A Miniaturized Variable Pressure Scanning Electron Microscope (MVP-SEM) for Mars

PI: Jessica Gaskin (NASA MSFC)
Jessica.Gaskin@NASA.gov

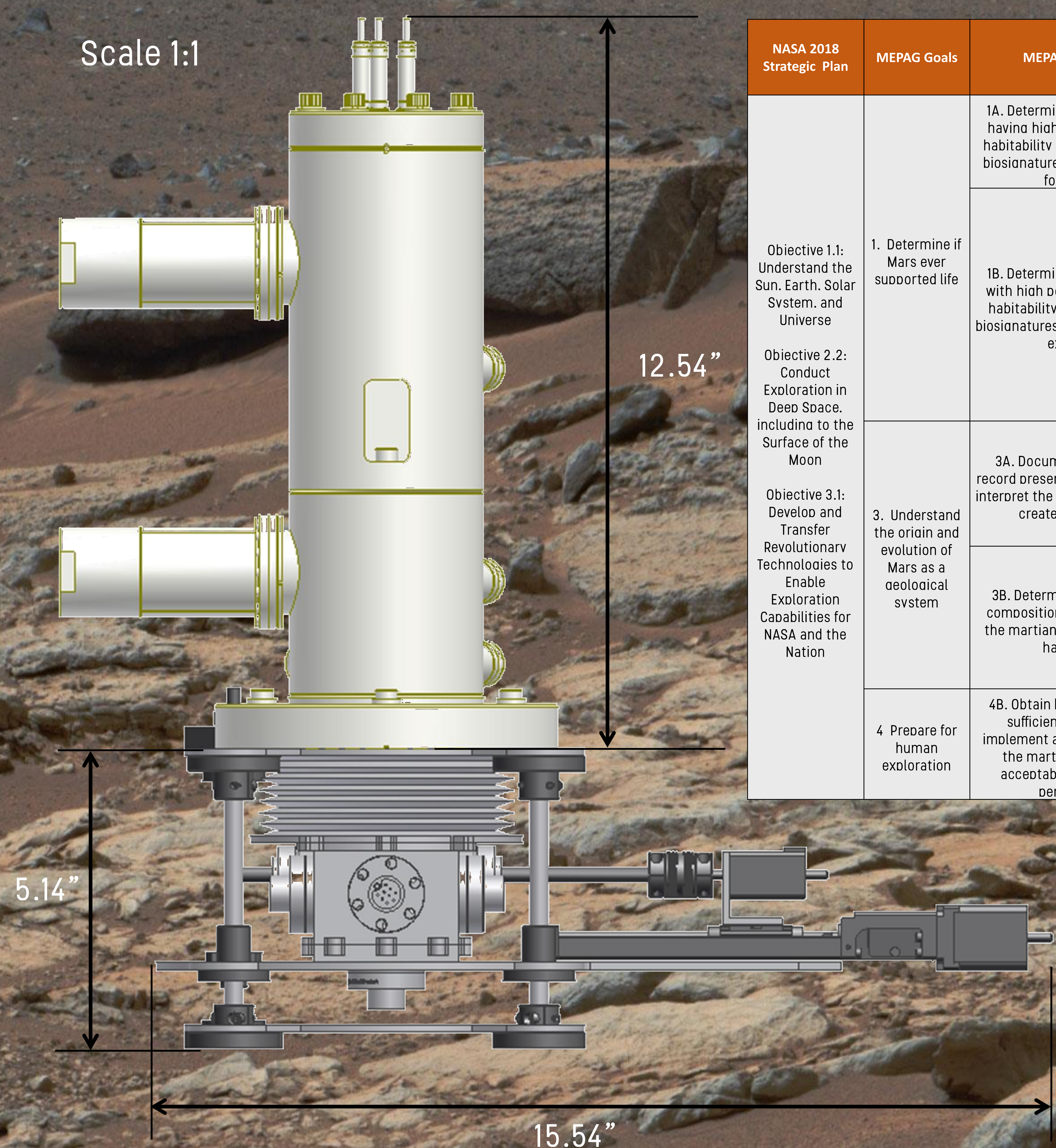
Technical Team
Gregory Jerman (NASA MSFC)
Gerald (Bud) Magera (APTech. Inc.)
William Mackie (APTech. Inc.)
Bob Kline-Schoder (Creare LLC)
Jurij Simcic (NASA JPL)
Mathieu Fradet (NASA JPL)

Contributors
Evan Neidholdt (1st Detect)
Gerasimos Danilatos (ESEM Research Lab)

Science Team
PS: Jennifer Edmunson (Jacobs/MSFC)
Andrew Needham (USRA/MSFC)
Nina Lanza (LANL)
Horton Newsom (UNM)
Aaron Noell (NASA JPL)
Hunain Alkhateb (U. Miss)
Debra Needham (NASA MSFC)
Caleb Fassett (NASA MSFC)
Amy Williams (Towson U.)
Mark Salvatore (Northern Arizona U.)
Zach Gallegos (UNM)
Ken Williford (NASA JPL)
J.R. Skok (SETI Institute)

A Miniaturized Variable Pressure Scanning Electron Microscope (MVP-SEM) was designed, built, and benchtop tested by a team at NASA's Marshall Space Flight Center, NASA Jet Propulsion Laboratory, Jacobs Space Exploration Group, Applied Physics Technologies, Inc. (AP-Tech), and Creare LLC, working with a large team of technical and science collaborators. Benchtop testing was successful, proving concept feasibility. Testing in a Mars environmental chamber at JPL will take place shortly after the submission of this proposal (Summer 2018). The variable pressure aspect of the SEM allows for unprepared (uncoated) samples to be analyzed by utilizing the carbon dioxide-rich Mars atmosphere for the neutralization of sample charging from the electron beam. This property of the MVP-SEM makes it ideal for use in locations where complex sample preparation is not desirable, such as the surface of Mars. In addition, the lack of sample preparation needed here simplifies the sample acquisition process and allows caching of the samples for future complementary payload use or eventual delivery to Earth. This work is funded under the NASA Planetary Instrument Concepts for the Advancement of Solar System Observations (PICASSO) Program.

Scale 1:1



<table>
<tr><th rowspan="2">NASA 2018 Strategic Plan</th><th rowspan="2">MEPAG Goals</th><th rowspan="2">MEPAG Objectives</th><th colspan="3">Scientific Measurement Requirements</th><th rowspan="2" colspan="2">Instrument Functional Requirements</th><th rowspan="2">Projected Performance</th><th rowspan="2">Mission Functional Requirements (Top Level)</th></tr>
<tr><th colspan="2">Physical Parameters</th><th>Observables</th></tr>
<tr><td rowspan="10">Objective 1.1: Understand the Sun, Earth, Solar System, and Universe

Objective 2.2: Conduct Exploration in Deep Space, including to the Surface of the Moon

Objective 3.1: Develop and Transfer Revolutionary Technologies to Enable Exploration Capabilities for NASA and the Nation</td><td rowspan="3">1. Determine if Mars ever supported life</td><td>1A. Determine if environments having high potential for prior habitability and preservation of biosignatures contain evidence for past life</td><td rowspan="10">Combined geological analyses such as:

Mineral and phase geochemistry

Mineral and phase morphology

Biological morphology

Grain size and shape

Location of concentrations of elements (X-ray mapping)</td><td rowspan="3">Geochemistry</td><td rowspan="2">Characteristic X-rays</td><td rowspan="2">Detection precision (major elements) using Energy Dispersive Spectroscopy</td><td rowspan="2">Errors less than 10% for major elements, 5% for minor elements, 15kV accelerating voltage for signal strength, pressure monitoring for C and O analyses</td><td rowspan="2">Errors less than 10% for major elements, 5% for minor elements including C and O</td><td rowspan="10">• Operation in the martian surface environment
• Little to no sample preparation
• Capability to analyze "infinite" samples
• Low vibration (instrument) and vibration isolation (housing) for increased imaging resolution
• Automated survey software and feature identification subroutines
• Data made available to the public through the Planetary Data System</td></tr>
<tr><td rowspan="2">1B. Determine if environments with high potential for current habitability and expression of biosignatures contain evidence of extant life</td></tr>
<tr><td>Backscattered Electrons</td><td>Sufficient contrast to note mineral and phase chemical zoning</td><td>0.2-2nA current at sample</td><td>0.2-2nA current at sample</td></tr>
<tr><td rowspan="5">3. Understand the origin and evolution of Mars as a geological system</td><td rowspan="2">3A. Document the geologic record preserved in the crust and interpret the processes that have created that record</td><td rowspan="7">Geomorphology</td><td rowspan="7">Imaging, Topography</td><td rowspan="3">Resolve uncoated objects</td><td rowspan="3">Environmental SEM mode</td><td>Sample Chamber Pressure Control to <1 Torr</td></tr>
<tr><td rowspan="2">Electron Gun Chamber Pressure Control to <1x10⁻⁶ Torr</td></tr>
<tr><td rowspan="3">3B. Determine the structure, composition, and dynamics of the martian interior and how it has evolved</td></tr>
<tr><td>FOV (at 175X)</td><td>0.75mm or greater</td><td>0.8mm</td></tr>
<tr><td>Resolution (Autofocus)</td><td>100nm in size or better</td><td>50nm</td></tr>
<tr><td rowspan="2">4 Prepare for human exploration</td><td rowspan="2">4B. Obtain knowledge of Mars sufficient to design and implement a human mission to the martian surface with acceptable cost, risk, and performance</td><td>Magnification</td><td>175X to 5000X or better</td><td>20,000X</td></tr>
<tr><td>Environmental Distance</td><td>Adjustable (2mm to 17mm)</td><td>2mm to 17mm ±0.05mm</td></tr>
</table>

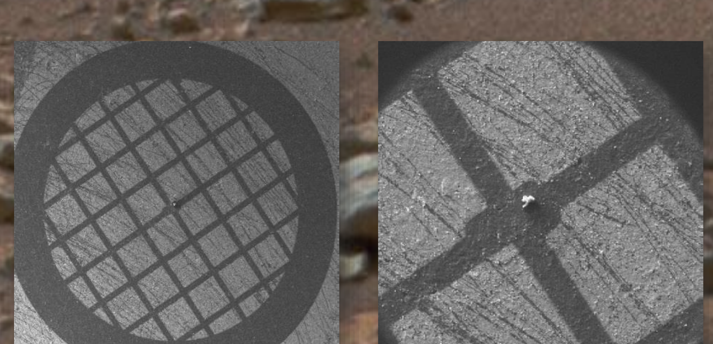
The *in-situ* use of the MVP-SEM on a future Mars mission would answer numerous outstanding questions about the petrology, evolution, and habitability of Mars while providing understanding of the surface environment that will be critical to the success and health of future human exploration.

- *What is the makeup of Martian dust?*
- *What is the "amorphous component"?*
- *What can we learn about the evolution of the Martian surface?*
- *Is, or was, there life on Mars?*
- *Can humans live (safely) on Mars?*

MVP-SEM Prototype

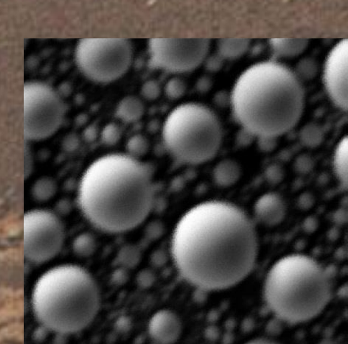
MVP-SEM Performance

Capability	Current Performance	Goal
Maximum Accelerating Voltage (kV)	15	5 - 15
Working Distance (mm)	20-23	20-23
Environmental Distance (mm)	2-5	2-5
Emission Current (μA)	30-50	30-50
Current at the sample (nA)	0.2-2	0.2-2
Imaging Resolution (nm)	100	< 50 (based on modeling)
Magnification Range	175X - 15kX	175X - 20kX
Field of View Diameter (mm)	0.8 @ 175X 0.004 @10kX	0.8 @ 175X 0.002 @ 20kX
EDS Quantitation Accuracy @ 0.6 Torr Chamber Pressure (Detector Dependent)	(Commercial EDS Accuracy) ±2% @ conc. > 10 wt% ±10% @ 1 - 10 wt% ±33% @ 0.3 - 1 wt%	(Est. MVP-SEM EDS Accuracy) ±5% @ conc. > 10 wt% ±25% @ 1 - 10 wt% ±75% @ 0.3 - 1 wt%



Copper TEM Grid Test Images

J-M Reef Ore Test Sample



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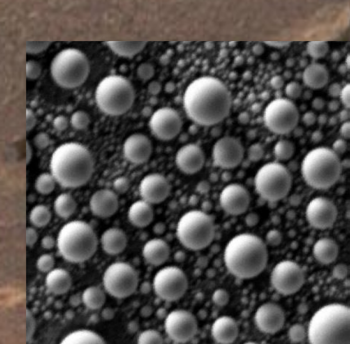

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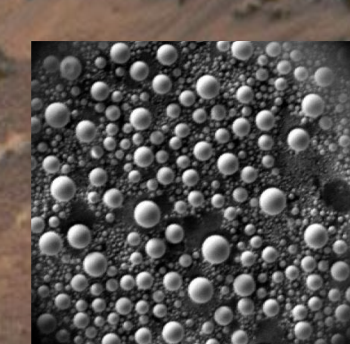

1200X

Sn Spheres on Carbon

Background Image Credit: NASA/JPL-Caltech/MSSS