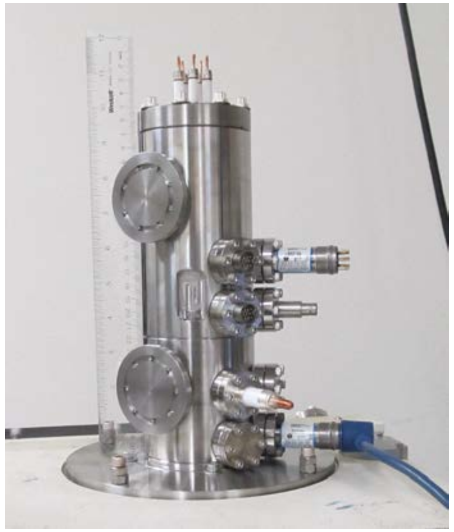
National Aeronautics and Space Administration

Applications of the Miniaturized Variable Pressure Scanning Electron Microscope (MVP-SEM) in the Search for Life on Mars

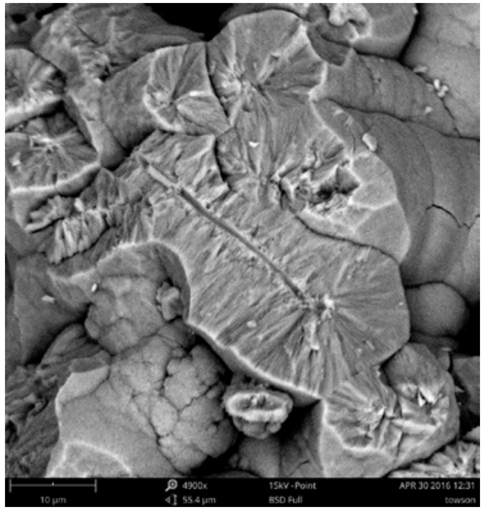
Dr. Jennifer Edmunson and the MVP-SEM Instrument Development and Science Teams | 16 February 2021

MVP-SEM Overview

Requirements

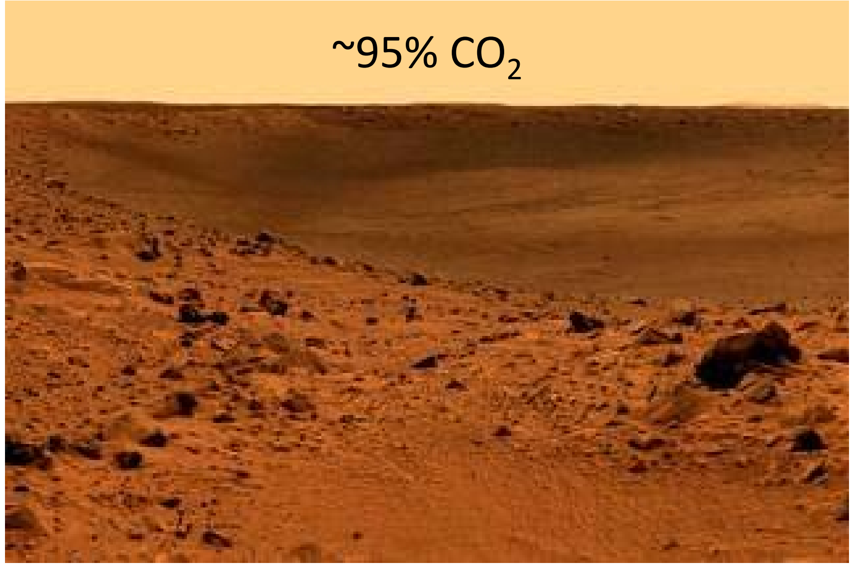


Instrument



Life Science Applications

MVP-SEM Requirements



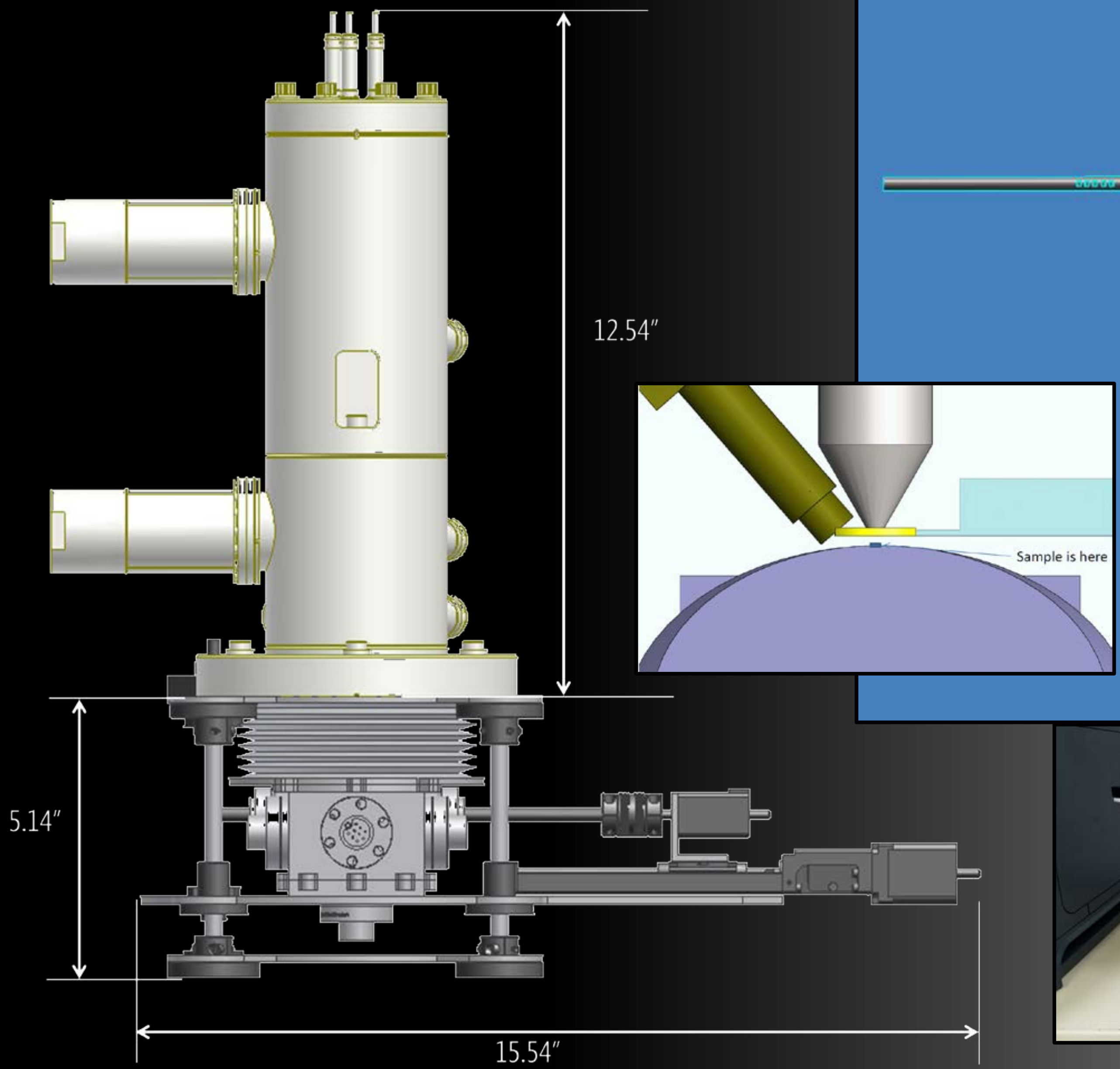
Parameter	Mars
Gravity	1/3 that of Earth
Pressure at surface	3-10 Torr ($4x10^{-3}$ to $1x10^{-2}$ ATM)
Surface Temperatures	-89 to -31 Celsius (Viking 1)
Radiation (solar wind particles, galactic cosmic rays)	Some protection offered by atmosphere
Surface reactivity	Perchlorates (highly oxidizing)

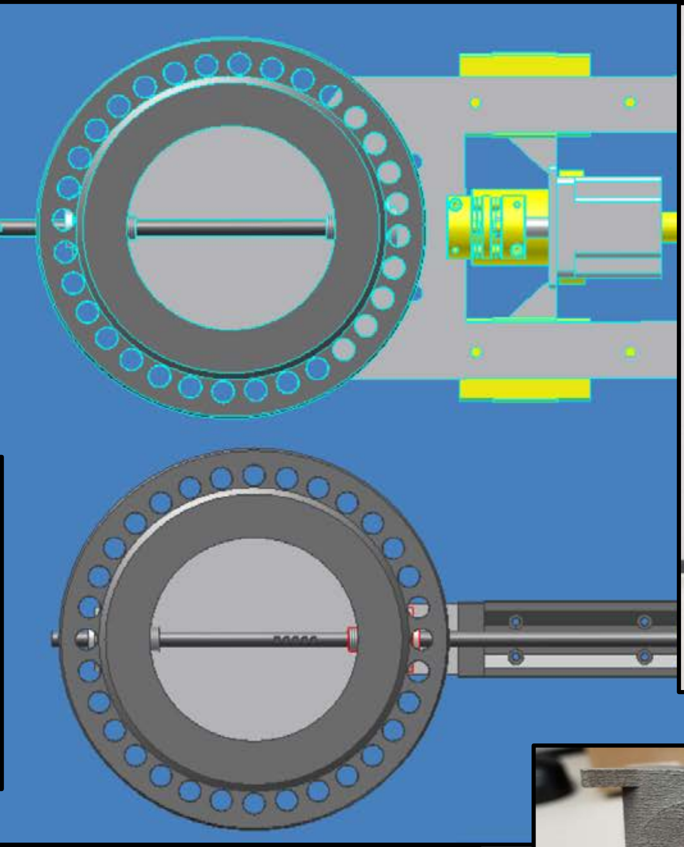
- Launch/Landing
  - Demonstrated survival of components during vibration testing
- Sample
  - Preparation is limited
  - Ideally analyze an infinite number
- Magnification
  - 175x to 5000x or better
- Resolution
  - 100nm or better
- Sample Chemistry / Element Mapping
  - Energy dispersive spectroscopy

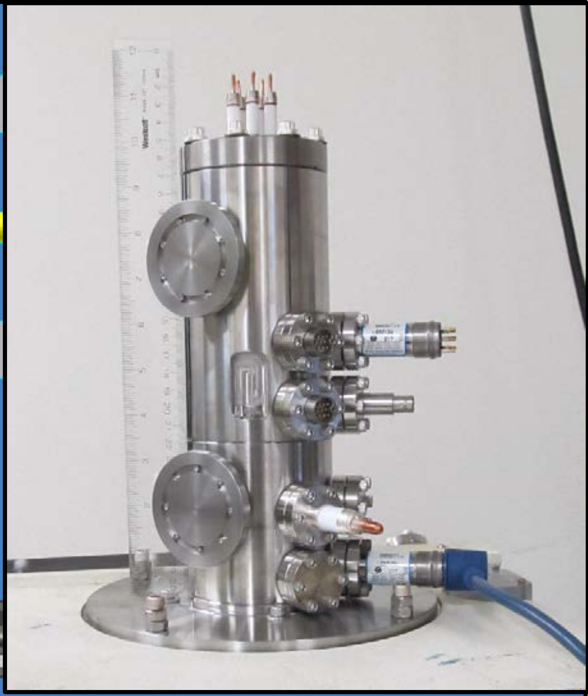
MVP-SEM Science Requirements

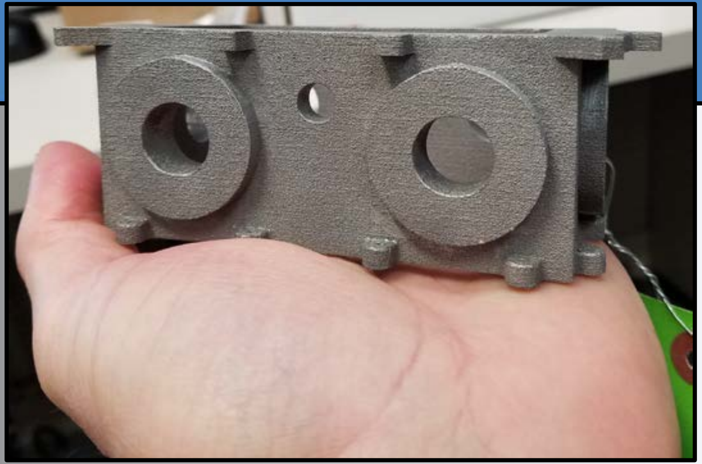
NASA 2018 Strategic Plan	MEPAG Goals 2018	MEPAG Objectives 2018	Scientific Measurement Requirements			Instrument Functional Requirements		Mission Functional Requirements (Top Level)
			Physical Parameters		Observables			
Objective 1.1: Understand the Sun, Earth, Solar System, and Universe Objective 2.2: 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	I. Determine if Mars ever supported life	IA. Determine if environments having high potential for prior habitability and preservation of biosignatures contain evidence for past life	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)	Geochemistry	Characteristic X-rays	Detection precision (major elements) using Energy Dispersive Spectroscopy	Errors less than 10% for major elements, 5% for minor elements, 15 kV accelerating voltage for signal strength, pressure monitoring for C and O analyses	• 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
		IB. Determine if environments with high potential for current habitability and expression of biosignatures contain evidence of extant life						
	II. Understand the processes and history of climate on Mars	IIA. Characterize the state of the present climate of Mars' atmosphere and surrounding plasma environment, and the underlying processes, under the current orbital configuration			Backscattered Electrons	Sufficient contrast to note mineral and phase chemical zoning	0.2-2 nA current at sample	
		IIB. Characterize the history of Mars' climate in the recent past, and the underlying processes, under different orbital configurations		Geomorphology	Imaging, Topography	Resolve uncoated objects	Environmental SEM mode	
		IIC. Characterize Mars' ancient climate and underlying processes						
	III. Understand the origin and evolution of Mars as a geological system	IIIA. Document the geologic record preserved in the crust and interpret the processes that have created and modified that record						
		IIIB. Determine the structure, composition, and dynamics of the martian interior and how it has evolved						
	IV. Prepare for human exploration	IVB. Obtain knowledge of Mars sufficient to design and implement a human mission to the martian surface with acceptable cost, risk, and performance				FOV (at 175X)	0.75 mm or greater	
		IVC. Obtain knowledge of Mars sufficient to design and implement a human mission to the surface of either Phobos or Deimos with acceptable cost, risk, and performance				Resolution (Autofocus)	100 nm in size or better	
		IVD. Obtain knowledge of Mars sufficient to design and implement sustained human presence at the martian surface with acceptable cost, risk, and performance				Magnification	175X to 5000X or better	
						Environmental Distance	Adjustable (2 mm to 17 mm)	

MVP-SEM Instrument









Images courtesy of Bud Magera, Mathieu Fradet, and Jurij Simcic

MVP-SEM Capabilities

<table>
<tr><th rowspan="2">NASA 2018 Strategic Plan</th><th rowspan="2">MEPAG Goals 2018</th><th rowspan="2">MEPAG Objectives 2018</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="14">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="2">I. Determine if Mars ever supported life</td><td>IA. Determine if environments having high potential for prior habitability and preservation of biosignatures contain evidence for past life</td><td rowspan="14">Combined geological analyses such as:

Mineral and phase geochemistry

Mineral and phase morphology

Biological morphology

Grain size and shape

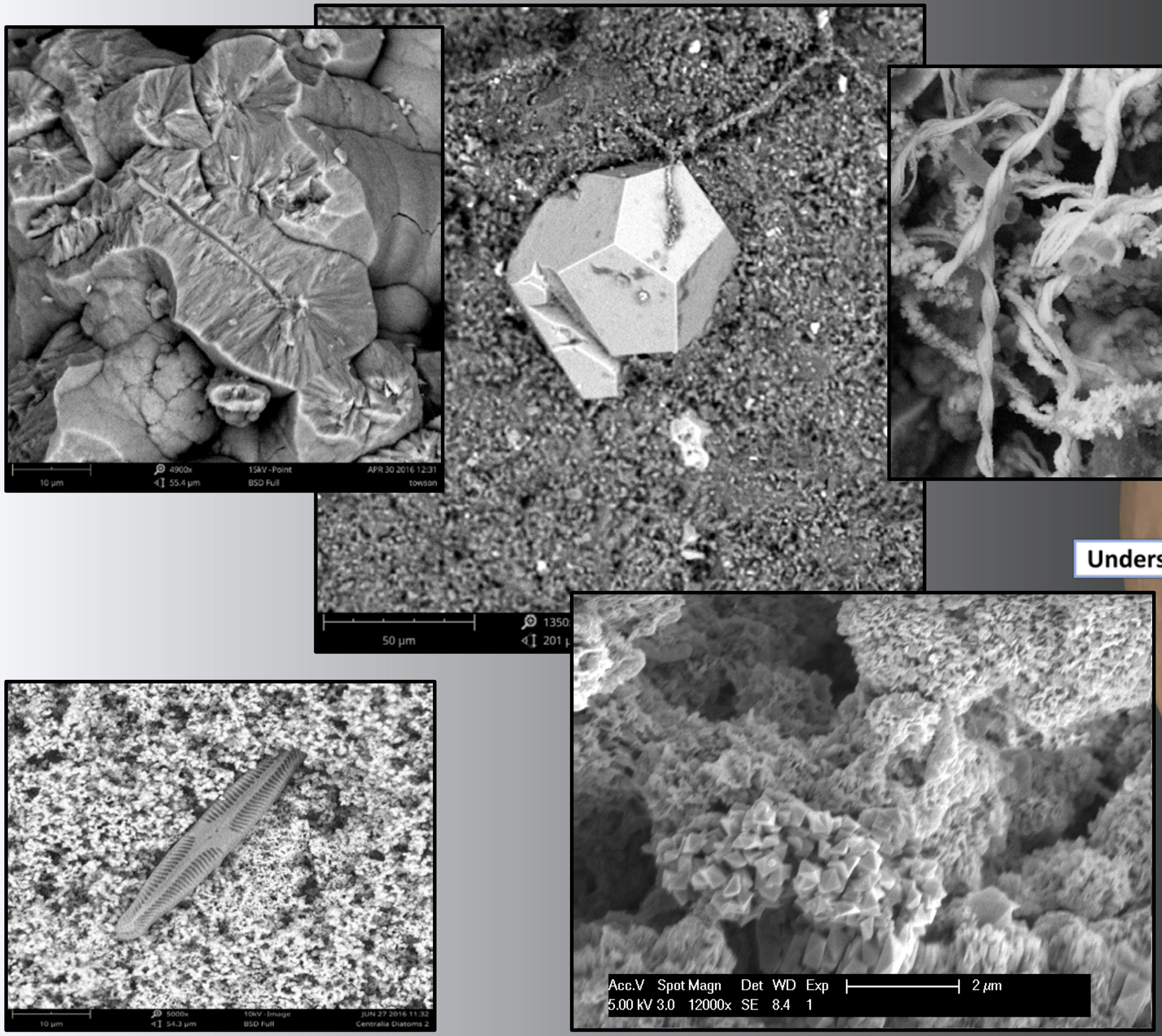
Location of concentrations of elements (X-ray mapping)</td><td rowspan="4">Geochemistry</td><td rowspan="2">Characteristic X-rays</td><td rowspan="2">Detection precision (major elements) using Energy Dispersive Spectroscopy</td><td rowspan="2">Errors less than 10% for major elements, 5% for minor elements, 15 kV 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="14">• 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>IB. Determine if environments with high potential for current habitability and expression of biosignatures contain evidence of extant life</td></tr>
<tr><td rowspan="4">II. Understand the processes and history of climate on Mars</td><td>IIA. Characterize the state of the present climate of Mars' atmosphere and surrounding plasma environment, and the underlying processes, under the current orbital configuration</td><td rowspan="2">Backscattered Electrons</td><td rowspan="2">Sufficient contrast to note mineral and phase chemical zoning</td><td rowspan="2">0.2-2 nA current at sample</td><td rowspan="2">0.2-2 nA current at sample</td></tr>
<tr><td rowspan="2">IIB. Characterize the history of Mars' climate in the recent past, and the underlying processes, under different orbital configurations</td></tr>
<tr><td rowspan="10">Geomorphology</td><td rowspan="10">Imaging, Topography</td><td rowspan="5">Resolve uncoated objects</td><td rowspan="5">Environmental SEM mode</td><td rowspan="3">Sample Chamber Pressure Control to <1 Torr</td></tr>
<tr><td>IIC. Characterize Mars' ancient climate and underlying processes</td></tr>
<tr><td rowspan="2">III. Understand the origin and evolution of Mars as a geological system</td><td>IIIA. Document the geologic record preserved in the crust and interpret the processes that have created and modified that record</td></tr>
<tr><td>IIIB. Determine the structure, composition, and dynamics of the martian interior and how it has evolved</td><td rowspan="2">Electron Gun Chamber Pressure Control to $<1x10^{-6}$ Torr</td></tr>
<tr><td rowspan="6">IV. Prepare for human exploration</td><td rowspan="2">IVB. Obtain knowledge of Mars sufficient to design and implement a human mission to the martian surface with acceptable cost, risk, and performance</td></tr>
<tr><td>FOV (at 175X)</td><td>0.75 mm or greater</td><td>0.8 mm</td></tr>
<tr><td rowspan="2">IVC. Obtain knowledge of Mars sufficient to design and implement a human mission to the surface of either Phobos or Deimos with acceptable cost, risk, and performance</td><td>Resolution (Autofocus)</td><td>100 nm in size or better</td><td>50 nm</td></tr>
<tr><td rowspan="2">Magnification</td><td rowspan="2">175X to 5000X or better</td><td rowspan="2">20,000X</td></tr>
<tr><td rowspan="2">IVD. Obtain knowledge of Mars sufficient to design and implement sustained human presence at the martian surface with acceptable cost, risk, and performance</td></tr>
<tr><td>Environmental Distance</td><td>Adjustable (2 mm to 17 mm)</td><td>2 mm to 17 mm ±0.05 mm</td></tr>
</table>

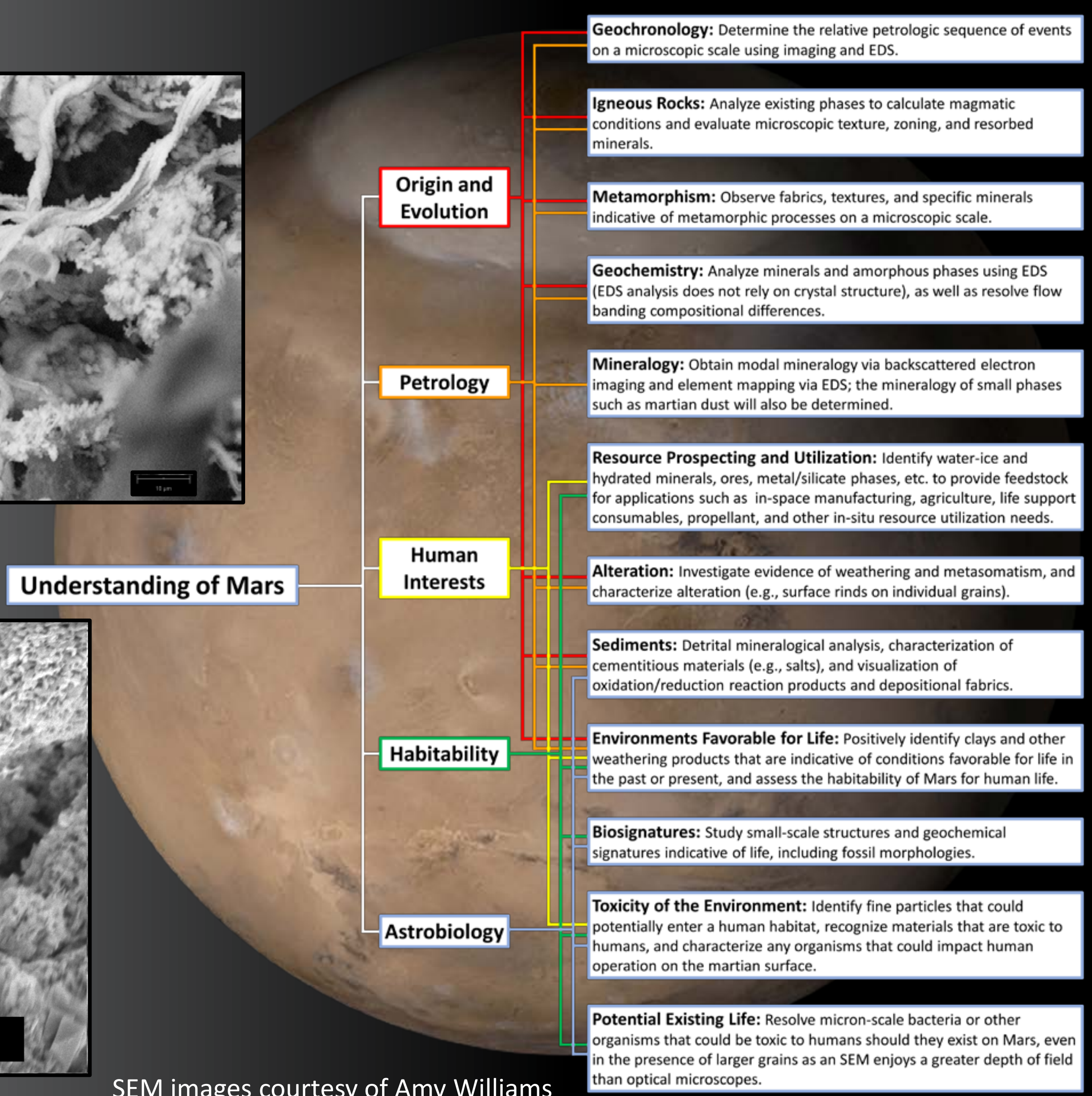
MVP-SEM SPRING Mission Requirements

Visions and Voyages Science Goals for the Study of Mars	SPRING Science Objective	How the MVP-SEM addresses SPRING objectives
1. Determine if life ever arose on Mars	1. Detect the presence of physical biosignatures in the near surface of Mars	Detect and identify biosignatures, brine materials, and minerals/phases known to be electron acceptors for the reduction of carbon in biological processes
2. Understand the processes and history of climate	2. Characterize the local environmental and geological history that lead to habitability	Evaluate precipitate phases and other phases affected by or indicative of pH and temperature
		Evaluate subsurface samples in concert with a drill to determine a near-surface stratigraphy of climate-influenced samples
		Determine the composition and characteristics of martian dust to infer how dust affects the martian climate, and how it would affect humans residing on the martian surface
3. Determine the evolution of the surface and interior	3. Characterize the regional resources to prepare for human exploration	Characterize grains (size, shape) and correlate with surface erosion, determine grain chemistry and source rock and if the chemistry is suitable for in-situ resource utilization

SPRING: Surface Probe Rover Investigating New Ground (J.R. Skok, Lead)

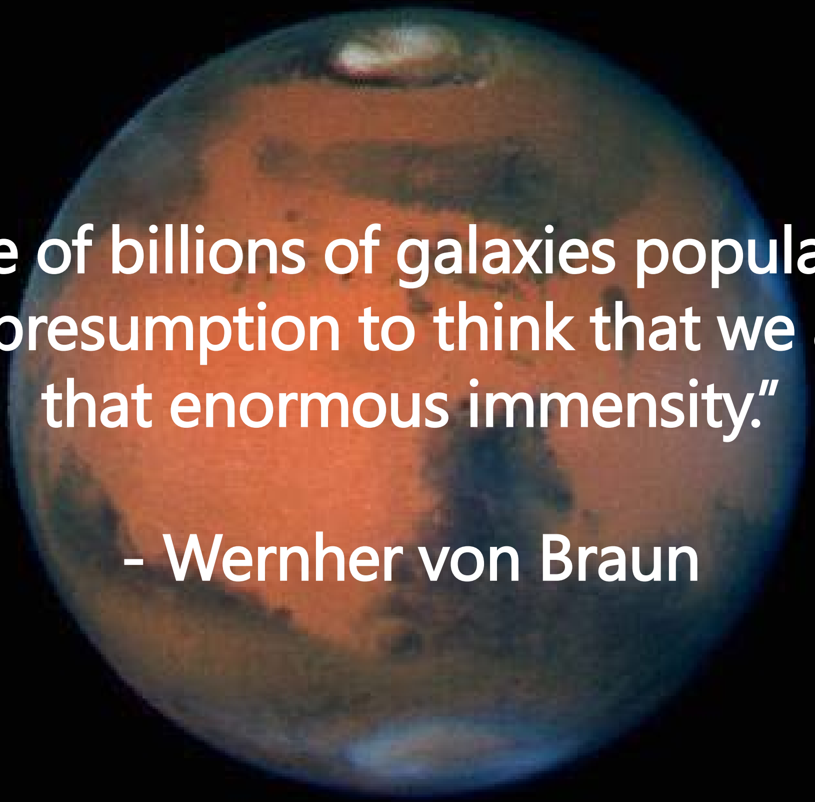
MVP-SEM Life Science Applications





SEM images courtesy of Amy Williams

Acknowledgements



“Our galaxy is one of billions of galaxies populating the universe.
It would be the height of presumption to think that we are the only living thing in that enormous immensity.”

- Wernher von Braun

Jessica Gaskin • Mike Effinger • Greg Jerman • J.R. Skok • Amy Williams • Andy Needham • Ivria Doloboff • Caleb Fassett • Nina Lanza • Hunain Alkhateb • Aaron Noell • Horton Newsom • Debra Needham • Mark Salvatore • Zach Gallegos • Ken Williford • Ralph Harvey • Robert Klein-Schoder • Bill Mackie • Bud Magera • Jurij Simcic • Mathieu Fradet • Evan Neidholdt • Gerry Danilatos • The Mars Science Community • The SPRING Mission Team • Various Contributors and Supporters