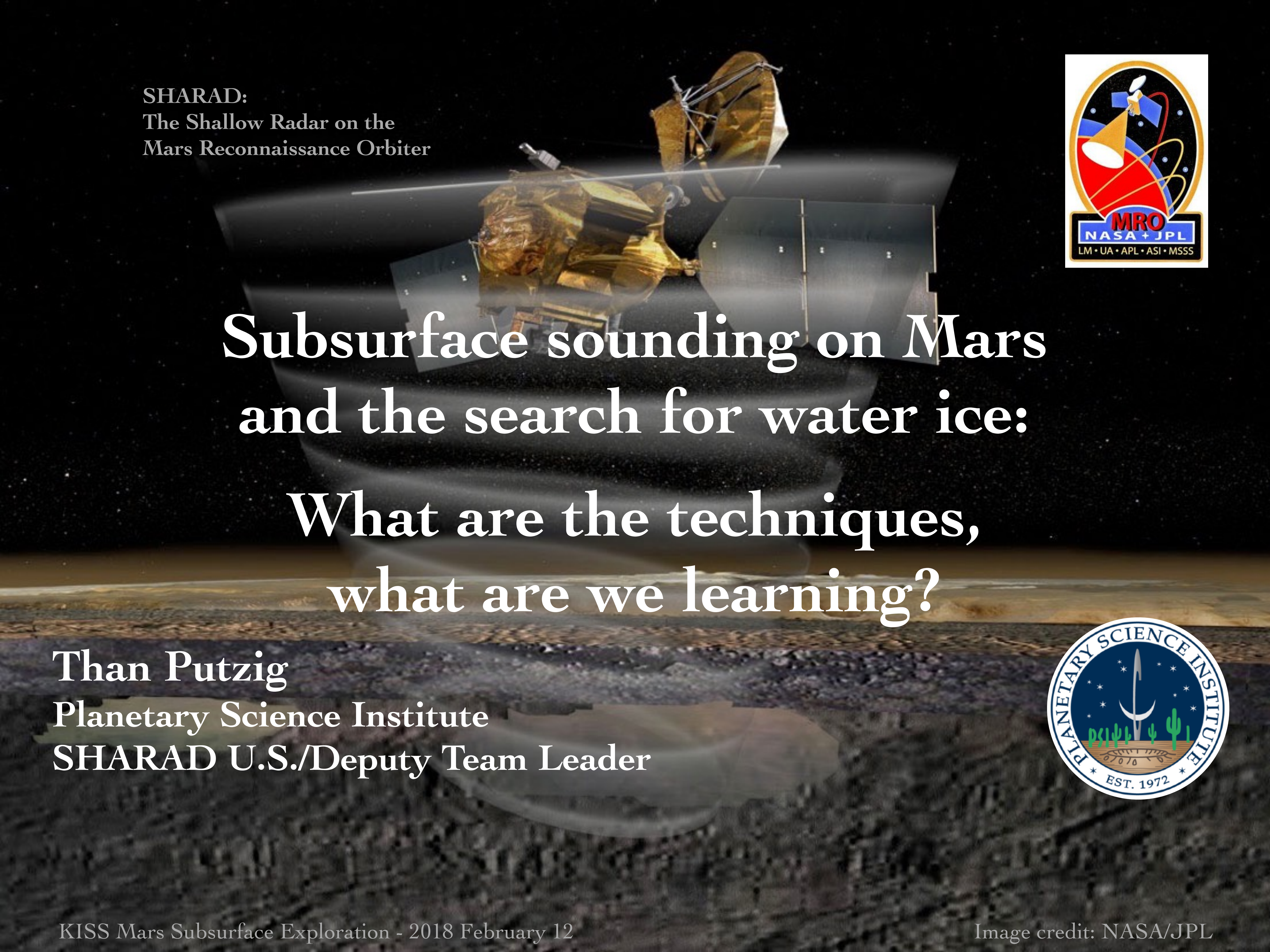


SHARAD:
The Shallow Radar on the
Mars Reconnaissance Orbiter

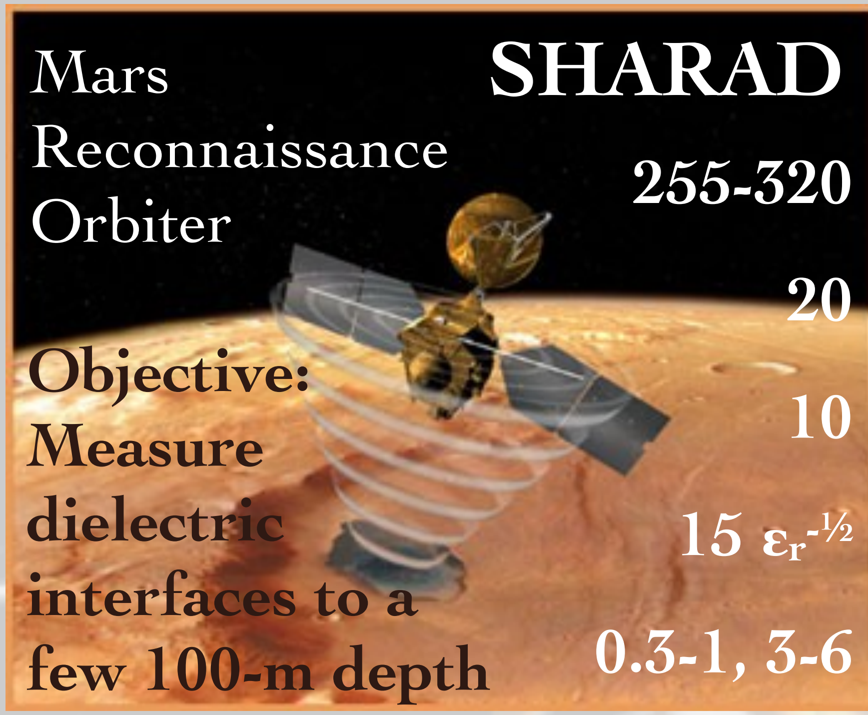
Subsurface sounding on Mars and the search for water ice:

What are the techniques, what are we learning?

Than Putzig
Planetary Science Institute
SHARAD U.S./Deputy Team Leader

Image credit: NASA/JPL

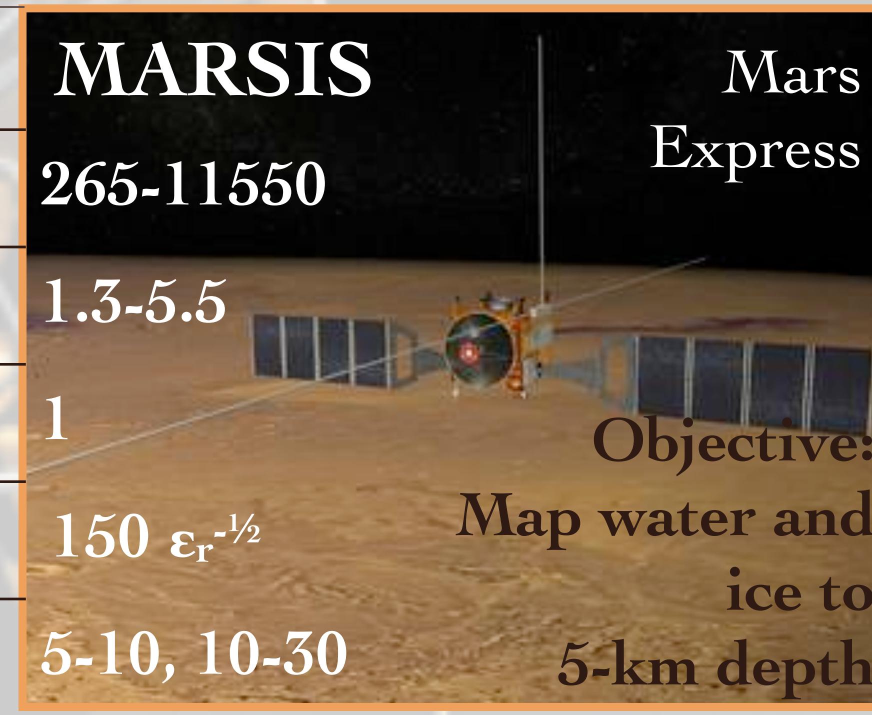
Orbital sounding radars at Mars



Mars Reconnaissance Orbiter

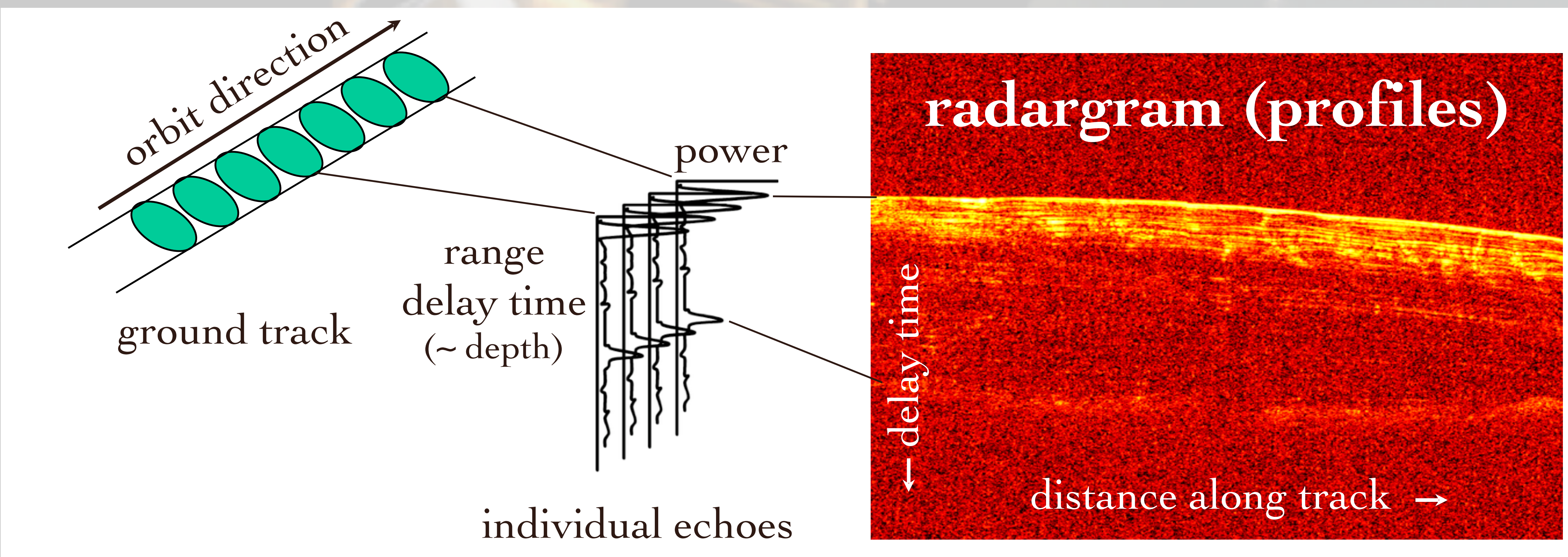
Objective: Measure dielectric interfaces to a few 100-m depth

SHARAD	instrument	MARSIS
255-320	orbit (km)	265-11550
20	center freq. (MHz)	1.3-5.5
10	bandwidth (MHz)	1
$15\ \varepsilon_r^{-1/2}$	range res. (m)	$150\ \varepsilon_r^{-1/2}$
0.3-1, 3-6	lateral res. (km)*	5-10, 10-30



Mars Express

Objective: Map water and ice to 5-km depth



* Inline resolution is improved using synthetic aperture radar (SAR) processing techniques

CAT Scan

http://www.bz-berlin.de/galerie-archiv/bg-ct-loewe-scan

Computed Axial Tomography:
Combination of many X-ray images taken from different angles to produce cross-sectional (tomographic) images (virtual "slices") of specific areas of a scanned object, allowing the user to see inside the object without cutting.

https://en.wikipedia.org/wiki/CT_scan

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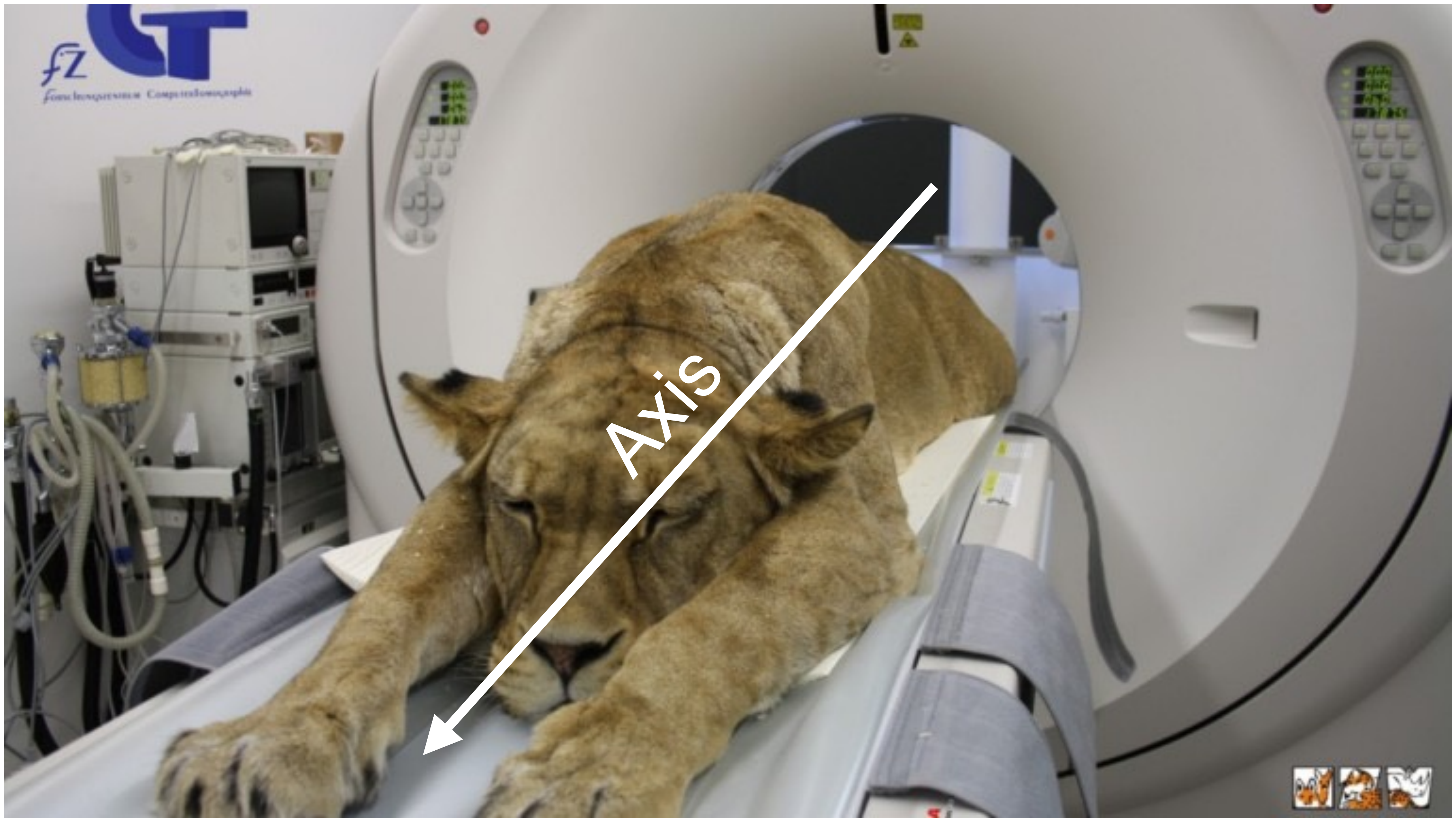

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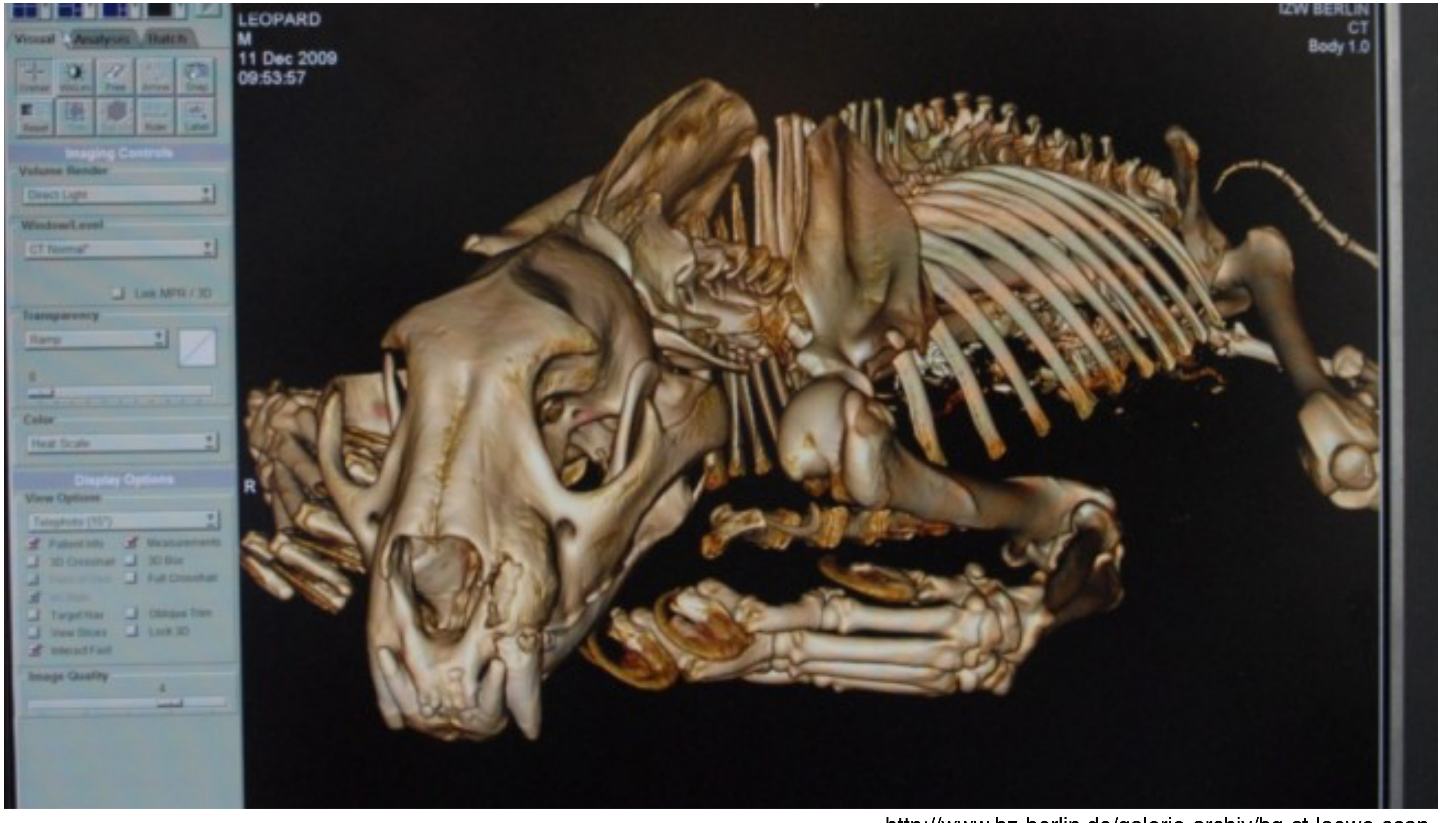

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MRO SHARAD objective: Map subsurface rock, regolith, water, and ice.

Movie available at https://photojournal.jpl.nasa.gov/catalog/PIA10653

Animation credit: NASA/JPL-Caltech/University of Rome/SwRI

MRO altitude: 255 to 320 km

Wavelength: 15 m (~8-m vertical resolution in water ice)

Transmitted sweep: 25 to 15 MHz

Lateral resolution: 3 to 6 km (0.3 to 1 km inline with SAR)

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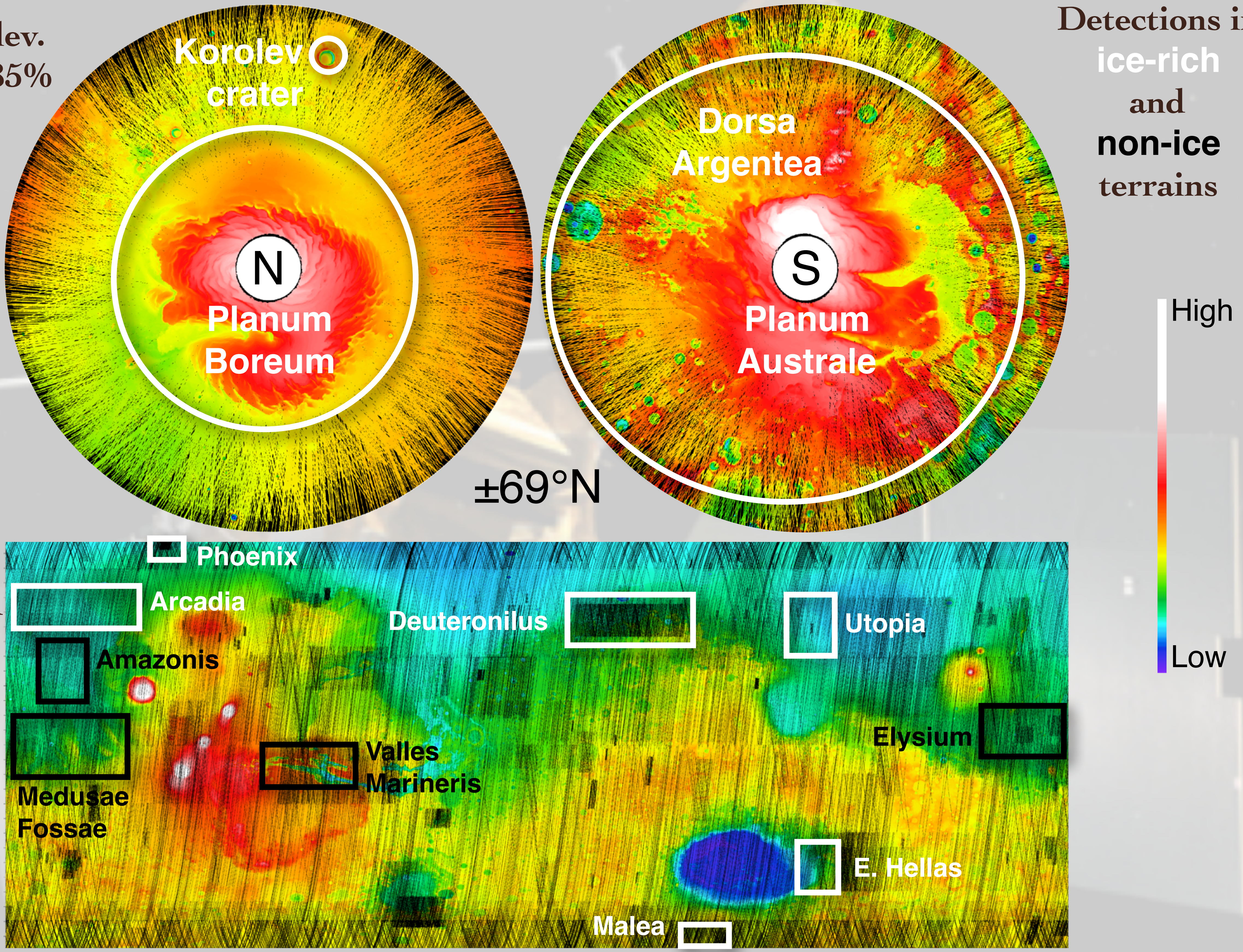
Current SHARAD Coverage

@ 3 km resolution

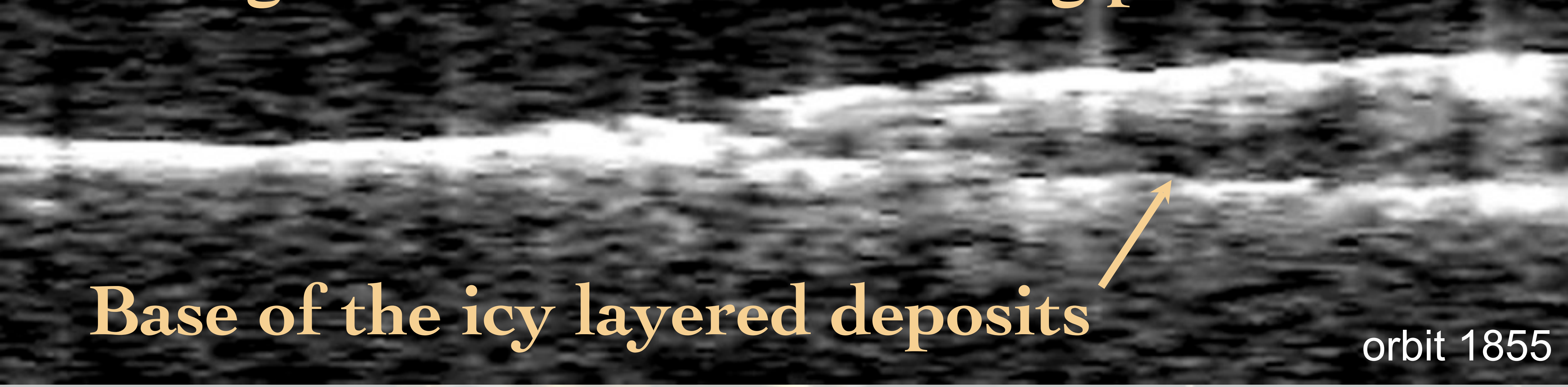
In MOLA elev.
N: 88%   S: 85%

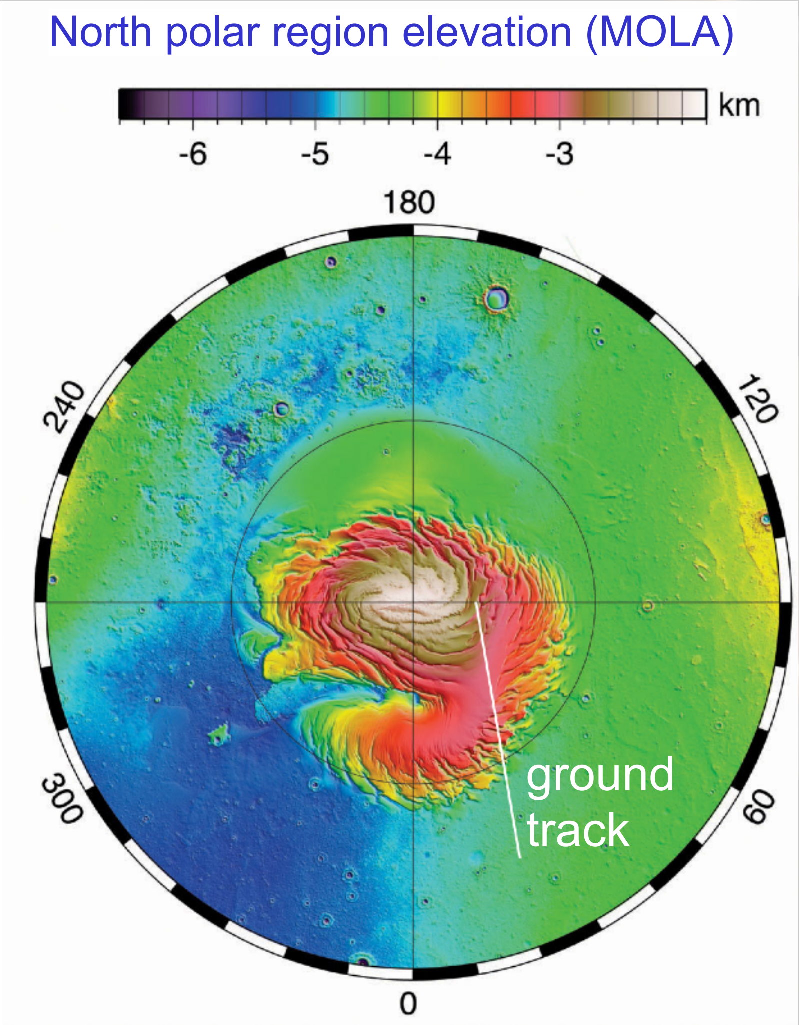
Detections in **ice-rich** and **non-ice** terrains



In black over MOLA elev: 31%

November 2005: A fortuitous discovery during MARSIS commissioning phase:





Strong basal reflector indicates very little path loss (< 1 dB) $\Rightarrow$ nearly pure, cold ice.

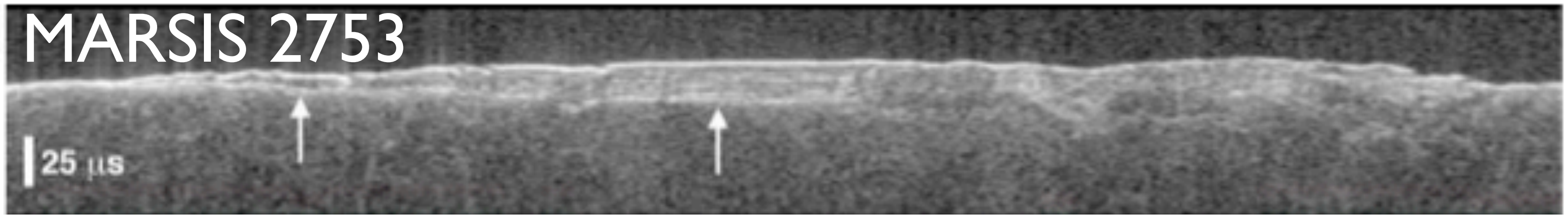
Also $\Rightarrow$ low silicate content

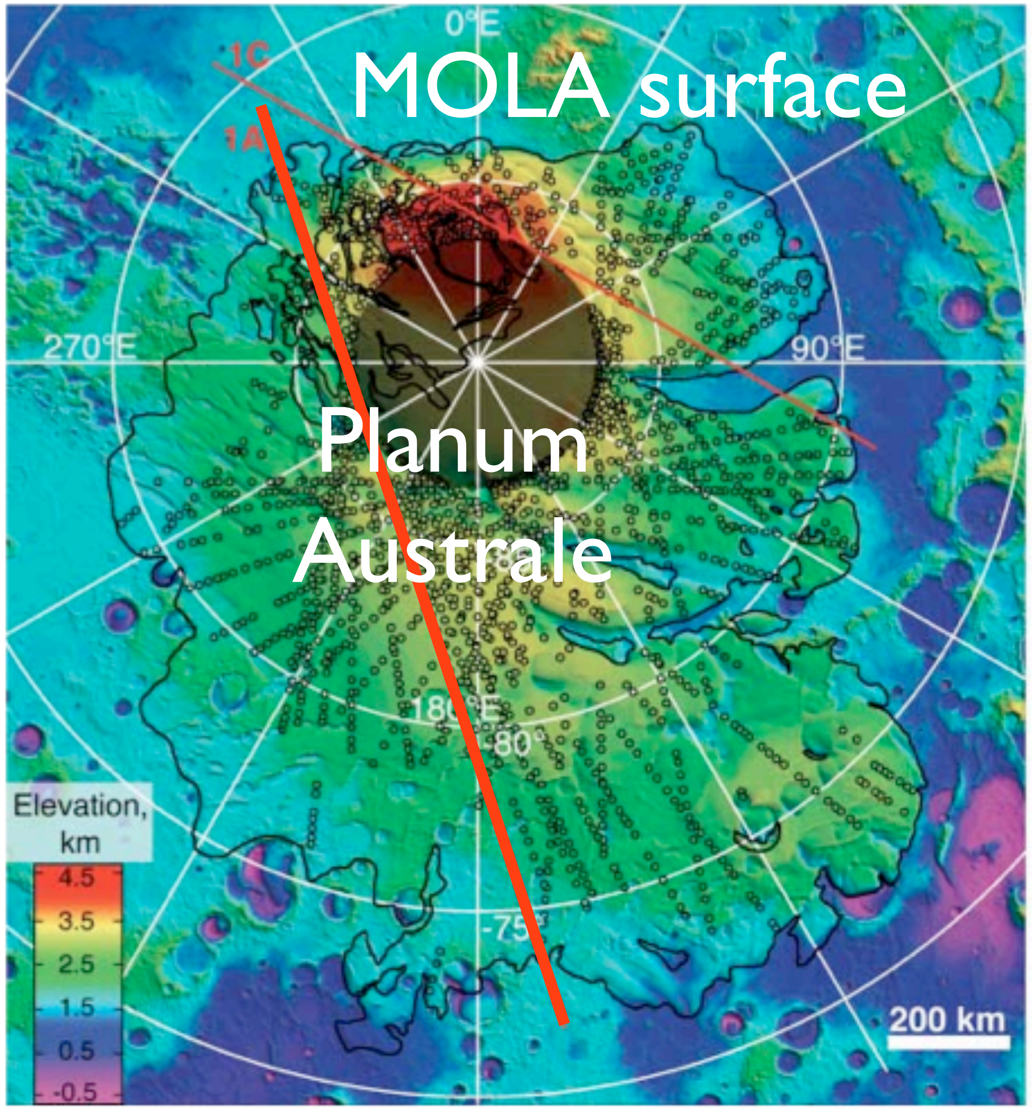
Picardi et al. (2005), *Science* **310**, 1925

The South Polar Region of Mars

Plaut et al. (Science 2007)

- A collecton of MARSIS radargrams were used to 'strip off' the layered deposits





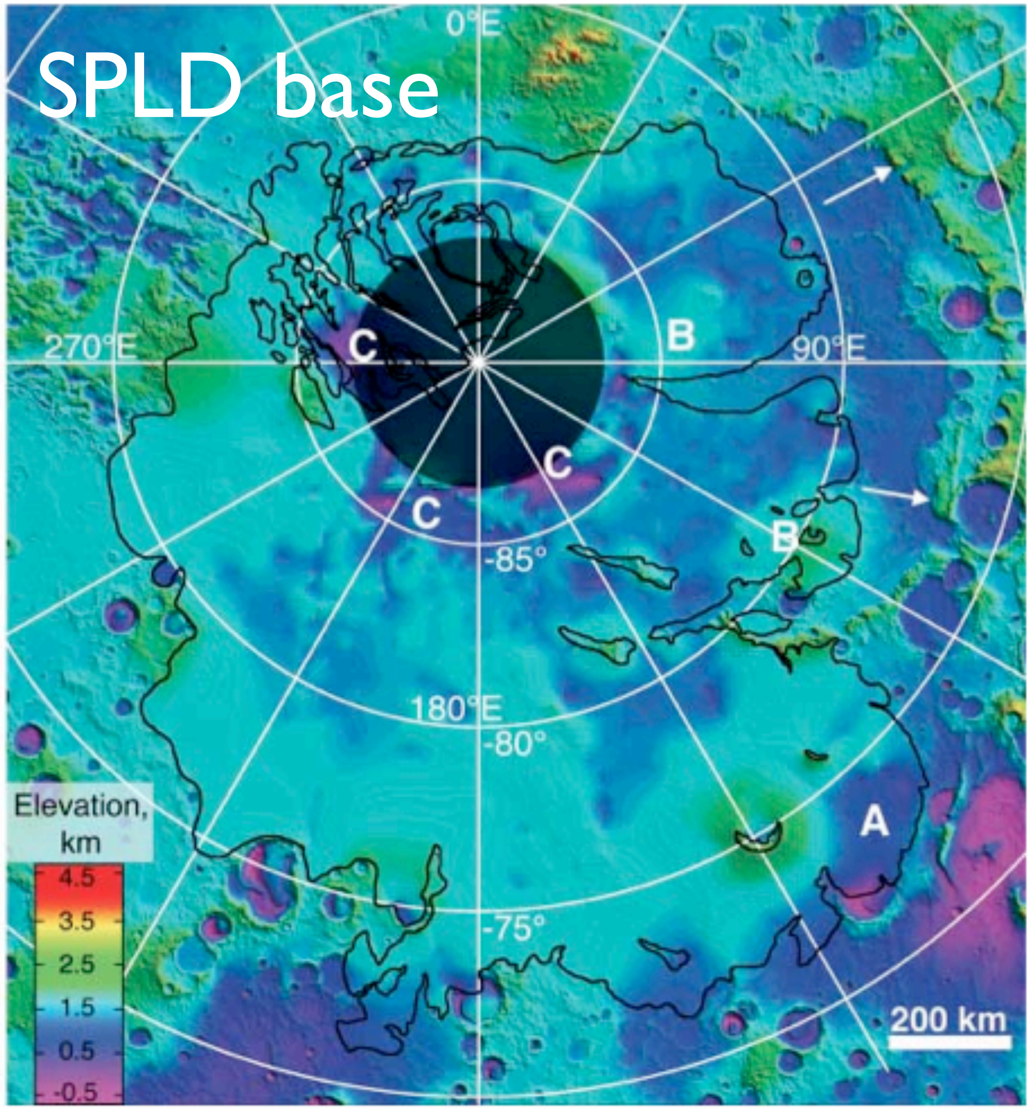
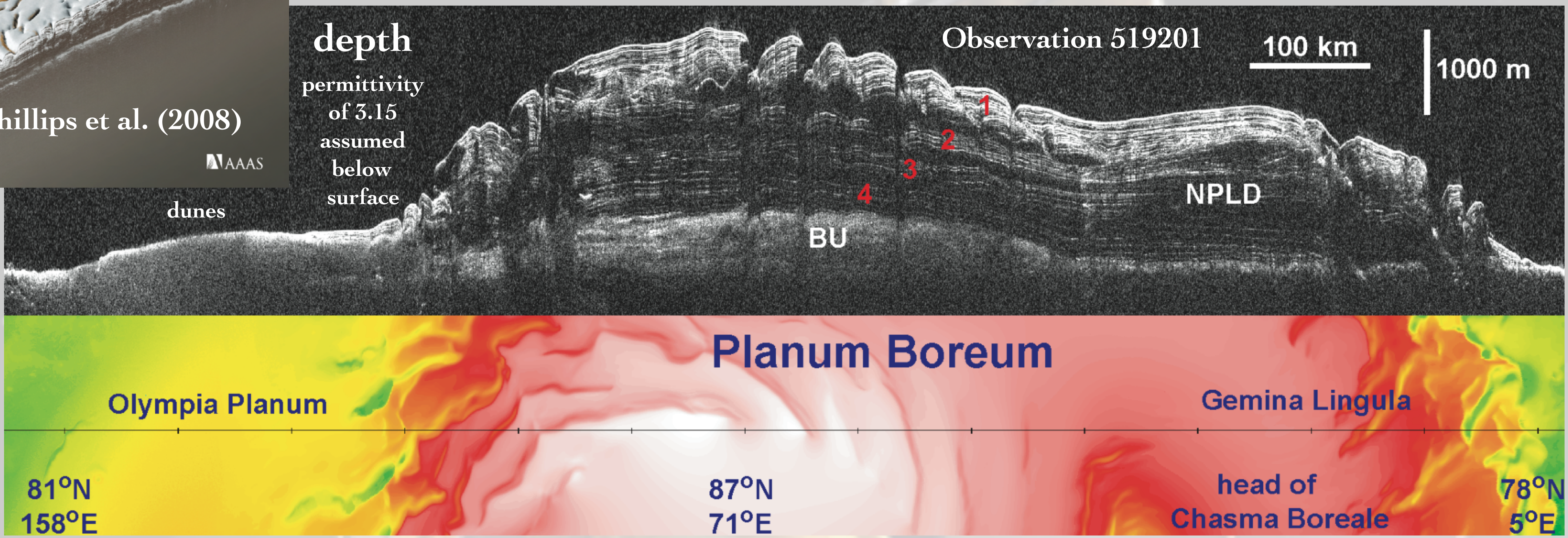


Fig. 2. **(left).** Topography of the south polar region of Mars from MGS MOLA data, with locations of MARSIS measurements of the SPLD thickness shown as open circles. The SPLD unit as mapped by (*15*) is outlined in black. Red lines indicate ground tracks of the orbits in Fig. 1. Apparent gaps in coverage are due to the lack of a discernible basal interface, and not to gaps in observations. No MARSIS data are available poleward of 87°S (dark circle in upper center). **Fig. 3 (right).** Same as Fig. 2, with topography at the SPLD basal interface shown, based on MARSIS measurements of SPLD thickness. A indicates a depression below a distal SPLD lobe. B indicates relative highs within the remnant Prometheus basin (the basin rim is indicated with arrows). C indicates depressions in the near-polar region.

In 2007, SHARAD began revealing the internal structure of the NPLD



- – Strong basal returns imply relatively pure ice (<~5% lithics)
- – NPLD layer-packet structure likely related to climate
- – Basal unit (BU) rarely layered, missing below >1/3 of NPLD
- **– Flat base ⇒ Mars' lithosphere is > 300 km (2-4× Earth's)**

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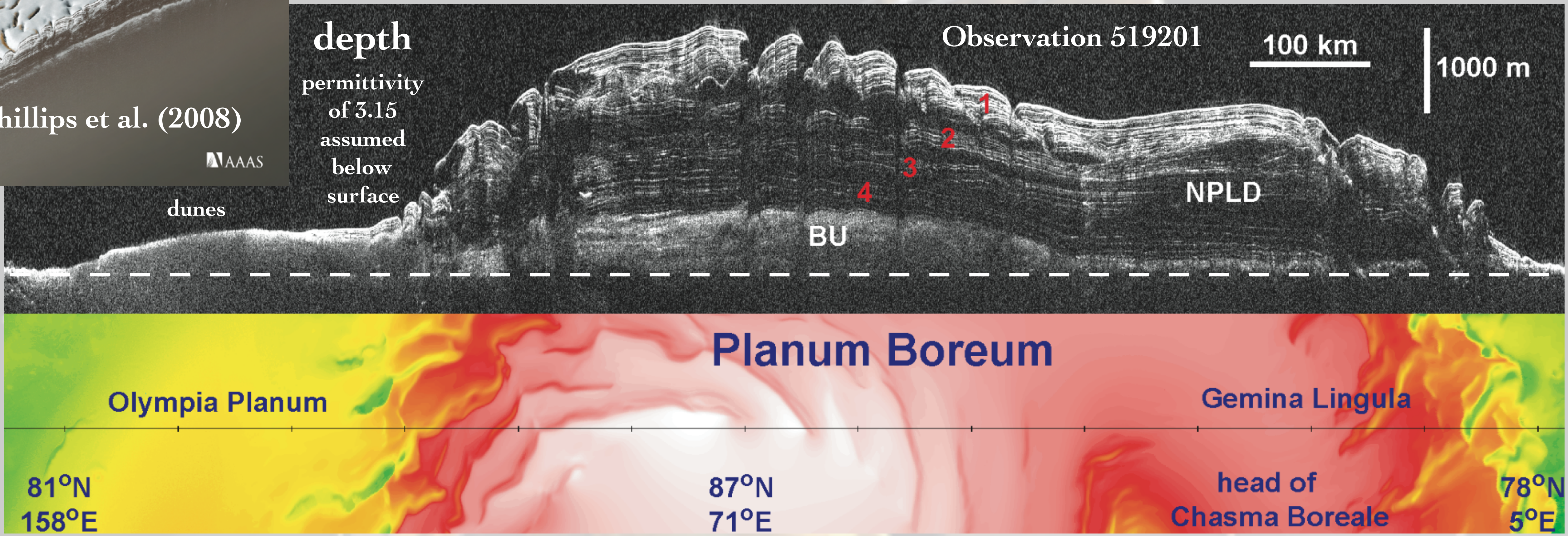

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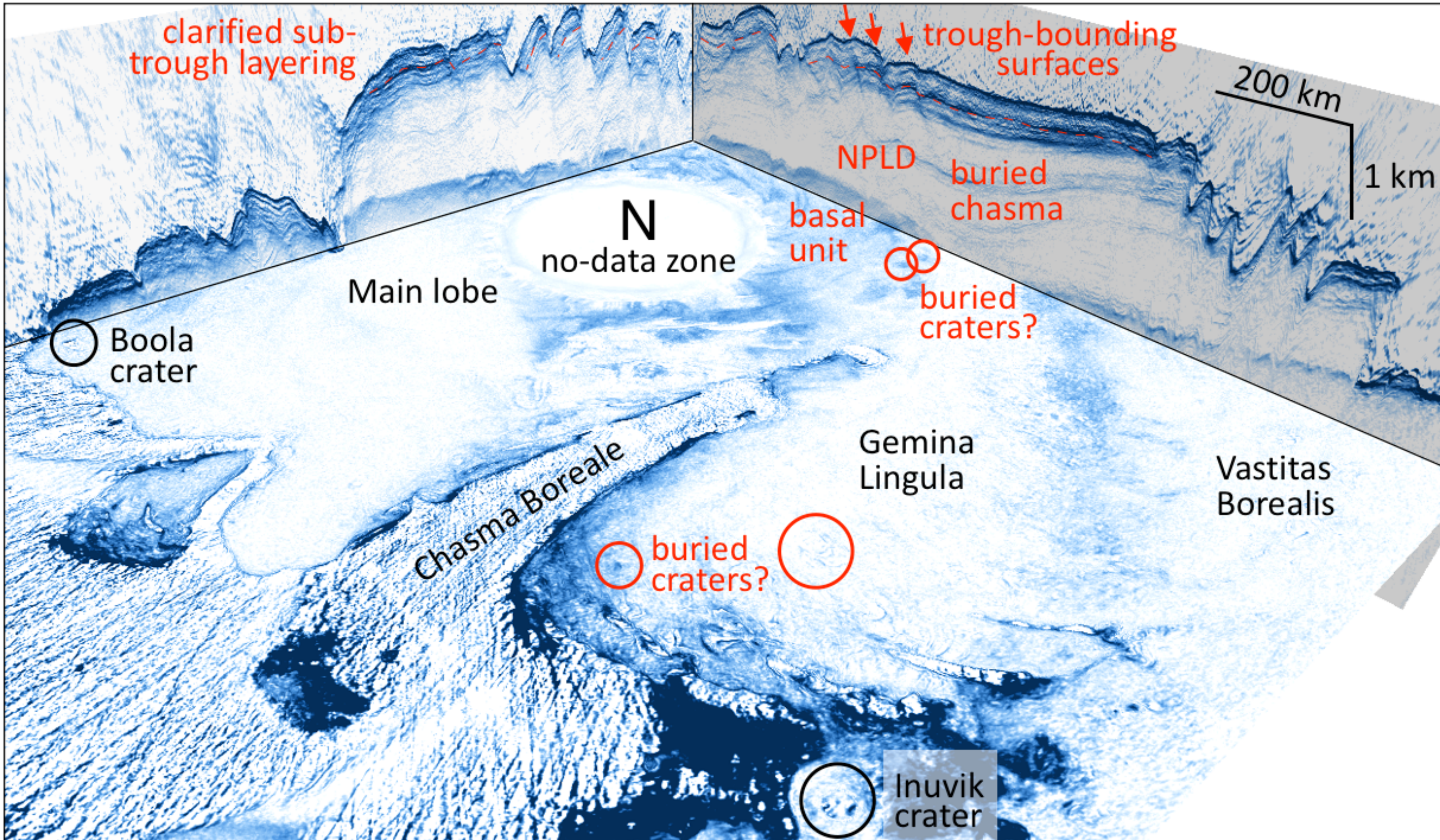
In 2017, we assembled SHARAD data from thousands of orbit passes to create 3D data volumes



Putzig et al., Icarus, in press

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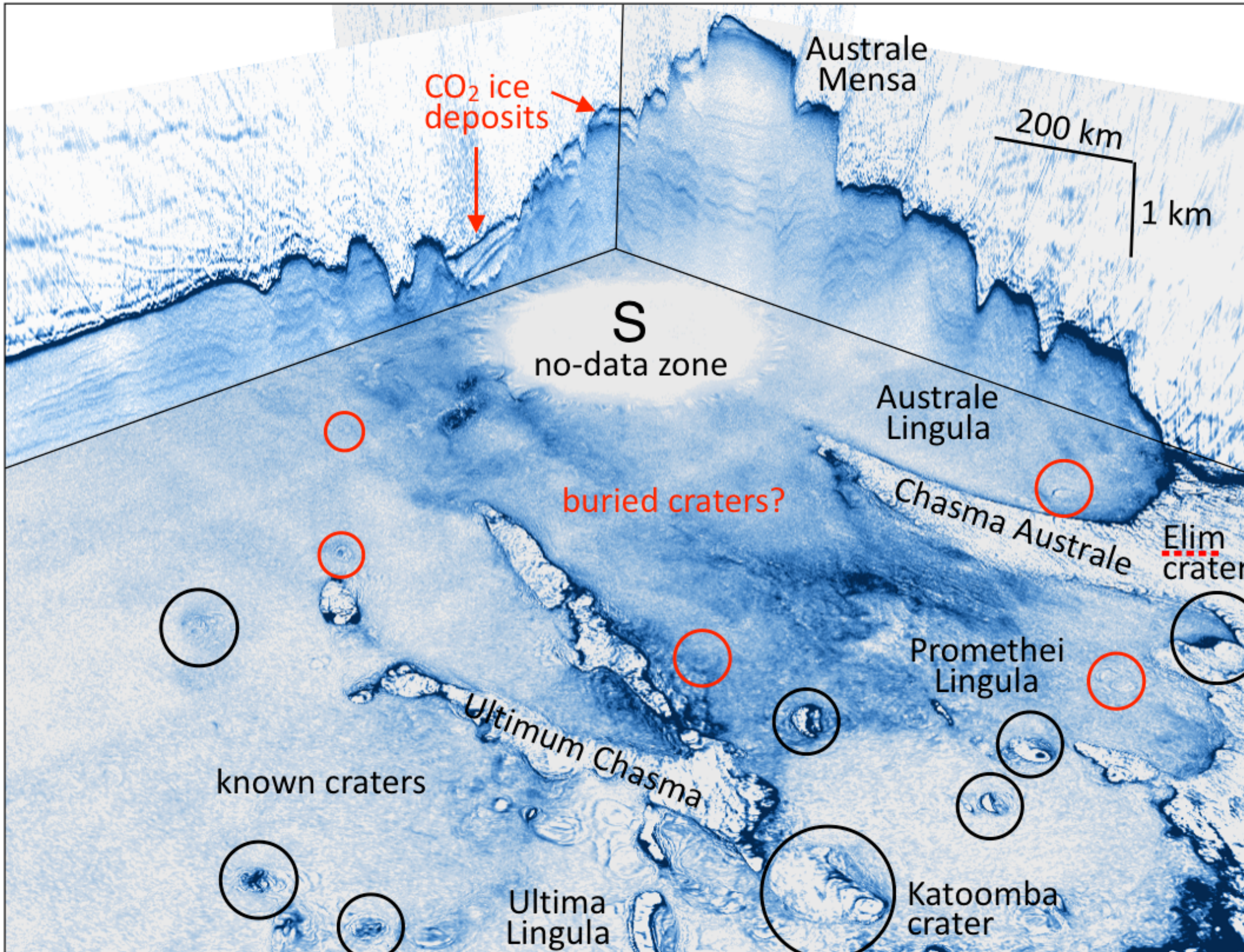
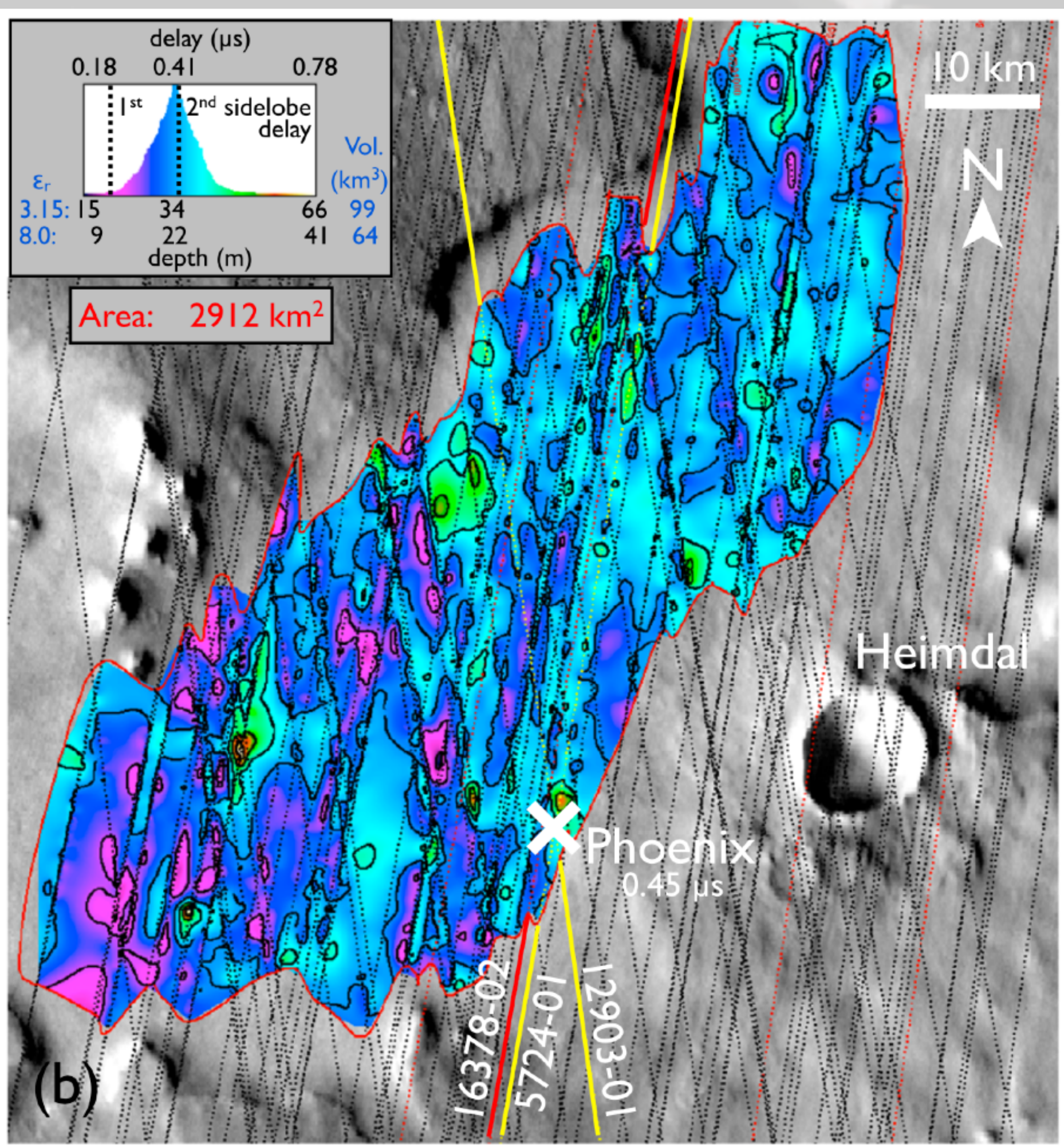


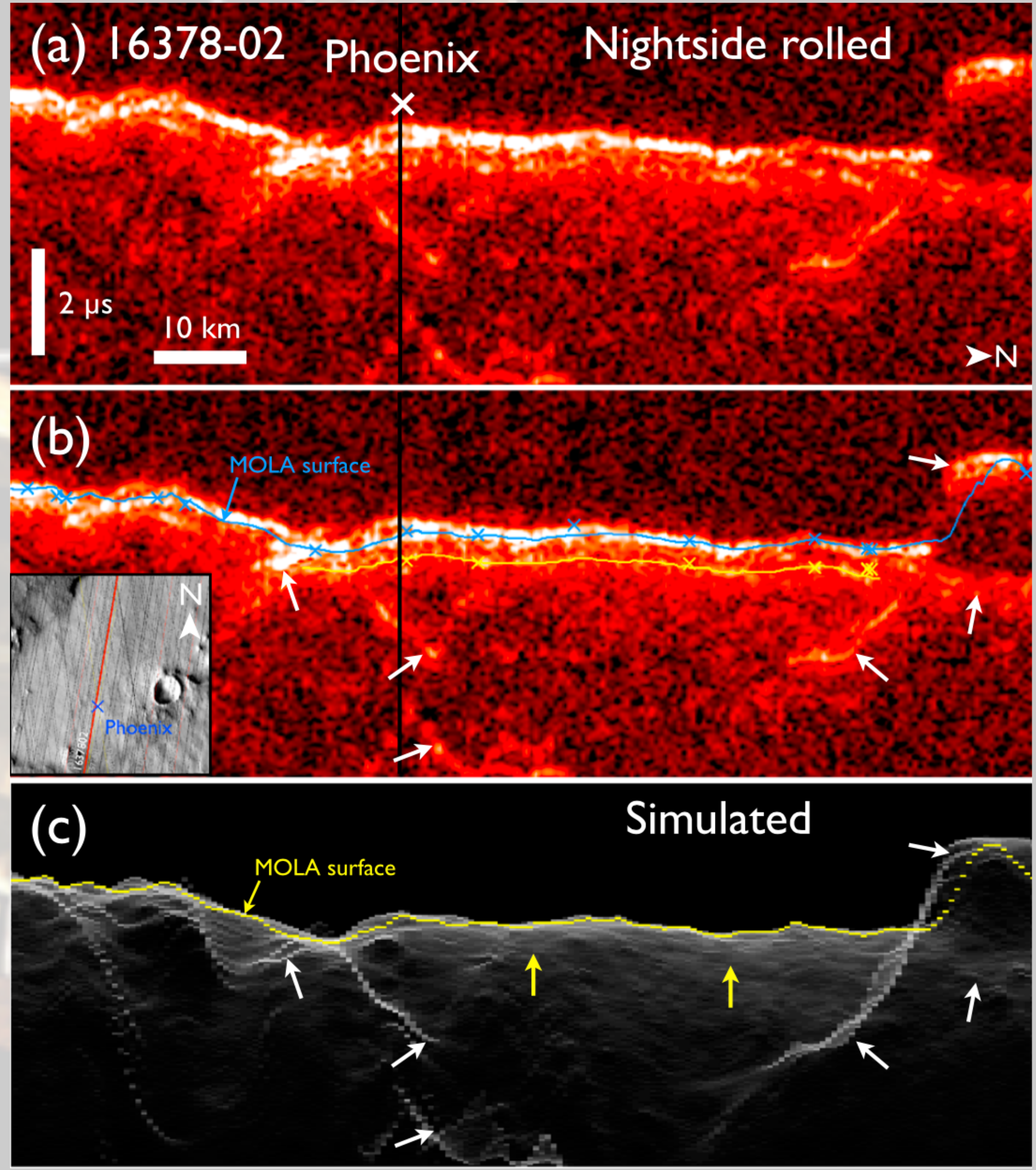
Putzig et al., Icarus, in press

SHARAD detects possible base of ground ice in region of Phoenix landing site

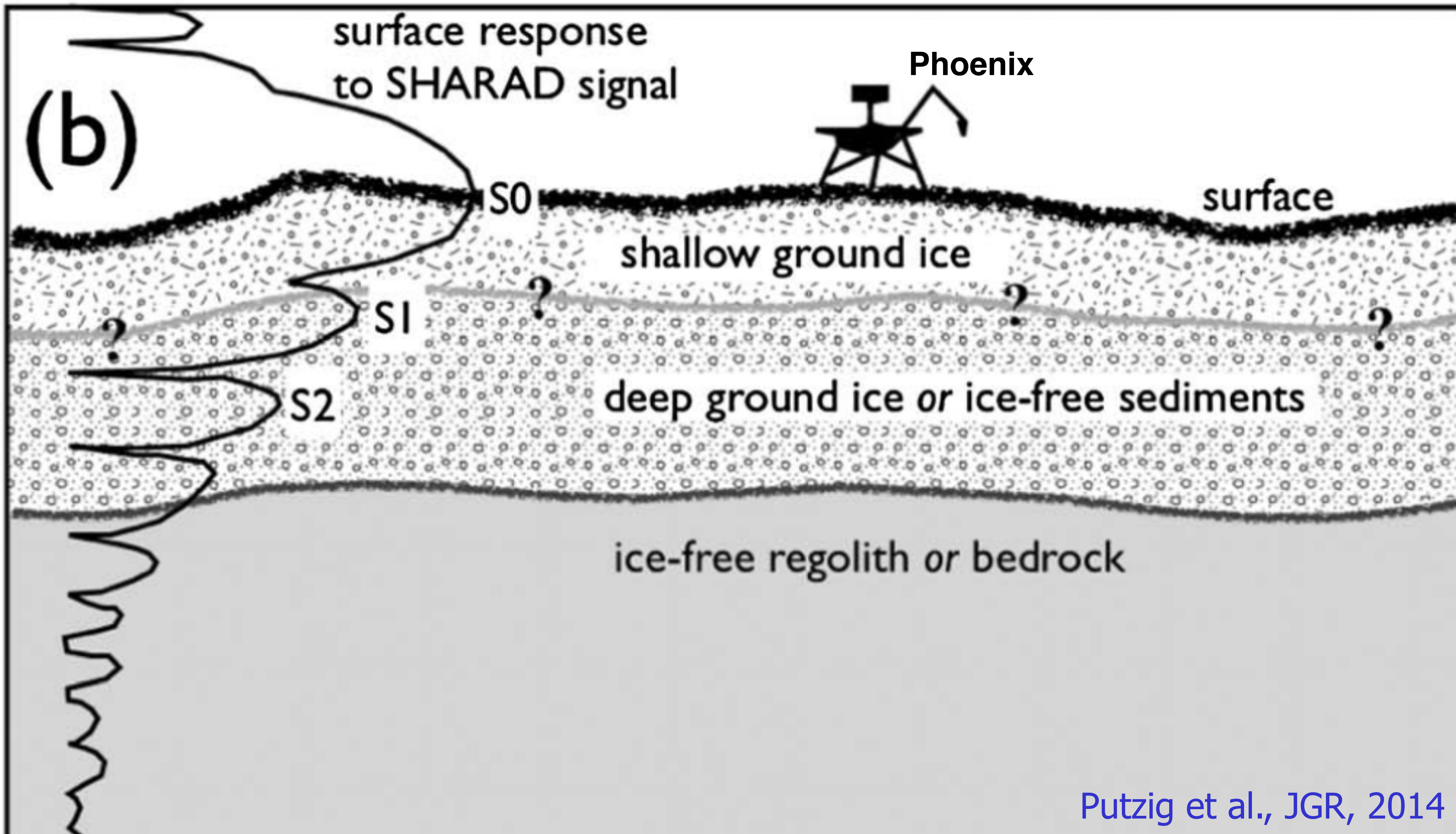
Putzig et al., JGR, 2014

Of all past landing sites, only Phoenix shows clear evidence of subsurface radar returns. We mapped what may be the base of ground ice at depths of ~15–66 m across 2900 km² in the depression where the lander resides.





Why no detection of top of ground ice? Too shallow.
Why possible base of ground ice?
⇒ Detections span surface sidelobe* zone.

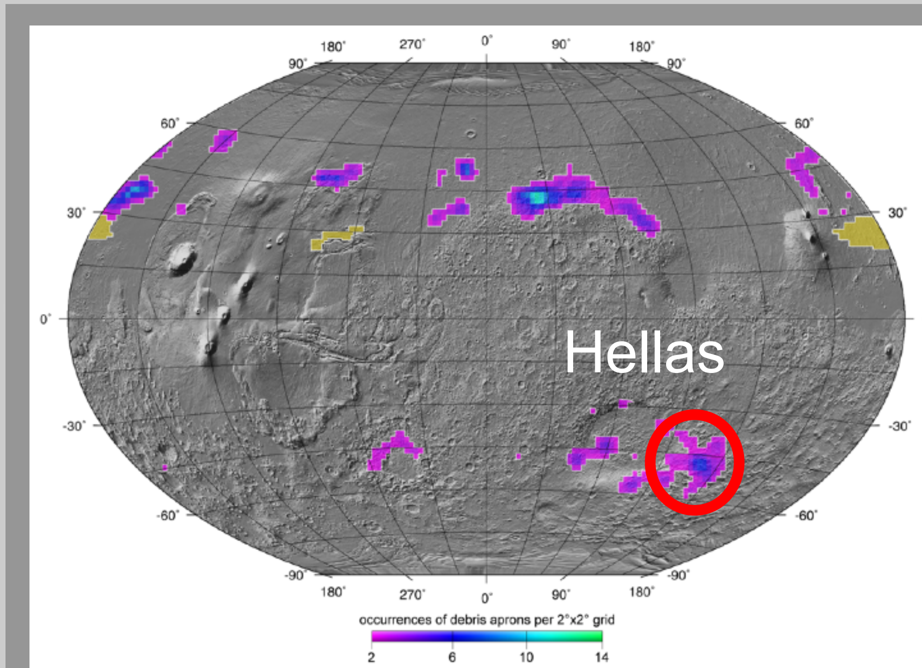


* Sidelobes are a product of processing the band-limited 15-25 MHz signals.

"Lobate Debris Aprons"

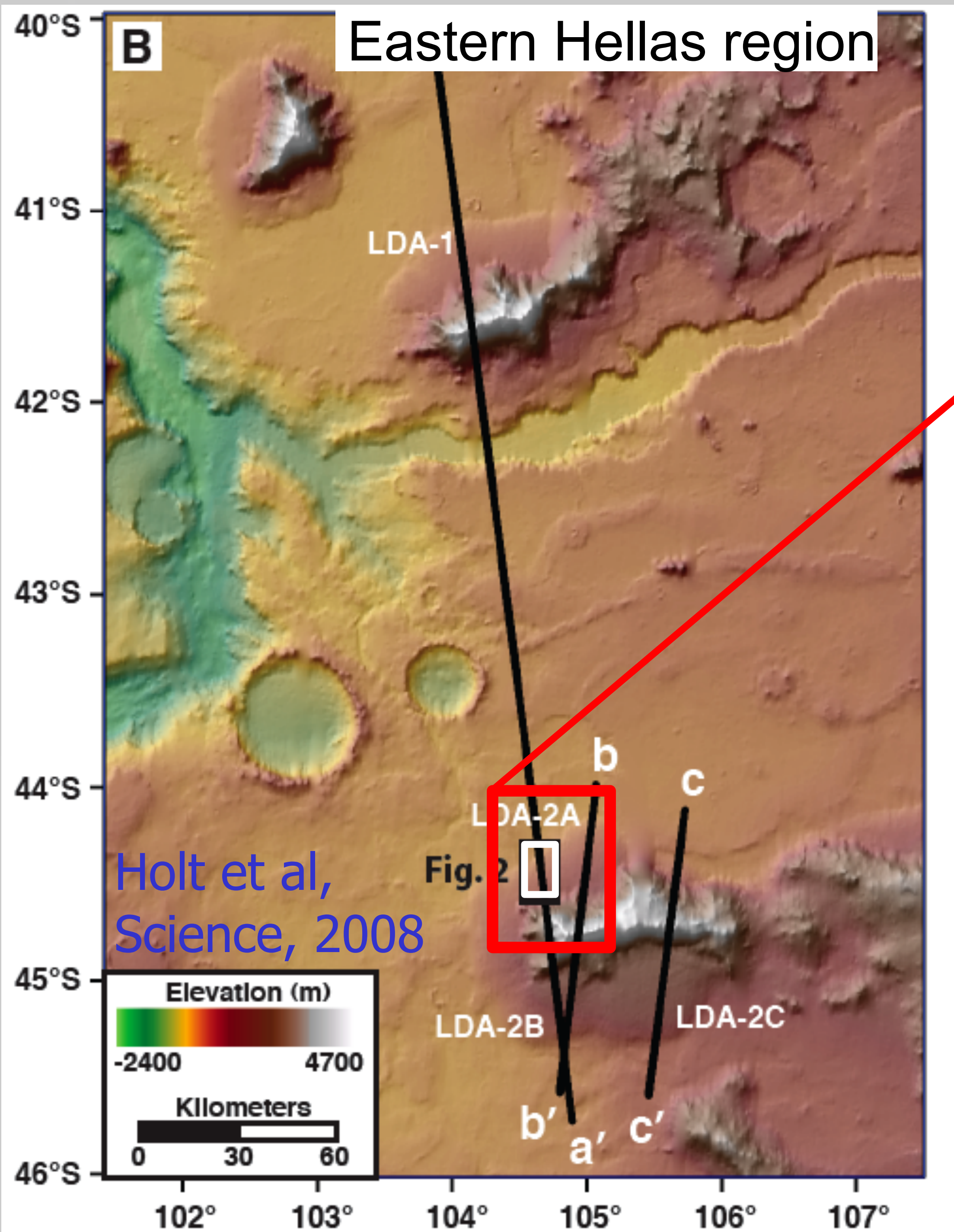
Morphology suggests water ice as a component, but amount was debated. End members:

- ~ 10%: ice-lubricated debris flow
- ~ 95%: debris-covered glaciers



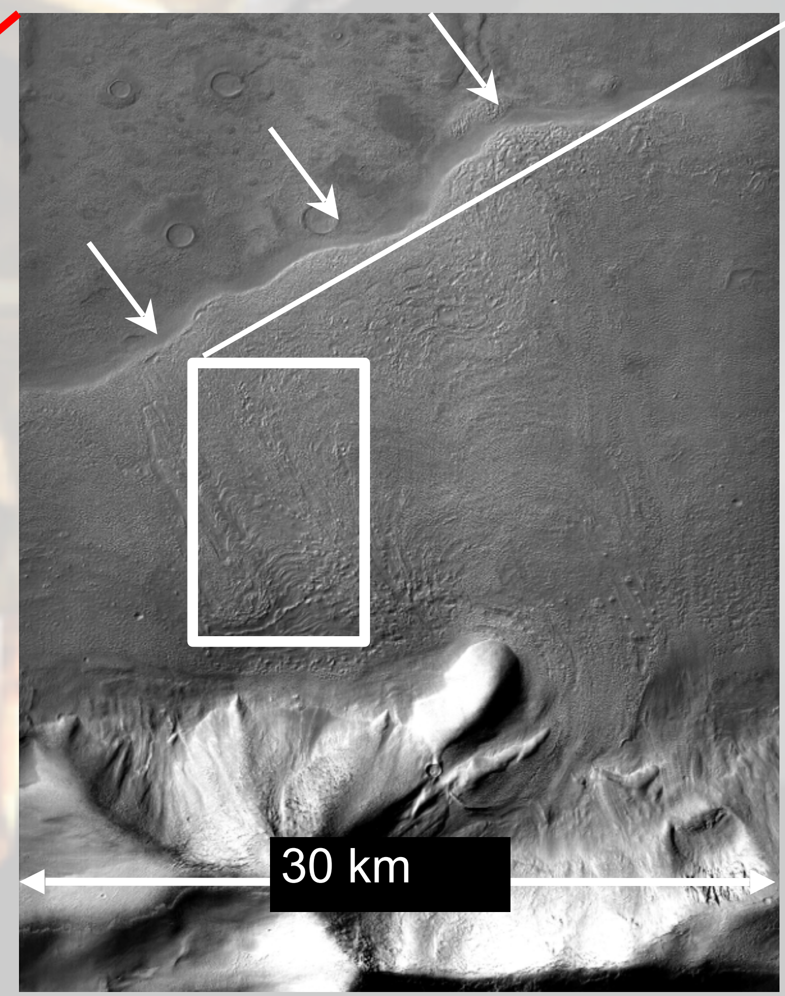
Global distribution

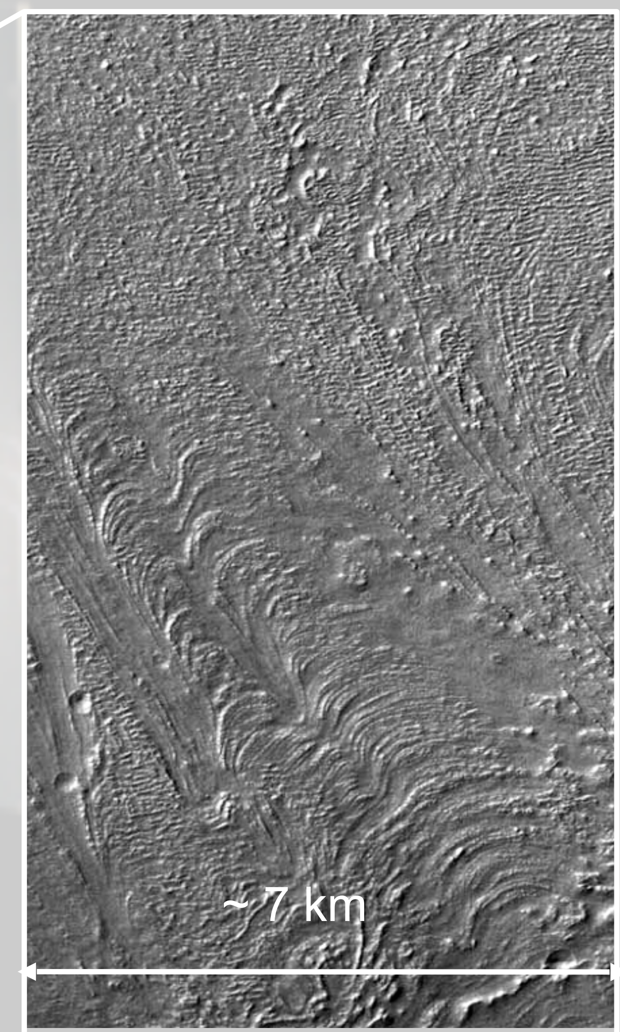
Hauber et al. (2008)

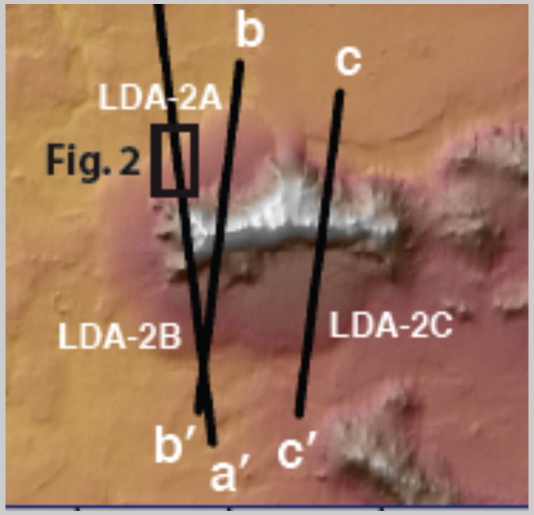


Holt et al, Science, 2008

From CTX image P03_002294_1349_45S255W





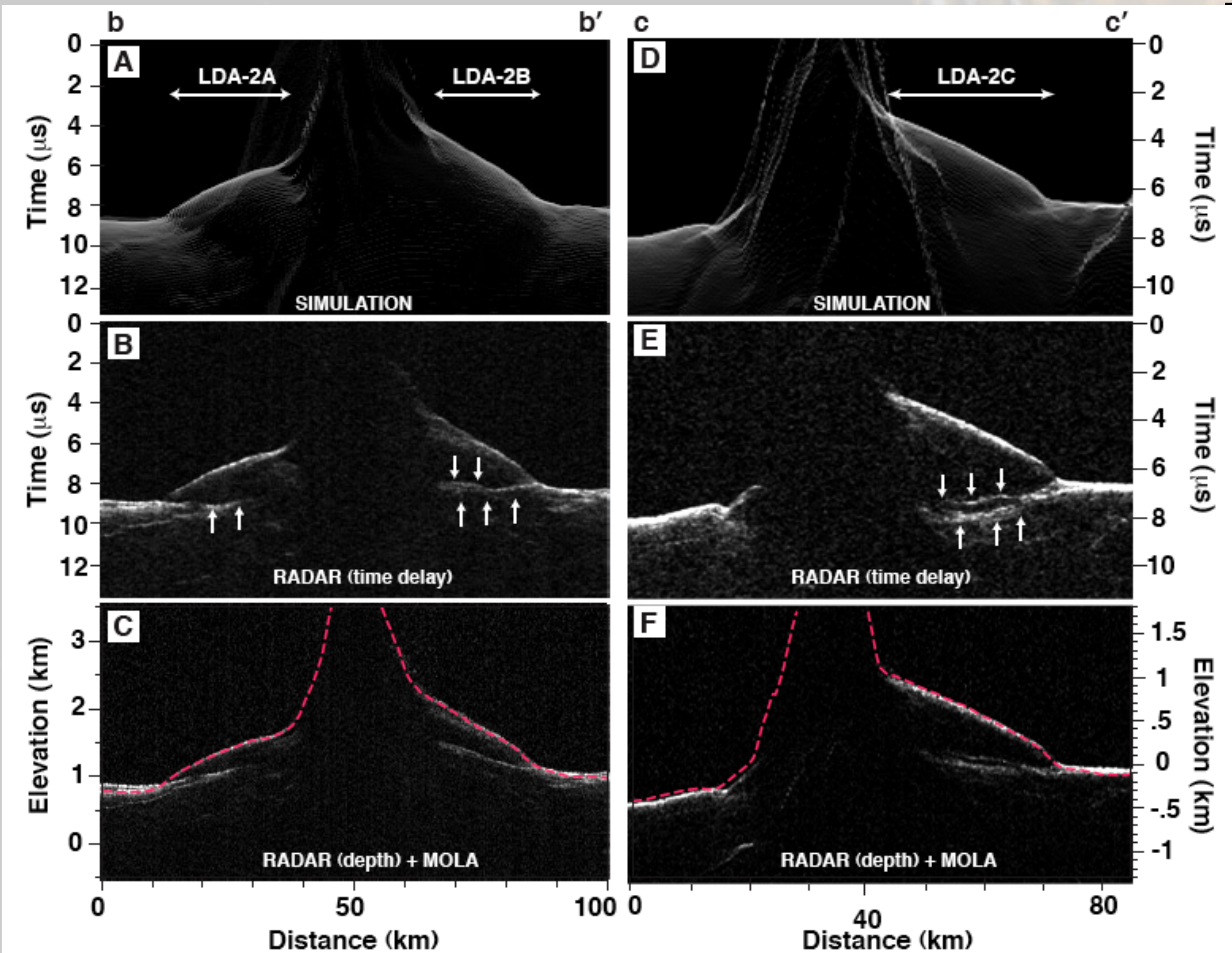


SHARAD results confirm the <u>debris-covered glacier</u> hypothesis

Two examples

1. Eastern Hellas

Holt et al, Science, 2008



Synthetic radargrams:
<u>Critical Step</u>: Modeling of surface clutter (from MOLA topography)

SHARAD data:

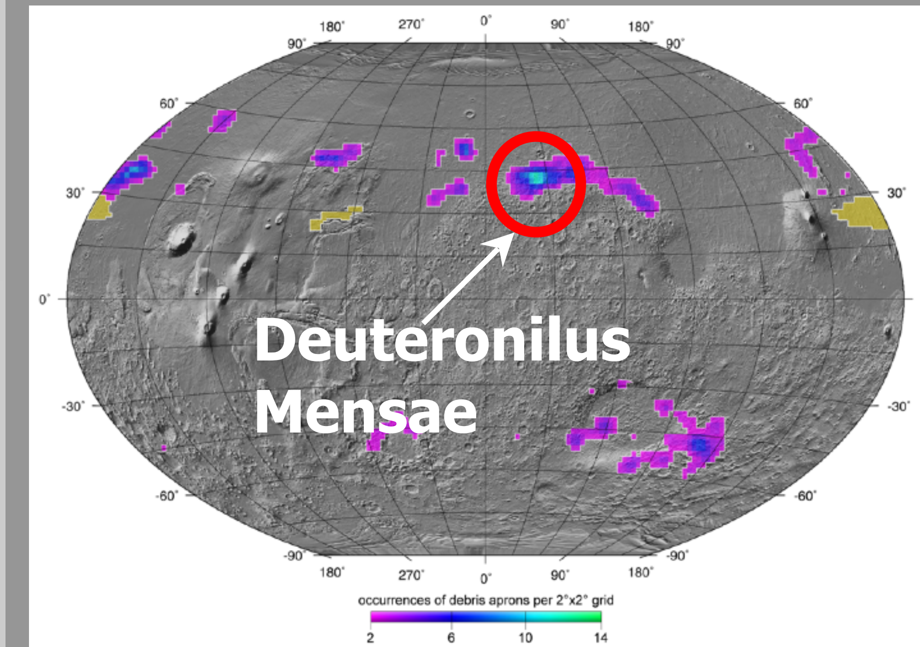
- Radar transparency.
- Little interior scattering.
- Losses similar to ice, PLD.
- Possible thin basal layers.

Depth-converted SHARAD data:
Shows true geometry, with MOLA surface in red

Debris-covered glaciers

2. Deuteronilus

Plaut et al., GRL, 2009



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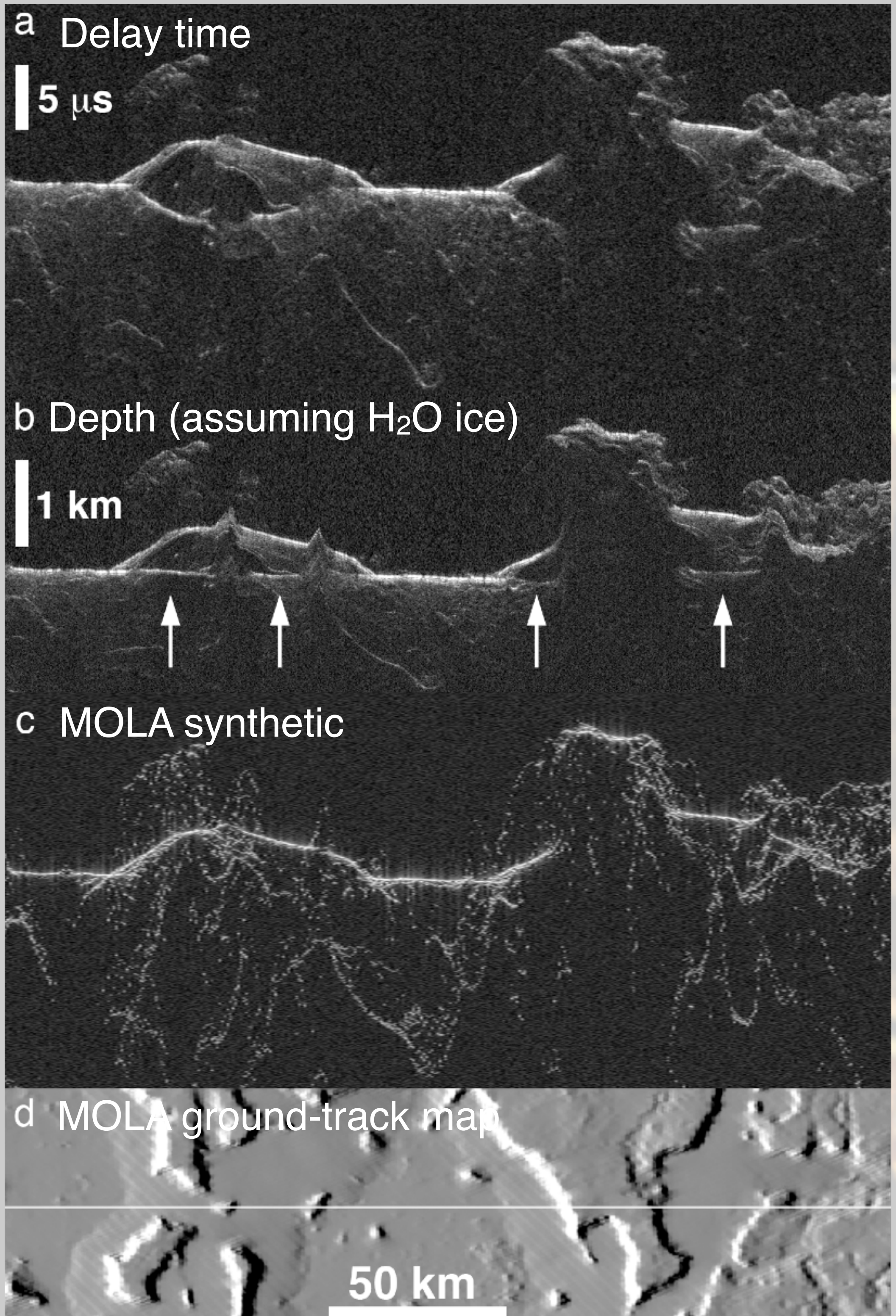
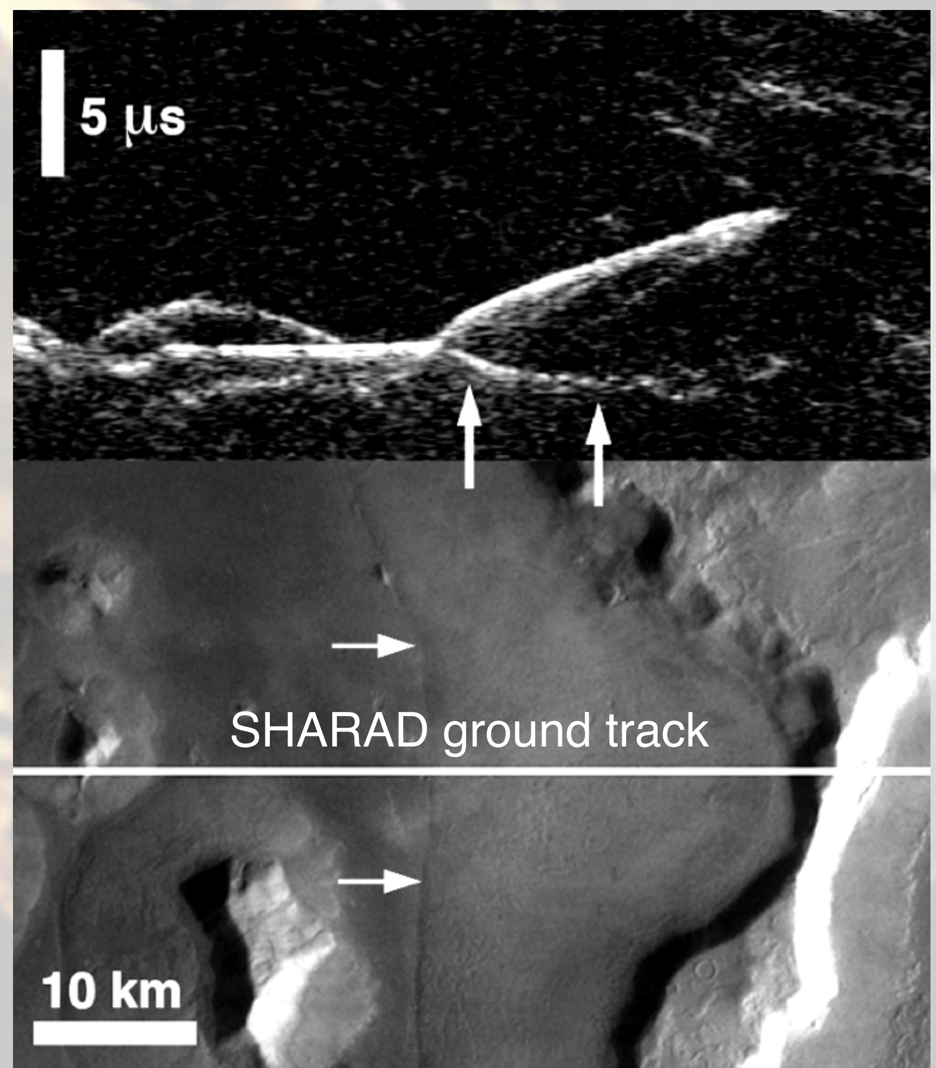




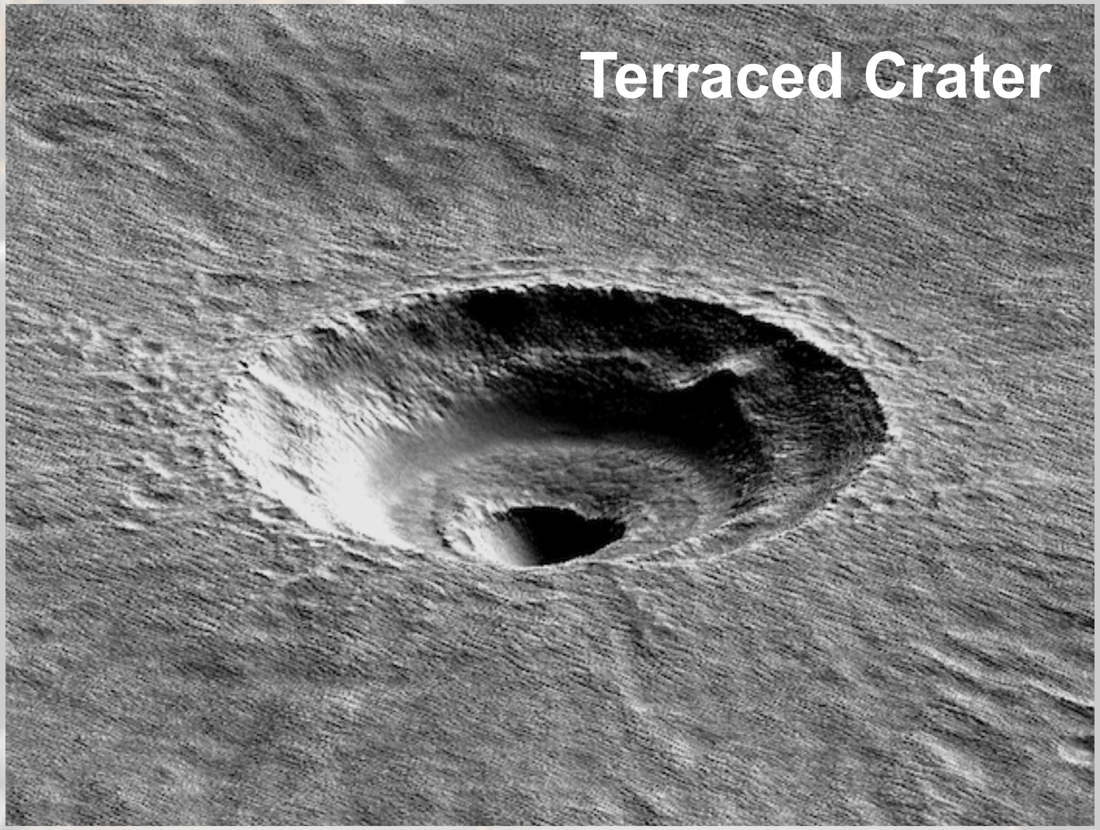
In all cases, the buried upper surface of the ice is not detected.

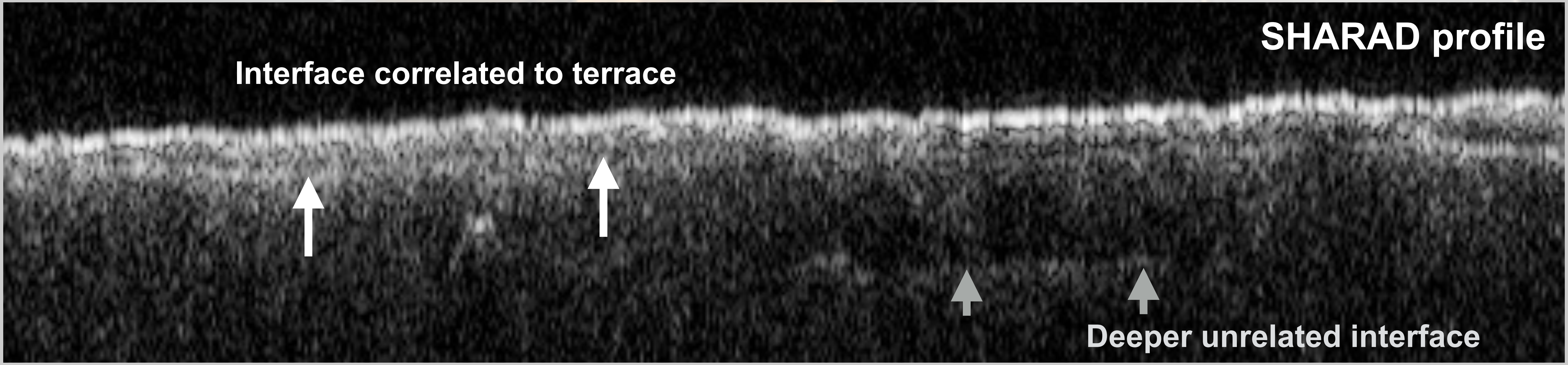
This lack of detection suggests the ice may be shallower than 10 or 20 m.

Widespread Buried Ice in Arcadia Planitia

Bramson et al., GRL, 2015

- MRO cameras have imaged many terraced craters, formed by impacts into layered surfaces. Dozens of these craters occur in Arcadia Planitia, where SHARAD also detects a subsurface layer.
- HiRISE stereo images provide the depth to the terraces, typically ~ 40 m. Comparing the terrace depths with their radar delay times, the layer appears to be composed mostly of water ice.
- This ice sheet covers an area of ~10^6 km^2 (California + Texas). It extends to 38°N latitude, where conditions are more favorable for human explorers than at the polar ice caps.

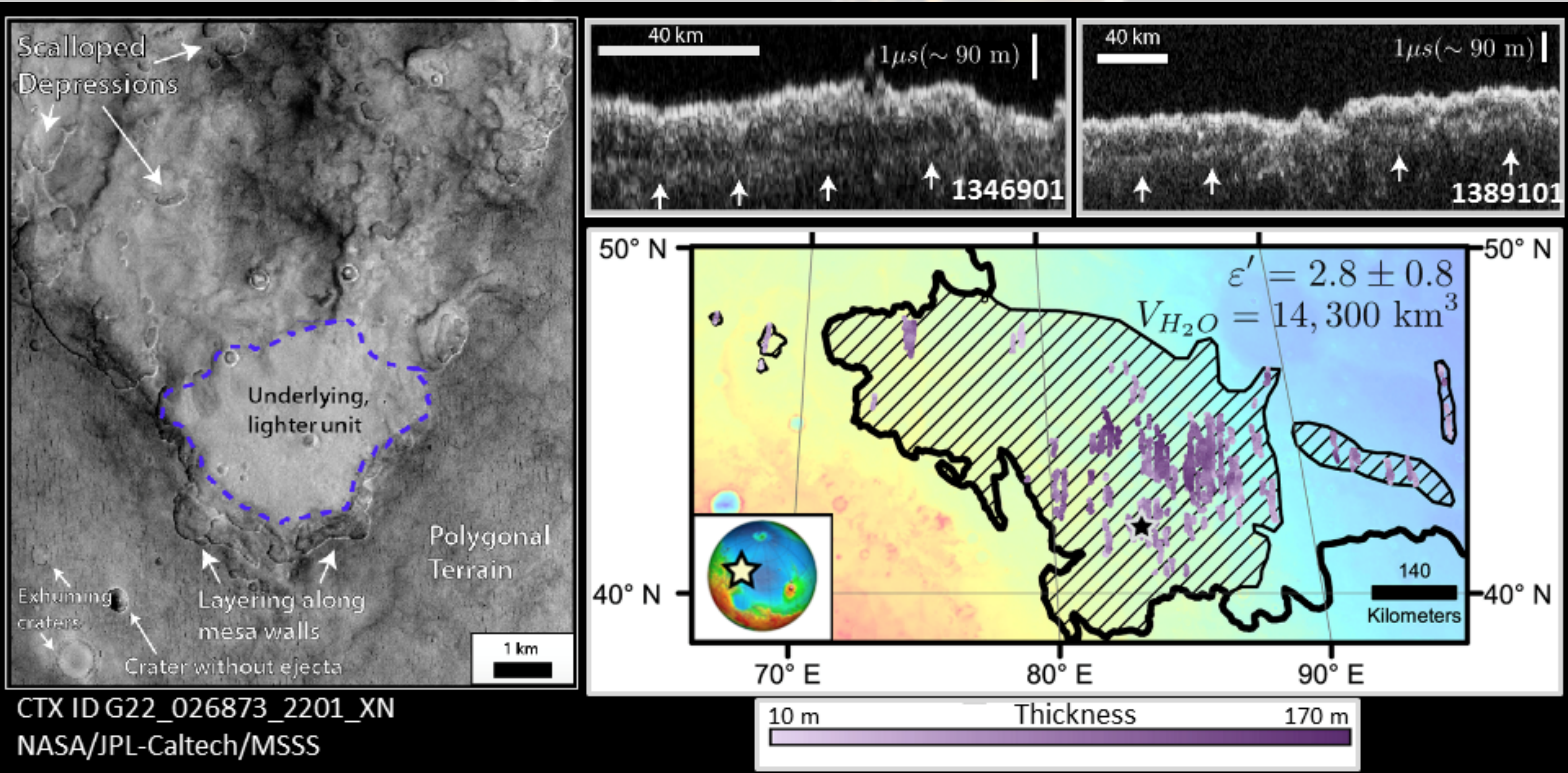




Widespread Buried Ice in Utopia Planitia

Stuurman et al., GRL, 2016

SHARAD detections reveal roughly 14,000 cubic kilometers (~ 1.2 times the volume of Lake Superior) of subsurface water ice in Utopia. Discovery confirms the idea of a water-ice cause for geologic features observed in the area (mesas capped by polygonal terrain), Adds to Mars' global inventory of water ice and to non-polar areas with resources potentially accessible during a human mission.



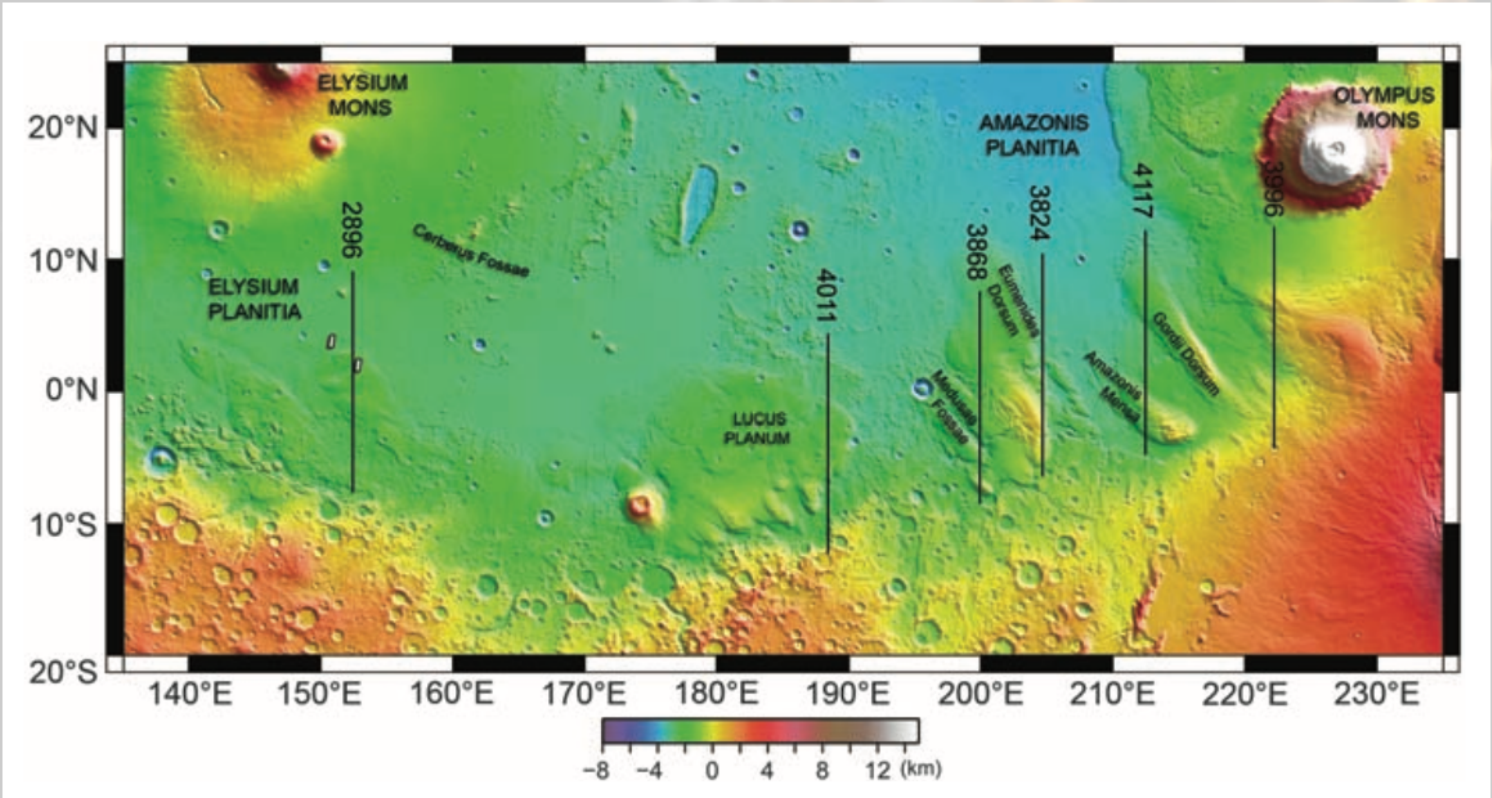
MARSIS at Medusae Fossae Formation Mars: Equatorial Ice or Dry, Low-Density Deposits?

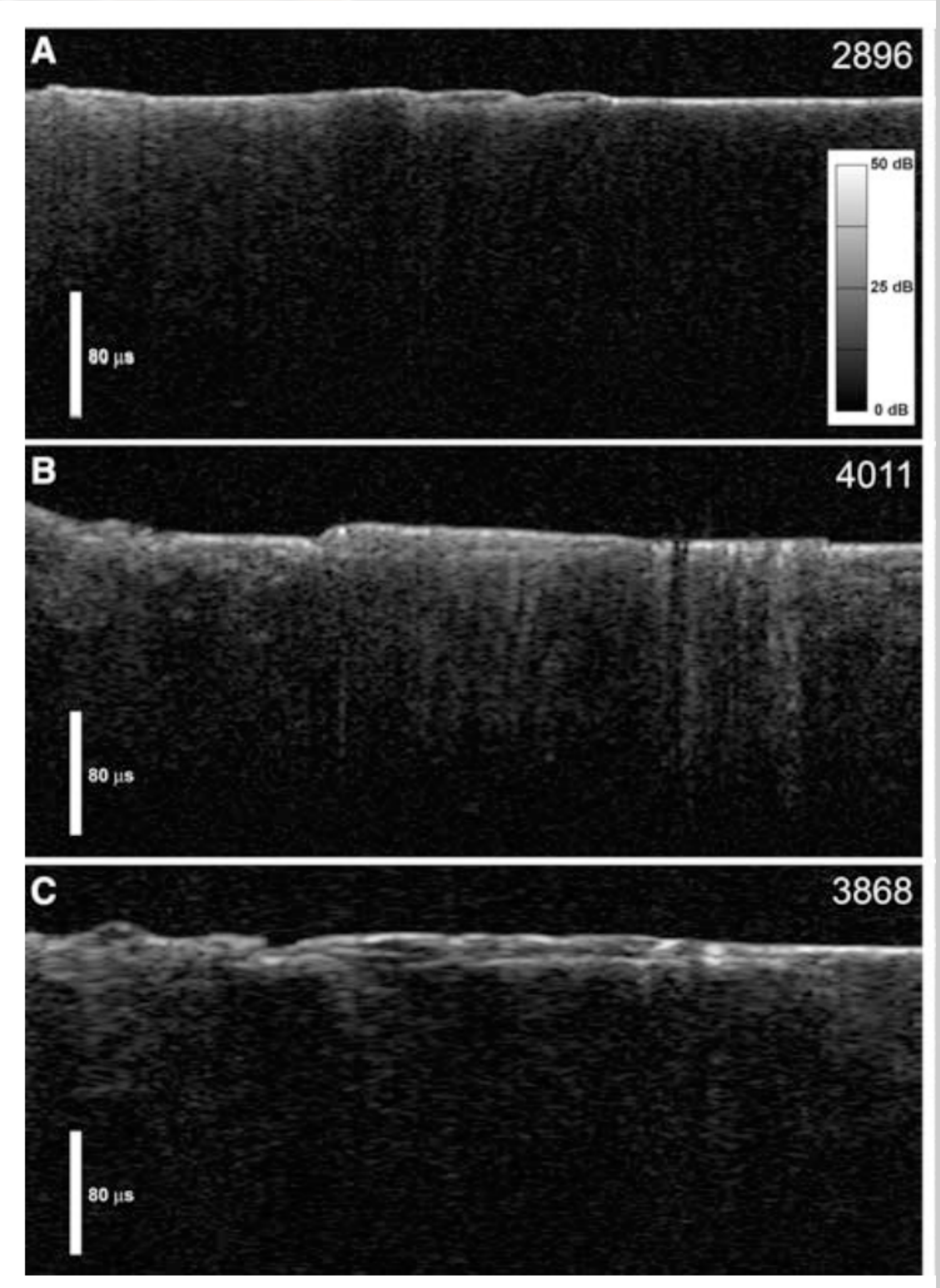
Watters et al., Science, 2007

Radar times to an apparent basal return of the . Medusae Fossae formation indicate a low dielectric constant consistent with either water ice or a low-density deposit such volcanic ash.

At the time, other data didn't demonstrate a clearly favorite of these interpretations.

Most people leaned toward the ash hypothesis. But this is an unsettled debate…



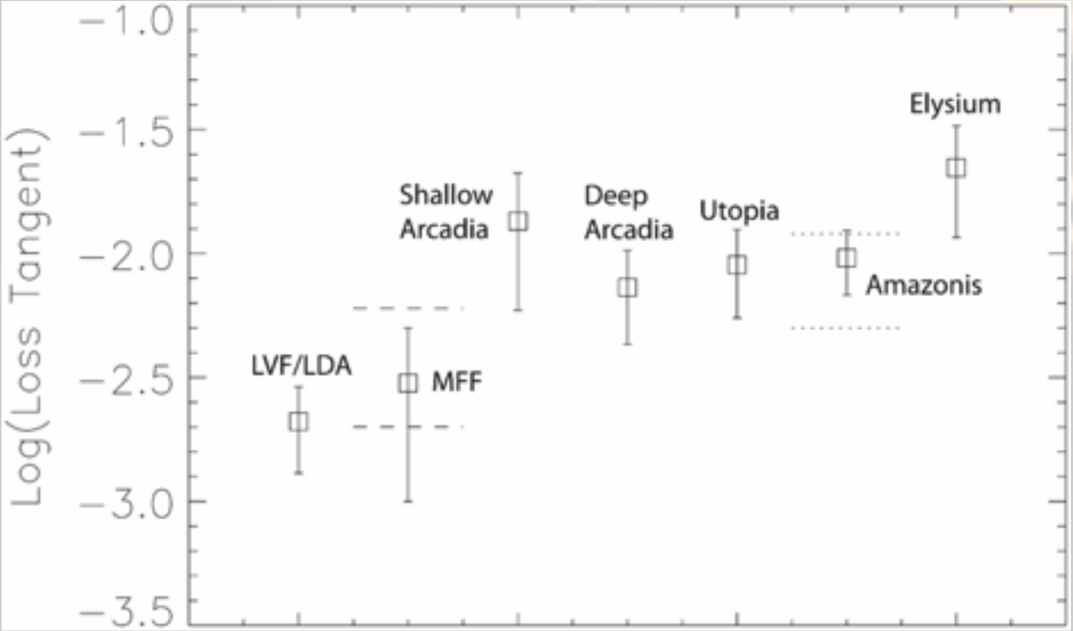


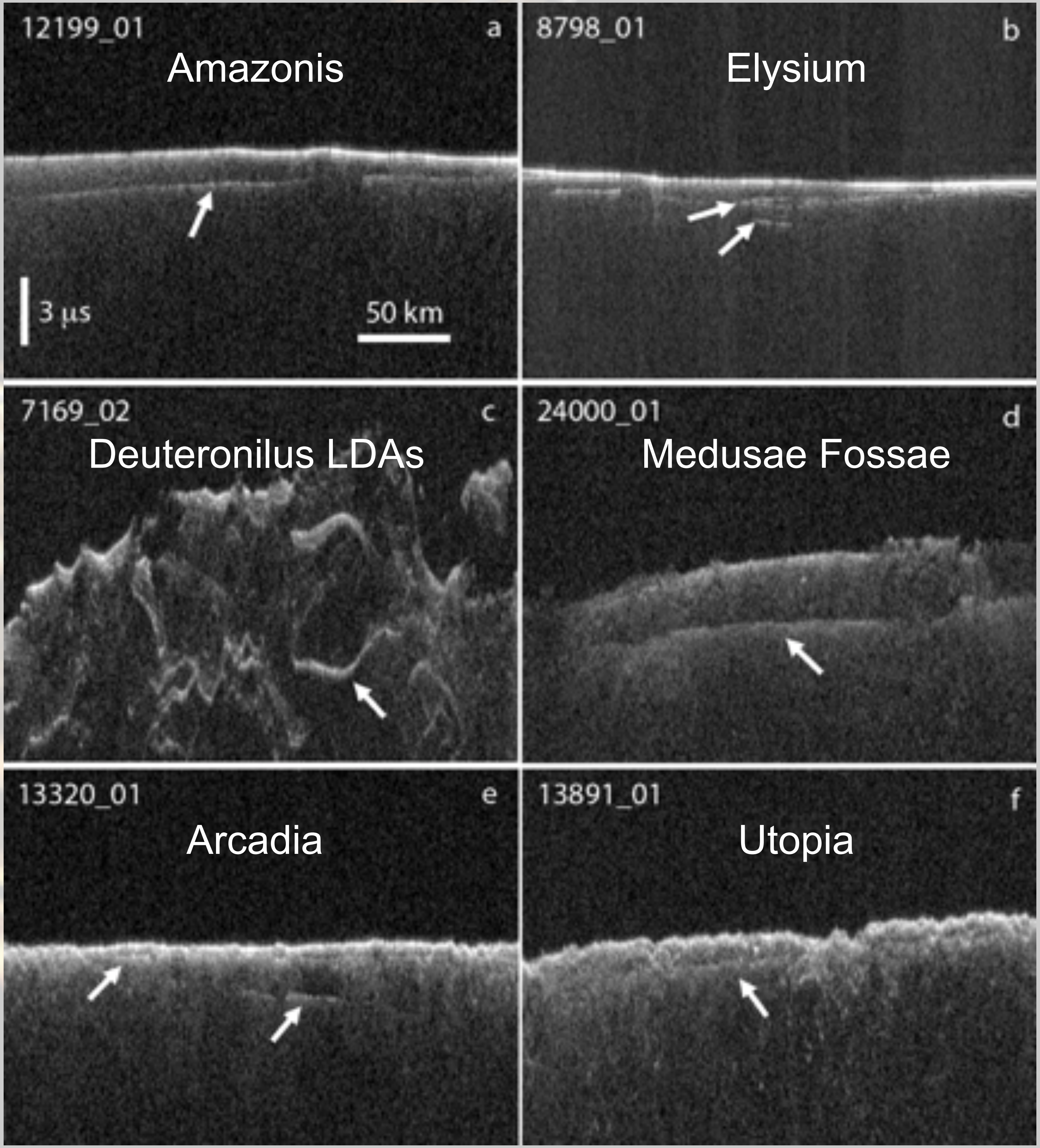
Breaking news…

Measuring Dielectric Losses in Potential Ice-Rich Terrain

Campbell and Morgan, GRL, in press

- **Analyzed variations in SHARAD power w/ frequency to measure loss tangent.**
- **Higher loss points to sediment/rock, lower loss may indicate water ice.**
- **Results show that:**
  - **Amazonis and Elysium materials are consistent with rock/dry sediments.**
  - **Lobate debris aprons and lineated valley fill are dominated by ice.**
  - **<u>Medusae Fossae materials are close in loss to LDAs, consistent with a large fraction of ice over full depth.</u>**
  - **<u>Arcadia and Utopia mantling materials have higher losses, allowing for only thin veneers of near-surface ice.</u>**





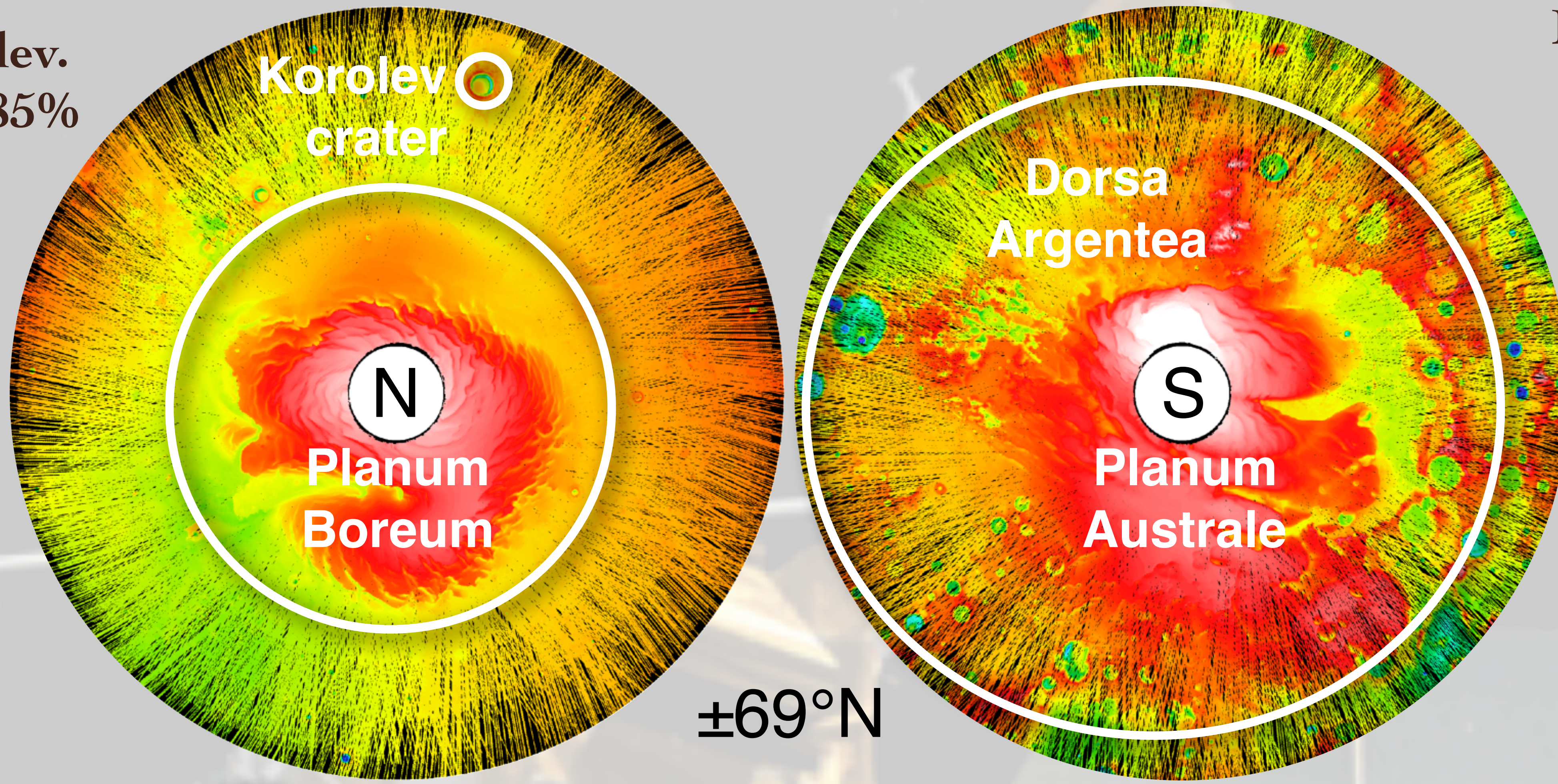
What have we learned?

- Radars have shed new light on the nature and timing of the polar deposits and their connection to the global climate of Mars.
- Strong basal returns show that mid-latitude glaciers are ice-rich, under a veneer of debris that is too thin for SHARAD to resolve.
- Weaker returns in other areas may represent extensive deposits of ground ice, extending into zones accessible to human missions.

Current SHARAD Coverage

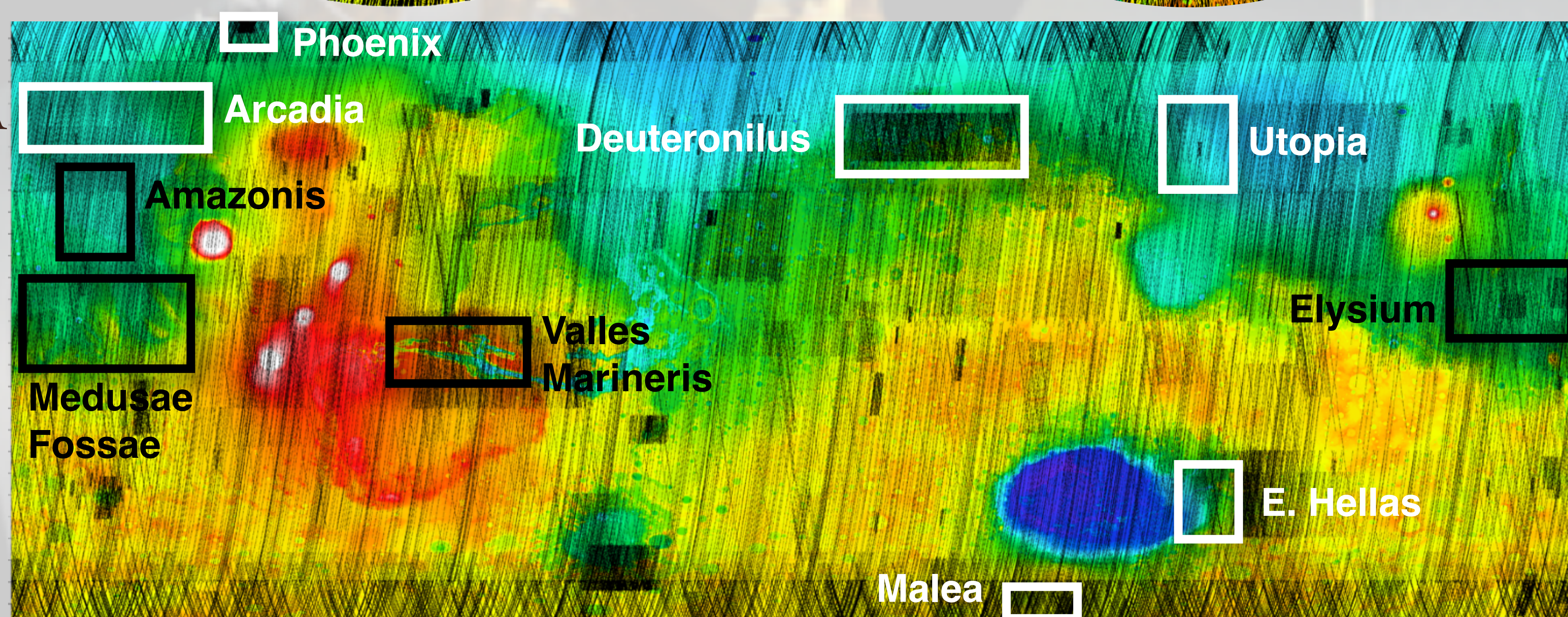
@ 3 km resolution

In MOLA elev.
N: 88%   S: 85%



Detections in **ice-rich** and **non-ice** terrains

In black <u>over</u> MOLA elev: 31%



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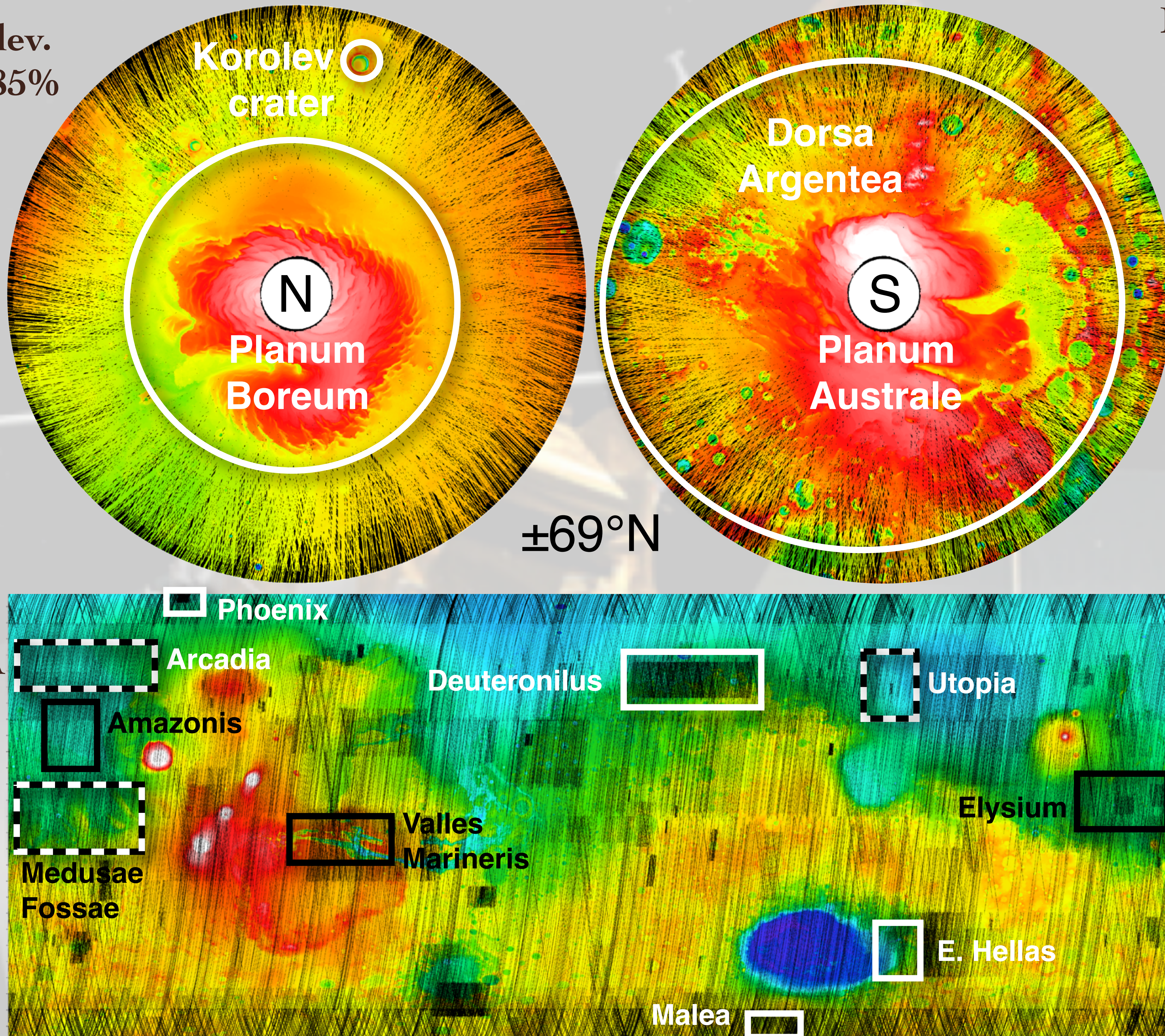

Detections in
ice-rich
and
non-ice
terrains

In black
over MOLA
elev: 31%

What do we need to learn?

- If we are really going to send people to Mars, we need better means to locate accessible ice and establish its depth and concentration.
- To do so over broad areas, we need a new orbital radar sounder operating with a broad bandwidth at higher frequencies.
- At landing sites, we need rovers equipped with ground-penetrating radars — as well as other tools, e.g., geophones and active seismic sources — and a means to mine the water!

Thank you!