INTERNATIONAL MARS ICE MAPPER MISSION

RECONNAISSANCE / SCIENCE
MEASUREMENT DEFINITION TEAM

Final Report

SUBMITTED TO

ASI | CSA | JAXA | NASA | NSO

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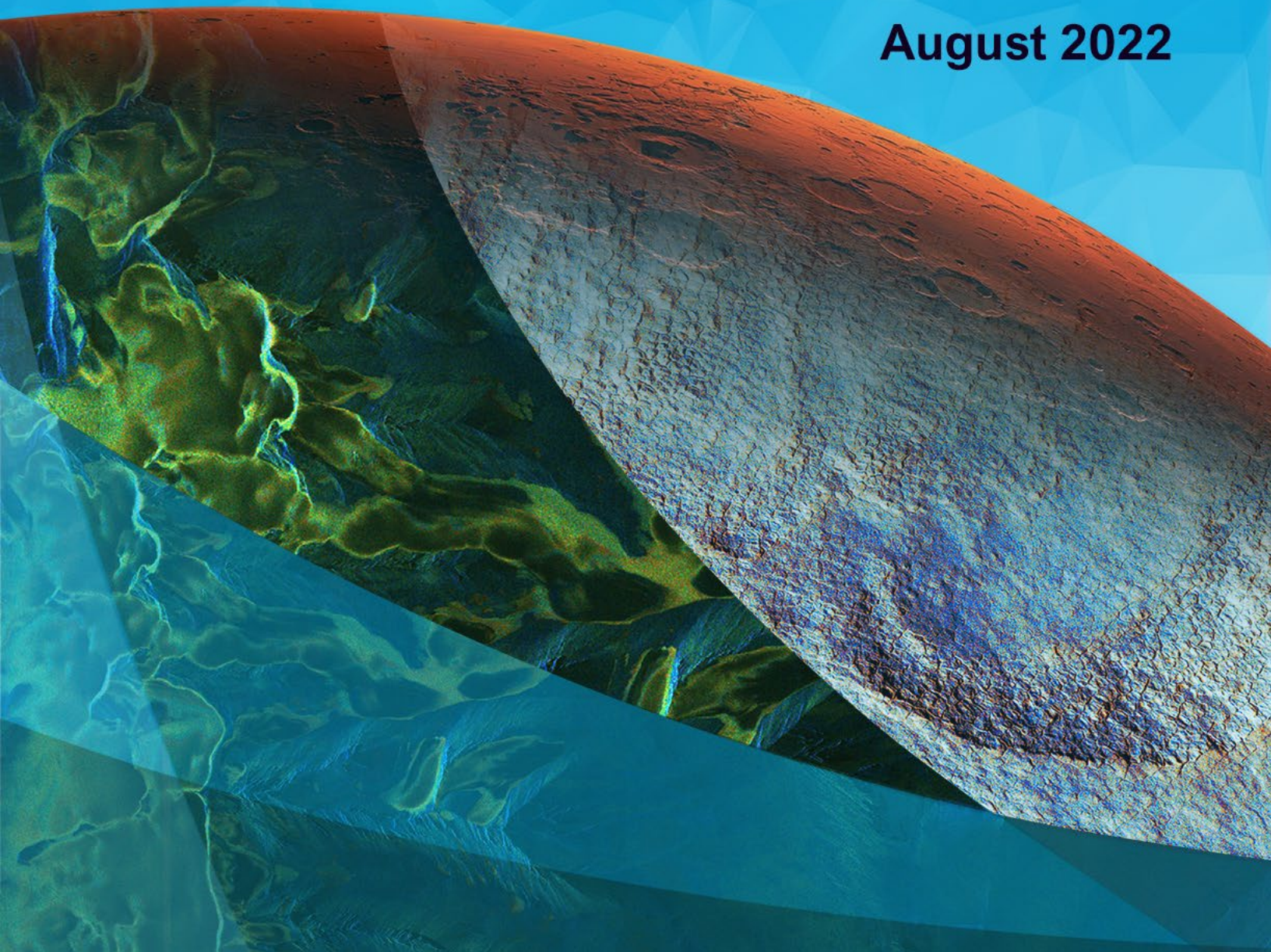


1 EXECUTIVE SUMMARY

The International Mars Ice Mapper (I-MIM) mission concept was developed by a multilateral team comprising space agencies from five countries: Canada, Italy, Japan, the Netherlands, and the United States. The primary goal of I-MIM is to map and characterize accessible, near-surface (within the uppermost 10 m) water ice and its overburden in mid-to-low latitudes to support planning for the first potential human surface missions to Mars.

Identifying adequate and accessible water-ice reserves enables the identification of candidate sites for potential scientific discoveries worthy of sending humans. It also enables the identification of water-ice resources to meet human operational needs on the Martian surface. The I-MIM partner Agencies also seek to maximize the mission's return on investment by supporting community-based scientific investigations, as a "supplemental value goal." To refine the mission concept and to define measurements with a set of prescribed tasks, the Agencies assembled a Reconnaissance/Science "Measurement Definition Team" (MDT). This report is the result of the work of the I-MIM MDT. The I-MIM Agency partners provided the MDT with the high-level mission goals, objectives, and the anchor payload: an L-band, polarimetric Synthetic Aperture Radar (SAR) and Sounder.

The Charter directed the MDT to perform three tasks:

TASK 1. Define measurements for the anchor payload that are traceable to requirements-driving Reconnaissance Objectives (ice detection, overburden characterization, and candidate human-site characterization) and ways to optimize the payload(s) for these purposes;

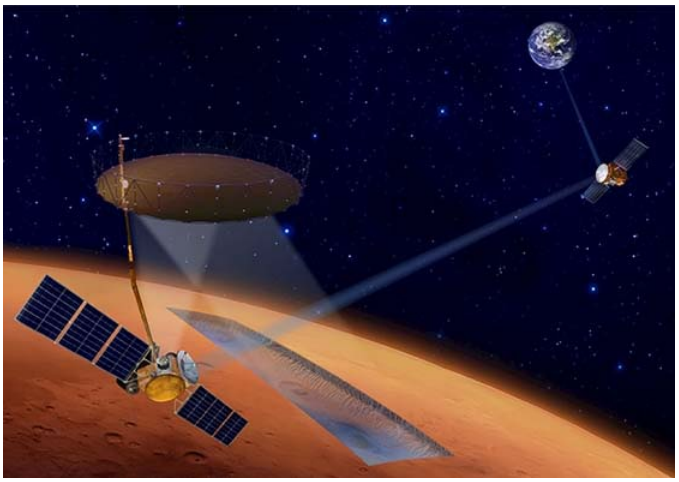
TASK 2. Provide findings on potential high-value, prioritized reconnaissance, science, and engineering augmentations that are synergistic with the anchor payload and might maximize the mission's return on investment within established mission boundary conditions; and,

TASK 3. Prepare a model concept of operations based on findings for Tasks 1 and 2.

OVERALL MDT SUMMARY FINDINGS

- An I-MIM mission will provide a new way to observe Mars, and will acquire essential information to enable human exploration.
- The mission's capabilities provide an opportunity to accomplish unique new science covering a broad range of international science priorities in addition to the primary goal of reconnaissance for human missions.
- Additional instruments could expand the capabilities of I-MIM to undertake high-priority science investigations and fill any gaps in meeting reconnaissance objectives.
- The primary reconnaissance goal can be accomplished in a nominal mission lasting one Mars year. The reconnaissance and science objectives would greatly benefit from an enhancement of data downlink capabilities.
- The Agency partners should continue to pursue development of the I-MIM mission as a key element in the future exploration of Mars.

TASK 1: RECONNAISSANCE OBJECTIVES



Artist Concept. *Credit: NASA*

FINDING 1. Most of the high-priority reconnaissance objectives can be met with the currently scoped radar instrument.

The MDT identified key parameters related to characteristics of surface or subsurface materials, the knowledge of which is important for advancing the mission reconnaissance goal. The MDT explored these parameters in detail, as summarized in a Reconnaissance Traceability Matrix (RTM).

For those parameters deemed of highest value for the reconnaissance objectives, the MDT found that the anchor radar payload could likely obtain a majority of them. These include:

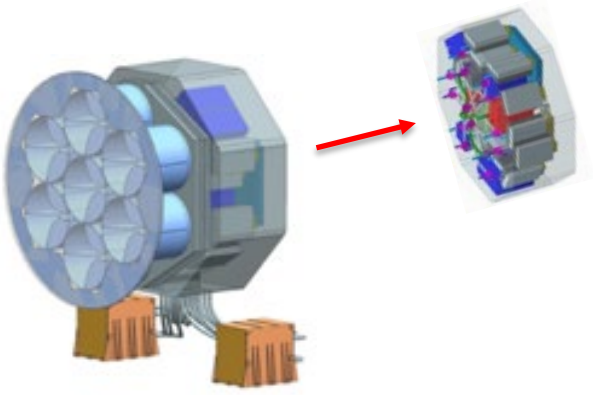
- the presence/absence of ice in the upper several meters;
- the ice concentration profile with depth (including depth to the top of the ice);
- the lateral extent and continuity of ice;
- ice/rock mixing ratio, density, and strength of the overburden; and,
- surface rock-size distribution.

FINDING 2. The combination of SAR, sounder, and polarimetric capabilities is unique and powerful to accomplish the ice mapping needed to pave the way for the human exploration of Mars.

The anchor payload, as presented to the MDT, is an L-band (930 MHz) radar system that can acquire SAR images (side-looking) in two circular polarizations, and can operate as a nadir sounder, similar in operation to the recent Mars orbital radar sounders MARSIS and SHARAD.

The MDT found that the combination of these capabilities at the selected frequency offers unprecedented capabilities to detect, map, and inventory the ice resources that would be used in a human mission to acquire new science and to access ice for utilization in surface operations.

Along with the polarimetric and repeat-pass capabilities, the synergy of the dual modes of the radar enhances the likelihood of meeting the reconnaissance objectives to locate the ice in three dimensions and to constrain its key characteristics, such as purity.



Primary Instrument:
Polarimetric SAR Seven-element Feed Array
Credit: CSA

FINDING 3. The core payload would have a high likelihood of finding ice deposits that could be readily accessed in situ (within the top few meters and not covered with large rocks).

The MDT assessed the likelihood of unambiguous detection of ice under various plausible scenarios of occurrence in the near subsurface (to a depth of 10 m) with the anchor radar payload. It found that the radar system could readily detect and map the mode of ice occurrence that is both likely to be widespread and of interest to human mission planning: ice in the upper few meters with a regolith overburden relatively free of large rocks.

This is a powerful combination of factors: easy to detect, of high interest for future missions, and possibly widespread in occurrence. Other ice deposits (deeper, rougher overburden, etc.) are also of great interest to the scientific community and could be investigated with an additional payload, specifically a nadir sounder operating at VHF (~100 MHz) frequencies.

Near-surface ice on Mars; Mars Phoenix Lander. *Credit: NASA/JPL-Caltech/University of Arizona/Texas A&M University*

FINDING 4. Two high-value complementary instruments identified by the MDT could be optimized to aid in achieving the reconnaissance objectives: a VHF sounder and a high-resolution imager with stereo capabilities.

As directed by its Charter, the MDT investigated ways to optimize the instrument payload to accomplish the reconnaissance objectives more fully. Among the many types of instruments and modifications to the radar payload that the MDT considered, two instruments stood out as providing the most value as complements to the L-band radar system: a VHF sounder and a high-resolution imager with stereo capabilities.

- The VHF sounder could fill a remaining gap between the near-surface (several m) sounding of the L-band sounder mode, and the lower boundary of the so-called "blind zone" of SHARAD, which extends to about 20 m. In doing so, the VHF sounder would extend the range of depths that could be investigated, and thus more comprehensively map the ice deposits in the mid-latitude “Reconnaissance Zone” where human exploration would be operationally viable, as well as elsewhere on the planet.

- A high-resolution imager (25 cm/pixel resolution in multiple colors) could provide direct corroboration of ice detections in the vicinity of fresh impacts and ice scarps. Stereo image pairs could be converted to digital elevation models to correlate reflectors with exposed surfaces and contacts for dielectric estimation and to model clutter, as is currently done at coarser resolution with MARSIS and SHARAD using MOLA topography.

TASK 2: SCIENCE OBJECTIVES

FINDING 5. A broad suite of additional high-priority scientific investigations can be accomplished with the anchor radar payload, including multiple themes of interest to the international Mars science community: atmospheric science, geology, and habitability.

The MDT assessed the potential to accomplish additional science investigations beyond those associated with the Reconnaissance Objectives, first using only the anchor radar payload. MDT panels evaluated the science potential in three theme areas aligned with overarching science goals for Mars of the partner Agencies.

The panels found that significant new science investigations would be possible with the anchor radar payload. The Science Traceability Matrix (STM) summarizes these investigations, with assessments of the measurable parameters, resolution needed, and the observational techniques to be applied.

Atmospheric Science

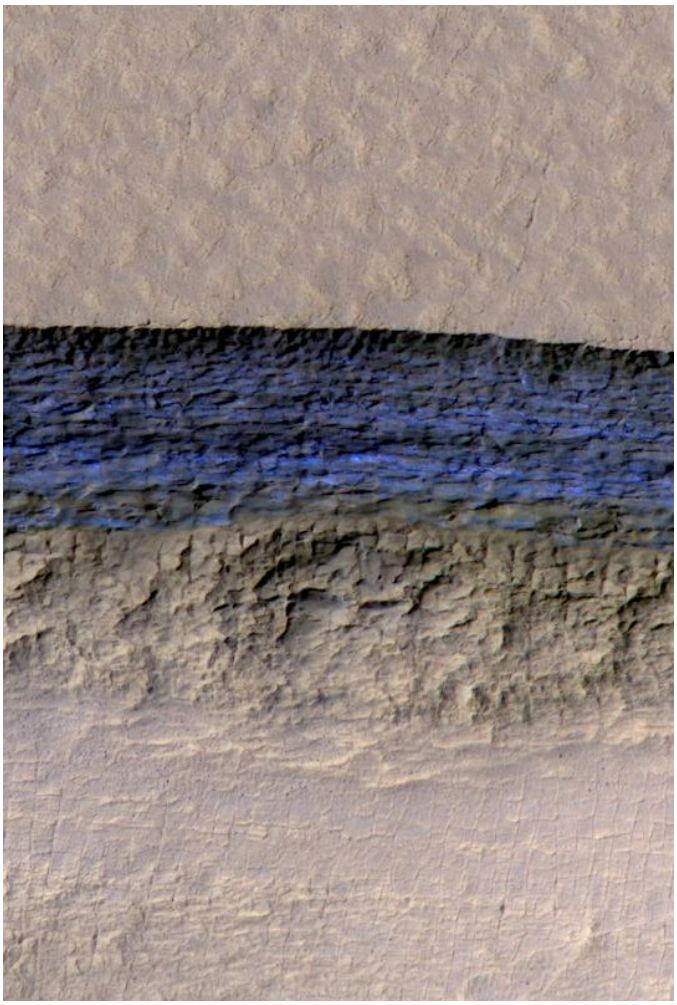
In support of climatology, the anchor radar payload can address surface-atmosphere cycling, recurring slope lineae, and ionospheric irregularities.

Geological Studies

The radar can address many processes acting over various timescales, including present-day activity, the recent past (e.g., volatile cycling over My timescales), and the more distant past. These include such diverse topics as polar processes, mid-latitude ice, volcanism, recent and ancient impacts, landforms such as valley networks, and unique radar terrains such as Medusae Fossae.

Habitability

The radar can contribute to locating ice and brines that may serve as present-day habitable environments, characterizing fluvial or glaciofluvial environments that might have hosted life in the past, and identifying subsurface habitats in the form of voids in the subsurface.



An ice-exposing scarp in the southern middle latitudes of Mars. Blue areas (color-enhanced) show ~80 vertical meters of exposed water ice. *Credit: NASA/JPL-Caltech/University of Arizona.*

FINDING 6. The complementary instruments identified by the MDT for ice reconnaissance (VHF sounder and visible imager) would significantly enhance I-MIM's scientific impact.

The science theme groups examined the additional benefit for science investigations of the complementary instruments identified for ice reconnaissance (VHF sounder and visible imager) in Task 1.

Many investigations would be significantly enhanced or be newly enabled by the addition of these instruments.

- The VHF sounder would enhance investigations of the subsurface in all theme areas and would contribute to the ionospheric irregularities investigation.
- The high-resolution imager would contribute to all theme areas, enhancing such investigations as geomorphology (for habitability and past climate and recent ice-related processes) and ongoing surface changes that may corroborate radar detections, and seasonal volatile exchange.

FINDING 7. I-MIM could increase its scientific impact by making supplemental measurements with additional instruments and/or platforms, which could be optimized to fill remaining high-priority gaps in meeting reconnaissance objectives.

The MDT considered a scenario in which the I-MIM platform(s) could accommodate supplemental science instruments beyond the anchor radar and the previously prioritized complementary instruments for ice reconnaissance. The Task 2 science theme groups identified instruments and associated measurements that would address remaining high-priority gaps in our knowledge of Mars. The MDT identified surface temperature measurements as providing high benefit to both science and ice reconnaissance. For atmospheric studies, additional instruments could target the structure and dynamics of the lower and upper atmosphere and their interconnections. The highest atmospheric priority is the global measurement of winds, with temperature structure, aerosols, water vapor, and mapping of aurora also considered important. Surface compositional information would greatly enhance geological and habitability investigations.

Additional instruments could support scientific studies of a number of ice- and non-ice-related processes on Mars including surface-atmosphere interactions and change detection, among others. Left to right: gullies and recurring slope lineae, high clouds over Gale Crater viewed by the Curiosity rover, polygonal terrain at the ice-rich Phoenix landing site. *Credit: NASA/JPL-Caltech/University of Arizona/MSSS/Texas A&M*

TASK 3: CONCEPT OF OPERATIONS

FINDING 8. The MDT developed a feasible concept of operations for a nominal mission timeframe of one Mars year, split into two phases.

The MDT found that a mission lasting one Mars year, in the proposed ~255 km altitude circular orbit, would be sufficient for accomplishing the reconnaissance objectives, given the anchor radar payload's estimated data production rate and the downlink capabilities provided by the mission concept team prior to the MDT deliberations.

Phase 1. The first 10 months of the mission would be dedicated primarily to acquiring 30 m SAR coverage of the Reconnaissance Zone (RZ). Allocating 80% of the returned data to the 30 m resolution SAR mode would ensure that all useful passes over the RZ can be downlinked during the first 10 months with sufficient margin. The remainder would be available for other modes of operations, such as nadir sounding and high-resolution SAR, and other complementary instrument(s), if provided.

Phase 2. The mission would perform targeted observations to obtain high-resolution SAR imaging and sounding of regions of interest, including new targets identified from the first phase.

FINDING 9. The mission as conceived is achievable within the provided constraints of consumables such as power and data volume, but I-MIM's reconnaissance and science investigations could be more easily and fully accomplished with increased capabilities for downlinking data to Earth, especially if additional instruments are provided.

The MDT found that total data volumes (over a Mars year) were constraining, particularly in the second phase when including the high-resolution SAR modes and potential complementary and supplementary payloads. The Agencies should explore options for increasing downlink capacity in subsequent mission development studies.

> Based on these findings, the MDT concludes that the Agency partners should continue to pursue development of the I-MIM mission as a key element in the future exploration of Mars.

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