Mapping ice deposits on Mars through subsurface radar sounding

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MARSIS and SHARAD teams

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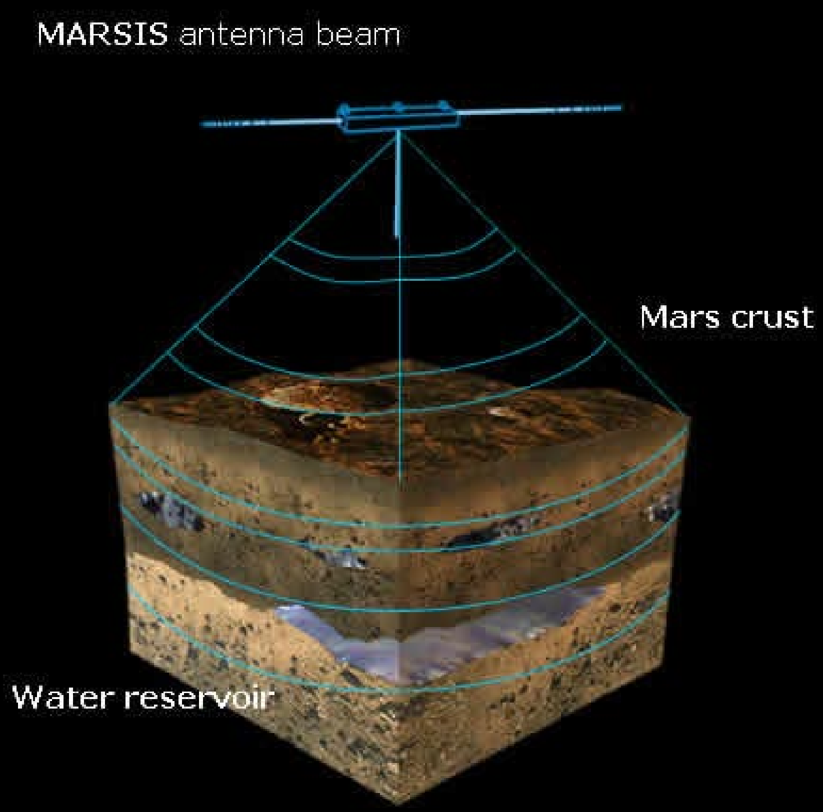
MARSIS and SHARAD

- MARSIS and SHARAD are synthetic-aperture, orbital sounding radars, carried respectively by ESA‘s Mars Express and NASA's Mars Reconnaissance Orbiter. They work by transmitting a low-frequency radar pulse that is capable of penetrating below the surface, and is reflected by any dielectric discontinuity present in the subsurface.
- MARSIS is capable of transmitting at four different bands between 1.3 MHz and 5.5 MHz, with a 1 MHz bandwidth. SHARAD operates at a central frequency of 20 MHz transmitting a 10 MHz bandwidth.
- Whereas MARSIS is optimized for deep penetration, having detected echoes down to a depth of 3.7 km over the South Polar Layered Deposits, SHARAD is capable of a tenfold-finer vertical resolution, namely 15 m or less, depending on the dielectric constant of the material being sounded.



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Getting to know the data

MARSIS and SHARAD data are affected by a number of artifacts:

- Clutter: lateral reflections reaching the radar after nadir echoes, can be taken for subsurface echoes
- Ionosphere dispersion: the echoes become blurred as different frequencies propagate at different speeds
- Multi-path propagation: changes in the refraction index of the ionosphere bend the ray in unexpected ways
- Variation of propagation velocity: within media with a dielectric permittivity greater than 1, it changes the apparent shape of subsurface features

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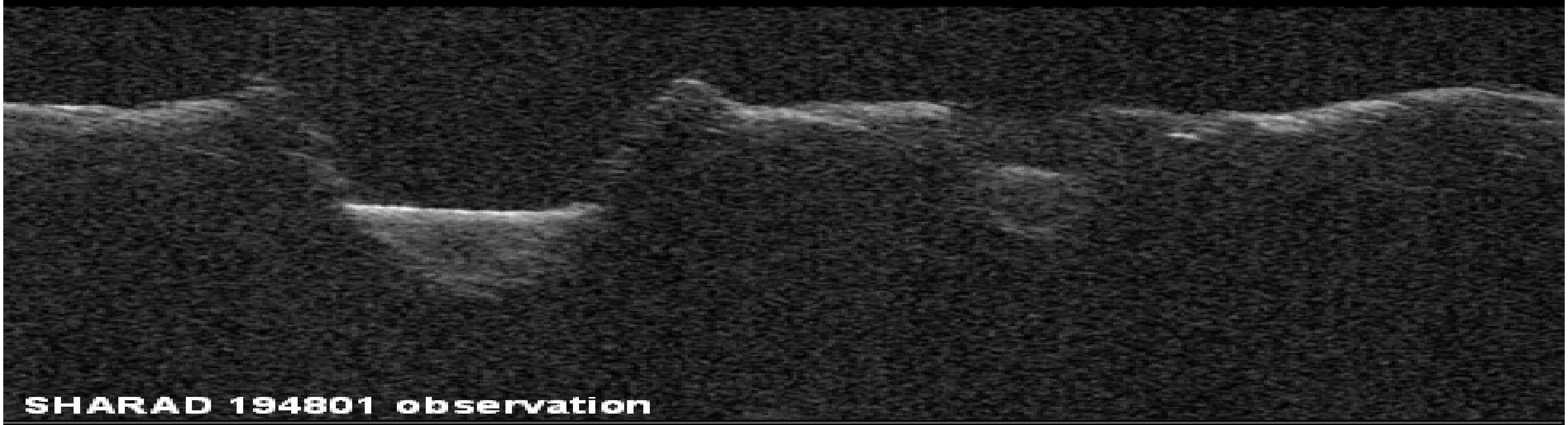
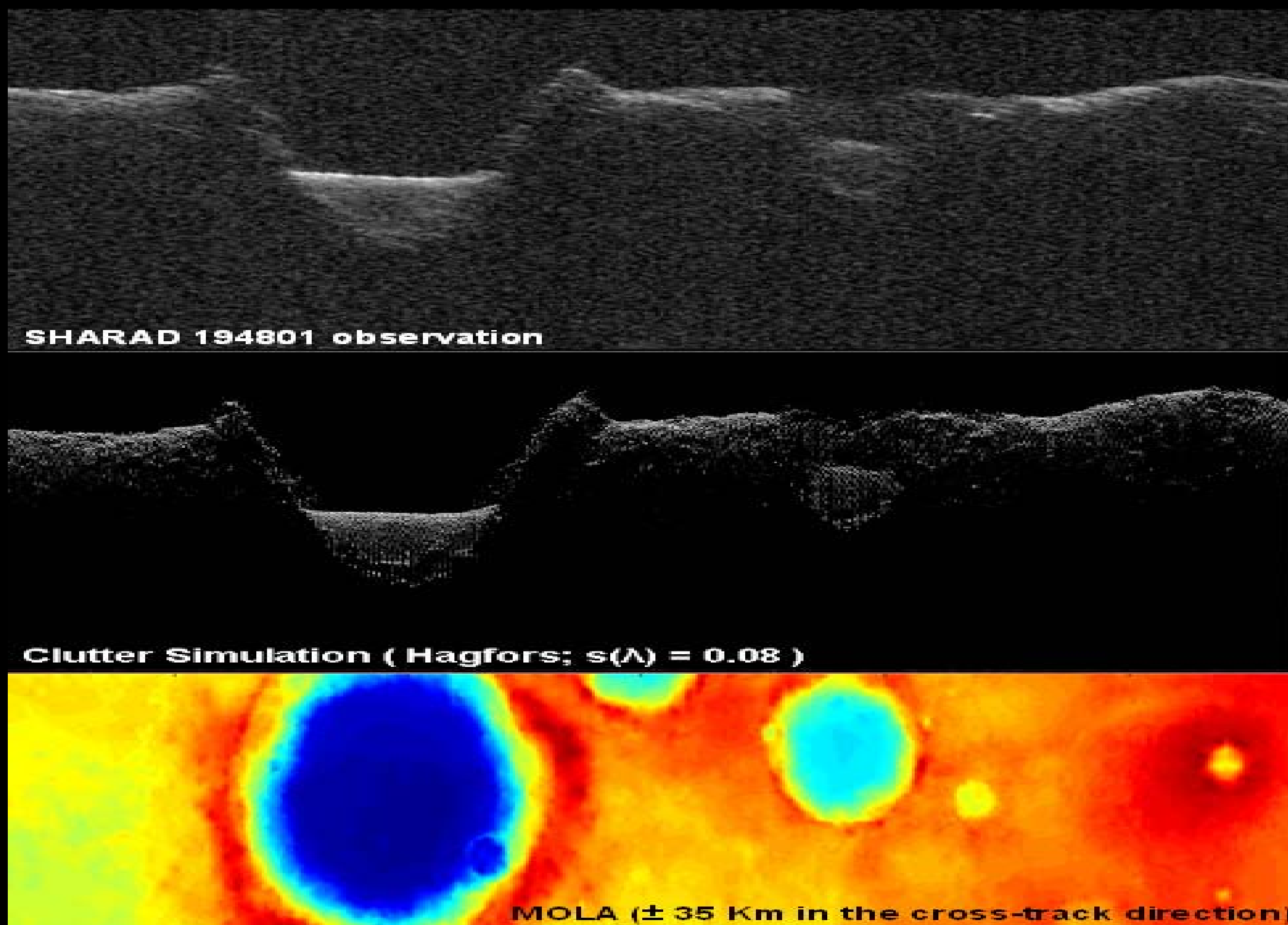
Clutter or subsurface detection?

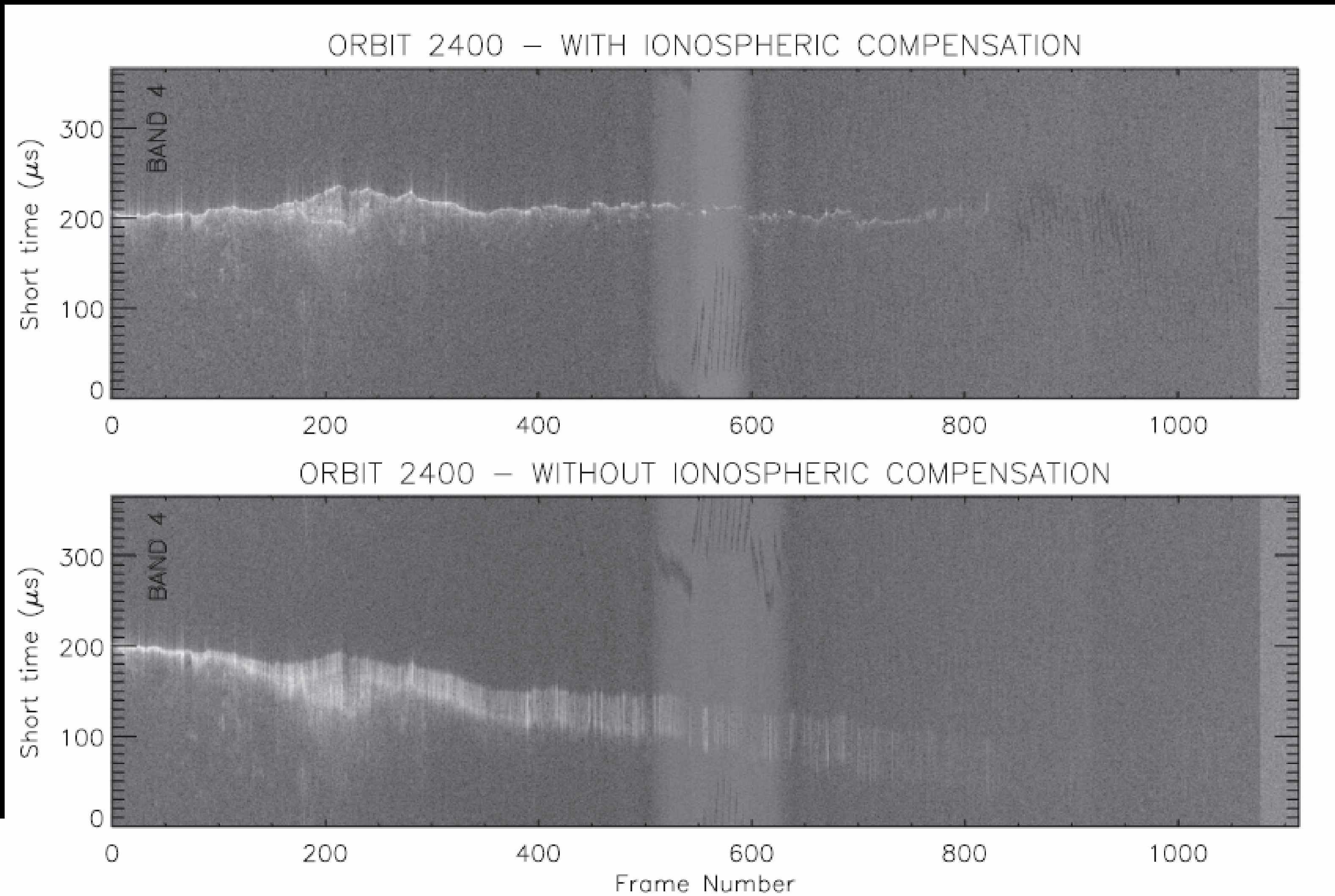


Data vs. simulations



Russo et al. 2008

Ionosphere dispersion



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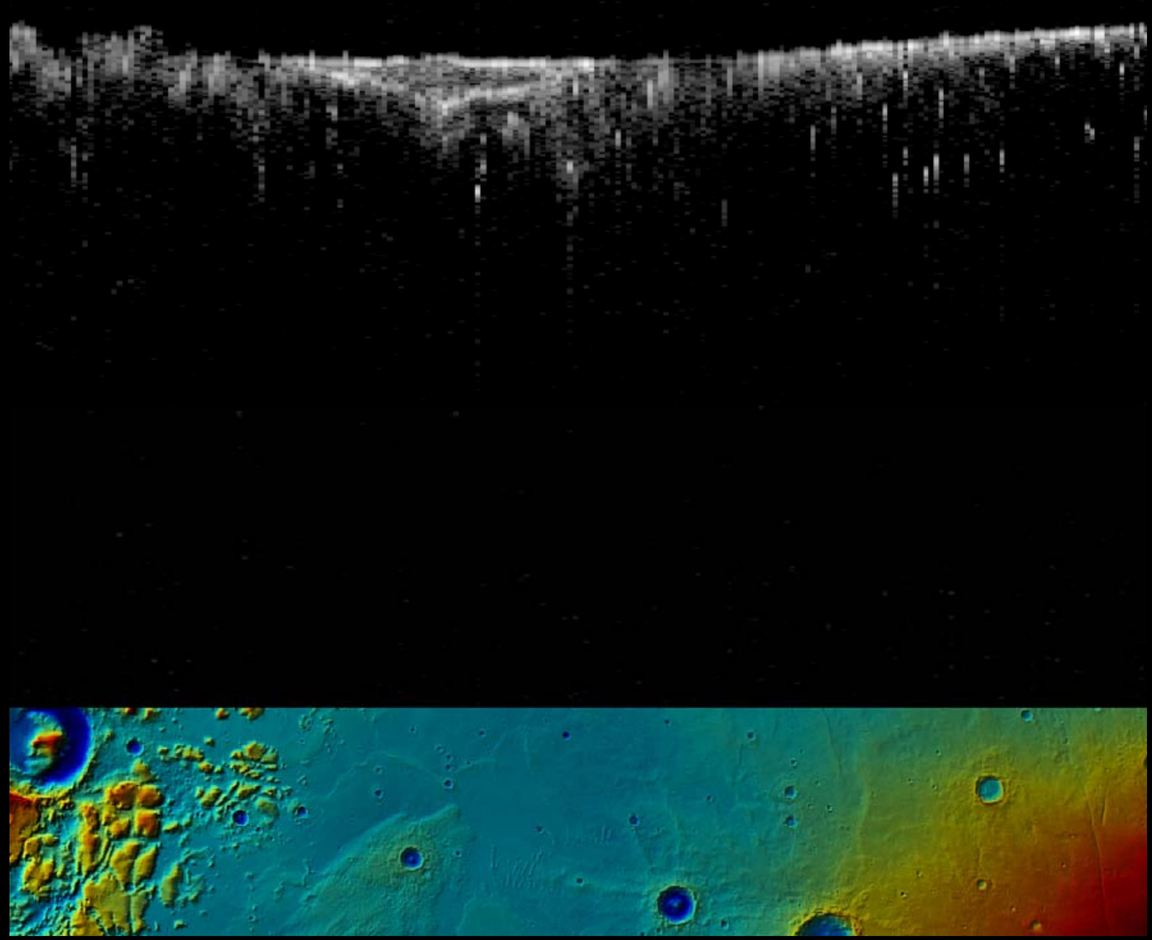
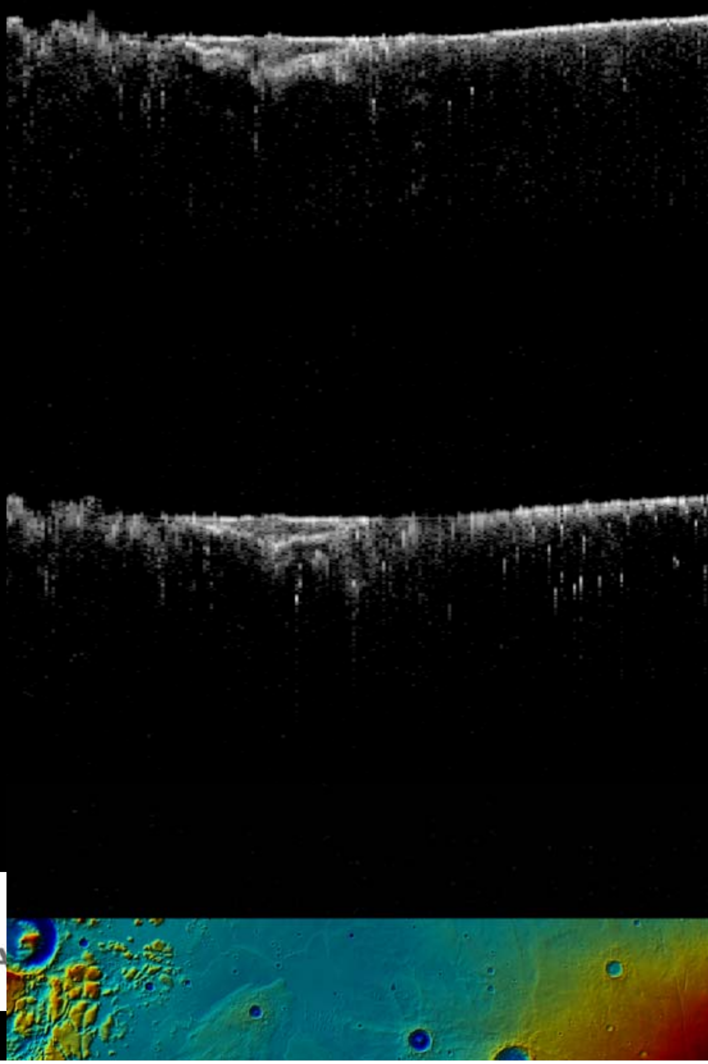
Mouginot et al. 2008

Multi-path propagation



Now there is, now there isn’t…

3821



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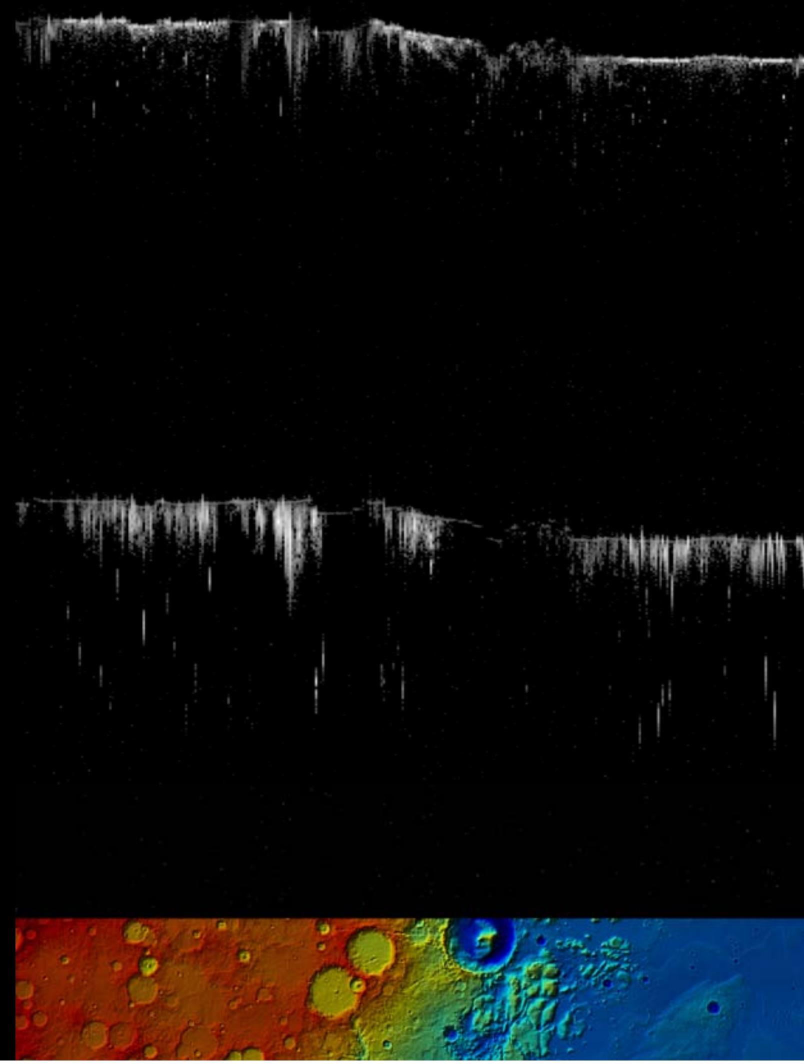
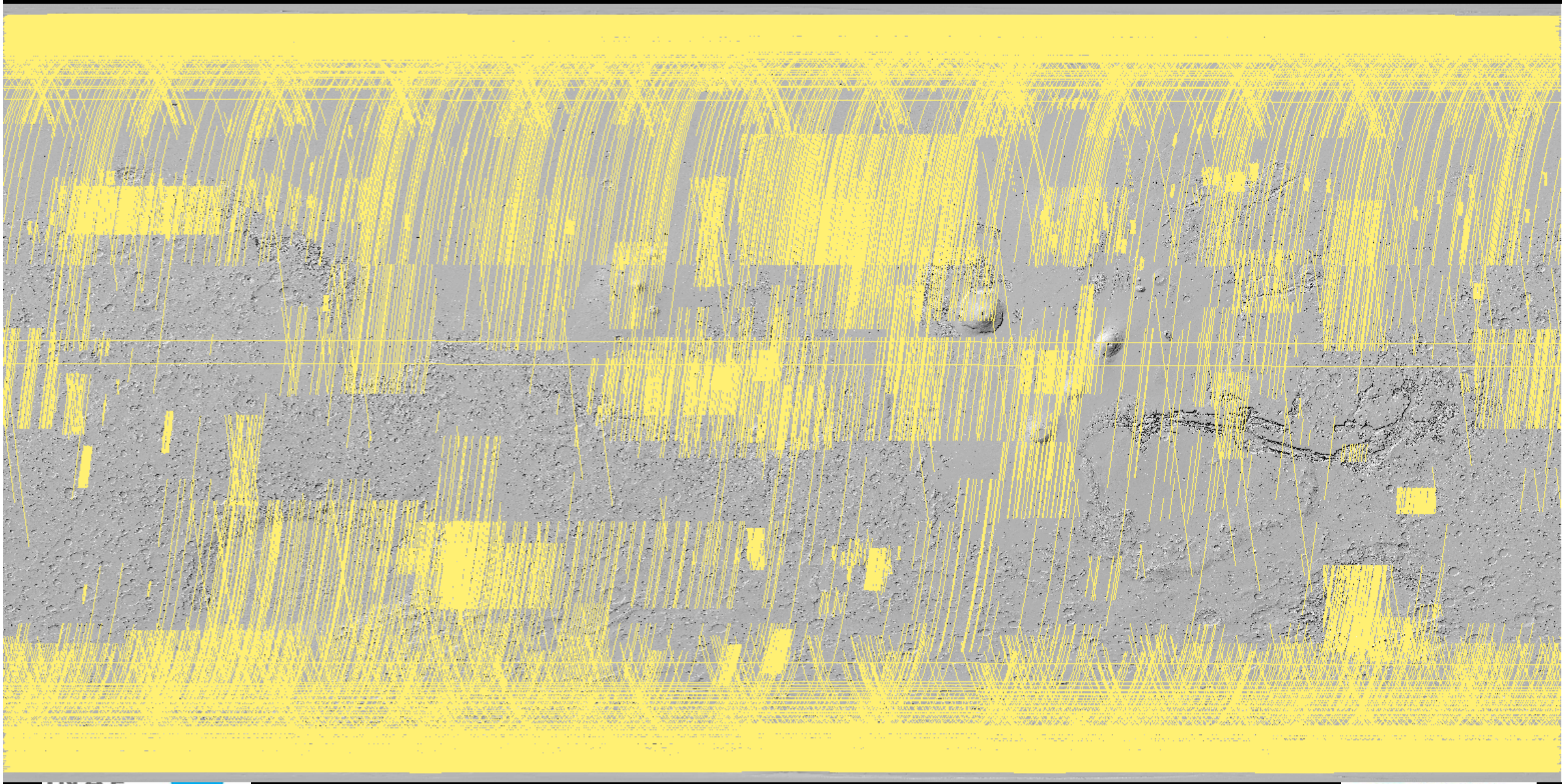


SHARAD coverage



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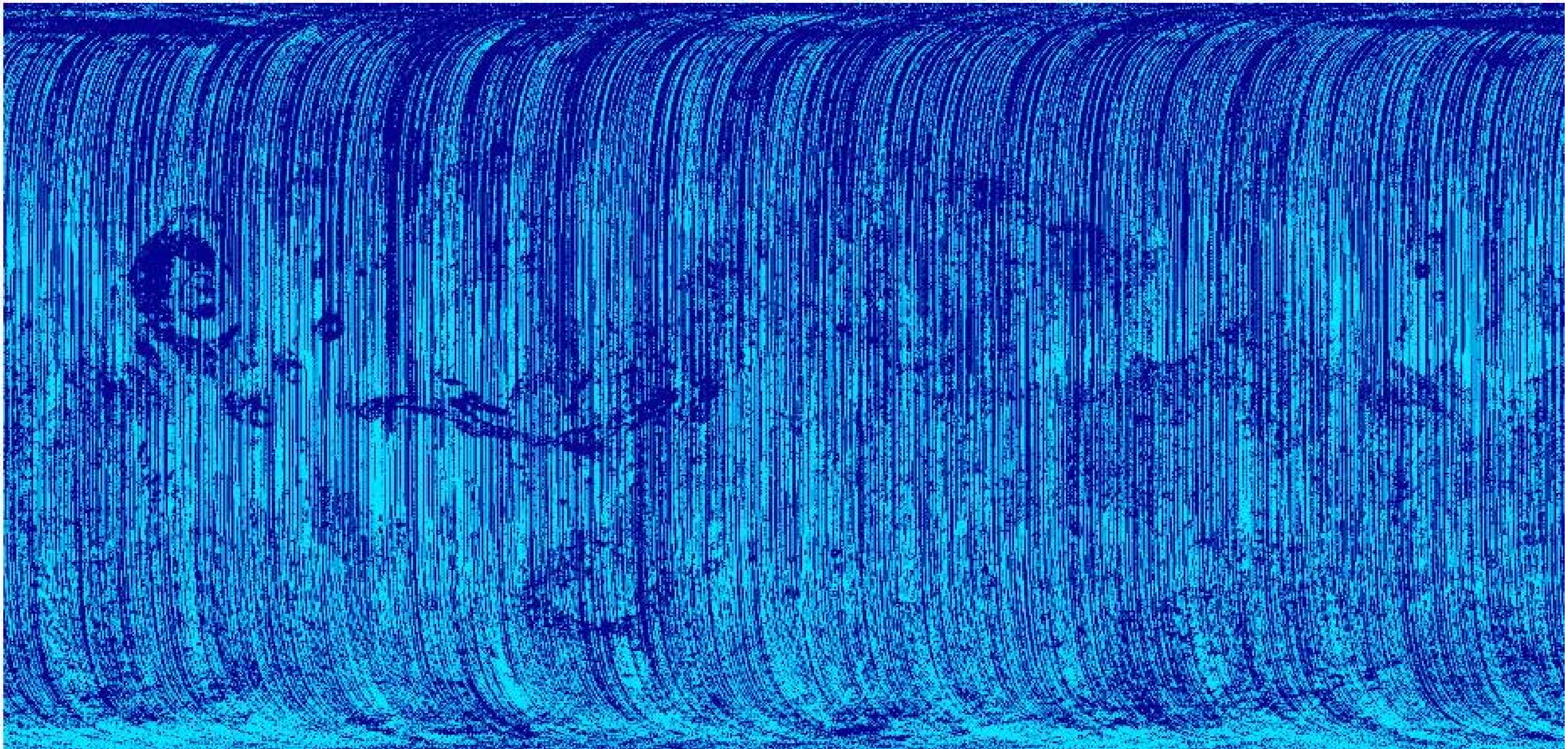
MARSIS coverage



MARSIS coverage (cont'd)

- After four years of operations, MARSIS has achieved a 42% coverage of Mars.
- Considering only the night-side orbits, coverage decreases to 30%.
- It was found that 15% (or more) of the surface has characteristics unsuitable to obtain good radar performances.
- Moreover the night coverage of the Northern Hemisphere is very sparse.

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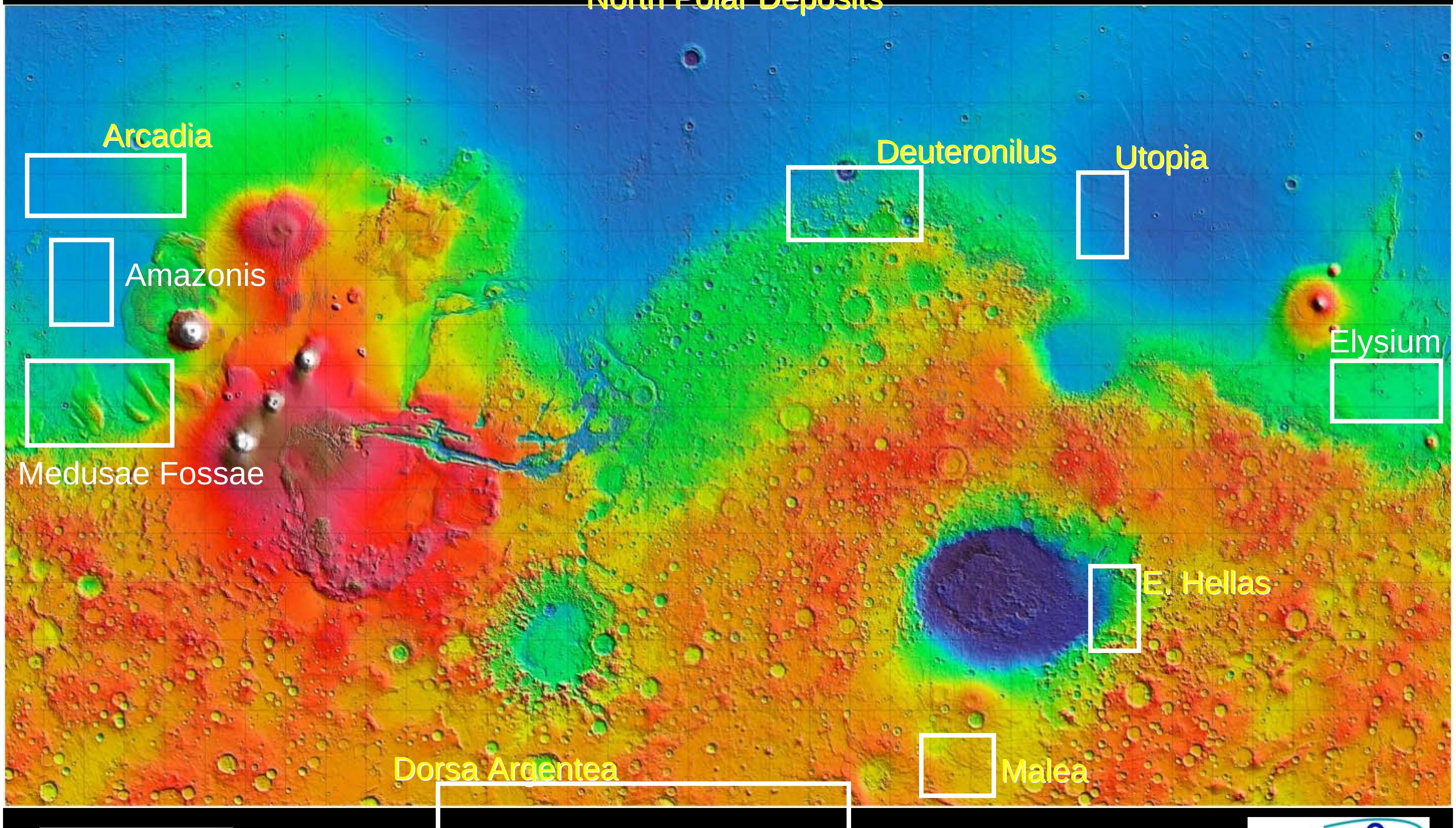
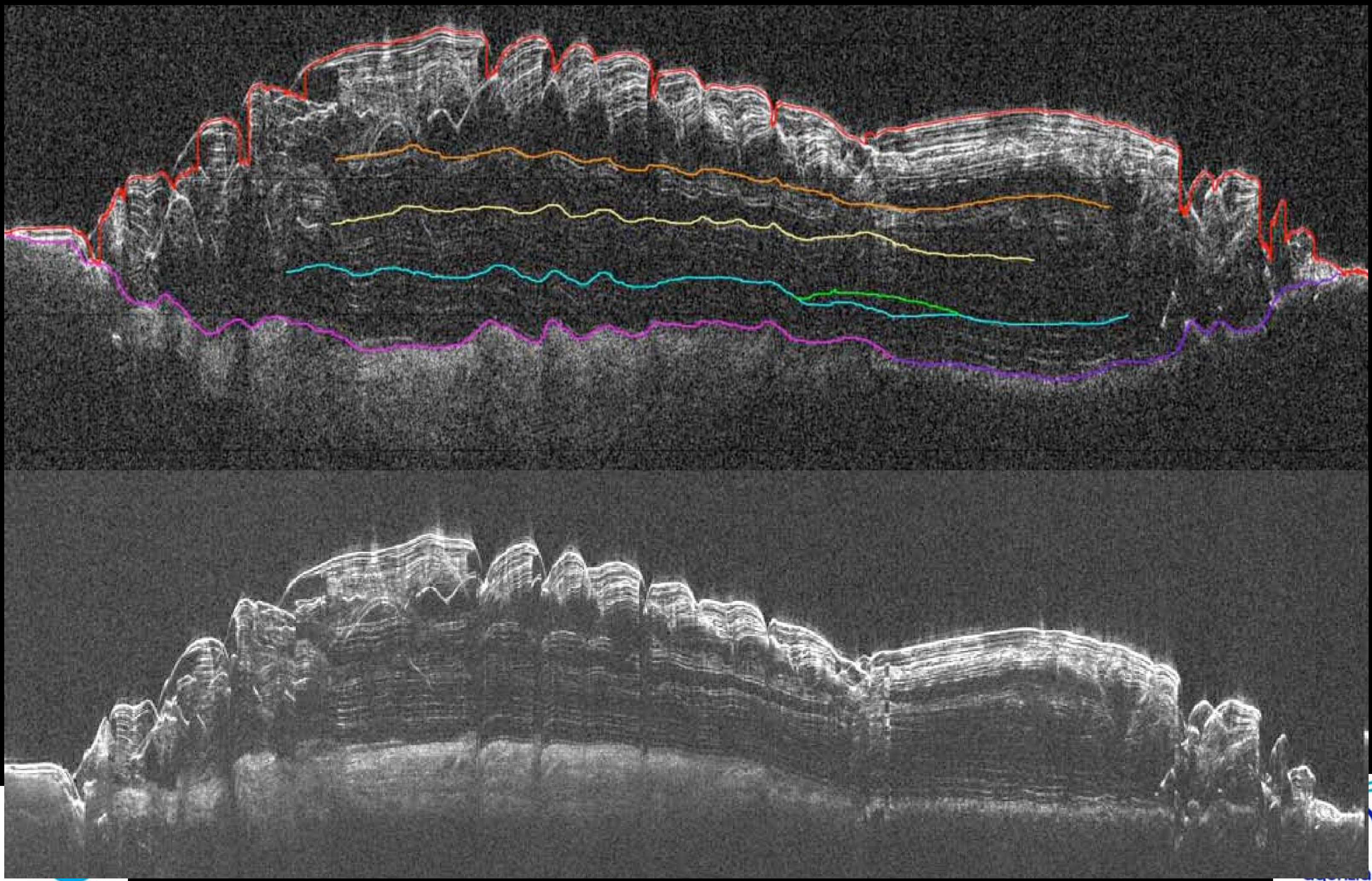
MARSIS and SHARAD Subsurface Detections



J. Plaut 2009

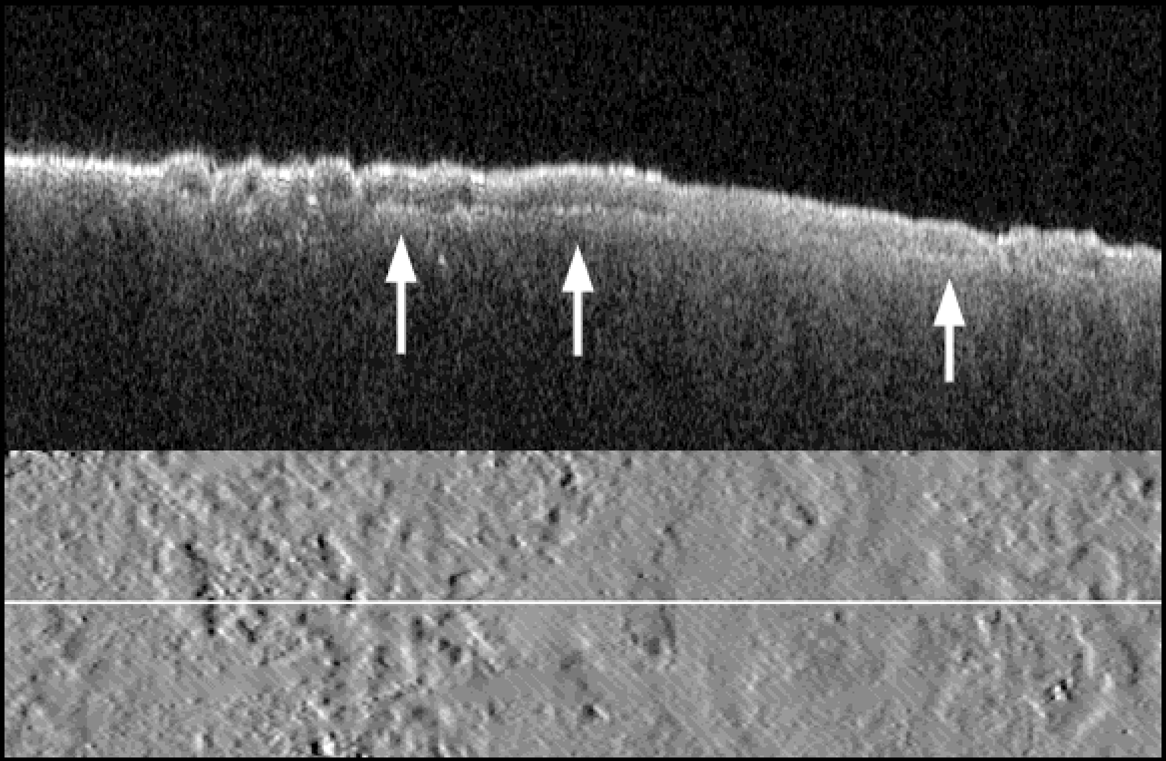
Yellow = Ice-rich

Planum Boreum



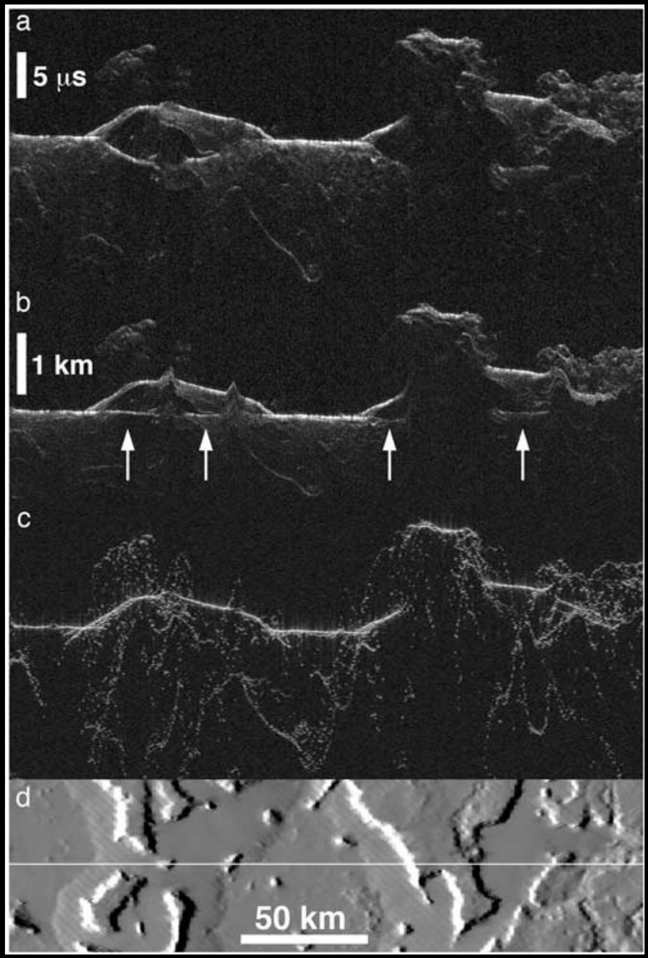
Putzig et al. 2009

Arcadia Planitia



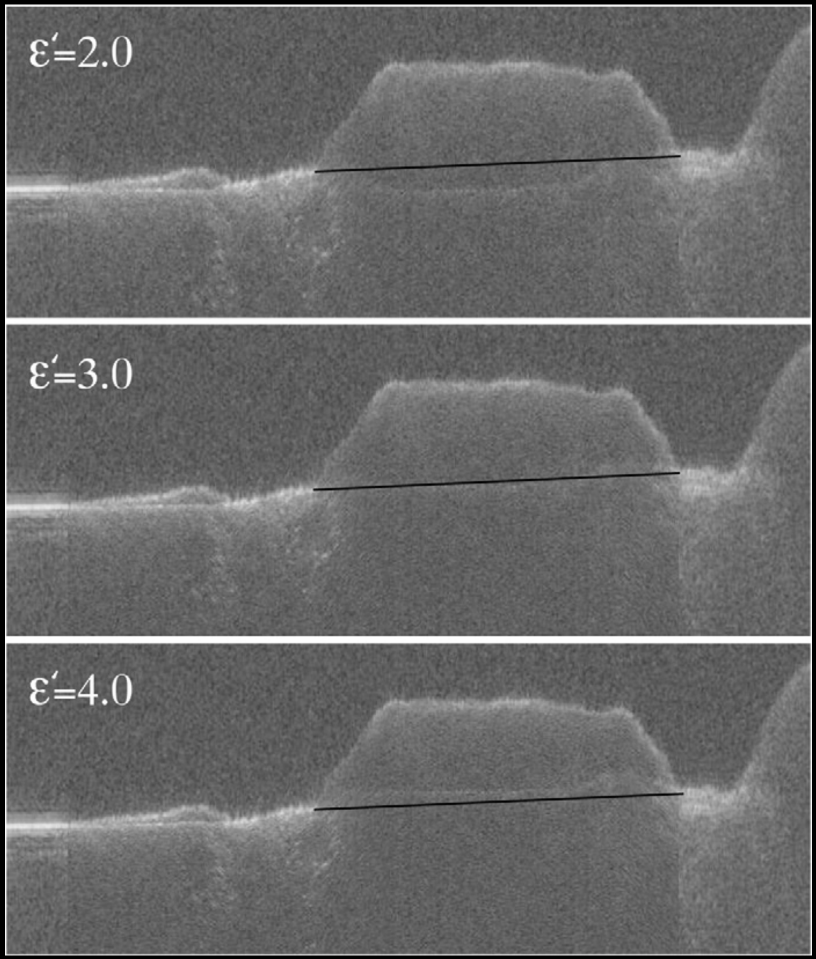
Plaut et al. 2009

Deuteronilus Mensae



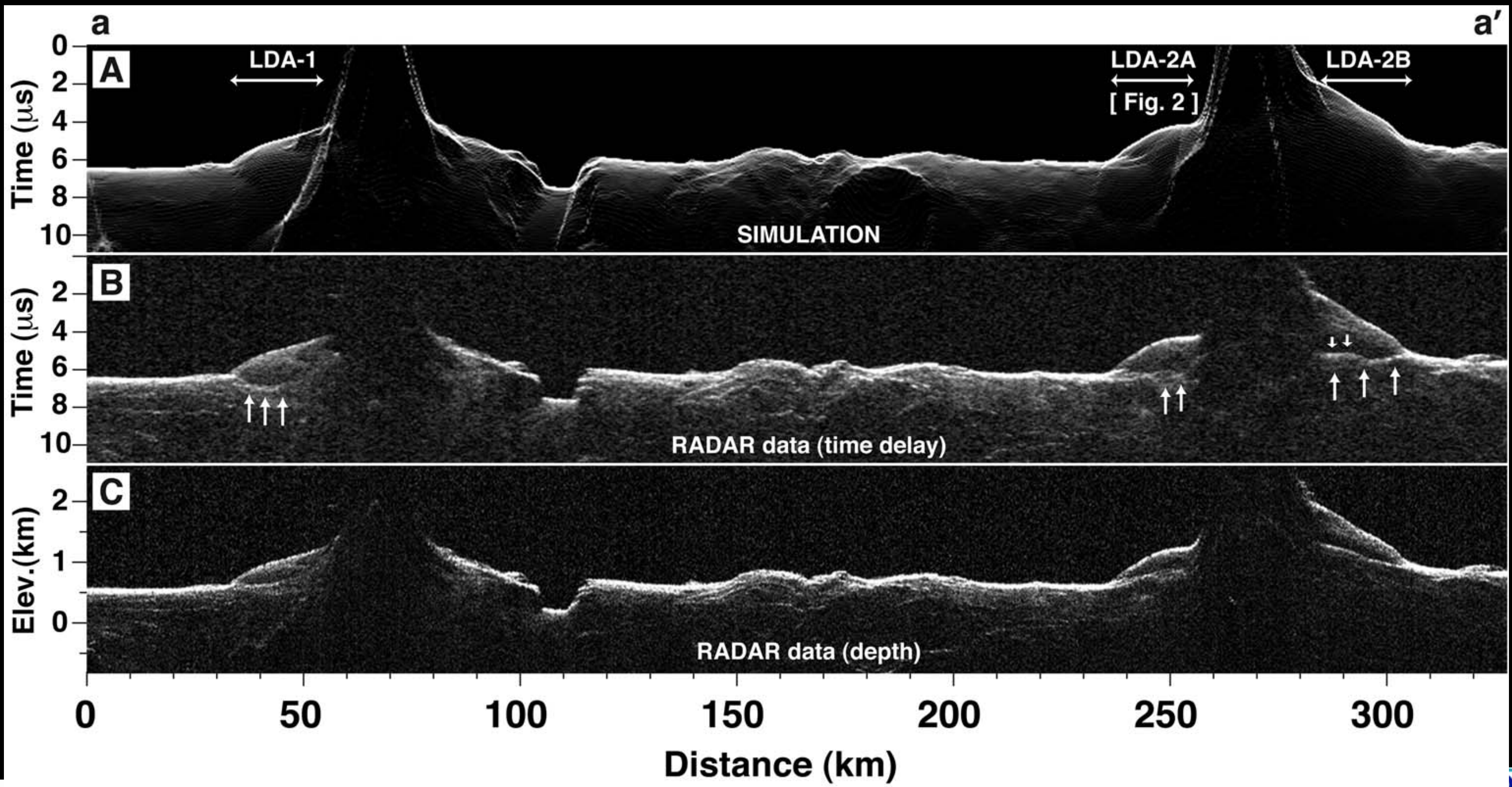
Plaut et al. 2009

Medusae Fossae Formation



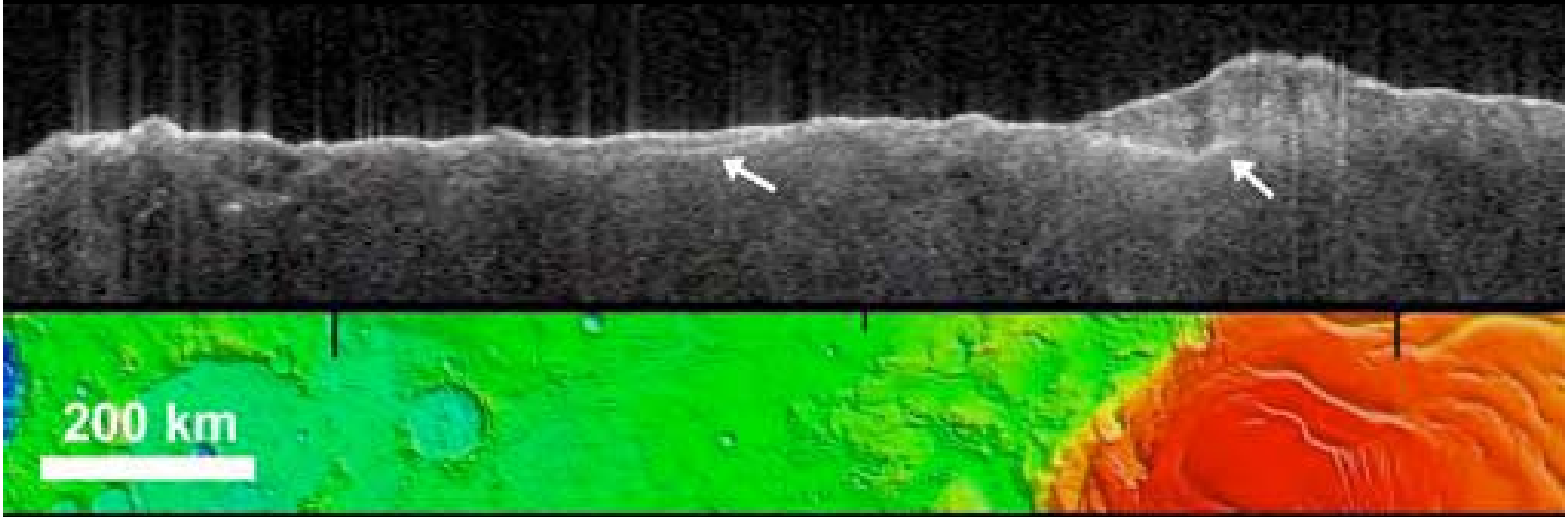
Carter et al. 2009

East Hellas



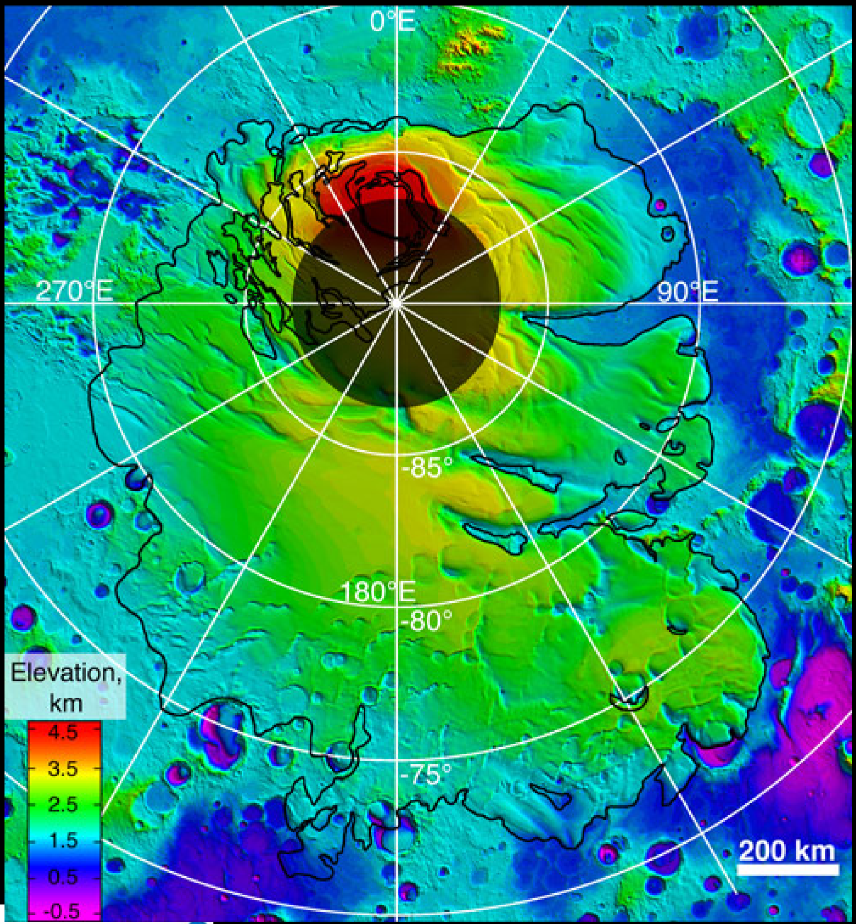
Holt et al. 2008

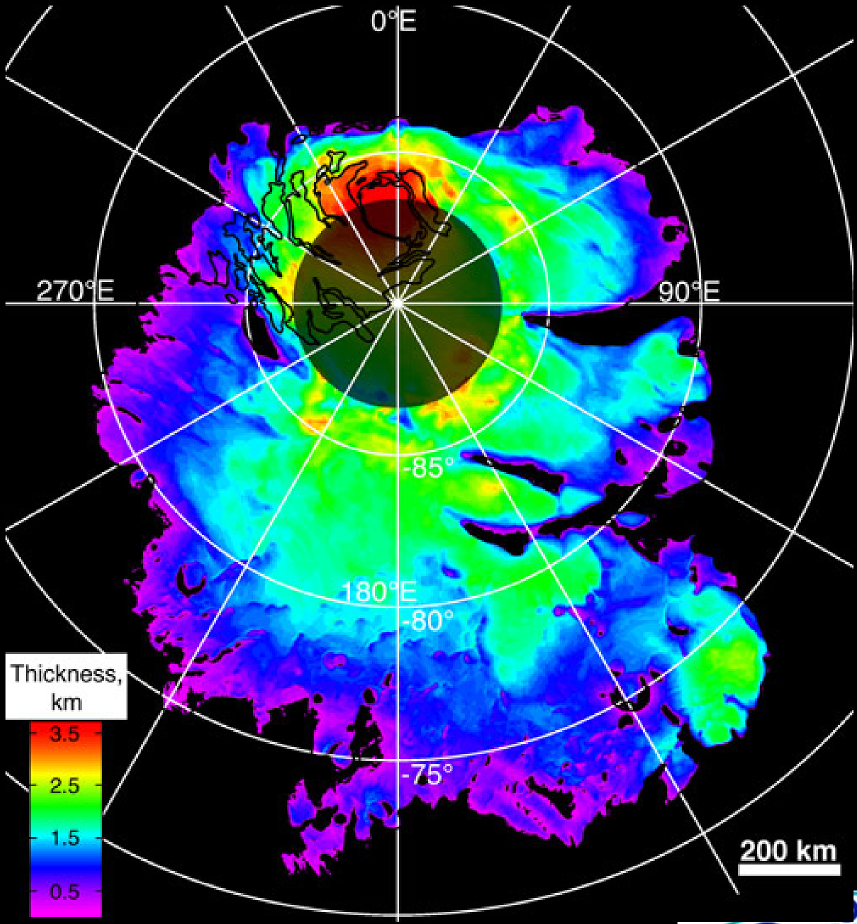
Dorsa Argentea Formation



Plaut et al. 2007

Planum Australe





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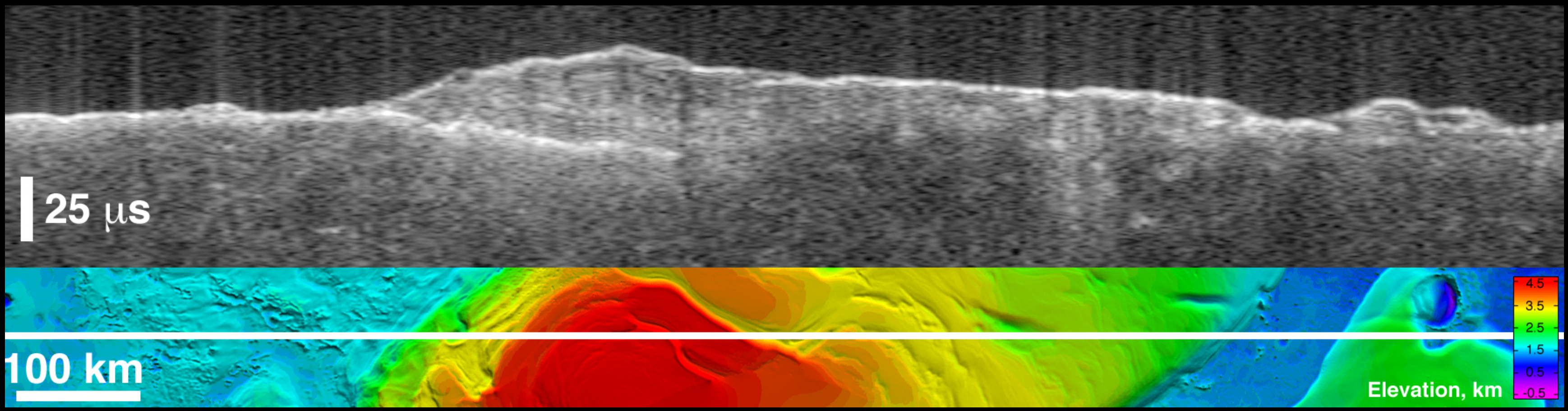
From Plaut et al. (2007)

Data over the SPLD



- There are areas in the SPLD where subsurface echoes are brighter than surface echoes, in spite of the attenuation resulting from propagation within a dielectric medium.

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From Plaut et al. (2007)

Model of surface and subsurface reflections

- We assume that the detected surface and subsurface echoes are specular reflections from plane parallel layers.
- We also assume that dielectric properties are uniform within the layers.
- The peak power of the specular return from the surface is then given by (Porcello et al., 1974) [Eq 1]
- The reflection coefficient at the surface/atmosphere boundary is [Eq 2]

$$P_s = P_t \left(\frac{G\lambda}{8\pi H} \right)^2 R_s^2$$

$$R_s = \frac{\sqrt{\epsilon_s} - 1}{\sqrt{\epsilon_s} + 1}$$

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Model of surface and subsurface reflections (2)

- The power reflected from a subsurface specular dielectric interface is given by [Eq 3]
- The subsurface interface reflection coefficient is given by [Eq 4]
- The time delay between echoes is related to the thickness and the the relative dielectric constant of the surface layer [Eq 5]

$$P_{ss} = P_t \left(\frac{G\lambda}{8\pi(H+X)} \right)^2 (1 - R_s^2)^2 R_{ss}^2 \cdot 10^{-2.74\tau f \tan\delta_s}$$

$$R_{ss} = \left| \frac{\sqrt{\epsilon_{ss}} - \sqrt{\epsilon_s}}{\sqrt{\epsilon_{ss}} + \sqrt{\epsilon_s}} \right|$$

$$\tau = \frac{2X\sqrt{\epsilon_s}}{c}$$

Radar wave propagation in the subsurface

- An electromagnetic wave reflected from the bottom of the SPLD is attenuated and scattered in several ways:
  - Surface scattering from the random rough SPLD surface
  - Attenuation within the dielectric SPLD material
  - Weak reflections within the SPLD due to the variation of dust concentration in ice with depth
  - Volume scattering caused by random variations of dielectric properties of the SPLD
  - Surface scattering from the random rough SPLD bottom.

Values of dielectric permittivity for natural materials

- CO_2 ice $\varepsilon \approx 2$
- H_2O ice $\varepsilon \approx 3$
- H_2O ice mixed with dust $\varepsilon > 3$
- Dry regolith $\varepsilon > 3$
- Dry rock $\varepsilon \approx$ 4-10
- Water-bearing rocks or regolith $\varepsilon > 10$
- Liquid water $\varepsilon \approx 80$

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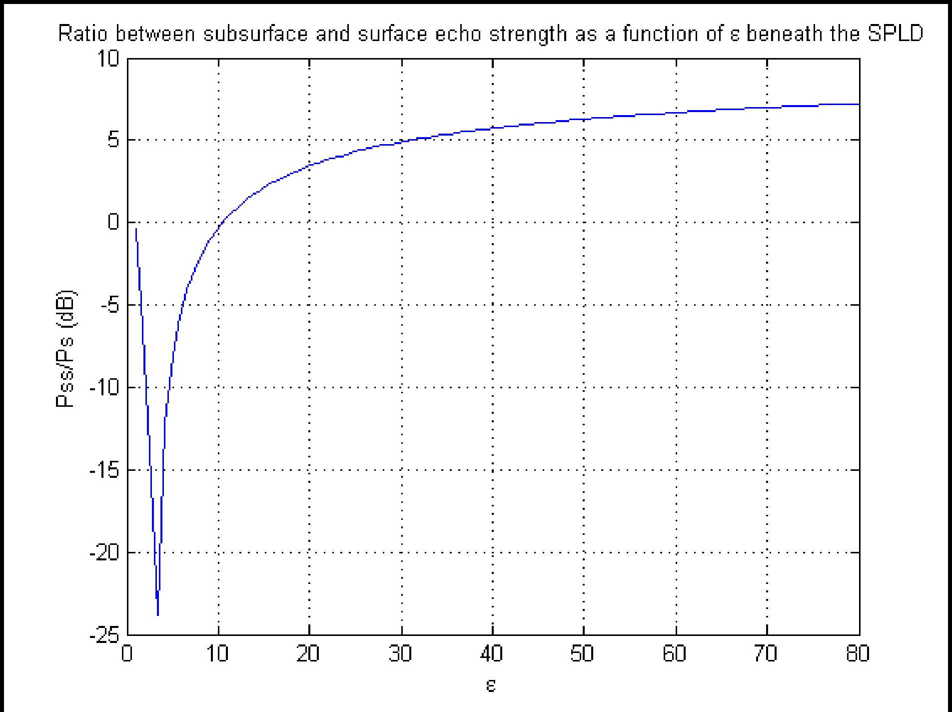
Implications for the values of the dielectric permittivity at the base of the SPLD

- Strong echoes imply a large difference between the dielectric permittivity of the SPLD and that of the material beneath the SPLD.
- If the SPLD are mostly made of water ice, then $\varepsilon \approx 3$.
- In this case, to produce a reflection from the bottom of the SPLD that is as strong as the surface reflection, $\varepsilon \approx 10$ for the material beneath the SPLD.

Effects of attenuation and scattering within the SPLD

- Because of the weakening of the radar signal as it propagates through the SPLD, the real dielectric contrast between the SPLD and the underlying material is probably higher, requiring $\varepsilon > 10$ beneath the SPLD.
- Could this imply the presence of liquid water, or is there another explanation?



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Summary

- Subsurface layers have been seen by the MARSIS and SHARAD radars only in limited areas of Mars.
- Determination of the composition of subsurface layers is based on the estimate of their dielectric properties.
- A rigorous determination of such properties requires the inversion of the radar signal.
- Many factors can affect the strength of subsurface echoes, and excluding the presence of subsurface liquid water on the basis of existing analyses seems premature.

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