MAPPING THE UPPER SUBSURFACE OF MARS USING RADAR POLARIMETRY. L. M. Carter[1], R. Rincon[1], L. Berkoski[2] [1]NASA Goddard Space Flight Center (Planetary Geodynamics Lab, Code 698, NASA Goddard Space Flight Center, Greenbelt, MD 20906; lynn.m.carter@nasa.gov), [2]Northrop Grumman Electronic Systems, Advanced Technology Lab, MS 3K24, Linthicum, MD 21090

Introduction: Future human exploration of Mars will require detailed knowledge of the surface and upper several meters of the subsurface in potential landing sites. Likewise, many of the Planetary Science Decadal Survey science goals, such as understanding the history of Mars climate change, determining how the surface was altered through processes like volcanism and fluvial activity, and locating regions that may have been hospitable to life in the past, would be significantly advanced through mapping of the upper meters of the surface.

Synthetic aperture radar (SAR) is the only remote sensing technique capable of penetrating through meters of material and imaging buried surfaces at high (meters to tens-of-meters) spatial resolution. SAR is capable of mapping the boundaries of buried units and radar polarimetry can provide quantitative information about the roughness of surface and subsurface units, depth of burial of stratigraphic units, and density of materials. Orbital SAR systems can obtain broad coverage at a spatial scale relevant to human and robotic surface operations. A polarimetric SAR system would greatly increase the safety and utility of future landed systems including sample caching.

Mars polarimetric radar: Radar wave penetration into the subsurface is proportional to the wavelength and depends on surface dielectric properties. Ground-based radar imaging of Mars at 2380 MHz (12.6 cm wavelength) has revealed complex lava flows units in the Tharsis and Elysium provinces [1]; because of the relatively short wavelength, imaging at this frequency penetrates through only thin dust layers. A longer wavelength, 500-1000 MHz radar would ensure that the radar can penetrate through at least 2-3 m, and as much as 10-15 m, of dust and regolith cover. This wavelength range would also compliment the current Mars sounding radar data, which does not resolve the top 15-30 meters of the surface.

Numerous terrestrial and planetary science studies have demonstrated that polarimetric data products provide important information about the nature of the surface and subsurface that cannot be obtained solely with backscatter power images [2,3,4,5]. Polarimetric products commonly used for dual-pol systems include the Circular Polarization Ratio (CPR, used as a measure of roughness), Degree of Linear Polarization (DLP, used to infer the presence of subsurface scattering), and linear co-polarization ratios (used to infer roughness and surface penetration). Polarimetry data are critical for distinguishing mantling deposits from smooth uncovered surfaces (Fig. 1), and for determining the roughness and continuity of geologic units. The added quantitative information about scattering that comes from polarimetry provides the only means to distinguish between different surface models, and the lack of polarimetry on the Magellan mission has led to ambiguities in data interpretation.

Climate and cryosphere: A major goal of Mars exploration is to understand how the climate has changed, and radar is particularly well suited for studies of ice and the Martian cryosphere. The SHARAD radar (20 MHz) has revealed layering in the Mars polar caps that may be caused by episodes of increased polar dust deposition [5]. SHARAD also detects the base of

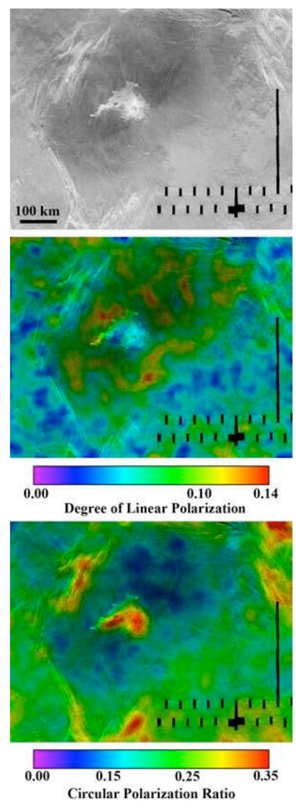

Figure 1: Radar polarimetry from the Arecibo Observatory radar system (2380 MHZ) demonstrates that a radar-dark region surrounding the crater Galina on Venus is covered in fine-grained mantling material [2]. From the Magellan data (top), it is not clear whether the dark region has been swept clear of rocks or whether it is mantled. Increased DLP values (middle) reveal that the radar wave penetrates into a surficial deposit, while low CPR values (bottom) demonstrate that the deposit is rock-poor. This dark area is therefore a smooth deposit of cm-sized or smaller material generated by the impact.

lobate debris aprons that may be left from a prior epoch where ice was stable at lower latitudes [6]. Radar imaging of these ice deposits can reveal internal structure at shallower depths than are visible with SHARAD. Ice also has a distinct radar polarization signature (high backscatter and CPR values) that can be used to locate buried ice deposits.

Polarimetric SAR imaging of the poles over a Mars year would provide detailed measurements of how the current seasonal cycle affects the polar caps. In a system with repeat-pass interferometry, pol-INSAR analysis can be used to detect changes in the density and thickness of ice and frost deposits. These analysis techniques are currently being used to study terrestrial ice sheets; pol-INSAR over Greenland ice sheets has revealed discrete scattering behaviors associated with different types of ice and snow deposits [7].

Surface processes and landing sites: Sample return missions and human exploration landing sites will most likely be located in mid-latitude and equatorial regions where it is particularly important to have high resolution imaging to precisely map boundaries between geologic units. Polarimetric SAR imaging would provide context for sample caching missions by highlighting crater ejecta and detecting buried interfaces that could contribute to the surface rocks at the landing site. For example, radar images of the Moon reveal crater ejecta deposits and impact melts that are not clearly visible in optical images (Fig. 2) [8, 9].

Polarimetric SAR data would also allow mapping of dust-covered volcanic units, which would address the questions of 1.) How the plains of Mars were formed and 2.) What types of volcanism and volcanic flows occurred near both large and small volcanoes and how might this have influenced climate. Prior studies have shown that radar polarimetry can distinguish pyroclastic deposits from regolith and can determine flow roughness (e.g. a'a vs pahoehoe), which is related to emplacement parameters such as velocity and lava viscosity [3, 2].

Radar data is sensitive to roughness at approximately wavelength scales, and can therefore detect features that are smaller than those observed by most optical cameras. The HIRISE camera has a resolution of 30 cm/pixel, but a radar system with a 50 cm wavelength will reflect from rocks, ridges, dunes, etc. that are somewhat smaller than a HIRISE pixel. The radar data is therefore useful for landing site hazard detection and for studying small-scale roughness elements like dunes, small ripples or rocky crater ejecta.

PolSAR instrumentation: Terrestrial orbital and airplane radar systems provide multi-mode measurements that meet these specifications. These systems are capable of changing modes to provide quad-pol or full-pol imaging at different resolutions and swath-widths, and they can obtain repeat pass interferometry. Earth observing L-band radar/radiometers for space have been implemented using a dedicated deployable perimeter truss antenna technology (Soil Moisture Active Passive mission). Alternate implementations of a Mars sensor could utilize a compact radar electronics package with a shared composite antenna with the communications system, using multiple feeds and frequency selective surfaces. High data rate communications such as a laser comm system would enable higher resolutions, increased spatial coverage, or shorter duration missions. These advanced polarimetric SAR systems would provide a detailed mapping of the upper meters of the Martian surface that would enhance the science return from sample caching and human exploration missions.

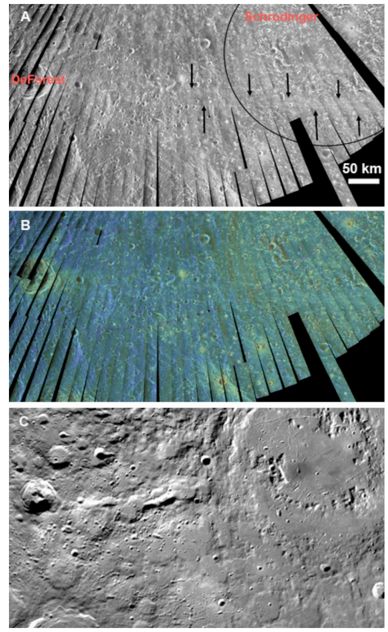

Figure 3: Radar backscatter (A) and CPR (B) mosaics of the lunar south pole from the Mini-RF SAR radar reveal long-distance crater ejecta not apparent in Lunar Reconnaissance Orbiter Camera Wide Angle Camera images (C) [9]. The bright streaks in A (arrows) are caused by centimeter to meter sized rocks that form a ray. The CPR data (B) show higher values to one side of the crater DeForest, indicating an oblique impact.

References: [1] Harmon and Nolan (2007), 7th Con. On Mars, #1353. [2] Carter et al. (2011) Proc. IEEE, 99, doi:10.1109/JPROC.2010.2099090. [3] Campbell and Campbell (1992), JGR, 97, 16293. [4] Campbell et al. (2004), JGR, 109, E07008, doi:10.1029/2004JE002264 [4] Stacy et al. (1993) Ph.D. Thesis, Cornell U. [5] Phillips et al. (2008), Science, 320, 1182. [6] Holt et al. (2008), Science, 322, 1235. [7] Doulgeris et al. (2009), Proc. PolINSAR 2009, ESA SP-668. [8] Carter et al. (2012), JGR, 117, E00H05, doi:10.1029/003862. [9] Carter et al. (2012) et al. 43rd LPSC, #1659 .