Patching Flight Software on Mars

Ed Benowitz / Mark Maimone
MSL Flight Software Developers
NASA/Jet Propulsion Laboratory
Caltech

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Agenda

- Spirit/Opportunity Rover Mission Overview
- Curiosity Rover Mission Overview
- Flight Software Architecture Overview
- Options for Changing Software in Flight
- Goals for Patching
- General Patching Approaches
- Trades
- How a FSW Image is Loaded
- Patch Scenarios
- Lessons learned

Spirit Mission Overview

NASA's Mars Exploration Rovers were designed to survive 90 days.

But Spirit explored Mars for 6 years!

A stalled wheel motor led to a serendipitous discovery proving Mars had freestanding pools of water.

FSW patches helped keep Spirit going even with failed actuators.

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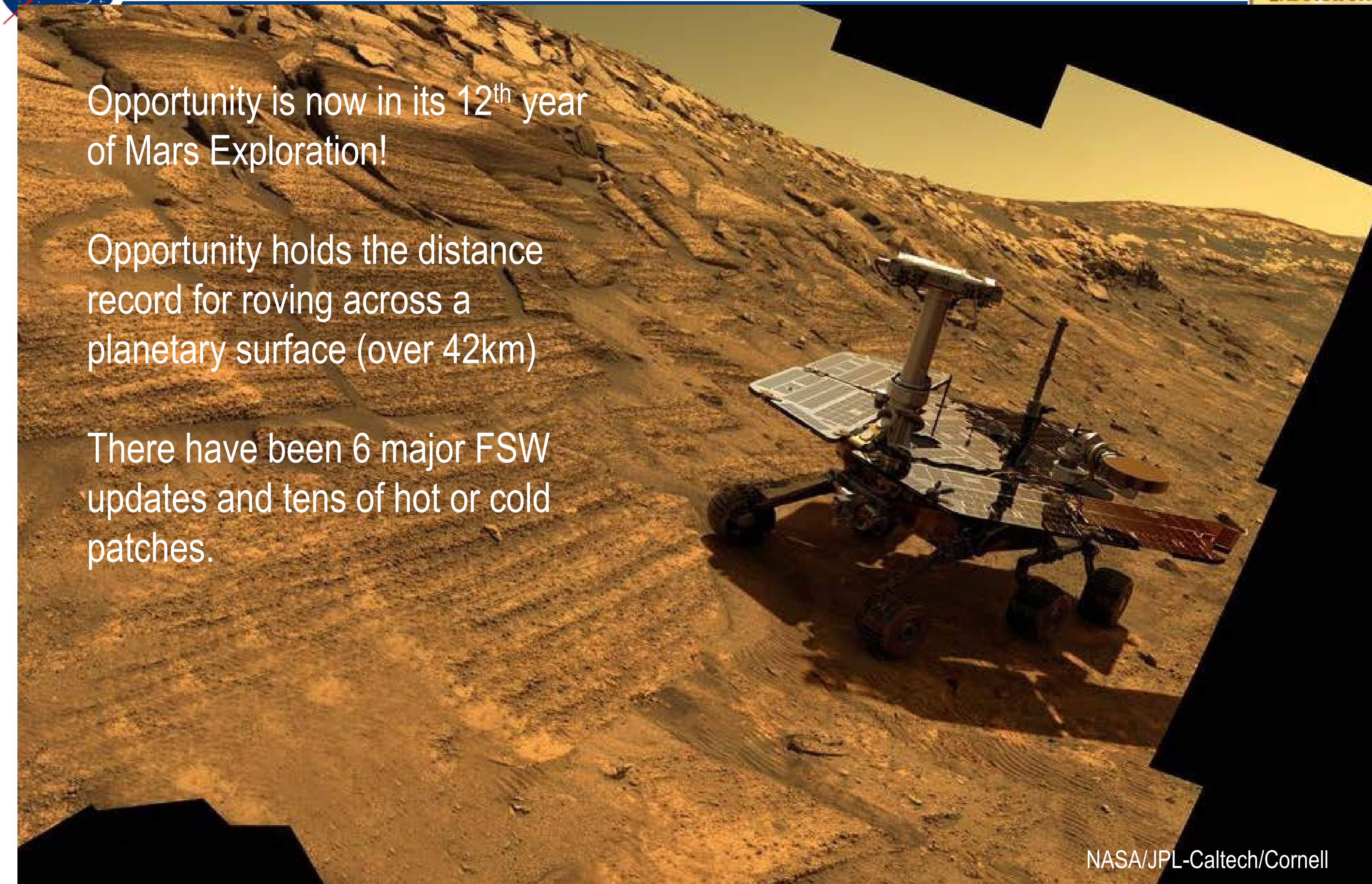
Opportunity Overview

Opportunity is now in its 12th year of Mars Exploration!

Opportunity holds the distance record for roving across a planetary surface (over 42km)

There have been 6 major FSW updates and tens of hot or cold patches.



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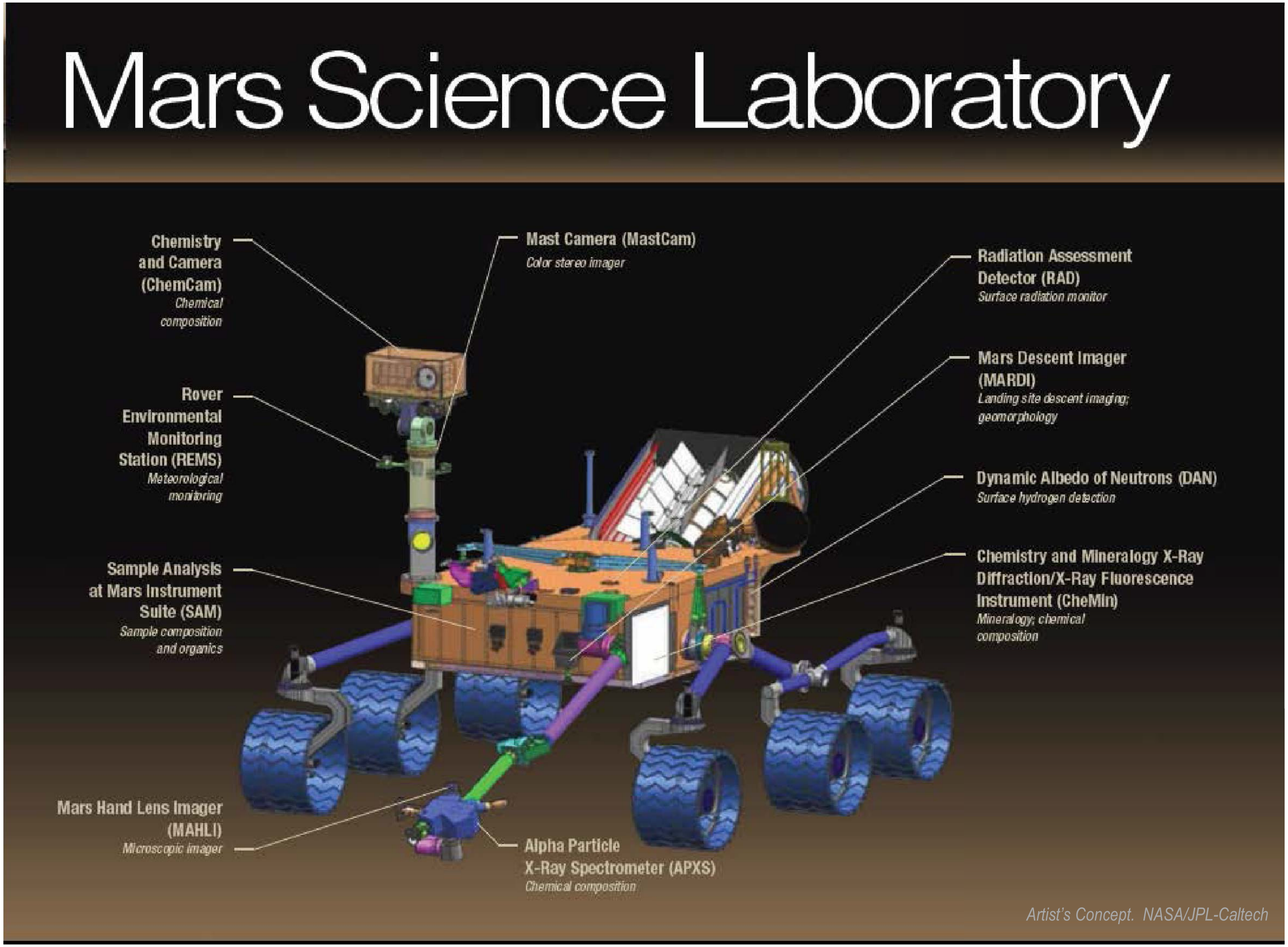
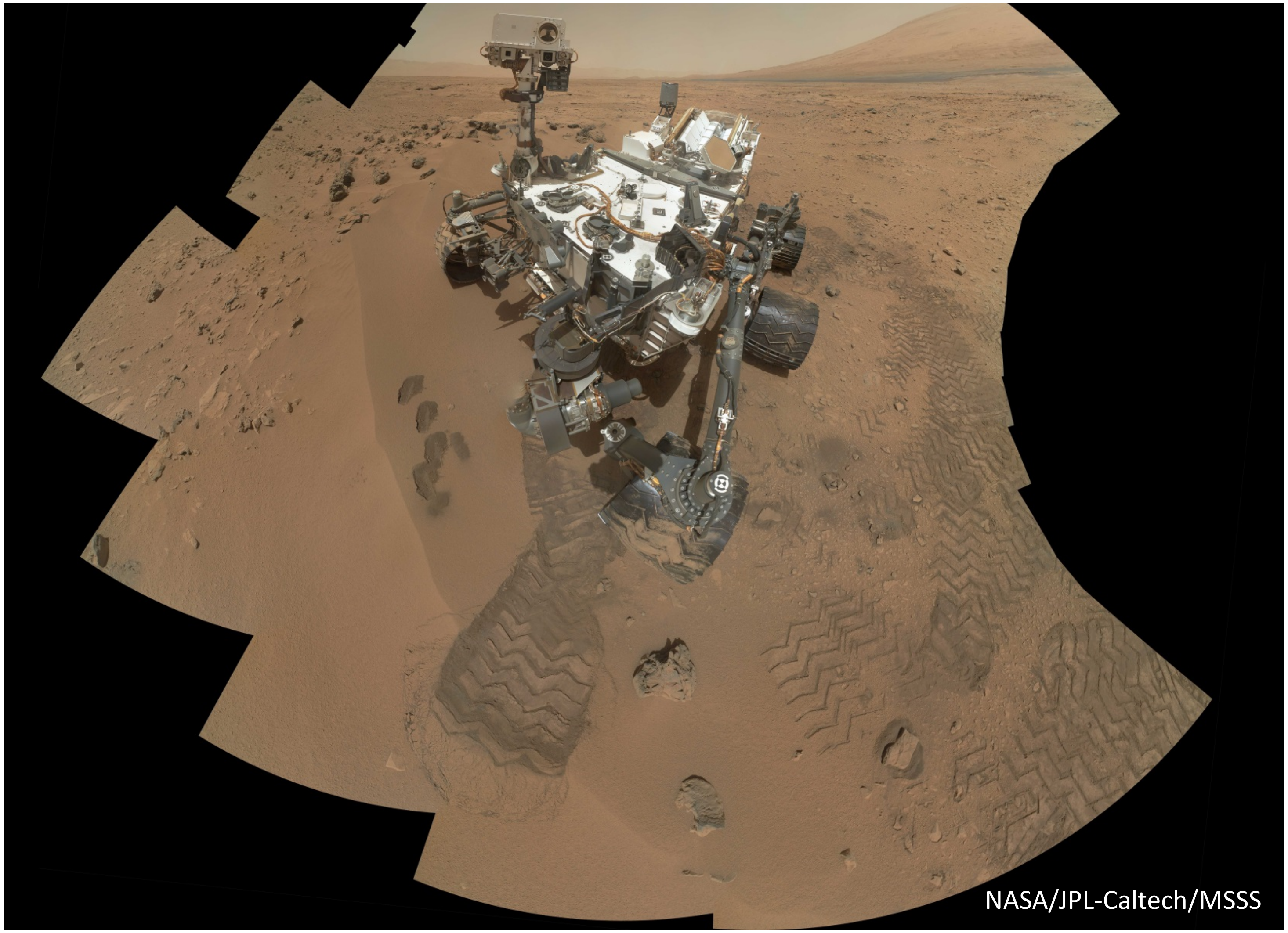
Spirit and Opportunity Rover Mission Overview

- Size
  - About the size of a golf cart -- 5 feet long (not including the arm), 6 feet wide and 5 feet tall
- Arm reach
  - About 3 feet
- Weight:
  - 185 kilograms (400 pounds)
- Mission:
  - Search for and characterize a wide range of rocks and soils that hold clues to past water activity on Mars.

Curiosity Rover Mission Overview



Curiosity Rover Mission Overview

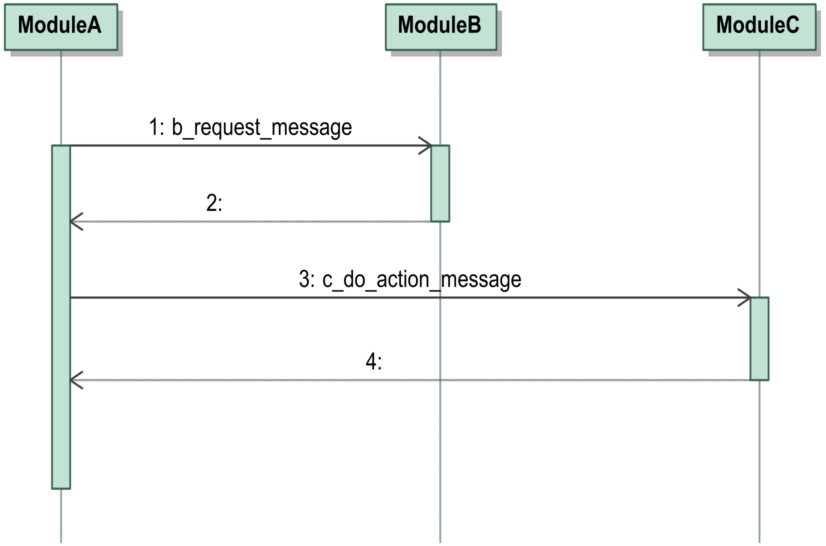


Curiosity Rover Mission Overview

- Size
  - About the size of a small car -- 10 feet long (not including the arm), 9 feet wide and 7 feet tall or about the height of a basketball player
- Arm reach
  - About 7 feet
- Weight:
  - 900 kilograms (2,000 pounds)
- Mission:
  - To search areas of Mars for past or present conditions favorable for life, and conditions capable of preserving a record of life

Flight Software Overview

- MER and MSL rovers all run the VxWorks operating system
  - Supports executing shell commands
    - Change variables
    - Dynamic code loading and execution
- MSL has over 100 flight software modules, most run as their own task
- Communication between tasks
  - Inter-process communication (IPC) messages
    - Send a message
    - Wait for a reply
    - Proceed



Options for Changing Software in Flight

- Uplink and install an entire flight software image
- Patch an existing flight software image
  - Modify or extend the existing onboard flight software image
- Extend FSW with a new software component
  - Dynamically load new code
  - Add a new .o and add new commands, telemetry, and data products using a FSW-provided API

Why Patch?

- Patching can:
  - Add entirely new functionality to flight software
    - Could include new commands and telemetry
    - May be necessary to work around newly discovered hardware behavior
    - Increase science return
  - Fix a flight software bug
    - Patching potentially a faster process than a full FSW image
      - A full FSW load typically requires that Validation and Verification (V&V) tests run against all FSW capabilities, even ones that are not changing

General Patching Approaches

- Hot patch
  - Changes code in RAM while we are running
  - VxWorks also allows dynamic loading of .o files
- Cold patch
  - Modify the flight software image stored in a non-volatile storage area.
  - The new code image would be used on a subsequent boot
  - Does not change the currently running code
- Trades
  - Risk
    - Simpler uninstall for a hot patch
      - Reboot would restore flight software back into a clean version.
  - Testing effort
  - Uplink bandwidth

General Patching Approaches

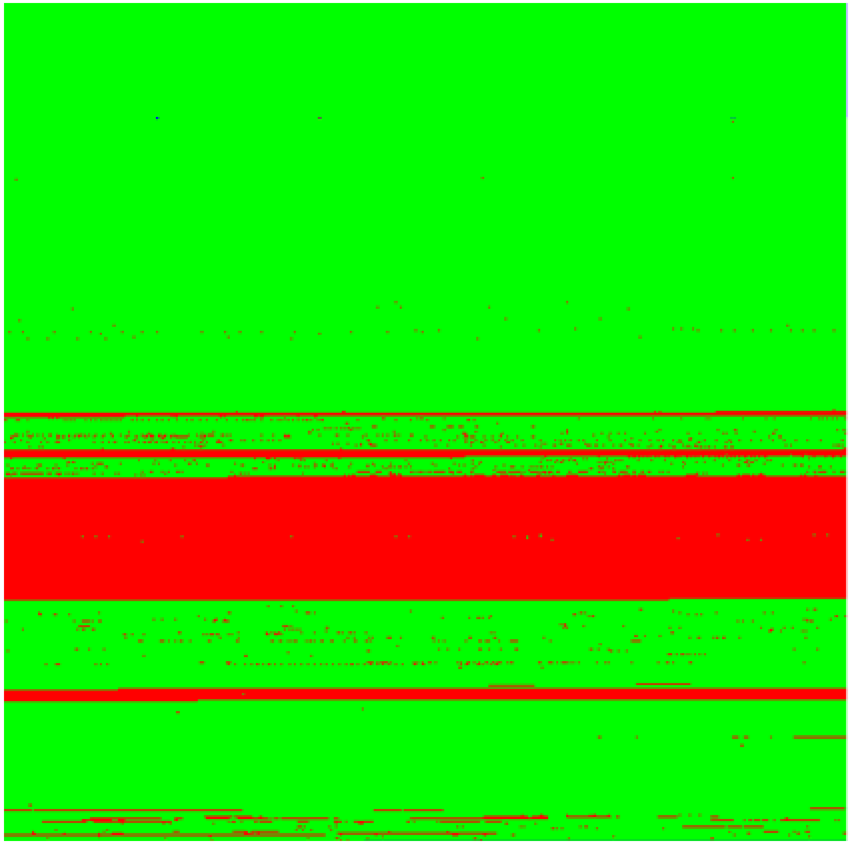
- Patches may need to
  - Add code to an existing function
  - Replace a buggy function with a new function
  - Remove code from an existing function
  - Add new global variables
  - Change or assign references to existing global variables, e.g. function pointers
  - Add new commands and telemetry
- And just in case the patch doesn't work
  - Have a plan for un-installing the patch

Trades

- Trade: Should flight software provide commands for patching?
  - MER and MSL had some support for patches
    - MER: Could apply patches to a copy of FSW in RAM and write to non-volatile storage
    - MSL has a command for adding a new FSW component module
      - But hot patches that change existing code require back-door methods
- Issues with a general built in patch capability
  - Trades FSW development resources against Ops resources
  - A small code change can result in a large difference in the FSW binary
    - If memory locations move, the size of a diff file can be large
  - Both missions had small amounts of RAM
    - MSL could not add padding inside binaries to allow for reduced diff file sizes
    - MER did have room to add padding

MER Example Patch Differences

Memory Start



Memory End

Green – No change
Red – At least one bit changed

How MSL Boots

- The boot loader loads the FSW image from the currently selected NOR bank
  - Copy from NOR to RAM
  - Execute the image image from RAM
- If the image fails to load, the boot loader uses another NOR bank

How MER boots normally

- MER had a Rad6K flight computer
  - FSW images were stored in EEPROM
  - Multiple, different FSW images could be stored

How A Full New Image is Installed

- The ground uplinks a new binary image to the file system
- Upon command, the new image is saved
  - Flight software loads the image into RAM
  - Flight software burns the NOR zone with the image
- MER
  - In addition to the above, MER also allowed patching the RAM image before burning to its nonvolatile storage in EEPROM

MSL Patch Scenario: Remove code

- A bug affecting both Cruise and Surface operations required the removal of several lines of code
  - Cruise: The spacecraft is always on
    - Hot patch approach: Patch the code in RAM only
      - Replace the original code with no-ops
        - » A memory assignment
  - Surface: The rover has a wakeup/shutdown cycle
    - Cold patch approach: Change the image in NOR
      - Load the original image into RAM
      - Modify the RAM image to add the no-ops.
      - Save the newly modified image into NOR
      - The bug fixes are retained across reboots

MSL Patch Scenario: Replacing a function

- Add code to a function to fix a bug
  - The function referenced global variables
- Implemented as a hot patch.
- Use a replacement function
  - Create a new .o file to be dynamically loaded by Vxworks containing
    - Replacement function
    - Pointers to the global variables
- Installation
  - Load the .o
  - Find the address of the old function
  - Poke an instruction into the old function to jump to the new function
  - Find the address of the global variables, and assign them to the new global variable pointers
- Install performed on every boot by a sequence

MSL Patch Scenario: Adding new functionality

- MSL can add new functionality
  - Special commands can install a new FSW component .o containing new code, commands, telemetry
- Registration to add new functionality
  - The new .o is dynamically loaded during the boot process
  - The new code may register new commands, telemetry, data products
  - The new code can hook into the existing wakeup and shutdown process
    - Functions are registered.
  - The registration is performed once
    - Registration information is stored in non-volatile memory

Lessons Learned

- We had to use back-door methods to change small parts of the existing flight code on MSL
  - Even though explicit commands were provided to add new functionality and load an entire new flight software image
- Onboard patching of small code changes was frequent enough to consider adding a patch command in future missions.
  - Running hot patch setup sequences has become a standard part of our nominal sequencing process

Thanks

- MSL flight software team
  - Led by Ben Cichy
  - Special thanks to Danny Lam
- MER flight software team
  - Led by Glenn Reeves

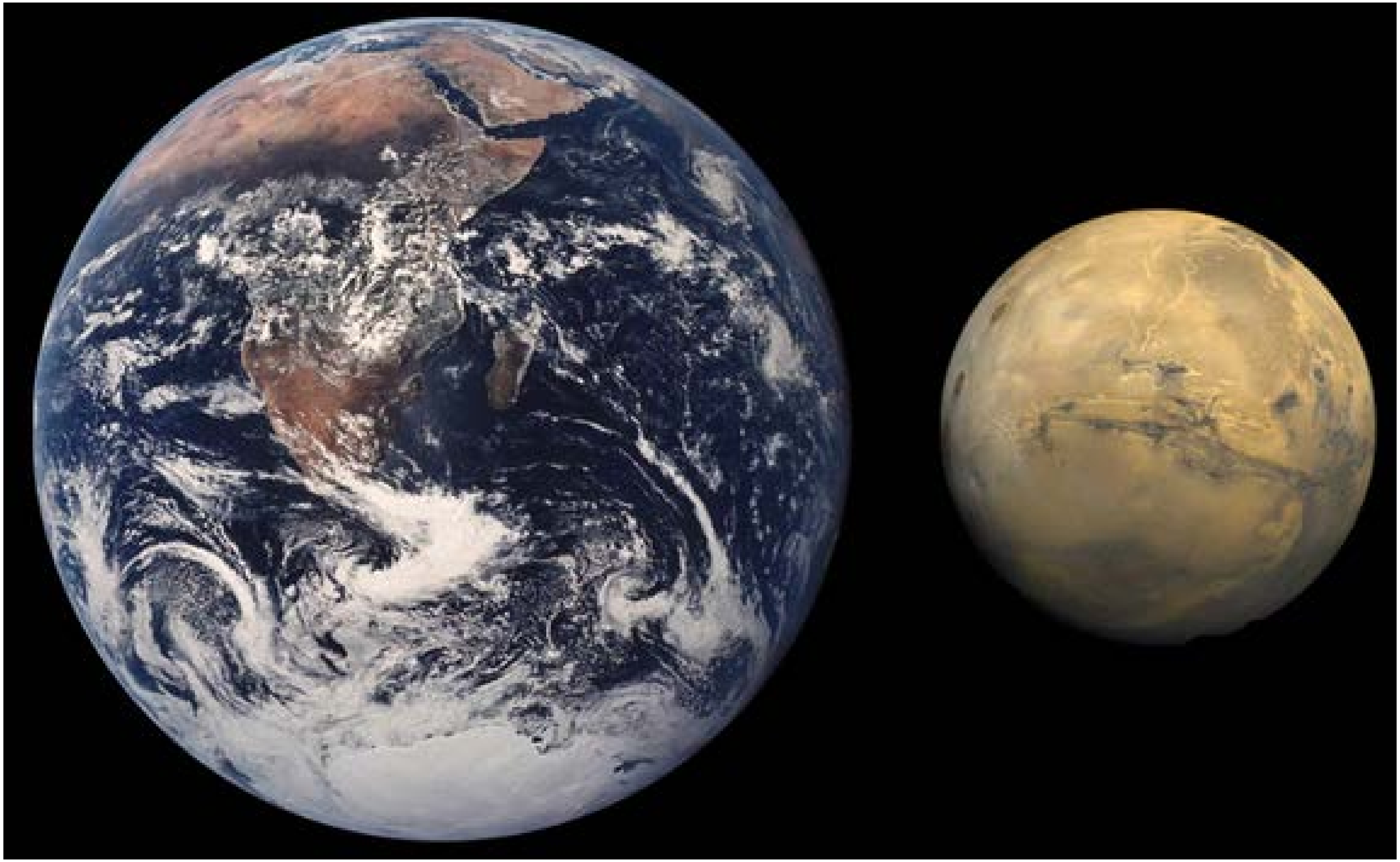
QUESTIONS?

BACKUP

Mars facts

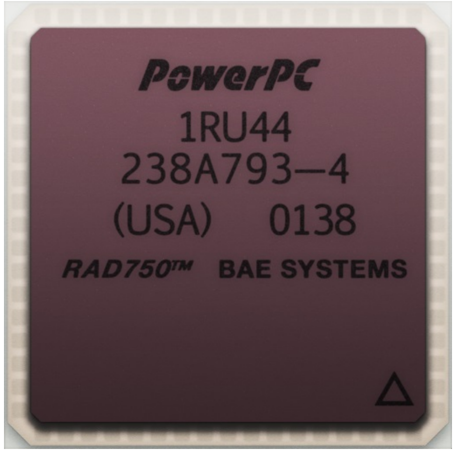
- Size:
  - Half the size of Earth, but same land area
- Weight:
  - 1/10th of what the Earth weighs
- Gravity:
  - 38% as strong as on Earth
- Average Temperature:
  - -81 degrees Fahrenheit
- Atmosphere:
  - Mostly carbon dioxide, with some water vapor
- Moons:
  - 2, Phobos and Deimos

Mars facts



MSL Flight Computer

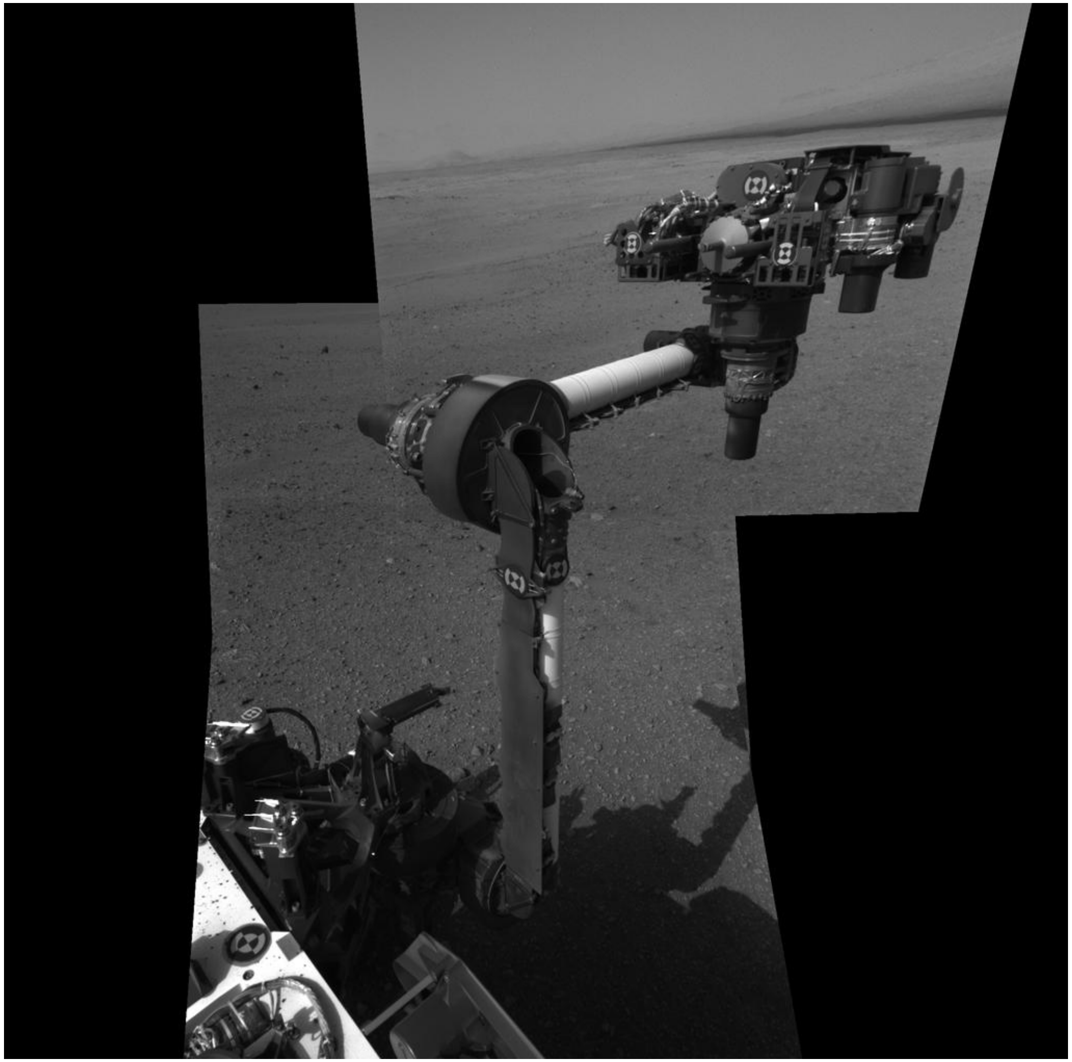
- Single Board Computer
  - RAD 750
- On-board memory includes 128 MB of volatile DRAM
- 4 GB of NAND non-volatile memory on a separate card
- Both with error detection and correction
- Runs on two flight computers
  - Prime and backup

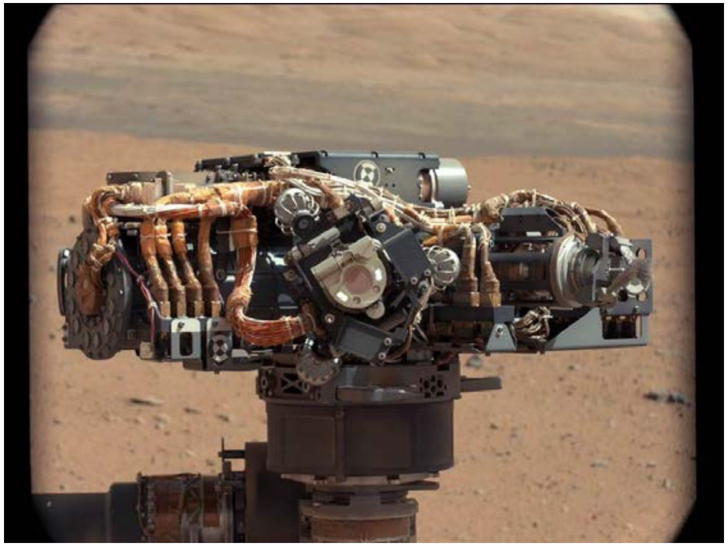


Cameras

- Cameras
  - Four Pairs of Engineering Hazard Avoidance Cameras (Hazcams):
    - Mounted on the lower portion of the front and rear of the rover, these black-and-white cameras use visible light to capture three-dimensional (3-D) imagery.
  - Two Pairs of Engineering Navigation Cameras (Navcams):
    - Mounted on the mast (the rover "neck and head"), these black-and-white cameras use visible light to gather panoramic, three-dimensional (3D) imagery. The navigation camera unit is a stereo pair of cameras, each with a 45-degree field of view
  - Four Science Cameras:
    - MastCam (one pair), will take color images, three-dimensional stereo images, and color video footage
    - The Mars Hand Lens Imager is the equivalent of a geologist's hand lens
    - Chemcam

Arm and Hand





Drill

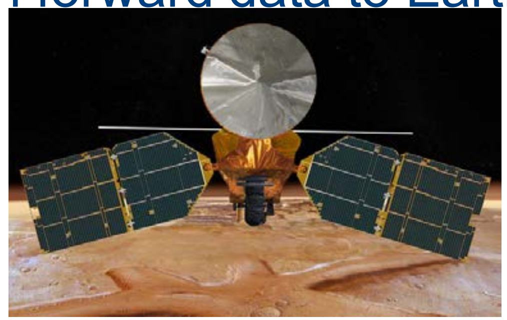
- Curiosity drilled on Mars

Instruments on Curiosity

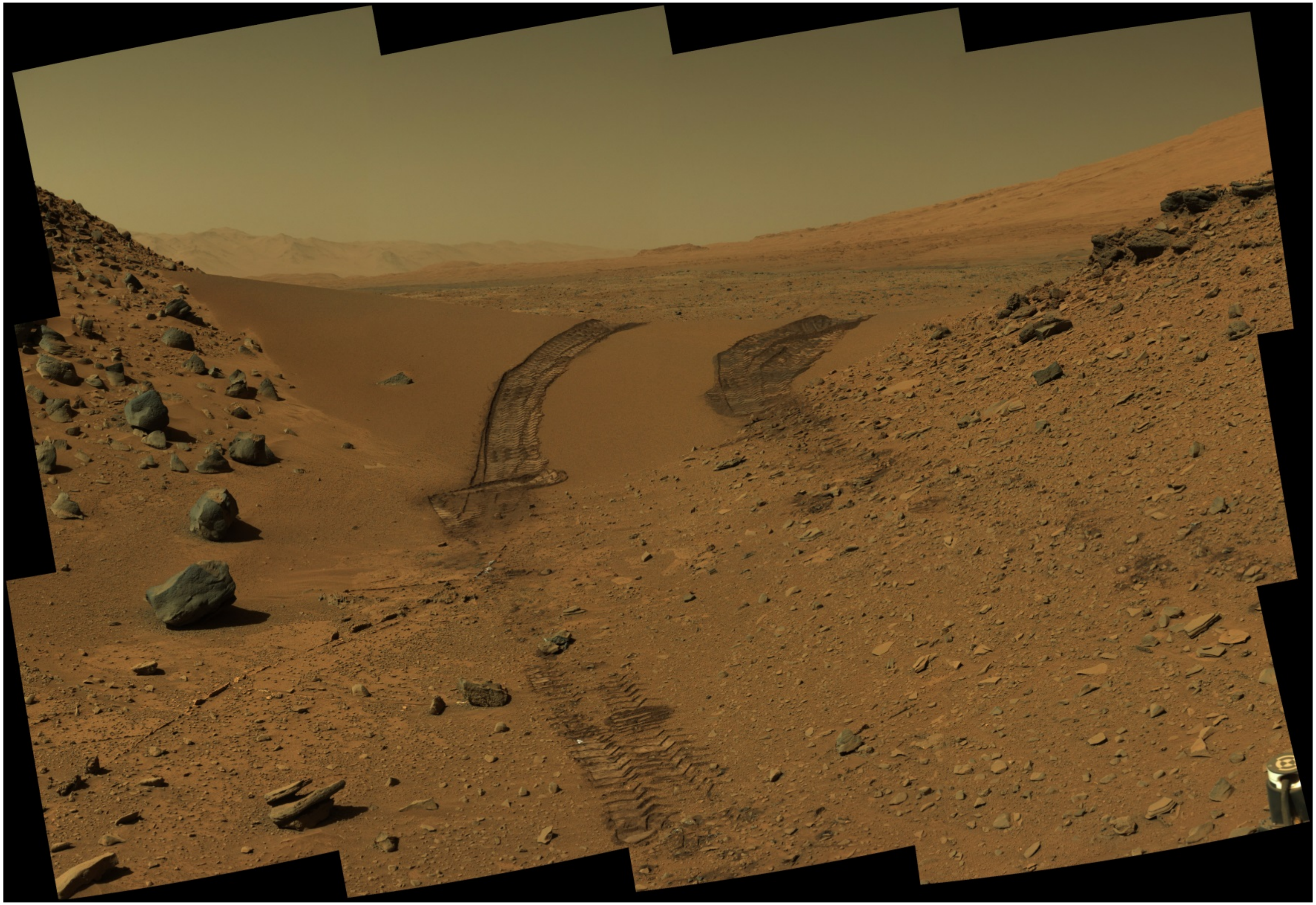
- ChemCam
  - Will fire a laser and analyze the elemental composition of vaporized materials from areas smaller than 1 millimeter on the surface of Martian rocks and soils.
- Chemin:
  - The Chemistry and Mineralogy instrument, or CheMin for short, will identify and measure the abundances of various minerals on Mars.
- SAM
  - The Sample Analysis at Mars features chemical equipment found in many scientific laboratories on Earth. SAM will search for compounds of the element carbon.
- REMS
  - A weather monitoring station
- RAD
  - Measures radiation

Communication

- Curiosity can communicate directly to Earth
- Typically Curiosity talks to satellites orbiting Mars
  - These orbiters then forward data to Earth

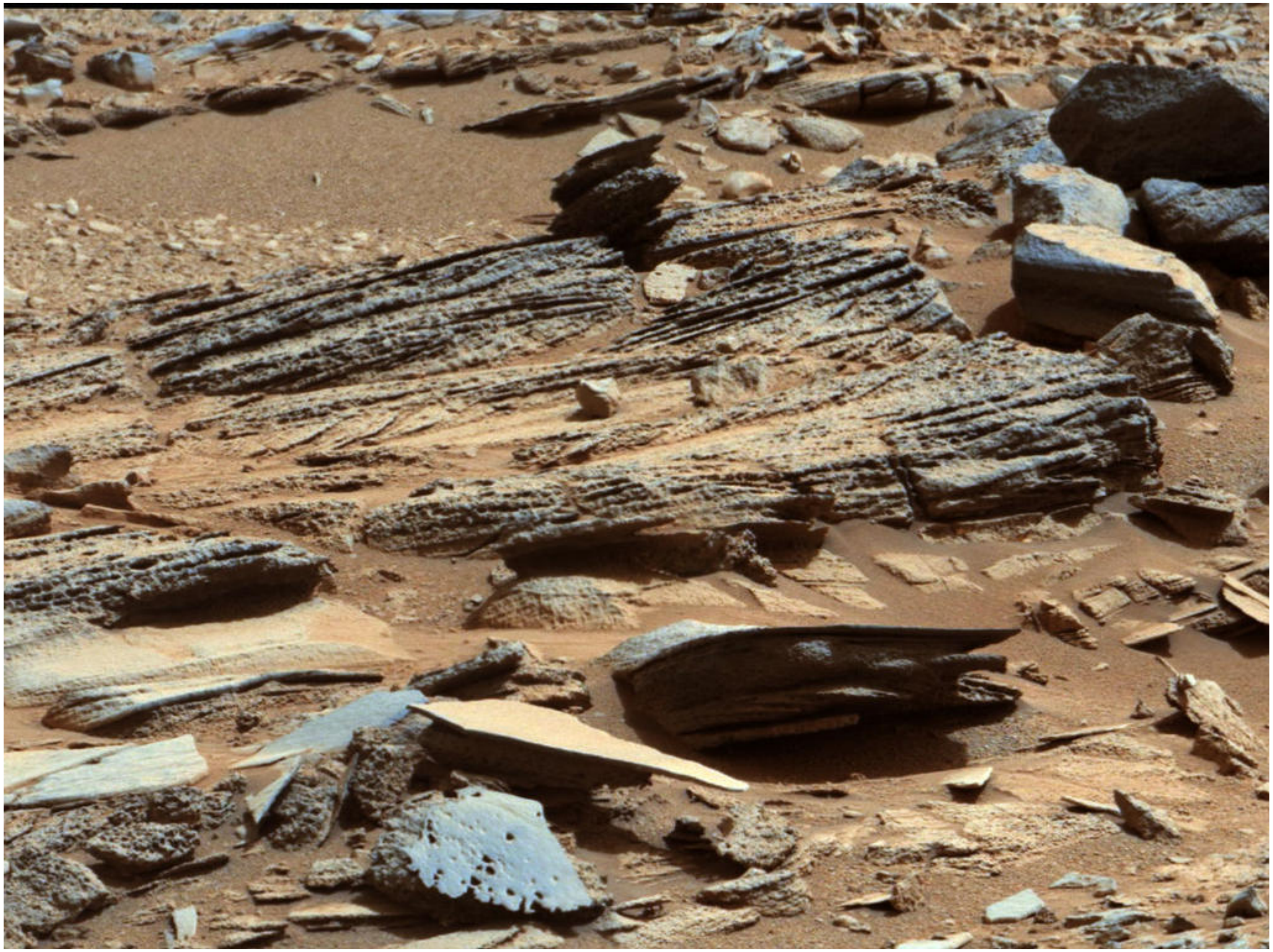


Photos from Mars



Photos from Mars

Photos from Mars



References

[1] J. Grotzinger, J. Crisp, A. Vasavada, R. Anderson, C. Baker, R. Barry, D. Blake et al. "Mars Science Laboratory mission and science investigation," Space science reviews 170, no. 1-4, 2012, pp. 5-56.

[2] http://mars.jpl.nasa.gov/msl/

[3] http://mars.nasa.gov/mer/