Candidate Scientific Objectives for the Human Exploration of Mars, and Implications for the Identification of Martian Exploration Zones

Scientific Objectives for the Human Exploration of Mars Science Analysis Group (MEPAG HSO-SAG)

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An earlier draft of this analysis was presented and discussed June 4, 2015 with the Human Landing Site Steering Committee, and this version incorporates feedback from that session. This document has been approved for unlimited release. *Copyright 2015. All rights reserved.*

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Statement of Task

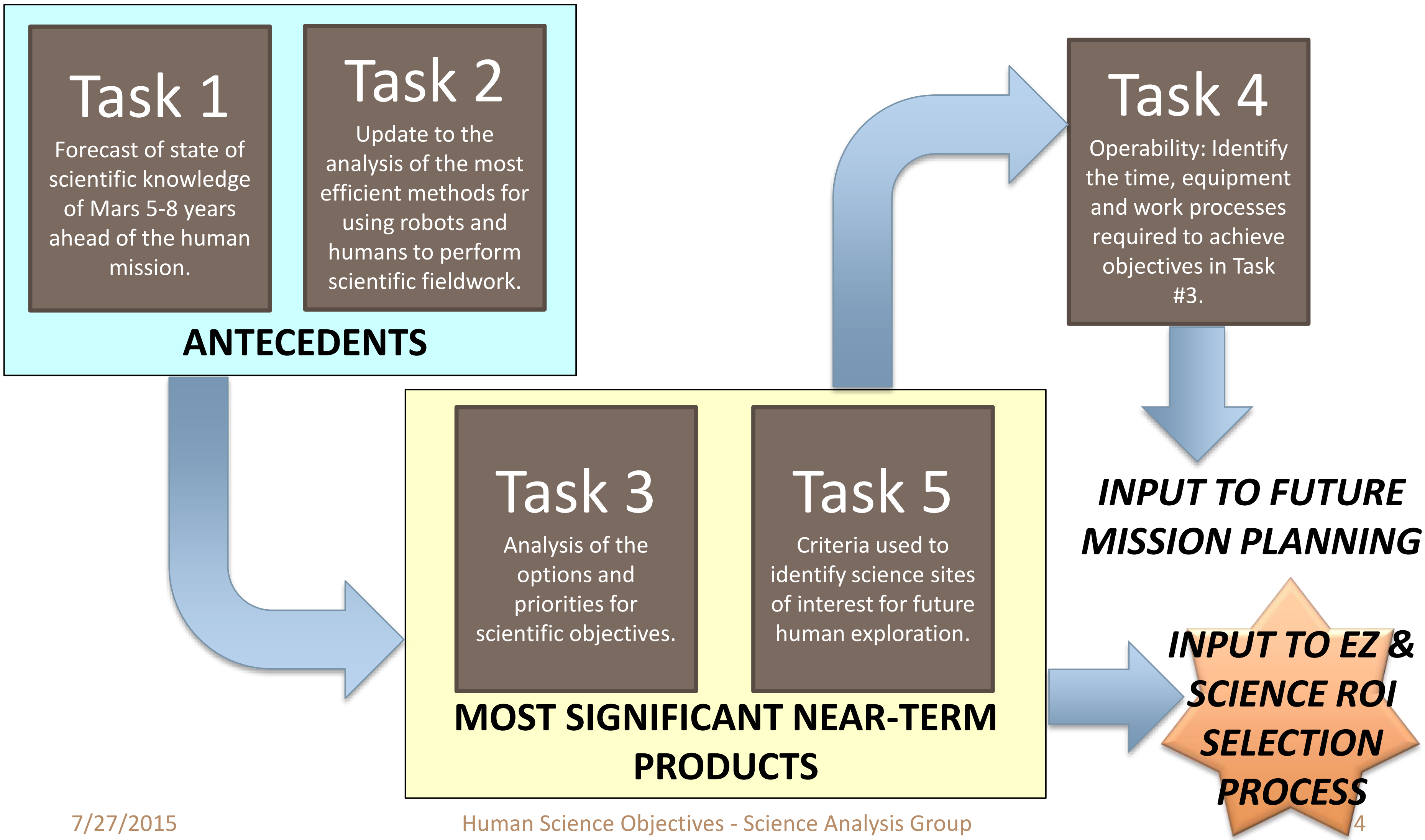
<u>Requested Tasks</u>

1. Prepare an update to the forecast of our state of scientific knowledge of Mars as of 5-8 years ahead of the human mission, including an analysis of how potential discoveries might change those priorities.
2. Prepare an update to the analysis of the most efficient methods for using robots and humans to perform scientific fieldwork, including what kinds of future technology could improve this efficiency.
3. Prepare an updated analysis of the options and priorities for scientific objectives that could be logically and productively assigned to recurring human missions to the Martian surface, in the context of Tasks #1-2 above. Rather than a single deterministic answer, it will be important to present a range of outcomes that can be scaled up or down depending on engineering constraints.
4. Operability. Identify the time, equipment and work processes likely to be required to achieve the candidate objectives in Task #3 above. Distinguish what might be achieved at a single Exploration Zone during a short-term stay (<50 sols), during a long stay (300-500 sols) and during repeated long stay visits, and the rationale. Identify those objectives that are most likely to need to be responsive to new discoveries made during the course of a mission, and whether that might require a significant change in the science operations plan.
5. Describe the criteria that could be used to identify science sites of interest for future human exploration.

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



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Charter Assumptions (1/2)

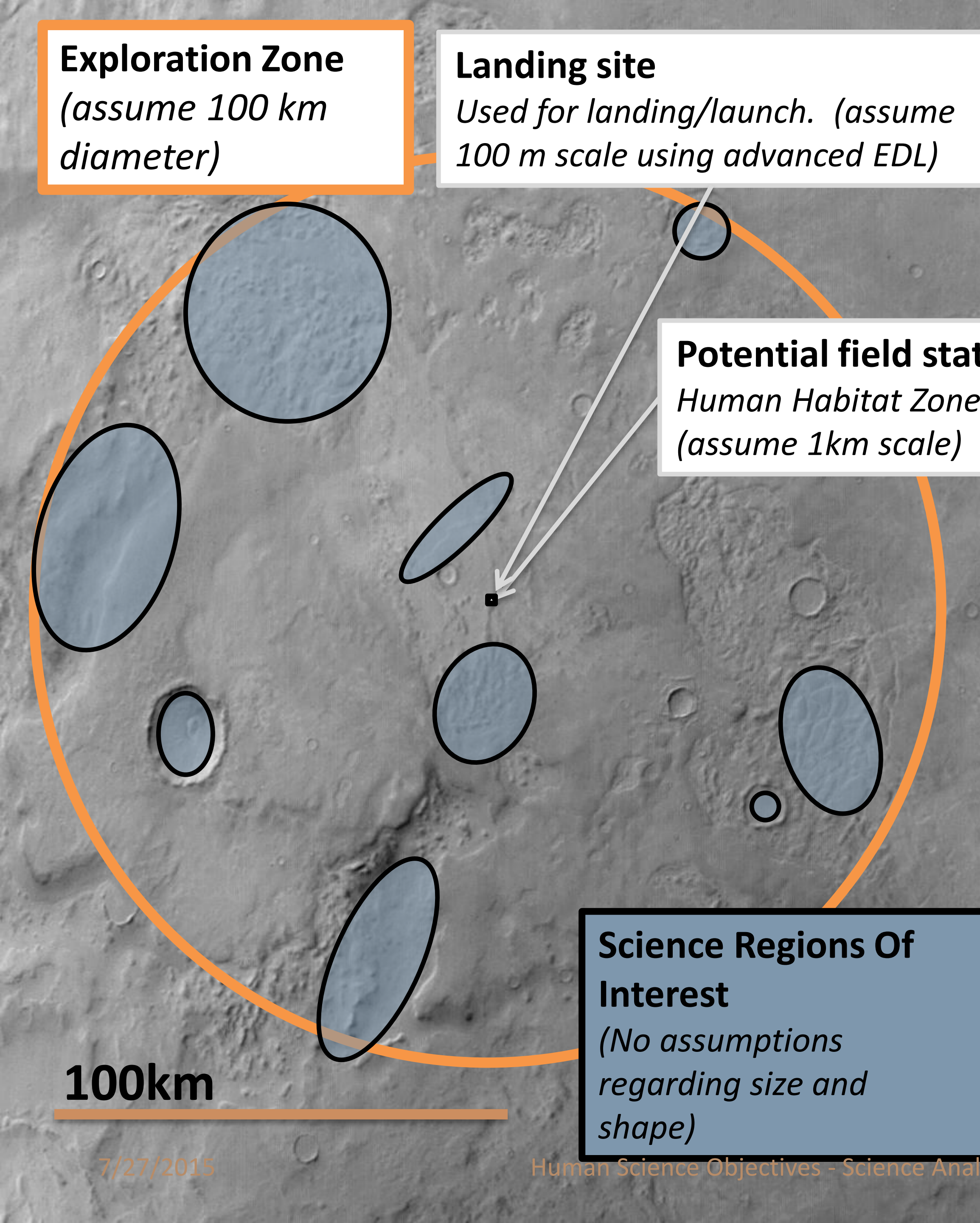
1. **<u>Launch Date</u>**: Date of launch of a human mission to the martian surface: 2035.
2. **<u>Precursor Robotic Missions</u>**: Assume that a program of robotic missions to Mars would take place before the first human mission, with a mixture of both scientific (MEPAG Goals 1-3) and preparation (MEPAG Goal 4) objectives. Thus, relative to what we know today, at the time of the first human mission our knowledge of Mars would be incrementally improved by the results of these missions.
3. **<u>Human Missions</u>**: Assume that more than one mission (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.

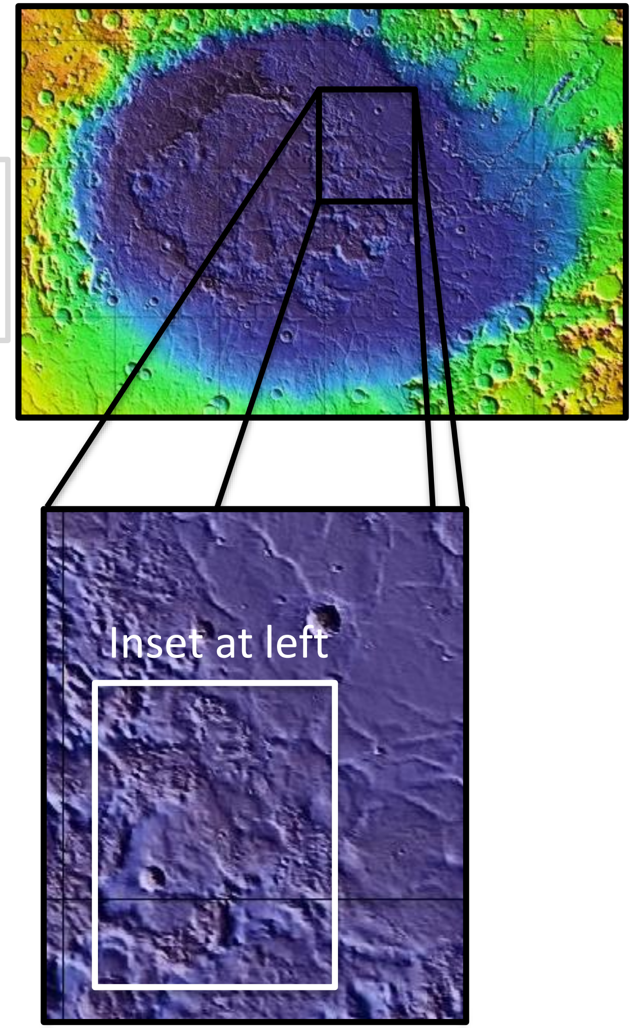
Charter Assumptions (2/2)

4. **<u>Crew Capabilities</u>**: Assume that the following capabilities are available to the crew during their time on the martian surface:
   a. Ability to traverse to sites at least 100 km away from the landing site.
   b. Laboratory facilities (of as-yet undefined functionality) located in a pressurized habitat.
   c. Multiple Extravehicular Activities (EVA) to gather samples, document visited sites, perform basic analyses, and emplace instrumentation.
5. **<u>Objectives</u>**: 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).

**Prior committees have pointed out that a human mission to Mars may create opportunities for observations related to astrophysics, heliophysics, or non-Mars solar system objects—all of this will be evaluated by others.*

Nomenclature





Example illustrated here is from Hellas Planitia

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Note About Planetary Protection

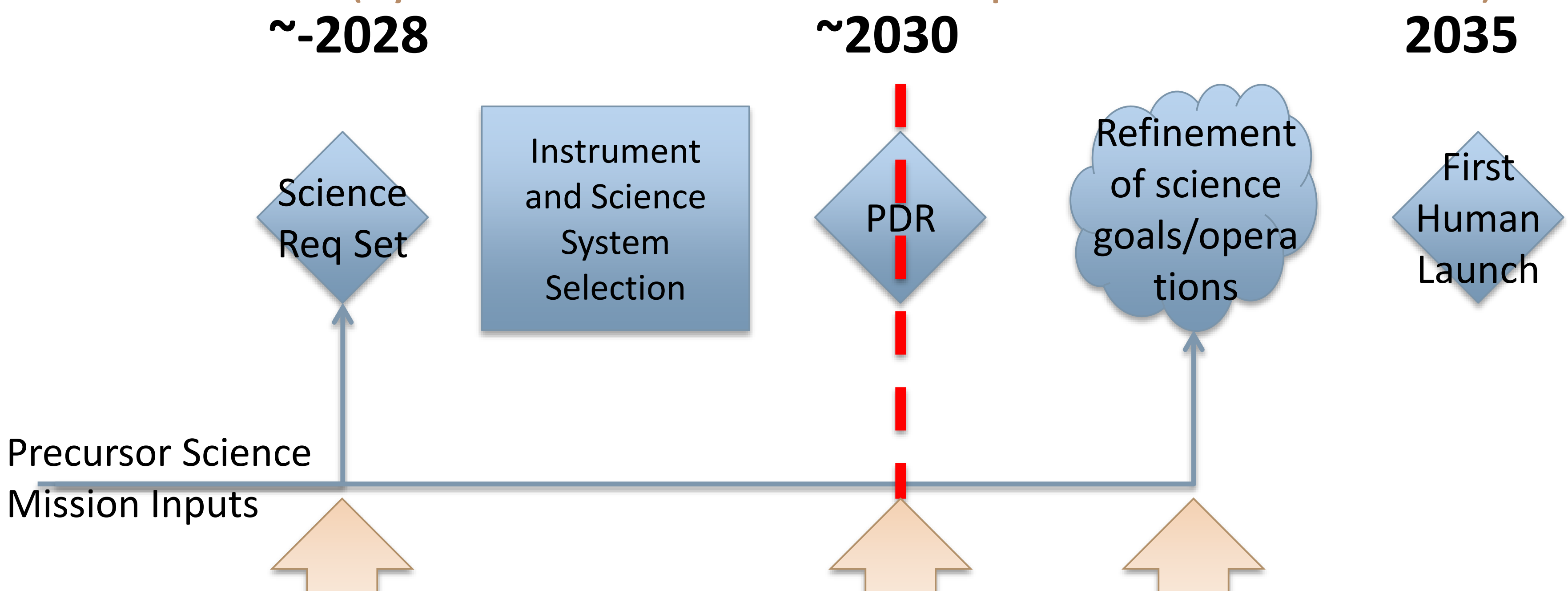
- There will be updates to the PP policies between now and 2035, but we cannot reliably forecast their technical specifics.
- Current PP policy allows for the exploration of all places on Mars, as long as the mission implementation is appropriate. We do not know the latter.
- Although PP considerations will be important to the planning of eventual human missions, the site criteria derived here are evaluated from science factors only.

Provide background for forecast of state of knowledge

FORECAST (TASK #1)

Generic Development Timeline for a Potential 2035 Mission

(cycle would continue for repeat human missions)



Scientific objectives for the 2035 launch would need to be established ~here.

Major mission scientific equipment for this launch would need to be decided by ~here.

Minor equipment for the this launch could be changed up to this point

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.

Mars Missions That Will/May Contribute New Data Prior to 2030

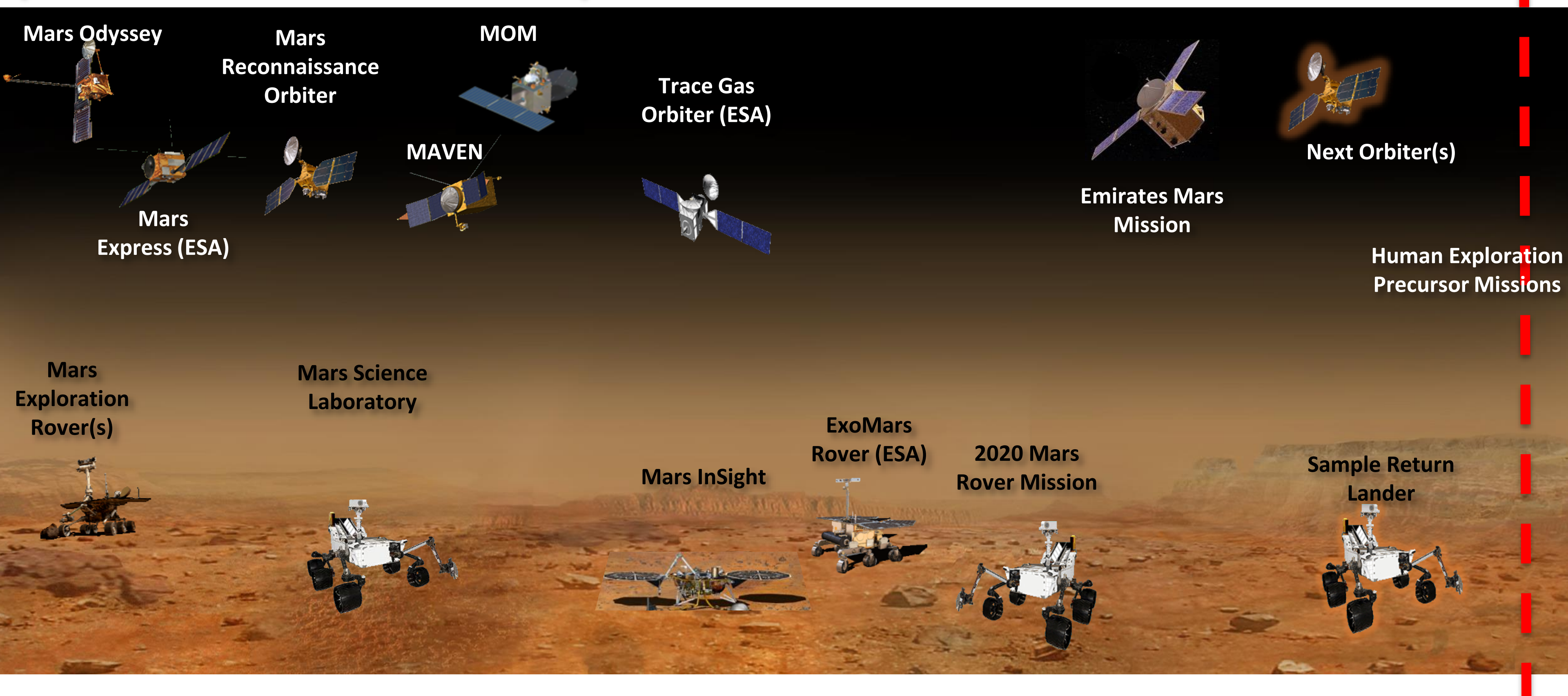
Active Missions as of 2015

Announced future missions

2016 2018 2020 2021

Potential Missions in the 2020s

2030



Potential Future Discoveries

- There are several upcoming missions that promise science results before 2030-2035.
- Additional exciting results are expected from ongoing analysis of data returned from present and past missions, Mars meteorite research, interdisciplinary insights, and technological advancements.
- Certain low probability, high impact events (e.g discovery of extant life) would have a significant influence on planning.

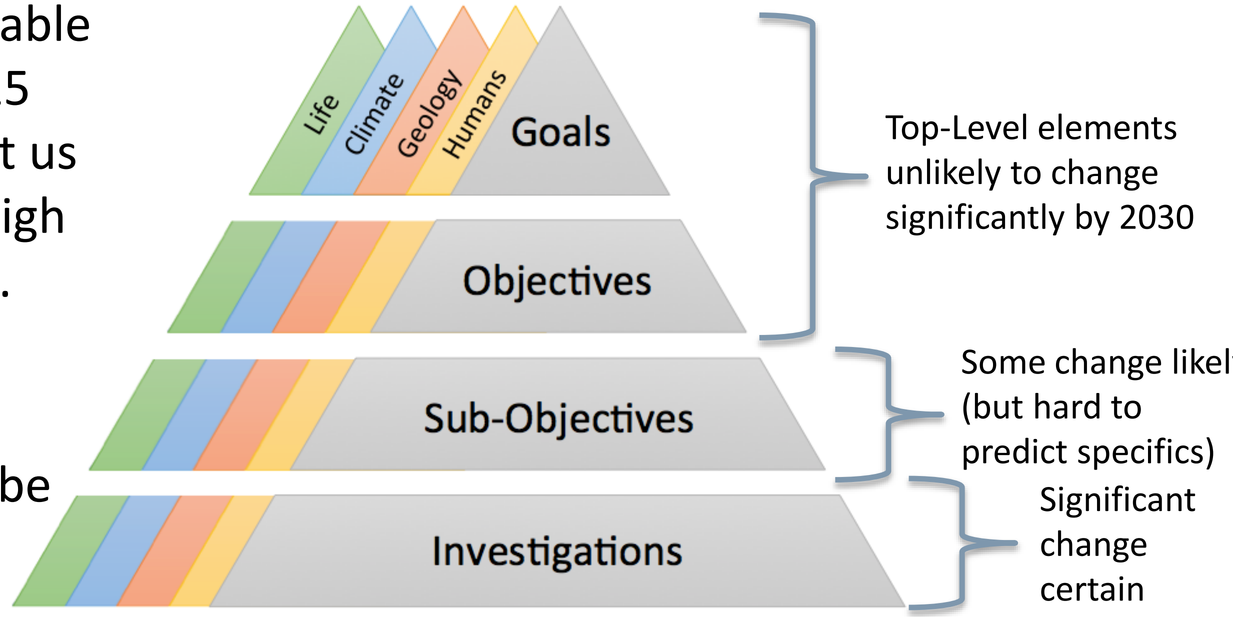
EXAMPLES OF SCIENTIFIC DISCOVERIES THAT ARE POSSIBLE BY 2035

A	Discovery of evidence for ancient life through future rover investigations, Mars sample return, ongoing data analysis, or Mars meteorite investigations.
B	Discovery of a potential subsurface source for trace gas emissions including methane through future orbital measurements or ongoing data analysis.
C	Discovery of buried equatorial ice or near surface water through future rover investigations, ongoing data analysis, or orbital measurements.

Note: List not exhaustive—many other discoveries possible/probable

Forecast of 2030s' Objectives

- However, the most probable discoveries of the next 15 years are unlikely to shift us away from the current high level objective structure.
- These scientific goals/objectives can therefore appropriately be used for 2035 mission planning.
- (See slides 50-51 for current MEPAG objectives.)
- See also: mepag.jpl.nasa.gov



MEPAG's 4-Tiered Hierarchy

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.

Outline proposed overlaps between robots and humans

ROBOTS AND HUMANS (TASK #2)

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The Major Advantages to Science of a "Proximal Human"

- A distinguishing feature of the potential 2035 mission concept would be the presence of a "proximal human". We use this term generically to include:
  - Work directly done by astronaut-explorers
  - Supervision/control of nearby robotic assets
  - "Proximal" may include interactions with humans in orbit—this possibility is TBD
- Science efficiency during a crewed mission could be enhanced by complementary operation between crew/humans and robots
  - Crew better at rapid cognition (robots improving), non-repeated tasks, science decisions, mapping and geologic interpretation, (others)
  - Robots better at/in repetitive tasks, precision tasks, hazardous or protected environments (others)

Finding 3:

A proximal human would add greatest value to science in four kinds of activities:

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

Value Added to Science Investigations by Proximal Humans: **Establishing Geologic Context**

- Establishing Geologic Context:
  - All geologic investigations have a high magnitude of advantage from proximal humans to understand, cross-correlate, and map the geology of the Exploration Zone.
  - Humans in the field can rapidly collect and process visual data to determine stratigraphic relationships, superposition relationships, rock types, structures, and landforms.
  - Humans can more efficiently make judgments in the field on which rocks are like each other, and which are different.
  - Humans can more easily manipulate the martian surface in effective ways to gather information about rock types, stratigraphic relationships, and surface properties.

Observations made of rocks in situ are crucial for establishing geologic context. Credit: Rawlings 1997

Value Added to Science Investigations by Proximal Humans: **Sampling**

- Sampling:
  - All investigations that require sampling have a high magnitude of advantage from proximal humans.
  - Sampling is an iterative process that requires knowledge of context: interrogating an outcrop or landscape and interacting with it.
  - Collecting the most meaningful samples requires using judgment and experience to combine multiple streams of data to build a conceptual model of the site to test multiple working hypotheses.
  - This ensures that when samples undergo further analysis, these measurements could be linked directly to the investigation or hypothesis that required samples in order to be addressed.
  - Human situational awareness improves the likelihood of identifying important samples of opportunity*.

Martian conglomerate including rock target "Harrison" taken by Curiosity. Credit: NASA/JPL-Caltech

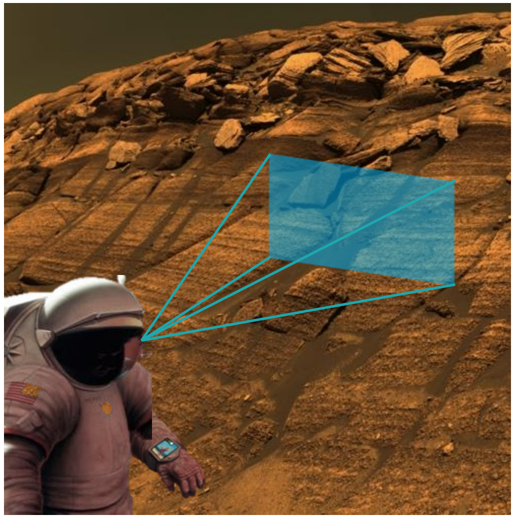
**samples of opportunity: Samples of unique value that are unexpectedly available to be sampled (e.g. xenoliths, meteorites, veins, certain breccia clasts, etc.)*

Value Added to Science Investigations by Proximal Humans: **Laboratory Measurements**

- Laboratory Analyses:
  - Many laboratory measurements made on the surface of Mars have significant advantages from human presence.
  - Humans can rapidly adapt when samples have unexpected properties (e.g., cloddy/sticky soil, unexpected oxidants).
  - Humans can manipulate and prepare samples in an unlimited variety of ways, ensuring that the right kinds of measurements are made on the most important part(s) of the sample to address the investigation.
  - Humans can respond to unexpected laboratory outcomes by modifying their sample collection strategy or methodology.

Value Added to Science Investigations by Proximal Humans: **Field Measurements**

- Field Measurements:
  - Many field measurements to be made on the surface of Mars have significant advantages from proximal humans.
  - Geophysical and geochemical sensor systems benefit from troubleshooting and optimization in order to improve the targeting or data collection parameters of the sensor. Humans both speed up the rate of measurement as well as improve its quality.



Astronaut on Mars examining outcrop. Image of Burns Cliff of Endurance Crater. Credit: NASA/JPL/Cornell

Human/Robot Interactions

- A human mission could possibly utilize robots effectively to more efficiently achieve some of its science objectives while others would be best accomplished by humans alone.
  - Key example: Sterilized robots may be able to explore special regions in order to minimize forward and backward contamination.
- High latency rover operations on Mars (where humans are operating from Earth) are well understood:
  - MER, MSL, future missions
- The types of robots that would be utilized and the model of human/robot operation for a human mission are not clearly defined.
  - There are several existing models of human robot interaction that could be useful:
    - International Space Station
    - Subsea oil rig repair
    - Teleoperated, minimally invasive surgical techniques
  - Overall concept of operations needs more development:
    - Interaction during field work
    - Exploration of special regions
    - Reconnaissance

Style of Crew Control and Interaction with Robots

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- The crew and robots would have several styles of interaction during a crewed mission:
  - Crew and Robot cooperating on tasks both inside and outside of a pressurized habitat
  - Crew and Robots handoff tasks between each other when appropriate
  - Robot operates independent of Crew
- The science objectives to be addressed during a crewed mission are influenced by robot involvement, the style of crew control and the style of crew/robot interaction that are supported by the mission architecture.
- Some objectives are better met by different combinations of robot involvement, crew control and crew/robot interaction.

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.

Range of Style of Human/Robot Control/Interaction

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Interaction:

Robot and crew together

Robot or crew work tasks independently in close proximity; hand off as appropriate

Robot works independently with no crew present

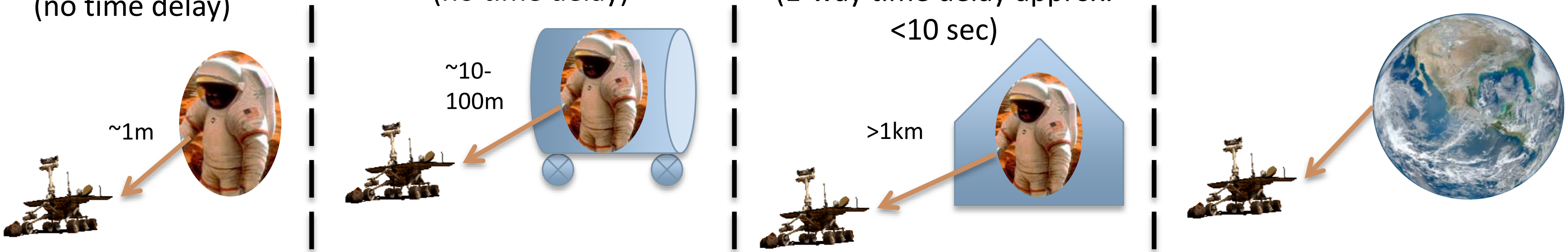
Control:

From Suit
(no time delay)

From Pressurized Rover
(no time delay)

From Habitat
(1-way time delay approx. <10 sec)

From Earth
(1-way time delay >600 sec)



Telepresence Beyond an Exploration Zone

- Robots operating beyond line of sight of crew could extend the human presence beyond the edge of the EZ (telepresence) (see Slide 7):
  - Telepresence elsewhere on Mars
  - Telepresence in protected areas on Mars
- Objectives to be met by telepresence operations should be identified as those that:
  - Benefit from crew operation in the Mars system
  - Support the overall science objectives of the human mission

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.

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EVA Time as a Critical Resource

- Crew time during a crewed mission is a limited resource; only a fraction of the total would be available for science operations
- A main rationale for a crewed mission is to enable EVA time; as such, EVA time must be used to conduct tasks that require a crew presence
- A critical role filled by the use of robots is an ability to ensure that crew time is dedicated to tasks that most benefit from a human presence
  - "let the robot prep the patient, have the human enter for the surgical procedure . . ."

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.

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Humans/Robots Summary

- The style of human/robot interaction may have implications for Exploration Zone selection:
  - Remote operations outside of Exploration Zone may expand the scope of science investigations.
  - What tasks could be accomplished by robots, and how could these be integrated into the human mission to enable the completion of the broadest range of high intrinsic value science objectives?
- One potential example is robotic deployment of science packages by autonomous robots inside or outside the Exploration Zone:
  - Robots could complete tasks such as deployment of science packages to accomplish high value goals while humans complete tasks that most beneficially involve their participation (sampling, lab work field analyses).
  - It is important that these robot-only activities support the overall science objectives of the human mission.

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.

Comprised of MEPAG sub-objectives and/or investigations grouped or split to reflect human-specific science objectives

SCIENTIFIC OBJECTIVES (TASK #3)

Identification and Prioritization of Science Objectives

- As in all missions, intrinsic scientific merit (e.g. MEPAG Goals Document) is a key prioritization criterion for a potential 2035 human mission.
- HSO-SAG also recognized three additional factors for identifying candidate scientific objectives:
  - Magnitude of the benefit of a proximal human (see Slides 13-17)
  - Opportunity to make simultaneous observations from different vantage points
  - Opportunity to deliver scientific payloads of higher mass/complexity
- Further evaluation of the candidate objectives will need to account for implementation factors such as mass, power, cost, risk to crew, etc. (not done in this study).

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

Note: No prioritization was made between candidate objectives in the different disciplines, although prioritization was made within some of the disciplines.

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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

	Objective	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.

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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 Objectives—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.

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Candidate Science Objective Set, First Human Mission to Mars

(not in priority order)

	Science Objective	Shorthand Title
A1	Past Life: search for and characterize past habitability potential in environments with highest preservation potential for ancient biosignatures.	Past Habitability
A2	Determine if evidence of past life is present in such environments.	Evidence for Past Life
A3	Present Life: search for and characterize modern environments with high habitability potential for extant life.	Modern Habitability
A4	Determine if evidence of extant life is present in such environments.	Evidence for Extant Life
A5	Investigate the exchange and cycling of material between the subsurface, surface and atmosphere.	Material Exchange
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.	Near Surface Chemistry
B1	Simultaneously quantify the atmospheric state and forcings near the surface at four or more locations supplemented by regular vertical atmospheric structure information.	Near Surface Atmosphere
B2	Constrain past climate states and atmospheric composition through analysis of samples from the Noachian and Hesperian, including trapped gases and inclusions.	Past Climate - Gases
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.	Sources and Sinks
B4	Quantify photochemical and electrochemical cycles and potential subsurface trace gas sources through the measurement of trace gases, heterogeneous reactions and the electrical environment.	Trace Gases
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.	Past Climate - Sediments
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.	Global Context
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).	Surface Unit Composition
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.	Relative and Absolute Age
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).	Interior
D1	Assuming the mission accesses at least one significant concentration of water at part of its ISRU operations, evaluate that deposit for its implications to astrobiology, atmospheric science, and geology.	ISRU
D2	Characterize the impact of humans on the martian environment.	Impact of Humans
D3	Evaluate variability in the martian radiation environment.	Martian Radiation

Candidate Objectives: Some Important Caveats

- HSO-SAG fully understands that the potential 2035 mission would be constrained in mass, power, volume, cost, mission risk, astronaut risk, and other things.
- It will not be possible to optimize the science objective set for a given set of resources:
  - Until the above constraints are applied in a systematic way,
  - Until the science objectives in different categories can be cross-prioritized against each other,
  - Until the limitations associated with different landings sites are understood.

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.

Time, equipment and work processes likely to be required to achieve the candidate objectives

SCIENCE OPERATIONS (TASK #4)

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Surface Science Operations

- As summarized on the following slide, achieving the scientific objectives would require a mission implementation with at least:

- mobility systems,
- significant EVA time,
- field-based mapping and sample selection capability,
- a habitat-based laboratory (of as yet undefined capability),

- capability for subsurface exploration (of as yet undefined method and depth),
- the deployment of long-period scientific instruments,
- and potentially, the placement and control of robotic assets outside the Exploration Zone.

- It will be important at some point to determine the fraction of the mission's resources that could be justified in carrying out each of the above activities. However, judging the priorities of these options requires information outside our visibility, such as total available resources (e.g. cost, down-mass, volume, energy), impact on risk (both to mission and to crew), limits on up-mass, etc.

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.

Preview of Task #4 (Mission Implementation)

Potential implementation implications of the candidate objective set:

ASTROBIOLOGY	ATM. SCIENCE	GEOLOGY
• EVA time needed to support subsurface exploration • Field measurements key • Sample-based studies and Hab lab important to the logic • Other?	• Deploy/maintain a comprehensive and properly accommodated surface weather station with vertical profiling capabilities. • EVA time needed for surf-atm exchange experiments • Sample-based studies and Hab lab important to the logic	• Major need for EVA time for outcrop studies • Mobility systems are essential • Sample-based studies and Hab lab important to the logic • Instrument deployment

Most important currently expressed interest in remote assets:

ASTROBIOLOGY	ATM. SCIENCE	GEOLOGY
Special Regions exploration	Secondary weather stations with simultaneous orbital data	Amazonian ice studies

Science site criteria derived from scientific objectives

SCIENCE SITE CRITERIA (TASK #5)

Site Criteria Traceability Matrix

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Science Site Criteria

Science Objectives

		Past Habitability	**Present Habitability/ Refugia**	Organic Matter	**Trapped Atmospheric Gasses**	Meteorological Diversity	Surface-Atmosphere Exchange	Amazonian Ice/ Sediment	Active Trace Gas Sources	**Two Datable Surfaces**	**Aqueous Processes**	**Stratigraphic contacts**	Igneous Rocks	Ice and/or Glacial	Noachian Bedrock	Remnant Magnetization	Diverse Impacts	Structural Features w/ context	Aeolian Features
A1	Past Habitability	■																	
A2	Evidence for Past Life	■																	
A3	Modern Habitability		■																
A4	Evidence for Extant Life		■																
A5	Material Exchange																		
A6	Near Surface Chemistry			■															
B1	Near Surface Atmosphere					■	▒												
B2	Past Climate - Gasses				■														
B3	Sources and Sinks					■	■												
B4	Trace Gasses					■	■		■										
B5	Past Climate - Sediments							■											
B6	Global Context																		
C1	Surface Unit Composition							▒		■	■		■	■	■		■	■	■
C2	Relative and Absolute Age									■		■	■						
C3	Interior								▒	■			■			■	▒		
D1	ISRU																		
D2	Impact of Humans																		
D3	Martian Radiation																		

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Site Selection Criteria

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.

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How to Use Criteria

- The criteria identify a desired characteristic that is based on scientific interpretation:
  - A successful Exploration Zone proposal should provide reasonable justification for how their zone meets the criteria through analysis of available data
  - Exploration Zone proposals should also indicate particular data needs that could be collected in the near future with available resources
- A credible scientific mission should meet all the “threshold” criteria.
  - These criteria are the highest priority criteria.
- The best Exploration Zone should meet multiple criteria from each discipline.
- The best Exploration Zone should also meet one or more criteria to a high degree of satisfaction.

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.
- We have identified a candidate set of scientific objectives 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, we have derived a set of draft science site criteria, organized into two priority levels.

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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.

BACKUP

HSO-SAG Charter - Introduction

Introduction

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 is 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.

HSO-SAG Charter - Background

Background

Beginning in March 2007, and concluding in February 2008, MEPAG carried out an analysis of the potential scientific objectives for the human exploration campaign described in DRA5.0 (Drake, 2009). For planning purposes, this campaign was assumed to consist of 3 separate landings, spaced one launch opportunity apart. MEPAG was asked to evaluate two major uncertainties in this planning of relevance to science: 1). Should the missions be short-stay or long-stay?, and 2). Should the assumed campaign of three missions be sent to the same site, or to different sites? MEPAG carried out this analysis by means of a Science Analysis Group referred to as HEM-SAG (2008).

In the 8 years since the HEM-SAG study was carried out, there have been a number of changes.

- There has been 8 years' worth of progress in the robotic exploration program (including successful launch and Mars arrival of MRO, PHX, MSL, MAVEN, and MOM). This has resulted in some important recent discoveries that fundamentally shift the possibilities for humans on Mars with regard to both science and utilization of in situ resources. In particular, multiple lines of evidence now indicate that water ice and brines may be present at or near the surface of Mars across a wide range of latitudes and landforms. Although this increases both the possibilities for human-relevant resources, and the scientific interest of such places, it also increases planetary protection concerns.
- It is now understood that Mars' obliquity cycle is inferred to destabilize the polar ice caps periodically and allow for the growth of mid-latitude glaciers and ground ice on timescales of tens to hundreds of thousand years. Viewing Mars as a dynamic planet with an active water cycle is a major shift from the prevailing view 10 years ago.
- There are a number of exciting Mars missions in development (including M-2020, ExoMars-TGO, ExoMars-Lander, and Insight) that promise additional progress in our understanding of Mars, before the arrival of humans.
- Human Exploration has become more probable and HEO has refined their concepts of the mission architecture, and has begun to test relevant hardware (such as the Orion spacecraft). In addition, new approaches such as the Evolvable Mars Campaign have been proposed, and these may have implications for the number of sites to be visited and the nature of the surface system (particularly in the area of ISRU).

HSO-SAG Charter - Assumptions

<u>Assumptions</u>

For the purpose of this study, please 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).

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HSO-SAG Charter - Deliverables

Timing & Format of deliverables

- It is anticipated that the SAG will begin its discussions in April, 2015.
- The SAG is expected to carry out most/all of its deliberations by telecons and e-mail exchange. If necessary, travel expenses for one face-to-face meeting can be supported.
- Higher-level preliminary results, for Tasks #1-3 &5 in PPT format, are requested by mid-May, 2015, and are expected to be reviewed by the MEPAG Executive Committee, and then presented for discussion at the HLS^2 Integration Workshop (currently scheduled for June 4-5, 2015).
- A preliminary report on all requested tasks in PPT format is requested by July 15, 2015.
  - The report should respond to feedback received at the HLS^2 Integration Workshop
- A final report, in text format, is requested by October 15, 2015.
  - The SAG is expected to arrange for peer review of its final report, so as to maximize technical credibility.
- Additional supporting documents can be prepared as needed.

HSO-SAG Charter – Usage, Signatories and References

How the report will be used

- After the report has been accepted (by the MEPAG Chair on behalf of MEPAG, and three customers named below), it will be posted on a publicly accessible website--this should be kept in mind as the report is prepared.
- The report should not contain any material that is ITAR-sensitive.

Michael Meyer, NASA Lead Scientist for Mars Exploration, NASA HQ
Ben Bussey, HEOMD: Chief Exploration Scientist
Richard (Rick) Davis, SMD: Assistant Director for Science & Exploration

March 26, 2015

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High-level 2015 MEPAG Science Goals & Objectives

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GOAL I: Determine if Mars ever supported life.	A. Determine if environments having high potential for prior habitability and preservation of biosignatures contain evidence of past life.
	B. Determine if environments with high potential for current habitability and expression of biosignatures host evidence of extant life.
GOAL II: Understand the processes and history of climate on Mars.	A. Characterize the state of the present climate of Mars' atmosphere and surrounding plasma environment, and the underlying processes, under the current orbital configuration.
	B. Characterize the history of Mars’ climate in the recent past, and the underlying processes, under different orbital configurations.
	C. Characterize Mars’ ancient climate and underlying processes.
GOAL III: Understand the origin and evolution of Mars as a geological system.	A. Document the geologic record preserved in the crust and interpret the processes that have created it.
	B. Determine the structure, composition, and dynamics of the Martian interior and how it has evolved.
	C. Determine the manifestations of Mars' evolution as recorded by its moons.

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High-level MEPAG sub-objectives

GOAL I: Determine if Mars ever supported life.	**A1.** Identify environments that were habitable in the past, and characterize conditions and processes that may have influenced the degree or nature of habitability therein.
	A2. Assess the potential of conditions and processes to have influenced preservation or degradation of biosignatures and evidence of habitability, from the time of formation to the time of observation. Identify specific deposits and subsequent geological conditions that have high potential to have preserved individual or multiple types of biosignatures.
	A3. Determine if biosignatures of a prior ecosystem are present.
	B1. Identify environments that are presently habitable, and characterize conditions and processes that may influence the nature or degree of habitability therein.
	B2. Assess the potential of specific conditions and processes to affect the expression and/or degradation of signatures of extant life.
	B3. Determine if biosignatures of an extant ecosystem are present.
GOAL II: Understand the processes and history of climate on Mars.	**A1.** Constrain the processes that control the present distributions of dust, water, and carbon dioxide in the lower atmosphere, at daily, seasonal and multi-annual timescales.
	A2. Constrain the processes that control the dynamics and thermal structure of the upper atmosphere and surrounding plasma environment.
	A3. Constrain the processes that control the chemical composition of the atmosphere and surrounding plasma environment.
	A4. Constrain the processes by which volatiles and dust exchange between surface and atmospheric reservoirs.
	B1. Determine how the chemical composition and mass of the atmosphere has changed in the recent past.
	B2. Determine the record of the recent past that is expressed in geological and mineralogical features of the polar regions.
	B3. Determine the record of the climate of the recent past that is expressed in geological and mineralogical features of low- and mid-latitudes.
	C1. Determine how the chemical composition and mass of the atmosphere have evolved from the ancient past to the present.
	C2. Find and interpret physical and chemical records of past climates and factors that affect climate.
	C3. Determine present escape rates of key species and constrain the processes that control them.
GOAL III: Understand the origin and evolution of Mars as a geological system.	**A1.** Identify and characterize past and present geologic environments and processes relevant to the crust.
	A2. Determine the absolute and relative ages of geologic units and events through Martian history.
	A3. Constrain the magnitude, nature, timing, and origin of past planet-wide climate change.
	B1. Identify and evaluate manifestations of crust-mantle interactions.
	B2. Quantitatively constrain the age and processes of accretion, differentiation, and thermal evolution of Mars.
	C1. Constrain the planetesimal density and type within the Mars neighborhood during Mars formation, as implied by the origin of the Mars moons.
	C2. Determine the material and impactor flux within the Mars neighborhood, throughout Mars' history, as recorded on the Mars moons.