

## HUMAN EXPLORATION OF PHOBOS AND DEIMOS: ROBOTIC PRECURSOR MEASUREMENTS

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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. 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 and implemented. 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.

**Method:** An initial list of precursor measurements was 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 [1], a goals document by the Mars Exploration Program Analysis Group [2], and some precursor measurements suggested by NASA's Office of Planetary Protection [3]. 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.

An early result is that given our updated list of Phobos and Deimos SKGs, at a minimum one, but possibly no more than one, robotic precursor mission that will interact actively with the surface of Phobos and Deimos in several locations on each body (in addition to doing remote investigations of each) will be required 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. 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.

**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 regoliths are among the most porous (and likely undercompacted) 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 macroporosity 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).

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.

**References:** [1] ISECG (2013) *Strategic Knowledge Gaps*. [2] Mars Exploration Program Analysis Group Goals Committee (2015) MEPAG Goals Document. [3] NASA, Office of Planetary Protection (2013) *Safe on Mars: Precursor Measurements Necessary to Support Human Operations on the Martian Surface*. [4] Abercromby et al. (2015) *Human Exploration of Phobos*. IEEE, March 2015.