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A Science Strategy for the Human Exploration of Mars

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

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A Science Strategy for the Human Exploration of Mars

Consensus Study Report

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 (M2M)
- Key synergies with exploration goals



A Science Strategy
for the Human
Exploration of Mars

Consensus Study Report

Our Mandate

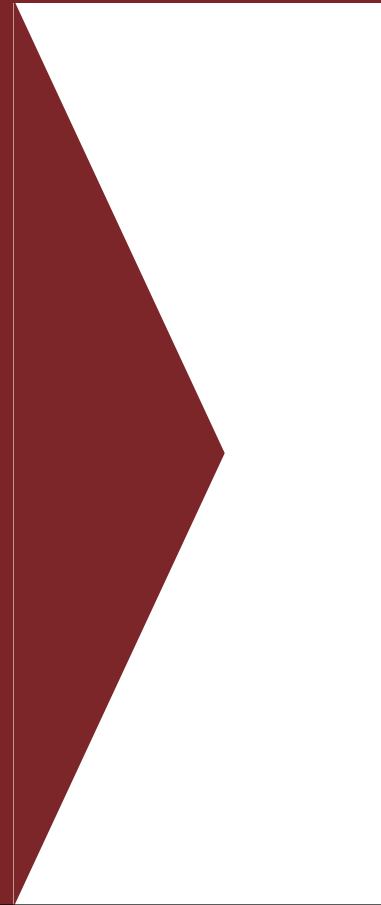
What science should humans pursue first on Mars?

Which mission campaigns achieve that?

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

What science should humans pursue first on Mars?

11 Priority Science Objectives



Priority Science Objectives

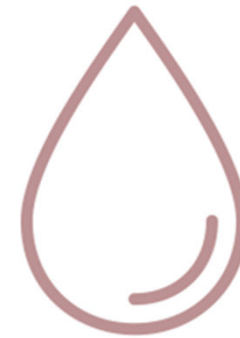
#1

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 CO₂ 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

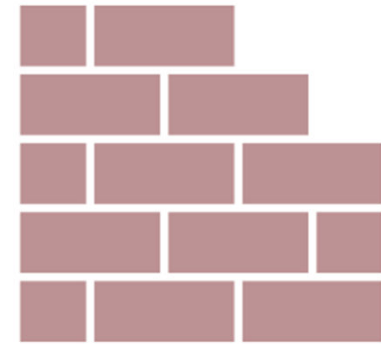
Determine what controls the onset and evolution of **major dust storms**, which dominate present-day atmospheric variability.



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

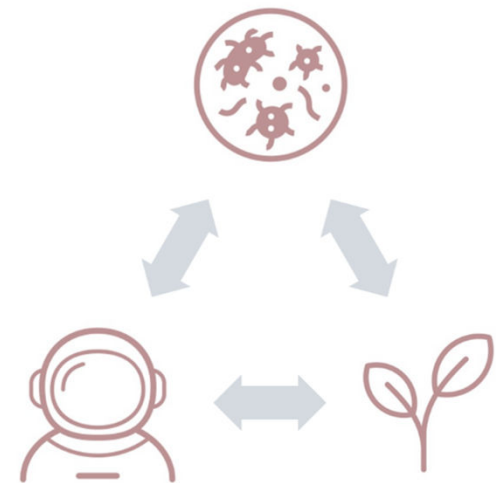
#9 Characterize the **effects of martian dust** on human physiology and hardware lifetime.



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

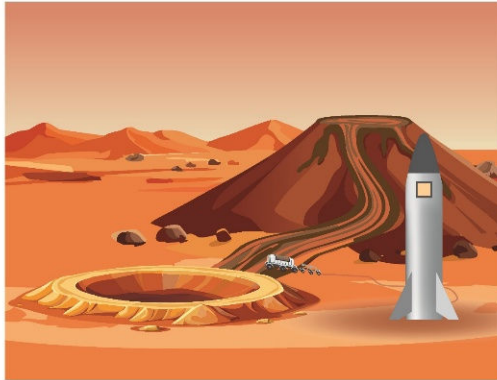
Characterize the **primary and secondary radiation** at key locations in the crew habitat and astrobiological sampling sites to contextualize sample collection and improve models of future mission risk.





The first human campaigns to **Mars**

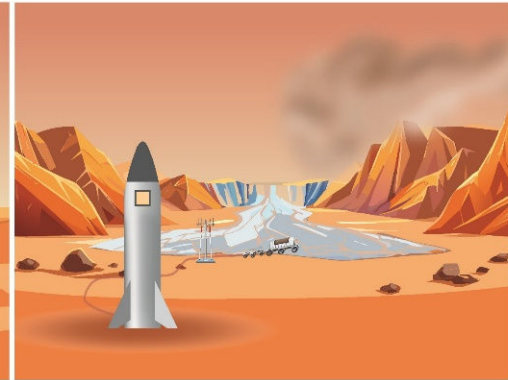
CAMPAIGN ARCHITECTURE



30 SOLS

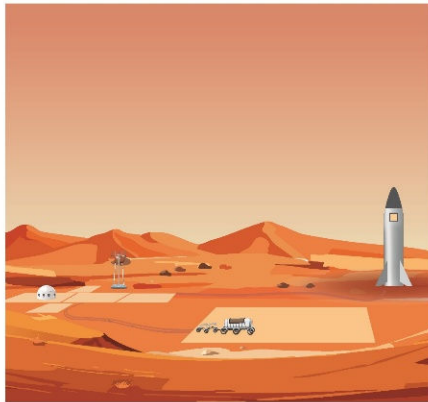


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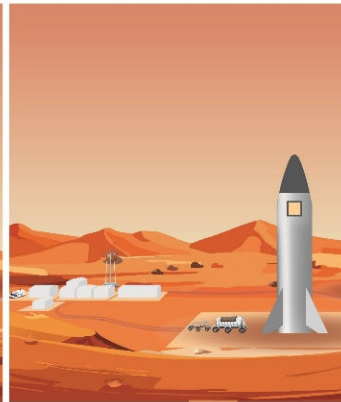


30 SOLS

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

CAMPAIGN

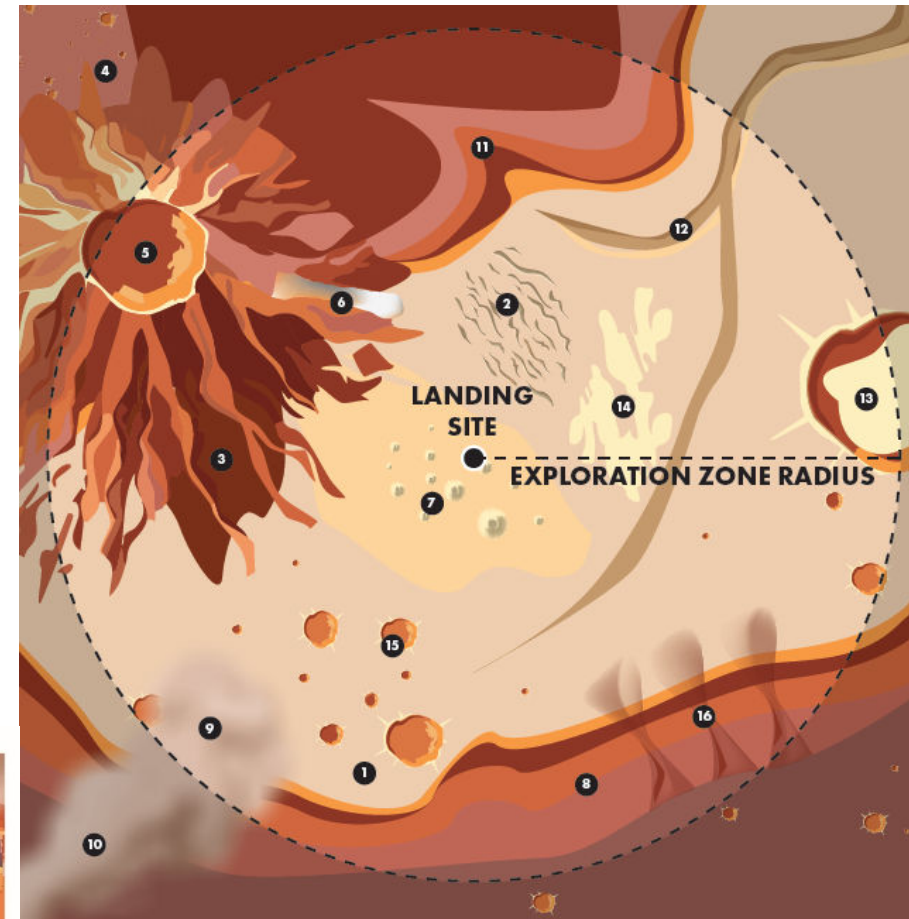
1

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.



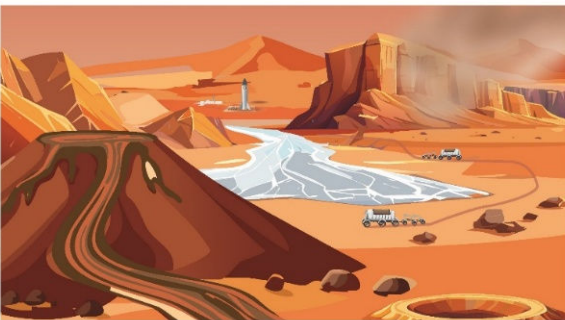
- | | | |
|---------------------|-------------------------------------|------------------------------|
| 1 Ancient Rocks | 7 Rootless Cones and Subsurface Ice | 13 Paleolake Deposit |
| 2 Dunes | 8 Canyon Wall | 14 Light-Toned Deposits |
| 3 Recent Lava Flow | 9 Dust Storms | 15 Impact Craters and Ejecta |
| 4 Ancient Lava Flow | 10 Autonomous Monitoring Station | 16 Gullies |
| 5 Volcano | 11 Sedimentary Deposit | |
| 6 Glacier | 12 Aqueous Flow Feature | |



30 SOLS
CREWED LOCAL EXPLORATION AND
INFRASTRUCTURE PREPARATION



CARGO
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300 SOLS
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SCIENCE AND EXPLORATION

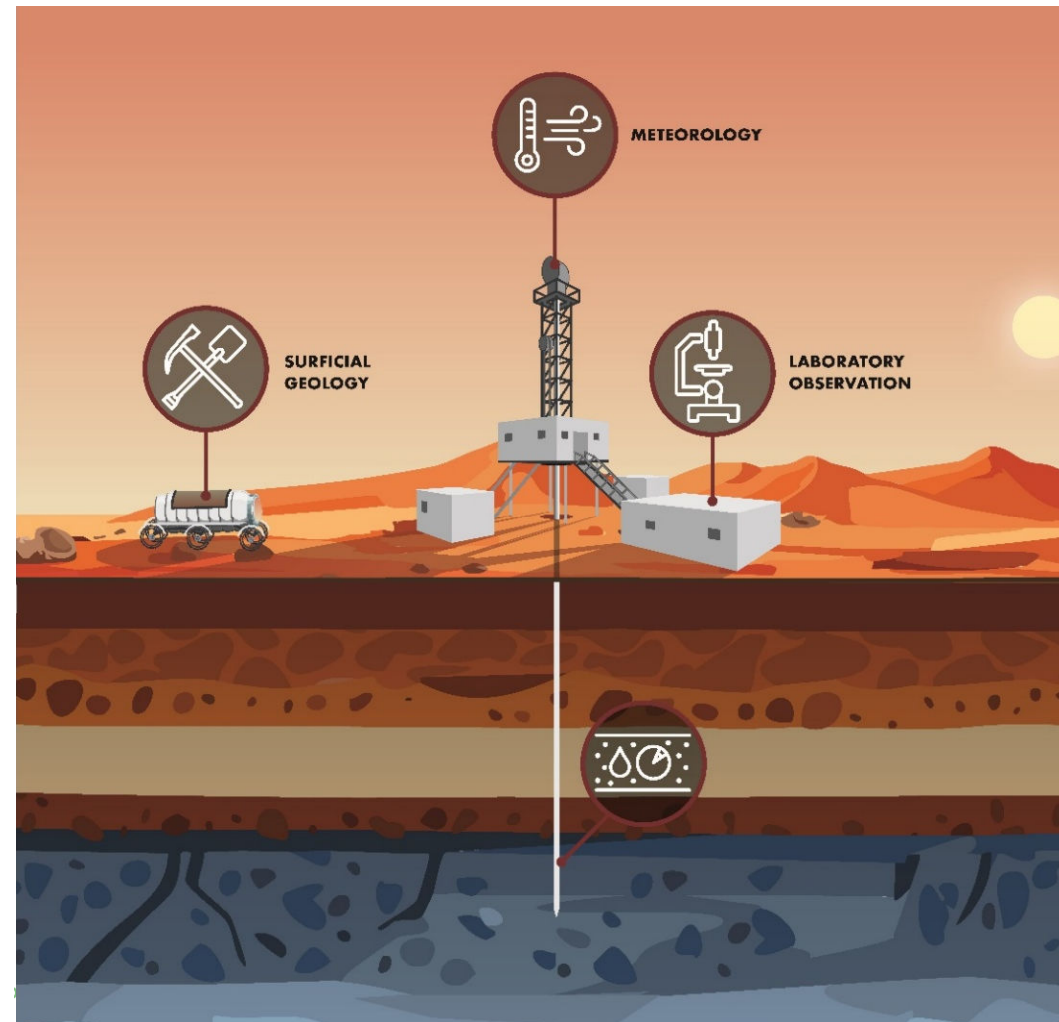
CAMPAIGN
2

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.



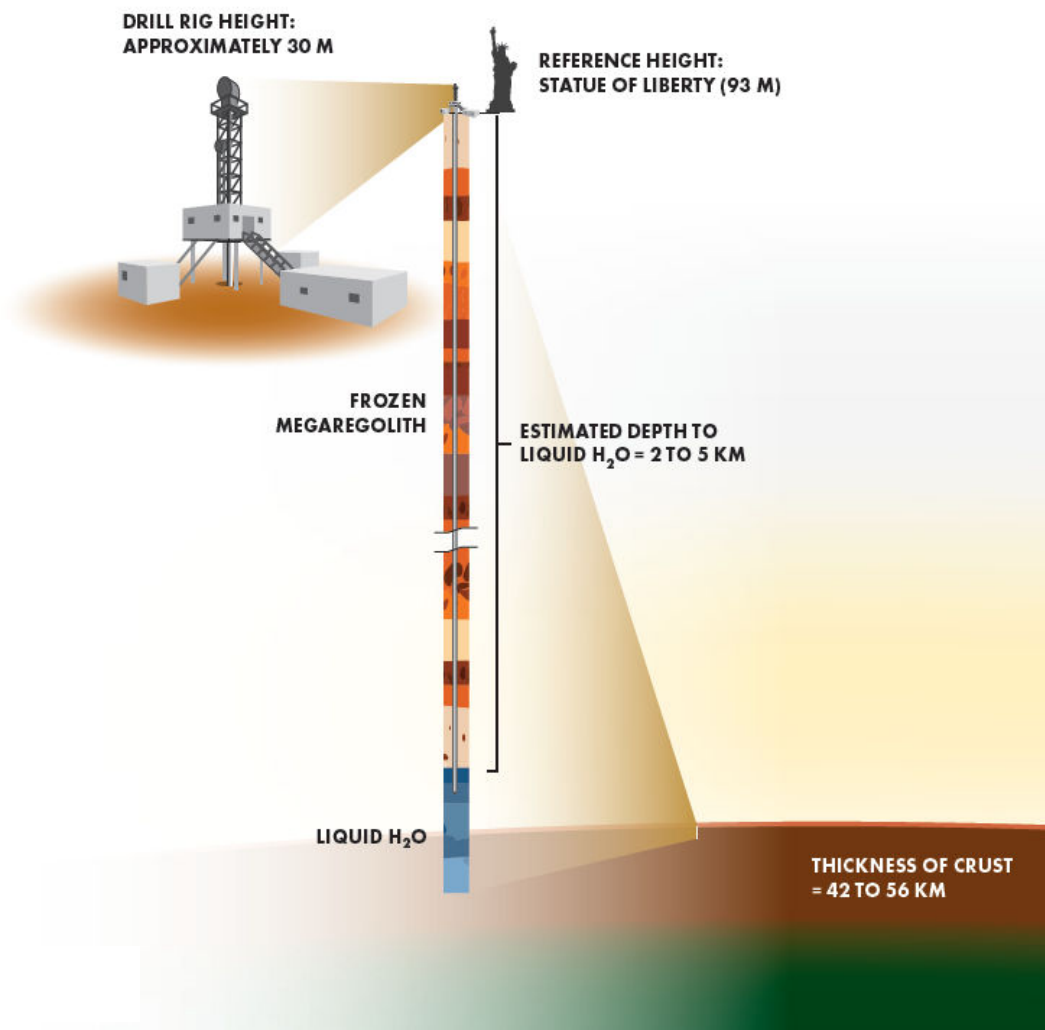
CAMPAIGN
3

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.

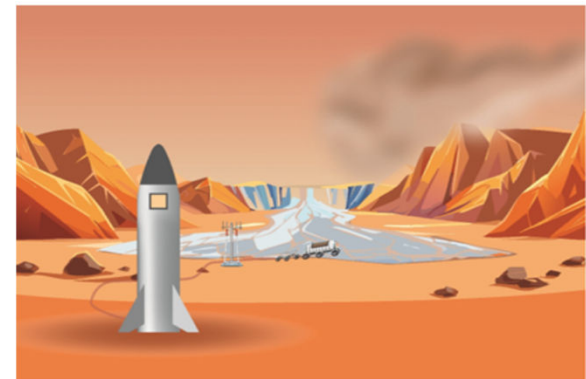
- Less risk for astronauts with shorter surface stays.
- Breadth of sites gives breadth of insight.
- Science addressed is broad but not deep.



30 sol



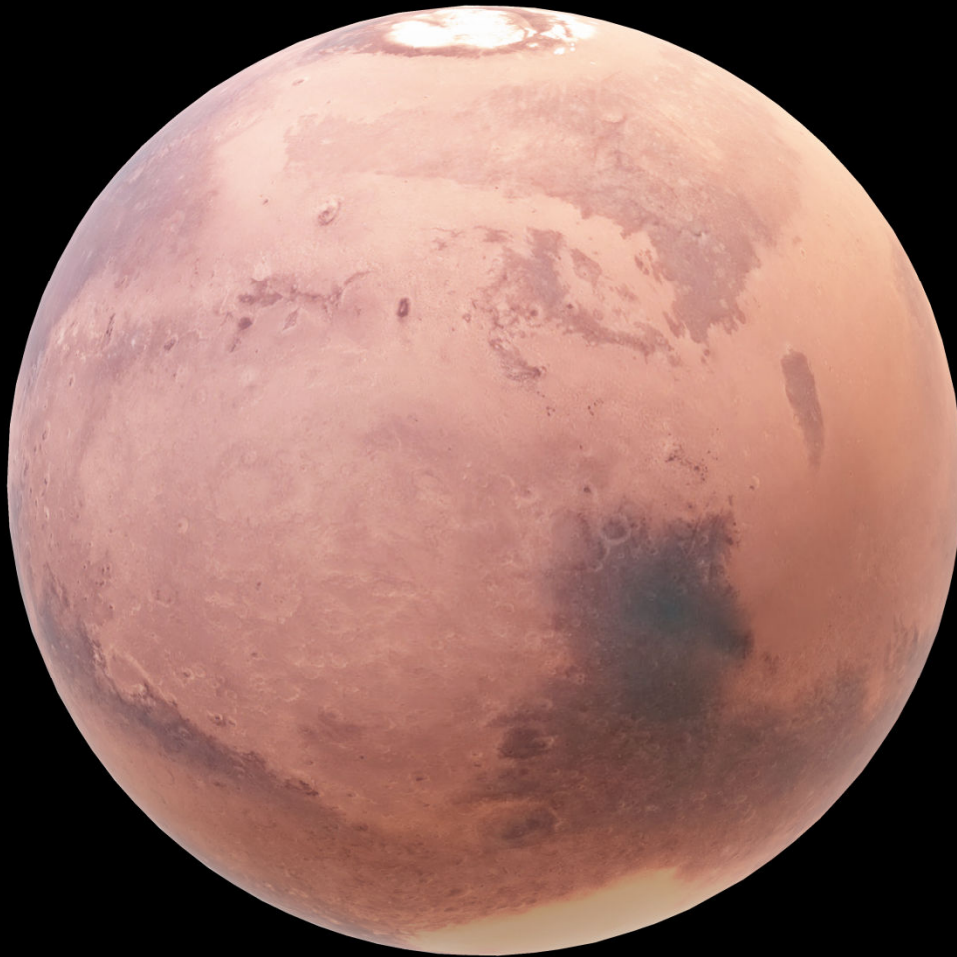
30 sol



30 sol

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





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.

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 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

Penelope Boston

NASA Ames Research Center

Christopher Carr

Georgia Institute of Technology

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Space Exploration Technologies

Wanda Sigur

National Academy of Engineering
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Erika Wagner

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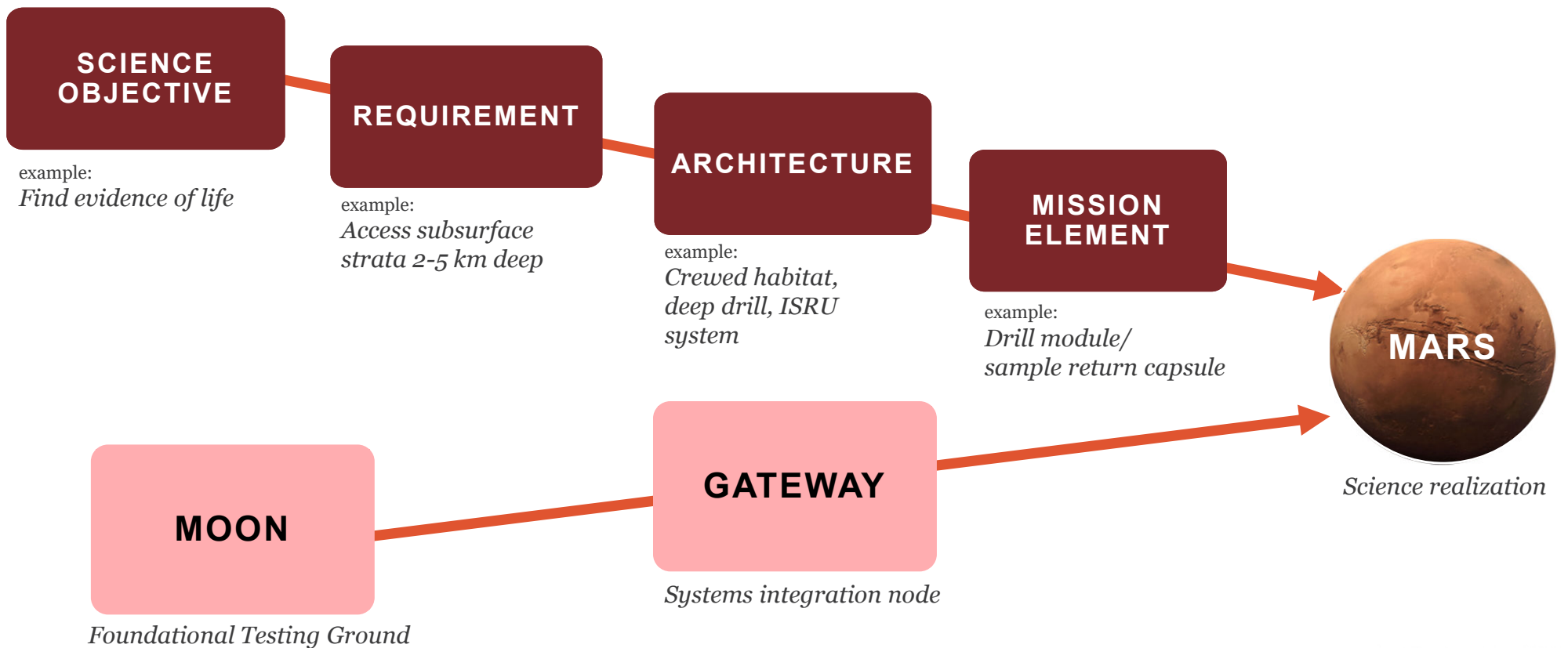
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TEC - PUBLIC

ADDITIONAL MATERIALS

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Science Leads, Design Follows, Mars Awaits



Report Recommendations

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

Planetary Protection

REPORT RECOMMENDATION #1

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

REPORT RECOMMENDATION #2

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

REPORT RECOMMENDATION #3

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

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.

Human-Agent Teaming