PHOBIOS AND DEIMOS SAMPLE RETURN TO EARTH-MOON L2 USING SMALL SEP SPACECRAFT IN 2018-2023. T. P. McElrath¹, N. J. Strange¹, J. J. Lang¹, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109.

Introduction: Phobos and Deimos are the most accessible part of the Mars system. In addition to being scientifically interesting, they may become the first destination for human exploration at Mars. Returning a sample from these moons in the near-term would significantly benefit both our understanding of key science objectives and the engineering development of human systems for Mars exploration.

Mission Architecture: Sample return missions to Phobos or Deimos have been proposed before – what makes this one different? And how can both moons be sampled affordably?

Two key factors would enable a significantly more cost-effective mission: 1) using multiple, single-string spacecraft with solar electric propulsion (SEP), and 2) sample return by way Earth-Moon L2 (LL2), assuming that the proposed human-tended spacecraft is there.

Multiple small SEP spacecraft. Current space-qualified components are widely available and highly reliable. Much of the cost of a new spacecraft design is in the analysis and the system-level testing (especially of the interactions of multiple elements in possible failure scenarios), and not in the components themselves or in the assembly of a flight system. By using the same design two or three times, the development cost is distributed. By restricting the redundancy to multiple independent flight elements, the complicated interactions between sub-systems are minimized, while still retaining high reliability of each flight system (due to high quality components), and providing even higher overall mission reliability.

The highly efficient SEP system allows the overall spacecraft mass to remain small, while enabling high mission flexibility. A plethora of SEP systems are currently flying on commercial satellites, and this experience, coupled with ongoing thruster development, makes SEP a low-risk propulsion choice. The low launch mass reduces the launch cost, permitting multiple units to fit on even a small launch vehicle.

LL2 sample return. Previous mission concepts have dragged an Earth entry vehicle all the way to Mars orbit and back, which is expensive for something that is only needed at the end of the mission. Any occasionally-crewed vehicle at LL2 would already have an Earth entry vehicle in residence. Mars sample return mission concepts also have had to plan to take special steps to mitigate any potential uncontrolled release of Mars materials at the Earth, with substantial mass and cost penalties. While all these factors would still need to be considered, they are all much easier to address from the base of a crewed vehicle, with its large payload capacity. The MPCV (or other crewed Earth return vehicle) is already engineered to the highest reliability standards, and has the payload mass to permit even more protection to be placed around the sample before stowage. Should the human LL2 presence be delayed, the SEP spacecraft and sample could be maintained indefinitely in cis-lunar space, or even retrieved robotically with a dedicated re-entry capsule.

Spacecraft Design: The small SEP spacecraft that makes all this possible would be a modest improvement on the Phobos Surveyor [1] shown in Figure 1.

The deployable ATK Ultraflex solar arrays could be built in a variety of sizes, and the required power output is within the planned capability for other systems. Phobos Surveyor would use a mass-efficient commercially available xenon tank, of which two could easily be included in this modified design.

Figure 1: Phobos Surveyor concept is a low cost, robust spacecraft providing flexible access to study the Mars system.

The required changes would include: 1) a sample acquisition and storage system, 2) a Hall thruster with performance similar to a BPT-4000 but one third the size, 3) larger solar arrays (5.5 kW vs 4 kW, at 1 AU), and 4) twice the xenon tankage.

Unlike a traditional sampling system, the post-acquisition handling would only require containment of the sample (vs. inserting it into a return capsule). The low acceleration would make leaving the sample canister at the end of a long boom for the return flight perfectly acceptable, greatly simplifying the mechanical design. Sufficient instrumentation would be retained to adequately determine the context of the sampling region.

Hall thrusters are exceptionally well-understood, so developing and qualifying a thruster with an Isp of 2000s, 83 mN of thrust, and a throughput capacity of 250 kg of xenon, all for a power input of 1.5 kW, would not be challenging, even in time for a potential 2018 launch. The analysis below uses a SEP system with these parameters, but other SEP system choices would be possible.

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All of these changes, taking into account the existing 50 kg payload capability for the Phobos Surveyor, would bring the dry mass of the spacecraft up to around 310 kg, including significant system mass margin. The launch mass would be 600 kg, with 290 kg of xenon loaded. Some of the xenon would be used by the resistojets when necessary for attitude control and higher thrust maneuvers around landing and ascent, but if it were all put through the Hall thruster, the spacecraft would achieve a remarkable 12.9 km/s of Δ-V.

**Mission Design:** The analysis here uses the 2018 Mars Type I/II opportunity, but other Mars opportunities would be feasible, perhaps with longer flight times. Using a lunar departure[2] would allow the launch vehicle to target a C3 of -2 km/s². A Falcon 9 block 2 can inject 2640 kg to this energy, potentially allowing 3 of these spacecraft to be launched. A few hundred m/s of pre-departure Δ-V is assumed here, due to potentially launching as a secondary payload [2], which accounts for the departure mass being below 600 kg, making this a worst-case scenario. Following Earth departure in April, 2018, each spacecraft would thrust for 11 months to reach Mars rendezvous in April 2019, as shown in Figure 2.

![Figure 2: Earth-Mars-Earth trajectory 2018-2023 opportunity. Mars stay is 1017 days. Lunar departure and arrival would be used at the Earth.](image)

Upon arrival, at least one spacecraft would start the descent to Phobos, while others could either spiral down to Deimos or wait in very high Mars orbit as a backup to the Phobos vehicle. The Phobos descent would be elliptical, as shown in Figure 3, to trade time for propellant. The transfer shown takes 483 days and consumes 28 kg of xenon, leaving 47 kg of xenon and 144 days for Phobos reconnaissance and sampling. The ascent to Mars escape would take 390 days and 24 kg of xenon. Note that the transfer to and from Phobos only requires about half the Δ-V of a spiral, albeit 3 times the duration. However, this Δ-V would be sufficient to spiral to and from Deimos within a year, while still leaving enough time to collect a sample, such that a Deimos sample could arrive at the Earth-Moon system by early 2021.

![Figure 3: Transfer trajectory from Mars rendezvous to Phobos. Thrust arcs are red, coast arcs are green. Total transfer Δ-V to Phobos is 1.18 km/s.](image)

The longer duration afforded by returning in 2023 would produce adequate time and propellant margins for the Phobos-bound vehicle. Were the current mass margin to prove unnecessary, or the SEP system performance to improve modestly, then a Phobos sample could be returned by 2021 as well.

In either case, the Moon would be used to capture the spacecraft, after the SEP system lowered the Vₐ to 2 km/s, as shown in Figure 2. A lunar flyby sequence lasting a few months would suffice to deliver the spacecraft to LL2, or it could loiter in a lower-maintenance orbit until the human outpost was ready to transfer the sample. In this analysis, a few hundred m/s of Δ-V is reserved for this purpose, represented by the return mass of 315 kg. The total SEP Δ-V for this trajectory would be 10.8 km/s.

**Conclusion:** A multi-spacecraft sample return mission to Phobos and Deimos would be within the scope of missions currently considered for the 2018 Mars opportunity. This mission would provide significant science and programmatic return, and leverage planned human exploration activity in cislunar space. The highly-capable vehicle described here could be used for other missions, both at Mars and elsewhere.

**References:**