The Mars Science Laboratory "Curiosity – The Mission and Parts Lessons Learned"

Presentation to European Space Components Conference (ESCCON)

Richard Kemski

MSL Mission Assurance Manager

Jet Propulsion Laboratory

California Institute of Technology

Mission and Rover Overview

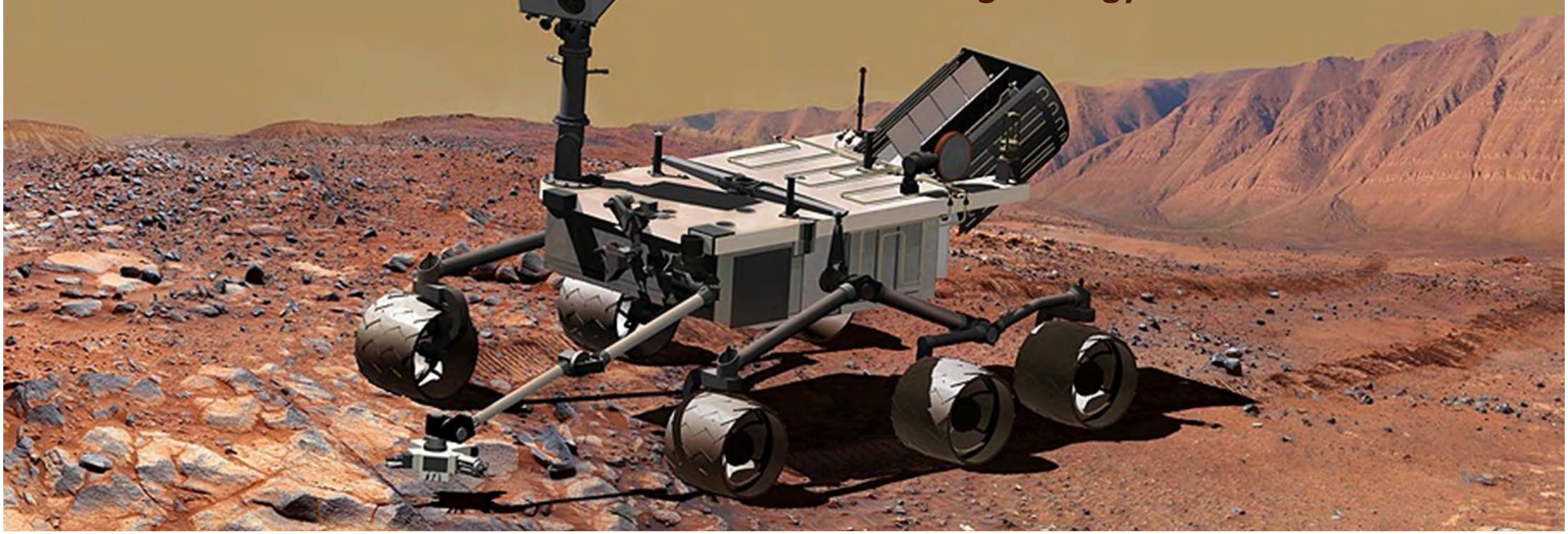
Curiosity’s Capabilities

A Robotic Field Geologist

- Long life, ability to traverse many miles over rocky terrain
- Landscape and hand-lens imaging
- Ability to survey composition of bedrock and regolith

A Mobile Geochemical and Environmental Laboratory

- Ability to acquire and process dozens of rock and soil samples
- Instruments that analyze samples for chemistry, mineralogy, and organics
- Sensors to monitor water, weather, and natural high-energy radiation



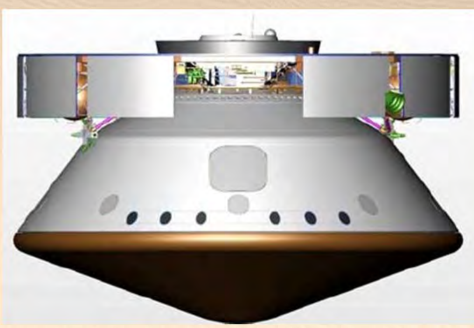
Curiosity's Science Goals

Curiosity's primary scientific goal is to explore and quantitatively assess a local region on Mars' surface as a potential habitat for life, past or present

Objectives include:

- Assessing the biological potential of the site by investigating any organic and inorganic compounds and the processes that might preserve them
- Characterizing geology and geochemistry, including chemical, mineralogical, and isotopic composition, and geological processes
- Investigating the role of water, atmospheric evolution, and modern weather/climate
- Characterizing the spectrum of surface radiation

Mission Overview



CRUISE/APPROACH

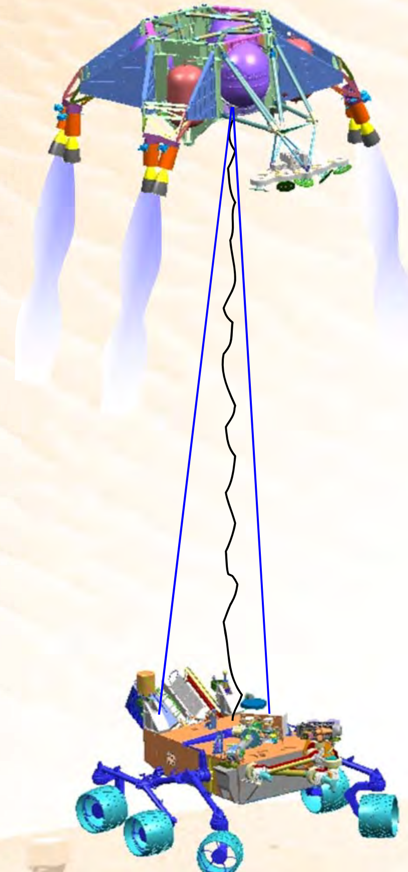
- 8 to 9-month cruise
- Arrive August 6-20, 2012

LAUNCH

- Window is Nov. 25 to Dec. 18, 2011
- Atlas V (541)

ENTRY, DESCENT, LANDING

- Guided entry and powered "sky crane" descent
- 20 × 25-km landing ellipse
- Access to landing sites ±30° latitude, <0 km elevation
- 900-kg rover

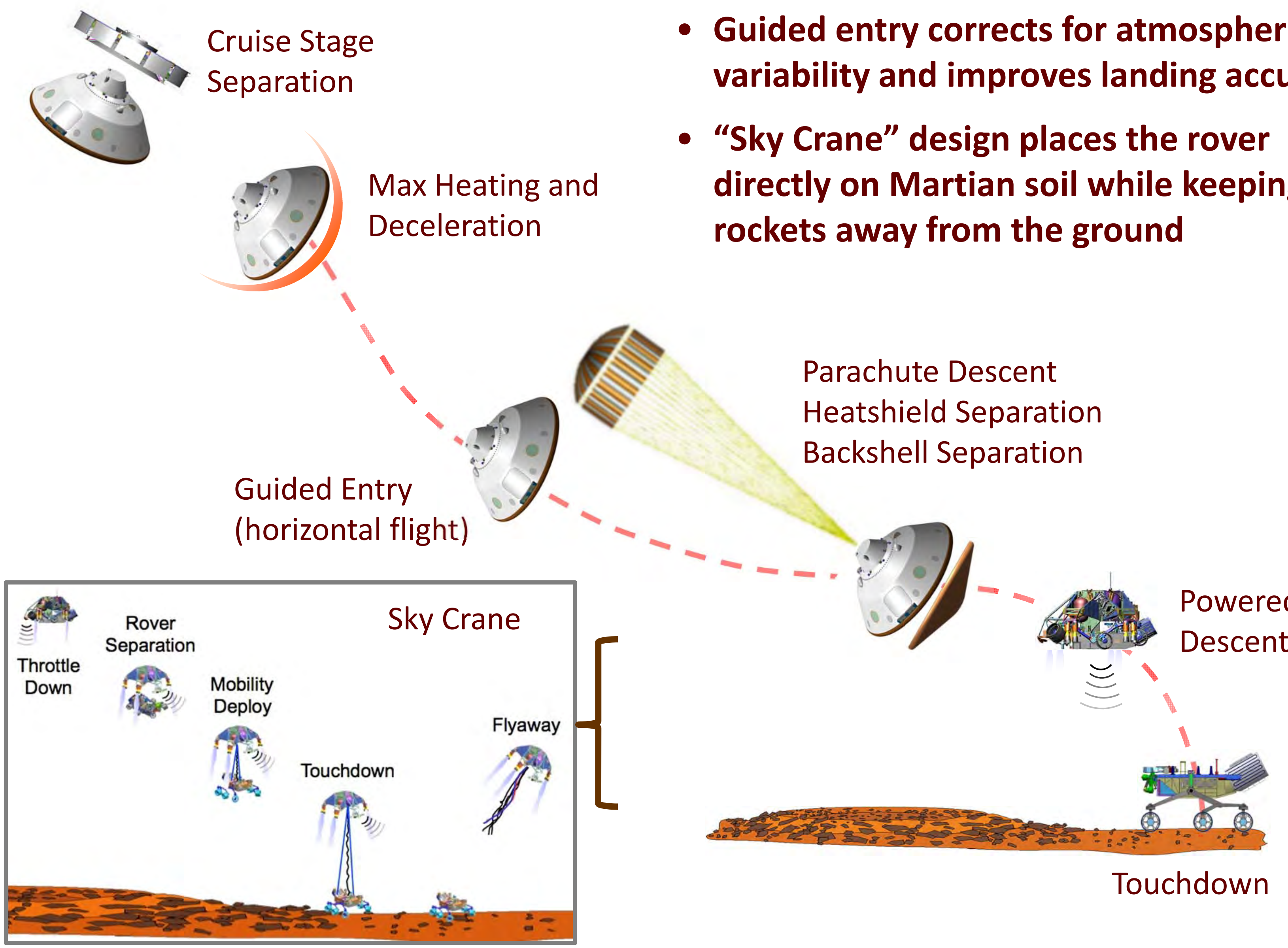


SURFACE MISSION

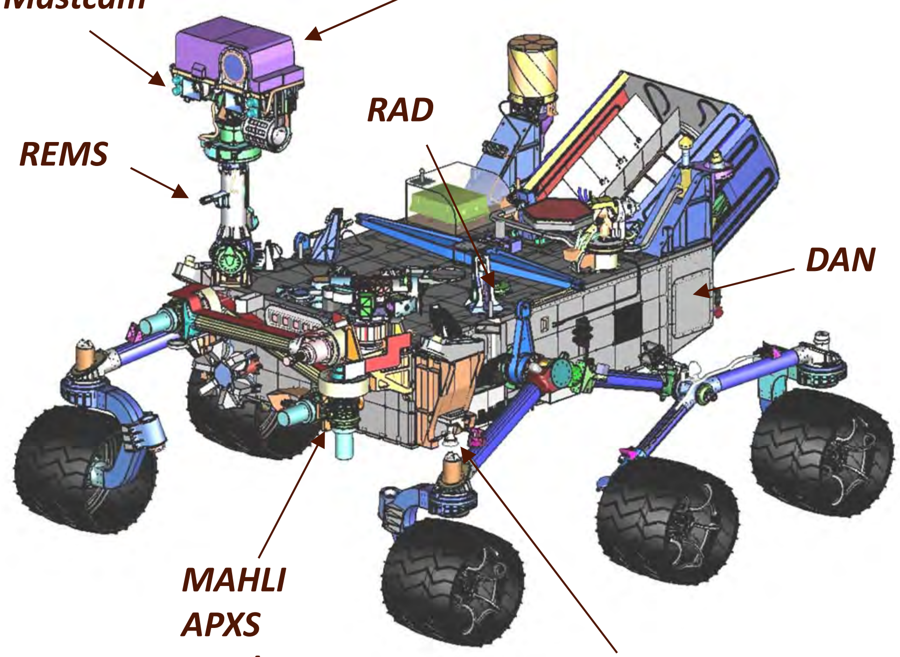
- Prime mission is one Mars year (687 days)
- Latitude-independent and long-lived power source
- Ability to drive out of landing ellipse
- 84 kg of science payload
- Direct (uplink) and relayed (downlink) communication
- Fast CPU and large data storage

MSL Entry, Descent, and Landing

- **Guided entry corrects for atmospheric variability and improves landing accuracy**
- **"Sky Crane" design places the rover directly on Martian soil while keeping the rockets away from the ground**



MSL Science Payload



Rover Width:	**2.8 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

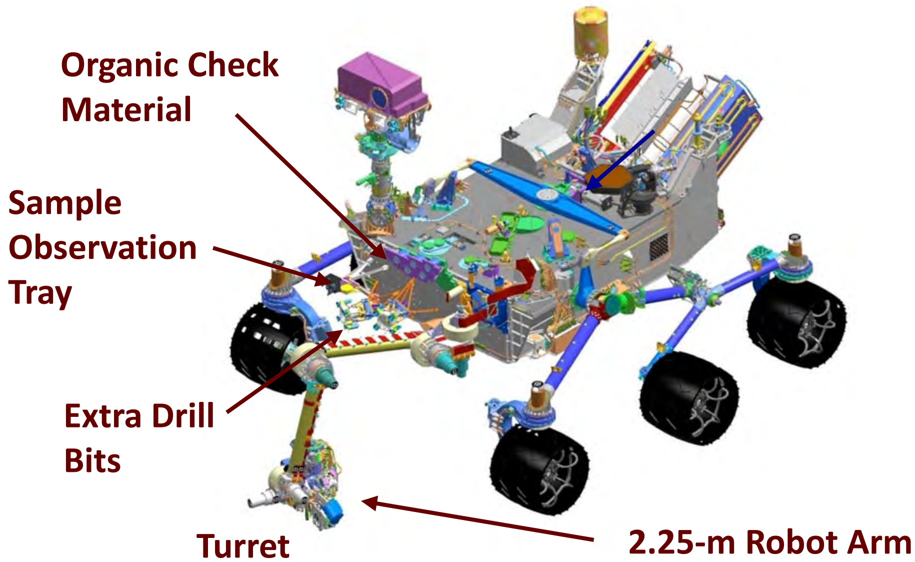
MARDI (M. Malin, MSSS) - Descent imaging

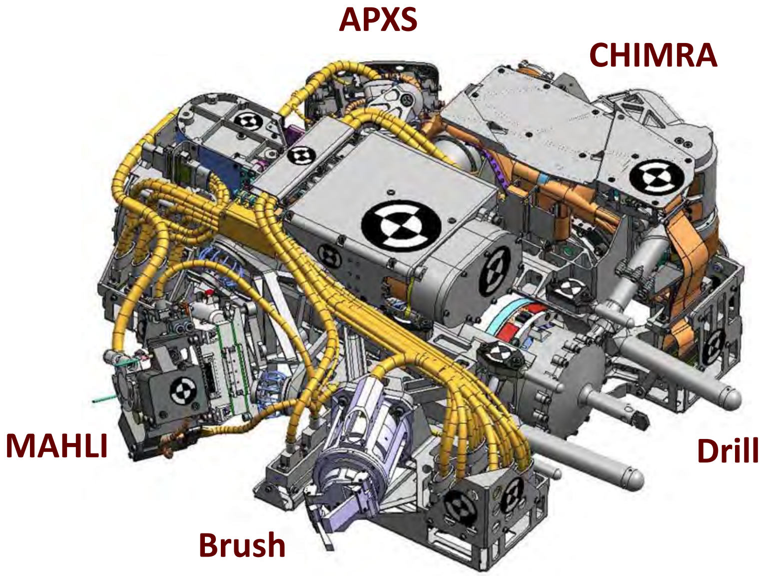
REMS (J. Gómez-Elvira, CAB, Spain) - Meteorology / UV

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

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

Sampling System





- Cleans rock surfaces with a brush
- Places and holds the APXS and MAHLI instruments
- Acquires samples of rock or soil with a powdering drill or scoop
- Sieves the samples (to 150 µm or 1 mm) and delivers them to instruments or an observation tray
- Exchanges spare drill bits

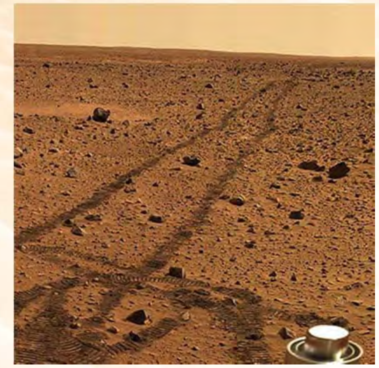
Science Operations

1. REMOTE SENSING

- Landscape imaging
- Sampling of rock and soil chemistry

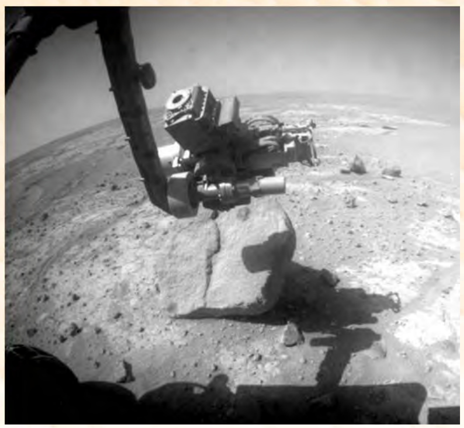
2. TRAVERSE/APPROACH

- Driving up to 100 m per sol
- Imaging and profiling chemistry along the drive
- Locating sampling targets



3. CONTACT SCIENCE

- Removal of surface dust
- Chemical and hand-lens observations of a specific target



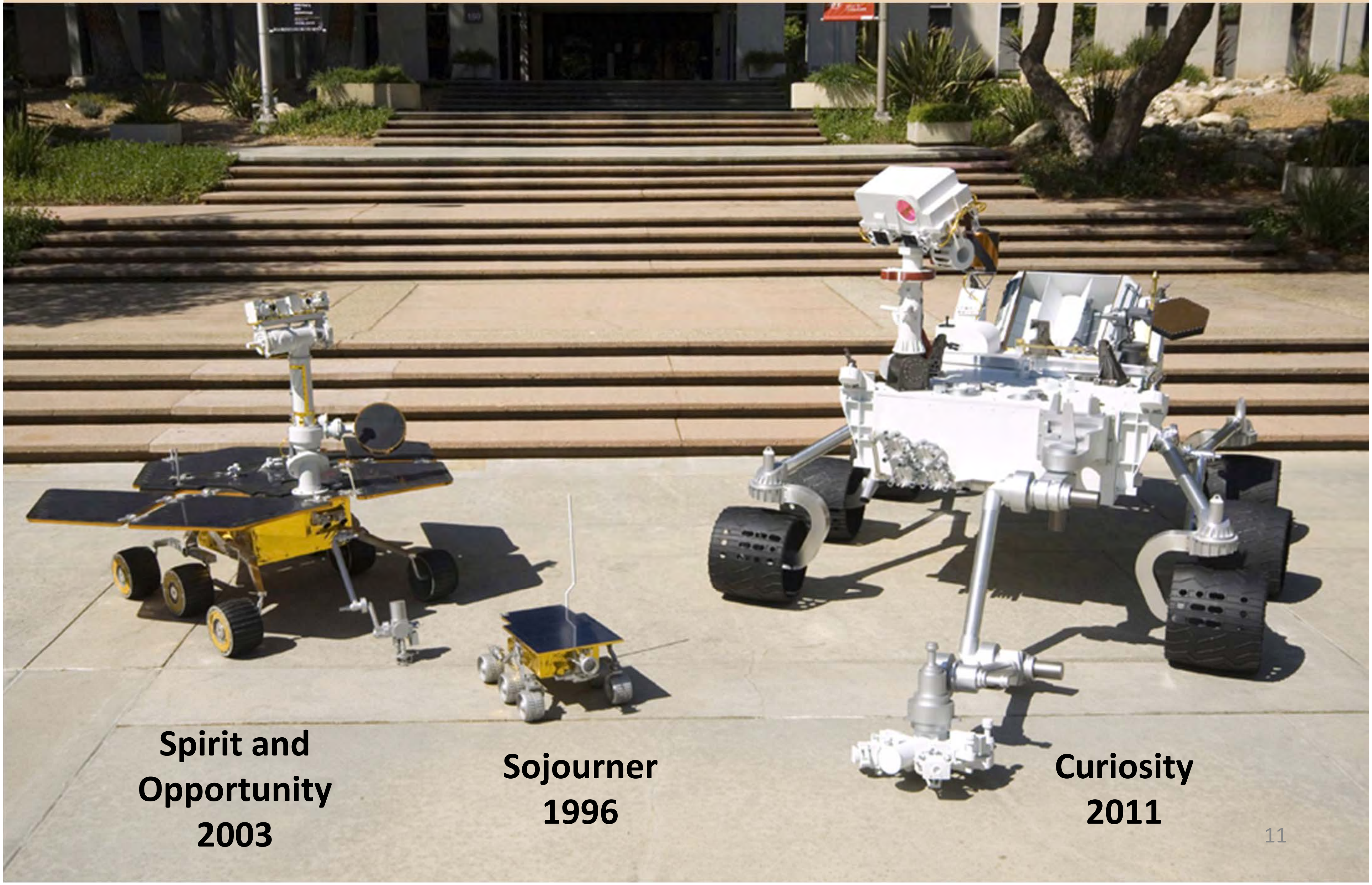
4. SAMPLE ACQUISITION/ANALYSIS

- Drilling, processing, and delivering sample material to the rover's lab instruments
- Analyzing for mineralogy, organics, elemental and isotopic chemistry

Each activity may require multiple sols. Results are reviewed on Earth before moving on to the next activity. Weather and radiation monitoring occur on all sols.

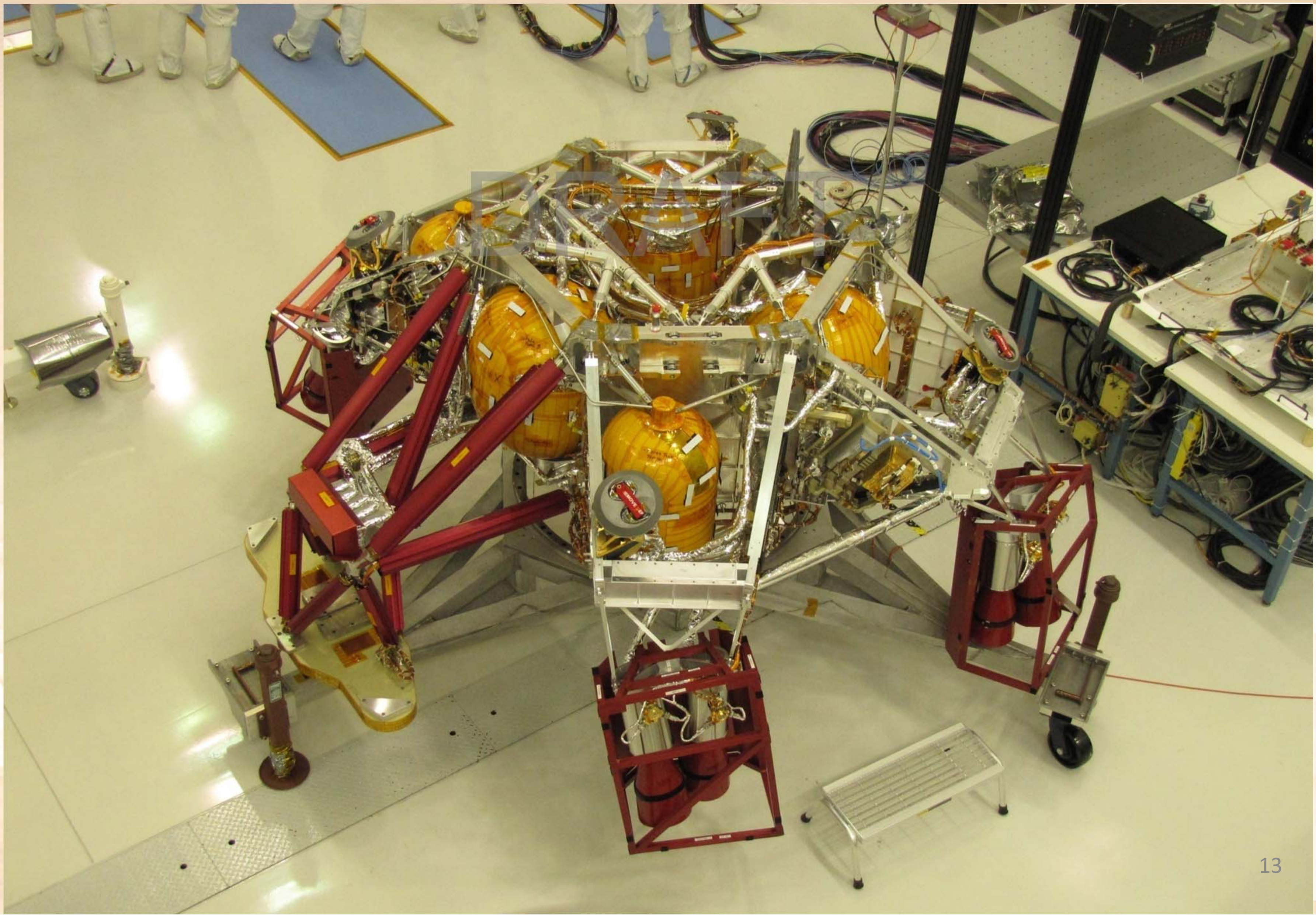
Rover and Spacecraft Pictures

Rover Family Portrait

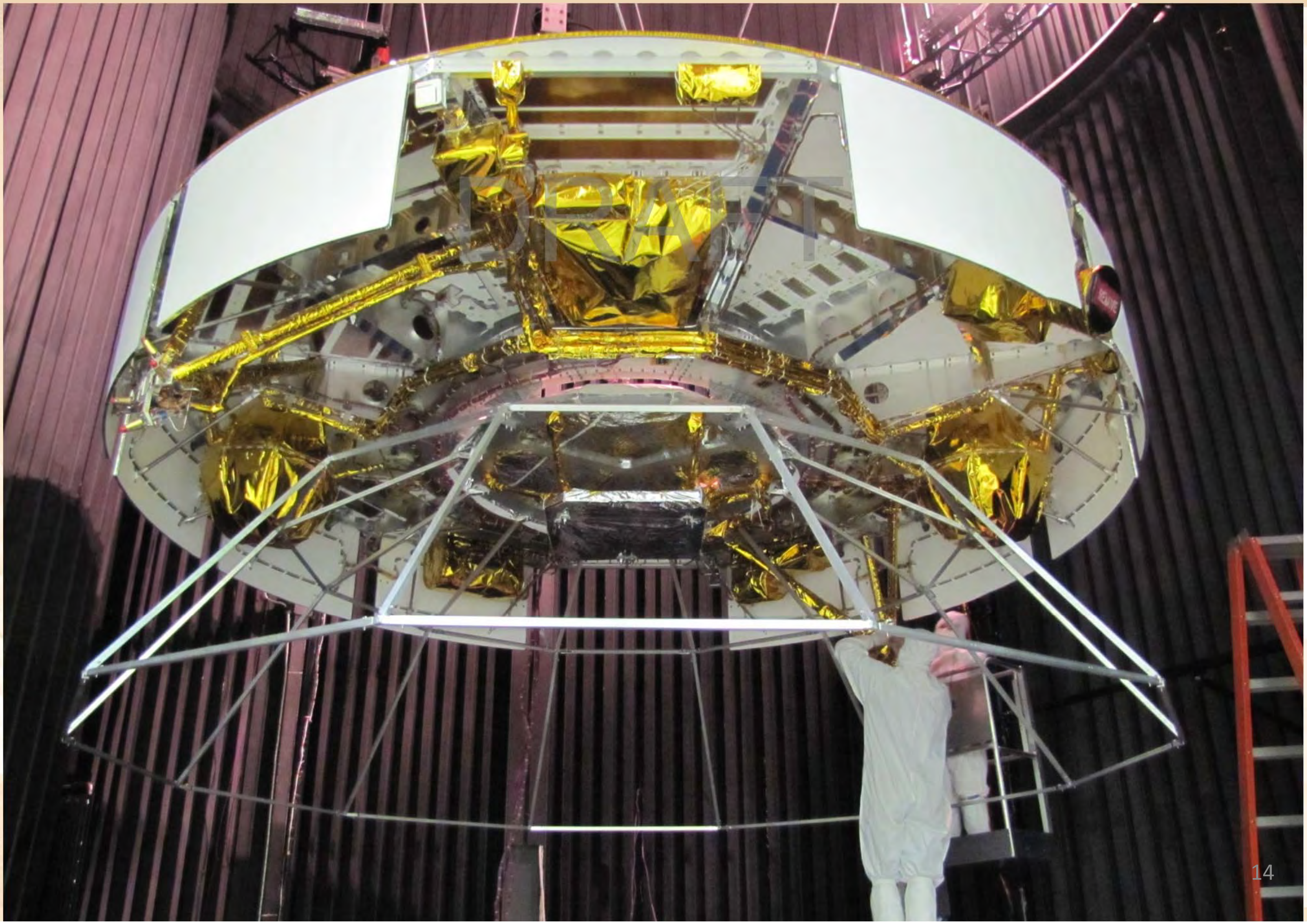


Rover Driving Test

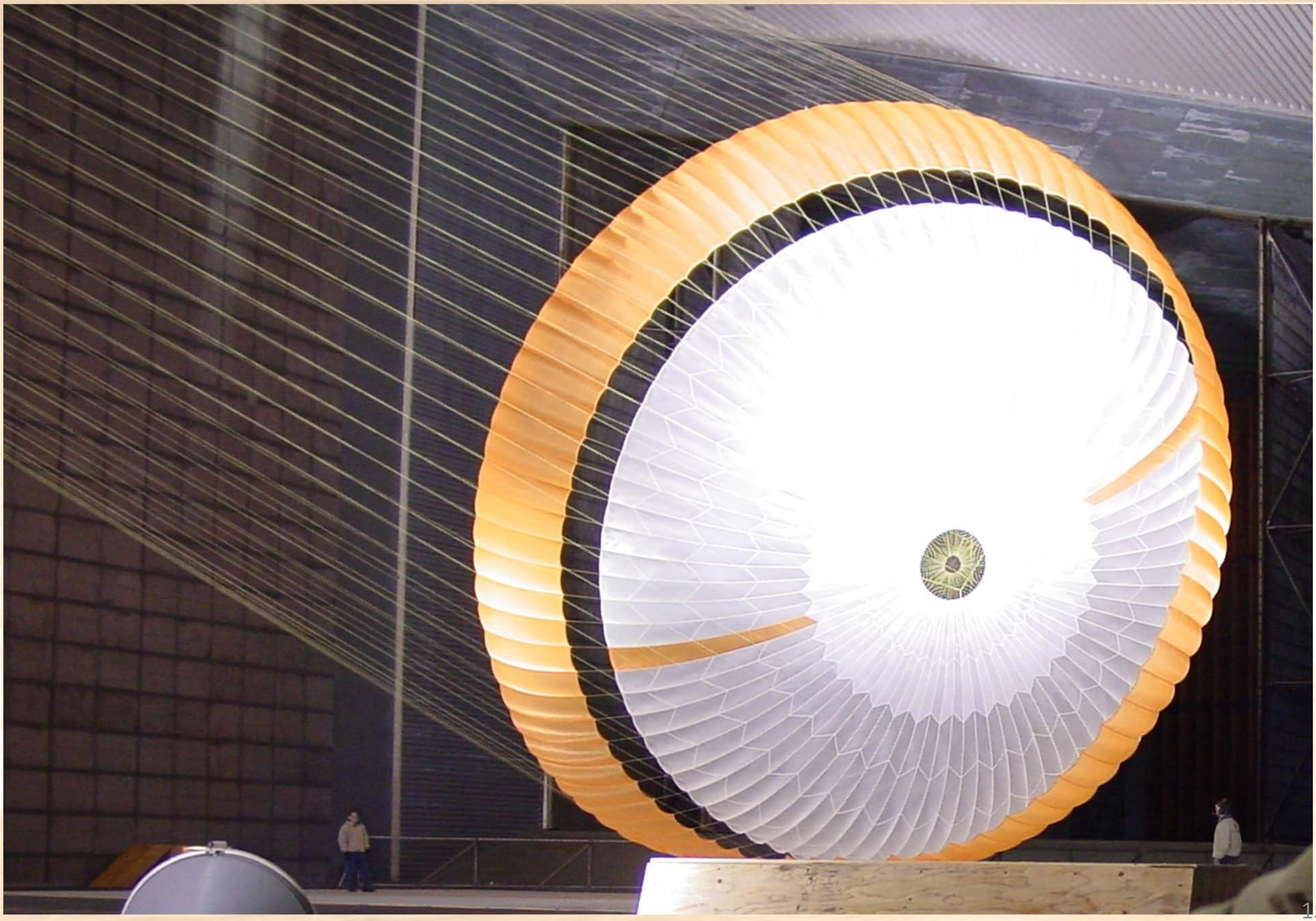
Descent Stage



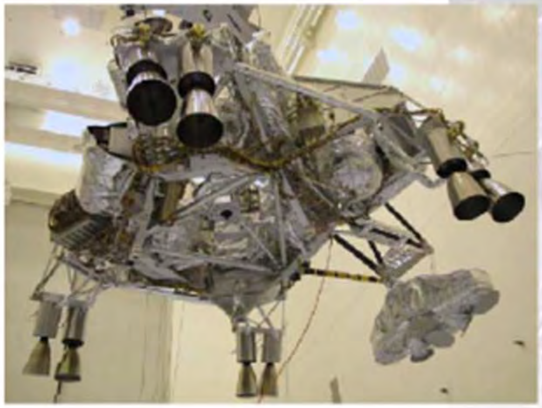
Cruise Stage

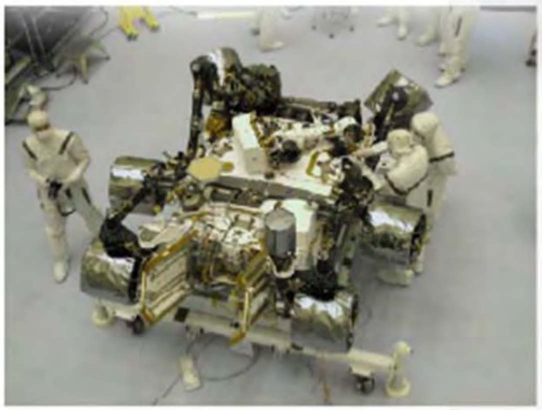


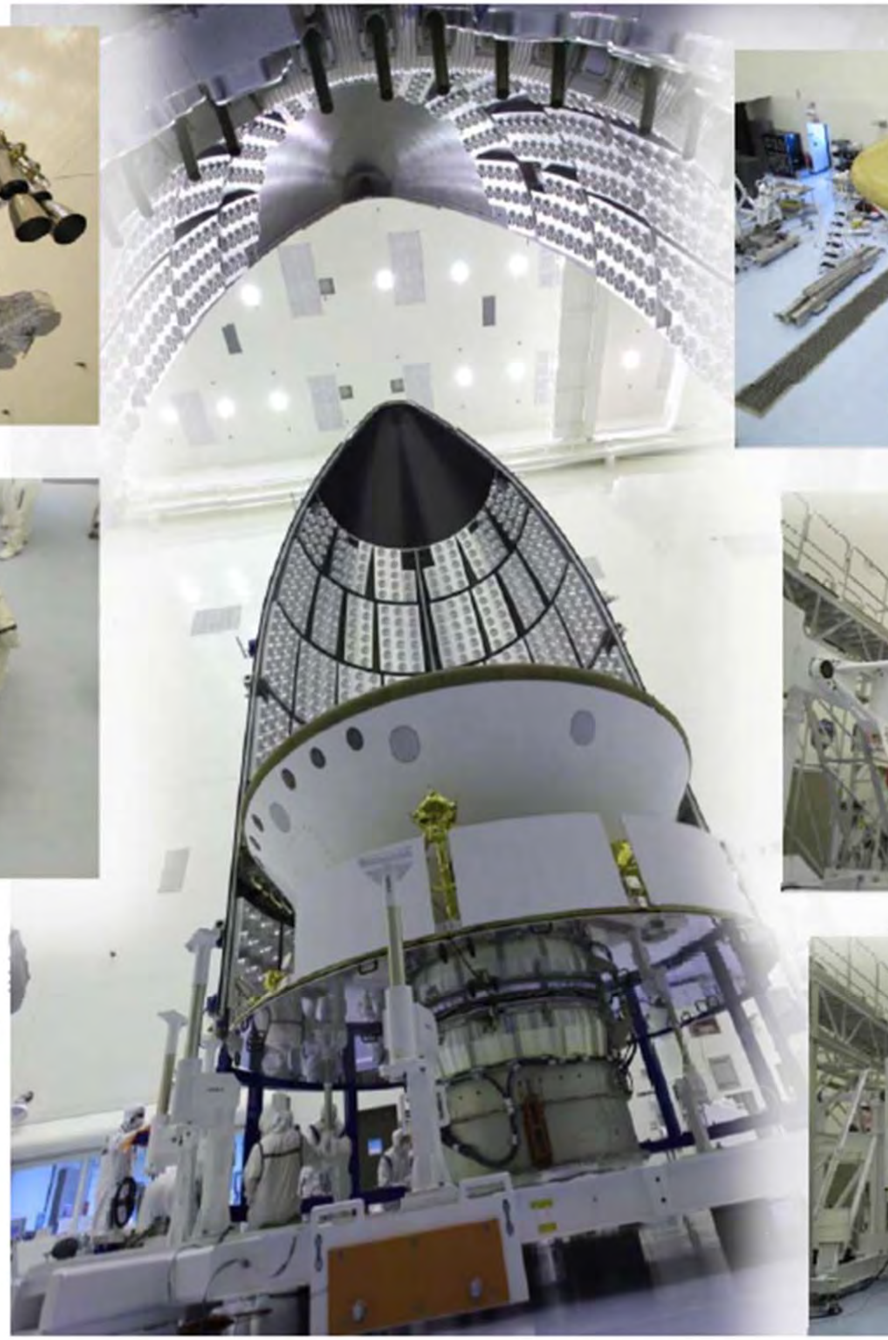
Parachute Test

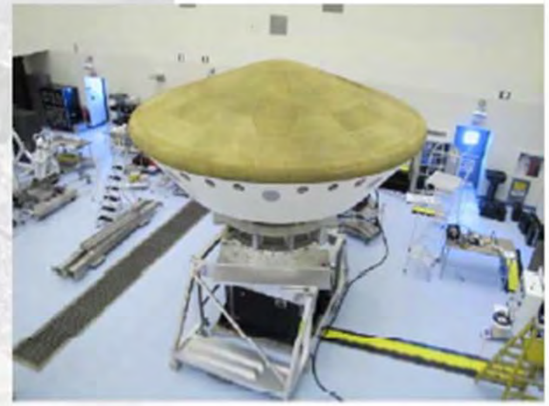


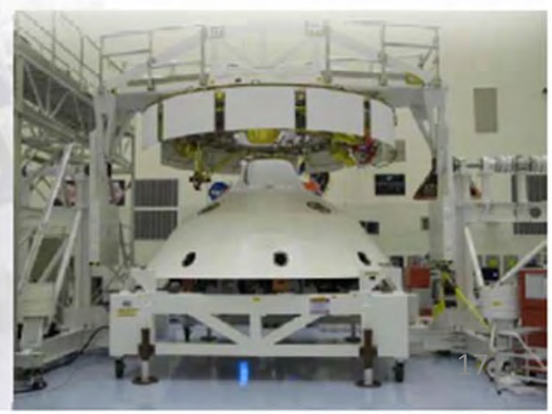
Assembled Spacecraft







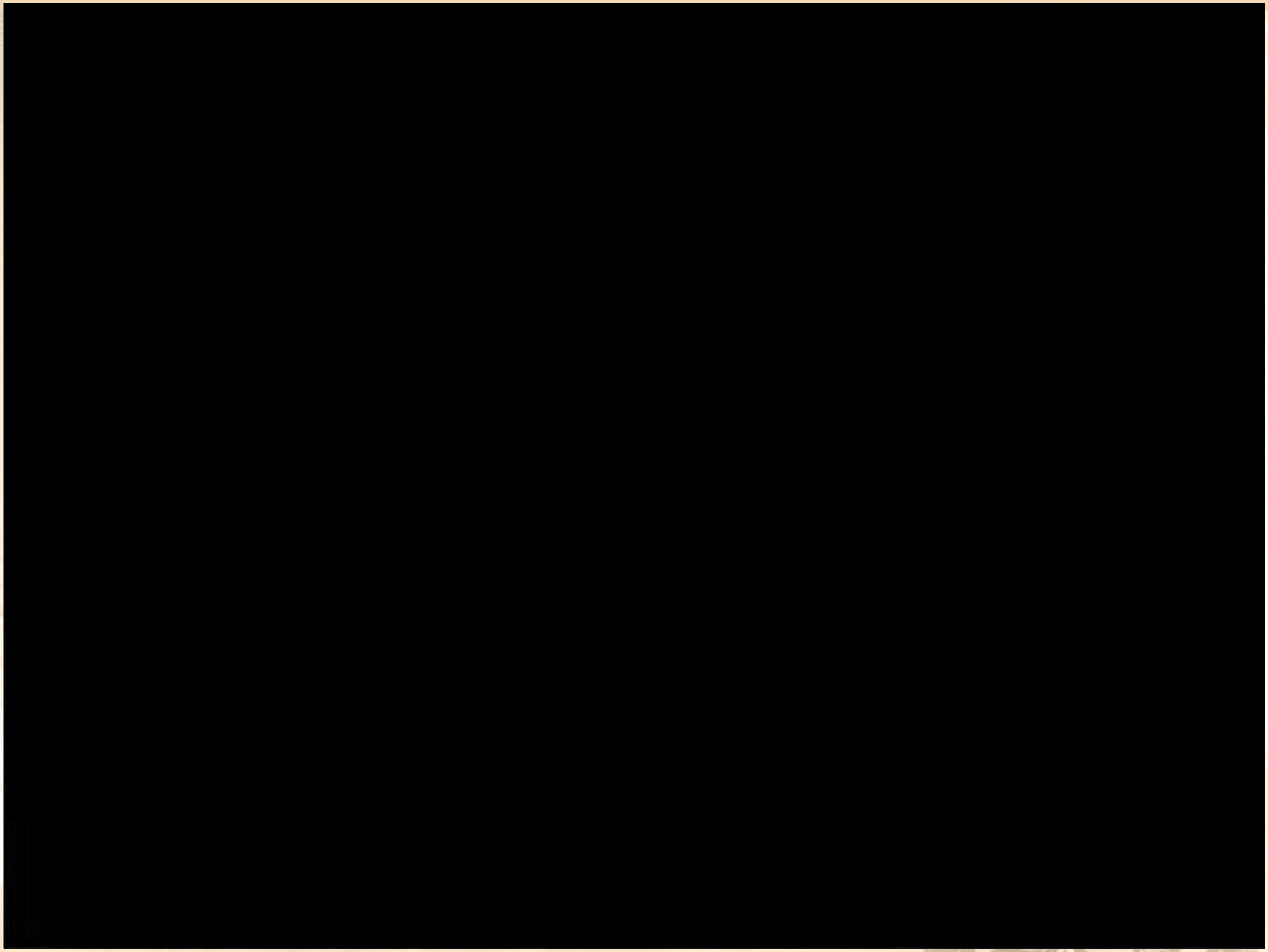




MSL Spacecraft Stack at KSC

Touchdown Test (real time)

Touchdown Testing (Slo-mo 1)



Touchdown Test (Slo-mo 2)

Parts Issues

EEE Parts Program

Part quality level

- Flight System
  - EEE INST-002 Level 1 parts for single string elements, Level 2+ parts for redundant elements
- Payload
  - EEE INST-002 Level 2 parts for all instruments

The part count for the Spacecraft and Rover consists of more than 6000 line items.

EEE Parts Program

Radiation

- Total Ionizing Dose (TID): 6.8 krad(Si) behind 100 mils Al, with RDF of 2
- Enhanced Low Dose Rate Sensitivity (ELDRS) for bipolar and BiCMOS devices: 0.005 rad(Si)/s
- Displacement Damage: 10^{11} n/cm^2
- Single Event Effects:
  - SEL: LET of 75 MeV-cm^2/mg
  - SEU: LET of 75 MeV-cm^2/mg or $< 10^{-10}$ bit errors/day
  - SEB/SEGR: BVCE/BVDS derated to 75% of survival voltage

Parts Issues…

Part type	Issue
Actel RTAX FPGA rework	Design changes required replacement of 624-pin CGA packages on flight boards. Extensive CGA rework qualification was performed to ensure reliable process.
Stacked EEPROM via resistance	TCE mismatch between via alloy and solder resulted in >1 Ohm path resistance, often resulting in open circuit. Thermal cycle induced, Spare parts thermal cycled and resistance measured. Parts that met < 1 Ohm requirement used in flight.
Surface mount resistor	Failure of metal alloy serpentine at end cap I/F. Fabrication process didn't account for lack of mechanical robustness. Low initial tolerance resistors chosen by designers (0.1%). Redesigned with more robust 1% tolerance without significant change in circuit performance.
SDRAM SEFI	A spacecraft using memory similar to what is used on MSL experienced multiple bit errors, resulting in extensive testing to determine impact to MSL design.
SRAM timing issues	SRAM Single Bit Errors at low temperatures. Screening approach used to validate part performance at temperature not the same as flight application. Parts replaced with new versions that have improved cold temperature performance
Hybrid module failure	TRM failure traced to presence of metallic shards on chip capacitors used in hybrid module. Shards were created during part manufacturer and not detected in standard visual inspection. Rework required on all flight TRMs to identify and remove additional shards.

Parts Lessons Learned

- Know the technology
  - Construction analysis, electrical testing
- Maintain good working relationship with the manufacturer
- Understand how the fabrication process will impact the part’s material properties
- Understand how the part will be used in the design (voltage, current, temperature, tolerance)
- Understand how the part will be applied in flight in the intended thermal and radiation environments

Interesting Mission Assurance Metrics

- Mission Assurance indicators of system complexity
  - Over 6,000 EEE Parts Line Items
  - Over 300 Reliability Analyses
  - Approximately 2,000 Environmental Tests/Analyses
  - Over 600 Requirements Waivers
  - Over 4,000 Problem Reports

7 Minutes of Terror

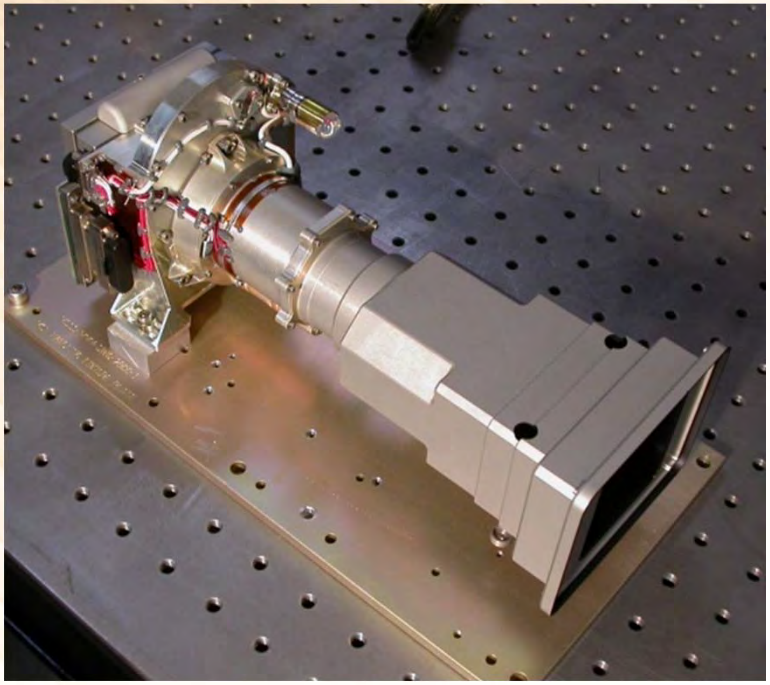
Science Investigations

Mast Camera (Mastcam)

Principal Investigator: Michael Malin

Malin Space Science Systems

Mastcam provides color and stereo imaging of the landscape, rocks, fines, frost/ice, and atmospheric features



- Narrow-angle (5.1° FOV) and medium-angle (15° FOV) cameras
- 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 frames/second, 1280×720 pixels
- Large internal storage: 256 MByte SRAM, 8 GByte flash

ChemCam

Principal Investigator: Roger Wiens

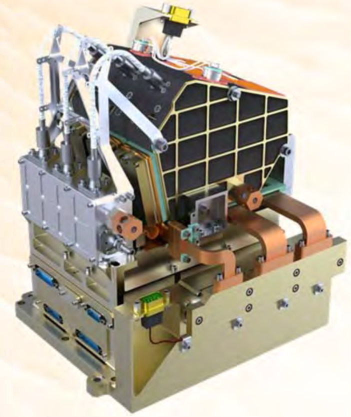
Los Alamos National Laboratory

Centre d'Etude Spatiale des Rayonnements

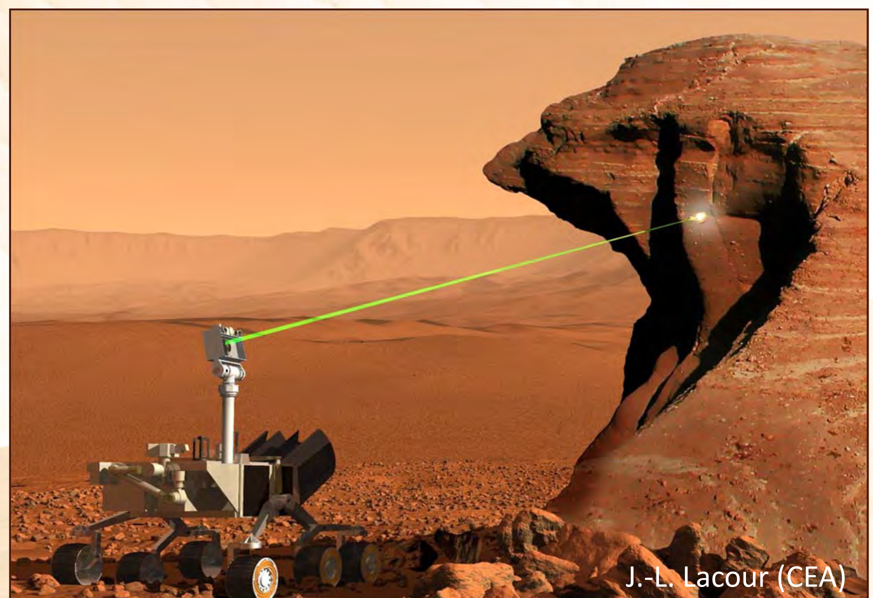
ChemCam performs elemental analyses through laser-induced breakdown spectroscopy (LIBS)

- Rapid characterization of rocks and soils up to seven meters away
- Will identify and classify rocks, soils, pebbles, hydrated minerals, weathering layers, and ices
- Analysis spot size < 0.5 mm
- 240-850 nm spectral range
- Dust removal; depth profiling to > 0.5 mm
- High-resolution context imaging (resolves ~1 mm at 10 m)

Mast Unit



Body Unit

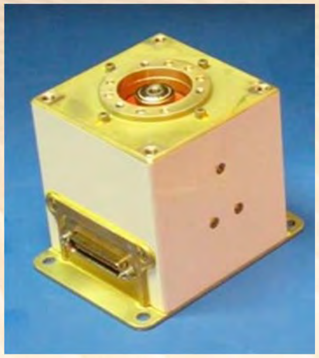


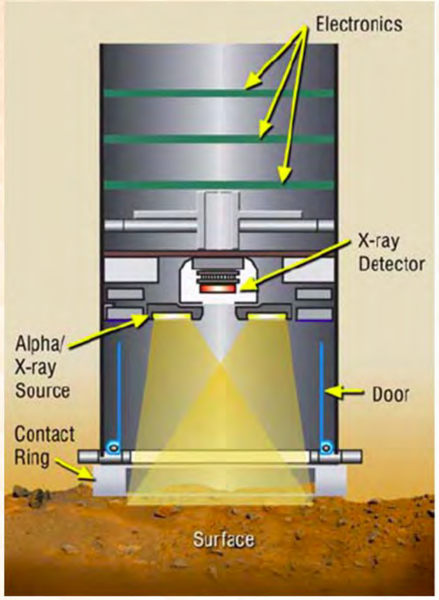
Alpha-Particle X-ray Spectrometer

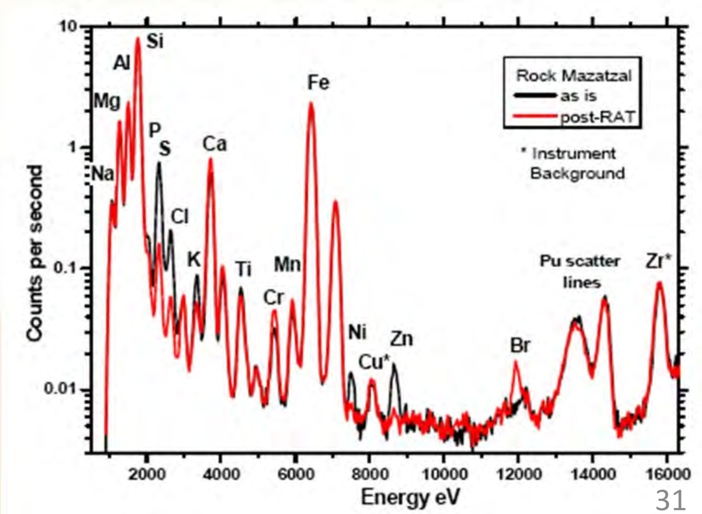
Principal Investigator: Ralf Gellert
University of Guelph, Ontario, Canada
Canadian Space Agency

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 of ~3 increased sensitivity; better daytime performance compared with MER







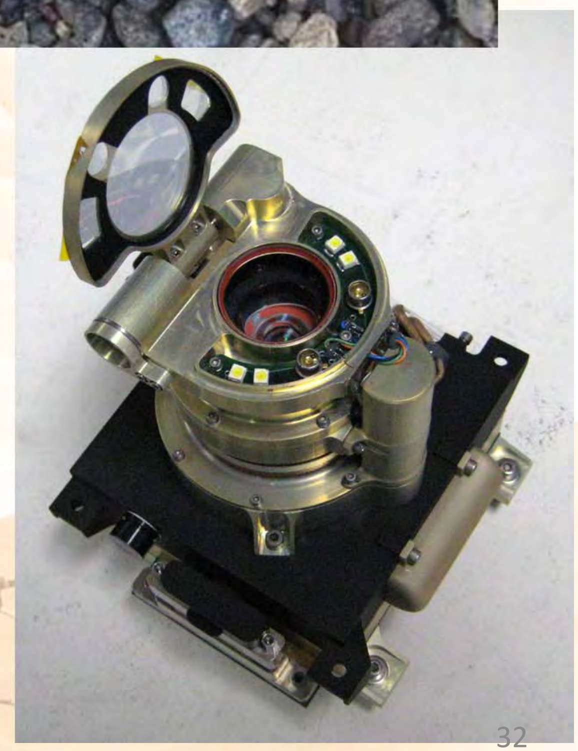
Mars Hand-Lens Imager (MAHLI)

Principal Investigator: Ken 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 micron to cm scale
- Returns 1600 × 1200-pixel color images and video; synthesizes best-focus images and depth-of-field range maps
- Highest possible spatial resolution is 14 μm/pixel
- Can focus at distances suitable for landscape and engineering support/diagnostic imaging
- White light and UV LEDs for controlled illumination, fluorescence



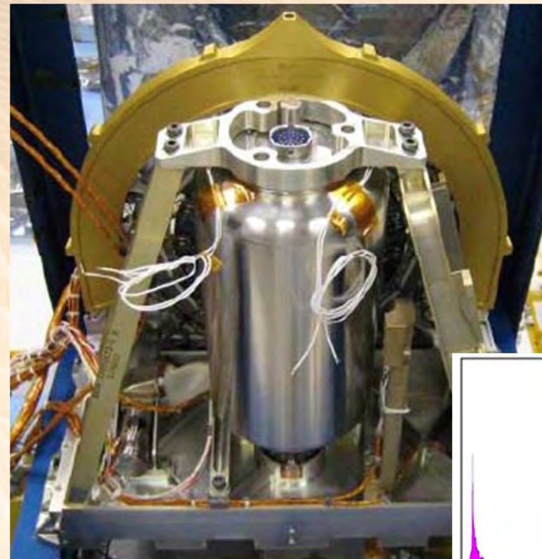
Chemistry and Mineralogy (CheMin)

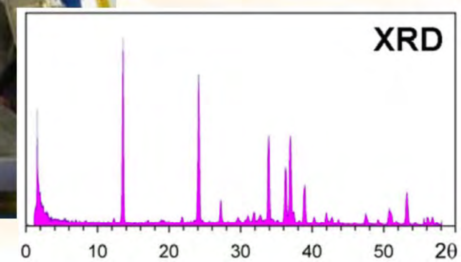
Principal Investigator: David Blake

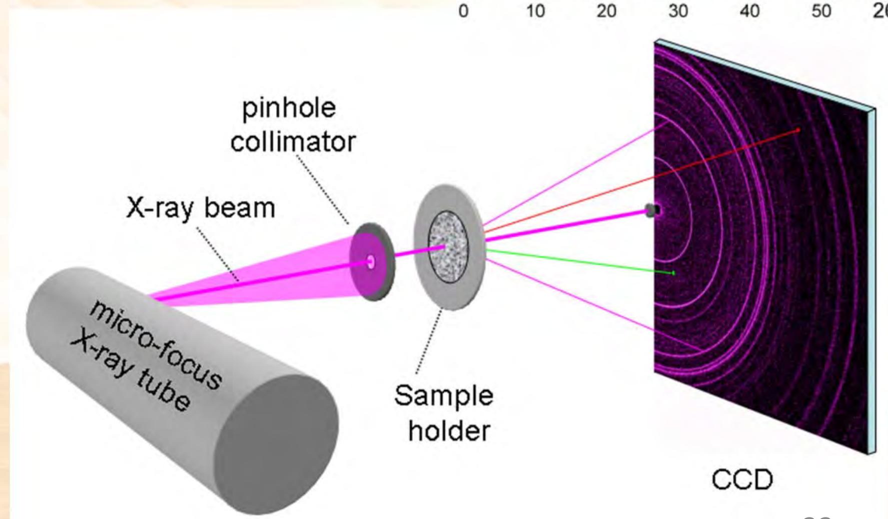
NASA Ames Research Center

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 (SAM)

Principal Investigator: Paul Mahaffy

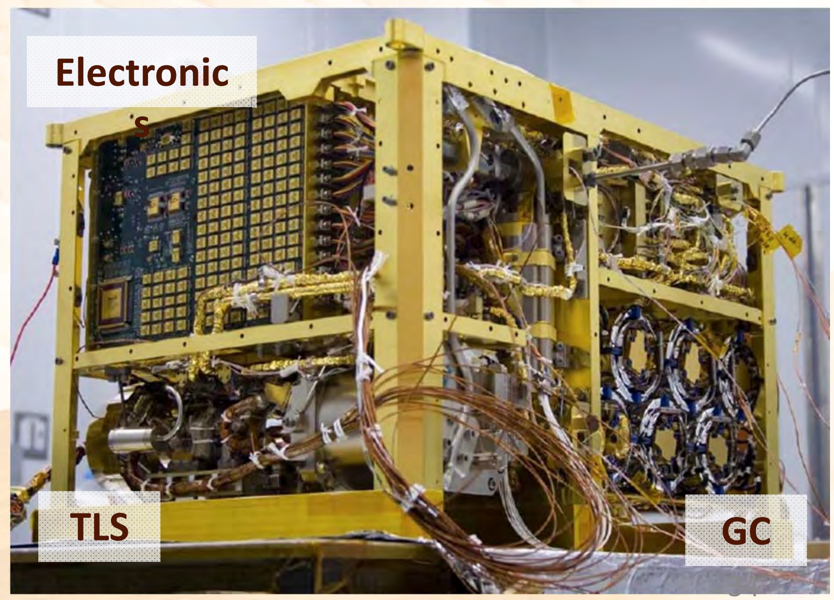
NASA Goddard Space Flight Center

SAM Suite Instruments

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

- Explore sources and destruction paths for carbon compounds, and search for organic compounds of biotic and prebiotic relevance
- Reveal chemical and isotopic state of other light elements that are important for life as we know it on Earth
- Study atmospheric/surface interactions expressed in trace species compositions
- 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 and isotopic composition of CH_4, CO_2, and H_2O



Dynamic Albedo of Neutrons (DAN)

Principal Investigator: Igor Mitrofanov

Space Research Institute (IKI), Russia

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

Thermal & Epithermal Neutron Detectors

Pulsing Neutron Generator

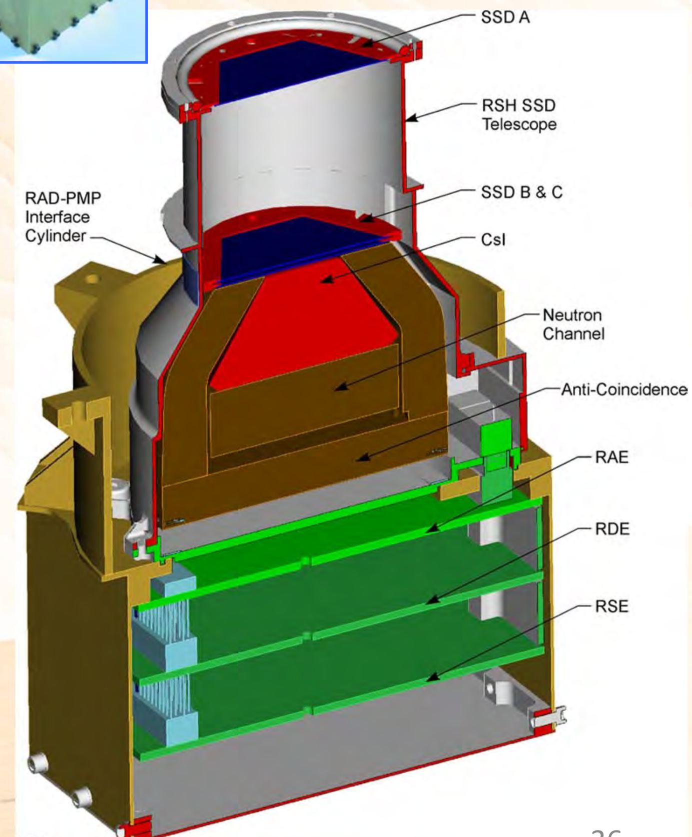
Radiation Assessment Detector (RAD)

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

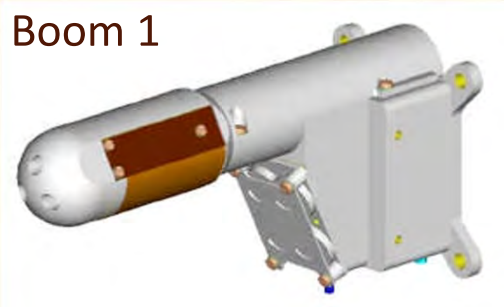


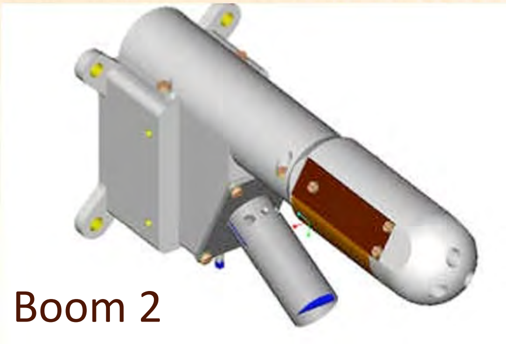
Rover Environmental Monitoring Station (REMS)

Principal Investigator: Javier Gómez-Elvira

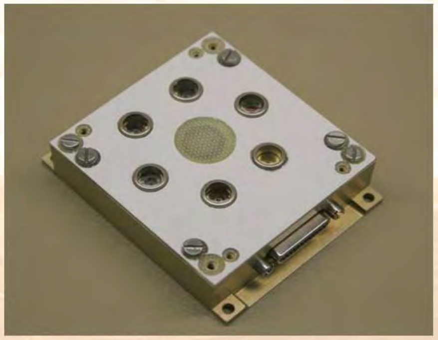
Centro de Astrobiología (CAB), Spain

Boom 1





Boom 2



UV Sensor

REMS measures the meteorological and UV radiation environments

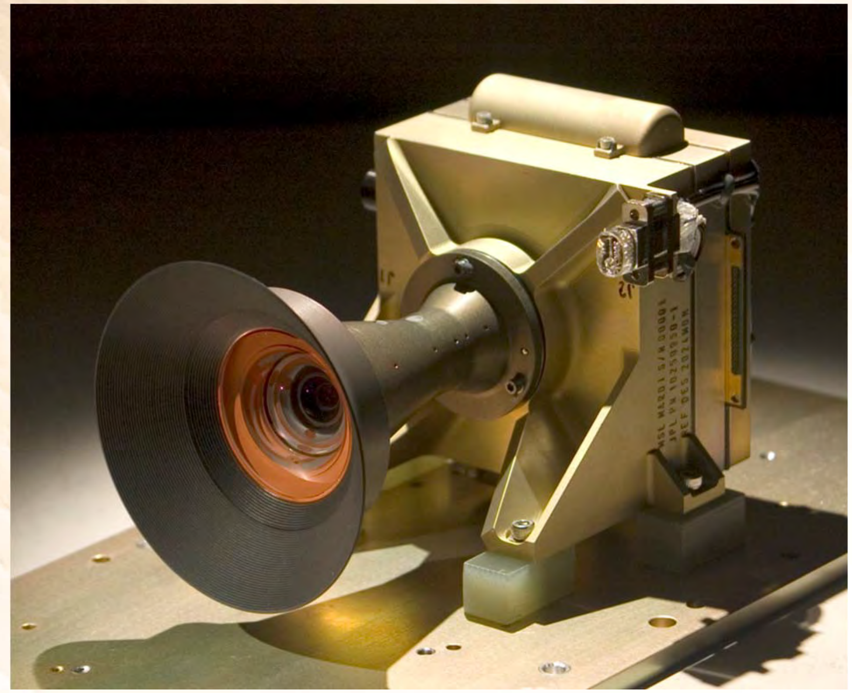
- Two 3-D wind sensors
- Air temperature sensors
- IR ground temperature sensors
- Pressure sensor
- Relative humidity sensor
- UV radiation detector (200 to 400 nm)
- 1-Hz sampling for 5 minutes each hour

Mars Descent Imager (MARDI)

Principal Investigator: Michael Malin

Malin Space Science Systems

MARDI provides detailed imagery of the MSL landing region

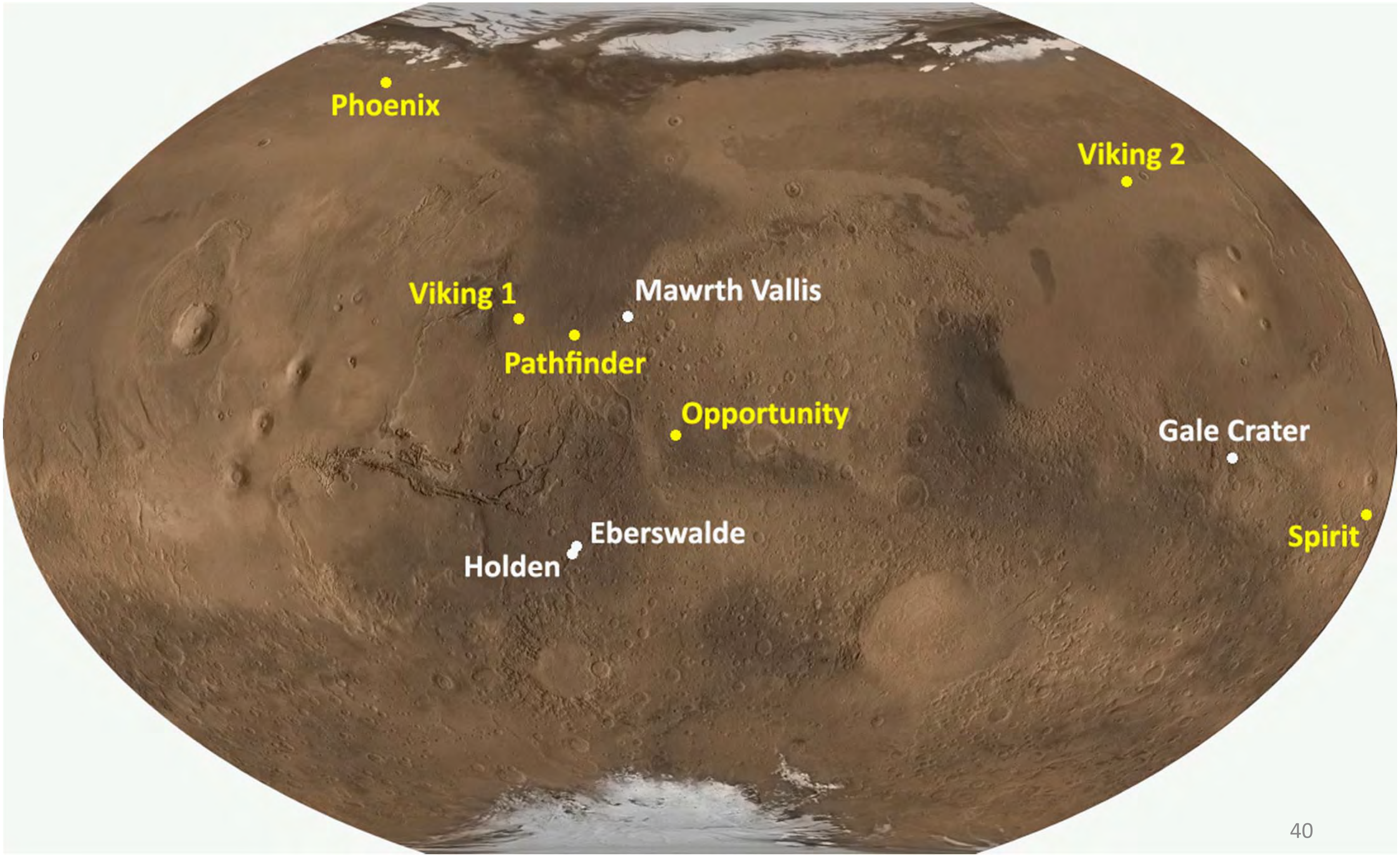


- Acquires images during powered descent ranging from 1.5 m/pixel to 1 mm/pixel at the surface. Ties post-landing surface images to pre-landing orbital images.
- Bayer pattern filter for natural color
- High-definition, video-like data acquisition (1600×1200 pixels, 4.5 frames per second)
- Large internal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

Landing Sites

Mars Landing Sites

(Previous Missions and MSL Candidates)



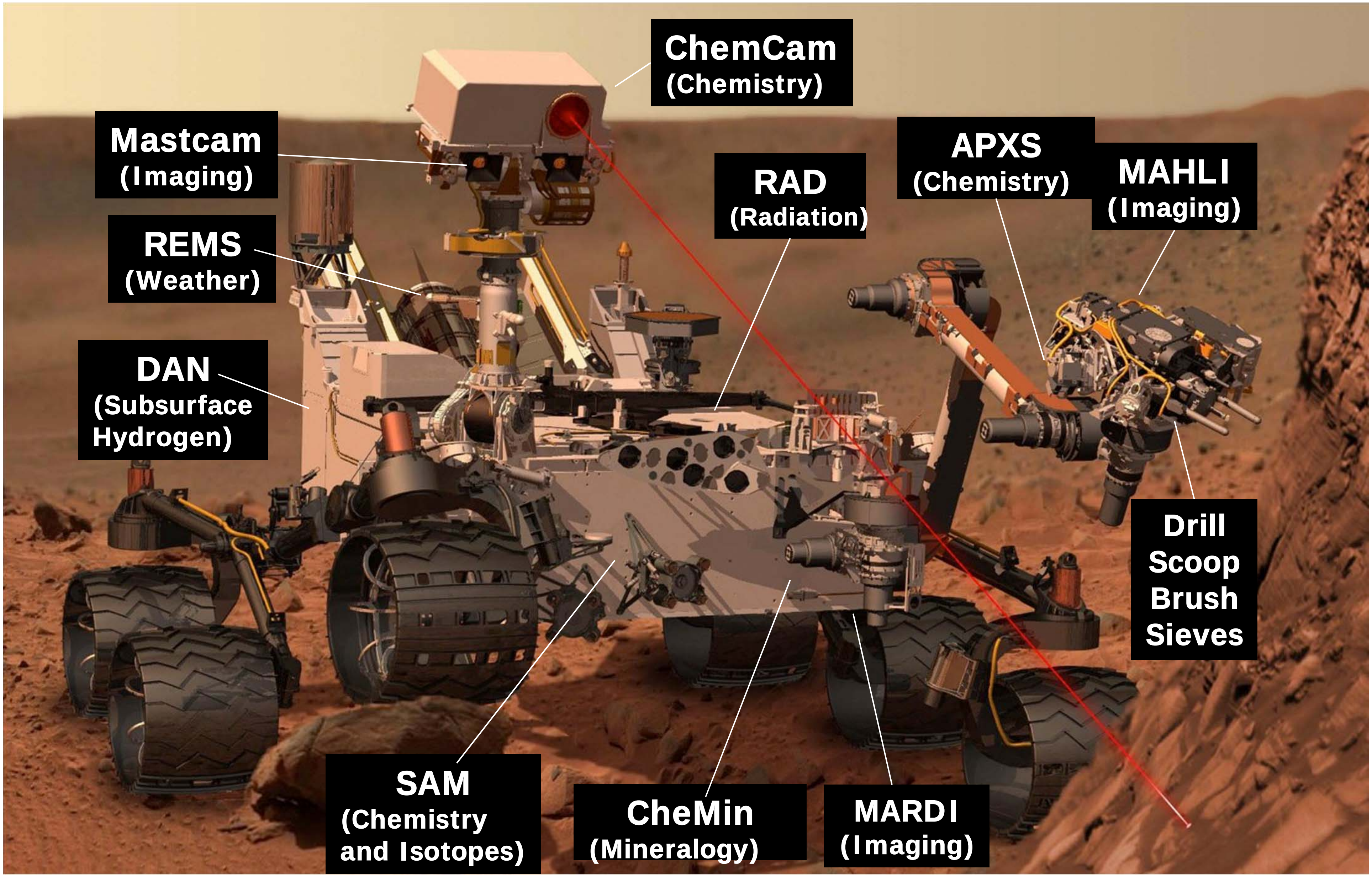
CURIOSITY

NASA/JPL-Caltech/MSSS

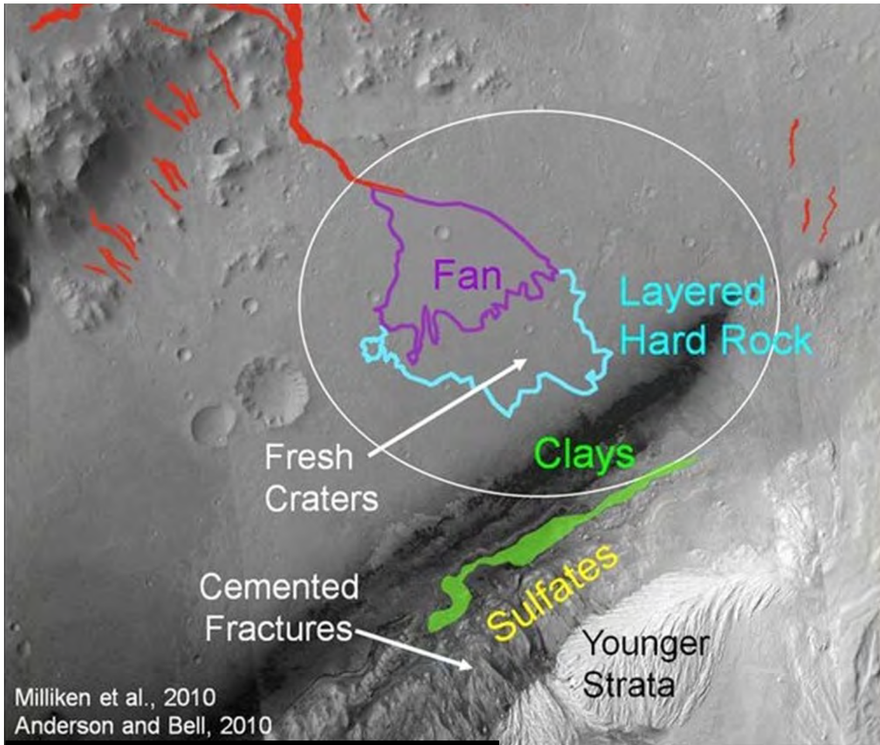
Initial Results from the Mars Science Laboratory

MSL Science Team

10/9/12



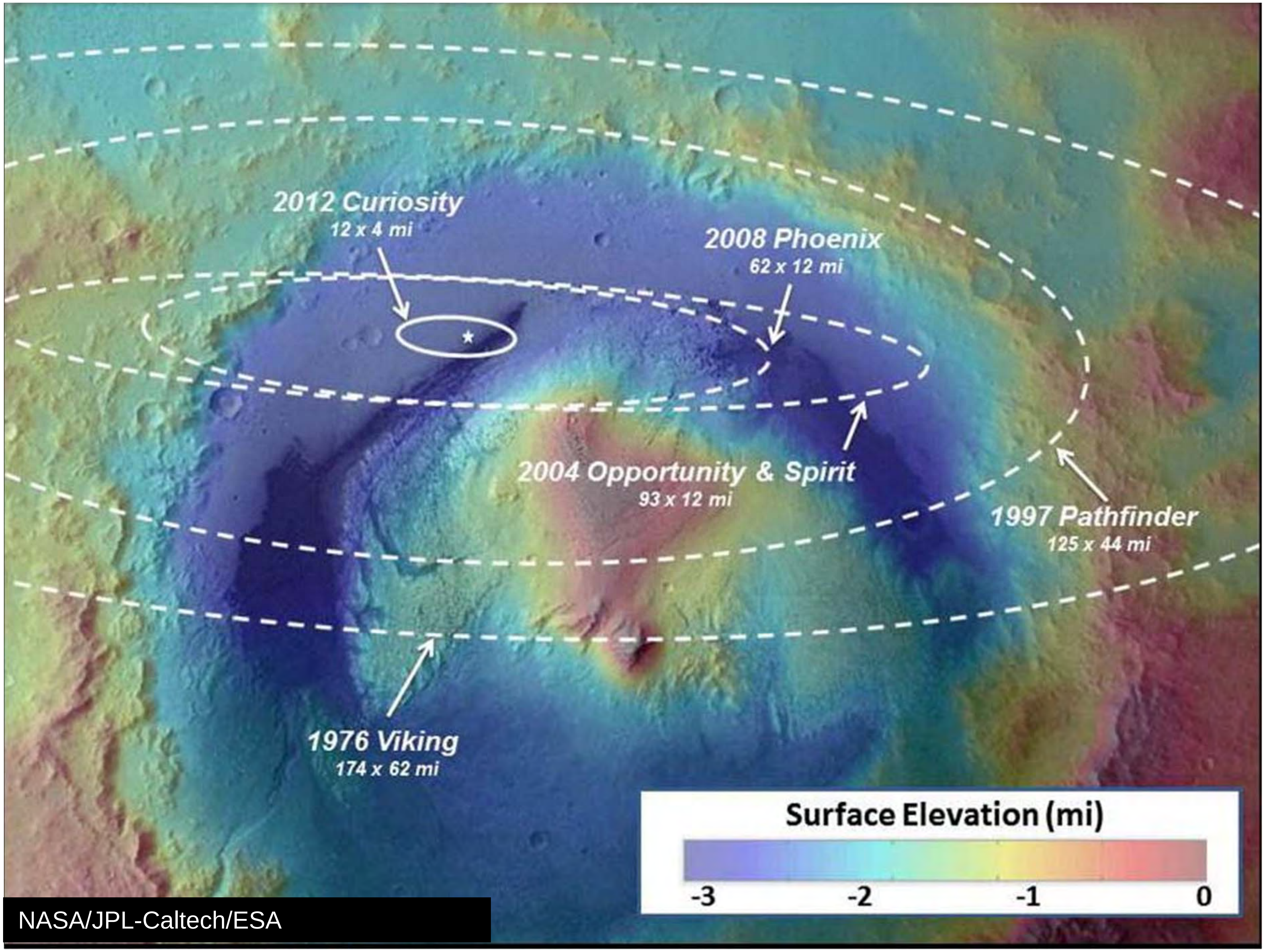
Curiosity’s Science Payload



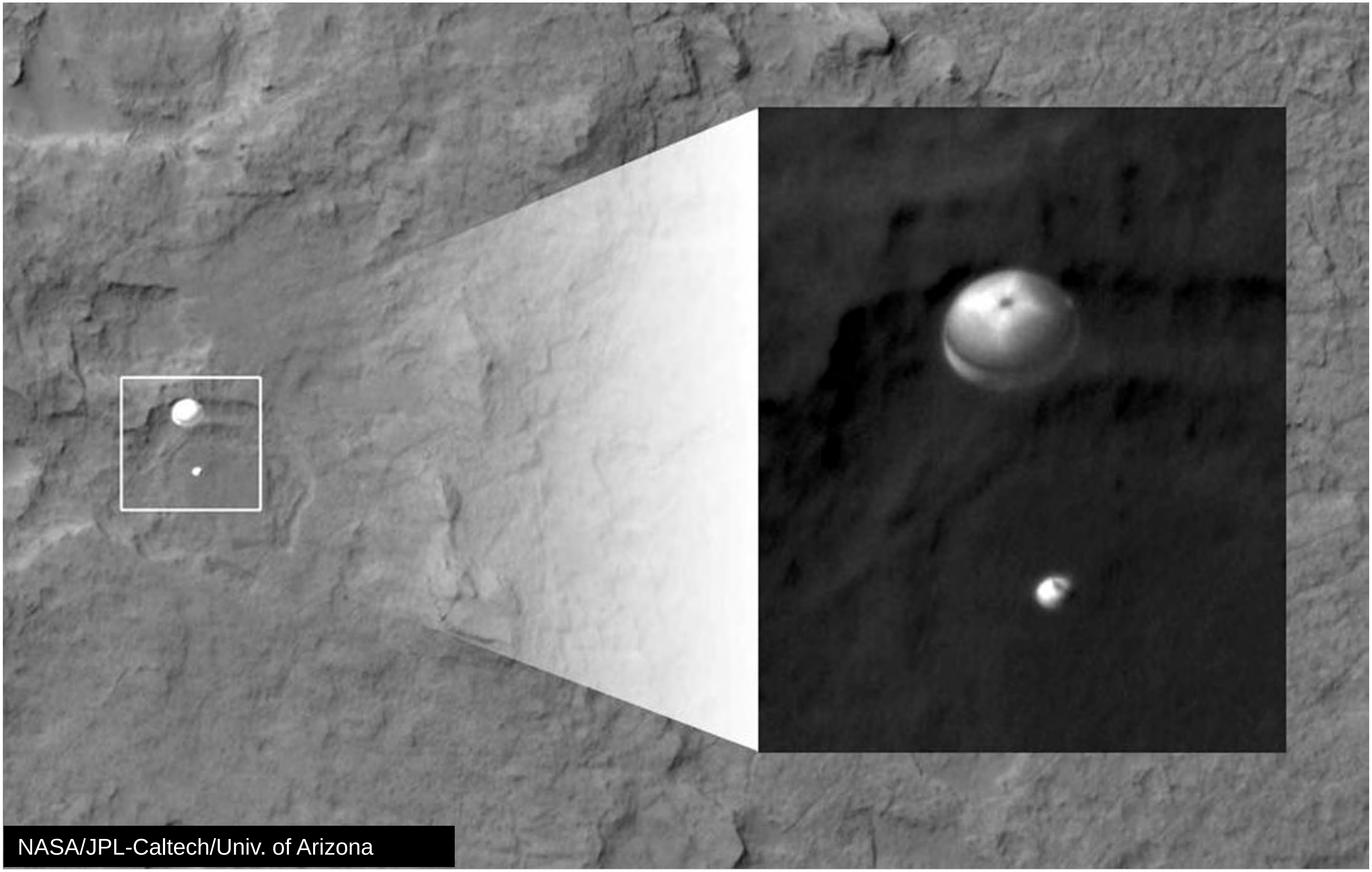
NASA/JPL-Caltech

NASA/JPL-Caltech/ESA/DLR/FU

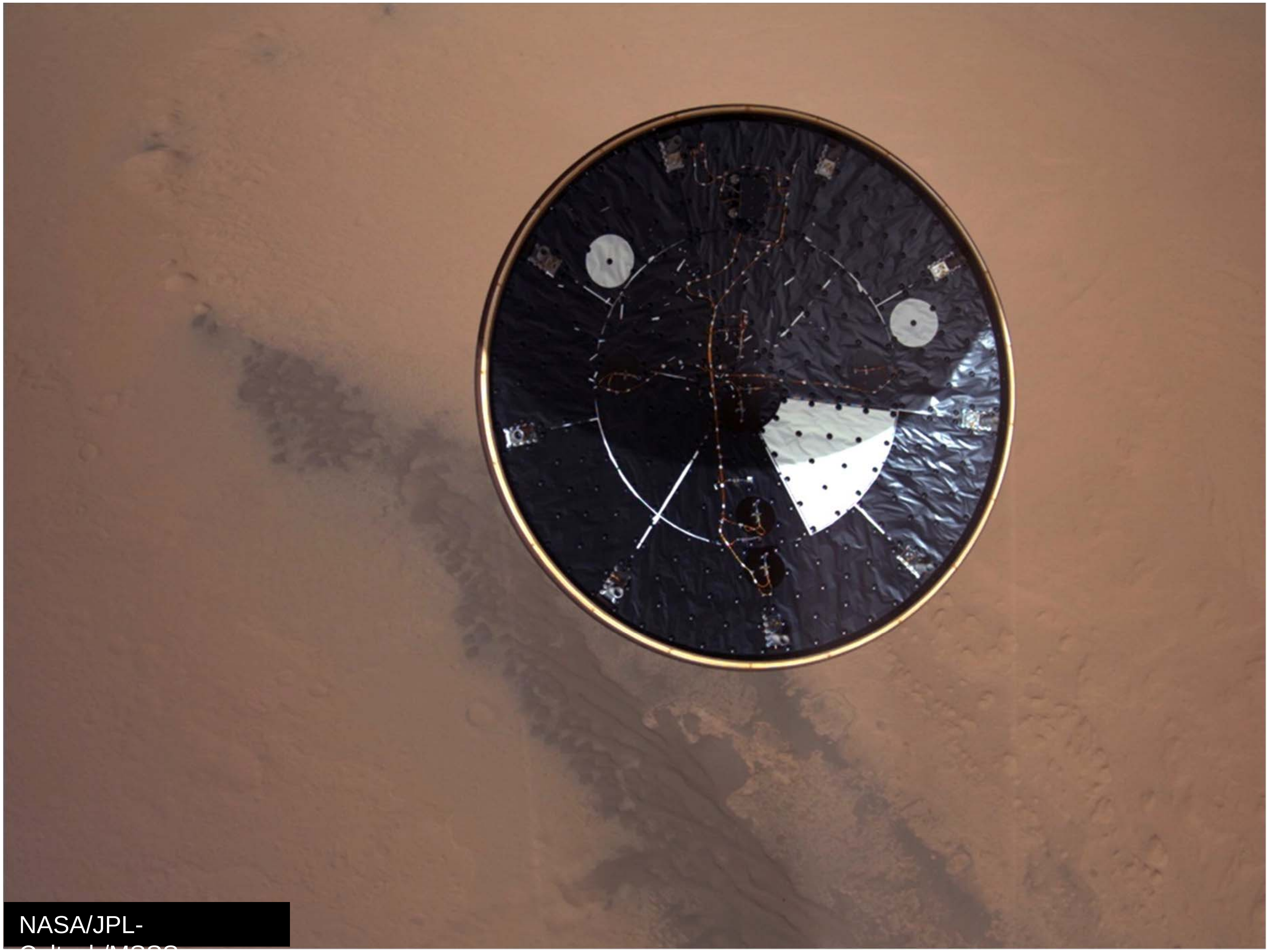
Target: Gale Crater and Mount Sharp



Landing precision for Curiosity and previous Mars surface missions

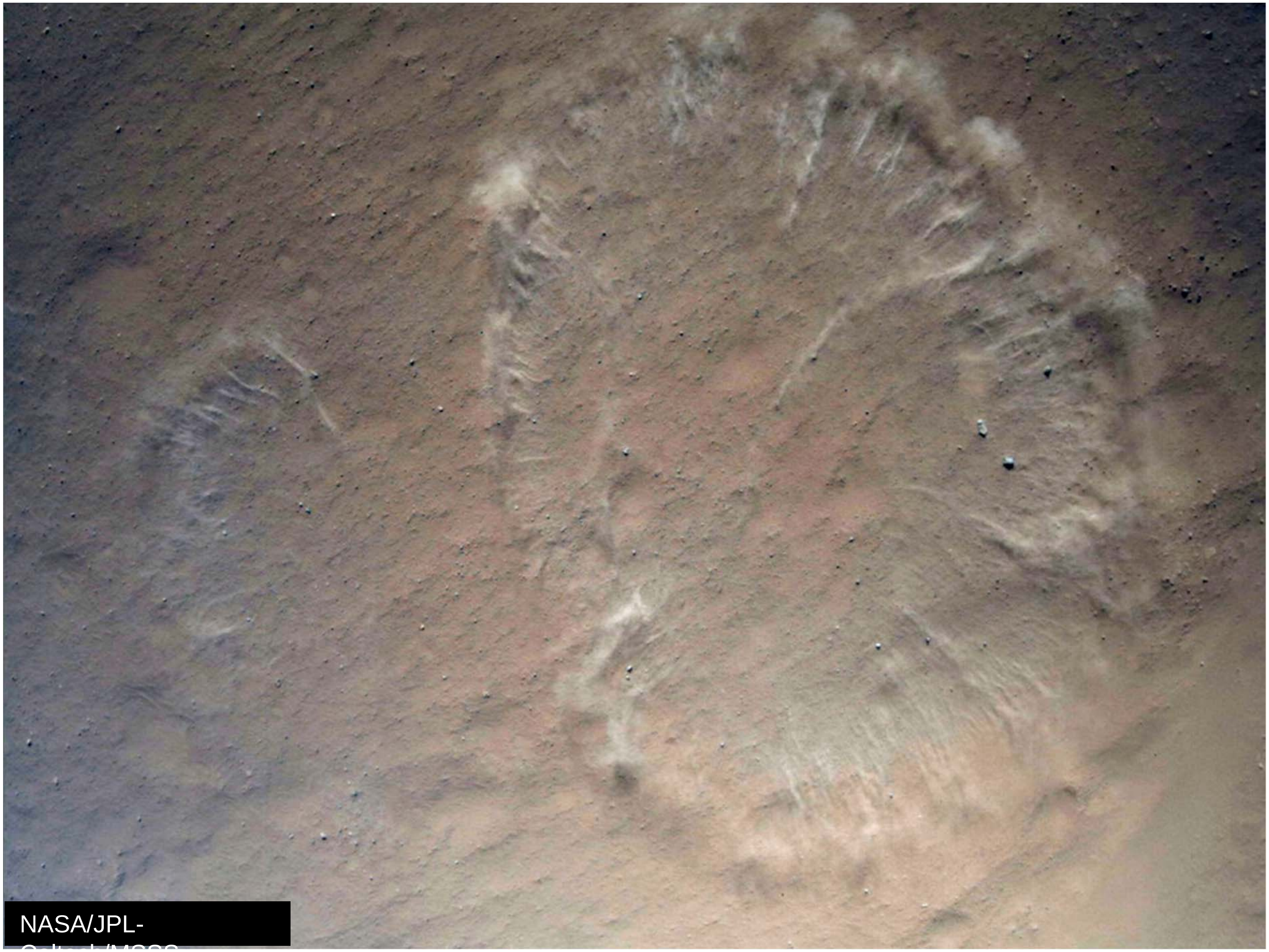


Curiosity on parachute, imaged by HiRISE on the Mars Reconnaissance Orbiter



NASA/JPL-Caltech/MSSS

Heat shield separation captured by Curiosity’s Mars Descent Imager



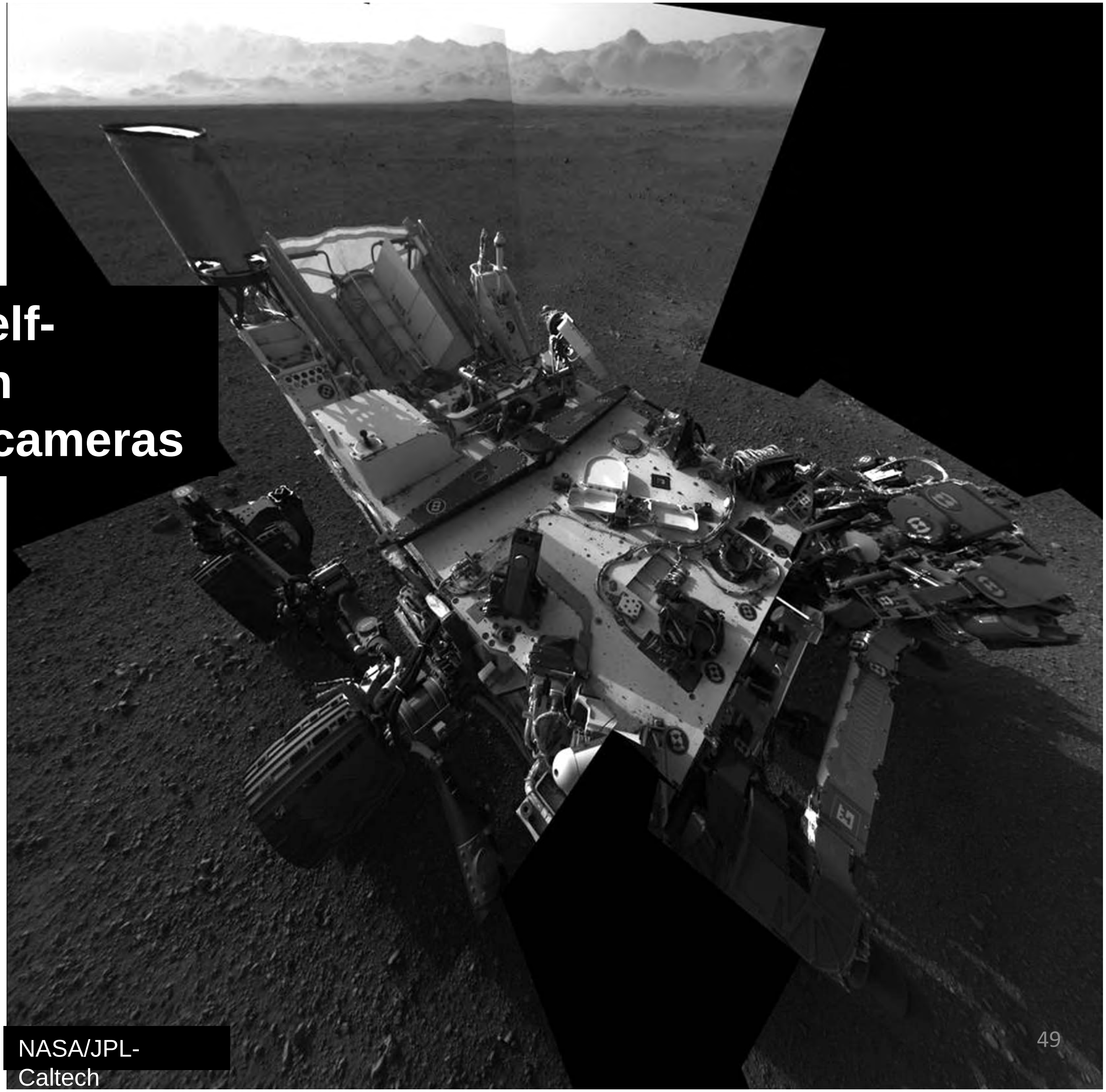
NASA/JPL-

Kicking up dust just prior to landing

CURIOSITY

“Touchdown confirmed.”
“Let’s see where Curiosity will take us.”

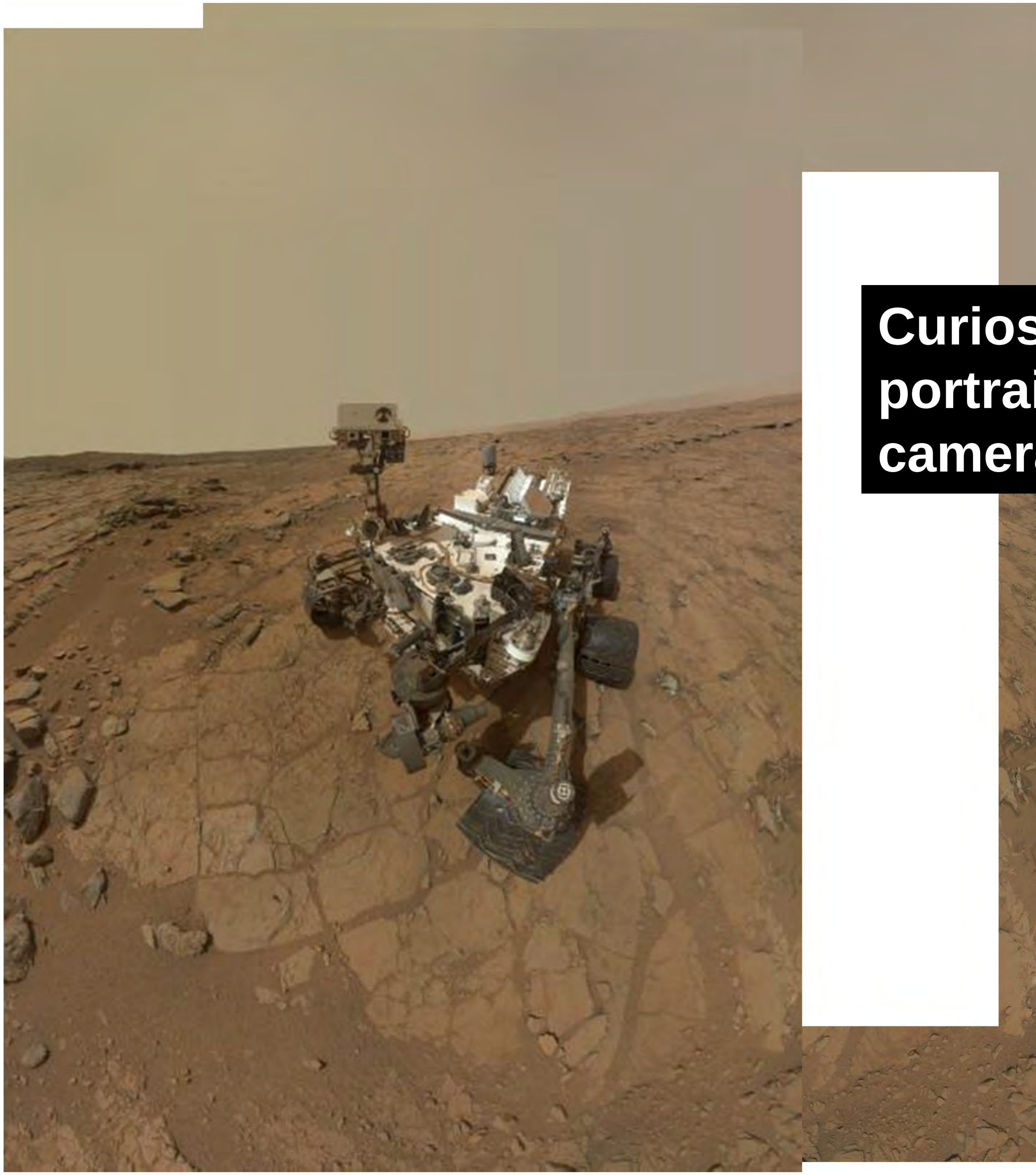
Curiosity self-portrait with navigation cameras



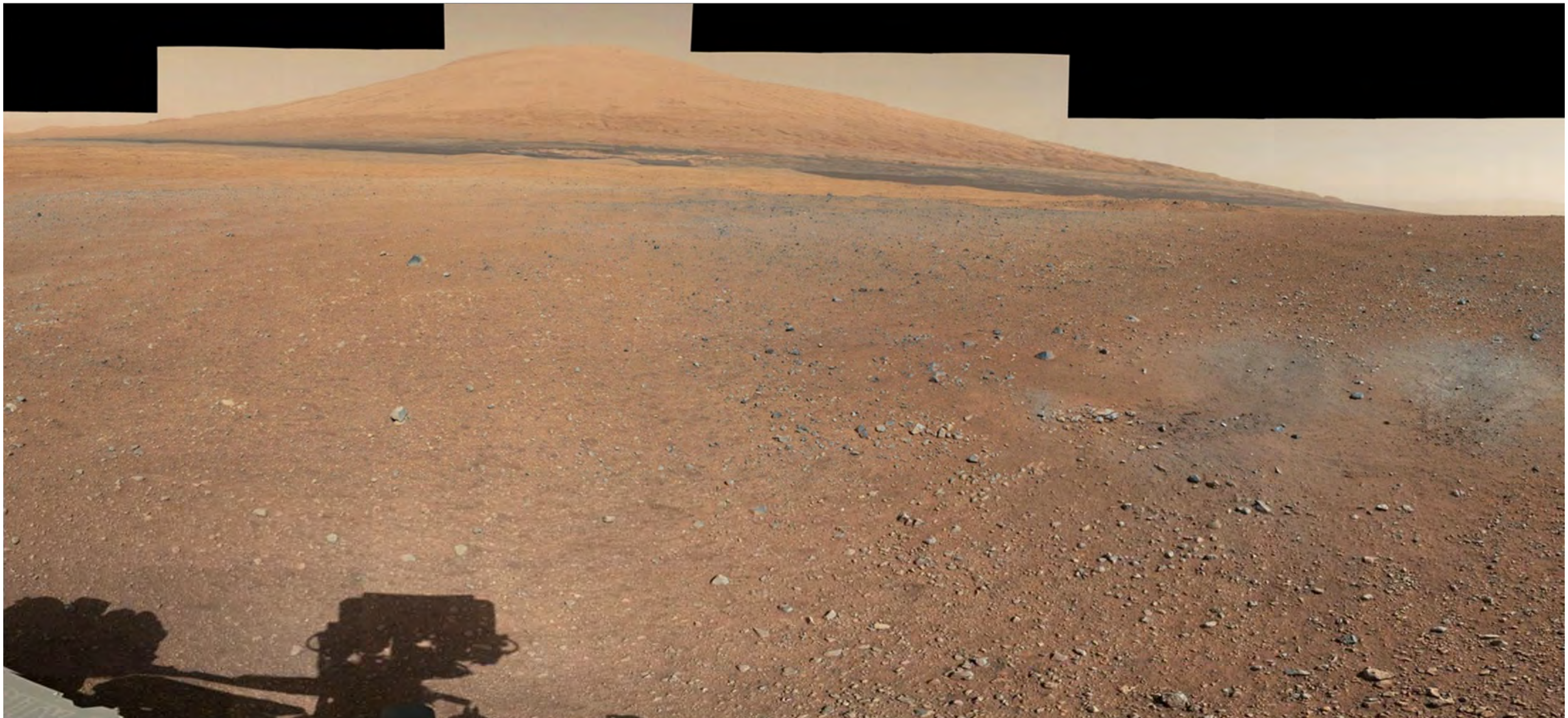
NASA/JPL-Caltech

NASA/JPL-Caltech

Navigation camera image showing the surface scour marks and rocks on the rover's deck

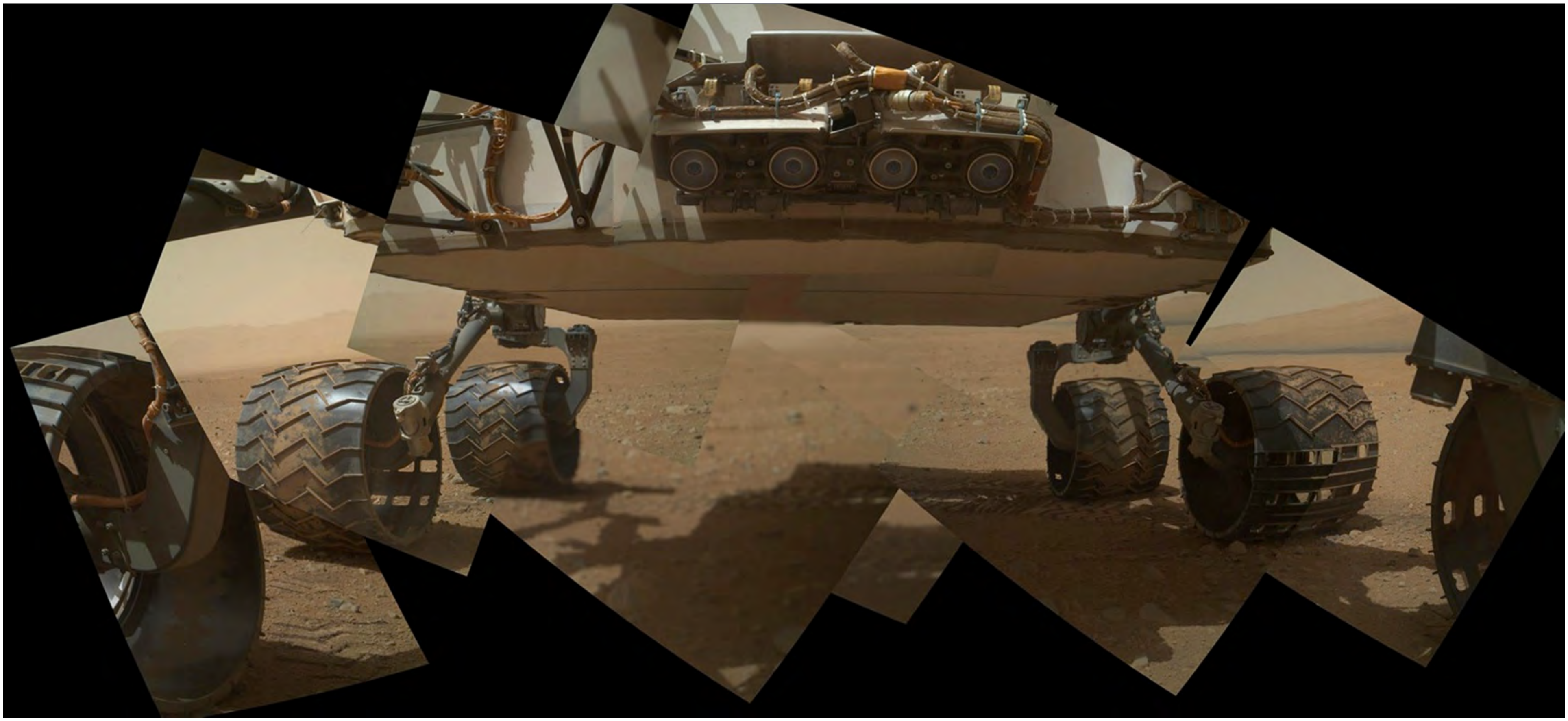


Curiosity self-portrait with MAHLI camera



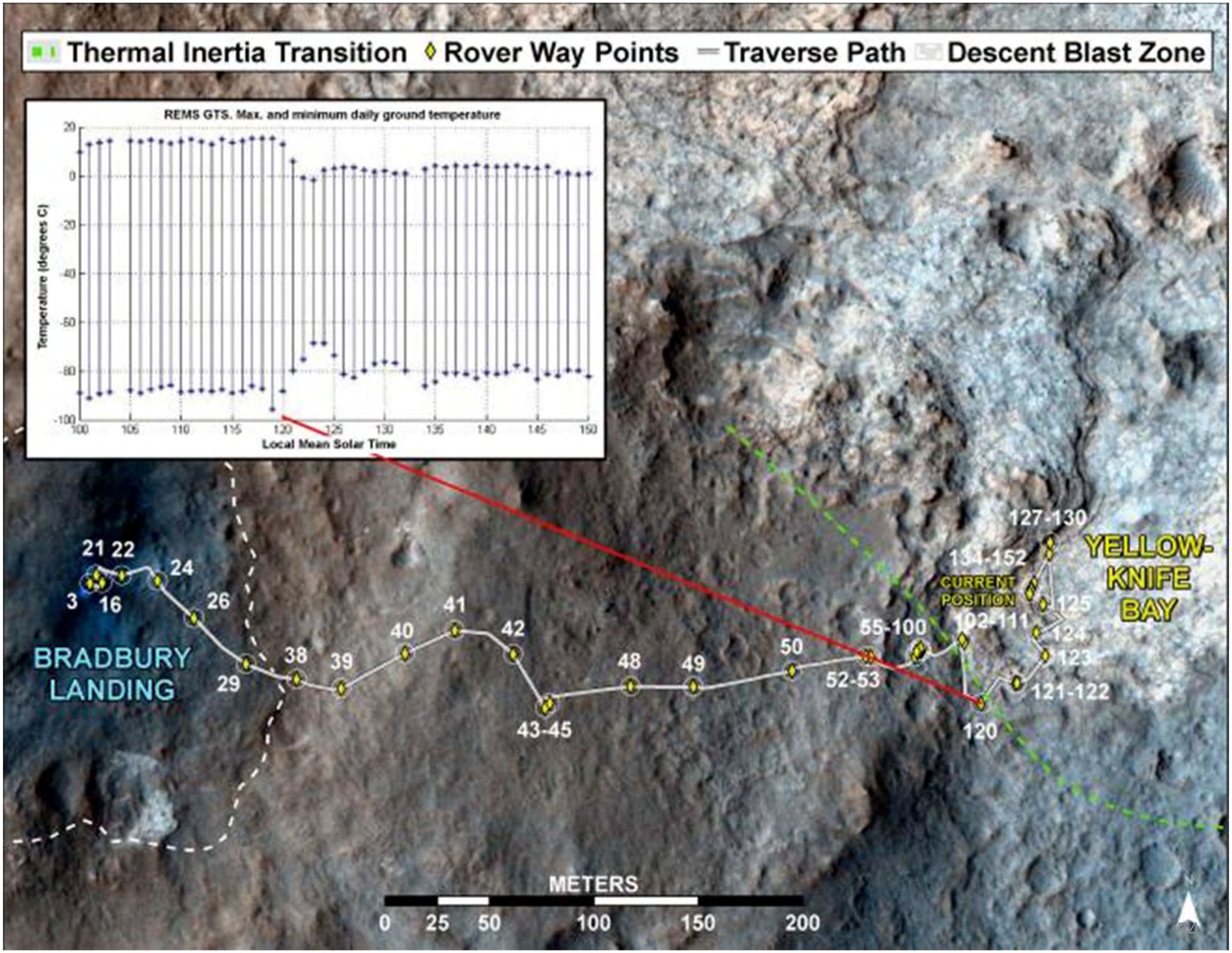
NASA/JPL-

Mastcam-34 mosaic of Mount Sharp, descent rocket scours, and rover shadow

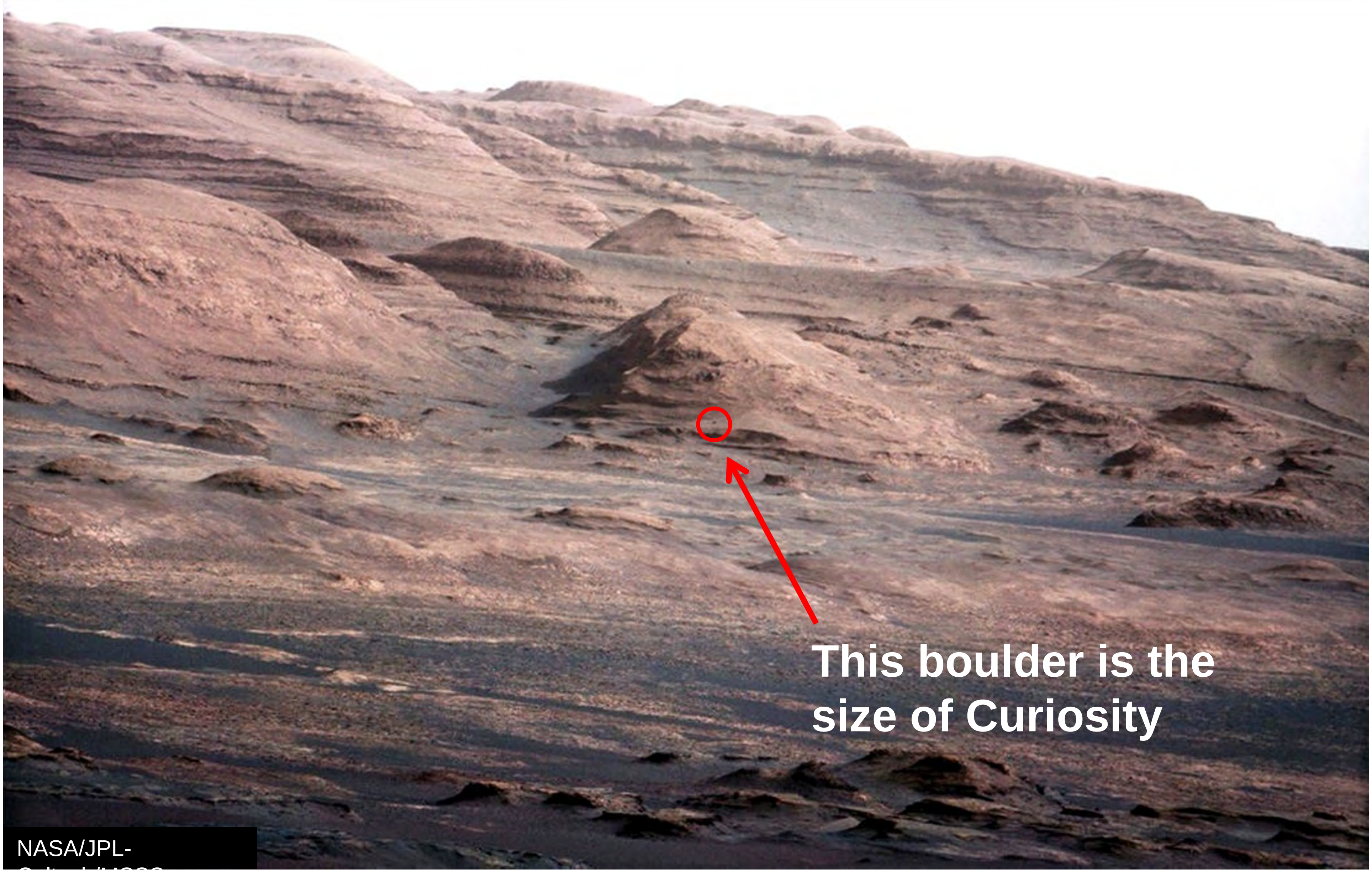


NASA/JPL-

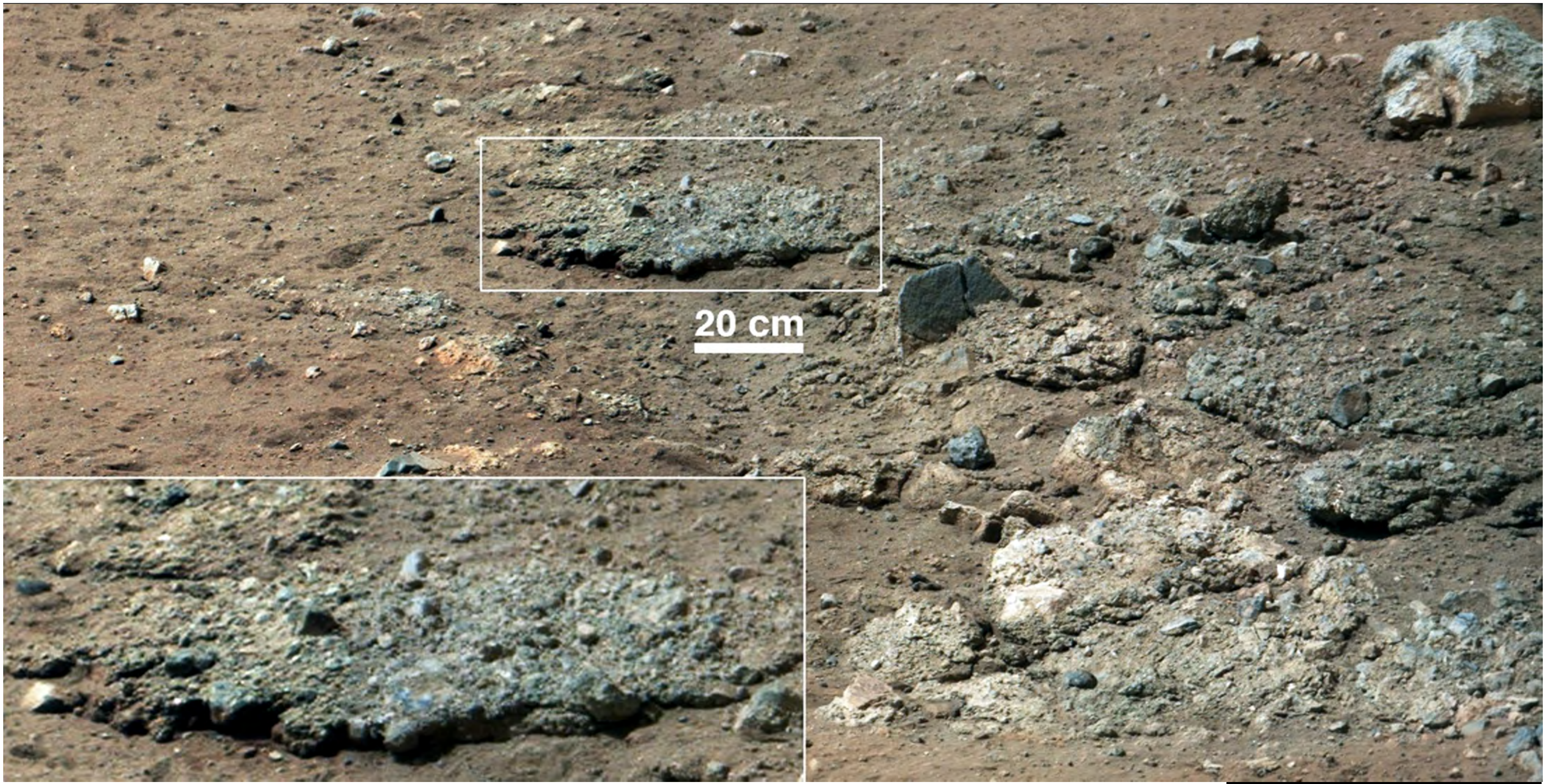
Curiosity images its undercarriage with its Mars Hand-Lens Imager



Thermal Inertia Transition
Rover Way Points
Traverse Path
Descent Blast Zone
REMS GTS. Max. and minimum daily ground temperature
Temperature (degrees C)
Local Mean Solar Time
BRADBURY LANDING
YELLOW-KNIFE BAY
CURRENT POSITION
METERS
0 25 50 100 150 200



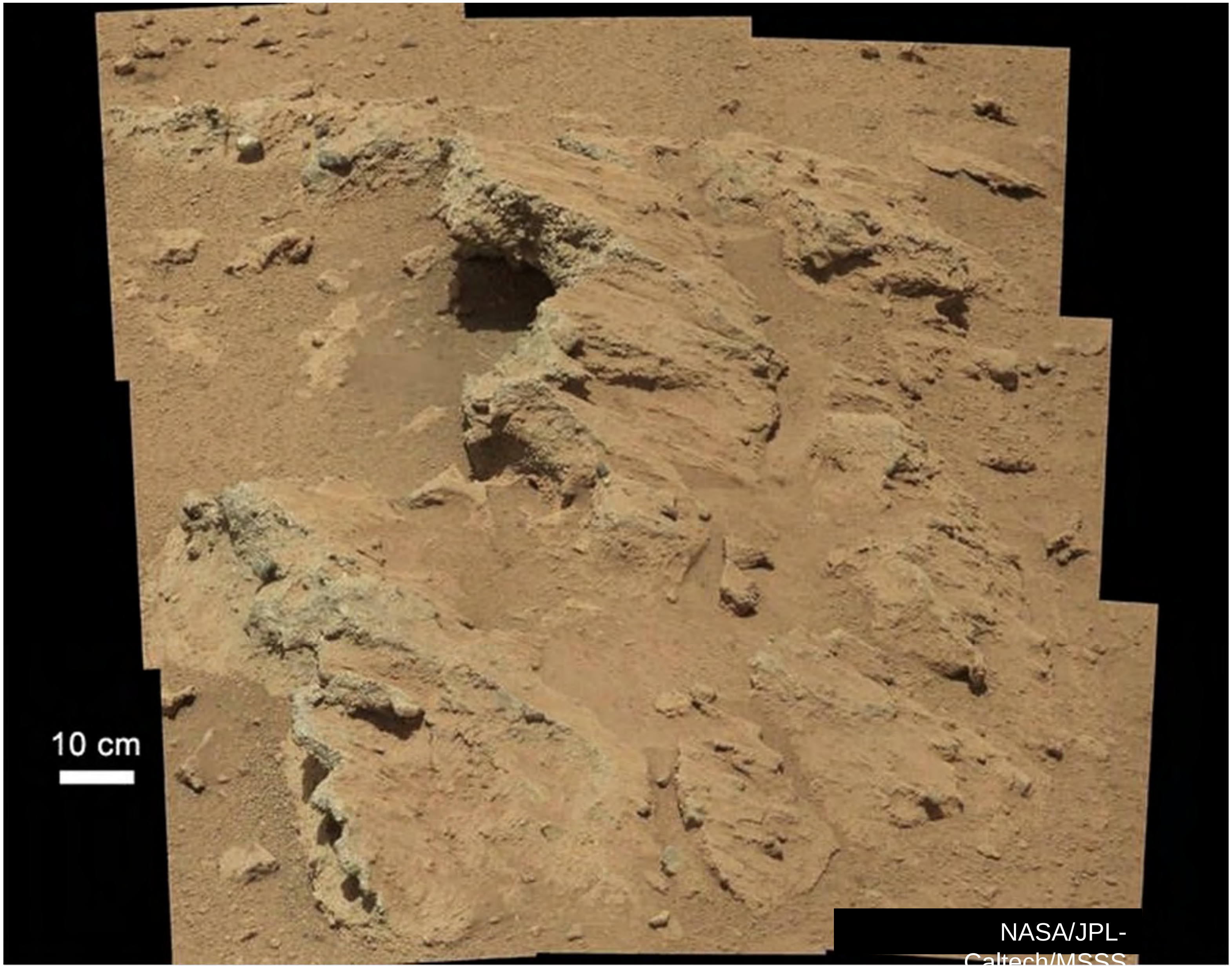
Mastcam-100 image of Mount Sharp’s layers, canyons and buttes



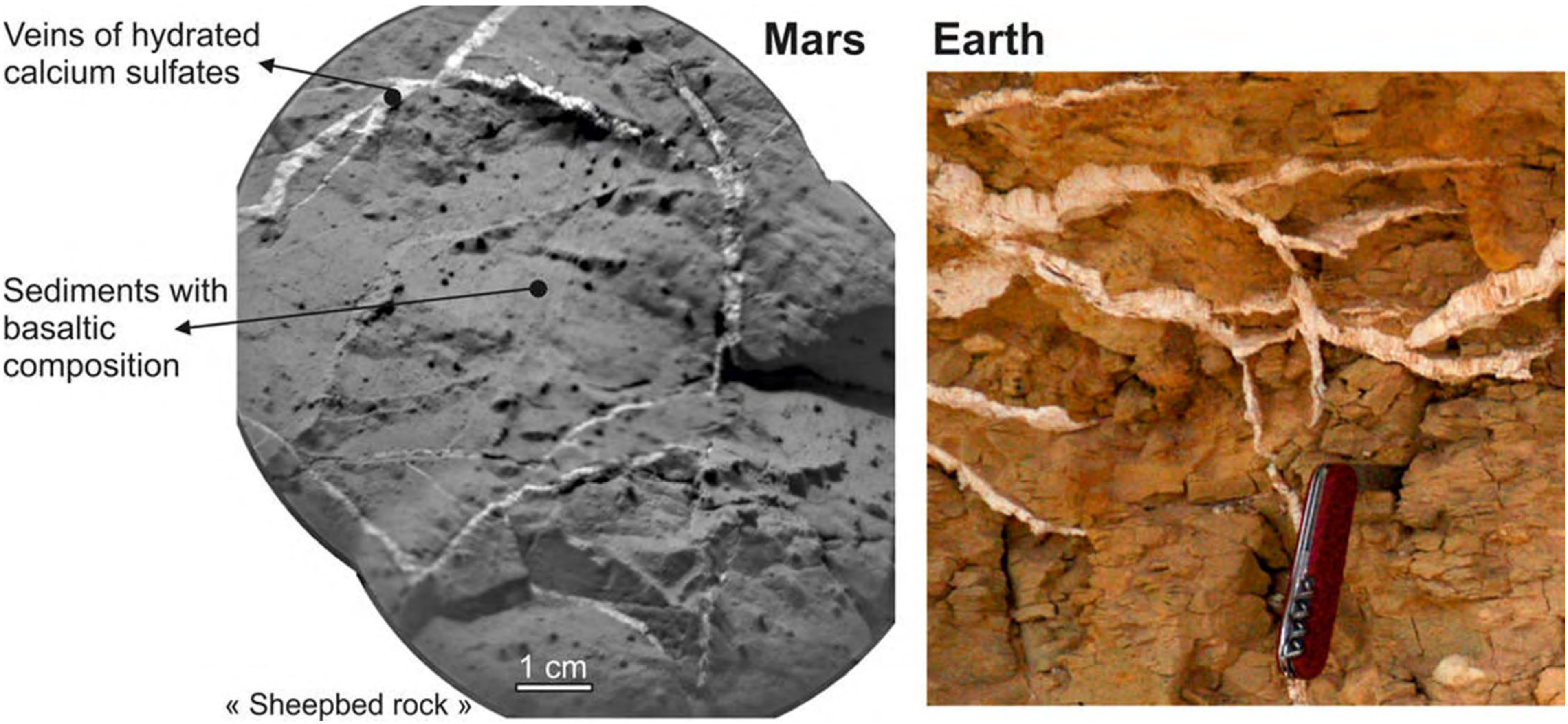
NASA/JPL-

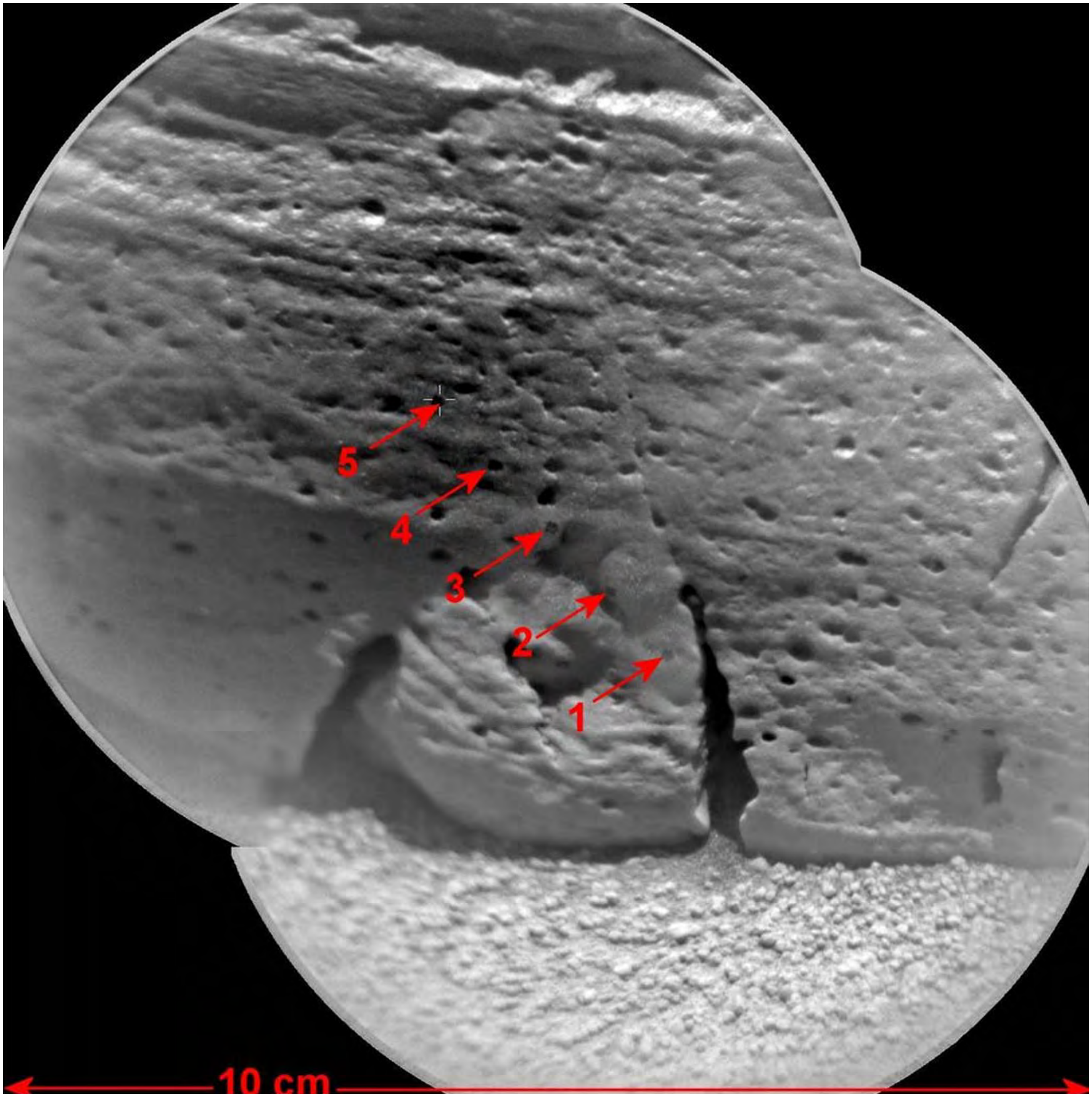
The Goulburn scour revealed the first look at underlying bedrock

The conglomerate “Link” with associated loose, rounded pebbles



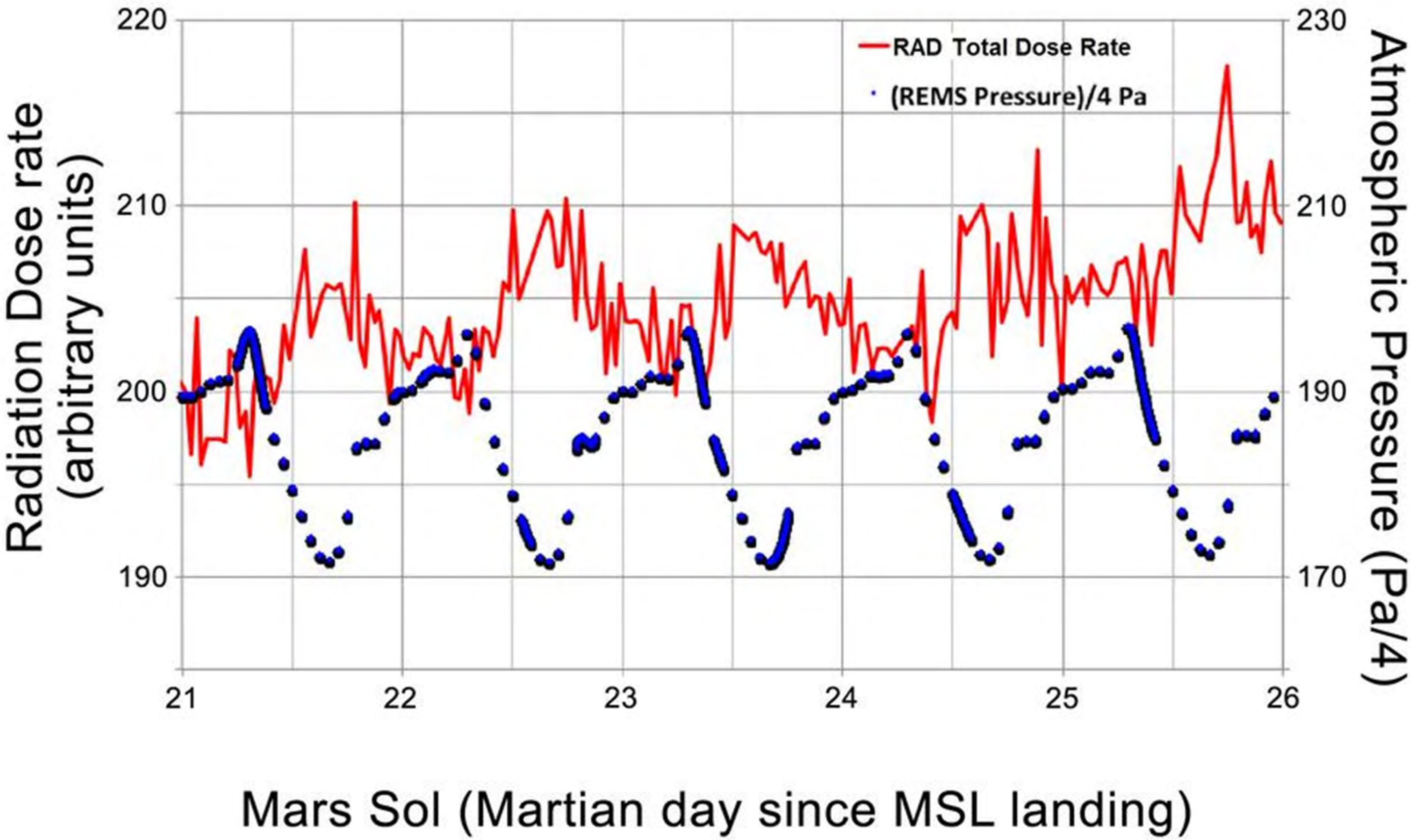
“Hottah” reveals additional conglomerate

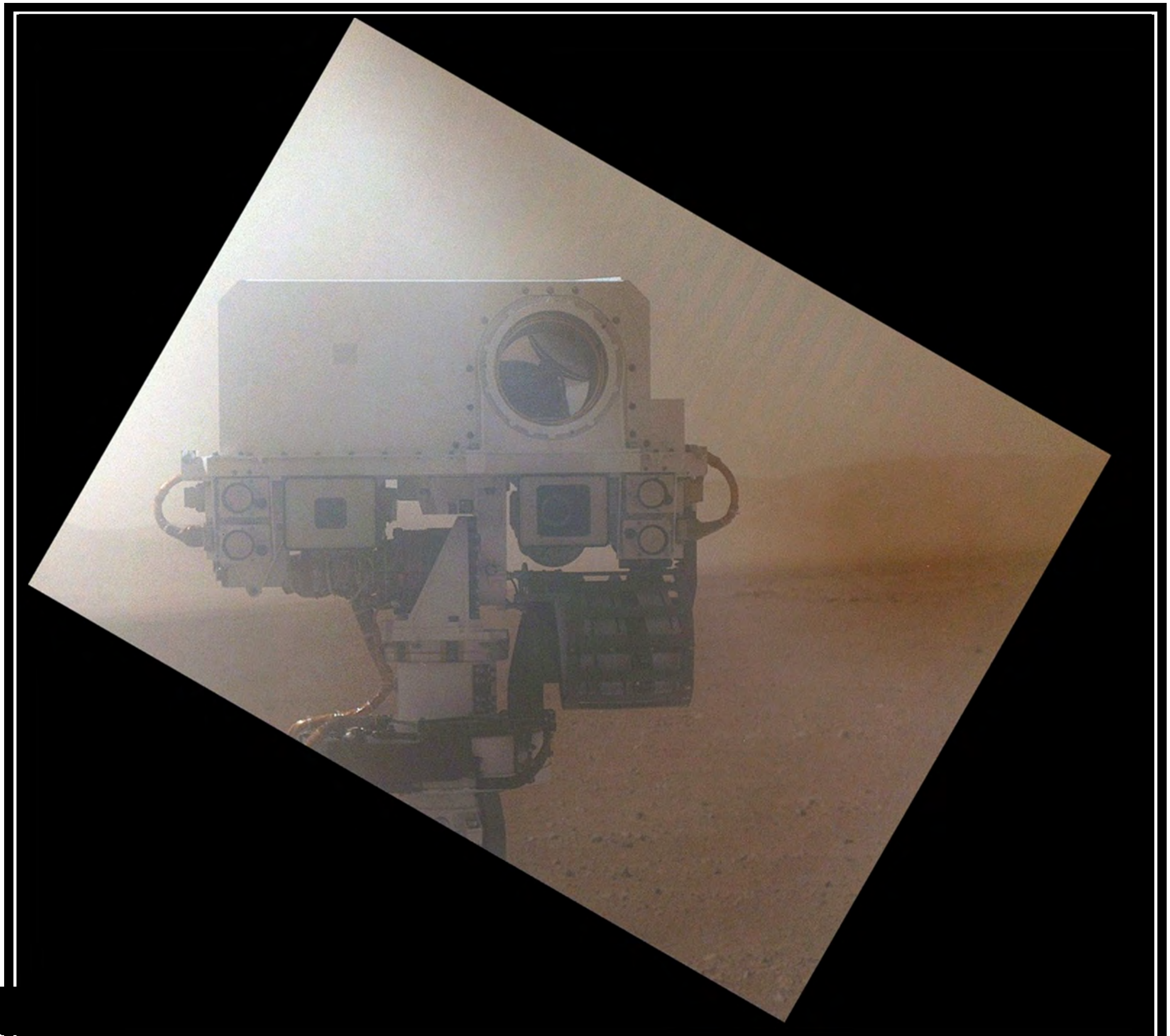

Veins of hydrated calcium sulfates
Sediments with basaltic composition
1 cm
« Sheepbed rock »
Mars
Earth



ChemCam
Laser Raster

Daily Variation of Radiation Dose on the Mars Surface





NASA/JPL-Caltech/MSSS

Curiosity self-portrait using the arm-mounted Mars Hand-Lens Imager, through dust cover

Learn More about Curiosity

Mars Science Laboratory

http://mars.jpl.nasa.gov/msl

MSL for Scientists

http://msl-scicorner.jpl.nasa.gov

Mars Exploration Program

http://mars.jpl.nasa.gov

MSL Candidate Landing Sites

http://marsoweb.nas.nasa.gov/landingsites

http://webgis.wr.usgs.gov/msl

Version: 1/11/2011

Contact: Ashwin Vasavada, JPL
ashwin@jpl.nasa.gov

Caltech/JPL holds patents for the Skycrane landing system and MSL rover
Skycrane: patent protected (US D505,105)
MSL rover: patent pending (US Pat Ser D29/342,596 and D29/342,598)