The Mars Science Laboratory Flight Software – A Platform for Science and Mobility

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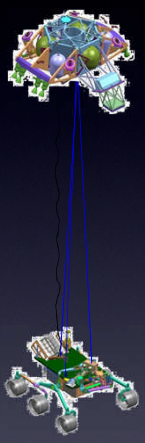
Mars Science Laboratory

ENTRY, DESCENT, LANDING

- Guided entry and controlled, powered "sky crane" descent
- 20 × 25-km landing ellipse
- Discovery responsive for landing sites ±30° latitude, <0 km elevation
- ~1000-kg landed mass



CRUISE/APPROACH

- 8.5 month cruise
- Spinning cruise stage
- Arrive Aug. 2012 at Gale Crater

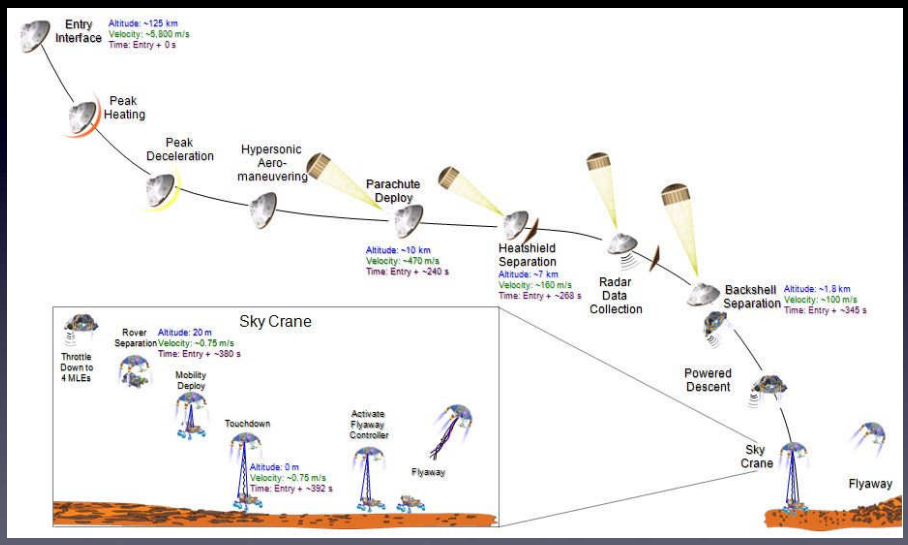
LAUNCH

- Nov. 2011
- Atlas V (541)

SURFACE MISSION

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

Entry Descent and Landing



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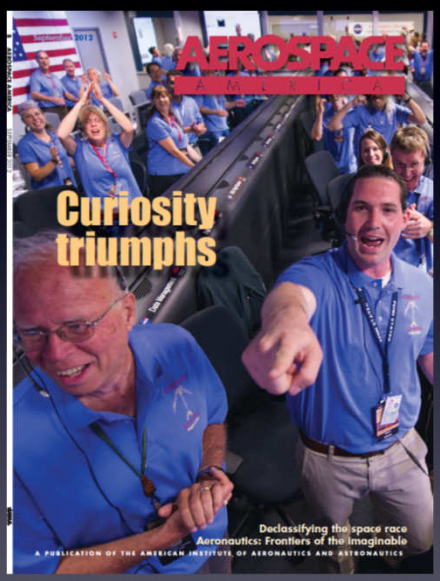
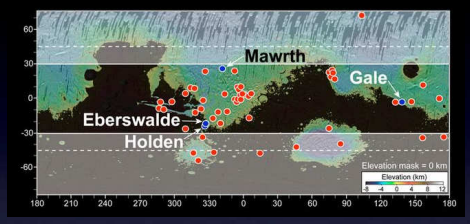
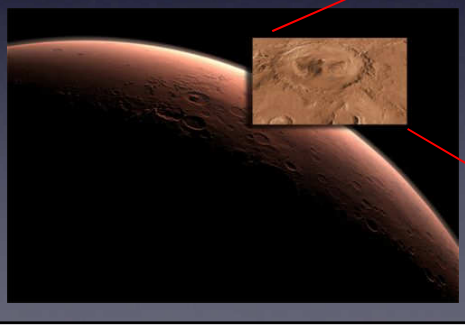


The Landing Site: Gale Crater

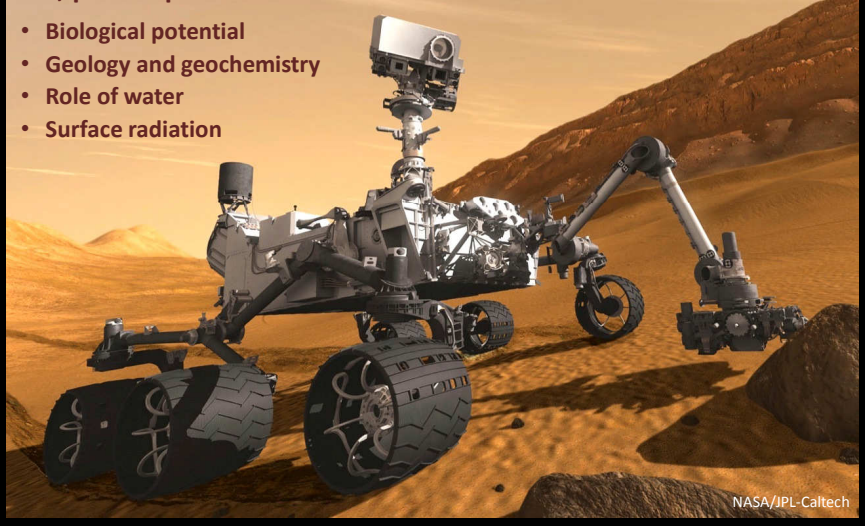
- Proposed Curiosity Landing Sites





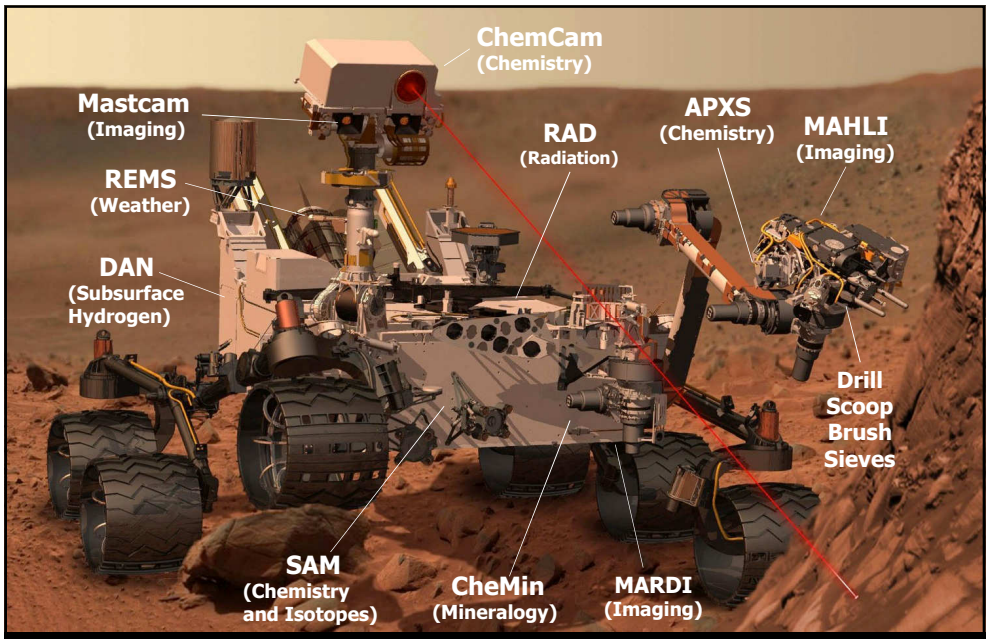
Curiosity's primary scientific goal is to explore and quantitatively assess a local region on Mars' surface as a potential habitat for life, past or present

- Biological potential
- Geology and geochemistry
- Role of water
- Surface radiation



CURIOSITY

Curiosity's Science Objectives



Curiosity's Science Payload

How do you deal with unprecedented complexity and mission objectives?

- **The goals for our 1ton super-rover:**
  - **Nail the landing**
  - **Drive somewhere cool**
  - **Do neat science stuff like…**
    - **Zap things with a laser**
    - **Scoop dirt**
    - **Take cool pictures**
- **It was our job to make that possible… but how?**

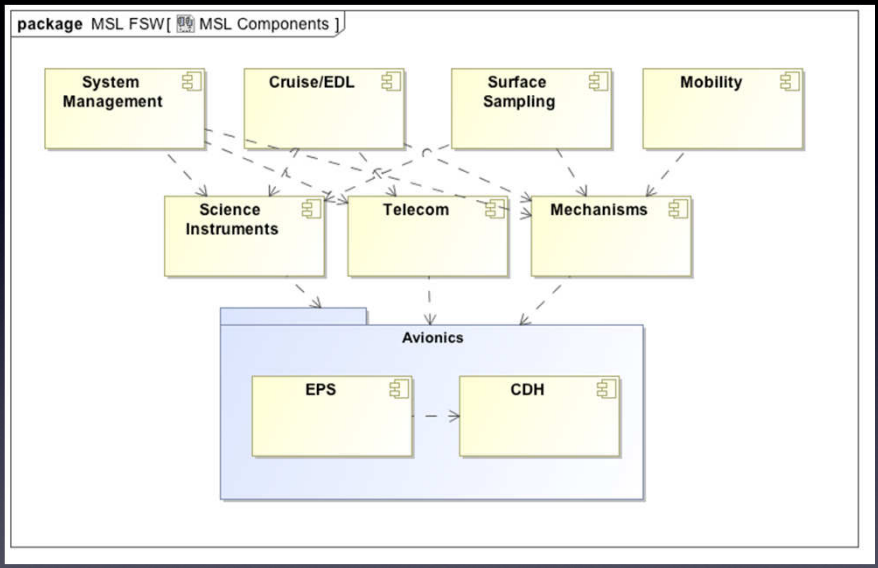
The MSL FSW Team

Then... (MPF)	Later… (MER)	And now… (MSL)
Lander / 10kg mini-rover	2 185kg Rovers	3 spacecraft in 1! Cruise, EDL, and a 1-ton Rover-on-steroids!
Airbag landing	Airbag landing	Skycrane landing
Single string	Single string	Dual string – cold backup – and a **LOT** of device redundancy!
RAD6K + VxWorks	RAD6K + VxWorks 128 MB RAM 256 MB Flash	RAD 750 + VxWorks 256 MB RAM 2 GB Flash
3 science instruments	6 science instruments	10 science instruments
30 sol mission (lander) 7 Sol mission (rover)	90 sol primary mission We are still roving with Opportunity!	2 year (687 sol) primary mission! Who knows how long we can go with that MMRTG!

Create a **robust FSW infrastructure** – a platform enabling EDL, Mobility, and Science

- Component Architecture
- Redundancy Management
- Design Patterns
- Fault Protection
- Leveraging Powerful Avionics

The MSL FSW Conceptual Architecture



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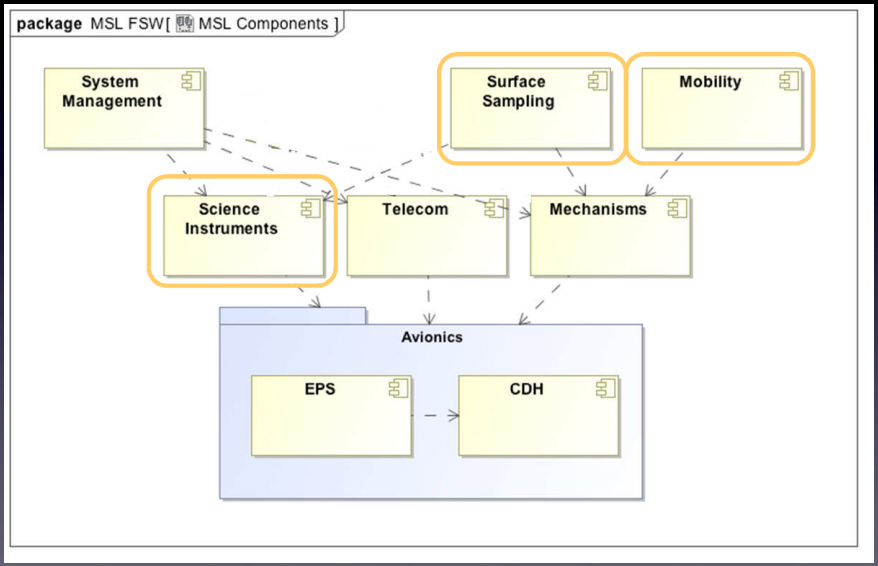


Functions vs. Activities

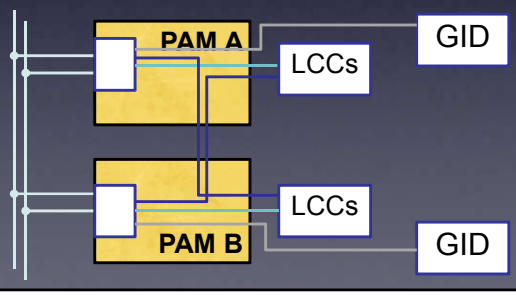
The Avionics-Layer components export *functional* interfaces. These functional interfaces provide access to performing primitive, atomic actions.

The Application-Layer components export *activity* interfaces. Activities decompose into a set of functions that, together, achieve a particular goal.

"Drive to a target" and "analyze a sample" are activities orchestrated by the Mobility and Surface Sampling components using the atomic functions provided by the FSW infrastructure

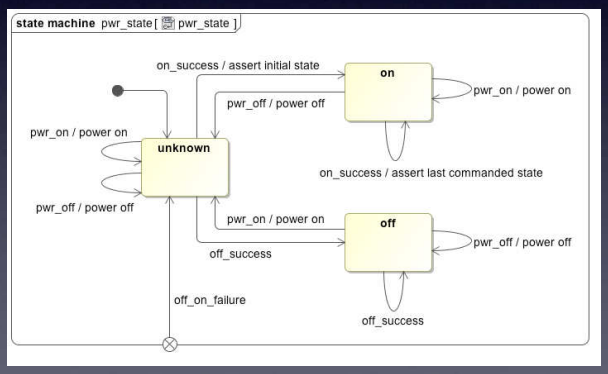
Redundancy Management

- Unprecedented amount of redundancy
  - From switches to entire boxes to multiple computers, MSL was nothing if not redundant
- Abstracted the underlying redundancy away from the application components
- Example: Device swaps during active attitude control



Use of Patterns

- **Due to the complexity and redundancy, we needed to ensure that the application components could rely – could expect – consistent behavior from the infrastructure …**
- **We achieved this in part through design patterns**



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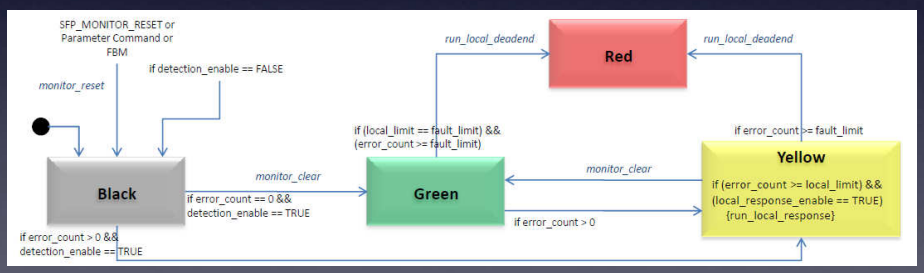
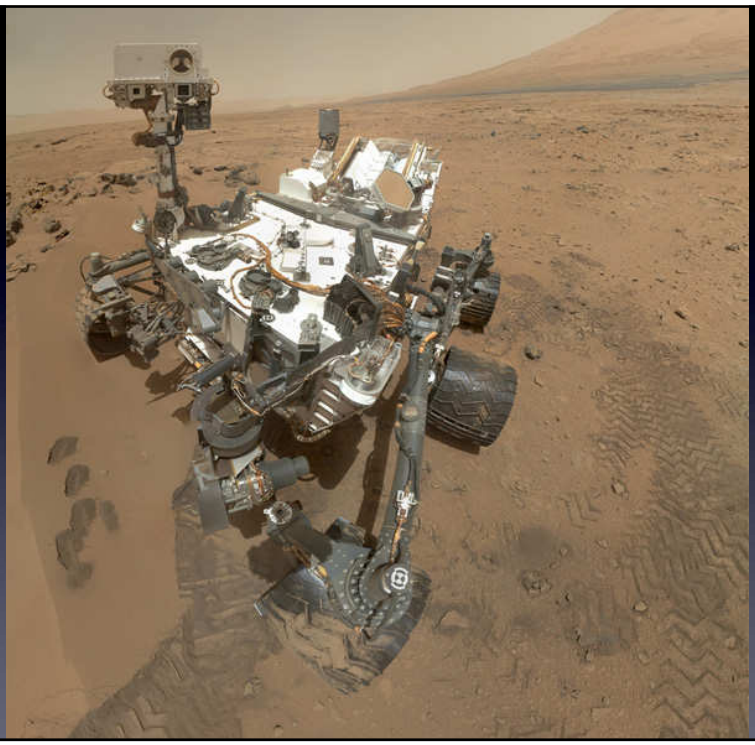


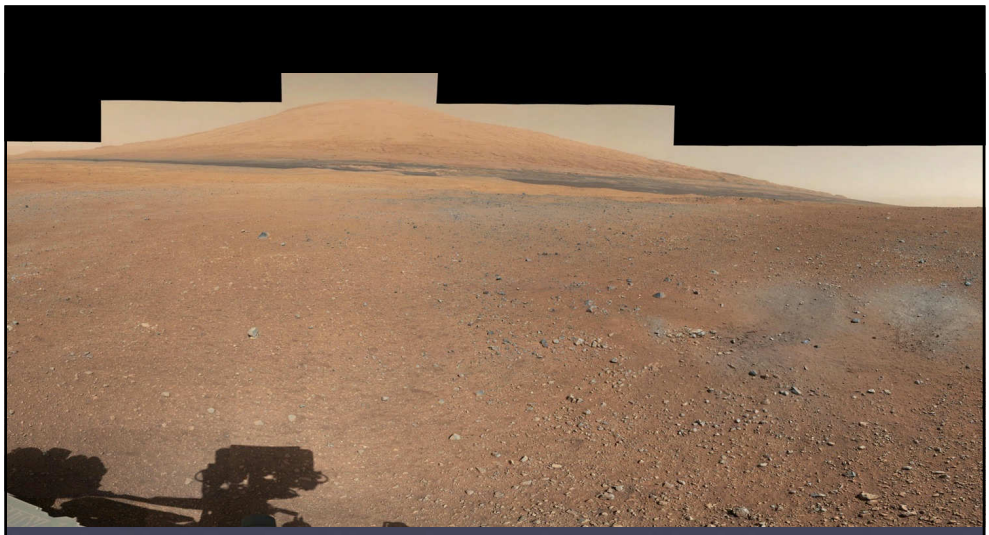
Fault Protection

- Mobility and Science should not have to worry about the safety of the vehicle
- Furthermore, the infrastructure must (1) keep the vehicle safe and (2) preserve the ability to use the wake cycle for mobility and science, not sitting in Safing
- **PRINCIPLE**: Fault monitors monitor system state, not events. Fault responses restore system state.
- **PRINCIPLE**: Faults should be detected and corrected as close to the fault as possible (i.e. at the lowest layer in the FSW possible).

Powerful Avionics

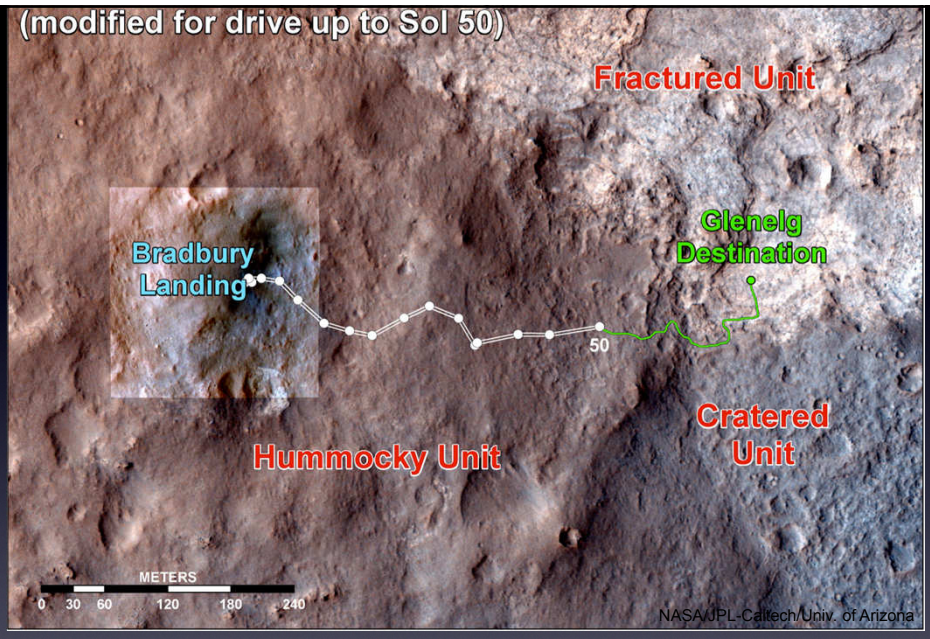
- MSL utilized extremely powerful FPGAs to augment our main computers
- The FSW utilized these capabilities to enhance the robustness and availability of our mobility and science platform
  - Example) autonomous wakeup and shutdown for recharging the batteries for the next day of operations
- MSL took this to the next level – we developed new and innovative approaches to saving battery life and extending the productivity of the operations window
  - Example) Dream Mode



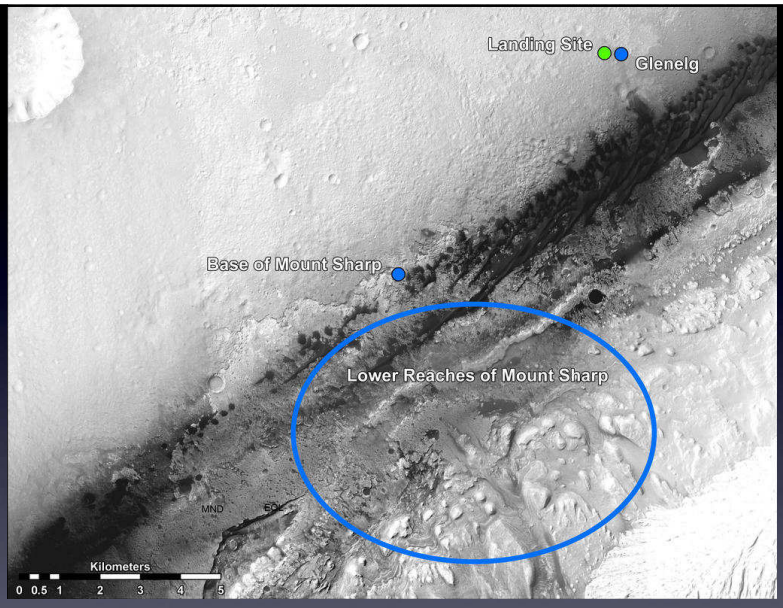


NASA/JPL-
Caltech/MSSS

Mastcam-34 mosaic of Mount Sharp, descent rocket scours, and rover shadow

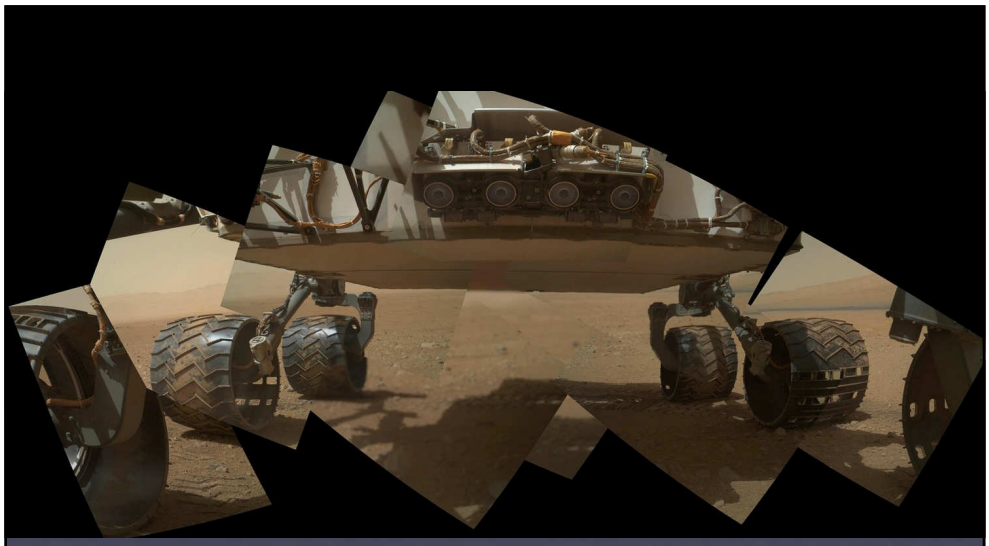


Curiosity is progressing toward Glenelg, where three distinct terrain types meet



NASA/JPL-Caltech/Univ. of Arizona

Curiosity's ultimate goal is to explore the lower reaches of the 5-km high Mount Sharp



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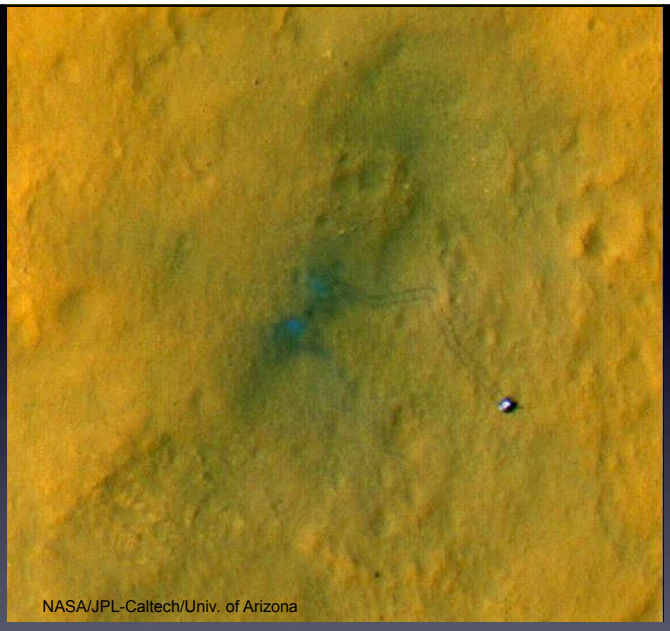
Curiosity images its undercarriage with its Mars Hand-Lens Imager



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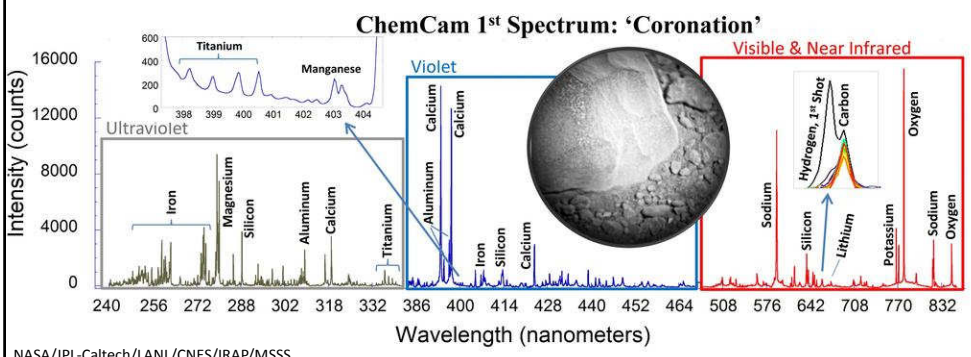
Curiosity and its tracks captured by HiRISE on the Mars Reconnaissance Orbiter



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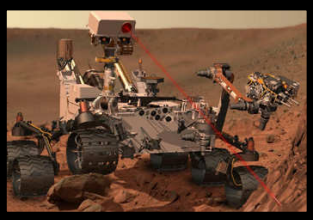
ChemCam spectra of Coronation

Target: Coronation (N165)
Sol 13
Shots: 30



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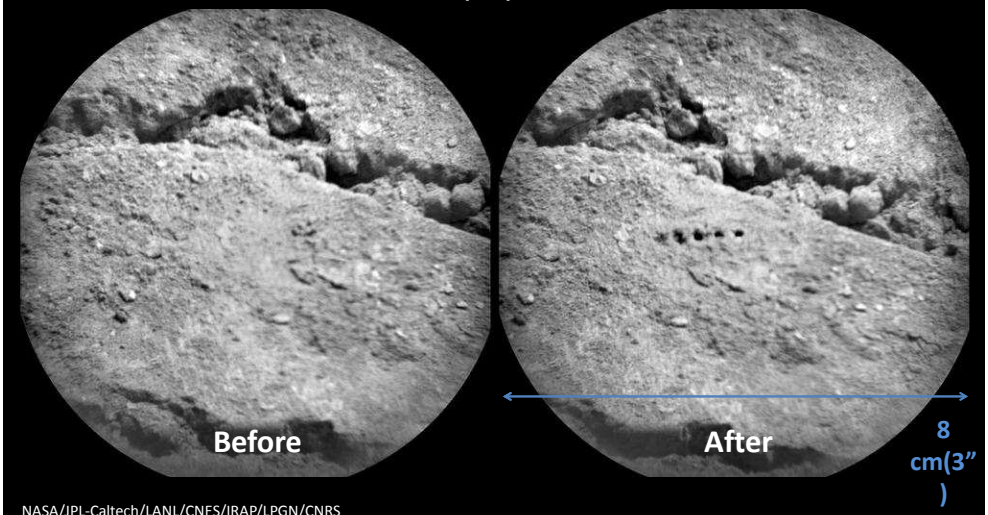
Target: Beechey (Sol 19)
Shots per point: 50



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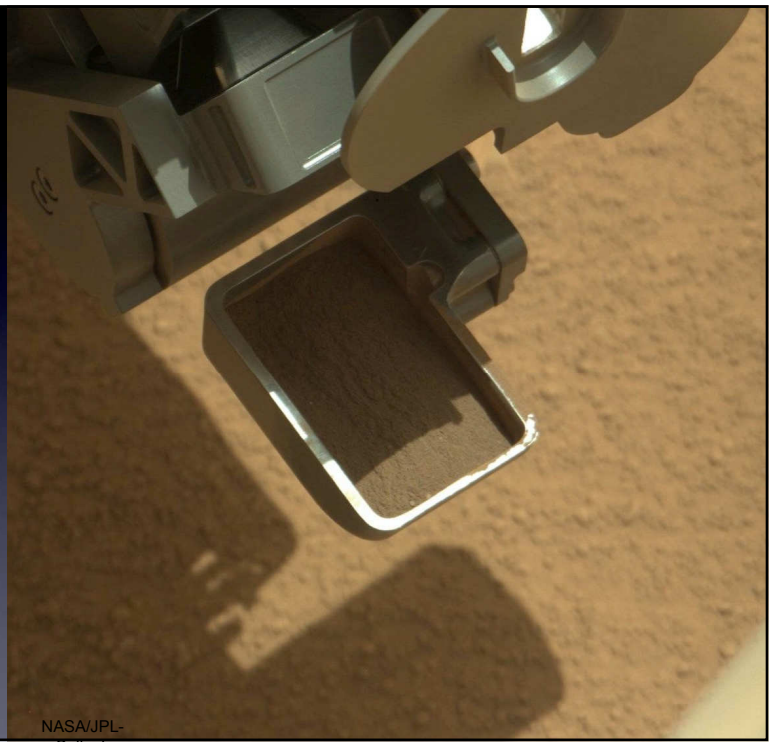
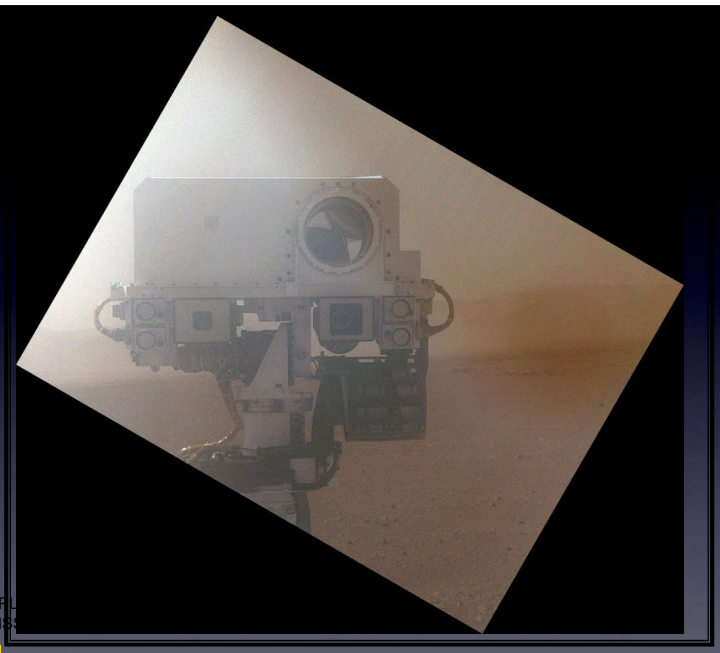
ChemCam's laser induced breakdown spectrometer acquires a 5-point raster

Wheel scuff to prepare for safe scooping

A scoop full of Mars sand





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Curiosity self-portrait using the arm-mounted Mars Hand-Lens Imager, through dust cover