Charter: Reconnaissance/Science Measurement Definition Team for an International Mars Ice Mapper (I-MIM) Mission Concept

1.0 Summary Statement of Intent

In January 2021, the Italian Space Agency (ASI), the Canadian Space Agency (CSA), the Japan Aerospace Exploration Agency (JAXA), and National Aeronautics and Space Administration (NASA) signed a joint Statement of Intent (SOI) to establish a multilateral "Concept Team" to assess the potential of an orbital Mars ice-mapping mission, to define their potential roles and responsibilities, and to consider partnership opportunities.

As part of its collaboration, the Concept Team intends to form an international Reconnaissance/Science **Measurement Definition Team** (MDT) to support refined definition of its pre-Phase A mission concept as a bridge to potential Phase A development. This process differs from traditional mission Science Definition Teams in that the Agency partners have pre-defined the high-level mission goals, objectives, and the anchor payload – an L-band, polarimetric Synthetic Aperture Radar (SAR)/SAR Sounder – along with other mission elements.

The MDT shall perform three tasks:

1. Define measurements for the anchor payload that are traceable to Reconnaissance Requirements (ice detection, overburden characterization, and candidate human-landing-site characterization) and ways to optimize the payload(s) for these purposes (see 2.1; 5.1).
2. Provide findings on potential high-value, prioritized reconnaissance/science/engineering augmentations that are synergistic with the anchor payload and might maximize the mission's return on investment within established mission boundary conditions (see 2.2; 5.2).
3. Prepare a model concept of operations based on findings for tasks 1 and 2 (see 2.3; 5.3).

The MDT will require international experts from the partner Agencies and other nations who collectively have expertise in a variety of domains, including planetary science, synthetic aperture radar and radar sounding, in situ resource utilization (ISRU), human-class entry, descent and landing (EDL) and ascent, and civil engineering. Working together in a transdisciplinary manner, MDT members will ensure optimal use of the SAR's full capabilities to support measurements required in advance of future human missions. At the same time, all partner Agencies are committed to ensuring the greatest possible reconnaissance, scientific, and engineering benefits for this and other current and future Mars missions. The Agencies anticipate that the I-MIM's MDT (and, later in the mission, its Reconnaissance/Science Team) will build shared interdisciplinary community knowledge and capabilities for a future sustained human-robotic presence on Mars, with increased international cooperation and greater discovery opportunities for all.

2.0 Background

The I-MIM Concept Team has mutually established a requirements-driving Reconnaissance Mission Goal and Reconnaissance Objectives (see 2.1). Reconnaissance is "what we need to know before humans go," as enabled by robotic spacecraft that address critical knowledge gaps related to the human exploration of Mars that must be addressed prior to sending crewed missions. Highest among reconnaissance priorities is identifying the location and extent of water ice reserves for potential scientific discoveries worthy of sending humans (e.g., ice coring for astrobiology/climatology) and characterizing adequate, accessible water-ice resources to meet human needs on the Martian surface (e.g., for ISRU).

On the basis of years of prior mission concept development and multi-Agency agreement, the identified anchor payload on the mission is a polarimetric Synthetic Aperture Radar (SAR) operating at a center frequency of 930 MHz (L-band), capable of both side-looking and nadir (sounding) measurements. Threshold SAR/Sounder measurements driving mission requirements shall be based on, and traceable to, the Reconnaissance Mission Goal and Reconnaissance Objectives. Additional baseline measurements may be considered to enhance the accuracy of required threshold measurements and/or to provide context for data from the anchor payload.

2.1 DRIVING REQUIREMENTS

The following provides background relevant to MDT Task 1: Define measurements for the anchor payload that are traceable to Reconnaissance Requirements (ice detection, overburden characterization, and candidate human-landing-site characterization) and ways to optimize the payload(s) for these purposes (See 5.1).

RECONNAISSANCE GOAL: The overarching **Reconnaissance Mission Goal** that enables human exploration by addressing a high-priority knowledge gap is: ***to map and characterize accessible (within the uppermost 10m) subsurface water ice and its overburden in mid-to-low latitudes to support planning for the first potential human surface mission to Mars.***

RECONNAISSANCE OBJECTIVES: The Agency partners have established three Reconnaissance Objectives (RO) that will drive measurement requirements within a region termed the "Reconnaissance Zone" (RZ)[1]:

- **RO-1: Location and Extent of Water Ice**
  In the Reconnaissance Zone, detect, map, and inventory the spatial distribution and depth-to-ice of water-ice resources in the near surface (top 0-10m).
- **RO-2: Accessibility of Water Ice**
  In the Reconnaissance Zone, detect, characterize, and map surface/near-surface geotechnical properties (roughness, compactness) to provide a fundamental understanding of the accessibility of water-ice resources (e.g., characterization 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**
  Based on analyses of the above surveys of the Reconnaissance Zone, provide detailed high-resolution maps of targeted areas of interest that: have adequate (RO-1) and accessible (RO-2) water ice, are as equatorward as possible, and model the potential for human-led surface science and human-class landing and ascent, ISRU, and civil engineering.

2.2 MAXIMIZING RETURN ON INVESTMENTS:

The following provides background relevant to MDT Task 2: Providing findings on potential high-value, prioritized augmentations that would be synergistic with the anchor payload and might maximize the mission's return on investment within established mission boundary conditions[2] (see 5.2).

SUPPLEMENTAL VALUE GOAL: The **Supplemental Value Goal** is: As possible, provide *high-value science opportunities* and *high-priority mission-support capabilities* that serve reconnaissance, science, and engineering.

[1] Mid-to-low-latitude, low elevation, terrain-favorable areas on Mars where human exploration is likely viable in terms of human-led science potential, in-situ resources, engineering constraints associated with human-class landing/launch and surface operations, civil engineering, and other such factors.

[2] Boundary conditions include the Reconnaissance Objectives, optimal SAR measurements, cost, timing, mass, power, operational complexity, and partner commitments, among others, as will be articulated to the MDT by the multilateral Concept Team.

SUPPLEMENTAL VALUE-DRIVEN OBJECTIVES WITHIN BOUNDARY CONDITIONS: Subject to addressing the RO as overarching priorities that drive the measurement requirements of the primary anchor payload, the Agency partners have established Supplemental Science Objectives (SSO) that maximize use of the SAR anchor payload and Mission Support Objectives (MSO) that further maximize potential returns on investment. None will drive mission requirements, but the Agencies are committed to the most benefits possible.

- **SSO-1: Augmented Water Ice Inventory**
  Use the anchor payload to extend the detection, mapping, and inventory of shallow water ice to a near-global scale. .
- **SSO-2: Reconnaissance/Science Investigations of Opportunity**
  Enable reconnaissance/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 natural geologic structures for radiation protection, etc.).
- **MSO-1: Optional Technology Demonstration: High-altitude Communications Relay Orbiter(s)**
  Provide a dedicated, first-generation, high-altitude MRN primarily to support I-IMIM'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.

3.0 Reconnaissance/Science Measurement Definition Team Members

The MDT is expected to support the pre-Phase A mission concept and its transition into Phase A. Post-MDT, should the I-MIM mission be confirmed for implementation after a suitable Phase A concept study, the mission partners intend to engage broader participation of the community as part of an international, competitively selected Mission Reconnaissance/Science team.

To meet its requirements-driven reconnaissance objectives and potential high-value reconnaissance/science/engineering enhancements, **the MDT requires a multidisciplinary team of subject-matter experts** who collectively have a comprehensive knowledge of microwave remote sensing of volatiles, geologic context for the subsurface sequestration of water ice (with associated climatology), astrobiology, glaciology/cryospheric science, hydrology, remote sensing (including imaging of geologic landforms related to water-ice detection), in situ resource utilization (ISRU), engineering, aspects of entry descent, and landing (EDL) and ascent, and civil engineering (CE), among other specialties. **The MDT will be led by co-chairs with specific expertise** (i.e., publications, flight leadership roles, and/or engineering leadership roles in analogue missions/environments or testbeds) tied to 1) water-ice detection, characterization, and quantitative analysis using microwave remote sensing paradigms; and, 2) water-ice-related ISRU to ensure the full potential of the anchor instrument to deliver measurements as targeted as possible to real-world needs of Mars human mission planners.

4.0 Primary Assumptions and Guidelines

- The SAR-carrying orbiter ("SARbird") and potential communications relay orbiters ("COMbirds"), would arrive at Mars by 2030 and orbit at ~300 km and ~6000 - 8000 km respectively.
- The baseline mission lifetime requirement is one Mars year (~ 690 Earth days).

- Mission pre-project activities will provide constraints on spacecraft design and configuration solutions to establish realistic boundary conditions for MDT consideration.
- The anchor payload is a polarimetric Synthetic Aperture Radar (SAR) operating at a center frequency of 930 MHz (L-band), capable of both side-looking and nadir (sounding) measurements. Any notional supplemental mission payloads or rideshares would require additional international partner commitments, should be synergistic with the anchor payload and align with reconnaissance, science, and mission-support objectives, and must not interfere with the measurement capabilities of the primary (SAR) instrument in accommodation and operations.

5.0 Statement of Task

5.1 TASK 1: DEFINE TRACEABLE LEVEL 1 THRESHOLD RECONNAISSANCE MEASUREMENT REQUIREMENTS AND WAYS TO OPTIMIZE THE PAYLOAD(S)

The MDT is tasked with determining a set of community-expert findings for Level 1 threshold reconnaissance measurement requirements that:

- evaluate the efficacy of the anchor payload in meeting the pre-defined Reconnaissance Objectives within the framework of an MDT-generated mission traceability matrix;
- assist the Concept Team in developing a feasible mission concept of operations;
- potentially consider additional opportunities that are synergistic with the anchor payload to strengthen the mission's ability to meet Agency requirements-driven reconnaissance goal and objectives; and,
- fit within available resources and associated levels of acceptable risk as provided by the multi-Agency Concept Team.

If and as directed by the Concept Team to support the RO, the MDT may also consider additional highest-priority payloads as potential baseline opportunities that either enable improved interpretation of the SAR-based measurements (e.g., understanding the form and concentration of ice) and/or better meet the priority needs of Mars mission planners for human exploration. (The MDT will make these reconnaissance-focused considerations in concert with completing Tasks 2 and 3 and in alignment with partner Agencies' additional reconnaissance, science, and engineering goals.) For example, a visible-wavelength imager of suitable spatial resolution or sensors that monitor water-vapor circulation might further support the requirements-driven reconnaissance objectives, as well as benefit supplemental science and mission-support objectives.

Questions to be answered include, but are not limited to:

- What measurements, traceable to the recon objectives, are required to satisfy detection and characterization of ice and its overburden?
- How can the full capabilities (e.g., interferometric, tomographic; high-resolution, spotlight) of the SAR/nadir SAR sounder and/or the mission concept of operations be optimized for reconnaissance-driven measurements?
- What approaches by the SAR, or in combination with existing data sets, would enable characterizing the "purity" (ice/ice-regolith mix) of the subsurface water ice?
- **To meet the reconnaissance measurement objectives**, are other synergistic payloads beyond radar needed to increase the accuracy/interpretation of the SAR results and/or lead to the certification of candidate (accessible, ice-rich) human landing sites? If so, what?

5.2 TASK 2: PROVIDE FINDINGS ON POTENTIAL HIGH-VALUE, PRIORITIZED (NON-REQUIREMENTS-BASED) AUGMENTATIONS THAT MIGHT MAXIMIZE I-MIM'S RETURN ON INVESTMENT

Complementing Task 1, the MDT will provide findings on potential augmentations that could contribute to high-community-value Mars reconnaissance/science outcomes or mission-support priorities. Findings must demonstrate a relationship to Agency partner interests provided by the Concept Team per the mission's supplemental value goal (e.g., atmosphere/weather/space weather/radiation environment sensors /radiation environment sensors for human-exploration-related knowledge gaps, radio science enhancements, tech demos, rideshares etc.). They should also align with documented partner Agency and community reports [e.g., *Vision and Voyages NASEM Planetary Decadal Survey*, *MEPAG Goals (2020)*, *Canadian Space Exploration – Science and Space Health Priorities for the Next Decade and Beyond*, *Documento di Visione Strategica per lo Spazio, 2020-2029*; *JAXA Strategic Mars Exploration Program (JSMEP)* (English version, Japanese version)].

Focused on maximizing potential returns on investment within boundary conditions rather than on considering required measurements, the MDT's Task 2 findings might:

- Identify spacecraft and anchor payload design characteristics that would extend ice detection/characterization to a global survey (SSO-1);
- Define the highest priority science investigations that could be conducted through "observations of opportunity" (SSO-2) utilizing the primary anchor payload and measurement capabilities identified in Task 1, along with a derived Supplemental Science Traceability Matrix (SSTM) that flows down from SAR payload capabilities to defined science objectives (and their community-vetted "high value" provenance); and,
- Evaluate the measurement benefits of the highest value "payloads of opportunity" (e.g., imager, water-vapor sensors, etc.), that are synergistic with the anchor instrument and reconnaissance objectives, align with mission-support objectives (MSO-2), and support any other articulated Concept Team interests:
  - by prioritizing the payload options as a function of critical resources (e.g., mass, volume, power, data-rate, accommodation requirements etc.); and,
  - by verifying they would neither conflict with mission operations of the primary SAR, nor change the required scope or capabilities of the orbiter/anchor payload.

Questions to be answered include, but are not limited to:

- How can the SAR/concept of operations be expanded for planet-wide coverage (without impacting requirements)?
- What science investigations of opportunity can be conducted using the "core" payload suite (anchor payload and any others identified for potential inclusion)? How would they be prioritized?
- Are there moderate augmentations to the core payload or flight that could significantly enhance reconnaissance or science return? How would they be prioritized?

5.3 TASK 3: PREPARE A MODEL CONCEPT OF OPERATIONS

In the process of completing Tasks 1 and 2, the MDT will additionally provide a model concept of operations (e.g., orbit altitude, local solar time, timing dedicated to data collection etc.) that reflects mission goals, objectives, requirements, and MDT findings, with supporting information from the mission's engineering teams about the primary mission (e.g., launch, arrival, duration) and I-MIM spacecraft/payload capabilities.

6.0 Methods & Schedule

The MDT will formally present its deliverables to Agency partners per the following schedule. Specific target dates will be presented to the MDT upon kickoff.

- **Mid-Sep, 2021** - MDT Kickoff
- **Mid-Nov, 2021** - Interim results (presentation format)
- **Mid-Dec, 2021** - Near-final summary, in which findings are not expected to change during preparation of a final report.
- **Late Jan, 2022** - Final text-formatted Final Report (as a "white paper")

Subject matter expert support from the mission partners will be available to the MDT as needed on issues related to mission systems engineering and conops, as well as the current state of, and critical gaps in, knowledge related to water ice distribution on Mars.

7.0 Operating Procedures

For reasons of cost, time, and safety, most of the MDT's work will be carried out using email and tele/video conferences. By submitting required application materials, applicants waive all claims associated with their MDT participation against any of the partner Agencies, entities, or persons. Members will also sign a statement confirming that they will not release any technical data or MDT information during proceedings and must receive approval for any additional presentations or research purposes.

The point of contact for this task is:

Richard M. Davis
Assistant Director for Science and Exploration
Program Executive, International Mars Ice Mapper (I-MIM) Mission
gsfc-imim-mdt@mail.nasa.gov