Analysis of Strategic Knowledge Gaps Associated with Potential Human Missions to the Martian System

Precursor Strategy Analysis Group (P-SAG)

(jointly sponsored by MEPAG and SBAG)

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Executive Summary

1. The Strategic Knowledge Gaps (SKGs) associated with each of the following goals have been defined:
   - First human mission to martian orbit (Goal IV-).
   - First human mission to land on either Phobos or Deimos
   - First human mission to the martian surface (Goal IV).
   - Sustained human presence on Mars (Goal IV+)
2. The SKGs have been broken down into Gap-Filling Activities (GFAs), and each has been evaluated for priority, required timing, and platform.
3. The relationship of the above to the science objectives for the martian system (using existing MEPAG, SBAG, and NRC scientific planning), has been evaluated.
   - Five areas of significant overlap have been identified. Within these areas it would be possible to develop exciting mission concepts with dual purpose.
4. The priorities relating to the Mars flight program have been organized by mission type, as an aid to future mission planners: orbiter, lander/rover, Mars Sample Return (MSR), and Phobos/Deimos.

Summary of Findings (1 of 2)

Finding #1	The high-priority gaps for a human mission to Mars orbit relate to a) atmospheric data and models for evaluation of aerocapture, and b) technology demonstrations.
Finding #2	A human mission to the Phobos/Deimos surface would require a precursor mission that would land on one or both moons.
Finding #3	The early robotic precursor program needed to support a human mission to the martian surface would consist of at least: • One orbiter • A surface sample return (the first mission element of which would need to be a sample-caching rover) • A lander/rover-based *in situ* set of measurements (which could be made from the sample-caching rover) • Certain technology demonstrations
Finding #4	P-SAG has not evaluated whether it is required to send a lander or rover to the actual human landing site before humans arrive.

Summary of Findings (2 of 2)

Finding #5	For several of the SKGs, simultaneous observations from orbit and the martian surface need to be made. This requires multi-mission planning.
Finding #6	There are five particularly important areas of overlap between HEO and science objectives (in these areas, <u>mission concepts with dual purpose would be possible</u>). 1. Mars: Seeking the signs of past life. 2. Mars: Seeking the signs of present life. 3. Mars: Atmospheric dynamics, weather, dust climatology. 4. Mars: Surface geology/chemistry. 5. P/D: General exploration of P/D.

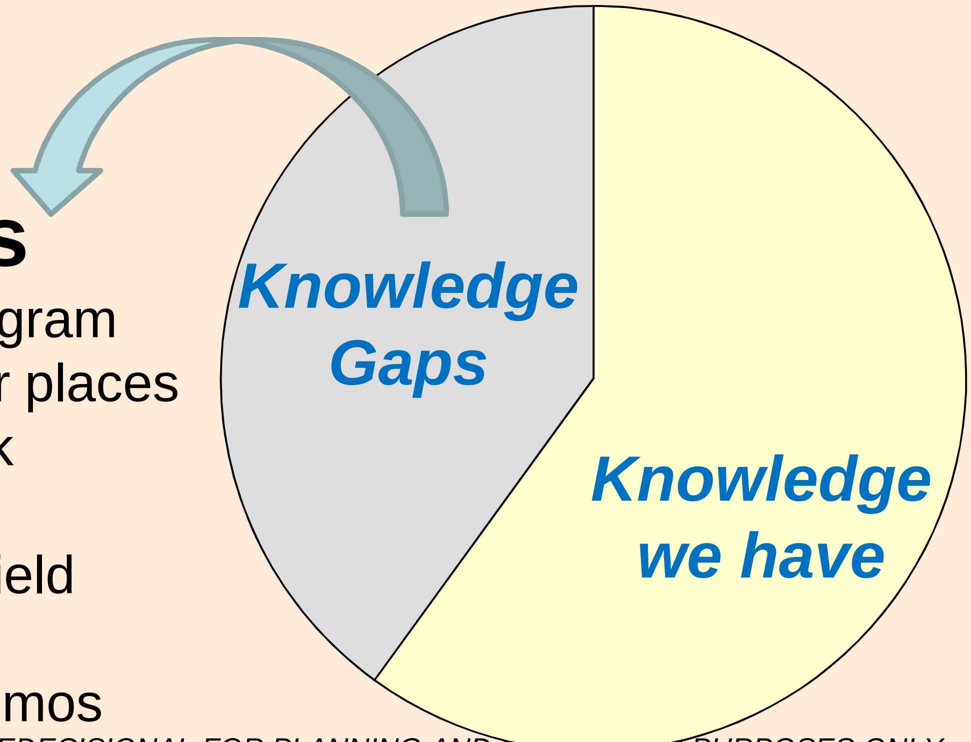
SKG and GFA: Definitions

1. **Strategic Knowledge Gap (SKG): The Gaps in Knowledge Needed to Achieve a Specific Goal.**
2. **Gap-Filling Activity (GFA): Work that contributes to closing an SKG.**

Total knowledge needed to achieve a goal

GFA areas

- Mars flight program
- Flights to other places
- Non-flight work (models, lab experiments, field analogs, etc.)
- Technology demos



INTRODUCTION to MEPAG and SBAG GOALS

SBAG SCIENCE GOALS

- Solar System Origins
- Solar System Dynamics
- Current State of the Solar System
- ISRU
- Hazards
- Astrobiology

MEPAG GOALS

I. Determine if life ever arose on Mars

II. Understand the processes and history of climate on Mars

III. Determine the evolution of the surface and interior of Mars

IV. Prepare for human exploration
   - Humans to orbit (Goal IV-)
   - 1st humans to surface (IV)
   - Sustained presence (IV+)

4 potential HEO Goals in the Martian system

SKGs can only be defined w.r.t. a specific goal.

Goals evaluated, this study

Ref.	*Goal*	*MEPAG*	*Linkage*
A.	**Achieve the first human mission to Mars orbit**	**Goal IV-**	
B.	**Achieve the first human mission to the martian surface**	**Goal IV**	Group A SKGs also needed
C.	**Achieve the first human mission to the surface of Phobos and/or Deimos**		Group A SKGs also needed
D.	**Sustained human presence on Mars**	**Goal IV+**	Group A,B, (C?) SKGs also needed

SKGs and Decomposition

- **We have identified 17 SKGs associated with the four HEO goals.**
  - ✓ **Full statements of the knowledge gaps are listed in Appendix I.**
- **About 60 Gap-Filling Activities (GFAs) have been identified that would address the 17 SKGs.**
  - ✓ **Detailed analysis of the GFAs is in Appendix II.**
  - ✓ **The GFAs have different priorities and degrees of urgency (see GFA Analysis on Slides #11-12)**
  - ✓ **Only about half of the GFAs would require use of the Mars flight program.**

Notes to Accompany GFA Analysis

- The following 2 slides are an abridged version of a large spreadsheet that has much more detail, including justification and implementation notes.

Priorities are defined as follows:	
High:	Recognized as an enabling critical need or mitigates high risk items (items can include crew or architectural performance)
Medium:	Less definitive need or mitigates moderate risk items
Low:	Need uncertain or mitigates lower risk items
Timing is defined as follows:	
IV-:	Needed to plan human missions to Mars orbit
IV- P/D:	Needed to plan human missions to Phobos/Deimos
IV Early:	Needed to plan architecture of the first human missions to the martian surface
IV Late:	Needed to design systems for first human missions to the martian surface
IV+:	Needed for sustained human presence on the martian surface

- The Technology items were given a quick prioritization, but not assessed in detail. This is future work that needs follow up.
- There are important linkages between science and technology that need further evaluation.
- The boundary between upper and lower atmosphere, as used in this report, is ~20 km elevation.
- Color coding: Orange—requires Mars flight; Blue—can be done on Earth; Yellow—technology, location varies.

GFA Analysis (1 of 2)

SKG		Gap-Filling Activity	Priority	Timing	Location
A1	Upper Atmosphere	A1-1. Global temperature field.	H	IV-	Mars Orbit
		A1-2. Global aerosol profiles and properties	H	IV-	Mars Orbit
		A1-3. Global winds and wind profiles	M	IV-	Mars Orbit
A2	Atm. Modeling	A2-1. Atm. Modeling.	H	IV-	Earth
A3	Orbital Particulates	A3-1. Orbital particulate environment	M	IV-	Mars Orbit
A4	Technology: To/from Mars System	A4-1. Autonomous rendezvous and docking demo	H	IV-	Earth or Mars Orbit
		A4-2. Optical Comm. Tech demo	H	IV-	Earth or Mars Orbit
		A4-3. Aerocapture demo	M	IV-	Earth or Mars Orbit
		A4-4. Auto systems tech demo	L	IV-	Earth
		A4-5. In space prop tech demo	H	IV-	Earth
		A4-6. Life support tech demo	H	IV-	Earth
		A4-7. Mechanisms tech demo	L	IV-	Earth
B1	Lower Atmosphere	B1-1. Dust Climatology	H	IV Late	Mars Orbit
		B1-2. Global surface pressure; local weather	H	IV Early	Mars surface
		B1-3. Surface winds	M	IV Early	Mars surface
		B1-4. EDL profiles	M	IV Early	Mars EDL
		B1-5. Atmospheric Electricity conditions	L	IV Late	Mars surface
		B1-6. EDL demo	H	IV Early	Mars EDL
		B1-7. Ascent demo	H	IV Early	Earth or Mars Surface
B2	Back Contamination	B2-1. Biohazards	H	IV Early	Sample return
B3	Crew Health & Performance	B3-1. Neutrons with directionality	M	IV Late	Mars surface
		B3-2. Simultaneous spectra of solar energetic particles in space and in the surface.	M	IV Late	Mars surface and Mars orbit
		B3-3. Spectra of galactic cosmic rays in space.	L	IV Late	NEAR EARTH
		B3-4. Spectra of galactic cosmic rays on surface.	M	IV Late	Mars surface
		B3-5. Toxicity of dust to crew	M	IV Late	Sample return
		B3-6. Radiation protection demo	H	IV Late	Earth or Mars Surface
B4	Dust Effects on Surface Systems	B4-1. Electricity	L	IV Late	Mars surface
		B4-2. Dust physical, chemical and electrical properties	H	IV Late	Mars Surface or Sample return
		B4-3. Regolith physical properties and structure	M	IV Late	Mars Surface or Sample return

See notes on page 10. For full statements of SKGs, see Appendix 1.

GFA Analysis (2 of 2)

SKG		Gap-Filling Activity	Priority	Timing	Location
B5	Forward Contamination	B5-1. Identify and map special regions	H	IV Late	Mars surface and Mars orbit
		B5-2. Model induced special regions	L	IV Late	Earth
		B5-3. Microbial survival, Mars conditions	M	IV Late	Earth
		B5-4. Develop contaminant dispersal model	M	IV Late	Earth
		B5-5. Forward Contamination Tech demo	M	IV Late	Earth or Mars Surface
B6	Atmospheric ISRU	B6-1. Dust physical, chemical and electrical properties	H	IV Late	Mars Surface or Sample return
		B6-2. Dust column abundances	L	IV Late	Mars surface
		B6-3. Trace gas abundances	L	IV Late	Mars Orbit
B7	Landing Site and Hazards	B7-1. Regolith physical properties and structure	M	IV Late	Mars Surface and Sample return
		B7-2. Landing site selection	M	IV Late	Mars surface and Mars orbit
		B7-3. Trafficability	L	IV Late	Mars surface
		B7-4. Auto rover tech demo	L	IV Late	Earth or Mars Surface
		B7-5. Env exposure tech demo	H	IV Late	Mars surface
		B7-6. Sample handling tech demo	L	IV Late	Earth or Mars Surface
B8	Tech: Mars Surface	B8-1. Fission power tech demo	H	IV Late	Earth
C1	Phobos/Deimos surface science	C1-1. Surface composition	H	IV- P/D	Phobos/Deimos rendezvous and lander
C2	Phobos/Deimos surface Ops	C2-1. P/D electric and plasma environments	L	IV- P/D	Phobos/Deimos rendezvous
		C2-2. P/D Gravitational field	M	IV- P/D	Phobos/Deimos rendezvous
		C2-3. P/D regolith properties	H	IV- P/D	Phobos/Deimos rendezvous and lander
		C2-4. P/D thermal environment	L	IV- P/D	Phobos/Deimos rendezvous and lander
C3	Technology P/D	C3-1. Anchoring and surface mobility demo	H	IV- P/D	Phobos/Deimos rendezvous and lander
D1	Water Resources	D1-1. Cryo storage demo	M	IV+	Earth
		D1-2. Water ISRU demo	M	IV+	Earth or Mars Surface
		D1-3. Hydrated mineral compositions	H	IV+	Sample return
		D1-4. Hydrated mineral occurrences	H	IV+	Mars Orbit
		D1-5. Shallow water ice composition and properties	M	IV+	Mars surface
		D1-6. Shallow water ice occurrences	M	IV+	Mars surface and Mars orbit
D2	Tech: Sustained Presence	D2-1. Repeatedly land	H	IV+	Earth
		D2-2. Sustain humans	H	IV+	Earth
		D2-3. Reduce logistical support	H	IV+	Earth

See notes on page 10. For full statements of SKGs, see Appendix 1.

GFA: Priority vs. Timing w Details
Humans to Mars Orbit or Phobos/Deimos

Priority	IV-	P/D

H	• A1-1. Global temperature field.
	  • Mid-IR sounder
	• A1-2. Global aerosols
	  • Mid-IR sounder
	  • Vis sounder
	• A2-1. Atm. Modeling.
	• A4-1. Autonomous rendezvous & docking demo
	• A4-2. Optical Comm.
	• A4-5. In space prop tech demo
	• A4-6. Life support tech demo
		• C1-1. P/D composition
		  • High resolution orbital spectroscopy
		  • Landed mineralogy/chemistry
		• C2-3. P/D regolith properties
		  • High resolution orbital imagery
		  • Landed geotechnical measurements
		• C3-1. P/D Tech demo

M	• A1-3. Global wind • A3-1. Orb Partic. • A4-3. Aerocapt.	• C2-2. Grav field
L	• A4-4. Auto sys • A4-7. Mech.	• C2-1. Elec/plasma • C2-4. Thermal

Color Key:
Mars Orbiter — Earth — Technology demo — Phobos / Deimos mission measurements

Findings: Humans to Mars Orbit Only or Phobos/Deimos

Humans to Mars Orbit

- For a human mission to Mars orbit only, the high-priority gaps that need filling are:
  - data sets and associated models of atmospheric dynamics needed for the evaluation and possible implementation of aerocapture
  - certain technology demonstrations.

FINDING #1. The high-priority gaps for a human mission to Mars orbit relate to a) atmospheric data and models for evaluation of aerocapture, and b) technology demonstrations.

Humans to Phobos/Deimos

- A human mission to the Phobos/Deimos surface would have three additional SKGs relative to a human mission to Mars orbit only. Closing those gaps would require a precursor mission that would land on one or both moons.

FINDING #2. A human mission to the Phobos/Deimos surface would require a precursor mission that would land on one or both moons.

GFA: Priority vs. Timing & Location
(Humans to the Martian Surface)

Priority \ Timing	IV-	IV early	IV late	IV+
H	• A1-1. Global T • A1-2. Aerosols • A2-1. Atm models • A4-1. Auto Rendez. • A4-2. Optical Comm • A4-5. Propul. demo • A4-6. Life supp. Demo	• B1-2. Surf Pressure • B2-1. Biohazards • B1-6. EDL demo • B1-7. Ascent demo	• B1-1. Dust clim. • B3-6. Rad. protect • B4-2. Dust prop. • B5-1. Special reg. • B6-1. Dust prop. • B7-5. Env expos • B8-1. Fission pwr	• D1-3. Hyd mins • D1-4. Min occur • D2-1. Land x N • D2-2. Sustain • D2-3. Logistics
M	• A1-3. Global wind • A3-1. Orb Partic. • A4-3. Aerocapture	• B1-3. Surf winds • B1-4. EDL profile	• B3-1. Neutrons • B3-2. SEPs • B3-4. Cosmic rays • B3-5. Toxicity • B4-3. Regolith • B5-3. Microbe • B5-4. Disprs model • B5-5. FPP • B7-1. Regolith • B7-2. Landng site	• D1-1. Cryo • D1-2. water ISRU • D1-5. Ice comp • D1-6. Ice occur
L	• A4-4. Auto sys • A4-7. Mech.		• B1-5. Atm elec • B3-3. Cosmic ray • B4-1. Elec • B4-4. Dust mit • B5-2. Model SpR • B6-2. Dust column • B6-3. Trace gas • B7-3. Trafficability • B7-4. Auto rover • B7-6. Samp handling	

Color Key:
Mars Orbiter — Earth
MSR — Technology demo
Mars Lander (Could be MSR landers)

High Priority, Early Timing—DETAIL
Humans to the Martian Surface

Timing

Priority	IV-	IV early

H	• **A1-1. Global temperature field.**
	  • **Mid-IR sounder***
	• **A1-2. Global aerosols**
	  • **Mid-IR sounder***
	  • **Vis sounder***
	• **A2-1. Atm. Modeling.**
	• **A4-1. Autonomous rendezvous & docking demo**
	• **A4-2. Optical Comm.**
	• **A4-5. In space prop tech demo**
	• **A4-6. Life support tech demo**
		• **B1-2. Global surface Pressure; local weather**
		  • **Pressure sensors***
		  • **Surface meteorology***
		  • **Upward looking sounder***
		  • **Pancam with sun filters***
		  • **Upward looking IR sounder***
		• **B1-6. EDL demo at human landing scale**
		• **B2-1. Biohazards**
		  • **Returned sample analysis***

* Example instruments. Other options may exist as well.

Color Key:	
Mars Orbiter	**Earth**
MSR	**Technology demo**
Mars Lander (Could be MSR landers)	

PREDECISIONAL FOR PLANNING AND DISCUSSION PURPOSES ONLY

Findings: Humans to the Martian Surface

FINDING #3. The early robotic precursor program needed to support a human mission to the martian surface would consist of at least:

- One orbiter
- A surface sample return
- A lander/rover-based *in situ* set of measurements (which could be made from a sample-caching rover)
- Certain technology demonstrations

FINDING #4. P-SAG has not evaluated whether it is required to send a lander or rover to the actual human landing site before humans arrive.

FINDING #5. Several landed measurements need to be made simultaneously with orbital measurements.

Relationship of SKGs to Science

If the SKG is addressed, how well is the science question answered.

Scientific Objectives, Martian System

SKGs

Objective		#	Investigation (from 2010 MEPAG Goals Document)	A1 Upper Atmosphere	A2 Atm. Modeling	A3 Orbital Particulates	A4 Technology: To/from Mars System	B1 Lower Atmosphere	B2 Back PP	B3 Crew Health and Performance	B4 Dust Effects	B5 Forward PP	B6 Atmospheric ISRU	B7 Landing Site and Surface Hazards	B8 Technology: Mars Surface	C1 Phobos/Deimos Science	C2 Phobos/Deimos surface Ops	C3 Technology: Phobo/Deimos	D1 Water Resources	D2 Technology: Sustained Presence
I. Life	A. Past habitability /life	1	PRIOR HABITABILITY OF SURFACE ENVIRONMENTS				Not addressed.								Not addressed.			Not addressed.	S	Not addressed.
		2	PRESERVATION POTENTIAL																	
		3	EVIDENCE OF PRIOR HABITABILITY OR BIOSIGNATURES																	
	B. Present habitability/life	1	PRESENTLY HABITABLE ENVIRONMENTS						E			E							S	
		2	DEGRADATION OF LIFE SIGNATURES						S			E								
		3	SEARCH FOR EXTANT LIFE						E			S								
	C. Evolution of habitability	1	CHARACTERIZE HYDROLOGICAL CYCLE																S	
		2	BIOESSENTIAL ELEMENTS																	
		3	POTENTIAL ENERGY SOURCES																	
		4	OXIDATIVE / RADIATION HAZARDS						E	E	S			S						
II. Climate	A. Present	1	WATER, CO2, AND DUST PROCESSES	E	E			E		S	S		E	S					S	
		2	PHOTOCHEMICAL SPECIES	S	S			S	E		S		E							
		3	VOLATILE AND DUST EXCHANGE	S	S			S			S		E							
		4	SEARCH FOR MICROCLIMATES						S		S	S	S							
	B. Recent	1	ISOTOPIC, NOBLE, & TRACE GAS CHANGES W/ OBLIQUITY																	
		2	STRATIGRAPHIC RECORD--PLD																	
		3	PERIGLACIAL PROCESSES																	
	C. Ancient	1	RATES OF ESCAPE OF KEY SPECIES																	
		2	PHYS AND CHEM RECORDS																S	
		3	ISOTOPIC, NOBLE, AND TRACE GAS EVOLUTION																	
III. Geology/ Geophysics	A. Crust	1	MINERALOGY OF GEOLOGIC UNITS							S	E			E					E	
		2	SEDIMENTARY PROCESSES AND EVOLUTION							S	S			S					S	
		3	ABSOLUTE AGES																	
		4	HYDROTHERMAL ENVIRONMENTS						E										S	
		5	IGNEOUS PROCESSES AND EVOLUTION																	
		6	SURFACE-ATM INTERACTIONS								S			S					S	
		7	TECTONIC HISTORY OF CRUST																	
		8	PRESENT STATE AND CYCLING OF WATER																E	
		9	CRUSTAL MAGNETIZATION																	
		10	EFFECTS OF IMPACTS																	
	B. Interior	1	STRUCTURE AND DYNAMICS OF INTERIOR																	
		2	ORIGIN AND HISTORY OF MAGNETIC FIELD																	
		3	CHEMICAL AND THERMAL EVOLUTION																	
	C. Phobos / Deimos	1	ORIGIN													E	S			
		2	COMPOSITION													E	E			
		3	INTERNAL STRUCTURE													E	E			

NO OVERLAP | EXCELLENT OVERLAP | SOME OVERLAP

Most Important Conclusion

<u>FINDING #6</u>. There are five particularly important areas of overlap between HEO and science objectives (in these areas, <u>mission concepts with dual purpose would be possible</u>).

1. Mars: Seeking the signs of past life (Goal I)/ Water ISRU (SKG #D1).
2. Mars: Seeking the signs of present life (Goal I)/Modern surface water/ice (Goals I,II&III/ SKG #D1)/ Forward and back PP (SKG #B2-B5).
3. Mars: Atmospheric dynamics, weather, dust climatology (Goal II/SKG #A1-A2-B1)
4. Mars: Surface geology/chemistry (Goals I&III/SKG #B3-B4-B7)
5. P/D: General exploration of P/D (SBAG/SKG #C1-C2)

Summary of Input into Planning

Next Potential Robotic Orbiter

- Orbital atmospheric information related to MOI/EDL is needed for any category of human mission to the martian system.
  - Atm T, aerosols, winds, pressure, and dust
    - Data very significantly enhanced by simultaneous surface measurements.
    - Long duration observations needed (>10 years)
- High resolution imaging and orbital spectroscopy of the surface needed to support:
  - Forward PP assessments, especially change detection potentially related to special regions
  - Landing site selection and certification, and resource identification.
    - The data needed later, but the measurements could be made early.
- Some technology demonstrations can be done from orbit
  - Optical communications is good overlap with high resolution imaging, providing bandwidth to return the data
- Radiation—simultaneous orbital and surface measurements valuable.

Summary of Input into Planning

Potential Robotic Sample Return

To prepare for a human mission to the martian surface:

- Sample return is the only implementation that would address the required Back PP SKG.
- MSR additionally the most effective way to address many other precursor information priorities (which could alternatively be done by *in situ* missions):
  - dust properties, regolith composition, hydrated mineral composition, regolith structure
  - Impact of dust on crew health/performance
- Could naturally make several high-priority technology demos:
  - Orbital rendezvous, ascent demonstration, sample handling
- Elements of the MSR campaign could also be augmented to address:
  - Measurements: surface atmospheric measurements, radiation measurements, atmospheric electricity measurements
  - Technology: Environmental exposure, autonomous rovers, dust mitigation, orbital rendezvous

Summary of Input into Planning

Next Potential Robotic Lander/Rover

To prepare for a human mission to the martian surface, the following measurements could be made from either a fixed lander or a rover:

- EDL profiles (while passing through the atmosphere),
- Dust properties, regolith composition, regolith structure
  - A key question is whether these observations need to be made at the actual human landing site before the humans arrive
- Atmospheric observations (pressure et al.) simultaneous with downward-looking orbital observations. Note that this could be optimized using a network of landed stations. Long lifetime is very important.
- Atmospheric electricity
- Radiation measurements. Needs to be done simultaneously with an orbital measurement.

- A lander/rover could make the following technology demos:
  - Sample handling, environmental exposure, autonomous rovers, dust mitigation

Summary of Input into Planning

Potential Phobos/Deimos Robotic Precursors

To prepare for a human mission to Phobos/Deimos,

- Precursor data are needed at both the remote sensing scale and the landed scale. Both kinds of data could be collected in a single mission, if it had the right design.
  - Mission could be a Phobos/Deimos rendezvous with a landed element(s).

STRATEGIC ISSUES

P-SAG has identified three strategic issues that have multiple effects on forward planning. For more complete descriptions see Appendix 2.

Possible Significance of Aerocapture (see Slide #8)

- Analysis of aerocapture indicates that it may provide a significant mass advantage when coupled with high-thrust propulsion, potentially leading to a reduction in the number of Earth launches.
- Performing aerocapture on a Mars orbit mission would mature aeroassist technology for potential application to a Mars surface mission.
- *P-SAG recommends that aerocapture analysis and technology development be continued particularly as strategic knowledge gaps identified in this report are filled with actual data. These analyses should include assessments of subscale demonstrations that could also benefit robotic precursor missions.*

Potential Exploitable Resources on Phobos/Deimos (see Slide #25)

- Future human missions to the Martian system, including exploration of the Martian surface, might be significantly enhanced by in situ resource utilization at Phobos and/or Deimos.
- A properly instrumented robotic precursor spacecraft with both rendezvous and landed elements should be able to determine whether exploitable resources exist on Phobos and Deimos.
- *P-SAG recommends that appropriate architectural assessments be made to determine the combination of in situ raw materials and human exploration infrastructure that would result in benefits for the future exploration of the Martian system. These assessments would help clarify robotic precursor spacecraft requirements needed to realize these benefits.*

Importance of Mars Sample Return (see Slide #38)

- Although it is clear from this analysis that a surface sample return is a prerequisite to a human mission to the martian surface, there are significant uncertainties in (a) whether MSR would need to be sent to the eventual human landing site and (b) what requirements future human-related PP constraints/policies would levy on samples to be returned.
- *P-SAG recommends further analysis of any issues that might connect MSR to the human spaceflight program.*

Conclusions

- **HEOMD, MEPAG and SBAG share several high priority measurement objectives in the Mars system**
- **These common objectives could be achieved by flying several kinds of precursor robotic missions to the martian system. The specific purpose, configuration, and timing of these missions is deferred to the advance planning process.**
  - **At least one orbiter**
  - **Mars surface sample return. This is an essential part of the robotic precursor campaign to retire early SKGs and to address the highest science priority for solar system exploration**
  - **A lander or rover (possibly the MSR sample caching rover, if configured properly)**
  - **A mission to Phobos and/or Deimos**

Next Steps

1. Technology development/demonstration. We need refined planning: Which of the technology elements requires flight demonstration at Mars or Phobos/Deimos? Precedence relationships—when do we need to have this technology? **ACTION: To be coordinated by HAT team and OCT.**
2. Integration of SKG precursor planning for the Moon, Mars, and asteroids. **ACTION: Mike Wargo.** Within the context of this activity,
    a) Recommend a comparative study of the strategic value to Mars missions of water-based resources at various locations in the solar system, including P/D, the martian surface, the Moon, and small bodies, taking into account the various issues associated with geological potential (concentration, state, extractability, etc.) that we either know or postulate.
3. Update MEPAG's Goal IV as needed. **ACTION: MEPAG.**
4. Follow-up. **ACTION: Future study teams.**
    a) Is a robotic precursor mission to the actual human landing site(s) on the surface of Mars required?
    b) Is a precursor sample return mission from Phobos/Deimos required before sending a human mission there?

APPENDIX 1.

Statements of Strategic Knowledge Gaps

SKGs (1 of 6)

GROUP A. To Achieve the Goal of Humans to Mars Orbit

1. **Upper Atmosphere.** The current Martian atmospheric observations (density, pressure, temperature, aerosols and dynamics) have significant limitations for supporting aerocapture and aerobraking design, especially for human-scale missions.
2. **Atmospheric Modeling.** The atmospheric models for Mars have not been well validated due to a lack of sufficient observational data, and thus our confidence in them (for use in mission engineering) is significantly limited.
3. **Orbital Particulates.** We have insufficient information about the orbital particulate environment in high-Mars orbit that may impact the delivery of cargo and crew to the Martian system.
4. **Technology: To/from Mars System.** In addition to the specific challenges listed above, we do not have the required technology available to: (1) sustain human life during long duration flight to/from Mars and around Mars; (2) launch and return human-scale payloads to/from Mars orbit.

List of SKGs (2 of 6)

GROUP B. To Achieve the Goal of Humans to the Martian Surface

All of the elements of GROUP A plus:

1. **Lower Atmosphere. We do not have sufficient martian atmospheric observations to confidently model winds, which significantly affect EDL design, or atmospheric electricity, in the forms of electric fields and conductivity, to understand the risks to ascent vehicles, ground systems, and human explorers.**
2. **Back Contamination to Earth. We do not know whether the Martian environments to be contacted by humans are free, to within acceptable risk standards, of biohazards that might have adverse effects on some aspect of the Earth's biosphere if uncontained Martian material were returned to Earth.**
3. **Crew Health & Performance. We do not understand in sufficient detail the factors affecting crew health and performance, specifically including the biological effects of the radiation environment at the martian surface and the potential toxic properties of the martian dust.**

SKGs (3 of 6)

4. **Dust Effects on Engineered Systems.** We do not understand the possible adverse effects of martian dust on surface systems.
5. **Forward Contamination to Mars.** We are not able to predict with sufficient confidence the potential consequences of the delivery and subsequent dispersal of a large bioload associated with a future human mission to the martian surface.
6. **Atmospheric ISRU.** We do not understand in sufficient detail the properties of atmospheric constituents near the surface to determine the adverse effects on ISRU atmospheric processing system life and performance within acceptable risk for human missions.
7. **Landing Site and Hazards.** We do not yet know of a site on Mars that is certified to be safe for human landing, and for which we understand the type and location of hazards that could affect the ability to safely carry out mobile surface operations.

SKGs (4 of 6)

8. **<u>Technology: Mars Surface.</u> In addition to the specific challenges listed above, we do not have the required technology available to: (1) land human-scale payloads on the martian surface; (2) sustain humans on the surface of Mars; (3) enable human mobility and exploration of the Mars surface environment; all within acceptable risk.**

SKGs (5 of 6)

GROUP C. To Achieve the Goal of Humans to Phobos/Deimos

All of the elements of GROUP A plus:

1. **Phobos/Deimos surface Science.** **We do not have enough understanding of the geological, compositional, and geophysical properties of Phobos and Deimos to be able to design focused human-based scientific investigations with specific objectives like those now possible for the Martian surface.**
2. **Phobos/Deimos surface Ops.** **We do not know enough about the physical conditions near/at the surface of the martian satellites (low gravity/loose regolith/significant temperature variations/etc.) to be able to design the close proximity and surface interactions (docking/anchoring/mobility) and other aspects of an operations plan.**
3. **Technology: Phobos/Deimos.** **We do not have all of the technologies required to carry out a crewed mission to Phobos and/or Deimos.**

SKGs (6 of 6)

GROUP D. To Achieve the Goal of Sustained Human Presence at Mars

All of the elements of GROUPS A-B, and potentially also C, plus:

1. **Resources.** **We do not adequately understand if resources (most importantly water, but also other useful material) on Mars or its moons occurs in a location/form that could influence the high-level architecture of the missions/infrastructure associated with a sustained human presence in the martian system.**
2. **Technology:** **In addition to the specific challenges listed in B-8, we do not have the required technology available to: (1) repeatedly land human-scale payloads on the martian surface; (2) sustain humans on the surface of Mars for long durations (multiple martian years); (3) acquire/extract/process key in situ resources to reduce logistical support; all within acceptable risk.**