PHOBOS AND DEIMOS: ROBOTIC EXPLORATION IN ADVANCE OF HUMANS TO MARS ORBIT.

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Summary: A robotic multiple landing and sample return mission to the two moons of Mars, Phobos and Deimos, offers a high-scientific return and minimal cost approach to filling several key knowledge gaps in science and engineering in preparation for future human missions to Mars orbit and to the martian surface.

Phobos & Deimos as Targets for Science. After 40 years of spacecraft exploration of the solar system, the origin of Phobos and Deimos remains a vexing mystery [1, 2]. Are they captured asteroids, remnants from Mars's formation, or reaccreted impact ejecta from Mars? From a scientific standpoint, the moons of Mars are unique in being at the crossroads of several central issues in solar system and planetary science. Their exploration would address at once small body origin and evolution, satellite formation, impact cratering, Mars evolution, and the origin and evolution of life [1, 2, 3]. Of particular interest for both science and human exploration is the notion that the regoliths of Phobos and Deimos might include a detectable fraction of martian material (mostly dust and sand-sized fragments, rarely larger fragments, collected from all over Mars and throughout the moons' orbital history [4-6]. A sample return mission from both Phobos and Deimos is considered to be the most effective way of addressing major science unknowns about them [7].

Phobos & Deimos as Targets for Human Exploration Robotic Precursor Missions: The robotic exploration of Phobos and Deimos can fill several strategic knowledge gaps (SKGs) identified by NASA's Precursor Science Analysis Group (P-SAG) in preparation for human missions to the martian system [8].

A critical SKG to Goal A of achieving Humans to Mars Orbit is to characterize the *orbital particulate environment in high Mars orbit*. As Phobos and Deimos are the most likely candidate sources of particulate material in high Mars orbit, quantifying and understanding their roles as sources and sinks of orbital particulates is essential. A robotic mission that will explore Mars's orbital environment near Phobos and Deimos and between them can fill this SKG.

Two critical SKGs to Goal B of achieving humans to the martian surface are to characterize *the potential adverse effects of martian dust* and *any risk of back contamination to Earth by potential biohazards on Mars*. For these planetary protection concerns, the regoliths of Phobos and Deimos might offer opportunities to investigate at minimal cost in advance of humans landing on Mars a broad sampling of martian surface dust and potential biosignatures [9]. A robotic mission that will allow "sifting through" the regoliths of Phobos and Deimos would address these two SKGs.

A third SKG of Goal B is the question of *how much H_2O resources might be available in the martian system in a form that could change the high level architecture of future human missions to the surface*. While no H_2O has been unambiguously identified spectrally at the surface Phobos or Deimos, what is known about their bulk physical properties (low density of 1.87 and 1.47 $g \cdot cm^{-3}$, resp. [10]), surface morphology (groove system on Phobos), and plausible evolutionary pathways, still leaves open the possibility that their interior is H_2O-rich (up to 20-30% by volume). While early human missions to Mars orbit or its surface would not be reliant on any H_2O from Phobos or Deimos, longer term high-level mission architectures could be profoundly affected by the moons' H_2O content. A robotic mission to Phobos and Deimos that will measure and map any near-surface and deeper H_2O is needed.

Two critical SKGs to Goal C of achieving humans to Phobos/Deimos are *to characterize sufficiently the geological, compositional, and geophysical properties of Phobos and Deimos in order to design focused human-based science and engineering exploration activities*, and *to characterize sufficiently the physical conditions near and on Phobos and Deimos to reliably and safely carry out proximity and surface operations for human-based science and engineering activities* [11, 12]. A robotic mission to Phobos and Deimos that will demonstrate docking, anchoring, and mobility, analyze surface materials (including their diversity), and probe the subsurface is required to fill these two SKGs.

There are other opportunities presented by Phobos and Deimos, while not discussed in the context of SKGs (yet?), that are important in their potential impact on planning future human Mars exploration:

Radiation Shelter. While the radiation environment on Mars is an SKG for Goal B, the radiation environments on Phobos and Deimos are also unknown. There is speculation that the sub-Mars region of Phobos might offer significant radiation shielding (from both Phobos and Mars). In-situ measurments are needed.

Mars Sample Return Caches. Phobos has been proposed as a caching site for samples collected robotically from many areas on Mars that would then be retrieved by an early human mission to Mars orbit [13]. Phobos's surface environment needs to be better understood for such a mission objective to be evaluated.

Robotic Mission Concepts: Several Phobos and Deimos robotic mission concepts are currently under investigation at the Mars Institute in collaboration with NASA, the SETI Institute, and other partners that would address all or a portion of the SKG questions identified above. The following are published:

Hall (named both after Asaph Hall, the American astronomer who discovered Phobos and Deimos, and Edwin Hall, the American physicist who discovered the Hall effect used in the spacecraft's electric propulsion system) is a NASA-led international Phobos *and* Deimos sample return mission [14]. The *Hall* mission concept was developed at NASA GSFC as a candidate New Frontiers class mission.

M4 (Mars Moons Multiple landings Mission) is a NASA-led international Phobos *and* Deimos orbital and landing mission that would dock twice with Phobos and once with Deimos to conduct in situ investigations [15]. The *M4* mission concept is under study at NASA ARC as a Discovery class mission.

ASAPH (Advance Spacecraft Assay of Phobos's Hydrogen) (also named after Asaph Hall) is a minimal-cost nano-spacecraft mission to characterize the near-surface environment of Phobos (gravity, orbital particles), image the surface (0.5 m /pxl), and globally map any hydrogen in the upper 1 m of Phobos's regolith. The spacecraft would eventually soft-dock with Phobos as a science enhancement option. The *ASAPH* mission concept is under study at NASA ARC.

In addition, the *MERLIN (Mars-Moon Exploration, Reconnaissance and Landed Investigation)* mission concept is under study at Johns Hopkins University's Applied Physics Lab. [16].

International Opportunities. Following the recent loss of *Phobos-Grunt*, the Russian Academy of Sciences and Roskosmos are studying a replacement mission that would launch in 2018-2020 and be open to international participation (A. Zakharov, *pers. comm.*.). Other mission concepts were also under study recently in Canada [17. 18] and Europe [19].

Conclusion: The robotic exploration of Phobos, Deimos, and the martian high orbit environment is responsive to key scientific goals of the NRC's Decadal Survey [3] and critical to filling several SKGs identified by the NASA P-SAG for planning future human missions to Mars orbit and the martian surface [8]. In order to address these science goals and SKGs in sufficient detail, a Phobos *and* Deimos multiple landings / sample return mission is likely required. It is proposed that a NASA *Phobos/Deimos Working Group* be formed that would work closely with MEPAG, SBAG, P-SAG and the broader planetary science and exploration community to help establish and define the requirements of this precursor mission.

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