APPENDIX 2.

Topical Analyses of Gap-Filling Activities

SKG breakdown
Atmospheric SKGs

- Large uncertainties in atmospheric models directly increase mission risk, reduce payload margins by increasing entry system mass, limit landing sites, and may force non-optimal technology choices.
- The atmospheric SKGs includes two aspects:
  - Increased numbers of observations of the Martian atmosphere (at Mars)
    - The atmospheric observations are designed to be synergistic. In particular, the surface measurements need to be acquired while the orbital observations are also being acquired.
    - Current orbital observations particularly lack local time coverage.
  - Improvement and validation of models used for architecture and system design (on Earth)
  - The observations are directly used to validate the models.
- Validation allows the models to be confidently used to create the extreme conditions (>99% distribution tail) necessary to select and design EDL, aerocapture, aerobraking, and launch systems.
  - Cannot acquire sufficient observations of extreme conditions.
- Many of these observations will take a decade (5 Mars years) to acquire
  - Atmospheric model validation and data assimilation can take multiple years, following data acquisition, and must be factored into phasing

SKG A1 breakdown
Atmospheric GFAs

- The altitude range of the atmospheric measurements requested for these GFAs has been slightly extended vertically to meet both IV- and IV needs. They start at the surface instead of ~20 km.
- **A1-1 Global Temperature Field:**

  Description: Measurements of the global temperature field (surface to 80 km) *at all local times* provide density profiles for model validation.

  Measurement Examples: Current techniques provide the necessary resolution and accuracy: mid IR limb and nadir sounding with radiometer or spectrometer; microwave radiometer

  Correlated Science Objectives: Measure the global atmosphere (< 80 km) vertical structure and meteorology, including daily, seasonal, and solar cycle trends [MEPAG Goals II-A1i and II-A2].
- **A1-2 Global Aerosol Profiles and Properties:**

  Description: Aerosols (dust and ice) are an important driver of the state of the atmosphere. Profiles of aerosols (surface to 60 km) are critical for modeling accuracy. Aerosol properties (optical properties and particle sizes) define their radiative effectiveness. Measurements are needed *at all local times*.

  Measurement Examples: Current techniques provide the necessary resolution and accuracy: visible plus mid-IR limb sounding, radiometer/bolometer or spectrometer; Orbital Lidar

  Correlated Science Objectives: Measure the spatial and vertical distribution of aerosols and clouds on daily to decadal timescales [MEPAG Goals II-A1i and II-A3].
- **A1-3 Global Winds and Wind Profiles:**

  Description: Winds are a sensitive diagnostic of the state of the atmosphere and are an important validation check for models. Winds are also important for successful pinpoint landing.

  Measurement Examples: Orbital Lidar, microwave radiometer

  Correlated Science Objctvs: Direct measurement of winds [MEPAG Goals II-A1i, II-A2 & II-A3].

SKG A2 breakdown
Atmospheric GFAs

- **A2-1 Atmospheric Modeling**
  - **Description:** There are 4 types of models/techniques to improve and validate:
    - MGCM (Mars General Circulation Models) - global temperature & wind fields
    - Mesoscale - local and regional weather and climate conditions
    - LES (Large Eddy Simulations) - small-scale local conditions (such as dust devils) that are superimposed on the regional weather
    - Data Assimilation - quantitatively combines observations and model fields
  - Model improvements are based on the data acquired as part of SKG A1, and for landing/takeoff at Mars, SKG B1.
  - **Correlated Science Objectives:** This GFA matches the goal of developing more realistic models of the climate of Mars. [MEPAG Goals II-A1i, II-A2]
- Atmospheric model validation and data assimilation can take multiple years, following data acquisition, and must be factored into phasing

SKG B1 breakdown (1 of 2)
Atmospheric GFAs

- **B1-1 Dust Climatology:**

  Description: Understand the statistics of dust events (size, location, horizontal area, and duration). These observations are synergistic with the temperature and aerosol profiles.

  Measurement Examples: Current techniques provide the necessary resolution and accuracy: Visible low resolution wide angle camera.

  Correlated Science Objectives: Measure the spatial distribution and transport of dust [MEPAG Goals II-A1i and II-A3]

- **B1-2 Global Surface Pressure; Local Weather:**

  Description: Measure the surface pressure to validate models and insure EDL architecture can handle the variations in atmospheric mass. Measure the surface and lower atmosphere (< 20 km) temperature and aerosol structure to validate models focused on the near-surface used for the final stages of EDL (and initial state during launch).

  Measurement Examples: Current techniques provide the necessary resolution and accuracy: MET package (including a pressure senor), upward looking mid-IR spectrometer/radiometer, Lidar, and sun tracking visible camera.

  Correlated Science Objectives: In-situ measurements of near-surface variables, including dust fluxes and aerosol radiative heating, and global mass exchange [MEPAG Goals II-A1(i, ii, iii), and II-A3]

- **B1-3 Surface Winds:**

  Description: Surface winds drive dust lifting and are also a sensitive tool of model validation. Winds are also important for successful pinpoint landing.

  Measurement Examples: Upward-looking Lidar, in-situ wind sensor (multiple technology options).

  Correlated Science Objectives: Measure near-surface winds [MEPAG Goals II-A1i, II-A1iii, & II-A3]

SKG B1 breakdown (2 of 2)
Atmospheric GFAs

- **B1-4 EDL Profiles:**

  Description: High vertical resolution profiles (< 1 km) of atmospheric density (or temperature), especially in the lower 20 km. These validate high resolution modeling of the fine atmospheric structure.

  Measurement Examples: Current techniques provide the necessary resolution and accuracy: Instrumented EDL/flight systems, Earth radio occultation, multi-orbiter mutual occultations ("GPS")

  Correlated Science Objectives: Limited overlap with the need for in-situ measurements of the temperature structure [MEPAG Goal II-A1i], some techniques can provide global temperature structure information [MEPAG Goal II-A1i]

- **B1-5 Atmospheric Electricity Conditions:**

  Description: Measure the electrical properties of the martian environment to asses the discharge events. These may impact surface communications and Mars take-off and ascent.

  Measurement Examples: AC radio receivers, relaxation probe, Gerdien condensers, conductivity probes, dust charge detectors, DC electric field meters.

  Correlated Science Objectives: Electro-chemical effects may be important for some chemical species [MEPAG Goal II-A2, some correlation]

- **B1-6 EDL Technology Demo:**

  Description: Demonstration of EDL system at the scale needed for human exploration of Mars.

- **B1-7 Ascent Technology Demo:**

  Description: Demonstrate a martian ascent vehicle and the support infrastructure. This could be at Mars (MSR return launch, for example) or on Earth.

SKG breakdown
Atmospheric GFAs

Measurement Priorities

Gap filling activity	Priority	Location	Measurements and demonstrations
A1-1. Global temperature field.	High	Mars Orbit	Global Temperature Field
A1-2. Global aerosol profiles and properties	High	Mars Orbit	Aerosol Profiles and properties, including optical properties, particle sizes, and number densities
A1-3. Global winds & wind profiles	Medium	Mars Orbit	Global coverage of wind velocity and direction
A2-1. Atm. Modeling.	High	Earth	Improve atmospheric models
B1-1. Dust Climatology	High	Mars Orbit	Dust and aerosol activity climatology
B1-2. Global surface pressure; local weather	High	Mars surface	Surface Pressure and Surface meteorology
B1-3. Surface winds	Medium	Mars surface	Vertical Profiling of surface winds from 0-15 km
B1-4. EDL profiles	Medium	Mars EDL	High Vertical Resolution Temperature Profiles
B1-5. Atmospheric Electricity conditions	Low	Mars surface	AC and DC electric fields, Ground and atmospheric electrical conductivity, Dust grain charge

- Long-lived orbiters with global diurnal coverage will provide the largest volume of atmospheric data to support model development and validation.
- Multiple landers providing simultaneous measurements with the orbiters are needed to acquire near-surface data correlated with upper atmosphere measurements, for model development and validation.

HIGH-LEVEL STRATEGIC ISSUE

Possible Significance of Aerocapture

- Aerocapture provides a significant mass advantage when coupled with high-thrust propulsion; it could reduce the number of Earth launches.
- Aerocapture coupled with high-thrust is an alternative that provides a backup approach depending on how the propulsion technologies progress.
- Aerocapture has no greater risk than EDL; aerocapture is much simpler than EDL—it stays in one flight regime, does not deal with surface interaction, does not necessarily depend on predeployed assets, and could actually lower overall architecture risk if launches are saved. Aerocapture may provide a backup MOI option in case the propulsive capture fails.
- Given the development path for inflatable/deployable decelerators and their planned use in Earth vicinity missions (another flight test this year, ISS downmass possibilities, L2 return of assets, etc.), they have a reasonable chance of maturing; use at Mars will be the natural extension.
- Performing aerocapture on the Mars orbit mission matures aeroassist technology for application to the Mars surface mission.

SKG breakdown

Mars Surface ISRU

- The first resource to be utilized would be O_2 from atmospheric CO_2. Extraction of H_2 from water ice or hydrated minerals is plausible in the further future.
- Recovery of O_2 from atmospheric CO_2
  - The key issue is how the abundance and the chemical and physical properties of atmospheric dust will affect extraction devices
- Ice and hydrated minerals
  - The distributions are anti-correlated: shallow ice occurs at mid- to high latitude; hydrated minerals at low latitude
  - Ice likely occurs in near pure form but overburden requires removal. The first unknown to determine is distribution. Mechanical properties are also unknown and should be determined next. There is overlap with possible present habitats and PP is a major issue
  - Hydrated minerals can be mapped at the surface but mechanical properties are uncertain. There is strong overlap with possible past habitable sites.
- A lander is higher priority; an orbiter can make valuable contributions

SKG B6 breakdown
Mars Surface ISRU GFAs

- **B6-1. Dust physical, chemical and electrical properties:**

  Description: Understand the size, shape, and chemistry of dust particles and their potential to interfere with atmospheric ISRU processing.

  Measurement Examples: Particle shape and size distribution; mineral composition

  Correlated Science Objectives: Measure the spatial distribution and transport of dust [MEPAG Goals II-A1i and II-A3]

- **B6-2. Dust column abundances:**

  Description: Understand high time and spatial frequency variations in column abundance of dust and their potential to interfere with atmospheric ISRU processing.

  Measurement Examples: Column abundance and size-frequency distribution, resolved at less than scale height daily or more frequently.

  Correlated Science Objectives: Measure the spatial distribution and transport of dust [MEPAG Goals II-A1i and II-A3]

- **B6-3. Trace gas abundances:**

  Description: Understand trace gas abundances and their potential to interfere with atmospheric ISRU processing.

  Measurement Examples: Trace gas abundances.

  Correlated Science Objectives: Measure the key photochemical species [MEPAG Goal II-A2]

SKG D1 breakdown

Mars Surface ISRU GFAs

- **D1-3. Hydrated mineral compositions**

  Description: Determine the chemical forms of bound water in soils and rock units.

  Measurement Examples: Mineral and elemental composition, including minor components.

  Correlated Science Objectives: Mineralogic structure of geologic units; past aqueous, hydrothermal environments; potential presently habitable environments such as recurring slope lineae (RSLs) [MEPAG Goals III-A1, III-A2, III-A4, and III-A6]

- **D1-4. Hydrated mineral occurrences**

  Description: Increase the spatial resolution of the distribution of bound water in soils and rock units, to the several-meter outcrop scale relevant to extraction.

  Measurement Examples: Occurrences and internal structure of deposits.

  Correlated Science Objectives: see D1-3 above

- **D1-5. Shallow water ice composition and properties**

  Description: Determine volatile type/amount released during soil heating, energy required as a function of temperature.

  Measurement Examples: Evolved volatiles & energy requirements for extraction.

  Correlated Science Objectives: Volatile cycling at the boundary layer, potential presently habitable environments [MEPAG Goals I-B1, II-A1, and III-A8].

- **D1-6. Shallow water ice occurrence**

  Description: Globally determine abundance, depth, and spatial distribution of water ice to the scale relevant to extraction.

  Measurement Examples: Abundance of ice within upper meter and variation with depth.

  Correlated Science Objectives: Present state/cycling of water, potential presently habitable environments (RSLs) [MEPAG Goals I-B1, II-A1, and III-A8].

SKG breakdown
Mars Surface ISRU

Measurement Priorities

- A landed mission is the highest priority to provide missing information on physical and chemical properties of resources.

Gap filling activity	Priority	Location	Measurements and demonstrations
B6-1. Dust physical, chemical and electrical properties	High	Mars Surface or Sample return	Particle shape and size distribution
B6-2. Dust column abundances	Medium	Mars Surface	Column abundance and size-frequency distribution, resolved at less than scale height
B6-3. Trace gas abundances	Low	Mars Surface or Orbit	Trace gas abundances
D1-3. Hydrated mineral compositions	High	Sample return	Mineral and elemental abundances, including minor components.
D1-4. Hydrated mineral occurrences	High	Mars Orbit	Occurrences and internal structure of deposits.
D1-5. Shallow water ice composition and properties	Medium	Mars surface	Evolved volatiles & Energy requirements for extraction
D1-6. Shallow water ice occurrence	Medium	Mars surface and Mars orbit	Abundance of ice within upper meter and variation with depth

SKG breakdown
Mars Surface Hazards SKGs

The properties of the surface and near-subsurface pose a variety of hazards to humans reaching the surface and carrying out mobile operations:

- Electrical/chemical/physical characteristics of the soil that will accumulate on surfaces and penetrate systems, leading to unknown impacts (e.g., abrasion) on key systems and equipment
- Blast ejecta from descent engines could exceed bearing capacity of soils
- Need sufficiently detailed knowledge that landing site(s) meets acceptable parameters for (potentially multiple) large vehicles
- Feature recognition during terminal descent to avoid major hazards
- Hazard identification for traverse planning to enable pre-determination of routes to interesting targets (efficiency of operations)
- Trafficability needs to be understood over potentially long traverse distances (e.g., dust deposits that could hinder mobility)

SKG B-4 breakdown

Mars Surface Hazards GFAs

- **B4-2 – Dust physical, chemical and electrical properties**

  Description: Knowledge of these properties of dust and near surface particulates are relevant to astronaut health and long-duration surface system operations

  Measurement Examples: Electric fields and monitoring, conductivity, mass spectroscopy, mineralogical spectroscopy, X-ray spectroscopy, granulometry, trenching, and collection/return of samples

  Correlated Science Objectives: Determination of these properties of Martian dust will contribute to our understanding of past/present habitable/aqueous environments and provide geochemical context for assessing whether life was or is present on Mars; we would obtain insight into the nature and evolution of crustal geologic processes and could demonstrate in situ sample processing

SKG B-7 breakdown
Mars Surface Hazards GFAs

- **B7-1 – Regolith physical properties and structure**

  Description: Knowledge needed to design, land, and safely operate on the Martian surface

  Measurement Examples: Determination of subsurface layering, shear and bearing strength, composition and ice content, flow rate index, particle shape and size distribution

  Correlated Science Objectives: Characterization of Mars' regolith provides insight into the past and/or present habitability, cycling of water, and volatile and dust cycling between the atmosphere and the surface

- **B7-2 – Landing site selection**

  Description: Orbital data needed to assist in landing site(s) selection as well as identification and avoidance of potential landing hazards; surface measurements needed to characterize surface and subsurface regolith properties relevant to landing

  Measurement Examples: Determination of subsurface layering, shear and bearing strength, ice content and composition, flow rate index, particle shape and size distribution

  Correlated Science Objectives: Investigation and identification of past and/or potentially habitable environments, evaluation of geologic processes affecting the Martian crust

- **B7-3 – Trafficability**

  Description: Knowledge needed to ensure adequate capability to traverse the Martian surface

  Measurement Examples: Determination of traction/cohesion in Martian soil/regolith, high-resolution (stereo) imaging, thermal inertia, etc.

  Correlated Science Objectives: Studies relating to trafficability inherently provide information about geologic processes affecting the surface of Mars

SKG B4 breakdown
Mars Surface Hazards

Measurement Priorities

Gap filling activity	Priority	Location	Measurements and demonstrations
B4-2. Dust physical, chemical and electrical properties	Medium	Mars surface	Determine the electrical conductivity of the ground, measuring at least 10-13 S/m or more, at a resolution DS of 10% of the local ambient value Combine the characterization of atmospheric electricity with surface meteorological and dust measurements to correlate electric forces and their causative meteorological source for more than 1 martian year, both in dust devils and large dust storms
B4-2. Dust physical, chemical and electrical properties	Medium	Sample return	Determine the charge on individual dust grains equal to a value of 10-17 C or greater, for grains with a radius between 1-100 microns

SKG B7 breakdown

Mars Surface Hazards

Measurement Priorities

Gap filling activity	Priority	Location	Measurements and demonstrations
B7-1. Regolith physical properties and structure	Medium	Mars surface	Surface bearing strength; Presence of significant heterogeneities or subsurface features of layering; An index of shear strength Gas permeability in the range 1 to 300 Darcy with a factor of three accuracy
B7-1. Regolith physical properties and structure	Medium	Mars Surface or Sample return	Ice content and composition to within 5% by mass Flow Rate Index test or other standard flow index measurement Particle shape and size distribution
B7-2. Landing site selection	Medium	Mars Orbit	Measure slopes; Map cliffs, scarps, craters/depressions, rock concentrations and other significant terrain features that could be potential surface hazards Map thermal inertia sufficient to identify dust accumulations that would cause either roving hazards.
B7-2. Landing site selection	Medium	Mars surface	Bearing strength via composition (in situ mineralogy)
B7-3. Trafficability	Low	Mars surface	Determine traction/cohesion in martian soil/regolith

SKG breakdown
Phobos/Deimos SKGs

- Uncertainties related to the environments, physical properties, and geologic characteristics associated with Phobos and Deimos impact mission architectures and risk for future human missions to the Martian system.
- The Phobos and Deimos SKGs can be broken down into three areas:
  1. Environment
     - An understanding of the orbital particulate population in high Mars equatorial orbit is warranted as it is a potential risk for spacecraft operation.
     - Knowledge of electrostatic charging and plasma environment surrounding each moon drives designs for vehicles and EVA systems operating in proximity to the moons.
     - Collection of data related to the measurement of radiation shielding/secondary effects from interaction with Phobos/Deimos materials may mitigate risk to crew.
  2. Physical Properties
     - Characterization of the thermal conditions near, at, and below the surface influences vehicle, EVA, and tool/equipment designs and their operation.
     - Measurement of the high order gravity field of the moons leads to more efficient planning of proximity and surface operations.
  3. Geologic Characteristics
     - Detailed understanding of the presently unknown surface composition will drive science and exploration objectives and may also influence systems designs.
     - More complete knowledge of the regolith characteristics is required for operations planning, surface interaction, and development of EVA/mobility systems.
- These SKGs can best be addressed by a combination of remote and *in situ* observations/investigations at Phobos and Deimos.

SKG A3 and C1 breakdown
Phobos/Deimos GFAs

- **A3-1 Orbital Particulate Environment:**

  Description: Measurement of the flux and size frequency distribution of particles in high Mars orbit located in and around the equatorial plane. These particles may be generated as ejecta that escape Phobos and Deimos, but remain a zone/ring surrounding each moon.

  Measurement Examples: Micrometeoroid or dust counters for direct measurement.

  Correlated Science Objectives: Understanding the orbital dynamics and lifetime of small particles generated from small bodies and the particulate environments associated with small bodies [SBAG – Solar System Dynamics, Current State of the Solar System; Visions and Voyages – Processes that affect small bodies].

- **C1-1 Surface Composition:**

  Description: Elemental and mineralogical composition determination of the surface and near sub-surface of Phobos/Deimos. Identification of geologic units for science and exploration, and materials for future *in situ* resource utilization operations.

  Measurement Examples: Gamma ray and neutron spectrometers, *in situ* science analyses (e.g., APXS, XRF, Mossbauer, Raman, *etc*.), mass spectrometers, contact microscopes, science instruments coupled to penetration/excavation mechanisms.

  Correlated Science Objectives: Understanding the composition of Phobos and Deimos as it relates to their formation and origin, and how these small bodies may provide resources for future operations [SBAG – Solar System Origins, Current State of the Solar System, ISRU; Visions and Voyages – Origin of water and organics in the terrestrial planets].

SKG C2 breakdown (1 of 2)
Phobos/Deimos GFAs

- **C2-1 Electrostatic and Plasma Environments:**

  Description: Flux measurements of electrostatic charge and plasma fields near the surface of Phobos and Deimos. Electrostatic potential differences have the capability for levitation and transport of particles on an airless body's surface.

  Measurement Examples: Langmuir probe combined with microchannel plates, particle instruments, double probe, electron drift instruments.

  Correlated Science Objectives: Understanding the environmental effects of solar interactions at and near the surface of small airless bodies [SBAG – Current State of the Solar System; Visions and Voyages – Processes that affect small bodies].

- **C2-2 Gravitational Field:**

  Description: Determination of the gravitational field to a sufficiently high degree and order to make inferences regarding the internal structure and/or mass concentrations of Phobos and Deimos.

  Measurement Examples: Radio science.

  Correlated Science Objectives: Understanding of the internal structure and mass concentrations of small bodies as it relates to their impact histories and formation mechanisms [SBAG – Solar System Origins, Current State of the Solar System; Visions and Voyages – Initial stages, conditions, processes of solar system formation].

SKG C2 breakdown (2 of 2)
Phobos/Deimos GFAs

- **C2-3 Regolith Properties:**

  Description: Measurement and characterization of the regoliths on Phobos and Deimos. The moons have distinct surface regoliths that may indicate differences in geologic history.

  Measurement Examples: High resolution imagers, microscopic imaging, geotechnical packages, penetrometers, surface seismic experiments.

  Correlated Science Objectives: Understanding the surface and near surface regoliths of small bodies and how they may have evolved over time [SBAG – Solar System Origins, Current State of the Solar System; Visions and Voyages – Processes that affect small bodies]

- **C2-4 Thermal Environment:**

  Description: Measure the surface and subsurface temperature regime of Phobos and Deimos to constrain the range of thermal environments of these moons. This has relevance for space weathering and evolution of volatile content at/near the surfaces of these objects.

  Measurement Examples: Thermal imagers, radiometers, surface and subsurface temperature probes.

  Correlated Science Objectives: Remote and *in-situ* measurements of thermal regimes and thermophysical properties of small bodies relative to diurnal and seasonal cycles, shape, and composition [SBAG – Solar System Origins, Current State of the Solar System, ISRU; Visions and Voyages – Processes that affect small bodies]

SKG C3 breakdown

Phobos/Deimos GFAs

- **C3-1 Anchoring and surface mobility systems - technology demonstration:**

  Description: Demonstration of anchoring techniques to airless body surfaces under low-gravity conditions. The surface properties may vary widely from object to object or even across individual objects. In addition, surface/proximity mobility systems must also be demonstrated for future exploration of small bodies under low-gravity conditions for both robotic and human explorers.

SKG breakdown

Visit Phobos/Deimos surface

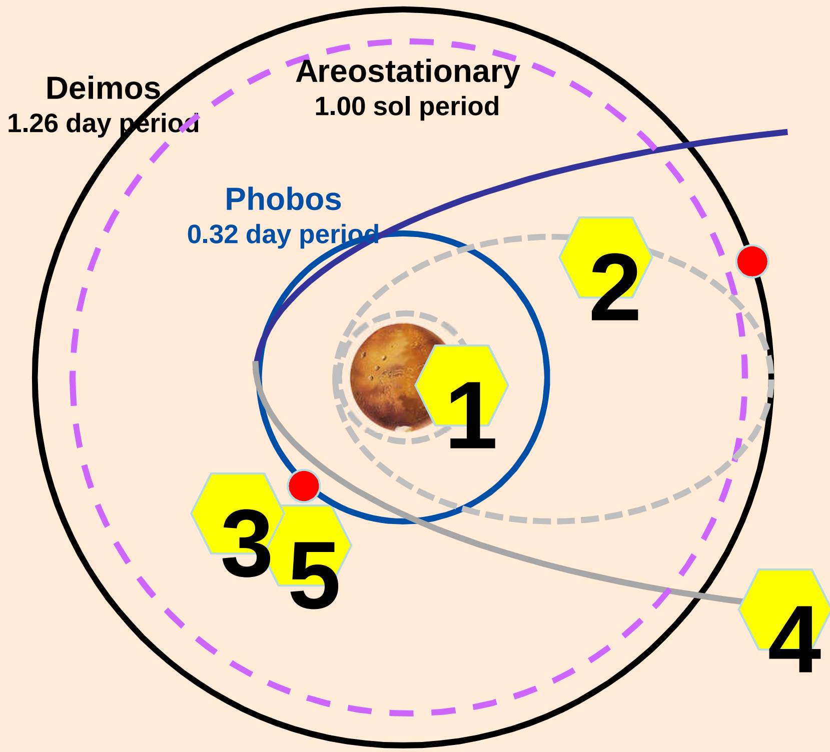
Measurement Priorities

Gap filling activity	Priority	Location	Measurements and demonstrations
A3-1. Orbital particulate environment	Medium	Mars Orbit	Spatial variation in size-frequency distribution of Phobos/Deimos ejecta particles in Mars orbit
C1-1. Surface composition	High	Phobos/Deimos rendezvous and lander	Elemental / chemical composition; spatial distribution of major geologic units; ISRU potential
C2-1. P/D electric and plasma environments	Low	Phobos/Deimos rendezvous	Electric fields in proximity to surface, plasma emanating from surface
C2-2. P/D Gravitational field	Medium	Phobos/Deimos rendezvous	Spherical harmonic terms of moons' gravitational fields
C2-3. P/D regolith properties	High	Phobos/Deimos rendezvous and lander	Elemental / chemical composition; spatial distribution of major geologic units; size-frequency distribution; density, compressibility, adhesion; spatial variation in thickness/properties; Cohesion, adhesion and their interaction of particulates to precusor spacecraft and science packages and/or rovers.
C2-4. P/D thermal environment	Low	Phobos/Deimos rendezvous and lander	Temperature variation diurnally, with depth

SKG breakdown

Visit Phobos/Deimos surface

Precursor platforms implied



1. Orbiter, low-Mars orbit
   - Addresses Mars atmosphere
2. Orbiter with high-Mars orbit, or elliptical orbit that has both low- and high- aspects
   - Addresses particulate environment; could collect partial information on temperature, mineralogy, gravity
3. Phobos and/or Deimos rendezvous and lander
   - Required to fully address SKGs at Phobos/Deimos

<u>The following requires additional analysis:</u>

4. Phobos and/or Deimos sample return

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HIGH-LEVEL STRATEGIC ISSUE

Potential Significance of Exploitable Resources on Phobos/Deimos

- If Phobos and/or Deimos are composed of the materials currently thought most likely, utilization of their in situ resources might significantly enhance future human exploration of the Martian system, potentially including exploration of the Martian surface.
  - A properly instrumented robotic precursor spacecraft with rendezvous and landed elements should be able to evaluate the potential for exploitable resources (primarily recoverable water or oxygen) on Phobos and/or Deimos prior to a human mission to the Martian system.
- Although detailed architectural assessments have yet to be conducted, identification of strategic on-orbit resources and demonstration of their practical utilization could offer:
  - Substantial reduction in launch mass of the fuel and cargo required to complete a human mission to the Martian system *(i.e.*, orbit and surface) and return to Earth, significantly reducing launch system complexity, numbers of launches required, and overall mission cost.
  - Reduction of risk to the crew through production of resources for fuel, life support, and radiation shielding. Extra resources translate into additional response options in contingency scenarios (*e.g.,* inability to safely descend to the surface, unplanned duration in orbit, loss of prepositioned supplies, *etc*.)
  - Increased potential for sustained human presence in the Martian system and extending human exploration beyond Mars
- P-SAG recommends that appropriate architectural assessments be made to determine what combination of *in situ* raw materials and human exploration infrastructure will result in the benefits described here. These results will help to clarify the robotic precursor spacecraft features needed to realize these benefits.

SKG breakdown

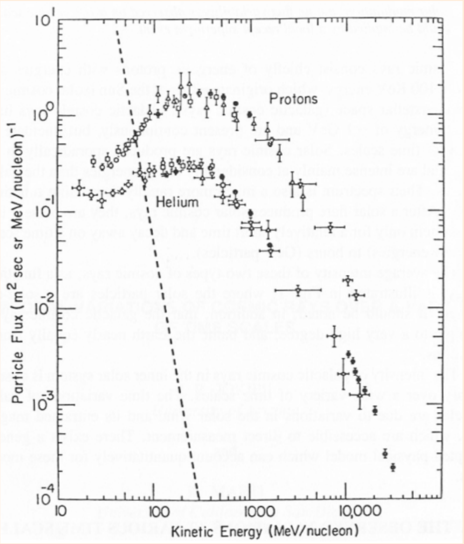
Crew Health and Performance

- There are two main areas in which we have insufficient information related to our ability to maintain crew health and performance

1. Radiation
   - Solar Particle Events (SPEs) come from the sun, and have been well-measured at Earth, including outside the van Allen belts. However, the details of this radiation at Mars will be different than at Earth.
   - GCRs come from outside the solar system, and to first order equally affect Mars, Earth, and the pathway between.
   - For both types, the effect of the martian atmosphere is unknown; the radiation intensity and spectrum at the top and bottom of the atmosphere may be different.
2. Toxicity of the martian dust/regolith: We have concerns in three areas:
   - Insults to the eyes
   - Insults to the lungs
   - Insults via ingestion

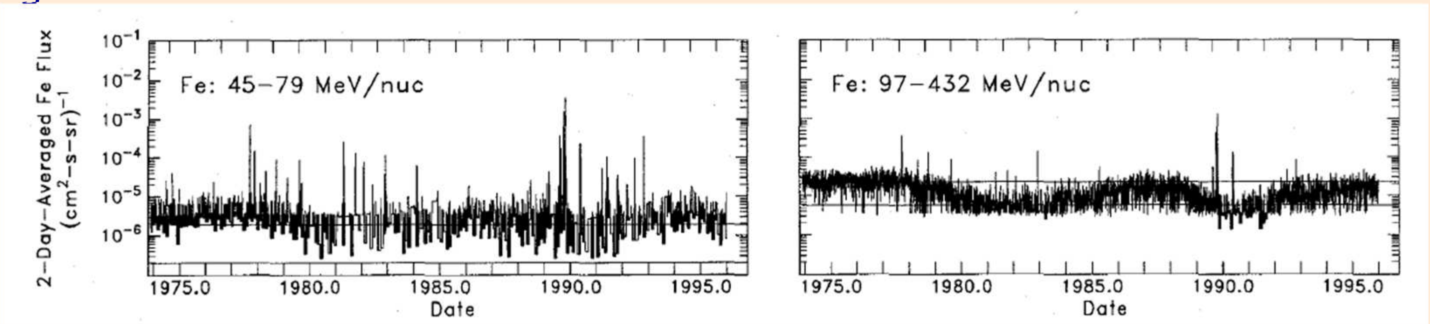
The Space Radiation Environment (*)

- Solar particle events (SPE):
  - Generally associated with Coronal Mass Ejections from the Sun – more frequent near solar maximum
  - Medium to high energy protons (A few hundreds MeV)
  - The magnitude, timing, character, and directionality of an SPE not currently predictable
  - Need to develop forecasting and warning capabilities
- Galactic Cosmic Rays (GCR):
  - High energy (> GeV) protons
  - Highly charged, energetic atomic nuclei (HZE particles) (> GeV/nuc)
  - Not effectively shielded (break up into lighter, more penetrating pieces, known as secondaries)
  - Abundances and energies relatively well known
  - Biological effects poorly understood at this time, but known to be the most significant contributor to astronaut dose



The observed intensity of cosmic rays at Earth orbit at quiet times. Shown are galactic cosmic ray protons and helium. The dashed line is a time average of solar energetic particles.

(*) Trapped particle models are not included here because they contribute very little to the organ dose for missions to Mars.



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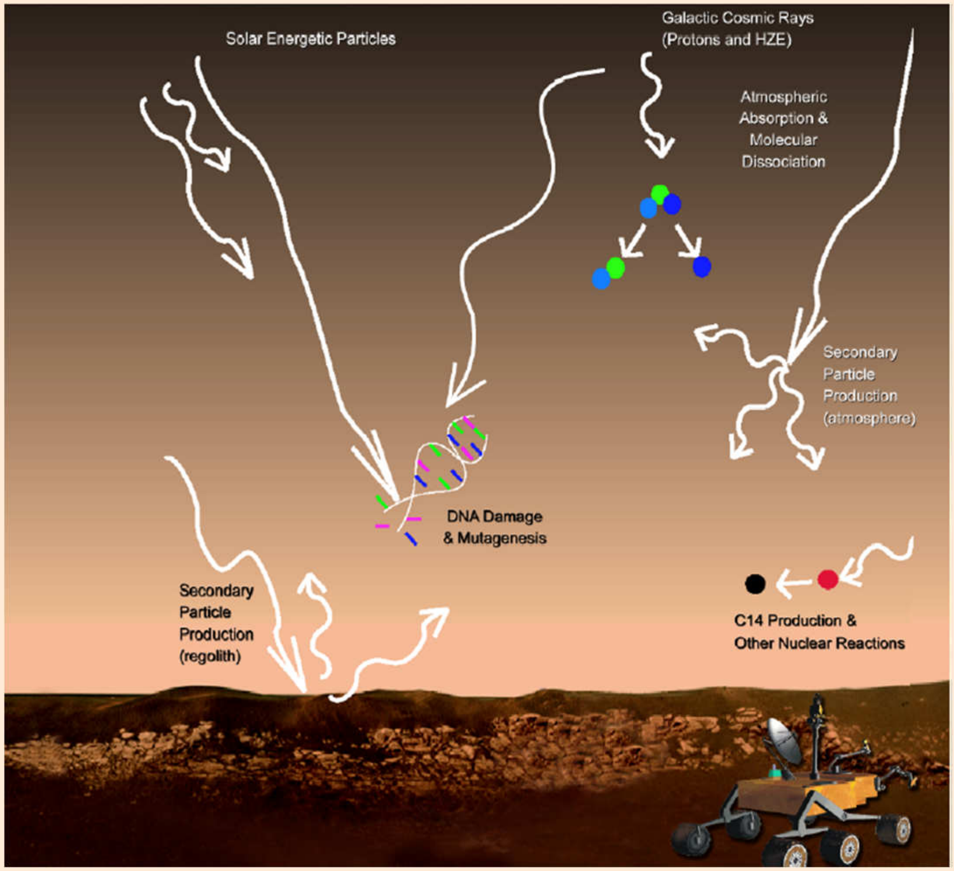
Mars Atmospheric Radiation Transport Characterization(*) Background

- Mars has no planetary magnetic field, unlike Earth, so any radiation attenuation is atmospheric based.
- Mars atmosphere density is 16 g/cm^2 (vs 1000 g/cm^2 on Earth) but highly variable.
- Radiation transport depends on both the altitude and atmospheric density
- Radiation is either absorbed, fragments to produce secondary particles, or propagates to the surface which will also result in secondary particles



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SKG breakdown

Crew Health and Performance

Measurement Priorities

Gap filling activity	Priority	Location	Measurements and demonstrations
B3-1. Neutrons with directionality	High	Mars surface	Measure neutrons with directionality from <10 keV to >100 M (The MSL RAD measures neutrons with > a few MeV, but no directionality)
B3-2. Simultaneous spectra of solar energetic particles in space & on the surface.	Medium	Mars surface and Mars orbit	Simultaneous orbital and surface measurements of spectra of solar energetic particles before and after atmospheric transmission (The MSL RAD measures the charged particle spectra)
B3-3. Spectra of galactic cosmic rays in space.	Low	Near Earth	Measure spectra of galactic cosmic rays (This can be done near Earth if no magnetospheric interference). 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.
B3-4. Spectra of galactic cosmic rays on surface.	Medium	Mars surface	Measure spectra of galactic cosmic rays after atmospheric transmission including secondary particles from interaction with regolith (the MSL RAD measures the charged particle spectra). 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.

SKG breakdown

Crew Health and Performance

Measurement Priorities

Gap filling activity	Priority	Location	Measurements and demonstrations
B3-5. Toxicity of dust to crew	Medium	Sample return	Assay for chemicals with known toxic effect on humans. Of particular importance are oxidizing species (e.g., CrVI) associated with dust-sized particles. May require a sample returned to Earth as previous assays haven't been conclusive enough to retire risk. Fully characterize soluble ion distributions, reactions that occur upon humidification and released volatiles from a surface sample and sample of regolith from a depth as large as might be affected by human surface operations. Previous robotic assays (Phoenix) haven't been conclusive enough to significantly mitigate this risk. Analyze the shapes of martian dust grains with a grain size distribution (1 to 500 microns) sufficient to assess their possible impact on human soft tissue (especially eyes and lungs).

SKG breakdown
Back Planetary Protection

- SKG
  - 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 materials were returned to Earth Despite the best intentions and best engineering it is likely that some uncontained martian dust and regolith would be returned to Earth with the crew.
- Gap filling activities
  - The safest and possible the only acceptable way to test for biohazards is to make measurements in terrestrial laboratories on sample returned from Mars. Prior to that mission, one or more diverse sets of regolith, rock and dust samples should be collected from sites representative of the diversity anticipated at human landing sites and returned to Earth for comprehensive biohazard testing similar to that outlined in Rummel et al., (2002) to determine whether any indigenous life is present and, if so, whether it presents a hazard to the Earth's biosphere.
  - A significantly more risky, and possibly unacceptable, approach to lessen the risk of returning uncontained living and potentially hazardous organisms with the crew is to identify zones of minimum biological risk (ZMBR's) as potential landing sites. Biologic risk to be indentified by:
    - Orbital measurements for signs of recent water activity
    - Orbital land lander measurements for presence of ground ice.
    - Lander measurements following TBD life detection protocols (total carbon, isotopes, etc) on near surface materials at potential landing sites.

SKG breakdown
Forward Planetary Protection

- Article IX of the 1967 Outer Space Treaty states that exploration of other celestial bodies shall be conducted so as to avoid their harmful contamination. Human missions will introduce onto the surface of Mars terrestrial organisms that could displace or destroy any indigenous life and organics that could hinder identification and characterization of any life forms, extinct or extant, and any pre-biotic chemicals that might be present.
- SKG's
  - Do not know whether there are locations (special regions) at or near the surface that are hospitable to terrestrial life, and if so where those locations are
  - We do not understand the processes and rates by which the contaminant load introduced by a human landing would be dispersed and progressively degraded, and the potential threat it might pose to potentially more hospitable sites elsewhere on the planet.
  - Do not know the extent to which human activities would create artificial special regions, contaminated with terrestrial organisms and what the broader impact of such regions would be.
- Gap-filling activities
  - Develop criteria to identify special regions and use orbiter observations to map exclusion zones for early human missions
  - Develop models to better predict dispersal patterns for contaminants across the planet
  - Understand the survivability of terrestrial organisms in Mars conditions.
  - Understand further the habitability of Mars for Terrestrial Microbiota

SKG B2 breakdown

Back Planetary Protection GFAs

- **B2-1 Biohazards**

Description: Return to Earth for comprehensive analysis one or more diverse sets of regolith, rock and dust samples collected from sites representative of the diversity anticipated at human landing sites.

Measurement Examples: Biohazard measurements on returned samples.

Correlated Science Objectives: The same sample set used for biohazard assessment could also be used address the following science goals:

1. Characterize present habitability and search for evidence of extant life [MEPAG Goal I-B]
2. Critically assess any evidence for past life or its chemical precursors, and place constraints on the past habitability and the potential for preservation of the signs of life [MEPAG Goal I-A]
3. Reconstruct the history of the surface and near-surface processes involving water [MEPAG Goal III-A2]
4. Assess the history and significance of surface modifying processes including, but not limited to: impact, photochemical, volcanic and aeolian [MEPAG Goal III-A1]
5. Constrain the magnitude, nature, timing and origin of past planet-wide climate change [MEPAG Goal II-C3]
6. Quantitatively constrain the age, context and processes of accretion, early differentiation and magmatic and magnetic history of Mars [MEPAG Goal III-A3]
7. Constrain the origin and evolution of the martian atmosphere. [MEPAG Goals II-C]

SKG B5 breakdown
Back Planetary Protection GFAs

- **B5-1 Identify and map special regions**

  Description: Orbital and lander measurements for signs of recent water activity and ground ice.

  Measurement Examples:

  Correlated Science Objectives:

  - Characterize present habitability and search for evidence of extant life [MEPAG Goal I-B]
  - Reconstruct the history of the surface and near-surface processes involving water[MEPAG Goal III-A2]
  - Characterize Mars' recent climate history and climate processes under different orbital configurations. [MEPAG Goal II-B]

SKG B2 & B5 breakdown

Forward & Back Planetary Protection GFAs

Measurement Priorities

Gap filling activity	Priority	Location	Measurements and demonstrations
B2-1. Biohazards	High	Sample return	Requires returned samples, allowing use of the full analytical capabilities of terrestrial laboratories and an analytical approach that could be both comprehensive and adaptive, with the analytical strategy changing as more is learned about Mars through the returned samples.
B5-1. Identify and map special regions	High	Mars surface and Mars orbit	Orbital measurements for signs of recent water activity Orbital and lander measurements for presence of ground ice.
B5-2. Model induced special regions	Low	Mars surface and Mars orbit	Develop criteria to identify special regions and use orbiter observations to map exclusion zones for early human missions
B5-3. Microbial survival, Mars conditions	Medium	Earth	Understand the survivability of terrestrial organisms in Mars conditions. Understand further the habitability of Mars for Terrestrial Microbiota
B5-4. Develop contaminant dispersal model	Medium	Earth	modeling

SKG breakdown

Technology Development Needs

- **To enable measurements and missions, technology developments and demonstrations are required to meet goals**

- **The technology development needs are based on human exploration architectural goals and robotic precursor missions that have human exploration applicability**
  – Activity is broken down by priority and timing requirements

- **List of technology development and demonstrations are based on initial inputs from Human Space Flight Architecture Team**

Technology Development Needs

Demonstration Priorities

Gap filling activity	Priority	Potential Demonstration Location
A4-1. Auto rendez & docking demo	High	In Earth orbit or Mars orbit
A4-2. Optical Comm. Tech demo	High	On Earth, in Earth orbit, or in Mars orbit
A4-3. Aerocapture demo	Medium	On Earth, in Earth orbit, or in Mars orbit
A4-4. Auto systems tech demo	Low	On Earth or in Earth orbit
A4-5. In space prop tech demo	High	On Earth or in Earth orbit
A4-6. Life support tech demo	High	On Earth or in Earth orbit
A4-7. Mechanisms tech demo	Low	On Earth or in Earth orbit
B1-6. EDL demo	High	On Earth or in Earth orbit
B1-7. Ascent demo	High	On Earth or on the Martian surface
B3-6. Radiation protection demo	High	On Earth, in Earth orbit, in Mars orbit, or on the Martian surface
B4-4. Dust mitigation demo	Low	On Earth or on the Martian surface
B5-5. Forward Contam. Tech demo	Medium	On Earth or on the Martian surface
B7-4. Auto rover tech demo	Low	On Earth or on the Martian surface
B7-5. Env exposure tech demo	High	On the Martian surface
B7-6. Sample handling tech demo	Low	On Earth or on the Martian surface
B8-1. Fission power tech demo	High	On Earth
C3-1. Anchoring & surface mobility systems	High	On a microgravity body
D1-1. Cryo storage demo	High	On Earth or in Earth orbit
D1-2. Water ISRU demo	Medium	On Earth or on the Martian surface

HIGH-LEVEL STRATEGIC ISSUE
MSR is on the Critical Path

- **Mars Sample Return (MSR) is the only known way to complete the biohazard/PP SKG**, which must be addressed to protect public safety. This mission is therefore on the critical path to a human mission to the martian surface.

Investigation	Importance
Life and biohazards	MSR Required
Resources	MSR Enhances
Atmosphere	MSR Enhances
Human Factors	MSR Enhances
Surface Hazards	MSR Enhances

- MSR would either be **a** way, or in some cases, **the best** way, to address the other SKGs listed above. However, non-MSR approaches for these are also possible.
- If MSR must happen for PP reasons, the other SKGs above can be addressed “for free”. The precursor program could therefore be minimized by building around MSR.

APPENDIX 3.

Analysis Spreadsheet (separate file: P-SAG Matrix Final.xlsx

At http://mepag.jpl.nasa.gov/reports/psag.html)