Science and The Human Exploration of Mars

Presented by

Dr. Richard W. Zurek

Jet Propulsion Laboratory

California Institute of Technology

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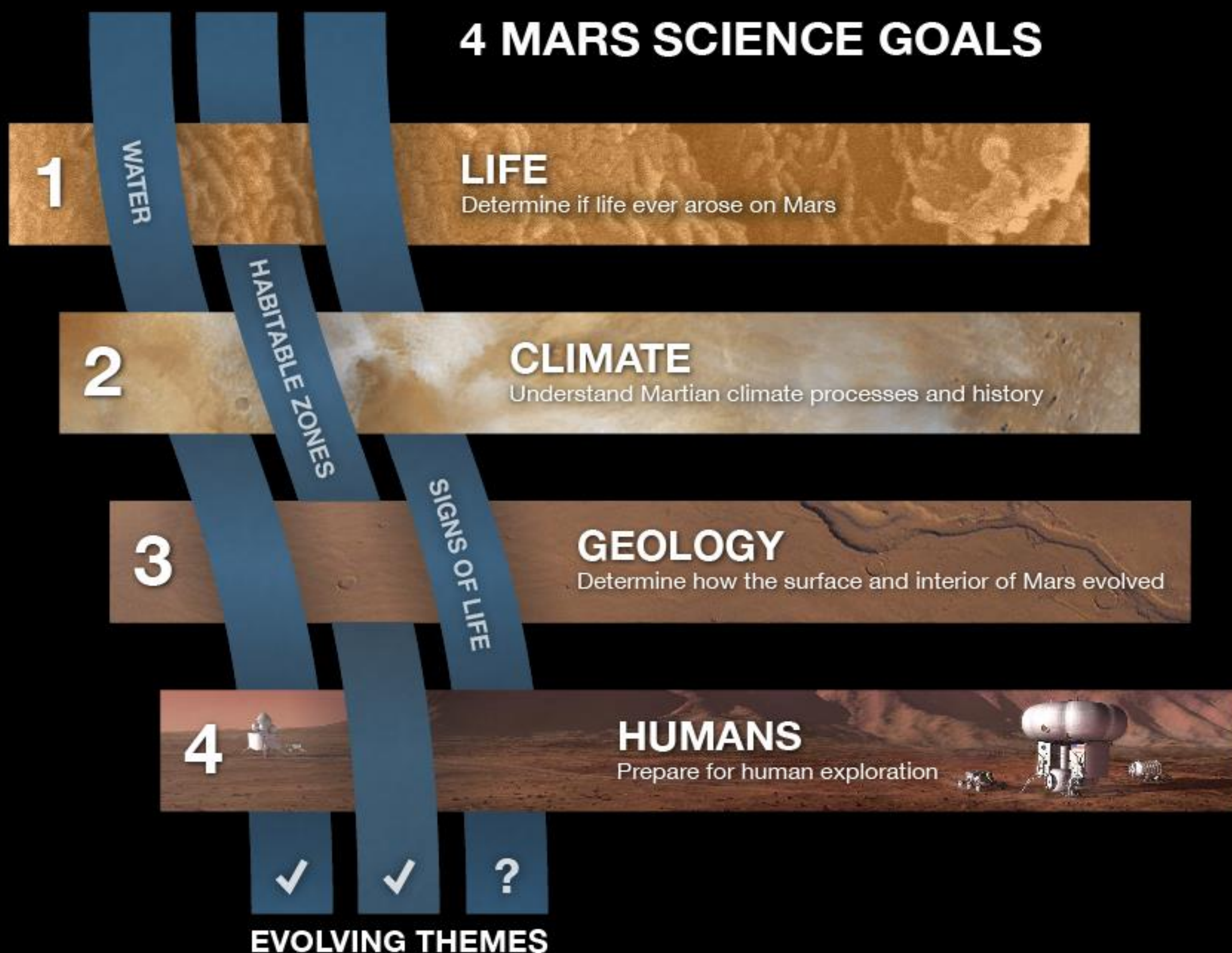
Science and Human Exploration for Mars: Starting Points

- **Of all the planets, Mars is arguably the best target for early exploration by humans:**
  - Mars is accessible in ways that other planets are not in terms of distance and the most Earth-like environment
  - Mars could answer age-old questions of whether life has originated elsewhere in the Solar System
  - Mars has undergone tremendous climate change through its long history
  - Evidence of that climate evolution and of early biogeochemical processes may be preserved on the Martian surface, in its atmosphere and crust
  - Mars offers the possibility of *in situ* resources (e.g., ground ice and hydrated minerals) that could sustain long-term exploration of its surface
- **All space exploration is by humans. For Mars the difference is where the humans are when they explore: On Earth, in orbit around Earth or Mars, on the moons of the two planets, and someday on Mars itself.**
  - Where the humans are makes a difference in the science that can be done.


4 MARS SCIENCE GOALS
1
LIFE
Determine if life ever arose on Mars
2
CLIMATE
Understand Martian climate processes and history
3
GEOLOGY
Determine how the surface and interior of Mars evolved
4
HUMANS
Prepare for human exploration
WATER
HABITABLE ZONES
SIGNS OF LIFE
✓
✓
?
EVOLVING THEMES

Science and Human Exploration

Stever, H. G. & the Committee on Human Exploration of Space (1990), A Review of NASA's 90-day Study and Alternatives, National Research Council, National Academy Press, Washington, D. C.

"It is useful to divide the scientific research issues into three broad categories."

1. Scientific studies that enable the initiative (of human exploration in space)
   - *Much has been learned about Mars in the last two decades of Mars exploration, but Strategic Knowledge Gaps (SKGs) remain.*
2. Studies and experiments that can only be conducted by humans, particularly on long-duration missions
   - Frequently, the advantages that humans bring are said to be speed, adaptability, and the ability to detect what is unexpected yet important
   - *Greatly aided by robotic aids and analytic tools that they have with them*
3. Studies that may be undertaken because humans are there, but which might be carried out otherwise if necessary (e.g., sample analysis, on Mars and back on Earth)

Other Previous Work

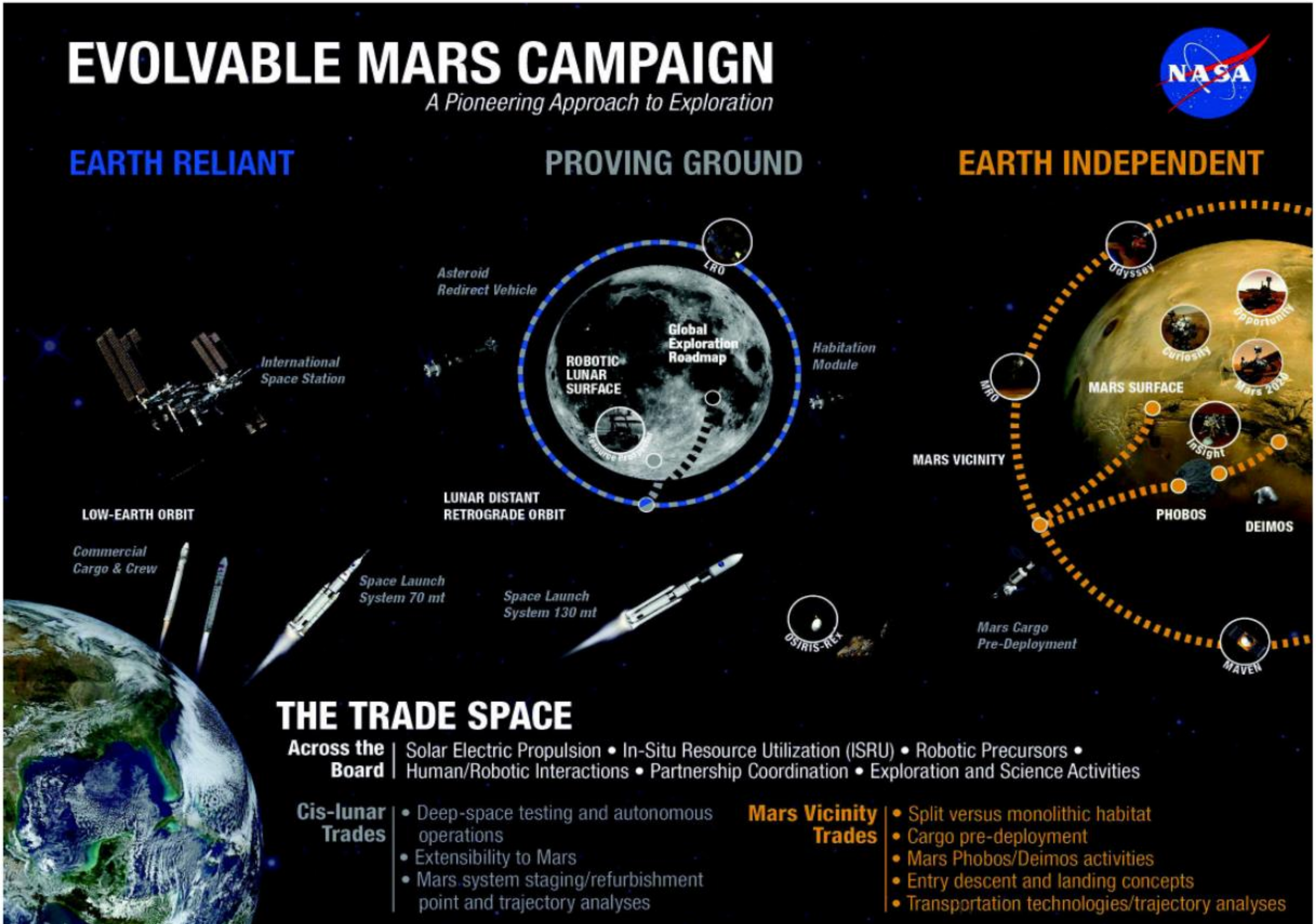
Drake, B. G. (2009), Human Exploration of Mars Design Reference Architecture 5.0, NASA-SP-2009-566.

Garvin, J. B., J. S. Levine, & the Human Exploration of Mars SAG (2008), Planning for the Scientific Exploration of Mars by Humans, Unpublished white paper, 92 pp., posted March, 2008, by the Mars Exploration Program Analysis Group (MEPAG) at http://mepag/reports/HEM-SAG_final_draft_4_v2-2.doc.

The above reports assumed a mission architecture in which successive human-piloted missions went to different sites on Mars.

A new mission architecture considers a situation in which successive missions go to the same Exploration Zone (EZ):

- This permits a build-up of infrastructure enabling longer and more productive stays by humans
- Takes advantage of our greater knowledge of Mars, indicating that there are sites with diverse regions of scientific interest and resources


EVOLVABLE MARS CAMPAIGN
A Pioneering Approach to Exploration
EARTH RELIANT
PROVING GROUND
EARTH INDEPENDENT
International Space Station
LOW-EARTH ORBIT
Commercial Cargo & Crew
Asteroid Redirect Vehicle
Space Launch System 70 mt
Space Launch System 130 mt
ROBOTIC LUNAR SURFACE
Global Exploration Roadmap
LRO
Habitation Module
LUNAR DISTANT RETROGRADE ORBIT
OSIRIS-REX
MRO
Odyssey
Opportunity
Curiosity
Mars 2020
InSight
MARS SURFACE
MARS VICINITY
PHOBOS
DEIMOS
Mars Cargo Pre-Deployment
MAVEN
THE TRADE SPACE
Across the Board | Solar Electric Propulsion • In-Situ Resource Utilization (ISRU) • Robotic Precursors • Human/Robotic Interactions • Partnership Coordination • Exploration and Science Activities
Cis-lunar Trades | • Deep-space testing and autonomous operations • Extensibility to Mars • Mars system staging/refurbishment point and trajectory analyses
Mars Vicinity Trades | • Split versus monolithic habitat • Cargo pre-deployment • Mars Phobos/Deimos activities • Entry descent and landing concepts • Transportation technologies/trajectory analyses

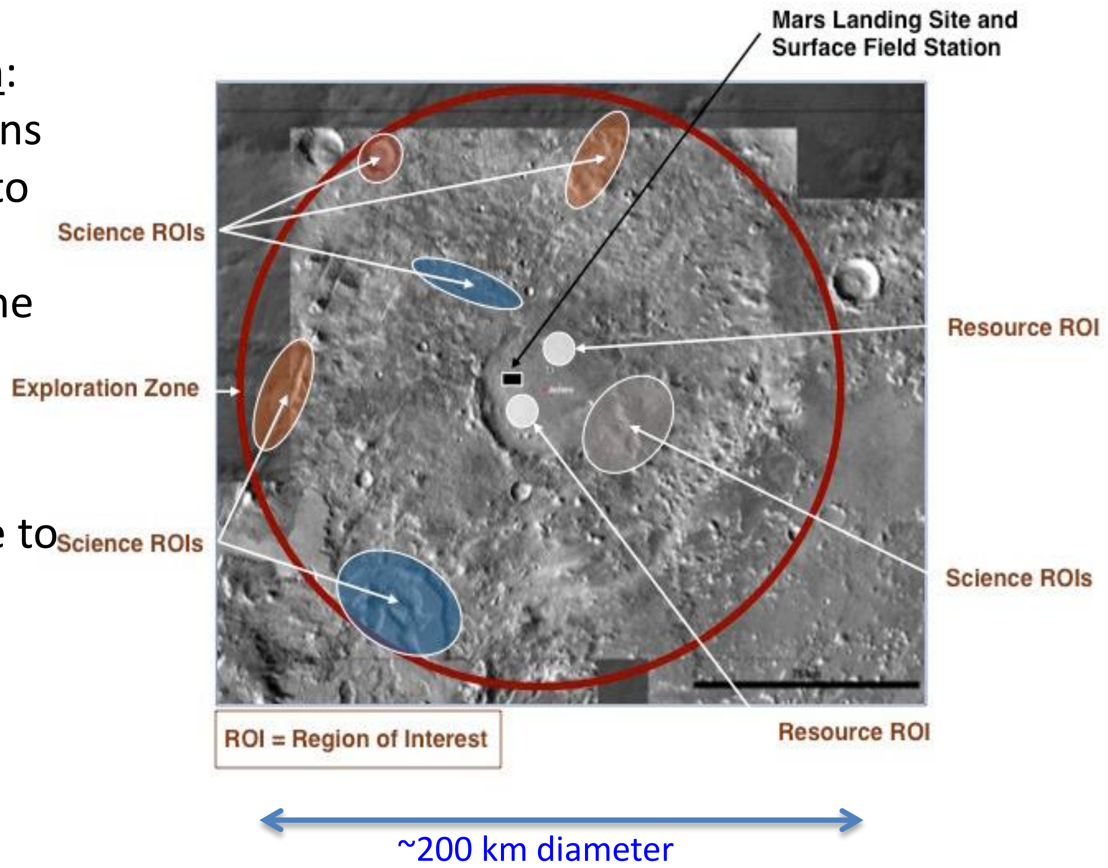
EMC: The Antarctic (McMurdo) Paradigm

Exploration Zone Layout Considerations

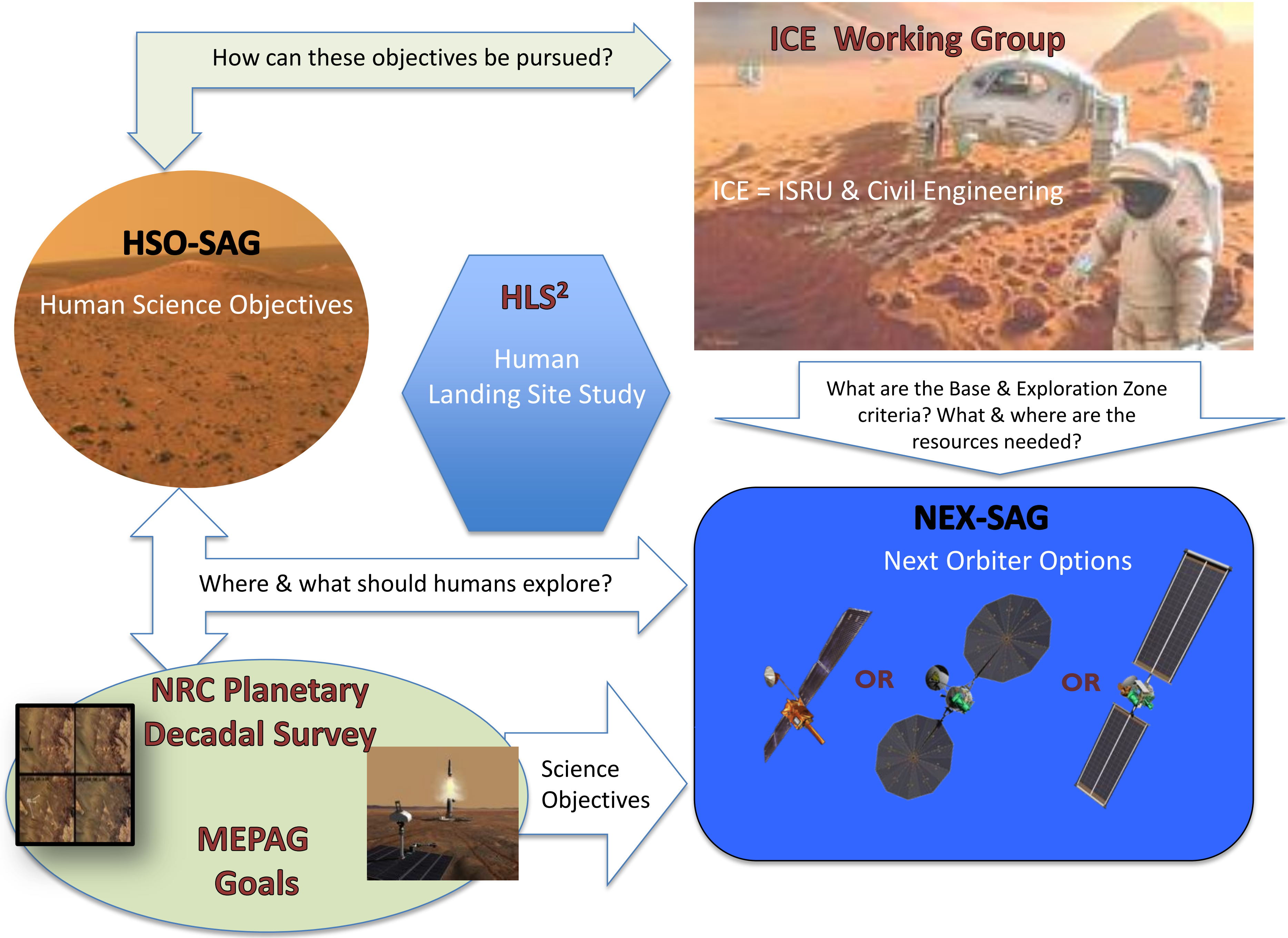
<u>New Paradigm</u>: Multiple Missions bring humans to the same Exploration Zone (EZ).

<u>This enables</u>:

- Build-up of infrastructure to support exploration
- Concentrated use of *in situ* resources



This site requires the EZ to have diverse regions of interest for scientific investigation and to have adequate resources *in situ*


How can these objectives be pursued?
ICE Working Group
ICE = ISRU & Civil Engineering
HSO-SAG
Human Science Objectives
HLS²
Human
Landing Site Study
What are the Base & Exploration Zone criteria? What & where are the resources needed?
NEX-SAG
Next Orbiter Options
OR
OR
Where & what should humans explore?
NRC Planetary
Decadal Survey
MEPAG
Goals
Science
Objectives

MEPAG HSO-SAG: A New Look

Beaty, D., P. Niles & the MEPAG Objectives for the Human Exploration of Mars SAG (2015), Candidate Scientific Objectives for the Human Exploration of Mars, and Implications for the Identification of Martian Exploration Zones, HSO-SAG report at http://mepag/reports/HSO-SAG

Charter:

Sending humans to Mars is a top NASA priority and the Agency believes that such missions will significantly expand the amount of science that can be accomplished on the planet. If carefully planned and executed, the Agency sees a natural and symbiotic interdependency between robotic and human missions to Mars.

The purpose of this SAG was to:

1. Estimate what our level of scientific knowledge will be by the time we send humans to Mars
2. Assess how humans on the surface can best be used to significantly enhance science achieved
3. Characterize and prioritize the science that will be achieved by humans.

MEPAG HSO-SAG Membership

Co-Chairs/Technical Support			
Beaty	Dave	Mars Program Office	cat herder
Niles	Paul	Johnson Space Center	Mars geochemistry
Hays	Lindsay	Mars Program Office	organic geochemistry/astrobiology
Members of the Science Community			
Bass	Deborah	Jet Propulsion Laboratory	martian polar processes, science operability
Bell	Mary Sue	Jacobs @ NASA/JSC	terrestrial analog programs including NEEMO, Desert RATS; meteorite studies
Bleacher	Jacob	Goddard Space Flight Center	geomorphology, volcanology, planetary geology, and remote sensing; field studies
Cabrol	Nathalie	SETI	Mars habitable environments and analog field work
Conrad	Pan	Goddard Space Flight Center	MSL-SAM, organic molecules, Mars Habitability, noble gases and atmospheric evolution
Eppler	Dean	Johnson Space Center	spacesuit design/field testing, geology
Hamilton	Vicky	Southwest Research Institute	chair--MEPAG Goals Committee, spectroscopy
Head	James	Brown University	Apollo, martian ice/glaciation, astronaut field science
Kahre	Melinda	Ames Research Center	Mars' climate evolution; dust, water, and CO2 cycles
Levy	Joseph	University of Texas - Austin	geological, hydrological, and ecological problems in ice deposits on Mars and Earth
Lyons	Tim	University of California - Riverside	biogeochemical cycles, isotopic compositions of carbon, sulfur
Rafkin	Scot	Southwest Research Institute	Mars climate simulations, Mars dust storms, radiation, Titan
Rice	James	Planetary Science Institute	field geology, astronaut training, MER and geomorphology
Rice	Melissa	Western Washington University	sedimentology, stratigraphy and mineralogy of planetary surfaces; MSL
Ex-Officio			
Bussey	Ben	NASA Headquarters	Chief Exploration Scientist, HEOMD
Davis	Rick	NASA Headquarters	Assistant Director for Science and Exploration, SMD
Meyer	Michael	NASA Headquarters	Lead Scientist for Mars Exploration Program; Microbiology of life in extreme environments
Supporting Resources			
Adler	Jacob	Arizona State University	EZ Rubric
Diniega	Serina	Mars Program Office	Goals Document
Parrish	Joe	Mars Program Office	Robotics
All members of the HLS^2 (Human Landing Site Selection) Steering Committee			

HSO-SAG Planning Overview

ANTECEDENTS

Task 1

Forecast of state of scientific knowledge of Mars 5-8 years ahead of the human mission.

Task 2

Update to the analysis of the most efficient methods for using robots and humans to perform scientific fieldwork.

MOST SIGNIFICANT NEAR-TERM PRODUCTS

Task 3

Analysis of the options and priorities for scientific objectives.

Task 5

Criteria used to identify science sites of interest for future human exploration.

Task 4

Operability: Identify the time, equipment and work processes required to achieve objectives in Task #3.

INPUT TO FUTURE MISSION PLANNING

INPUT TO EZ & SCIENCE ROI SELECTION PROCESS

HSO-SAG Charter - Assumptions

<u>Assumptions</u>

For the purpose of this study, use the following planning assumptions (that are subject to change):

1. Date of launch of a human mission to the martian surface for the purposes of this study: 2035.
2. Assume that a program of robotic missions to Mars would take place before the first human mission, with a mixture of both scientific (MEPAG Goals 1-3) and preparation (MEPAG Goal 4) objectives. Thus, at the time of the first human mission, our knowledge of Mars would be incrementally improved by the results of these robotic missions.
3. Assume that several crews (nominally 4 people per crew) will visit the same surface location at different times and each crew will spend 300-500 sols during their mission on the surface of Mars.
4. Assume that the following capabilities are available to the crew during their time on the martian surface:
    a. Ability to traverse to sites 10s-100s of kilometers away from the landing site
    b. Access to a pressurized habitat that will also house laboratory facilities
    c. Be able to perform multiple Extravehicular Activities (EVA) to gather samples, document visited sites, perform basic analyses, and emplace instrumentation
5. Assume that the objectives of possible human missions to Mars can be organized into three categories: i) Mars planetary science objectives, ii) scientific objectives not related to Mars, and iii) non-scientific objectives. This SAG is asked to limit its attention to only the first of these categories (but an actual future mission would likely have objectives in all three areas).

HSO-SAG Findings (1 of 2)

Finding 1: New discoveries could influence the design of a 2035 mission only through about 2030, and discoveries through at least 2035 could influence how that system is operated.

Finding 2: Although the coming Mars exploration missions and scientific research of the late 2010s and 2020s will make eagerly anticipated discoveries, we expect that the high level science objectives and priorities for Mars will not change significantly prior to 2030.

Finding 3: A proximal human would add greatest value to science in 4 kinds of activities:

- Establishing geologic context (field observations & field measurements)
- Sampling
- Sample prep and analysis in a habitat-based laboratory
- Field investigations/analyses

Finding 4: The range of possible science objectives to be addressed during a crewed mission would be broader if crewed mission architecture supports the development of and an ability to routinely switch between styles of robot involvement, crew control and crew/robot interaction to achieve tasks.

Finding 5: Operation of robots out of the line of sight of crew could be used to extend the human presence beyond the EZ or into protected areas.

HSO-SAG Findings (2 of 2)

Finding 6: Use of robots to support EVA-related activities could increase the number of or degree of satisfaction of a science objective(s) be enabling crew to focus on tasks that benefit from a human presence.

Finding 7: Preparation for a potential Mars surface mission requires more focus on the development and testing of operations concepts that include human-robotic interaction. This also requires development and testing of supporting technologies and systems.

Finding 8: A multi-disciplinary set of candidate mission-level scientific objectives, organized by astrobiology, atmospheric science, and geoscience, has been identified.

Finding 9: Because it is probable that no single exploration zone on Mars would allow a crewed mission to achieve all of the candidate objectives to a sufficient degree of satisfaction, the identification of a human mission Exploration Zone and the further development of the mission concept would result in changes to the science objective set.

Finding 10: A defensible evaluation of surface science operations options and candidate scenarios cannot be done at this time—we recommend deferring this to a future team.

Candidate Objectives: Astrobiology

(not listed in priority order)

A1	Past Life: search for and characterize past habitability potential in environments with highest preservation potential for ancient biosignatures.
A2	Determine if evidence of past life is present in such environments.
A3	Present Life: search for and characterize modern environments with high habitability potential for extant life.
A4	Determine if evidence of extant life is present in such environments.
A5	Investigate the exchange and cycling of material between the subsurface, surface and atmosphere.
A6	Investigate the complex chemistry (e.g., degree of covalency, organic chemistry and redox gradients) in the ***near surface***, understand the mechanisms for organosynthesis, alteration and destruction.

Prioritization note: A key unknown is the relative prioritization of the two pairs A1-A2 and A3-A4. A realistic assessment of this would require an analysis that has more dimensions (including risk factors) than HSO could carry out.

Candidate Objectives: Atmospheric Science

		Priority
B1	Simultaneously quantify the atmospheric state and forcings near the surface at four or more locations supplemented by regular vertical atmospheric structure information.	High
B2	Constrain past climate states and atmospheric composition through analysis of samples from the Noachian and Hesperian, including trapped gases and inclusions.	High
B3	Characterize the local source and sinks in the dust, water and CO_2 cycles, and the key parameters that determine these sources and sinks across a diversity of surfaces.	Med
B4	Quantify photochemical and electrochemical cycles and potential subsurface trace gas sources through the measurement of trace gases, heterogeneous reactions and the electrical environment.	Med
B5	Infer previous climate states and atmospheric composition under different orbital configurations through chemical and isotopic analysis of sediments and water ice emplaced during the Amazonian.	Low
B6	Provide simultaneous context for near-surface atmospheric characterization through the global monitoring and quantification of the atmospheric state, forcings, and the distribution of airborne aerosols and trace gases.	Low

- Listed in order of approximate overall scientific return (and secondarily, added value of proximal humans with respect to B6) if carried out by a 2035 human mission to the martian surface.
- Note: B6 should only be done in conjunction with one (or more) of Objectives B1, B2, or B5.

Candidate Objectives: Geoscience

		Priority
C1	Characterize the composition of surface units and evaluate the diverse geologic processes and paleoenvironments that have affected the martian crust; determine the sequence and duration of geological events, and establish their context within the geologic history of Mars to answer larger questions about planetary evolution (to be refined based on discoveries during the next decade). See next slide for additional detail.	High
C2	Determine relative and absolute ages of geologic events and units, determine their history of burial, exhumation, and exposure, and relate their ages to major events through martian history.	High
C3	Constrain the dynamics, structure, composition and evolution of the martian interior, to answer larger questions about planetary evolution (to be refined based on discoveries during the next decade). See next slide for additional detail.	High/ Med

- C1, C2 and C3 all have very high science merit. C1 and C2 have high potential for benefit from proximal human presence, and C3 has slightly less (medium to high) potential for benefit from proximal human presence.
- The relative prioritization reflects the exploration logic and epistemological approach used in all geoscience disciplines: 1) assess what can be learned about the surface and interior from ground level, 2) generate quantitative measurements of the rates and timing of processes and events, and 3) use this knowledge to inform investigations of the deep interior that is not physically accessible from the surface.

Geoscience Objective: Additional Detail

Larger questions about the planet and its evolution (to be refined based on discoveries during the next 2 decades) addressable by Objectives C1 and C3:

Q1. How have the mineralogical and geochemical properties of martian igneous rocks changed over geological time and across global length scales, and how do these changes reflect changing conditions in the martian interior?

Q2. In what ways are the oldest martian rocks similar or different in composition or formation mechanism to the oldest terrestrial and/or lunar rocks.

Q3. How has the mineralogy and geochemistry of alteration products changed over geological time (epochs and obliquity cycles), and what does that indicate about changing climate or subsurface environmental properties?

Q4. How do impacts disrupt and redistribute crust and mantle material?

Q5. What were the processes of magmatic activity on Mars, how did they change with time, does volcanism persist to the present, and how does this contribute to crustal formation and resurfacing?

Q6. What is the nature and diversity of tectonism (faulting and flexure) over martian geological history?

Q7. What was the role of ice-related processes in modifying the martian surface?

Q8. What was the history and abundance of surface water and groundwater on Mars, and how is this reflected in the sedimentary and geochemical record?

Q9. How has the atmosphere of Mars changed over time and how has it affected sedimentary and erosional processes?

Q10. What was the history of the martian dynamo, and what was the cause and history of its cessation?

Q11 What was the compositional and dynamical evolution of Mars' mantle?

Q12. What is the structure of the martian interior?

Q13. What was the origin of Mars and its thermal evolution?

Q14. What are the modern sources of seismicity on Mars and how do they relate in magnitude or location to global tectonic or structural processes that have been active in the past?

(not in priority order)

Candidate Objectives: Cross-Cutting

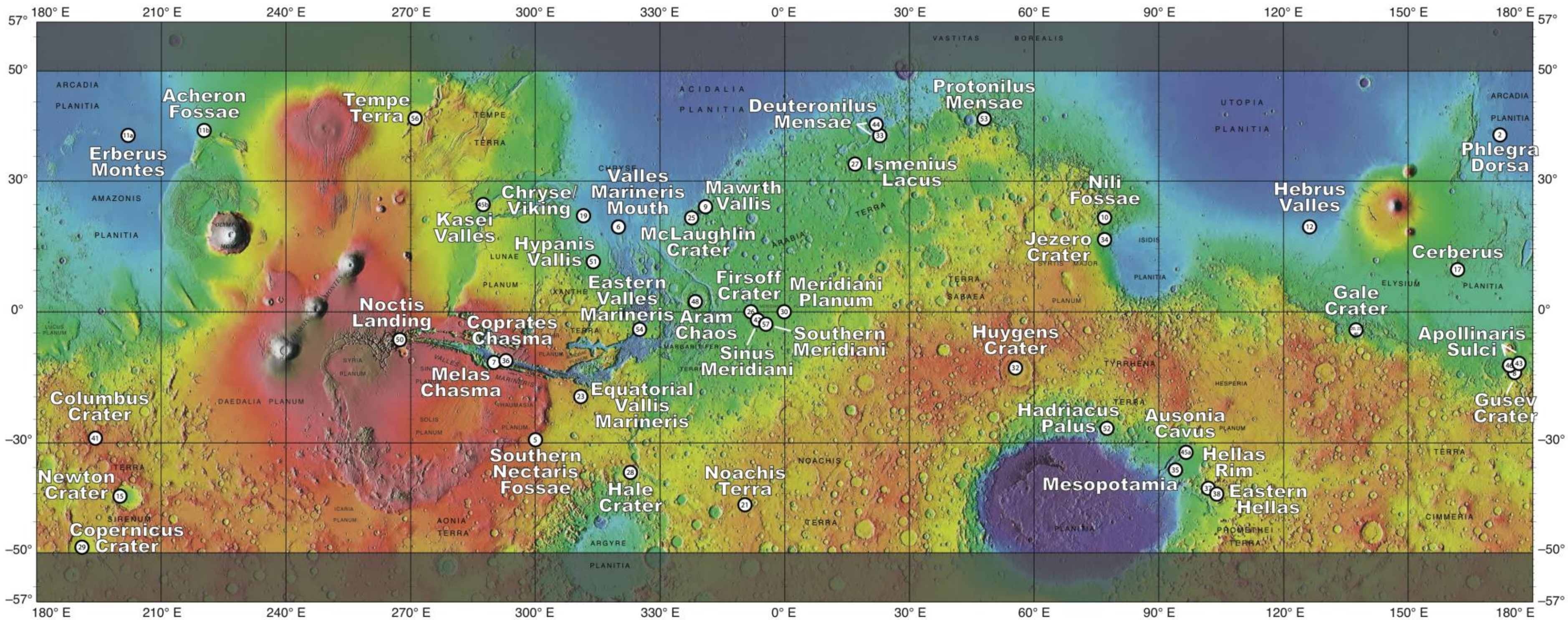
D1	Assuming the mission accesses at least one significant concentration of water as part of its ISRU operations, evaluate that deposit for its implications to astrobiology, atmospheric science, and geology.
D2	Characterize the impact of humans on the martian environment.
D3	Evaluate variability in the martian radiation environment.

Site Selection Criteria for Human Mars Missions

Exploration Zone Criteria Full Description	Shorthand Title
Astrobiology	
* **Access to deposits with a high preservation potential for evidence of past habitability and fossil biosignatures.**	**Past Habitability**
Presence of sites that are promising for present habitability, e.g. as a refugium.	**Present Habitability/ Refugia**
Access to deposits with high potential for containing organic matter (indigenous or exogenous) with various lengths of surface exposure.	Organic Matter
Atmospheric Science	
Noachian and/or Hesperian rocks in stratigraphic context that have high likelihood of containing trapped atmospheric gasses.	**Trapped Atmospheric Gasses**
Presence of meteorological diversity in space and time.	Meteorological Diversity
High likelihood of surface-atmosphere exchange of dust (e.g., aeolian and dust devil activity) and water across a diverse range of surface types (e.g., dust cover, albedo, thermal inertia, surface roughness, and rock abundance).	Surface-Atmosphere Exchange
Access to Amazonian-aged subsurface ice, high latitude water ice (e.g., polar layer deposits), and Amazonian-aged sedimentary deposits.	Amazonian Ice/ Sediment
High likelihood of active surface trace gas sources.	Active Trace Gas Sources
Geosciences	
Exposures of at least two crustal units that have regional or global extents, that are suitable for radiometric dating, and that have relative ages that sample a significant range of martian geological time.	**Two Datable Surfaces**
Access to outcrops with morphological and/or geochemical signatures (with preference given to sites that link the two) indicative of aqueous processes or groundwater/mineral interactions.	**Aqueous Processes**
Identifiable stratigraphic contacts and cross-cutting relationships from which relative ages can be determined.	**Stratigraphic Contacts**
Access igneous rocks that can be clearly tied to one or more distinct igneous provinces and/or from a range of different martian time periods.	Igneous Rocks
Access to near-surface ice and/or glacial or permafrost-related sediments.	Ice and/or Glacial
Access to Noachian or pre-Noachian bedrock units.	Noachian Bedrock
Access to outcrops with remnant magnetization.	Remnant Magnetization
Access to diverse deposits from primary, secondary, and basin-forming impacts.	Diverse Impacts
Access to structural features that have regional or global context.	Structural Features w/ Context
Access to a diversity of aeolian sediments and/or landforms.	Aeolian Features

__Notes__: 1). Threshold criteria are listed in bold. 2). The astrobiology threshold criteria are linked by a logical AND/OR--at least one of the two must be present, but they are not both required.

Potential Exploration Zones for Human Missions to the Surface of Mars



Exploration Zones proposed for humans to Mars.
Numbers correspond to the abstract submission #
At the equator, circles are ~100km radius

version 2.0 Sept 11, 2015

Prepared By: Lindsay Hays, Mars Program Office
lhays@jpl.nasa.gov

"First Landing Site/Exploration Zone Workshop for Human Missions to the Surface of Mars" held at LPI on October 27-30, 2015

HSO-SAG Conclusions

For a potential 2035 martian surface human mission:

- Program-level scientific objectives at that point in the future are interpreted to be close to what they are today.
- A candidate set of scientific objectives has been identified that could be assigned to this mission that would be both compelling scientifically, and would take advantage of the unique attributes of this mission.
- Robotic-human partnership would be important for this mission, and the details would affect the quantity and character of the science returned.
- From the objectives, a set of draft science site criteria, organized into two priority levels, has been identified.

HSO-SAG Recommendations for Future Studies

1. We recommend further definition of the candidate objectives as the real constraints associated with human missions to Mars become better known, and as the constraints/opportunities associated with actual martian Exploration Zones are more fully defined. This is likely to require a team of mixed scientists and engineers.
2. The astrobiology objectives/priorities are highly dependent on potential discoveries that may be made in the next 15 years--thus, it is important that this analysis be revisited periodically in light of future exploration results. This is especially true of strategies and implementation options for subsurface access—this has the potential to dominate the mission implementation, so careful prioritization and decision-making is especially important.
3. The possible future PP constraints associated with the pursuit of certain kinds of scientific objectives needs better definition.

Science and Human Exploration for Mars: Summary Points

- The science goals for humans exploring on the surface of Mars are principally the same as for missions operated by humans at a distance.

- What humans bring is the ability to deal with the unexpected, to quickly make decisions which enhances flexibility, mobility and productivity.
  - Humans can go outside their “programming”, revising the plan in response to discovery
  - Their ability to access interesting areas is limited by their equipment (including suits) and the mission risk posture

- For humans to be effective, they must have the right tools (e.g., analytic labs with sample preparation and support equipment (communications, reconnaissance, life support, and transport capability) and they need time => long-duration stays
  - This infrastructure enables science that otherwise might not be done
  - To investigate the diversity of Mars takes time.

- Long-duration stays imply in-situ resource utilization.

- The very introduction of human beings onto the Mars surface, the utilization of Mars resources, and the production of sustaining materials raises planetary protection issues that need discussion to inform future architecture & procedures.