

MARS Ice Mapper

Connecting Us with our Human and Robotic Future on Mars

Soaring above Mars.

Recon for arriving explorers.

Finding water, seeking habitats for life.

Monumental data streams for discovery.



INNOVATIVE
PARTNERING
AMONG WORLD LEADERS



International Mars Ice Mapper Mission



Reconnaissance in the 2020s
for Human Exploration in the 2030s

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Presentation Overview

1. Mission Context

- Mission concept overview: Mapping Accessible Near-surface Water Ice
- International partnerships
- Mission objectives + concept guiding principles

2. Primary Payload: L-Band Polarimetric SAR/Sounder

- The case for Synthetic Aperture Radar (SAR) at Mars
- Mapping reconnaissance objectives to exploration goals
- Payload description

3. Science Benefits and Science Community Involvement

- Supplemental science investigations
- Models for science community participation
- Next-gen communication capability



1. Mission Context



The Importance of Accessible Near-Surface Ice

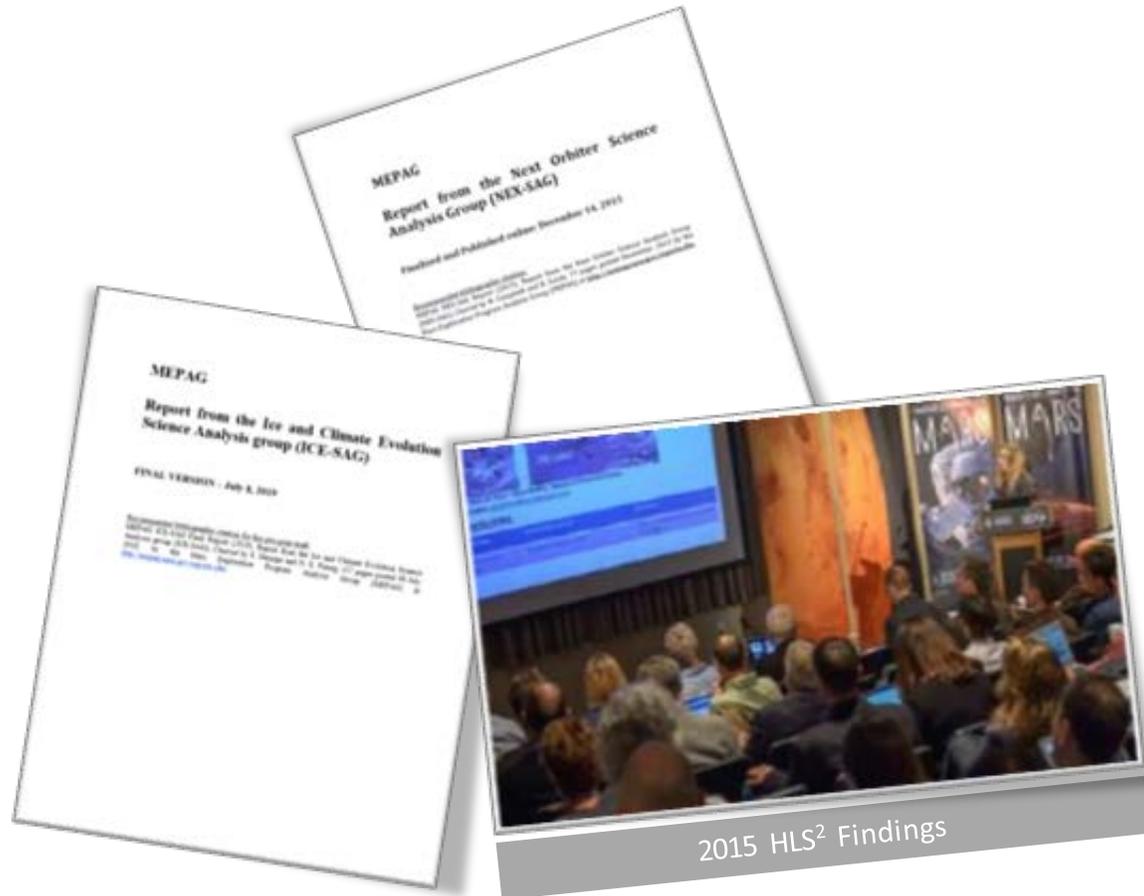
- Resource for human exploration (water, fuel)
- Target for eventual human *in situ* science investigations (e.g., ice coring)
- Rich science potential: geologic & climatic history, astrobiology

Reconnaissance Approach

- “What do we need to know before we go?”
- Targets high-priority science applications for human exploration with significant benefits for planetary science (and all four MEPAG science goals)
- Drives eventual human landing site selection and a human mission architecture

NASA Agency-level Priority

- Intentional multilateral approach with co-equal international partners follows the Exploration framework for future collaboration in the human exploration of Mars
- Limited number of launch opportunities for highest priority reconnaissance to prepare for human missions in the 2030s
- Not the ‘typical’ science/SMD-driven mission, with more similarities to LRO



2015 HLS² Findings

Community Support for Mars SAR

- Numerous concept studies / proposals over the past 20 years
- Most recently outlined in Science Definition Team report for NASA's Next Mars Orbiter (NeMO)
 - Also discussed in NEX-SAG, ICE-SAG and recent NAS PSA White Papers (2020)
- Multidisciplinary Human Landing Site Studies (HLS²) Community advocated for future missions to address priority critical knowledge gaps
 - Highest priority among gaps: accessible water ice for science, ISRU, and Civil Engineering

Advantages / Benefits

- Polarization of signal allows for enhanced interpretation of accessible surface/subsurface ice and materials (polarimetric decomposition)
- Increased center frequency and high bandwidth could permit resolving finer layers in near subsurface
 - Nadir or near-nadir SAR sounder with fine range resolution (like CryoSat-II)

Multiple constituencies & studies endorse the importance of water-ice



INTERNATIONAL



CROSS-AGENCY



INTERDISCIPLINARY



INTERGENERATIONAL

PARTIAL LIST OF REPORTS

- [MASWG, 2020](#)
- [MEPAG, 2020](#)
- [ICE-SAG, 2019](#)
- [SWIM 1, 2019](#)
- [GER, 2018](#)
- [AM-VI, 2018](#)
- [M-WIP, 2016](#)
- [NEX-SAG, 2015](#)
- [HLS², 2015](#)
- [ICE-WG, 2015](#)
- [SR-SAG, 2014](#)
- [MSO-SAG, 2013](#)
- [P-SAG, 2012](#)
- [HEM DRA 5.0, 2009](#)
- [HEM-SAG, 2008](#)
- [MHP-SSG-TI, 2005](#)
- [MHP-SSG, 2005](#)

Pre-decisional Planetary Mission Concept Studies:

- MORIE** (Mars Orbiter for Resources, Ices and Environment)
- MOSAIC** (Mars Orbiters for Surface-Atmosphere-Ionosphere Interactions)

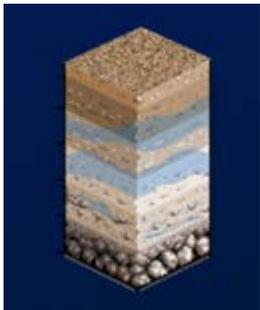
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Water Ice Resources

- Where is near-surface water ice accessible for both ISRU and human investigations (e.g., coring)?
- How spatially extensive, thick, and deep are the deposits?
- How 'pure' is the ice (ice vs. icy-regolith mixture)?

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Terrain

- How much regolith is on top of buried water-ice resources?
- How porous is the regolith at prospective landing sites?
- How rough is the terrain (as an engineering boundary condition)?



Martian Hydrosphere / Environment

- What geologic features lie beneath the dust or sedimentary mantling deposits?
- What do they reveal about the volcanic, fluvial, impact, & other processes in Mars's history?
- What can we learn about Mars's environmental processes from seasonal changes?

Mission Concept Development: Guiding Principles

Timely Critical Data for Human Mission Planning

- Provide highest priority datasets in the 2020s to inform architecture for human Mars missions as early as the 2030s; relies on high TRL systems and subsystems

Maximized Multilateral Partnership Model

- Initiate a highly leveraged international collaboration that builds on the heritage and traditional strengths of the partner agencies, promoting an innovative, collaborative, multilateral model for future human exploration
- Enable Agency partners to meet unique national and common goals for Mars exploration in a cost-shared, achievable manner that otherwise would not be programmatically viable given the resource-limited environment for all

Prioritization of Reconnaissance Objectives

- Design decisions tailored to identify and characterize near-surface, accessible ice

MARS Ice Mapper

Connecting Us with our Human and Robotic Future on Mars



Primary Payload

- L-band pol. SAR/Sounder
- Decades of EO SAR expertise through RADARSAT missions



Spacecraft

- Developing plan for spacecraft bus
- Extensive spacecraft & SAR expertise (Hayabusa, Hayabusa2, MMX, ALOS L-band, GPM SAR)



Systems Architect / Mission Lead

- Launch capabilities
- High-altitude communications constellation
- Decades of experience at Mars

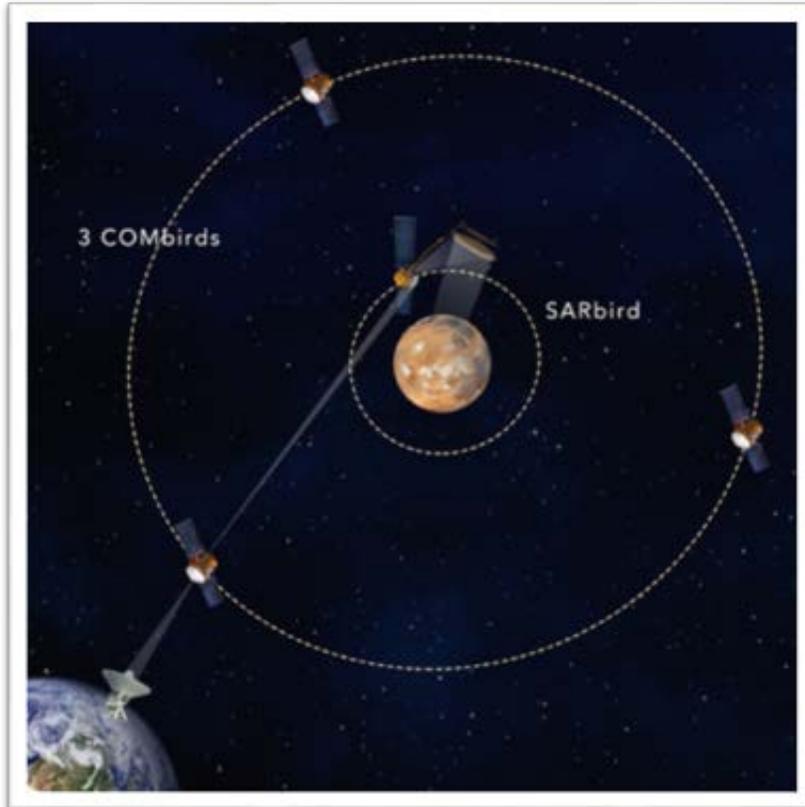


Communications Subsystem

- Comms system on SARBird
- Decades of radar + communications expertise (Cassini, JUICE, Bepi Columbo)



* Indicates Concept Team roles only; partners have not yet made flight commitment



Schematic Diagram of Ice Mapper Concept

SAR Reconnaissance Spacecraft in Low Mars Orbit

- Polarimetric L-band SAR/Sounder to investigate upper 5-10 m of Martian surface
- DTE + to-COMBird communication system (in Mars orbit for relay)
- TBD potential for other international payloads (contributed or competed)

High-Altitude Constellation of Linked Comm Relay Spacecraft

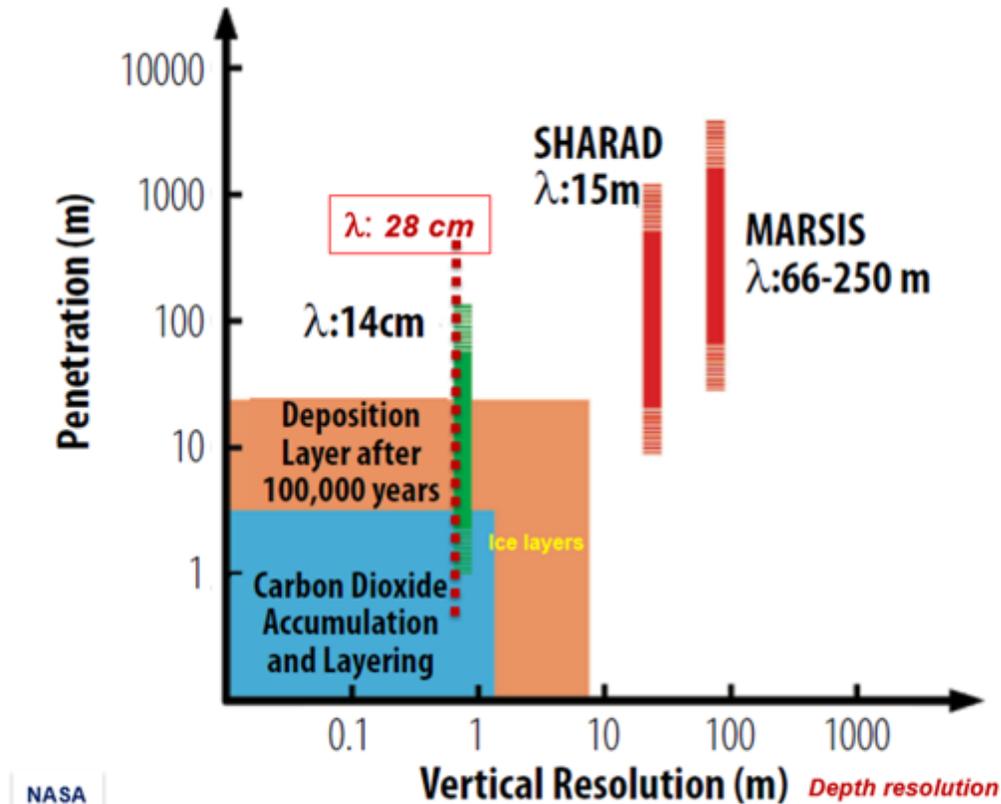
- Enable continuous connectivity from Mars surface and low Mars orbit to/from Earth
- Generate data rates and data return, orders of magnitude greater than present capability
- Provides robustness for Mars Sample Return as well as critical infrastructure for future Mars missions, including large SAR data sets and small-sat missions of opportunity

Targets prime mission completion by 2030 to inform Exploration Planning.



2. Primary Payload: L-Band Polarimetric SAR / Sounder

SAR Sounder: Depth to Ice Potential Detection at L-Band ($\lambda \sim 28$ cm)



after Garvin & Raney

Ice Mapper will fill a critical knowledge gap in upper 5-10 m of subsurface.



Draft* Reconnaissance Objectives (Level 0)

- **R0-1:** Detect and map the spatial distribution and depth-to-ice of water-ice resources and any possible liquid water in the upper 5-10m of the Reconnaissance Zone
- **R0-2:** Detect and map surface / near-surface geotechnical properties (roughness, compactness) in the Reconnaissance Zone to provide a fundamental understanding of the accessibility and sufficiency of water-ice resources and the structural stability of the terrain for landing large payloads and civil engineering on the surface for human exploration
- **R0-3:** From the above surveys, identify and characterize potential Exploration Zones (100-km-radius areas) for targeted study, leading to a thorough investigation of, and contributions to, landing-site safety certification for at least two sites
- **R0-4:** Based on returned data on water-ice resources and geotechnical properties in Exploration Zones, identify high-priority research investigations that could be conducted by robot-assisted, proximal humans in Science Regions of Interest.

**In development. Subject to modifications, per current multilateral deliberations among Concept Team Agencies.*

Traceability of Recon Objectives to 2011 Decadal Survey & MEPAG Goals

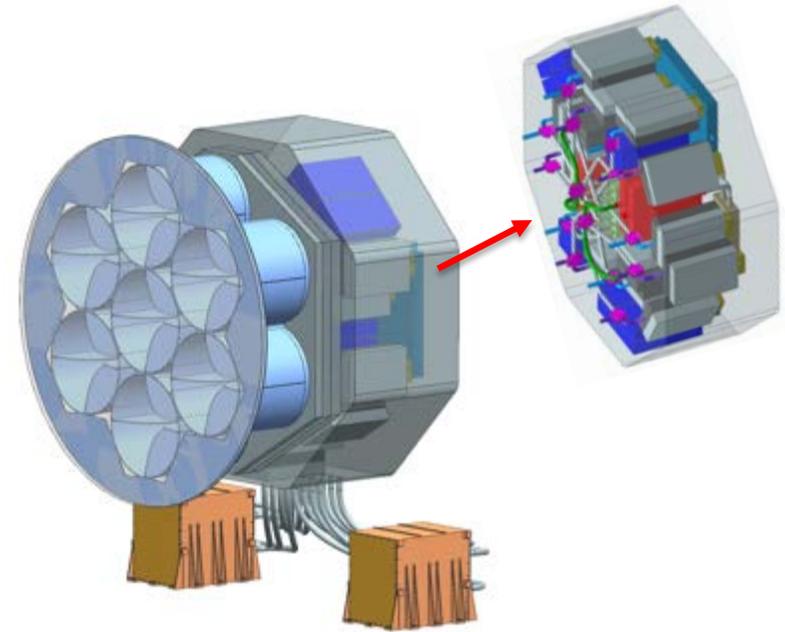
MARS ICE MAPPER MISSION: HIGH-LEVEL RECONNAISSANCE TRACEABILITY MATRIX

Decadal Survey (V&V, 2011) Reconnaissance Connections for Human Exploration:	Relation to NASA Goals	Exploration-driven Mission Goal	Mission Reconnaissance Objectives	Mission Investigation	Required Measurements	MEPAG Science Goals (2020)			
						Goal I: Life	Goal II: Climate	Goal III: Geology	Goal IV: Human
<ul style="list-style-type: none"> Precursor Robotic Missions: To reduce the cost and risk for future human exploration, robotic precursors to acquire information about potential resources.... Need for Mars Relay capabilities Preparation for “Human-tended Science”: Mars “invariably, the target of greatest interest” for “answering questions relating to the search for past or present biological activity” International Cooperation <i>Complementary Science:</i> <i>Water re.</i> <ul style="list-style-type: none"> • <i>Building New Worlds</i> • <i>Planetary Habitability</i> 	ISRU Water Resources & Civil Engineering Properties	Map and characterize <u>accessible</u> (top 5-10m) subsurface ice and its overburden in mid-low latitudes to support planning for the first potential human surface mission in the 2030s.	RO-1 Ground Ice as a Resource	Detection of Shallow Water Ice	Identification of Regions with Water Ice Present within 5-10 m of Surface	<i>Science Synergies:</i>	<i>See Slide 21</i>		A3.1
				Characterize Material Properties & Thickness of Dry Overburden	Identification of Regions where depth of dry overburden is < 2 m, and estimation of material thickness & consolidation				B4.1
	RO-2 Landing Site Geotechnical Properties		Surface Properties	Roughness; Slopes; Surface Texture, and Load-bearing Strength	B4.2				
	RO-3 Identifying Candidate Exploration Zones		Characterizing ice-rich candidate human Exploration Zones	Characterizing Resource Regions of Interest (RROIs) and Science Regions of Interest (SROIs)	C2.1				
RO-4 Science Regions for Proximal Human investigations	D1.1								
	Landing Site Selection								B4.1
									B4.2
									C2.1
									C2.2
									D1.1
									D4.1

Ice Mapper will significantly contribute to advancing Science Goal IV: Preparation for Human Exploration.

CSA OVERVIEW

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	40-45°
Horizontal Resolution	5-30 m
Penetration Depth	> 6 m
Sounder	
Vertical Resolution	< 1 m (based on RF BW)
Along-track Spacing	30 m
Across-track Footprint	1.5 km



CSA: Primary Instrument Polarimetric SAR
Seven-element Feed Array
(requires 6m reflector antenna, *not shown*)



Concept Performance Evaluation

US-led Peer-Review

- Mission and payload concepts assessed by experts in planetary radar
- Conclusion: hybrid-pol L-band SAR/Sounder is the most appropriate selection to meet mission requirements
- White Paper summarizing results (in progress) will be made available to the community

Laboratory Measurements

- NASA-led dielectric properties of SNC meteorites to constrain radar performance (new loss tangents)

Numerical Simulations

- CSA-led surface and subsurface scattering models demonstrate effectiveness of CPR for ice detection
- NASA-led subsurface scattering model indicates ice-detection depths of L-band at > 6 m

In-Flight Demonstration

- CSA-led experiment using RADARSAT-2 as a polarimetric sounder reduces surface clutter (even at C-band)



3. Science Benefits and Science Community Involvement

Maximizing Science



LRO: Analogous Exploration-driven, Science-serving Mission Model

- Originally conceived for human exploration purposes with supplemental science (hybrid: ORDT process)
- In operations since 2009, science-driven after exploration goals were achieved (> 1 petabits)
- LRO model cited in Decadal (2011) as a “positive example of synergy between the human exploration program and science”; MIM can be as well

Draft* Ice-Mapper Concept of Operations

- Priority: Reconnaissance Zone: Achieve reconnaissance Level 1 objectives, while maximizing science observations of opportunity
- Augmented: Near-global Coverage: Predominantly focus on investigation-driven research supplemental science objectives
- Extended mission possibilities for scientific discovery (similar to LRO model)
- Paradigm-shifting opportunities for scientific discovery
 - *Vastly more science data return for Ice Mapper and future missions using next-gen communications relay network*



Draft* Ice Mapper Mission Supplemental Science Objective:

SO-1: Taking advantage of “scientific observations of opportunity” during operations, when feasible, geographically expand to near-global coverage of the Martian surface in order to advance the state of knowledge about the Martian cryosphere, the climatic and geological history of Mars, and the potential for past or present microbial life.

Draft* Topics Supporting the Supplemental Objective (aligned with 2011 Decadal Survey & 2020 MEPAG Science Goals)

- **SO-1A:** Distribution & Origin of Ice Reservoirs
- **SO-1B:** Planetary Habitability
- **SO-1C:** Dynamic Surface Processes on Mars
- **SO-1D:** Geologic Evidence for Environmental Transitions

Once mission team partnerships are secured, intend to engage broader science community in exploring how to maximize the potential of the mission.

**In development. Subject to modifications, per current multilateral deliberations among Concept Team Agencies.*

Traceability of Draft Supplemental Science Objectives & MEPAG Alignment

MARS ICE MAPPER: POTENTIAL SUPPLEMENTAL SCIENCE OBJECTIVES								
Relation to NASA Goals	Supplemental Science Objective	Draft Supplemental Science Topics	Sample Investigations	Required Measurements	MEPAG Science Goals (2020)			
					Goal I: Life	Goal II: Climate	Goal III: Geology	Goal IV: Human
High Decadal Survey Priority	Science Observations of Opportunity	SO-1A Distribution & Origin of Ice Reservoirs	Distribution of buried water & CO ₂ ice, plus relationship to surficial polar deposits	Extent and Volume of Water Ice in Non-polar Regions	A2.1 A2.5	A2.2	A1.3 A1.4 A1.5	
				Extent & Volume of Buried CO ₂ Ice in the Polar Caps		B1.1 B1.2 B1.3		
				Shallow Subsurface Structure of Polar Cap & Layered Terrain		B2.1 B2.2 B3.1		
SO-1B Habitability		Understanding whether a past or present environment on Mars could sustain life	Establishing the distribution of water, its geologic history, and the processes that control its distribution	A2.1 A2.5 B1.3 B2.4	A2.2 B2.1 B2.2	A1.1 A1.2 A1.4		
New Discoveries / High MEPAG Priority	SO-1C Dynamic Surface Processes on Mars	Role of liquid water in Recurring Slope Lineae (RSL)	Surface / Shallow Subsurface Hydration State as a Function of Season & Time of Day	A2.1 A2.5		A1.1 A4.3		
	SO-1D Geologic Evidence for Environmental Transitions	Diversity of Ancient Aqueous Deposits	Fine-scale Composition & Morphology in Ancient Terrain		B1.1 C2.1	A1.2 A1.5 A2.1 A2.5 A4.3 A4.7		

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Draft* Avenues for International Science Community Involvement

Core SAR Instrument Team

- Payload development, observation planning, commanding, health monitoring, data processing & archiving, delivery of L1 reconnaissance objectives; competed prior to or during Phase A (member Agencies determine own TBD processes)

Investigations

- **Option 1 – Recon/Science Measurement Team:** reconnaissance (and supplemental science) measurement and observation planning, data analysis, delivery of high-level data products; competed as early as Phase A (member Agencies determine own TBD processes)
- **Option 2 – Observatory Proposal Teams:** teams bid to carry out observation campaigns; work with core science team to generate necessary data and analyze results
- **Option 3 – Hybrid:** combination/variation of Options 1 & 2

Observations of Opportunity

- Currently considering models
 - Notional Example: “SAR-Wish” modeled after Hi-Wish for HiRISE; users submit targets of interest and receive data to complement ongoing independent investigations

**In development. Subject to modifications, per current multilateral deliberations among Concept Team Agencies.*



Expanding Science Opportunities with Tomorrow's Mars Telecom

- Mission-enabling communication support for the high data volume of Mars Ice Mapper's SAR
- Provides communications redundancy for Mars Sample Return
- Additional Key Advantages
 - Reduces costs and risks of future Mars missions that would not have to carry their own comm system
 - Increased return on investment of all missions based on greater science-data return from each
 - Replaces aging communications assets at Mars with next-generation capabilities
 - Continuous /near-continuous support to landers, rovers, *and* orbiters
 - Vastly higher Mars-to-Earth data rates, enabling complete hi-res mapping of Mars at increased spatial, spectral, and temporal resolution
 - Support to orbital users, allowing low-cost “smallsat” orbiters to achieve “bigsat” science return
 - Greatly increased instantaneous data rates and total data return for landers/rovers
 - Increased opportunity for ground-in-the-loop interactions with science/exploration assets at relatively short (10-40 min) RTLT – possibility for many Earth-Mars decision loops per sol

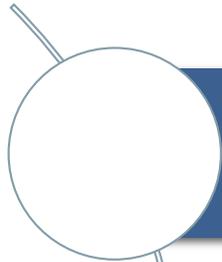
Identification of Regions of Interest at ice-rich candidate human landing sites will enable future human explorers to target specific sites for resources and high-priority, human-led scientific investigations on the Martian surface (e.g., ice coring).

Expands the rich history of landing site selection for robotic missions and promotes the high-value science proximal human explorers can achieve.

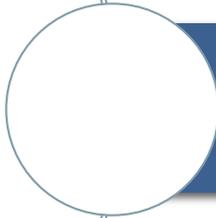




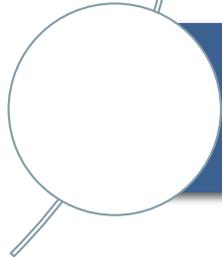
4. Summary and Conclusions



The international Mars Ice Mapper mission is an exceptional opportunity to address simultaneously human exploration and international science goals, while augmenting the communications infrastructure at Mars.



The mission's international partnership is being solidified, representing decades of expertise in respective fields.

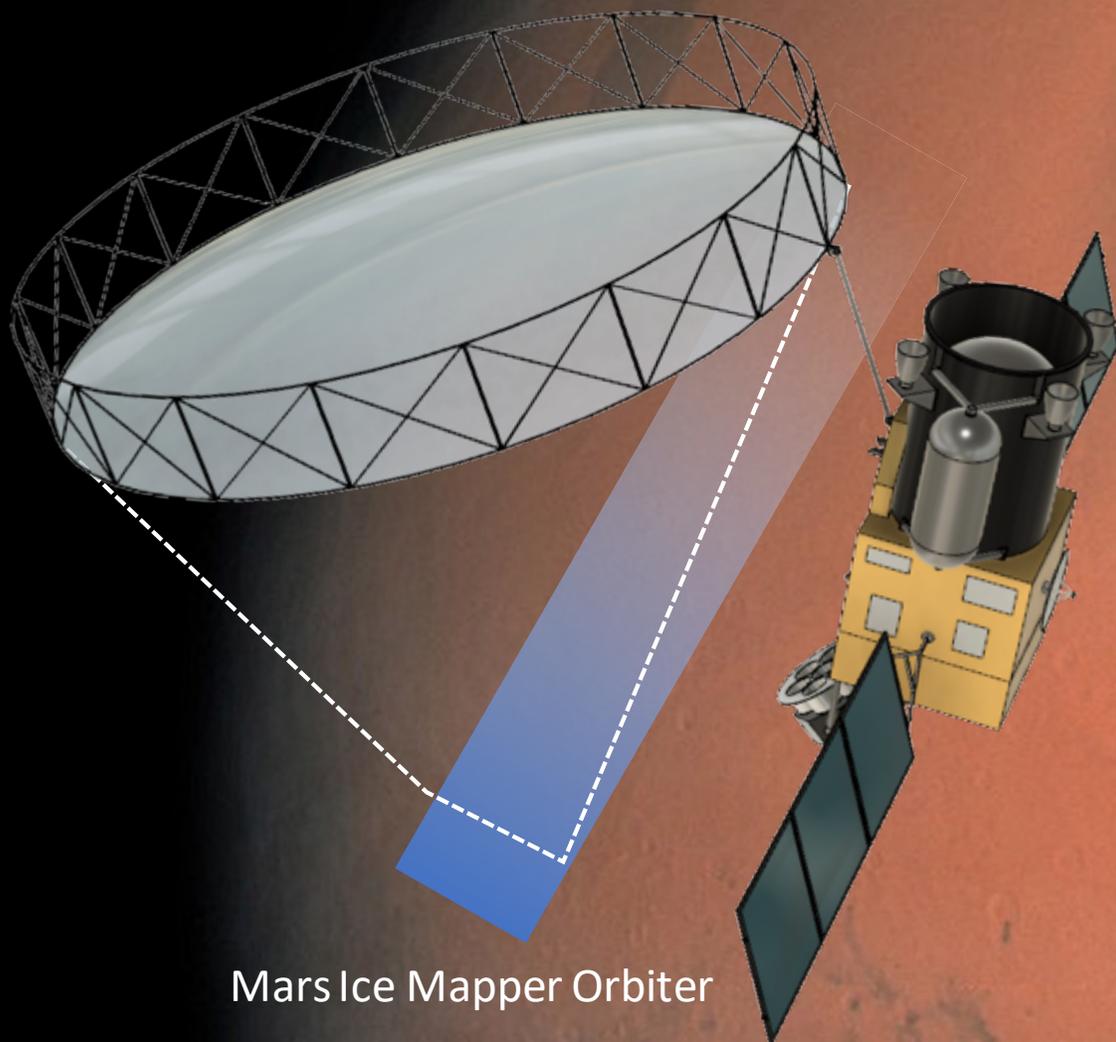


Although driven by human reconnaissance objectives, numerous opportunities enable the international science community to conduct high-priority research investigations.



BACKUP

JAXA OVERVIEW



SUMMARY OF DRAFT CONCEPT

Transfer orbit from Earth to Mars

2028 Launch Earth to Mars with a total delta V of 2.4 km/s

Mission Orbit

Dawn/Dusk Local Mars Solar Time

310 km altitude; sun synchronous

Altitude periodically changes from 220 to 370 km

Mass and Power

Approx. 2,800 kg, including 1,900 kg of propellant
(Direct Insertion from Earth)

1,000 W power generation at EOL

Communications

Above 1 Mbps with 3 COMbirds

NASA OVERVIEW

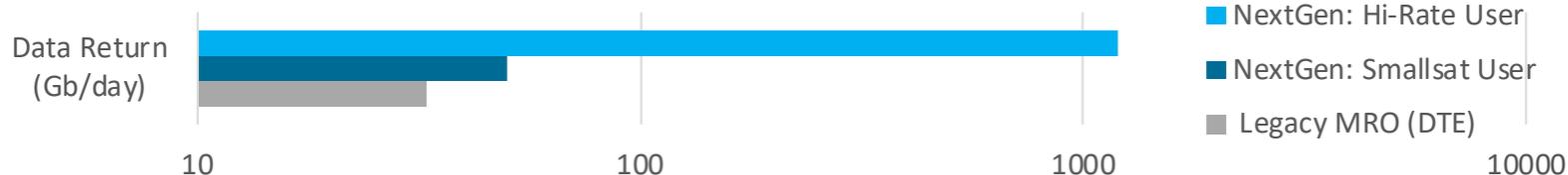


SUPPORT TO A SCIENCE ORBITER

Reference: MRO @ 33 Gb/day

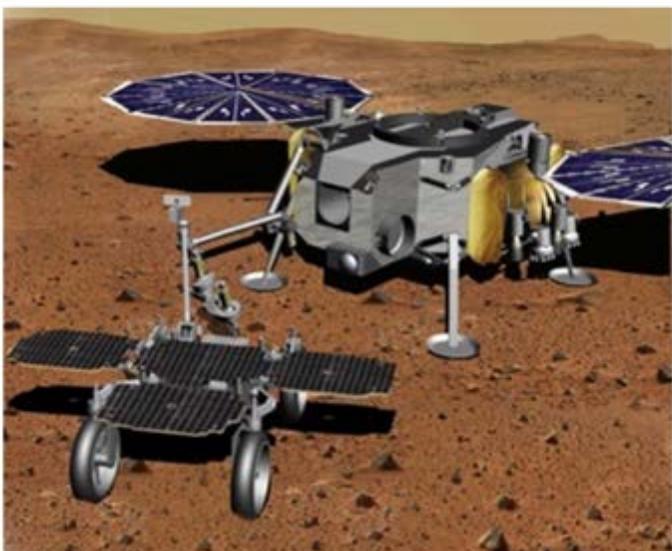
High-rate User

X-band, 15 W, 30 cm HGA, 8 hrs/day
1,200 Gb/day



Smallsat-class User

X-band, 5 W, 10 cm HGA, 8 hrs/day
50 Gb/day

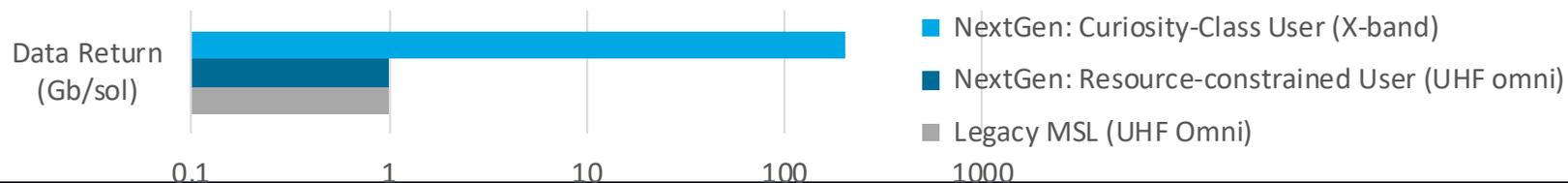


SUPPORT TO A SCIENCE LANDER/ROVER

Reference: MSL @ 1 Gb/sol

Future Curiosity-class User

X-band, 15 W, 30 cm HGA, 2 hrs/sol
200 Gb/sol



Resource-constrained User

UHF, 10 W, omni, 30 min/sol
1 Gb/sol

MULTIPLE POTENTIAL OPPORTUNITIES FOR SCIENCE INVOLVEMENT:

GOAL: Maximize Science Return while Delivering on Driving Reconnaissance Requirements

Concept Team developing preliminary ideas on populating recon/science teams for the mission

- Currently crafting traceability matrix: recon mission requirements, proposed measurements to meet those requirements, and required data products
- Developing Permanent Multidisciplinary Mission Recon/Science Team involving all Mission Partners
 - TBD path for participation of international radar experts and others
- Considering “Observatory Model” for Supplemental Science (common in astronomy), with individual investigations competed
 - Considering objectives for supplemental science “observations of opportunity” that either complement the SAR-focused recon requirements and/or have been identified as priority objectives by the international Mars science community (e.g., MEPAG 2020 Goals)

Potentially Creates Whole New Mission-Enabling Paradigm for Mars Exploration

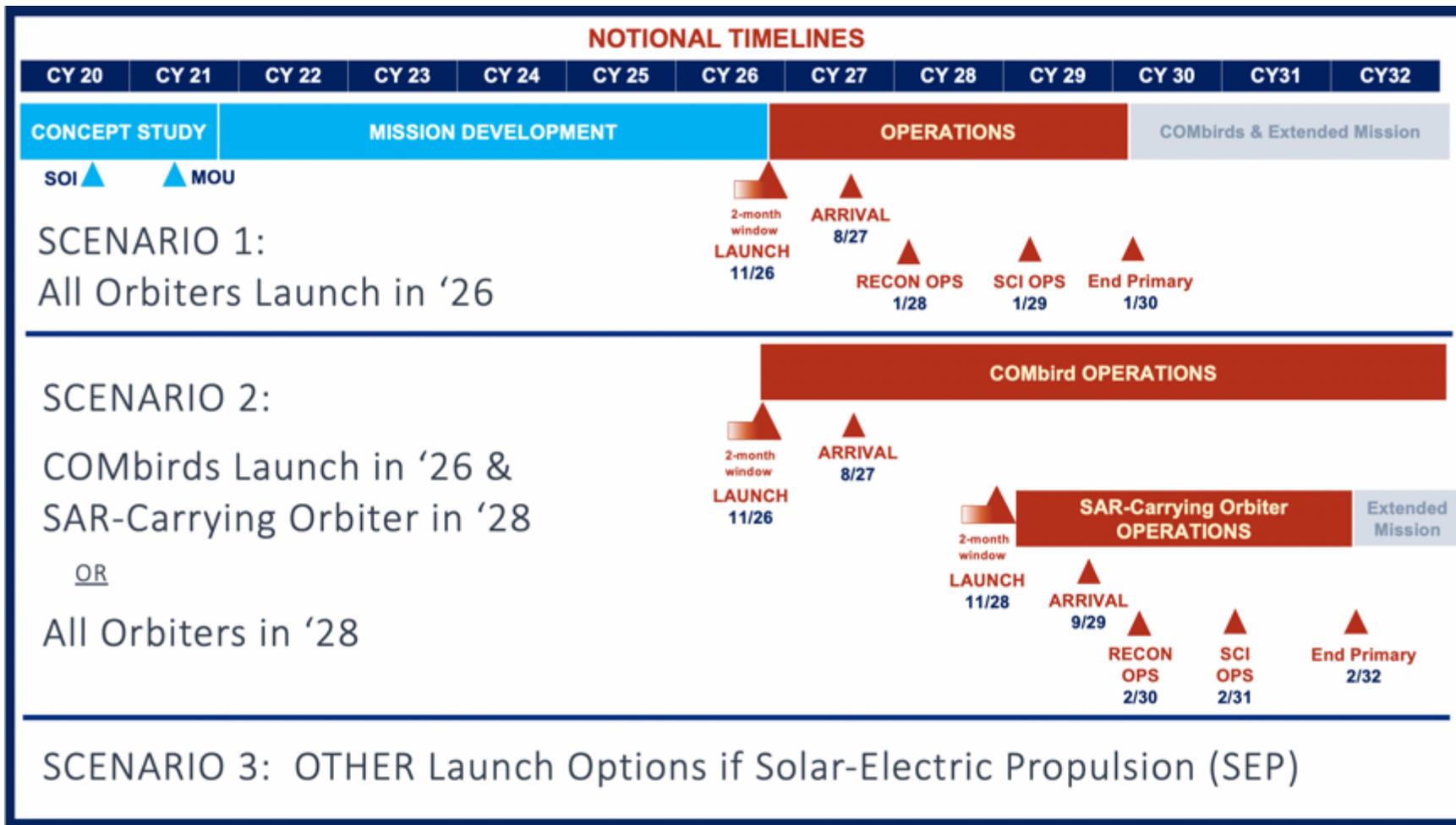
- Significantly Enhanced, Scalable, Interoperable Communications Capability for Future Mars Missions
 - Greater return on investment for large and small robotic missions: more data throughput, more science return, and cost savings without need for each mission to carry its own communications system
 - Initial infrastructure supporting international human exploration (and science investigations conducted by astronauts on the surface)
- Potential Rideshares – these separate payloads would remove constraints on instruments otherwise posed by the primary SAR instrument, thus deconflicting mass, power, operational complexity etc. in accommodations

Breakthrough increases in Mars telecommunication capability across multiple service characteristics and for a wide range of user spacecraft.

	CURRENT CAPABILITY	NEXT GEN MARSCOM CAPABILITY
Aggregate Mars Bandwidth to Earth	40 Tb/yr	1000 Tb/yr
Relay Support to Curiosity-class Lander/Rover	1 Gb/sol (@UHF)	200 Gb/sol (@ X-band)
Relay Availability for Surface Assets	20 min/sol (MRO relay)	Continuous (±40 deg LAT)
Relay Service to Low-Altitude Mars Orbiters	Not Available	Continuous High-Rate X-band Relay

MISSION OVERVIEW

LAUNCH OPTIONS





SAR (RADAR) DETAILS

- The L-band polarimetric Synthetic Aperture Radar (SAR) instrument inventories the context, extent, location, and potential “resource volume” of buried water ice deposits on Mars that may be suitable as exploration and/or scientific resources in the future.
- The SAR is an agile, multi-mode instrument capable of measuring aspects of the uppermost several meters of the Martian surface layer using state-of-the-art techniques pioneered on Earth via aircraft (JPL UAVSAR and AirSAR) and space [CSA Radarsat-1, Radarsat-2, Radarsat Constellation Mission (RCM), NASA SRTM and SIR-C, etc.].
- These unique modes allow the radar system to detect, map, characterize, and inventory buried ice deposits in ways not possible today with existing assets, and could serve to identify critical human exploration landing zones on the basis of their accessibility to shallow water-ice reservoirs (and for associated scientific interrogation via astrobiological techniques).
- All modes are complementary and synergistic, as engineering-quality inventory and assessment requires multiple perspectives that the L-band SAR can provide (see next slide).

Operational SAR modes enable multiple measurements:

MODE 1: SIDELOOKING POLARIMETRIC SAR IMAGING

Approach: Baseline

Horizontal Resolution: 30 m

Goal: wide area detection of buried ice

With extremely high sensitivity, buried water-ice could be detected down to depths as great or greater than ~5m (depending on the mantling of Martian regolith and dust on top of, or intermixed with, it), with mapping of boundaries and associations with other subsurface geologic structures (at meso-scales of tens of meters).

Approach: High-resolution

Horizontal Resolution: 5 m

Goal: “zoom in” on buried ice

With particular sensitivity to meter-scale surface and shallowly buried features that could impact landing site safety, this mode could produce high-resolution maps of the ruggedness of future landing sites in association with near-surface ice to add to the arsenal of data used in the Mars landing site certification process, which has proven successful for NASA MEP missions.

Approach: Interferometry

Horizontal Resolution: 30 m

Goal: assess topographic change detection

Requiring a repeat orbit and precision tracking, the InSAR mode can measure the local surface and subsurface topography at high resolution and measure potentially centimeter-scale changes, even in areas with cloud-cover, high dust opacity, as well in the polar night (darkness).

Approach: Tomography

Horizontal Resolution: 5m

Goal: delineate layering within subsurface

Using high-resolution SAR, multiple passes over a specific target area can show fine-scale subsurface layering in stacked SAR imagery and characterize the physical properties of each layer, as well as differences between ice-poor and ice-rich areas clearly distinguishable (via classical tomographic techniques).

MODE 2: NADIR SAR SOUNDING

Approach: Baseline

Along-Track Spacing: 30 m

Goal: identify depth to buried ice layers

With sub-meter (< 1m vertical resolution) ranging precision, this mode maximizes the depth of penetrating radar on spatially extensive water-ice layers, distinguishes the depths of distinct subsurface layers (to better than 1m), characterizes their physical and electrical properties, and provides wavelength-scale roughness profiles (as done for Earth & Venus). Can also use special ice detection methods known as “CBOE” to improve definitive detection.

Approach: Repeat pass

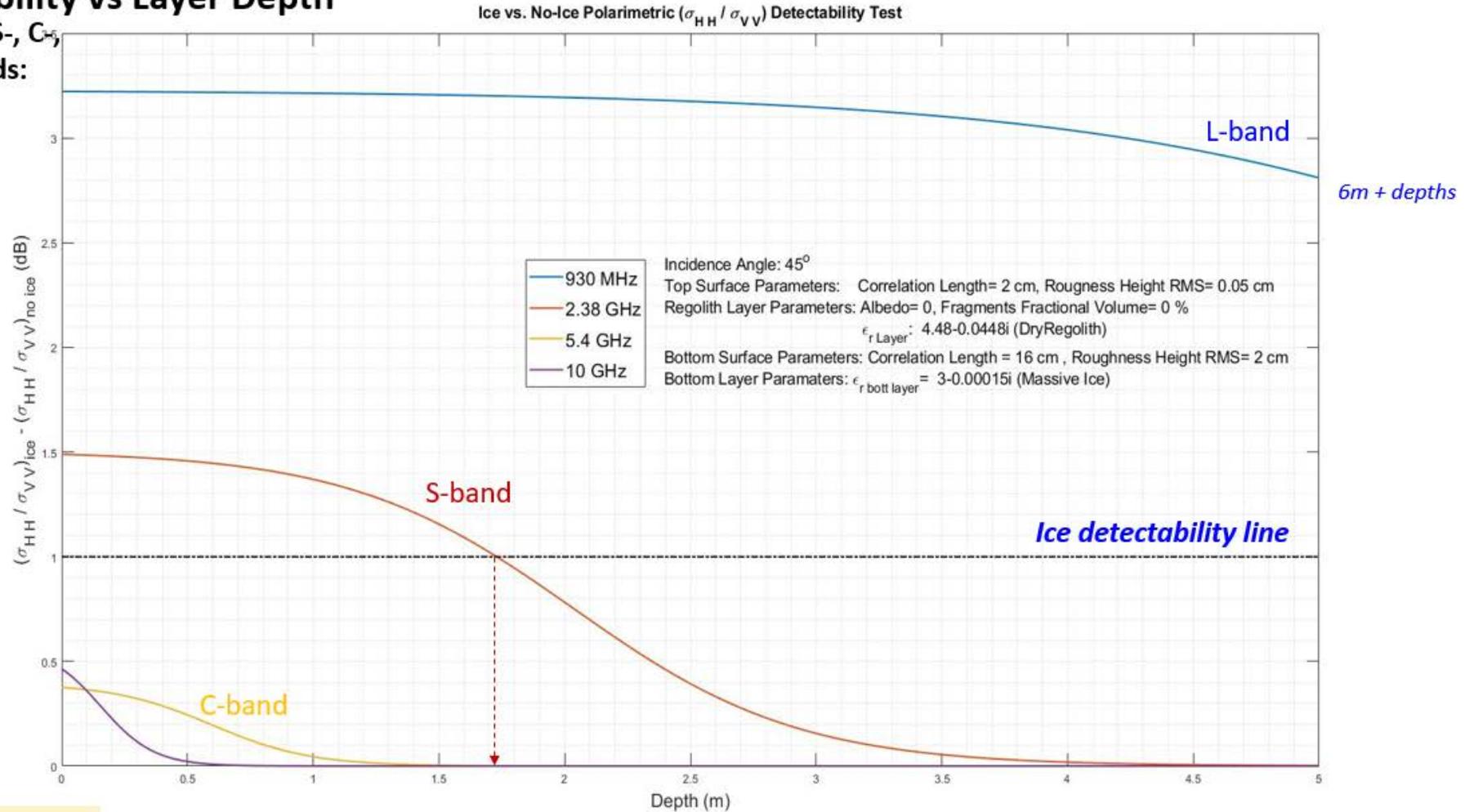
Along-Track Spacing: 30 m

Goal: identify depth to buried ice layers

While similar to the single-pass sounder mode, three passes over a targeted “corridor” provide even better near-surface data quality in the critical 1-10m shallow zone.

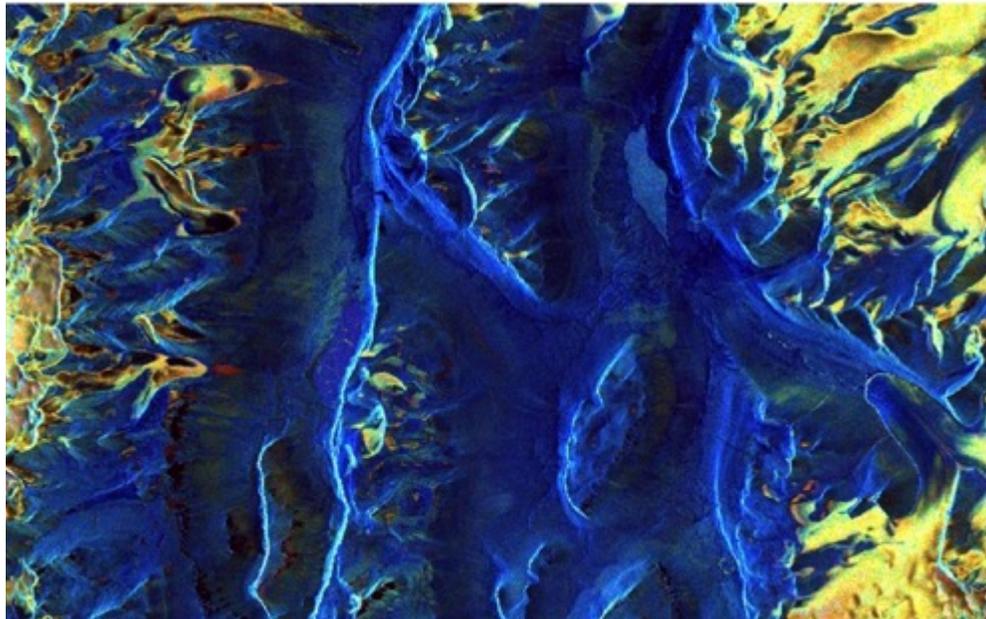
Detectability vs Layer Depth

At L-, and S-, C-,
and X-bands:



X, C bands do not readily detect buried ice on Mars

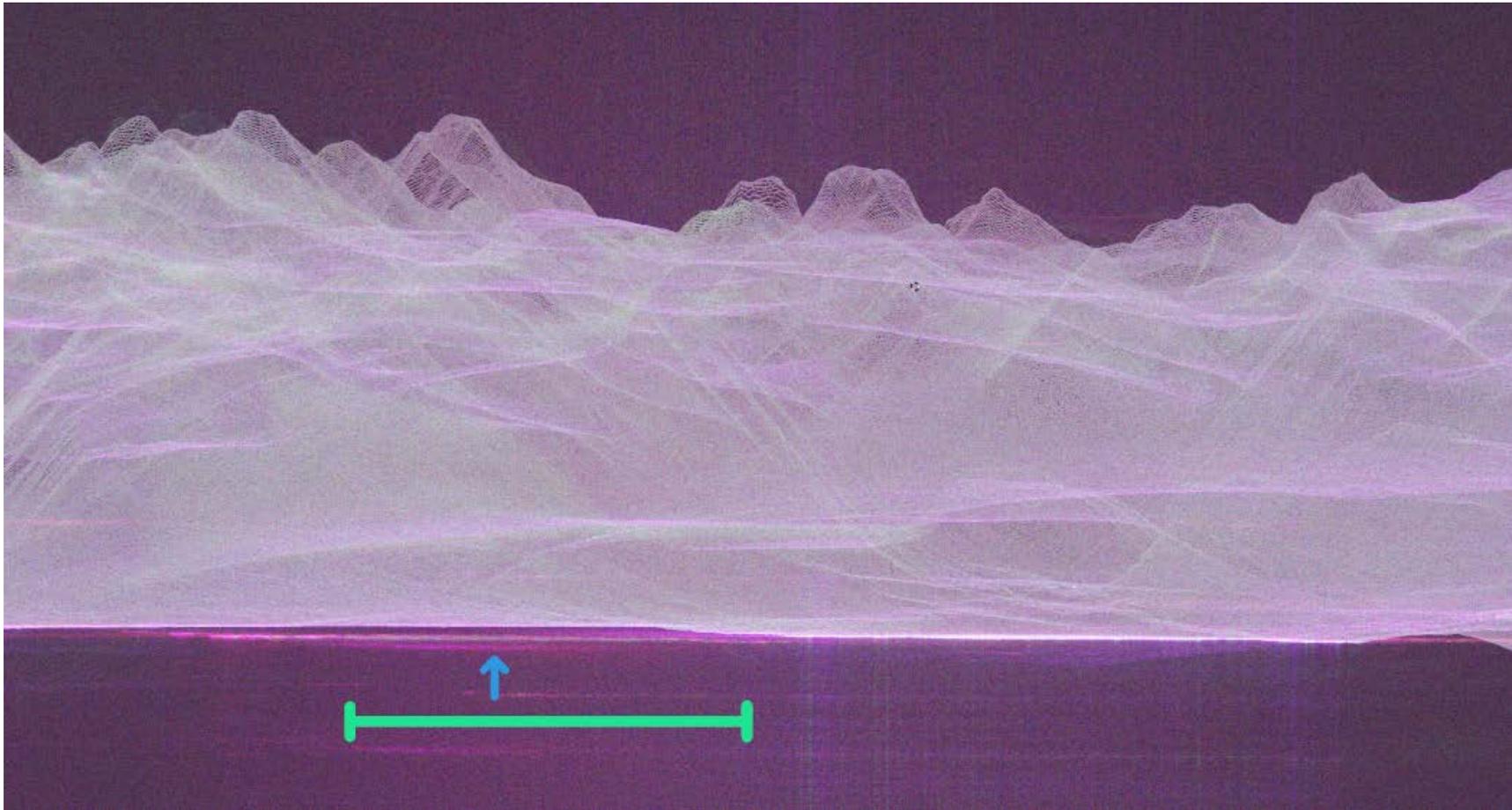
Examples of Polarimetric SAR Images



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Polarimetric SAR Image of the Dry Valleys, Antarctica from CSA Radarsat-2 (quad-pol data).

- BLUE:** Bragg scattering likely arising from surface reflection.
- RED:** Double bounce scattering that can be associated with reflection from large boulders, step cliffs, or the presence of ice.
- GREEN:** Some level of penetration within the subsurface.
- STRONG YELLOW** Associated with the presence of glacial ice, but the same type of color is also found in the valley, indicating potential subsurface ice.



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A section of Radarsat-2 nadir SAR sounder pass over Wright Valley, Antarctica, with a simulated overlay on top of the Pauli decomposition. The arrow indicates a suspected ice deposit, and the bar indicates the approximate azimuth extent of the deposit.



READINESS: Significant pre-decisional mission planning, experience, & heritage.



SIGNIFICANT RADAR EXPERIENCE AT MARS & CO-INVESTMENT

- **ASI Contributions: Communications Sub-systems and Mars Radar Expertise**
- Demonstrated collaboration on many major international human and robotic space missions, including leadership in Mars radar instruments: MARSIS on Mars Express and SHARAD on Mars Reconnaissance Orbiter; multi-mission involvement in Earth Radar Missions

SIGNIFICANT SAR HERITAGE & CO-INVESTMENT



- **CSA Contributions: SAR + in-depth cost study \$ estimate.**
- Demonstrated Canadian leadership in Earth-observing SAR:
 - successful RADARSAT (1995) and RADARSAT-2 (2007) programs on which MDA served as the prime contractor; RADARSAT Constellation Mission (RCM successfully launched June 12, 2019) uses a three-satellite configuration to provide daily access to 90% of the world's surface through polarimetric SAR imaging



SIGNIFICANT SAR HERITAGE & CO-INVESTMENT

- **JAXA Contributions: Plan for the SAR-carrying radar bus with partnering opportunities**
- Demonstrated leadership in both human and robotic space missions
 - Historical success of JAXA bus systems for Earth (observation, communication, positioning) satellites and flight-proven subsystems , including radar
 - Experience in astronomical and deep-space probes, including MMX (Mars Moon Explorer)

READINESS: Significant pre-decisional mission planning, experience, & heritage.



SIGNIFICANT HERITAGE: MARS ROBOTIC MISSIONS

- **Evidence of subsurface water-ice:** SHARAD sounding radar at intermediate scales (multiple kms to 100s of kms) and other data (HiRISE images showing water-ice in exposed fresh craters, Phoenix ground-truthing, MARSIS, MCS thermal inertia)

EXTENSIVE MEPAG NEX-SAG STUDY (related to future orbiter concept "NEMO")

- **Multidisciplinary Orbiter Study:** makes a strong case for polarimetric SAR and finds that it addresses a full set of robotic and human objectives given the considerable synergy among science, resource strategic knowledge gaps, and reconnaissance interests (expert SMD/HEOMD/international Mars Science community participation)

NASA: EXTENSIVE, INTEGRATED STUDIES & MISSION EXPERIENCE

- **NASA Extensive Spaceflight Experience: 50+ Years of Mars Exploration,** including developing, integrating, testing, and operating deep-space orbiters and communications relay systems; multi-instrument testing, integration and flight operations of radars in space; NASA practical experience with Mars missions through instrument development and operations
- **Case Study of Viable Early Readiness Solution for Mars Water-ice Detection:** Amplifying the NEX-SAG Study, provides a cost- and schedule-optimized ice-mapping radar orbiter concept for Mars developed through two independent designs (US/International SAR) on the basis of NASA HQ driving requirements (vetted externally by planetary & radar experts to ensure integrity and to avoid bias in SAR acquisition source/approach)

DSN Near-term Upgrades

Fully Funded Upgrades

+

Funded Technology Development

Element	Status
Network Sustainment	70m antennas' service life extension to 2030
DAEP (4x34m antennas per site, arrayed operation)	
Canberra	Complete
Madrid	By 2020
Goldstone	
DSS-23	By 2024
DSS-33	By 2026
Common platform with digital signal processing and 4-MSPA	
Sardinia Radio Telescope upgrade	In progress
High-rate processing (150 Mbps)	By mid-2019
DTN operational	By 2021

Element	Status
DSOC	Psyche in 2022

Proposed Upgrades:

- n-MSPA
- High rate Ka-band uplink

Partially funded:

Mars Network Enhancements

- Mars Relay Satellite (2028)

Technology Development

- UST
- Gen 2 DSOC

DSN Near-term Upgrades: Potential Configurations

DSN content from Nov2018 TIM in Seattle

- Support for detailed 3-year Mars reconnaissance with est. total data volume of 13.2 Tb/day would need a DTE link with a persistent data rate of ~76 Mbps over min-max Mars distance.

	Configuration 1	Configuration 2
Spacecraft Side	5m HGA, Ka-band 200W transmitter	3m HGA, Ka-band 200W transmitter
DSN Side		
Earth/Mars (E/M) distances supported by:		
1x34m station	~1.64 AU	~0.98 AU
2x34m array	~1.64 AU to ~2.32 AU	~0.98 AU to ~1.39 AU
3x34m array	~2.32 AU to ~2.67 AU (E/M max)	~1.39 AU to ~2.67 AU (E/M max)

- DSN station(s) supporting this mission would also be simultaneously supporting all other Mars missions using MSPA.
 - 4-MSPA would be sufficient for NASA-only Mars mission set (including Odyssey, MAVEN, MRO).
 - To cover non-NASA missions, the n-MSPA (where $n > 4$), not currently funded, may be necessary.
- To benefit from DSN Ka-band high-rate processing, the spacecraft Ka-band 200W transmitter and UST (capable of 100 Mbps) are required.



READINESS: PRIOR EXPLORATORY JOINT PARTNER STUDY

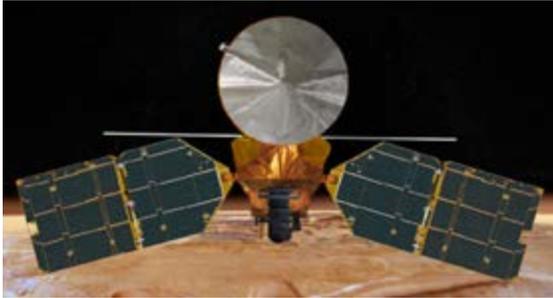


- 9 Months of collaborative planning: 2 in-depth, face-to-face, expert meetings and numerous virtual exploratory discussions
- RADARSAT-2 experiment significantly bolsters NASA exploratory studies with **spaceflight demonstration of nadir radar tests on water-ice analogs on Earth** (Antarctic Dry Valleys, ilis Kerguelen ice fields, Chilean salars) by demonstrating proof-of-concept for polarimetric sounding to reduce ground clutter.
- **Demonstration that good polarimetric SAR is ideally at L-band** because its potential RF bandwidth capabilities (over 160 MHz) allow extremely high resolution and detailed vertical profiling into the upper layers with excellent ranging precision (< 1m).

Results of All Heritage, Expertise, Flown Validation Tests & Joint Exploratory Collaborations:

**High-TRL, flight-ready polarimetric, L-band SAR mission
for buried water-ice is possible for a 2026 and/or 2028 launch.**

Today's Mars Telecom Capability and Limitations



- Every orbiter needs to carry its own high-rate telecom system
 - Large mass/power requirements
- Mapping orbiters can only map a tiny fraction of the planet at inherent instrument resolutions
 - Only < 5 % of Mars has been mapped at HiRISE 30 cm/pixel resolution, after well over a decade of orbital operation
- Landers/rovers have very limited capability to communicate directly to Earth due to the extreme Earth-Mars distance and the limited mass/power available to these landed spacecraft (~1 kb/s or less)
- Current relay orbiters have helped, but offer just a handful of short (~10 min), intermittent contact opportunities at rates of 0.1 – 2 Mb/s

Relay Network Design Considerations

Desired Network Capability

Increased service availability (increased contact time between users and relay orbiter)



High-altitude relay orbit

High instantaneous data rates for high-capability users (with beam steering capability)



Directional, high-frequency proximity links

Energy-efficient data return for low-capability users (with only omnidirectional capability)



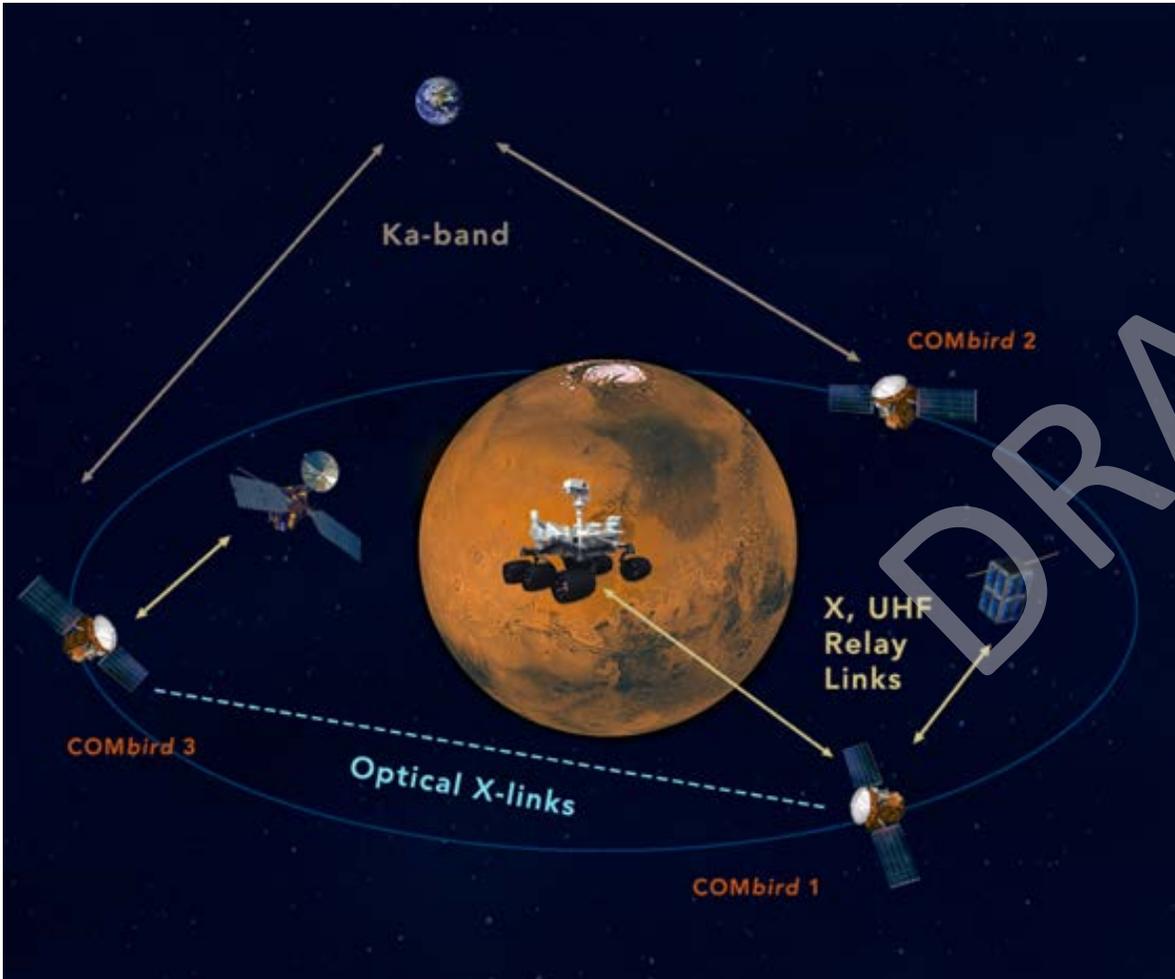
Low-altitude relay orbit to minimize $1/R^2$ losses for omnidirectional links

Optimal telecom support for a wide range of orbital and surface users is best served by a *mix* of relay assets

- ***High-altitude Orbiters*** with *directional high-frequency proximity links for high-capability users*
 - *High-performance trunk links to Earth*
- ***Low-altitude Orbiters*** with *omnidirectional user proximity links for resource-constrained users*
 - *Shuttle data up to High-altitude Orbiters for trunk link to Earth*

A Telecom Network for the Future of Mars Exploration (1 of 2)

NOTIONAL NEXT-GEN DESIGN CHARACTERISTICS



HAWK Subnet (High-Altitude Wideband Comsats):

- **3-satellite constellation**
 - Circular, equatorial orbits @ 6000 km orbit altitude
 - Provides continuous visibility to low-altitude Mars orbiters and to low-latitude landing sites
- **High-performance Ka-band link to Earth**
 - 3m High-Gain Antenna w/ 200 W Txmt power
 - Aggregate 30 Mb/s Mars-to-Earth data return @ 1.5 AU
- **High-rate, energy-efficient X-band and UHF relay links to users**
 - 1m steered X-band antenna supports MARSCOM user relay rates up to 150 Mb/s
 - Legacy UHF link capability (limited data rates due to long slant range)