INTERNATIONAL MARS ICE MAPPER MISSION: RECONNAISSANCE FOR THE HUMAN EXPLORATION OF MARS.
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Introduction: The International Mars Ice Mapper (I-MIM) mission concept is being developed by partner Agencies [Agenzia Spatiale Italiana (ASI), the Canadian Space Agency (CSA), the Japan Aerospace Exploration Agency (JAXA), and National Aeronautics and Space Administration (NASA)] with a primary human exploration reconnaissance goal of characterizing adequate, accessible water-ice in the upper 0-10 m to meet future human exploration goals and objectives for Mars (e.g., accessing the ice to understand the climate/geological history of Mars, identification of astrobiological targets, as well as *in situ* resource utilization). The anchor payload would be a polarimetric (hybrid-compact pol or "HCP") L-band (930 MHz) Synthetic Aperture Radar (SAR) provided by CSA that would operate in side-looking imaging and nadir sounding SAR modes at high RF bandwidth. Possible secondary payloads (e.g., visible wavelength camera, atmosphere/space weather sensors) under consideration may augment the baseline measurements of the SAR to address the human reconnaissance objectives and enhance the scientific return.

Reconnaissance Objectives: The Agency partners have established three mission Reconnaissance Objectives (RO), where reconnaissance is defined as "what we need to know before humans go," as enabled by robotic spacecraft that address critical knowledge gaps related to the future human exploration of Mars:

RO-1: Location and Extent of Water Ice: Inventory the spatial distribution and depth-to-ice of water-ice resources in the near surface layer (upper 0-10 m).

RO-2: Accessibility of Water Ice: Detect, characterize, and map surface/near-surface geotechnical properties (roughness, compactness) to provide a fundamental characterization of the accessibility of water-ice resources (e.g., engineering-level evaluation of the overburden for drilling/ISRU and the structural stability of the terrain for landing/launch, construction, trafficability, and other human-related surface operations).

RO-3:Candidate Human Landing Site Assessment: Provide detailed high-resolution maps of targeted areas of interest that: (1) have adequate (RO-1) and accessible (RO-2) water ice, (2) are as equatorward as possible, and (3) model the potential for human-led surface science and human-class landing and ascent, ISRU, and civil engineering.

Each of these Reconnaissance Objectives will drive measurement requirements within a defined Reconnaissance Zone (RZ). The RZ is the mid-to-low latitude, low elevation, terrain-favorable areas on Mars where human exploration is favored, defined by human-led science potential, in-situ resources, engineering constraints, civil engineering, and other factors. Ongoing related studies such as the Subsurface Water Ice Mapping (SWIM) at Mars project are working to improve definition and characterization of the RZ for subsurface ice deposits [1].

Additionally, new 3D radar scattering models for side-looking and nadir SAR performance assessment have been developed for tailoring the L-band SAR for optimal ice detection as a function of upper layer properties. We are also planning analog field campaigns at terrestrial locations with periglacial and glacial ice and dry overburden to further evaluate instrument performance and measurement requirements.

Maximizing Return on Investments: In addition to the primary Reconnaissance Goals, the Supplemental Value Goal of I-MIM is to provide high-value science opportunities and mission-support capabilities that serve reconnaissance, science, and engineering. On the basis of this goal, the Agency partners have established Supplemental Science Objectives (SSO) that maximize the use of the SAR anchor payload and Mission Support Objectives (MSO) that further maximize potential returns on investments:

SSO-1: Augmented Water Ice Inventory: Use the anchor payload (HCP SAR) to extend the detection, mapping, and inventory of shallow water ice to a near-global scale tied to priority climate/geology goals.

SSO-2: Reconnaissance/Science Investigations of Opportunity: Enable reconnaissance and science observations of opportunity aligned with high-priority, international, and multidisciplinary community goals (e.g., Martian climatology and geology, the volatile history of Mars, habitability, search for geologic structures for radiation protection, etc.).

MSO-1: Optional Technology Demonstration: High-altitude Communications Relay Orbiter(s): Provide a dedicated, next-generation, high-altitude Mars Relay Network (MRN) primarily to support I-MIM's expected high data volume and its delivery at high data rates (e.g., raw SAR data), and, secondarily, to support future Mars missions (including backup for Mars Sample Return and the testing of a precursor MRN infrastructure that is replenishable, scalable, and interoperable for both robotic and human exploration).

MSO-2: Complementary Payloads for Reconnaissance, Science, and Engineering: Consider additional payloads, rideshares, extended operations, and leverage of capabilities for future human and robotic Mars missions.

L-Band SAR Measurements to Meet Reconnaissance and Supplemental Science Objectives: I-MIM's L-band polarimetric SAR instrument (Table 1) was chosen on the basis of over 20 years of studies and proposals by the community and Agency partners that support the desire for an orbital active microwave instrument to interrogate the martian surface and subsurface [e.g., 2]. The baseline design choices for the L-band SAR were made to optimize the retrieval of the properties of accessible subsurface water ice deposits and its overburden within the top 10 m. The L-band center frequency at 930 MHz allows interrogation of the subsurface to >6 m depth with vertical resolution (in sounder mode) of < 1 m depending on the physical properties of top-layer and subsurface materials. The hybrid, compact polarimetric design allows for the determination of the four essential Stokes parameters for distinguishing between scattering regimes and to measure the polarimetric signatures of subsurface ice (e.g., the coherent backscatter opposition effect or CBOE for thick ice layers). The different SAR imaging and nadir sounding modes provide complementary measurements to further characterize subsurface electrical and physical properties. For example, the sounding mode would be able to identify the vertical and horizontal extent of subsurface interfaces due to layers of overburden and ice in targeted regions that may be suggested by a strong polarimetric response in the side-looking SAR imaging products.

Baseline Data Products: Anticipated baseline products derived from the anchor SAR payload include: maps of estimated dielectric permittivity (real part) for depth-integrated material "composition" and lateral ice and overburden variation, polarimetric decomposition products (e.g., circular polarization ratio and *m-chi* decomposition) to discriminate between backscatter mechanisms, and sub-meter scale roughness over the integrated depth. For the nadir sounder mode, anticipated baseline products would include: model-based surface dielectric permittivity (real part), subsurface reflections to delineate the depth to and areal extent of interfaces between regolith and ice at sub-meter vertical ranging, and along-track surface roughness. Possible advanced products could include repeat-pass InSAR and SAR tomography for three-dimensional subsurface mapping.

Measurement Definition Team: The I-MIM mission concept continues to be developed with key input from the scientific, human exploration, and engineering communities. A multi-national Measurement Definition Team (MDT) was assembled in November 2021, with tasks to suggest threshold reconnaissance measurement requirements for the mission, provide findings on potential high-value augmentations to maximize I-MIM's return on investment, and to prepare a model concept of operations. A final report of the MDT is targeted for mid-2022 to feed into further concept development in preparation for critical Agency reviews and start of Phase A. Further details on MDT activities are provided in [3].

Table 1. Characteristics of the I-MIM SAR/Sounder concept.

Property	Value
Center Frequency	930 MHz (L-band)
Antenna	6 m deployable mesh
Sensitivity (NESZ)	-30 db @ 5 m resolution -40 db @ 30 m resolution
RF Peak Power	2000 W
Configuration	Multi-feed offset fed reflector
Operational Modes	SAR and nadir SAR Sounder
Polarization	Hybrid (circular transmit, dual linear reception)
SAR	
Swath Width	30 km
Incidence Angle	40-45deg
Horizontal Resolution	5-30 m
Penetration Depth	>6 m
Sounder	
Vertical Resolution (free space)	< 1 m (based on RF BW)
Along-track Spacing	30 m
Across-track Footprint	1.5 km

Science Participation: The Agency partners are eager to engage the scientific community in mission activities, and formulation of plans are evolving during current multilateral deliberations. Possible opportunities for the community to engage could include: (1) *Core Recon/Science Team:* SAR Anchor Payload development, observation planning, commanding, health monitoring, data processing & archiving, delivery of Level 1 reconnaissance requirements. (2) *Investigations:* Observatory Proposal Teams could bid to carry out observation campaigns and work with core science team to target necessary data acquisitions and analyze results. (3) *Observations of Opportunity:* A notional example includes a "SAR-Wish" modeled after Hi-Wish (as done for MRO's HiRISE), where users submit targets of interest and receive data to complement ongoing independent investigations as "guest observers".

References: [1] Morgan, G.A. et al. (2021) *Nature Astronomy* 5, 230–236. [2] MEPAG NEX-SAG Report (2015), http://mepag.nasa.gov/reports.cfm (see also BAAS 43, March 2021 updated version of NEX-SAG: https://doi.org/10.3847/25c2cfeb.da7b0e6a). [3] Haltigin, T. et al. (2022) *LPSC LIII* (this meeting).