THE MARS ADVANCED RADAR AND LIDAR ORBITER (MARLO) FOR HIGH-RESOLUTION INVESTIGATIONS OF GLOBAL TOPOGRAPHY, SURFACE ROUGHNESS, SUBSURFACE VOLATILES, STRATIGRAPHY AND STRUCTURE WITHIN THE SHALLOW- AND DEEP-SUBSURFACE.

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Introduction: The MARSIS and SHARAD orbital radar sounders have given us a 3-D understanding of the internal structure and stratigraphy of of the Martian polar layered deposits (PLD) and tantalizing glimpses of the nature and properties of the subsurface over much of the rest of the planet [1,2]. Unfortunately, to accommodate these investigations onboard spacecraft with other high-level investigations, MARSIS and SHARAD had to accept compromises in instrument design and operation that have limited their ultimate performance. Here we describe a proposal for an Mars Advanced Radar and LIDAR Orbiter (MARLO) – that includes a low-frequency sounder, P- and X-band imaging SAR, and 9-beam laser altimeter array -- for high-resolution investigations of global topography, surface roughness, subsurface volatiles, stratigraphy and structure of the shallow- and deep-subsurface.

Science Goals: The chief science goals of this mission are to investigate the stratigraphic and structural evolution of the Martian subsurface and PLD, as well as the distribution and state of subsurface water (whether present as a brine or as massive ice deposits) through the acquisition of a global set of high-resolution radar sounding data to depths ranging from several centimeters to ~1 km in ltihic environments and 4 km in the PLD. MARLO will also acquire critical data sets relevant to human exploration and landing site certification, such as surface roughness, regolith ice content, and other potential geotechnical hazards.

MARSIS and SHARAD have clearly demonstrated the capability of deep-sounding radar to conduct investigations of the PLD [3-5], mid-latitude lobate debris aprons [6, 7], pedestal craters [8], the Medussa Fossea Formation [9. 10], the volcanic 'frozen sea' in Athbasca Vallis [11], as well as map the variation in global surface dielectric properties to depths of ~60-80 m [12]. MARLO is expected to significantly improve on this performance by taking advantage of spacecraft and mission designs optimized for radar sounding, SAR imaging, and high-resolution laser altimetry.;

In the context of the Concepts Workshop, MARLO most directly addresses the following two challenges:

i. Interrogating the shallow subsurface from orbit.

ii. Orbital measurements of surface characteristics.

providing important insights into the geologic, hydrologic and climatic evolution of the planet, as well as the location of subsurface volatiles and surface and subsurface geologic hazards that will be of critical importance to future human explorers.

Methodology: Over its 2-yr primary mission, MARLO's dual-band (1.8-5 MHz and 15-25 MHz), polarimetric orbital radar sounder will compile a global 3-D map of spatial variations in dielectric properties with a horizontal resolution of ~1 km and vertical resolution of ~10 - 20 m within the top 1 km of the subsurface (in lithic environments), with a maximum potential sounding depth in excess of 4 km in the PLD

The identification of structural, lithologic, and volatile signatures will be aided by a spacecraft orbit that is similar to that of NASA's Mars Reconnaissance Orbiter, being nearly sun synchronous at 92.6˚ at an altitude 300 km. This orbit results in the acquisition of 13 complete ground tracks across the planet each solar day, with an orbital precession rate of about 500 m/day. Thus, a full global survey can be completed in two Martian years.

The sounder has a radiated power of 100 W (an order of magnitude greater than either MARSIS or SHARAD) that it transmits through two orthogonal 80-m half-wave dipole antennas to conduct full polarimetric investigations of the subsurface – transmitting with single-, dual-, or right circular polarization and receiving the H- and V- components (and their phase difference) coherently – to calculate the four Stoke's parameters and Circular Polarization Ration (CPR) in a manner similar to the Mini-RF on the Lunar Reconnaisance Orbiter, [13]. High CPR (>1) is a radar characterisitic of both very rough surfaces and icy environments, a measurement that has been used to identify the presence of ice in the permanently shadowed regions of the Moon [14] and Mercury [15]. Such a technique, applied to deep-sounding investigations on Mars, could help determine whether the low surface permittivities that characterize the top ~60-80 m of the northern plains of Mars [16] originate from dry, high porosity (~35%) sediments or a high volumetric content (~65%) of water ice.

2-D SAR processing is used to maximize both along- and cross-track resolution and clutter suppression, while onboard along track processing minimizes the downlink data rate. Synthetic aperture and cross-track array processing minimize the effects of surface clutter and improve the effective depth of sounding. The large synthetic aperture in cross track is formed by sequential orbital passes. The orbits are sufficiently random to eliminate grating lobes. Array processing techniques, such as constrained optimization, can then be used to steer nulls in the direction of the surface clutter. The spacecraft's computer has sufficient processing and memory for on-board signal processing, thus reducing the output data rate needed for downlink.

Examples of a terrestrial radar sounding investigation, employing similar techniques, can be found at: https://www.cresis.ku.edu/sites/default/files/images/CReSIS_Radar_Depth_Sounder_3D_Imager.pdf

The investigations of the deep subsurface by the low-frequncy sounder are complemented at shallow depths by those of MARLO's second radar inmstrument: an X- and P-band polarimetric imaging SAR. With an effective wavelength of 70 cm, P-band radar has the ability to penetrate the subsurface to a maximum depth of ~3-5 m in lithic environments (and ~2-3x deeper in ice) – while X-band radar, with an effective wavelength of 3 cm and maximum penetration depth of ~10 cm (in lithic environments), can provide an even higher resolution understanding of the near-subsurface.

Operated together, a P- and X-band imaging SAR offers an ability to conduct high-resolution investigations of the shallow (<5 m) subsurface, enabling identification of fine-scale layering within the PLD (and elsewhere) and offering an ability to map the geology beneath mantled terrains – including buried impact craters, faults, polygonal terrain, and ancient drainage networks [17, 18]. Indeed, similar SAR investigations of the Earth, such as those conducted over the Sahara by Shuttle Imaging Radar SIR-A, [19], have resulted in the identification of numerous (and previously undetected) paleodrainage channels – buried just a few meters beneath the sands of eastern Libya, western Egypt and northern Sudan. SAR investigations of the Martian densely-cratered southern highlands are expected to yield similar results – effectively peeling away several billion years of eolian mantling, to reveal the full extent and density of the Martian valley networks. In this way, an orbital SAR will help address some of the most recent (PLD) and oldest (valley network) evidence of climate change on Mars – providing a unique window into the planet's past.

Imaging SAR investigations can also provide important insights into the distribution and state of near-surface water. For example, by utilizing the same polarimetric techniques and processing, as described earlier, a dual-band imaging SAR can be an effective tool in mapping the distribution of near-surface ground ice – to depths as much as an order of magnitude greater than those achieved by the GRS instrument on the Mars Odyssey spacecraft. An imaging SAR can also monitor changes in soil moisture – such as those arrising from the formation of near-surface brines, which may be responsible for the occurrence of dark streaks on equatorward-facing slopes, during the Martian spring and summer [20]. Such changes can be observed as differences in surface reflectivity/dielectric constant or as a phase difference in HH- and VV-polarization [18].

Finally, an imaging SAR can also provide critical information on global topography, surface roughness and clutter – which can be used to greatly enhance the processing and analysis of radar sounding data.

The inclusion of a 9-beam (3x3) laser altimeter array (an advanced version of the 5-beam LOLA array used on LRO [X]) will provide independent, high-resolution data on Martian topography and surface roughness – measurements that will greatly enhance the processing and interpretation of the radar data, especially with regard to the identification of surface clutter.

A 9-beam (3x3) altimeter array would cover an area of ~60 m x 60 m on the Martian surface. Assuming a spacecraft velocity of ~3km/s, and a pulse rate of 30 Hz on each of the altimeter's 9 beams, this would yield 3 profiles 30 meters apart across track and spots every 30 meters along track.

Summary: MARLO was originaly developed in response to NASA's request for Mars Scout Mission Concepts in 2001 [21]. The present concept benefits from the lessons learned from MARSIS [1], SHARAD [2], Mini-RF on LRO [13], and a family of 3D imaging SARs developed by the University of Kansas for the investigation of terrestrial ice sheets and glaciers (https://cms.cresis.ku.edu/research/sensors-development/radar). MARLO demonstrates that significant improvements can be made in an orbital radar's performance when the spacecraft and mission are optimized for this purpose. The flight of MARLO would greatly expand our understanding of the geologic, hydrologic, and climatic evolution of the planet, as well as the accessibility of critical *in situ* resources for sustaining future human explorers.

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