



Patching Flight Software on Mars

Ed Benowitz / Mark Maimone
MSL Flight Software Developers
NASA/Jet Propulsion Laboratory
California Institute of Technology

Copyright 2015 California Institute of Technology. Government sponsorship acknowledged.

Artist's Concept. NASA/JPL-Caltech



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.

NASA/JPL - Caltech/Cornell



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.





Spirit and Opportunity Rover Mission Overview



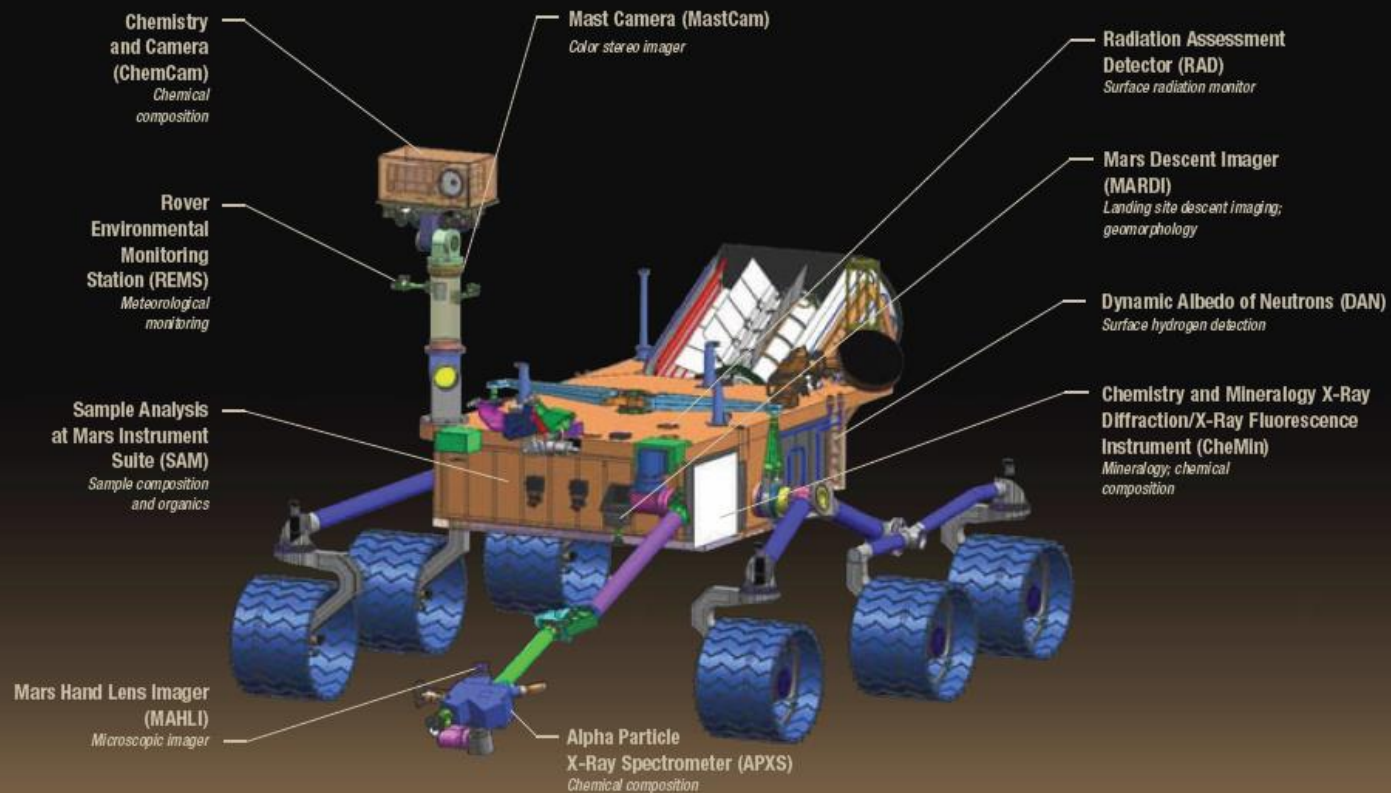
- Size
 - About the size of a golf cart -- 5 feet long (not including the arm), 6 feet wide and 5 feet tall
- Arm reach
 - About 3 feet
- Weight:
 - 185 kilograms (400 pounds)
- Mission:
 - Search for and characterize a wide range of rocks and soils that hold clues to past water activity on Mars.



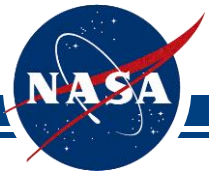
Curiosity Rover Mission Overview



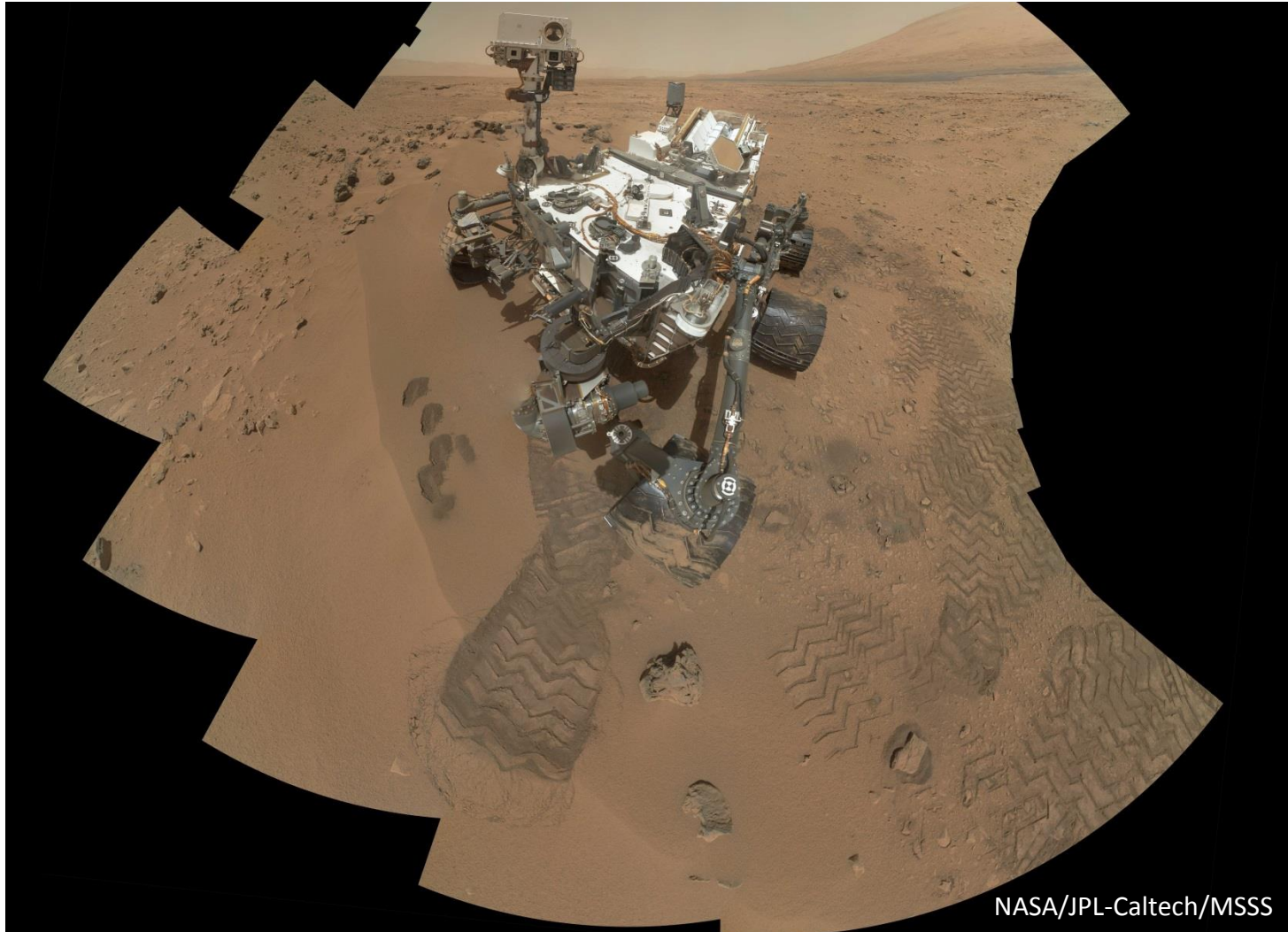
Mars Science Laboratory



Artist's Concept. NASA/JPL-Caltech



Curiosity Rover Mission Overview



NASA/JPL-Caltech/MSSS



Curiosity Rover Mission Overview



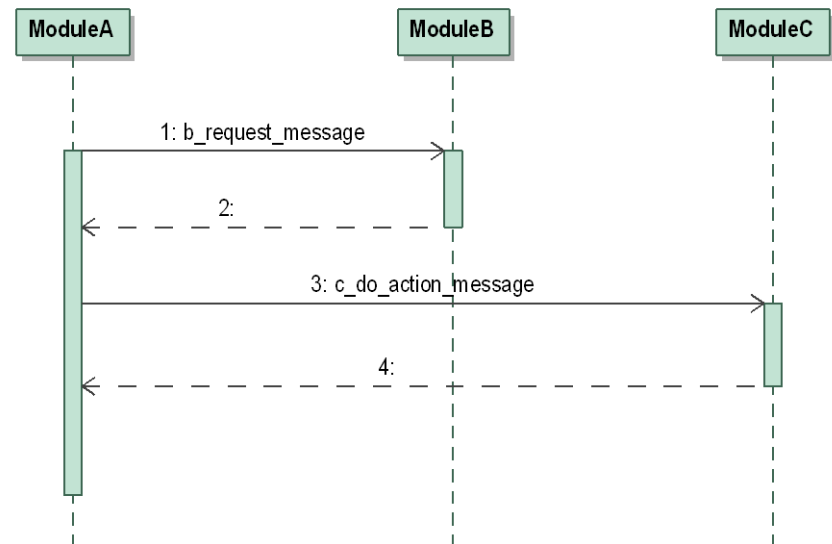
- Size
 - About the size of a small car -- 10 feet long (not including the arm), 9 feet wide and 7 feet tall or about the height of a basketball player
- Arm reach
 - About 7 feet
- Weight:
 - 900 kilograms (2,000 pounds)
- Mission:
 - To search areas of Mars for past or present conditions favorable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



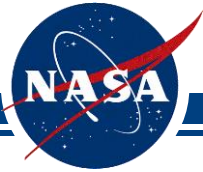
- Hot patch
 - Changes code in RAM while we are running
 - VxWorks also allows dynamic loading of .o files
- Cold patch
 - Modify the flight software image stored in a non-volatile storage area.
 - The new code image would be used on a subsequent boot
 - Does not change the currently running code
- Trades
 - 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



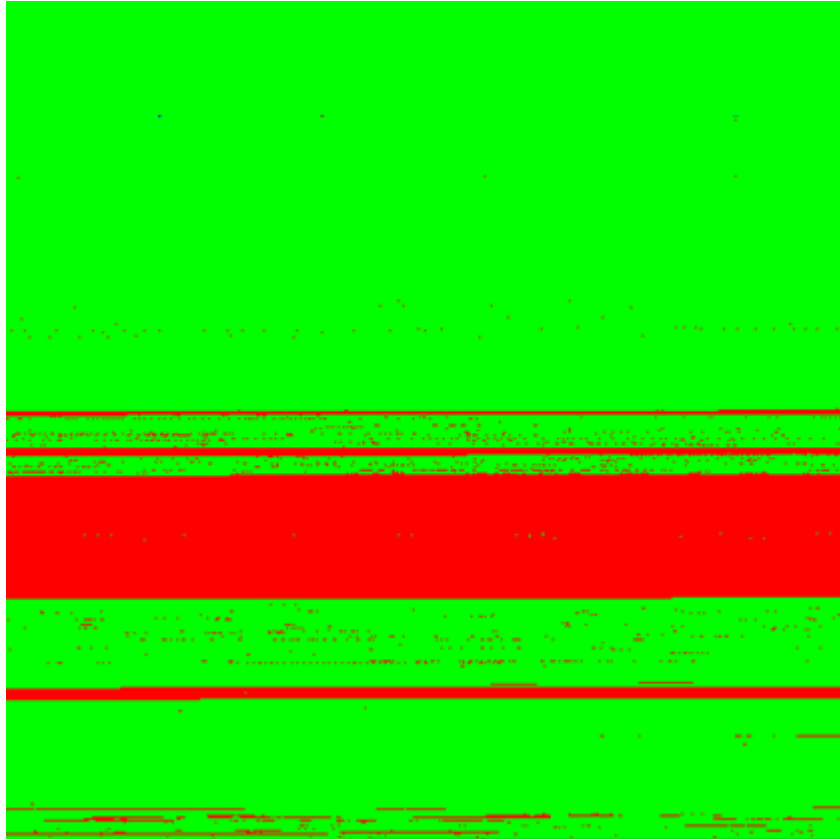
- Trade: Should flight software provide commands for patching?
 - MER and MSL had some support for patches
 - MER: Could apply patches to a copy of FSW in RAM and write to non-volatile storage
 - MSL has a command for adding a new FSW component module
 - But hot patches that change existing code require 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





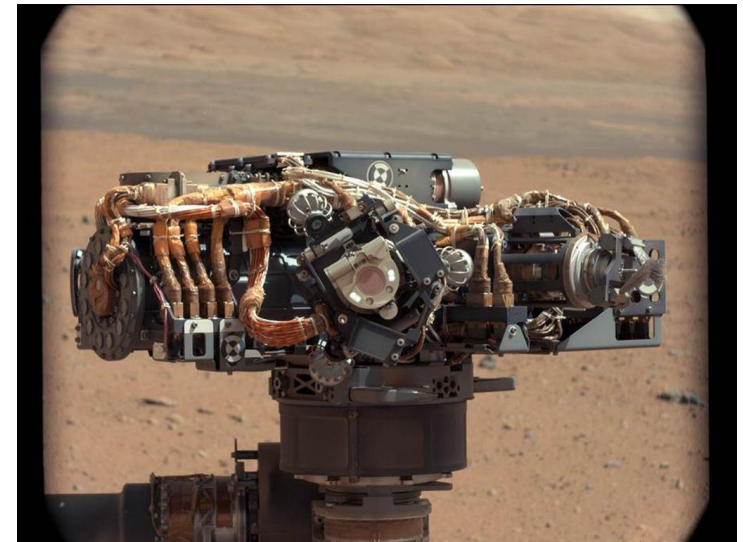
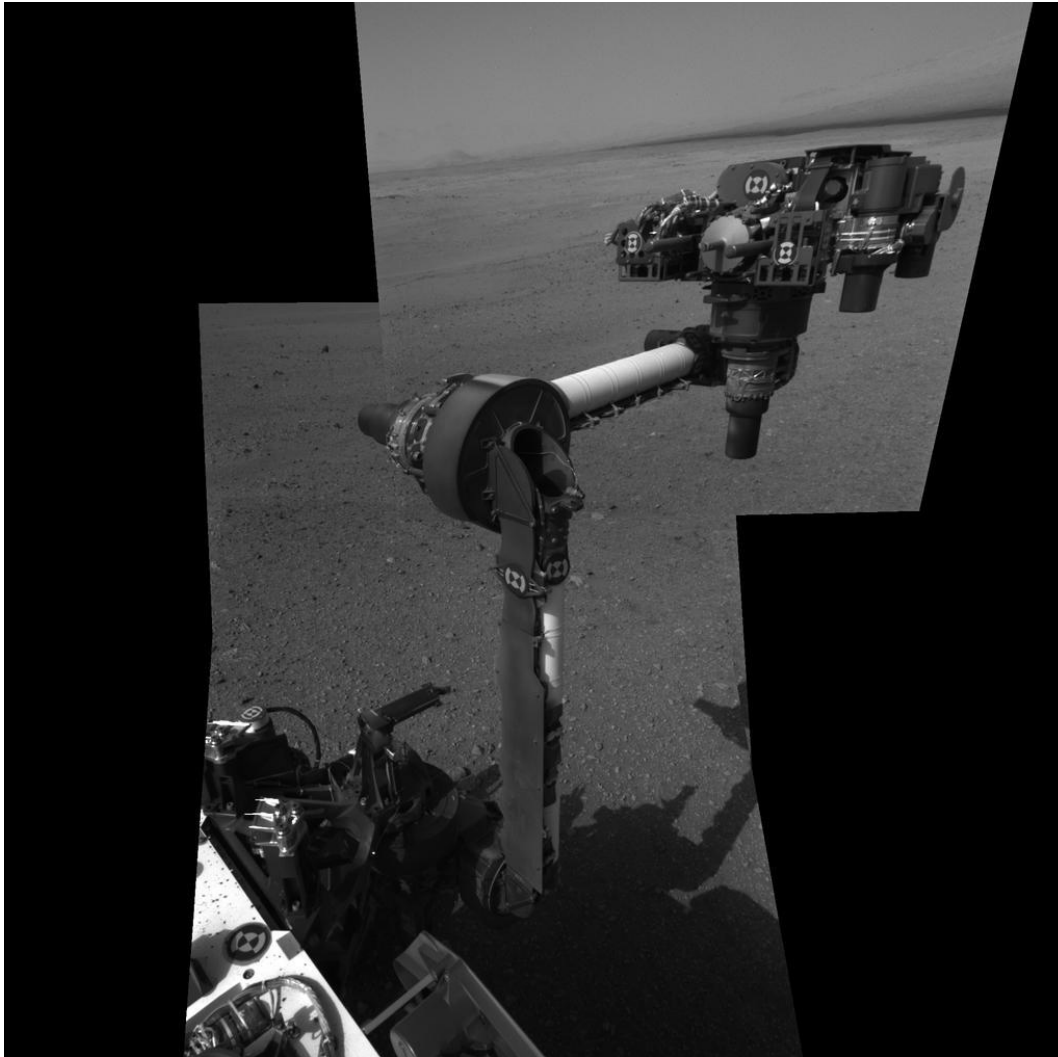
Cameras



- 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



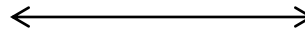
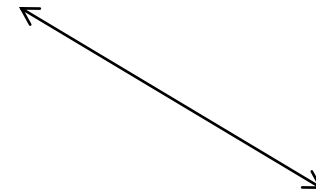
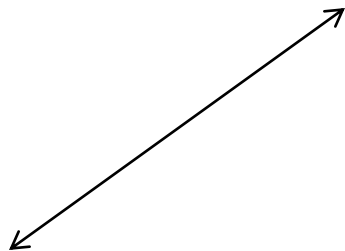
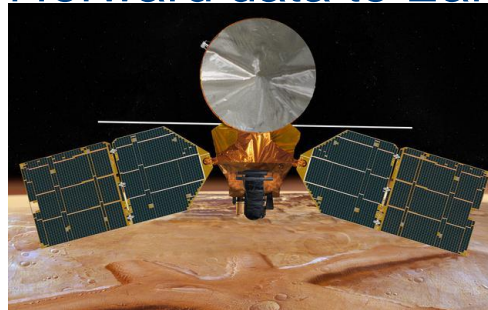


Instruments on Curiosity



- 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

- 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/>