Exploration Leading to Low-Latency Telepresence on Mars from Deimos

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1 Introduction

The strategy of using robotic precursor spacecraft to prepare for human space exploration at a common venue has its roots in the Lunar Orbiter [1] and Surveyor [2] missions leading to initial Apollo Program human landings on the Moon in 1969. In connection with the current Artemis Program's human return to the Moon, robotic precursors are being instigated through NASA's Commercial Lunar Payload Services (CLPS) initiative [3]. These lunar precursors tend to be science-centered, but they also incorporate technology demonstration objectives addressing human factors and in-situ resource utilization (ISRU) knowledge gaps.

Looking farther along NASA's human exploration roadmap into the 2030s and beyond, venues proximal to Mars become prominent. Robotic precursors in this context begin with the first flyby spacecraft Mariner 4 in 1965 [4], the first orbiter Mariner 9 in 1971 [5], the first lander Viking 1 in 1976 [6], and the first rover *Sojourner* in 1997 [7]. Exploration with these precursors and their successors has been impeded by enormously high *data latency* compared with lunar communications. Even at the speed of light, a command issued from Earth and immediately carried out on Mars will not be confirmed with data received back at Earth for 6 to 44 minutes, depending on positions of the Earth and Mars about the Sun. In practice, it takes *days* to command and receive response data from NASA's latest Mars rover, *Curiosity*. Since landing on Mars in 2012, *Curiosity* has consistently logged an average speed near 0.3 to 0.4 meters per hour [8]. At this rate, it will take decades just to comprehensively survey Mt. Sharp, *Curiosity*'s scientific exploration site.

The degree of scientific productivity achieved by *Curiosity* on Mars will be dwarfed by orders of magnitude once humans land there, as Apollo extravehicular activities (EVAs) demonstrated from 1969 through 1972 [9]. In a Mars context, however, the Apollo exploration model is challenged by multiple issues.

- 1) Minimum mass to be landed on Mars in support of human exploration there is about 20 metric tons [10, p. 54]. No Mars landing technique with payload mass capacity much beyond *Curiosity*'s one metric ton has been demonstrated.
- 2) Mars roundtrips for humans entail 500-day loiters at Mars awaiting an Earth return opportunity [10, p. 5]. Radiation exposure during Mars loiter must therefore be minimized whenever possible [11, pp. 16-17]. A subsurface habitat employs local regolith as ISRU shielding mass, virtually eliminating shielding mass transport requirements and ideally reducing exposure rates to those at sea level on Earth.
- 3) Every hour of EVA requires about two hours of crew activity, typically involving additional crewmembers in support of those who are to work outside a pressurized habitat. Activities include pure oxygen pre-breathe, retrieving/checking/donning/doffing/restowing equipment, airlock depressurization/re-pressurization, and recharging EVA consumables. Over a 500-day loiter on Mars, this overhead is considerable even under radiation exposure constraints precluding frequent EVAs.
- 4) Consumables limit the range an EVA human can traverse away from a facility at which those consumables can be recharged. Limited EVA range is only marginally expanded by a rover without onboard recharging capability because rover breakdowns must be addressed. The possibility of such mishaps requires every traverse be planned to permit

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anytime walk-back to a recharging facility before EVA consumables are depleted. This planning results in traverses with minimal stops outbound to a most distant EVA location, followed by a more leisurely return. Over a 500-day Mars loiter, only a limited number of these walk-back traverses can be made (in all practical directions from a single subsurface habitat) before routes must be repeated.¹

- 5) Prospects for extant life on Mars raise forward and backward planetary protection concerns rendering a human presence near Mars *Special Regions* inadvisable [12, p. 53, New Finding 6-1]. Unfortunately, Special Regions tend to be precisely where ISRU water for human hydration and hygiene, together with rocket propellant, is most likely to be found in abundance. This apparent conflict between human operations and astrobiology interests is only enhanced by recent discovery of widely distributed subsurface water ice on Mars [13].

The foregoing challenges to productive exploratory EVAs on the surface of Mars are formidable indeed. Apollo's outdated game plan must therefore evolve to an exploration strategy using *low-latency telepresence* (LLT) [14, Section 9]. In this mode of exploration, humans operate robotic surrogate assets on the surface of Mars from a subsurface habitat on the outer moon Deimos. With Deimos orbiting less than 20,100 kilometers above the equatorial surface of Mars, a dedicated line-of-sight communications link with surface assets would produce roundtrip data latencies less than 0.14 seconds [14, Figure 7.4]. This degree of data latency permits even the most dexterous Mars surface tasks to be performed by Deimos-resident humans [14, p. 101 **Latency** definition]. Freed of EVA constraints, these humans would each day realize a level of exploration productivity far beyond the Apollo astronauts' experience on the Moon. If human landings on Mars become possible and advisable, the same LLT techniques pioneered beneath Deimos would be relevant from a subsurface Mars habitat too. Long before humans land on Mars, however, they could explore the planet just as productively from Deimos at lower cost and at lower risk [14, Section 7.3.1].

Before LLT from Deimos becomes an operational reality, key knowledge gaps about the physical properties of Deimos, including its ISRU prospects, must be addressed. These gaps include detailed composition and topography, potential natural hazards including orbiting companion objects/dust, and internal homogeneity. Operational techniques yet to be developed at Deimos are rendezvous and proximity operations, anchoring/docking, and load/haul/dump actions to support excavation and habitat emplacement. In addition, human/cargo transfer (ideally, intravehicular in a shirtsleeve environment) between a completed subsurface habitat and a visiting vehicle such as an interplanetary transport must be developed. All these knowledge gaps are addressable by robotic precursor missions to Deimos [15, Objectives 3.2, 3.3, and 3.4, pp. 33-41].

¹ Looking beyond Apollo Program technology, a pressurized rover could conceivably carry EVA recharging consumables, enabling multi-EVA traverses. But radiation exposure within a pressurized rover will limit traverse durations to only a few days. Consequently, pressurized rover traverses would be capable of accessing locations only a few times more distant from a habitat than would a traverse constrained by walk-back contingency planning. Only a limited number of unique pressurized rover traverse routes would therefore be possible from a single habitat.

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2 Why Deimos?

As illustrated in Figure 1, there are only two moons of Mars from which an orbiting habitat can most readily obtain vital radiation shielding mass in the form of ISRU regolith. Both moons orbit over the planet's equator, their rotation/orbit periods are synchronized such that one side is always turned toward Mars, and their irregular dimensions are all on the order of 10 kilometers. But even in the absence of detailed physical properties knowledge about these moons, the strategic value of the outer moon Deimos is manifestly superior to that of the inner moon Phobos in a Mars exploration context employing LLT. Here is why [16, Section II].

- 1) Due to its lower altitude, Phobos can only view Mars surface latitudes up to 69.8° from the equator, while the limiting latitude for Deimos is much greater at 84.1° .² Deimos therefore supports deployment of LLT surface assets over more of Mars than does Phobos without any "bent pipe" communications relay infrastructure and related data latency increases.
- 2) At its lower altitude, the orbit period of Phobos is shorter than that of Deimos. From an equatorial Mars surface point, Phobos rises in the west and sets in the east just 4.2 hours later. In contrast, an equatorial Mars surface point sees Deimos rise in the east and set in the west 59.6 hours later. Therefore, LLT from Deimos is able to maintain uninterrupted direct communications with robotic Mars surface assets at a particular exploration site for a significantly longer interval than LLT from Phobos. During the 71.8 hours this site is hidden from Deimos, another set of assets on the opposite side of Mars could be available for 59.6 hours of continuous LLT. A simulation of Mars as observed from Deimos can be viewed at <https://www.youtube.com/watch?v=X10GAqA4Ky4> starting about 5 minutes and 40 seconds into the video (accessed 30 April 2020). From a Mars surface perspective, lower angular rates in the sky make tracking Deimos with a high-bandwidth LLT communications antenna far easier than tracking Phobos (although higher power is required to span greater distances to Deimos at a specified bandwidth).
- 3) Near a Mars equinox, Phobos spends a maximum 12% of its orbit in the shadow of Mars cast by the Sun. Each of these eclipses lasts 54 minutes, and 3 occur in 24 hours. A maximum-duration eclipse at Deimos lasts 84 minutes, but this event only spans 4.6% of the orbit and only occurs once in 24 hours. Eclipse seasons extend over 228 days for Phobos, but for Deimos, they last only 83 days. Deimos therefore has far better prospects for solar power generation than does Phobos.
- 4) The foregoing solar geometry at Mars also applies to Earth geometry at Mars. Thus, Deimos offers far better direct communications prospects with Earth than does Phobos.
- 5) Because Phobos is deeper in the gravity well of Mars than is Deimos, more propulsive consumables are required to transfer mass between Phobos and interplanetary space than are required for equivalent Deimos mass transfers. Thus, Earth crew and cargo logistics are more efficient at Deimos than at Phobos. Similarly, Deimos will be more accessible than Phobos if ISRU deliveries from nearby asteroids are found to be desirable.
- 6) Orbiting so deeply in the Mars gravity well, Phobos is subject to greater tidal effects than is Deimos. Depending on this moon's physical characteristics, Mars tides may render the surface of Phobos unstable, particularly when subjected to human or robotic disturbances. These tidal instabilities have implications for proximity operations and infrastructure

² These latitude limits ignore the masking effects of local terrain near a limit.

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emplacement (including a subsurface habitat) favoring such activities at Deimos versus Phobos.

Figure 1. Mars-centered orbits of Phobos (red) and Deimos (green) are plotted in the planet's equatorial plane. Time ticks ("+" markers) appear at 30-minute intervals and are annotated with 4-5 July 2020 UT in "day-of-year/hour:minute" format. The shaded area of Mars is its nightside, and the small circle near the planet's center is at 80° N Latitude. Axis units are kilometers.

Incidentally, LLT science and ISRU with humans in a subsurface Deimos habitat can also be conducted with robotic assets on Phobos and Deimos itself. These orbital assets might be the exploration focus when Mars surface assets are not in view of Deimos. The two moons remain in view of each other for 8.6-hour intervals interleaved with 1.7-hour occultation intervals during which Phobos and Deimos are hidden from each other by Mars. This is nearly an ideal cadence for a shift of LLT activity, followed by a less extended handover interval to an oncoming LLT shift. At the beginning and end of an occultation interval, roundtrip light-time data latency between Phobos and Deimos is greatest at 0.21 seconds. These Phobos/Deimos dynamics are simulated with 3-dimensional space visualization software named *Celestia* [17].

3 Establishing a Deimos Focus Among Precursor Missions Orbiting Mars

At 3 m resolution, the most detailed imagery of Deimos currently available was obtained on 15 October 1977 by the Viking 2 orbiter from a distance of 30 kilometers [18]. Among U.S. Mars

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lander missions, the two Viking flight profiles are unique because they each use a dedicated orbiter. All subsequent U.S. Mars landers never planned to orbit that planet. With an apoapsis altitude near 33,000 kilometers, well above the orbit of Deimos, it was practical to maneuver the Viking 2 orbiter into close flybys of this moon in October 1977 [19]. Since these flybys were conducted over a short period of time from a highly elliptical orbit, their high-resolution imagery coverage of Deimos is extremely limited.

Mars orbiters other than those of the Viking Program have focused on remote sensing of the planet and have functioned as communication relays between landers and Earth. Consequently, any initial orbit higher than that of Deimos is promptly lowered, usually by aerobraking, to facilitate more detailed Mars observations and more robust communication links with landers. Despite its state-of-the-art imaging capabilities, the Mars Reconnaissance Orbiter (MRO) has been able to obtain Deimos views with no better than 60 m resolution [20], presumably because close flybys are not possible from its apoapsis altitude near 316 kilometers [21].

The only substantive plans to visit Deimos are associated with JAXA's Martian Moons eXploration (MMX) mission, currently targeting launch in the early 2020s [22]. These plans were recently revised to return samples only from Phobos. This preference is likely because MMX is driven by planetary science objectives distinct from this paper's LLT exploration advocacy. Phobos is thought to harbor sterile Mars samples from impact ejecta on the planet in greater profusion than on Deimos due to the inner moon's greater proximity to those impacts. Any decision to exclude Deimos sample return by MMX should be reconsidered in the context of this moon's strategic importance to Mars exploration. The next Deimos encounter by a precursor mission should, at a minimum, conduct a global imaging campaign with meter-class resolution supplemented by a comprehensive survey of surface and near-surface composition [23, p. 32].

Ideally, the favorable attributes Deimos offers to human exploration of Mars through LLT would figure prominently in MMX priorities and those of other Mars-orbiting missions. Such prioritization requires managers adopt a broader view of mission objectives than one limited to planetary science findings associated with the moons of Mars. Also relevant to any Mars orbiter is the mission's contribution as a robotic precursor to far more productive science mission returns from LLT exploration and ISRU on Mars and Phobos conducted by humans in a subsurface Deimos habitat.

Because copious sample mass will undoubtedly be returned by HSF expeditions to off-Earth destinations, state-of-the-art curation facilities on Earth are an inescapable requirement. Curation is necessary to provide planetary protection for Earth's biosphere, sample preservation, and sample distribution to qualified researchers over time. Sample returns by *Hayabusa2* in 2020 [24] and the Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) in 2023 [25] illustrate the time-critical need for adequate curation facilities and personnel. Sufficient financial support for world-class sample curation is an investment as necessary to the study of Deimos as are the funds required to collect and return samples to Earth [26, 3rd finding from SBAG 22].

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4 Conclusion

With virtues of low-latency telepresence (LLT) becoming better understood in a Mars exploration context, the outer moon Deimos has become the strategic "high ground" at which to deploy LLT's human component based on current knowledge (see Figure 2). Nevertheless, gaps in Deimos physical properties knowledge must be filled before a sustainable Deimos subsurface habitat can be emplaced to establish a human exploration foundation proximal to Mars.

Conflicting Mars exploration objectives have diverted attention from exploring the physical properties of Deimos in recent decades. This oversight can be addressed by applying the well-proven strategy of robotic precursor exploration to Deimos as a critical path toward LLT exploration of Mars. In the long run, pursuing this path (with MMX as a likely first step) will be in the interest of planetary science. Elevated priority for near-term robotic missions to Deimos will result in unparalleled planetary science advances from highly productive Mars exploration through LLT with humans in a subsurface Deimos habitat. With LLT, as opposed to any other mode of human or robotic exploration, more can be learned about Mars sooner while incurring less expense and risk.

Figure 2. Deimos (left, 22 kilometers distant) and Mars (right, 20,000 kilometers distant) are rendered by *Celestia* 3-dimensional space visualization software [17].

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