Six Wheels on the Ground:

NASA's Mars Rovers

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Brian Wilcox

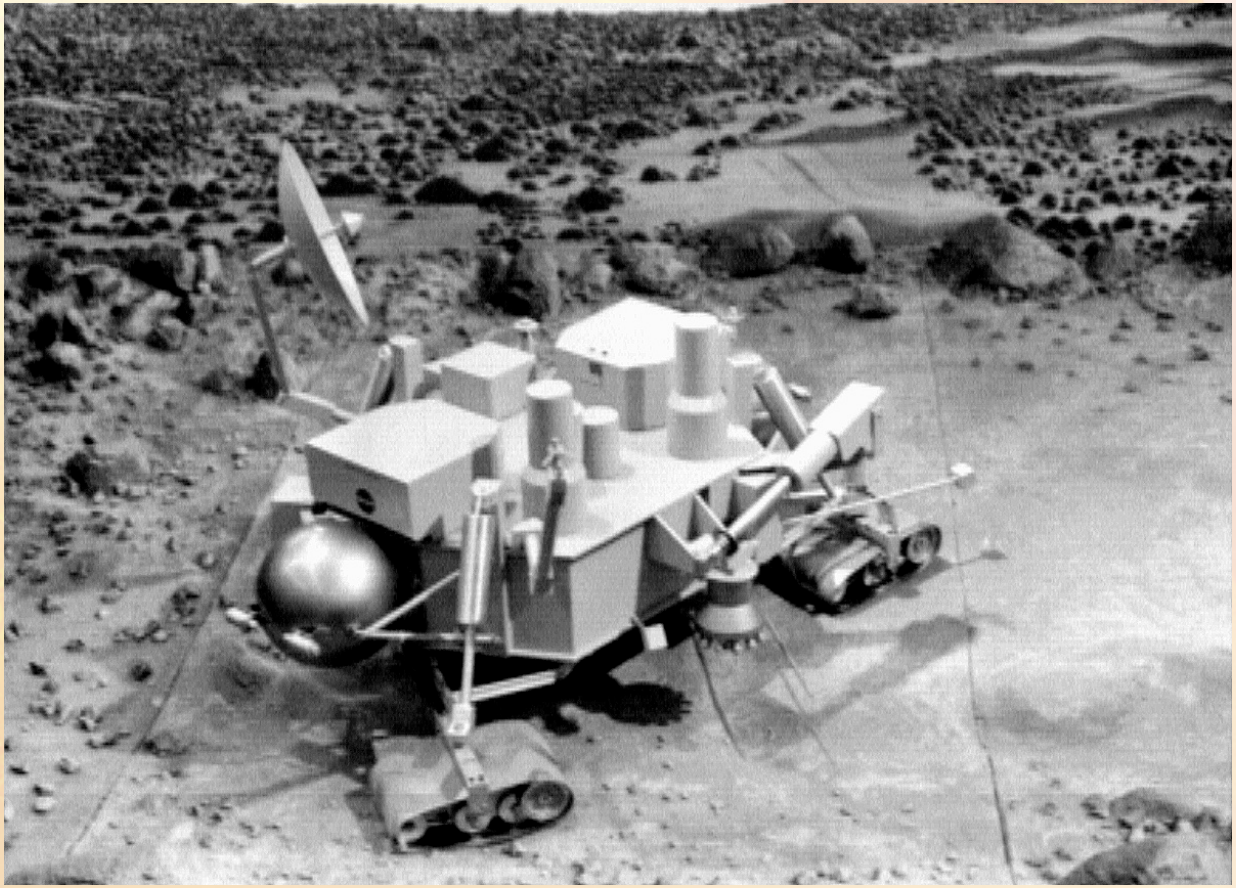
Family Portrait

“In the Beginning…”

- *The first golden age of Mars Exploration culminated with the Viking lander missions in 1976*
  - *Significant increase in understanding of Mars surface environment*
  - *Clear recognition of limitations inherent in static landers*
- *Interest in surface mobility increased dramatically & immediately*
  - *Suspension/mechanical design concepts relied on large scale vehicle heritage from Apollo*
  - *Key technology challenge was control & sensing approach*
    - *JPL and RPI started efforts to develop technology to detect and avoid hazards using on-board sensing and processing*
    - *Because the round-trip time delay to Mars can range from 7-30 minutes, the "move and wait" strategy would not work for Mars.*
    - *Human operator on Earth was in a "supervisory“ role in choosing goal locations and activity sequences.*
    - *Using off-board processing by some of the largest mainframe computers then available, the robot could barely navigate as fast as it would under Earth-based "move and wait" control.*
- *Progress slowed when NASA priorities shifted away from Mars exploration in late ‘70s/early ‘80s*

Viking On Loop Wheels, 1979

- *Proposed as a follow-on to Viking ('76-77)*



Microrovers

- *In the late-80's the rover research program renewed it's focus on long-range, autonomous navigation.*
  - *Partially driven by increased interest in conducting a flagship class Mars Rover Sample Return mission*
  - *Rapid development of microelectronics made it possible to incorporate on-board processing which was greater than anything used off-board in the 70's.*
  - *This vehicle demonstrated a 100 meter autonomous traverse within about 4 hours in mid-1990, which approximately matched the requirements of MRSR.*

Robbie, 1990

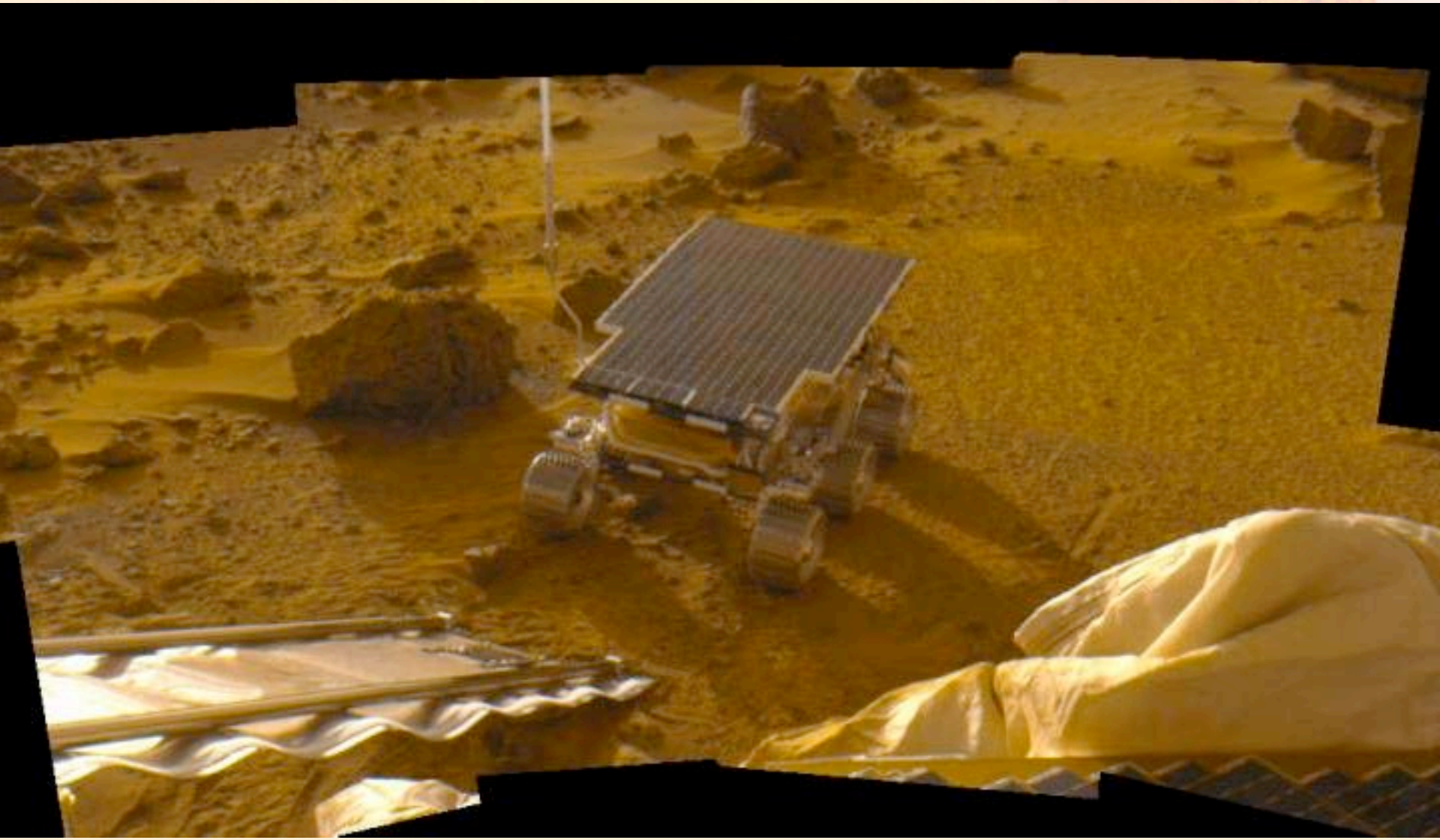
- *Mission planning for a Mars Rover Sample Return mission concluded that the such a mission could cost $10 billion or more and was deemed unrealistic*
- *Planning turned toward landing multiple smaller landed instrument packages to perform in-situ analysis*
  - *Microrovers, with a mass of around 10 Kg or less, were first proposed in late 1986*
  - *The range of the initial microrovers would be small so Computer Aided Remote Driving was considered as a control approach*

SOJOURNER

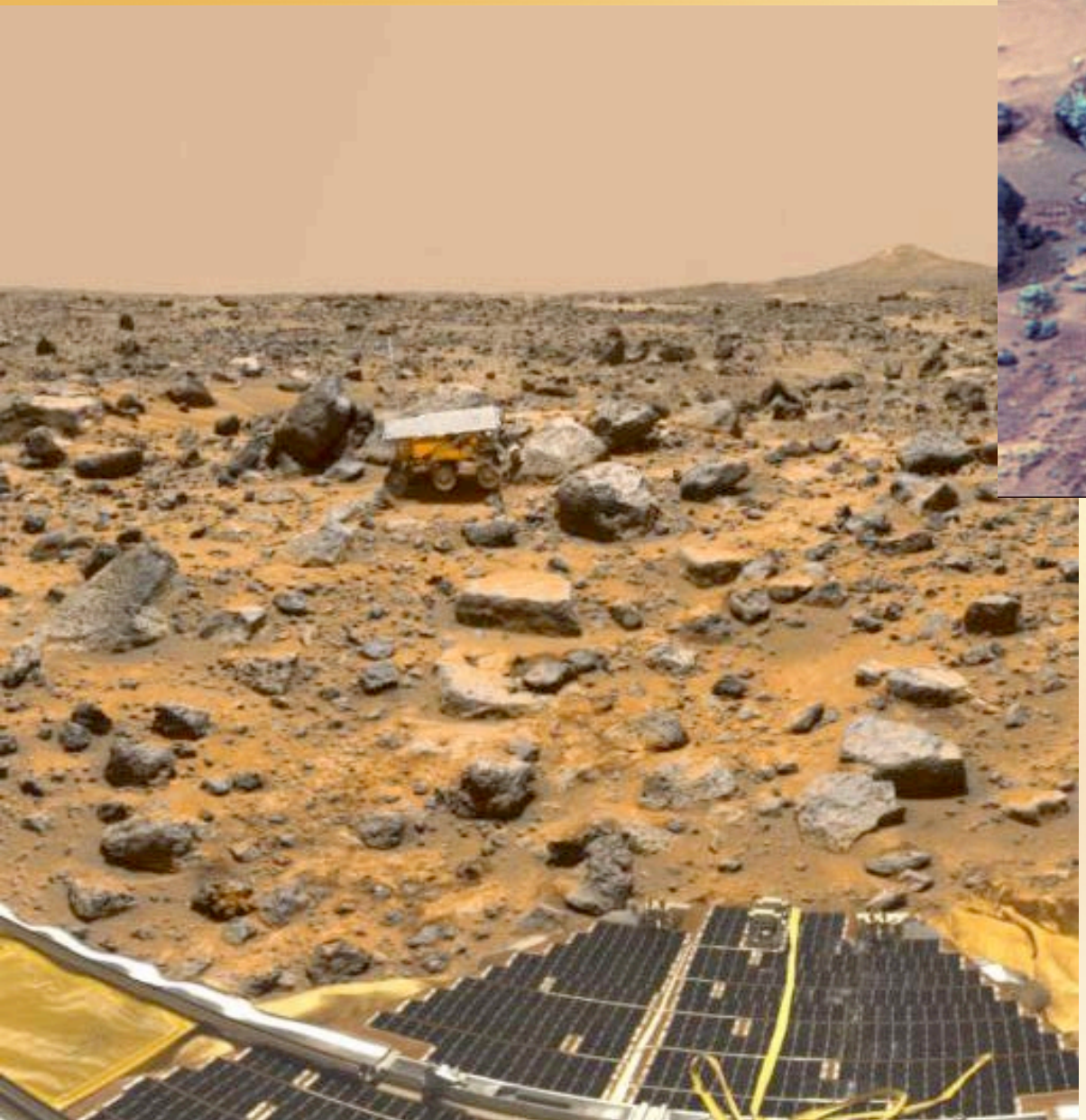
Sojourner

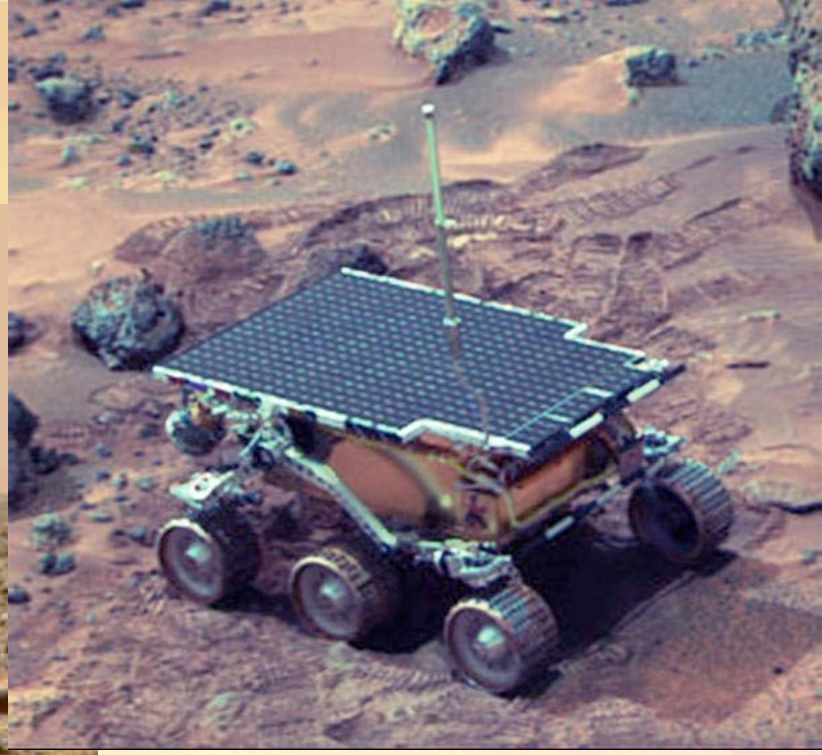
- *The first attempt to demonstrate microrover technology on Mars was the Mars Pathfinder Sojourner rover.*
- *Mission objectives*
  - *Demonstrate the feasibility and assess the performance of a mobile vehicle on the surface of Mars*
  - *Rover design life: 1 week, Lander: 1 month*
- *Design features*
  - *11.6kg single instrument mobile geologist with another 4kg of supporting equipment (e.g. transponder) on the land*
  - *Highly integrated rover design relying on an 80c86 processor for all control*
  - *The hazard avoidance sensors were CCD imagers and laser stripe projectors which allow a wide range of plausible terrain hazards to be detected prior to a possible fatal engagement with the vehicle.*
- *Mission Performance*
  - *Landed on July 4, 1997*
  - *Met all mission performance requirements, operated for >90 days and was a technical, scientific and public relations success*

First Tracks



Driving



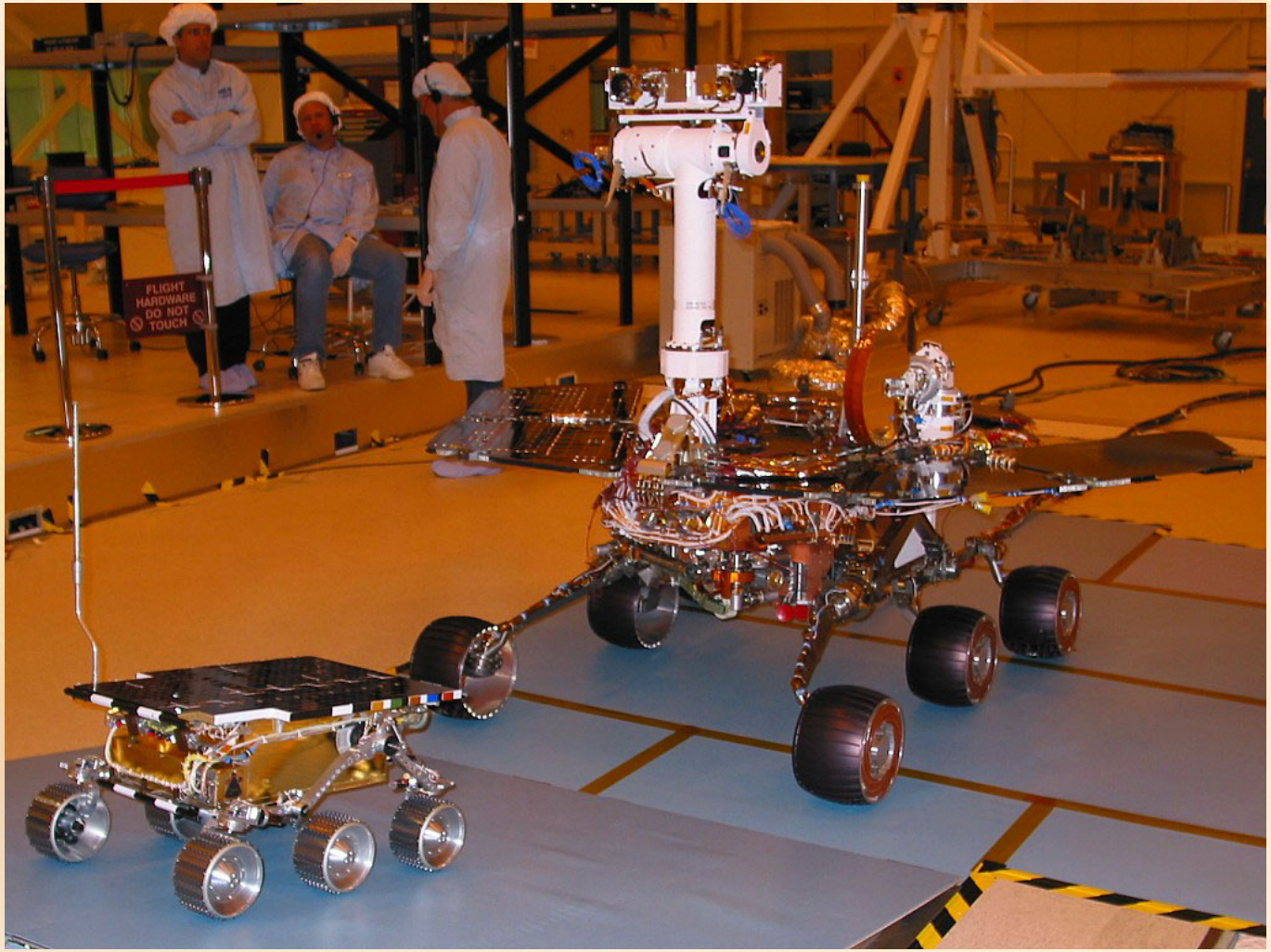


MARS EXPLORATION ROVER (aka SPIRIT & OPPORTUNITY)

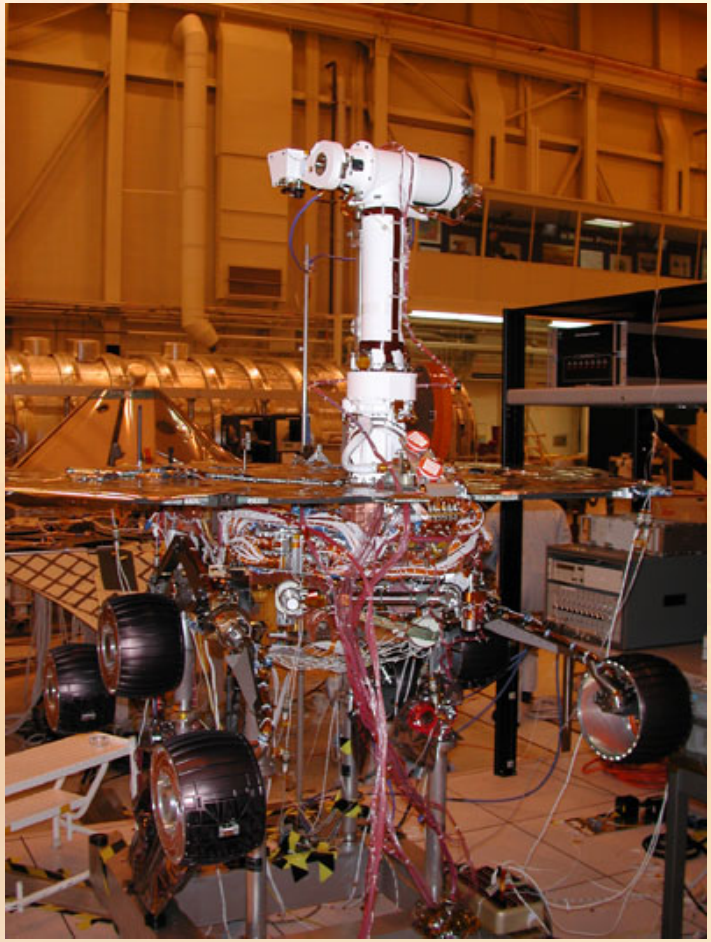
Mars Exploration Rovers

- *Conceived in 2000 as a rebuild of Mars Pathfinder with a new rover design that integrated all the operational electronics into the mobile vehicle.*
  - *Evolved into a twin, single string rover missions with an almost completely new design*
  - *90 day nominal design life*
- *Mission objectives*
  - *Determine the history of climate and water at two sites where conditions may once have been favorable to life*
- *Design features*
  - *Pathfinder-like entry, descent and landing, with addition of terminal horizontal sensing and correction capability*
  - *180 kg mobile field geologist*
  - *Highly integrated rover design due to constraints of the Pathfinder aeroshell and lander*
- *Mission Performance*
  - *Spirit landed on January 4, 2004*
  - *Opportunity landed on January 24,*
  - *Both missions have been technical, scientific and public relations successes*

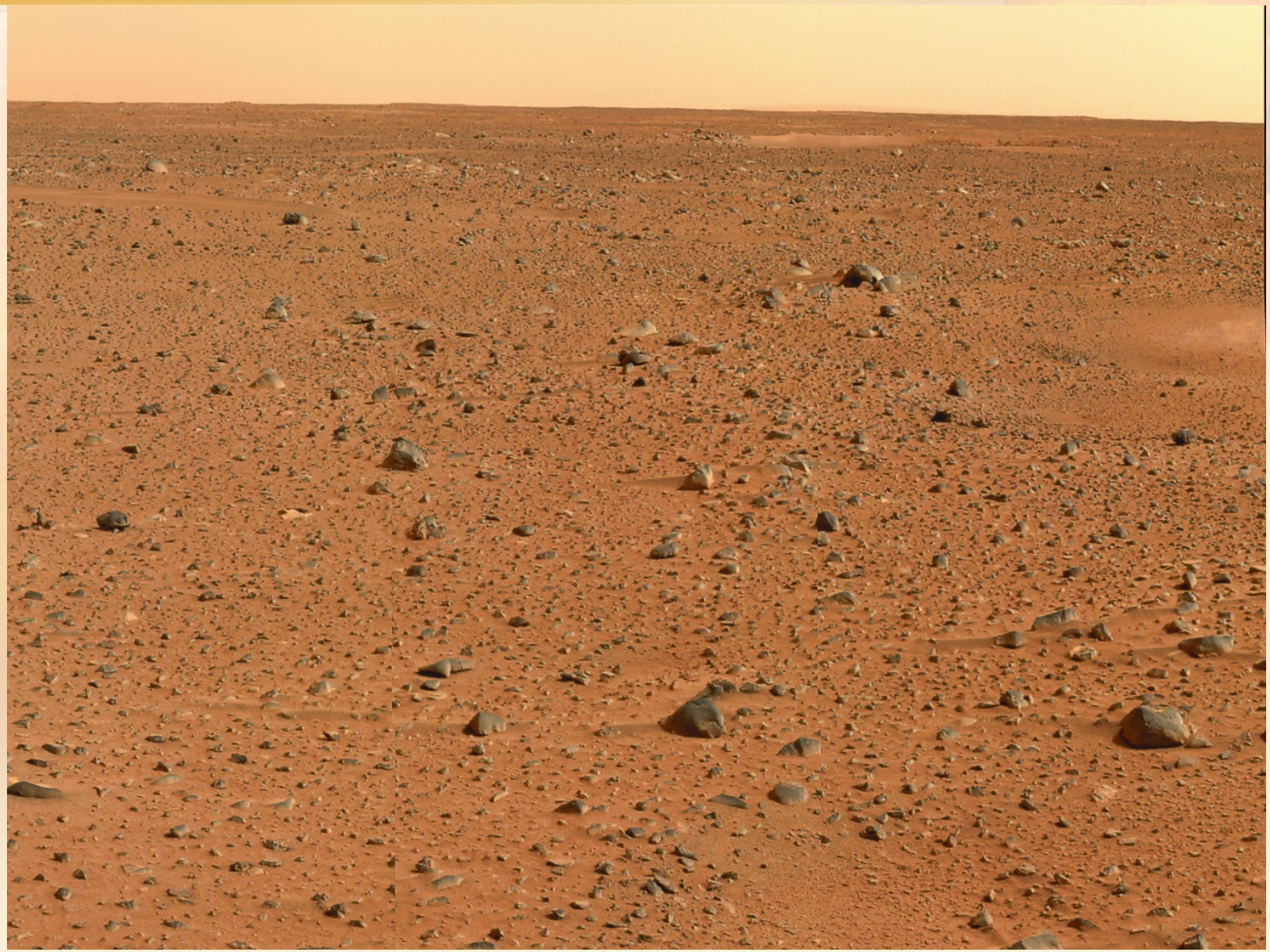
Marie Curie and Spirit



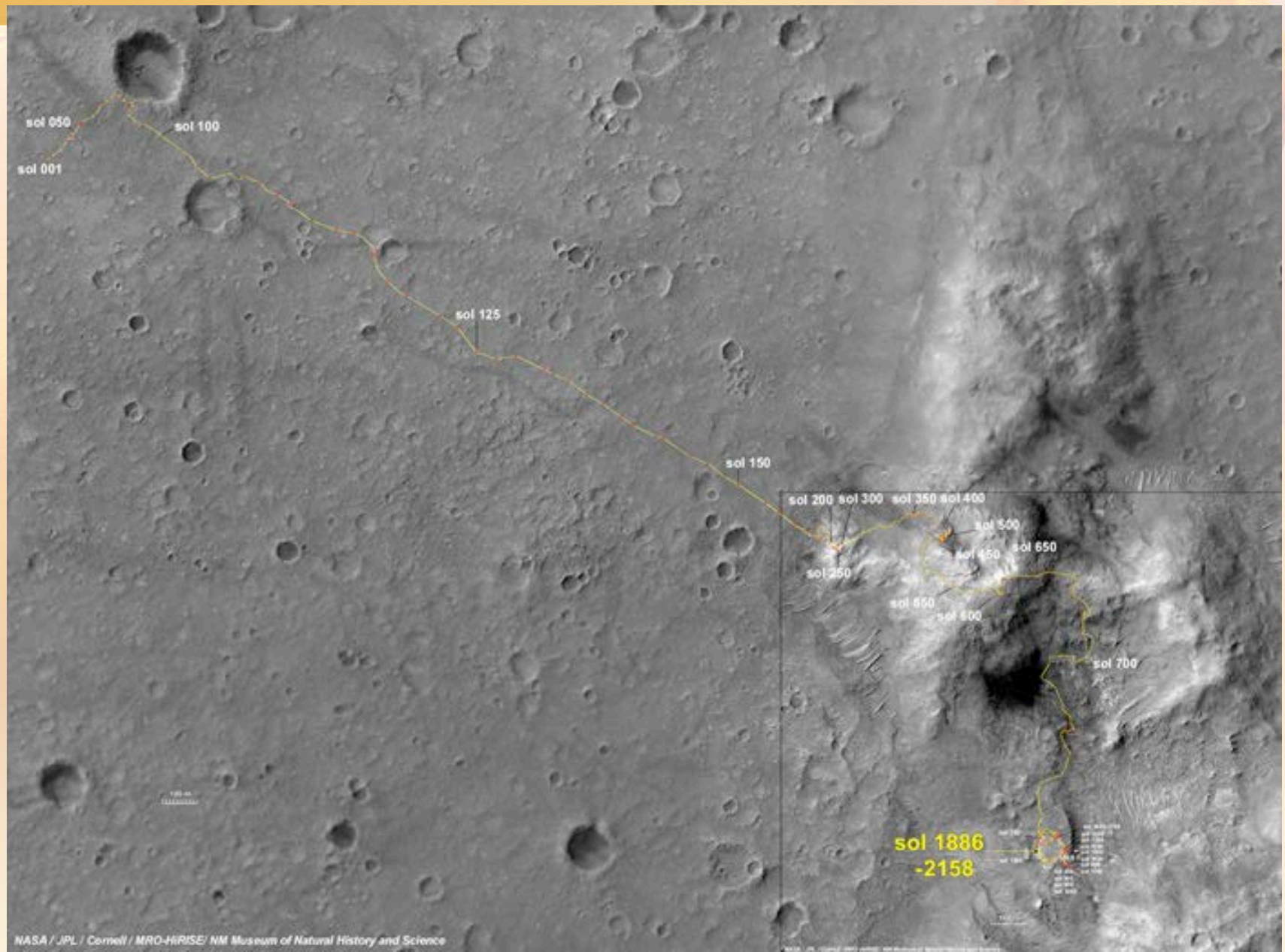
MER Hardware



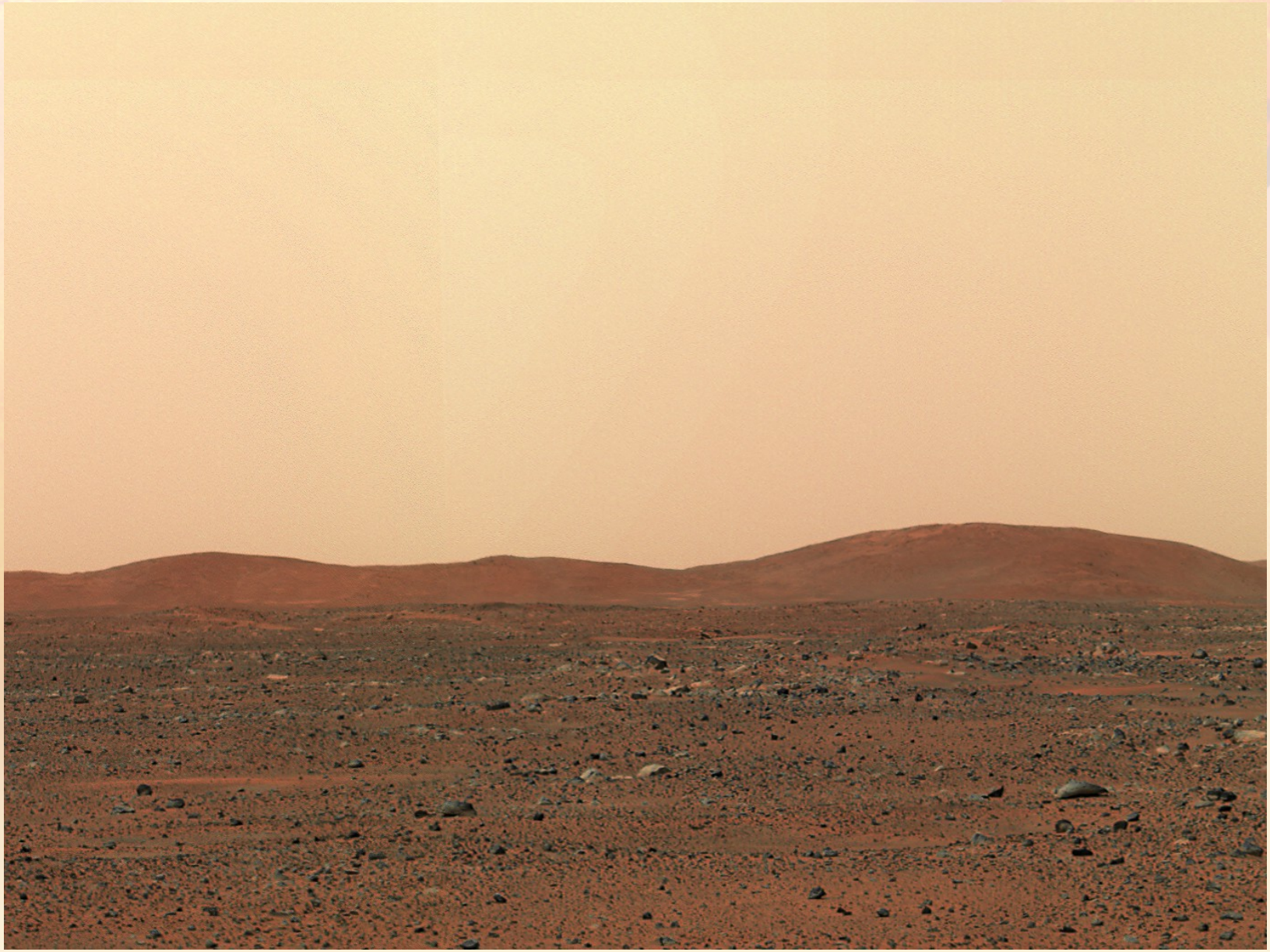
Spirit Landing Site



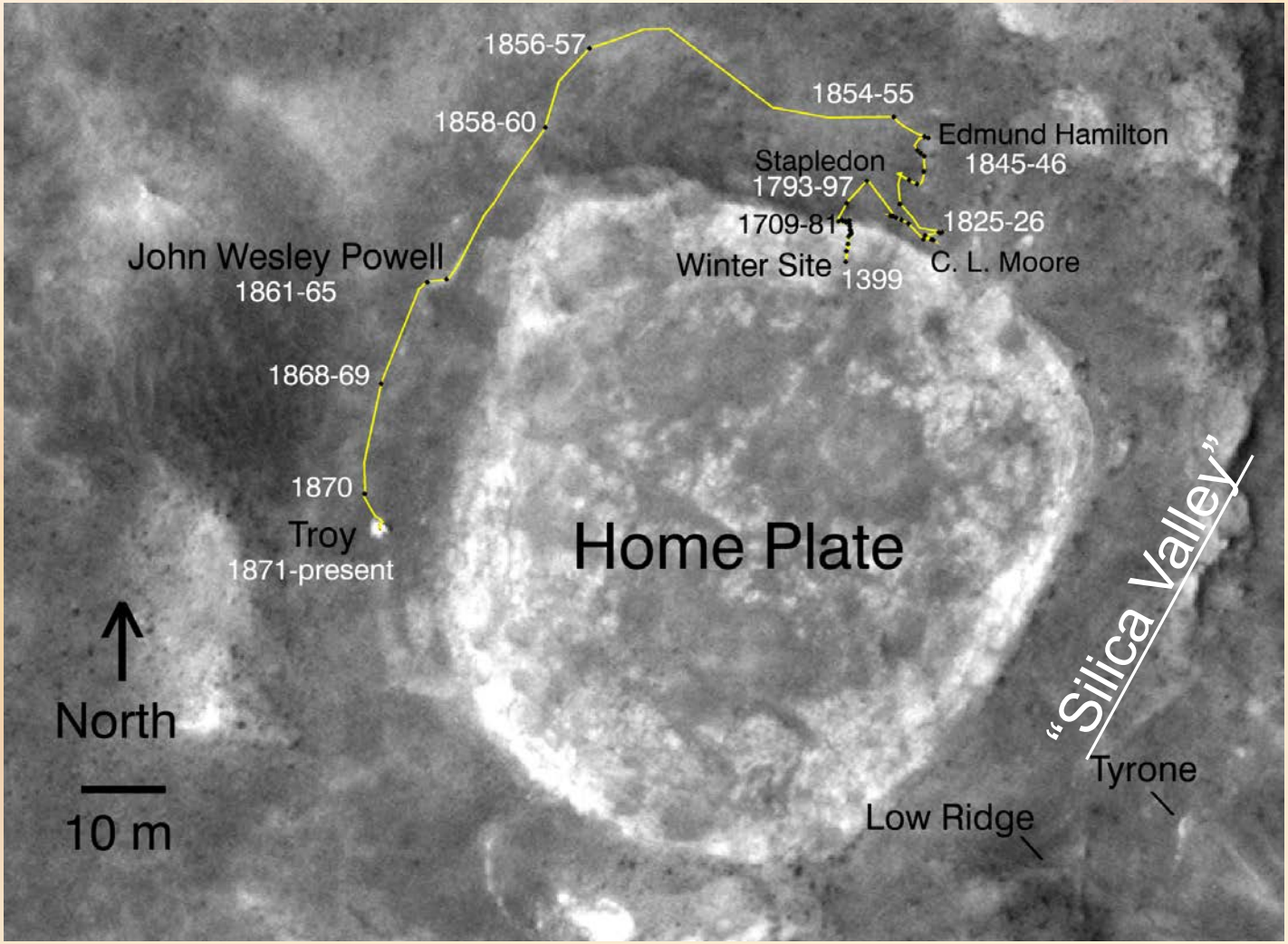
Spirit Traverse (7.7 km)



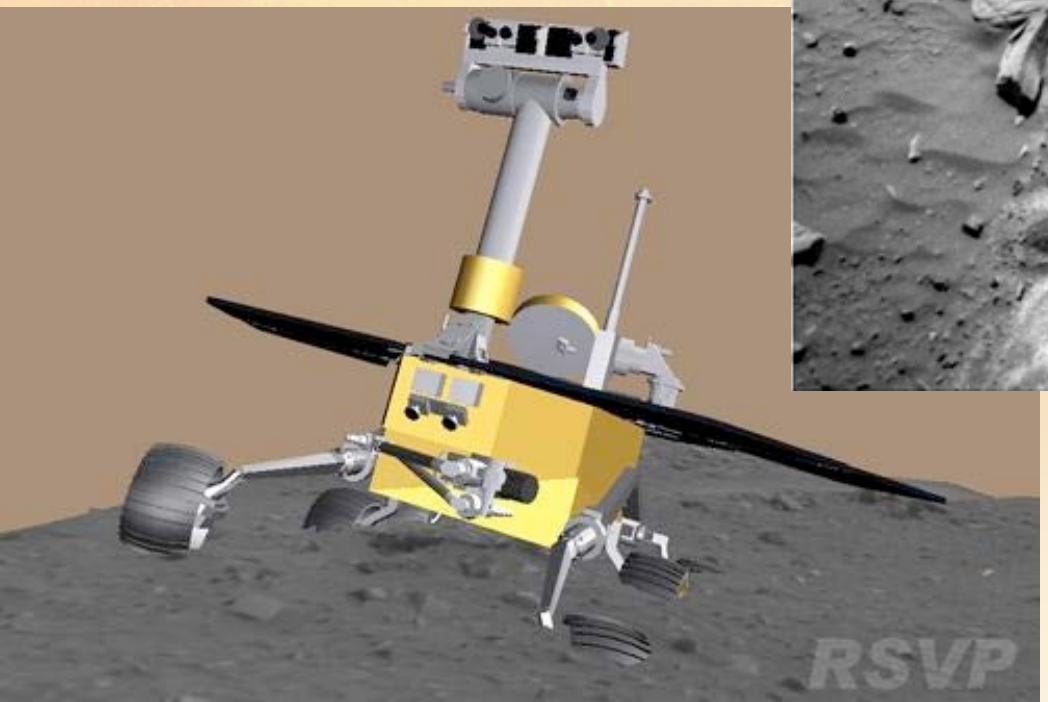
The Columbia Hills



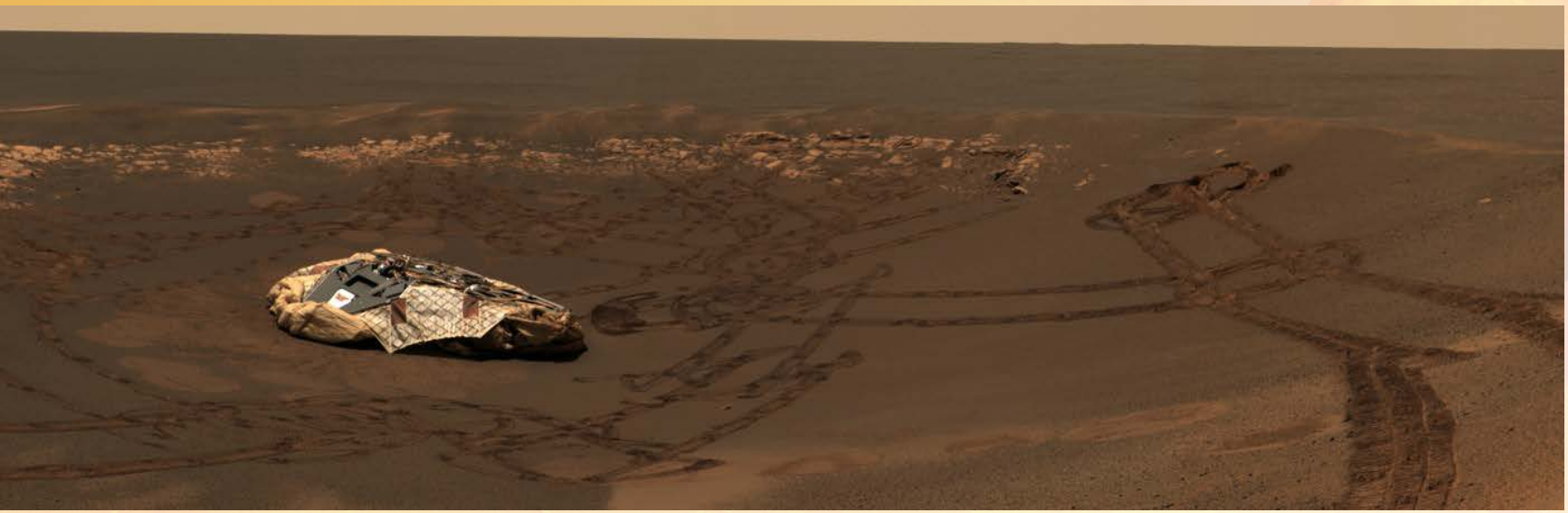
Home Plate

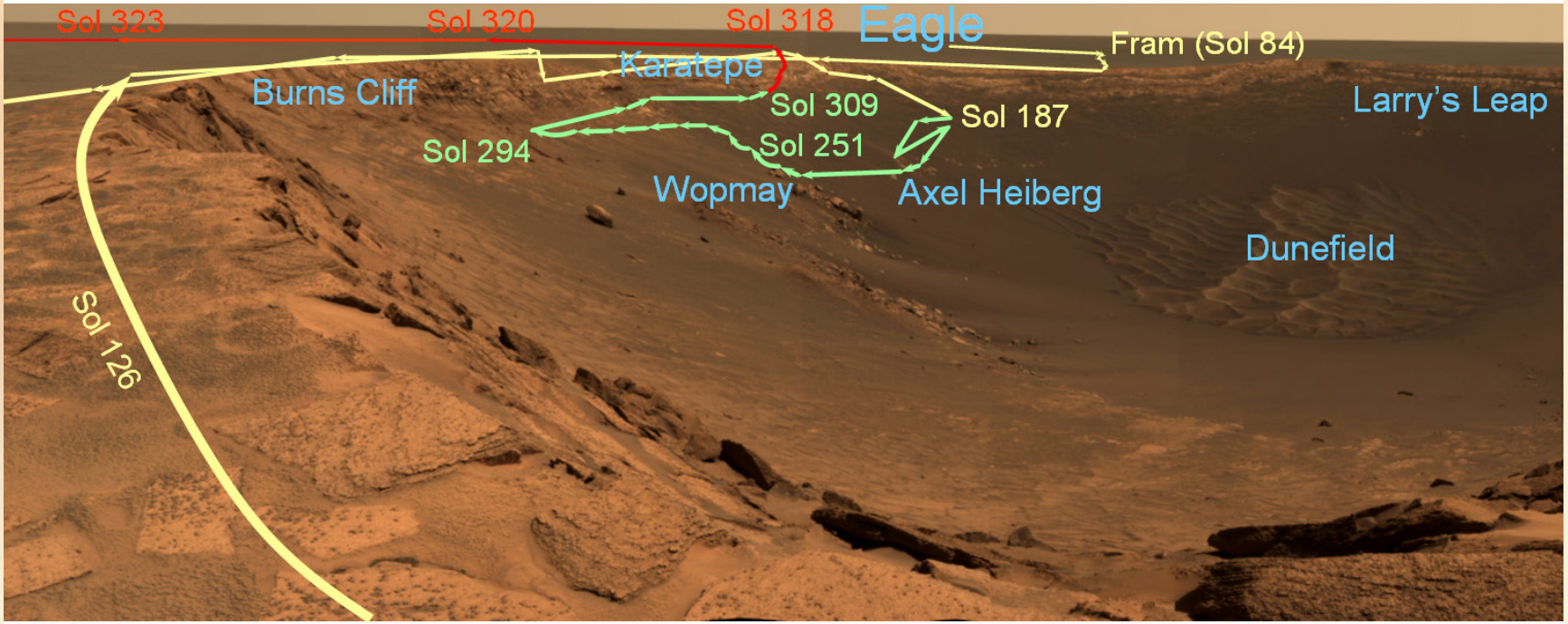

1856-57
1854-55
1858-60
Edmund Hamilton
1845-46
Stapledon
1793-97
1709-81
1825-26
John Wesley Powell
1861-65
Winter Site
1399
C. L. Moore
1868-69
1870
Troy
1871-present
Home Plate
"Silica Valley"
North
10 m
Tyrone
Low Ridge

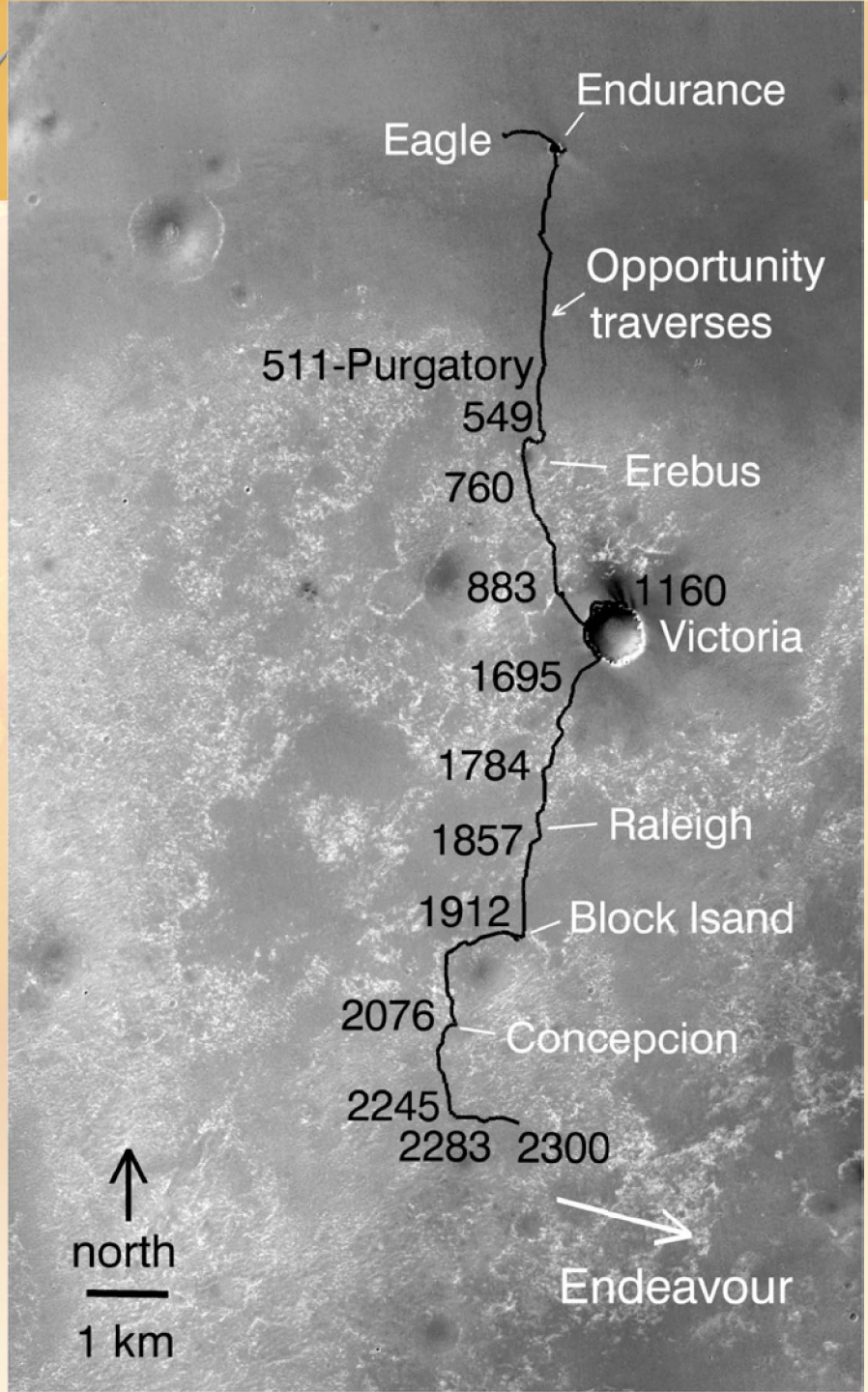
Roving Perils



Eagle and Endurance Craters







Opportunity Traverse (22 km and growing)

Opportunity
Cape Verde
Duck Bay

MARS SCIENCE LABORATORY (aka CURIOUSITY)

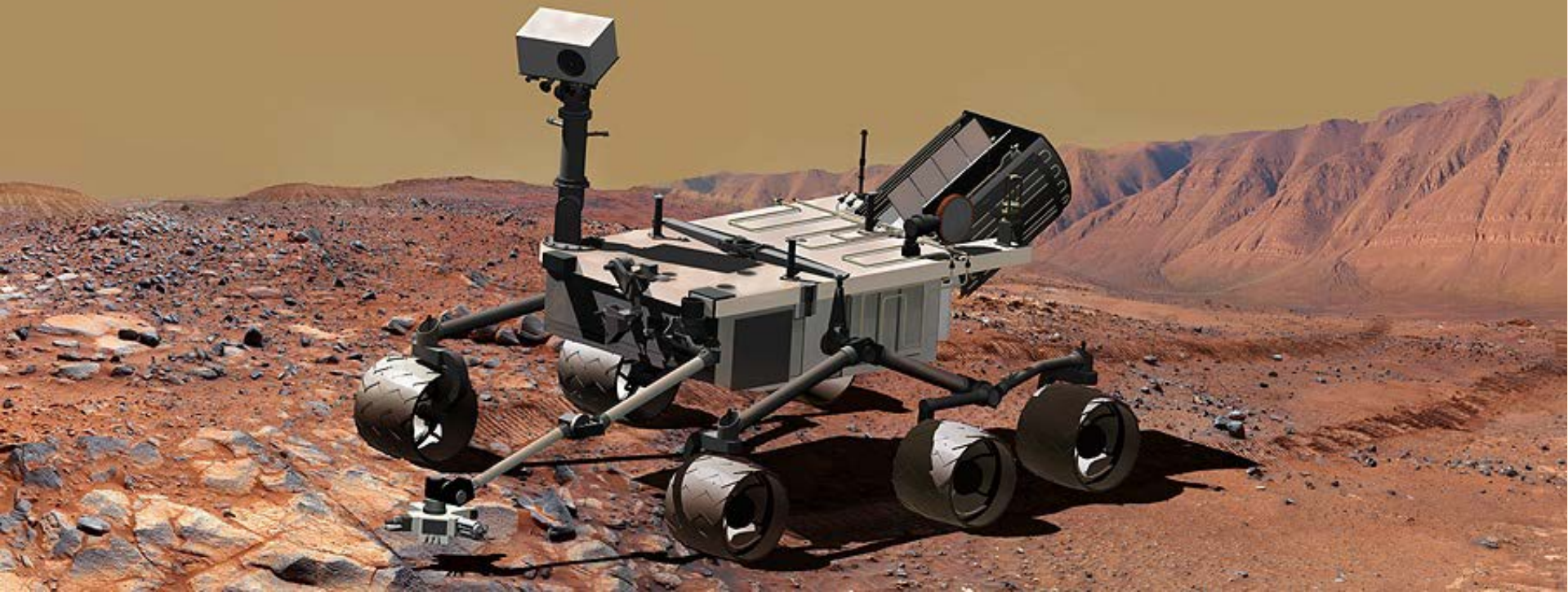
Science Objectives

Is Mars a potential habitat for life (past or present)?

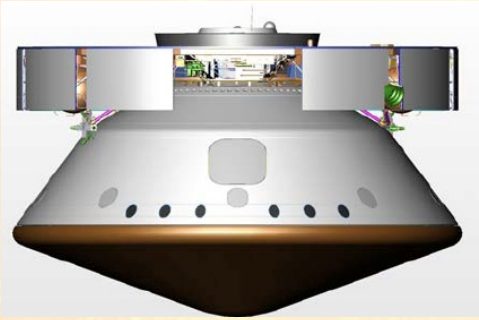
- *Address the following questions*
  - *Assess the biological potential*
  - *Characterize the geology and geochemistry*
  - *Investigate planetary processes of relevance to past habitability, including the role of water.*
  - *Characterize the broad spectrum of surface radiation, including galactic cosmic radiation, solar proton events, and secondary neutrons.*

Enabling Capabilities

- A long-lived, roving, robotic laboratory capable of visiting many sites
- Access to a wide range of candidate landing sites assessed by orbiting spacecraft
- A broad and flexible payload including advanced geochemical instruments used in Earth labs
- A system to acquire and process dozens of rock and soil samples
- An integrated science team and operations strategy



MSL Mission Overview



CRUISE/APPROACH

- 9 month cruise
- Spinning cruise stage
- Arrive N. hemisphere summer

ENTRY, DESCENT, LANDING

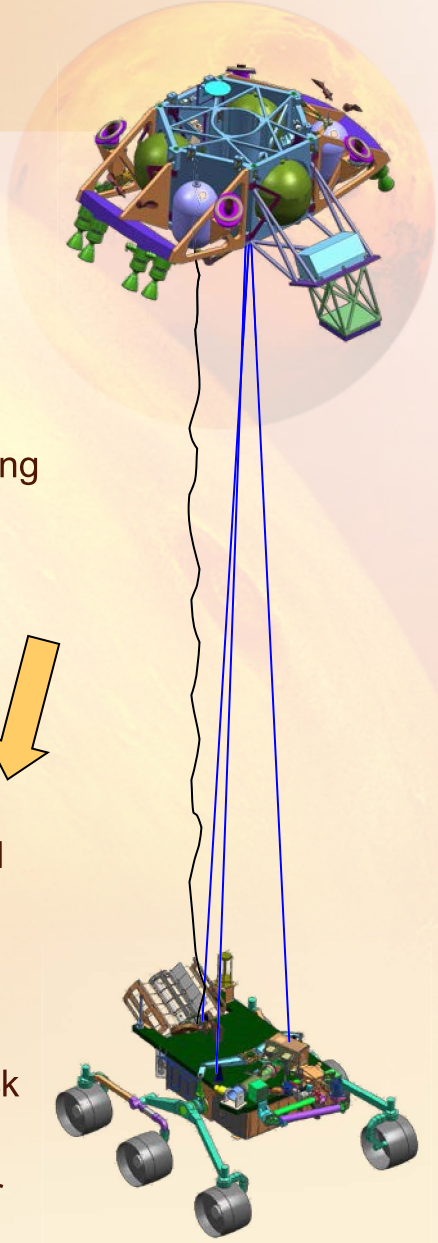
- Guided entry and controlled, powered “sky crane” descent
- 20 × 25-km landing ellipse
- Discovery responsive for landing sites ±30º latitude, <0 km elevation
- 900-kg landed mass

SURFACE MISSION

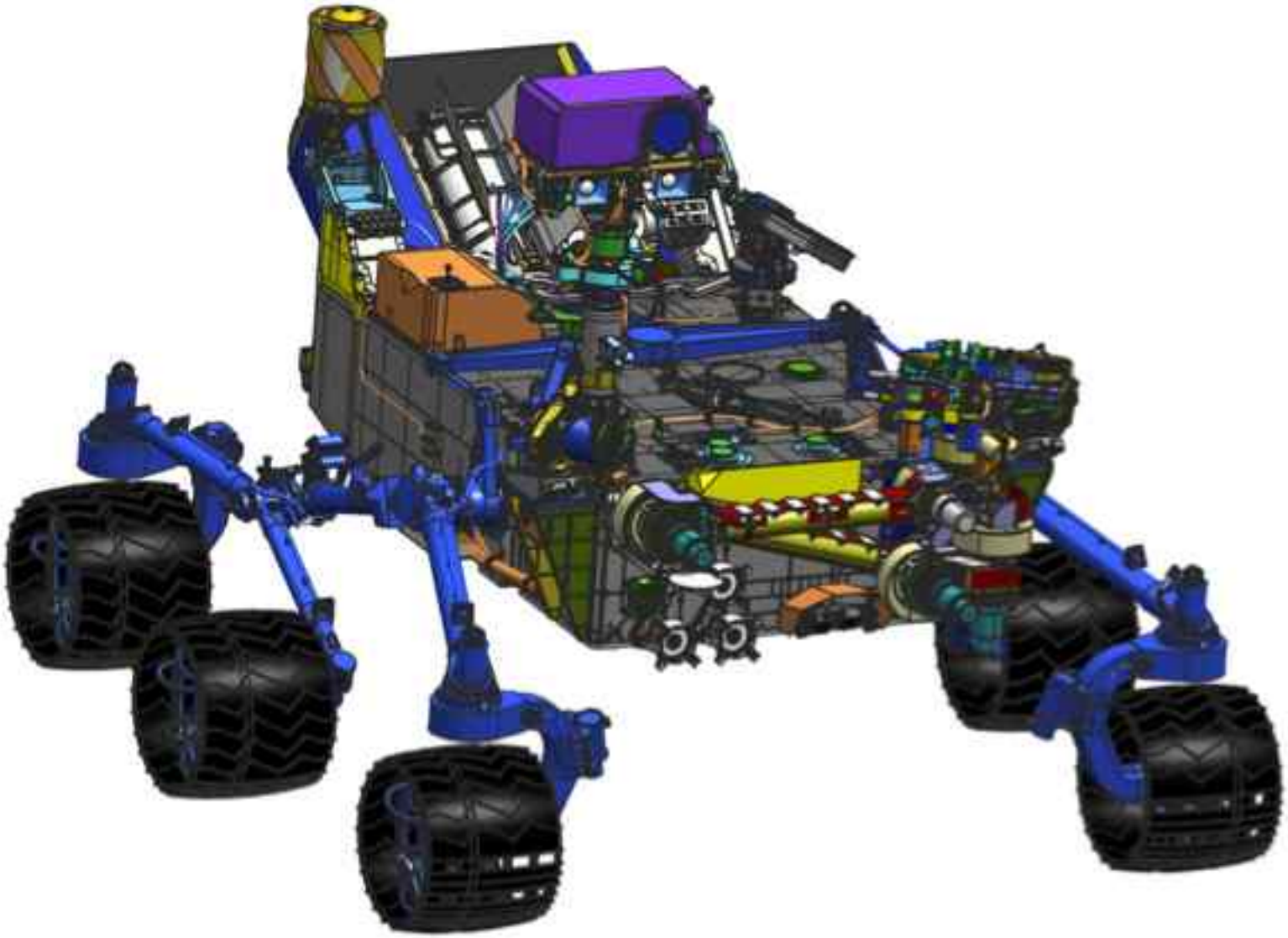
- Prime mission is one Mars year
- Latitude-independent and long-lived power source
- 20-km range
- 80 kg of science payload
- Acquire and analyze samples of rock or soil
- Large rover, high clearance; greater mobility than MPF, MER

LAUNCH

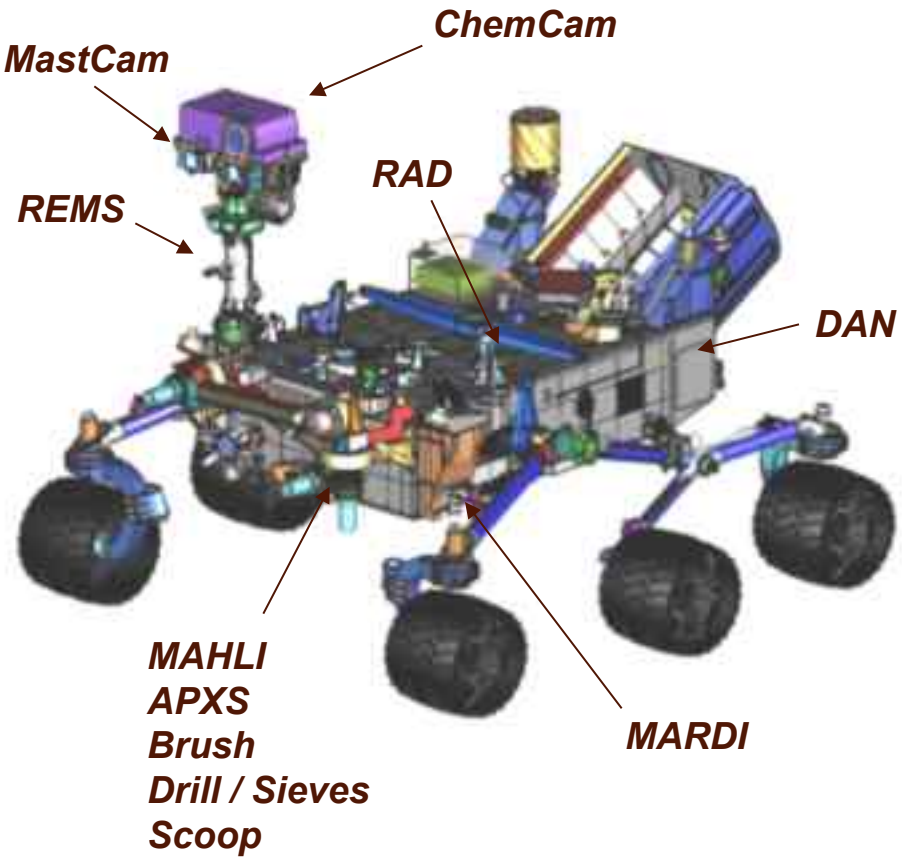
- Nov. 2011
- Atlas V (541)



Design



Payload



Wheel Base:	**2.2 m**
Height of Deck:	**1.1 m**
Height of Mast:	**2.2 m**

REMOTE SENSING

Mastcam (M. Malin, MSSS) – Narrow and wide angle color imaging, atmospheric opacity

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

CONTACT INSTRUMENTS (ARM)

MAHLI (K. Edgett, MSSS) - Microscopic 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

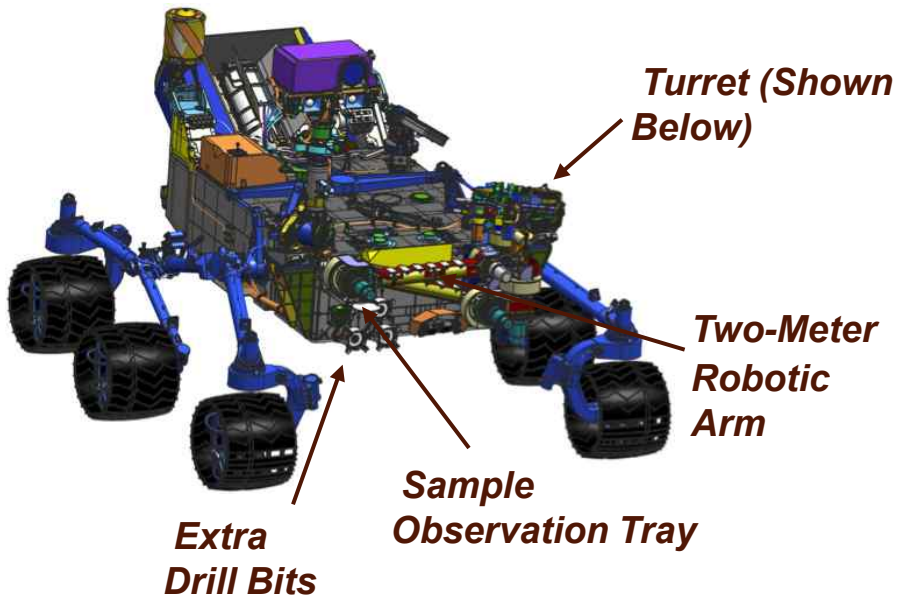
MARDI (M. Malin, MSSS) - Descent imagery

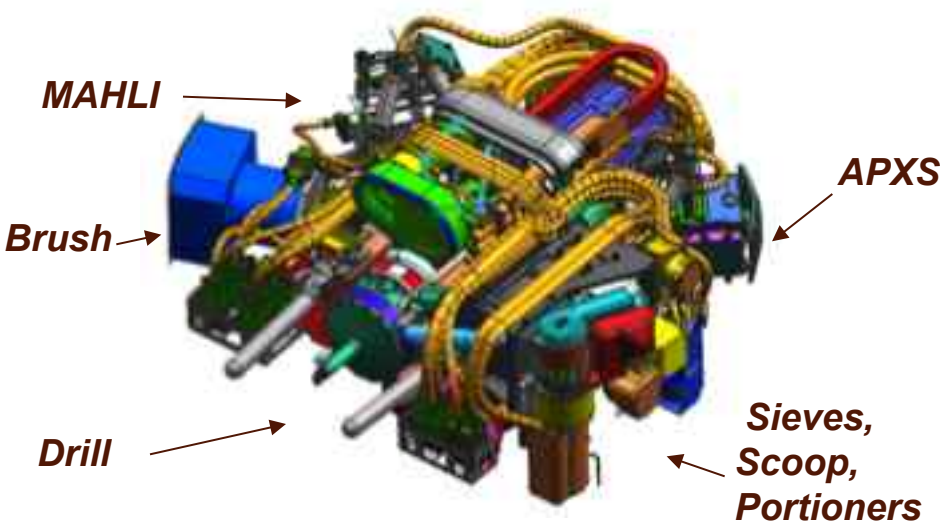
REMS (J. Gómez-Elvira, CAB, Spain) - Meteorology / UV

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

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

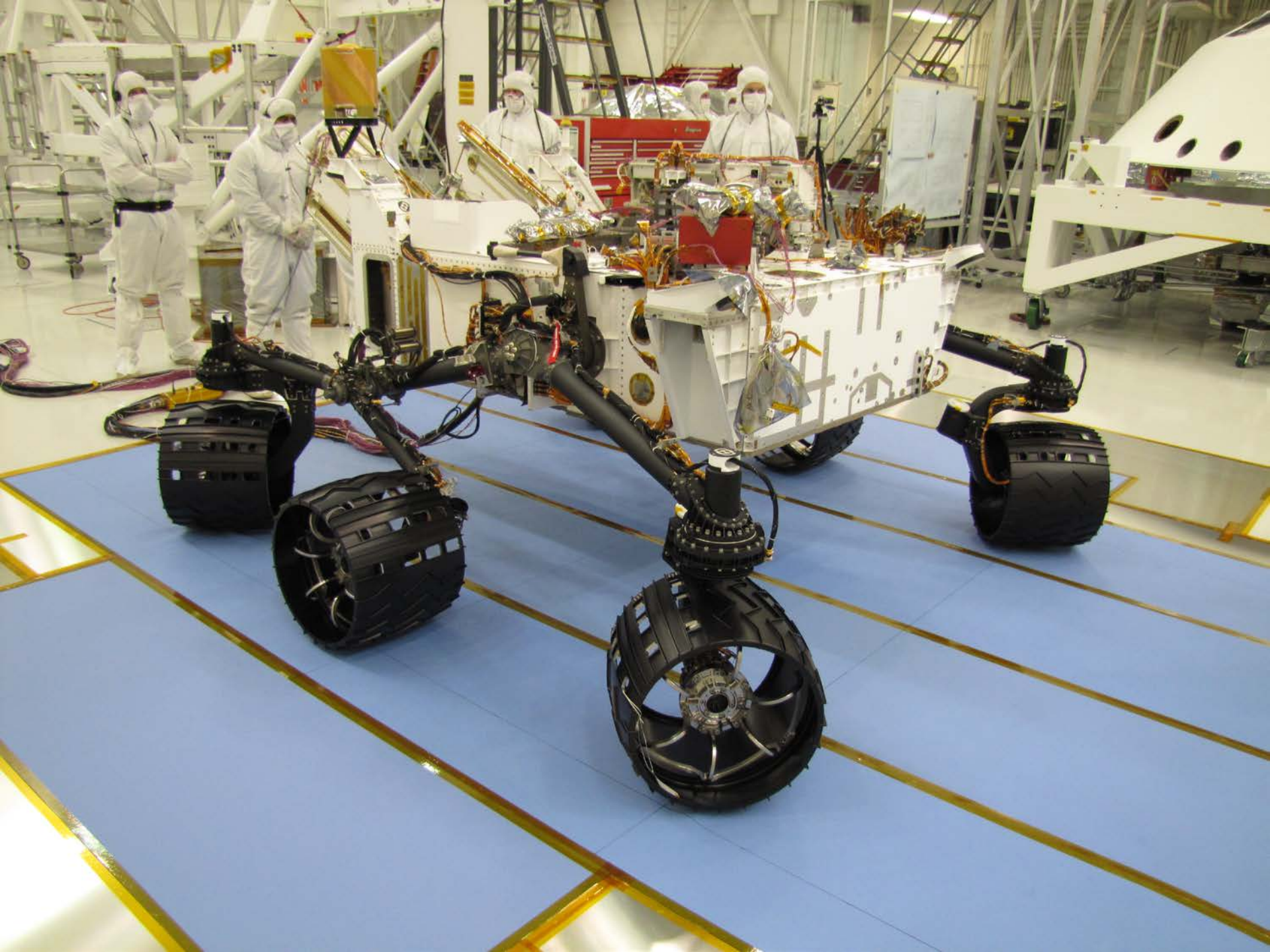
Sample Acquisition, Processing, & Handling





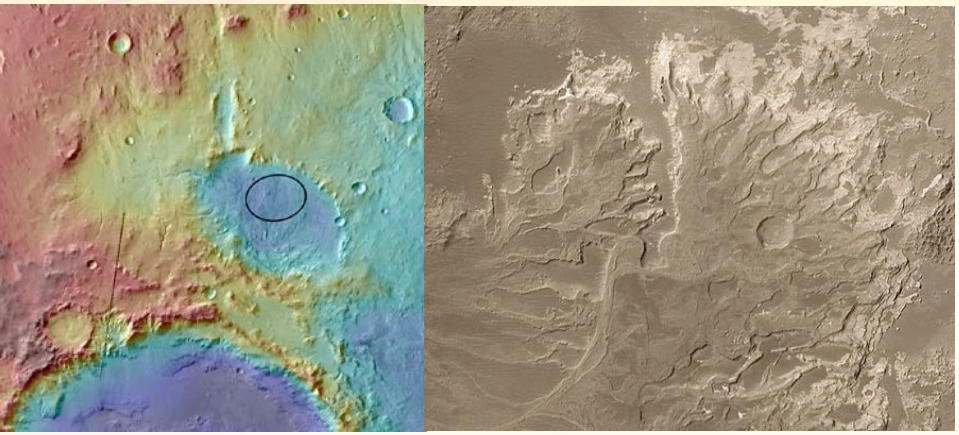
MSL's sampling system can:

- Brush rock surfaces
- Place and hold contact instruments
- Acquire samples of rock or soil via powdering drill and scoop
- Sieve samples into fines and deliver the processed material to the analytical lab instruments
- Place sample material on an observation tray
- Exchange drill bits

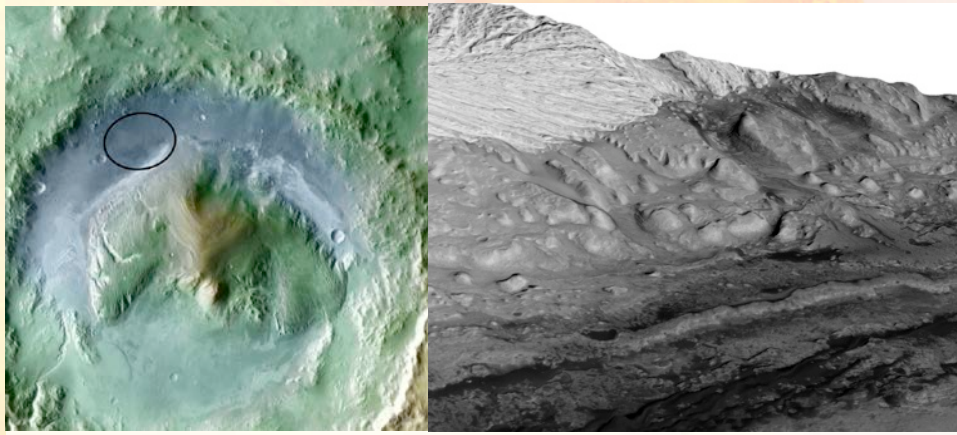


DANGER
KEEP OUT
3-3053
DANGER

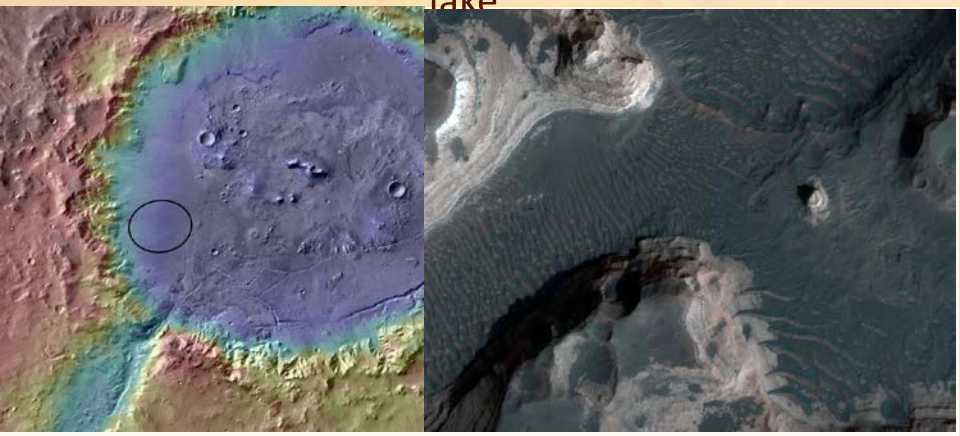
Four Candidate MSL Landing Sites



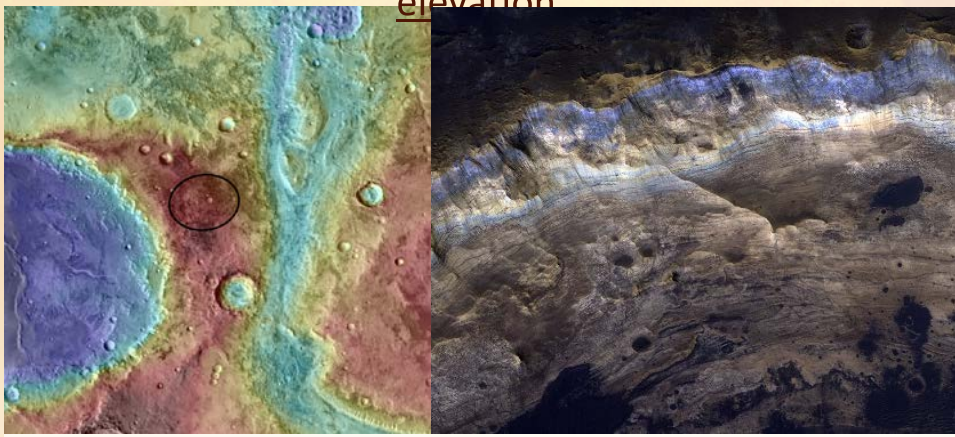
Eberswalde Crater (24° S, 327° E, -1.5 km) contains a clay-bearing delta formed when an ancient river deposited sediment, possibly into a lake



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.