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. B. A. Campbell[1], J. A. Grant[1], J. J. Plaut[2], A. Freeman[2], and the Eagle Discovery Proposal Team, [1]Smithsonian Institution, Center for Earth and Planetary Studies, PO Box 37012, Washington, DC 20013-7012, campbellb@si.edu, [2]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109.

Introduction: We present the science and resource-mapping capabilities of a synthetic aperture radar (SAR) sensor that can be accommodated on a Discovery class bus or as part of the instrument suite of a MRO/MAVEN scale spacecraft. Results from the Phoenix site, orbital neutron observations, and HiRISE studies of fresh craters all confirm the presence of water ice close to the surface in mid-latitude regions of Mars [1-3]. These ice deposits represent a fundamentally important resource for human presence and potential sites of current habitable environments. Observations of seasonally reoccurring slope streaks suggest that such ice bodies may supply releases of water onto the surface [4]. Hydrated mineral exposures associated with past habitable settings are also targets for sample return and potential resources for human presence [5, 6]. An orbital SAR is uniquely suited to penetrate mantling dust and sediments, providing detailed maps of shallow ice, measuring the physical properties of slope streaks to verify the presence of brines, and revealing the geologic context of hydrated mineral exposures. Such observations are critical to understanding the evolution of Mars, and are key elements in selecting sites for sample return and in-situ resource studies.

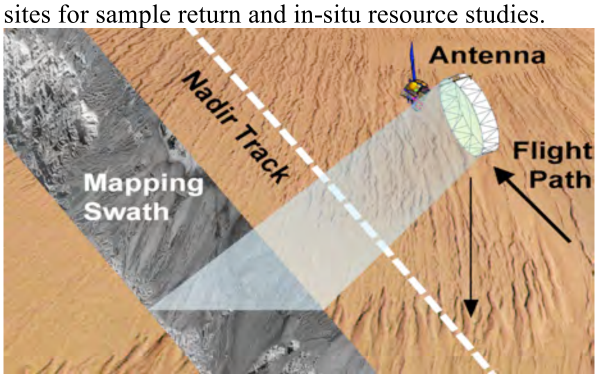

Fig. 1. Imaging radar viewing geometry.

Synthetic Aperture Radar: SAR is an active imaging sensor, providing a map of the region illuminated from the side by an orbiting instrument (Fig. 1). Radar sounders such as MARSIS and SHARAD provide along-track profiles of material interfaces that are 30 m or more below the surface with relatively coarse (km-scale) spatial footprints. In contrast, an orbiting SAR has spatial resolution comparable to visible-light sensors like THEMIS-VIS, and each pixel represents the radar echo from geologic features (layering, rocks, ice, brine) within the upper several meters of the landscape. This fine spatial resolution and depth-penetration capability makes SAR an ideal tool to extend our knowledge of the geology and resources of Mars into the shallow subsurface region accessible to robotic and human explorers.

Ice Detection and Mapping: Ice deposits that are of the meter scale or more in thickness, and relatively pure, have a strongly diagnostic radar signature. Ice layers have high radar echoes due to low microwave loss and the presence of cracks and voids that act as strong scatterers [7]. These attributes also lead to enhancement of the circular polarization ratio (CPR), greatly exceeding the typical range observed for dry, rocky settings [8]. Imaging radar identifies ice in permanently shadowed craters on Mercury (Fig. 2) [9], and similar scattering signatures are observed for the icy satellites [7, 10]. A Mars-orbiting SAR will penetrate mantling material [11] to map ice deposits within a few meters of the surface, and analysis of the backscatter amplitude and polarization will allow estimation of their depth of burial and degree of purity. This type of detailed mapping fills a key knowledge gap in targeting shallow ice for resource utilization and astrobiology studies.

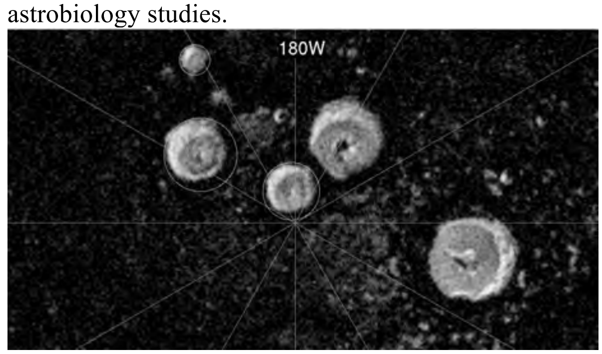

Fig. 2. Arecibo radar view of craters at Mercury's north pole [9]. The strong echo from regions of permanent shadow is attributed to volume scattering by ice.

Brine Detection: Recent studies show that some mid-latitude crater walls on Mars exhibit patterns of streak formation and disappearance consistent with outflows of liquid water under seasonally warmer conditions [4]. Existing data cannot, however, rule out the possibility of dry material flow. Repeat-pass radar imaging will answer this question by measuring the change in physical properties associated with the streaks. Typical geologic materials have microwave reflectivity in the 0.1-0.2 range. If water is present to form even a thin brine interface, the reflectivity can jump to 0.5 or more. Such a shift in radar echo from transient brine, even at sub-pixel scales, would be distinguishable from modest changes in surface roughness along the streaks. The penetration capability of the radar sensor also means that brine could be identified over a longer interval as it recedes beneath a dessicated cap; interferometric repeat-pass observations might also permit a survey of new streaks as they form. Mapping with confidence the locations of reservoirs for water outflows will increase understanding of recent climate and settings amenable to current habitability.

Geologic Context of Hydrated Minerals: Hydrated minerals exposed at the surface have been mapped by infrared spectroscopy and used to infer a progression of climatic and hydrologic conditions on early Mars [5, 6]. These sites are favored for sample return and possible in situ resource utilization, but mantling dust and sediment often obscures details of their extent and how their distribution relates to regional geology. As such, our knowledge of early martian water-related features, the fate of that water, and the interplay of water/ice and volcanism, is incomplete. Imaging radar is a demonstrated and versatile method of mapping features beneath dust and sand, and an orbiting SAR will answer these questions by revealing the hidden landscape of Mars.

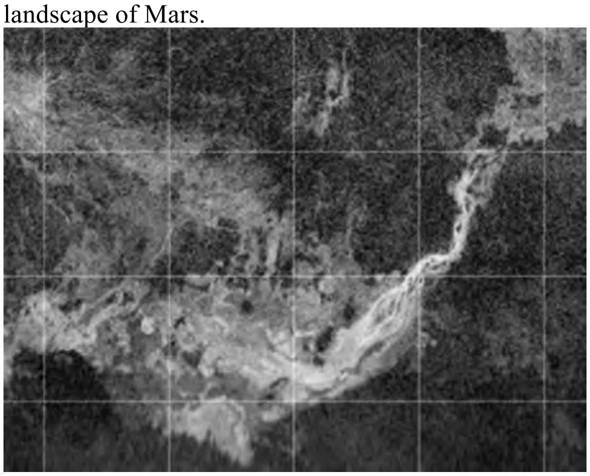

Fig. 3. Arecibo radar view of roughness changes in lava flows across Elysium Planitia [14].

A SAR with readily achievable requirements can in nine months provide a *global* map at 75-m resolution of the subsurface geology through 3-5 m of mantling dust or sand. Spatial resolution comparable to THEMIS-VIS at 18 m per pixel can be achieved with the same penetration depth, and spotlight SAR processing can provide even finer resolution for targeted sites. Loss properties of materials on Mars have been directly measured using SHARAD and MARSIS [12, 13], and confirm the expected depth of penetration.

Direct support for the success of an orbital SAR comes from Earth-based radar maps of Mars, which reveal stunning details of lava flows and other features hidden by dust (Fig. 3) [14]. An orbital sensor will yield 50-100 fold finer spatial resolution and about 5-fold greater depth of penetration than the Arecibo measurements. These results will transform our understanding of regional geology and the processes that lead to the emplacement, preservation, and exposure of hydrated minerals. The radar maps will play a key role in defining sites for sample return and in-situ resource demonstrations.

Instrument Requirements: A SAR optimized for penetration of surface materials and mapping of shallow ice, brine, and geologic features can be readily accommodated by a Discovery-class spacecraft, or as part of a complementary instrument suite on a larger bus. The radar requires an antenna; a 6-m deployable mesh (Fig. 1) is adequate for the science described here and has been well demonstrated on Earth-orbiting spacecraft. The same antenna serves for data downlink. The radar wavelength should be 30-60 cm, based on modeling [11] and experience with subsurface lunar probing [15]. Measurement of the CPR is a minimum requirement for polarimetry, and we advocate a system with selectable modes up to fully polarimetric to allow for flexibility in probing ice and other deposits. Peak power of about 500 W, with much lower average consumption, allows for the noise threshold of about -35 dB required for at least 3 m of probing at spatial resolution of 18 m per pixel. Instrument electronics mass is about 30 kg.

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