A CASE FOR SMALL SPACECRAFT MISSIONS TO MARS: ENABLING FUTURE SURFACE INVESTIGATIONS.

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Introduction: Our understanding of Mars has been developing and refining at a remarkable pace, as scientific missions from multiple space agencies have contributed exponentially greater observations. The last decade saw the addition of the InSight lander (2018), the Trace Gas Orbiter (2016), the Mangalyaan (2013) and MAVEN (2013) orbiters, and the Mars Science Laboratory rover (2011) [1]. These assets joined several orbiters that remain in service: the Mars Reconnaissance Orbiter (2005), Mars Express (2003), and Mars Odyssey (2001) [1].

Moving into the next decade, several missions are currently funded to investigate Mars. Missions of particular interest are the UAE's Hope orbiter, NASA's Mars 2020 rover and ESA's ExoMars/ Rosalind Franklin rover, all of which are scheduled for launch during the summer of 2020. Over the past decades, progress has been made to develop the multi-stage Mars Sample Return (MSR) mission concept. The proposed MSR architecture would be completed over 4 stages: 1) scientific samples would be collected and cached by Mars 2020 rover, 2) a sample return lander would collect the cached samples and put them in orbit, 3) a return orbiter would retrieve the samples and return to Earth, and 4) a facility would be created on Earth to process the returned samples [2]. Although MSR has not yet been officially selected by NASA, this science goal has significant support and was the top Planetary Science priority in the current Decadal Survey report [3].

However, key Mars science questions remain that are not addressed by MSR [e.g. 4]. This study describes how small spacecraft missions could enable additional, future Mars science investigations, helping to fill key gaps – with a focus on science that could potentially be addressed by small landers.

Small Spacecraft: The Small Spacecraft Technology Program (SSTP), a program under NASA's Space Technology Mission Directorate (STMD), focuses on the development and demonstration of small spacecraft technologies relevant to NASA's science missions [5]. Spacecraft are often categorized by their wet (i.e. operating) mass and the SSTP has provided several mass-dependent subcategories for spacecraft: picosatellites (<1 kg), nanosatellites (1-10 kg), microsatellites (10-100 kg), and minisatellites (100-500 kg) [5-6]. The SSTP terminology also states that the term "small spacecraft" can refer to any spacecraft with a mass of 180 kg or below [5]. For the purpose of this study, we will be using the SSTP terminology to describe the mass of lander-style spacecraft only (i.e. no orbital spacecraft).

Enabling Martian Science with Small Landers: Small spacecraft appear capable of addressing a diverse range of key questions in martian science in the coming decade with quick, opportunistic mission concepts. Small spacecraft masses provide a logistical advantage against traditional-sized landers in that they can launch more frequently through rideshare opportunities with larger missions. Smaller spacecraft missions also present the opportunity to loosen mission risk postures, compared to traditional sized landers, in order to investigate harsh thermal environments (i.e. polar regions or winter periods [7]), non-traditional terrains such as steep sloping crater walls or narrow canyons, and advance lower TRL instruments. Lastly, small spacecraft can support a variety of mission concepts enabling ongoing and new science investigations; ways to enable new science include, but are not limited to, accessing higher risk regions of the martian surface, providing continuous monitoring of a local environment, and contemporaneous monitoring over multiple locations/ times of day.

Compared to NASA's previous martian landers (i.e. InSight, Phoenix, and Viking Landers 1-2), the mass restriction for a small spacecraft has the potential to make this style of mission more cost effective than the traditional larger landers. For example, NASA's 2018 Small Innovative Missions for Planetary Exploration (SIMPLEx) program solicited missions for small spacecraft (i.e. <180 kg), cost capped at $55M - a significant difference from the cost of Discovery ($500M in 2019) or New Frontiers ($850M in 2017) missions.

Future Science Investigations: For missions targeting Mars, the science objectives should be connected with the Mars Exploration Program Analysis Group (MEPAG) Goals, which organize major Mars science objectives into 4 broad goals: 1) Determine if Mars ever supported life, 2) Understand the processes and history of climate on Mars, 3) Understand the origin and evolution of Mars as a geological system, and 4) Prepare for human exploration [8].

In preparation for the upcoming 2023-2032 planetary science decadal survey, which helps to identify and prioritize science questions and by extension, the aims of potential planetary missions, a handful of summary documents from various meetings, workshops and conferences have been published highlighting key Mars science objectives. Common themes in the key science objectives across these reports include, but are not limited to, dust/ volatile transport and preservation, interpreting records of volatiles outside of the polar regions on seasonal and diurnal timescales, understanding the distribution and history of martian water, and the search for life - past or present [4, 9-10]. The dust cycle is not well understood [10] and records of dust, volatiles, or other materials are crucial to learning more about the history of the martian climate, especially in the polar layered deposits (PLD) [9]. Continuous high-resolution monitoring of surface activity on seasonal and diurnal timescales is currently restricted to equatorial regions with Insight and MSL. In order to understand volatile records outside of the polar regions [9] or during the polar night [4], continuous monitoring by one or more contemporaneous surface assets would be needed. Understanding the history [10] and distribution [4] of martian water ice has been a longstanding objective of Mars science as water is a building block of life, is a driver for many geologic and climatic processes, and would be an important resource for potential human explorers.

The brief overview of key science objectives listed above are only a few of the high-priority objectives identified by members of the martian community. The traceability of these objectives through multiple summary documents suggests they are ranked highly within the Mars community. This presents an important opportunity for new science missions in the coming decade as nearly all these objectives can be addressed with small spacecraft mission concepts.

Current Small Mars Lander Concepts: A few small spacecraft mission concepts aiming to address the above key science objectives are currently in development. In order of proposed lander mass, these mission concepts are Mars Polar$_{\text{DROP}}$ [11], Mars DartDrop [4,12], and the Next-Gen Planetary Aeolian and Meteorological Investigation (PAMI) mission concept [13].

Mars Polar$_{\text{DROP}}$ is a concept that utilizes 1 or more Mars$_{\text{DROP}}$ style landers [14], approximately the size of a soccer ball descending to the surface via parawing (guided or unguided), to deliver a ~1 kg science payload to the PLD surface [11]. Measurements by this concept would address questions pertaining to material fluxes in the polar regions, chemical and physical processes that modify PLD layers, and any record of time recorded in the PLD [7].

Using the Mars$_{\text{DROP}}$ style lander, the Mars DartDrop mission concept targets Recurring Slope Lineae (RSL) for in-situ measurements with several small "darts" [4, 12]. This concept aims to discern the contemporary habitability of the widespread RSL features on the martian surface.

The PAMI mission concept utilizes the interaction of an orbital asset with 1 or more landers based on the SHIELD lander design. A SHIELD lander is capable of delivering a 5 kg science payload to the surface in a hard impact landing [15]. This concept addresses key science questions pertaining to surface-atmosphere interactions on Mars with a focus on continuous monitoring of surface winds and meteorological conditions [13].

The small spacecraft mission concepts described above are by no means an exhaustive list and more concepts will be added as this study continues and information becomes available.

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