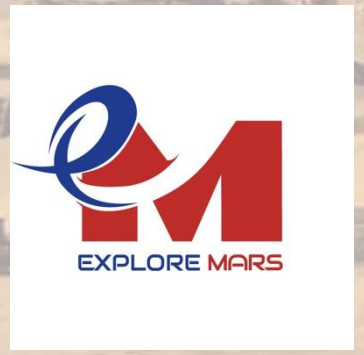
The Twelfth Community Workshop for Achievability and Sustainability of Human Exploration of Mars (AM-XII)

5-7 May 2026, American Institute of Physics, Washington, DC
Sponsored by *Explore Mars, Inc.*
Final Meeting Report, 17 June 2026



[Image from "The Martian]

AM-XII Workshop: Integrating Multiple Disciplines Into Mars Human-Mission Planning

Bruce Jakosky, *Univ. of Colorado/Univ. of Washington*, Co-Chair
Timothy Kokan, *L3Harris*, Co-Chair
Jennifer Rochlis, *Advancing Frontiers*, Co-Chair
G. Scott Hubbard, *Stanford Univ.*, Planning Committee Representative

Chris Carberry and Rick Zucker, *Explore Mars, Inc.*, Logistics Co-Chairs

[Image from "The Martian]

Executive Summary (1 of 2)

- The Achieving Mars XII workshop focused on integrating engineering, science, human health and performance, and planetary protection for the first time into a single approach to designing and implementing a human mission to Mars
- Human Mars exploration faces several fundamental challenges that *must* be solved interactively
  - Planning for a successful human mission must integrate input from the four component disciplines from the beginning; adding areas later is very ineffective when some designs are already cast in stone
  - Integration across disciplines can't be done in a single meeting or interaction between groups, it must be an ongoing *process* of frequent interaction and exchange
- Implementing "Moon to Mars" requires a strategic approach of looking at the entire program rather than only the next mission in the queue; identifying relevant activities for the Moon now allows for development of appropriate feed-forward to Mars missions
- Precursor landed and orbital missions (e.g., *Curiosity* and *Perseverance* on the surface, *Mars Reconnaissance Orbiter* and *Mars Express* from orbit) have tremendous value and are necessary for defining science, planning mission ops, and determining surface geotechnical properties for a safe human landing

Executive Summary (2 of 2)

- Specific recommendations:
  - NASA should coordinate early with the engineering/architecture, science, health and human performance, and planetary protection communities so that all aspects have input into architecture and mission planning and to ensure that there is an integrated mission concept and design
  - Either a NASA task force with broad community representation or a community group chartered through a NASA advisory group should be commissioned to stand up quarterly or semi-annual workshops modeled on AM XII. The goal of such a recurring event would be to continue to drive toward an actual integrated mission concept and specific landing-site recommendations.
  - NASA should begin development of the mission architecture now to enable identification and development of areas within these four disciplines that require long lead time.
  - NASA should fly a high-resolution imager to support landing site hazard analysis and mission planning; *MRO* and HiRISE are well beyond their design lifetimes, and HiRISE data quality has become degraded.
  - These recommendations need to be implemented now in order to keep human missions from always being a generation in the future.

Workshop On Integrating The Component Disciplines Into Human-Mission Planning

- Workshop held on 5-7 May 2026 in the facilities of the American Institute of Physics in Washington, DC
- 37 participants representing the full range of disciplines and types of institutions
- This 2.5-day workshop focused on taking a first look at the necessary integration across the different disciplines that must work together to have a successful Mars human mission:
  - Engineering/architecture
  - Science
  - Human health and performance
  - Planetary protection
- Science objectives were taken from the recent National Academies of Science (NASEM) report on human-mission science objectives at Mars, and were not revisited here
- We examined interactions between these areas for missions to two *example* potential landing sites for the first mission in order to have concrete discussions of mission details; one site focused more on *in situ* resources and the other focused more on science objectives. The first site would likely require more reconnaissance, while the second has the best orbital coverage to date, as well as in-situ validation.
- The goal was to develop concepts of how these four disciplines can work together during an actual landed mission, with possibly different mission architectures and precursor knowledge, not to evaluate possible landing sites or to enumerate landing-site characteristics.
- Participants were hand selected to ensure that each discipline was represented and that participants would actively participate

Detailed Discussion, Recommendations, And Conclusions

Necessity Of Interdisciplinary Collaboration And Integration

- All discipline areas must be integrated into a single mission concept to ensure mission success:
  - Engineering and mission architecture
  - Science
  - Human health and performance
  - Planetary protection
- Effective integration requires that these disciplines must be integrated together from the very beginning in planning human missions
  - The groups must work shoulder to shoulder, using a common understanding of terms, concepts, goals, and issues
  - Each discipline provided complementary insights that, when brought together, provide for a more coherent picture of what a human Mars campaign actually requires
- This can't be done in a single meeting or interaction between groups, it must be an ongoing *process* of interaction and exchange; small workshop environments like this foster significant and constructive interaction and are much more effective than larger groups
- As the *Artemis* program to the Moon is a prelude to Mars exploration, integration of these disciplines must start with *Artemis*

Planning For Moon To Mars Requires Strategic Thinking

- Planning for M2M requires a strategic approach of planning for the entire program as a single entity, rather than a tactical approach of only looking at the next mission
  - The approach of “architect from the right”, considering the full extent of missions, allows development of necessary concepts and hardware now
  - Taking this approach allows us to identify and mitigate issues that will be important at Mars that can be addressed either during the *Artemis* missions or during the time prior to a Mars mission
  - “Moon **then** Mars” pushes any consideration of Mars into the distant future; it is not strategic
- If the program really is “Moon to Mars”, then some advance planning is required for implementing a human Mars mission
  - To ensure that the *Artemis* program at the Moon will provide the desired feed forward in hardware design, mission architecture, and science approach and implementation to Mars
  - To take advantage of the current tremendous expertise of the Mars environment and spacecraft issues, design, and operations (including nine successful robotic landings on the surface) through continuity of the Mars data analysis and robotic exploration programs
  - To identify issues that will require significant analysis and advance lead time and can be addressed starting now; appropriate technology development needs to start now

Do We Need Precursor Missions Before Humans Go? (1 of 3)

- The breadth and value of potential precursor missions is well described in the NASEM report on science from human missions to Mars; we focus on integrating specific aspects that are important for advance planning and integration among disciplines
- We can't just go to a random site – Observations in advance of human missions are required for reducing risk, enabling mission planning, and enhancing science return from human missions
  - High-resolution orbital imaging for landing-site hazard analysis and for planning traverses and sampling sites
  - Determining geotechnical properties of the surface to allow safe landing of large (~20-40 T) vehicles
  - Measurements to support atmospheric-transport models for local/regional/global redistribution of contaminants, relative to planetary protection
  - Precursor robotic orbital and landed missions both may be necessary for a mission focused on determining whether accessing ice is feasible for in-situ resource utilization (ISRU)
- The experience with *Perseverance* at Jezero Crater demonstrates the critical necessity of having on-the-ground exploration in preparation for humans:
  - Preliminary analysis of potential sampling sites to maximize what the astronauts can accomplish in their limited time on the surface, especially for the first 30-day mission
  - Determine geotechnical properties of the surface to ensure a safe landing for a large (~20-40 T) vehicle
  - Inform strategies for planning and operations for human missions
  - Although not discussed in detail, we expect that the *Curiosity* observations at Gale Crater are comparable for these purposes at that site

Do We Need Precursor Missions Before Humans Go? (2 of 3)

- If we had to pick a landing site without having additional precursor missions, it should be either Jezero or Gale given our tremendous wealth of necessary precursor data related both to hazard identification and expected science return
  - Any other landing site likely will require comparable advance *in situ* robotic exploration for risk reduction
  - Both of these sites are viable from the science perspective
  - The *Spirit* and *Opportunity* sites should also be considered
- The need to refresh our orbital high-resolution imaging capability
  - The HiRISE instrument on *MRO* has been providing imaging for lander missions in support of hazard detection and definition for EDL
  - That instrument has been degrading, such that obtaining comprehensive coverage with full-resolution imaging of potential landing sites is extremely difficult or impossible today
  - High-resolution imagery in advance is required for terrain-relative navigation and pinpoint landing
  - Flying a new instrument for that purpose is required for evaluating landing-site hazards for other potential landing sites, planning rover and/or astronaut traverses, and documenting changes in the surface at sites already imaged
  - Additional high value in planning missions would come from flying a moderate- or high-resolution compositional remote-sensing instrument (analogous to CRISM on *MRO*) or from orbital radar mapping (especially in search of ice for an ISRU-focused mission)

Do We Need Precursor Missions Before Humans Go? (3 of 3)

- The need to return Mars samples to Earth in advance of sending humans for risk reduction
  - Identify hazardous chemicals to ensure astronaut safety, as some hazardous chemicals are known to exist (perchlorates, chloromethanes)
  - Characterize very fine dust particles that could cause potential respiratory issues in astronauts
  - Characterize dust and regolith properties for spacesuit design and wear patterns
  - Search in advance of the arrival of humans for evidence of extant life that could be hazardous
  - Demonstrate implementation of planetary-protection protocols
  - Enhance astronaut effectiveness on the surface and science return from human missions by providing initial context and analysis
- Demonstrate successful round-trip to Mars
  - To include successful round-trip travel, EDL, and ascent from the surface with human-class vehicles
  - To demonstrate implementation of planetary protection protocols for samples

Human Health And Performance – Strategic Framework

Human operational state must be tracked and sustained as a dynamic system variable throughout the mission (identified and discussed in the NASEM human Mars mission report).

- Integration Requirements:
  - Human readiness is not a trait the crew brings, it is a condition created or eroded by the system they are embedded in
  - Mars demands concurrent performance under finite crew capacity and operational stress - fundamentally different from individual task validation in benign conditions
  - If human operational state is not tracked, owned, and protected as a level-1 requirement, it will be traded away during resource competition
- Operational Design Principles:
  - Recovery time is critical architectural margin, not schedule slack (“unallocated” does not mean “available for allocation”)
  - Design for degraded cognitive performance (which varies throughout a mission), not peak capability
  - Crew decision authority is required due to communications limitations and lack of abort capability
  - Build margin for discovery science, not just contingency, in normal operations
- Medical and Behavioral Health:
  - Planning responses in the event of significant injury, illness, or death of a crew member, including minimum crew thresholds and backup skills for critical-path functions
  - Realistic assessment of radiation risk (not currently thought to be a significant issue)
  - Medical and pharmaceutical resources and capability
  - Food safety, variety and nutritional content is critical to both physical and mental health
  - Team cohesion changes over mission phases—must be actively managed, not assumed

Human Health And Performance – The Moon as Proving Ground

Lunar missions are the essential testing ground for validating integrated human-system performance under Mars-relevant constraints.

- Lunar missions must “stress-test” the physical and operational systems designed for Mars
  - Concurrent task performance under degraded conditions, realistic crew availability and operational stress
  - Track of human performance as a dynamic system variable with assigned ownership
  - Demonstrate crew autonomy and Earth-independent decision-making under pressure
  - Measure and sustain physical, mental and emotional readiness of the crew and individuals over extended duration
  - Validate integrated human system performance when one or more crew members are at reduced capacity

Planetary Protection Concerns

- Reminder that the goal of planetary protection is not to avoid contamination but, rather, to ensure that contamination will not preclude being able to do the science; planetary protection should enable exploration, not prevent it
  - For example, an extreme view that we could not carry out an EVA due to contamination issues, and therefore could not do the science for the mission, would run counter to the mandates of planetary protection
- Planetary protection protocols for human missions are still under development; they must include:
  - Forward protection to protect science in the landing and exploration region
  - Understanding issues related to potential widespread contamination resulting from transport of material by the wind
  - “Breaking the chain” of contact with Mars in returning to Earth
  - Backward protection to ensure protection of the Earth from possible Martian organisms
- Planetary protection protocols must be incorporated early into the planning for human missions in order to be integrated effectively
  - Doing this also requires protocols to be developed early, as they do not currently exist
  - Recognize that planetary protection concerns can vary significantly by landing site type

Surface Operations During A Mission

- Astronauts on the ground will need to obtain a detailed geological overview of a site to augment precursor measurements from orbit, a drone, or a rover; this will feed into real-time revisions of traverse and sample planning for the mission
- Surface operations will require use of hand-held science instruments in the field (e.g., hand-held LIBS, XRF, Raman, and VNIR spectroscopy) to aid in selecting samples, and of more-complex ("benchtop") science instrumentation in the habitat
  - Requirements for hand-held and hab-lab instrumentation have not yet been defined
- Missions should take advantage of the enhanced capabilities from combining robotic measurements and human activities, taking advantage of the unique capabilities that they each have
- There has not been adequate discussion of the use of "robotic field assistants", aerial drones, or other mobility augmentations in surface ops that would allow us to evaluate their utility in enhancing crew efficiency or effectiveness
- There has not been adequate discussion of the integration of human health and performance issues during the mission or of measurements during the mission to support monitoring of astronaut health
- It is unclear whether sample life detection on the ground at Mars prior to a human mission is required to support astronaut (and Earth) health and safety
- Specific measurements that are required in order to achieve science objectives are described in the NASEM report on human exploration of Mars; they are not repeated here

The Role Of Commercial And International Collaboration

- Commercial and international participation likely will be required for successful human missions to Mars
  - Detailed discussion of commercial participation is required in advance, as there is no common understanding of what this entails
  - Roles and responsibilities for international partners need to be defined
- We expect that NASA will lead overall architecture development, but current NASA planning for human Mars missions does not allow for potential commercial or international collaboration or partnership in a meaningful way
- Commercial and international participation will require significant lead time, so NASA should include their participation in planning from the very beginning; discussion of roles and responsibilities should begin now

Recommendations

- NASA should coordinate early with the engineering/architecture, science, health and human performance, and planetary protection communities so that all aspects have input into architecture and mission planning and to ensure that there is an integrated mission concept and design
- Either a NASA task force with broad community representation or a community group chartered through a NASA advisory group should be commissioned to stand up quarterly or semi-annual workshops modeled on AM XII. The goal of such a recurring event would be to continue to drive toward an actual integrated mission concept and specific landing-site recommendations.
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Appendix 1. Thank you to our sponsors

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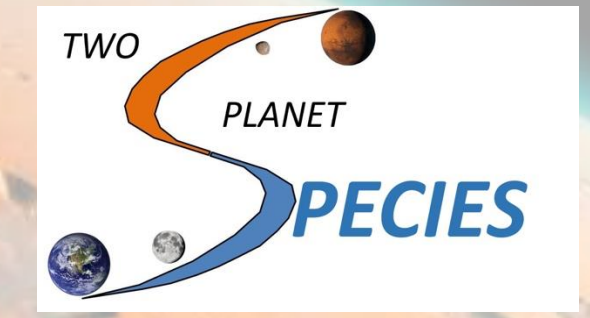

EXPLORE MARS

Appendix 2. Reiterating The Value Of Humans In Exploring Mars

- Humans combine incredible fidelity of their eyes with tremendous capability of their brains to carry out all functions in exploring Mars with great effectiveness and efficiency
- Humans have the ability to instantly integrate results from disparate scales and relationships, and to intelligently select samples based on orbital, landed, and field observations
- Humans can identify issues and processes once on the surface that had not been identified previously in advance by orbital or landed observations
- Humans have flexibility to respond to unexpected results and incidents and to innovate and improvise quickly as necessary
- The value of humans is not only mobility — it is cognition, synthesis, prioritization, and improvisation
- Humans can tell stories and bring the humanity to exploring Mars, thereby supporting all three pillars for NASA's human exploration – science, inspiration, and national posture
- There is not a debate on "humans versus robots" in exploring Mars; each contributes in substantive ways that are not duplicated or replaced by the other, and we expect "human-agent teaming" to be important going forward

Appendix 3. "Achieving Mars" Workshops

- This is the 12th in a series of workshops dating back to 2013 designed to provide independent community input on issues related to planning human missions to Mars
- The workshops have been organized and run by *Explore Mars, Inc.*, a non-profit organization that provides a communications interface between NASA HQ, the Mars scientific and technical community, and the public.
- Each workshop is planned by co-chairs selected from the different relevant disciplines, with the co-chairs developing the specific focus of each workshop and incorporating input from a larger planning committee.
- Typically, the final report from the workshops is vetted through the co-chairs and leads and then the participants, and is then briefed out to the human-mission planning groups and science directorate leaders at NASA HQ, relevant congressional staffers and members, the Office of Management and Budget, and the discipline communities.

Process For This Workshop

- The workshop was organized by *Explore Mars, Inc.*, held in the Washington, DC, facilities of the *American Institute of Physics*, and sponsored by *L3Harris*, *Lockheed Martin*, and *2 Planet Species*
- The workshop included experts from all four discipline areas that would contribute to the success of a mission, and included people from NASA, academia, and industry; invited participants were selected to ensure representation of all of the relevant communities and to have active participation in the discussions
- We provided a day of background talks, to educate everybody in key aspects of each discipline and to foster common ground and terminology for communications
- Discussion centered on two potential landing sites, one that would include potential access to ground ice for in-situ resource utilization and one that would focus on the science for that site; these were used solely as examples to allow concrete discussion, and do not constitute a starting list of potential human landing sites
- Discussion focused on interactions between the disciplines and identifying how constraints from each discipline affected the operations and success of a mission
- General discussion following the landing-site discussions allowed integration of results, identification of issues and concerns, and generalization to other potential landing sites

Appendix 4. Important Topics Not Discussed Or Beyond Our Purview At This Meeting

- “Day in the Life” for the astronauts during a mission
- Human-agent teaming (e.g., the role of A.I. in mission ops)
- Strategy for evaluating nuclear thermal versus nuclear electric propulsion versus other propulsion technologies
- Strategy for a campaign beyond the first mission
- Discussion and assessment of feed forward from the Moon to Mars
- Realistic assessment of how to access, collect, and utilize *in situ* resources (such as water ice)
- Architecting how to manage, transmit, store, and utilize data
- Science requirements for human health and performance
- Requirements for hand-held field instrumentation or “in the hab” instrumentation to influence traverse and sample-collection planning during the mission
- Instruments and facilities to operate after humans return or between missions, if to the same site.
- Astronaut activities during the cruise periods to and from Mars

Appendix 5. Workshop Participants

Erik Antonsen
Nathan Barba
David Beaty
Michael Beavin
Nick Benardini
Mark Benton
Chris Carberry
Luis Carrio
Joe Cassady
Neil Cheatwood
Steph Connell
Sydney Do
Colin Dundas
Anton Ermakov
Taania Girgla
Matt Golombek
John Grant
Jim Green
Vicky Hamilton
Scott Hubbard
Bruce Jakosky
John Karas
Tim Kokan
Pam Melroy
Michael Meyer
Michael Mischna
Bob Moses
Jack Mustard
Dava Newman
Shawna Pandya
Hoppy Price
Than Putzig
Holly Ridings
Jennifer Rochlis
Annika Rollock
Mitch Schulte
Rich Zurek

Appendix 6. Meeting agenda

Agenda, day 1

Day 1 – Reaching a Common Understanding, 8:30 a.m. – 5:30 p.m.

Half hour allotted for each talk unless otherwise indicated (nominally 20 minutes presentation, 10 minutes Q&A and discussion)

8:00-8:30	**Coffee, etc.**
8:30-9:00	Welcome and Introduction – *Workshop Co-chairs*
9:00-9:30	M2M Policy Priorities, Issues, and Concerns – *Holly Ridings*
9:30-10:00	Results from NASEM Report on Science in Human Missions – *Dava Newman*
10:00-10:30	Astronaut Perspective on Mission Aspects – *Pam Melroy*
10:30-11:00	**Break**
11:00-11:30	Science Objectives for Mars – *Jack Mustard*
11:30-12:00	Exploration and Utilization of Resources – *Than Putzig*
12:00-12:30	Human Health and Performance Issues and Concerns – *Jennifer Rochlis*
12:30-1:30	**Lunch**

Agenda, day 1 (continued)

1:30-2:00	Engineering/Architecture Planning – *Luis Carrio*
2:00-2:30	Planetary Protection Issues and Concerns – *Nick Benardini*
2:30-3:00	Realistic Time Utilization and Allocations for a 30-Day Mission – *Erik Antonsen*
3:00-3:30	**Break**
3:30-4:35	Introduction to Landing Sites • Overview of the two sites and concepts *(John Grant)* • Jezero landing site *(Matt Golombek, Sydney Do)* • Phlegra landing site *(Matt Golombek, Sydney Do)*
4:35-4:50	Working across multi-disciplinary groups – *Scott Hubbard*
4:50-5:15	Plans for Day 2 – *Workshop Co-chairs*

Agenda, day 2

Day 2 – Multi-Disciplinary Landing Site Perspectives

Morning Session: 2020/Jezero Site (8:30-12:10)

Moderators: Michael Meyer and Hoppy Price

8:30 - 8:45 Introduction of Discussion Topics *(15 min., Workshop Chairs)*

8:45 - 9:00 Moderator and Panelist Introductions *(10 min.)*

9:00 - 9:30 Short Panelist Presentations to Seed Discussion *(30 min., 5 mins each)*

Panelists: Matt Golombek, Jack Mustard, Sydney Do, Tim Kokan, Erik Antonsen, and Nick Benardini

9:30 - 11:40 Group Discussion of Capabilities and Limitations/Issues *(120 min.)*

Perspectives from Science, Human Health and Performance, Engineering, Planetary Protection

11:40 - 12:10 Moderators Summarize and Wrap Up Discussion *(30 min.)*

12:10 - 13:30 **Lunch Break**

Agenda, day 2 (continued)

Afternoon Session: Phlegra/Arcadia Site (13:30 – 17:30)

Moderators: Rich Zurek and Erik Antonsen

13:30 - 13:40 Moderator and Panelist Introductions *(10 min.)*

13:40 - 14:10 Short Panelist Presentations to Seed Discussion *(30 min., 5 mins each)*

Panelists: Than Putzig, Sydney Do, Matt Golombek, Tim Kokan (or Tim Cichan), Jen Rochlis, and Nick Benardini

14:10 - 16:20 Group Discussion of Capabilities and Limitations/Issues *(120 min.)*

Perspectives from: Science, Human Health and Performance, Engineering, Planetary Protection

16:20 - 16:50 Moderators Summarize and Wrap Up Discussion *(30 min.)*

16:50 - 17:30 **General discussion**

Agenda, day 3

Day 3 – Integration and Recommendations

8:30 a.m. – 14:00 p.m.

Consolidation of discussions, summary conclusions from Day 1 and Day 2, integrated lessons learned, development of recommendations, plans for development of final report, plans for dissemination of report

14:00 p.m. Adjourn (no later than)