Robotic Precursor Measurements For Human Exploration of Phobos and Deimos

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Introduction

We identify a series of specific robotic precursor measurements required to fill NASA's Strategic Knowledge Gaps (SKGs) for planning future human missions to the two moons of Mars, Phobos and Deimos. NASA is currently developing space exploration architectures and systems for an Evolvable Mars Campaign that will enable the human Journey To Mars, similar to that shown in Figure 1. Reaching Mars orbit is identified as an important early milestone in achieving human landed missions on Mars itself. This humans-to-Mars orbit phase creates an opportunity to explore and use Phobos and Deimos as part of the Evolvable Mars Campaign. There remain, however, a number of unknowns concerning Phobos and Deimos that need to be addressed - likely by at least one robotic precursor mission - before human missions to the surface of these small bodies may be adequately planned. These unknowns are Phobos and Deimos-specific SKGs. Phobos and Deimos SKGs have been identified in previous studies, but they have been lacking in quantitative specificity. The present study represents an effort to review NASA latest SKG list for Phobos and Deimos, and to identify wherever possible the specific measurements that would be needed to fill the gaps.

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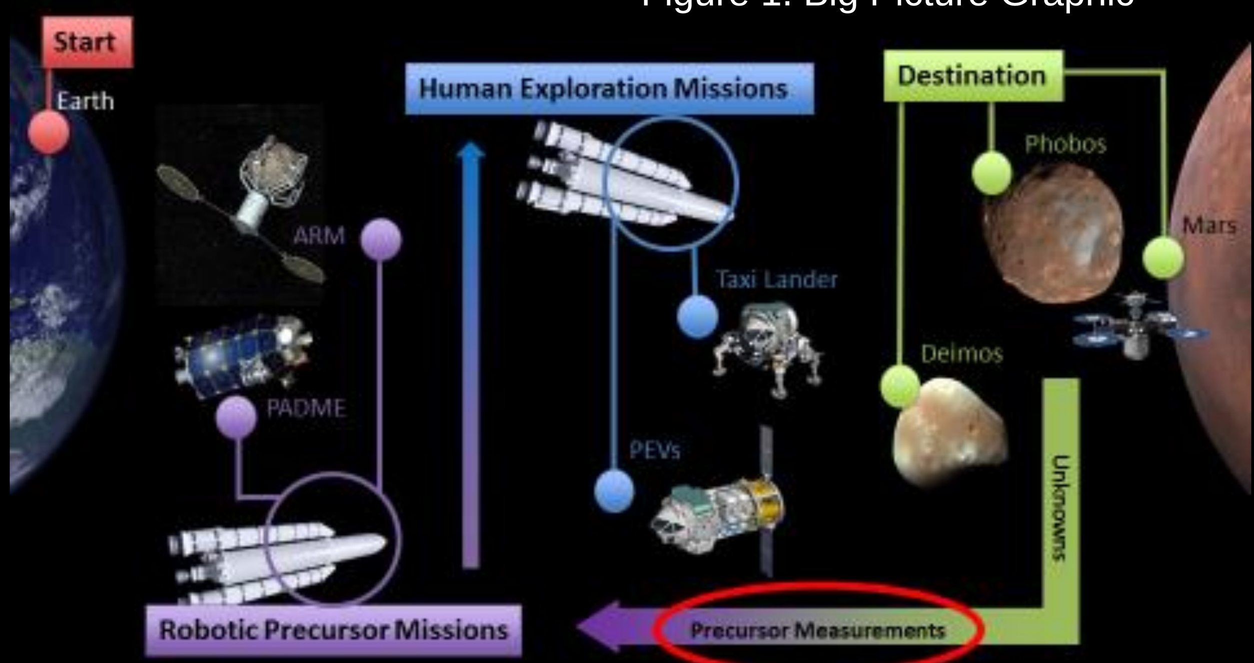
Figure 1. Big Picture Graphic



Methods

An initial list of precursor measurements were derived from analyzing previous NASA studies of SKGs for the Moon, Small Bodies, and Phobos and Deimos. Data was also compiled from the Strategic Knowledge Gaps developed by ISECG [3], a goals document by the Mars Exploration Program Analysis Group [4], and some precursor measurements suggested by NASA's Office of Planetary Protection [8]. The list was then updated and quantified wherever possible on the basis of ongoing discussions within NASA's Human exploration Architecture Team (HAT) focusing on Phobos and Deimos [4]. The list of required SKG measurements was then structured and formatted to ensure easy incorporation and use in different mission plans and scenarios.

Methods (cont)

An early result is that given our updated list of Phobos and Deimos SKGs, around only one robotic precursor mission, that will interact actively with the surface of Phobos and Deimos in several locations on each body (in addi-ion to doing remote investigations of each), is needed to fill all Phobos and Deimos SKGs. To begin developing a concept for a SKG-filling robotic precursor mission for humans to Phobos and Deimos, we organized the updated list of SKGs in themes and, within each, in categories and examples as shown on Table 2. Whenever possible, one or more specific examples of how the SKG may be filled is provided. Each SKG is then treated as an Investigation Objective. For each Investigation Objective, we define Measurement Requirements, and identify the specific Physical Parameters and Observables that need to be measured, following the classic NASA Science Traceability Matrix (STM) structure. However, the current STM does not extend to defining specific instrument or mission functional requirements, which may be better approached as a broader science and exploration community effort.

Table 1

Science and Exploration Objectives (SEO)	Strategic Knowledge Gaps (SKGs) Themes	Categories	Examples
1. **Determine surface geology and Minerology [9]**	I. Understand how to work/interact with the surface of PhD	IA. Potential hazards for crew, recon, and operation [1,2,6]	I-A-1 Geological and natural hazards [1,2]
2. **Sample collection [9]**			I-A-2 Particulate hazards [1,2]
3. **Determine of origin of PhD [9]**		IB. Surface Properties [1,2]	I-B-1 Geotechnical Measurements of Regolith[1,2]
		IC. Overall geological understanding	I-C-1 Identification of Geological Units
			I-C-2 Geodetic grid and high resolution mapping [7,9]
		ID. Maneuverability and Mobility [1,2,6]	I-D-1 Anchoring for tethered activities [1,2]
			I-D-2 Surface Pertubations
	II. Understand the PhD environment and its effects	IIA. Radiation Environment beyond surface [1,2]	II-A-1 Solar Event Prediction and Flare Activity [1,2]*
			II-A-2 GCR Activity and properties [1,2]
			II-A-3 Secondary Source Activity [1,2]
		IIB. Radiation Environment at surface*	II-B-1 Charged surface particle environment [5]
			II-B-2 Plasma presence
		IIC. Thermal Environment	II-C-1 Temperature
		IID. Atmospheric and Orbital Environment [1,2,5]	II-D-1 Orbital Torus Particulate Characteristics [1,2]
			II-D-2 Near-Surface levitating particles [1,2]
		IIE. Regolith Environment [1,2,5]	II-E-1 Regolith composition [1,2,5]
			II-E-2 Disturbed and ejected regolith particulate properties [1,2]
		IIF. Internal Environment	IIF. Internal Composition
	III. Understand the PhD resource potential	IIIA. Solar Resources*	III-A-1 Solar illumination mapping*
		IIIB. In-situ Resource Utilization (ISRU) [1,2]	III-B-1 Surface Operation techniques for in-situ in micro-g: extraction, collection, storage, refining [1,2]
			III-B-2 Subsurface parameters for operations
		IIIC. Surface assets [6]	III-C-1 Identification of geological surface utilization
		IIID. Sub-surface and surface resource potential [3]	III-D-1 Volatile Properties
			III-D-2 Volatile location

Future Work

To enable humans to reach Mars Orbit and explore Phobos and Deimos by the mid-2030s as currently considered by NASA, all key Phobos and Deimos SKGs must be filled by the mid-2020s, which means that identifying the objectives and requirements for a robotic precursor mission(s) and begin developing mission concepts must begin no later than now. It is ideal to still continue adding detail to all of the precursor measurements, specifically a measureable quantity for each qualitative parameter. Reducing the amount of measurements to about 20 should also be aspired to reduce precursor missions and increase efficiency.

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Results

Compared to exploring Near-Earth Asteroids, the exploration of Phobos and Deimos present us with specific issues and challenges. For instance, both are relatively large small bodies; both lie in Mars' gravity well; their near-surface regolith are among the most porous (and likely under compacted) of any small body known. The present synthesis study identifies a total of at least 30 Phobos and Deimos SKG parameters that need to be determined quantitatively, including geotechnical parameters such as the adhesion, compressibility, and macro-porosity of the regolith, and planetary protection parameters such as the toxicity and organics content of near-surface materials. Some parameters identified are likely key to any human mission goals at Phobos and Deimos (e.g., characterizing in detail the dust environment or the gravity field around each moon), while others might be needed only in certain mission scenarios (e.g., assessing resources such as water and loose regolith (for radiation shielding) that might be present in the subsurface beyond 1 m depth).

Table 2

Relevant Measurements (RM)

#	Parameter (characteristic)	Measurement (actual observable)	Description	SKG fullfilled
RM_1	Mineral content of regolith [3,4,5]	chemical composition of surface particles	Determination of inorganic substances located on the surface; can be fullfilled through reflectance spectrum	I-C-1, II-D-1, II-D-2, II-E-1, III-C-1
RM_2	Mineral content of levitating particles [3,4,5]	chemical composition of levitating particles in close proximity of surface	Determination of inorganic substances located below and above surface; can be fullfilled through sampling	I-C-1, II-D-1, II-D-2, II-E-1, III-C-2
RM_3	Regolith property	Grain size distribution of regolith particles[3,5]	Micrometer to centimeter scale structure [5]	I-A-2, I-B-1, I-D-2, I-E-1, II-D-1, II-E-1
RM_4	Regolith property	grain size- frequency distribution of regolith [3,5]	Micrometer to centimeter scale structure [5]	I-A-2, I-B-1, I-D-2, I-E-1, II-D-1, II-E-2
RM_5	Particulate size range	Grain size of Mars torus solid particulates (ejecta particles in Mars orbit) [3,5]	Micrometer to centimeter scale structure [5]	I-A-2, I-B-1, I-D-2, I-E-1, II-D-1, II-E-3
RM_6	Particulate Size distribution	Size-frequency distribution of Mars torus solid particulates (ejecta particles in Mars orbit) [3,5]	Micrometer to centimeter scale structure [5]	I-A-2, I-B-1, I-D-2, I-E-1, II-D-1, II-E-4
RM_7	Toxicity of Particulates	pH and buffer capacity of solid particulates^	must be <150ppm^	I-A-2, II-E-1
RM_9	Macro-proposity; solubility; compaction of regolith	Size of macropores in regolith	size around 75microm	I-B-1, I-D-1, I-E-1, II-E-2,
RM_10	Macro-proposity; solubility; compaction of regolith	Size of macropores in orbital particulates	size around 75microm	I-B-1, I-D-1, I-E-1, II-E-2,
RM_11	Bearing capacity of soil	Ultimate resistance of soil per unit area	understand sinkage properties of surface^	I-B-1, I-D-1, I-D-2, I-E-1, III-B-1 , III-B-2
RM_12	Yield strength of overall surface^	Stress at which the surface begins to deform with tested load per unit area	understand sinkage properties of surface^	I-B-1, I-D-1, I-D-2, I-E-1, III-B-1 , III-B-2
RM_13	Shear failure occurrence	Internal Friction angle^ of soil	understand sinkage properties of surface^	I-B-1, I-D-1, I-D-2, I-E-1, III-B-1 , III-B-2
RM_14	Improved global topography data sets*	Elevation data	200 m/pixel* accuracy of topography; possibly done through direct survey or remote sensing	I-D-1, III-C-1

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