A LOW-COST, LOW-RISK MISSION CONCEPT FOR THE RETURN OF MARTIAN ATMOSPHERIC DUST: RELEVANCE TO HUMAN EXPLORATION OF MARS. M. Wadhwa[1], L. Leshin[2], B. Clark[3], S. Jones[4], A. Jurewicz[1], S. McLennan[5], M. Mischna[4], S. Ruff[1], S. Squyres[6], and A. Westphal[7], [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287, [2]Worcester Polytechnic Institute, Worcester, MA 01609, [3]Space Science Institute, Boulder, CO 80301, [4]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, [5]Department of Geosciences, Stony Brook University, Stony Brook, NY 11794, [6]Department of Astronomy, Cornell University, Ithaca, NY 14853, [7]Space Science Laboratory, University of California, Berkeley, CA 94720.

Introduction: SCIM—**S**ample **C**ollection to **I**nvestigate **M**ars—is a revolutionary concept for a low-cost, low-risk mission that would bring back the first-ever samples from Mars. Using an innovative mission design, SCIM would gather samples of martian dust during a Mars aeropass, without landing or even entering orbit around Mars (Fig. 1). Utilizing the extensive experience gained from the Stardust and Genesis missions, these samples would then be returned to Earth. This mission would collect a suite of samples that is distinct from that currently being planned for other sample return missions that are under consideration. As such, SCIM would serve as a scientific, technological and operational pathfinder for future surface sample return and human exploration to Mars.

Figure 1. Artist's concept of the SCIM spacecraft making a Mars aeropass at an altitude of ~40 km to collect dust particles.

Mission overview: The baseline payload for the SCIM mission concept consists of aerogel collector modules (similar to those successfully flown by Stardust) and a camera. SCIM would incorporate stringent planetary protection features consistent with COSPAR and NASA Planetary Protection policies (https://planetaryprotection.nasa.gov). Only after both the aeropass and the sterilization processes have been successfully implemented would deep space maneuvers retarget SCIM back to Earth, where the Sample Return Capsule would descend by parachute in an identical manner to the Stardust mission.

SCIM is responsive to MEPAG and Planetary Science Decadal goals: NASA's systematic Mars exploration approach over the previous decade has deployed missions that have studied martian processes with increasing precision, resolution, and specificity. As highlighted in the most recent National Academies Planetary Science Decadal Survey [1], the next major step in Mars exploration is returning samples to terrestrial laboratories for analysis, where the variety and precision of measurements far exceed practical in situ or remote sensing capability. Sample return missions enable the analytic capability required to achieve high-priority science as defined by the science community as well as to address concerns specific to future human exploration.

Surface sample return missions to Mars are necessarily faced with significant challenges of entry, descent, landing, surface operations, followed by launch and orbit rendezvous, and planetary protection, which result in high mission risk as well as cost. SCIM uses a novel, innovative mission design to lower the mission risk by eliminating many of these challenging steps while returning the first martian samples with a much lower risk. Recently returned Stardust and Genesis samples illustrate the value of applying high precision, cutting edge terrestrial laboratory instruments to extraterrestrial materials collected and returned to Earth. In particular, experience with the comet Wild 2 coma dust particles collected in aerogel and returned by the Stardust mission validates the approaches that would be used for the collection, extraction and analysis of martian atmospheric dust by SCIM (Fig. 2). Indeed, analysis of the Stardust samples has resulted in findings that have fundamental implications for the origin of cometary bodies and their components (e.g., [2] and references therein). Martian dust samples returned to terrestrial laboratories by SCIM and analyzed with state-of-the-art instrumentation in Earth-based laboratories (Fig. 3) would likewise provide fundamental new constraints on martian hydrologic, sedimentary, volcanic, and climatic processes, and a unique comparative basis for understanding how and why Mars has evolved so differently from Earth. In doing so, SCIM would be responsive to two of the three themes identified in the recent Planetary Science Decadal Survey [1], i.e., (1) Planetary habitats—searching for the requirements for life, and (2) Workings of solar systems—revealing planetary processes through time.

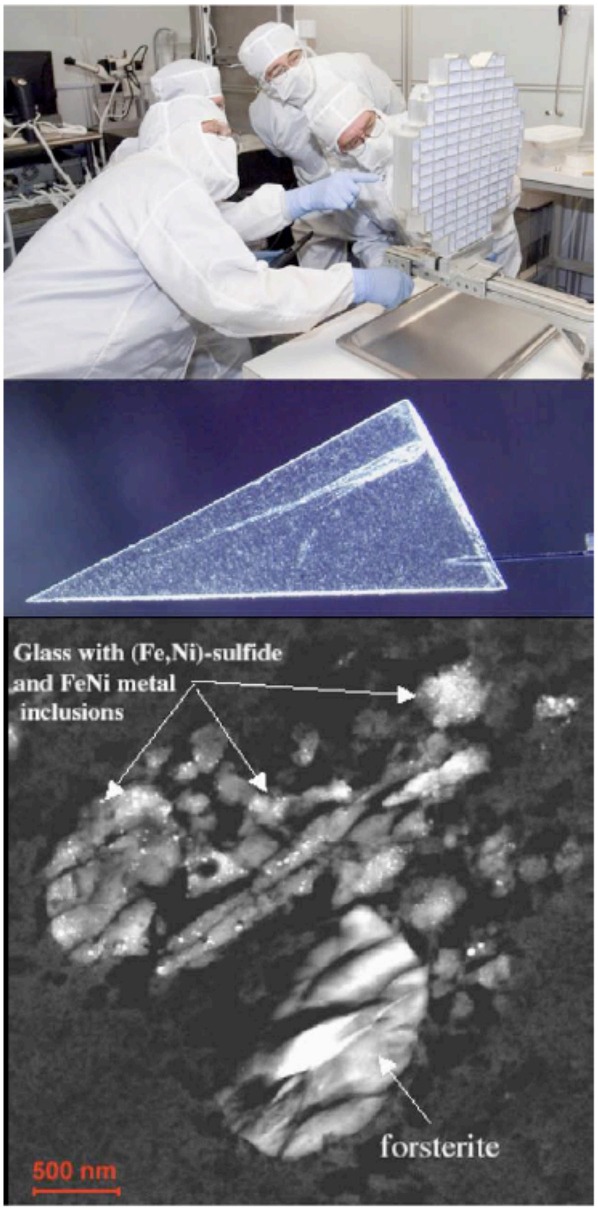

Figure 2. Top: The Stardust team examines the sample tray in the Johnson Space Center curation facility. Middle: A slice of Stardust aerogel with a 5 mm long particle track. Bottom: Electron microprobe dark field image of a 5 micron grain. Image credit: NASA.

The particular priority questions within these themes that would be addressed include: (a) Did Mars host ancient aqueous environments conducive to early life, and is there evidence that early life emerged?; (b) Can understanding the roles of physics, chemistry, geology and dynamics in driving planetary atmospheres and climates lead to a better understanding of climate change on Earth?; (c) How have the myriad chemical and physical processes that shaped the solar system operated, interacted and evolved over time?

Moreover, SCIM would also fulfil some key objectives of three of the four goals identified by MEPAG [3], i.e., goals II (understand the processes and history of climate on Mars), III (understand the origin and evolution of Mars as a geological system), and IV (prepare for human exploration). Mars atmospheric dust is thought to approximate a global average of the martian crust and, furthermore, represents the only planetary regolith besides Earth's known to have been exposed to hydrolytic, atmospheric, and possibly even biologic weathering processes. As such, this dust provides an opportunistic sample of crustal materials, likely including both primary igneous and secondary altered materials. Accordingly, atmospheric dust was also recognized by the End-to-End International Science Analysis Group (E2E-iSAG) [4] as a high priority sample for return to Earth, but one that may be problematical to obtain from the Mars surface. The return of even a small amount of martian fines as represented by the atmospheric dust samples to be returned by SCIM would complement the future return of a cache of well-characterized geologic samples from a specific, compelling landing site, as advocated by MEPAG.

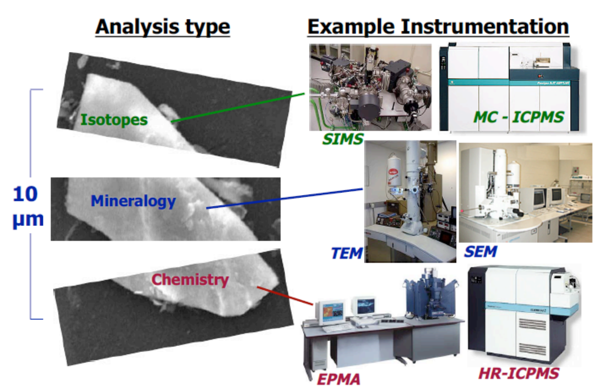

Figure 3. Recent advances in the manipulation and preparation of small samples as well as in analytical techniques have made it possible to fully characterize the chemistry, mineralogy and isotope compositions of micron-sized individual particles.

SCIM is relevant to human exploration of Mars: As discussed in the previous section, SCIM would fundamentally advance our knowledge of the geology, climate and habitability of Mars. However, analyses of Mars atmospheric dust samples returned by SCIM would also provide critical constraints for assessing the potential hazards that this dust presents for future human exploration of Mars.

The martian atmosphere typically contains 10-400 billion metric tons of dust [5], ranging in diameter from <1 to >10 μm [e.g., 6,7]. The ubiquity, abundance and fine-grained nature of this dust makes it a potentially significant hazard for human health as well as the engineering aspects of future crewed missions to Mars. While some of the bulk characteristics of martian fines have now been characterized (e.g., [8-10]), there is still a lot of uncertainty about the detailed mineralogy and geochemistry of the fine-grained atmospheric dust (particularly at the sub-micron spatial scale, and for components that may be present at the minor or trace levels). Understanding in detail the composition of the martian dust sample that would be returned by SCIM would help to more rigorously assess the hazard posed by this material. Without this, the uncertainties in the potential risks posed by this dust could drive the design and costs of human missions.

Finally, SCIM would advance the goals of human space exploration of Mars not only through its science, but also through its systems. It would demonstrate our ability to perform a round-trip to Mars, and would do so while traversing deep into the atmosphere, allowing "aerocapture-like" atmospheric parameters to be measured in the process. However, the entry angle and streamlined shape of SCIM's aeroshell would not allow it to be captured, but rather it will exit the atmosphere and retain enough velocity to return to Earth. The SCIM shape, more slender than blunt, is comparable to the vehicle designs that may be flown to Mars for crewed missions. SCIM would allow NASA to gain experience flying such vehicles prior to sending actual crewed spacecraft. Moreover, by performing the entry and exit through the upper atmosphere for the aeropass, SCIM would provide valuable new data on atmospheric conditions that could be compared to that obtained with prior missions and would enhance the data set needed for accurate targeting of landing sites by future missions, including crewed missions to Mars.

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