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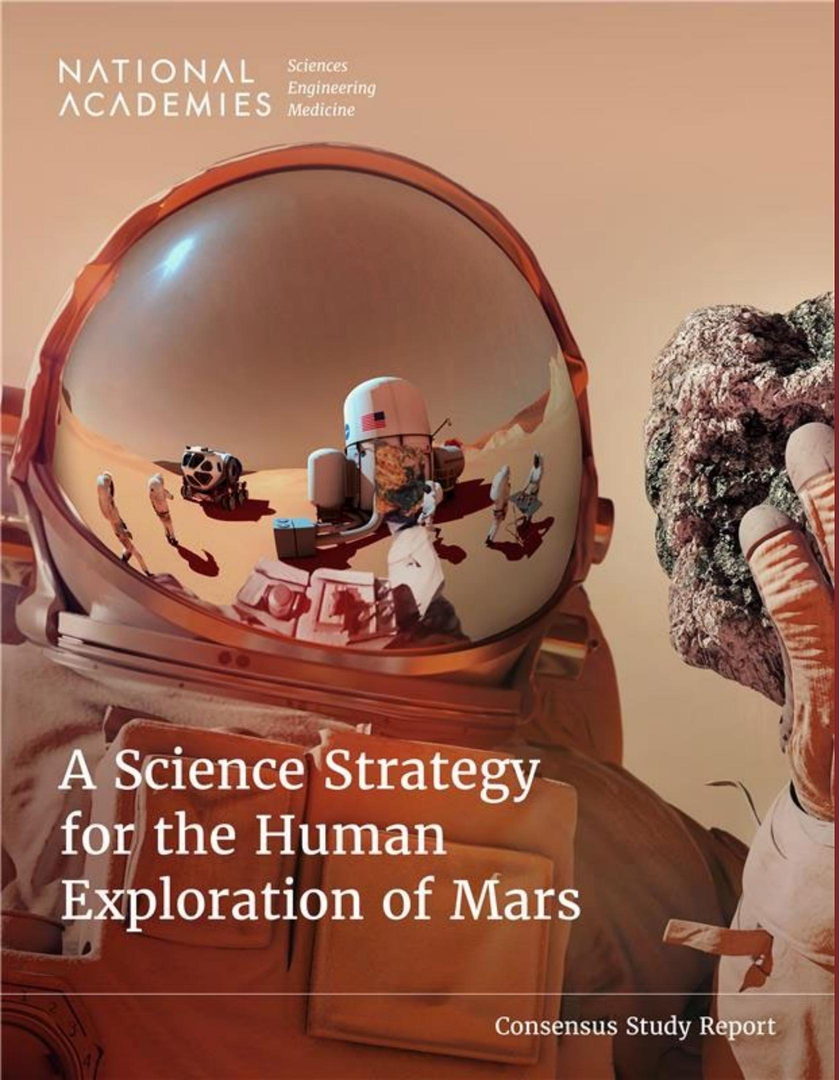
A Science Strategy for the Human Exploration of Mars

Linda Elkins-Tanton & Dava Newman, Study Co-Chairs

DECEMBER 2025



Our New Report

A Science Strategy for the Human Exploration of Mars

Available on December 9 for digital download at

nationalacademies.org/humans-on-mars

Print edition expected Q2 2026

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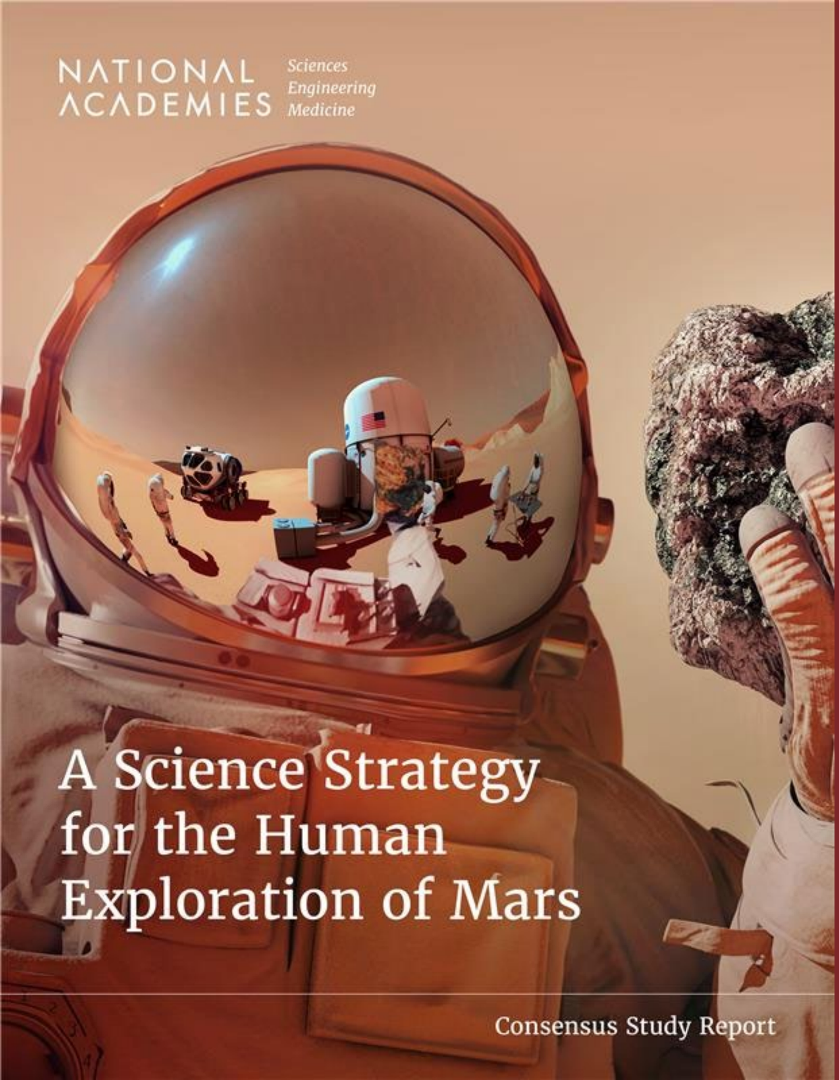

Transparency Notice

This committee operates under the
NASEM Federal Advisory Committee Act *(FACA):*

- All **data collection** is done in public
- All **deliberative discussions** are confidential in perpetuity, including after publication of the report.

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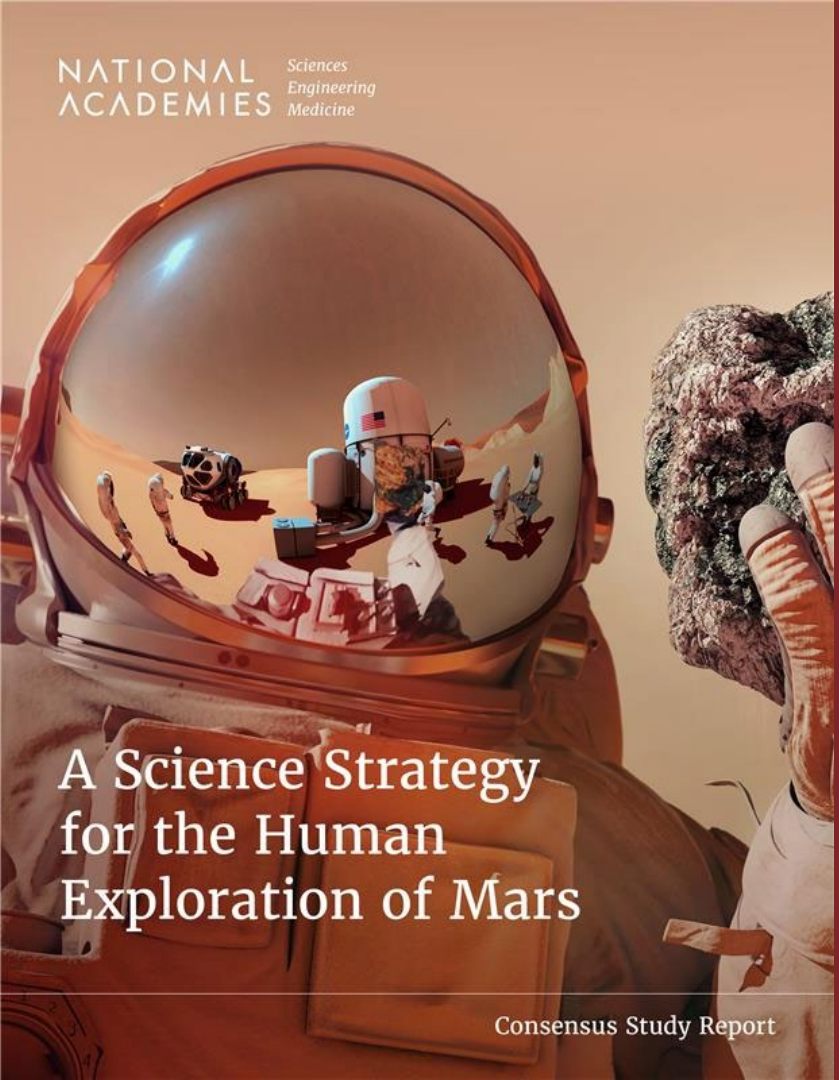
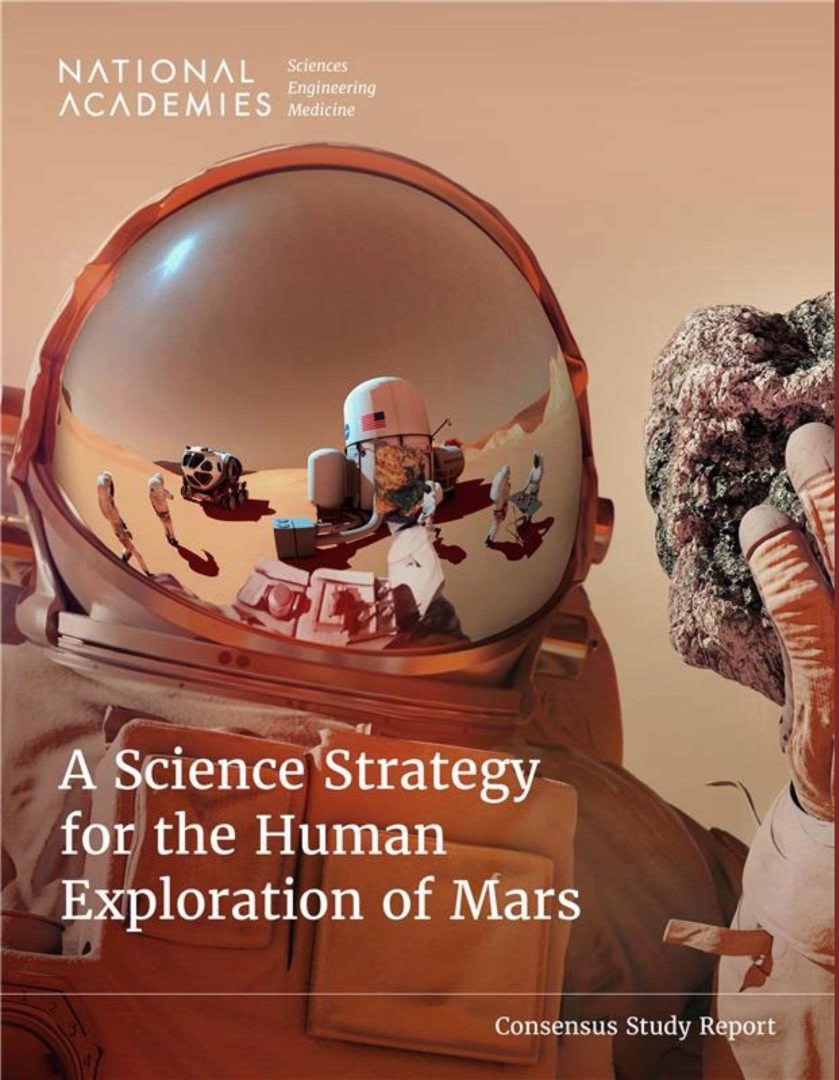


Study Purpose

The National Academies will identify high priority science objectives (in all relevant disciplines) to be addressed by human explorers across the first three human-scale landings on the surface of Mars.

- Highest priority science objectives
- Types of samples and measurements
- Prioritize several science campaigns that encompass the first three landings
- Preliminary criteria for appropriate landing sites
- Key equipment
- Commonalities with Moon exploration
- Key synergies with exploration goals



Our Mandate

What science should humans pursue first on Mars?

Which mission campaigns achieve that?

How does this align with NASA's Moon-to-Mars strategy?

What informed this study?

CONVENING EXPERTS

39
Committee meetings

87
Panel meetings

EXPLORING THE FIELD

70
events attended by study members

400
people providing input

RIGOROUS RESEARCH

400
citations in the final report

What science should humans pursue first on Mars?

11 Priority Science Objectives

Priority Science Objectives

#1

Determine if, in the exploration zone, evidence can be found for any of the following: **habitability, indigenous extant or extinct life**, and/or **indigenous prebiotic chemistry**.

Priority Science Objectives

#2

Characterize past and present **water and CO_2 cycles and reservoirs** within the exploration zone to understand their evolution.

Priority Science Objectives

#3

Characterize and map the **geologic record and potential niche habitats** within the exploration zone to reveal Mars's evolution and to provide geologic context to other investigations, including the study of bolide impacts, volcanic and intrusive igneous activity, the sedimentary record, landforms, and volatiles, including liquids and ices.

Priority Science Objectives

#4

Determine the **longitudinal impact of the integrated martian environment on crew** physiological, cognitive, and emotional health, including team dynamics, and confirm effectiveness of countermeasures.

Priority Science Objectives

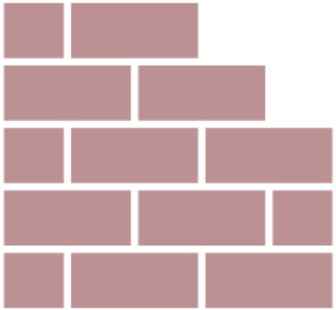
#5

Determine what controls the onset and evolution of **major dust storms**, which dominate present-day atmospheric variability.

Priority Science Objectives

#6

Characterize the martian environment for **in situ resource utilization (ISRU)** and determine the applications associated with the ISRU processing, ultimately for the full range of materials supporting permanent habitation but with an early focus on water and propellants.



Priority Science Objectives

#7

Determine whether the **integrated martian environment affects reproduction or the functional genome** across multiple generations in at least one model plant and animal species.

Priority Science Objectives

#8

Determine throughout the mission whether or not **microbial population dynamics and species distribution in biological systems and habitable volumes** are stable and are not detrimental to astronaut health and performance.

Priority Science Objectives

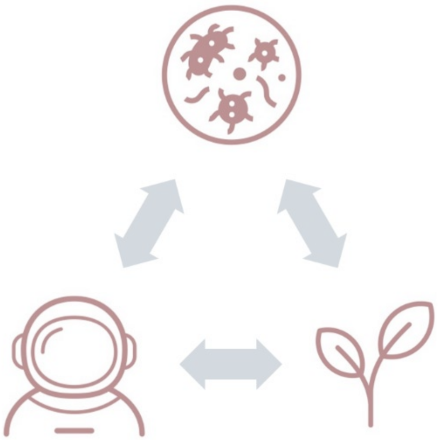
#9

Characterize the **effects of martian dust** on human physiology and hardware lifetime.

Priority Science Objectives

#10

Determine the **longitudinal impact of the integrated martian environment on plant and animal physiology and development** across multiple generations where possible as part of an integrated ecosystem of plants, microbes, and animals.



Priority Science Objectives

#11

Characterize the **primary and secondary radiation** at key locations in the crew habitat and astrobiological sampling sites to contextualize sample collection and improve models of future mission risk.

Report Recommendations

The committee has set four recommendations that comment on critical questions from the field

REPORT RECOMMENDATION #1

Planetary Protection

Human missions to Mars should be designed to meet scientific and exploration objectives. Many of these objectives are limited by current planetary protection guidelines, notably the search for extinct and extant life with human explorers. **NASA should continue to collaborate on the evolution of planetary protection guidelines, with the goal of enabling human explorers to perform research in regions that could possibly support, or even harbor, life.**

Surface Lab

NASA should include as part of its crewed surface infrastructure a Mars surface laboratory consisting of a variety of geologic, astrobiologic, and biomolecular analytical tools and analysis capabilities.

Sample Return

Samples from every human mission to Mars should be returned to Earth. NASA should engage the science community to determine the number, type, mass, and environmental conditioning required for samples before the first human missions commence. Sample return guided by human interpretation of in situ measurements should be a priority for all human missions.

REPORT RECOMMENDATION #4

Human-Agent Teaming

NASA should initiate a recurring “Mars Human–Agent Teaming Summit” that captures emerging trends in the field. The goal of this summit should be to maximize the amount of time on Mars available for astronauts to perform scientific research, and to maximize the quality of that science.

Human-Agent Teaming

REPORT RECOMMENDATION #4

In planning these summits, NASA should cover, at a minimum, the following topics:

- Updating detailed task analyses necessary to complete science objectives on Mars;
- Identification of tasks best suited to human and automated agents;
- Updates on the development of reliable, trusted, and environmentally robust artificial intelligence, including machine learning capabilities, as components of human–agent teams on Mars;
- Communication between human and artificial agents; and
- Decision making.

The first human campaigns to **Mars**

CAMPAIGN ARCHITECTURE

30 SOLS | **30 SOLS** | **30 SOLS**

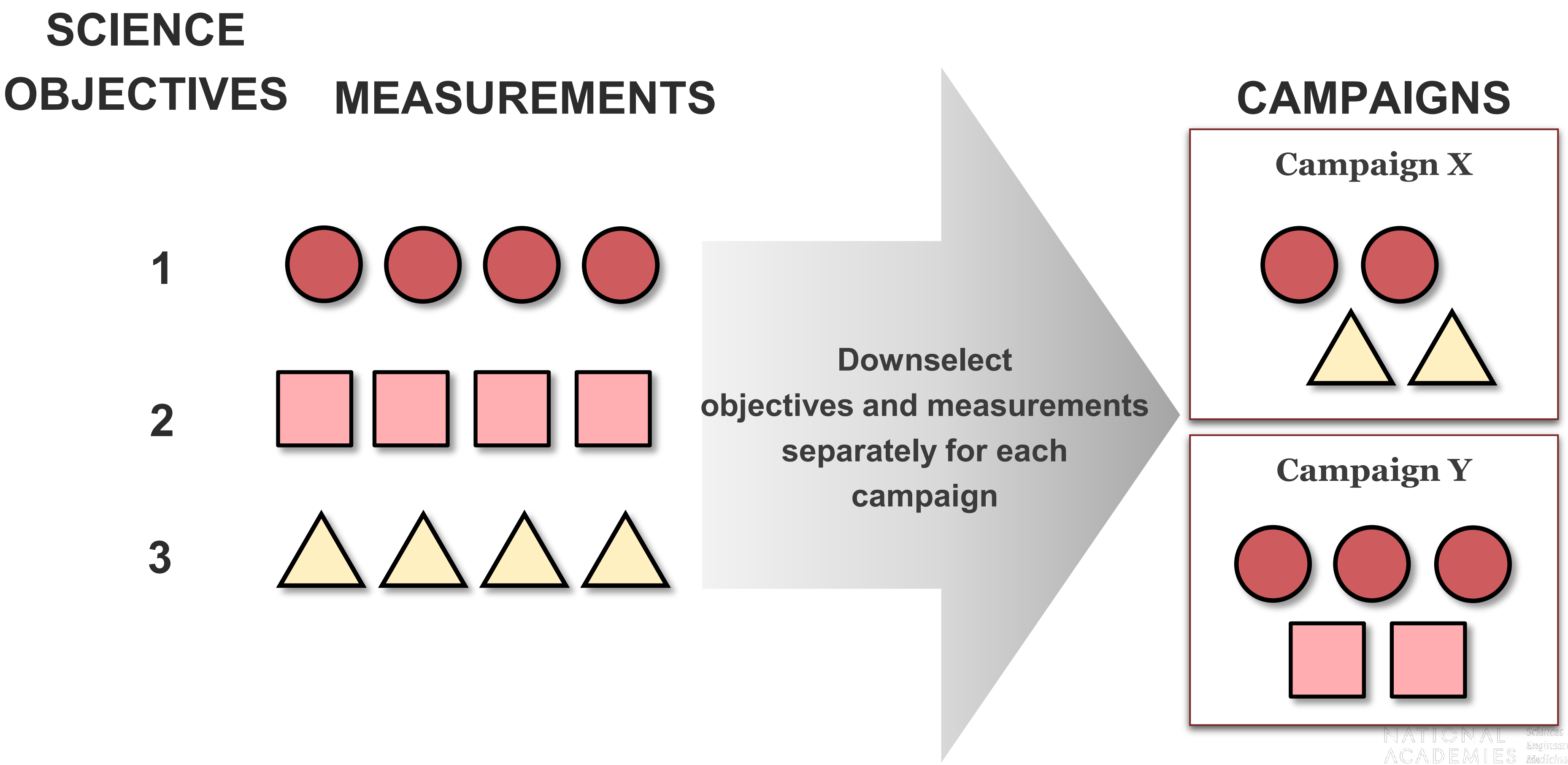
THREE CREWED MISSIONS OF TARGETED SCIENCE EXPLORATION AT ONE TO THREE LOCATIONS

30 SOLS
CREWED LOCAL EXPLORATION AND INFRASTRUCTURE PREPARATION

CARGO
UNCREWED INFRASTRUCTURE DELIVERY AND DEPLOYMENT

300 SOLS
CREWED WIDE RANGING SCIENCE AND EXPLORATION

Designing Campaigns



Science Objectives That Can Be Addressed on Any Campaign

#4 Longitudinal impact of the integrated martian environment on crew

#7 Integrated martian environment affects reproduction or the functional genome

#8 Microbial population dynamics, species distribution in biological systems and habitable volumes

#9 Effects of martian dust

#10 Longitudinal impact of the integrated martian environment on plant and animal physiology and development

#11 Primary and secondary radiation

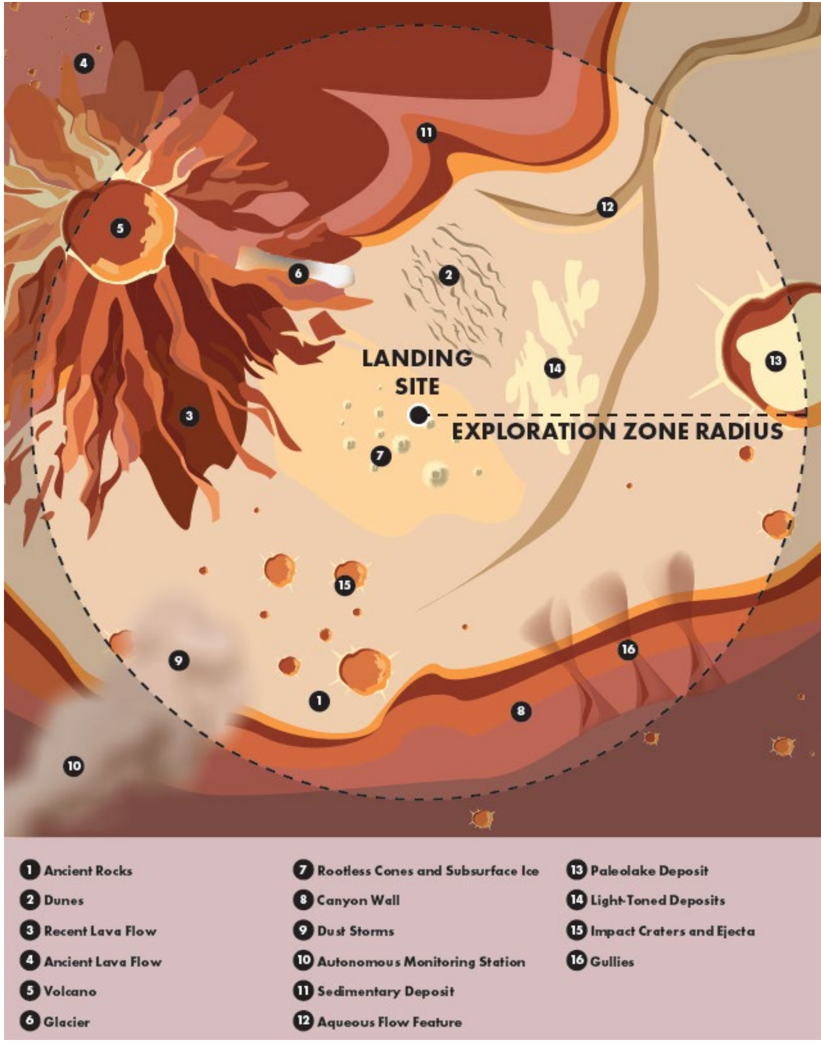
CAMPAIGN
1

Mars Science Across an Expanded Exploration Zone

30-CARGO-300 CAMPAIGN ARCHITECTURE

Explore up to 100 km from a single landing site to pursue nearly all top science objectives.

- The top-ranked campaign by the steering committee: The best science payoff per mission.
- Requires strategically-selected landing site with high heterogeneity.
- Enables repeated sampling and analysis.



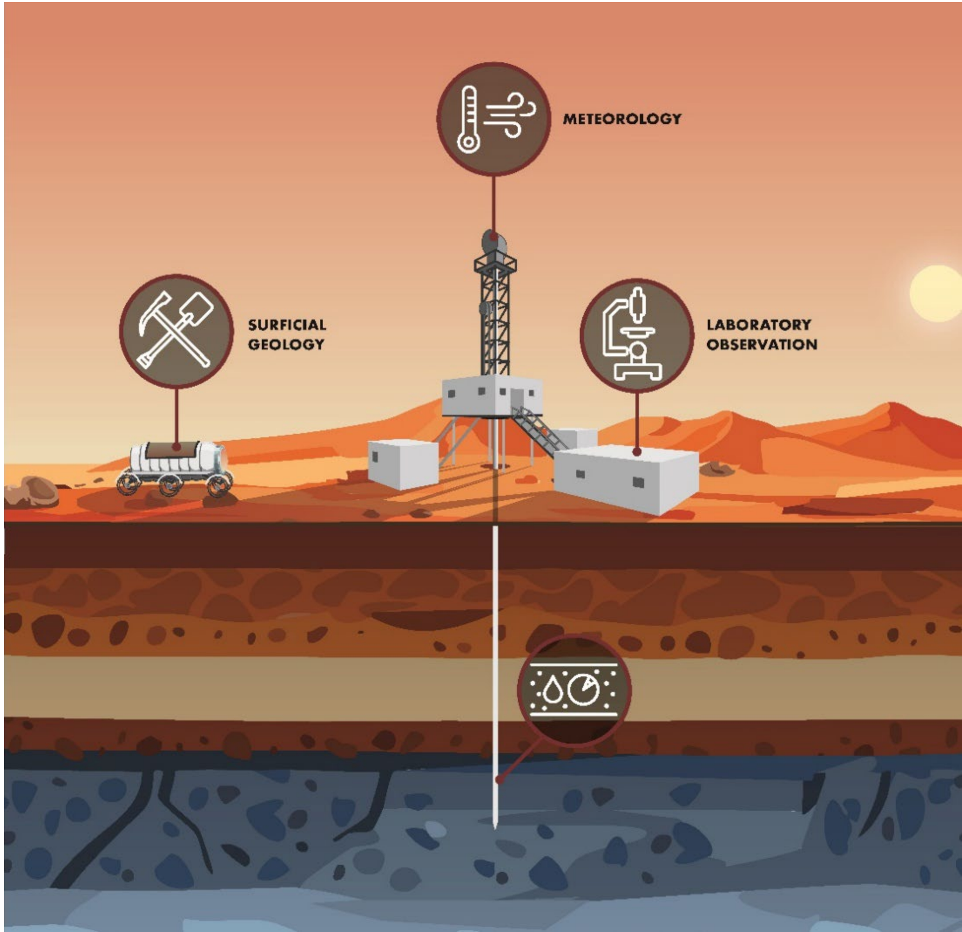
CAMPAIGN 2

Synergy of Mars Science Measurements

30-CARGO-300 CAMPAIGN ARCHITECTURE

Shared measurements across life, water, geology, and resources build a 4-dimensional view of Mars.

- Maximizes science per measurement.
- Flexible and efficient mission design: Can be accomplished at a wide variety of landing sites.
- Addresses every science objective.



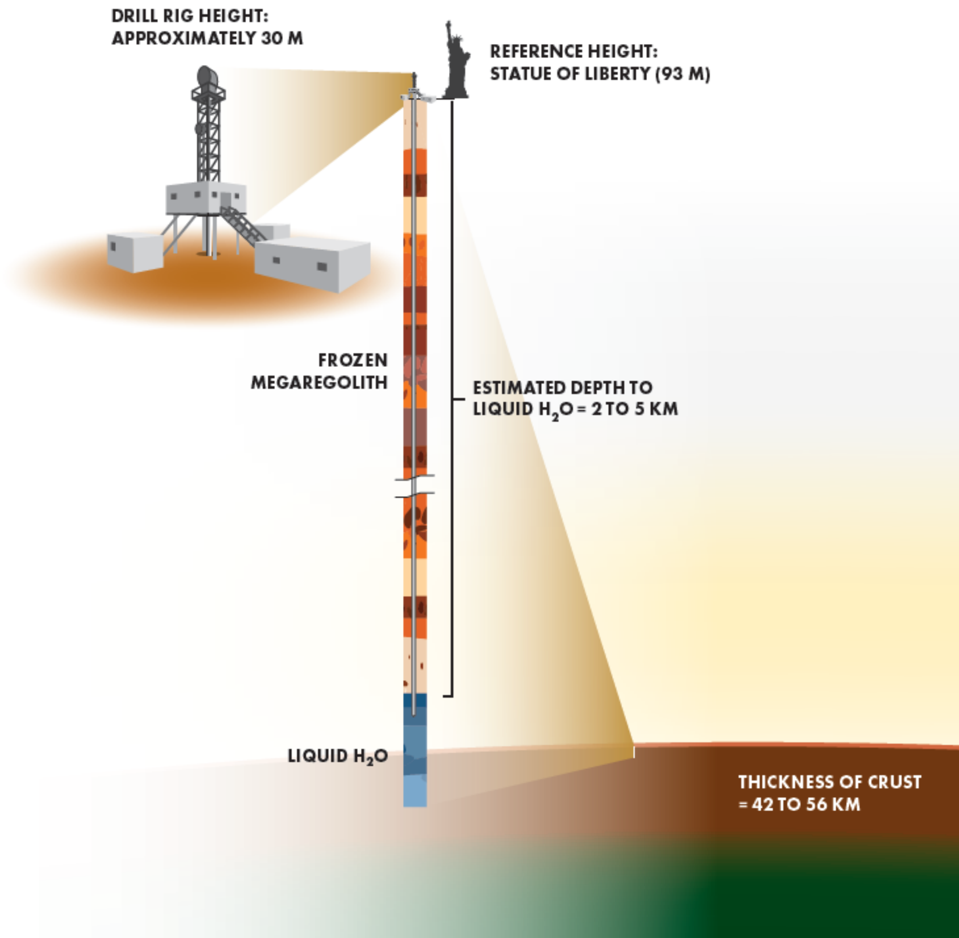
CAMPAIGN 3

Seeking Life Beneath the Martian Icy Crust

30-CARGO-300 CAMPAIGN ARCHITECTURE

Drill 2–5 kilometers into Mars's cryosphere to access samples and search for extant life.

- Accessing samples below the lower boundary of the martian cryosphere is the top priority.
- Highest potential for detecting life.
- Advances deep-drilling technology.



CAMPAIGN

4

Investigating Mars at Three Sites

30-30-30 CAMPAIGN ARCHITECTURE

Capture Mars's diversity and establish a geologic and climatic timeline with three 30-sol missions.

- Less risk for astronauts with shorter surface stays.
- Breadth of sites gives breadth of insight.
- Science addressed is broad but not deep.

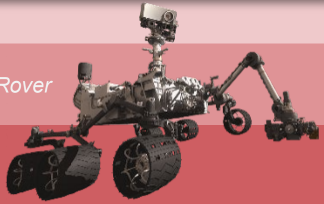
30 sol

30 sol

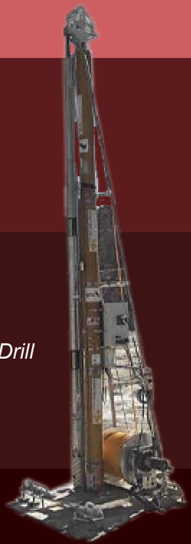
30 sol

Science Depth Requirements Determine Tech Needs

DEPTH BAND		CAPABILITY NEEDED
0cm – 10cm		Surface sampling
1m – 10m	*Campaign 4 (2-5 m)* *Campaign 1 (2-10 m)*	Shallow subsurface
10m – 100m		Mid-depth ISRU, habitability science
100m – 1km		Stratigraphy, ice access
1km – 5km	*Campiagn 2 (1 km)* *Campaign 3 (2-5 km)*	Life-search, organics-protected zones



Curiosity Rover



Planetary Deep Drill

Integration with **NASA's Moon to Mars** Architecture

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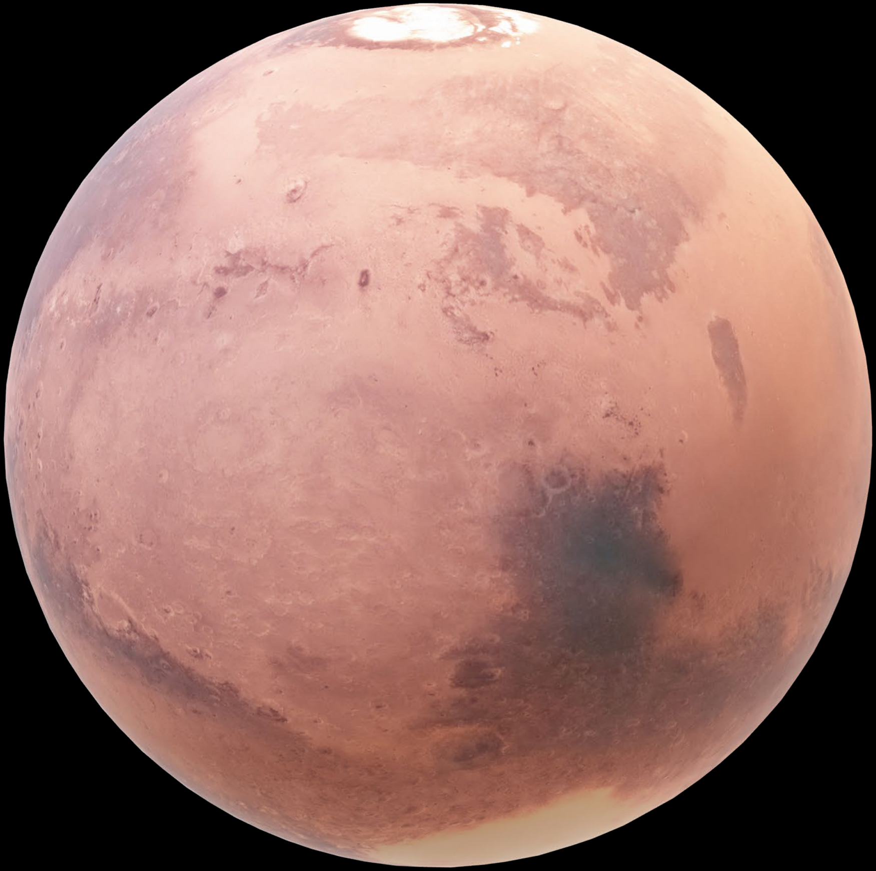
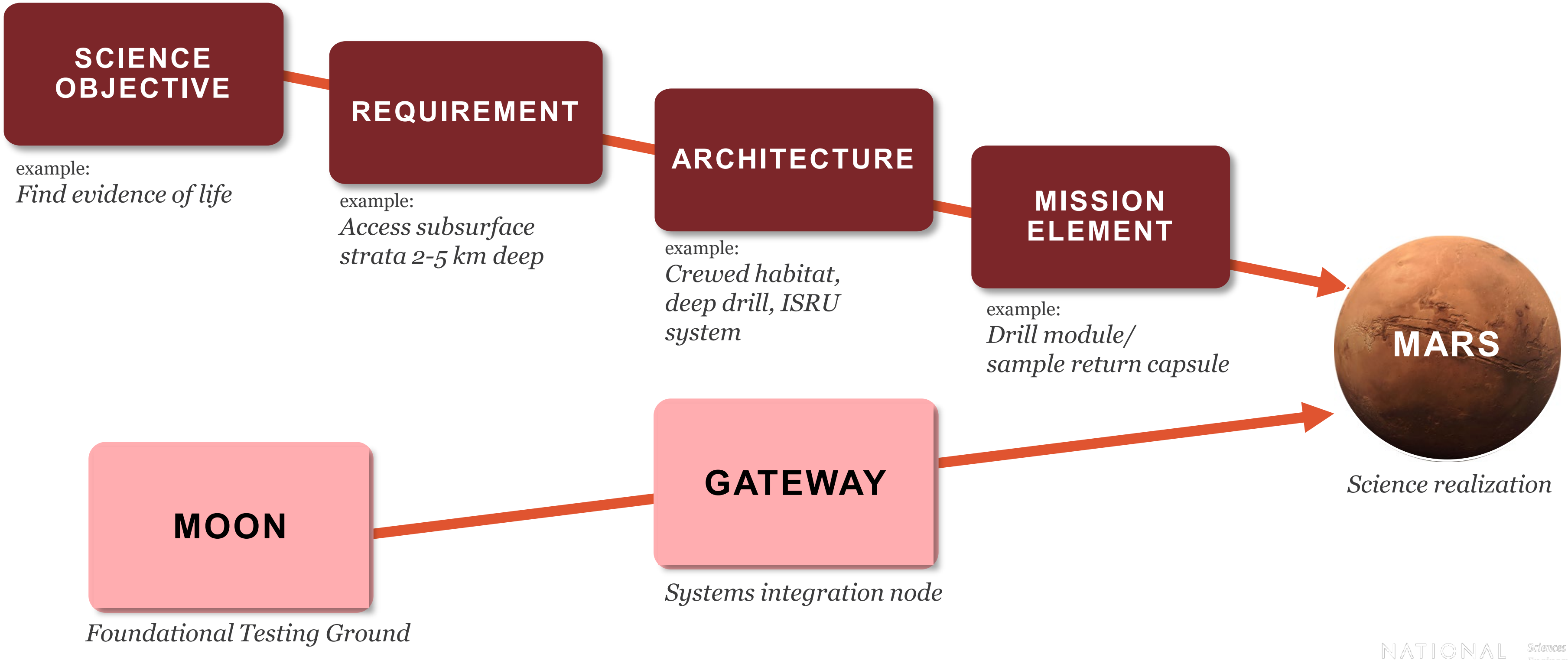


Discovery-Driven Science

Each discovery question becomes a design requirement, every requirement becomes architecture, and every architecture becomes the mission elements we fly.

The same principle connects the Moon, Gateway, and Mars with each step translating science into capability.

Science Leads, Design Follows, Mars Awaits

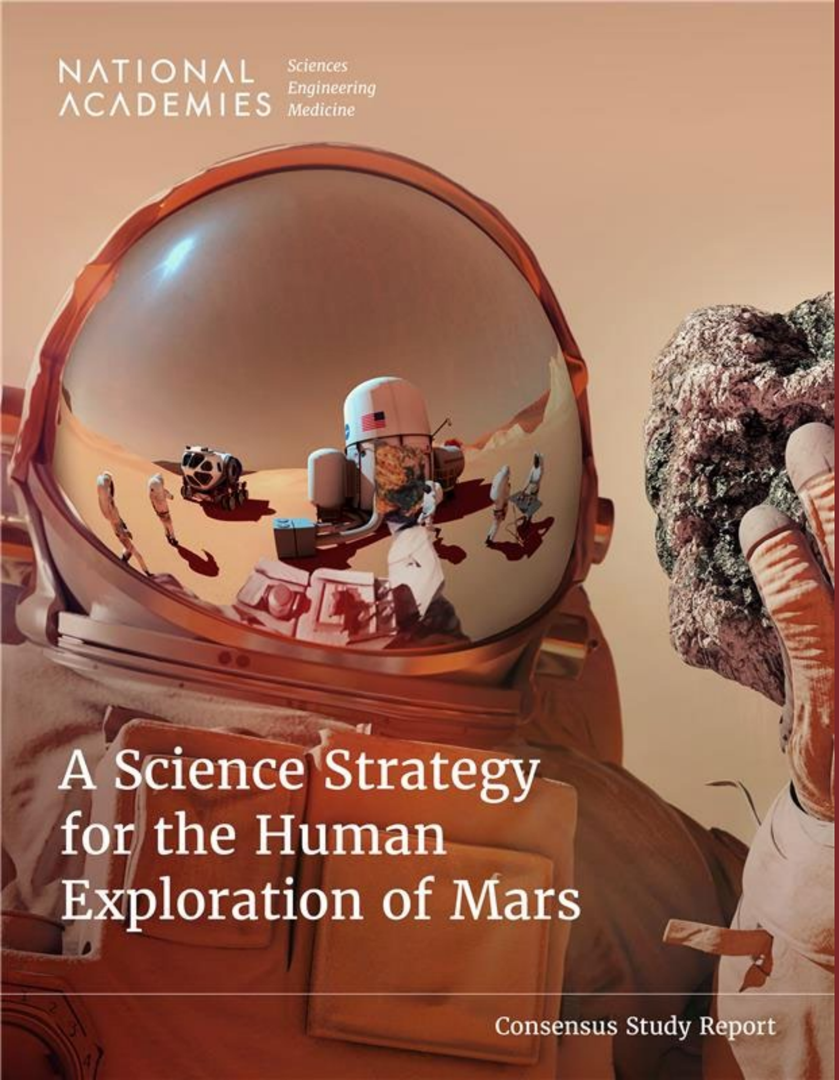


Tech NASA Can Invest in to Make Mars Science Achievable

5 ENABLING TECHNOLOGY PILLARS

Communications, Observation, and Power Infrastructure	*Keeps crews and instruments connected and operational*
Deep Drilling Systems	*Reaches the protected depths where life is most detectable*
Human-Robot-AI Teaming	*Combines human judgement with robotic reach and AI speed*
Long-Duration Human Exploration *(Habitat, Life Support, EVA)*	*Supports healthy productive crews for months-long science.*
Robotics / Sample Return/ Surface Lab	*Enables high-fidelity analyses and preserves scientific value.*

These technology investments will enable full achievement of the study's prioritized science objectives.



Report Snapshot

1. Introduction
2. Defining the Science for Campaigns
3. Campaigns
4. Disciplinary Science Priorities
5. Putting Science in the Moon to Mars Architecture
6. Synopsis

Appendices

- Statement of Task
- Panel Reports
- Implications of Artificial Intelligence for Human Mars Exploration
- If Life is Found
- Science Traceability Matrices for Panels

Upcoming Schedule

DEC 9-10

Briefings for NASA, Capitol Hill

Report Released

Public Briefing

NAS Committee on Planetary Protection

DEC 16

AGU Town Hall

JAN 21

COSPAR PPP

JAN

Podcasts: Science Friday, The Astro Ben Podcast

FEB 3

Goddard Space Flight Center Seminar

FEB 19

National Academies' DC Art Science Evening Rendezvous: Human Exploration of Mars

FEB 20

Aerospace Space Policy Show

MAR 10

LPSC townhall

MAR 11

Panel at the IEEE Aerospace Conference

MAR 26

USRA symposium

MAY 5-6

Twelfth Achievability and Sustainability of Mars Workshop

MAY 17-18

AbSciCon

AUG 1-9

COSPAR

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Report Authoring Committee

STUDY CO-CHAIR
Lindy Elkins-Tanton
National Academy of Sciences
University of California, Berkeley

STUDY CO-CHAIR
Dava Newman
Massachusetts Institute of Technology

Dominic (Tony) Antonelli
Antonelli Consulting Company, LLC

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National Academy of Engineering
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Erika Wagner
The Exploration Company

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Abigail Sheffer, Kelsie Krafton, Linda Walker

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Laurie Barge
Hugo Castillo
John M. Eiler, *National Academy of Sciences*
Drew Gorman-Lewis
Betül Kaçar
Michael A. Meyer
Jorge I. Núñez
Laura E. Rodriguez
Nicole Schmitz
Amy J. Williams

PANEL ON ATMOSPHERIC SCIENCE AND SPACE PHYSICS

Leslie K. Tamppari, *Chair*
Christopher Boxe
Yaireska Collado-Vega
Jasper S. Halekas
Alain S.J. Khayat
Ralph D. Lorenz
Sara Navarro López
Claire E. Newman
Susanne P. Schwenzer
Alejandro Soto
Mark Thiemens, *National Academy of Sciences*

PANEL ON GEOSCIENCES

Jennifer L. Heldmann, *Chair*
William B. Banerdt
Ali Bramson
Veronica Bray-Durfey
Alex Halliday, *National Academy of Sciences*
Jeffrey Roy Johnson
John F. Mustard
Chiang Shih
Kirsten Leigh Siebach
Marcella Aveline Yant

PANEL ON BIOLOGICAL AND PHYSICAL SCIENCES AND HUMAN FACTORS

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Anna-Lisa Paul, *Co-chair*
Daniel Ammon, *National Academy of Engineering*
Serena Maria Auñon-Chancellor
Jay C. Buckey
Ana Diaz Artiles
Nick Kanas
Craig E. Kundrot
Bruce M. Link
Donna Roberts
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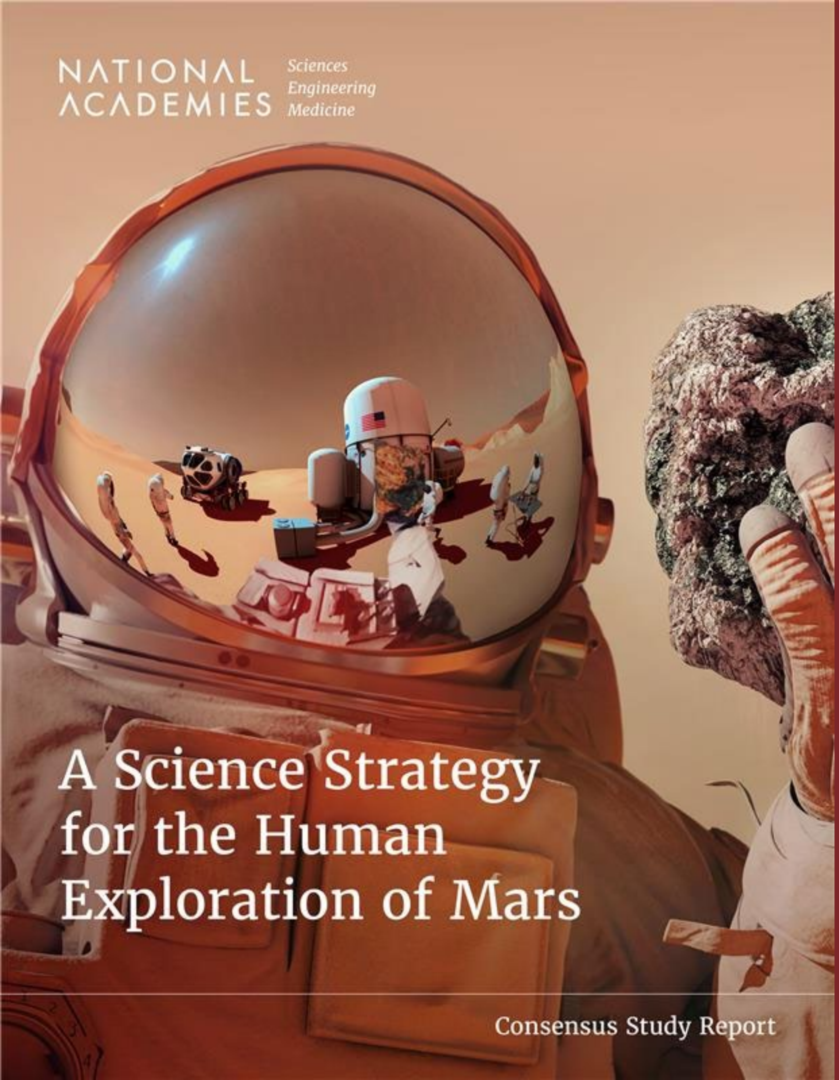

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