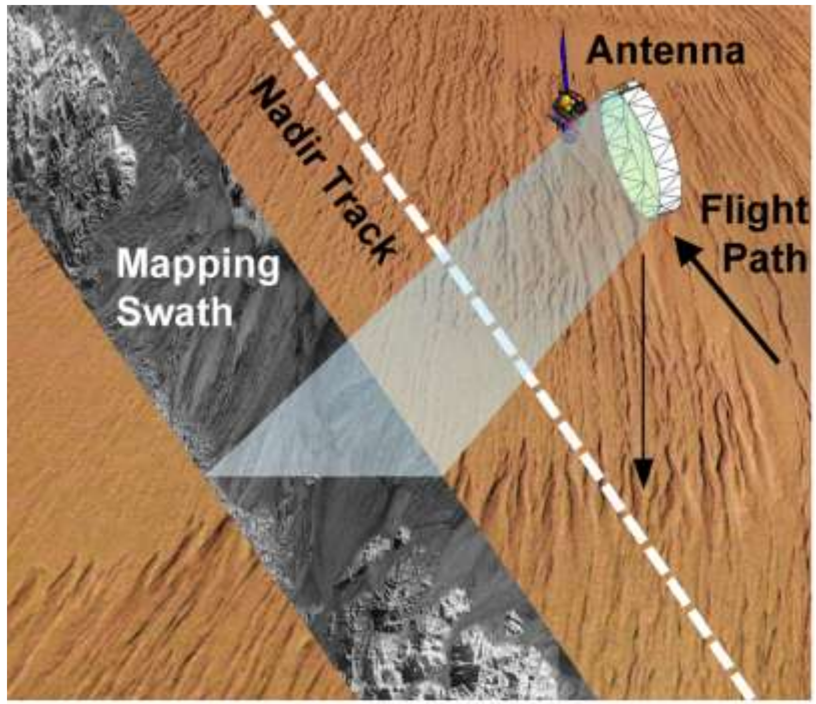
NEAR-SURFACE ICE, TRANSIENT WATER RELEASES, AND THE GEOLOGIC CONTEXT OF HYDRATED MINERAL EXPOSURES: SAMPLE RETURN AND HUMAN EXPLORATION BENEFITS OF AN ORBITAL IMAGING RADAR FOR MARS



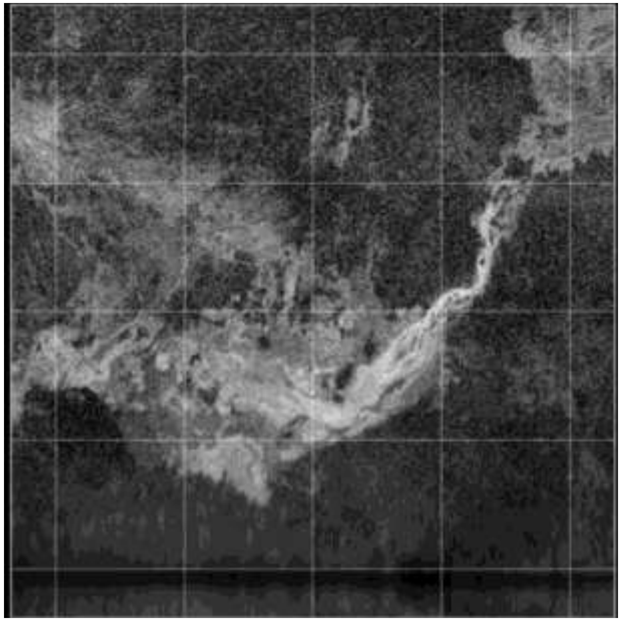
Imaging radar offers the spatial resolution of a camera with much greater depth of penetration.

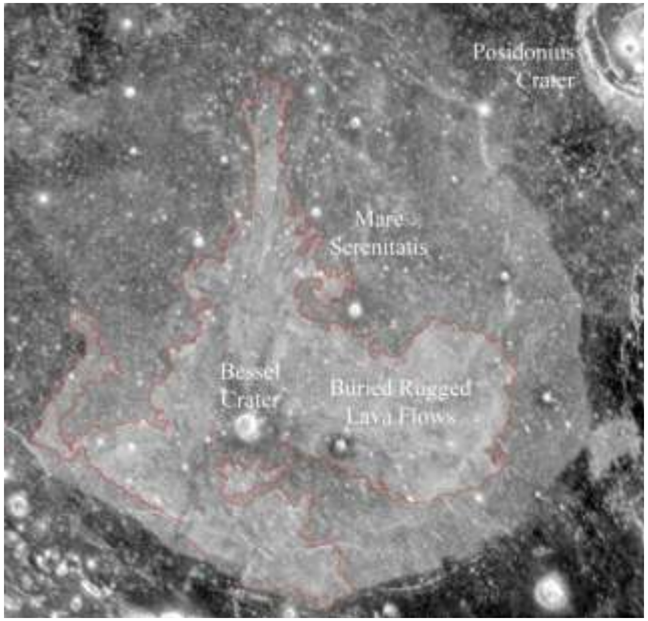
Bruce Campbell, John Grant, Jeff Plaut, Tony Freeman, Eagle Discovery Team

October 11, 2012

Hidden Landforms and Geologic Context

Radar is an imaging sensor that can map geologic landforms beneath mantling sediment to reveal volcanic history, the context of hydrated mineral outcrops, and the role and fate of water.





Earth-based 12.6-cm radar view (left) of Elysium Planitia lava flow patterns through dust cover, and 70-cm view (right) of rugged lava flows hidden by 4-8 m of regolith in Mare Serenitatis.

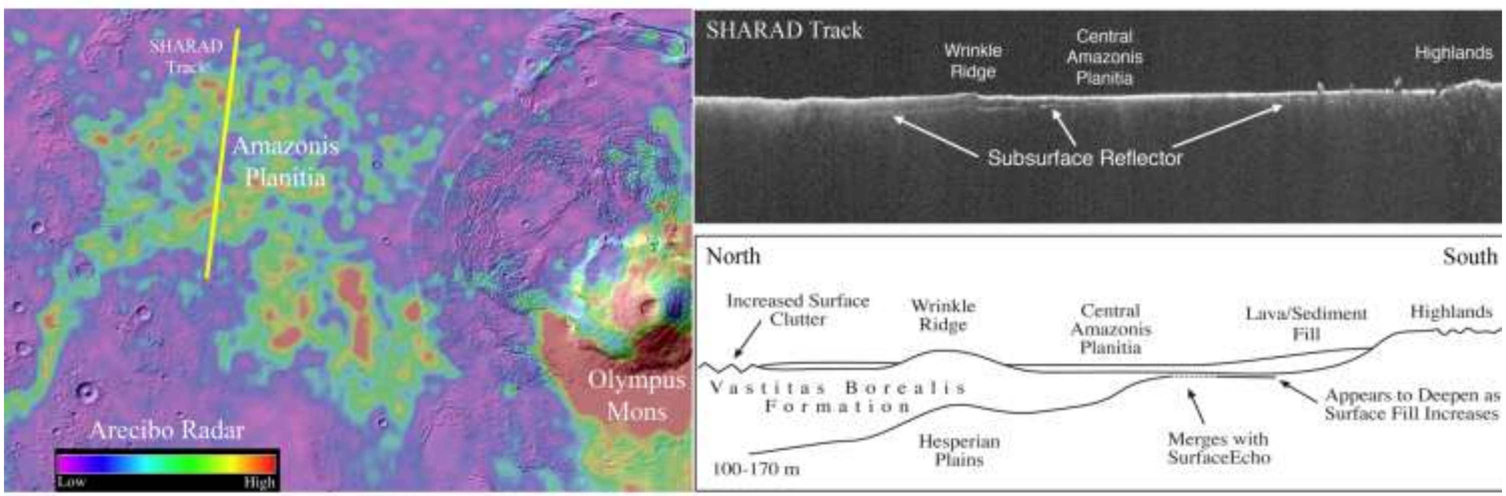
DECADAL: What is the geologic record of climate change? How do the polar layered deposits and layered sedimentary rocks record the present-day and past climate and the volcanic and orbital history of Mars?

Complementing Radar Sounding

MARSIS and SHARAD detect radar reflections from subsurface geologic interfaces, from about 30 m to a few km beneath the surface, in a profiling mode with few-km spatial footprints.

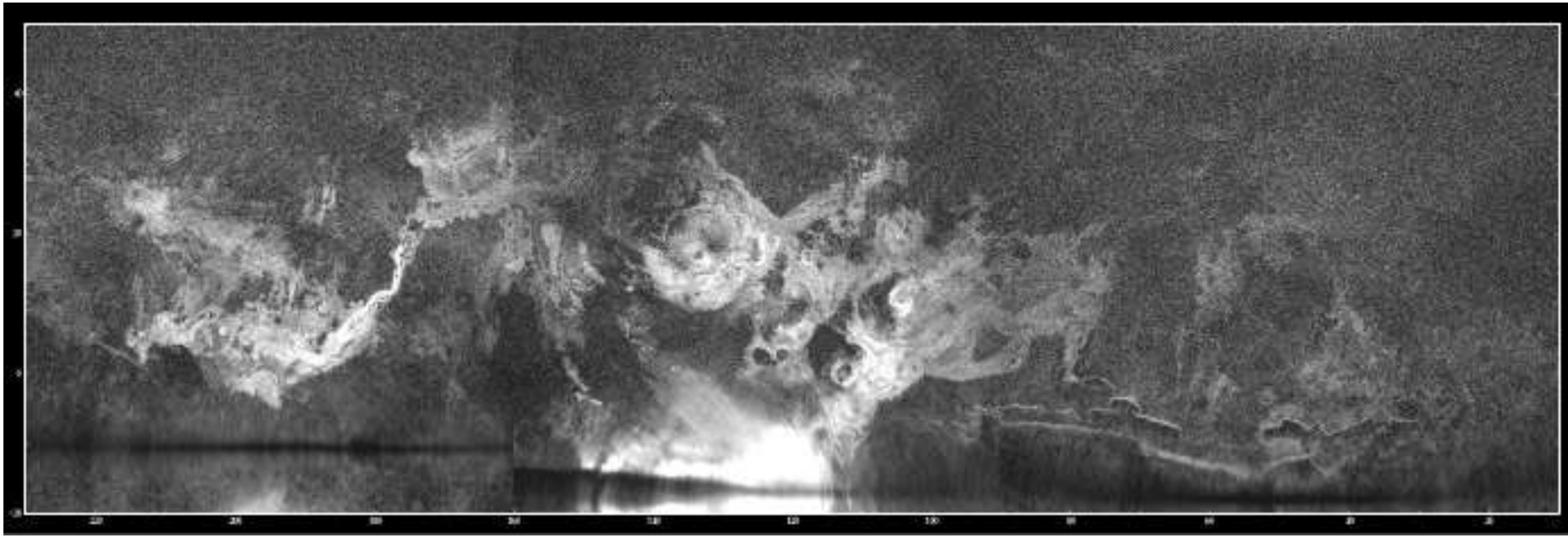
An orbital imaging radar would reveal geologic features and ice beneath 3-5 m or more of mantling material, covering large regions with spatial resolution as fine as THEMIS VIS data.

Operated in a nadir mode, the same system could sound the upper 100 m of the PLD to complete our understanding of layering and physical properties.



SHARAD and Earth-based radar work together to reveal rugged lava flows capping sediments that fill southern Amazonis Planitia. Orbital radar data offer 5-fold greater penetration and 50–100-fold finer spatial resolution than Earth-based radar, permitting detailed geologic studies that complement SHARAD subsurface profiling.

A New Landscape



Arecibo view of the northern mid-latitudes at 12.6 cm wavelength

Harmon et al., Icarus, 2012

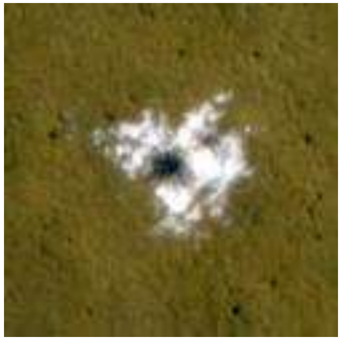
A radar in orbit will have 50-100X finer spatial resolution, and about 5X greater depth of penetration.

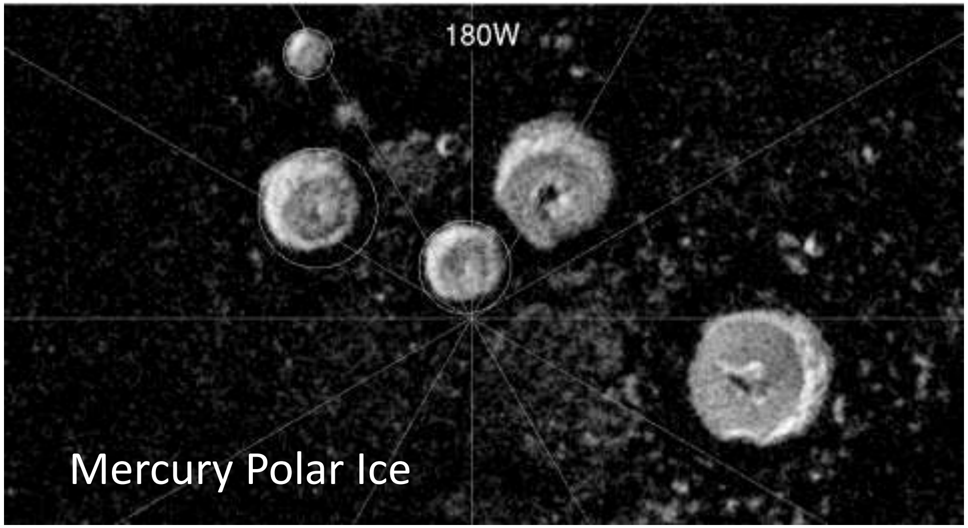
Ice Detection and Mapping

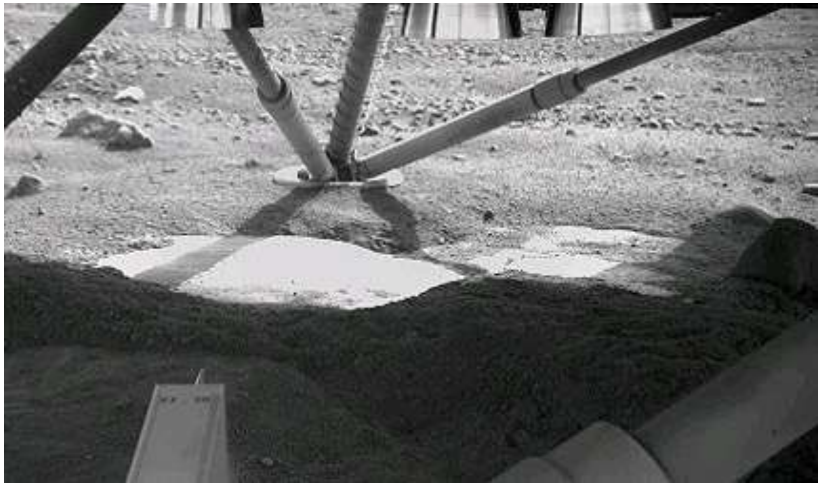
Shallow deposits of clean ice at shallow depth:

- represent a major potential resource for ISRU
- may harbor evidence of past life and climate conditions
- may supply transient water films and outflows for current habitability

Radar imaging and polarimetry can detect and map clean, shallow ice
Radar measurements have spatial resolution for rover/drill planning



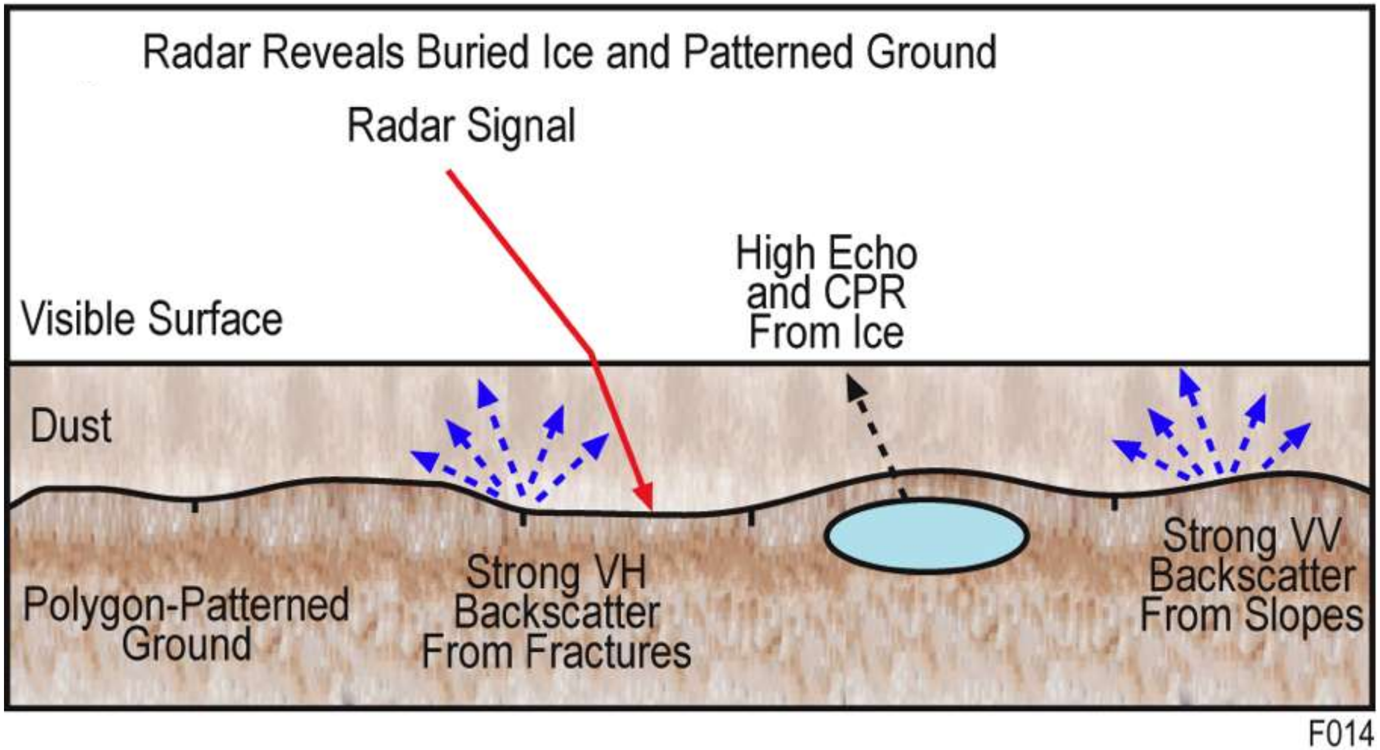




DECADAL: Do habitable environments exist today that may be identified by atmospheric gases, exhumed subsurface materials, or **geophysical observations of the subsurface**? What is the global history of ice on Mars? What is the origin of the latitude-dependent ice mantle? To reduce the cost and risk for future human exploration, robotic precursor missions would be needed to acquire information concerning **potential resources and hazards** …

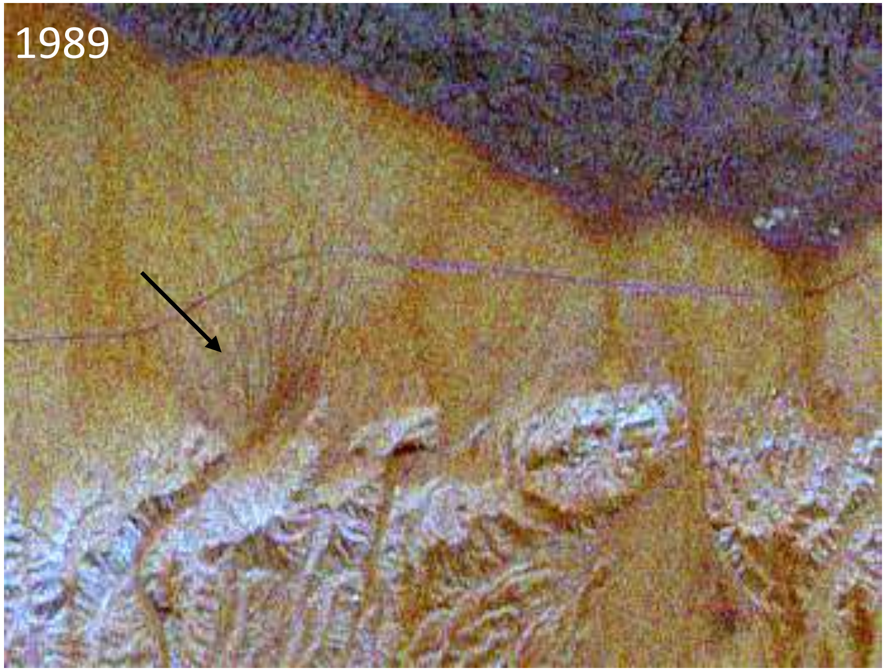
Subsurface Ice and Patterned Ground

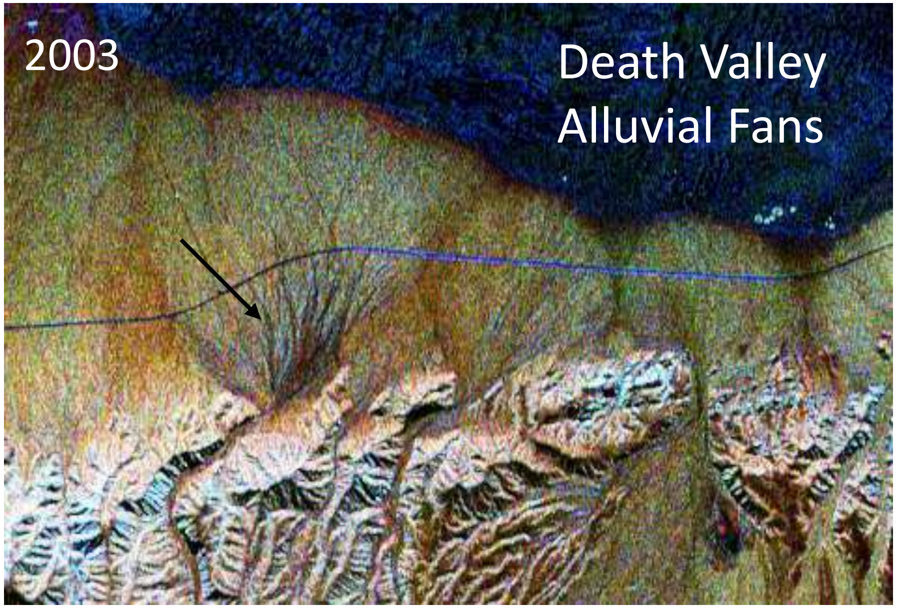
An imaging radar in Mars orbit will map patterned ground signatures, regional ice accumulations, and localized masses of ice beneath meters of mantling sediment.



Radar polarization information is crucial to distinguishing ice from other materials.

Temporal Change and Transient Brine



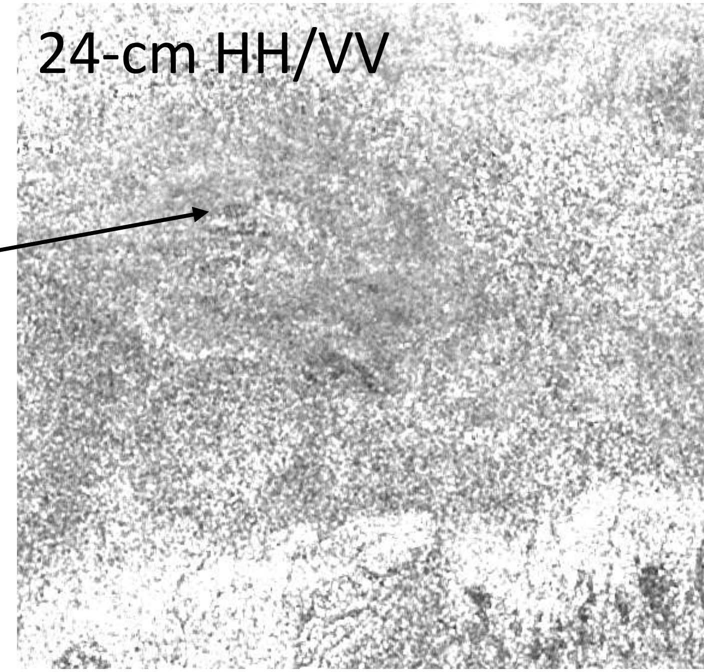


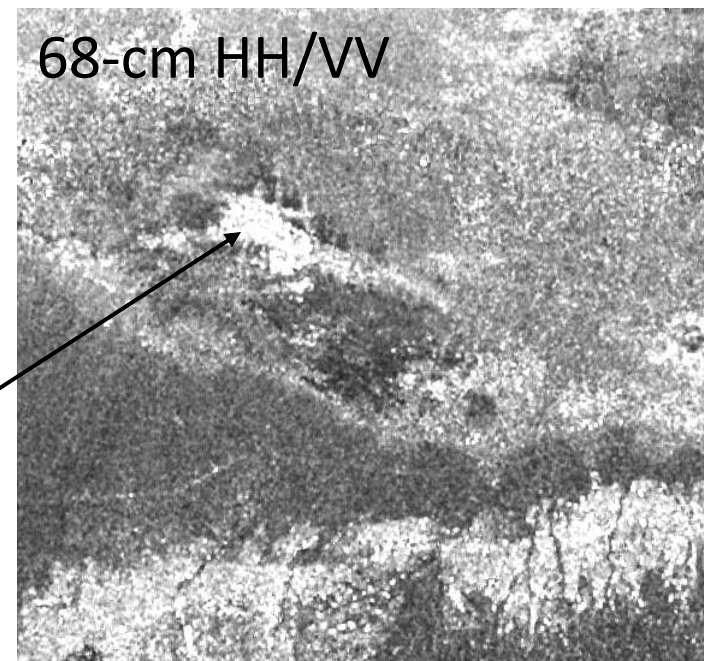
Brine has a much higher microwave reflectivity than dry soil or water ice, and will raise the radar brightness (even where the area covered is sub-pixel). Dry sediments will reduce the brightness.

DECADAL: How, when, and why did environments vary through Mars's history and were these environments habitable?

Brine Detection with Airborne Radar

Shorter wavelengths "see" only dry sand layer at surface.





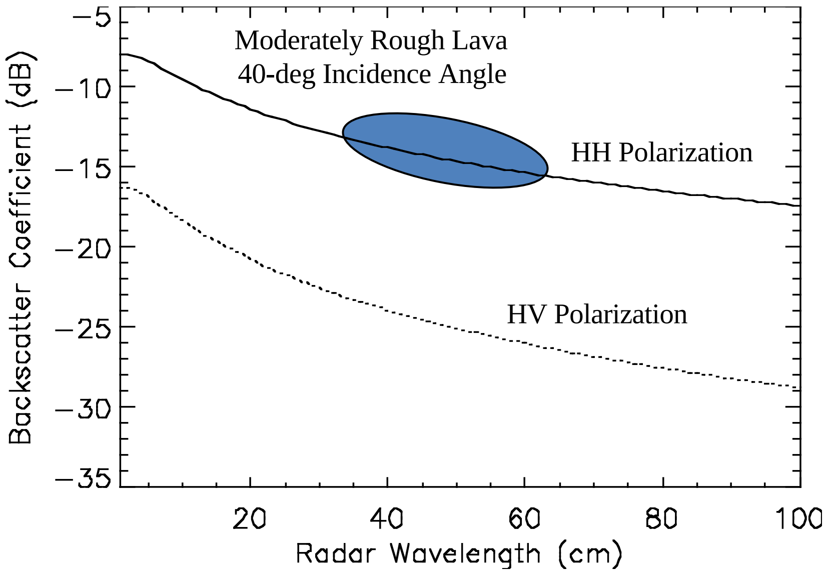
Long wavelength penetrates sand to reveal strong scattering by brine.

As with ice mapping, radar polarization plays a strong role in making clear conclusions.

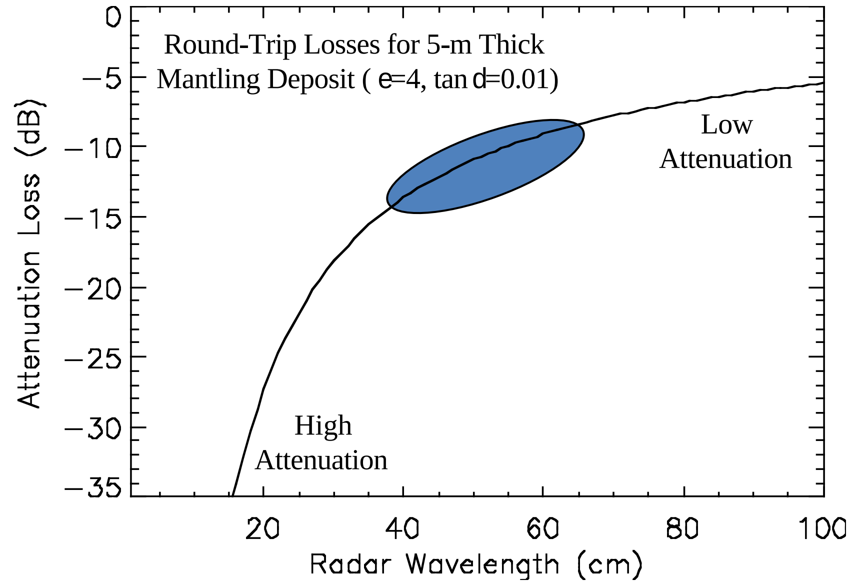
What is the Best Wavelength?

Detecting buried rough interfaces with side-looking radar is a trade between:

Decreasing radar-perceived surface roughness at greater length scale.



Increasing depth of penetration with longer radar wavelength.

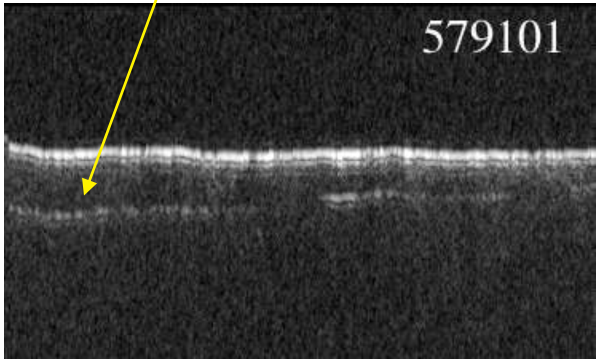


A radar wavelength in the 30-60 cm range will optimize the characterization of ice and buried bedrock geology.

Longer wavelengths also have less scattering loss due to small rocks in a layer.

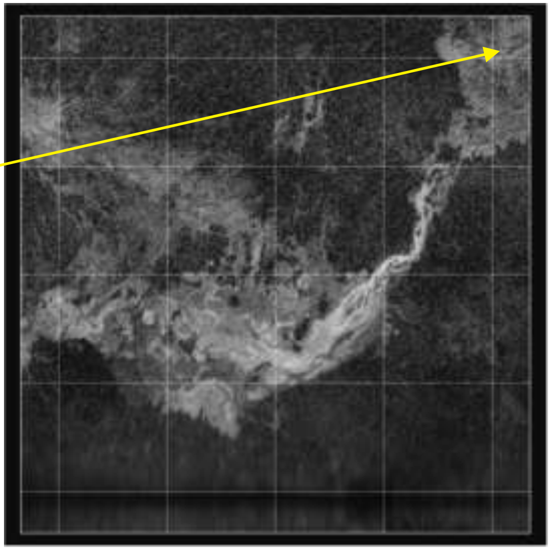
Material Properties are Favorable for Radar Probing

- Sounding radar data directly measures loss tangent for sloping reflectors:
  - Vastitas Borealis sediments and veneer of Amazonian lava from SHARAD = 0.005-0.012
  - Medusae Fossae Formation from MARSIS probing = 0.002-0.006
  - Ascraeus Mons lava flows from SHARAD = 0.01-0.03
  - Polar layered terrain from MARSIS and SHARAD = <0.001



- Non-polar dielectric losses fall between dried terrestrial rocks (0.01-0.10) and low-Ti lunar basalt (0.001-0.01).

- Earth-based 13-cm observations:
  - Good penetration even where HiRISE shows 2 m or more of surface debris (central Amazonis).
  - Moderate echoes from the northern plains, with no evidence for pervasive high-loss geologic materials such as hematite.



Reasonable Goals for Orbital Radar

- Detect and map regional accumulations and localized bodies of ground ice (10's of meters in lateral extent and at least a few meters in thickness) within 5 m of the surface.
- Characterize lag deposits on lobate aprons and other potential sites of equatorial ice preservation.
- Identify temporal changes in surface properties related to seasonal discharge of water.
- Map process-diagnostic geologic landforms beneath 3-5 m or more of mantling dust or sediment.
- Map the distribution and thickness of fine-grained deposits as site hazards, and calibrate existing dust index and thermal inertia data.

- With 12 months of operation, obtain a global survey at 75-m resolution, and 18-m observations of ~100 targeted sites (250x250 km).

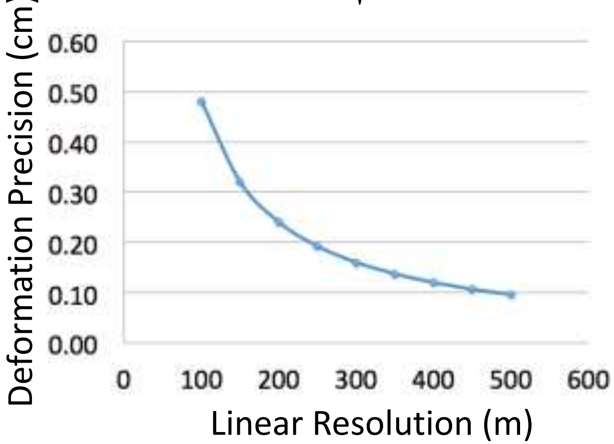
Bonus: Radar Interferometry at Mars

- Radar interferometry combines data from two observations separated in time and or space and obtains two basic measurements:
  - **Phase:** This is a measure of the differential range to a point between two observations that can be made with millimeter level precision.
  - **Correlation:** This is a measure of the similarity of the signal received at the two antennas that has sensitivity to wavelength changes on the surface (centimeter scale for a P-band radar), **temporal correlation**, and to the vertical arrangement of scatters within a resolution element, **volumetric correlation.**

Deformation

- Deformation can be measured to millimeter precision.

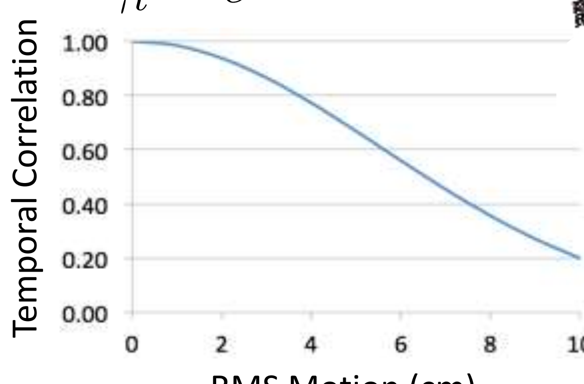
$$\sigma_{def} = \frac{\lambda}{2}\frac{1}{\sqrt{2N_L}}\sqrt{\frac{1-\gamma^2}{\gamma^2}}$$



Temporal Correlation

- Temporal correlation, valued between 0 and 1 can sensitively detect small scale surface disturbances.

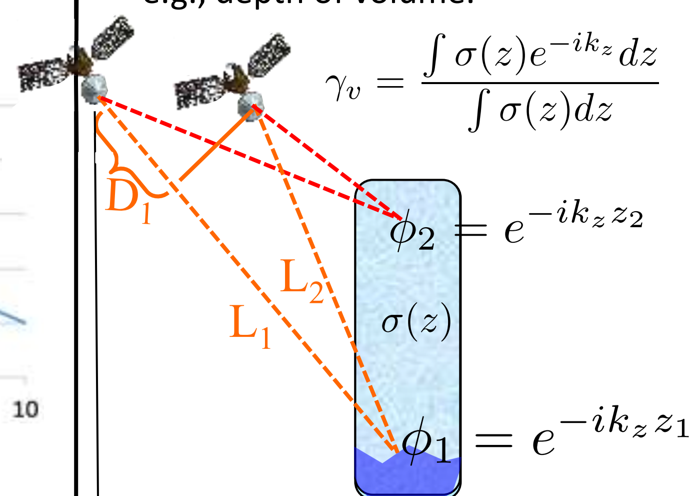
$$\gamma_t = e^{-\frac{1}{2}\left(\frac{4\pi}{\lambda}\right)^2\sigma^2_{rms}}$$



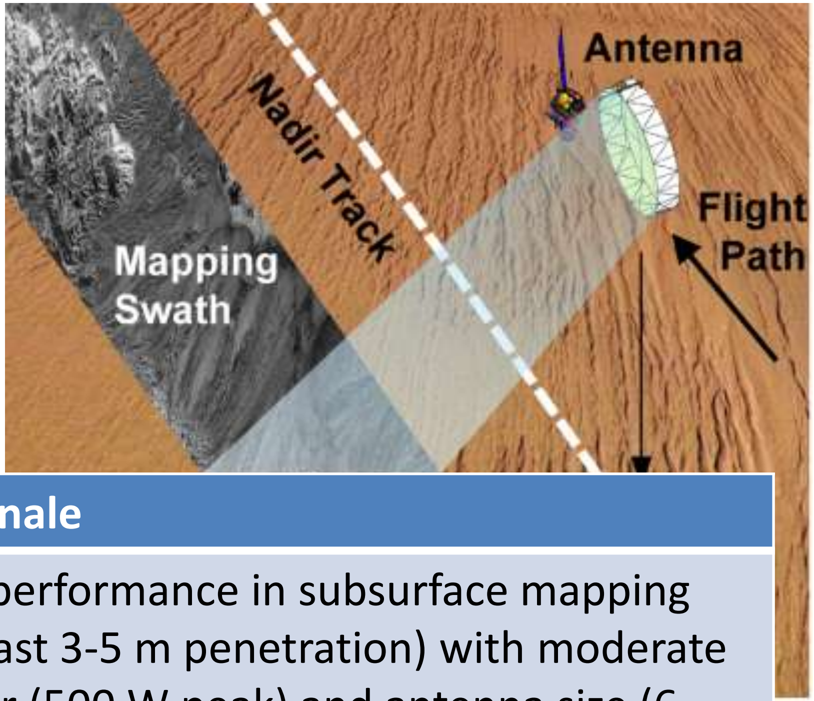
Volumetric Correlation

- Volumetric correlation can used used to estimate information about scattering from a volume, e.g., depth of volume.

$$\gamma_v = \frac{\int \sigma(z)e^{-ik_z}dz}{\int \sigma(z)dz}$$



Instrument Requirements
(Compatible with Discovery-class to MRO/Maven buses)



Requirement	Rationale
Single-frequency synthetic aperture radar with wavelength of about 60 cm.	Best performance in subsurface mapping (at least 3-5 m penetration) with moderate power (500 W peak) and antenna size (6 m). Strong science heritage from AIRSAR and Earth-based radar studies.
Selectable polarization from dual-pol (e.g., VV and VH) to fully polarimetric operation (HH, HV, VV, VH polarizations).	Ice detection confidence greatly improved by fully polarimetric measurements.
Spatial resolution of 75 m for regional surveys, 18 m for targeted sites.	Best performance in subsurface mapping and polarimetry for reasonable bandwidth.
Noise-equivalent sigma-zero of -35 dB	SNR performance to meet goal of 3-5 m penetration in martian materials as characterized by MARSIS and SHARAD.