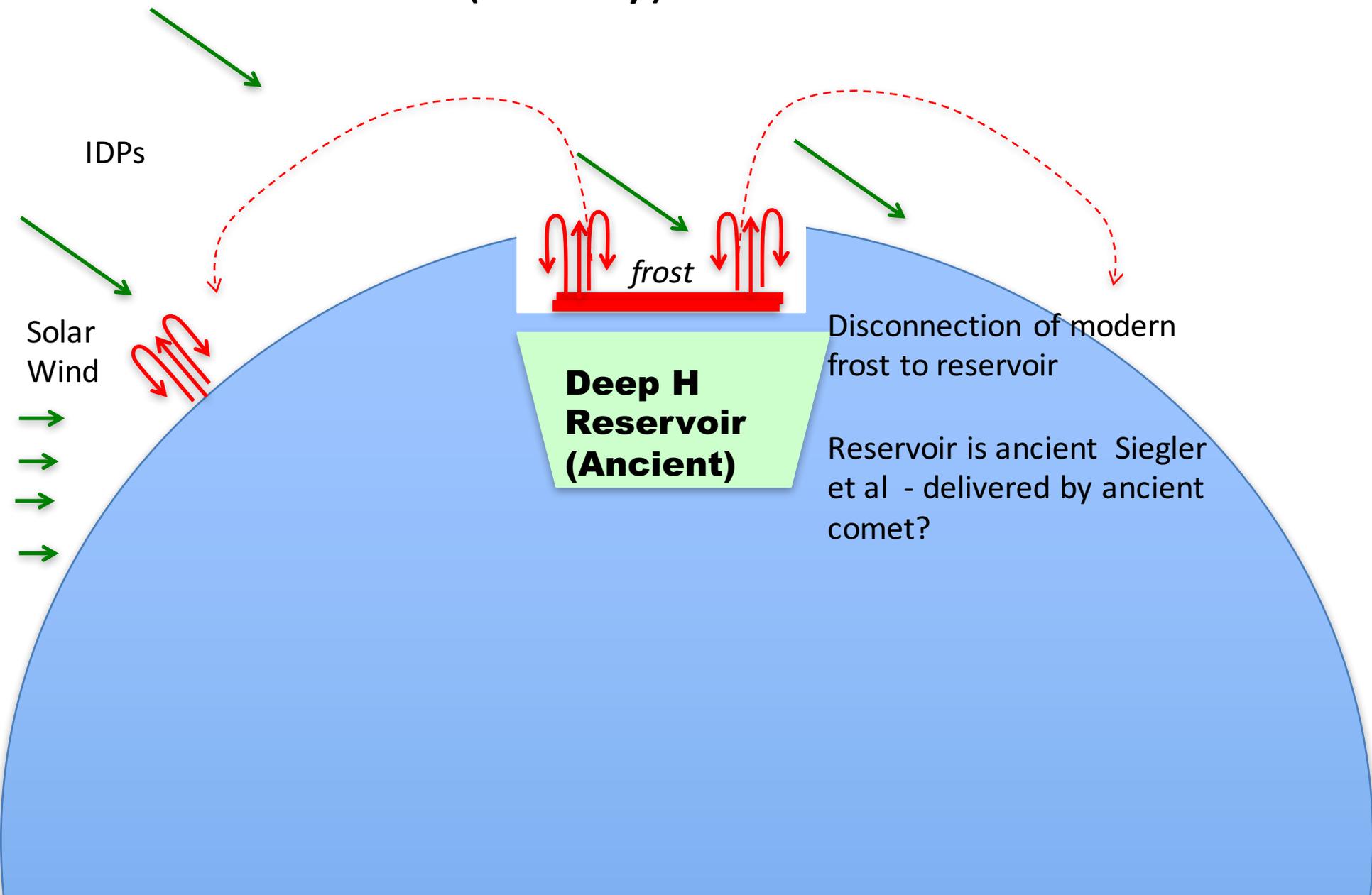
**If true, might expect frost
and reservoirs to be
spatially aligned**

Scenario #2 – Cycle-Reservoir Quasi-disconnected



Scenario #3 – No Cycle, Volatile Frost via Infall

A (mostly) local effect



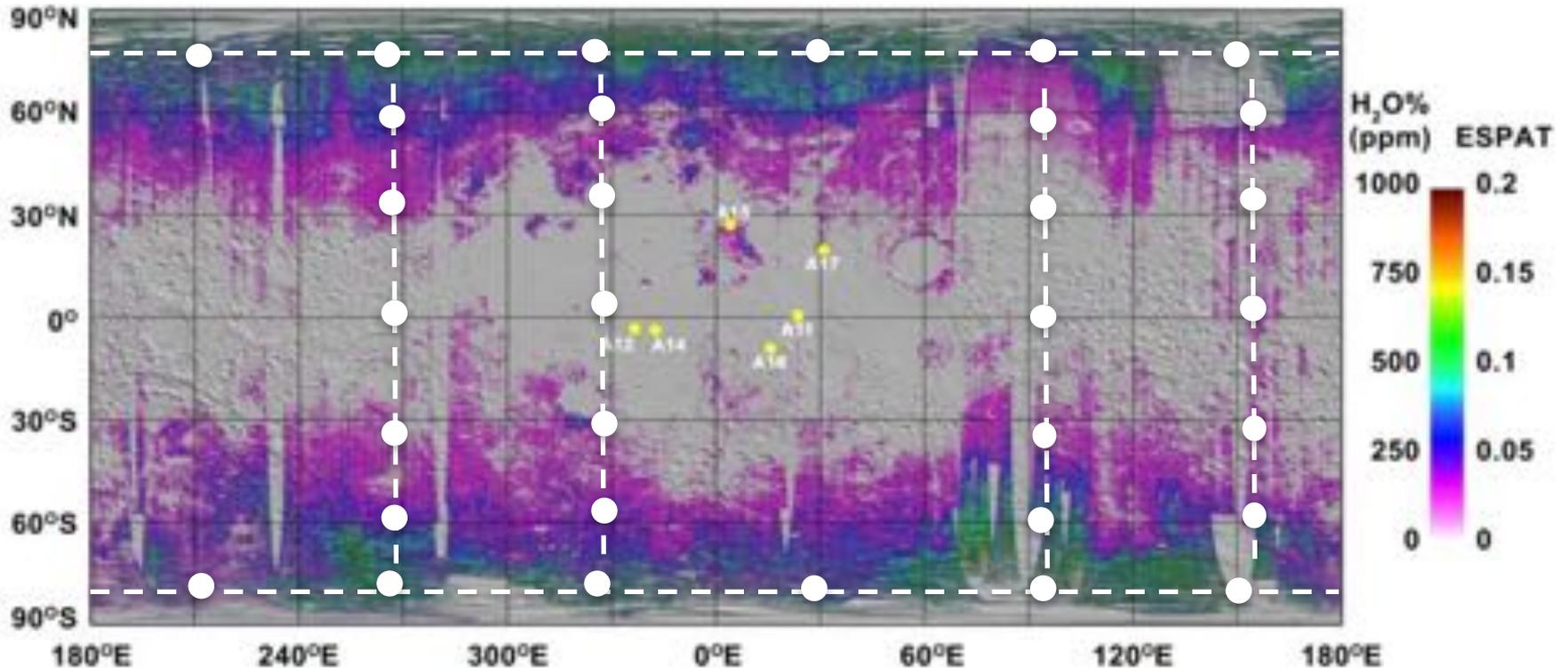
LVN Questions

- Do water molecules and other volatiles actively migrate poleward or to equator – to get trapped in PSRs?
- Is the modern frost in PSRs locally generated?
- Is the modern frost in PSRs connected or disconnected from the deeper neutron-sensed H reservoirs?
 - Is 10 cm enough to separate the modern H cycle from the deeper H-reservoir in PSRs?
- How is the space environment connected to volatile manufacturing and transport?

LVN Concept

- Assumption: Have Flagship⁺ level of funding (maybe why we are the 'Dream team'...keep dreamin'!)
- Assumption: Strong political shift toward the Moon
- Place a set of small landers to observe any migration of volatiles along the lunar surface
- Make use of environmental extreme events: lime meteor showers, solar storms, passages into/out of magnetosphere [LADEE/MAVEN approach]

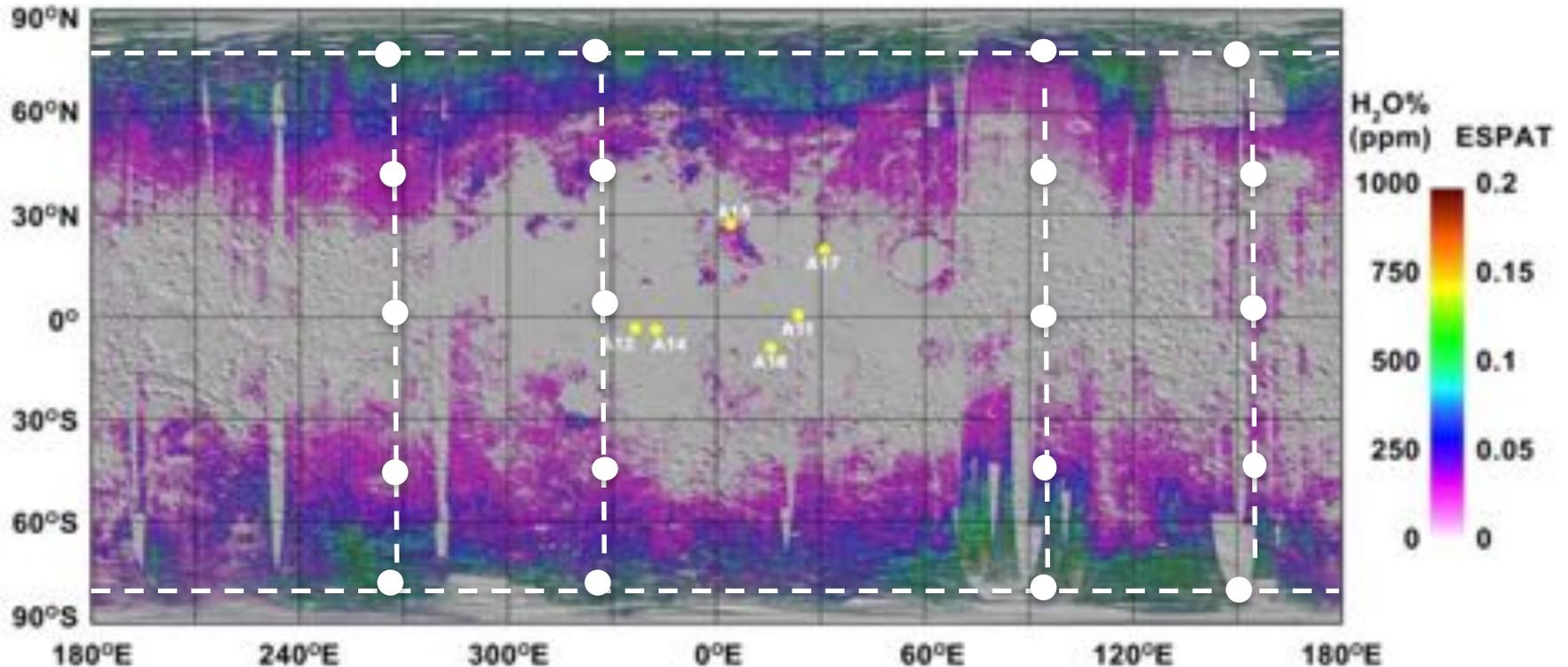
LVN Placement: Ring around the Poles



Li and Milliken 2017 – Map of surficial OH in the IR from M³

32 stations and PSR stations

LVN Placement: Ring around the Poles



Li and Milliken 2017 – Map of surficial OH in the IR from M³

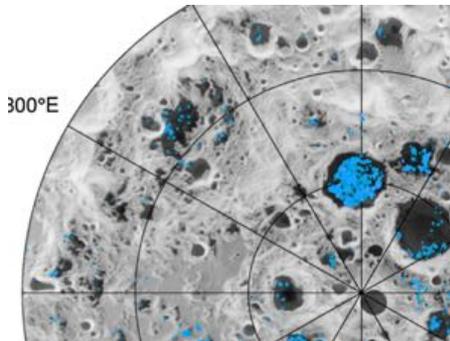
20 stations and PSR stations

Instrument Complement

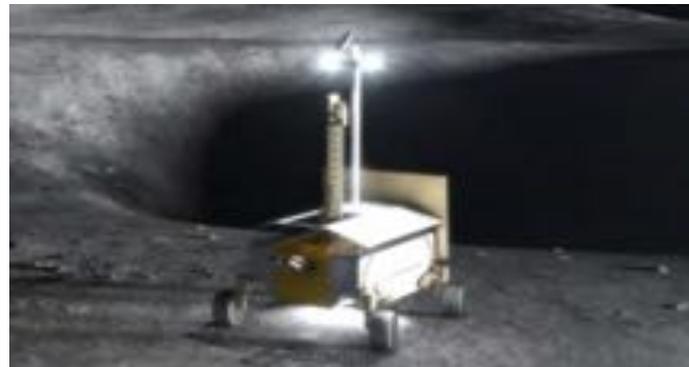
- Look down at Surface: Near IR, UV, Plasma, Dust Detector, 3 micron LIDER, Drill?
- Look up at Exosphere: UV, Laser fluorescence system? (any other recommendation?)
- Release Experiment: Lander at mid-latitudes release D cloud to be tracked by other landers
- Orbiter: Provides context
- Use both orbiter and landers to feed to modern models of the volatile system on daily basis – observations-based forecast modeling tool

Polar Cold Trap Lander

- A dedicate lander to be placed into a south pole crater like Cabeus
 - Has both surface frost and deeper H reservoir
- Assume it would be short-lived
- Add drill to get at the H reservoir



From Hayne et al 2015



RP at crater edge (illustration)

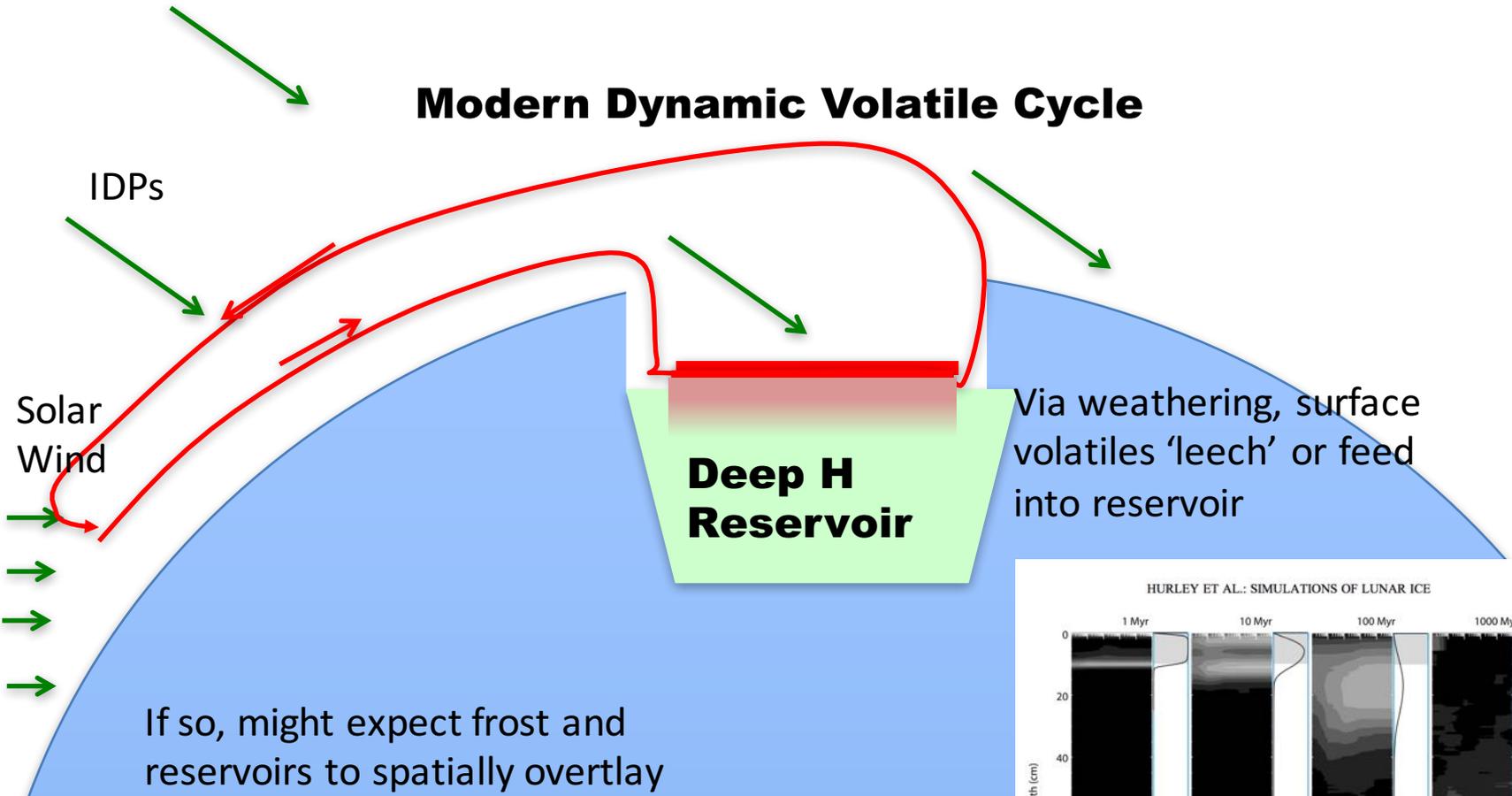
Conclusions

- LVN Concept still ‘loosely defined’, high level here
 - However, parallel’s ARC’s Bob Haberle’s Pascal Scout mission to place network weather landers on Mars
 - If you can talk about a Mars Weather Network to feed GCMs, why not a Lunar Volatile Network to feed migration models?
- Issues:
 - Strategic: Costs and fit to Flagship/NF program
 - Tactical: Exosphere observations from landed platform
- Solutions:
 - Since this a form of resource prospecting, could be a joint SMD-HEOMD-STMD program
- To do: Better define where this fits....Discovery, NF, Flagship; Embodiment of the landers

Backup

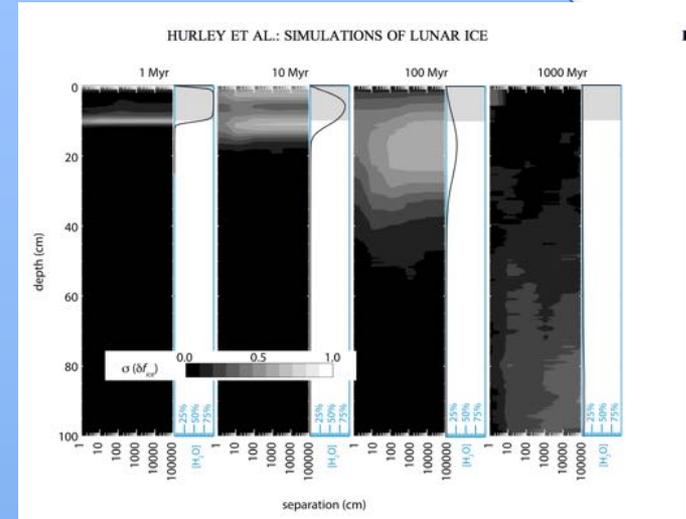
Scenario #1 – Strong Cycle-Reservoir connection

Modern Dynamic Volatile Cycle

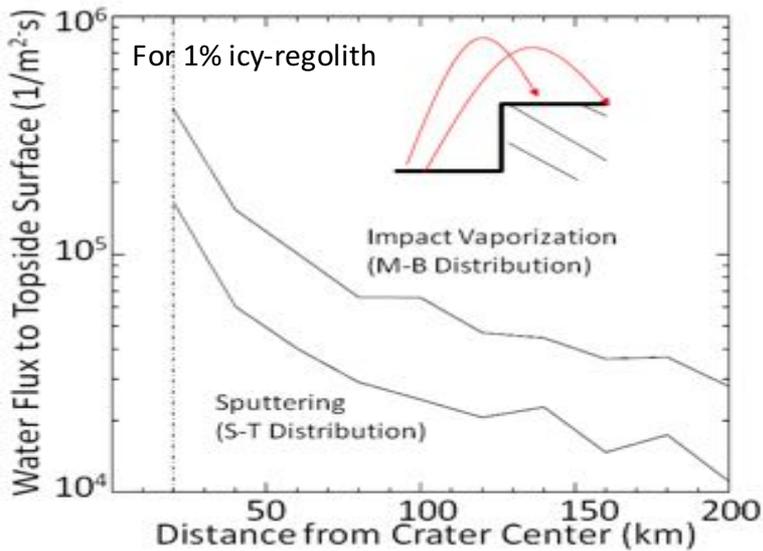


Via weathering, surface volatiles 'leech' or feed into reservoir

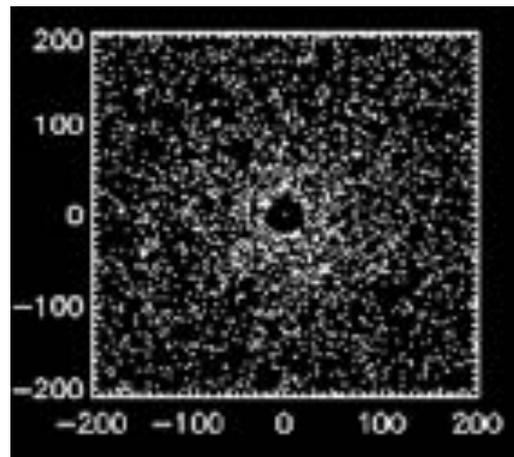
If so, might expect frost and reservoirs to spatially overlay



'Spillage' of polar crater volatiles onto adjacent polar terrain



Water test particles in 200 km region about polar crater (via Impact Vaporization)



- Prompt impact vaporization can release water to topside terrain
- Monte Carlo models of impact vaporization and sputtering release
- **Dynamic Equilibrium:** LRO/LAMP detects a light water 'frost' on regolith
 - DREAM2 models set water loss rates near $10^8/m^2\cdot s$ for 1% icy regolith
 - Dynamic source of water has to exist to offset environmental losses