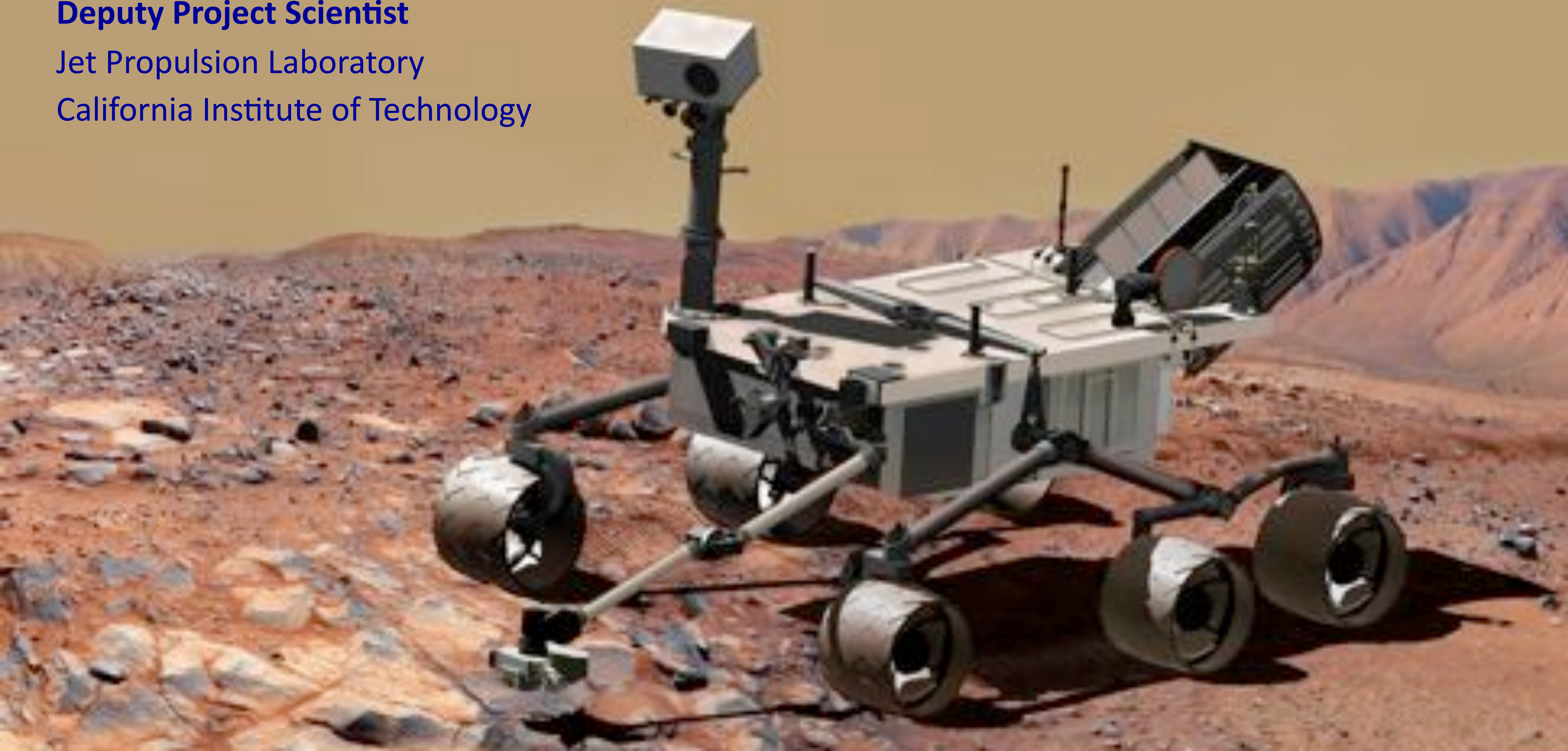
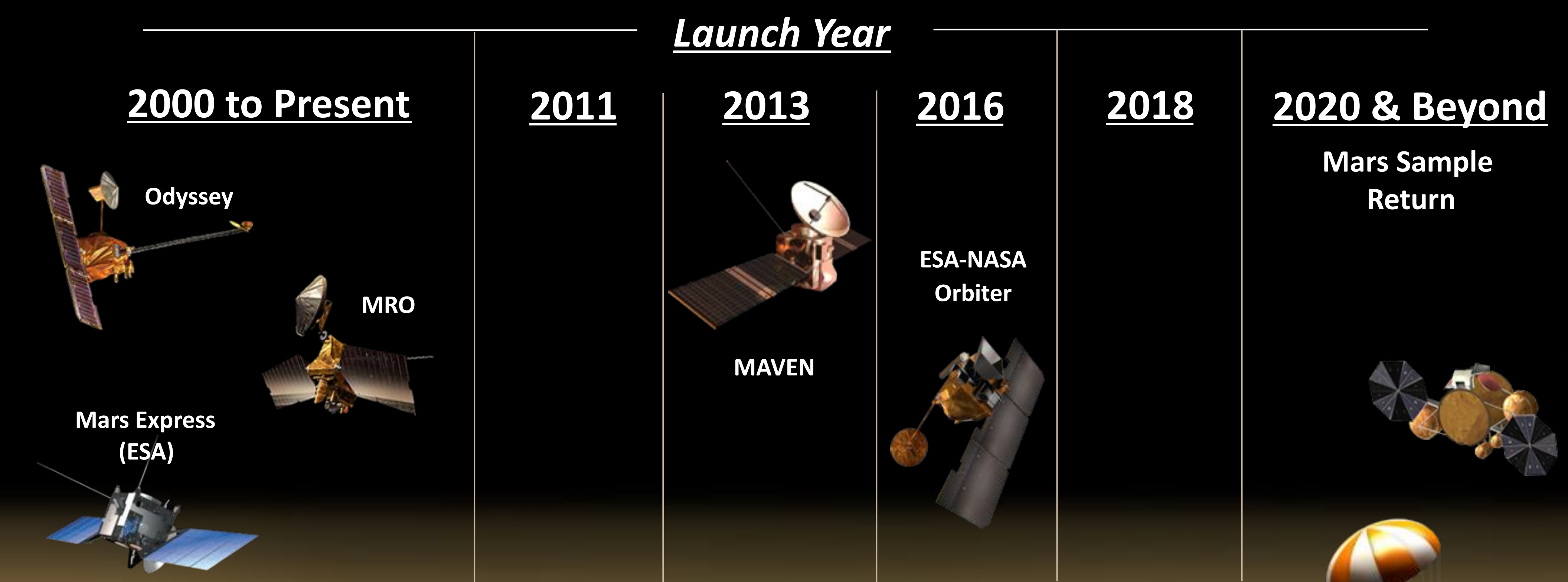
Mars Science Laboratory

Ashwin Vasavada
Deputy Project Scientist
Jet Propulsion Laboratory
California Institute of Technology



NASA's Mars Exploration Program



Recent missions have discovered that Mars' surface reveals a diverse and dynamic history, including evidence for sustained interactions with liquid water.

By studying a potentially habitable, ancient environment, MSL is a bridge to future missions that focus on life detection or returning samples.

Scientific Objectives for MSL

Explore and quantitatively assess a local region on Mars' surface as a potential habitat for life, past or present

A. Assess the biological potential of at least one target environment.
   1. Determine the nature and inventory of organic carbon compounds.
   2. Inventory the chemical building blocks of life (C, H, N, O, P, S).
   3. Identify features that may represent the effects of biological processes.

B. Characterize the geology and geochemistry of the landing region at all appropriate spatial scales (i.e., ranging from micrometers to meters).
   1. Investigate the chemical, isotopic, and mineralogical composition of martian surface and near-surface geological materials.
   2. Interpret the processes that have formed and modified rocks and regolith.

C. Investigate planetary processes of relevance to past habitability, including the role of water.
   1. Assess long-timescale (i.e., 4-billion-year) atmospheric evolution processes.
   2. Determine present state, distribution, and cycling of water and CO_2.

D. Characterize the broad spectrum of surface radiation, including galactic cosmic radiation, solar proton events, and secondary neutrons.

Enabling Capabilities

A Robotic Field Geologist

- Access to a site mapped from orbit
- Long life, mobility, capability to explore a local region
- Remote sensing and contact science

A Mobile Geochemical Laboratory

- A broad and flexible payload including analytical laboratory instruments
- Ability to acquire and process dozens of rock and soil samples
- An integrated science team and operations strategy

MSL Mission Overview

CRUISE/APPROACH

- 10-11 month cruise
- Spinning cruise stage
- Arrive northern summer

ENTRY, DESCENT, LANDING

- Guided entry and controlled, powered “sky crane” descent
- 20×25-km landing ellipse
- Discovery responsive for landing sites ±30° latitude, <0 km elevation
- 900-kg landed mass

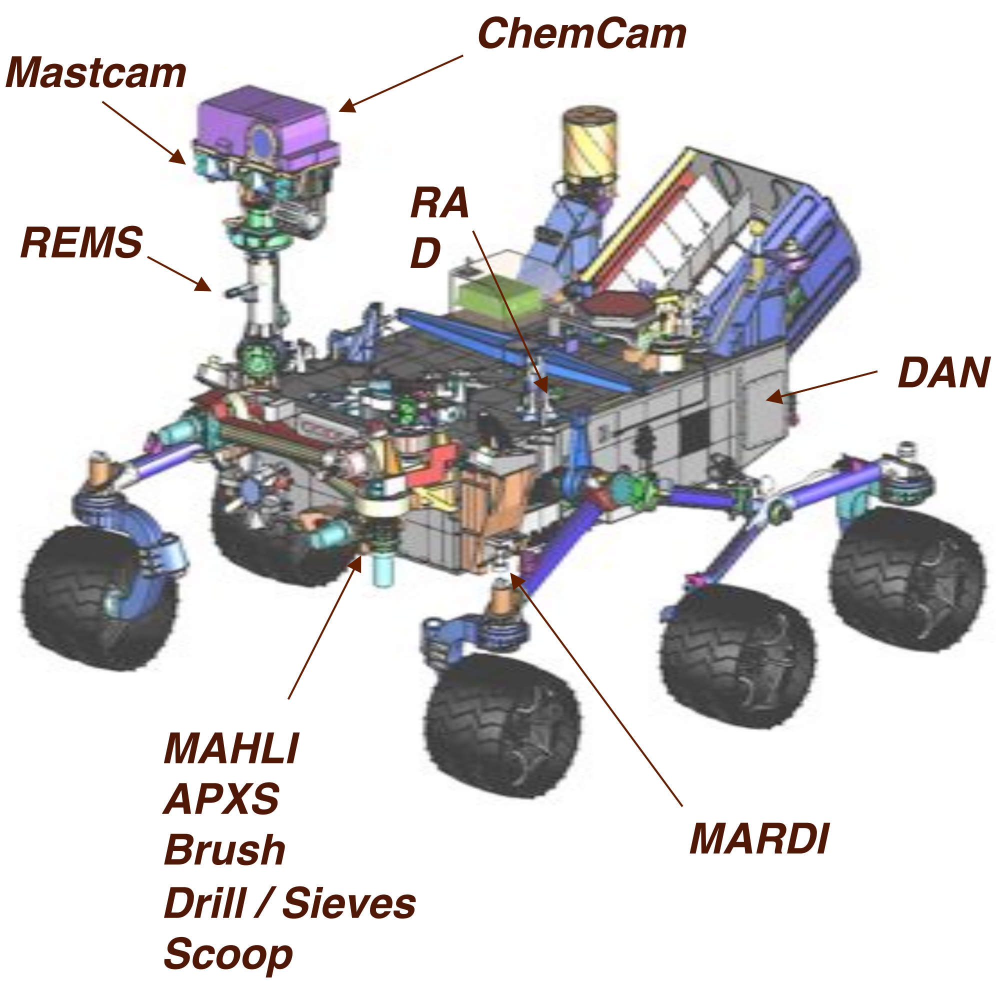
LAUNCH

- Late 2011
- Atlas V (541)

SURFACE MISSION

- Prime mission is one Mars year
- Latitude-independent and long-lived power source
- Ability to drive out of landing ellipse; high clearance
- Fast CPU and substantial data storage
- 80 kg of science payload
- Ability to acquire and analyze samples of rock and soil

MSL Payload



Rover Width: 2.7 m
Height of Deck: 1.1 m
Ground Clearance: 0.66 m
Height of Mast: 2.2 m

REMOTE SENSING

Mastcam (M. Malin, MSSS) - Color and telephoto imaging, video, atmospheric opacity

ChemCam (R. Wiens, LANL/CNES) – Chemical composition; remote micro-imaging

CONTACT INSTRUMENTS (ARM)

MAHLI (K. Edgett, MSSS) – Hand-lens color imaging

APXS (R. Gellert, U. Guelph, Canada) - Chemical composition

ANALYTICAL LABORATORY (ROVER BODY)

SAM (P. Mahaffy, GSFC/CNES) - Chemical and isotopic composition, including organics

CheMin (D. Blake, ARC) - Mineralogy

ENVIRONMENTAL CHARACTERIZATION

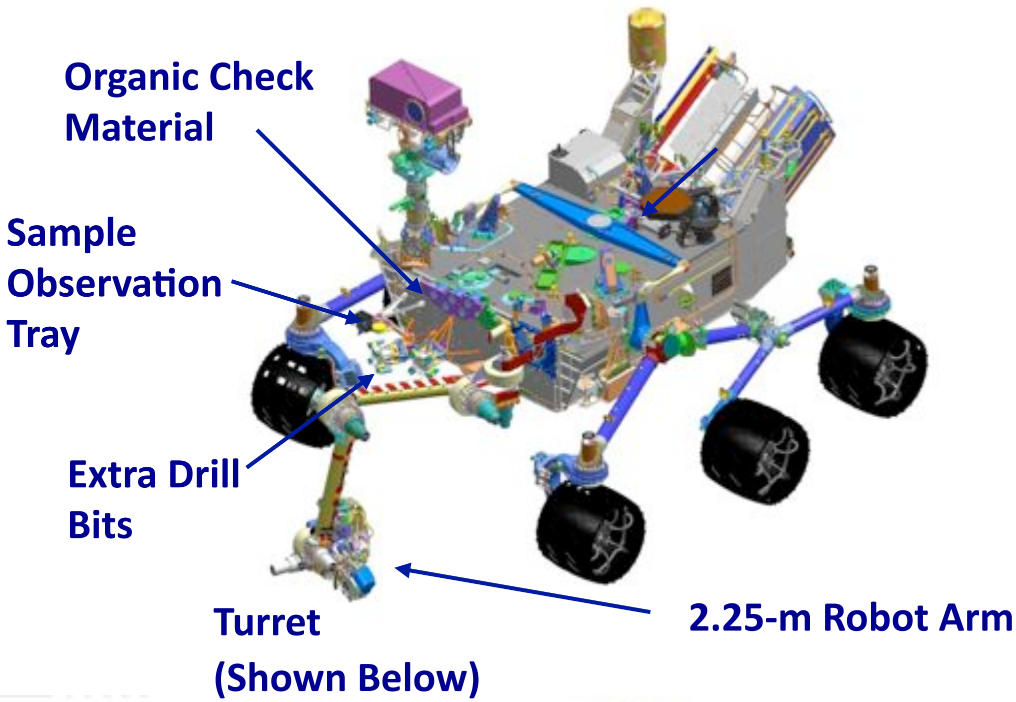
MARDI (M. Malin, MSSS) - Descent imaging

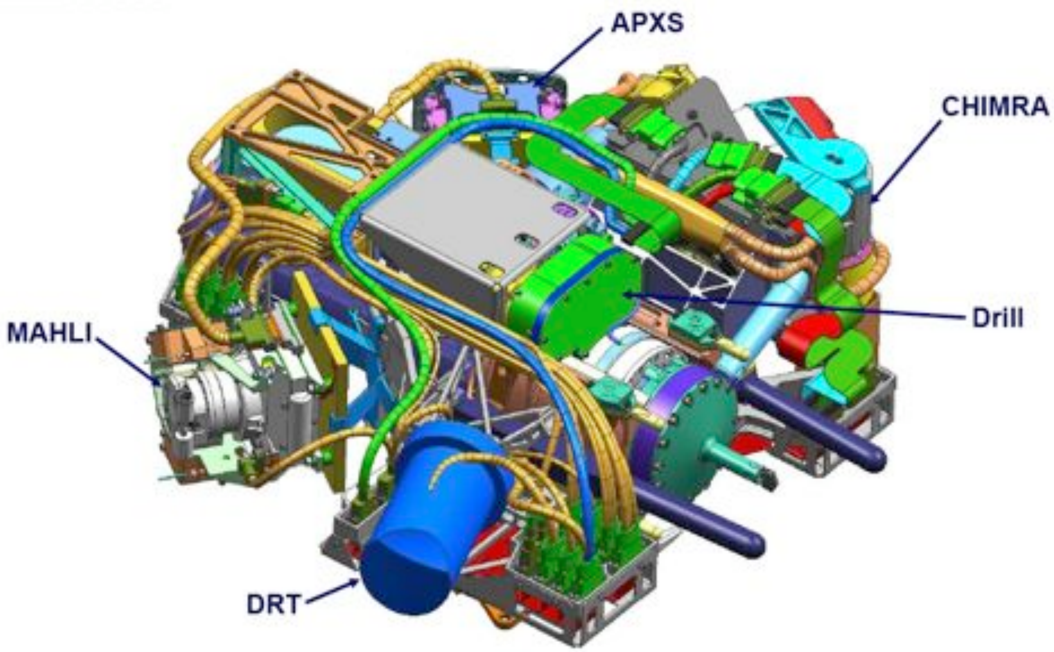
REMS (J. Gómez-Elvira, CAB, Spain) - Meteorology / UV

RAD (D. Hassler, SwRI) - High-energy radiation

DAN (I. Mitrofanov, IKI, Russia) - Subsurface hydrogen

Sample Acquisition, Processing, and Handling





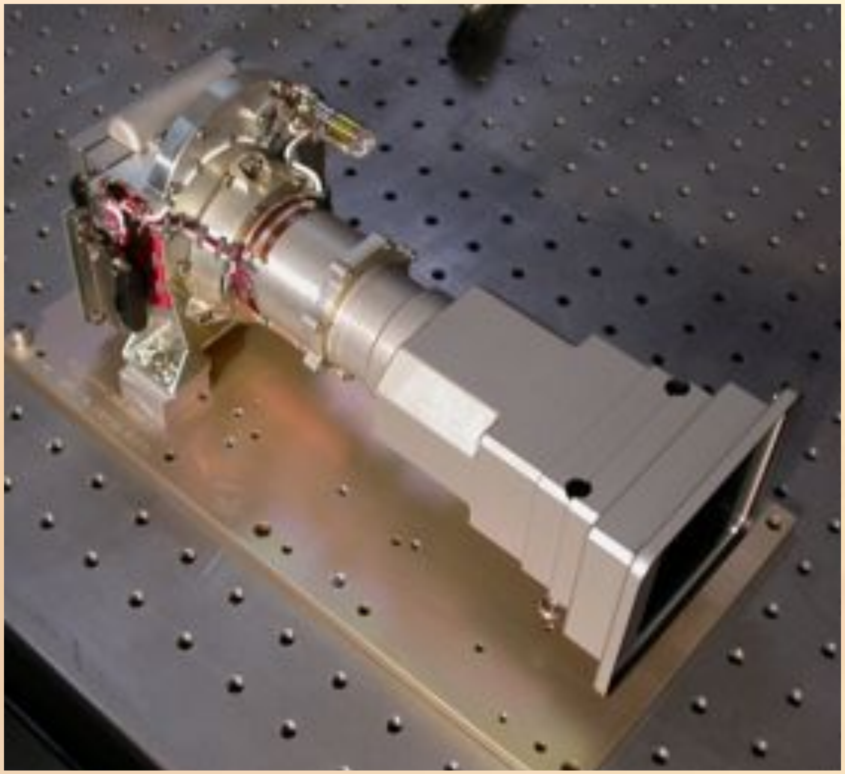
MSL's sampling system can:

- Clean rock surfaces with a brush
- Place and hold the APXS and MAHLI
- Acquire samples of rock or soil with a powdering drill or scoop
- Sieve the samples and deliver them to SAM, CheMin, or a tray for observation
- Exchange spare drill bits

Mastcam

Principal Investigator: Michael Malin

Malin Space Science Systems



Mastcam observes the geological structures and features within the vicinity of the rover

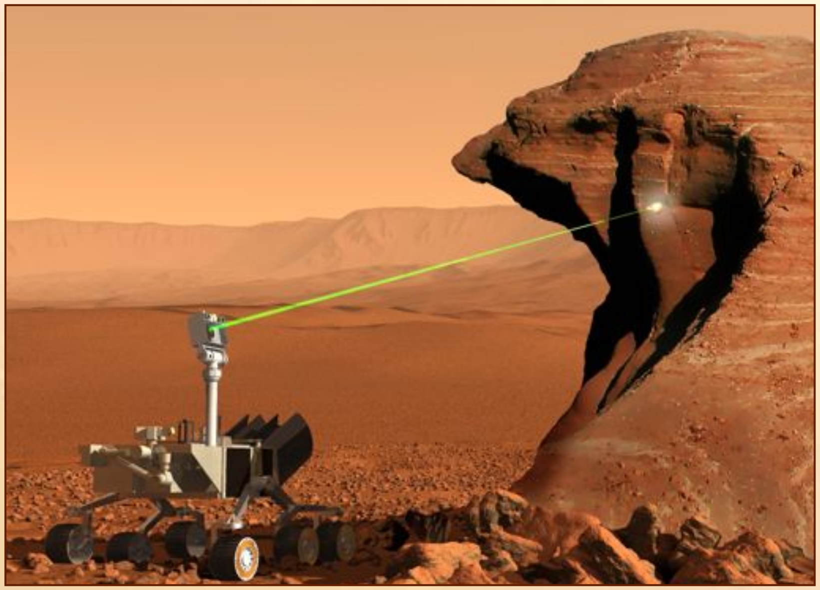
- Studies of landscape, rocks, fines, frost/ice, and atmospheric features
- Narrow-angle (5.1° FOV) and medium-angle (15° FOV) camera; stereo where they overlap
- Bayer pattern filter design for natural color plus narrow-band filters for scientific color
- High spatial resolution: 1200×1200 pixels (0.2 mm/pixel at 2 m, 8 cm/pixel at 1 km)
- High-definition video at 5-10 FPS, 1280×720 pixels
- Large internal storage: 256 MByte SRAM, 8 GByte flash

ChemCam

Principal Investigator: Roger Wiens

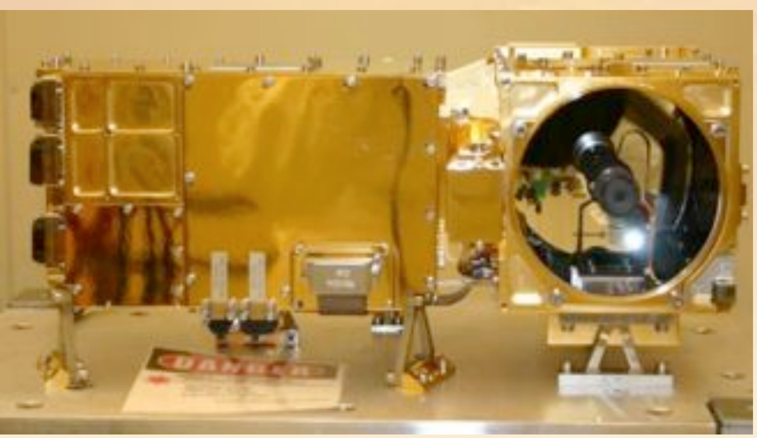
Los Alamos National Laboratory

Centre d’Etude Spatiale des Rayonnements



ChemCam performs elemental analyses through laser-induced breakdown spectroscopy

- Rapid characterization of rocks and soils from a distance of up to seven meters
- 240-800 nm spectral range
- Dust removal over 1 cm; depth profiling within a 1-mm spot
- Will identify and classify rocks, soils, pebbles, hydrated minerals, weathering layers, and ices
- High-resolution context imaging (resolves ~0.8 mm at 10 m)

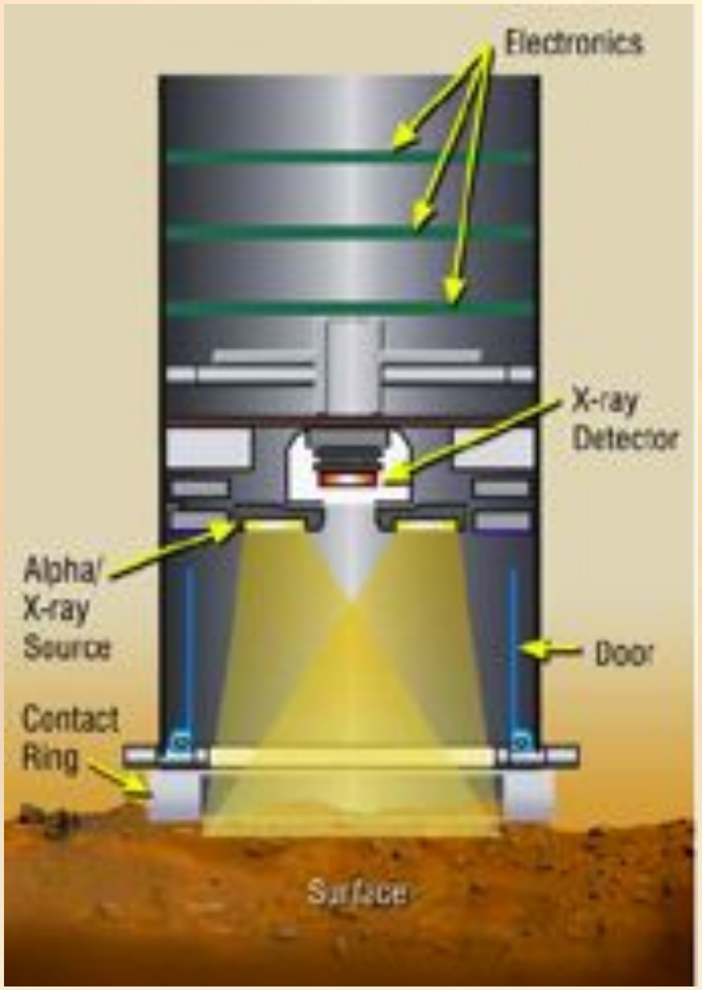


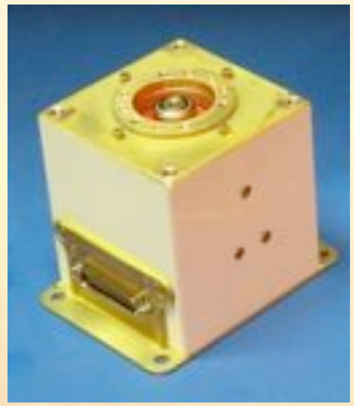
Mast Unit

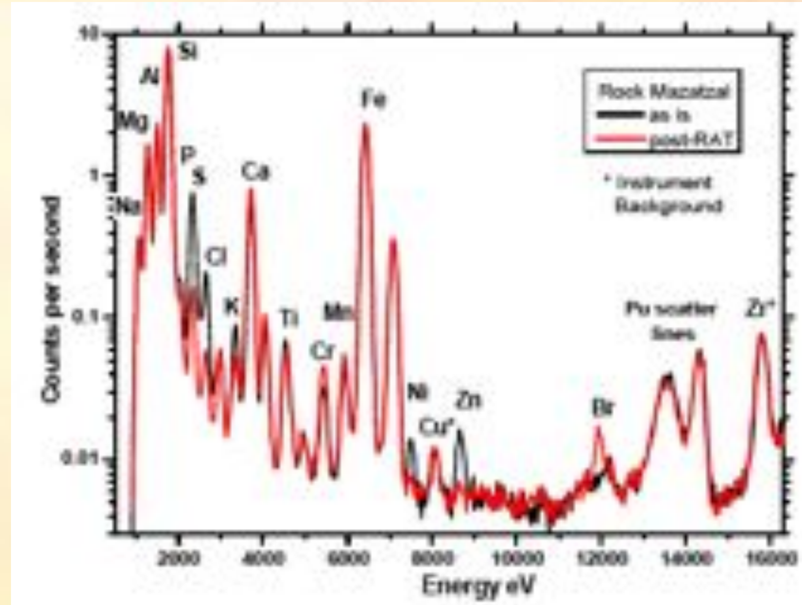
Body Unit

Alpha-Particle X-ray Spectrometer

Principal Investigator: Ralf Gellert
University of Guelph, Ontario, Canada
Canadian Space Agency







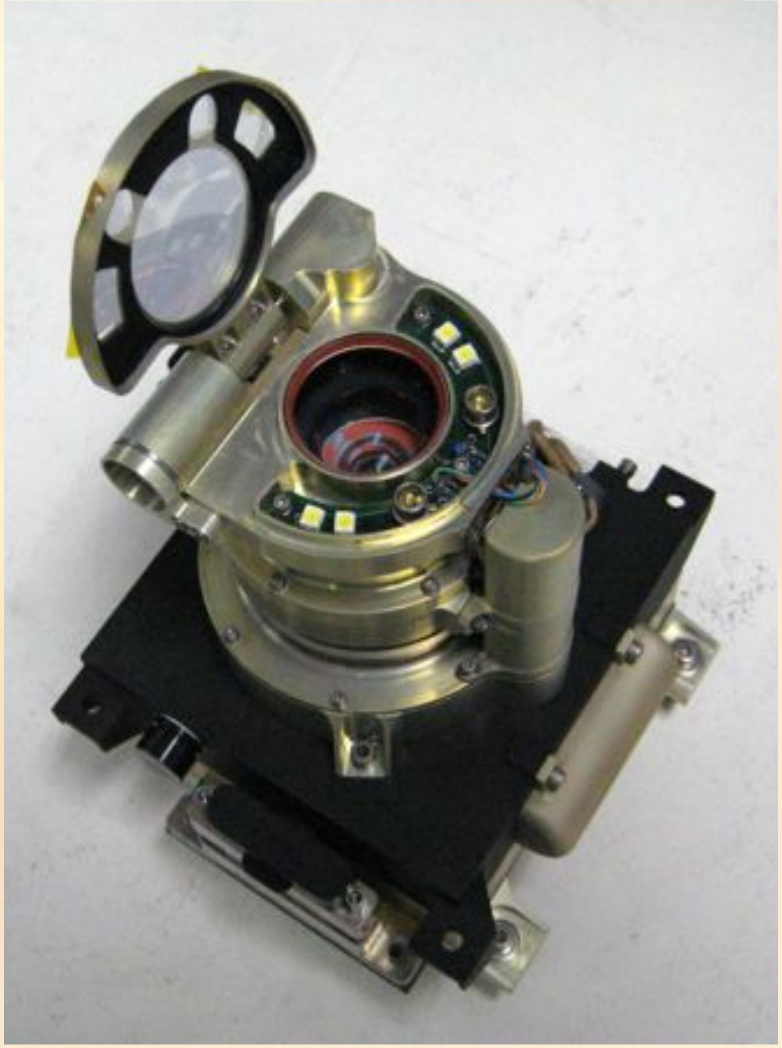
APXS determines the chemical composition of rocks, soils, and processed samples

- Combination of particle-induced X-ray emission and X-ray fluorescence using ^{244}Cm sources
- Rock-forming elements from Na to Br and beyond
- Useful for lateral / vertical variability, surface alteration, detection of salt-forming elements
- Factor ~3 increased sensitivity; better daytime performance compared with MER

Mars Hand-Lens Imager (MAHLI)

Principal Investigator: Kenneth Edgett

Malin Space Science Systems



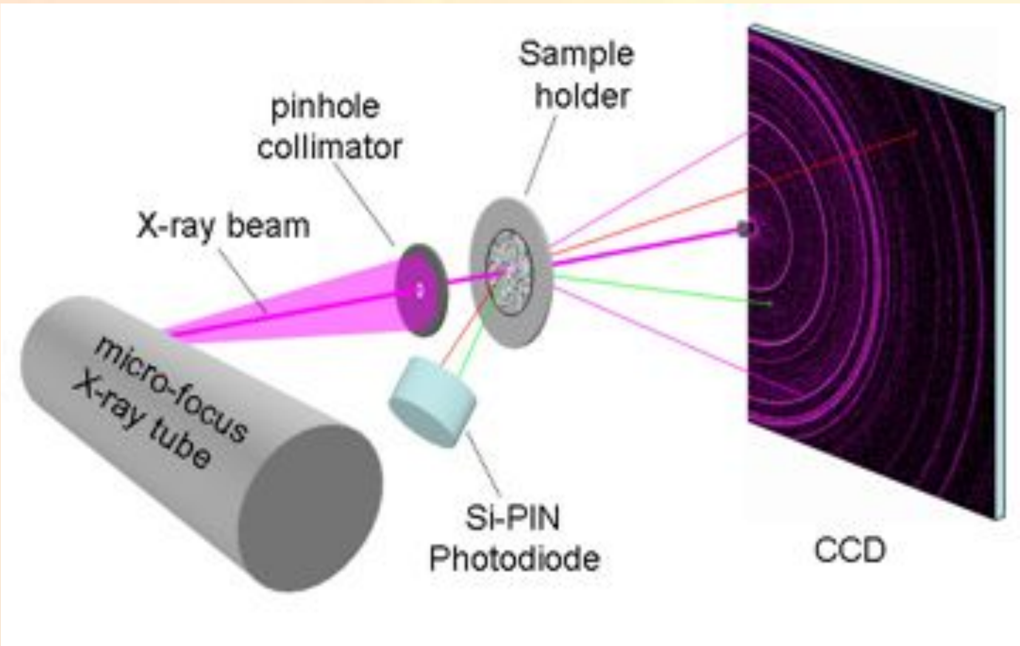
MAHLI characterizes the history and processes recorded in geologic materials

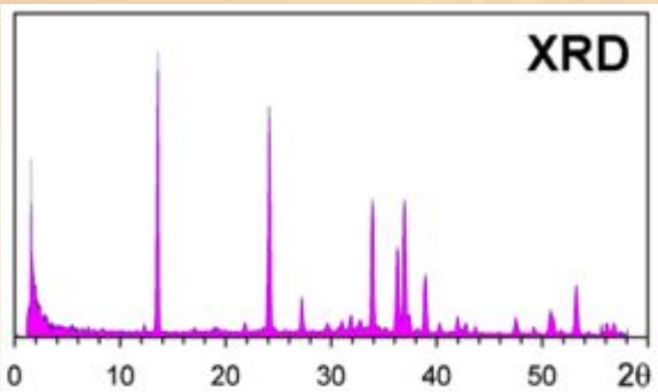
- Examines the structure and texture of rocks, fines, and frost/ice at micrometer to centimeter scale
- Returns 1600×1200-pixel color images; synthesizes best-focus images and depth-of-field range maps
- Wide range of spatial resolutions; can focus at infinity; highest spatial resolution possible is 14 μm/pixel
- White light and UV LEDs for controlled illumination, fluorescence

Chemistry and Mineralogy (CheMin)

Principal Investigator: David Blake

NASA Ames Research Center





CheMin derives definitive mineralogy

- X-ray diffraction (XRD); standard technique for laboratory analysis
- Identification and quantification of minerals in geologic materials (e.g., basalts, evaporites, soils)
- Will assess role of water in formation, deposition, alteration
- Accuracy of ±15% in concentration for major mineral components

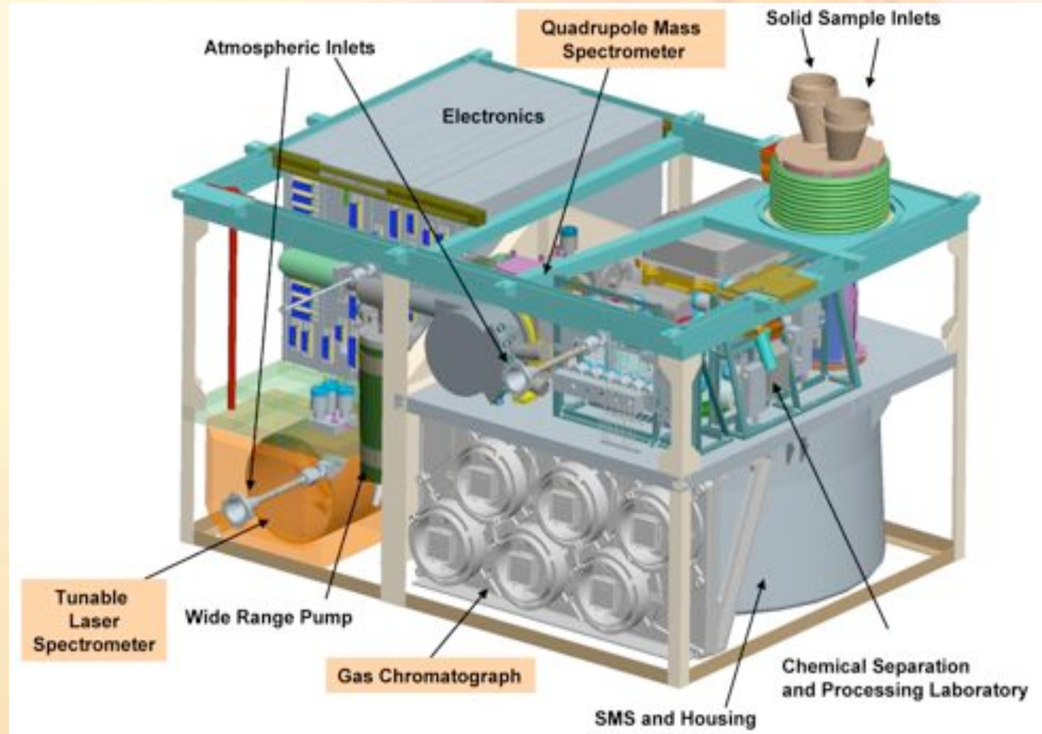
Sample Analysis at Mars

Principal Investigator: Paul Mahaffy

NASA Goddard Space Flight Center

SAM Suite Instruments

Quadrupole Mass Spectrometer (QMS)
Gas Chromatograph (GC)
Tunable Laser Spectrometer (TLS)



- Search for organic compounds of biotic and prebiotic relevance, including methane, and explore sources and destruction paths for carbon compounds
- Reveal chemical state of other light elements important for life as we know it on Earth
- Study the habitability of Mars by measuring oxidants such as hydrogen peroxide
- Investigate atmospheric and climate evolution through isotope measurements of noble gases and light elements

- **QMS:** molecular and isotopic composition in the 2-535 Dalton mass range for atmospheric and evolved gas samples
- **GC:** resolves complex mixtures of organics into separate components
- **TLS:** abundance of CH_4, CO_2, and H_2O; precision (<10 per mil) isotopic composition of CH_4, CO_2

Dynamic Albedo of Neutrons (DAN)

Principal Investigator: Igor Mitrofanov

Space Research Institute (IKI), Russia

Thermal & Epithermal Neutron Detectors

Pulsing Neutron Generator

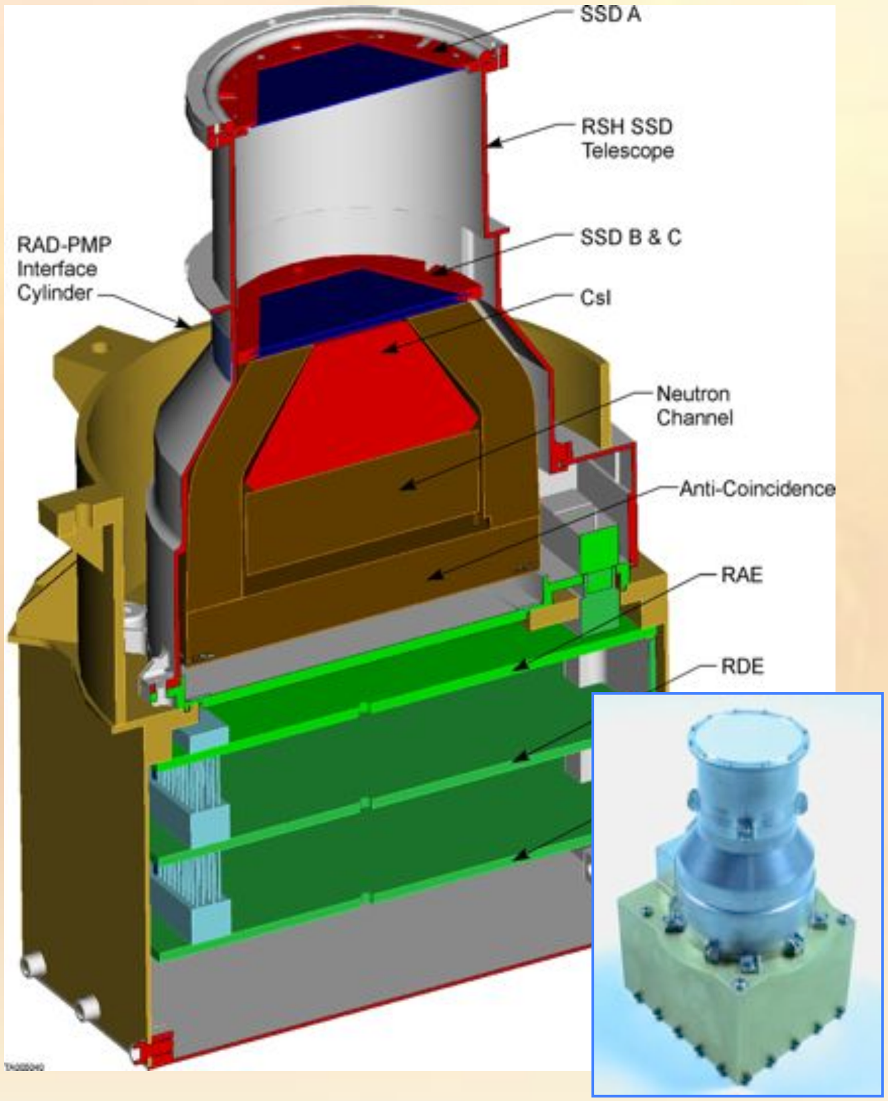
DAN measures the abundance of H- and OH-bearing materials (e.g., adsorbed water or hydrated minerals)

- Active neutron spectroscopy with pulsed 14 MeV neutrons or passive
- Creates profiles along traverses and with depth to 1 m
- Resolves time decay curve and energy spectrum of returned pulse
- Accuracy of 0.1-1% by weight of water (or water-equivalent hydrogen) depending on observation type

Radiation Assessment Detector

Principal Investigator: Donald M. Hassler

Southwest Research Institute



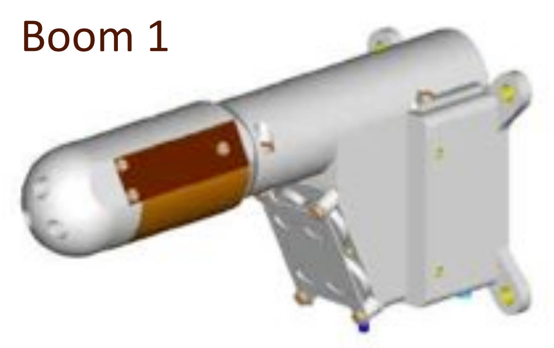
RAD characterizes the radiation environment on the surface of Mars

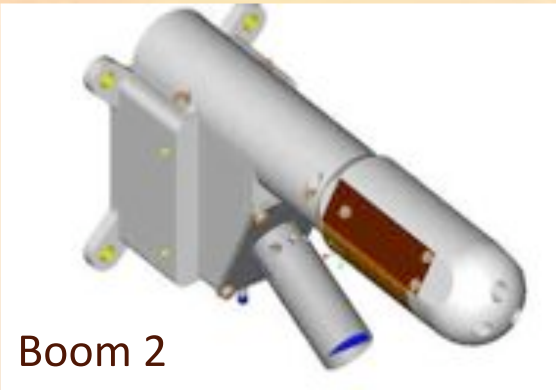
- Measures galactic cosmic ray and solar energetic particle radiation, including secondary neutrons and other particles created in the atmosphere and regolith
- Determines human dose rate, validates transmission/transport codes, assesses hazard to life, studies the chemical and isotopic effects on Mars' surface and atmosphere
- Solid state detector telescope and CsI calorimeter. Zenith pointed with 65° FOV
- Detects energetic charged particles (Z=1-26), neutrons, gamma-rays, and electrons

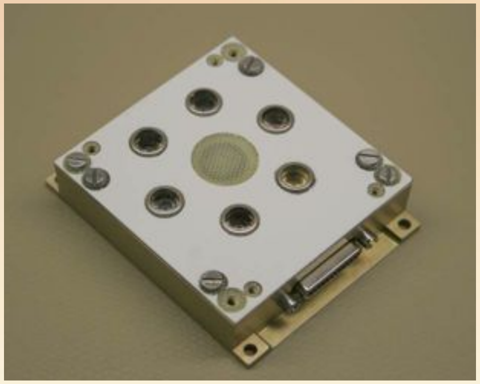
Rover Environmental Monitoring Station (REMS)

Principal Investigator: Javier Gómez-Elvira

Centro de Astrobiología (CAB), Spain







UV Sensor

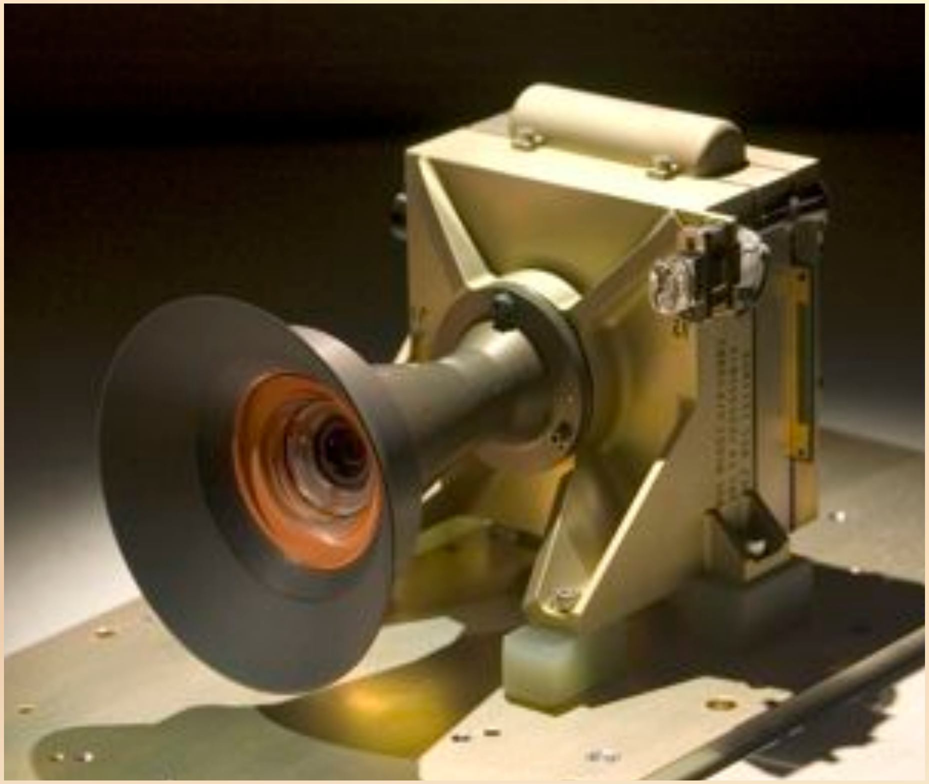
REMS measures the meteorological and UV radiation environments

- Two 3-D wind sensors
- Air temperature sensors
- IR ground temperature sensors
- Pressure sensor
- Relative humidity sensor
- UV radiation detector (200 to 400 nm)
- 1-Hz sampling for 5 minutes each hour

Mars Descent Imager (MARDI)

Principal Investigator: Michael Malin

Malin Space Science Systems



MARDI provides detailed imagery of the MSL landing region

- Acquires images during powered descent ranging from 1.5 m/pixel to 1 mm/pixel at the surface. Ties post-landing surface images to pre-landing orbital images.
- Bayer pattern filter for natural color
- High-definition, video-like data acquisition (1600×1200 pixels, 4.5 frames per second)
- Large internal storage: 256 MByte SRAM, 8 GByte flash

MSL Science Theme Groups

Organic Geochemistry and Biosignatures

- Chemical and isotopic composition of organic compounds in solid and gas samples; other elements/compounds of relevance to habitability
- Textural, chemical, mineralogical and isotopic biosignatures

Inorganic Geochemistry and Mineralogy

- Chemical, mineralogical, and isotopic composition of rocks and soils

Geology

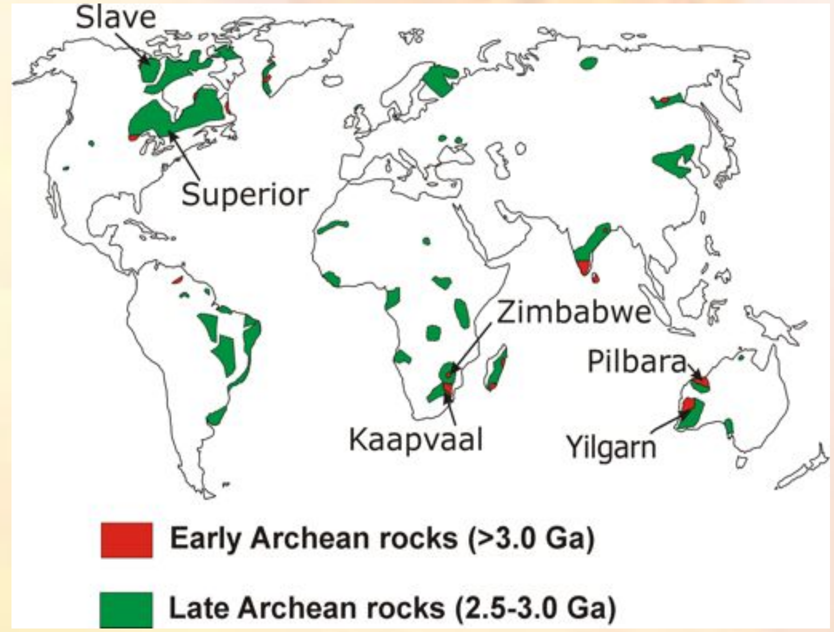
- Bedrock geology, geomorphology, and stratigraphy
- Rock and soil textures
- Rock and soil physical properties

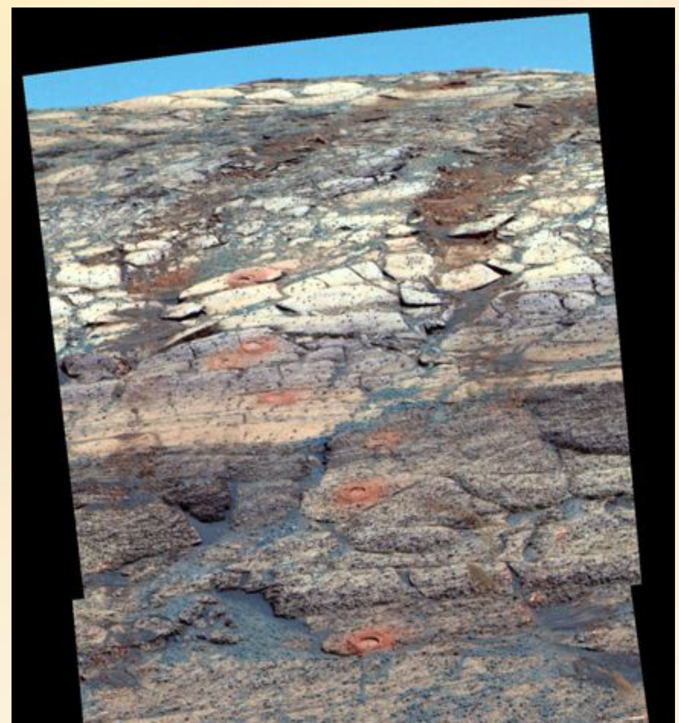
Atmosphere and Environment

- Meteorology and climate
- Distribution and dynamics of water and dust
- Solar, UV, and high-energy radiation
- Atmospheric chemical and isotopic composition

Ancient Geologic Records

- Ancient Earth is mostly gone, but Mars' geologic record goes back to the planet's earliest history.
- Even if old rocks can be found, the proxies for environmental conditions and life must be *preserved*.
- MSL seeks to quantitatively assess the habitability of early Mars through investigations of environmental conditions and biosignatures.
- Climatologists and paleontologists search for rock minerals and textures, chemical isotopes, fossilized bodies, traces of activities, biological molecules, byproducts, and other biosignatures.
- Most biological evidence is found in fine-grained sediments (like clay or silt) or evaporites formed in ancient lakes and oceans and deposited quickly.



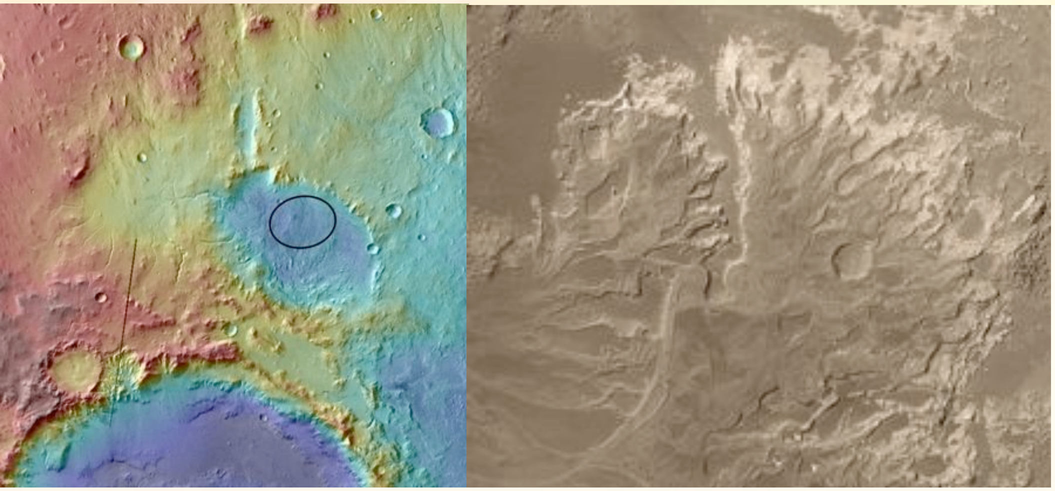


Landing Site Selection

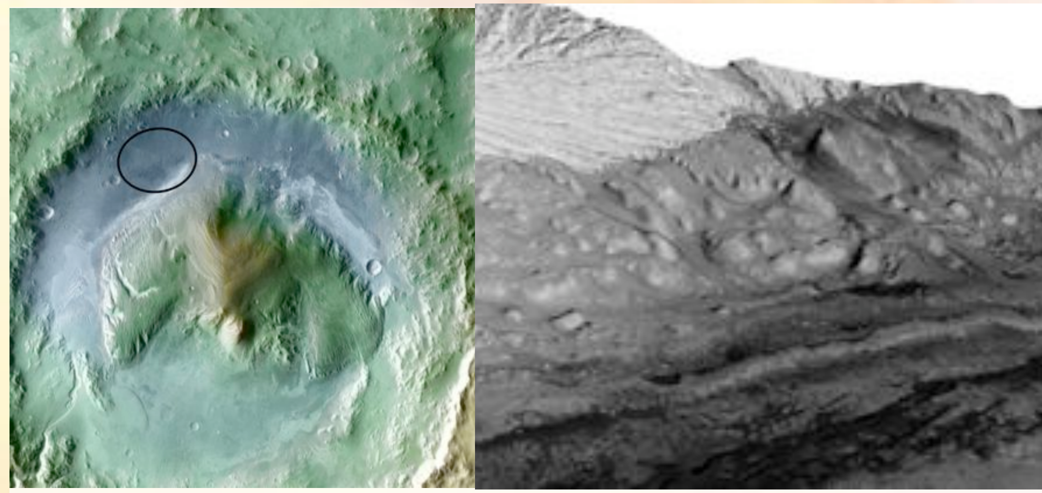
- An ideal landing site candidate would have strong evidence suggestive of a habitable environment that is accessible to and interpretable by MSL and its payload.
- To increase the chance of scientific success given our limited understanding, landing sites also should have a diversity of geological or mineralogical features and an understandable regional context.
  - Previous orbiters and landers have identified environments where water has played a role in mineral precipitation and/or landscape evolution.
  - Traces of past life on Earth are often preserved in fine-grained sediments (like clay or silt) or evaporites left by ancient lakes and oceans that were deposited rapidly and then undisturbed.
- Candidate sites identified in the data from landers and orbiters currently at Mars are evaluated in a series of open workshops.

Previous and Future Mars Landing Sites

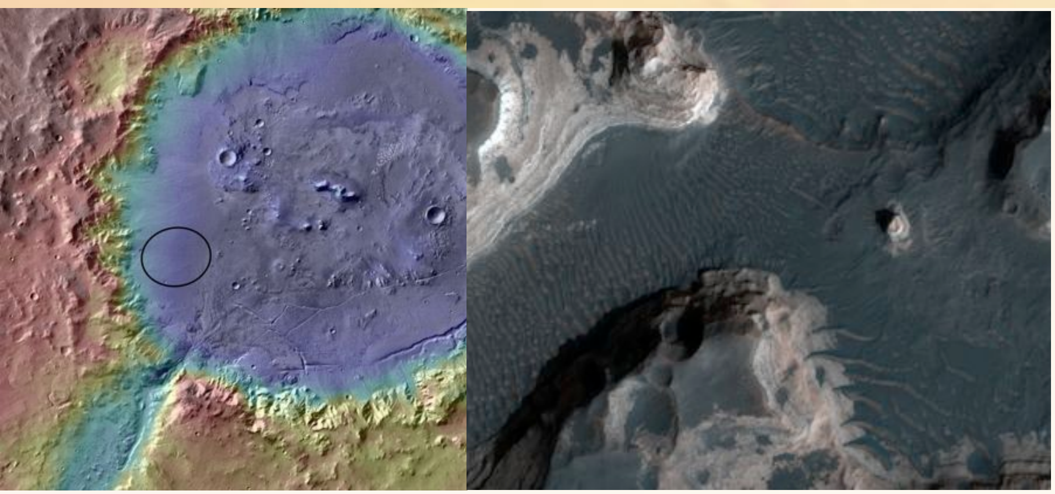
Final Candidate MSL Landing Sites



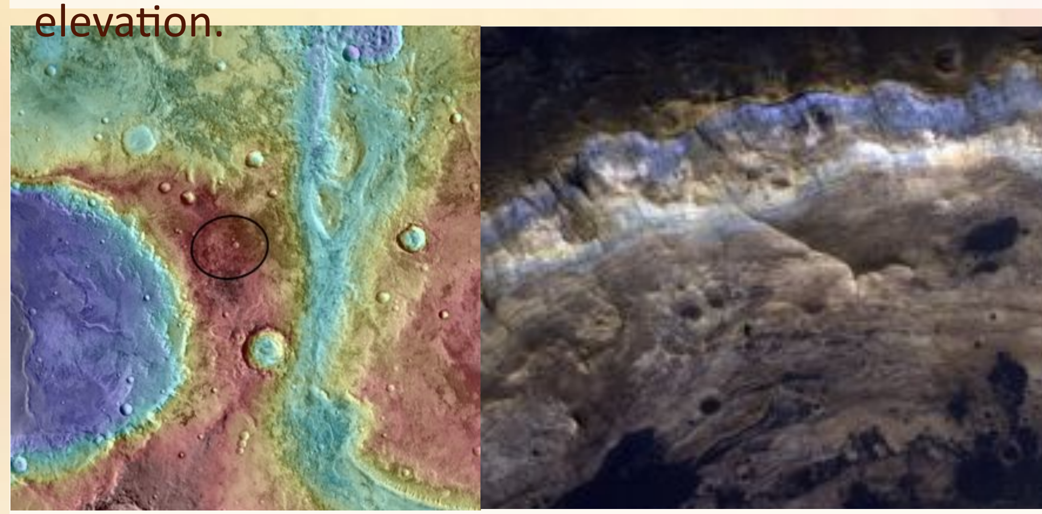
Eberswalde Crater (24°S, 327°E, -1.5 km) contains a clay-bearing delta formed when an ancient river deposited sediment, possibly into a lake.



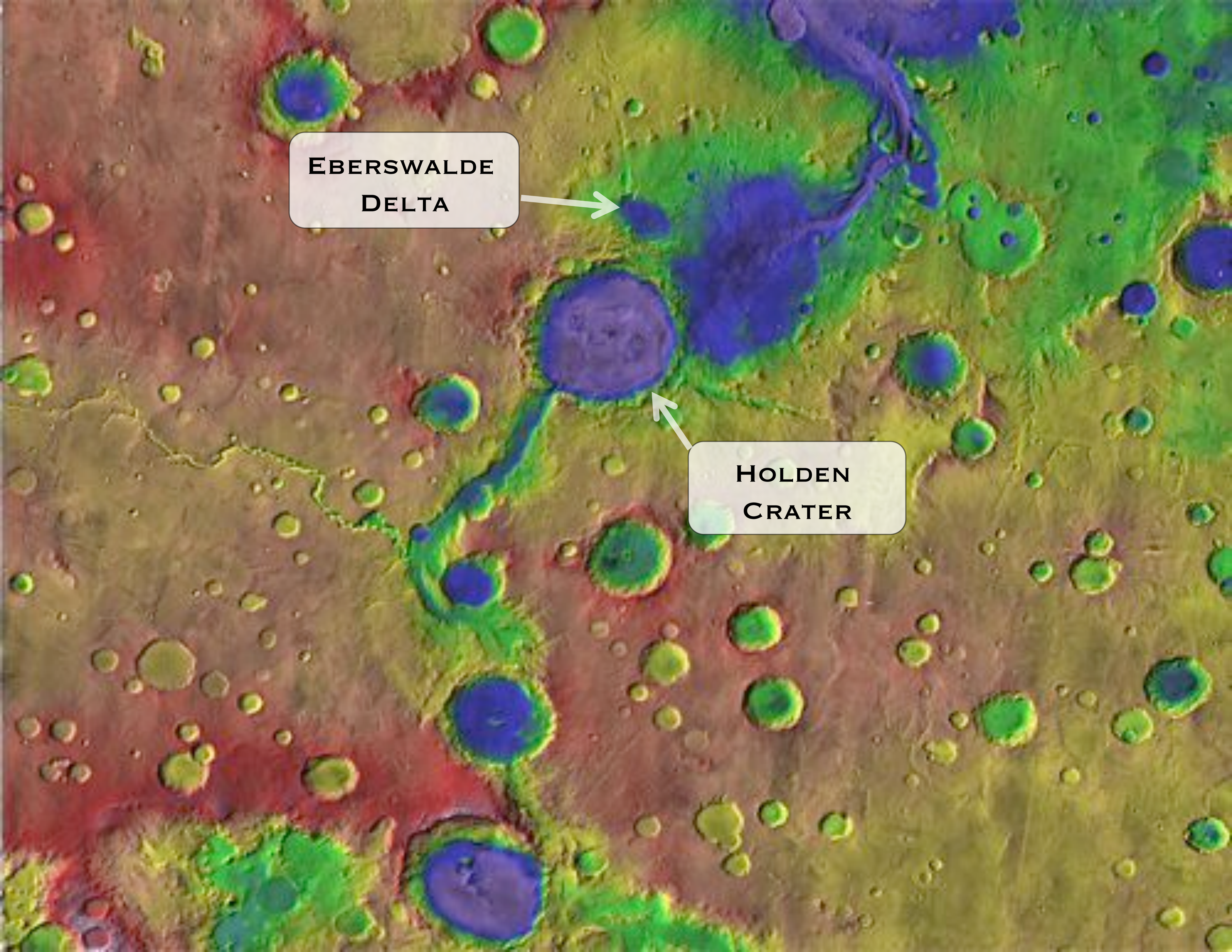
Gale Crater (4.5°S, 137°E, -4.5 km) contains a 5-km sequence of layers that vary from clay-rich materials near the bottom to sulfates at higher elevation.



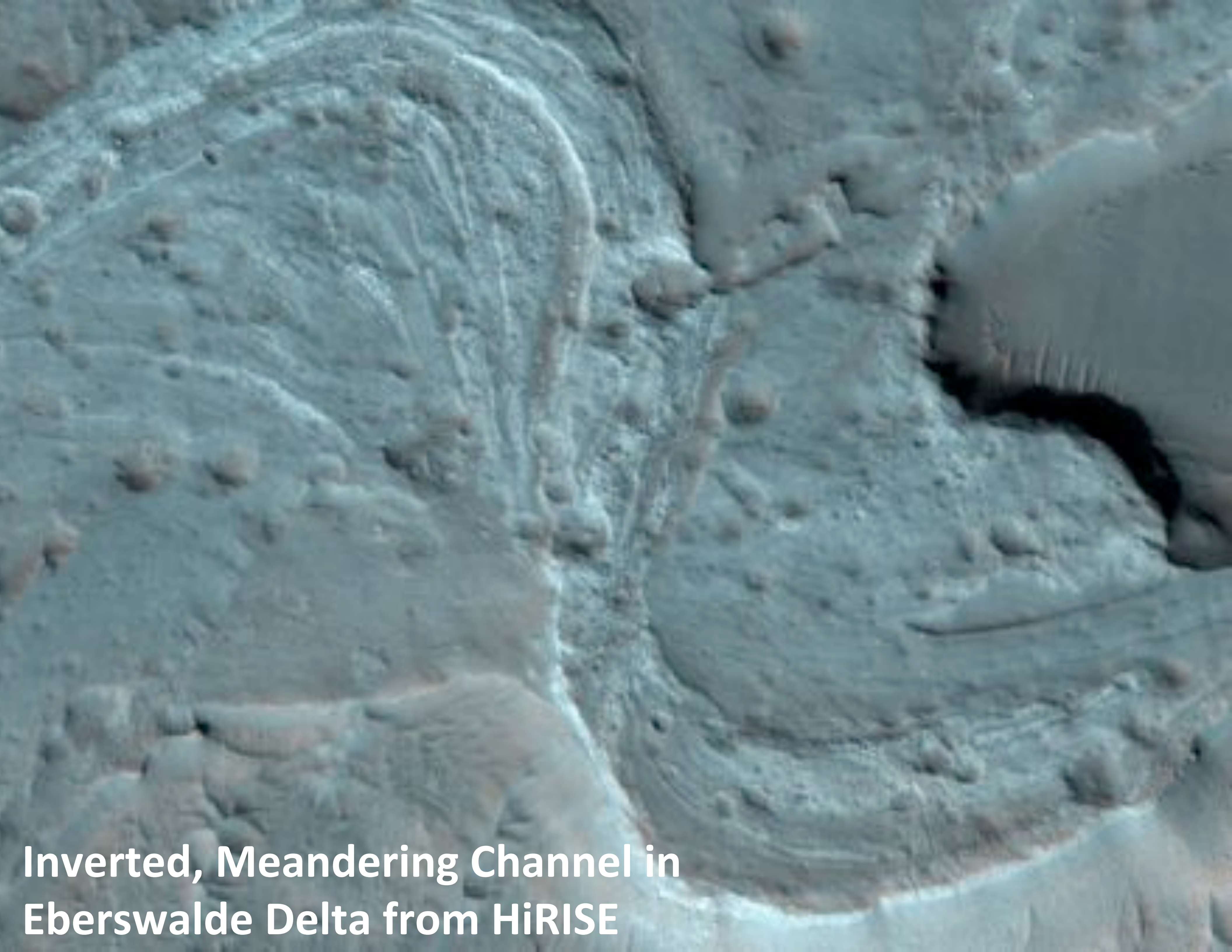
Holden Crater (26°S, 325°E, -1.9 km) has alluvial fans, flood deposits, possible lake beds, and clay-rich sediment.



Mawrth Vallis (24°N, 341°E, -2.2 km) exposes layers within Mars' surface with differing mineralogy, including at least two kinds of clays.

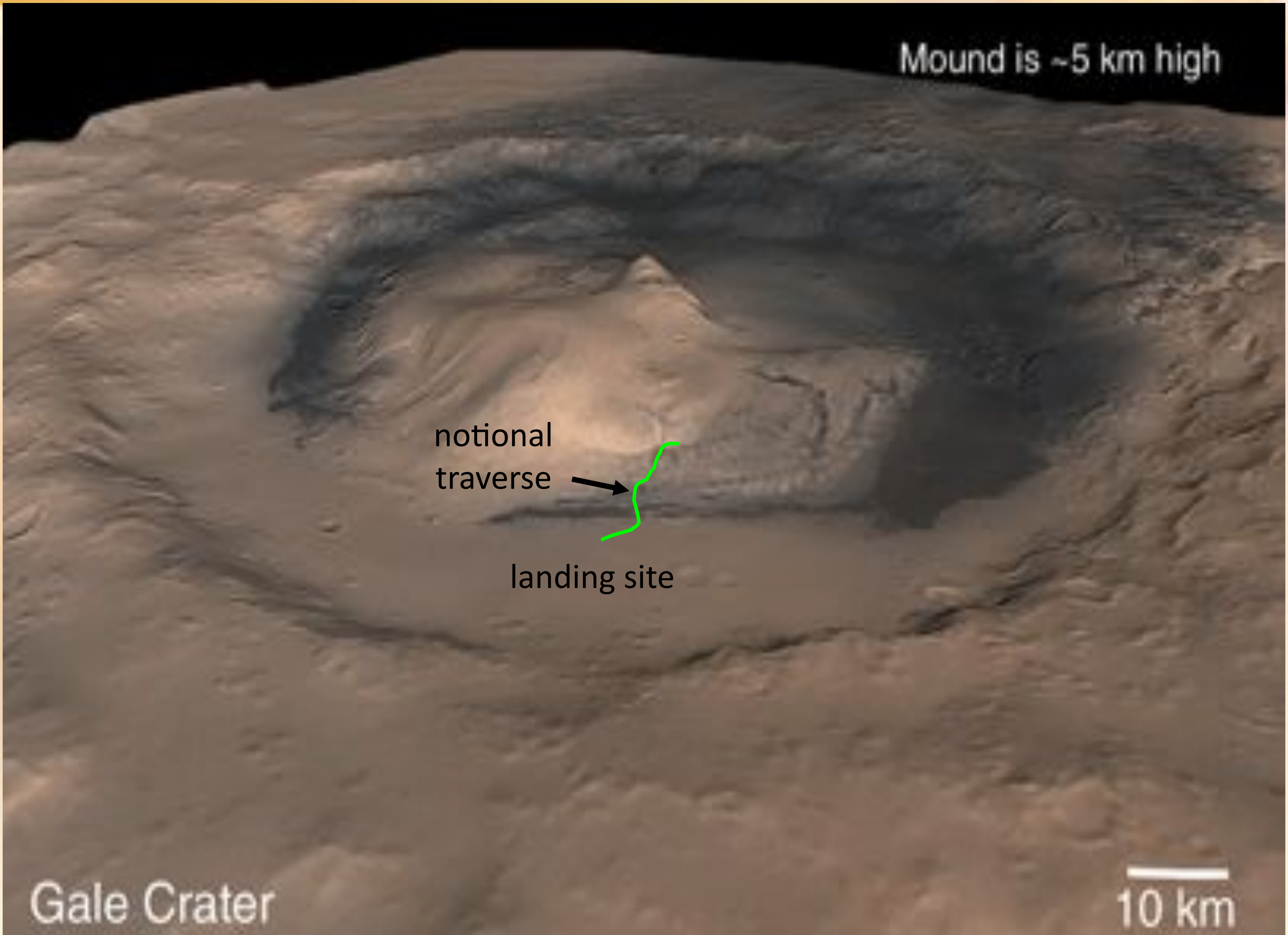

EBERSWALDE DELTA
HOLDEN CRATER

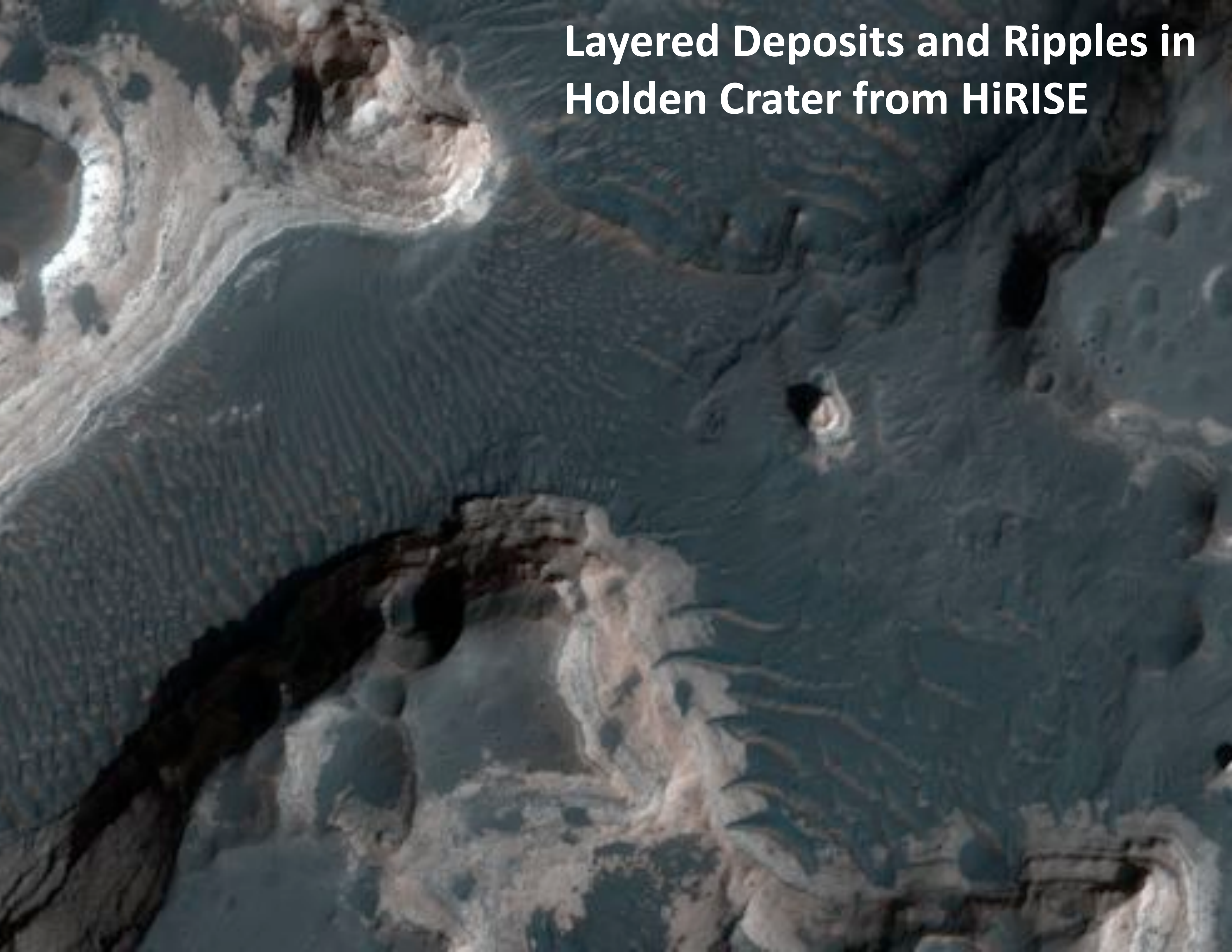
Eberswalde Delta from MOC


Inverted, Meandering Channel in
Eberswalde Delta from HiRISE


Light-Toned Material in Mawrth Vallis from HiRISE

Gale Crater


Mound is ~5 km high
notional traverse
landing site
Gale Crater
10 km


Layered Deposits and Ripples in
Holden Crater from HiRISE

JPL Rover Family Portrait

MSL and its Human Managers

MSL Descent Stage

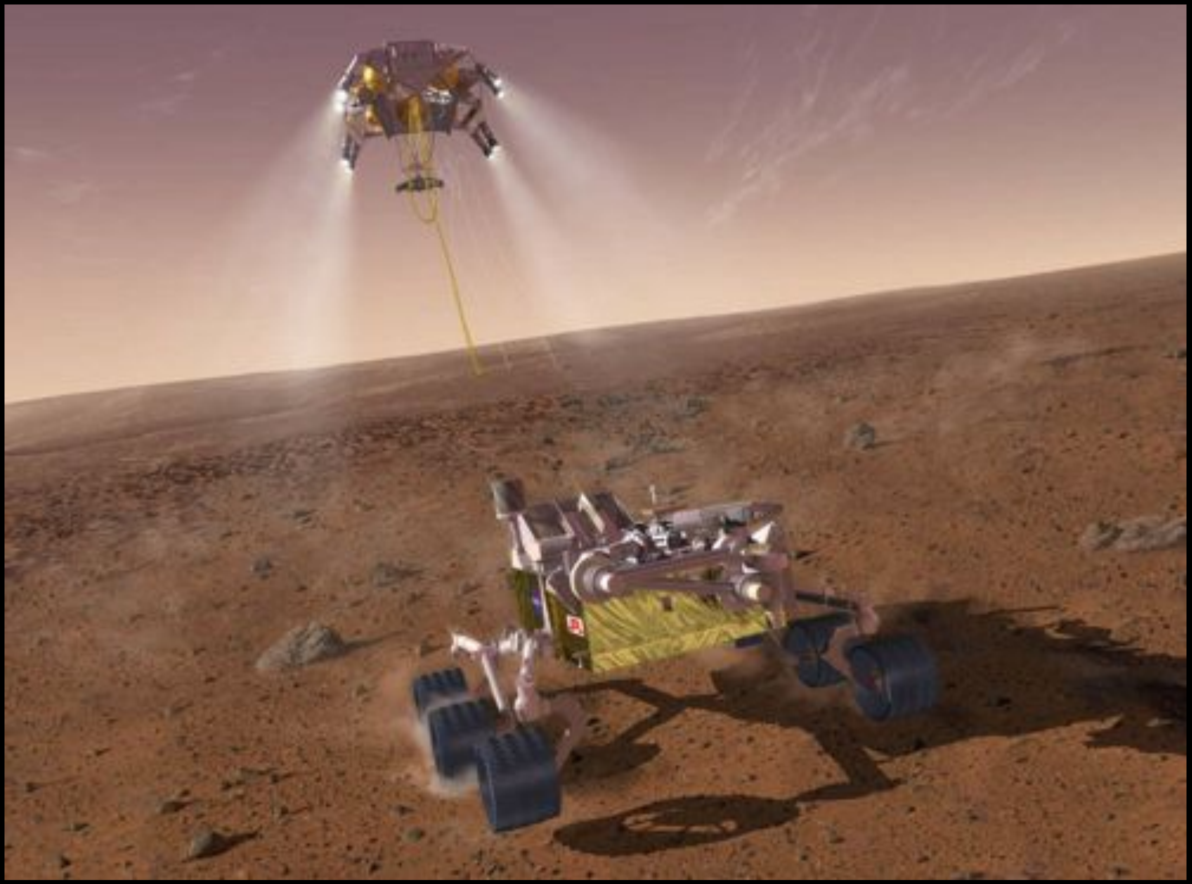
Rover Body and Wheels

Launch/Cruise Environmental Test

First Spacecraft Integration

This document has been reviewed for export control and it does NOT contain controlled technical data.

October 2011



August 2012

Stay Tuned!

Possible MEX-MSL Collaborations

- Landing Site Scientific Studies (ongoing)
  - HRSC studies of geologic context and OMEGA mineralogy
- Entry, Descent, and Landing Support
  - Atmospheric temperature/dust profiles in near real time during MSL approach
- Context for In-Situ Atmospheric CH_4
  - MSL-SAM will take periodic measurements of CH_4 to assess abundance, carbon isotopic ratio, and seasonal variation. MEX-PFS can provide planetary context and a multi-annual record.
- Traverse Planning and Hazard Avoidance
  - HRSC and OMEGA data can help the MSL science team identify traverse targets and traverse paths that avoid obstacles, both before MSL arrival and during MSL operations
- Simultaneous Atmospheric Measurements (Temperatures and Water Vapor)