



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

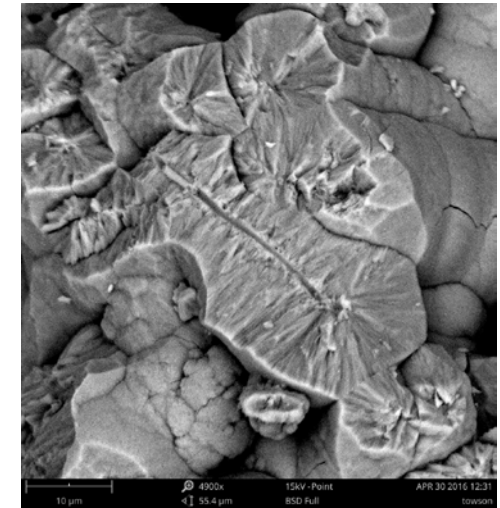
MVP-SEM Overview



Requirements



Instrument

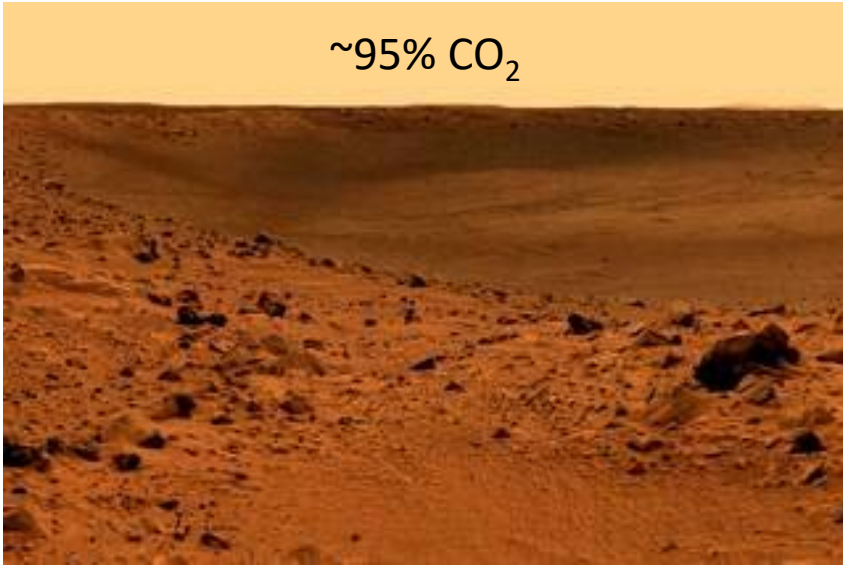


Life Science Applications

MVP-SEM Requirements



~95% CO₂



Parameter	Mars
Gravity	1/3 that of Earth
Pressure at surface	3-10 Torr (4×10^{-3} to 1×10^{-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

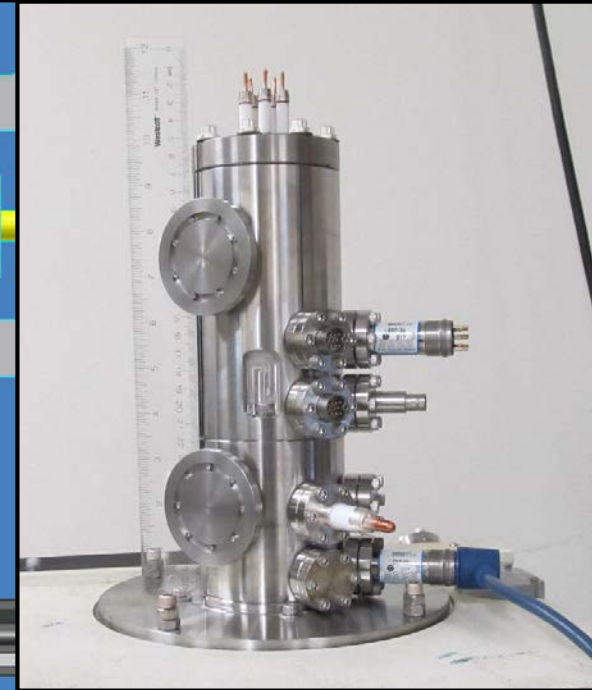
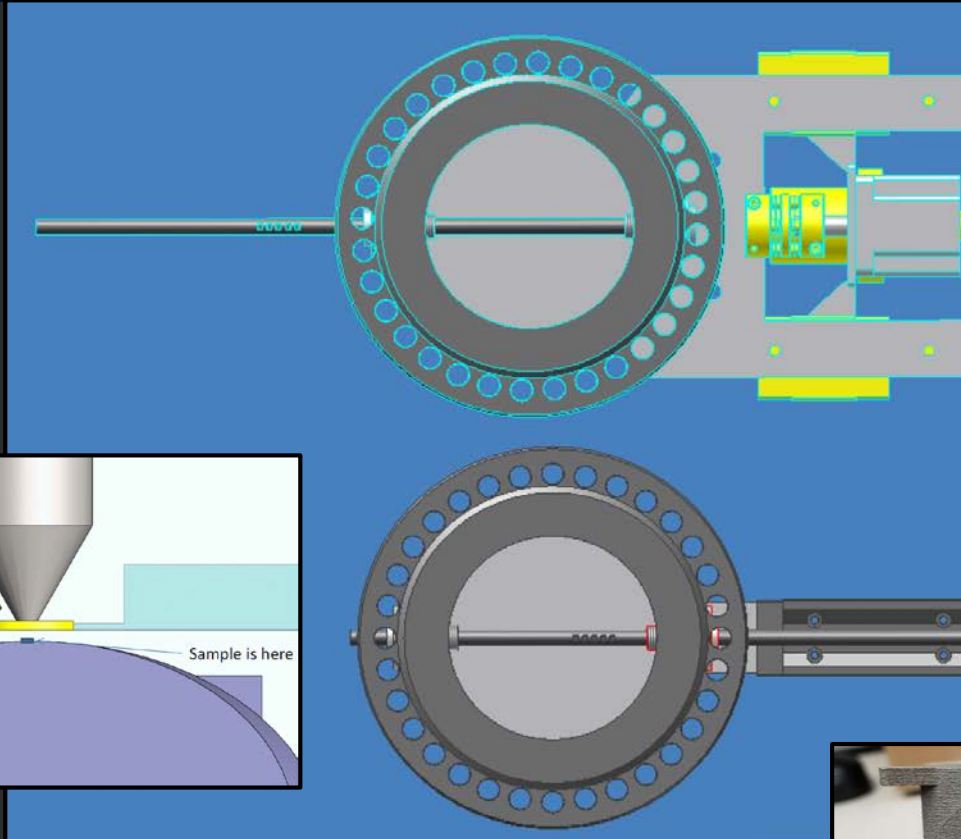
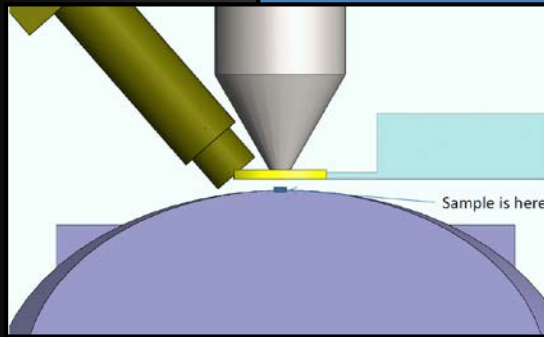
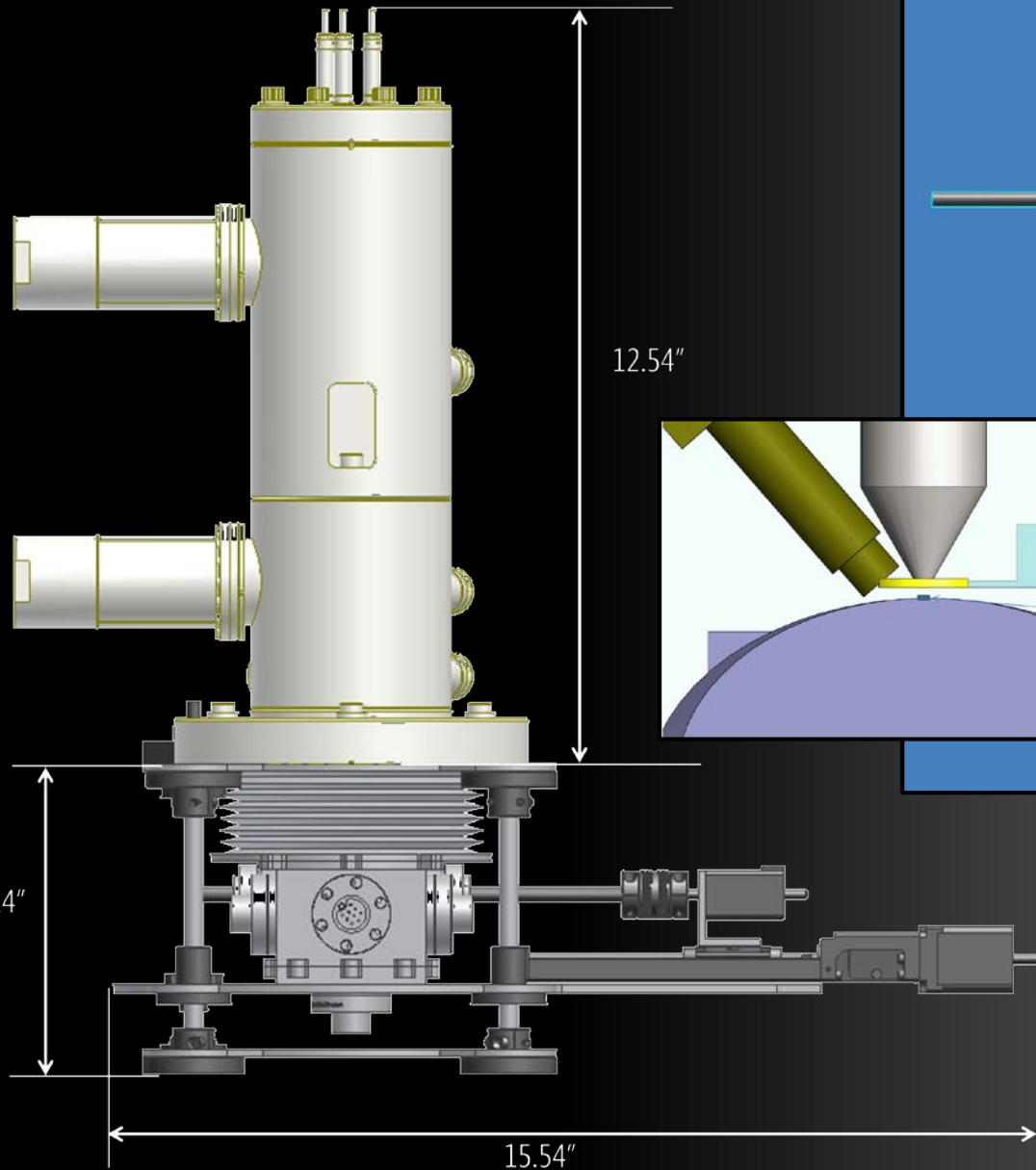
- Energy dispersive spectroscopy

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							
<p>Objective 1.1: Understand the Sun, Earth, Solar System, and Universe</p> <p>Objective 2.2: Conduct Exploration in Deep Space, including to the Surface of the Moon</p> <p>Objective 3.1: Develop and Transfer Revolutionary Technologies to Enable Exploration Capabilities for NASA and the Nation</p>	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:	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	<ul style="list-style-type: none">• 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							Backscattered Electrons	Sufficient contrast to note mineral and phase chemical zoning	0.2-2 nA current at sample
	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		Mineral and phase geochemistry	Imaging, Topography	Resolve uncoated objects	Environmental SEM mode				
		IIB. Characterize the history of Mars’ climate in the recent past, and the underlying processes, under different orbital configurations							Mineral and phase morphology		
		IIC. Characterize Mars’ ancient climate and underlying processes	Biological morphology								
	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		Grain size and shape							
		IIIB. Determine the structure, composition, and dynamics of the martian interior and how it has evolved	Location of concentrations of elements (X-ray mapping)								
	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		Imaging, Topography	Resolve uncoated objects	Environmental SEM mode					
		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					FOV (at 175X)		0.75 mm or greater		
		IVD. Obtain knowledge of Mars sufficient to design and implement sustained human presence at the martian surface with acceptable cost, risk, and performance								Resolution (Autofocus)	100 nm in size or better
		Magnification									
Environmental Distance			Adjustable (2 mm to 17 mm)								

MVP-SEM Instrument



Images courtesy of Bud Magera, Mathieu Fradet, and Jurij Simcic 5

MVP-SEM Capabilities



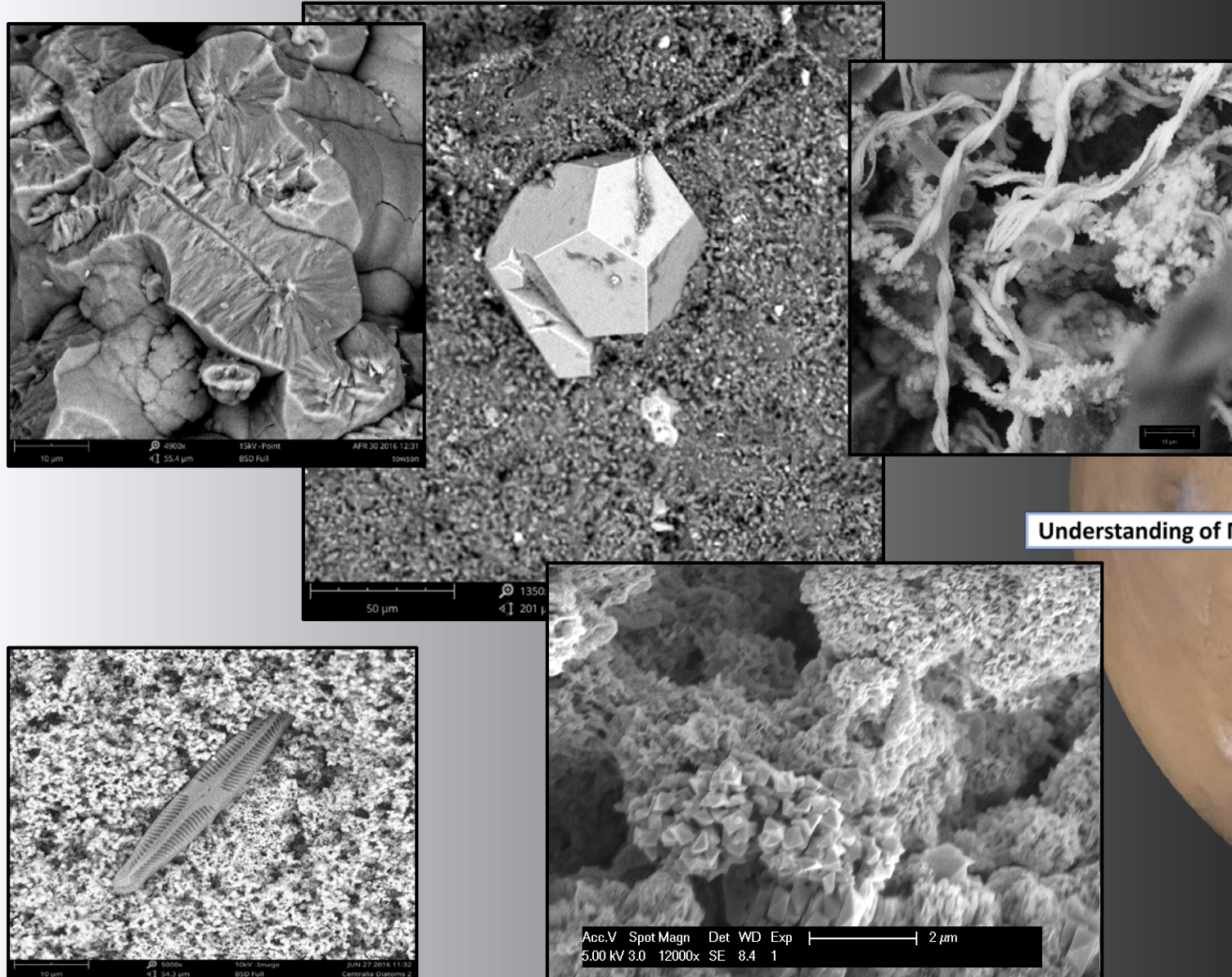
NASA 2018 Strategic Plan	MEPAG Goals 2018	MEPAG Objectives 2018	Scientific Measurement Requirements		Instrument Functional Requirements		Projected Performance	Mission Functional Requirements (Top Level)								
			Physical Parameters	Observables												
Objective 1.1: Understand the Sun, Earth, Solar 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:	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	Errors less than 10% for major elements, 5% for minor elements including C and O	<ul style="list-style-type: none">• 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								Backscattered Electrons	Sufficient contrast to note mineral and phase chemical zoning	0.2-2 nA current at sample	0.2-2 nA current at sample			
	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			Mineral and phase geochemistry	Imaging, Topography	Resolve uncoated objects	Environmental SEM mode						Sample Chamber Pressure Control to <1 Torr		
		IIB. Characterize the history of Mars’ climate in the recent past, and the underlying processes, under different orbital configurations								Mineral and phase morphology	Electron Gun Chamber Pressure Control to <1x10 ⁻⁶ Torr					
		IIC. Characterize Mars’ ancient climate and underlying processes	Biological morphology													
	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		Grain size and shape	FOV (at 175X)					0.75 mm or greater	0.8 mm					
		IIIB. Determine the structure, composition, and dynamics of the martian interior and how it has evolved	Location of concentrations of elements (X-ray mapping)									Resolution (Autofocus)	100 nm in size or better	50 nm		
	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		Magnification											175X to 5000X or better	20,000X
		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														
		IVD. Obtain knowledge of Mars sufficient to design and implement sustained human presence at the martian surface with acceptable cost, risk, and performance														
						Environmental Distance	Adjustable (2 mm to 17 mm)	2 mm to 17 mm ±0.05 mm								

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

MVP-SEM Life Science Applications



Understanding of Mars

Origin and Evolution

Geochronology: Determine the relative petrologic sequence of events on a microscopic scale using imaging and EDS.

Igneous Rocks: Analyze existing phases to calculate magmatic conditions and evaluate microscopic texture, zoning, and resorbed minerals.

Metamorphism: Observe fabrics, textures, and specific minerals indicative of metamorphic processes on a microscopic scale.

Geochemistry: Analyze minerals and amorphous phases using EDS (EDS analysis does not rely on crystal structure), as well as resolve flow banding compositional differences.

Petrology

Mineralogy: Obtain modal mineralogy via backscattered electron imaging and element mapping via EDS; the mineralogy of small phases such as martian dust will also be determined.

Resource Prospecting and Utilization: Identify water-ice and hydrated minerals, ores, metal/silicate phases, etc. to provide feedstock for applications such as in-space manufacturing, agriculture, life support consumables, propellant, and other in-situ resource utilization needs.

Human Interests

Alteration: Investigate evidence of weathering and metasomatism, and characterize alteration (e.g., surface rinds on individual grains).

Sediments: Detrital mineralogical analysis, characterization of cementitious materials (e.g., salts), and visualization of oxidation/reduction reaction products and depositional fabrics.

Habitability

Environments Favorable for Life: Positively identify clays and other weathering products that are indicative of conditions favorable for life in the past or present, and assess the habitability of Mars for human life.

Biosignatures: Study small-scale structures and geochemical signatures indicative of life, including fossil morphologies.

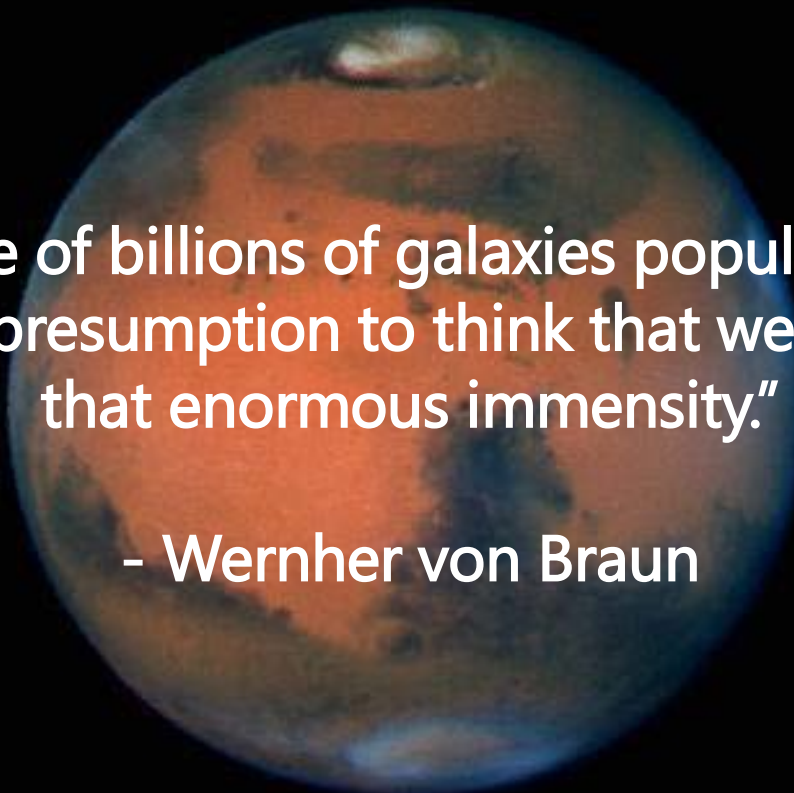
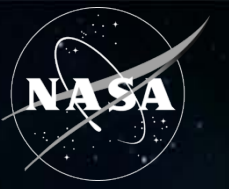
Astrobiology

Toxicity of the Environment: Identify fine particles that could potentially enter a human habitat, recognize materials that are toxic to humans, and characterize any organisms that could impact human operation on the martian surface.

Potential Existing Life: Resolve micron-scale bacteria or other organisms that could be toxic to humans should they exist on Mars, even in the presence of larger grains as an SEM enjoys a greater depth of field than optical microscopes.

SEM images courtesy of Amy Williams

Acknowledgements

A large, detailed image of the planet Mars is centered in the background. It shows the reddish-orange surface with darker regions and polar ice caps at the top and bottom.

"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

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