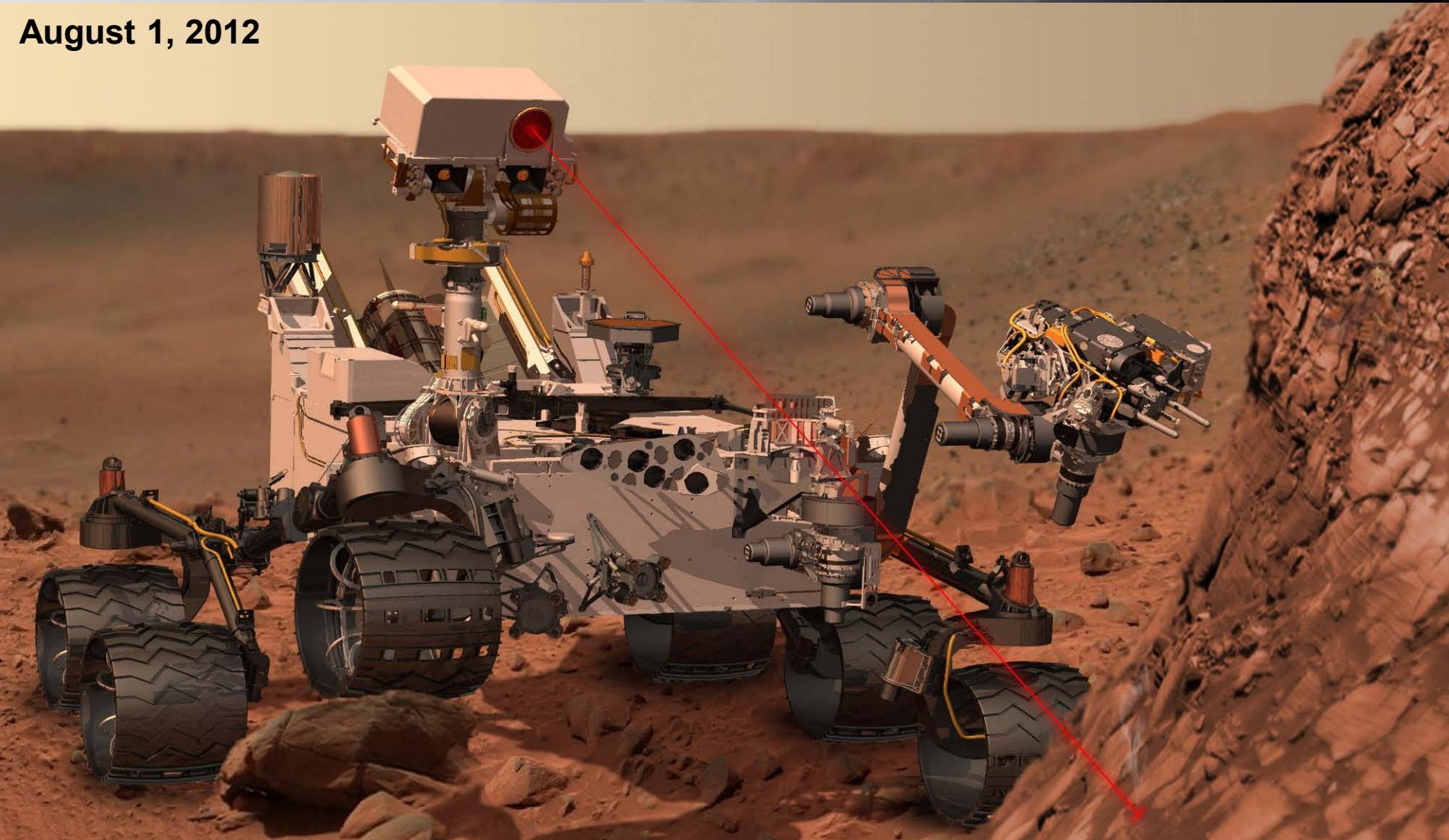


The Mars Science Laboratory's MMRTG: A Mission's Perspective

August 1, 2012



David Woerner, Jet Propulsion Laboratory, California Institute of Technology
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MMRTG = Multi-Mission Radioisotope Thermoelectric Generator



The Science and Mission of MSL

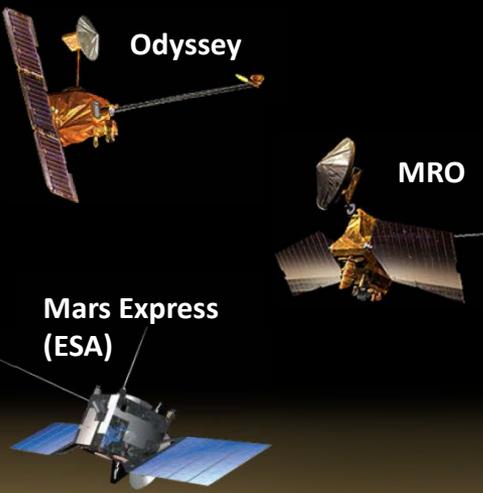
Perspective on MMRTG



NASA's Mars Exploration Program

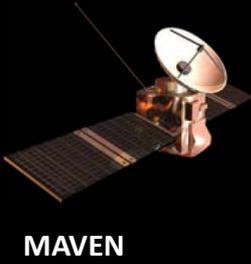
Launch Year

2000 to Present



2011

2013



2016



2018

In Planning

2020 & Beyond



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.

MER Phoenix Mars Science Lab



MARS SCIENCE STRATEGY: Follow the Water!

Common
Thread

W

A

T

E

R

When?
Where?
Form?
Amount?

Determine if Life
Ever Arose on Mars

LIFE

Characterize
the Climate

CLIMATE

Characterize
the Geology

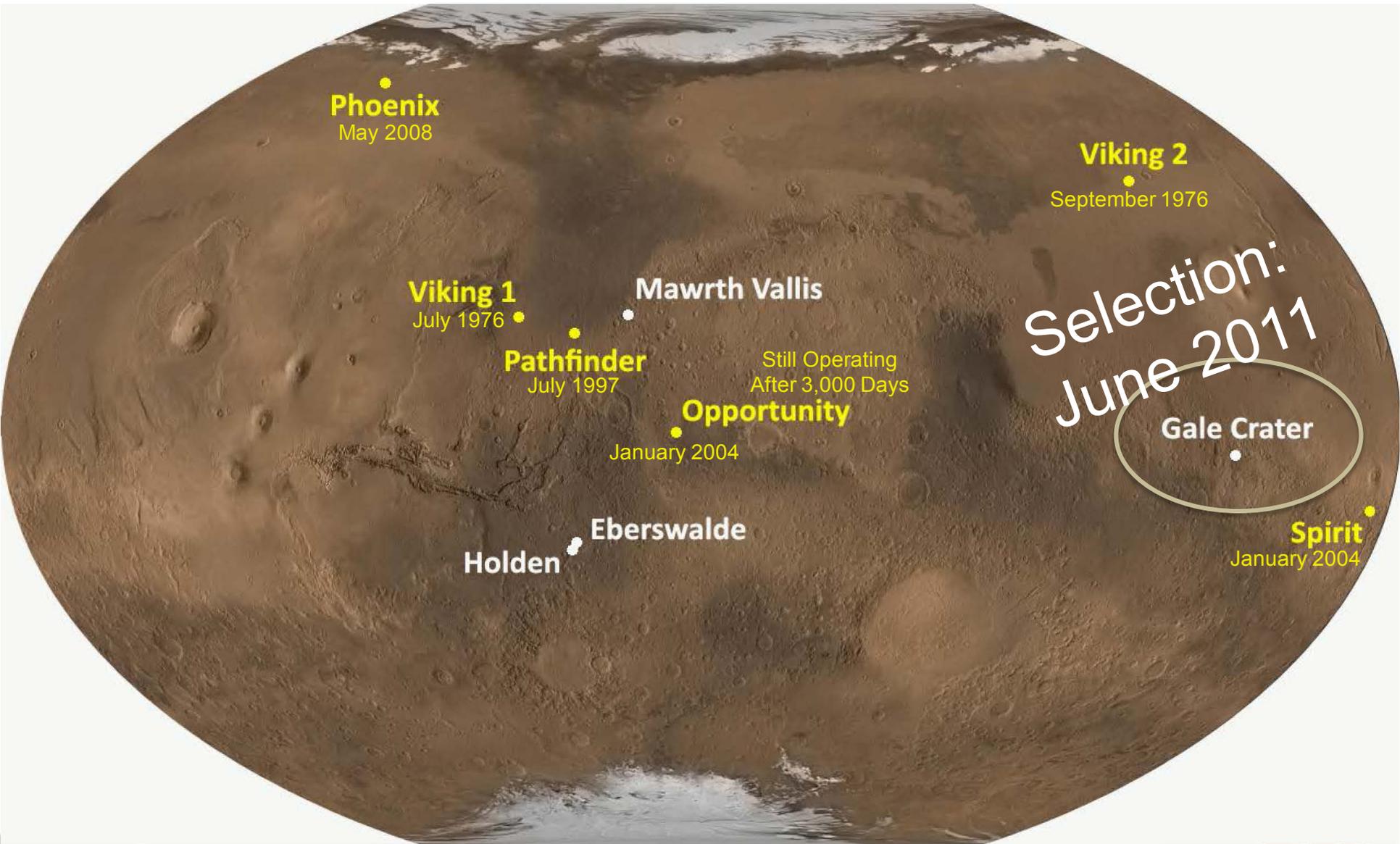
GEOLOGY

Prepare for Human
Exploration

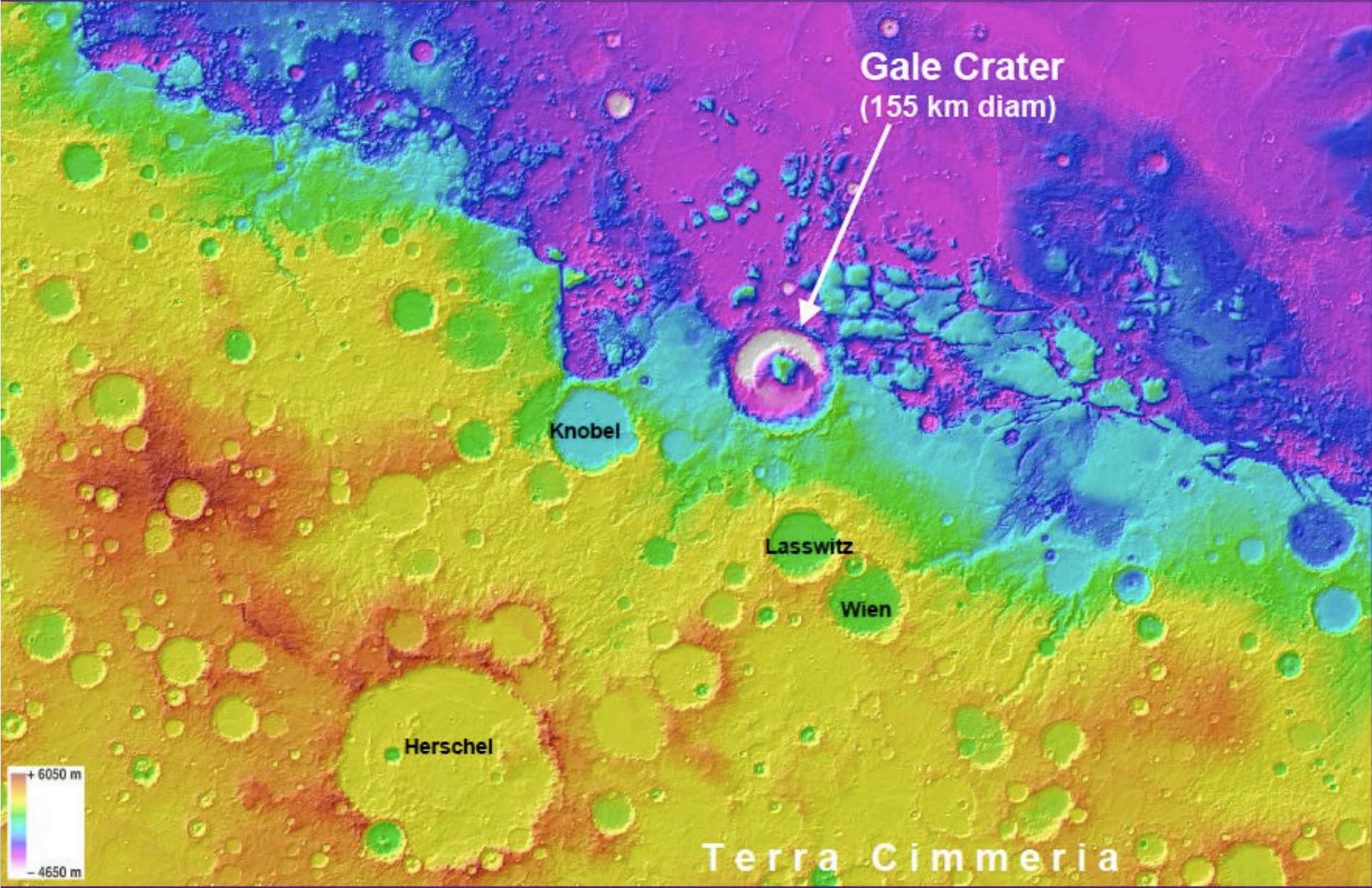
HUMAN



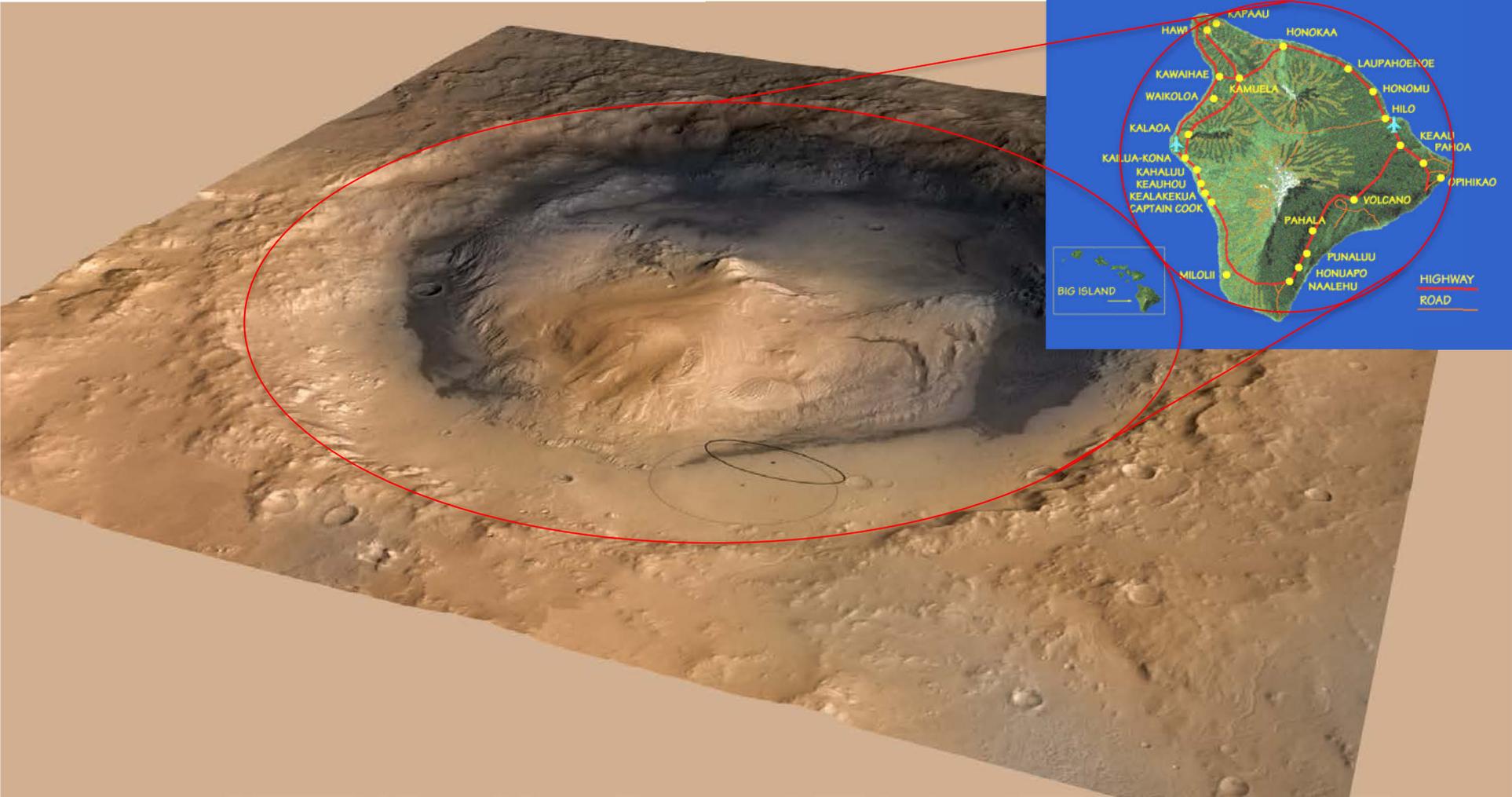
Previous missions and MSL's top four landing sites



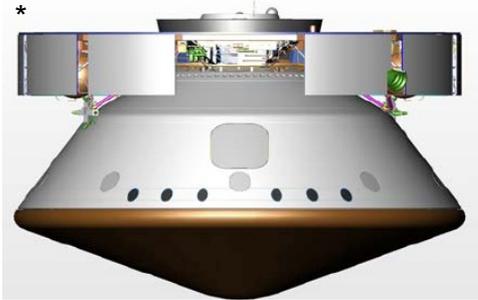
Gale crater is on the Dichotomy Boundary (Elevation map)



Gale Crater: Thickest Stratigraphic Section (partially filled crater)



MSL Mission Overview



CRUISE/APPROACH

- ~8 1/2 month cruise
- Spin stabilization
- Arrive N. hemisphere summer

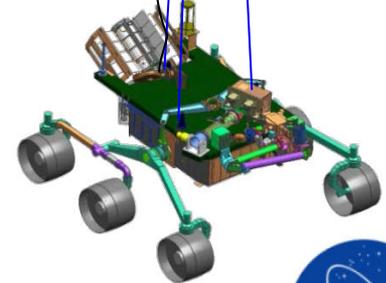
ENTRY, DESCENT, LANDING

- Guided entry and controlled, powered “sky crane” descent
- 6x18-km landing ellipse
- Discovery responsive for landing sites $\pm 30^\circ$ latitude, < 0 km elevation
- ~899-kg landed rover



SURFACE MISSION

- Prime mission is one Mars year, landing, Aug 5, 2012 (PDT)
- Latitude-independent and long-lived power source
- 20-km range
- 85 kg of science payload
- Acquire and analyze samples of rock, soil, and atmosphere
- Large rover, high clearance; greater mobility than MPF, MER



LAUNCHED

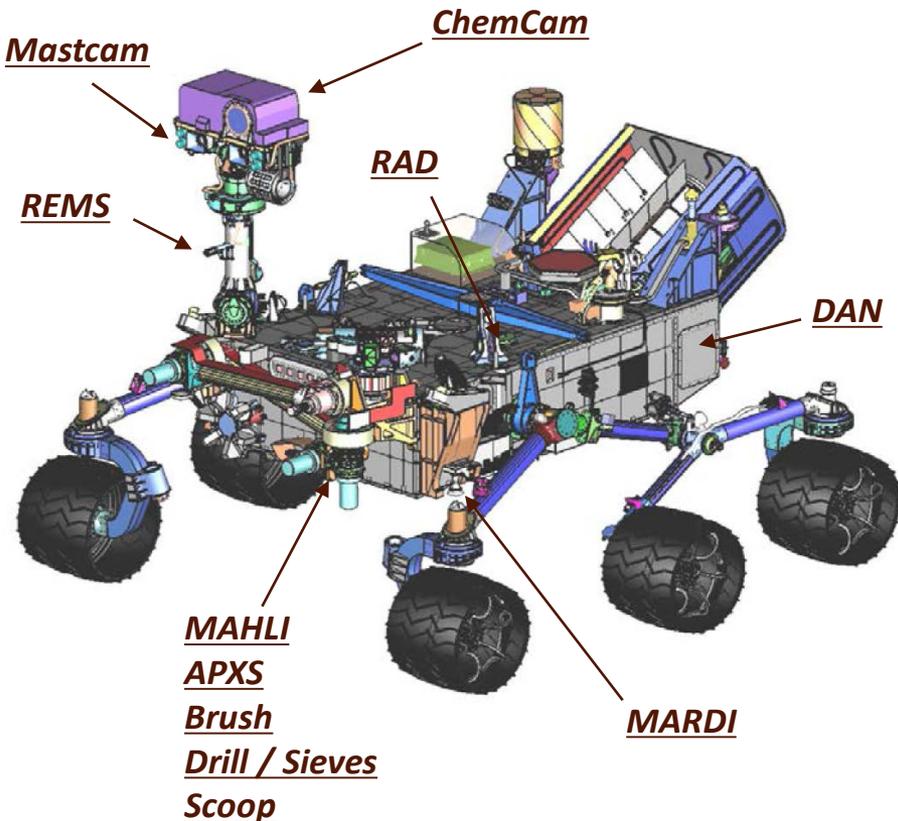
- Nov. 26, 2011
- Atlas V (541)
- Mass: 3,839 kg



* Artist's Renderings

7 Minutes of Terror

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

That's why Curiosity is so large. It takes a car-sized rover to carry so many tools.



Spirit/Opportunity (2004)

Sojourner (1997)

Curiosity (2011)

Curiosity is twice the size of Mars rovers Spirit and Opportunity and five times as heavy

165 lbs	Instruments	11 lbs
2000 lbs	Weight	384 lbs



Curiosity



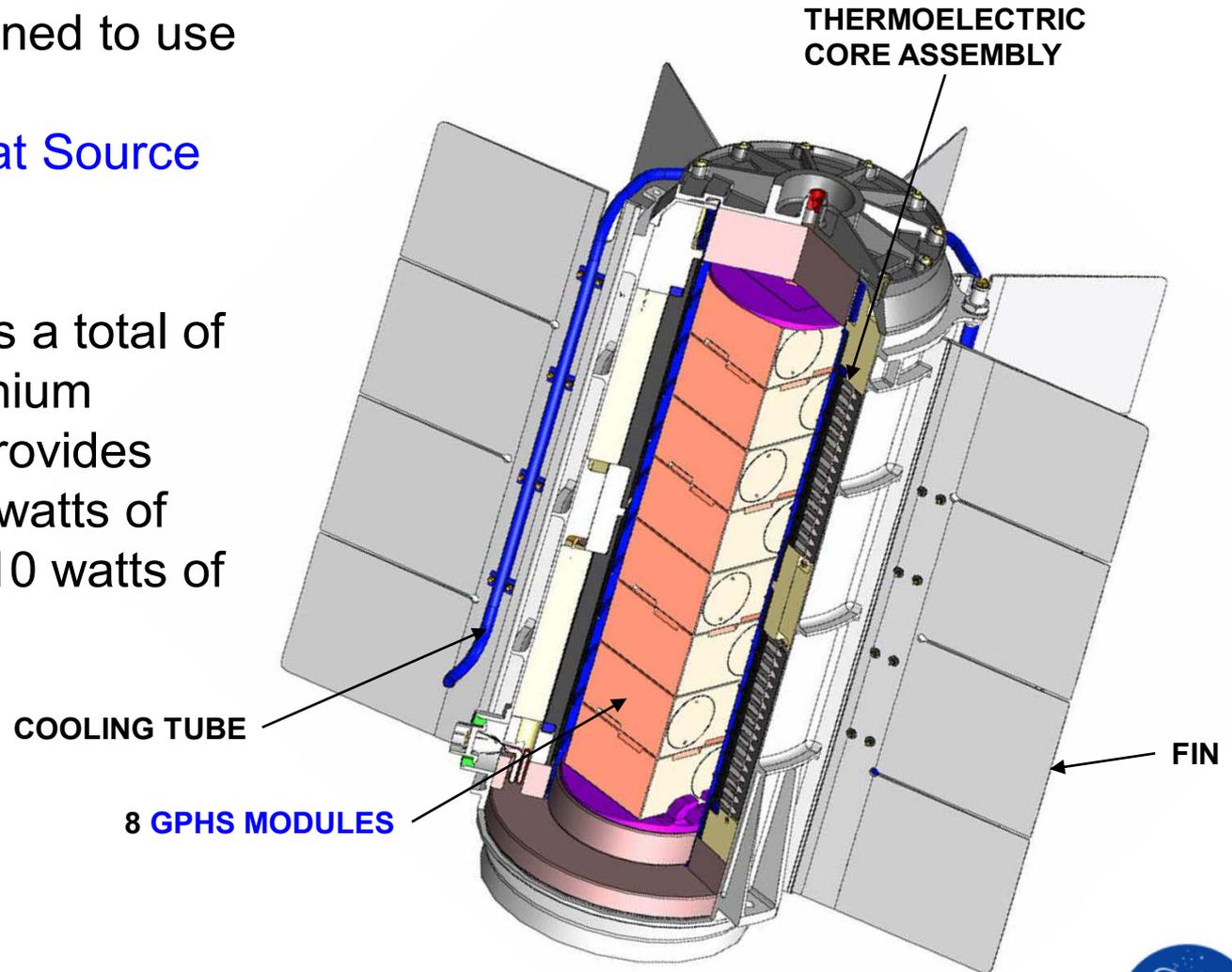
Mars Exploration Rover

Artist's Concept. NASA/JPL-Caltech

MMRTG: Cutaway view

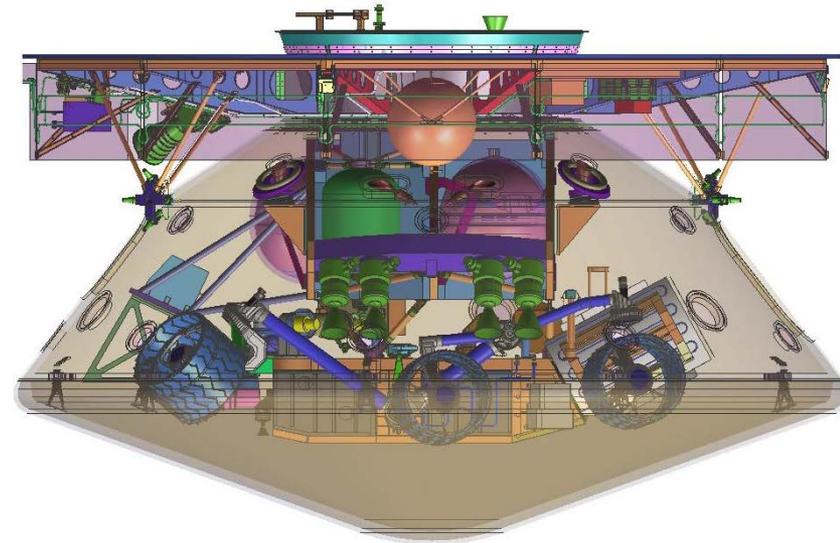
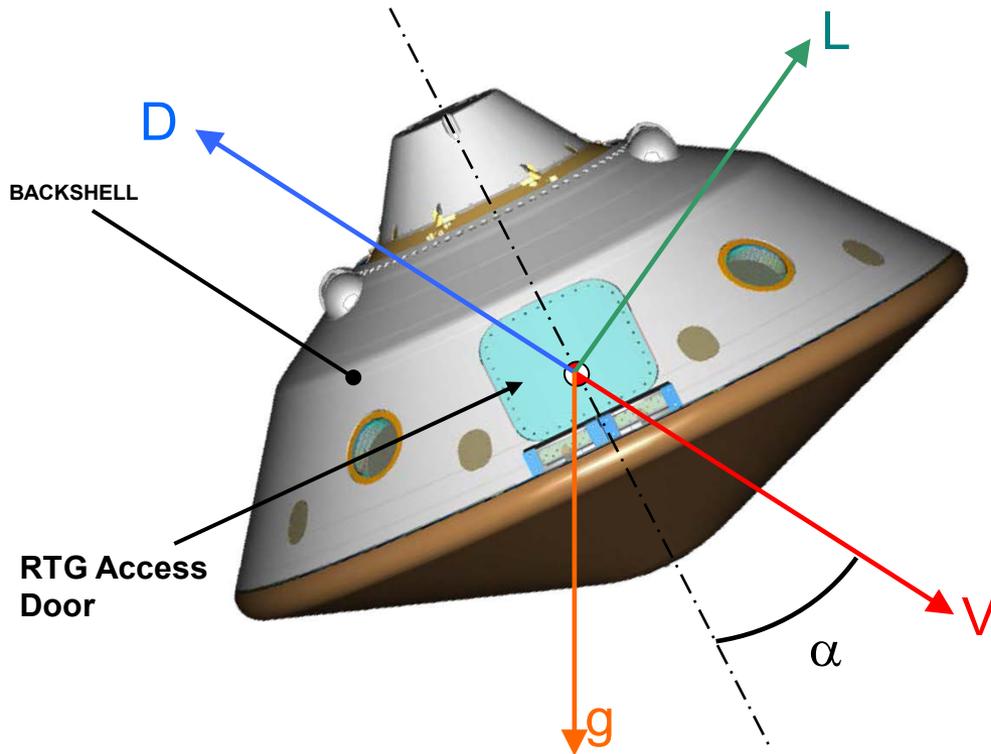
The MMRTG is designed to use heat from **General Purpose Heat Source (GPHS)** modules.

The MMRTG contains a total of 4.8 kg (10.6 lb) plutonium dioxide that initially provides approximately 2,000 watts of thermal power and 110 watts of electrical power.



What does MSL see in the MMRTG?

Mass, volume, integration



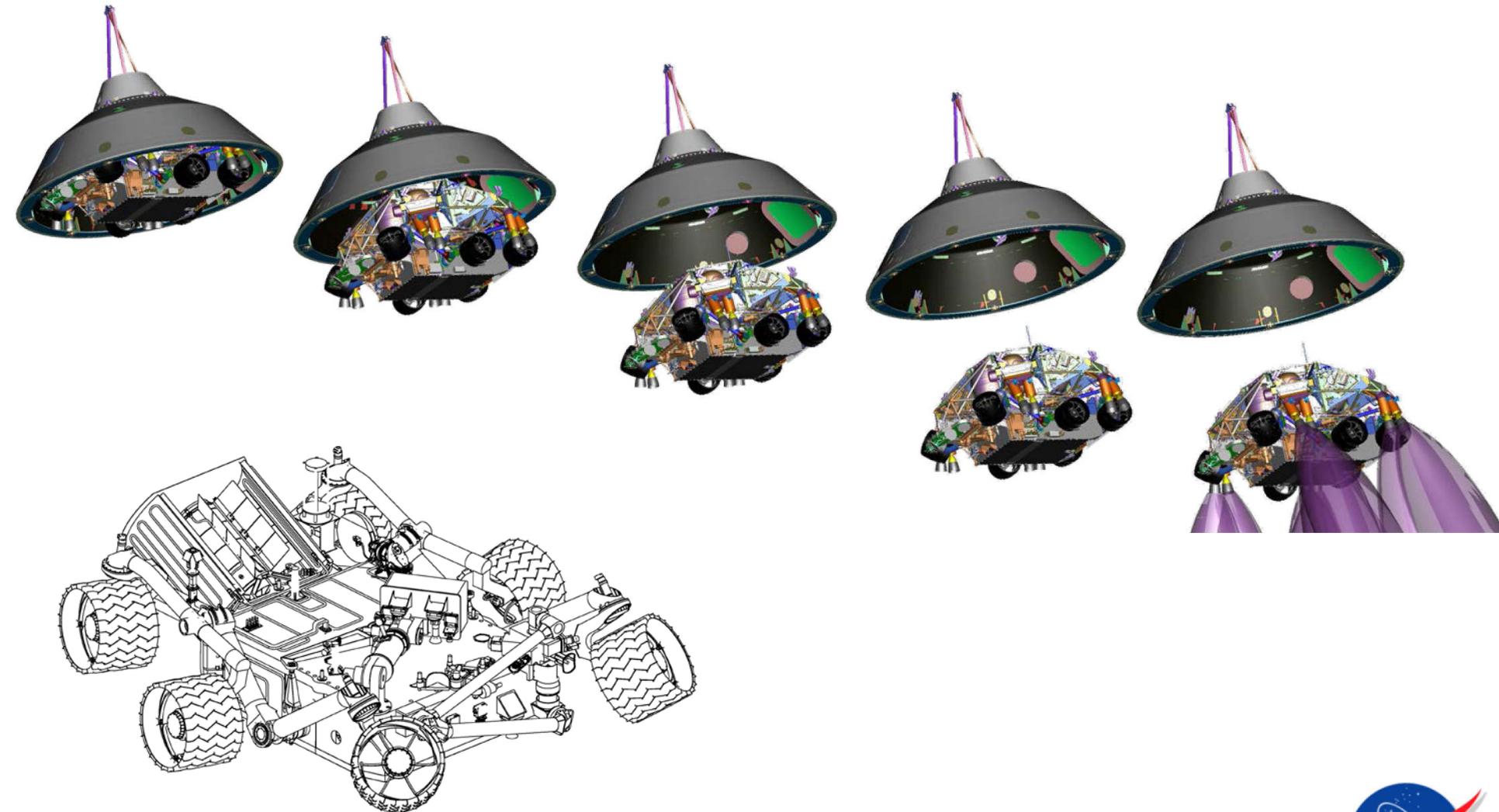
The MMRTG is the right size.

An MMRTG's mass is ~45 kg

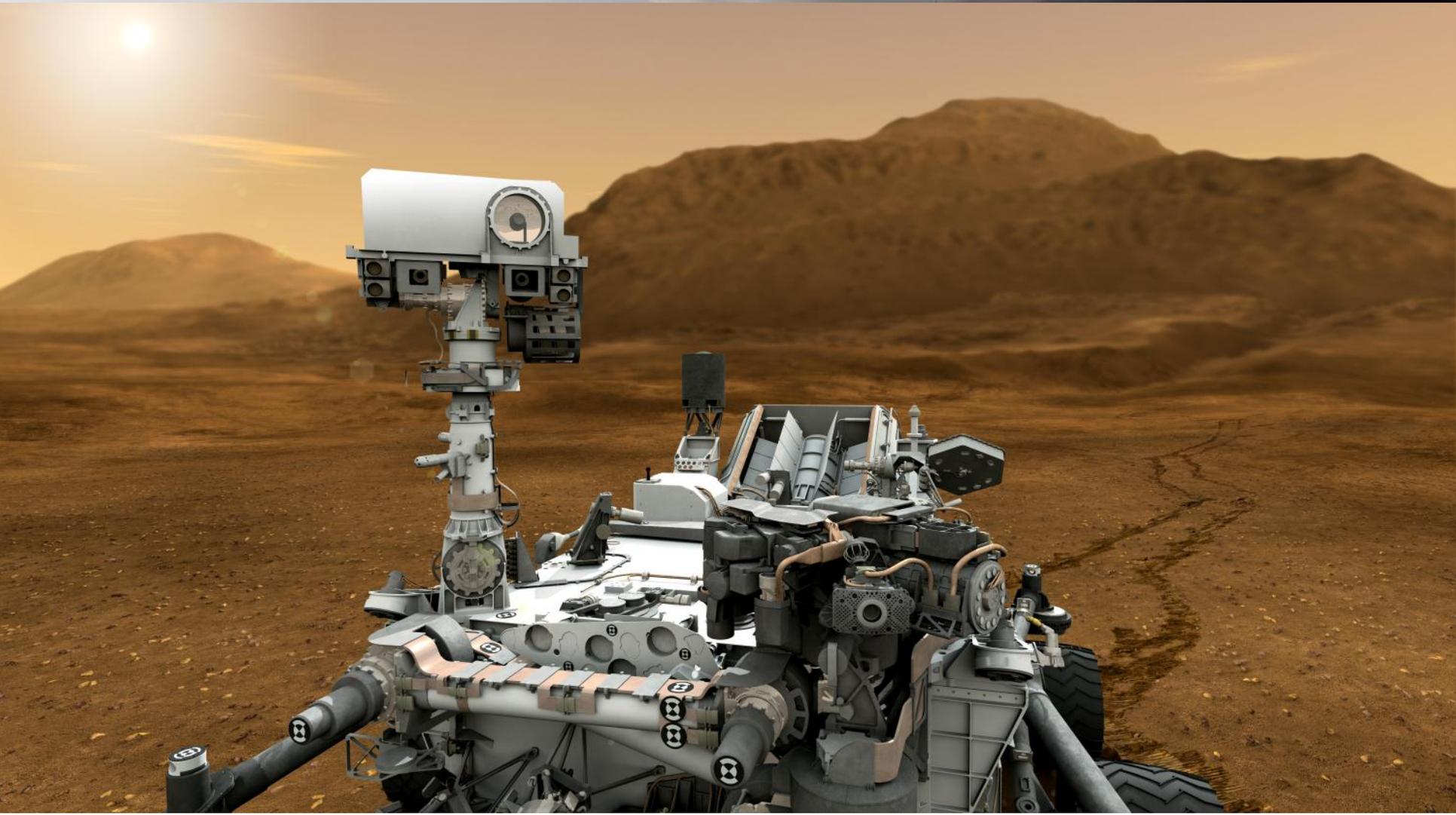
An MMRTG's dimensions, 25" W x 26" H, make the generator small enough to fit comfortably in the space within the MSL entry body

What does MSL see in the MMRTG?

Volume

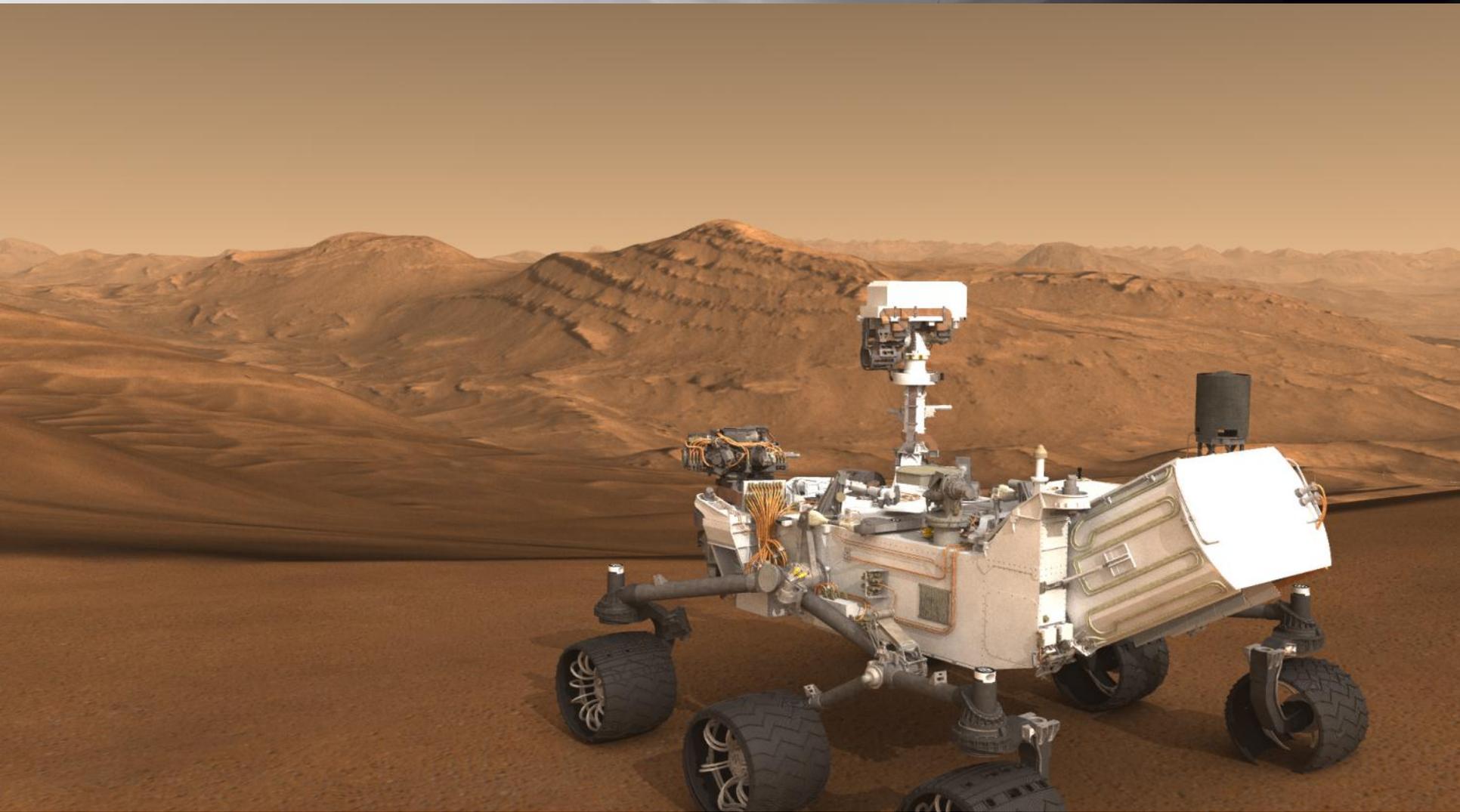


MMRTG between the two heat exchangers at the aft-end of Curiosity



Artist's Concept. NASA/JPL-Caltech

Forward facing view of the MMRTG between heat exchangers and behind wind breaker.



Artist's Concept. NASA/JPL-Caltech

What does MSL see in the MMRTG?

Reliability, robustness to the Martian environment

A reliable power system first

- RTGs have been used in space for the last few decades and have survived well past their planned mission lifetimes

The MMRTG will largely be unaffected by the dusty Martian environment

- The optical properties of the MMRTG closely match the optical properties of Martian dust
- Dust settling on the generator will not have much effect on the MMRTG

Lots of waste heat means some of the heat can be captured and distributed.

- Curiosity has a pumped fluid loop that circulates liquid that is heated by waste heat from the MMRTG.
- The heated fluid is channeled through tubes mounted on the Rover Avionics Mounting Plate (RAMP), and by controlling this process, heat is delivered to spots on the RAMP that need the heat.
- This minimizes temperature swings the electronics experience and hence enhances rover life.
 - Martian weather extremes can achieve -175 deg F (-115C)

What does MSL see in the MMRTG?

Robustness to the planetary atmospheres

The MMRTG is designed to operate in planetary atmospheres.

Mars has a thin atmosphere (0.087 psi), compared to Earth's sea level average of 14.69 psi, largely consisting of CO₂ (95.2%) that would have a deleterious effect on the generator if the generator was not designed correctly

The MMRTG thermocouples are sealed in a vessel and operate without contamination or degradation induced by a planetary atmosphere.

What does MSL see in the MMRTG?

Robustness to environments for space missions

The MMRTG was designed and qualified as a **Multi-Mission** RTG.

It was tested at random vibe and pyroshock environments suited for more aggressive missions than MSL.

- Performance remained in spec as expected.
- This test indicated MSL mission environments would be relatively benign
- Hence the generator's robustness was shown to exceed that needed for MSL

In addition, the MMRTG has been tested for entry, descent, and landing and performed within spec.

In addition, an MMRTG was aged ~3.25 years, then tested against shock levels (for EDL) that MSL will see at Mars.

- Aging combined with an environmental test made no difference in power output.

What does MSL see in the MMRTG?

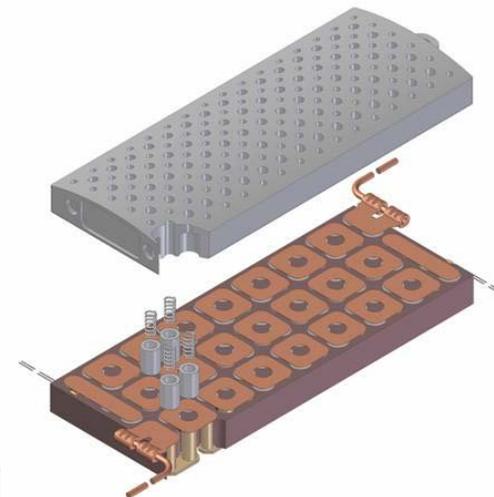
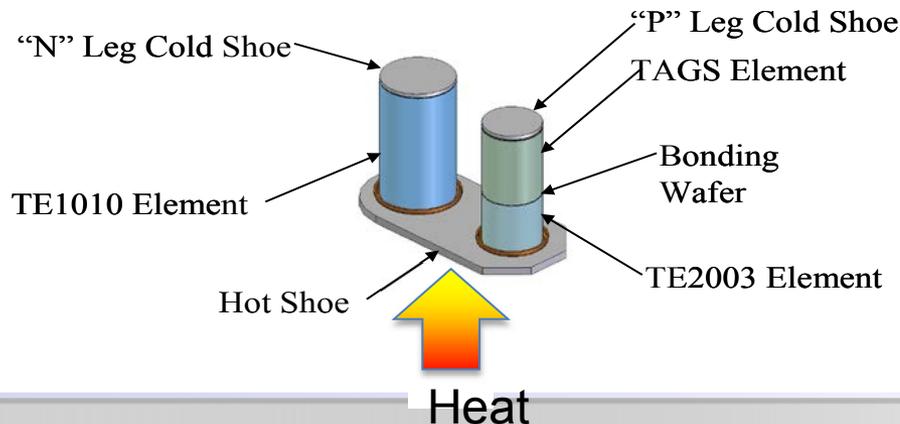
Graceful degradation in the face of faults

The MMRTG is designed so power output degrades gracefully.

- Clearly, the fuel decay degrades and the thermocouple performance of the generator degrades, but what about faults?
- Does the generator design include features to stave off complete or large power drops?

The MMRTG is wired internally in a series-parallel circuit so should one of its hundreds of thermocouples fail, MSL will experience no measurable change in power output.

In addition, all thermocouples are held in place by compression to counteract forces that might create an open in a thermocouple were the compression forces not in place.



Status of the MMRTG

MMRTG Update:

Flight unit #1 performing as expected for MSL.

The life test unit has now completed ~4.5 years of life test and is performing as expected

Flight unit #2 is assembled, tested, and in storage.

Flight unit #3 will be complete in spring of next year.

F2 is now available for NASA to use and F3 will be available for NASA to use in <1 year.

NASA is also funding development of improved thermocouples so upgraded and/or advanced MMRTGs may be built and flown

Thank you

- The Odyssey and Mars Reconnaissance Orbiters are on-station at Mars and prepared to support MSL.
- All MSL systems and teams are ready for EDL and the surface mission.

MSL is looking forward to a successful landing.

Touchdown:

August 5, 10:31 p.m., Pacific

August 6, 1:31 a.m., Eastern

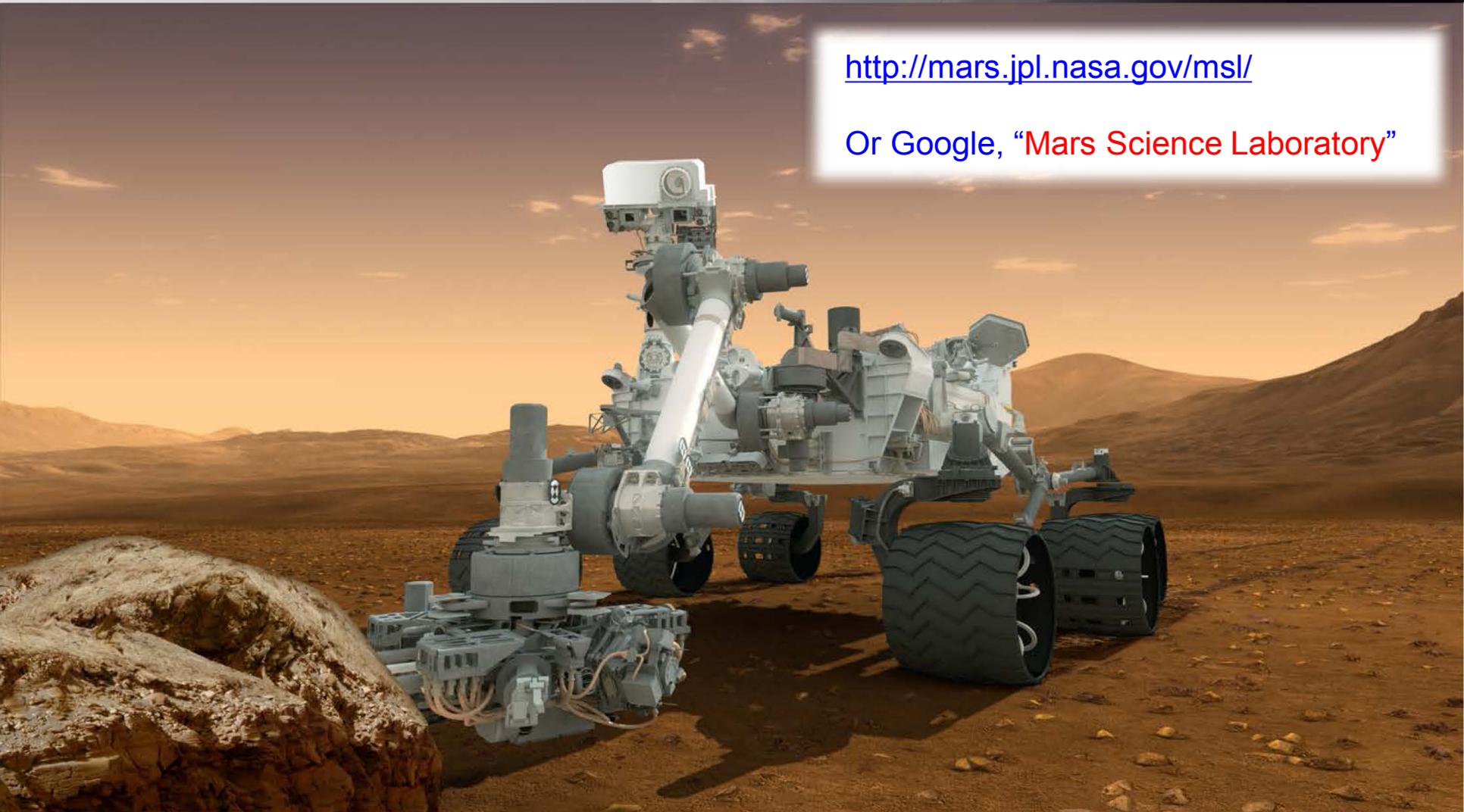
(plus or minus a minute and including one-way light time)



The Mars Science Laboratory Mission MMRTG

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

Or Google, “Mars Science Laboratory”



David Woerner