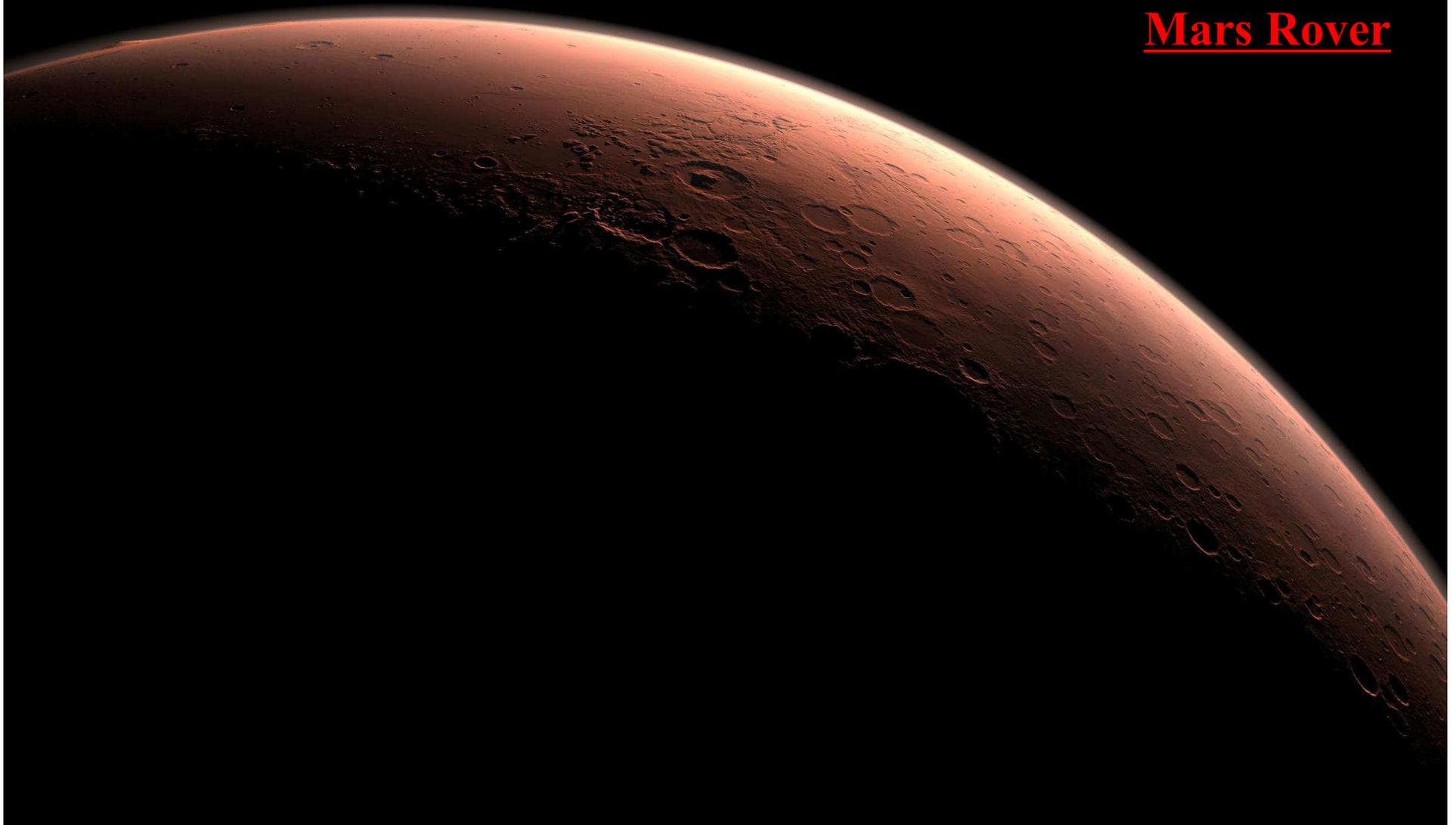
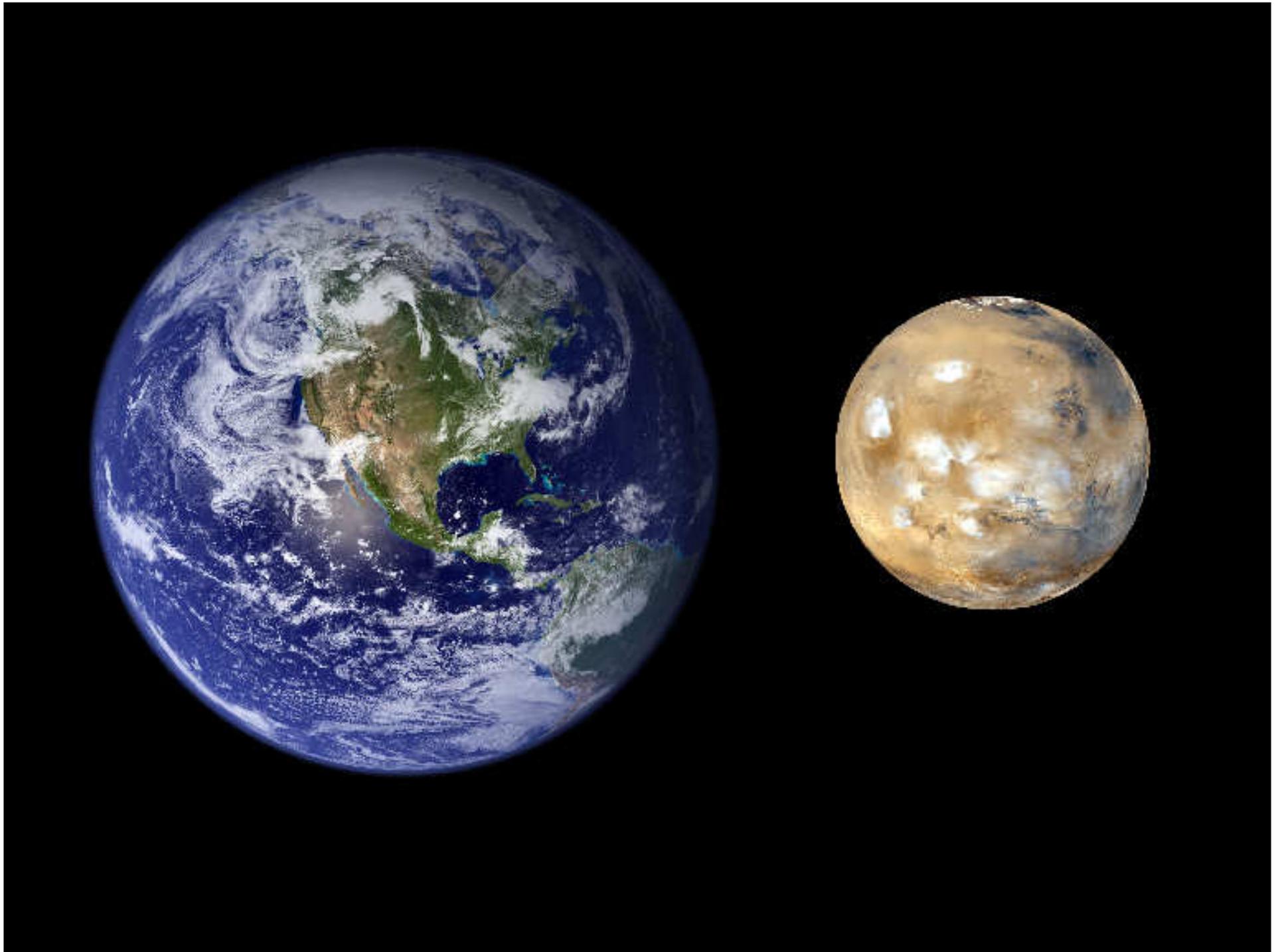


National Aeronautics and Space Administration
Jet Propulsion Laboratory, California Institute of Technology



MSL/Curiosity
Mars Rover



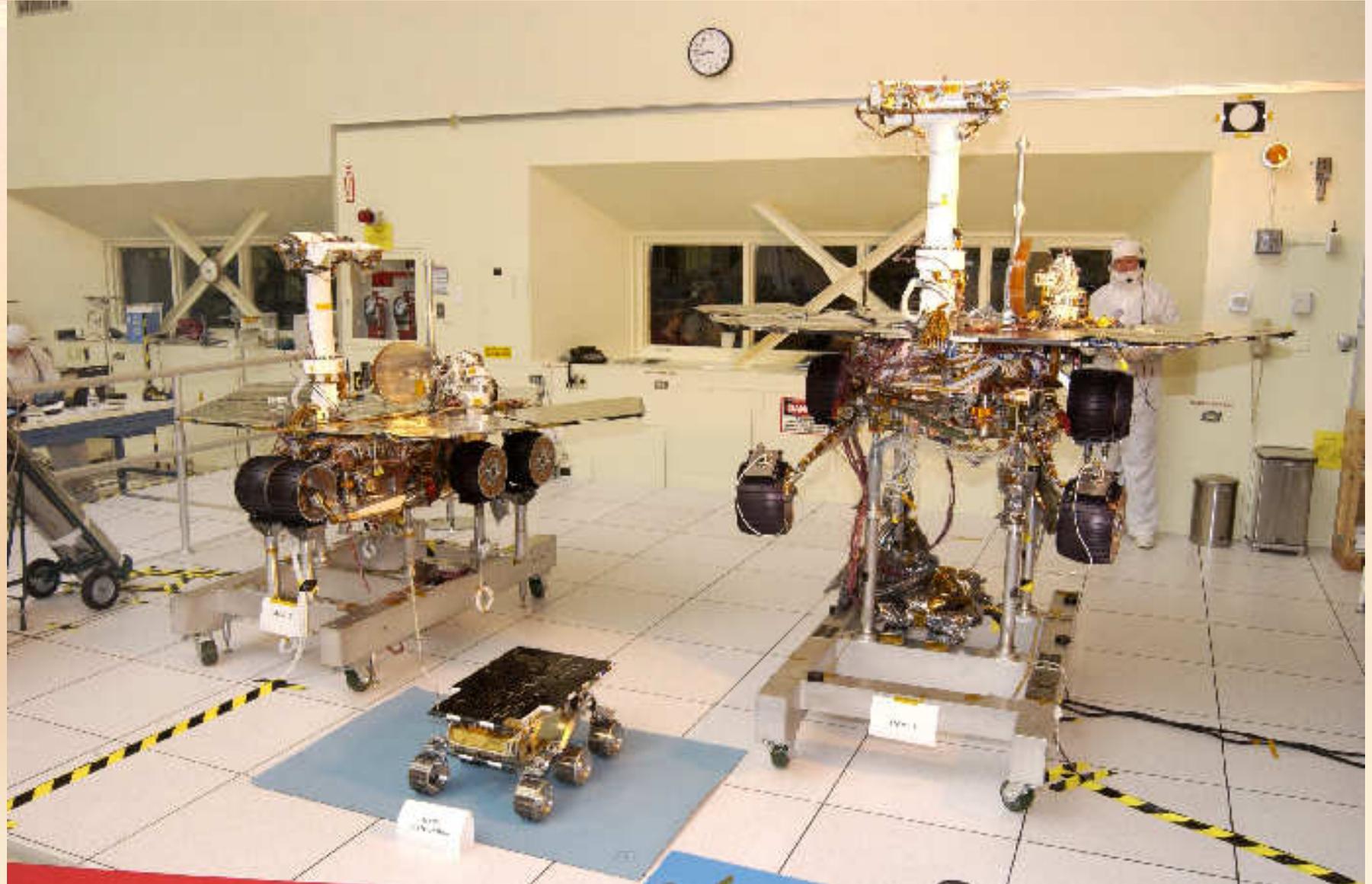


*Mars
Pathfinder*





Mars Exploration Rovers in test with 1997 Sojourner rover





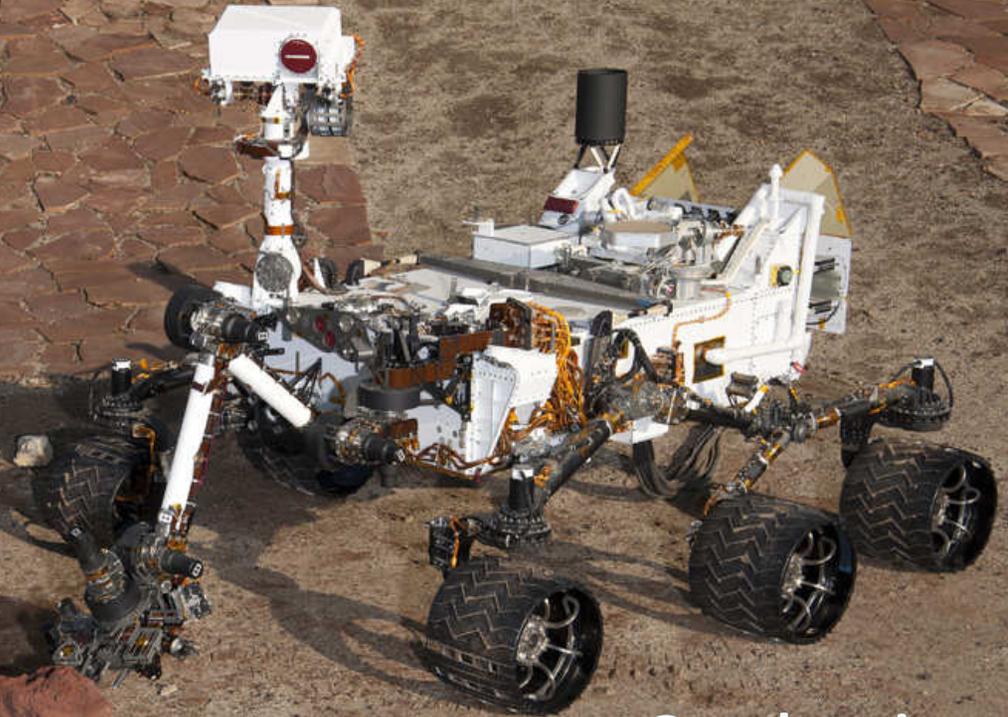
10.5 kg → 174 kg → 900 kg

**Geologist:
Spirit/Opportunity
(2004)**



**Experimentalist:
Pathfinder /
Sojourner (1997)**

**Geochemist:
Curiosity (2012)**

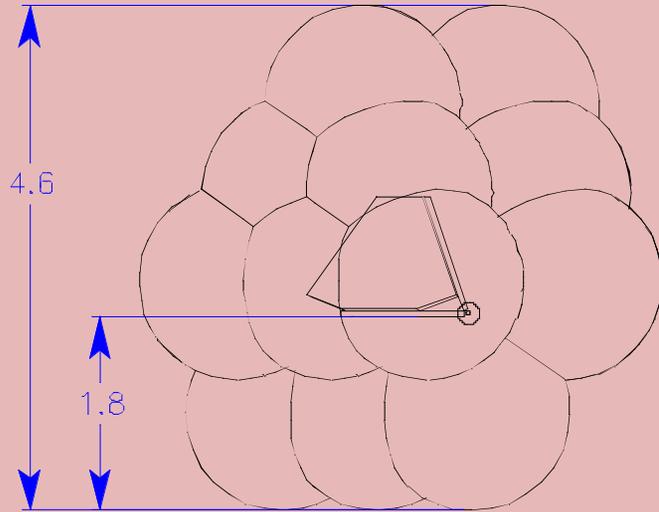




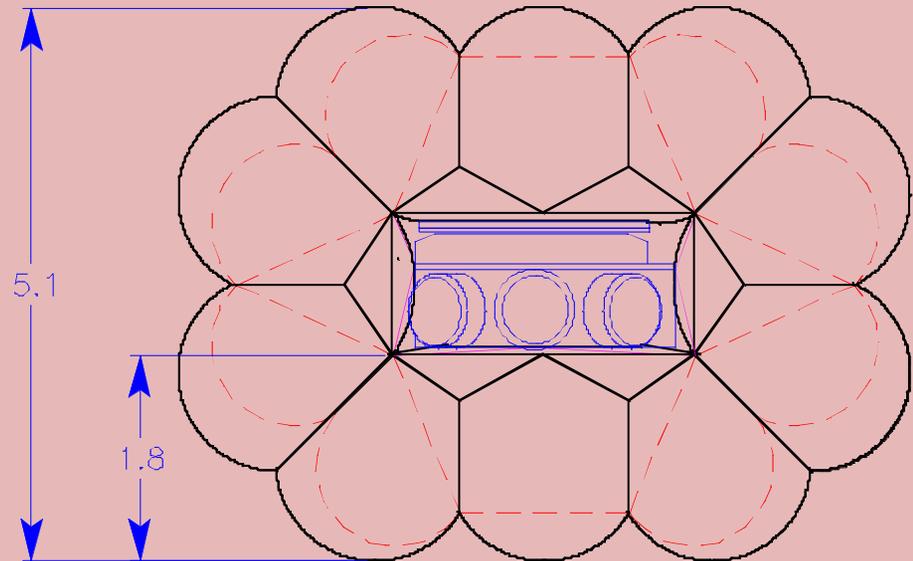
But how do you get it there?



Huge airbags?

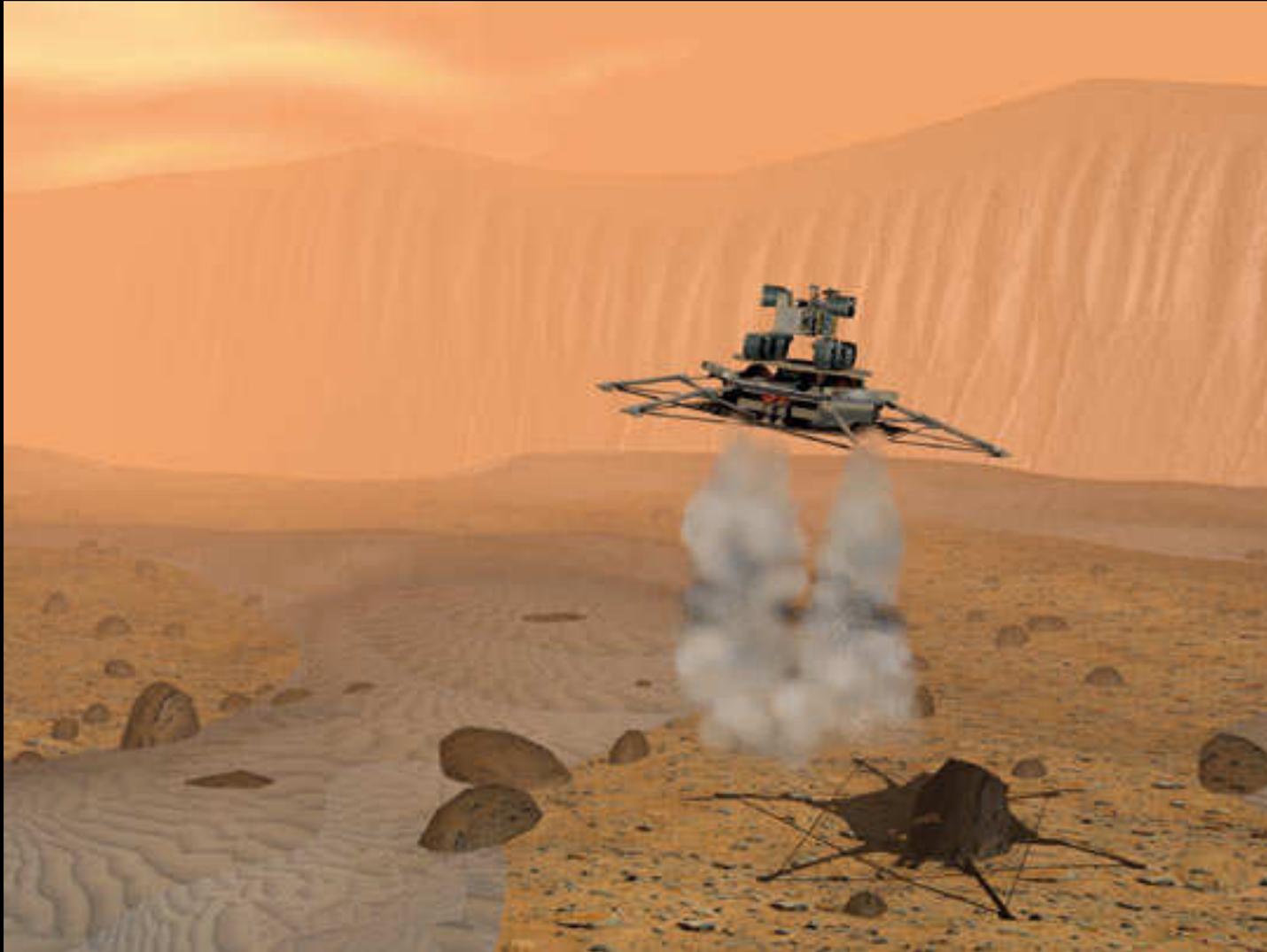


Mars Pathfinder Airbag Configuration



Mega Rover Airbag Configuration

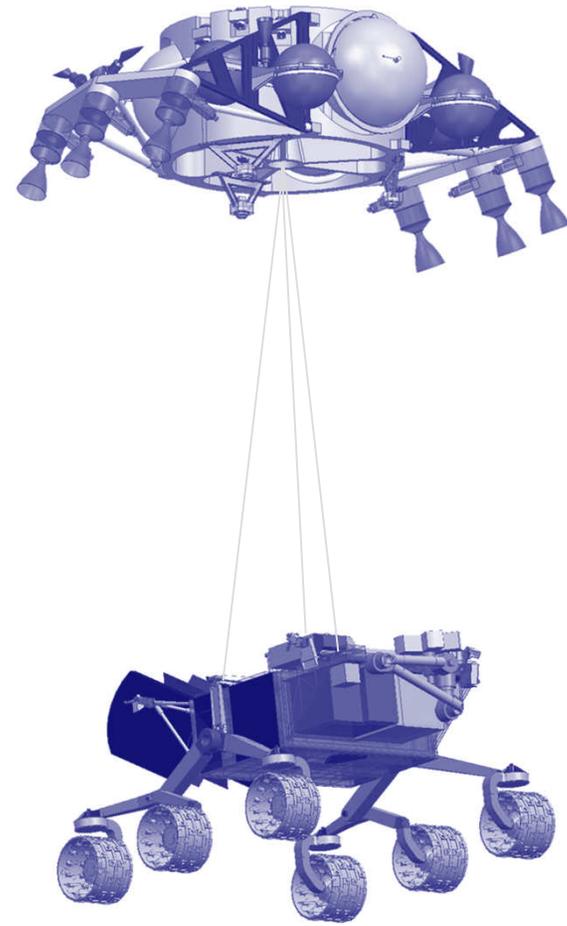
On a Pallet?

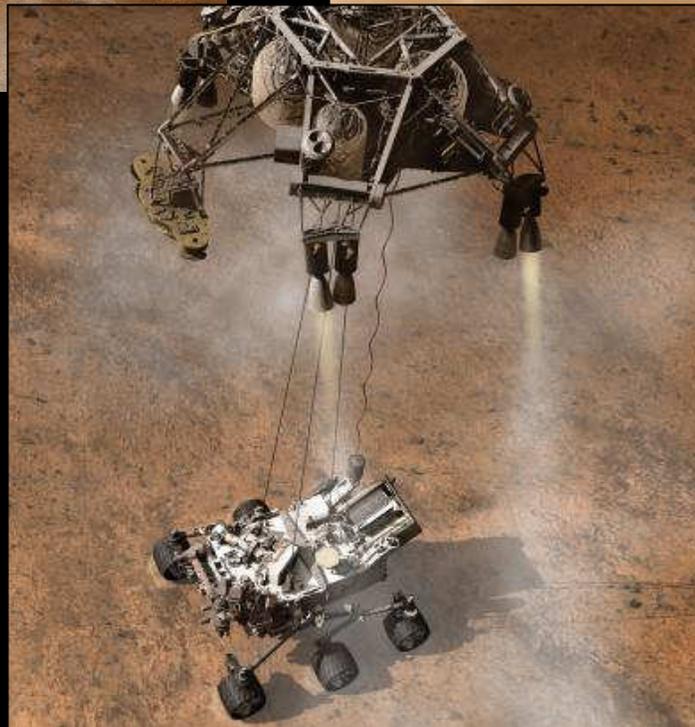




2003: The Skycrane maneuver is born

Mars Science Laboratory

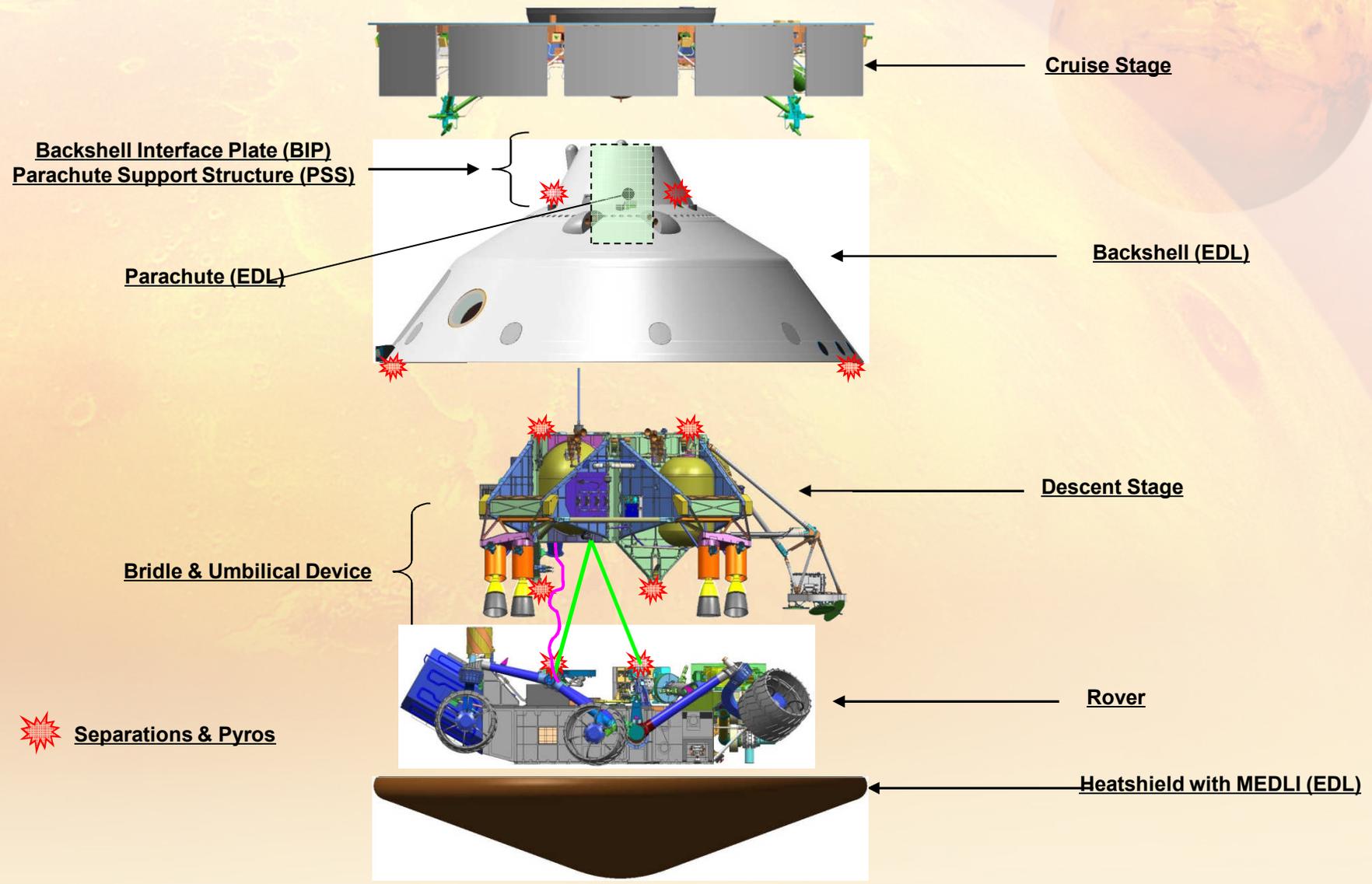


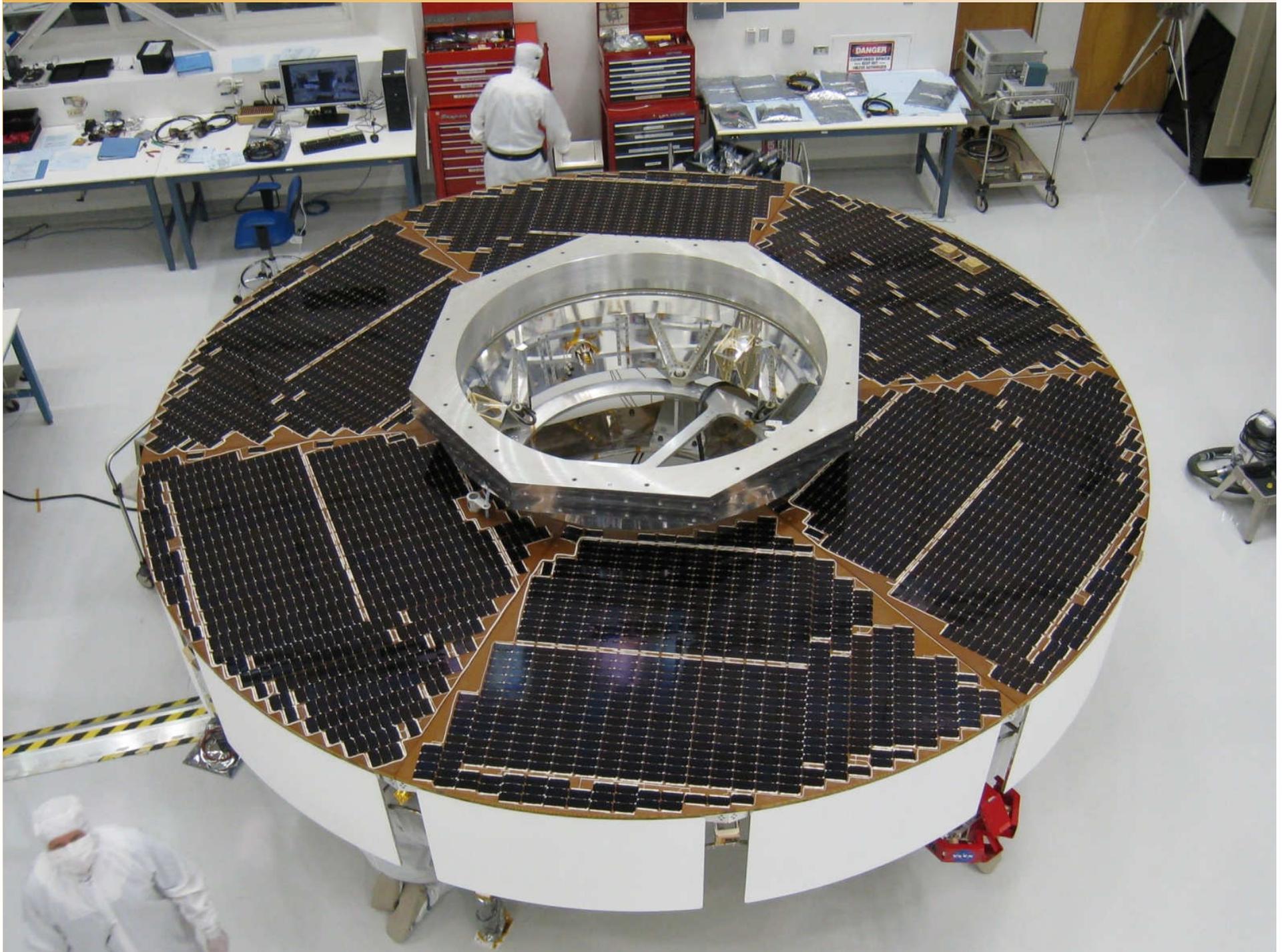


September 27, 2012

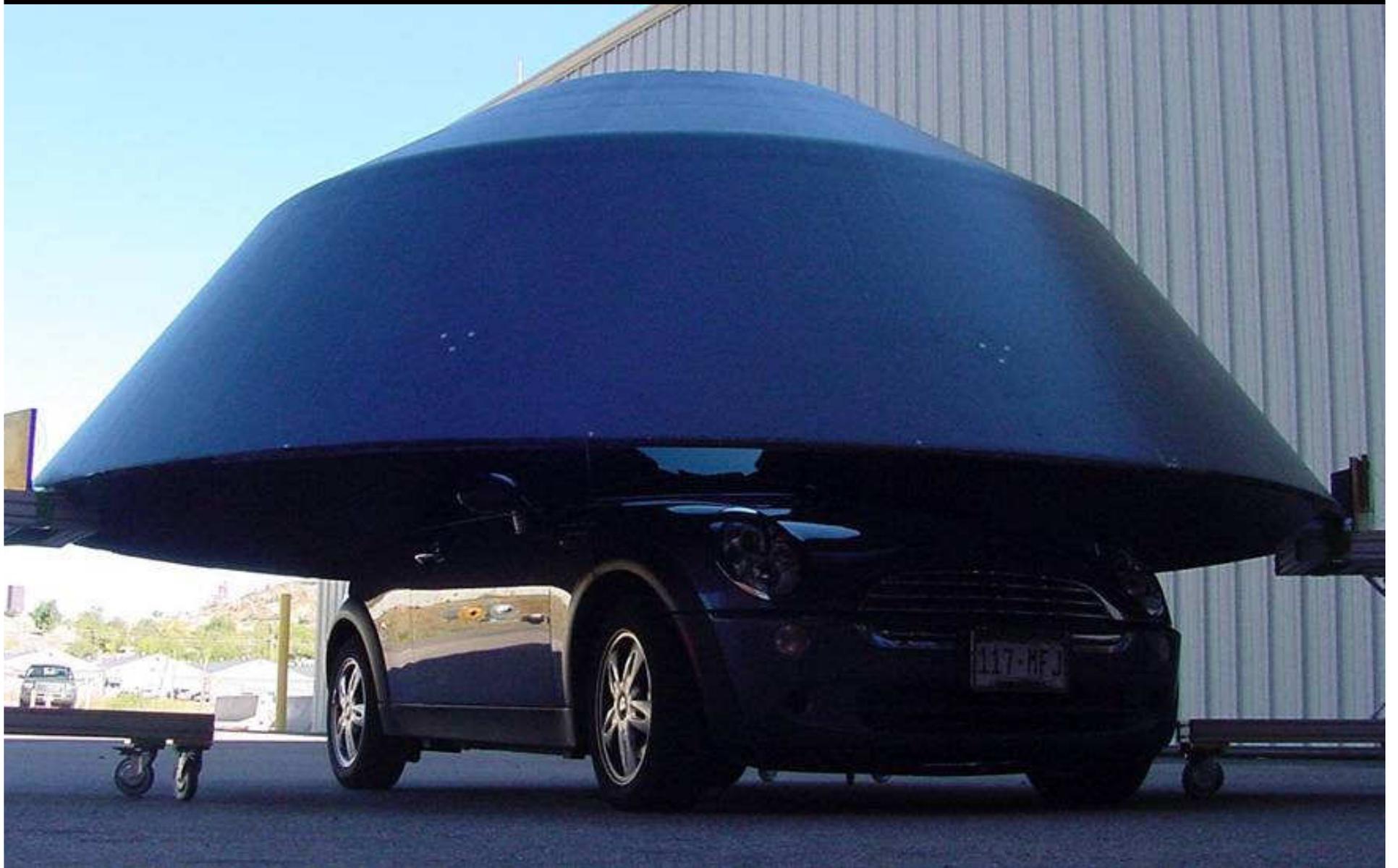


MSL Spacecraft Major Elements





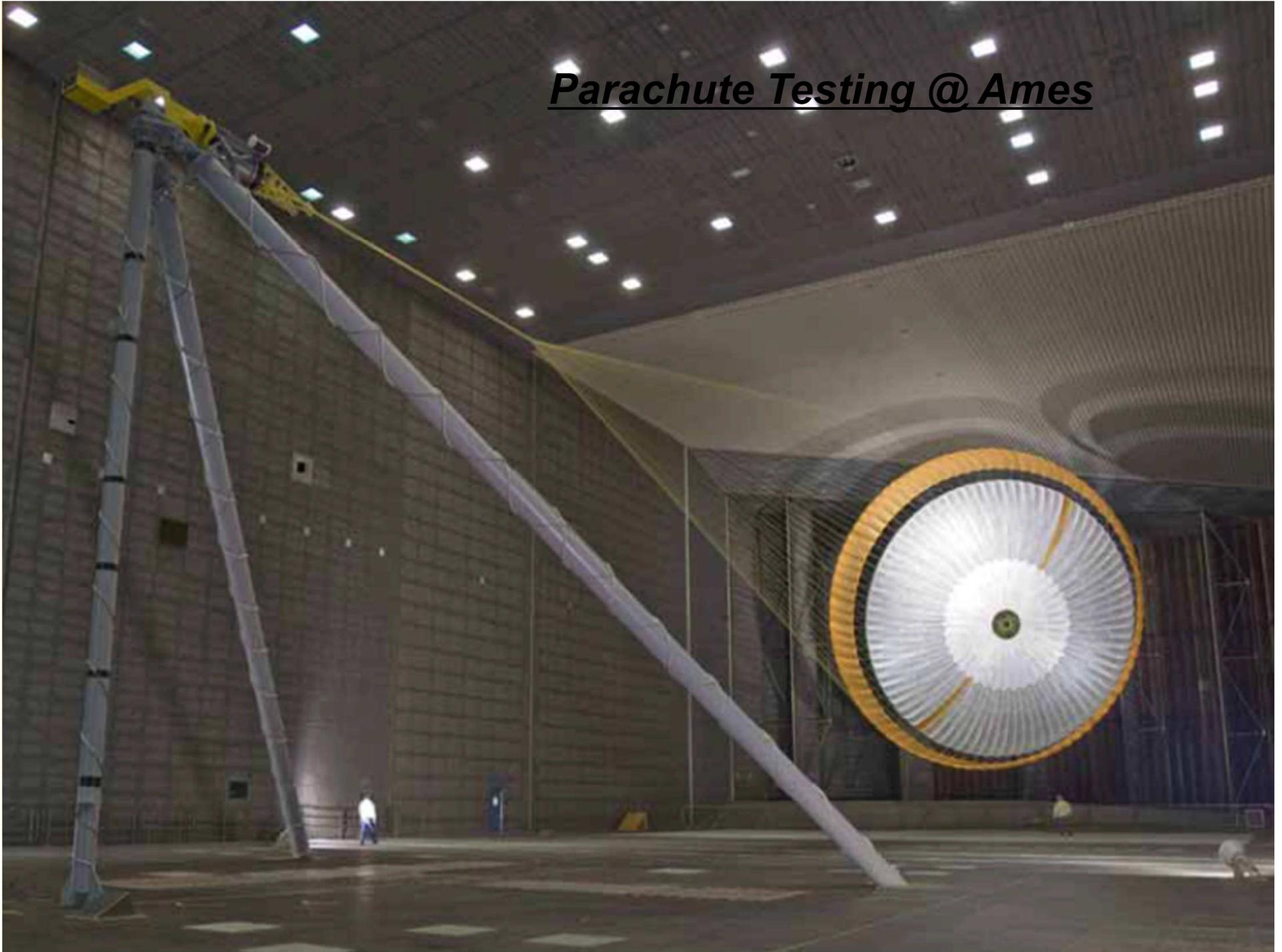


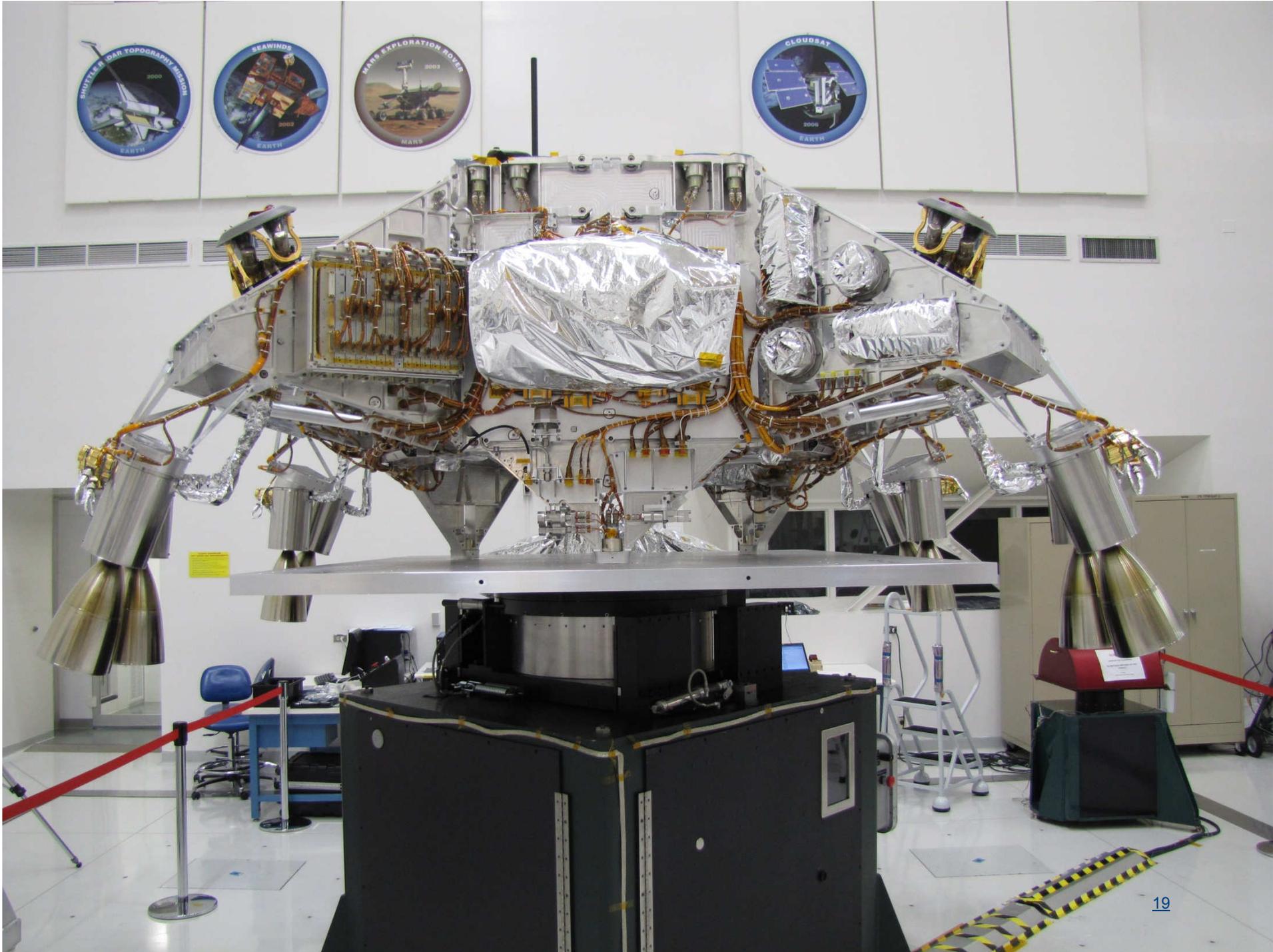




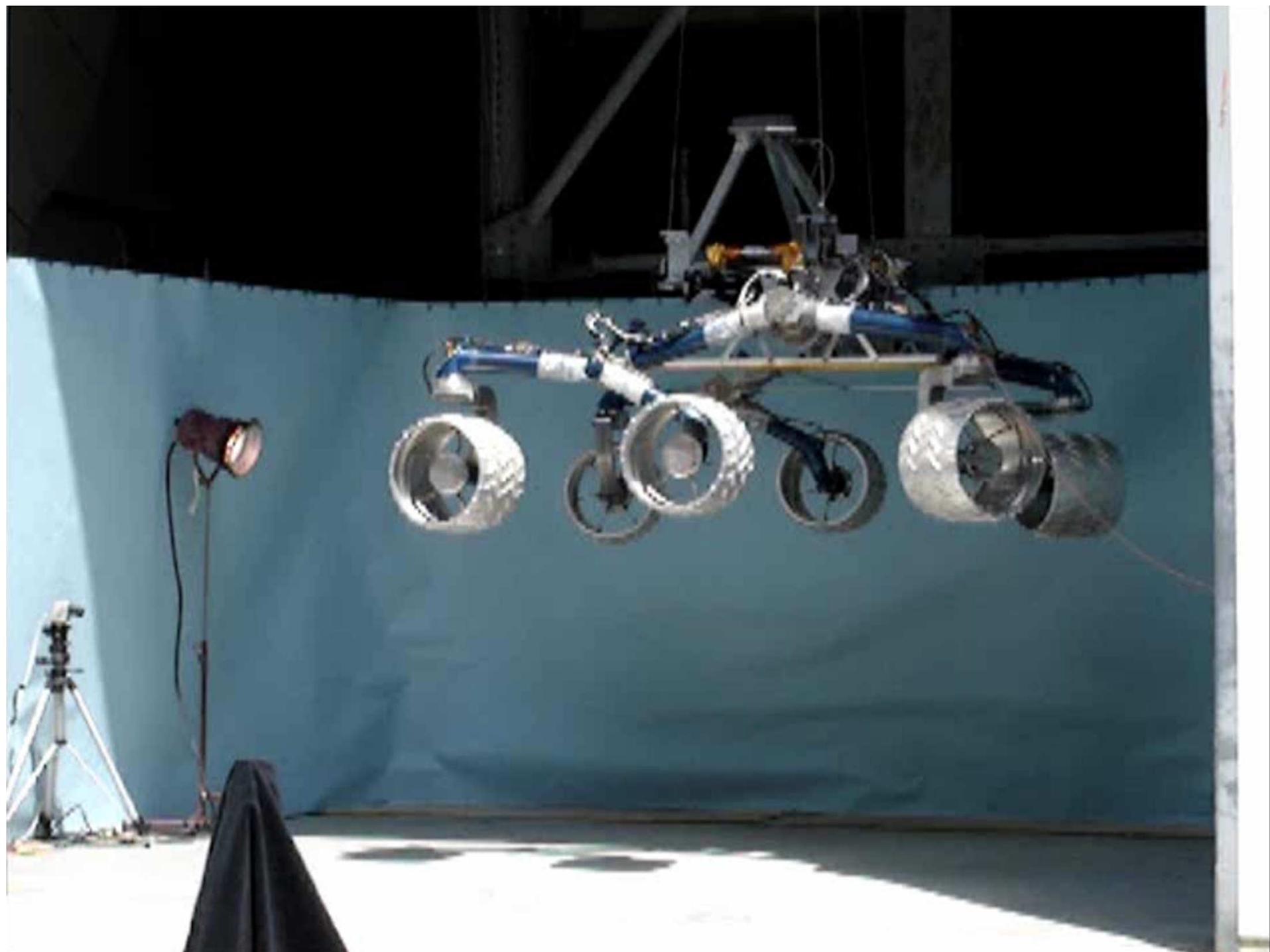
ROTATION CONTROL SYSTEM
EMPTY WEIGHT 2000 LB.
LOADED WEIGHT 6100 LB. CRITICAL 2 INCH LEAD

Parachute Testing @ Ames



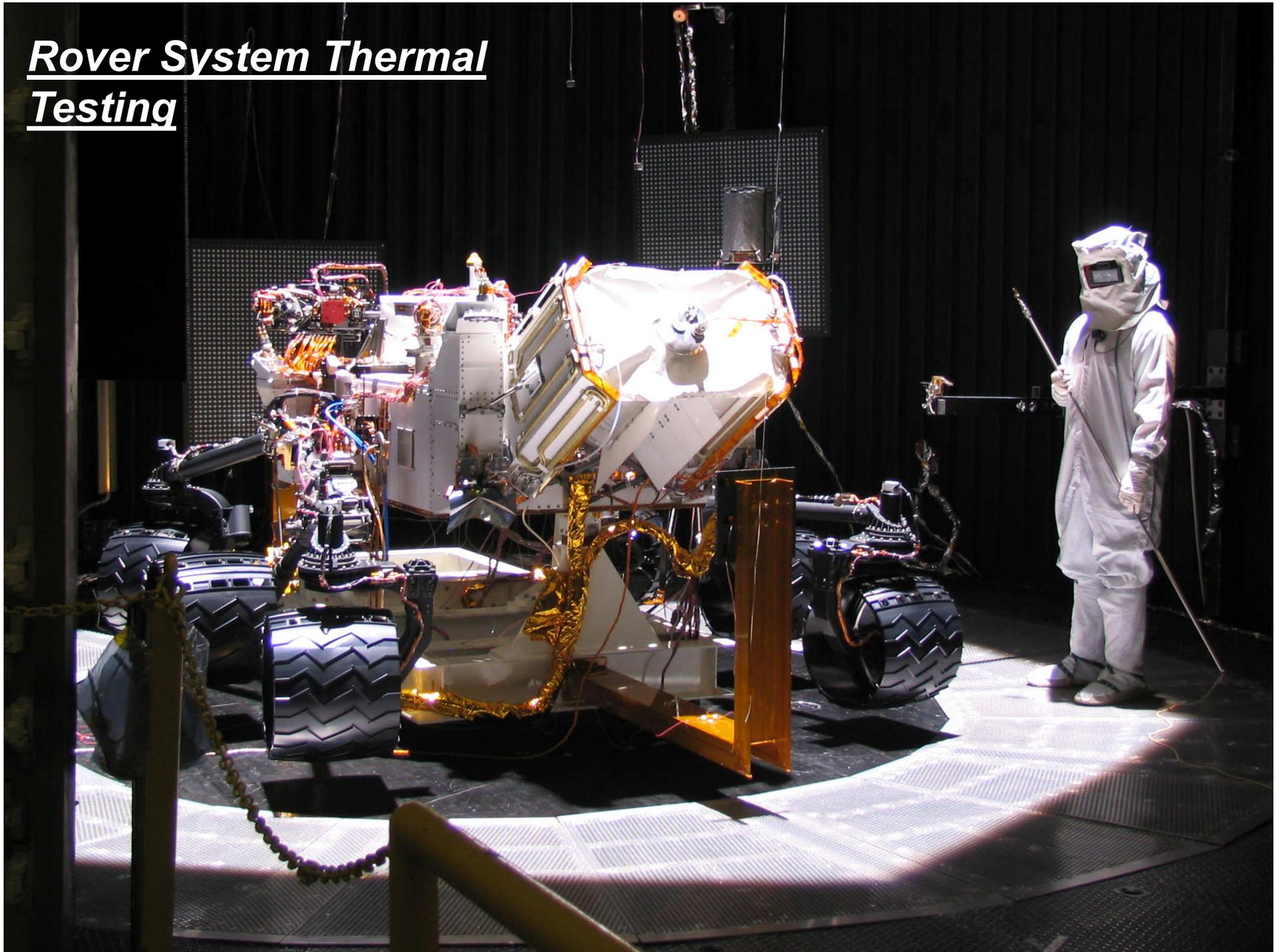








*Rover System Thermal
Testing*



Launch date: Nov. 26, 2011
Cape Canaveral, Florida



September 27, 2012

The mission

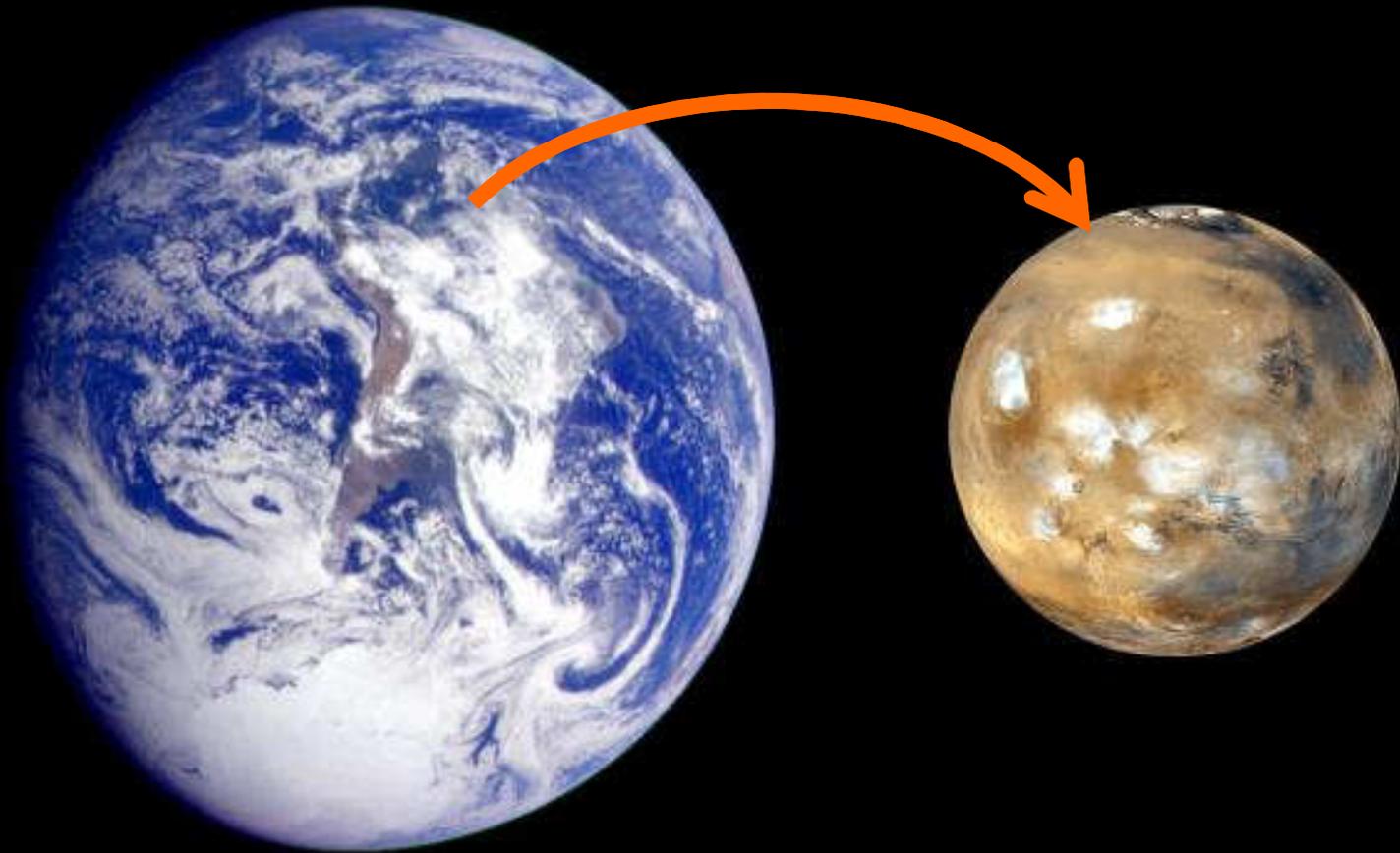
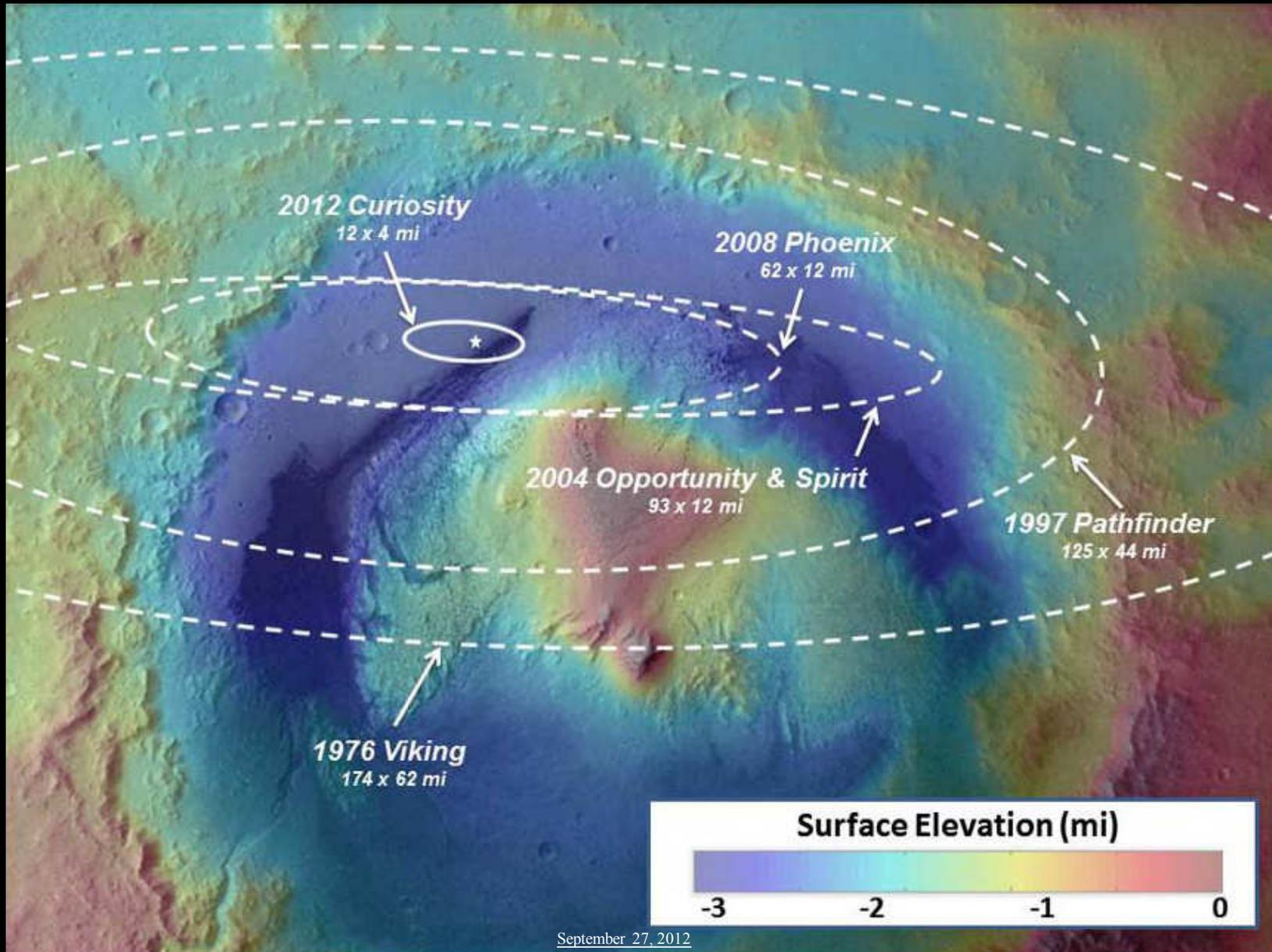




image: Bernhard Braun 2011
raw data: NASA/JPL/University of Arizona/Malin Space Science Systems

Landing Accuracy



Mars Exploration Family Portrait

40: Mars Science Laboratory Curiosity
November 26, 2011
Mission to Gale Crater

39: Phobos-Grunt
November 8, 2011
Stranded in Earth orbit

1, 2: MARS 1M No. 1 / MARS 1M No. 2
October 10 / October 14, 1960
Both destroyed during launch

38: Phoenix
August 4, 2007
Landed, dug for water

3, 4, 5, 8: MARS 2MV-4 No. 1 / Mars 1 / Mars 2MV-3 No. 1 / Zond 2
October 24 / November 1 / November 4, 1962 / November 30, 1964
Broke up in Earth orbit / Radio failure en route / Stranded in Earth orbit / Radio failure en route

37: Mars Reconnaissance Orbiter
August 12, 2005
Orbiting Mars

6, 7: Mariner 3 / Mariner 4
November 5 / November 28, 1964
Payload fairing failed to open / First flyby and picture return

35, 36: Mars Exploration Rovers Spirit and Opportunity
June 10 / July 7, 2003
Both landed on surface, Opportunity still in operation

9, 10: Mariner 6 / Mariner 7
February 25 / March 27, 1969
Both flew by, returned pictures

34: Mars Express / Beagle 2 lander
June 2, 2003
Orbiting Mars, Beagle lost after separation

11, 12: Mars 1969 A / Mars 1969 B
March 27 / April 2, 1969
Both destroyed during launch

33: Mars Odyssey
March 7, 2001
Orbiting Mars

13, 17: Mariner 8 / Mariner 9
May 8 / May 30, 1971
Destroyed during launch / First probe to orbit Mars

32: Mars Polar Lander
January 3, 1999
Crashed on surface

14, 15, 16: Cosmos 419 / Mars 2 / Mars 3
May 10 / May 19 / May 28, 1971
Failed in Earth orbit / Lander crashed / Lander failed

31: Mars Climate Orbiter
December 11, 1998
Crashed due to imperial/metric unit mixup

18, 19, 20, 21: Mars 4 / Mars 5 / Mars 6 / Mars 7
July 21 / July 25 / August 5 / August 9, 1973
Missed planet / Orbited planet / Lander failed (6 and 7)

30: Nozomi
July 4, 1998
Missed planet

22, 23: Viking 1 / Viking 2
August 20 / September 9, 1975
Both landed on surface, returned data

29: Mars Pathfinder
December 4, 1996
Landed on surface, deployed Sojourner rover

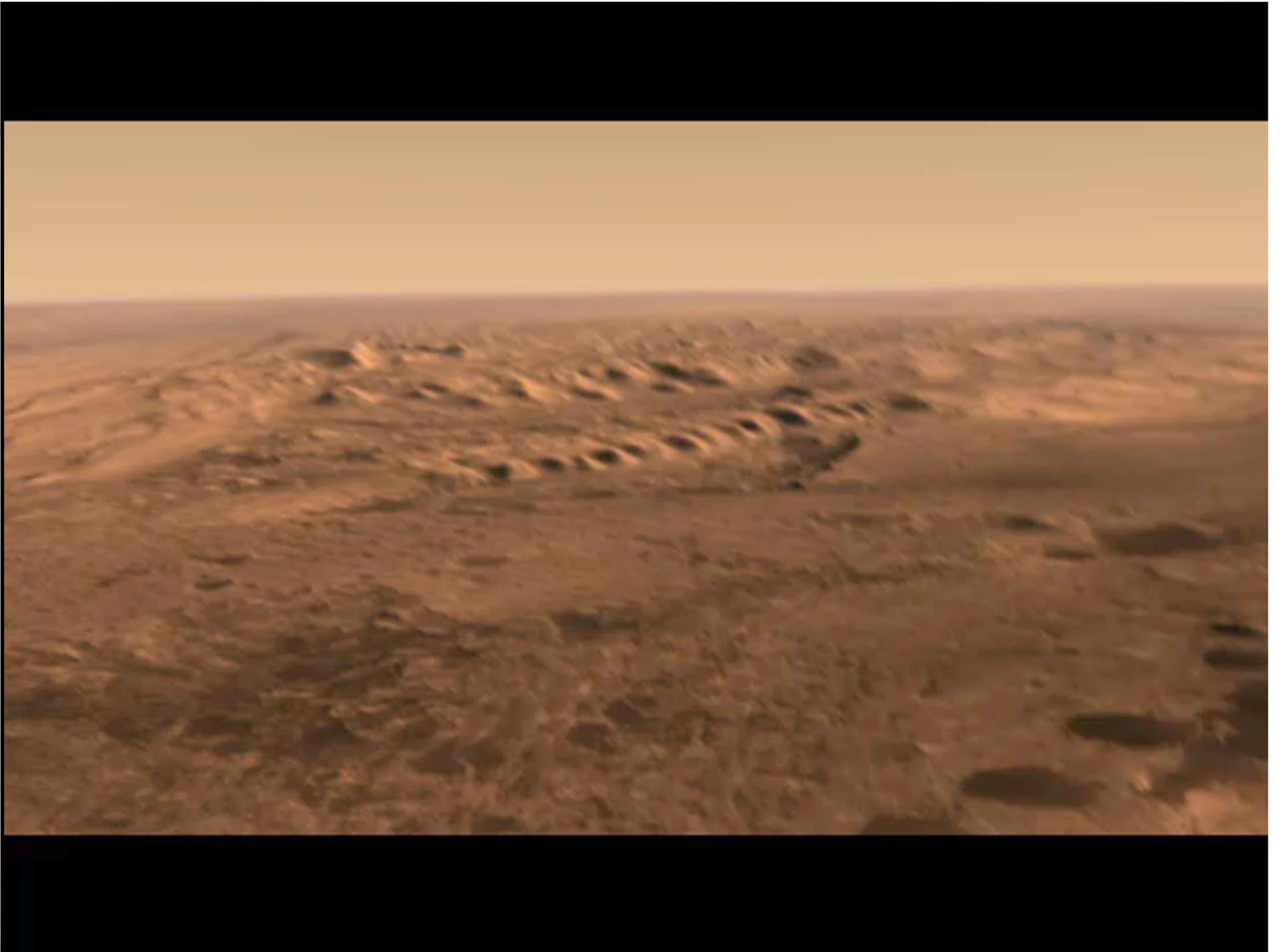
24, 25: Phobos 1 / Phobos 2
July 7 / July 12, 1988
Lost communication en route / Lost communication near Phobos

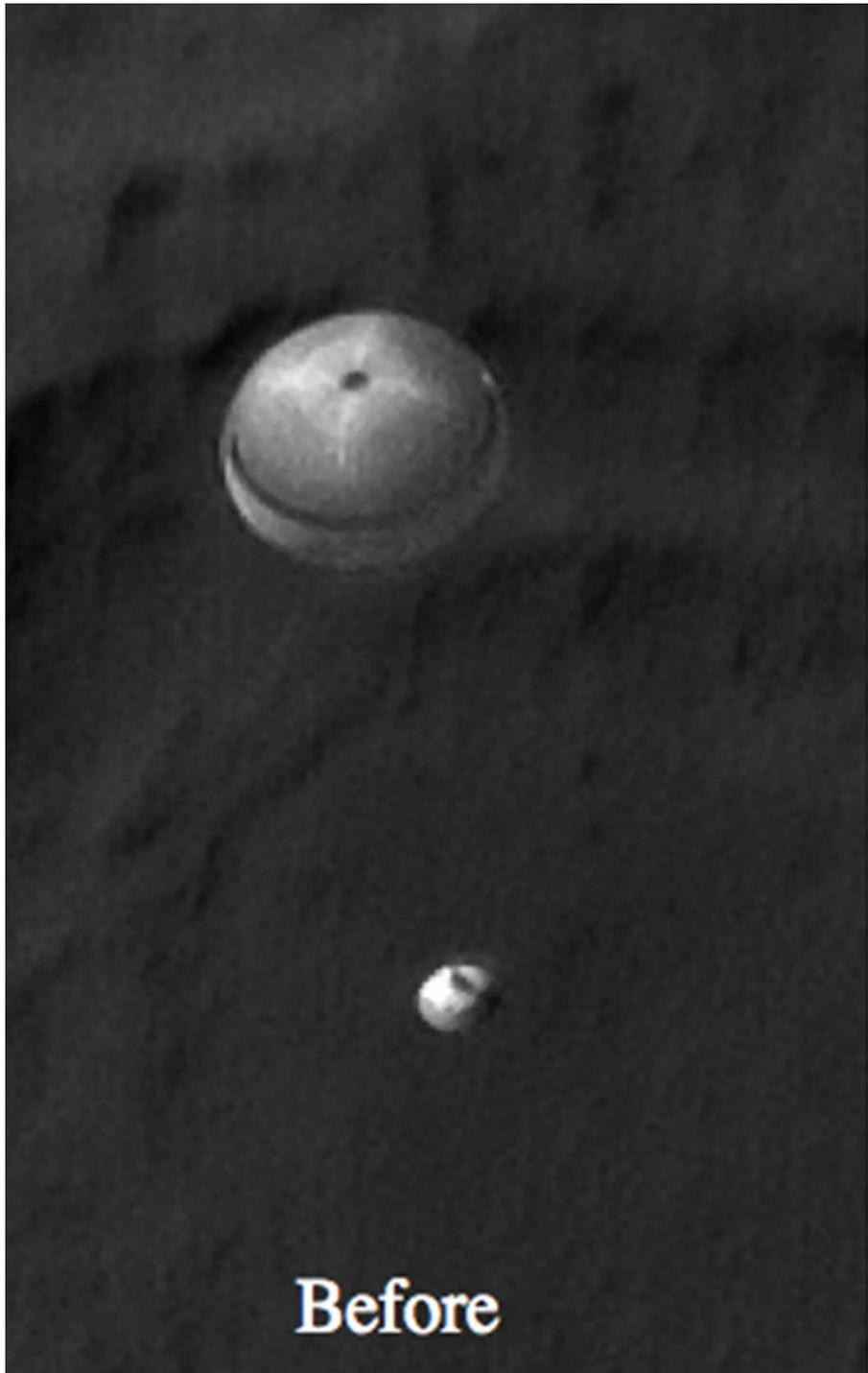
28: Mars 96
November 16, 1996
Destroyed during launch

26: Mars Observer
September 25, 1992
Lost communication near Mars

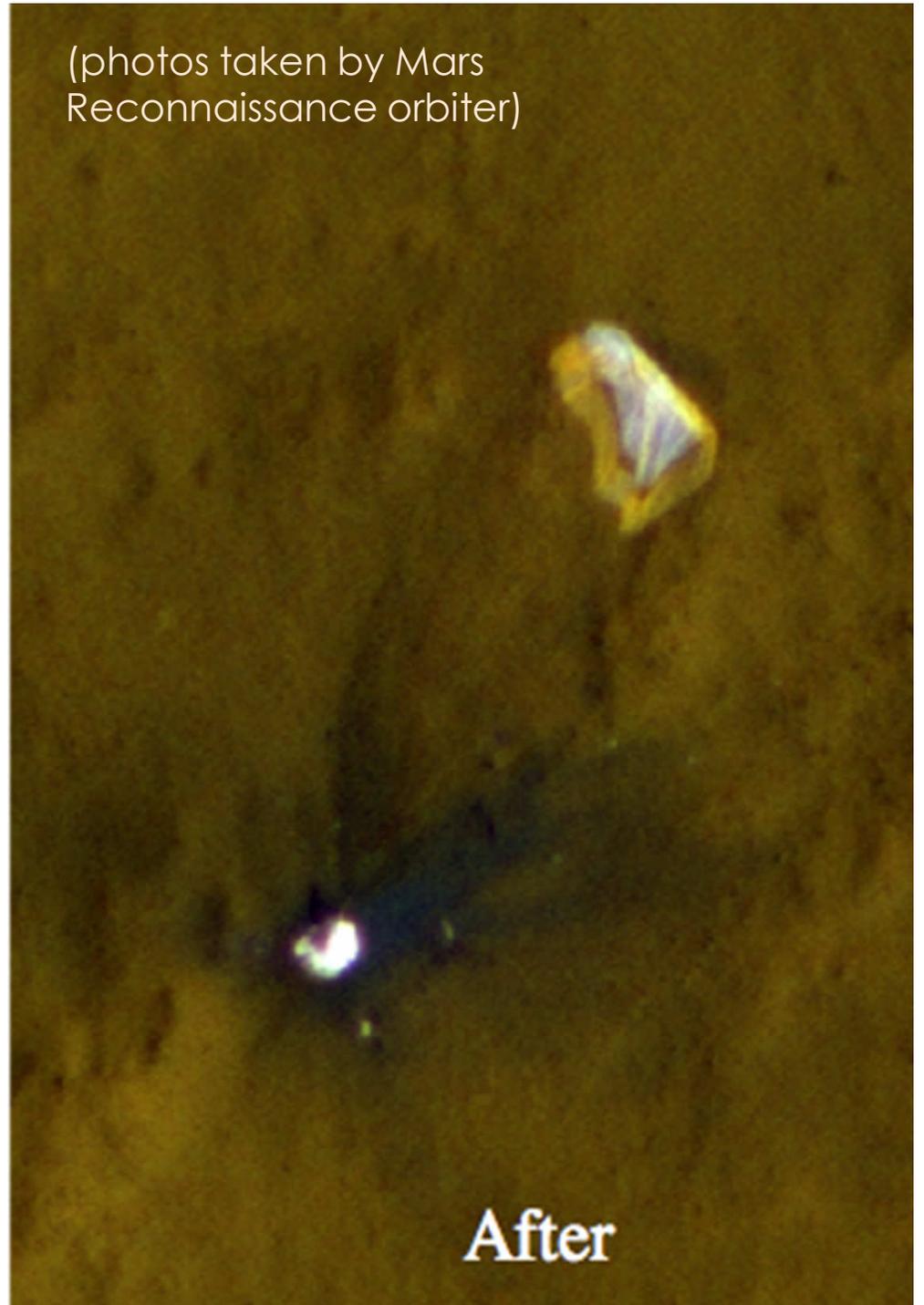
27: Mars Global Surveyor
November 7, 1996
Orbited and returned data

Failed 24
Succeeded 15

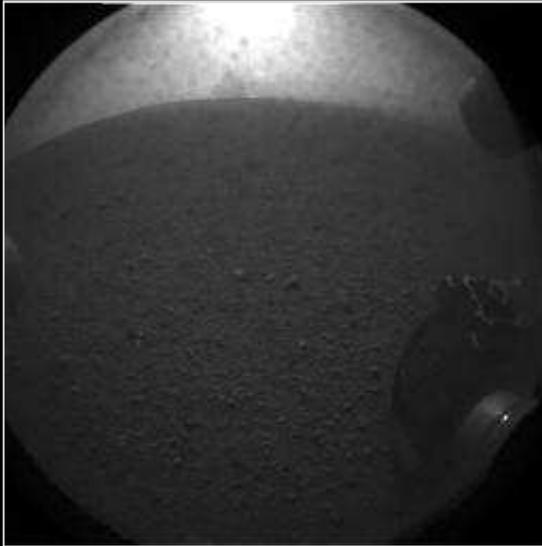




(photos taken by Mars
Reconnaissance orbiter)



First Images from Mars



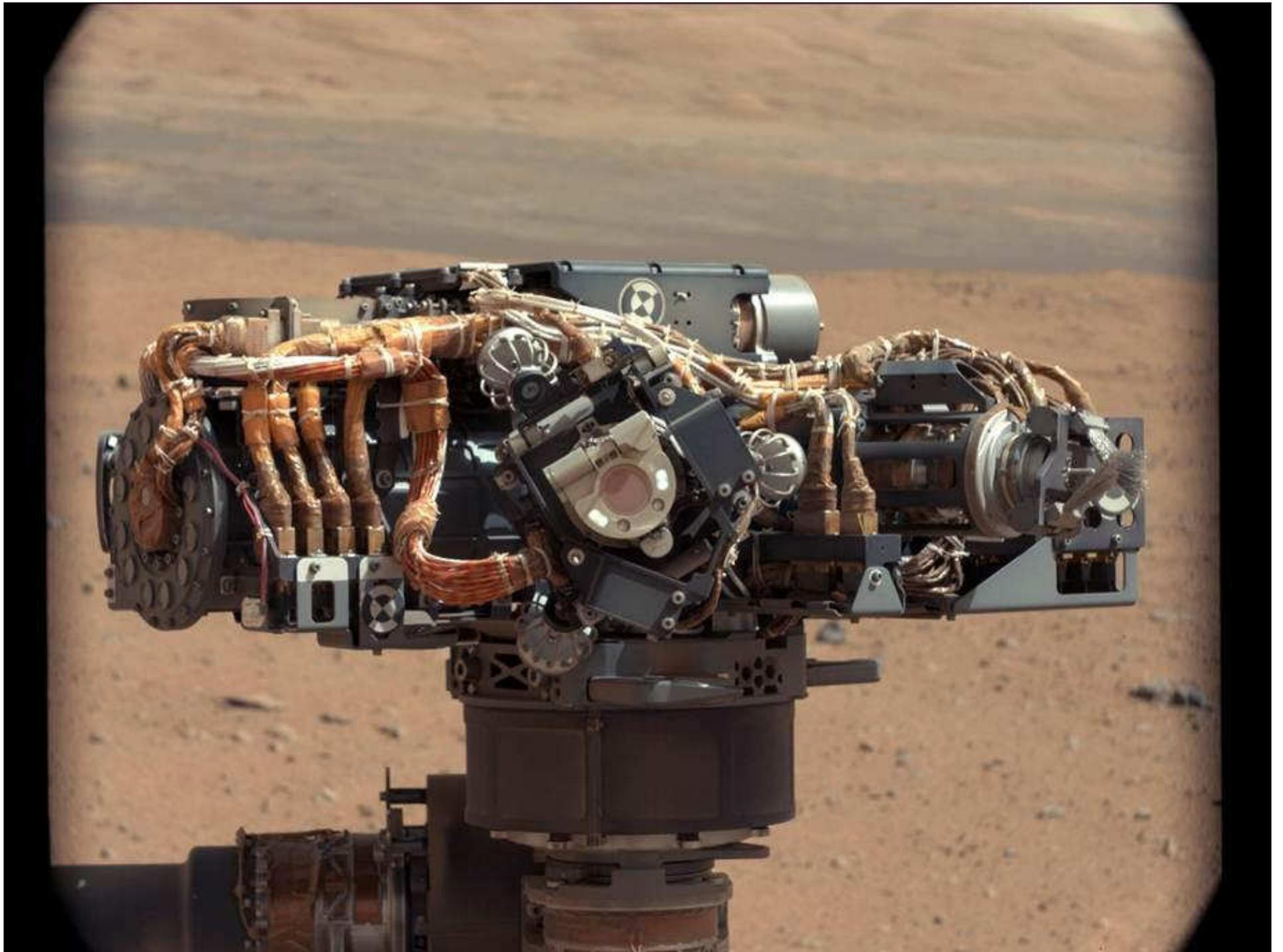
September 27, 2012

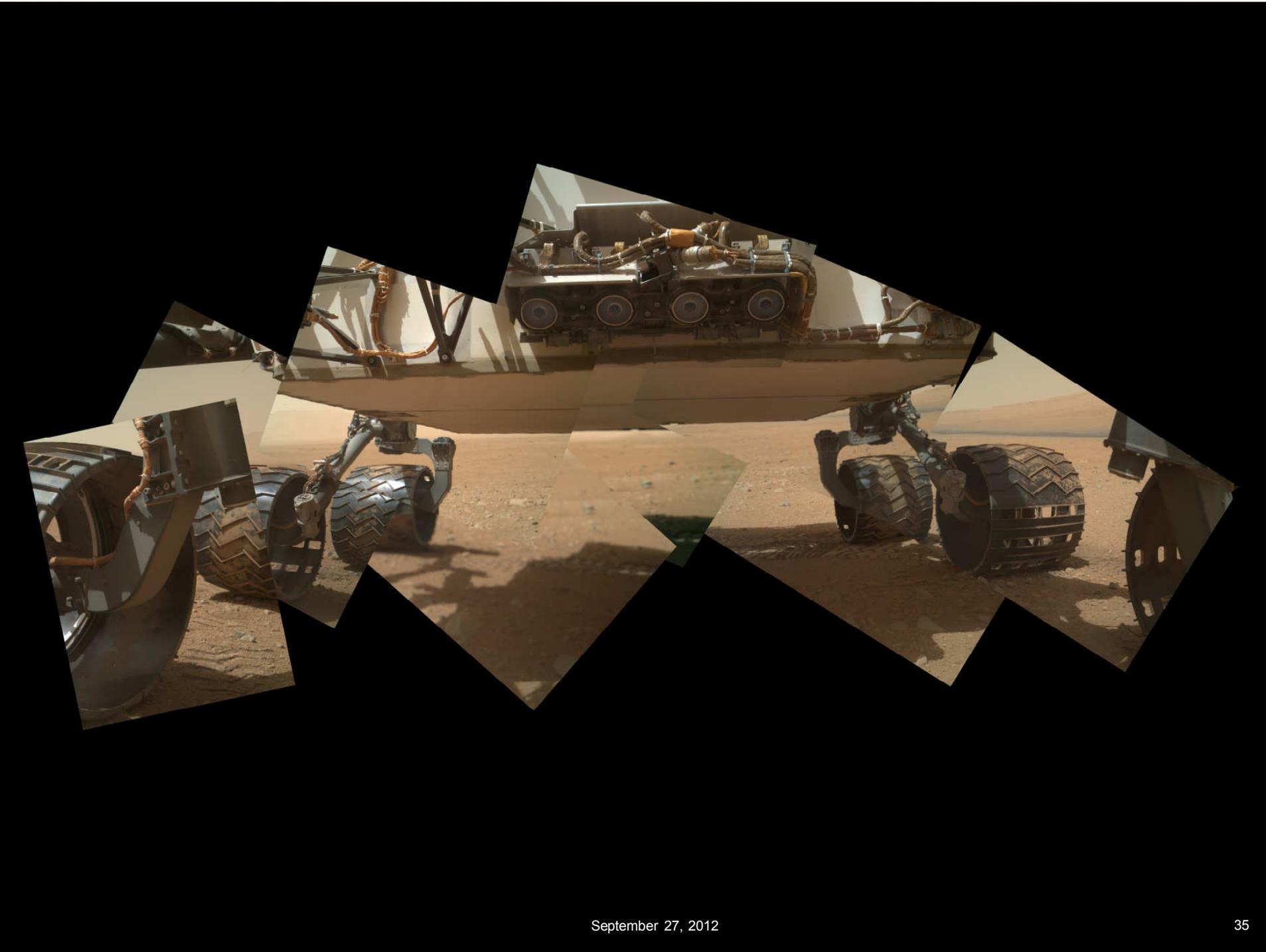


September 27, 2012

Looking North to Crater Rim



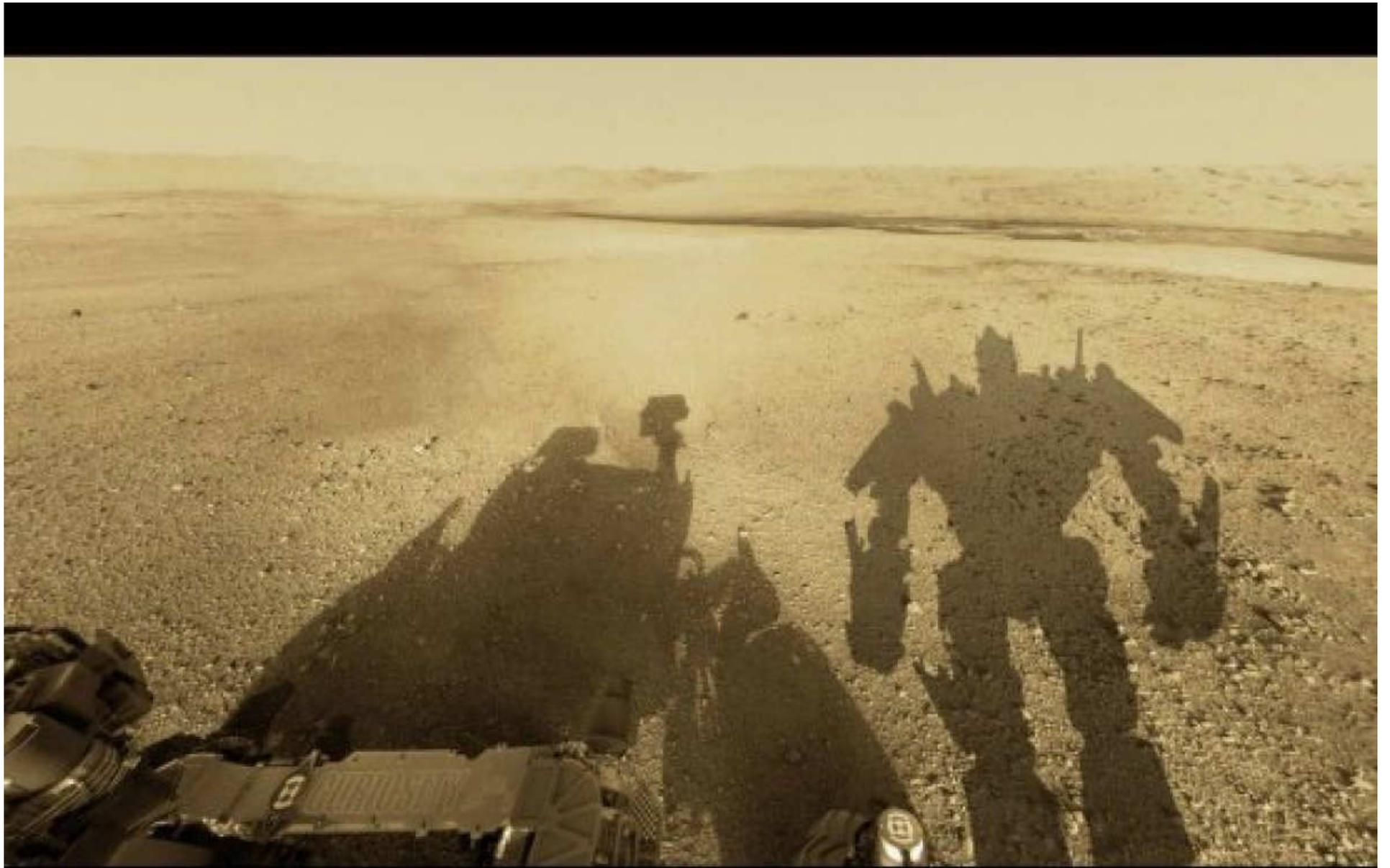




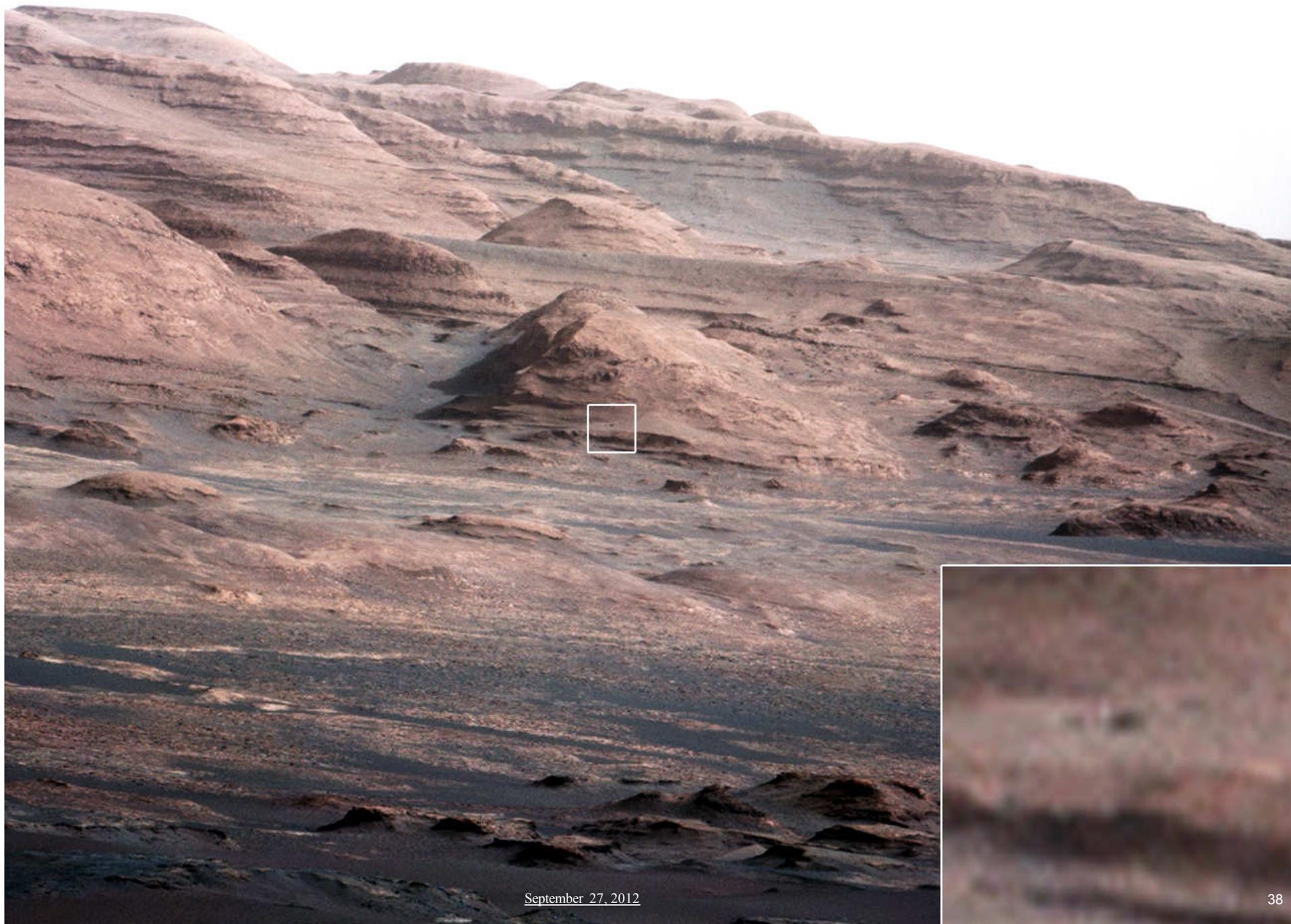
September 27, 2012



September 27, 2012

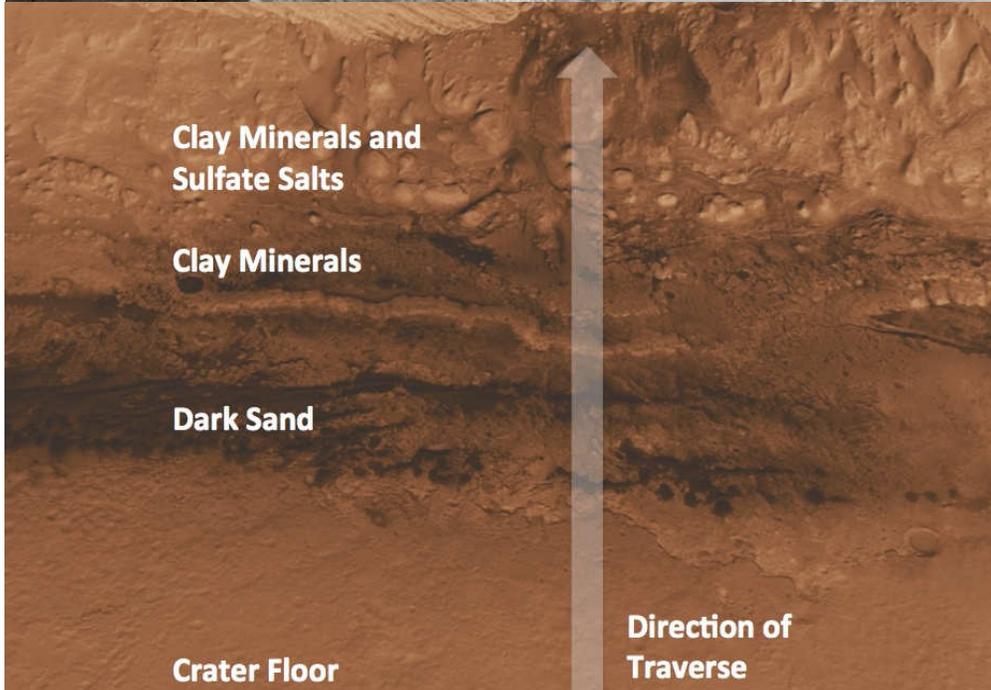
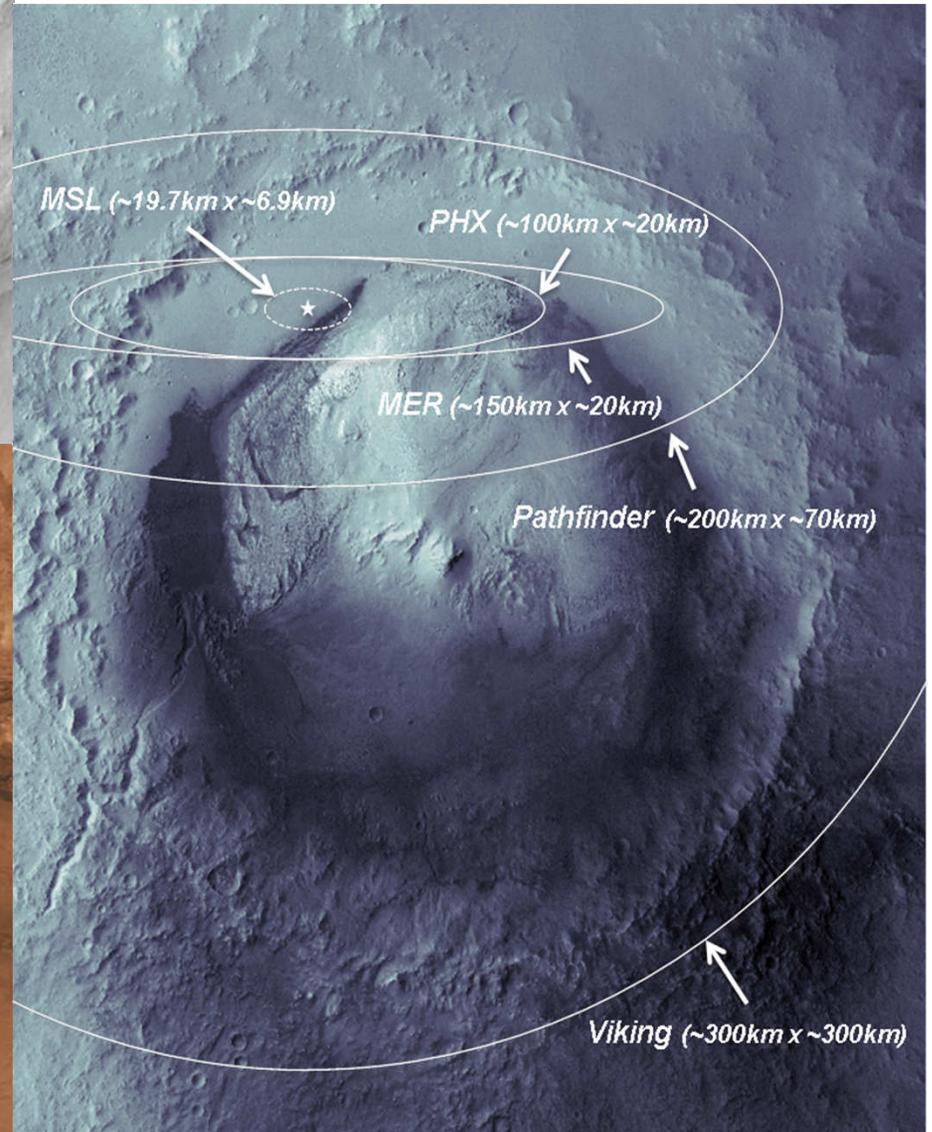
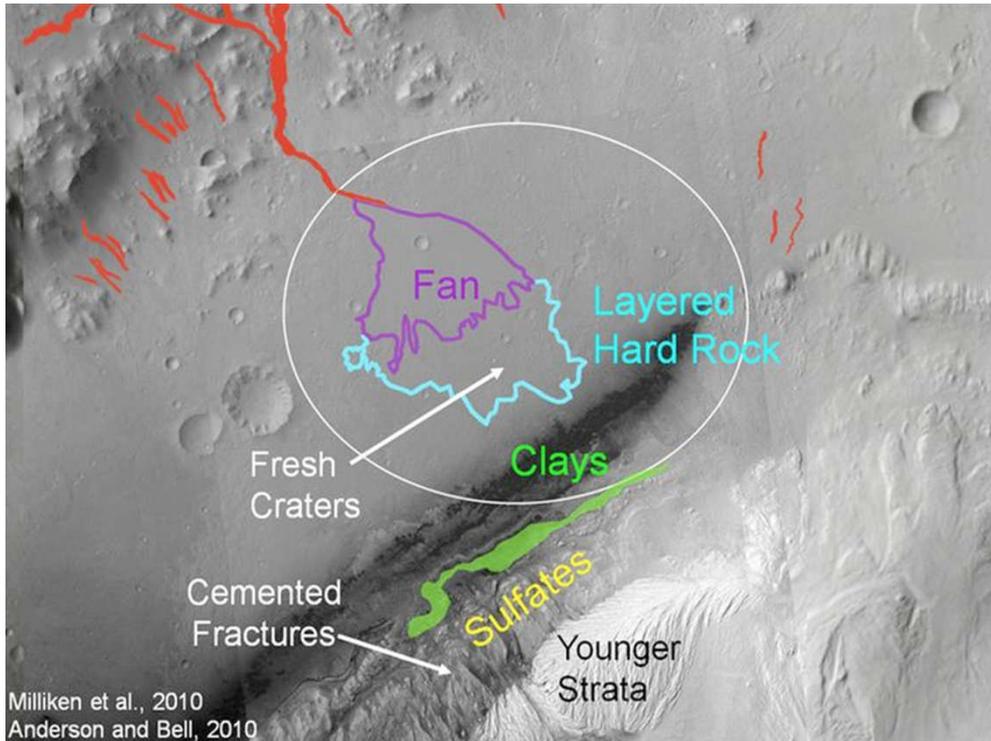


User: wrighteous5280

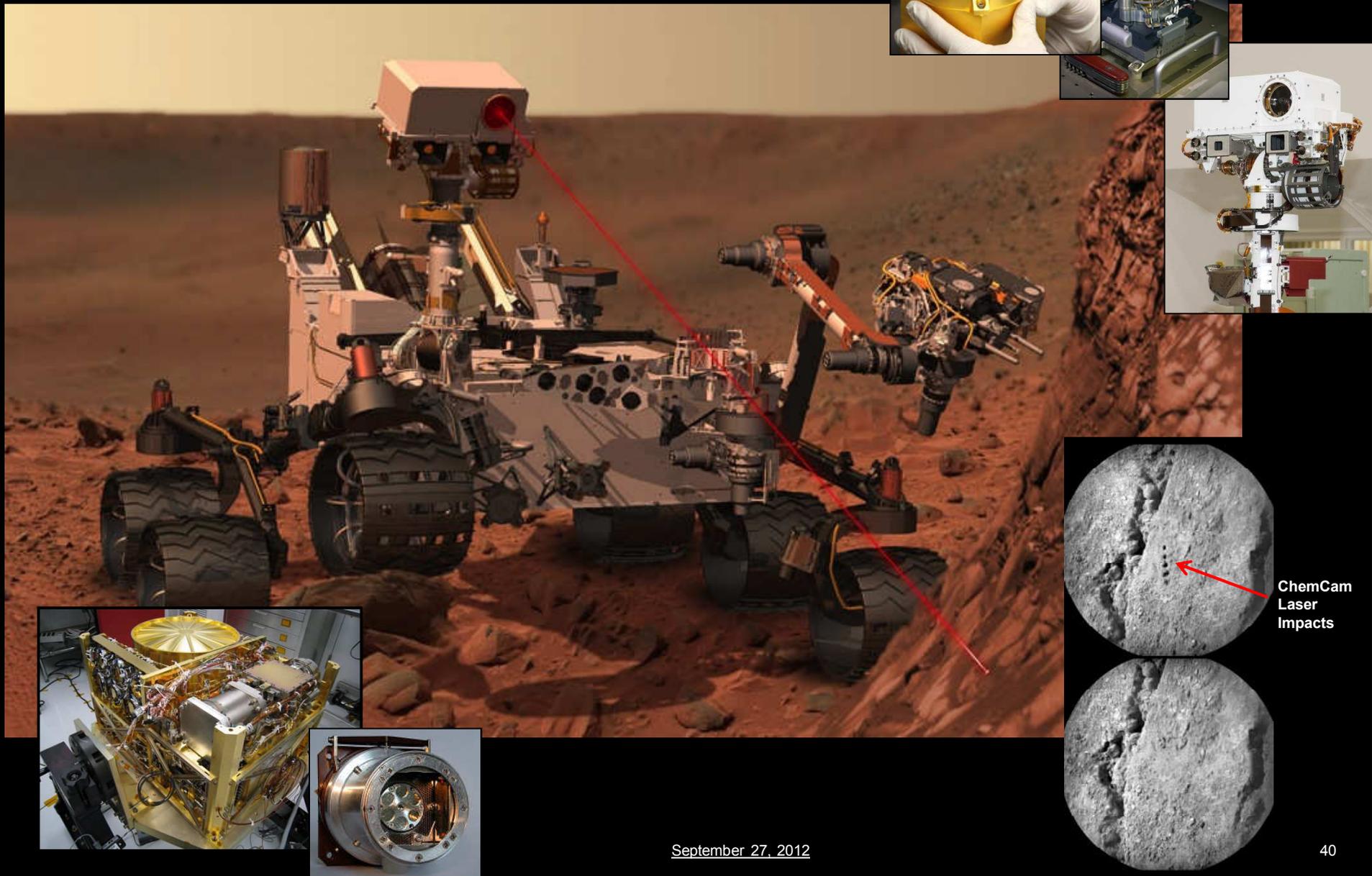


September 27, 2012

The Landing Site



Among Curiosity's tools are
17 cameras, a laser to zap rocks,
and a drill to collect rock samples.



September 27, 2012



September 27, 2012

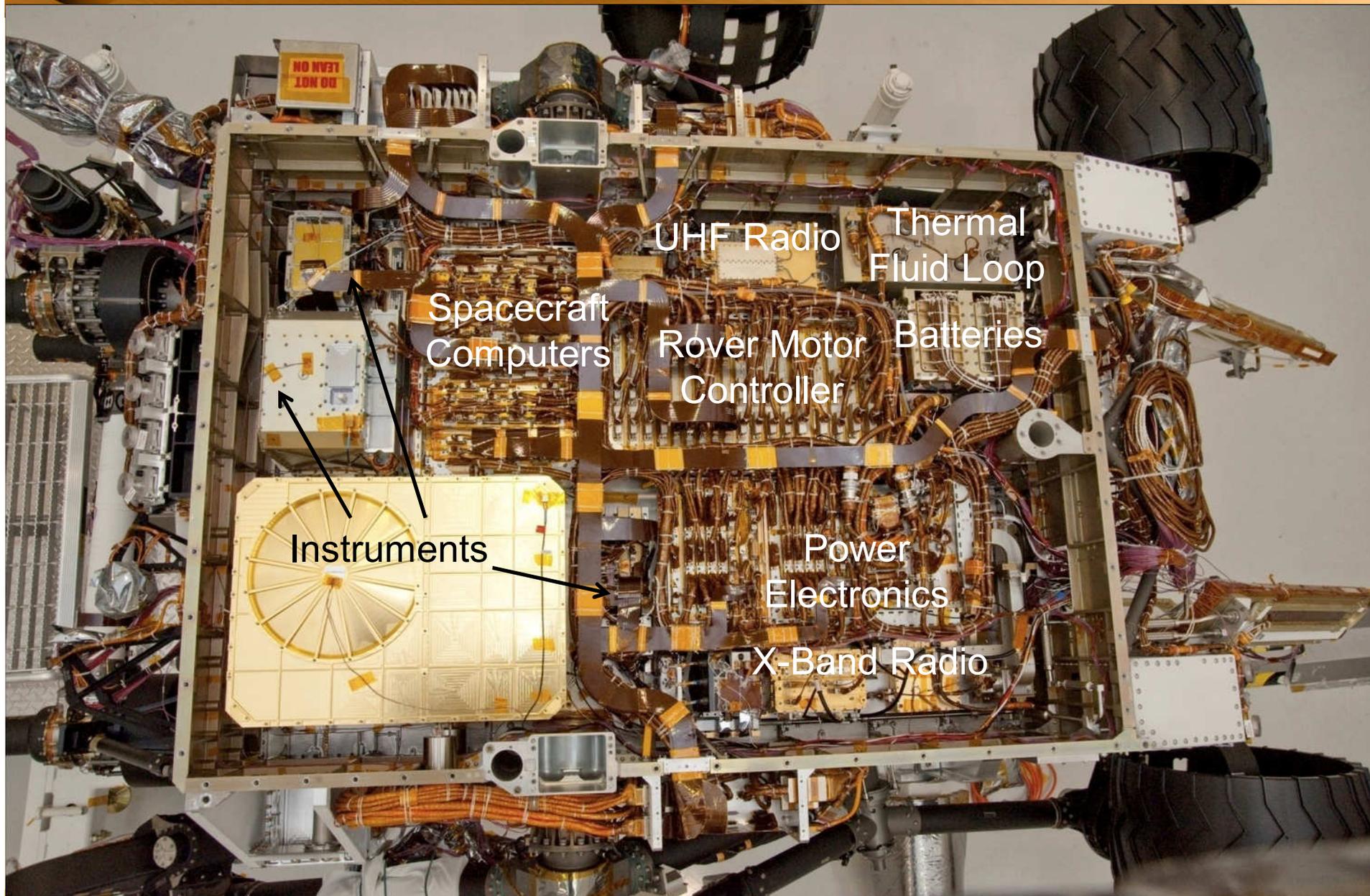




**SEES BRITAIN IS HOSTING THE
OLYMPICS**

LANDS ON MARS

What's under the Hood



EEE Parts Program

Part quality level

- Flight System
 - EEE INST-003 Level 1 parts for single string elements, Level 2+ parts for redundant elements
- Payload
 - EEE INST-003 Level 2 parts for all instruments

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

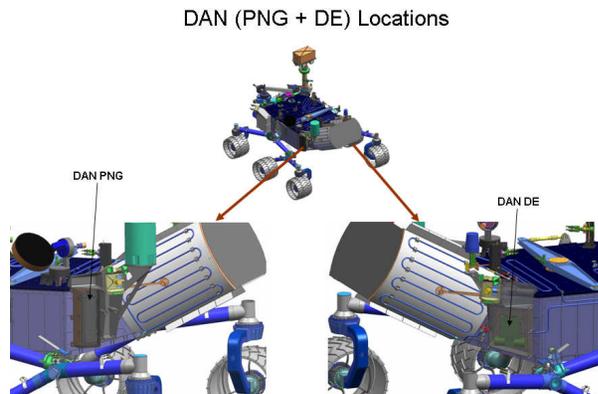
So many parts, so many problems...

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.
DC/DC Converter failure	Failure occurred during constant acceleration testing. Root cause: The supplier of a transformer used internal to hybrid changed to Pb-free lead finish, resulting in excessive stress on solder joints.
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.

Electronic parts in a 14 MeV Neutron Environment

DAN (Dynamic Albedo of Neutrons), an instrument contributed by the Russian Federal Space Agency, contains a pulsing neutron generator used to detect water ice below the soil through neutron activation measurements. DAN generates 14 MeV neutrons, which is not a typical radiation environment found in space.

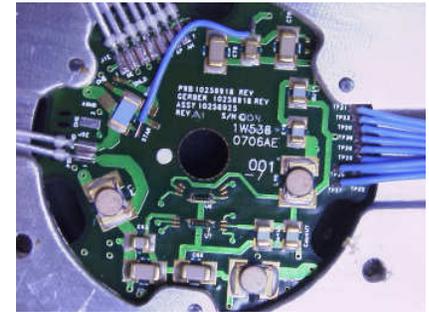
Characterization testing was performed using 14 MeV neutron beam on various part types to determine sensitivity of microelectronics to single event effects (SEE). The test results showed the effects of 14 MeV neutrons were comparable to background Galactic Cosmic Rays (GCR).



Cold Encoder Electronics

The Cold Encoder controls the actuators at each motor location outside of the Warm Electronic Box, so the electronics were limited by two primary constraints:

- Reduced form factor
- Exposure to temperature cycling from -130°C to $+85^{\circ}\text{C}$ on surface of Mars



These unique environmental and packaging requirements resulted in:

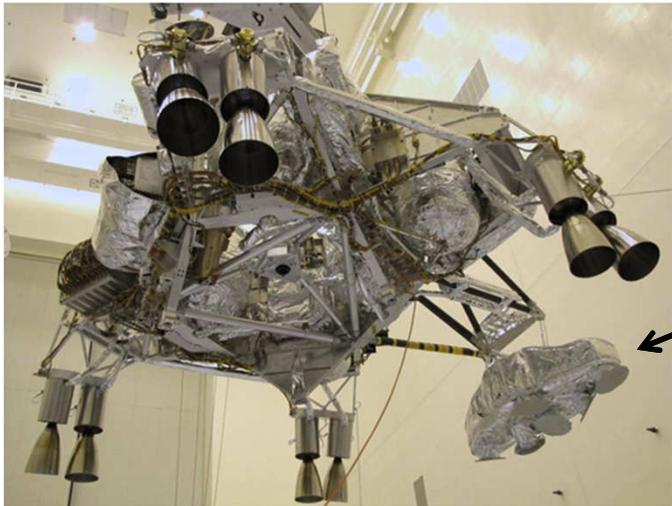
- Qualification of COB (Chip on Board) packaging to define optimal board material, solder type, and conformal coating.
- Large Sample Characterization for each lot of parts from $+125^{\circ}\text{C}$ to -135°C to establish performance over temperature to support worst case analysis.
- Burn-in of active devices at die level to ensure acceptable performance and reliability prior to board assembly.

MSL DLI Capacitor Failures

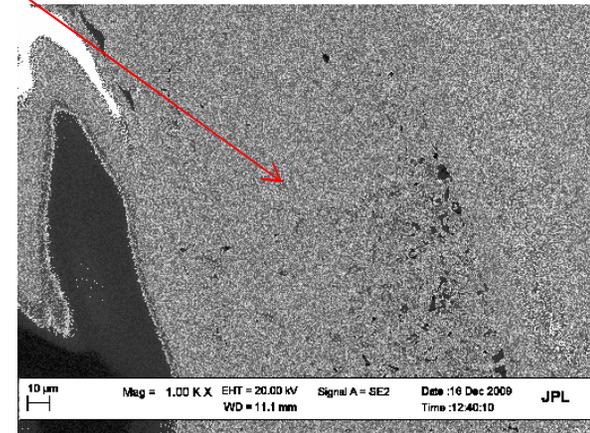
System-level failure in RF Module occurred due to short as a result of termination material flaking off of commercial DLI capacitor.

- Parts had all been screened by the manufacturer to mil specs.
- Inherent problem with design of capacitor resulting in need for extensive inspection and special handling requirements with no guarantee that shards will be eliminated.
- **Corrective action:** All capacitors inspected within modules to fullest extent possible and replaced if necessary.

Gold shard can create short.



Radar



“If anybody has been harboring doubts about the status of U.S. leadership in space, well, there’s a one-ton, automobile-size piece of American ingenuity, and it’s sitting on the surface of Mars right now.”

-- John P. Holdren, president’s science adviser



Rover Family Portrait

