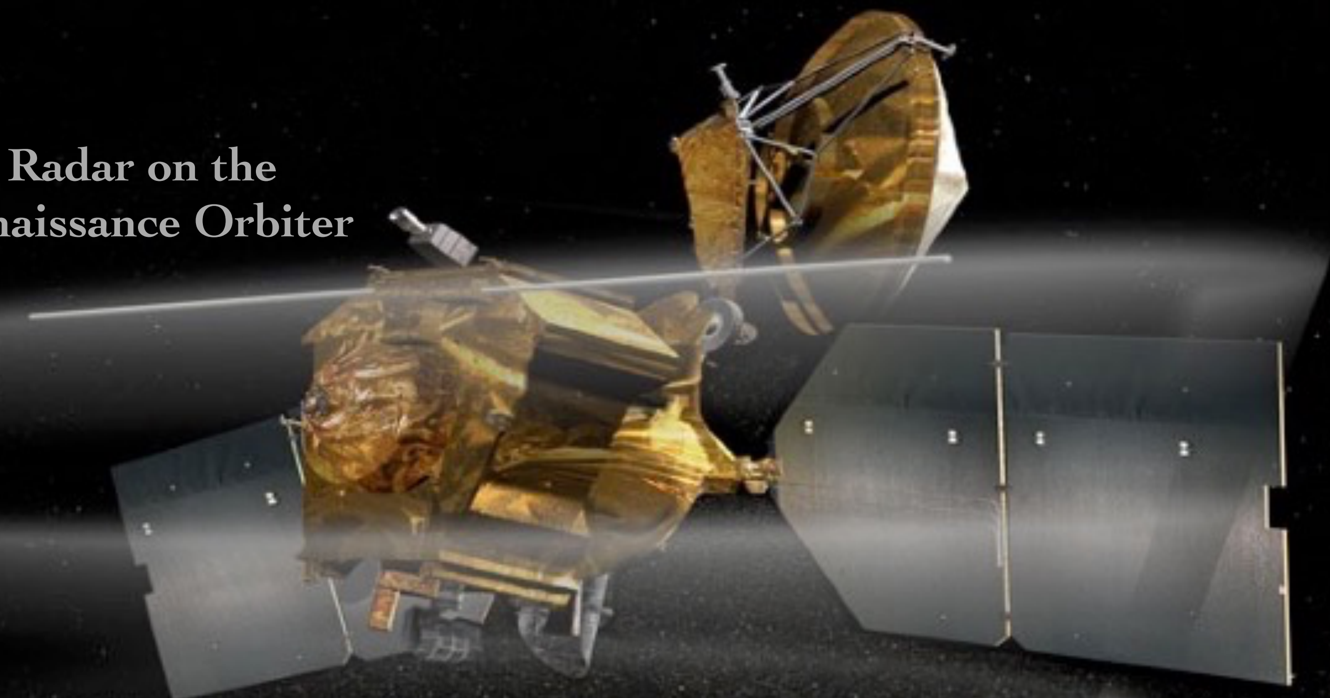
SHARAD:
The Shallow Radar on the
Mars Reconnaissance Orbiter



Remote-Sensing Approaches from Orbit and Surface: Radar and Seismic Methods

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

KISS Workshop - 2017 August 9

Image credit: NASA/JPL

SHARAD objective: Map subsurface dielectric interfaces and interpret them in terms of the occurrence and distribution of expected materials, including rock, regolith, water, and ice.

Animation available at: https://www.nasa.gov/mission_pages/MRO/multimedia/sharad-20080515.html

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

MRO altitude: 255 to 320 km

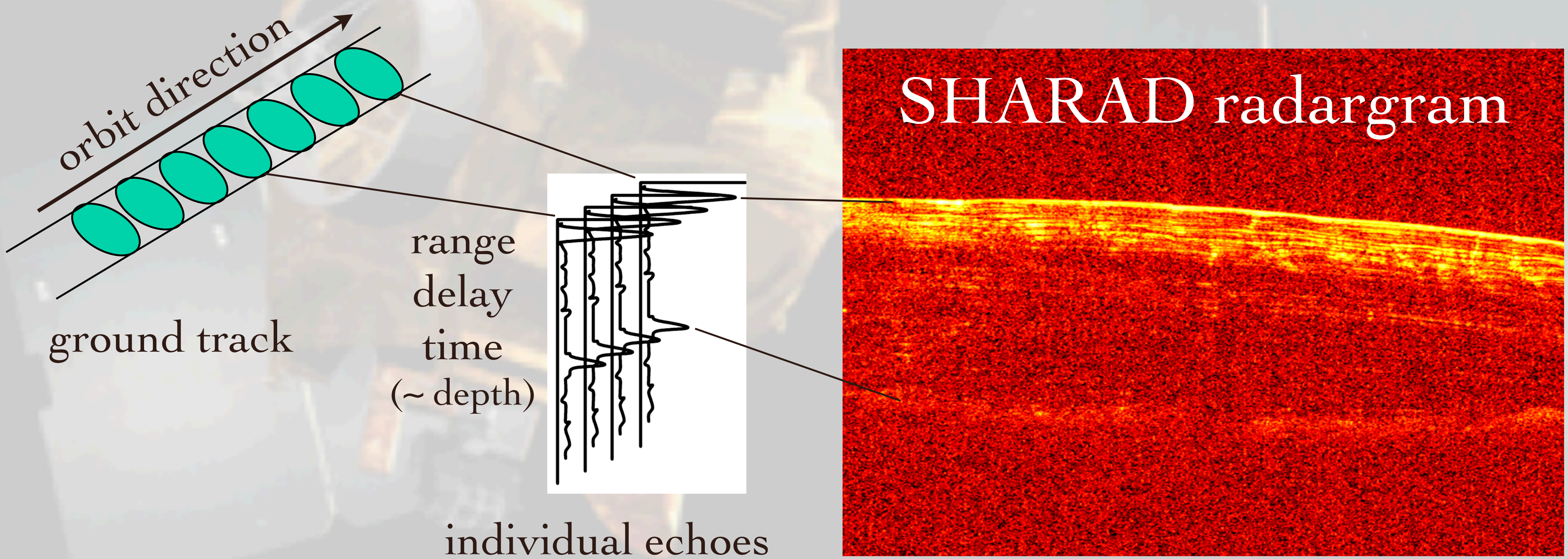
Wavelength: 15 m (~8-m vertical resolution in water ice)

Transmitted sweep: 25 to 15 MHz

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

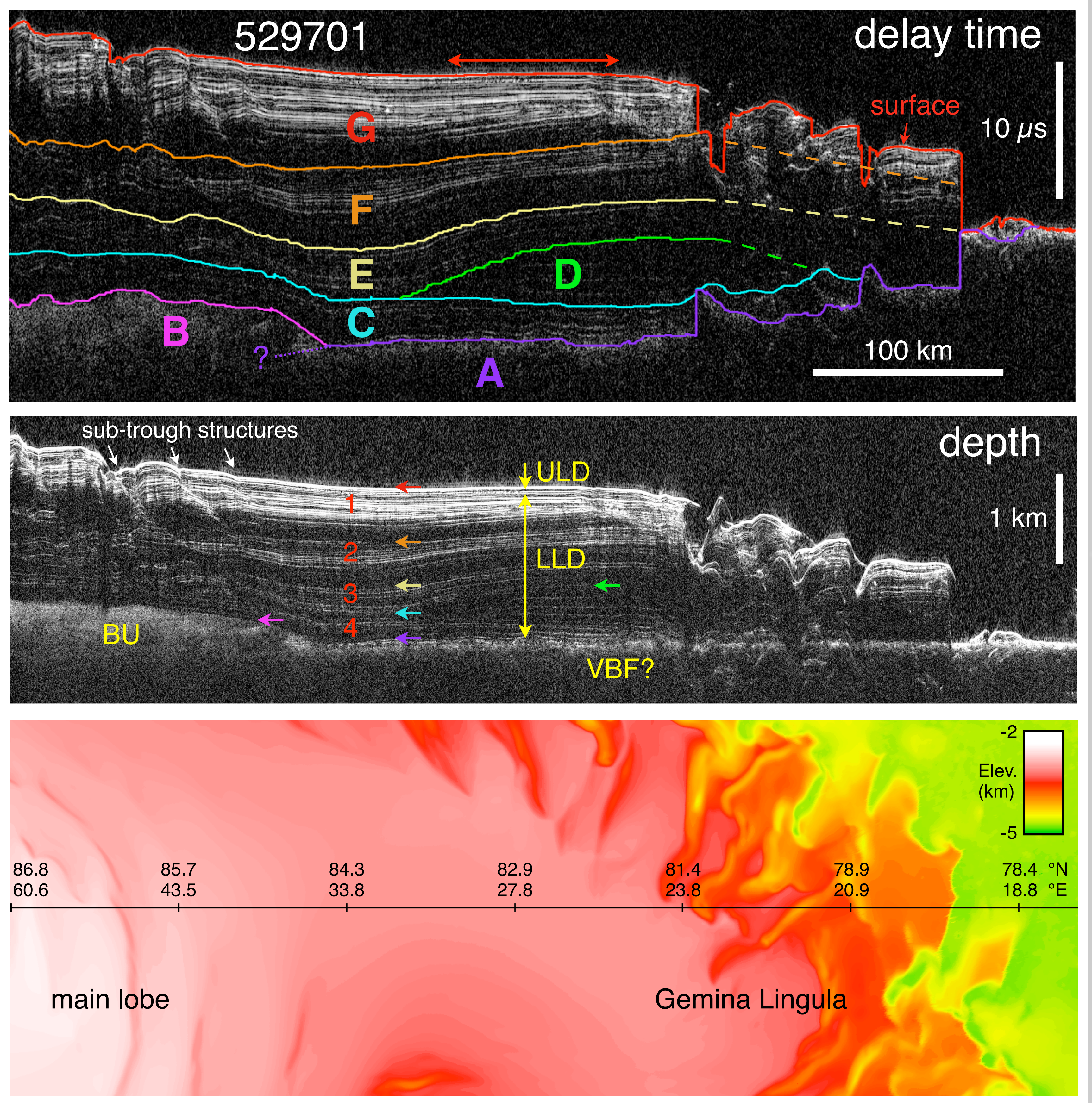
Mars orbital radar acquisition

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



2-D radar analysis

- Delineate units and reflectors.
- Interpolate through clutter* and between orbital tracks.
- Map reflecting surfaces in 3D, calculate volumes.



Putzig et al. (Icarus 2009)

**Clutter = interfering off-nadir returns*

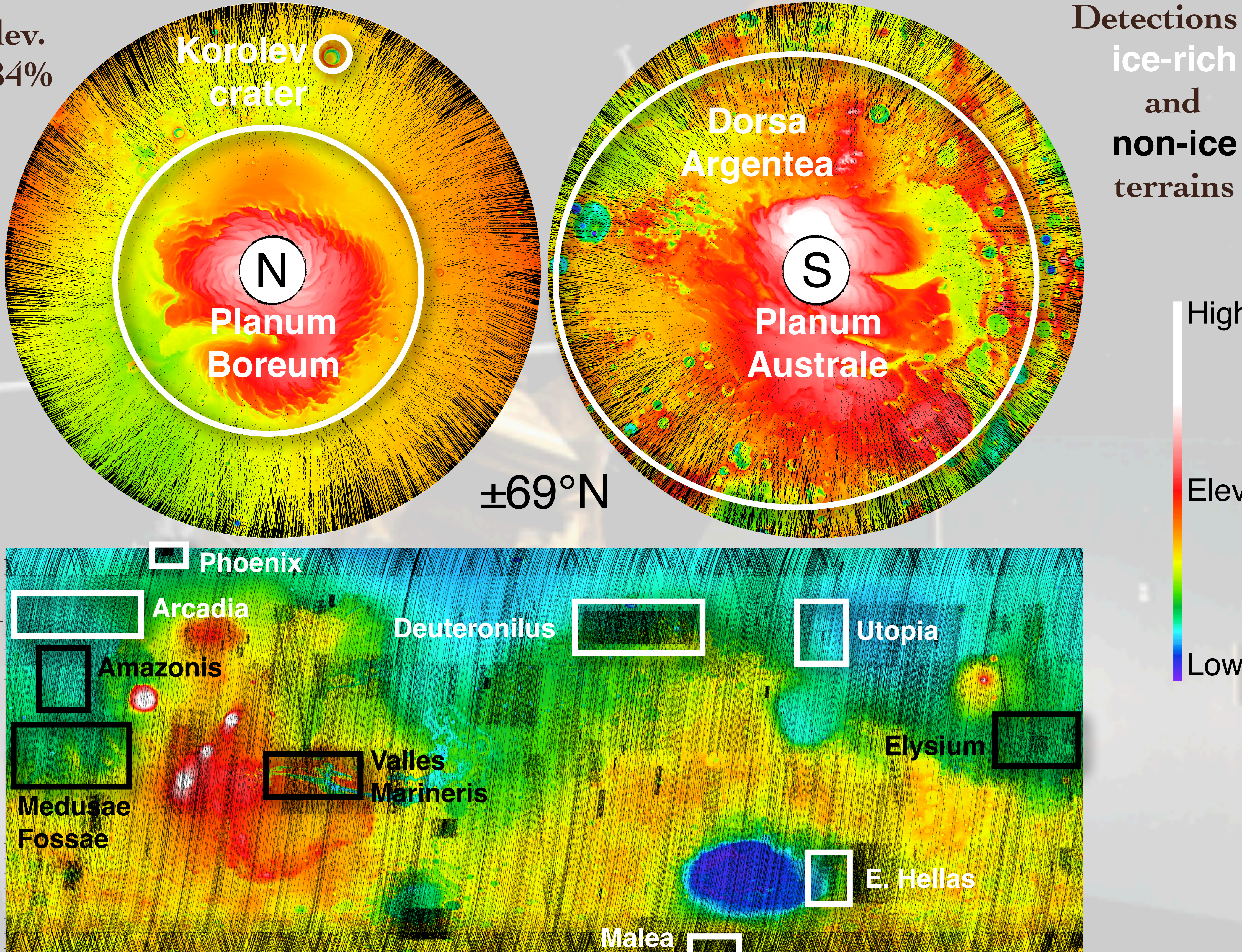
Current SHARAD Coverage

@ 3 km resolution

In MOLA elev.
N: 85%   S: 84%

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

In black over MOLA elev: 25%



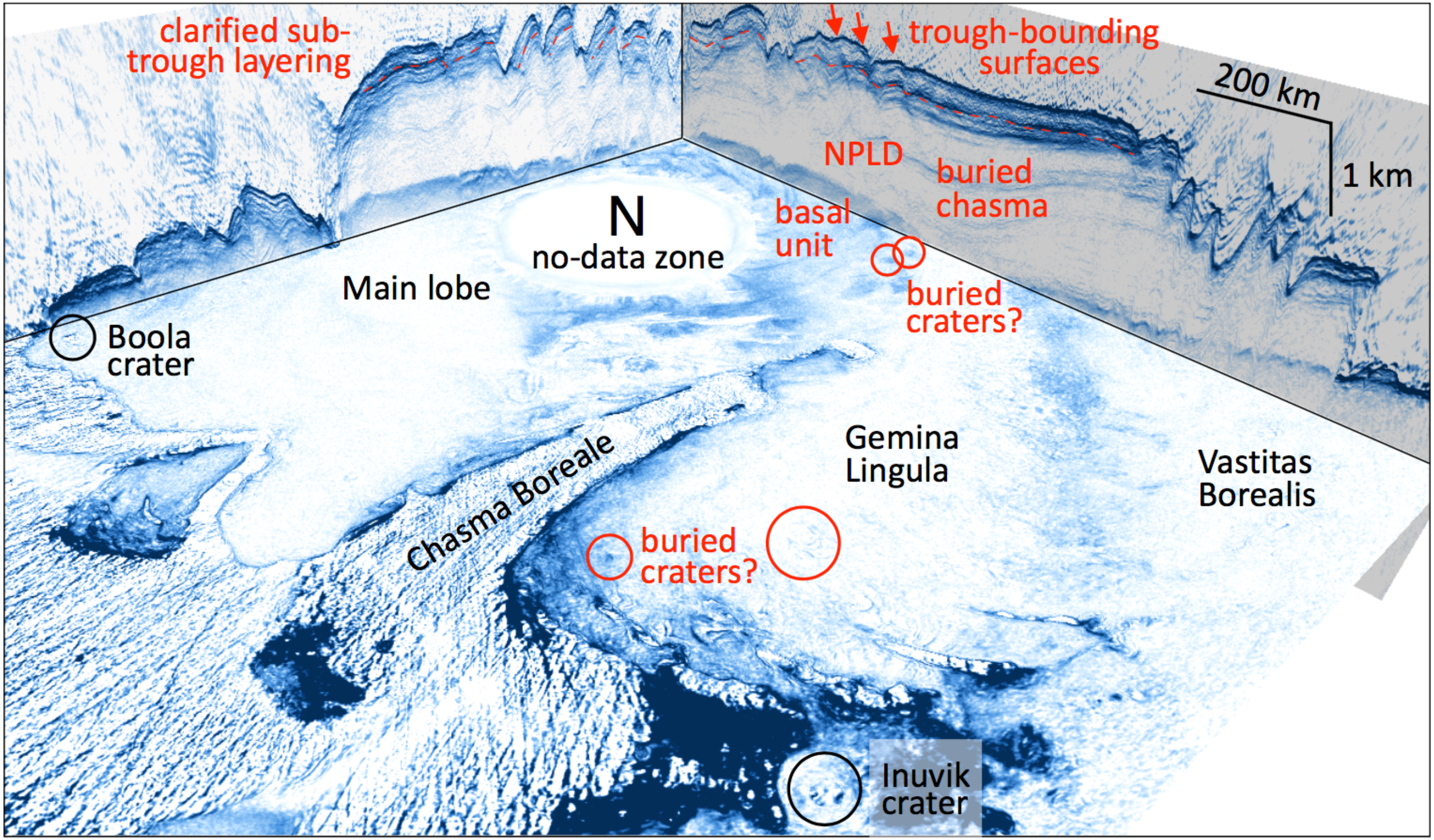


Figure 2. Cut-away perspective view (toward 150°E) into the depth-converted Planum Boreum SHARAD 3-D volume, showing radar-return power (blue high, white low) from previously known (black) and buried (red) features within the north polar cap. The SHARAD no-data zone is due to MRO's orbit inclination. Depth conversion assumes pure water ice ($\epsilon' = 3.15$). Scale is approximate (varies in this perspective), with vertical exaggeration of 136:1.

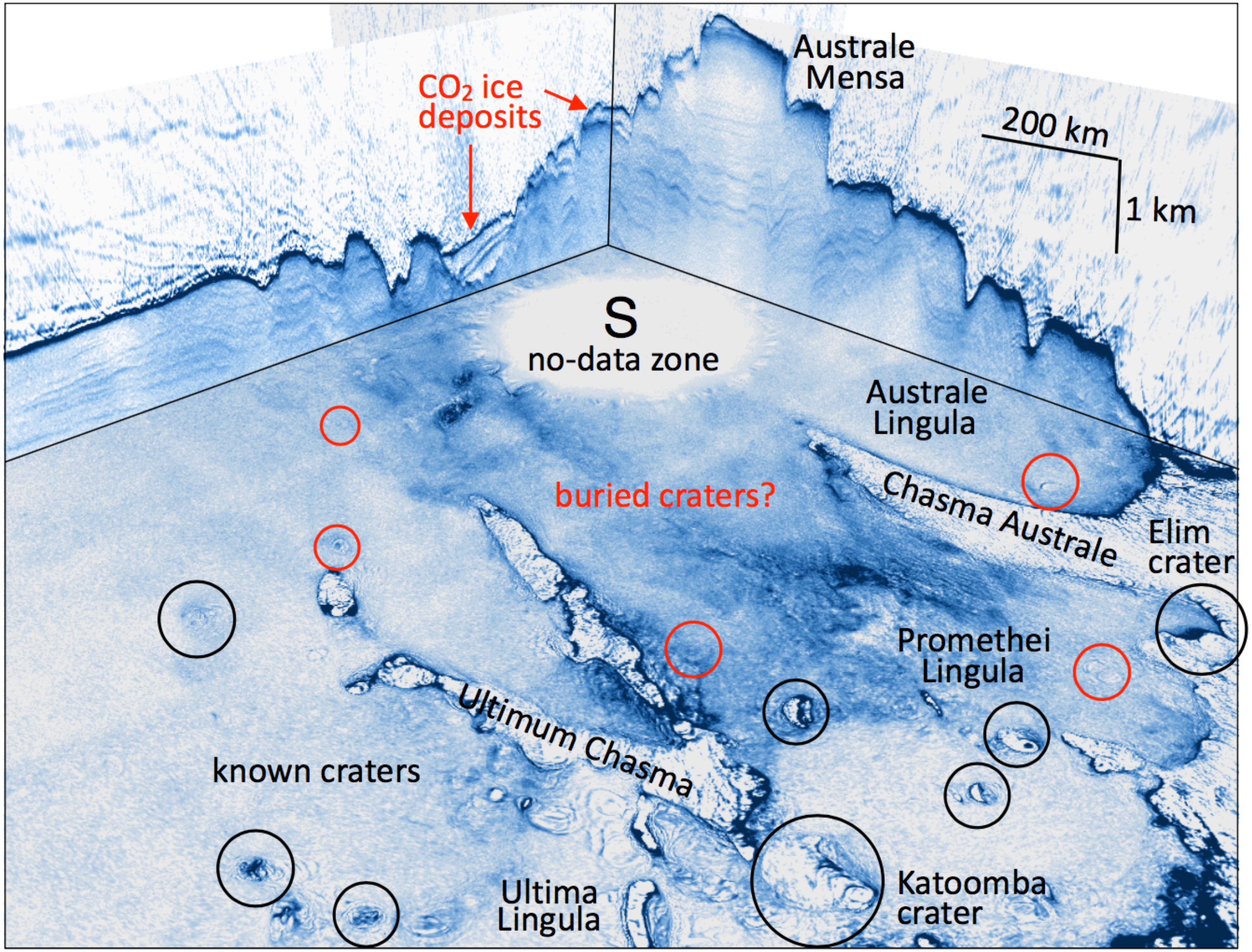
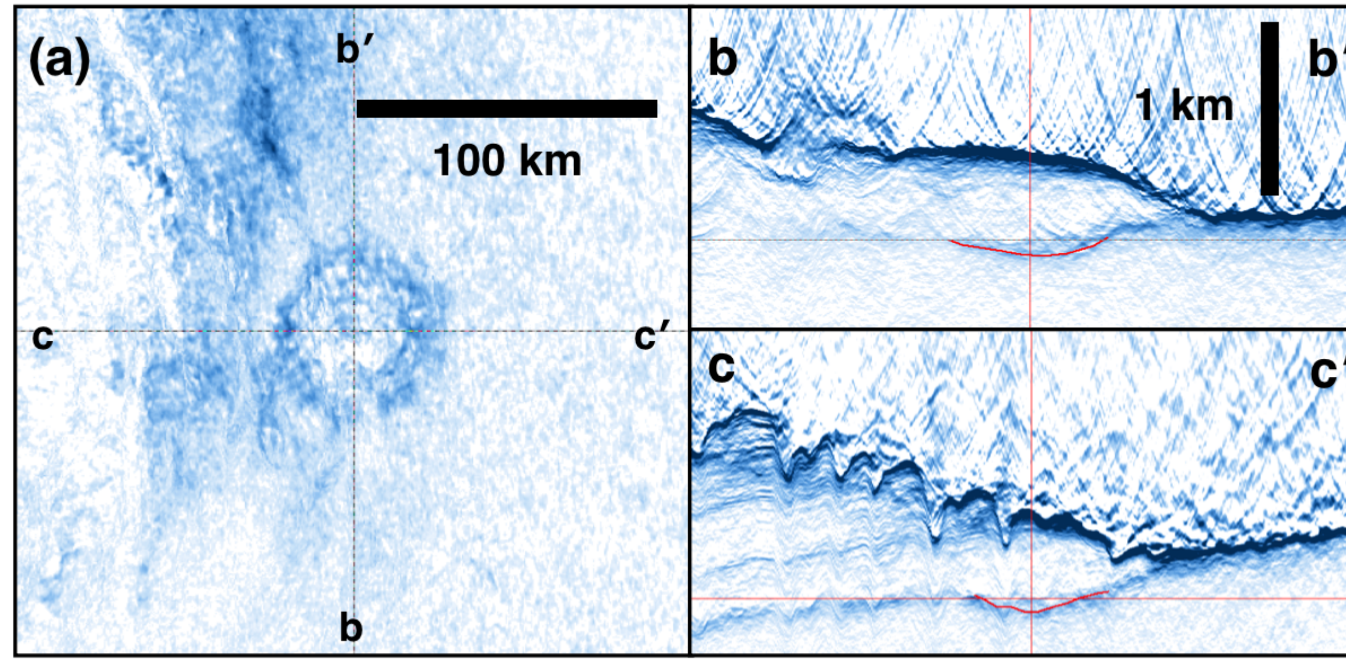


Figure 3. Cut-away perspective view (toward 315°E) into the depth-converted Planum Australe SHARAD 3-D volume, showing radar-return power (blue high, white low) from previously known (black) and buried (red) features within the south polar cap. The SHARAD no-data zone is due to MRO's orbit inclination. Depth conversion assumes pure water ice ($\epsilon' = 3.15$). Scale is approximate (varies in this perspective), with vertical exaggeration of 136:1.

Putzig et al. (in rev.)

Orthogonal views within SHARAD 3-D volume (right) show bowl-shaped features consistent with buried impact craters.

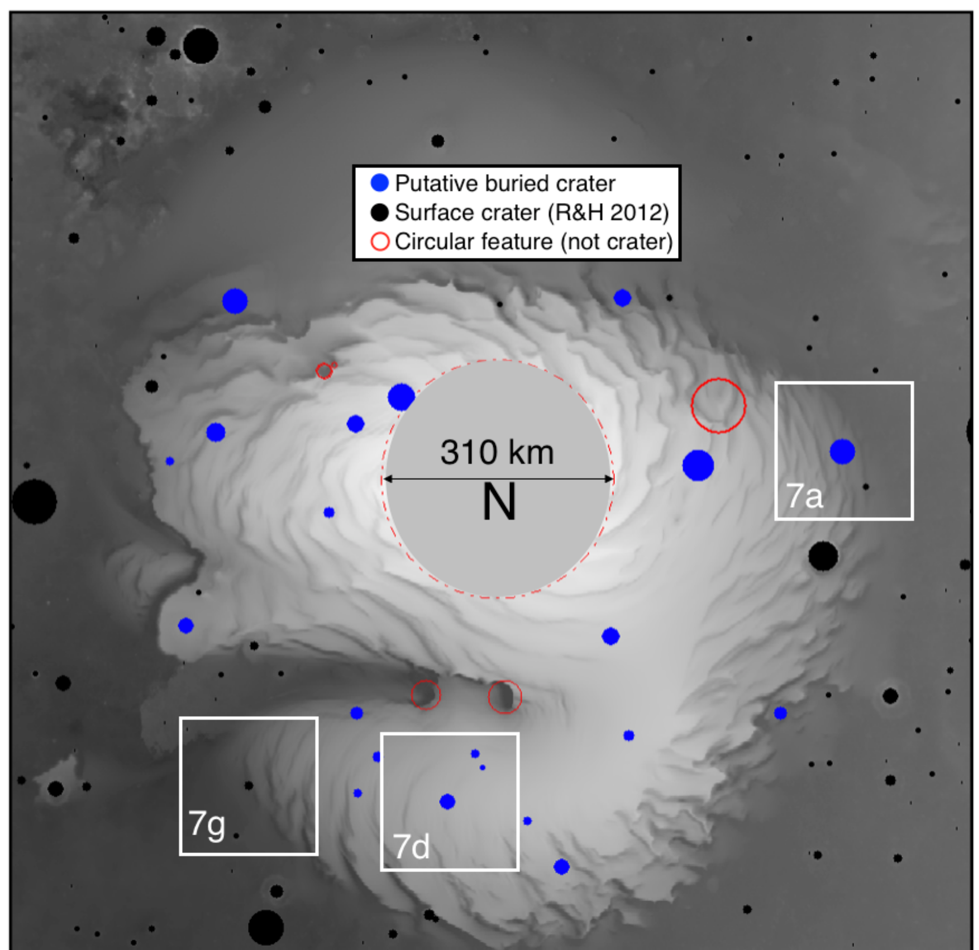
To test the impact-crater hypothesis for these features, we mapped all apparent craters at the base of the finely layered ices. If that buried surface is of the same age as the plains surrounding the ice cap, then one may expect to find a similar distribution of craters.



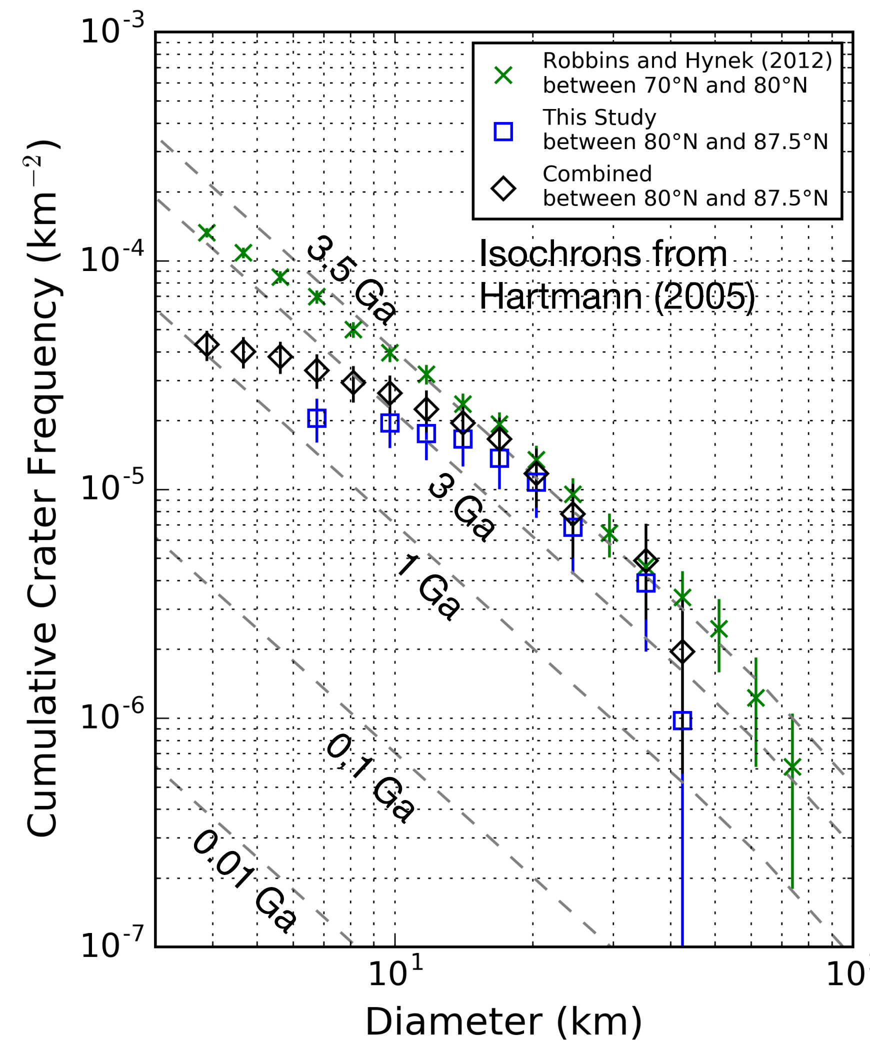
SHARAD 3-D depth slice (a) shows circular planform and orthogonal vertical profiles (b-b’, c-c’) reveal a depression consistent with an impact crater at the base of the ice.

We found 21 fully buried apparent craters (blue circles) with diameters of 7 to 45 km at the base of the icy layers. Smaller craters are difficult to image with the SHARAD resolution limits.

The overall distribution matches well with that of the surrounding plains (graph, far right), with an age of 3.5 billion years.



Map of known (black) and buried (blue) craters at base of north polar layered deposits.



What's Next?

From the MEPAG Report of the Next Orbiter Science Analysis Group (NEX-SAG)

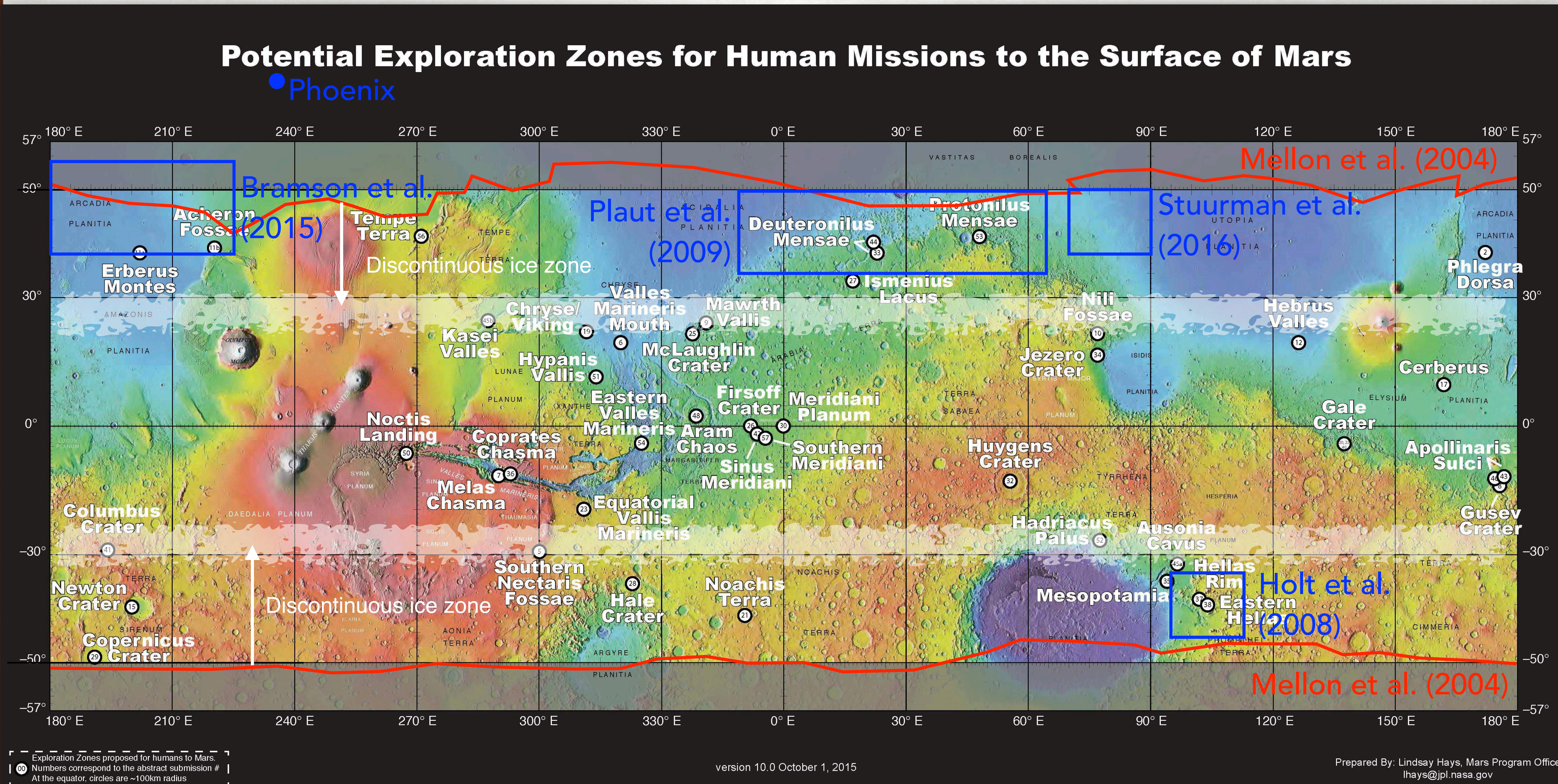
- **Polarimetric synthetic aperture radar (PSAR)** for:
  - Imaging mode (side-looking) to map shallow (<10 m) **ground ice at ~15 m lateral resolution**.
  - Sounding mode (nadir-pointing) to:
    - Map thickness, volume of **perennial CO_2 ice** at S pole
    - Map **upper (50-100 m) PLD at (~10-cm) resolution**.
- A **separate sounder might be ideal**, but could be a harder sell (likely more mass, a second team of investigators).

Sounding at the surface

- I don't believe much thought has been given to subsurface sounding from the surface for polar regions of Mars.
- So let's think out of the box and consider what's going on at lower latitudes…

PROPOSED HUMAN LANDING SITES

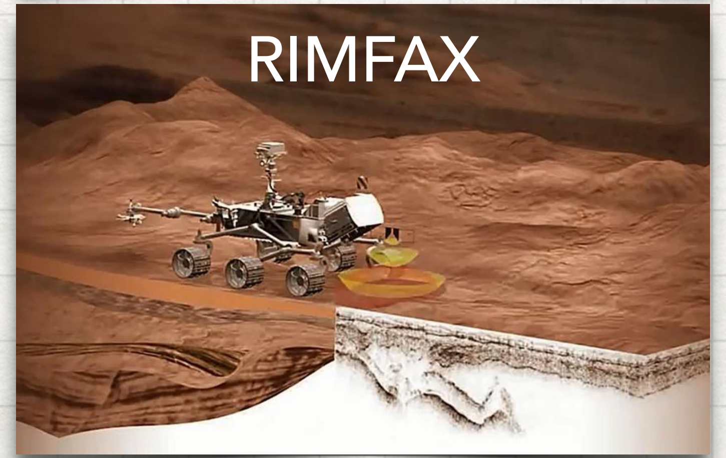
WITH 30-CM ICE STABILITY AND SHARAD ICE BASAL DETECTIONS



THE ELEPHANT IN THE ROOM

IS THERE ACCESSIBLE WATER ICE?

- MONS and thermal data are limited to detections above ~1 m while SHARAD is limited to detections below ~20 m. **There is no current capability at Mars to detect interfaces between 1 and 20 m depth.**
- Mars 2020 and ExoMars rovers will have ground-penetrating radars (GPRs) purportedly capable of detecting ice in this zone.
- NEX-SAG: Next MRO-class orbiter may have a radar capable of detecting ice in this zone.



FLY IN THE OINTMENT

WILL NEW RADARS ACTUALLY DO THE TRICK?

- Terrestrial GPRs are often limited to a couple meters depth (largely in wet soils).

- SHARAD detects basal interfaces of ice in a few areas, but **vast regions – in and out of MONS-detected ice zones – have no SHARAD returns.**

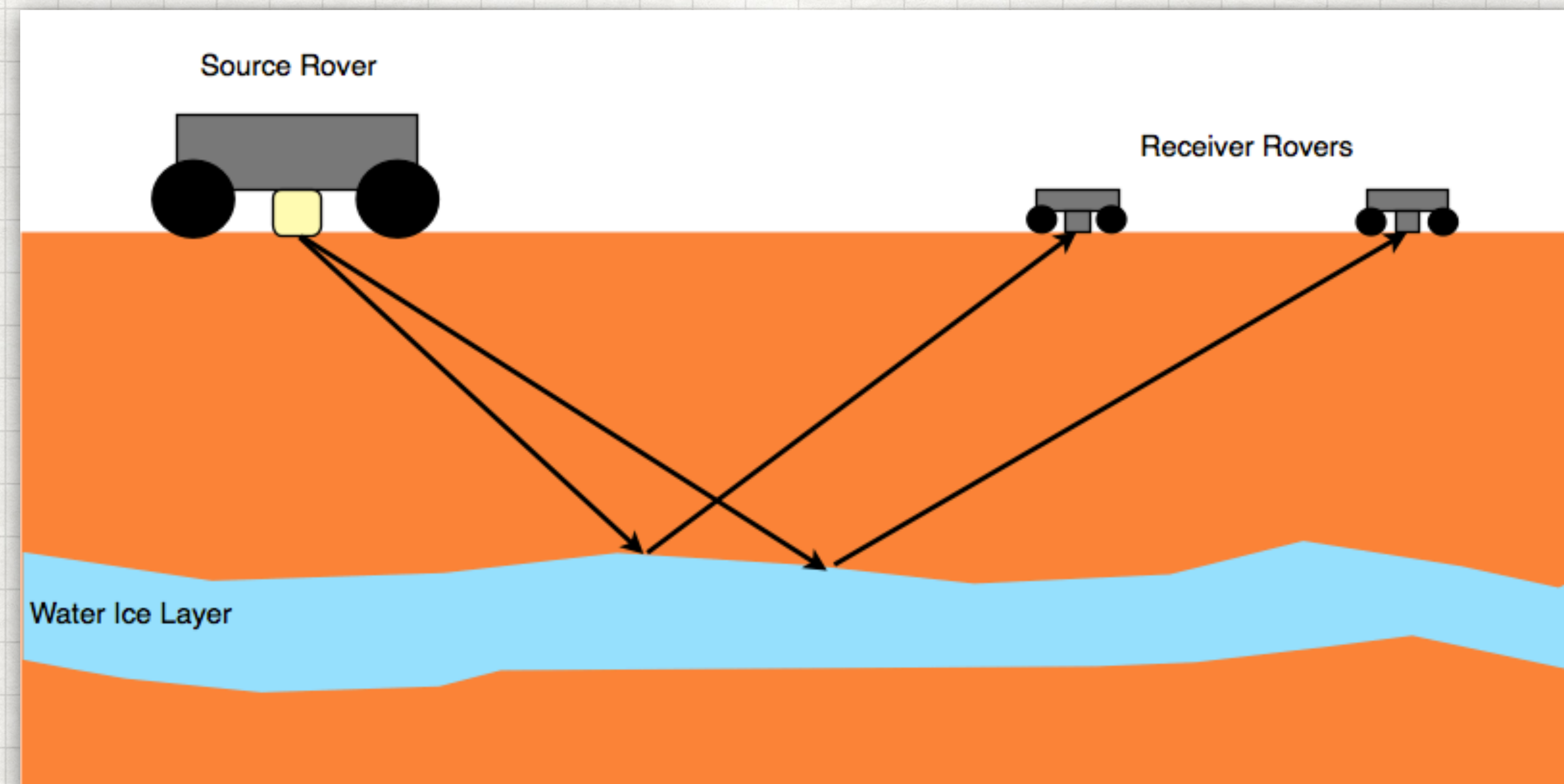
- This lack of widespread SHARAD returns may be due to **severe attenuation of the radar signal by iron oxides or hydrated minerals** [e.g., Stillman and Grimm, 2011].

B2 Stealth Bomber (Image credit: www.defense.gov)

A SOUND ALTERNATIVE

ACTIVE-SOURCE SEISMIC METHODS

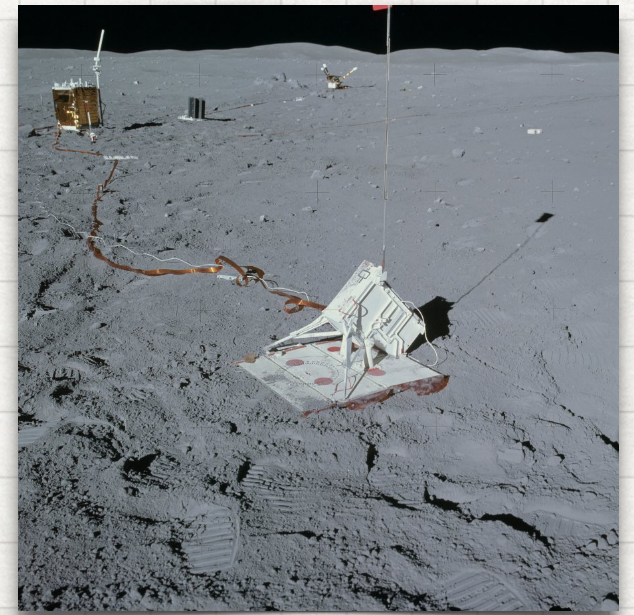
Seismic methods use acoustic waves, which are not subject to the same scattering and attenuation considerations of radar. A fixed or mobile source combined with one or more mobile receivers can map out a profile or volume of subsurface data. The offset between elements enables analysis of subsurface properties.



SEISMIC SURVEY EQUIPMENT

SOURCES AND RECEIVERS

Sources:	Vibrating or impulsive (e.g., explosive, air gun, weight drop)
Receivers:	Typically 1- or 3-component geophones (ground-motion sensors)
	⇒ less sensitive/complex vs. earthquake/InSight-class seismometers



The mortar used during Apollo 16 for the Active Seismic Experiment (NASA image).

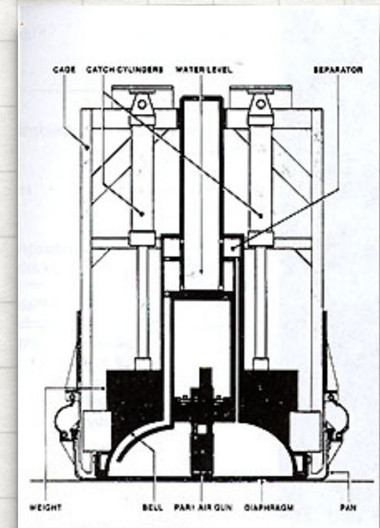


Figure 2. Land Air Gun

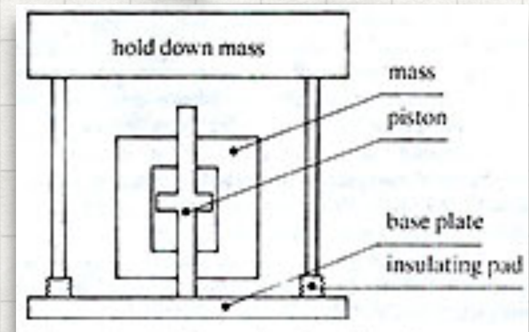


Figure 3. Schematic for vibrator.

Figures from: http://www.geol.lsu.edu/jlorenzo/ReflectSeismol97/eczimmermann/WWW/eczimmermann.html

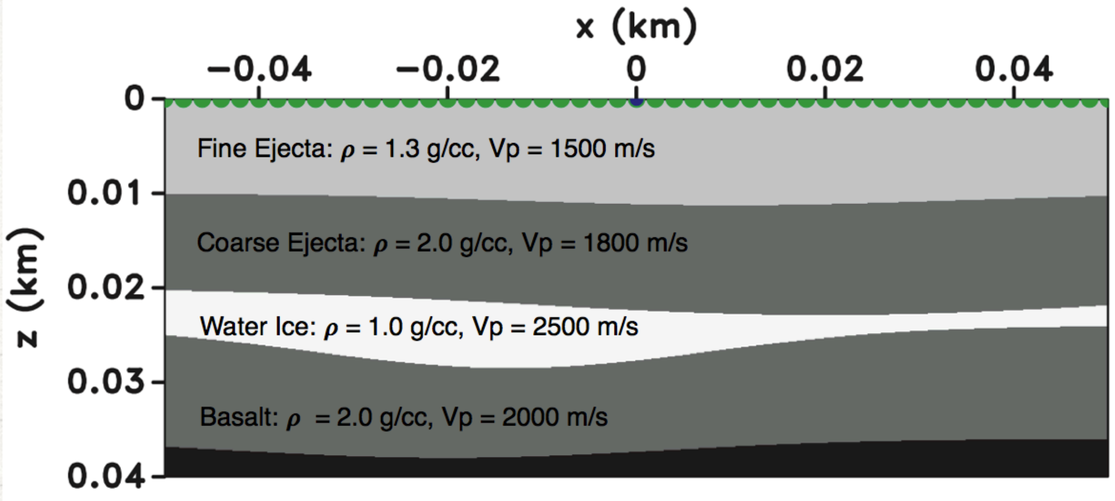
The NuSeis *NRU 1C* Wireless, entirely self-contained geophone [Geophysical Technology, 2017].

The Colorado School of Mines *Geobot*. An autonomous survey tool that can be remote controlled or follow a pre-programmed path. Here it is outfitted to preform GPR surveys, but it could be used to transport seismic sources or wireless receivers.

SEISMIC MODELING

SAM COURVILLE, SENIOR DESIGN (CSM)

2-D cross section for a potential target scenario. Green dots at top are receiver locations. Model is a case where SHARAD would likely be unable to differentiate the top and bottom of a thin ice layer.



Simulated seismic data from model with a single source at x=0. Traces running parallel to the travel-time (t) axis show amplitudes of reflected seismic waves at each receiver location.

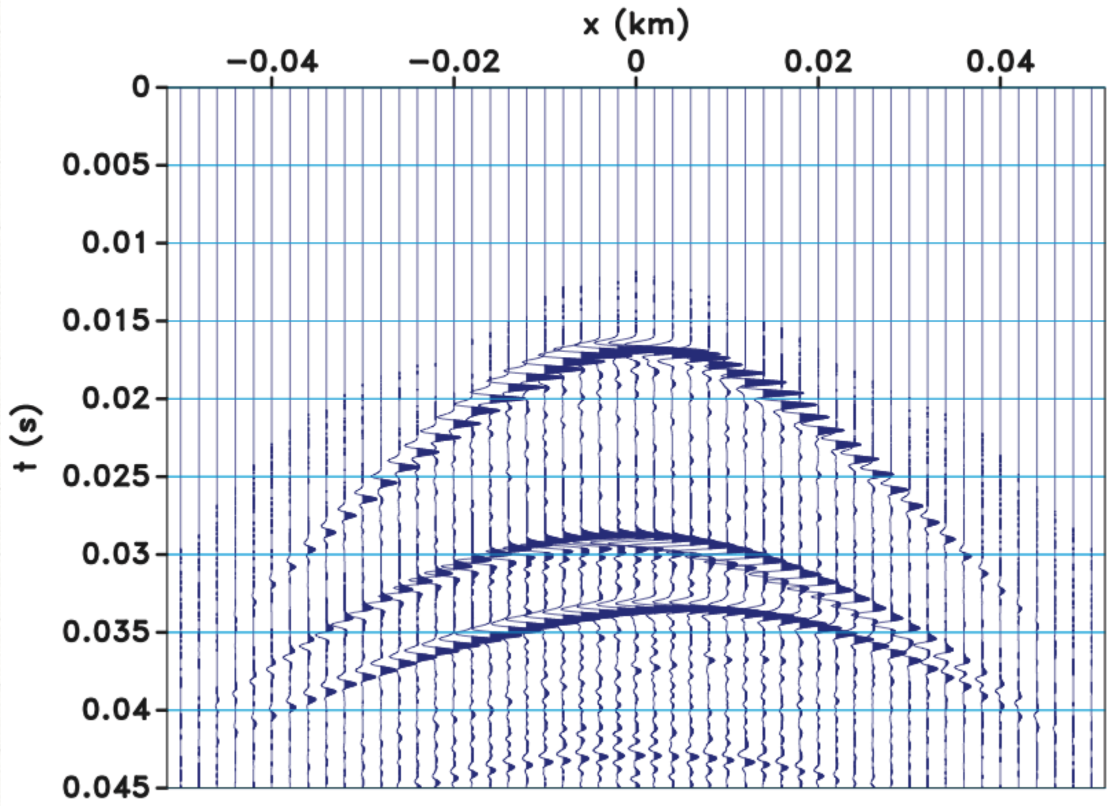
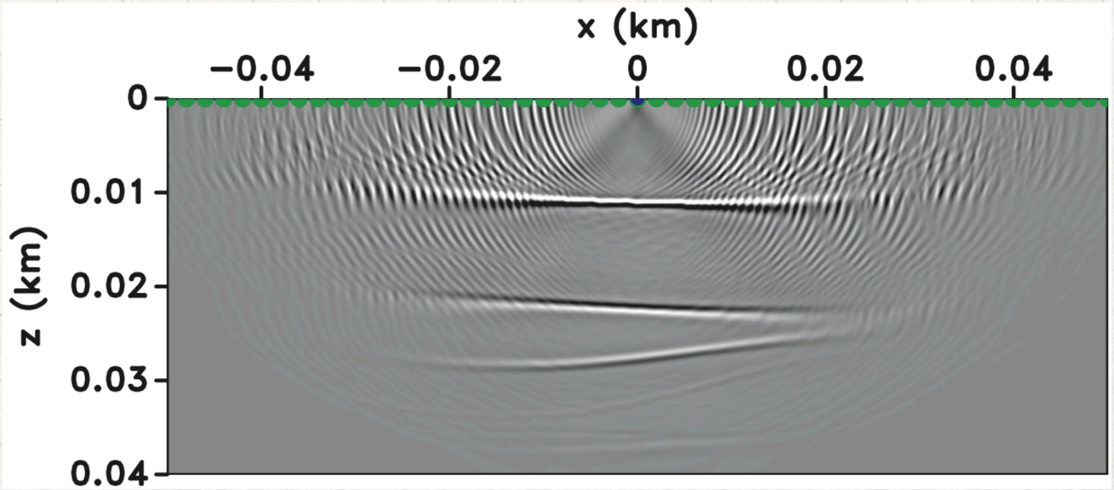


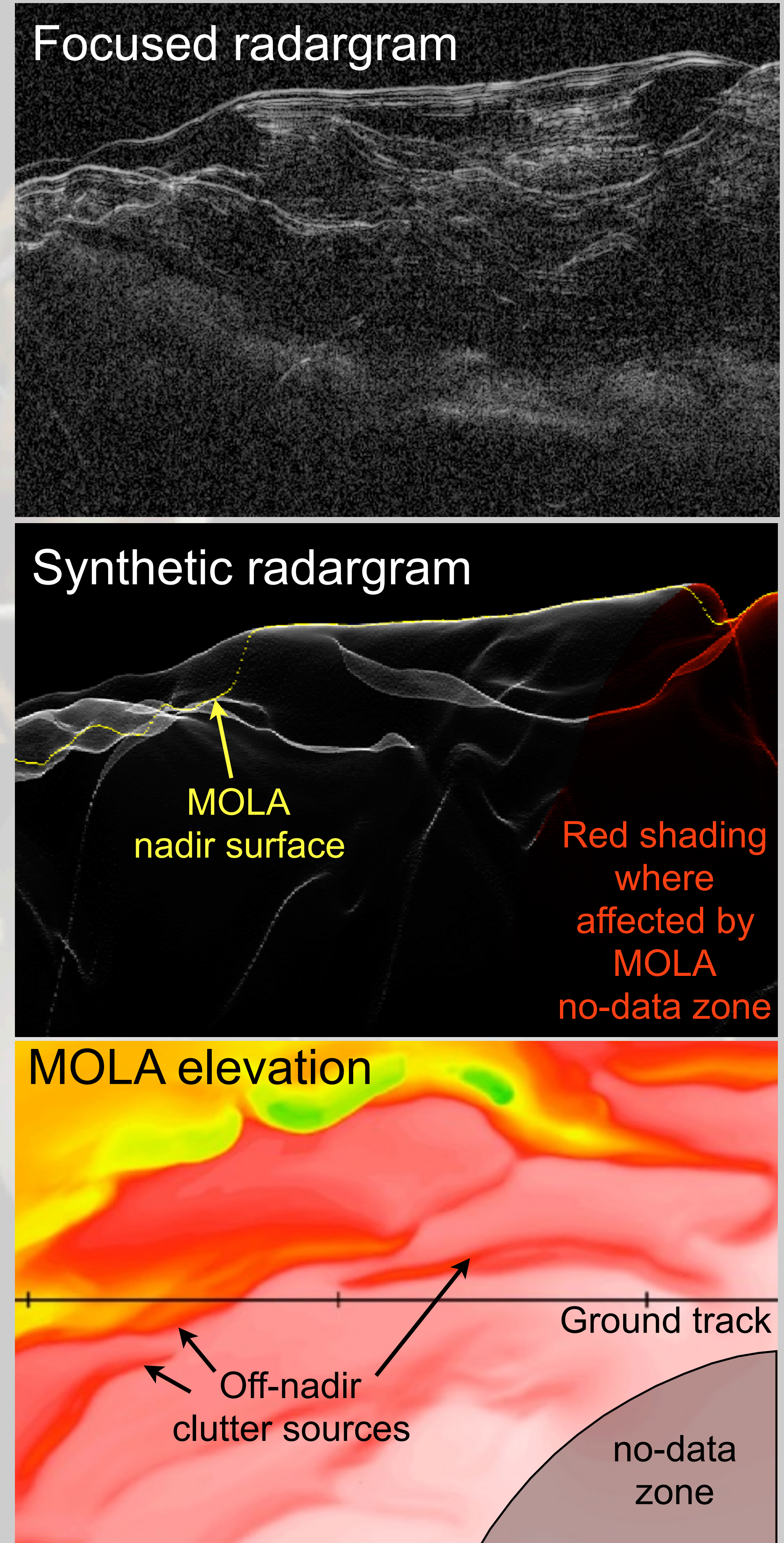
Image created from simulated data. Subsurface reflectors correspond to layer bounds within the model in top panel.



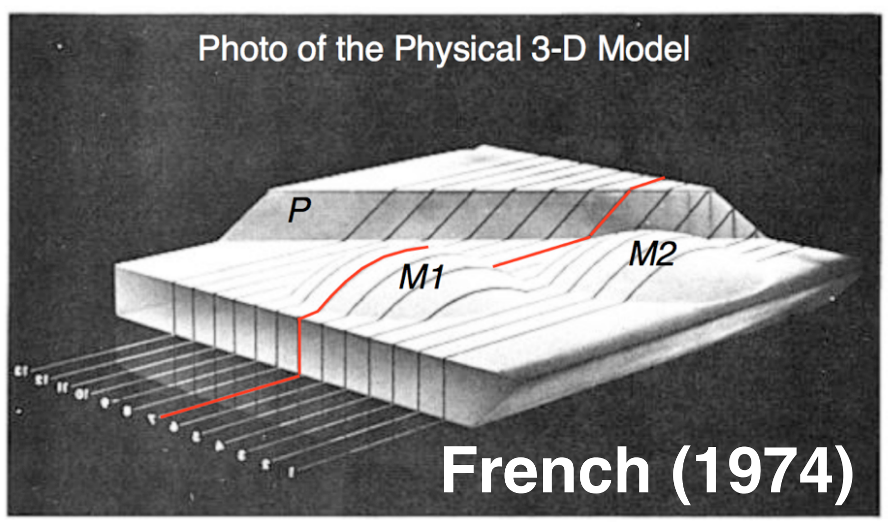
Limitations of 2D SHARAD analysis

- No returns from features at nadir that slope away from the radar.
- Off-nadir returns (clutter) interfere with or are mistaken for nadir returns. 2D radar focusing reduces inline clutter but distorts crossline clutter.
- Synthetics help identify surface-clutter signals, which are then dismissed as "noise."
- In many areas, intense clutter can make data largely uninterpretable.

Mapping features at depth is often challenging and tedious.



Solution: Apply 3-D migration processing



3-D migration will **collapse diffractions (D)** and **reposition out-of-plane returns (M2)** to their source locations. Energy from adjacent profiles will be restored, thereby **imaging features oriented obliquely to the profile (P)**.