Science Opportunities in Human mission architectures

Affording Mars II:

Science Breakout Session (SBS) Chair: ***Dr. Jim Garvin (NASA)***

Findings and Comments completed:

Nov. 18, 2014

Presented at CAPS April 1, 2015

Affording Mars II: Science Breakout Session

Science enabled and enhanced by humans in the vicinity of Mars

October 15, 2014 (continuing until Nov. 2014)

Chair: **Jim Garvin (NASA)**

SUMMARY for Discussion

CAPS meeting

April 1, 2015

Event first held at the : California Institute of Technology

OUTLINE

- Science opportunities associated with different Human architectures for Mars (from AM-II and elsewhere) is overarching theme
- Convene a "test group" of Mars scientists to discuss as part of AM-II using a structured approach (representative cross-section)
- Science activities and pursuits guided by 2011 NRC *Planetary Decadal Survey* Mars priorities and latest MEPAG Goals
- Intended to identify trends and themes, rather than as an exhaustive analysis (that requires broad community input)
- MEPAG is launching a Human Science Objectives SAG in the near-term to address the science value proposition (beyond 2007-2008 HEM-SAG study)
- Today: Snapshot of the approach and "findings" for CAPS discussion

Science Breakout Session (SBS) in person participants

- Jim Garvin (NASA): *Chair*
- Dan McCleese (JPL)
- Michael Meyer (NASA)
- David Beaty (Mars Program Office, JPL)
- Deborah Bass (JPL)
- Rich Zurek (Mars Program Office, JPL)
- Abby Allwood (JPL/Caltech)
- Bethany Ehlmann (Caltech)
- Serina Diniega (Mars Program Office) *(documentarian)*
- Cassie Conley (NASA) *[planetary protection]*
- Betsy Pugel (NASA) *[planetary protection]*

- Louis Barbier (HQ, Office of the Chief Scientist) [NASA]

- *OTHERS from general AM-II Meeting:*
  - *Pat Troutman (NASA LaRC)*
  - *John Guidi (NASA HQ)*

- *with:* ***Chris Carberry*** *(ExploreMars and Co-Chairman of AM-II)*

Mars Science Breakout Team at *Affording Mars II* on Oct. 15, 2014 at Keck

Garvin, Allwood, McCleese, Diniega, Beaty, Bass, Ehlmann, Zurek, Meyer (with Barbier, Conley, Pugel, Trout, Guidi, Carberry <u>not shown</u>)

Findings and Evaluation of added science value and abilities, by a human mission over a robotic mission

Oct. 15, 2014 Face to Face session

and continuing online interaction/iteration until Nov. 15

Final submitted Nov 18 to AM-II Final report

Reviewed previous work by HEM-SAG and Phobos/Deimos studies before treating the question at hand (Science Value of H2M over Robotic)

GOAL: fill in this TABLE using a simple "adjectival scoring" KEY (E, VG, G, P, F, and N/A) : *capture DISCUSSION*

Different types of Human mission architectures for Mars

Planetary Decadal 2013-2023: Science Goals *(Mars relevant)*	*Mars Flyby (i.e., dropping something off)*	*Science in orbit*	*Science from aerosync orbit (telepresence to Mars surface)*	*Humans on the Phobos surface (without Mars comm network)*	*Humans on the Mars surface (30days; 10s km) NOT assuming precursor mission*	*Humans on the Mars surface (30days; 10s km) + assuming precursor robotic fieldwork*	*Humans teleoperating on Mars surface (limited EVA, 500days)*	*Humans on the Mars surface (500days; 100s km) NOT assuming precursor mission*	*Humans on the Mars surface (500days; 100s km) assuming precursor mission*
Crosscutting: Building New Worlds									
Crosscutting: Planetary Habitats									
Crosscutting: Workings of Solar System									
Mars: Determine If Life Ever Arose on Mars									
Mars: Understand the Processes and History of Climate									
Mars: Determine the Evolution of the Surface and Interior									
Small bodies: Decipher the record in primitive bodies of epochs and processes not obtainable elsewhere									
Small bodies: Understand the role of primitive bodies as building blocks for planets and life									
Notes									

Table 1: Science Value Added by having a human mission versus an all robotic one, for different Human Mission Architectures

(see **KEY** on *next* page)

Mission Architectures → / **Planetary Decadal 2013-2023: Science Goals** ↓	*Mars Flyby (i.e., dropping something off)*	*Science in orbit*	*Science from aerosync orbit (telepresence to Mars surface)*	*Humans on the Phobos surface (without Mars comm network)*	*Humans on the Mars surface (30days; 10s km) NOT assuming precursor mission*	*Humans on the Mars surface (30days; 10s km) + assuming precursor robotic fieldwork*	*Humans teleoperating on Mars surface (limited EVA, 500days)*	*Humans on the Mars surface (500days; 100s km) NOT assuming precursor mission*	*Humans on the Mars surface (500days; 100s km) assuming precursor mission*
Crosscutting: Building New Worlds	P	P	P	F	P	P	P	P	P
Crosscutting: Planetary Habitats	P	P	P	F	G	VG	E	VG/E	E
Crosscutting: Workings of Solar System	P	P	P	P	P	P	P	P	P
Mars: Determine If Life Ever Arose on Mars	P	P	P	F	G	VG	E	VG/E	E
Mars: Understand the Processes and History of Climate	P	P	P	P	G	VG	VG/E	E	E
Mars: Determine the Evolution of the Surface and Interior	P	P	P	P	G	VG	VG/E	E	E
Small bodies: Decipher the record in primitive bodies of epochs and processes not obtainable elsewhere	P	P	P	G	P	P	P	P	P
Small bodies: Understand the role of primitive bodies as building blocks for planets and life	P	P	P	G	P	P	P	P	P
Notes →				Mars meteorites, organics on Phobos			would not contaminate study areas (at the time of the mission and for future studies)		precursor --> could do science before contamination by humans

KEY to Table 1 (Added Science Value, Mission Architectures vs NRC DS Science)

- *Possible "scores" P/F/G/VG/E = usual 5 level scale :*
  Poor/ Fair/ Good/ Very Good/ Excellent

- Evaluated increase (*delta*) in **science value** by means of a human mission, compared to an all robotic mission of a *generally similar* architecture

- Note : the participants tried to consider only improvements in the nature of the science investigation that can be conducted, and not improvements due to changes in operability, etc. (NB: This latter evaluation is shown on Table 2, *next slide*):

  - *For example, tele-operations from orbit would not yield different science investigations than tele-operations from Earth (i.e., only operability changes) → **Poor** increase in science value [see notes at end however]*

  - *For example, on Phobos, one can conduct studies of organic material on Phobos (if any) and this is a benefit, but Mars surface and climate science would not be greatly changed from what could be undertaken with traditional robotic missions → **Poor** increase in science value*

Table 2: Added Ability to conduct science, on the basis of having a human mission at Mars [*Operability*]

Mission Architectures ➔	**Mars Flyby**	**Science from aerosynch orbit (telepresence to Mars surface)**	**Humans on the Phobos surface (without assuming Mars comm network)**	**Humans on the Mars surface (30days; 10s km), NOT assuming a precursor mission**	**Humans on the Mars surface (30days; 10s km) + assuming precursor robotic fieldwork**	**Humans teleoperating on Mars surface (limited EVA, 500 days)**	**Humans on the Mars surface (500days; 100s km), NOT assuming a precursor mission**	**Humans on the Mars surface (500days; 100s km), assuming a precursor mission**
Increase in science access through addition of human (vs. robotics)	FR	FR+, IO	FR+, IO	FR+, IO+	FR+, IO+	FR+, IO+	FR+, IO++	FR+, IO++
Aiding Mars sample return	R	R, C-	R, C-, M	R, C	R, C	R, C+	R, C+	R, C+

Key (Table 2)

FR : Getting (mass) a *Free Ride* to the Mars vicinity

FR+ : Getting a *Free Ride* to the Mars vicinity along with increased power, mass, complexity, etc. than would be likely for a traditional robotic mission

IO: Higher "operability" of surface assets possible due to decreased latency, higher dexterity, etc.; allowing us to achieve maximal science value associated with key objectives

IO+ : Even higher "operability", due to having multiple advantages

IO++ : highest increase in operability (i.e., enables direct contact between humans and science)

R: retrieval (*of samples acquired via a precursor mission*) is possible

C: enables collection (perhaps remotely) during mission

C-: requires additional mission element (e.g., MAV) to retrieve during-mission collection

C+: enables sample selection and collection during mission, with diversity and careful consideration of samples

M: Improved access to Mars meteorites

Select FINDINGS from the AM-II Science Breakout Session (1 of 2)

Findings derived from discussion and generation of *Science* Tables 1 and 2:

1) We assume that the deployment of human flight systems would bring enhanced capability for science (as in Apollo). [SBS-F1]

2) Putting humans into the vicinity of Mars would have the potential to reduce the latency of science asset operations, if the astronauts have sufficient decision-making autonomy. [SBS-F2] *{see also : Cognition and Dexterity findings in Back-up materials}*

3) Increased human interactions with the martian environment and materials, especially direct contact, would dramatically increase science return. [SBS-F3]

4) More time for analysis would improve the results (e.g., 30 days vs. 500 days), especially time for conducting *in situ* fieldwork [SBS-F4]:
   - *However, this time doesn't require human boots on the ground ➔ robotic precursors (operated from Earth or Mars vicinity) could contribute towards fieldwork and site characterization.*

5) A human landing on *Phobos* (or *Deimos*) would be clearly valuable to small-body science but it would be of minimal direct value to the science of Mars itself [SBS-F5].

Select FINDINGS reached at the AM-II Science Breakout Session (SBS) (2 of 2)

6) Tele-operation of assets on the surface of Mars from either high Mars orbit (*areosynchronous*) or from the surfaces of either Phobos or Deimos may be a feature of a future human mission to the Mars system, but would <u>not</u> contribute enough of an advancement in operability, and thus science value [SBS-F6] :

- *We have not yet recognized compelling advantages over the operation of such assets from Earth (limited experience base)*
- *This requires further, in-depth study, as human architectures are developed, including those with humans to Mars orbit* *{incomplete assessment by community as of Fall 2014}*

7) In order for one of the scientific objectives of a human landing or any future mission on Mars to feature the *exploration of Special Regions for extant life* (including by tele-operation of sterile rovers from a martian surface base station), some complicated issues involving <u>forward planetary protection</u> must be addressed [SBS-F7].

***** there were 7 consensus findings from the SBS discussion *****

BACKGROUND MATERIALS

Background Materials, **<u>including:</u>**

- (I) Discussion notes, from the SBS on Oct 15, 2014 (*at CalTech*)
- (II) Presentations materials shown at the start of the SBS on Oct 15, 2014, to catalyze the discussion
- (III) Presentation shown at Plenary session on Oct 15, 2014, to share initial SBS results with full *Affording Mars II* workshop attendees

Background Materials, **Part I**

Discussion notes, from the Science Breakout Session on Oct 15, 2014.

A few examples will be highlighted…
and then onto SUMMARY

Discussion during Science Breakout Session face-to-face

OPEN DISCUSSION OF:

The value added by humans at Mars:

(1) to go to Mars AND BACK ➔ could return samples [*higher mass to Earth than all-robotic mission architectures*].

(2) larger infrastructure needed and allowed ➔ could carry more and more complex analysis tools [*piggybacking science, including high mass/power relative to all-robotic cases*].

(3) Increase in cognition/decrease in latency ➔ could do more and do it faster/more adeptly [*if humans in the loop with low-latency either themselves or via telepresence*].

(4) Increase in dexterity and adaptability ➔ could do more complex activities and can vary actions, yielding a better diversity of observations and work (and samples collected).

(5) Could leave behind/begin building a network [*intrinsic value of human flight systems and their mass carrying capacity*].

Discussion during AM-II SBS face-to-face

OBSERVATION:

Humans in the vicinity of Mars could improve operability of assets for science.

This is the watershed jump due to Cognition.

Q: *If using telepresence, what paradigm shift is needed to fully take advantage of the decrease in latency?*

For teleoperating/telepresence to improve efficiency, high autonomy is required.

This likely means that some tasks (e.g., with a known and well-defined aim, such as acquiring a sample or drilling) could be accomplished much more quickly (than robotic).

Higher-level tasks that require very broad and deep expertise (i.e., a full fieldwork campaign) would likely still require assistance from the "backroom" on Earth (as is required today).

Autonomy could also be achieved via ***AI*** advancements and more trust in the S/C.

➔ *If a human were teleoperating from the surface of Mars (vs. in orbit), then in addition to more constant contact and lower latency, they could repair the robotics and switch out sensors, etc. This greatly expands the use of robotics – in time and activity.*

OBSERVATION:

Increased human interactions with the Mars environment and materials, especially direct contact, could dramatically increase science return:

This is the watershed jump due to Dexterity.

Discussion during AM-II SBS face-to-face

More time for analysis improves the science results (e.g., 30 days vs. 500 days), especially time conducting *in situ* fieldwork.

However, this time doesn't require human boots on the ground → robotic precursors (operated from Earth or in the Mars vicinity) could contribute towards fieldwork and site characterization:

- **NOTE**: *except perhaps for Life studies (due to contamination concerns)*, human time would count for more than robotic asset time
- A 30 day human surface mission would require a robotic precursor mission for intensive site characterization (and optimization):
  - ~7 EVA's would not be enough for careful sample selection and acquisition. (Note that some participants disagreed. They did not believe full site characterization was required, but did assume a 1 m scale geologic map of the region → *some detailed reconnaissance is required beforehand*.)
- 500 days with a human crew on the surface (for some portion of the time) would significantly enable diversity in sites and samples:
  - *Additional advantages in human time vs. over a robotic precursor mission are:*
    - *Allows for samples to be collected and then changed out later, and returning to sites.*

Discussion during AM-II SBS face-to-face

Use of Phobos would be a science convenience, not a good science objective for Mars itself (*but could be of benefit to Small Body science*):

- Additionally, none of the key science objectives [Planetary Decadal Survey] require humans for accomplishment.
- For telepresence science, latency is much less (to the surface of Mars) but contact would still be episodic (discontinuous) and limited unless there is a full communication network in place (i.e., orbital network of Comsats).
- Also, involving the martian moons (vs. a free-orbiting S/C, such as areosynchronous) may add complexity to the mission.
- However, for humans at Mars, the martian moons could provide some protection from GCR (up to 35% additional shielding, quoted during the breakout).

- **NOTE**: *Main contribution towards Mars science would be access to Mars meteorites (on Phobos/Deimos) and all that comes with taking humans into the Mars vicinity (larger HSF infrastructure, ability to pick up a sample capsule from orbit, etc.)*

Additional thoughts for further discussion or analysis

Other thoughts brought up (*for future discussions?):*

- **Strong desire (by SBS) to conduct Mars-related science at ISS:**
  Able to have a closed system. (maybe relying on ISRU? (partial?))
  Potentially evaluate telepresence for Mars-related science?
  Human Life sciences (for long-stays in deep space/on Mars)

- As part of heavy-lift development and testing (**SLS**), science participants would like to conduct a flight before humans go → putting a large mass to Mars (all-robotic). ***What could/should we do with this opportunity in terms of science ?***

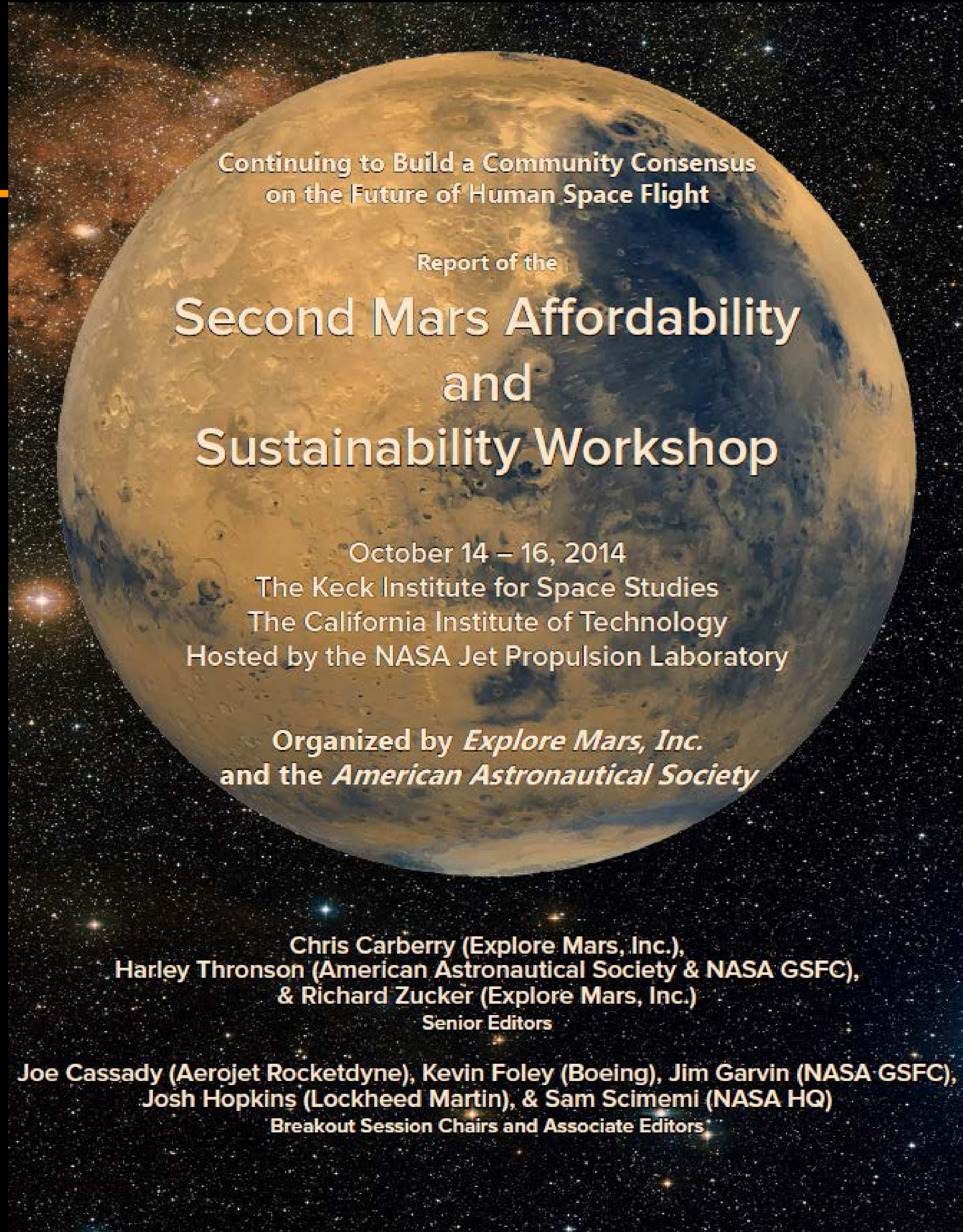
- What Goals must be (or can only be) achieved before the first human mission(s) (e.g., Human *Life sciences studies*) ?

- The strategy for identifying *in situ* resources is currently not a high priority within SMD (for science) – *could HEOMD or others support state-of-the-art remote sensing for identification of resources?*

NEXT STEPS for this discussion, in context of **AM-II Meeting**

- **Science Breakout Session at AM-II was an excellent start of a dialogue**
- There are many open issues with how science could make humans to Mars "affordable" (one *is possible requirement for a robotic sample return*)
- The two tables generated are a key first step for identifying science opportunities and priorities.
- Revisitation of the 2008 HEM-SAG activities (as chartered by HQ and MEPAG) may be necessary in the context of "affordable" architectures
- More work is needed in consideration of how low-latency telepresence at Mars (with humans nearby but not on the surface) will achieve science.
- Mars-related science at ISS deserves consideration by the community over the next 5+ years (could include telepresence, life sciences etc.)
- A follow-up meeting in 2015 may be advantageous (part of MEPAG ?)

For further information, please see the final AM-II report (*available on the web*)


Continuing to Build a Community Consensus
on the Future of Human Space Flight

Report of the

Second Mars Affordability
and
Sustainability Workshop

October 14 – 16, 2014
The Keck Institute for Space Studies
The California Institute of Technology
Hosted by the NASA Jet Propulsion Laboratory

Organized by *Explore Mars, Inc.*
and the *American Astronautical Society*

Chris Carberry (Explore Mars, Inc.),
Harley Thronson (American Astronautical Society & NASA GSFC),
& Richard Zucker (Explore Mars, Inc.)
Senior Editors

Joe Cassady (Aerojet Rocketdyne), Kevin Foley (Boeing), Jim Garvin (NASA GSFC),
Josh Hopkins (Lockheed Martin), & Sam Scimemi (NASA HQ)
Breakout Session Chairs and Associate Editors

SPECIAL THANKS TO:

- SBS participants from JPL and Caltech and NASA HQ
- Strong support for SBS session by *Dr. Chris Carberry*
- Excellent documentation by *Dr. Serina Diniega*
- Superb organization by *Dr. David Beaty*
- Support for the activity by *Dr. Michael Meyer* (HQ)
- Encouragement by *Dr. John Grunsfeld (HQ)*

The scientists involved in this activity recognize the enormous contributions of Dr. Noel Hinners in his lifelong work promoting scientific exploration of Mars by robots and humans

APPENDICES and BACKUP

Background Materials, Part II.

Presentations materials shown at the start of the SBS on Oct 15, 2014, to catalyze the discussion. (as shown)

Affording Mars II: Science Breakout Session

Science enabled and enhanced by humans in the vicinity of Mars

October 15, 2014

Chair: J. Garvin

Background material provided by Garvin (HEM-SAG), Beaty (Phobos-Deimos, HAT), and Bass (Telepresence, HAT)

The Second Affording Mars Community Workshop

October 14 – 16, 2014

Keck Institute for Space Studies

California Institute of Technology

Science Objectives for the First Human Missions to Mars

by the MEPAG Human Exploration of Mars Science Analysis Group (HEM-SAG)

James B. Garvin, NASA

based on the Final HEM-SAG report, originally presented in 2008

How to Capitalize on the Unique Attributes of Human Explorers

Unique attributes human explorers can bring to bear in comparison to robotic explorers:

<u>Cognition</u>

- **Rapidly recognize and respond to unexpected findings; sophisticated, rapid pattern recognition (structural/morphological biosignatures).**

<u>Dexterity</u>

- **Humans are capable of lifting rocks, hammering outcrops, selecting samples, etc. much better than robotic manipulation.**

<u>Adaptability</u>

- **Humans are able to react in real time to new and unexpected situations, problems, hazards and risks.**

<u>Efficiency</u>

- **Robotic manipulation require several sols to accomplish what humans can do in a matter of minutes.**

Possible Objectives, Program of First Three Human Missions

(Not in priority order)

Goals I-III: Traditional Planetary Science

- Search for **ancient life** on Mars
- Make significant progress towards the goal of understanding whether or not **martian life** forms have persisted to the present (extant biological processes).
- Quantitative understanding of early Mars **habitability** and early Mars possible **pre-biotic biogeochemical cycles and chemistry**.
- Quantitative understanding of **martian climate history** with attention to the modern climate/weather system
- Quantitative characterization of the different components of the **martian geologic system** (at different times in martian geologic history), and understand how these components relate to each other (in 3D).
- Characterize the structure, composition, dynamics, and evolution of the **martian interior** (core to crust)

Goal IV+: Preparation for later sustained human presence

- Learn to make effective use of **martian resources**, including providing for crew needs, and if possible, power and propulsion consumables.
- Develop reliable and robust **exploration systems**; Increase the level of self-sufficiency of Mars operations
- Address **planetary protection** concerns regarding sustained presence
- Promote the development of **partnerships** (international, commercial, etc.) and sustain **public engagement**

Goal V: Ancillary Science

- **Heliophysics**: Understand the processes that control Mars' space environment and the influence of planetary magnetic fields/interaction with solar wind
- **Astrophysics**: improve knowledge of Mars' range and rotational dynamics

Two different sets of priorities for key program attributes from different stakeholders

PLANETARY SCIENCE

	Short Stay	Long-Stay
One Site	BELOW SCIENCE FLOOR	BRONZE STANDARD
Multiple Sites	SILVER STANDARD	GOLD STANDARD

SUSTAINED PRESENCE

	Short Stay	Long-Stay
One Site	BRONZE STANDARD	GOLD STANDARD
Multiple Sites	BRONZE STANDARD	SILVER STANDARD

National Aeronautics and Space Administration

Scientific Objectives for the Mars-Phobos-Deimos Mission

David Beaty, JPL

Based on a Final Report by the Human Spaceflight Architecture Team (HAT) subteam

Originally presented May 6, 2012

Proposed Statements of Scientific Objective

1. Understand the origin and evolution of Phobos and Deimos as planetary objects, and how the major processes that have affected them relate to Mars and to other small bodies.
2. Advance our scientific understanding of Mars in the areas of its potential as a past or present abode for indigenous life, its climate and climate history, and the nature and evolution of geologic processes that have created and modified its crust and deep interior.
3. Capitalize on the science opportunities associated with the Mars-Earth neighborhood (some of which can be planned in advance and some of which are pathway-dependent opportunities) beyond those related directly to Mars and Phobos/Deimos.

Prioritization Criteria

1. Intrinsic scientific merit
   - *With reference to major scientific prioritization documents (e.g., Decadal Survey, MEPAG, SBAG, etc).*
2. Degree to which the implementation proposed would achieve the objective (assuming that the implementation works perfectly)
3. Advantages of implementation by a human crew

   Crew could make real time adjustments during encounter to maximize science (e.g., for flyby observations) without time delay and sequencing issues. They also could deploy/retrieve equipment repeatedly and collect/return for examination on Earth

Note: Early in the process it was identified that all important scientific objectives can be achieved in a short stay mission.

DESTINATION and TRANSIT SCIENCE: Prioritization of Science Objectives

OBJ.	INVESTIGATIONS	
#2A	**Fill the role of the third mission of the MSR Campaign**	HIGH
#1A	Phobos / Deimos **Field Science Package--Rocks**	
#1B	Determine the **absolute ages** of Phobos' and Deimos' materials	
#1C	Constrain the **conditions of formation** of Phobos' and Deimos' materials	
#1D	Phobos / Deimos **Field Science Package--Regolith**	
#2B	Top Objectives that can be achieved by **returning Mars meteorites**	MEDIUM
#1E	Identify and characterize the presence and distribution of any potential **volatile or organic species**	
#1F	Determination and **characterization of near surface and interior structure** at global and regional scales	
#3C	Measure the **radiation environment** at the Mars vicinity.	
#3B	Quantification of the **fluxes of material in the Martian system**	LOW
#1G	Quantify Phobos and Deimos energy budgets	
#2D	Top Objectives that can be achieved through **teleoperation** from one of the moons of a controllable asset on the martian surface	
#2C	Top Objectives that can be achieved through **remote sensing of Mars from Phobos or Deimos**	
#3D	Survey of Mars' **Trojan asteroid** population	
#3A	**Pathway-dependent science** package	
#3-E	**Heliophysics**	
#3-F	**Astrophysics**	

A comment about meteorite collection (2B)

Objective 2: Origin and Evolution of Mars

2B: Collect Mars meteorites from the surface of Phobos/Deimos, and return to Earth for detailed study

Objectives potentially achievable using P/D meteorites but not Antarctic meteorites:

a) Search for organic carbon in Martian meteorites on Martian moons (avoid terrestrial contamination).

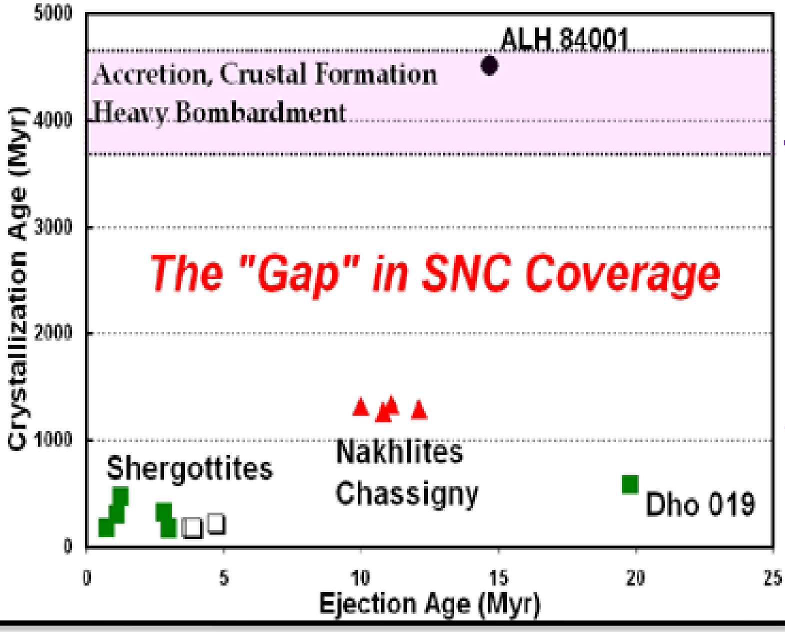
b) Investigate Mars meteorites that have not spent a lot of time in inter-planetary space.

c) Collect information on igneous petrology through time (fill in the meteorite gap).

However, objectives potentially achievable using Mars surface samples but not P/D meteorites:

a) Geologic context and known source region.

b) Selection of sample.



Courtesy Dan Britt

Phobos-Deimos Design Reference Mission – Telerobotic Operations Summary

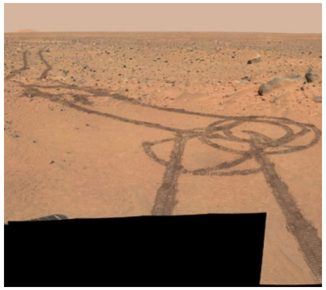
Deborah Bass, JPL

Based on a Final Report by the Human Spaceflight Architecture Team (HAT) subteam
Originally presented May 6, 2012

What are the benefits of In-System Crew? Candidate Teleoperations

- Exploration of Mars Surface and Atmosphere

  - Activities that benefit from real-time operations (i.e. drilling, brushing, coring, digging)
  - Observation of transient phenomena (i.e. dust devils)
  - Exploration of extreme terrain such as lava tubes and cliff walls
    - Employing robotic platforms that could be enabled through real-time ops, such as aerial vehicles and cliff climbers



- Exploration of Phobos and Deimos

  - Activities that benefit from real-time operations (i.e. drilling, brushing, coring, digging)
  - Reconnaissance for human exploration landing/traverses

Current Risk Posture
How are Mars Surface Assets Controlled NOW?

Earth Day #1

- Surface asset commanded to do activity.

Mars Sol #1

- Surface asset executes commands.
- Data (scientific and housekeeping) collected throughout martian sol (day).
- Collected data sent to mission control for evaluation at end of sol.

Earth Day #2

- Data received from surface asset.
- Data (scientific and housekeeping) evaluated and interpreted.
- Decisions made on what to do next.
- Next sol's commands written and sent to the surface asset as it wakes up.

Mars Sol #2

- Surface asset executes commands.
- Data (scientific and housekeeping) collected throughout martian sol (day).
- Collected data sent to mission control for evaluation at end of sol.

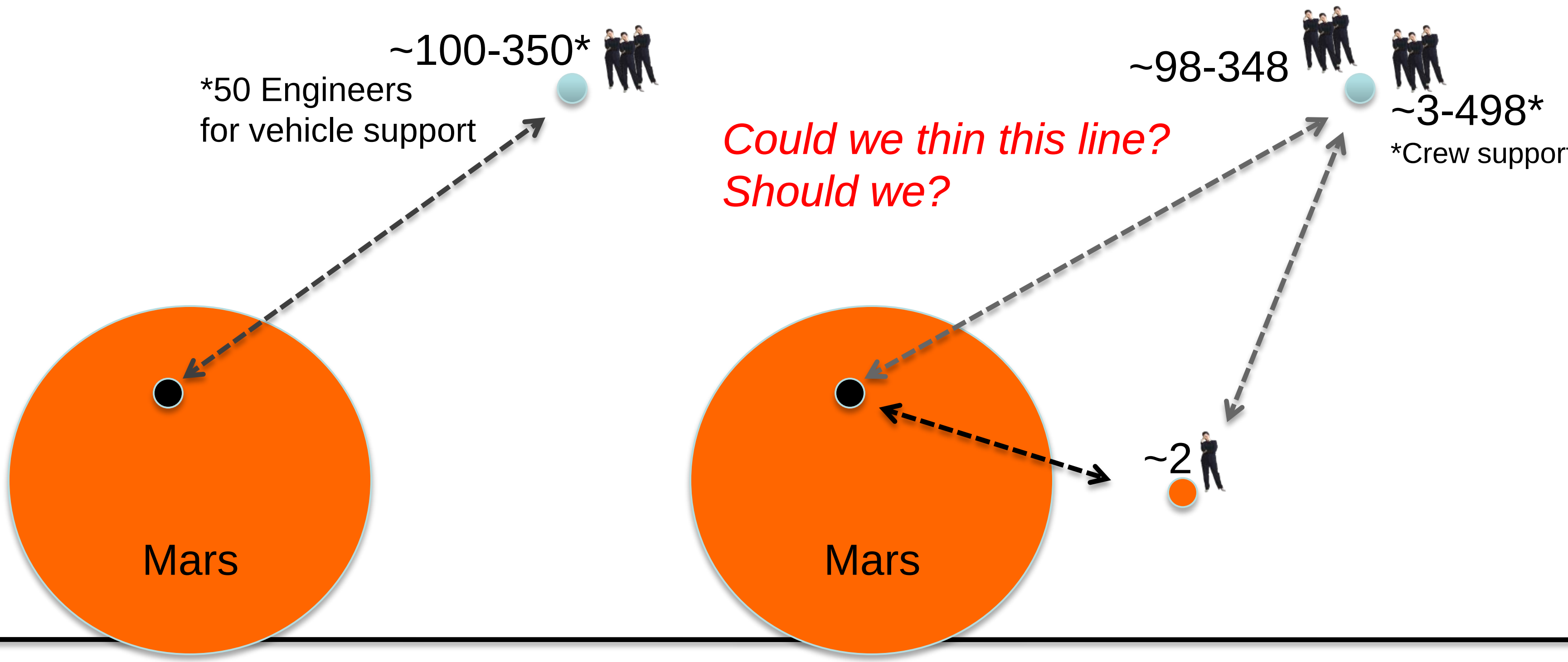
This cycle requires a one day turnaround to minimize vehicle risk

Comparison of Two Pathways for Asset Control

*__EXPERIENCE__: Safe operation of Mars surface assets **and crew** requires a multi-disciplinary science/engineering team of ~100-500 people, incl. ~250 engineers.*

__PATHWAY A__: Science/engineering team on Earth commands surface asset 1/sol for DSN “sharing” with other assets and command cycle

__PATHWAY B__: From Phobos commands sent 2/sol. However, the comm cycle between Earth Mission Control and Phobos is still 1/sol



Mars surface, Phobos/Deimos exploration – Are there enhancing or enabling benefits to telerobotic operation?

Mars Science Objectives	Phobos/Deimos Exploration
Atmospheric Phenom. (transient)	Recon. for human expl landing/traverse
Weather Phenom. (unpredictable over a day)	Transient Phenom. (meteoritic impact)

- Benefits from telerobotic operations
  - Increased situational awareness
    - For hazard detection and avoidance
    - Risky or off nominal actions
  - More rapid progress due to multiple decision points per sol
    - Quick decision making with respect to site selection for sampling or processing
  - Fewer forward/backward planetary protection issues
- Suggested Best Practices:
  - Aerostationary orbit over a given vehicle for at least some period of time to provide consistent line-of-site between crew and surface assets
  - Choice of vehicle type influences degree of benefit, e.g., hopper, drill, airplane
  - For Moons: Employ mature technologies (e.g., rover) due to extremely low gravity
  - Near- to real- time streaming of data
  - Advanced analysis software for increased situational awareness
  - Highly Specialized Scientist/Engineering Astronaut Operators
  - Ground and Mission Control for long term decision-making