Jet Propulsion Laboratory
California Institute of Technology

NASA'S JOURNEY TO

MARS

State of Strategic Knowledge Gaps (SKGs) in Mars Science in support of Human Exploration

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Mars Human Exploration Community-defined Goals

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

Mars Exploration Community-defined Goals

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

Eventual Goal

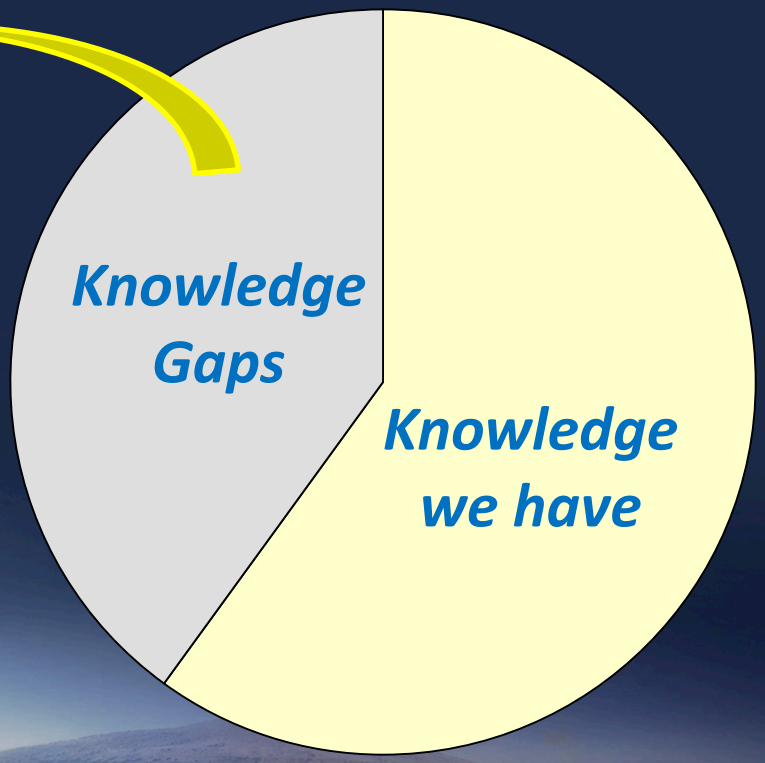
2012 Study: Defined 17 SKGs

Strategic Knowledge Gap (SKG): The gaps in knowledge needed to achieve a specific goal.

Total knowledge needed to achieve a goal

2012 Study:
60 GFAs, different priorities, urgency

Gap-Filling Activity (GFA): Work that contributes to closing an SKG.



GFA Options

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

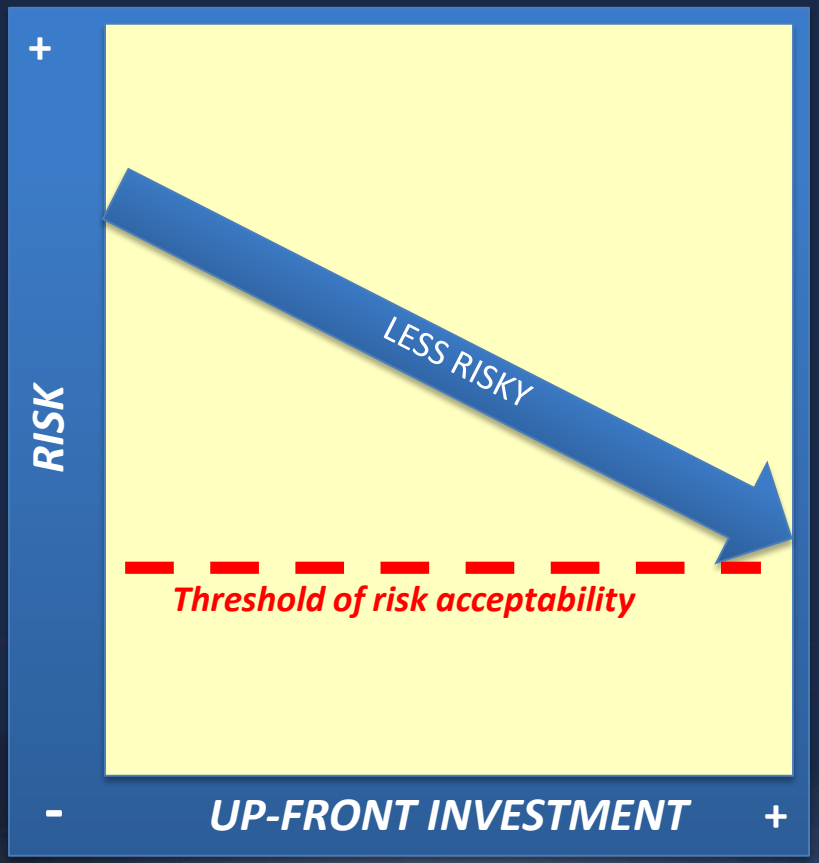
GFA Fulfillment Methods

~½ *Mars Flight Program*

~½
- *Flights to other bodies (including cis-lunar space)*
- *Non-flight work (models, lab experiments, field analogs, etc.)*
- *Technology demos*

- **Mars Flight** addressed **initially** due to long lead time, significant investment
- BUT half the GFAs can be addressed through other means
- Technology items should be examined in greater detail (future work)
- Linkages between science and technology also need to be addressed

How much risk is acceptable?



Options for risk retirement

- Acquire Knowledge
- Engineer against it
- Accept Risk

Initial risk levels identified by scientists, engineers and policy-makers from broad community segment

There have been regular, periodic updates … but risk postures change with time … and HEO and the nation would decide what level of risk is acceptable.

Gap-Filling Activity (GFA) Analysis (1 of 2)

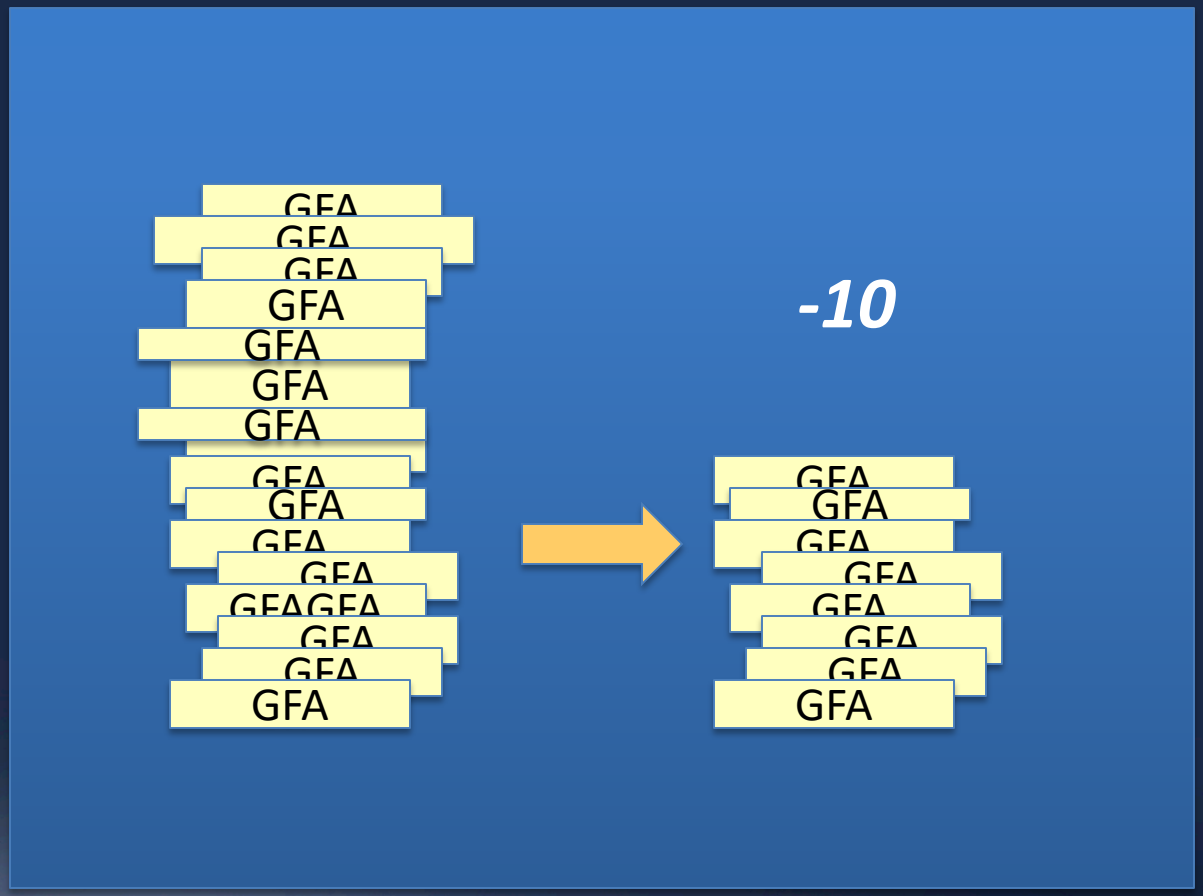
SKG		Gap-Filling Activity	Priority	Timing	Location
A1	Upper Atmosphere	A1-1. Global temperature field.	H	IV-	Mars Orbit
		A1-2. Global aerosol profiles and properties	H	IV-	Mars Orbit
		A1-3. Global winds and wind profiles	M	IV-	Mars Orbit
A2	Atm. Modeling	A2-1. Atm. Modeling.	H	IV-	Earth
A3	Orbital 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

- Color coding: Orange—requires Mars flight; Blue—can be done on Earth; Yellow—technology, location varies.

Gap-Filling Activity (GFA) Analysis (2 of 2)

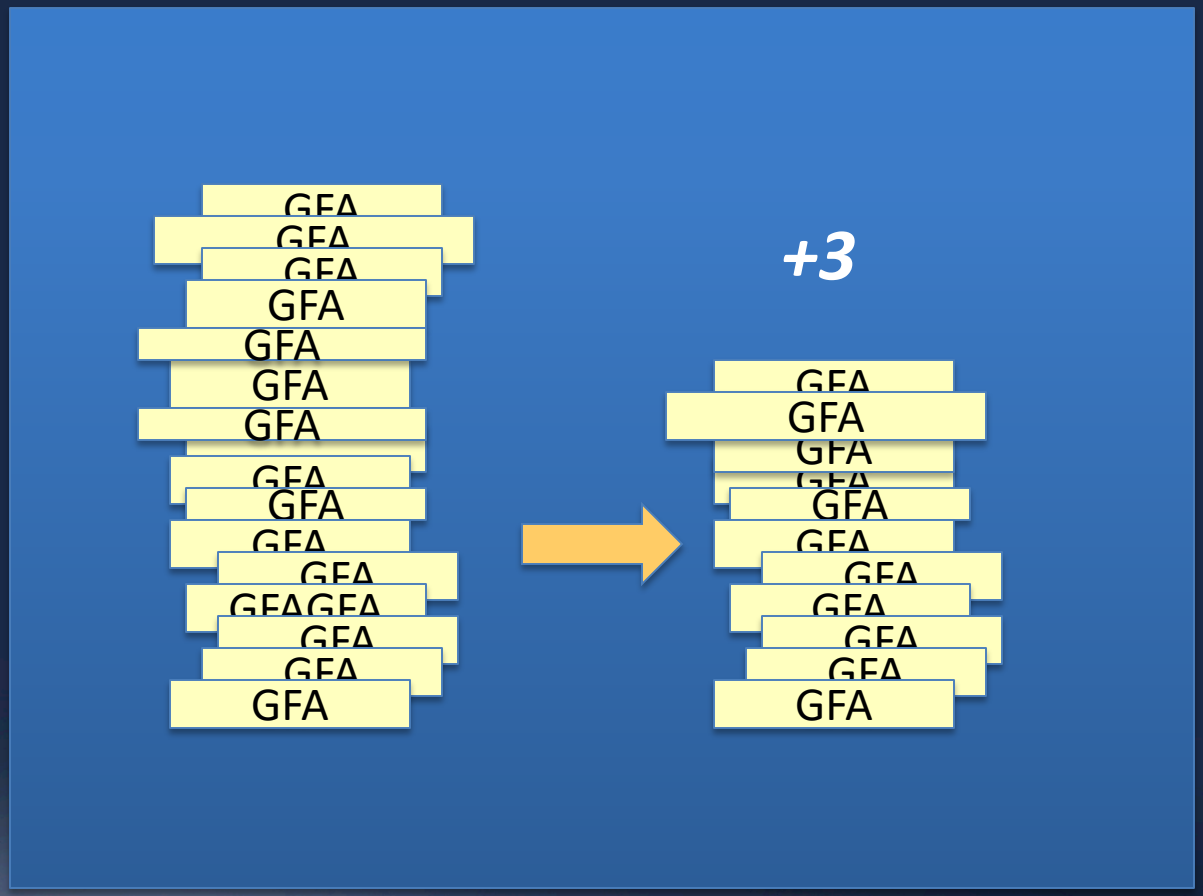
SKG		Gap-Filling Activity	Priority	Timing	Location
B5	Forward Contamination	B5-1. Identify and map special regions	H	IV Late	Mars surface and Mars orbit
		B5-2. Model induced special regions	L	IV Late	Earth
		B5-3. Microbial survival, Mars conditions	M	IV Late	Earth
		B5-4. Develop contaminant dispersal 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

We have made progress!



We now have a better understanding of global and surface winds, dust and soil properties, special regions

We have made progress!



…but there are updated GFAs
(water resource locations, energetic particle activity at surface, atmospheric ISRU)
and some GFAs are not completely closed (dust properties, surface winds)

EXAMPLE

Radiation: Significant Changes (Retire)

- ***(WAS B3-2). Simultaneous with surface measurements, a detector should be placed in orbit to measure energy spectra in solar energetic particle events.***
- ***(WAS B3-4). Identification of charged particles at the surface from hydrogen to iron and measure particle energies from 10 MeV/nuc to 400 MeV/nuc along with LET measurement during solar min.***

2012 Priority:

LOW/

MEDIUM

2016 Priority:

RETIRED

What has changed?

- **Measurements from instruments on Earth-based satellites or those at other locations in the heliosphere made in conjunction with those on Mars' surface should be sufficient to measure estimated exposures from SEP events relevant to human exploration.**
- **The RAD instrument at MSL has made measurements at the surface for over one Mars year of continuous data during the solar maximum.**

EXAMPLE

Radiation Cycle: Significant Changes (Update)

- ***(B6-2) Measure the charged particle spectra, neutral particle spectra, and absorbed dose at the Martian surface throughout the ~11 year solar cycle (from solar maximum to solar minimum) to characterize "extreme conditions" (particle spectra from solar maximum and minimum, as well as representative "extreme" solar energetic particle (SEP) events), and from one solar cycle to the next.***

2012 Priority:

UPDATE

2016 Priority:

MEDIUM

What has changed?

- **This was added to better focus on investigations B3-2 and B3-4 that both were concerned with surface radiation environments that affected Crew Health & Performance**

Curiosity RAD instrument still need to measure full solar cycle and SEP event.

What's Next

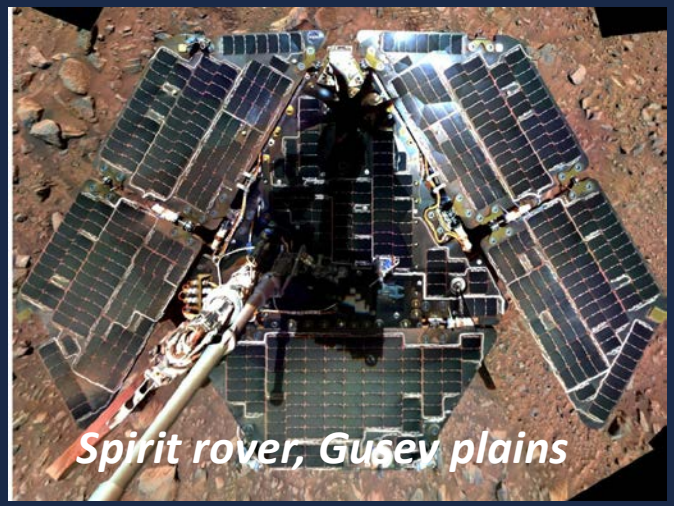
Strategic Knowledge Gap (SKG)	Gap Filling Activity (GFA)	Goals Doc 2015 Investigation #	POST MSL Priority	POST M2020 Priority	POST 2022-24 Orbiter Priority	POST MSR Priority
A1. Upper Atmosphere	A1-1. Global temperature field	A1-1				
	A1-2. Global aerosol profiles and properties	A1-2				
	A1-3. Global winds and wind profiles	A1-3				
A3. Orbital Particulates	A3-1. Orbital particulate environment	A2-1				
B1. Lower Atmosphere	B1-1. Dust Climatology	B1-1				
	A1-2. Global aerosol profiles and properties	B1-2				
	B1-2. Global surface pressure; local weather	B1-3				
	B1-4. Surface winds	B1-4				
	B1-5. EDL profiles	B1-5				
	B1-6. Atmospheric Electricity conditions	B1-6				
B2. Back Contamination	B2-1. Biohazards	B2-1				
B3. Crew Health & Performance	B3-1. Neutrons with directionality	B6-1				
	~~B3-2. Simultaneous spectra of solar energetic particles in space and in the surface~~	~~B7-RET~~				
	~~B3-4. Spectra of galactic cosmic rays on surface~~	~~B7-RET~~				
	Spectra of solar energetic particles on the surface (Update)	B6-2				
	B3-5. Toxicity of dust to crew	B6-3				
		B6-4				
		B6-5				
B4. Dust Effects on Surface Systems	B4-2. Dust physical, chemical and electrical properties	B7-1				
	B4-1. Electricity	B7-2				
	B6-2. Dust column abundances	B7-3				
B5. Forward Contamination	B5-1. Identify and map special regions	B3-1				
B6. Atmospheric ISRU	~~B6-3. Trace gas abundances~~	~~B5-RET~~				
	Atmospheric ISRU processing (Update)	B4-1				
B7. Landing Site and Hazards	B7-2. Landing site selection	B5-1				
	B7-1. Regolith physical properties and structure	B5-2				
	~~B7-3. Trafficability~~	~~B6-RET~~				
		~~B6-RET~~				

Priority color code key

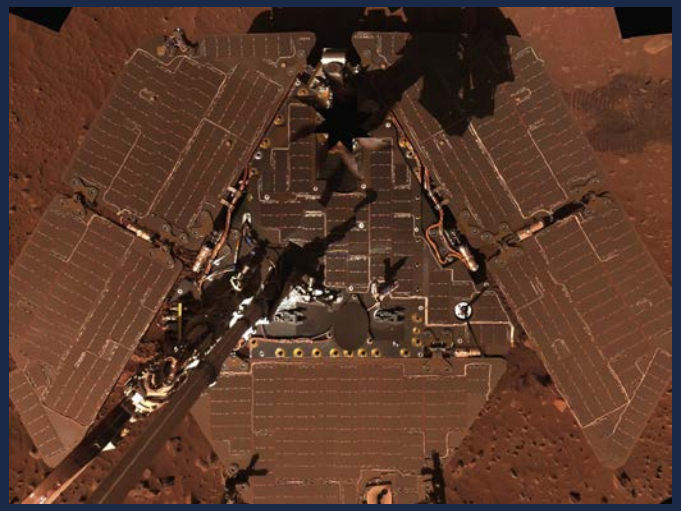
- New
- High
- Medium
- Low
- Retired
- Low/Ret

SKGs Category C and D are not treated here because they can be executed Significantly after A and B.

Astronauts would be exposed to ubiquitous dust

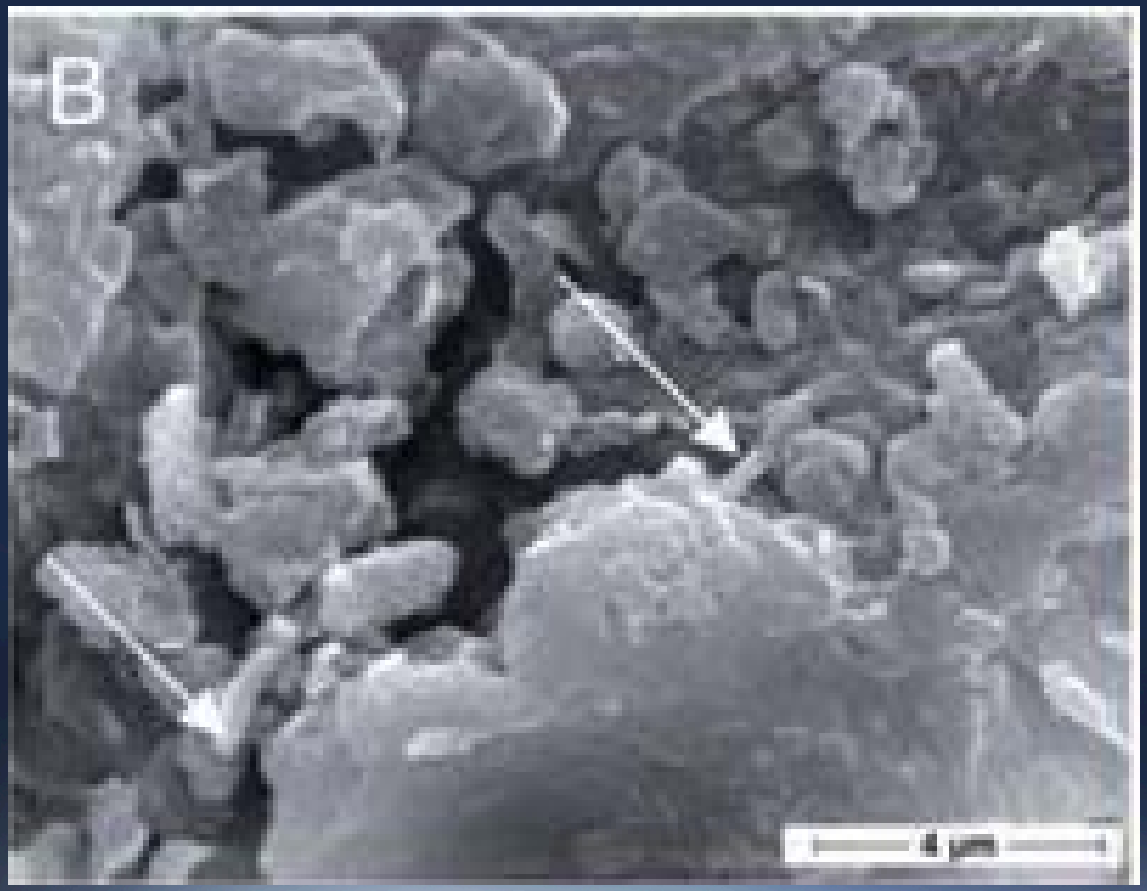


2004



2008

On Earth, airborne dust is a vector for microbe movement



Aeolian dust collected by Charles Darwin over the Atlantic, 1838

- Originated in the Sahara
- Contains many viable microbes and fungi
- Can survive for centuries, easily survives transport across the ocean

Does the same thing happen on Mars?

Like Apollo, returned crew would need to be treated as hazardous

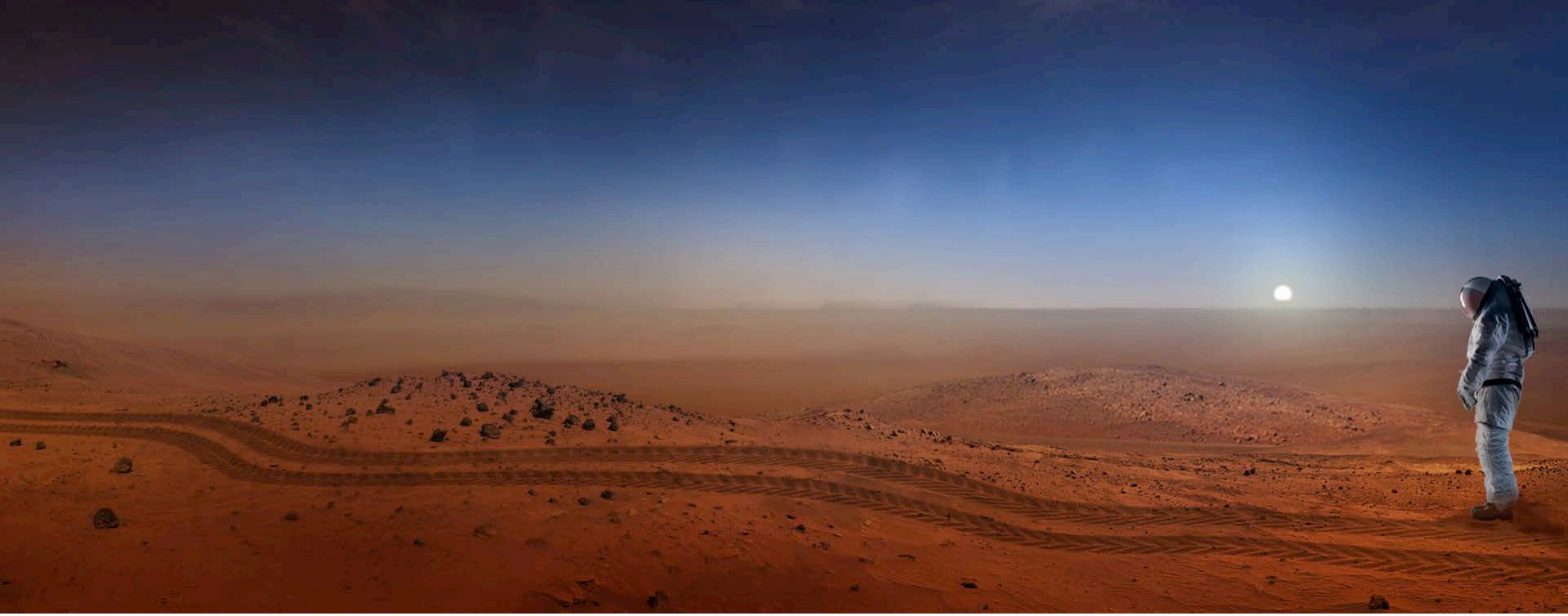
…until proven otherwise

Harmful to Earth's biota?

The only way to definitively make these analyses is in terrestrial laboratories

Take-Aways

- We are systematically buying down risk using GFAs in flight projects, technology demonstrations and lab experiments
- We should continue extended missions to further complete GFAs
- We will complete the critical Back Planetary Protection SKG only through Mars Sample Return



BACKUP MATERIAL

Detail: Retired or Decreased Priority GFAs

Retired:

- ***Simultaneous spectra of solar energetic particles in space and ion the surface***
- ***Spectra of galactic cosmic rays on the surface***
- ***Trace gas abundances***
- ***Determine traction/cohesion in martian regolith***
- ***Determine vertical variation in regolith***
- ***High spatial resolution maps of mineral composition and abundance***
- ***High spatial resolution maps of subsurface ice depth and concentration***

Decreased Priority:

- ***Making long-term measurements of winds and wind directions (improvements in EDL technologies have decreased the importance of this measurement)***
- ***Profile the near-surface winds (improvements in EDL technologies have decreased the importance of this measurement)***
- ***Dust physical, chemical and electrical properties (rover data from multiple locations has provided sufficient information on these properties)***

Detail: GFAs with Updated or Increased Priority

Updated:

- ***Measure solar energetic particles at the martian surface throughout the ~11 year solar cycle to characterize "extreme conditions"***
- ***Test ISRU atmospheric processing system to measure resilience with respect to dust and other environmental challenge performance parameters.***
- ***Identify a set of candidate water resource deposits that have the potential to be relevant for future human exploration.***

Increased Priority:

- ***Image selected potential landing sites to sufficient resolution to detect and characterize hazards to both landing and trafficability at the scale of the relevant landed systems.***
- ***Prepare high spatial resolution maps of at least one high-priority water resource deposit that include the information needed to design and operate an extraction and processing system with adequate cost, risk, and performance.***

Winds: Significant Changes (Decrease)

- ***(A1-3). Make long-term (>5 Martian years) observations of global winds and wind direction with a precision ≤5 m/s at all local times from 15 km to an altitude >60 km. The global coverage would need observations with a vertical resolution of ≤5 km and a horizontal resolution of ≤300 km. The record needs to include a planetary scale dust event.***

2012 Priority:

HIGH

2016 Priority:

MEDIUM

What has changed?

- **Knowledge of the winds is very important for missions that use a parachute.**
- **We have not collected data on any aspect of this GFA.**
- **However, the baseline EDL system has shifted to a propulsive descent, which is significantly less vulnerable to winds.**

Winds: Significant Changes (Decrease)

- ***(B1-4). Profile the near-surface winds (<15 km) with a precision ≤2 m/s in representative regions (e.g., plains, up/down wind of topography, canyons), simultaneous with the global wind observations. The boundary layer winds would need a vertical resolution of ≤1 km and a horizontal resolution of ≤100 m. The surface winds would be needed on an hourly basis throughout the diurnal cycle. During the daytime (when there is a strongly convective mixed layer), high-frequency wind sampling would be necessary.***

2012 Priority:

HIGH

2016 Priority:

MEDIUM

What has changed?

- **Knowledge of the winds is very important for missions that use a parachute.**
- **We have not collected data on any aspect of this GFA.**
- **However, the baseline EDL system has shifted to a propulsive descent, which is significantly less vulnerable to winds.**

Trace Gas: Significant Changes (Retire)

- ***(WAS B5-1). Measure the trace gas composition of the martian atmosphere with sufficient resolution and accuracy to determine the potential effects on atmospheric ISRU.***

2012 Priority:

LOW

2016 Priority:

RETIRED

What has changed?

- **The SAM instrument on MSL (launched 2011) has successfully measured the composition of the martian atmosphere in detail, including trace gases of potential relevance to atmospheric ISRU processing systems.**

Location-dependent ISRU & Sustained Presence

Field Station Analog:
McMurdo, Antarctica

Even if we don't plan to install ISRU until here

Emplacement

British National Antarctic Expedition - 1902 R.F. Scott's "winter quarters hut" - Used for both local scientific research and as a logistical base for traverses inland.

Consolidation

Permanent occupation - 1955 Naval Air Facility McMurdo - Part of "Operation Deep Freeze" to support the International Geophysical Year; included a collection of semi-permanent structures (e.g., tents, Jamesway huts).

McMurdo Station - Today Antarctica's largest community and a functional, modern-day science station, including a harbour, three airfields (two seasonal), a heliport, and more than 100 permanent buildings.

Utilization

We need to plan for site-dependent resources here

<u>HOWEVER</u>, if we are not planning for sustained presence in any one location, there is less value in investing in location-dependent ISRU

Atm ISRU: Significant Changes (Update)

- ***(B4-1) Test ISRU atmospheric processing system to measure resilience with respect to dust and other environmental challenge performance parameters that are critical to the design of a full-scale system.***

2012 Priority:

UPDATE

2016 Priority:

HIGH

What has changed?

- **This was added to improve upon the retired investigations B5-1 that focused on establishing environmental conditions relevant to atmospheric ISRU, with a renewed focus on actually testing the system.**

Imaging: Significant Changes (Increase)

- ***(B5-1) Image selected potential landing sites to sufficient resolution to detect and characterize hazards to both landing and trafficability at the scale of the relevant landed systems.***

2012 Priority:

MEDIUM

2016 Priority:

HIGH

What has changed?

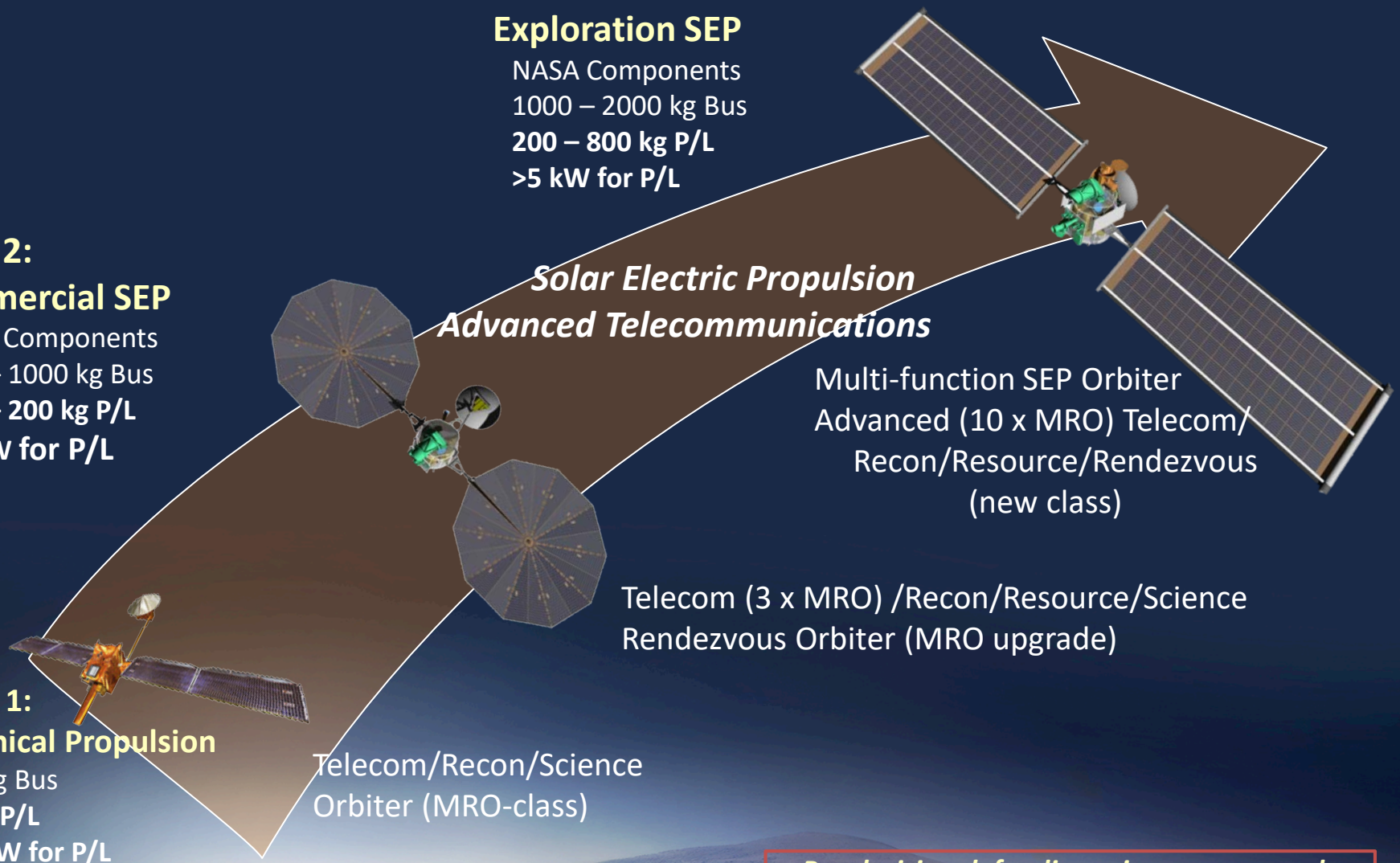
- **This is very important for robotic missions and likely will be equally important for human missions.**
- **This is an ongoing task for MRO HiRISE.**

2022-2024 Orbiter Concept Options

Class 3:
Exploration SEP
NASA Components
1000 – 2000 kg Bus
200 – 800 kg P/L
>5 kW for P/L

Class 2:
Commercial SEP
COTS Components
500 – 1000 kg Bus
100 – 200 kg P/L
>2 kW for P/L

Solar Electric Propulsion
Advanced Telecommunications



Multi-function SEP Orbiter
Advanced (10 x MRO) Telecom/
Recon/Resource/Rendezvous
(new class)

Telecom (3 x MRO) /Recon/Resource/Science
Rendezvous Orbiter (MRO upgrade)

Class 1:
Chemical Propulsion
800 kg Bus
80 kg P/L
~150 W for P/L

Telecom/Recon/Science
Orbiter (MRO-class)

Pre-decisional; for discussion purposes only

Trafficability: Significant Changes (Retire)

- ***(WAS B6-6). Determine traction/cohesion in Martian regolith throughout planned landing sites; where possible, feed findings into surface asset design requirements.***
- ***(WAS B6-7). Determine vertical variation of in situ regolith density within the upper 30 cm for rocky areas, on dust dunes, and in dust pockets to within 0.1 g cm3.***

2012 Priority:

LOW

2016 Priority:

RETIRED

What has changed?

- **The rovers Spirit, Opportunity, and Curiosity have driven for years across a variety of regolith types, systematically recording data about the regolith's physical properties.**
- **Even though we don't have data on the actual human landing site (which is not yet identified), we have enough general knowledge of this potential hazard to support engineering design work.**

Dust: Significant Changes (Decrease)

- ***(B7-1). Analyze regolith and surface aeolian fines (dust), with a priority placed on the characterization of the electrical and thermal conductivity, triboelectric and photoemission properties, and chemistry (especially chemistry of relevance to predicting corrosion effects), of samples of regolith from a depth as large as might be affected by human surface operations.***

2012 Priority:

HIGH

2016 Priority:

LOW

What has changed?

- **Although the measurements are provincial, we have a relatively good understanding of physical properties for the regolith and dust.**

Imaging: Significant Changes (Retire)

- ***(WAS D1-4). High spatial resolution maps (~2 m/pixel) of mineral composition and abundance. Verification of mineral volume abundance and physical properties within approximately the upper 3 meters of the surface. Mineral identification must also be verified.***
- ***(WAS D1-6). High spatial resolution maps (~100 m/pixel) of subsurface ice depth and concentration within approximately the upper 3 meters of the surface. Verification of ice volume abundance and physical properties within approximately the upper 3 meters of the surface.***

2012 Priority:

HIGH/

MEDIUM

2016 Priority:

RETIRED

What has changed?

- **CRISM detects hydrated minerals at the surface or exposed by impacts. New impact craters observed by CTX and HiRISE sometimes reveal the distribution of subsurface ice. SHARAD detects ice layers at depths greater than 10m.**

Imaging: Significant Changes (Update)

- ***(D1-1) Identify a set of candidate water resource deposits that have the potential to be relevant for future human exploration.***

2012 Priority:

UPDATE

2016 Priority:

HIGH

What has changed?

- **This was added as a new investigation to follow on work from the retired investigations D1-4 and D1-6 that both were focused on identification of mineral composition and ice depth, with a focus on identifying specific deposits.**

Imaging: Significant Changes (Increase)

- ***(D1-2) Prepare high spatial resolution maps of at least one high-priority water resource deposit that include the information needed to design and operate an extraction and processing system with adequate cost, risk, and performance.***

2012 Priority:

MEDIUM

2016 Priority:

HIGH

What has changed?

- **In conjunction with increased focus on identifying specific resource deposits for potential future human exploration, this was increased to focus on the creation of maps for this deposit that would help with future assessments.**

Gap Filling Activity Priority, Timing

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

GFA: Priority vs. Timing w Details

Humans to Mars Orbit or Phobos/Deimos

Priority	IV-	P/D

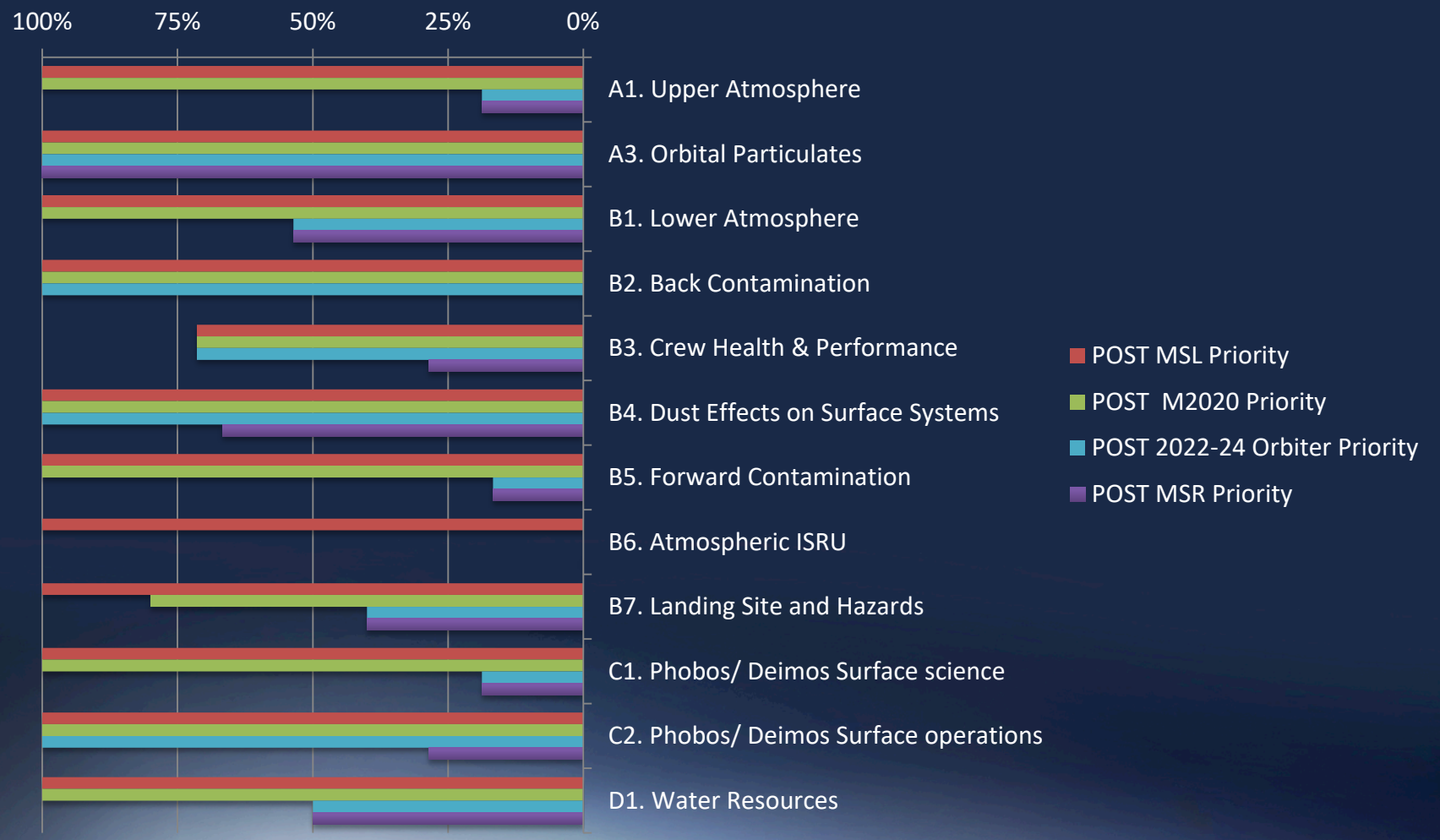
H	• A1-1. Global temperature field.
	  • Mid-IR sounder
	• A1-2. Global aerosols
	  • Mid-IR sounder
	  • Vis sounder
	• A2-1. Atm. Modeling.
	• A4-1. Autonomous rendezvous & docking demo
	• A4-2. Optical Comm.
	• A4-5. In space prop tech demo
	• A4-6. Life support tech demo
		• C1-1. P/D composition
		  • 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

What's Next?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A1. Upper Atmosphere
A3. Orbital Particulates
B1. Lower Atmosphere
B2. Back Contamination
B3. Crew Health & Performance
B4. Dust Effects on Surface Systems
B5. Forward Contamination
B6. Atmospheric ISRU
B7. Landing Site and Hazards
C1. Phobos/ Deimos Surface science
C2. Phobos/ Deimos Surface operations
D1. Water Resources
POST MSL Priority
POST M2020 Priority
POST 2022-24 Orbiter Priority
POST MSR Priority