Subglacial liquid water on Mars

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56th session STSC

Wien – 14-2-2019

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MARTIAN GEOLOGY

Radar evidence of subglacial liquid water on Mars

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The presence of liquid water at the base of the martian polar caps has long been suspected but not observed. We surveyed the Planum Australe region using the MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding) instrument, a low-frequency radar on the Mars Express spacecraft. Radar profiles collected between May 2012 and December 2015 contain evidence of liquid water trapped below the ice of the South Polar Layered Deposits. Anomalously bright subsurface reflections are evident within a well-defined, 20-kilometer-wide zone centered at 193°E, 81°S, which is surrounded by much less reflective areas. Quantitative analysis of the radar signals shows that this bright feature has high relative dielectric permittivity (>15), matching that of water-bearing materials. We interpret this feature as a stable body of liquid water on Mars.

The presence of liquid water at the base of the martian polar caps was first hypothesized more than 30 years ago (1) and has been inconclusively debated ever since. Radio echo sounding (RES) is a suitable technique to resolve this dispute, because low-frequency radars have been used extensively and successfully to detect liquid water at the bottom of terrestrial polar ice sheets. An interface between ice and water, or alternatively between ice and water-saturated sediments, produces bright radar reflections (2, 3). The Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) instrument on the Mars Express spacecraft (4) is used to perform RES experiments (5). MARSIS has surveyed the martian subsurface for more than 12 years in search of evidence of liquid water (6). Strong basal echoes have been reported in an area close to the thickest part of the South Polar Layered Deposits (SPLD), Mars' southern ice cap (7). These features were interpreted as due to the propagation of the radar signals through a very cold layer of pure water ice having negligible attenuation (7). Anomalously bright reflections were subsequently detected in other areas of the SPLD (8).

On Earth, the interpretation of radar data collected above the polar ice sheets is usually based on the combination of qualitative (the morphology of the bedrock) and quantitative (the reflected radar peak power) analyses (3, 9). The MARSIS design, particularly the very large footprint (~3 to 5 km), does not provide high spatial resolution, strongly limiting its ability to discriminate the presence of subglacial water bodies from the shape of the basal topography (10). Therefore, an unambiguous detection of liquid water at the base of the polar deposit requires a quantitative estimation of the relative dielectric permittivity (hereafter, permittivity) of the basal material, which determines the radar echo strength.

Between 29 May 2012 and 27 December 2015, MARSIS surveyed a 200-km-wide area of Planum Australe, centered at 193°E, 81°S (Fig. 1), which roughly corresponds to a previous study area (8). This area does not exhibit any peculiar characteristics, either in topographic data from the Mars Orbiter Laser Altimeter (MOLA) (Fig. 1A) (11, 12) or in the available orbital imagery (Fig. 1B) (13). It is topographically flat, composed of water ice with 10 to 20% admixed dust (14, 15), and seasonally covered by a very thin layer of CO_2 ice that does not exceed 1 m in thickness (16, 17). In the same location, higher-frequency radar observations performed by the Shallow Radar instrument on the Mars Reconnaissance Orbiter (18) revealed barely any internal layering in the SPLD and did not detect any basal echo (fig. S1), in marked contrast with findings for the North Polar Layer Deposits and other regions of the SPLD (19).

A total of 29 radar profiles were acquired using the onboard unprocessed data mode (5) by transmitting closely spaced radio pulses centered at either 3 and 4 MHz or 4 and 5 MHz (table S1). Observations were performed when the spacecraft was on the night side of Mars to minimize ionospheric dispersion of the signal. Figure 2A shows an example of a MARSIS radargram collected in the area, where the sharp surface reflection is followed by several secondary reflections produced by the interfaces between layers within the SPLD. The last of these echoes represents the reflection between the ice-rich SPLD and the underlying material (hereafter, basal material). In most of the investigated area, the basal reflection is weak and diffuse, but in some locations, it is very sharp and has a greater intensity (bright reflections) than the surrounding areas and the surface (Fig. 2B). Where the observations from multiple orbits overlap, the data acquired at the same frequency have consistent values of both surface and subsurface echo power (fig. S2).

The two-way pulse travel time between the surface and basal echoes can be used to estimate the depth of the subsurface reflector and map the basal topography. Assuming an average signal velocity of 170 m/μs within the SPLD, close to that of water ice (20), the depth of the basal reflector is about 1.5 km below the surface. The large size of the MARSIS footprint and the diffuse nature of basal echoes outside the bright reflectors prevent a detailed reconstruction of the basal topography, but a regional slope from west to east is recognizable (Fig. 3A). The subsurface area where the bright reflections are concentrated is topographically flat and surrounded by higher ground, except on its eastern side, where there is a depression.

The permittivity, which provides constraints on the composition of the basal material, can in principle be retrieved from the power of the reflected signal at the base of the SPLD. Unfortunately, the radiated power of the MARSIS antenna is unknown because it could not be calibrated on the ground (owing to the instrument's large dimensions), and thus the intensity of the reflected echoes can only be considered in terms of relative quantities. It is common to normalize the intensity of the subsurface echo to the surface value (21)—i.e., to compute the ratio between basal and surface echo power. Such a procedure has the advantage of also compensating for any ionospheric attenuation of the signal. Following this approach, we normalized the subsurface echo power to the median of the surface power computed along each orbit; we found that all normalized profiles at a given frequency yield consistent values of the basal echo power (fig. S3). Figure 3B shows a regional map of basal echo power after normalization; bright reflections are localized around 193°E, 81°S in all intersecting orbits, outlining a well-defined, 20-km-wide subsurface anomaly.

To compute the basal permittivity, we also require information about the dielectric properties of the SPLD, which depend on the composition and temperature of the deposits. Because the exact ratio between water ice and

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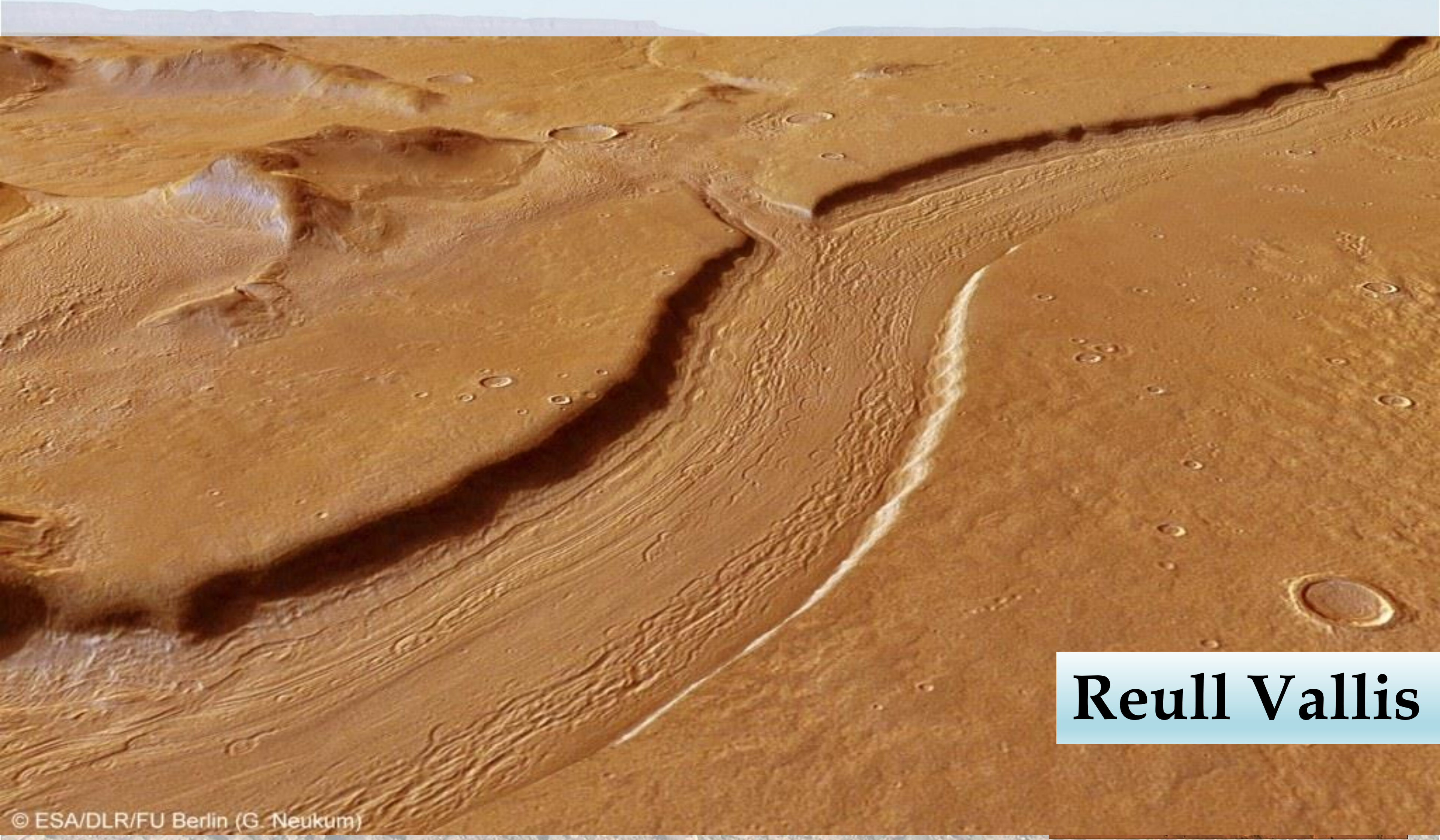
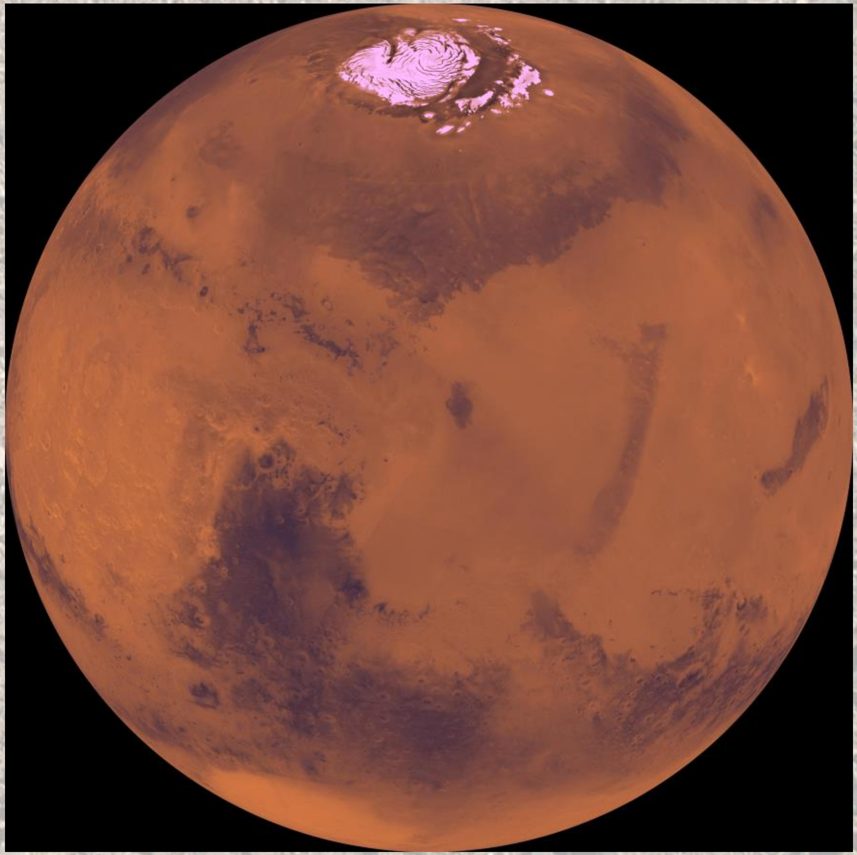
Subglacial liquid water on Mars



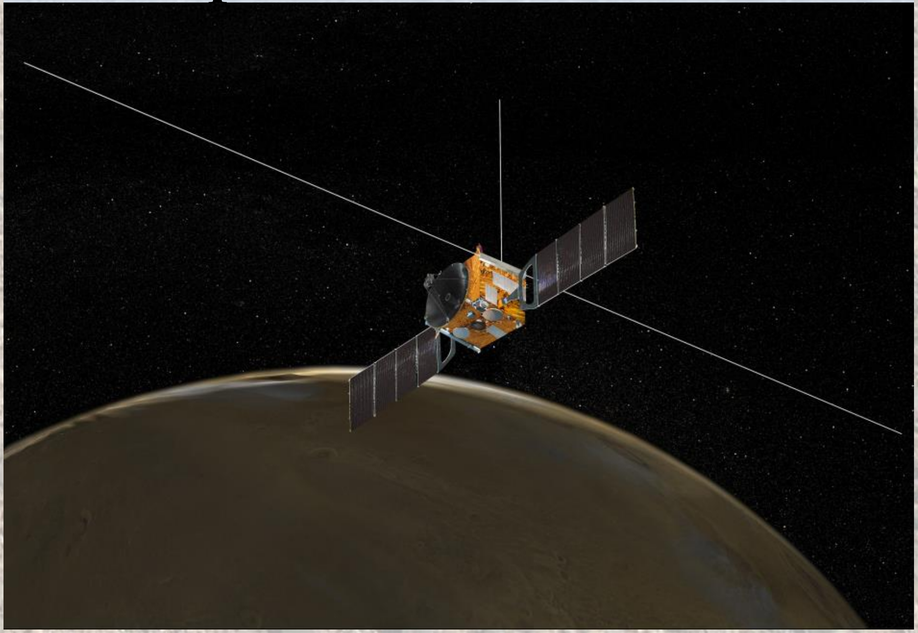
Subglacial liquid water on Mars

Presently most of the water is present on Martian surface as ice in the North polar caps and also in in the South pole seasonally covered by CO_2 ice. Part of it is also trapped in permafrost.
A large amount has been swept out by the solar wind. However, water should be still present in the subsurface and could be in the liquid form.



Subglacial liquid water on Mars

- On December 1996, during the IMEWG meeting held in Cocoa Beach, ESA announced the intention to realize a class F mission.
- ASI Delegation proposed to include in the P/L a new instrument , a radar sounder to analyse the structure of the Martian subsurface and search water reservoirs in the depths: MARSIS
- Mars Express was launched on June 2, 2003, MARSIS started to operate on July, 5 2005 and is still in operations



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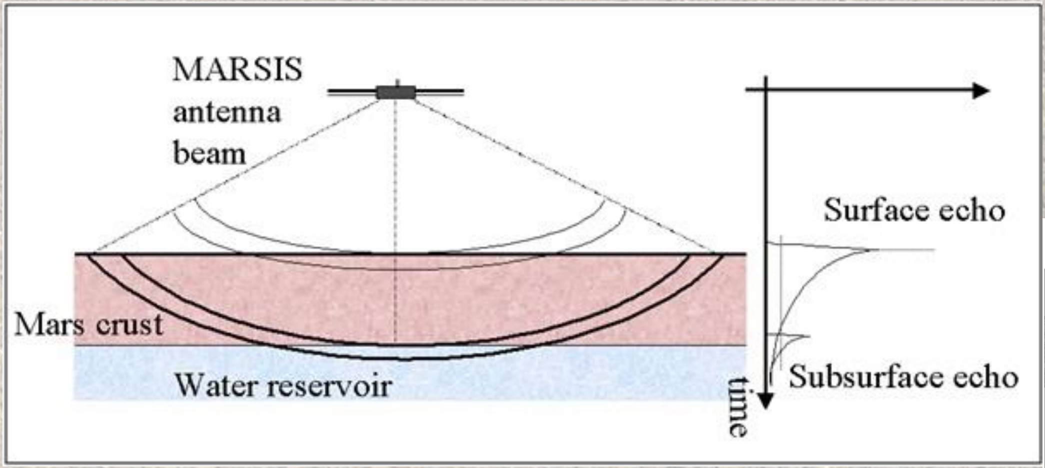
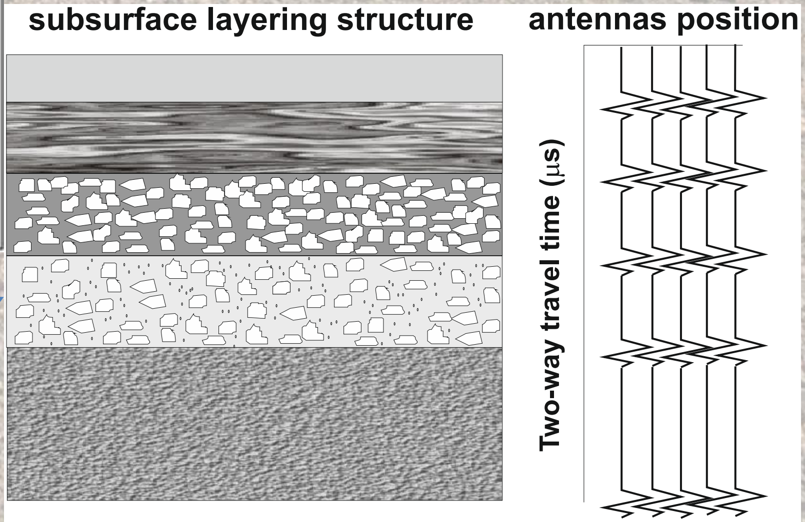
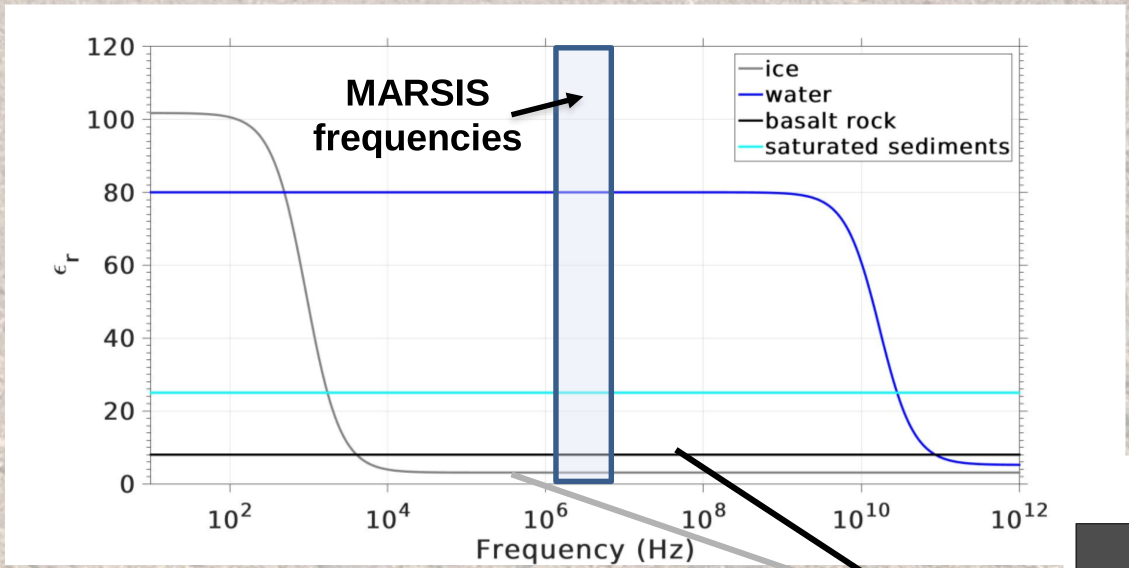




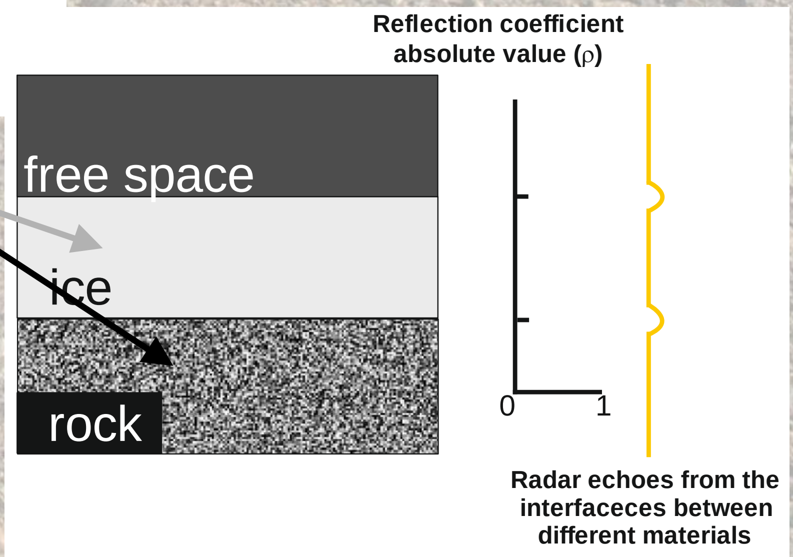
Interfaces between layers having different electrical properties

Subglacial liquid water on Mars



The capability to detect liquid water under the ice depends on the dielectric contrast between materials

Dry and/or cold geological materials are favorable environments for deep radio wave propagation as wave attenuation is usually low.



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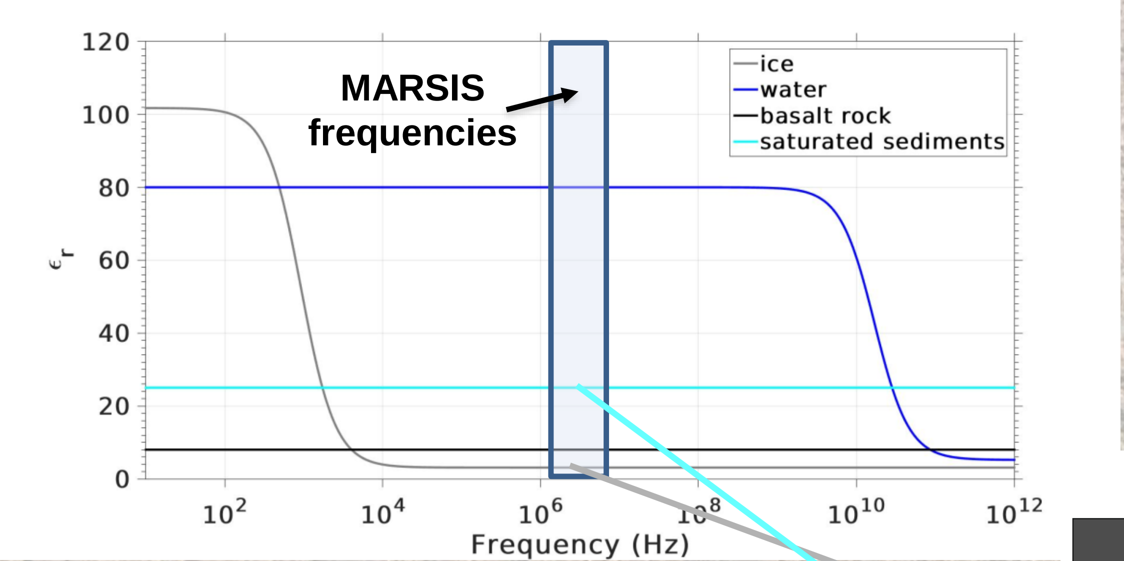

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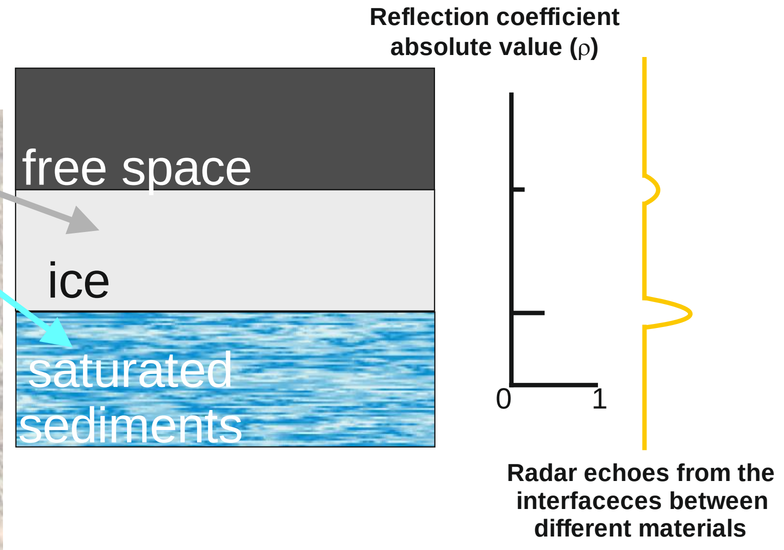

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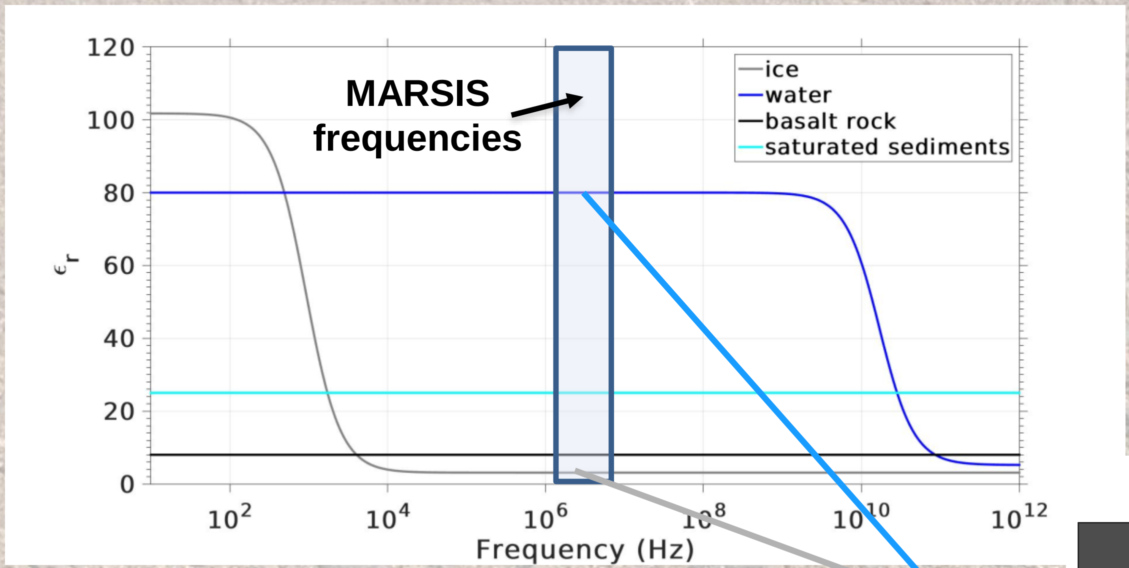

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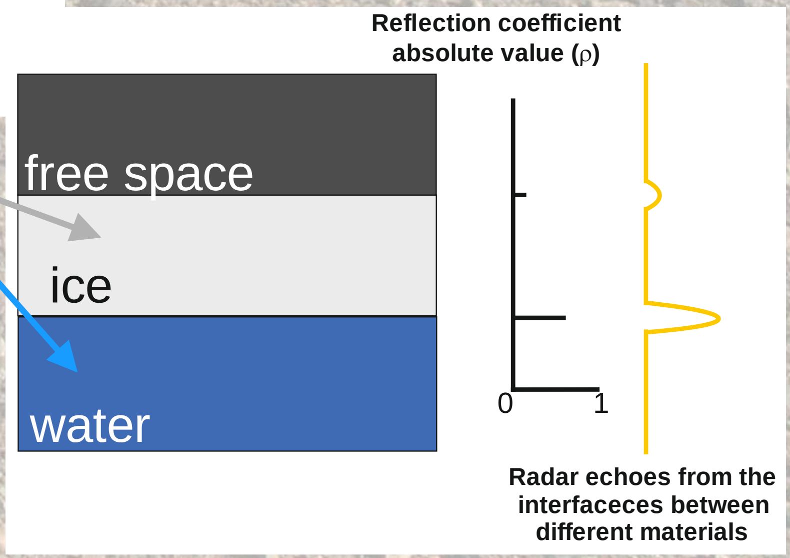

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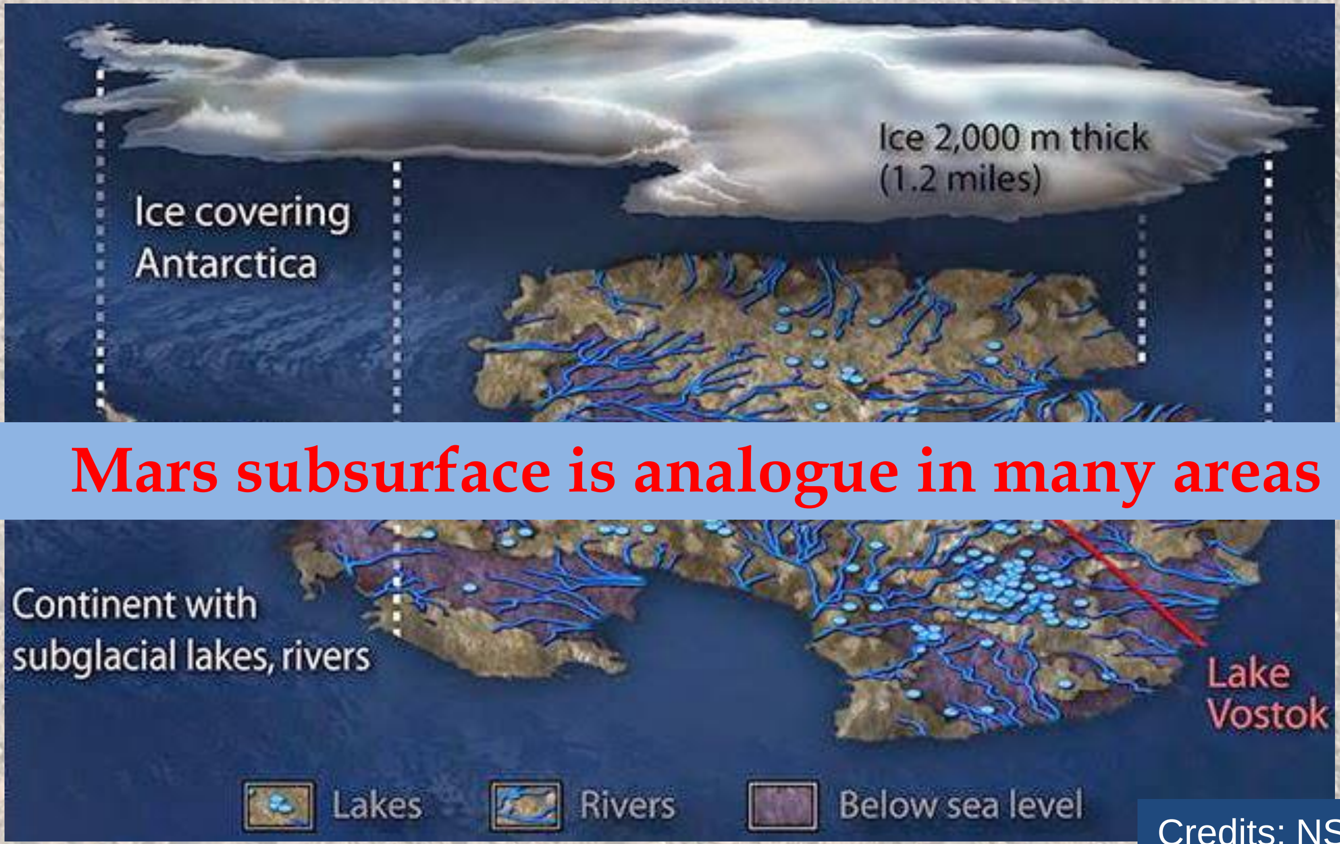
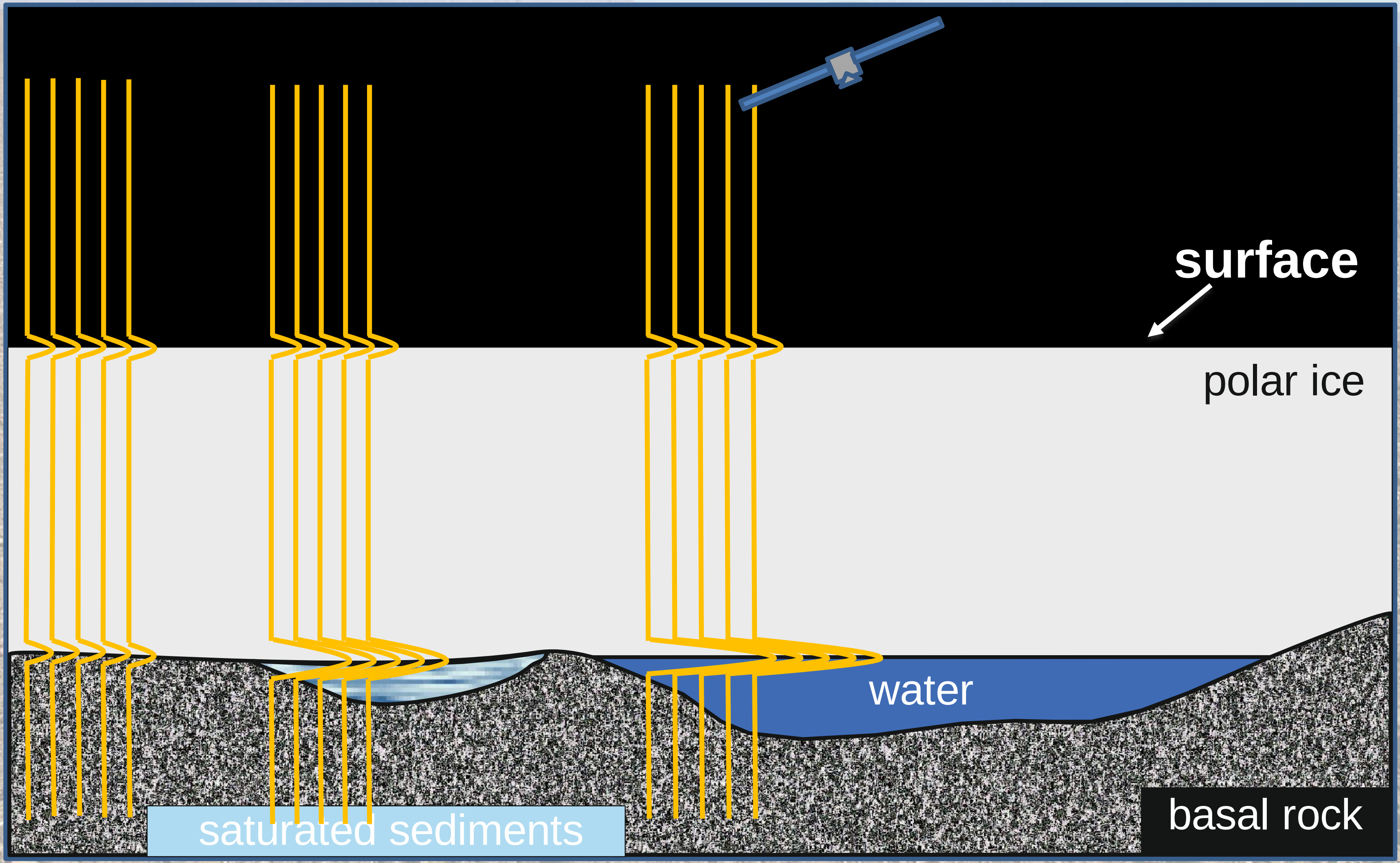
Radar echo sounding (RES) has been extensively used to detect subglacial lakes in Antarctica



Mars subsurface is analogue in many areas

Credits: NSF/Zina Deretsky

Subglacial liquid water on Mars



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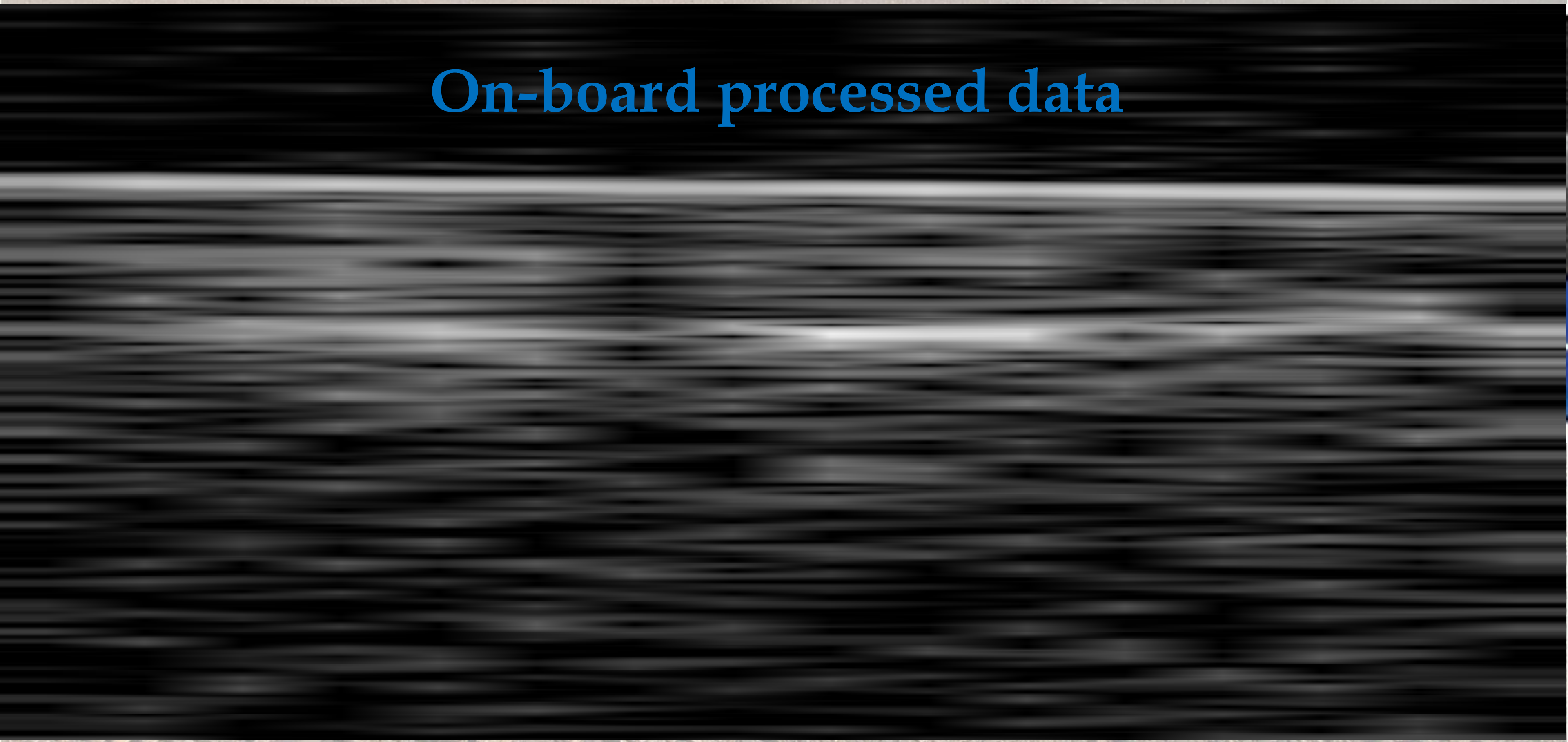
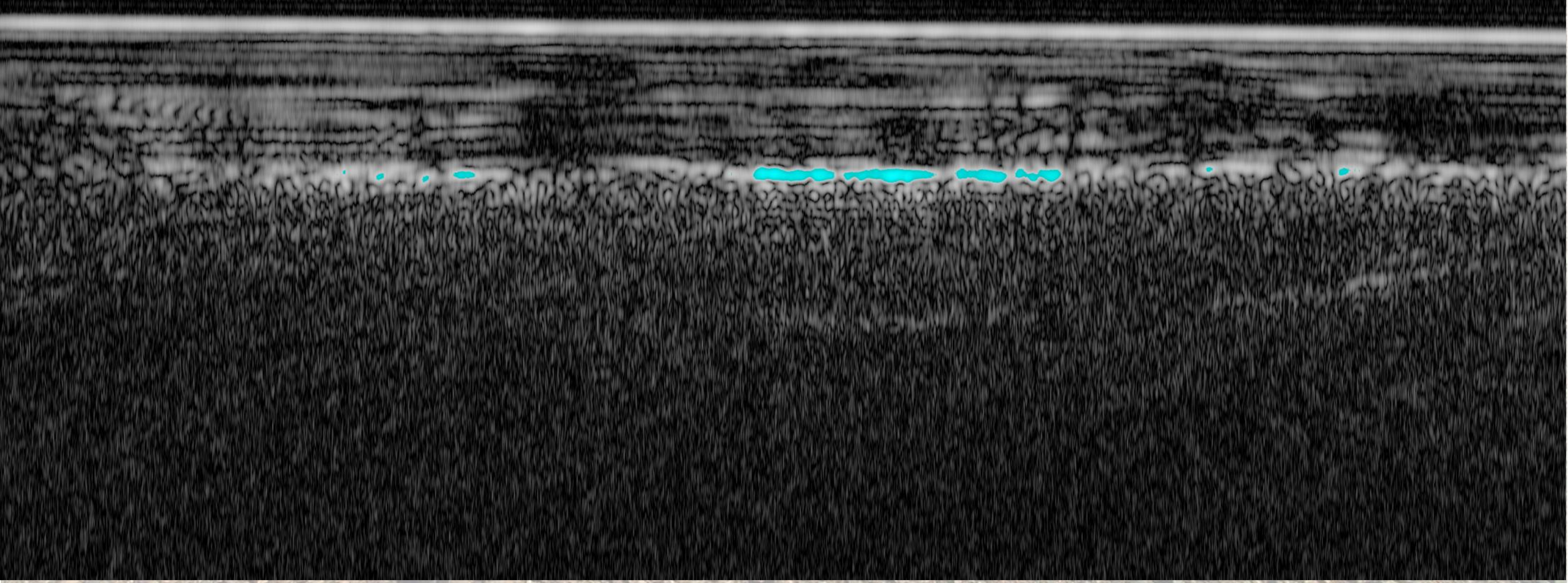


Subglacial liquid water on Mars

Raw uncompressed data stored in Flash memories



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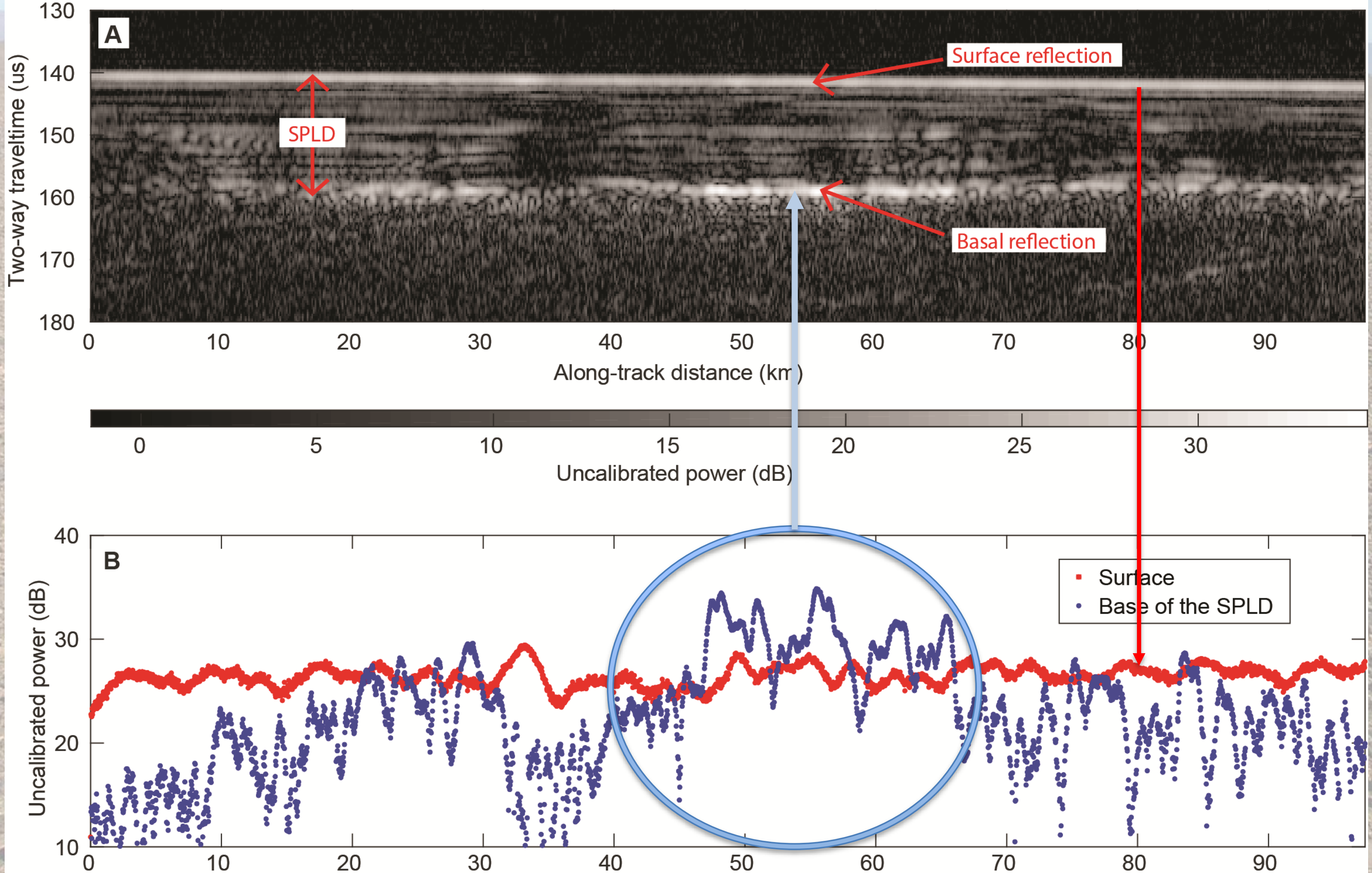

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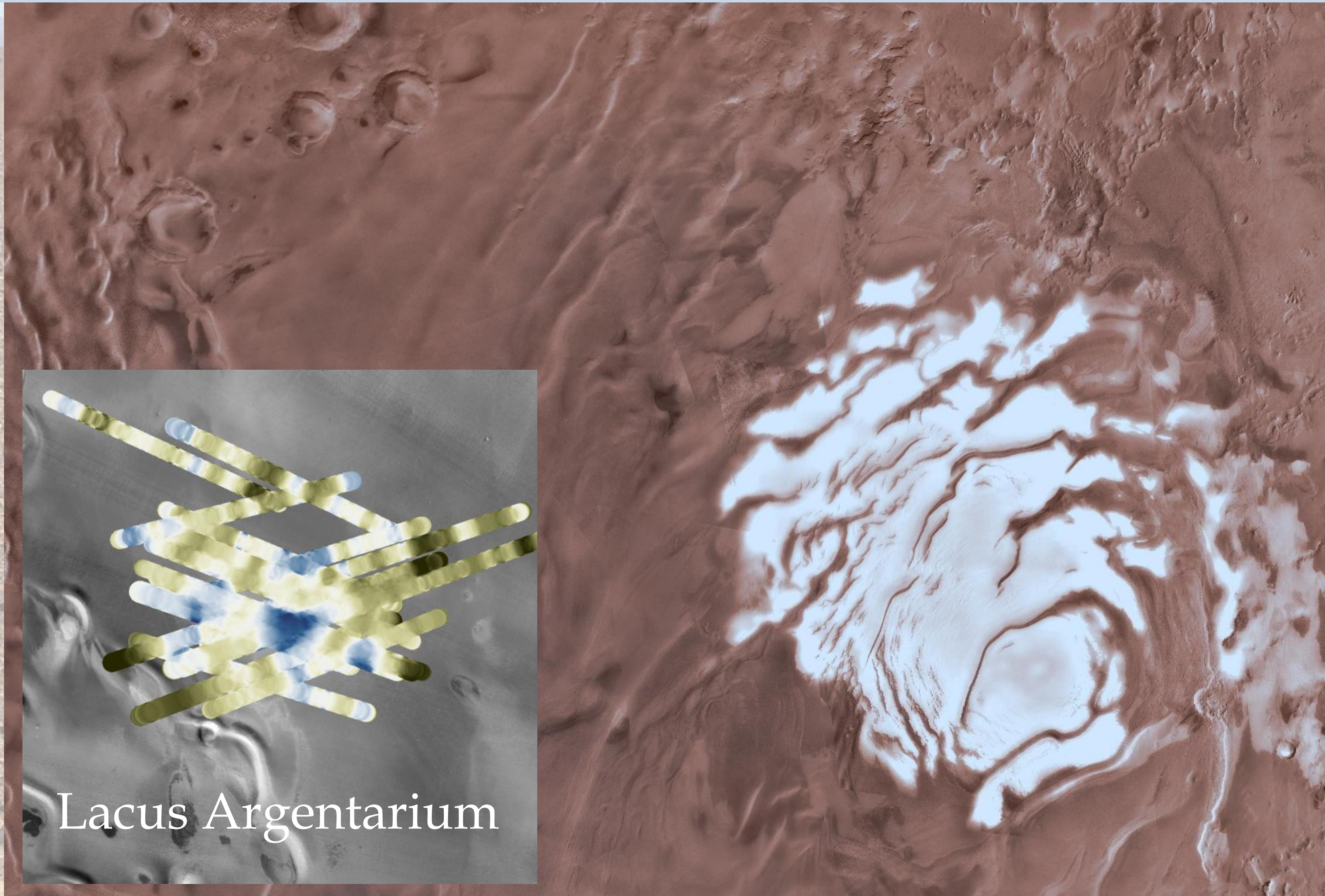

Thanks