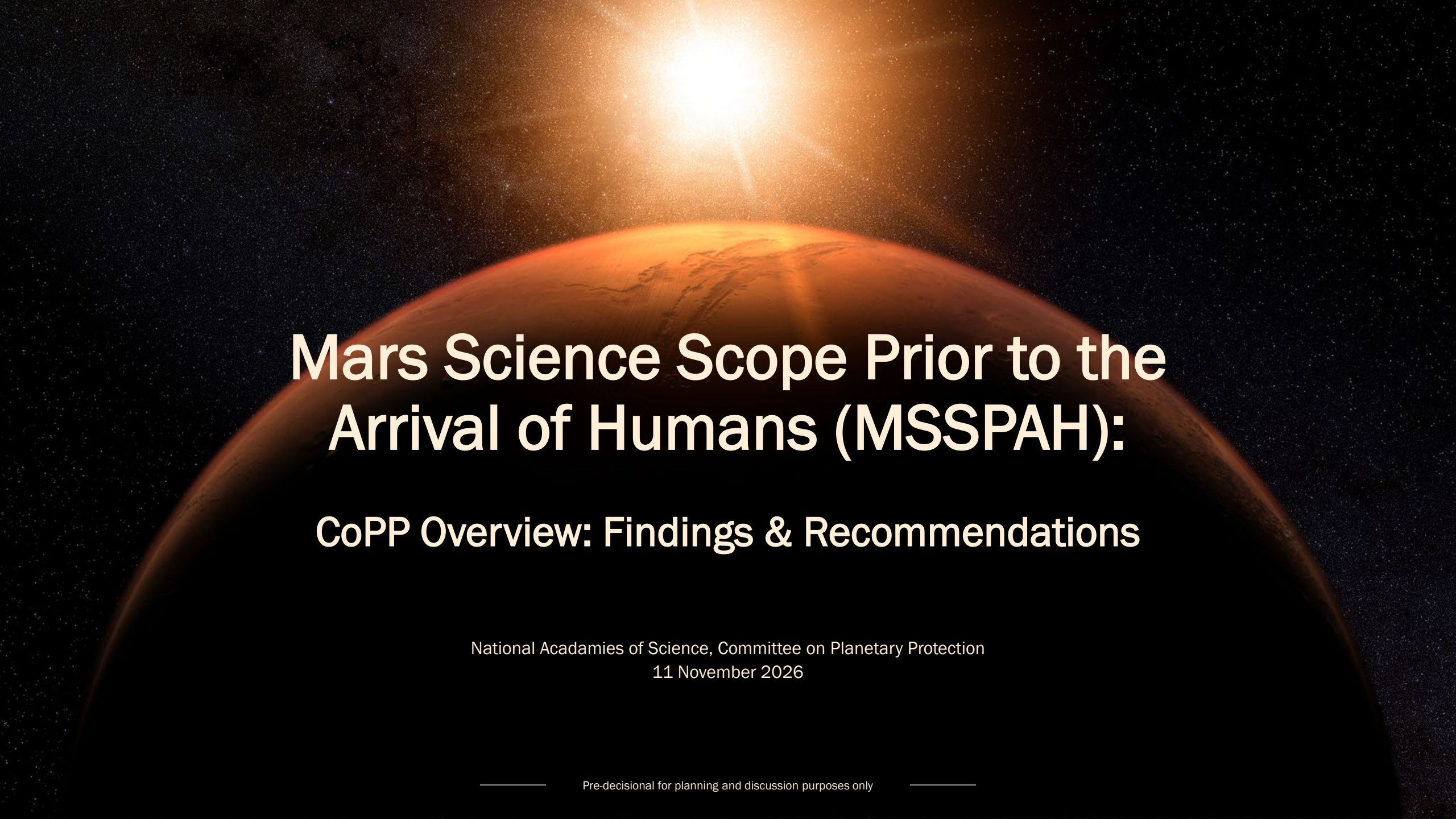


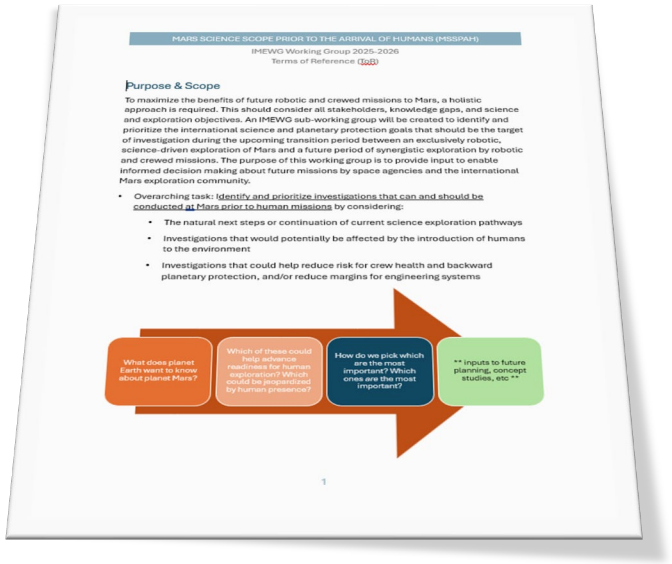
Mars Science Scope Prior to the Arrival of Humans (MSSPAH):

CoPP Overview: Findings & Recommendations

National Acadamies of Science, Committee on Planetary Protection
11 November 2026

Pre-decisional for planning and discussion purposes only

MSSPAH Charter


MARS SCIENCE SCOPE PRIOR TO THE ARRIVAL OF HUMANS (MSSPAH)

IMEWG Working Group 2025-2026

Terms of Reference (ToR)

Purpose & Scope

To maximize the benefits of future robotic and crewed missions to Mars, a holistic approach is required. This should consider all stakeholders, knowledge gaps, and science and exploration objectives. An IMEWG sub-working group will be created to identify and prioritize the international science and planetary protection goals that should be the target of investigation during the upcoming transition period between an exclusively robotic, science-driven exploration of Mars and a future period of synergistic exploration by robotic and crewed missions. The purpose of this working group is to provide input to enable informed decision making about future missions by space agencies and the international Mars exploration community.

- Overarching task: Identify and prioritize investigations that can and should be conducted at Mars prior to human missions by considering:
  - The natural next steps or continuation of current science exploration pathways
  - Investigations that would potentially be affected by the introduction of humans to the environment
  - Investigations that could help reduce risk for crew health and backward planetary protection, and/or reduce margins for engineering systems

What does planet Earth want to know about planet Mars?

Which of these could help advance readiness for human exploration? Which could be jeopardized by human presence?

How do we pick which are the most important? Which ones are the most important?

** inputs to future planning, concept studies, etc **

1

➢Purpose

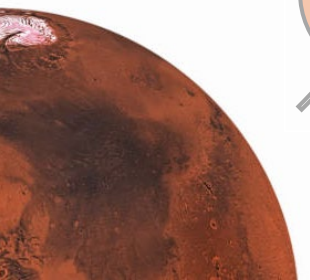
- Chartered by IMEWG in Fall 2025
- Provide input to enable informed decision-making about future missions by space agencies and the international Mars exploration community

➢Task

- Identify and prioritize investigations that can and should be conducted at Mars prior to human missions by considering investigations that:
  - ➢ Have high science value
  - ➢ Would potentially be affected by the introduction of humans to the environment
  - ➢ Could help reduce risk for crew health and backward planetary protection, and/or reduce margins for engineering systems

Take-Home Messages

- This report represents a synthesis of international Mars science objectives to be addressed prior to the first crewed Mars mission.
- Priority science conducted via robotic missions—including landed, orbital, and sample return—should continue until and after humans arrive on Mars.
- Many priority science investigations would also substantively advance readiness for human exploration including revision of planetary protection requirements.
- Limited global resources mean international coordination and participation are needed to maximize both scientific return and preparation for the first human mission.



Study Team

MSSPAH Exec


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Co-Chair


Jorge Vago
Co-Chair

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Bonnie Teece


Bruce Jakosky


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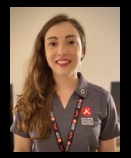

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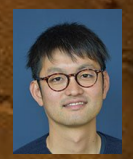

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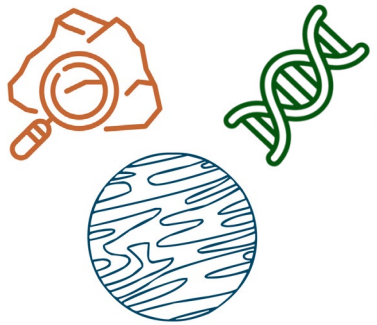

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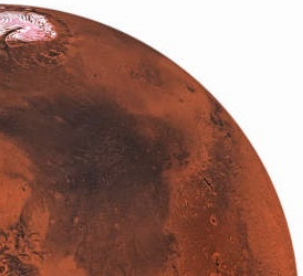
Scientific Objectives: Approach



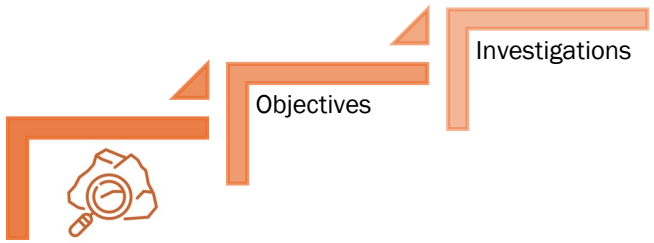
Full team subdivided into three discipline working groups:

- Geology
- Astrobiology
- Climate/Atmospheres



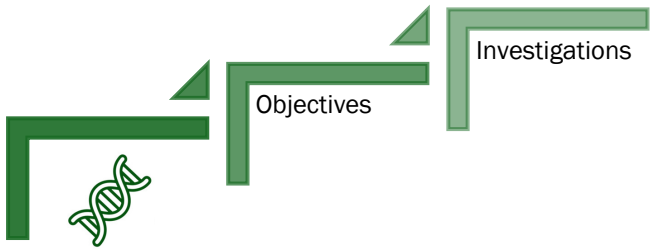


Scientific Objectives: Overview



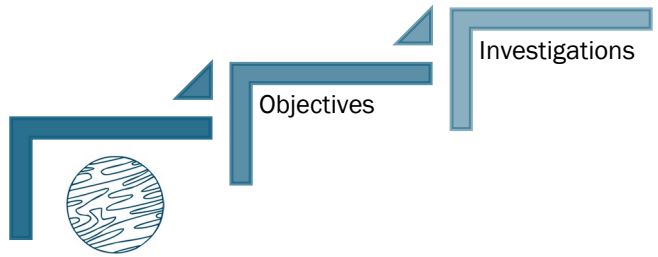
Geology

ID	Objective	# Inv
Geo-1	Mars Interior Structure	4
Geo-2	Mars as a Planetary System	3
Geo-3	Crustal Formation, Structure, and Evolution	7
Geo-4	Volatiles & Climate Evolution	4
Geo-5	Surface Processes, Sedimentary Systems, and the Geologic Record	5
Geo-6	Modern-day Surface Activities	5



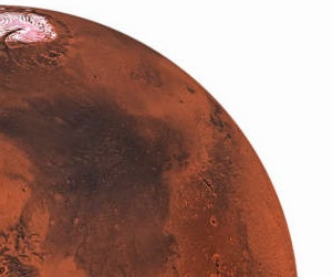
Astrobiology

ID	Objective	# Inv
AB-1	Abiotic / Prebiotic Chemistry & Abiotic Background	3
AB-2	Origin & Nature of Life	2
AB-3	Paleohabitability	4
AB-4	Biosignature Preservation	3
AB-5	Ancient Biosignatures	3
AB-6	Modern Habitability	3
AB-7	Extant Life & Modern Biosignatures	5



Climate/Atmospheres

ID	Objective	# Inv
Atm-1	Seasonal Cycles	6
Atm-2	Ice	4
Atm-3	Orbital Elements	4
Atm-4	Surface-Atmosphere Exchange	5
Atm-5	Trace Gases	8
Atm-6	Liquid Water	5
Atm-7	Ionizing Radiation	8
Atm-8	Upper Atmosphere	6
Atm-9	Escape to Space	4
Atm-10	Early Climate & Volatiles	8
Atm-11	Volatiles & Planetary Formation	3



Conceptual Task Flow

Starting with synthesized list of science objectives for Mars

➢Scientific Impact

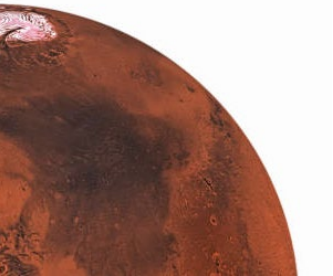
- What investigations would most strongly influence our understanding of Mars?

➢Scientific Integrity

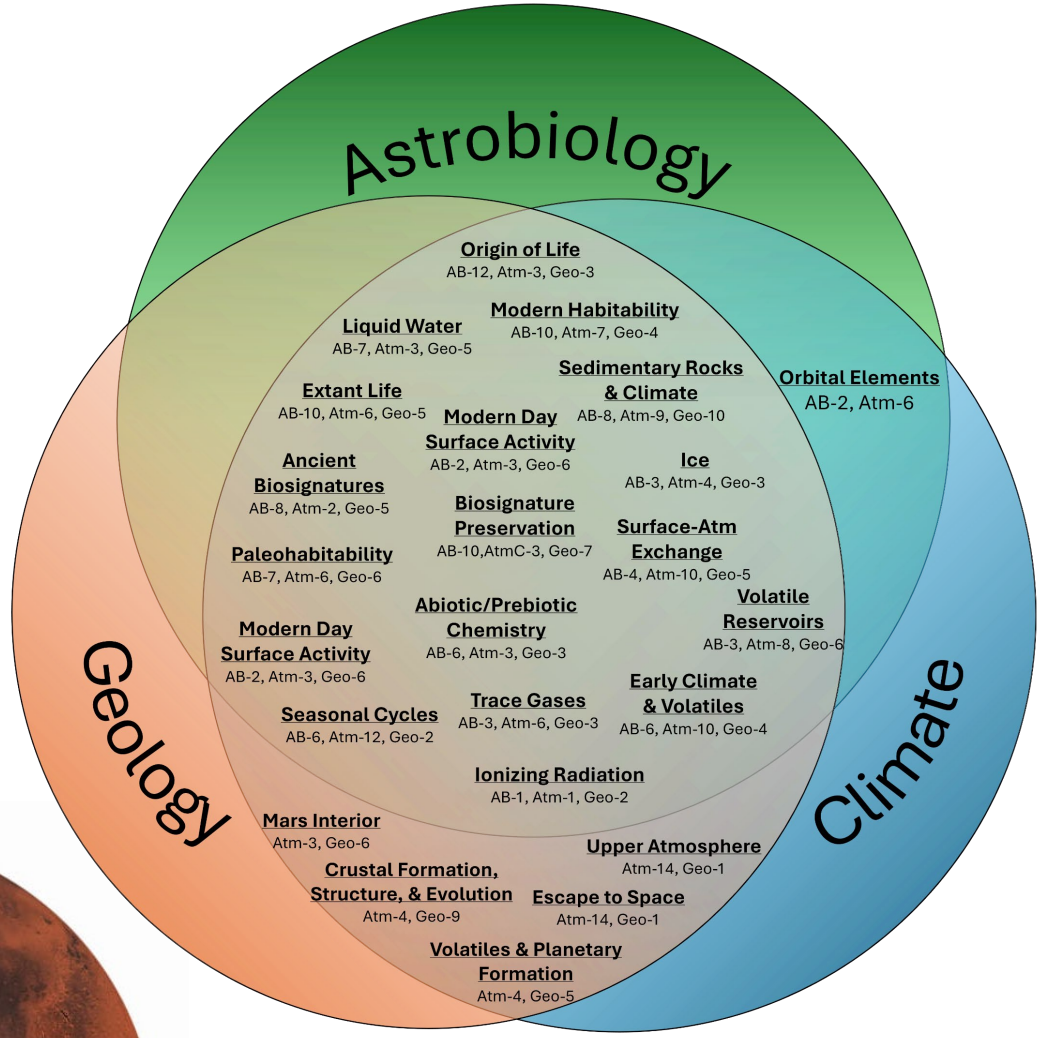
- What investigations could be compromised by human presence?

➢Scientific Utility

- Which investigations could inform architecture or planetary protection decisions?



Science Objectives: Cross-Cutting Nature



All highest-priority investigations can advance objectives in other disciplines given high overlap in measurement types / datasets

Each highest-priority investigation was evaluated to determine which additional objectives across all disciplines would be advanced

Scientific Objectives: Findings

Significant scientific breakthroughs would be enabled through continued robotic exploration of Mars.

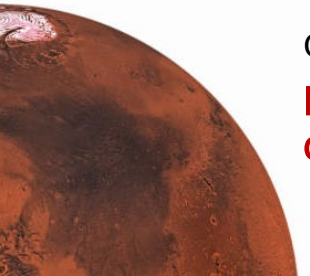
- The MSSPAH team identified 24 high-priority science objectives and more than 100 associated investigations that would substantially enhance our understanding of Mars and the solar system in the coming years.

High-priority investigations in astrobiology, climate, and geology are highly crosscutting and would answer fundamental questions about Mars.

- The highest-priority science investigations identified would deliver important data products addressing several priority objectives spanning multiple scientific disciplines.

While the range of potential planetary science investigations is diverse, they collectively support a small number of overarching exploration themes.

- The highest-priority investigations that also address human exploration and planetary protection knowledge gaps can be organized around four cross-cutting themes: (1) Mars as a habitable and potentially inhabited world; (2) Early planetary evolution and geological history; (3) Climate evolution and atmospheric dynamics, and; (4) Ice and volatile deposits as an environmental marker and as a resource.



Potential Impact of Human Presence

- Each investigation was evaluated against the list of potential impacts of human exploration for:
  - **likelihood** that it would be impacted by human presence, and;
  - potential **consequence** to the science of that impact
- A high potential consequence was assigned for investigations where it is uncertain whether impacts would be regional or short-lived

Potential Impacts of Human Exploration
1. Impacts from the Surface Vehicles
1A. Heatshield ablation products in the atmosphere
1B. Jettisoned parachutes
1C. Rocket plume exhaust in the atmosphere during entry and ascent
1D. Radiation from fission surface power
1E. Heat rejected from radiators
1F. Landing plume disturbances
1G. Mobility disturbances
1H. Landing and ascent events impact on science (physical disturbance)
2. Impacts from the People
2A. Habitat and suit leakage (O, N, CO_2, H_2O), microrganisms
2B. Human waste products
2C. Regolith and rock disturbances (e.g., displacement, broken outcrops)
2D. Drilling waste products
3. Impacts from new infrastructure
3A. Precursor robotic landers at the crewed landing site
3B. Mars telecom network (and navigation)
3C. New imaging orbiters
3D. Local area surface networks
3E. Mars climate stations
3F. Science laboratories (surface and orbit)



Impact of Human Presence: Evaluation

➢Key Knowledge Gaps Identified

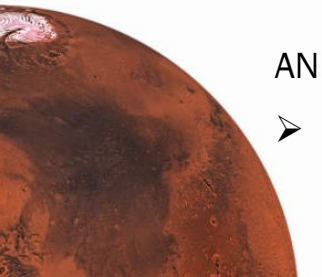
- Contamination lifetimes
- Contamination transport

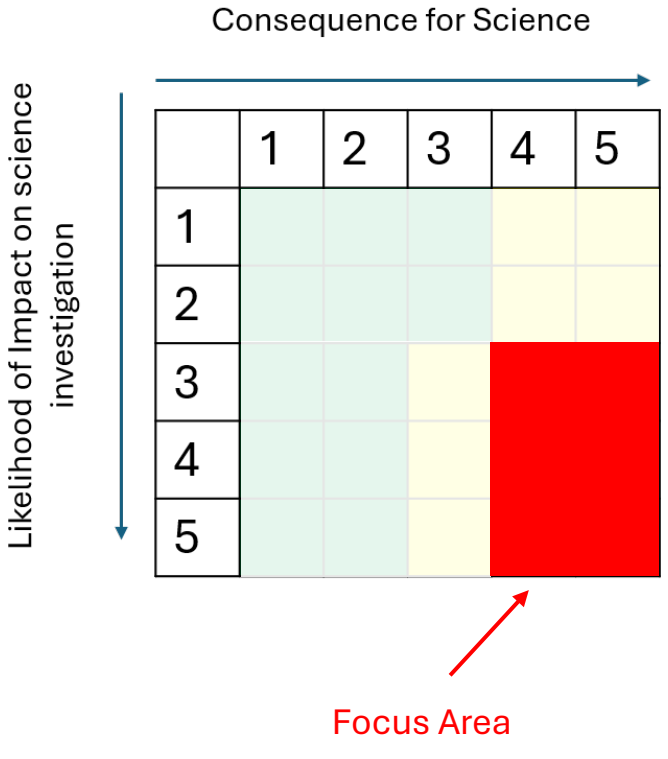
➢Implications

- Care must be exercised to preserve the integrity of <u>life and biosignature investigations and of trace gas measurements, which are most likely to be negatively impacted</u>
- To reduce the risk to these science objectives:
  - ➢ The knowledge gaps regarding contamination lifetimes & transport should be addressed so the risk can be understood.

  AND/OR

  - ➢ The investigations should be carried out before the arrival of humans





Key Objectives:

AB-1 Abiotic/Prebiotic Chemistry & Abiotic Background
AB-2 Origin & Nature of Life
AB-5 Ancient Biosignatures
AB-6 Modern Habitability
AB-7 Extant Life & Modern Biosignatures

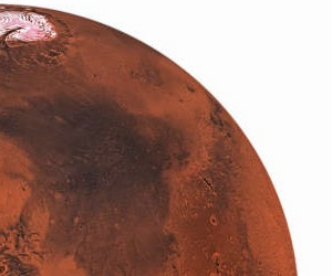
n/a

Atm-5 Trace Gases

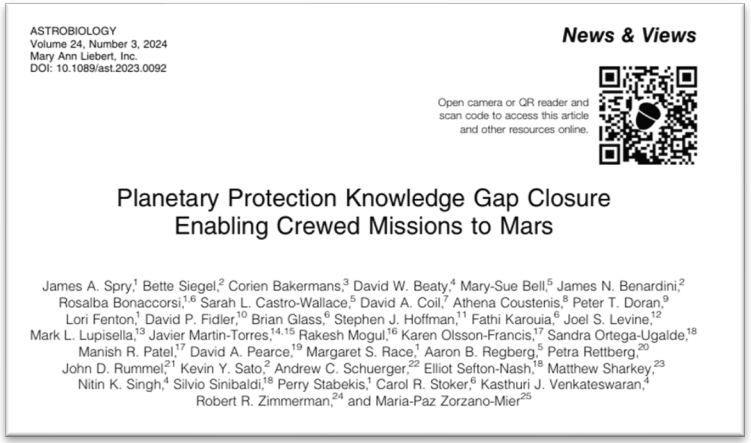
Potential Impact of Human Presence: Finding

Biological, organic, and trace gas investigations are the most vulnerable to contamination from human presence, and significant risks arise from unknowns regarding contamination persistence and transport

- Uncertainties regarding contamination lifetimes and transport pathways mean that particular care must be exercised to preserve the integrity of **life and biosignature investigations and of trace gas measurements.** It is crucial to reduce these uncertainties by obtaining key measurements or to carry out these investigations before human arrival to mitigate these concerns.



MSSPAH: Application to Planetary Protection



ASTROBIOLOGY
Volume 24, Number 3, 2024
Mary Ann Liebert, Inc.
DOI: 10.1089/ast.2023.0092

News & Views

Open camera or QR reader and scan code to access this article and other resources online.

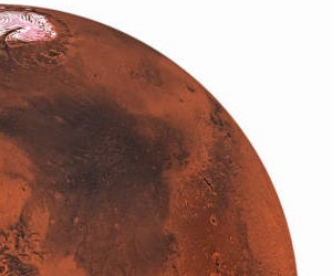
Planetary Protection Knowledge Gap Closure Enabling Crewed Missions to Mars

James A. Spry,[1] Bette Siegel,[2] Corien Bakermans,[3] David W. Beaty,[4] Mary-Sue Bell,[5] James N. Benardini,[2] Rosalba Bonaccorsi,[1,6] Sarah L. Castro-Wallace,[5] David A. Coil,[7] Athena Coustenis,[8] Peter T. Doran,[9] Lori Fenton,[1] David P. Fidler,[10] Brian Glass,[6] Stephen J. Hoffman,[11] Fathi Karouia,[6] Joel S. Levine,[12] Mark L. Lupisella,[13] Javier Martin-Torres,[14,15] Rakesh Mogul,[16] Karen Olsson-Francis,[17] Sandra Ortega-Ugalde,[18] Manish R. Patel,[17] David A. Pearce,[19] Margaret S. Race,[1] Aaron B. Regberg,[5] Petra Rettberg,[20] John D. Rummel,[21] Kevin Y. Sato,[2] Andrew C. Schuerger,[22] Elliot Sefton-Nash,[18] Matthew Sharkey,[23] Nitin K. Singh,[4] Silvio Sinibaldi,[18] Perry Stabekis,[1] Carol R. Stoker,[6] Kasthuri J. Venkateswaran,[4] Robert R. Zimmerman,[24] and Maria-Paz Zorzano-Mier[25]

Each investigation evaluated for applicability to knowledge gaps identified by Spry et al., 2024
(DOI: 10.1089/ast.2023.0092)

Table 1. Summary Descriptions of the Knowledge Gap Topic Areas, Based on the 2016 (First) COSPAR Planetary Protection Knowledge Gaps for Human Missions to Mars Meeting Outcome (Table view)

Microbial and human health monitoring
1A. Microbial monitoring of the environment
1B. Microbial monitoring of humans
1C. Mitigation of microbial growth in spacecraft systems
1D. Operational guidelines for planetary protection and crew health
Technology and operations for contamination control
2A. Bioburden/transport/operations during short vs. long stays
2B. Microbial/organic releases from humans and support systems
2C. Protocols for decontamination and verification procedures
2D. Design of quarantine facilities/methodologies at different mission phases
2E. Martian environmental conditions variation over time with respect to growth of Earth microorganisms
2F. Research needed to make ISRU and planetary protection goals compatible
2G. Acceptable contamination level from wastes left behind, including constraints on vented materials
ORIGINAL 2H. DELETED (merged with 2B.)
2I. Approaches to achieve "Break the chain" requirements
2J. Global distribution/depth of subsurface ice and evidence of extant life
2K. Evolution of planetary protection requirements/goals from robotic precursor through to human missions and exploration zones
Natural transport of contamination on Mars
3A. Measurements/models needed to determine atmospheric transport of contaminants
3B. Measurements/models for subsurface transport of contaminants
3C. Effect of biocidal factors on survival/growth/adaptation of microorganisms
3D. Determination of acceptable contamination rates and thresholds
3E. Protection mechanisms for organisms on Mars
3F. Degradation of landed materials by martian environment
3G. Induced environmental conditions around structures
3H. Sensitivity of nonculturable species to biocidal factors



Planetary Protection: Results

Very high overlap between highest science priorities and PP knowledge gaps



Key Objectives:

AB-1 Abiotic/Prebiotic Chemistry & Abiotic Background
AB-6 Modern Habitability
AB-7 Extant Life & Modern Biosignatures



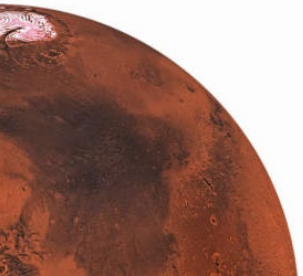
Key Objectives:

Geo-4 Volatiles & Climate Evolution
Geo-5 Surface Processes, Sedimentary Systems, and Geologic Record



Key Objectives:

Atm-1 Seasonal Cycles
Atm-2 Ice
Atm-4 Surface-Atmosphere Exchange
Atm-6 Liquid Water
Atm-7 Ionizing Radiation



Planetary Protection: Finding

Science-driven robotic exploration would deliver important advances for planetary protection.

- High-priority investigations focused on **life and biosignatures, climate and water evolution, and active surface-atmosphere processes** would generate data products that substantively address key planetary protection knowledge gaps necessary to derive requirements for the first nominal crewed missions.



MSSPAH: Application to Human Architecture

Very high overlap between highest science priorities and architecture knowledge gaps



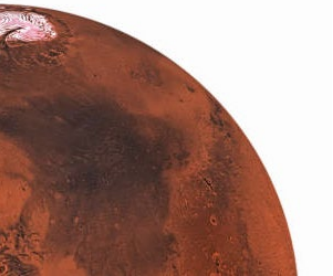
(https://www.nasa.gov/wp-content/uploads/2025/12/add-revision-c-20251211.pdf?emrc=02371b)

Key Objectives:

AB-1 Abiotic/Prebiotic Chemistry & Abiotic Background
AB-2 Origin & Nature of Life
AB-6 Modern Habitability
AB-7 Extant Life & Modern Biosignatures

Geo-3 Crustal Formation, Structure & Evolution
Geo-4 Volatiles & Climate Evolution
Geo-5 Surface Processes, Sedimentary Systems, and Geologic Record
Geo-6 Modern-Day Surface Activities

Atm-1 Seasonal Cycles
Atm-2 Ice
Atm-4 Surface/Atmosphere Exchange
Atm-6 Liquid Water
Atm-8 Upper Atmosphere



Each investigation evaluated for applicability to data gap identified in NASA Moon to Mars Architecture Definition Document Rev C and any other considerations the team believed could advance readiness for human exploration

Human Architecture: Finding

Science-driven robotic exploration would contribute directly to human mission planning.

- High-priority investigations would generate data products needed to address knowledge gaps relevant to the design and implementation of future human missions, particularly those focused on **characterization of dust, regolith, and landing sites; water and ice presence; understanding and modeling climate and atmospheric dynamics; and identifying potential life and biosignatures**.



Crosscutting influence on Future efforts

➢Impacts of Human Presence

Science objective can address uncertainties regarding transport of contaminants



➢Planetary Protection

Inform transition from prescriptive requirements to probabilistic framework



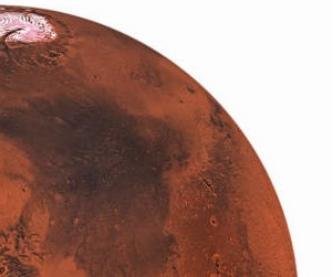
➢Human Architecture

Address Mars Data gaps in Architecture definition document

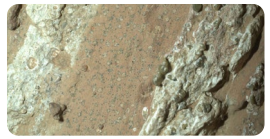
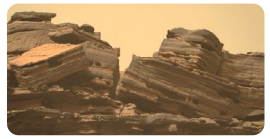
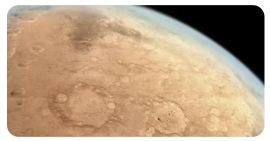
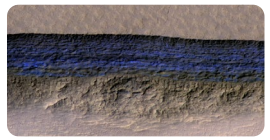


Obj	Human	PP	Arch
AB-1	X	X	X
AB-2	X	X	X
AB-5	X		
AB-6	X	X	X
AB-7	X	X	X
Geo-3			X
Geo-4		X	X
Geo-5		X	X
Geo-6		X	X
Atm-1		X	X
Atm-2		X	X
Atm-4		X	X
Atm-5	X		
Atm-6		X	X
Atm-7		X	
Atm-8			X

AB-1 Abiotic/Prebiotic Chemistry & Abiotic Background
AB-2 Origin & Nature of Life
AB-5 Ancient Biosignatures
AB-6 Modern Habitability
AB-7 Extant Life & Modern Biosignatures
Geo-3 Crustal Formation, Structure & Evolution
Geo-4 Volatiles & Climate Evolution
Geo-5 Surface Processes, Sedimentary Systems, and Geologic Record
Geo-6 Modern-Day Surface Activities
Atm-1 Seasonal Cycles
Atm-2 Ice
Atm-4 Surface/Atmosphere Exchange
Atm-5 Trace Gases
Atm-6 Liquid Water
Atm-7 Ionizing Radiation
Atm-8 Upper Atmosphere



Tracing Objectives to Themes

		AB-1	AB-2	AB-5	AB-6	AB-7	Geo-3	Geo-4	Geo-5	Geo-6	Atm-1	Atm-2	Atm-4	Atm-5	Atm-6	Atm-7	Atm-8
Search for Life, Past & Present		X	X	X	X	X		X	X	X		X	X	X	X	X	
Early Planetary Evolution and Geologic History		X					X	X	X	X		X					
Climate Evolution and Atmospheric Dynamics		X			X		X	X		X	X	X	X	X	X		X
Ice and Volatile Deposits					X	X		X		X		X	X		X		



Science objectives & investigations address multiple figures of merit and overarching exploration themes

Take-Home Messages

This report represents a synthesis of international Mars science objectives to be addressed prior to the first crewed Mars mission.

- The working group included experts from nine countries, spanned a breadth of science and engineering disciplines, incorporated publicly available international science and space agency documentation, and sought input from the broader international community through consultation and review activities.

Priority science conducted via robotic missions—including landed, orbital, and sample return— should continue until and after humans arrive on Mars.

- A variety of orbital, landed, and sample return missions prior to human arrival would address critical questions about Mars, the Martian system, and the Solar System as a whole.

Many priority science investigations would also substantively advance readiness for human exploration including revision of planetary protection requirements.

- Many of the investigations required to meet the highest-priority scientific objectives would also generate data products that resolve key planetary protection and human exploration knowledge gaps.

An internationally coordinated robotic exploration strategy focused on key scientific themes could maximize both scientific return and preparation for human exploration.

- Given limited time and resources, international space agencies would maximize return on investment and best prepare for human exploration by prioritizing missions focused on life detection and habitability, early planetary evolution and geological history, climate evolution and atmospheric dynamics, and water-ice and volatile resource characterization.



Mars Science Scope Prior to the Arrival of Humans (MSSPAH) Science Objectives Virtual Community Briefing

IMEWG chartered the international committee to synthesize near-term robotic science priorities before human arrival.

24 proposed science objectives

7 ASTROBIOLOGY **11 CLIMATE & ATMOSPHERES** **6 GEOLOGY**



COMMUNITY FEEDBACK REQUESTED

- Are the objectives complete and representative of international aspirations?
- Are the top-third, highest-impact investigations the right priorities?



Nov 18, 2026
9 AM PST / 12 PM EST / 6 PM CET

MICROSOFT TEAMS

Meeting ID 272 291 953 351 353 4
Passcode Hx2iJ2gv

FEEDBACK DUE NOVEMBER 25

forms.gle/17BYbbfmo75TGn79A

Attendance is not required to provide feedback.

Feedback form includes full list of science objectives and investigations

Comments submitted by November 25 will be considered by the MSSPAH committee.

Impacts & next steps in the context of Planetary Protection

- **This report offers a unique input from the science community**
  - Identifies the synergy between high-priority science objectives open questions in planetary protection knowledge gaps
  - Identifies the science objectives that are most sensitive to potential contamination from crewed missions
  - Details on specific objectives / knowledge gaps / contamination sensitivity from the full report could be valuable input to next CoPP/ NASEM Space Week meeting

