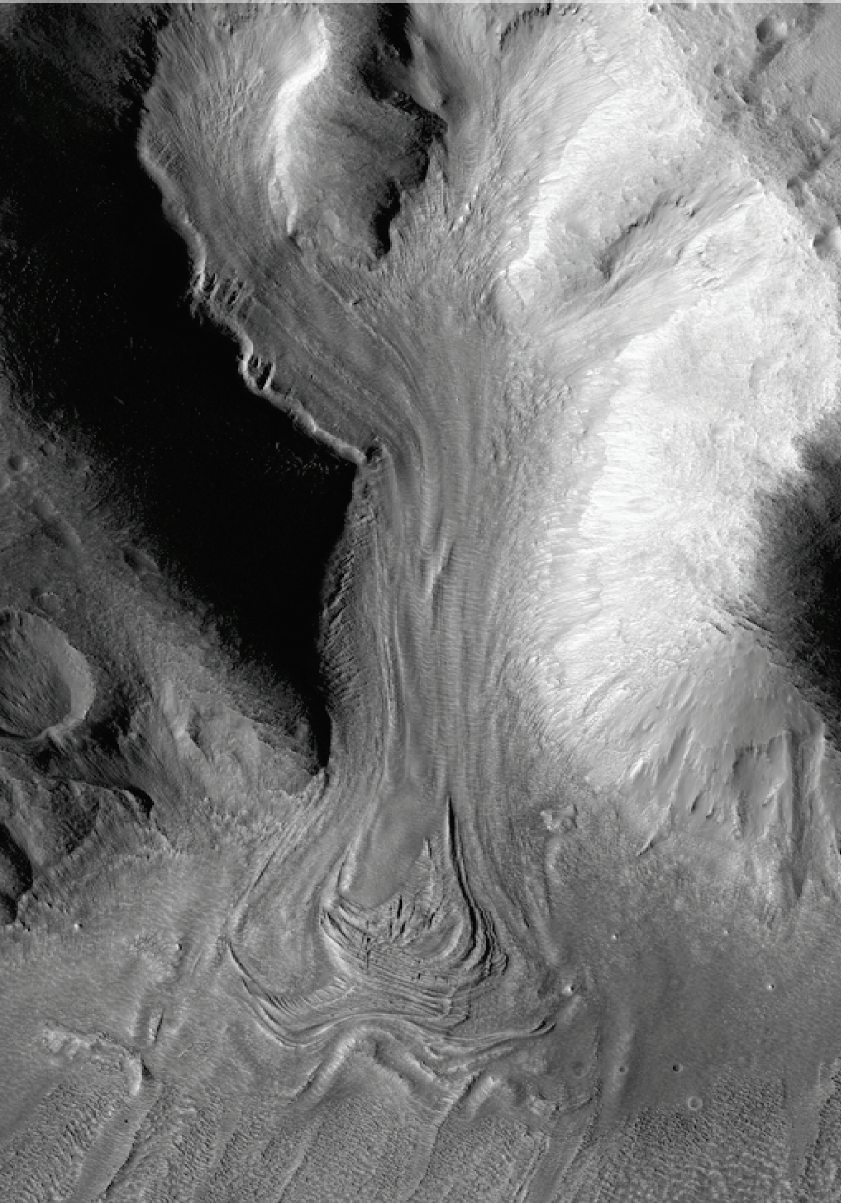
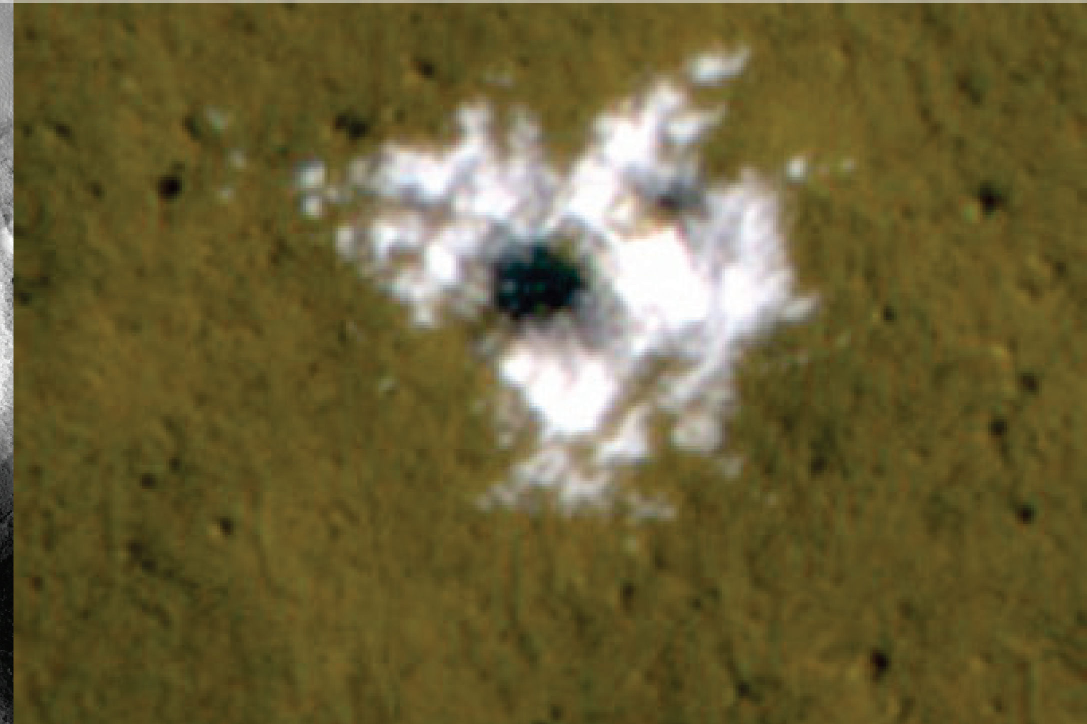
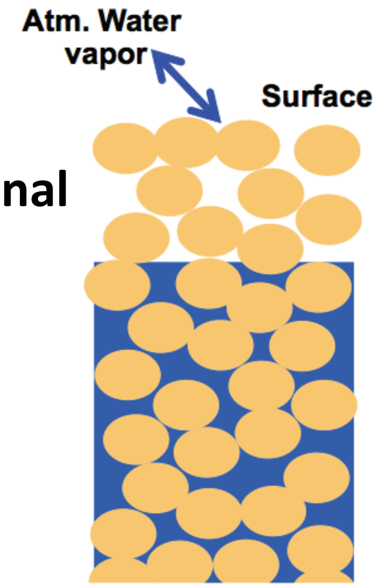
Shallow Excess Ground Ice on Mars

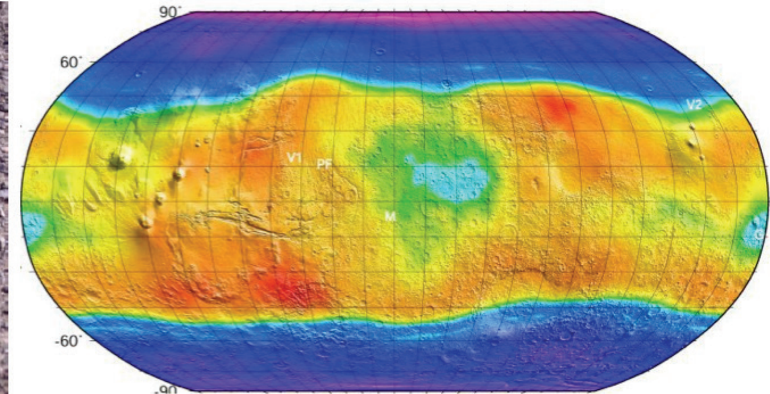
S. Byrne (LPL)





The conventional picture...





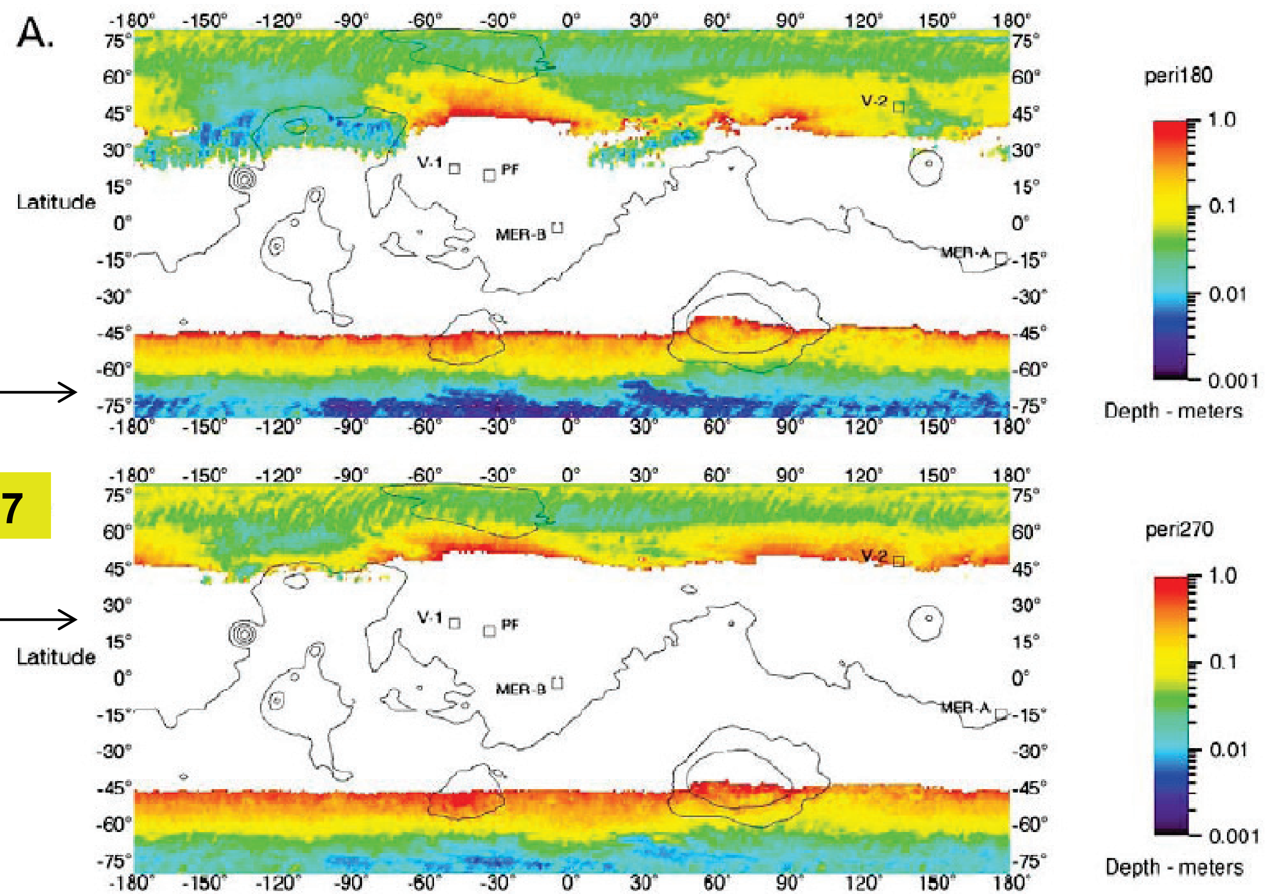
GRS results
(Boynton and Feldman et al.)

Ground ice extent is very sensitive to climatic conditions and should be young and pore-filling

10 kyr ago

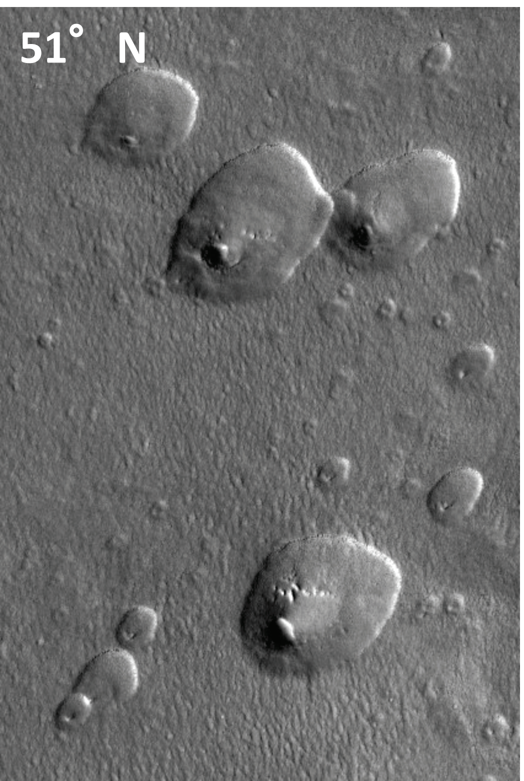
Chamberlain and Boynton, 2007

3 kyr from now



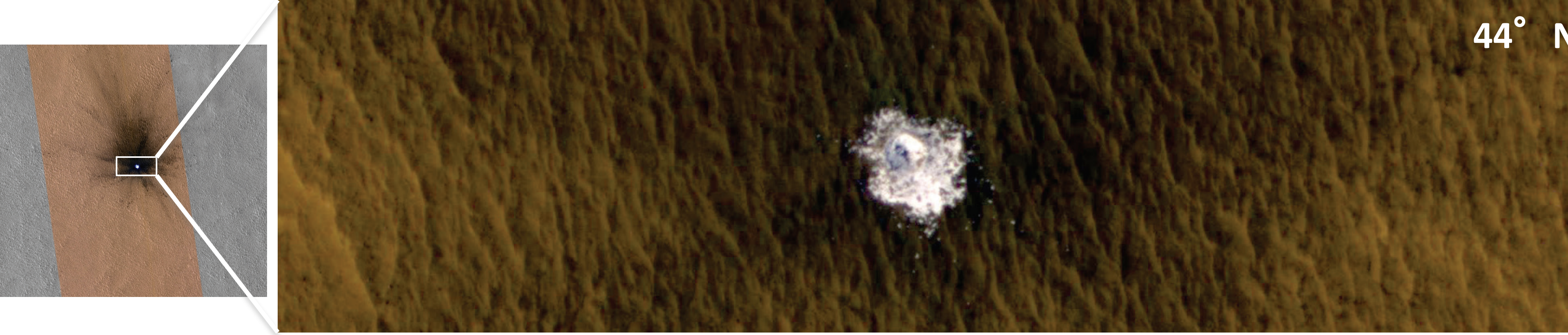
Evidence now points to widespread mid-latitude excess ice

- Excavation at the Phoenix site
- Ice-exposing impact craters
- Scallops & Expanded craters (thermokarst)



Possible Sources

- Ice lenses from frost heave
  - Liquid films difficult at these temperatures (salt assisted?)
- Snowfall
  - But there's superposed boulders…
- Dry thermal cycling
  - Appears to require long timescales

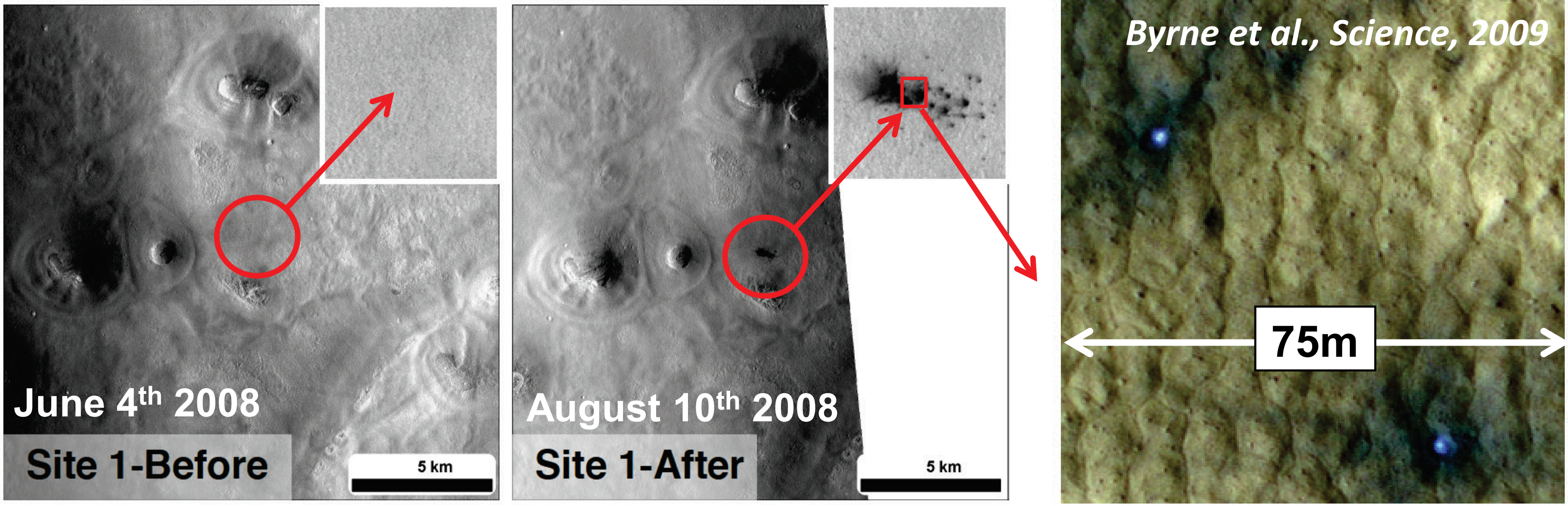


Who Cares

•Mars climate information is encoded in the locations/ages of this ice – we've come to realize that it's much thicker and more extensive than thought

- ISRU technology is luckily more mature than this
- Yet if astronauts can dig up almost pure water that's only decimeters below the surface then that's easier and more reliable than
  - Atmospheric extraction
  - Breaking down hydrated minerals

Mark Watney tries to make water – The Martian

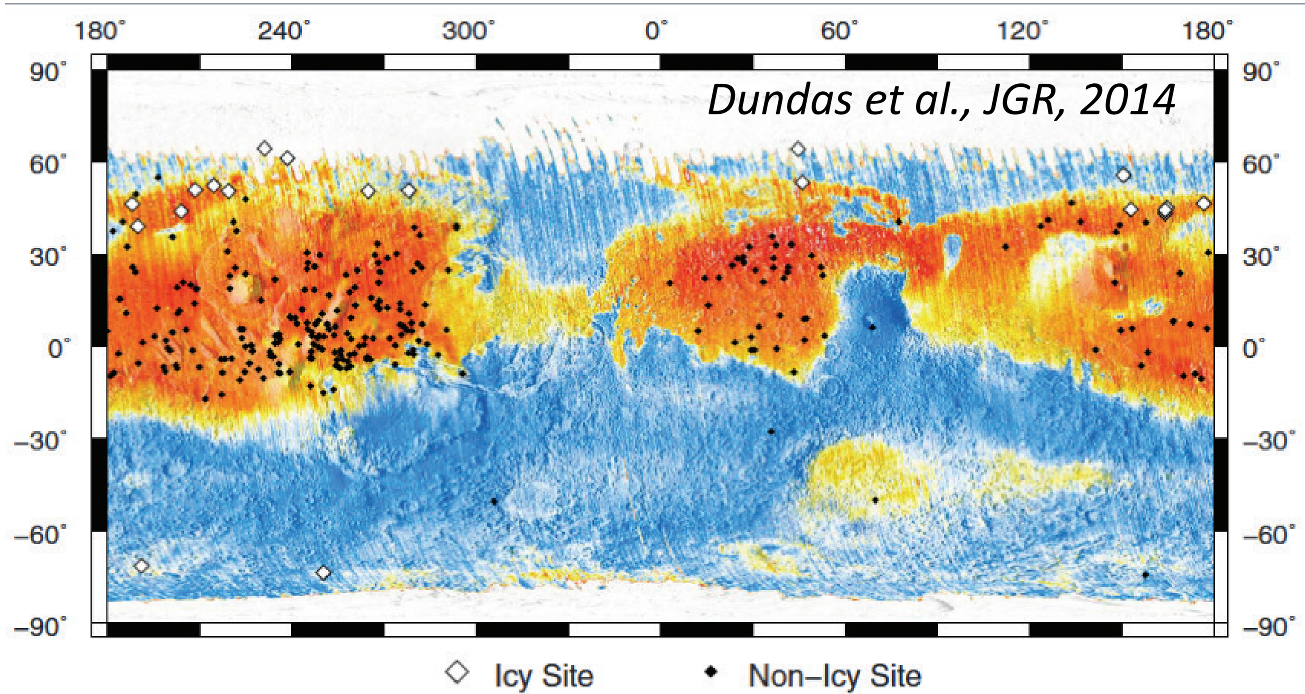


- Combining low- and high-resolution imaging has allowed us to find 100s of new impacts and 10s of ice-exposing impacts

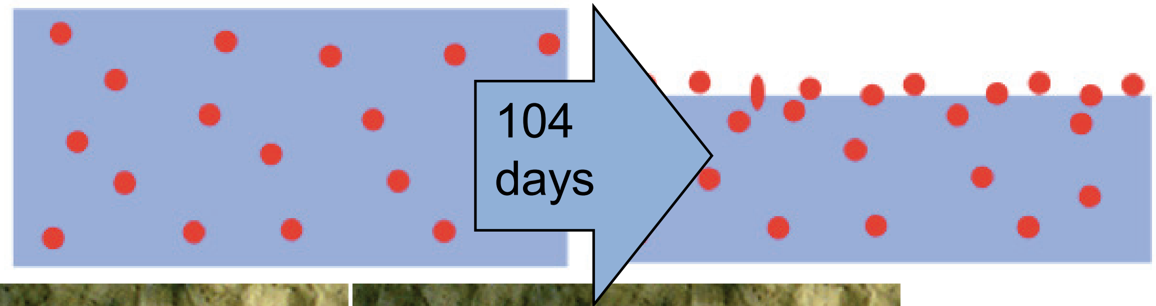
- Restricted to dusty areas

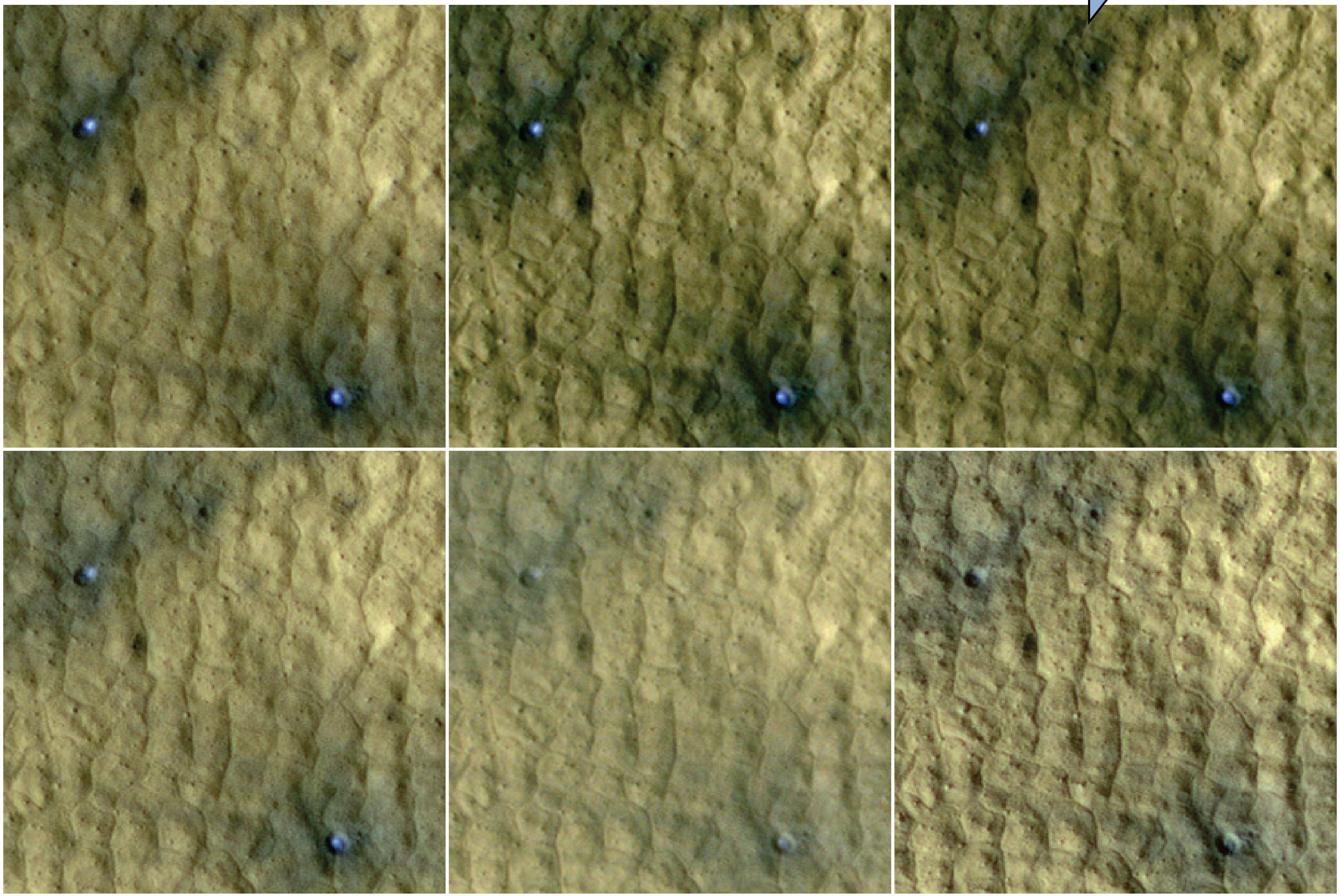
- Almost pure excess ice is widespread (ubiquitous?) in the northern mid-latitudes

- Lowest latitude confirmed so far is 39N

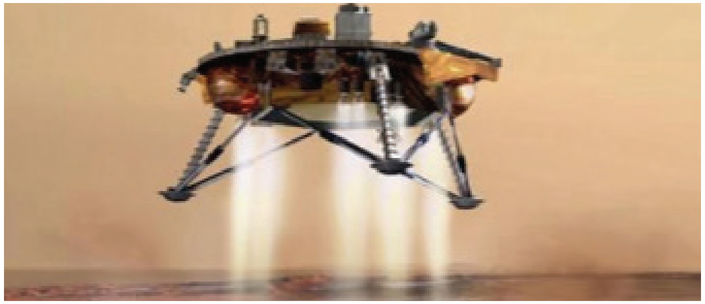


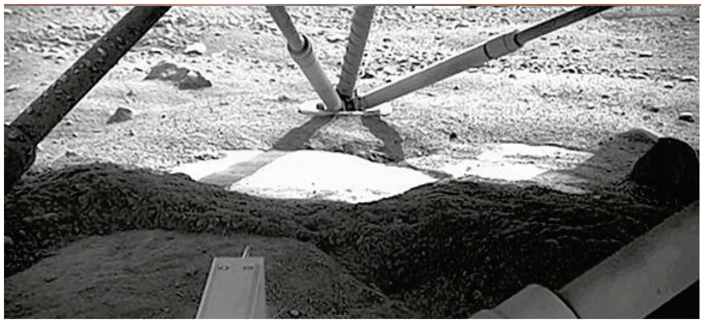
- *These ice-exposing craters have an 'expiration date'*
- Fast high-resolution followup is needed

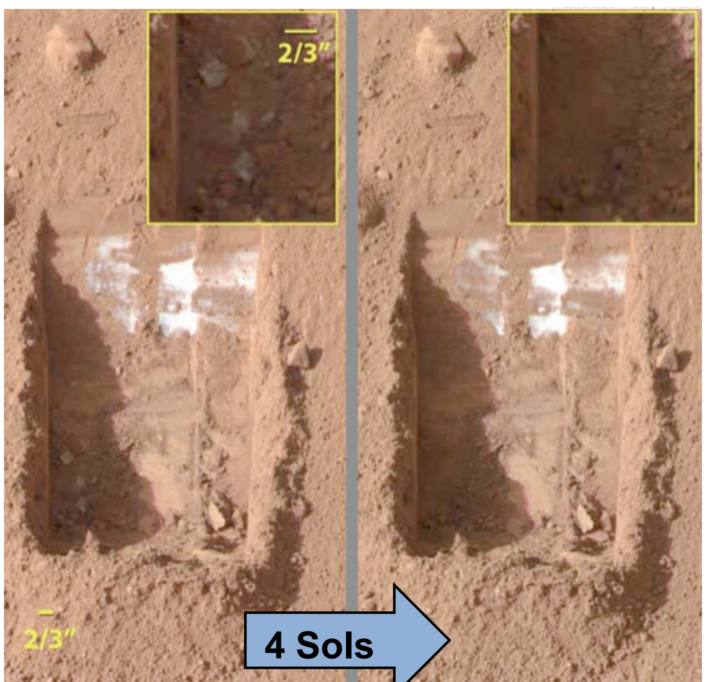




Dundas and Byrne, Icarus,2010





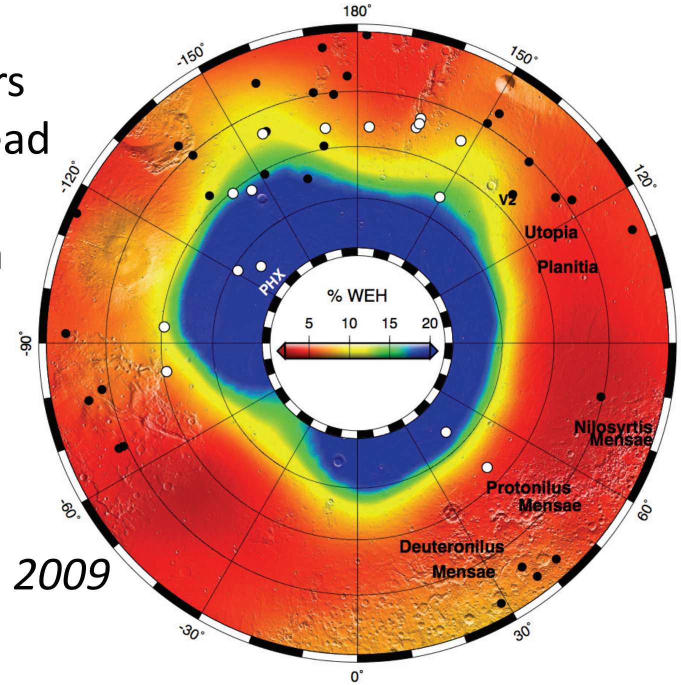


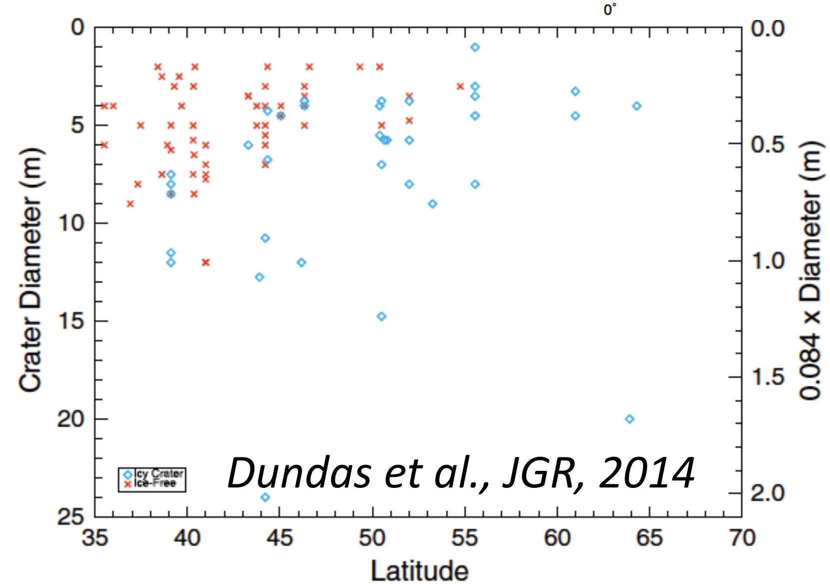
- The Phoenix lander discovered excess ice within cm of the surface (*Smith et al., Science, 2009)*

- Ice exposing craters show it's widespread (including under Viking Lander II) in upper decimeters

Footprint of GRS ●

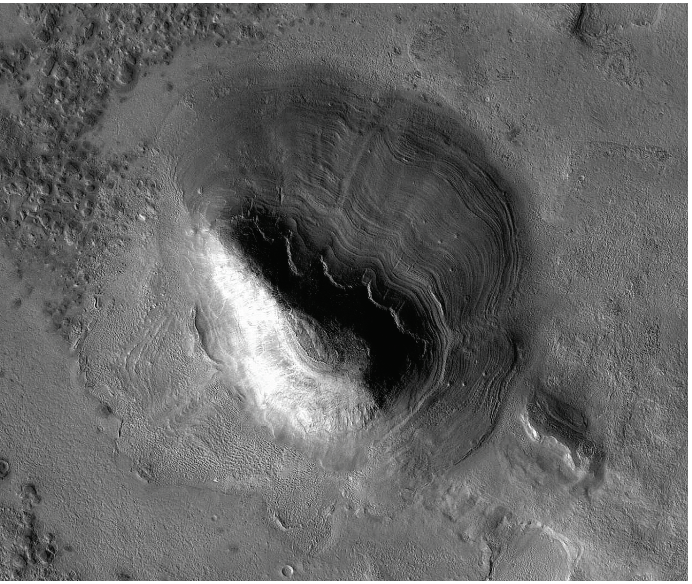
Byrne et al., Science, 2009

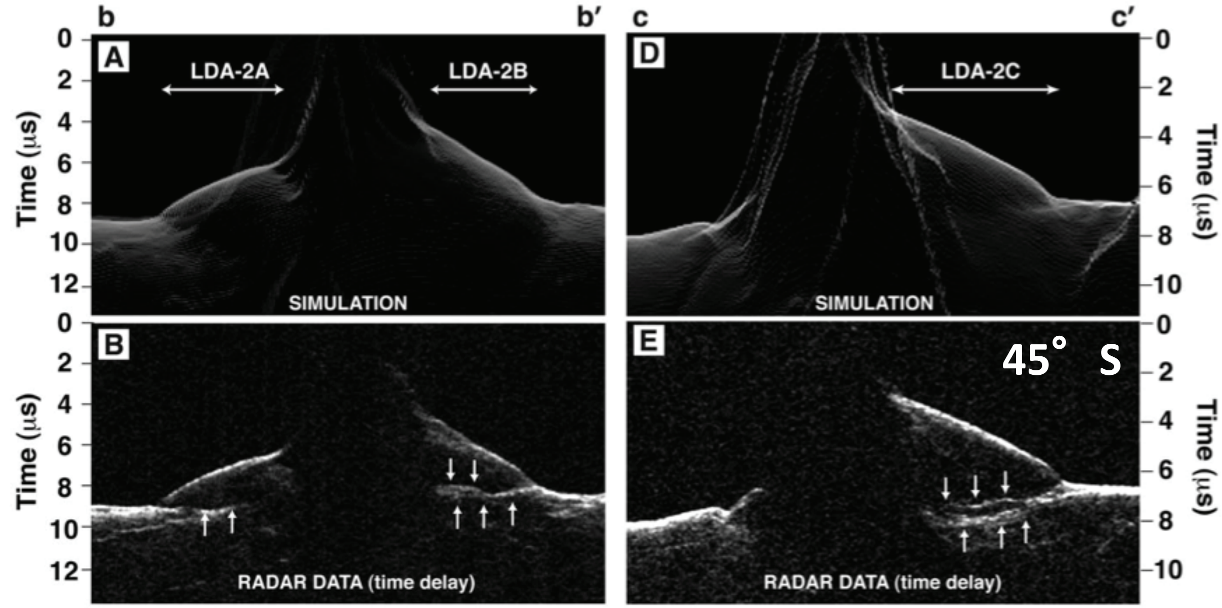


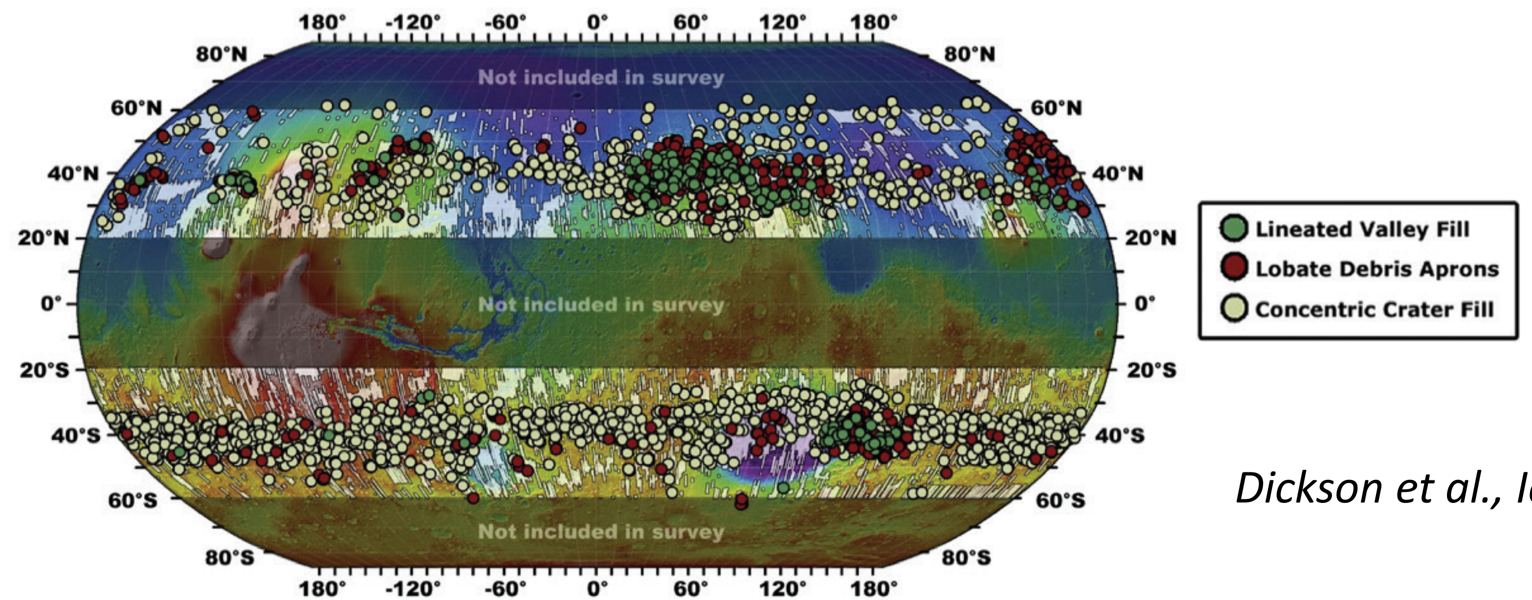


RADAR detections of excess ice are both local and regional...

- Lobate aprons are almost pure ice *(Holt et al. Science 2008; Plaut et al. GRL 2009)*
- Widespread features with similar morphologies for valley and crater fill



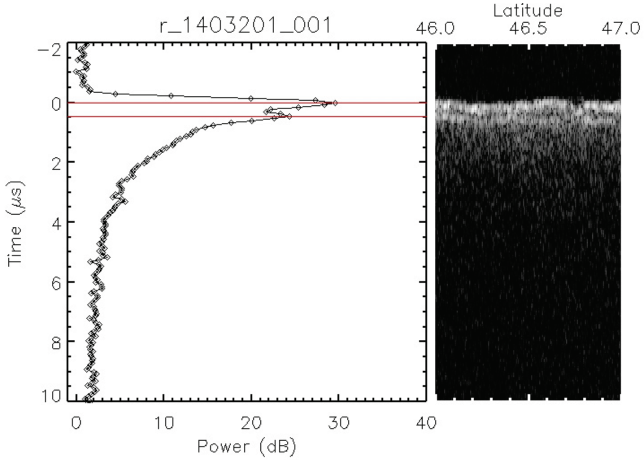


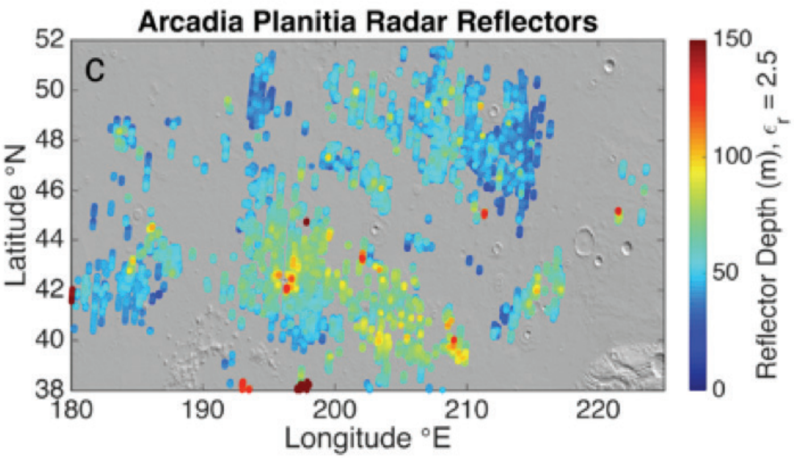


Dickson et al., Icarus, 2012

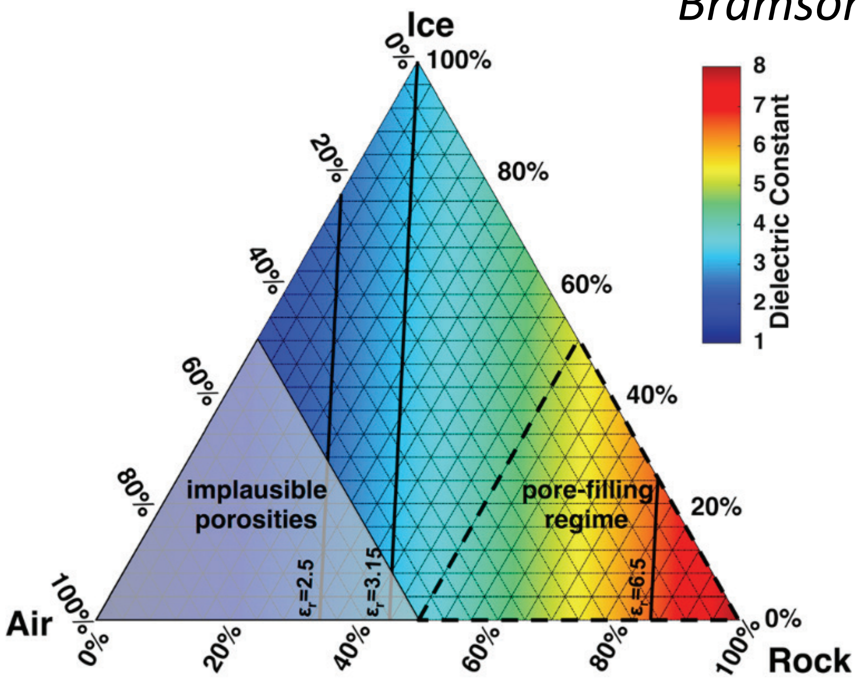
Arcadia and Utopia Planitia are especially Ice rich…

- Terraced craters and radar reflections both map out subsurface interfaces
- Combining these data yield the dielectric constant and so compositions





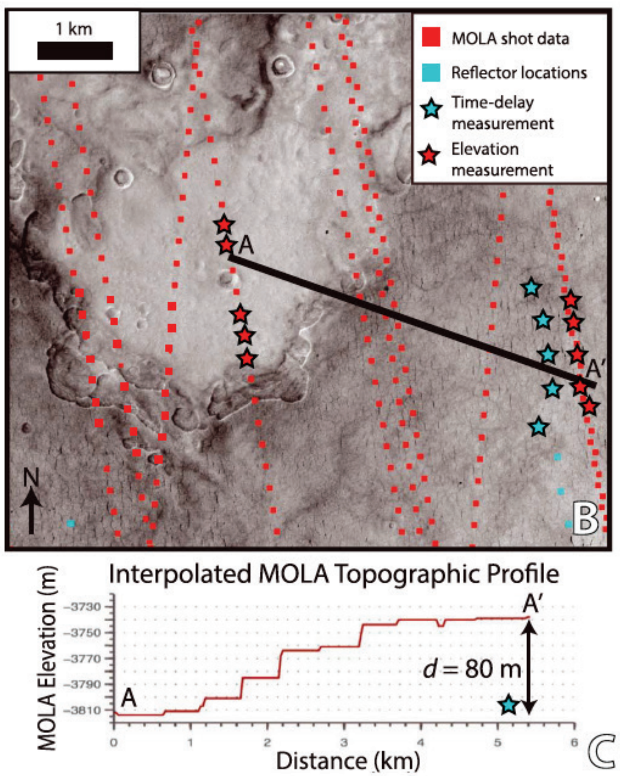
Bramson et al., GRL, 2015.



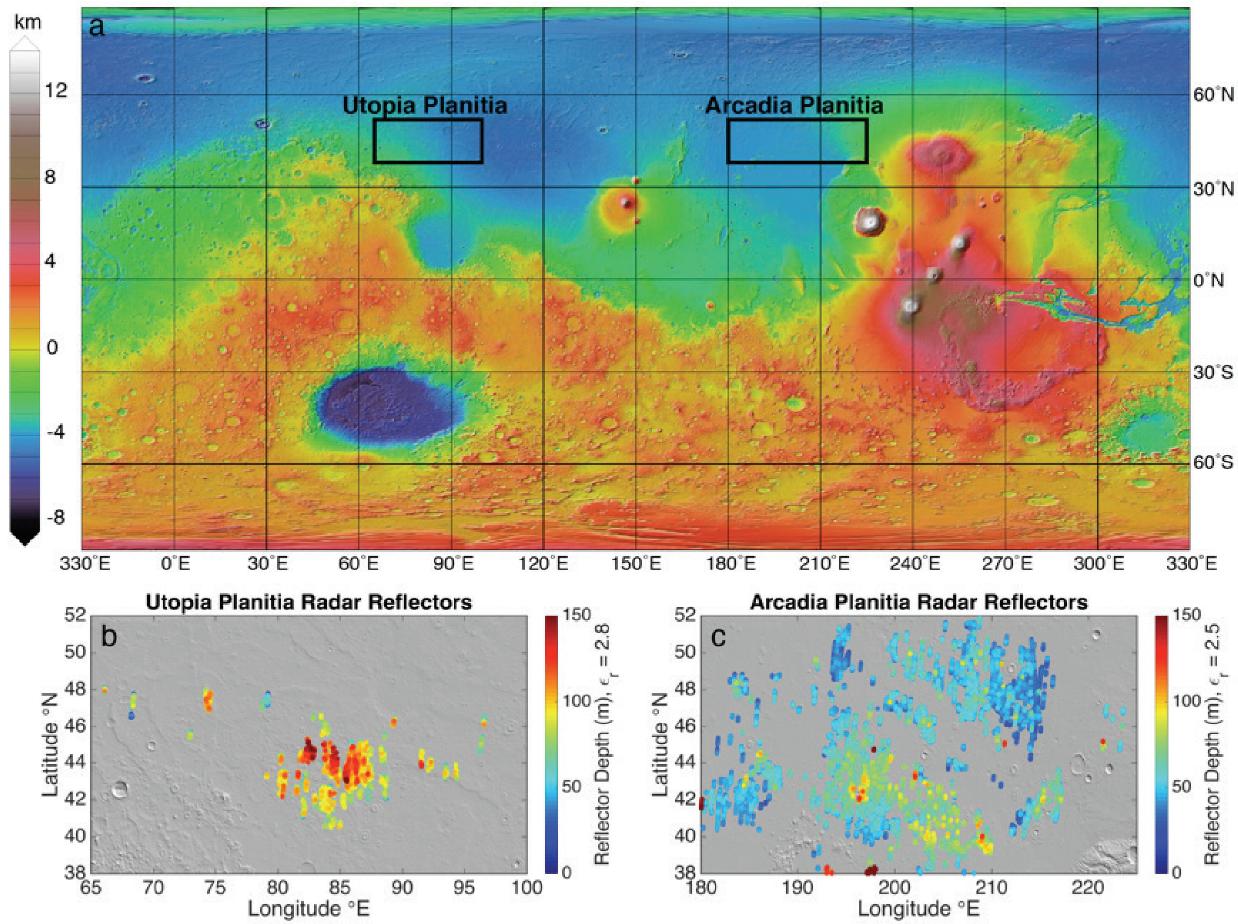
Answer:

- Contiguous sheets of snow/ice that are decameters thick and 100s km across
- Dirt content is low
- Porosity is high

- Utopia Planitia yielded similar compositions and a thicker deposit (Stuurman et al. GRL 2016)
- Ice is much more extensive, but hard to see with SHARAD
- SHARAD reflections this close to the surface are difficult to pick out and this is the limiting factor for finding thinner deposits in rougher areas



Stuurman et al., GRL, 2016

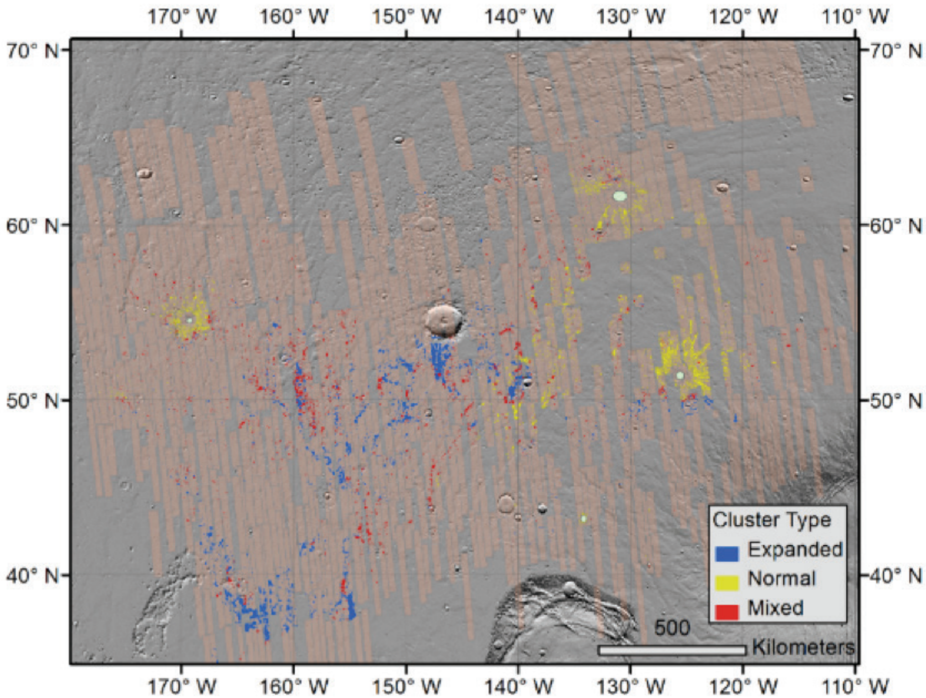


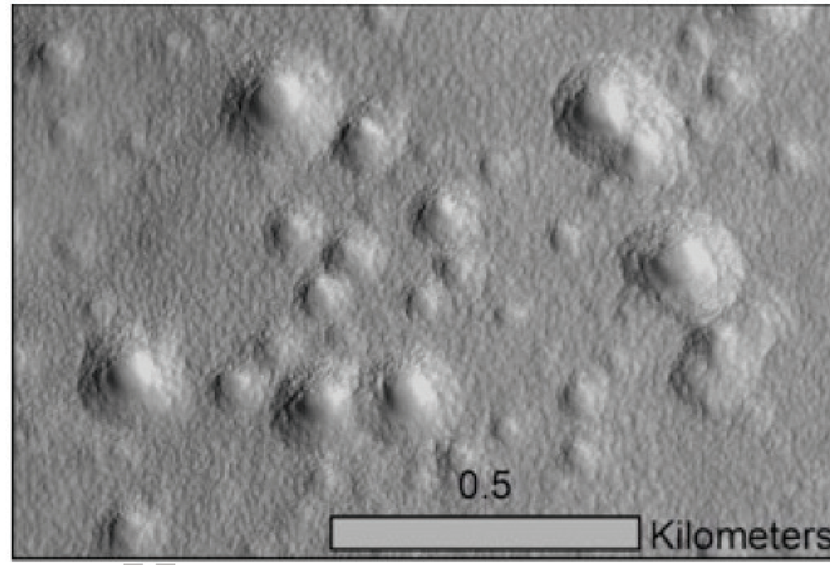
Results of Stuurman et al., GRL, 2016

Results of Bramson et al., GRL, 2015

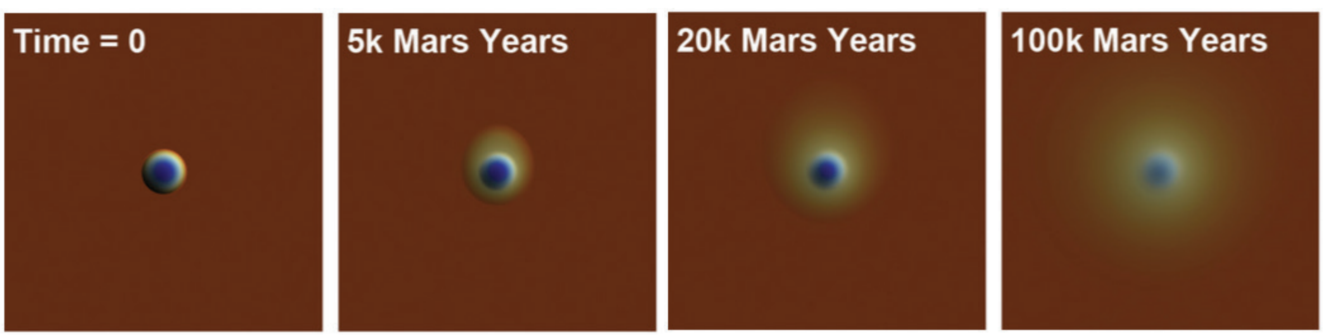
Thermokarst features also reveal excess ice in both Arcadia and Utopia Planitia

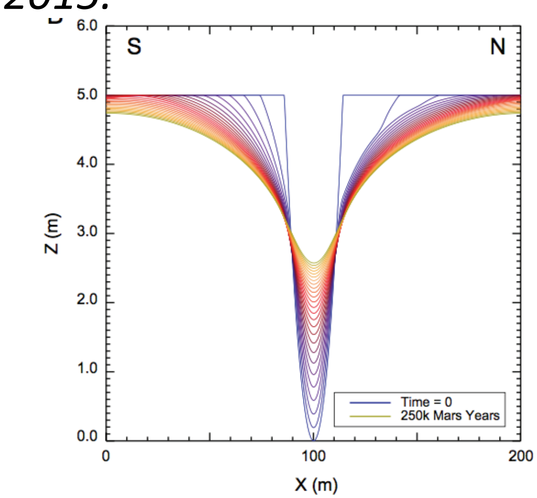
- Removal of ice after disturbance by a secondary crater – leads to "expanded craters"
- Excess ice must be meters thick at least (bridges the gap between ice-exposing impacts and SHARAD results)
- Excess ice must be **10s of Myr old** at least – A major upset in our understanding?





Viola et al., Icarus, 2015.





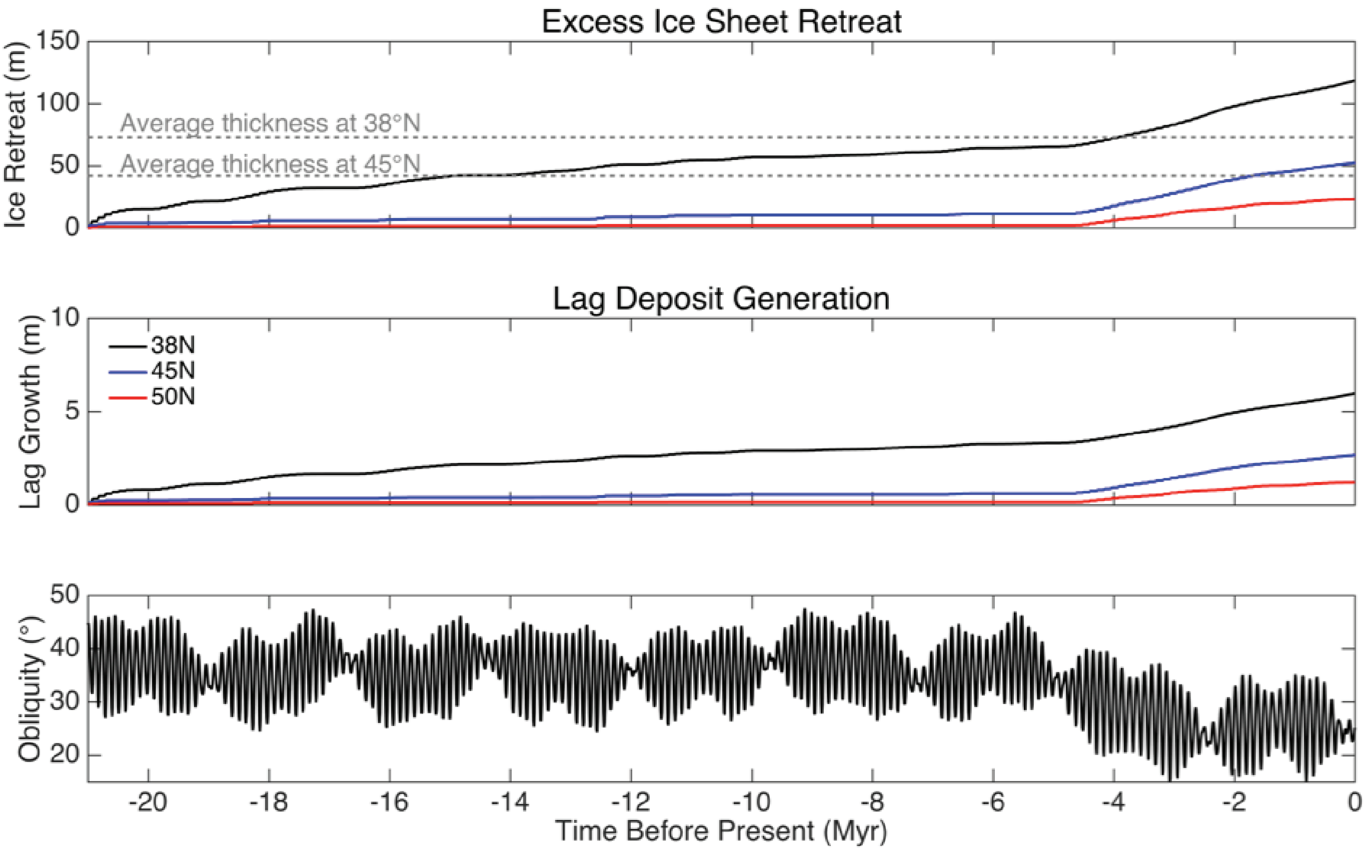
Dundas et al., Icarus, 2015

Can clean porous ice survive for 10s of Myr – previous models suggest not, but...

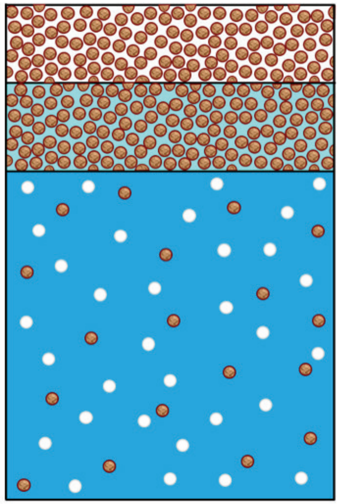
•Some combinations of ice properties can satisfy the dielectric constants (constrains lag thickness and ice properties) and age of ice

•Simulations of ice loss and lag generation suggest

- Lag deposits of a few meters – ice exposing craters suggest it's less, but the upper meter or two may be complex
- About half to two thirds of the ice has been lost



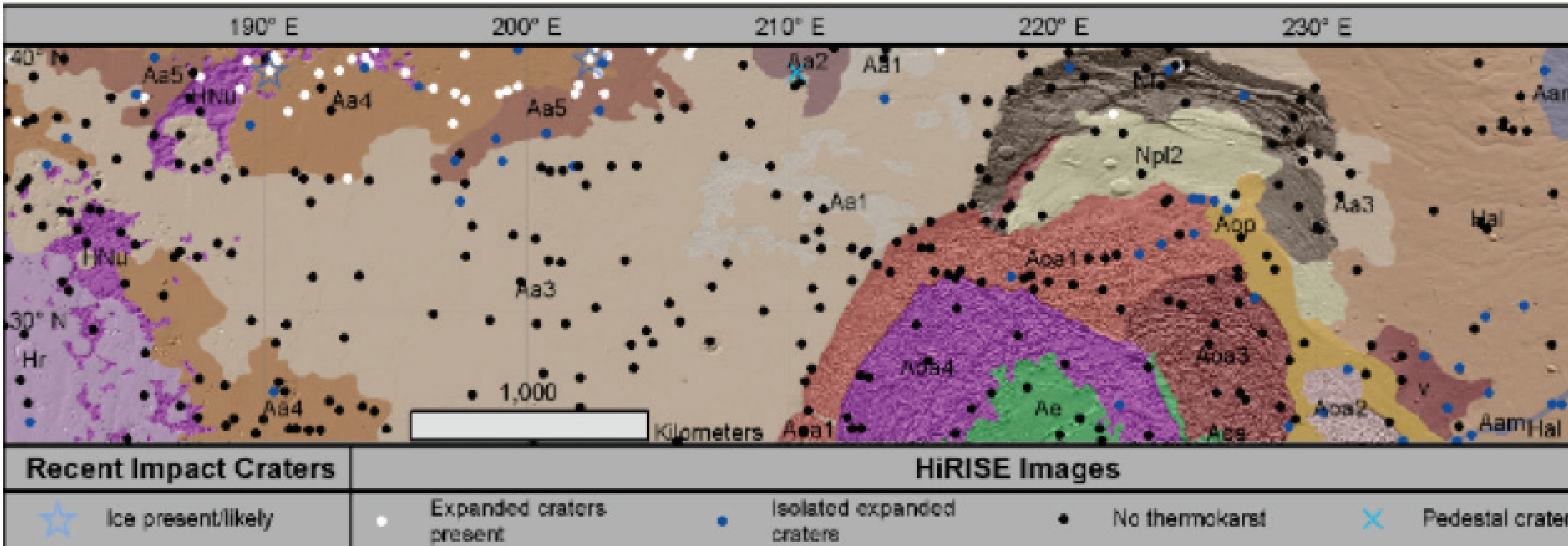
Bramson et al., Submitted, 2017



Where Humans and Excess Ice might overlap...

- Contiguous sheets of pure snow/ice are mostly poleward of 38N
  (Not preferred for human exploration for energy reasons)

- Expanded craters in isolated patches in slope-created microclimates persist down to the tropics (25N)



Viola et al., submitted, 2017.

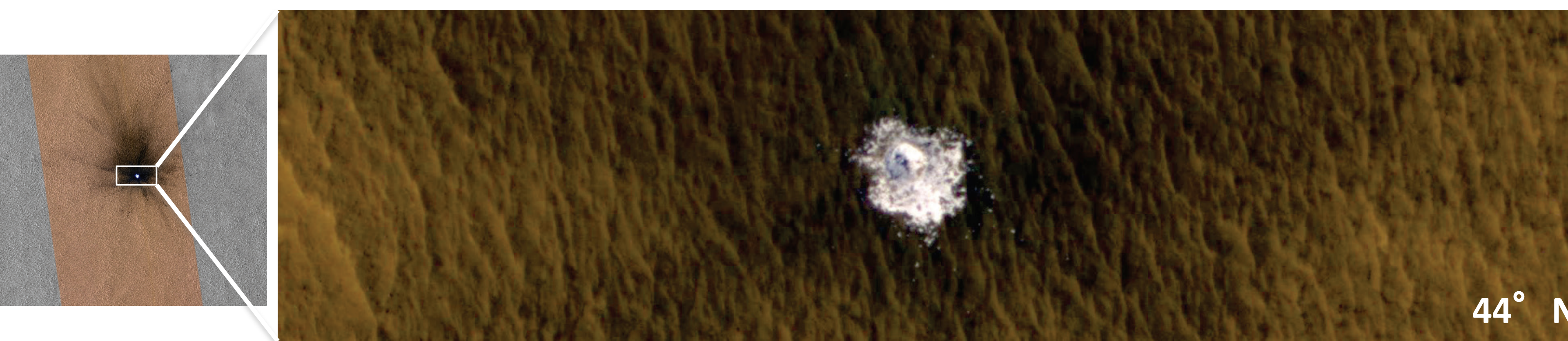
- Characterizing smaller isolated patches of excess ice would require a much higher resolution sounder than SHARAD
- Which in turn requires high-resolution topography than MOLA for clutter simulations

Motivation for further investigation

- Contiguous sheets of excess ice are now known to cover much of the martian mid-latitudes
- This ice is old (> 10s Myr) and contains climatic information about the Amazonian that's longer than the polar layered deposits although not as detailed
- Isolated patches of excess ice are known as far south as the tropics and could be mined for ISRU

Open Questions/Issues

- Buried snowpacks explain most observations; however boulders litter the surface in many locations, which is hard to explain
- The full distribution of ice locations is unknown, expanded craters only occur in some areas and ice-exposing impacts are filling this information in very slowly
- Ice depth, thickness and structure the upper meter or two is key to ISRU and climate interactions, but current radar data is unsuited to these investigations

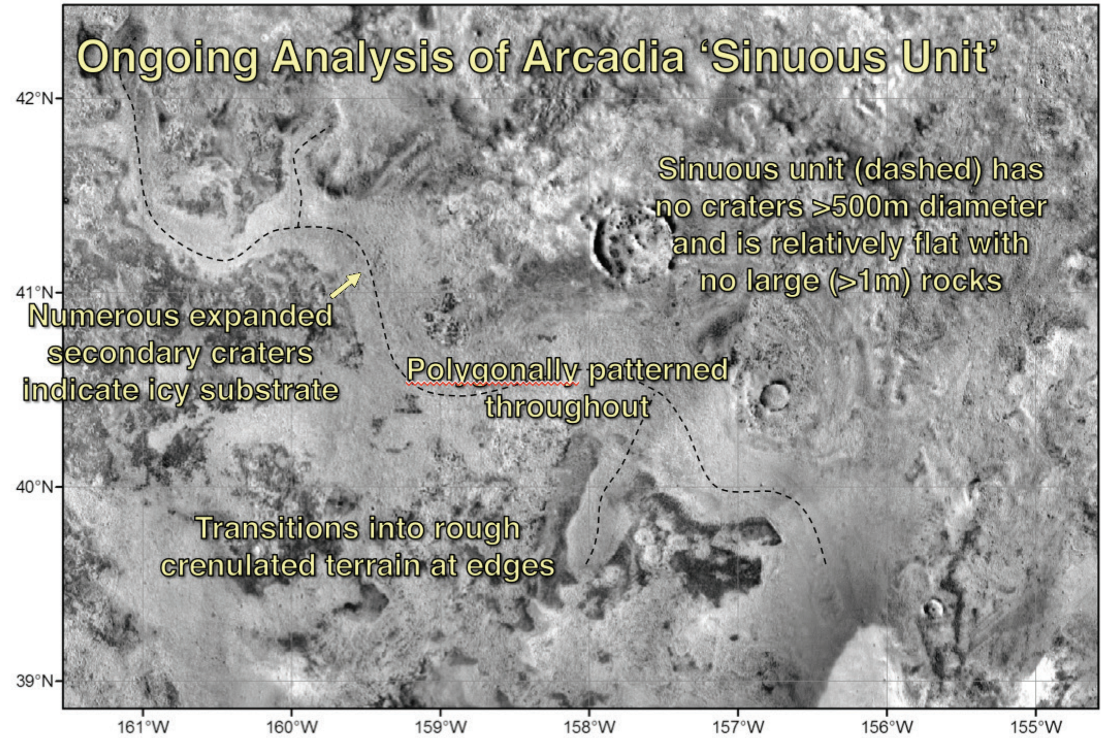


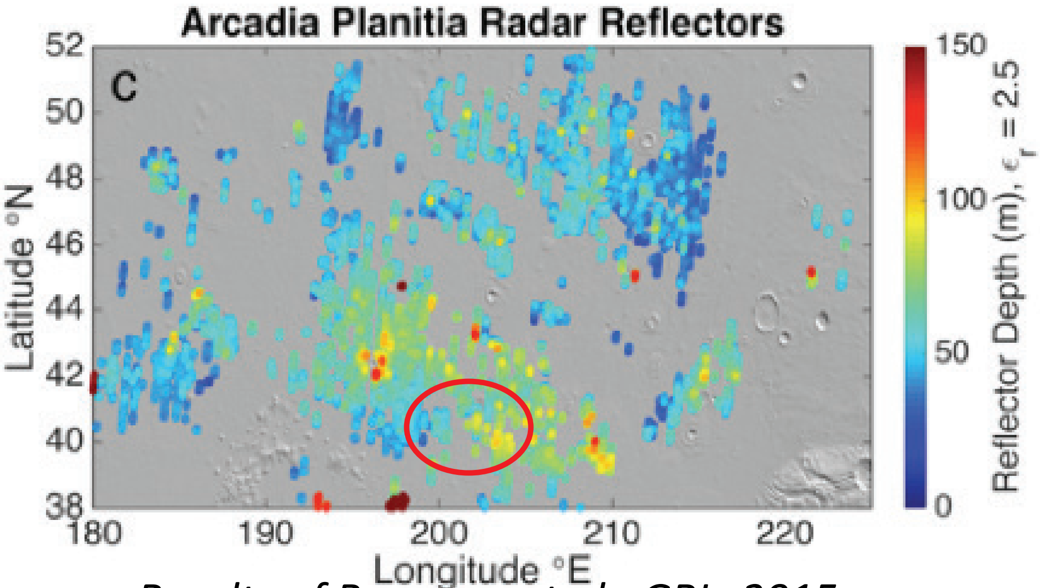
Interest from SpaceX

SpaceX is interested in going to Arcadia Planitia with their Red Dragon capsule

Support from N. Williams and M. Golombek (JPL) in selecting landing site

Abundant evidence of near-surface ice for ISRU and few surface rocks



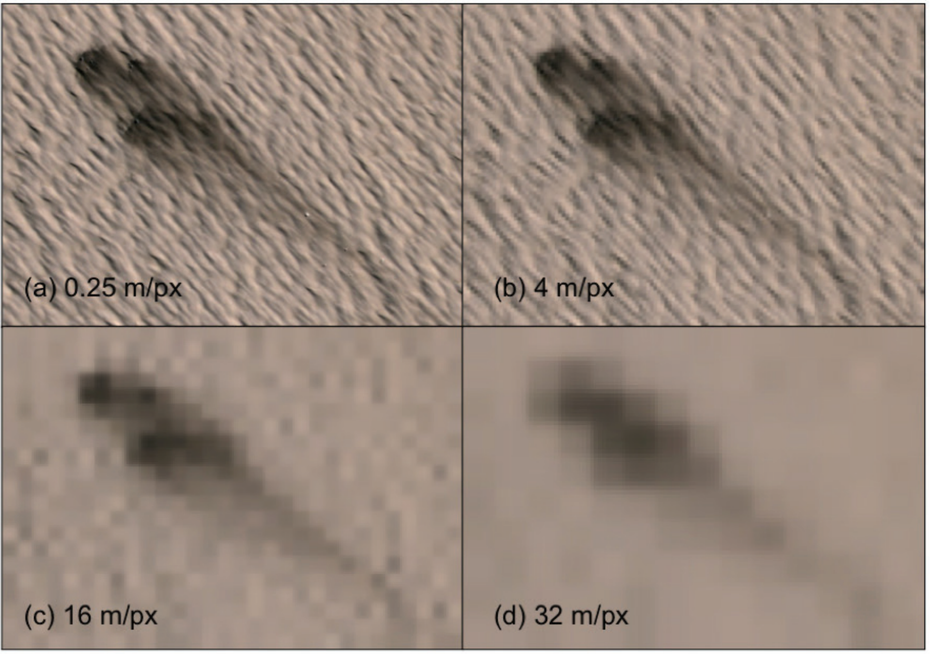


Results of Bramson et al., GRL, 2015

What Should the Mars Exploration Program be doing to advance this? e.g. Next Mars Orbiter

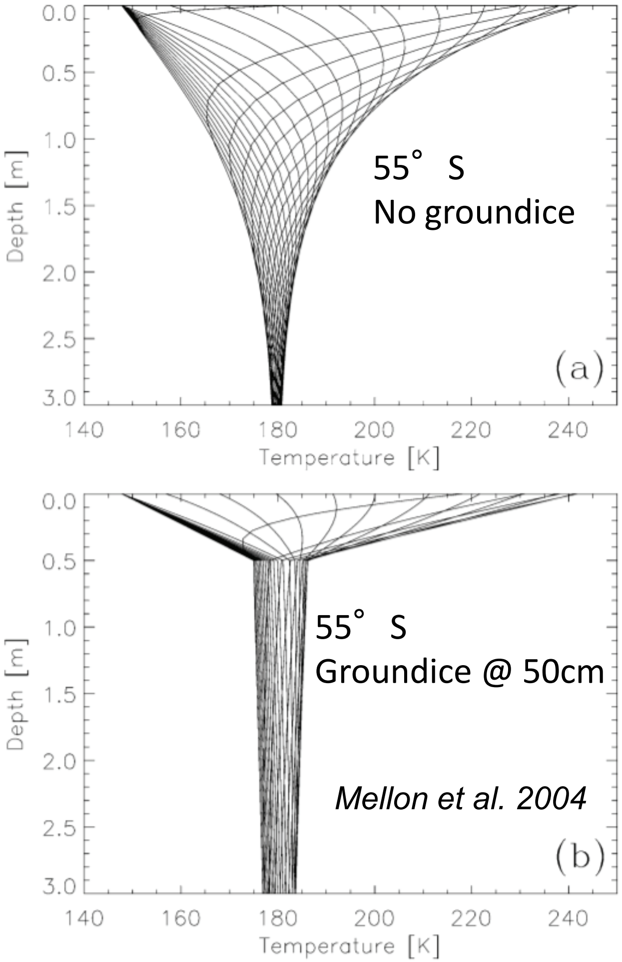
•Search for new craters – map out the clean ice distribution

Daubar et al. (2012)

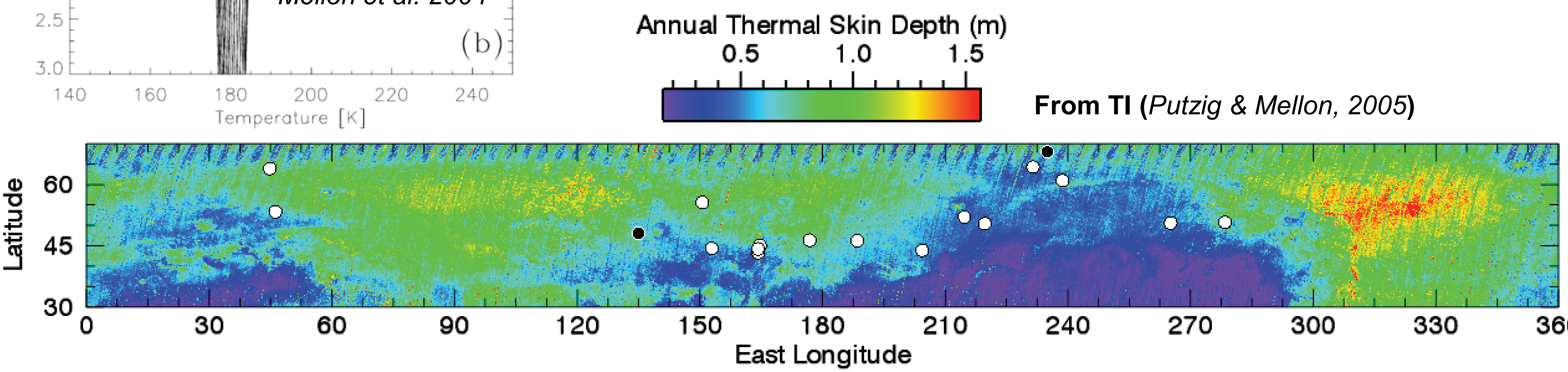


- Context style imaging at 15m/px, high SNR, and a 60km swath width.
  - Cover latitude 45° with 250 images
  - Achievable in 20 days with standard near-polar orbit (small 9° rolls would avoid recent coverage)
  - Ability to replay sections of images at higher resolution would be beneficial
- Higher-resolution imaging (m/px) in color
  - Rapid follow required so we need a roll-able spacecraft or instrument pointing mechanism
- Limited to dusty areas, but sensitive to ice down to ~1m

• High-Resolution Thermal measurements



- If ice-table is within the annual thermal skin depth then it affects surface temperatures in a predictable way
  - Typical annual skins depths are 0.5-1m
- Thermal imaging at 10m/px
  - Temperature accuracy ~1K for warm periods
  - Robust CO_2 frost detection in cold periods
- High-res topography necessary for interpretation of thermal data
  - Stereo imagery from a High-resolution camera (a few m/px imaging yielding slope info at 10/px)



From TI (*Putzig & Mellon, 2005*)

SAR

- P-band (wavelength ~70cm) SAR has been shown to be feasible for many investigations at Mars (*Campbell et al., JGR, 2004; Paillou et al., JGR, 2006*).

- Quad-pol SAR data can distinguish between pore-filling and excess ice near the surface based on phase coherency and polarization (coherent backscatter)

- Depth to shallow ice may also be inferred from interferometry of repeat-pass, offset observations (but is considered challenging)

VHF Radar sounder

- SHARAD (~20 MHz, 15m wavelength) can detect the base of larger lobate aprons and with more difficulty the bottom of contiguous ice sheets 10s meters thick
  - Large footprint leads to clutter from off-nadir topography
  - Wavelength limits the scale of layering that can be detected

- 100-200 MHz (1.5-3 m wavelength) will penetrate the surface more easily than p-band.
  - Designed for very shallow investigations – less penetration than SHARAD
  - Better discrimination of vertical structure than SHARAD
  - Phased antenna array can narrow footprint to investigate smaller features
  - Clutter simulations require hi-res topography (stereo imagery)

We can (and should) understand a lot more about martian ground ice from orbit before any landed Investigation (robotic or human)

Questions that can be answered from orbit

- Long-term Climate: What is the extent and depth of ground ice today?
- Short-term Climate: What is the structure of the upper meter or two of the ice?
- ISRU: Where can we find low-latitude isolated patches of excess ice?

	Cameras for crater detection	Thermal	SAR	Radar sounder
Ice Extent	✔	✔	~	~
Ice Depth	~	✔	~	~
Ice Thickness				✔

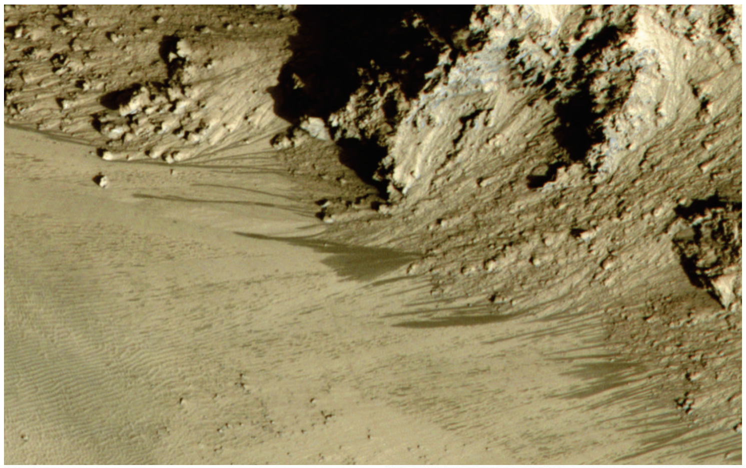
Possible payload

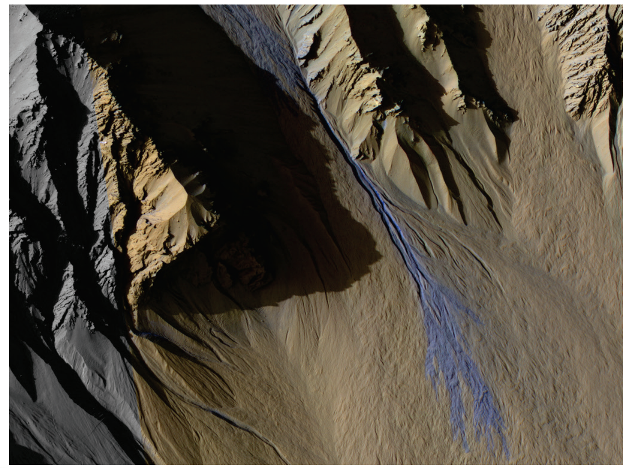
Two high-SNR cameras	Thermal imaging	P-band SAR	VHF radar sounder
1. 15m/px, 60km Swath 2. <1 m/px, color, stereo	• 10m/px • 1K accuracy	• 4 polarizations	• 200 MHz • Phased array

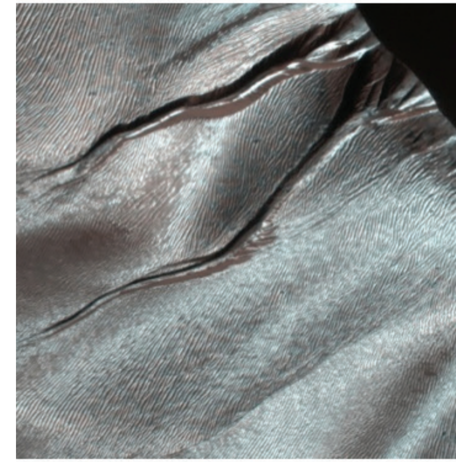
Extras

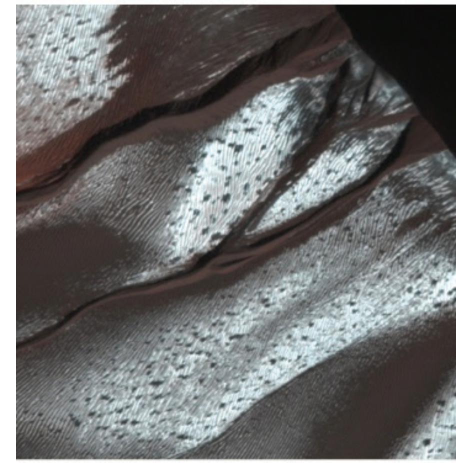
Collateral Benefits

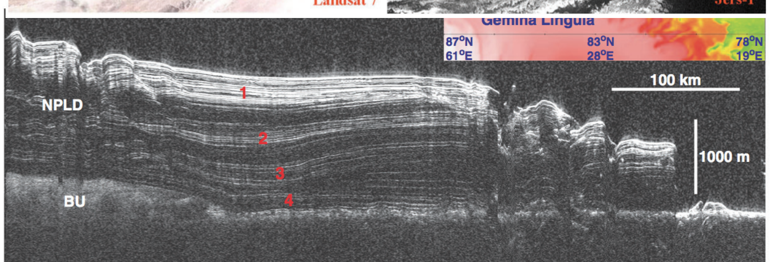
- Current Impact Rate
- Other mid-latitude activity e.g.
  - Gullies
  - RSL







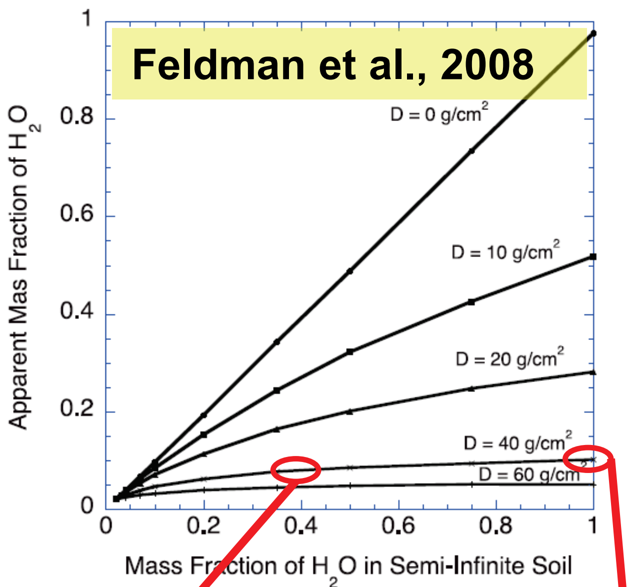




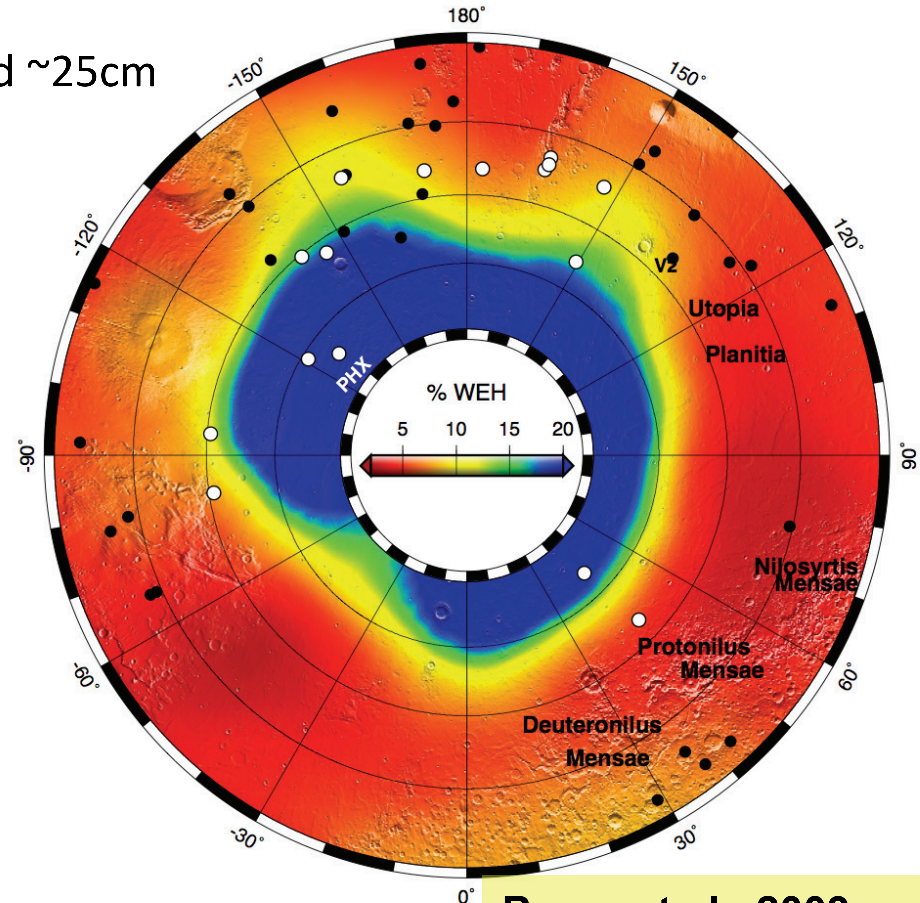
- SAR studies over dust mantled regions, moisture detection in the regolith etc…
- High Resolution Radar sounding of the Polar Layered Deposits
- High-resolution stereo color imagery for many scientific problems

In the mid-latitudes:

- Nature of ground ice is ambiguous when buried ~25cm
- Groundice is more widespread than thought



Footprint of GRS



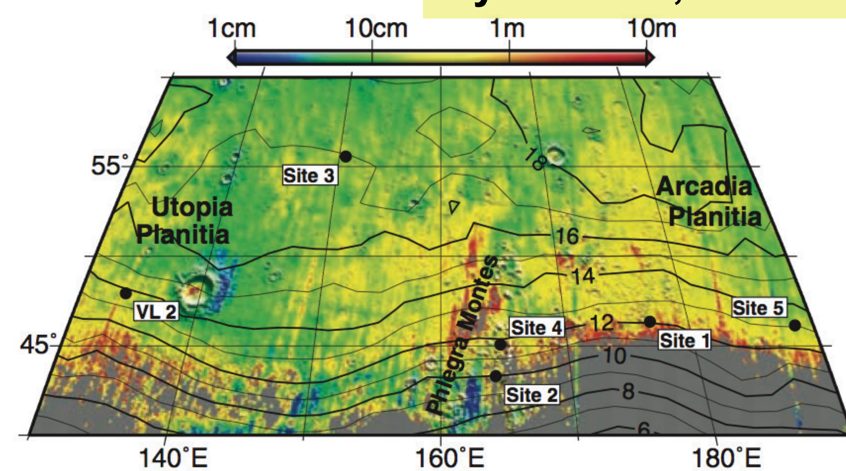
?

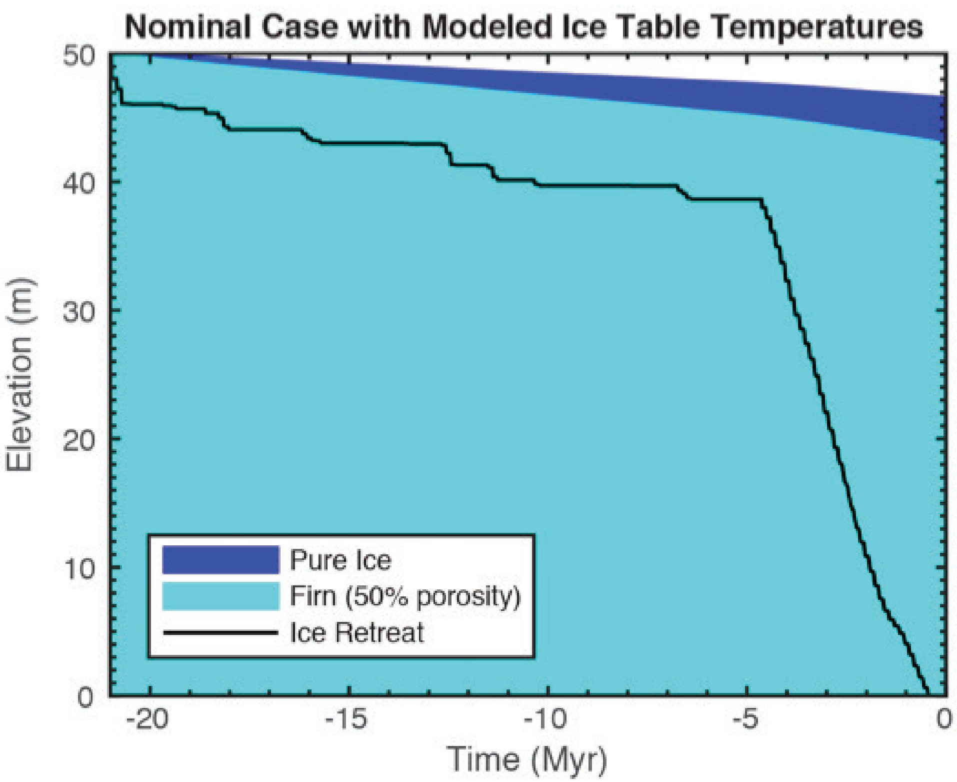
?

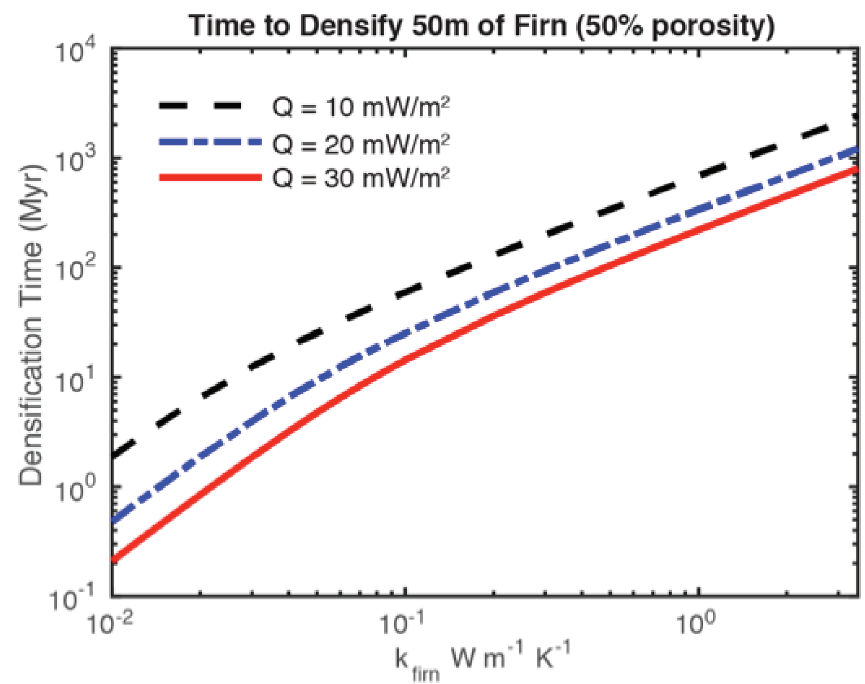
Pore-filling ice

Excess ice

Byrne et al., 2009

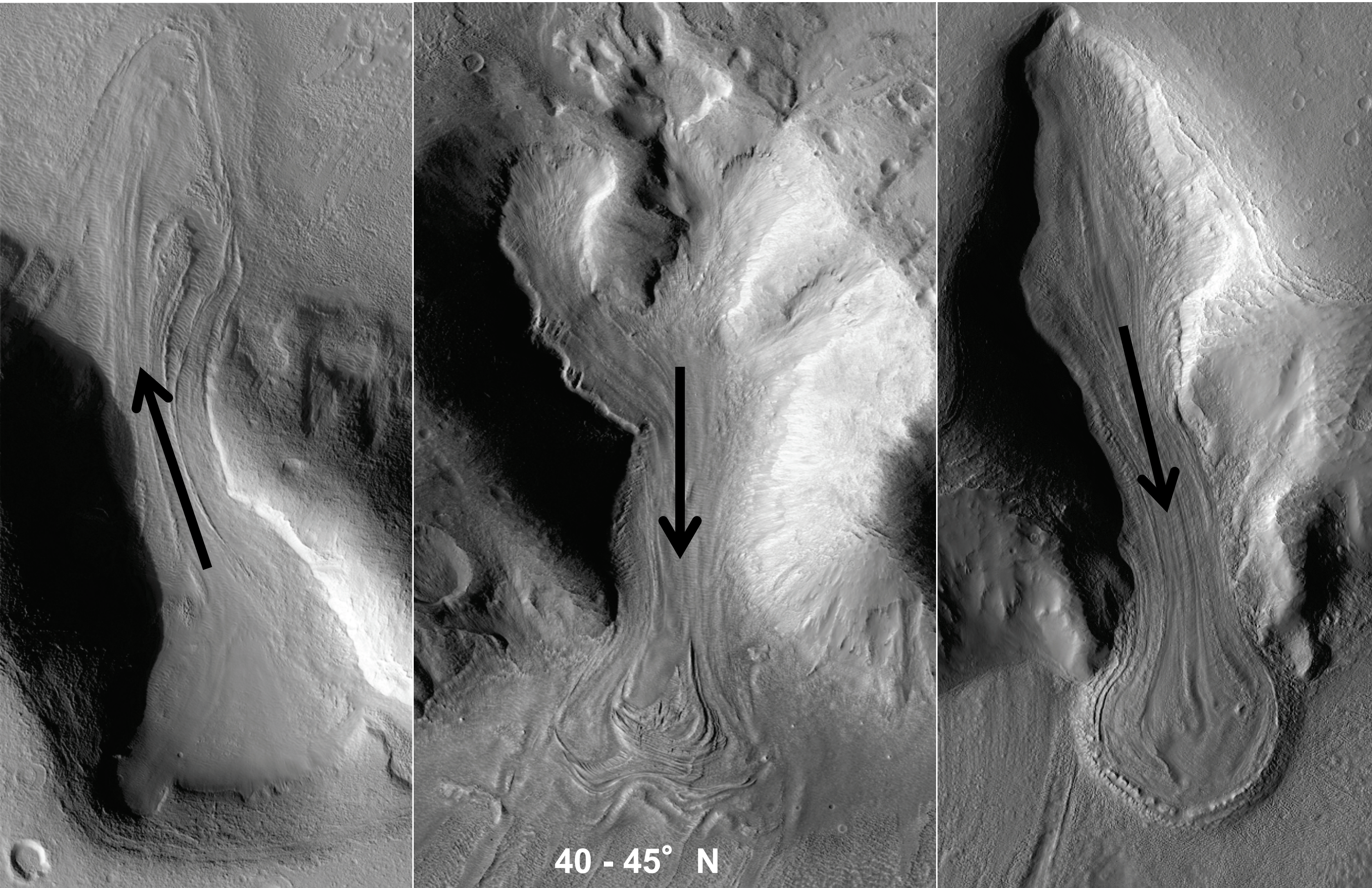




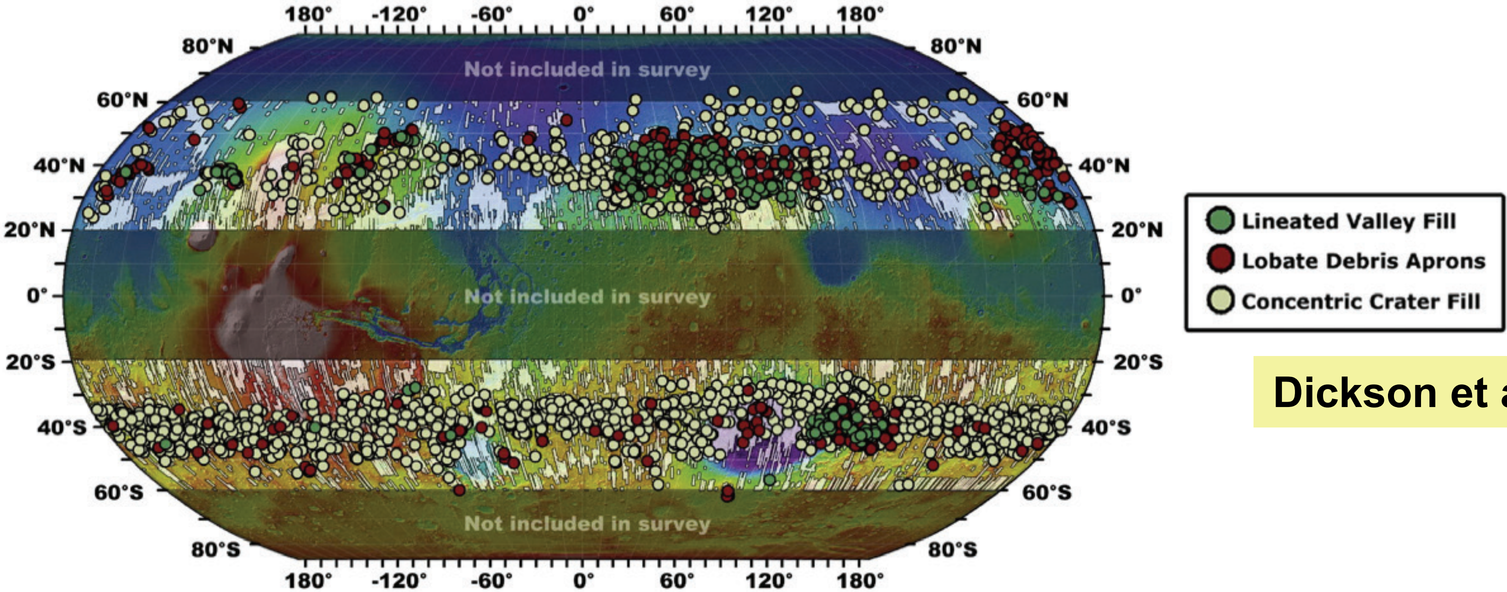


Bramson et al., Submitted, 2017

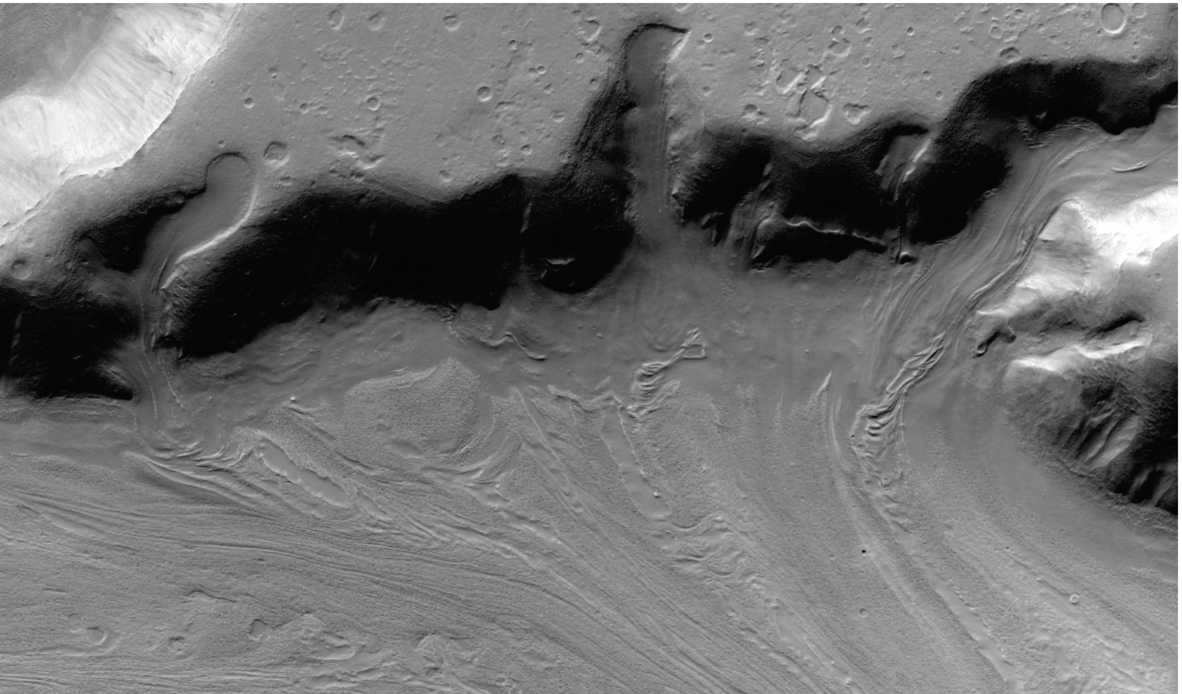
- Hundreds of mid-latitude glaciers exist
  - Obvious flow morphologies in contrast to the much-thicker Polar Layered Deposits
  - Record of past climates

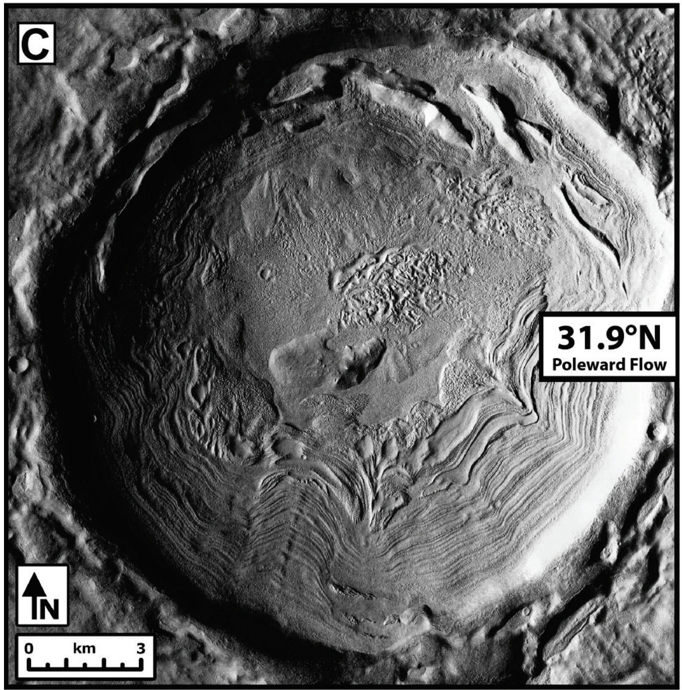


- Evidence of ice flow is everywhere in the mid-latitudes
- Rheological constraints mean this must all be almost pure ice (e.g. Parsons et al. Icarus 2011)

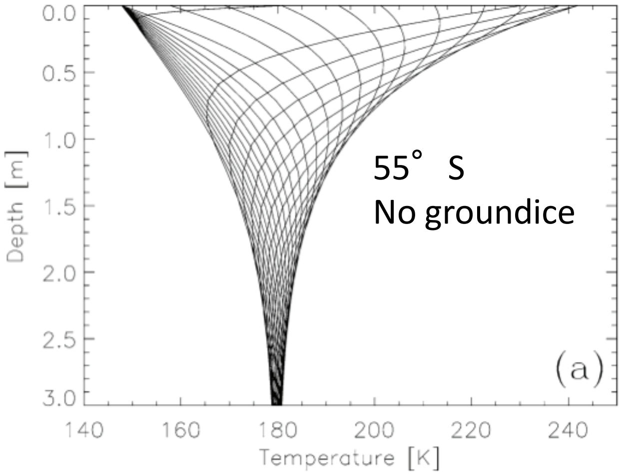


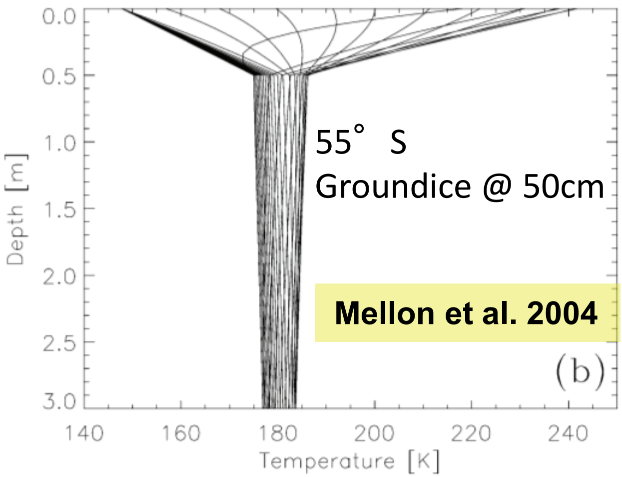
Dickson et al., Icarus, 2012



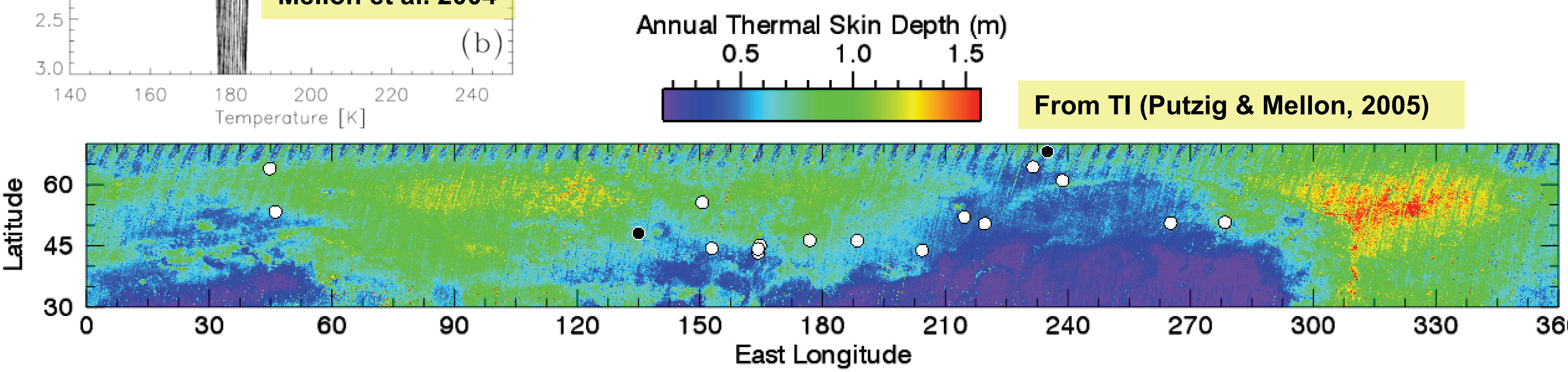


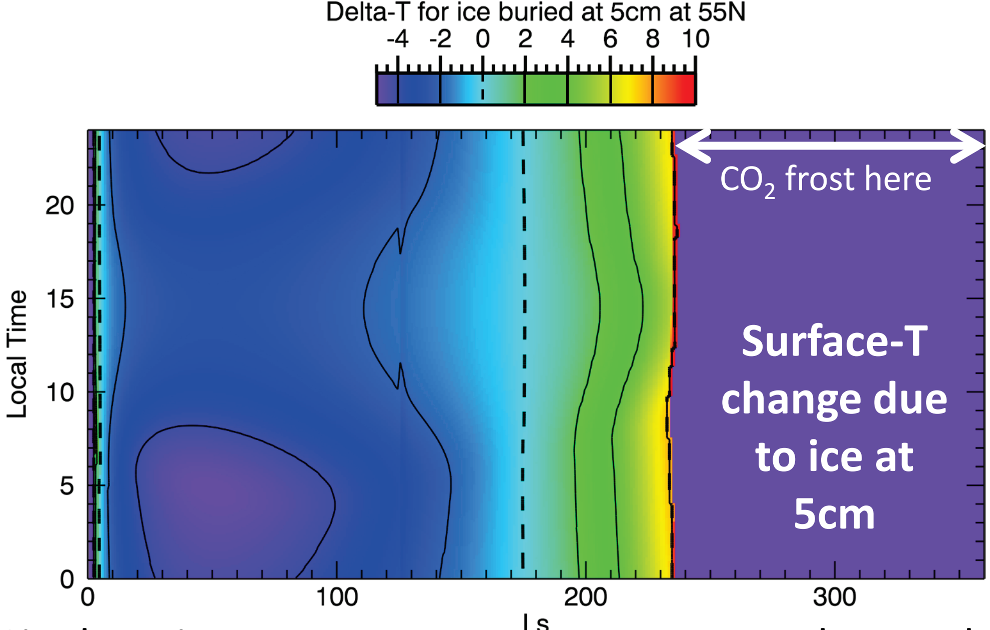
• High-Resolution Thermal measurements

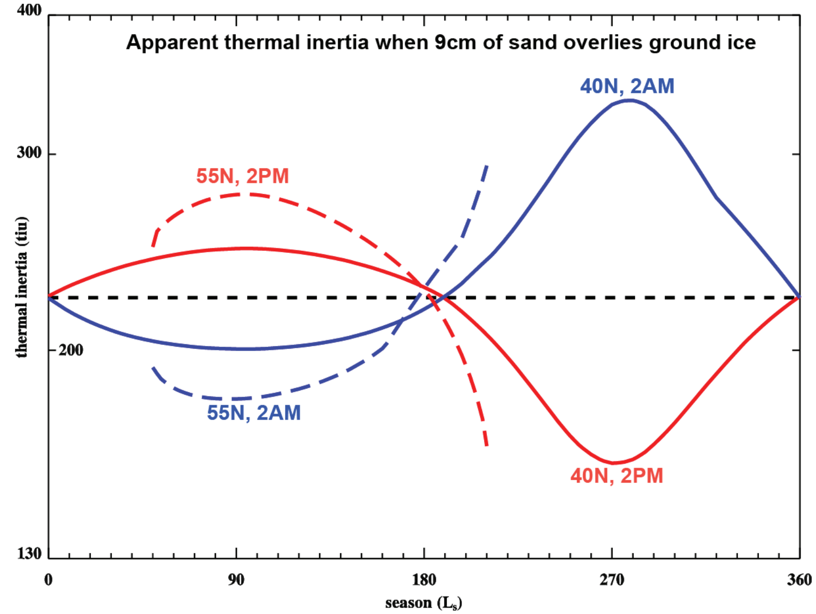




- If ice-table is within the annual thermal skin depth then it affects surface temperatures in a predictable way
  - Typical annual skins depths are 0.5-1m
- Thermal imaging at 10m/px
  - Temperature accuracy ~1K for warm periods
  - Robust CO_2 frost detection in cold periods
- High-res topography necessary for interpretation of thermal data
  - Along track stereo imagery from the High-resolution camera (2m/px imaging yielding slope info at 10/px)



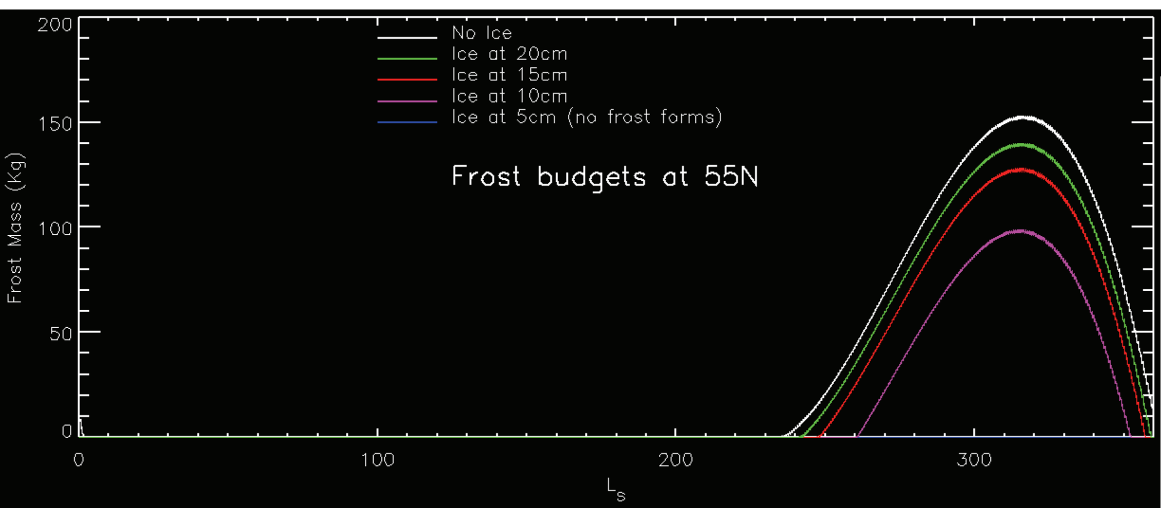


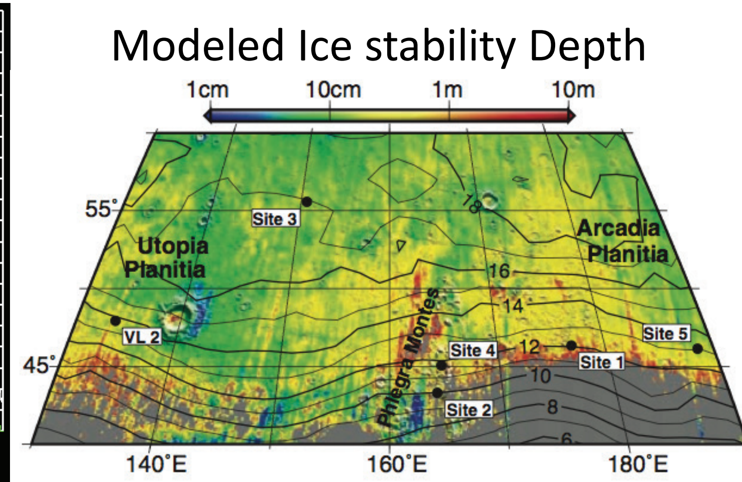


Single point temperature measurements show only a small thermal effect, but…

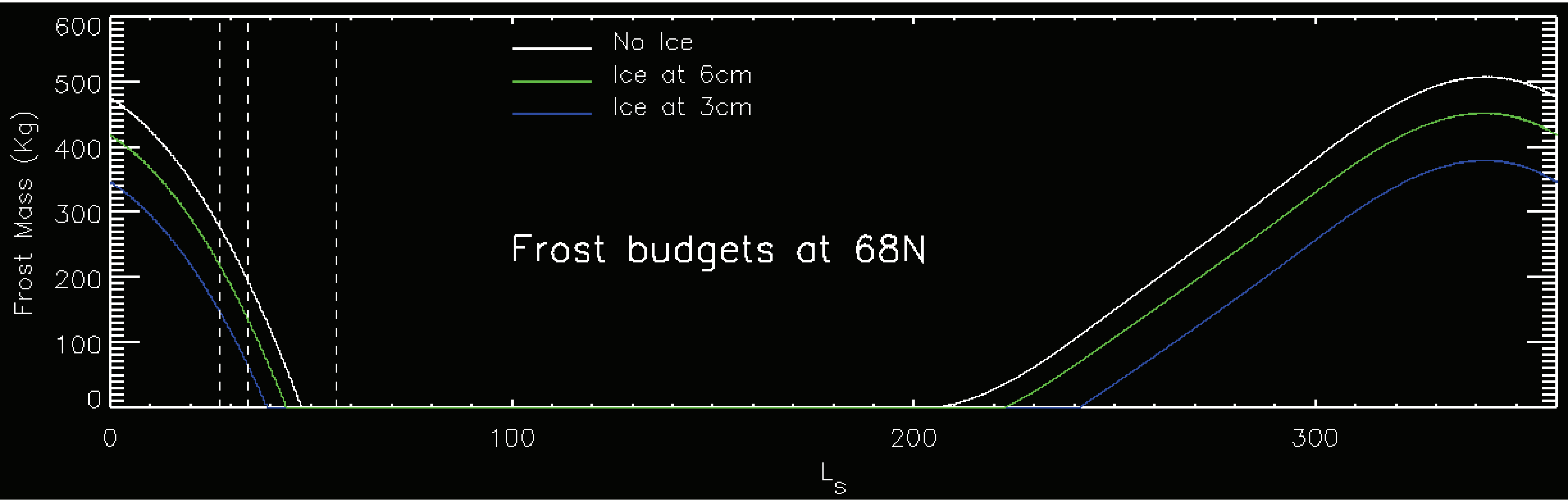
(Late Fall and pre-dawn in the summer are the best times/seasons)

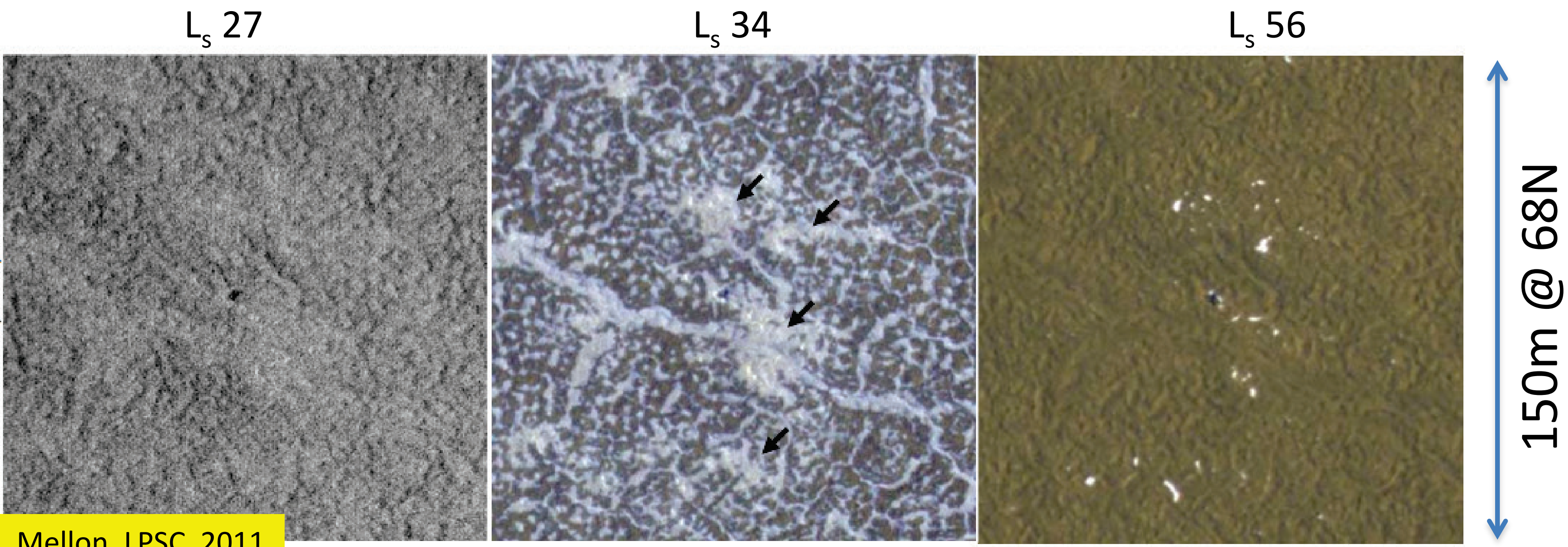
1. Temperatures from multiple times of day over the course of a year can yield both surface thermal inertia and buried ice depth
2. Date of CO_2 frosting and defrosting is sensitive to the depth to ice depth



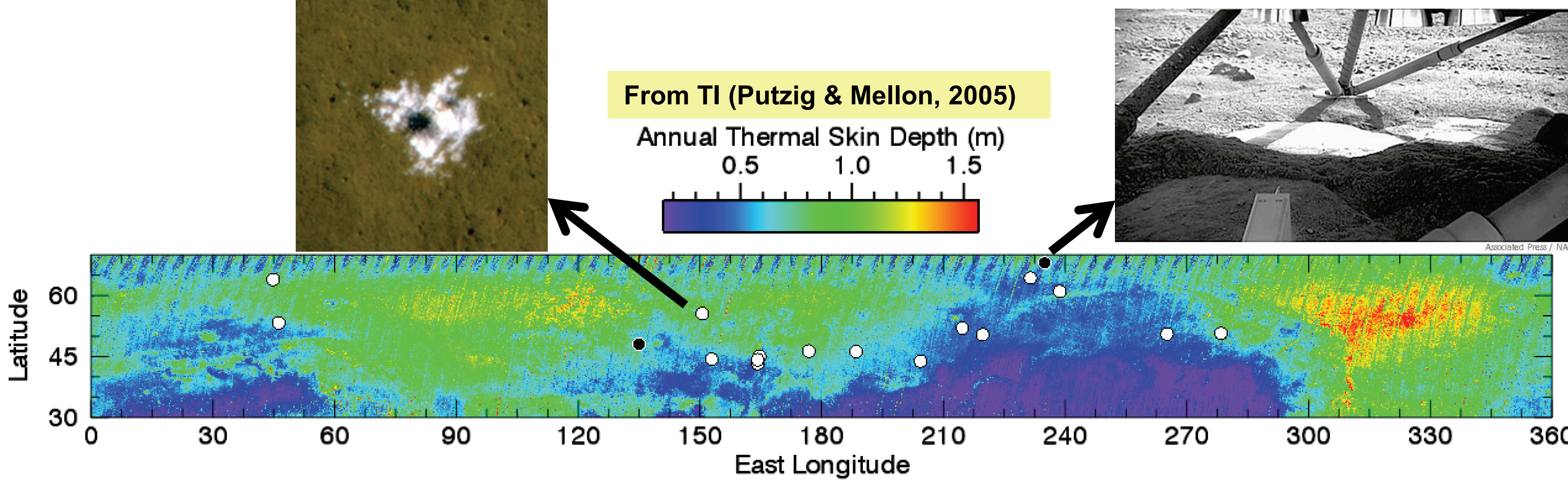


- This 2nd approach is being done already for the Phoenix site, but CO_2 and H_2O frost are hard to tell apart in visible images





Mellon, LPSC, 2011



From TI (Putzig & Mellon, 2005)

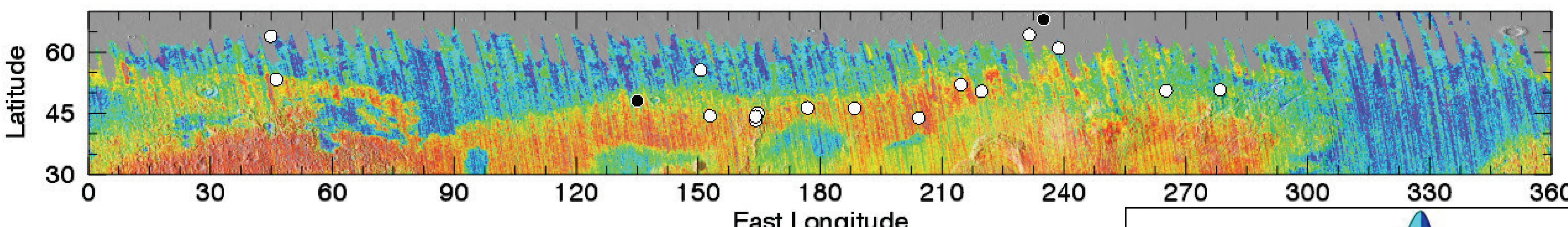
Annual skin depths >> ice table depth

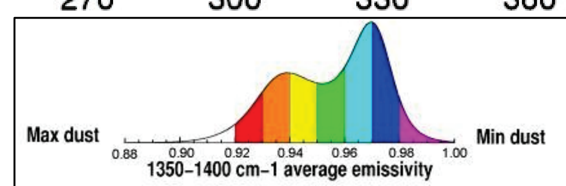
Allows us to determine the ice depth with temperature measurements

Annual skin depth ≤ ice table depth

i.e. Low thermal Inertia (dusty) areas that are well suited to impact crater searches

~1 detectable crater forms somewhere on this map every day (Hartmann 2005)





TES dust index (Ruff and Christensen, JGR, 2002)