

Orbital Radar Observations of Shallow Ice on Mars

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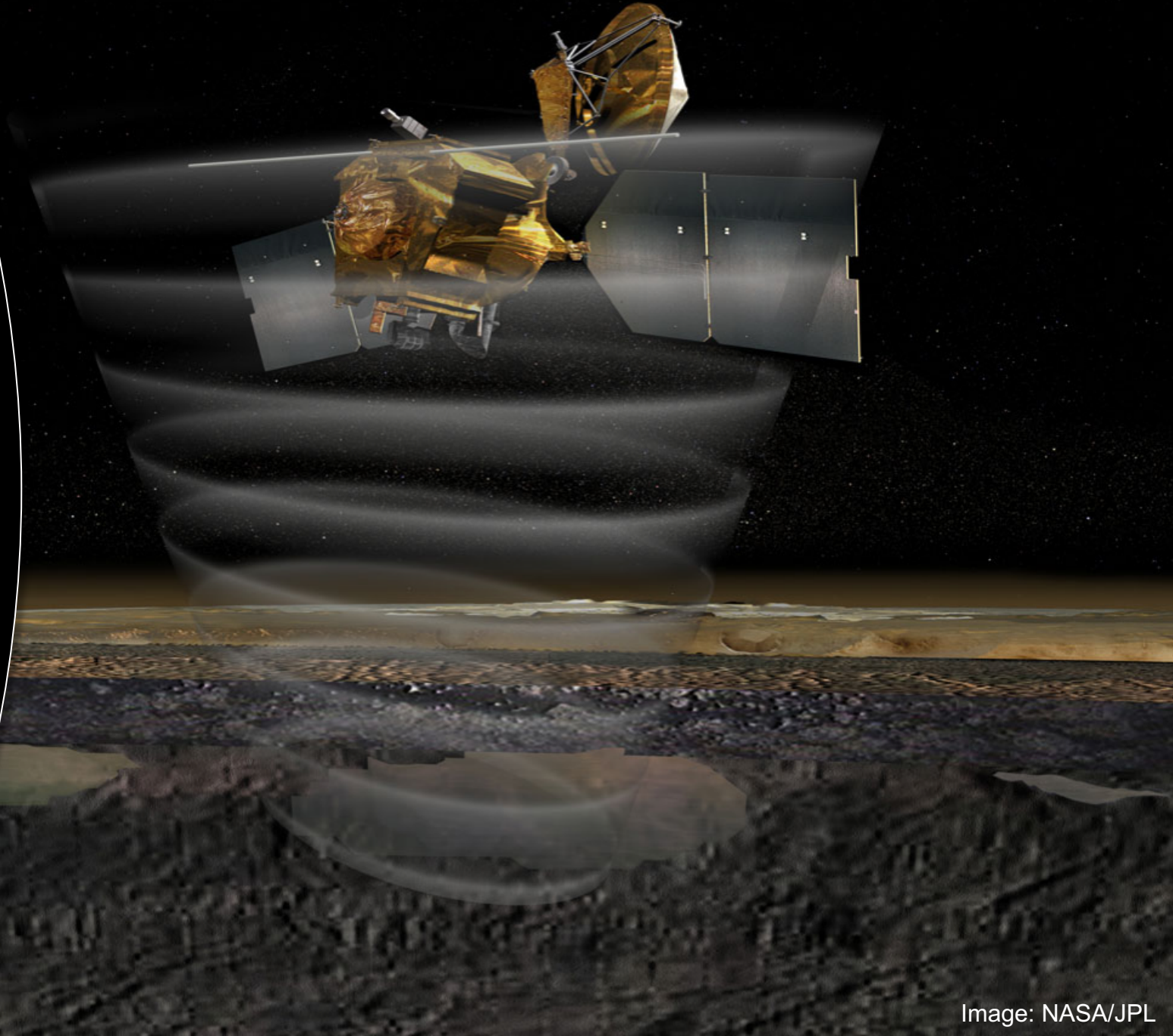


Image: NASA/JPL

There are two radar sounders in orbit around Mars.

	SHARAD	MARSIS
Spacecraft Onboard	Mars Reconnaissance Orbiter	Mars Express
Center Frequency	20 MHz	1.8, 3.0, 4.0 and 5.0 MHz
Bandwidth	10 MHz	1 MHz
Vertical resolution (in free space)	15 m	150 m
Horizontal resolution (along track)	0.3–1 km	5–10 km
Horizontal resolution (cross track)	3–6 km	10–30 km

Seu et al. 2007

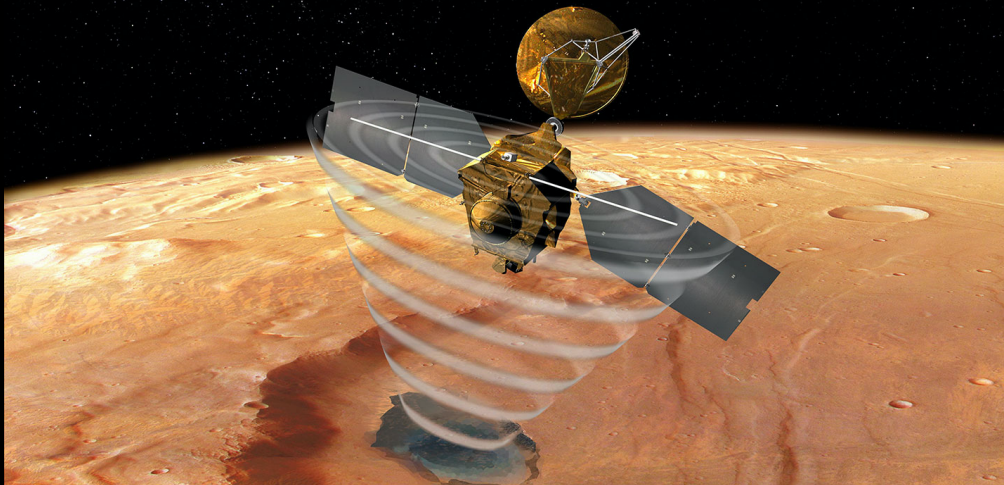


Image: NASA/JPL-Caltech

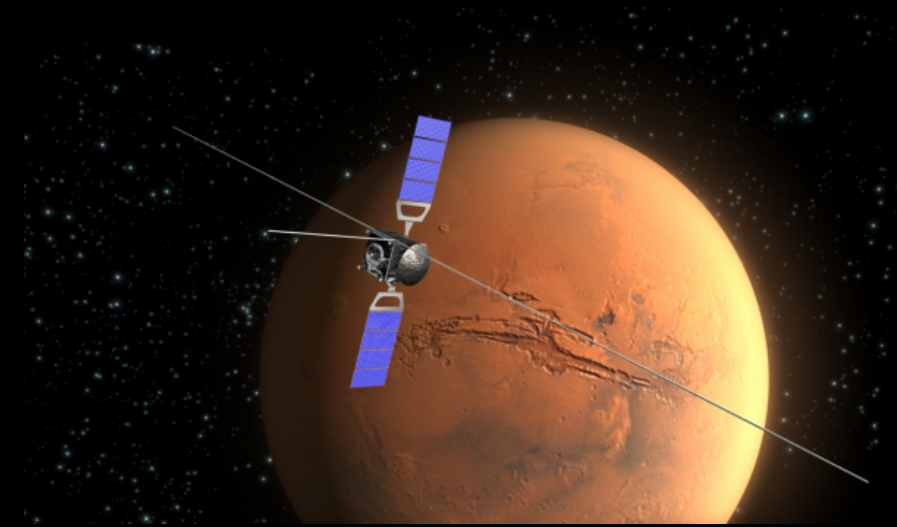
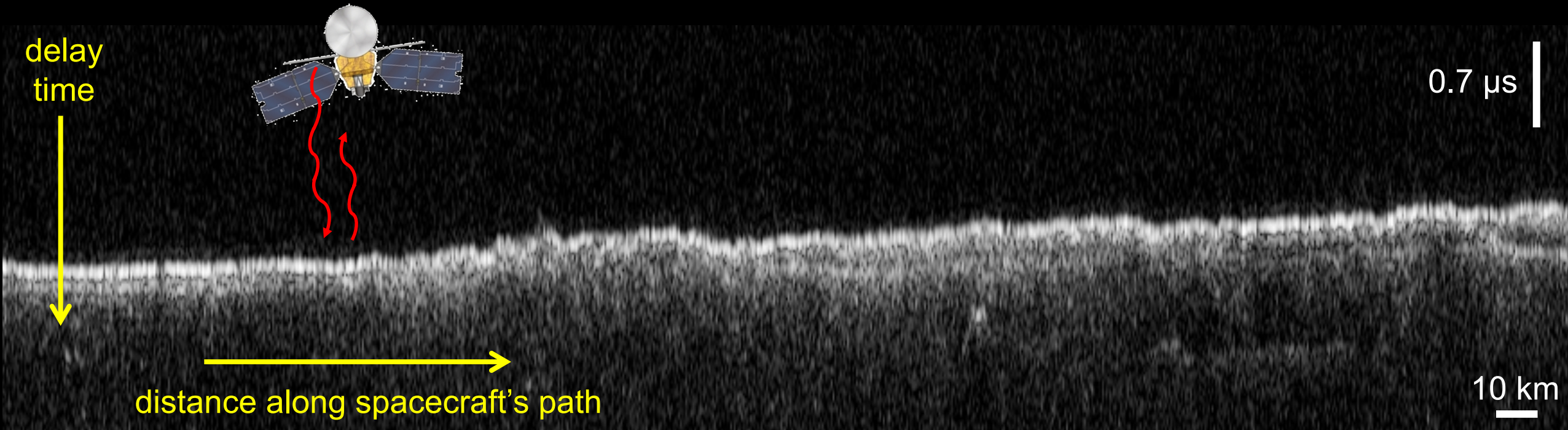


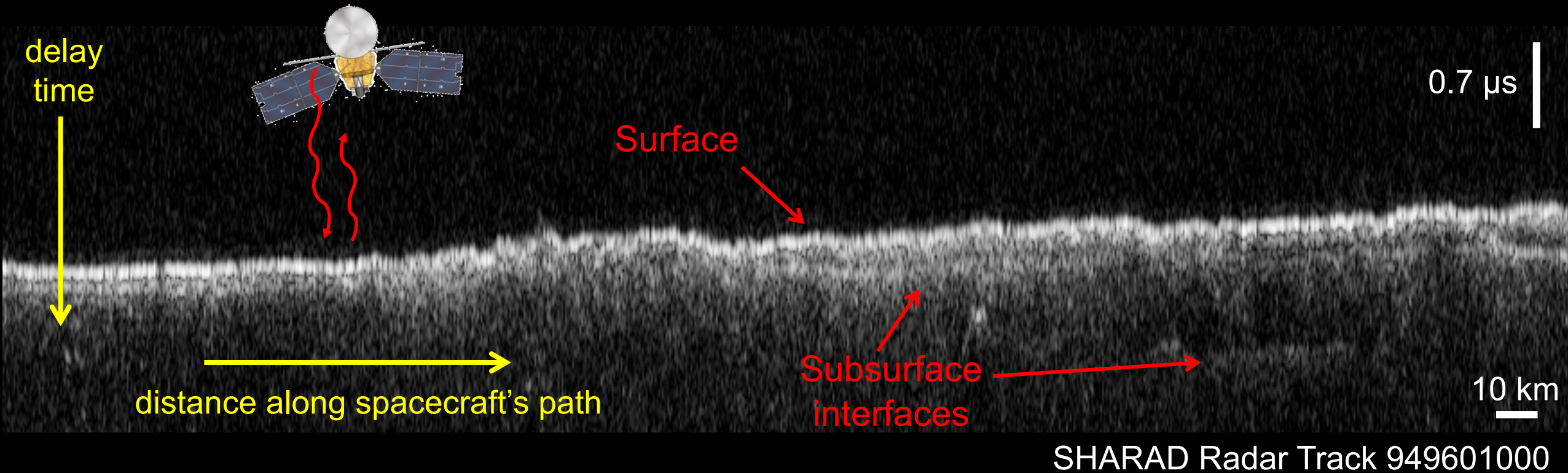
Image: ESA, C. Carreau

Radar sounding “radargrams” display radar power vs. time delay.



SHARAD Radar Track 949601000

Radar sounding “radargrams” display radar power vs. time delay.



Radar waves bounce off interfaces with a sharp contrast in dielectric properties (e.g. atmosphere-surface boundary; subsurface layers).

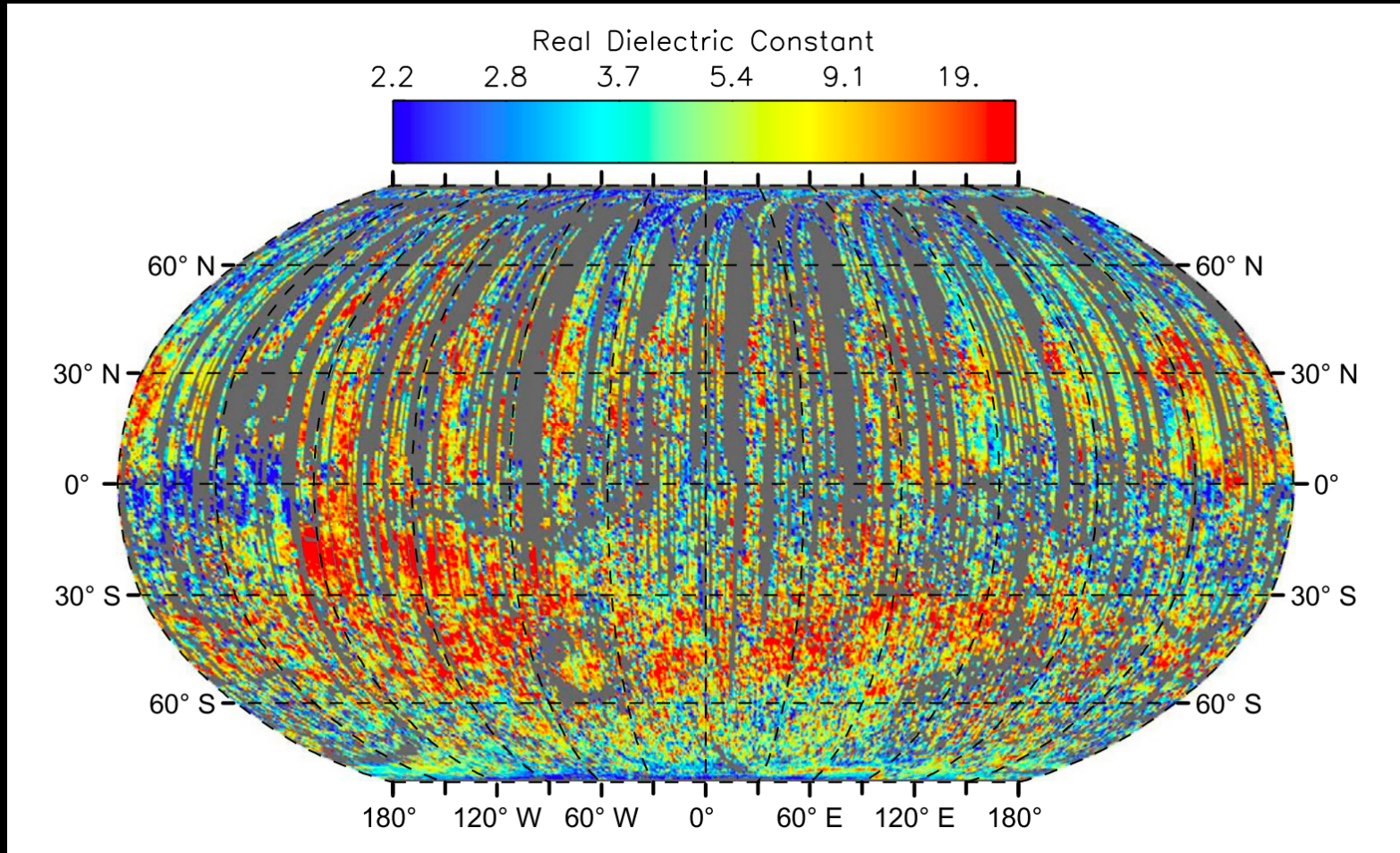
Dielectric constant (permittivity) can be estimated...

Real component (ϵ_r)	Imaginary Component (“dielectric loss”)
How much has the radar wave been slowed down compared to the speed of light in a vacuum?	How much of the radar signal is dissipated by the material?
Method: Combine one-way travel time (dt) between reflectors with independent estimate of thickness (dx) to compute propagation velocity of the wave	Method: Analyze the reduction in power returned vs. depth for a subsurface reflector
Air/Vacuum $\epsilon_r = 1$ Water ice $\epsilon_r \sim 3.15$ (e.g., Matsuoka et al., 1997) Basalts $\epsilon_r \sim 7.5\text{--}9$ (e.g., Rust et al., 1999; Campbell and Ulrichs, 1969) (Note: mixtures give non-unique results – water ice can give low ϵ_r as can high porosity materials)	Air/pore space, H ₂ O ice, and CO ₂ ice are relatively loss-less. Lithic materials and liquid water dissipate a lot of the radar power.

...providing constraints on composition.

Additionally, the surface echo power gives a proxy for shallow surface density (top ~5 m for SHARAD; 10s of m for MARSIS).

(Mouginot et al. 2010; Grima et al. 2012; Castaldo et al. 2017; Morgan et al. accepted to Nature Astro.)

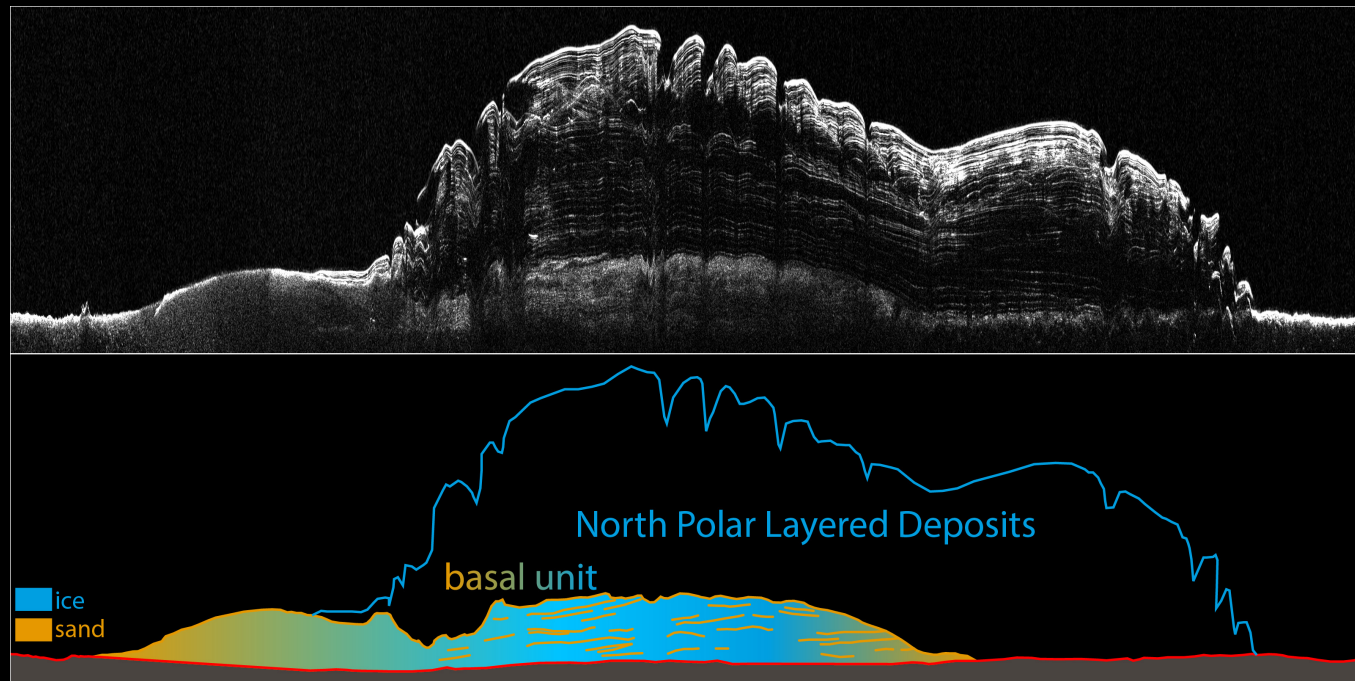


Mouginot et al. 2010

Radar signal of polar caps and debris covered glaciers consistent with nearly pure ice.

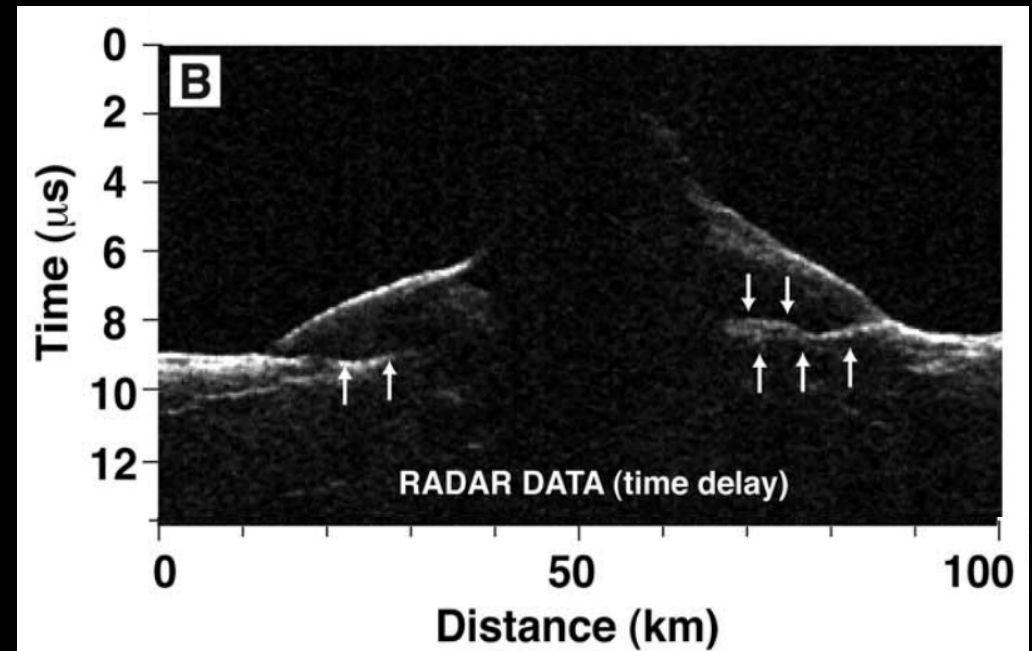
(e.g. *Plaut et al. 2007; Grima et al. 2009; Holt et al. 2008; Plaut et al. 2009; Petersen et al. 2018*)

North Polar Ice Cap



Nerozzi et al. 2019

Debris Covered Glaciers



Holt et al. 2008

Widespread subsurface radar reflectors in the northern plains have been interpreted to be due to decameters-thick ice.



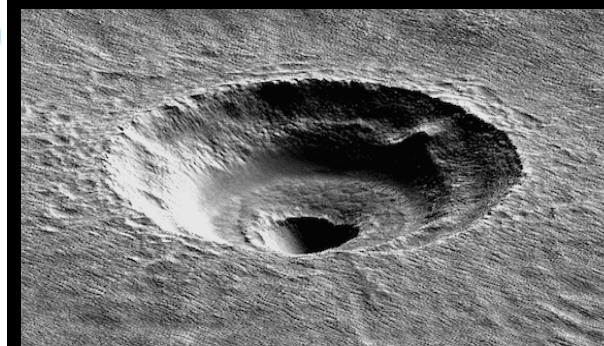
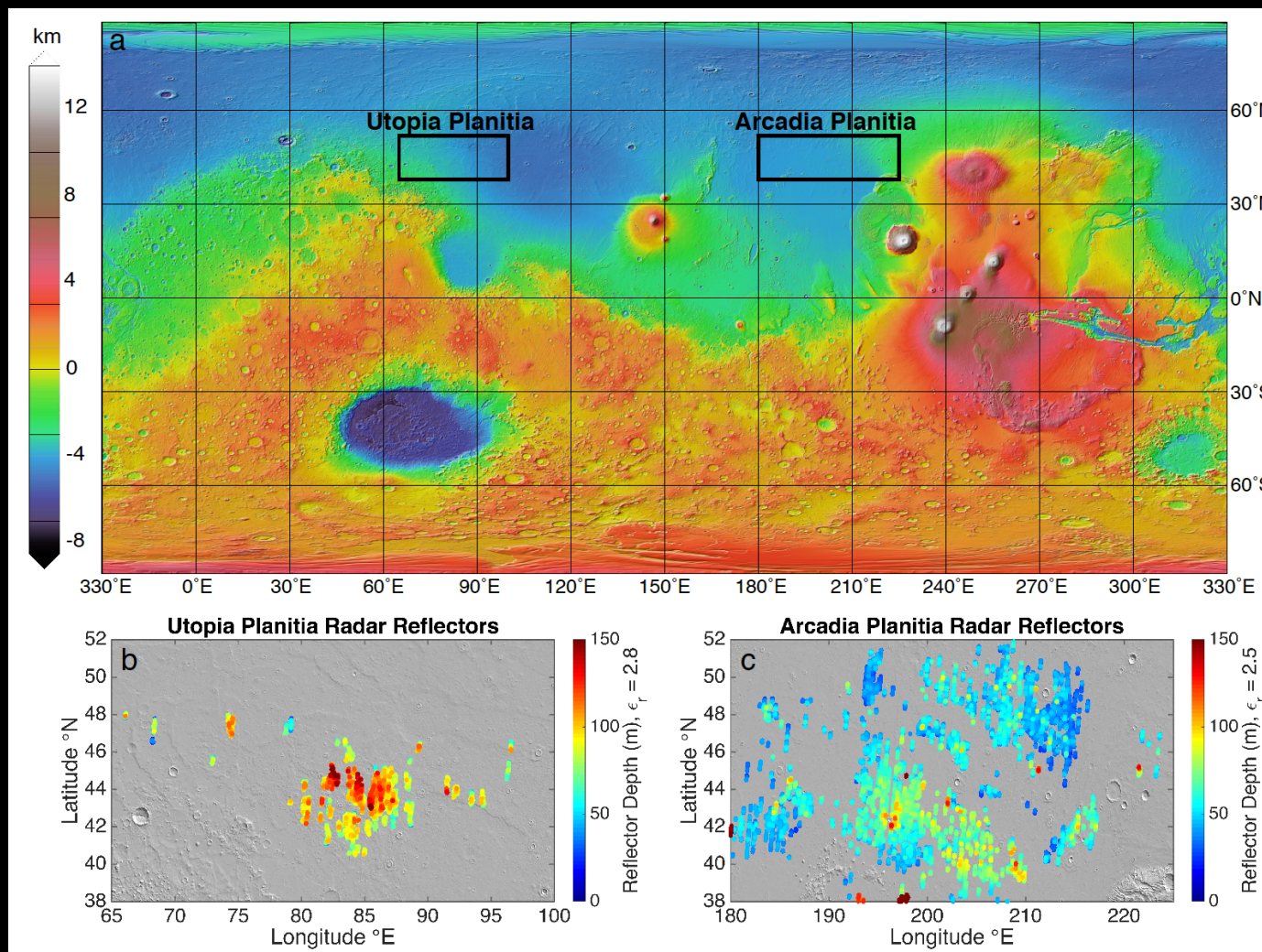
Utopia Planitia

Stuurman et al. 2016

$\sim 10^4 \text{ km}^3$

$\sim 80\text{--}170 \text{ m thick}$

$\epsilon_r = 2.8 \pm 0.8$



Arcadia Planitia

Bramson et al. 2015

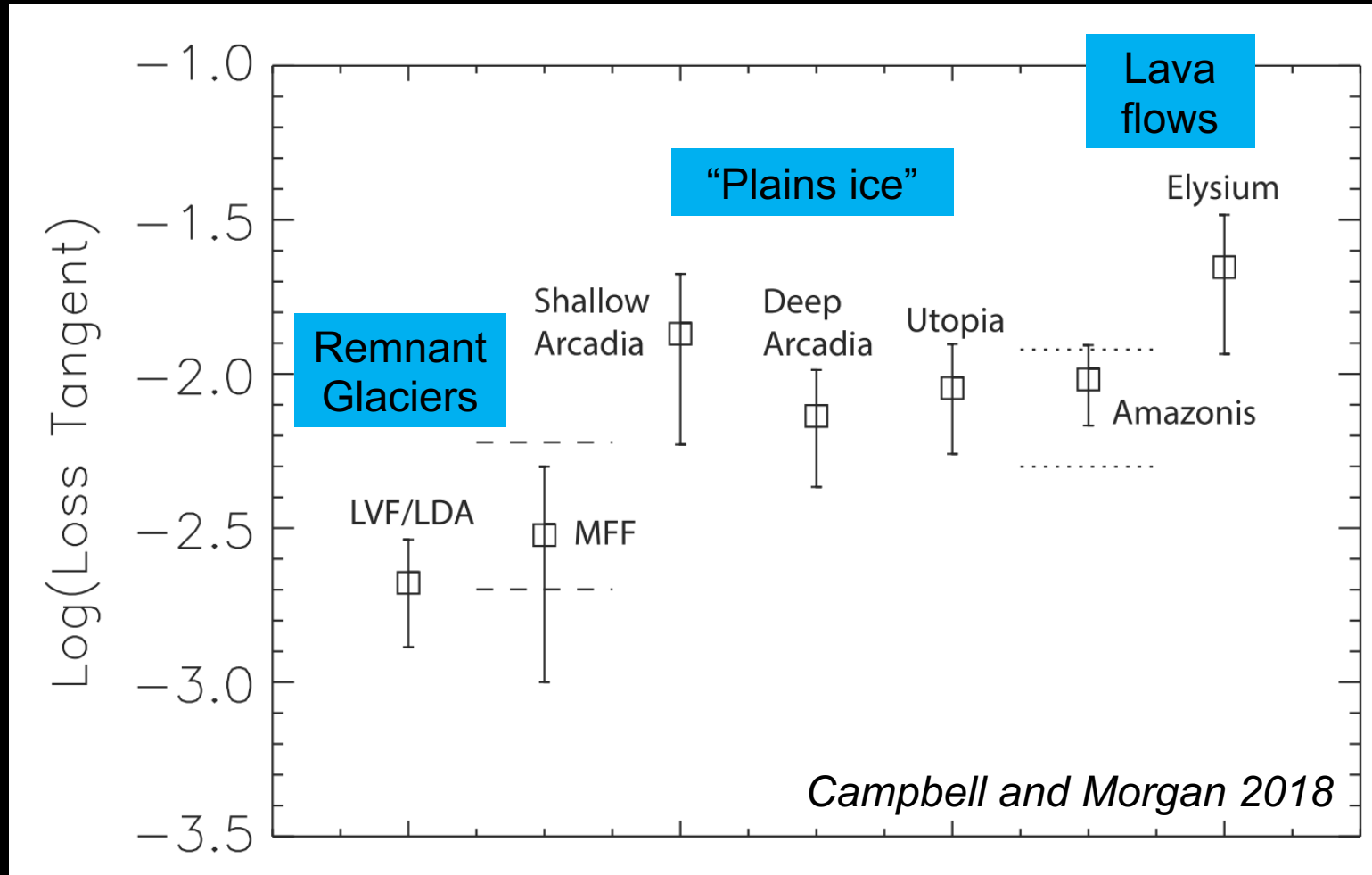
$\sim 10^4 \text{ km}^3$

$\sim 25\text{--}80 \text{ m thick}$

$\epsilon_r = 2.5 \pm 0.28$

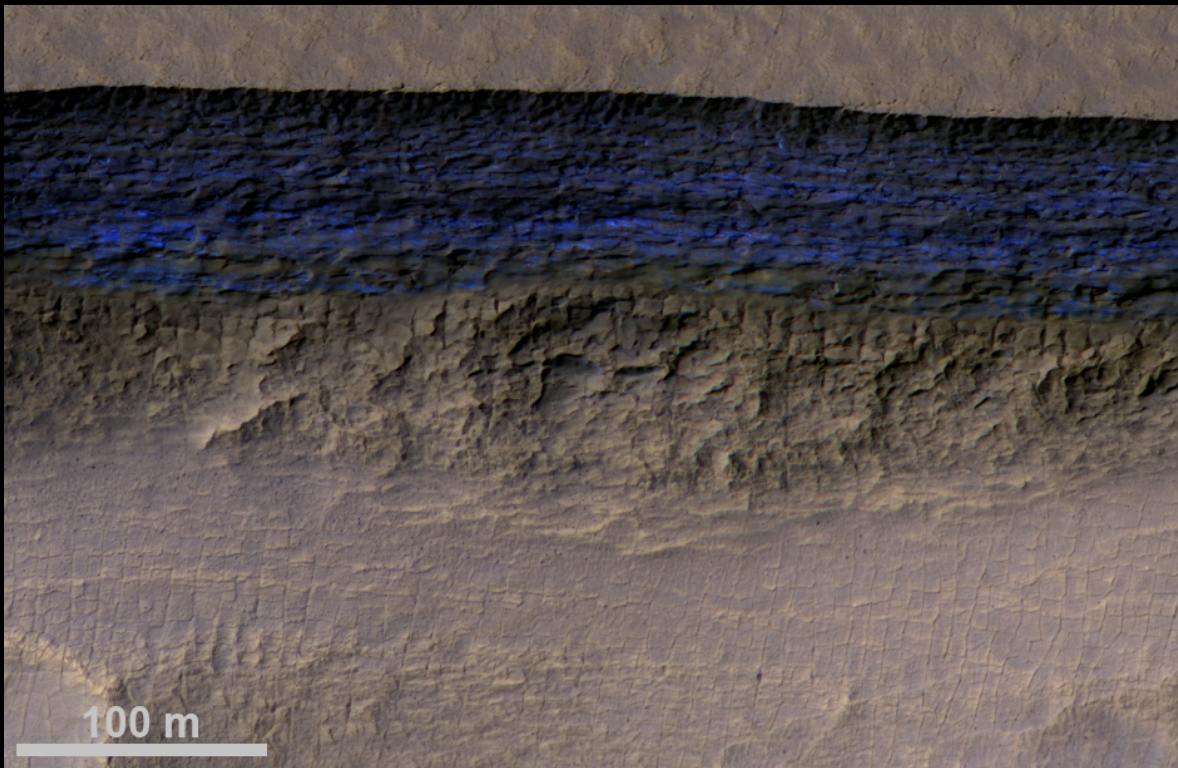
Fig. from Bramson et al. 2017

Loss tangents show glacial features have low loss (consistent with nearly pure ice) while the plains reflectors have higher loss, indicating higher fraction of lithic material.



Radar has unlocked key capabilities for characterizing the distribution, volumes, and properties of Mars' ice.

Huge advances have been made in the last decade! But current radar systems can't resolve the top ~15 m, and huge questions remain, especially regarding the structure, heterogeneities, and depths of shallow ice.



Dundas et al. 2018



Byrne et al. 2009; Dundas et al. 2014