Robotics for Space Exploration Today and Tomorrow

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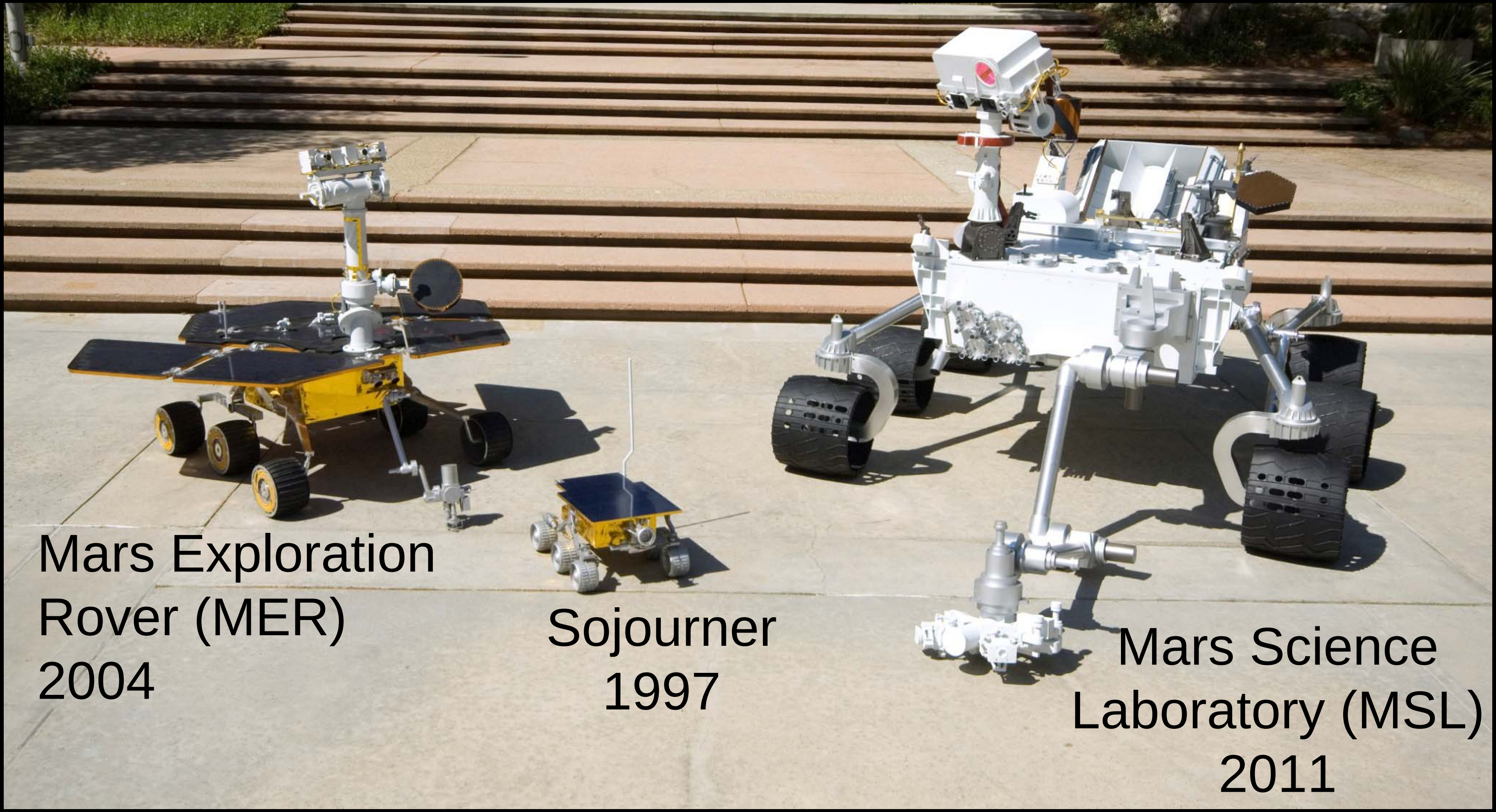
The Goal and The Problem

- Explore planetary surfaces with robotic vehicles
  - Understand the environment
  - Search for signatures of life
  - Prepare for eventual human exploration

- Time delays range from minutes to hours

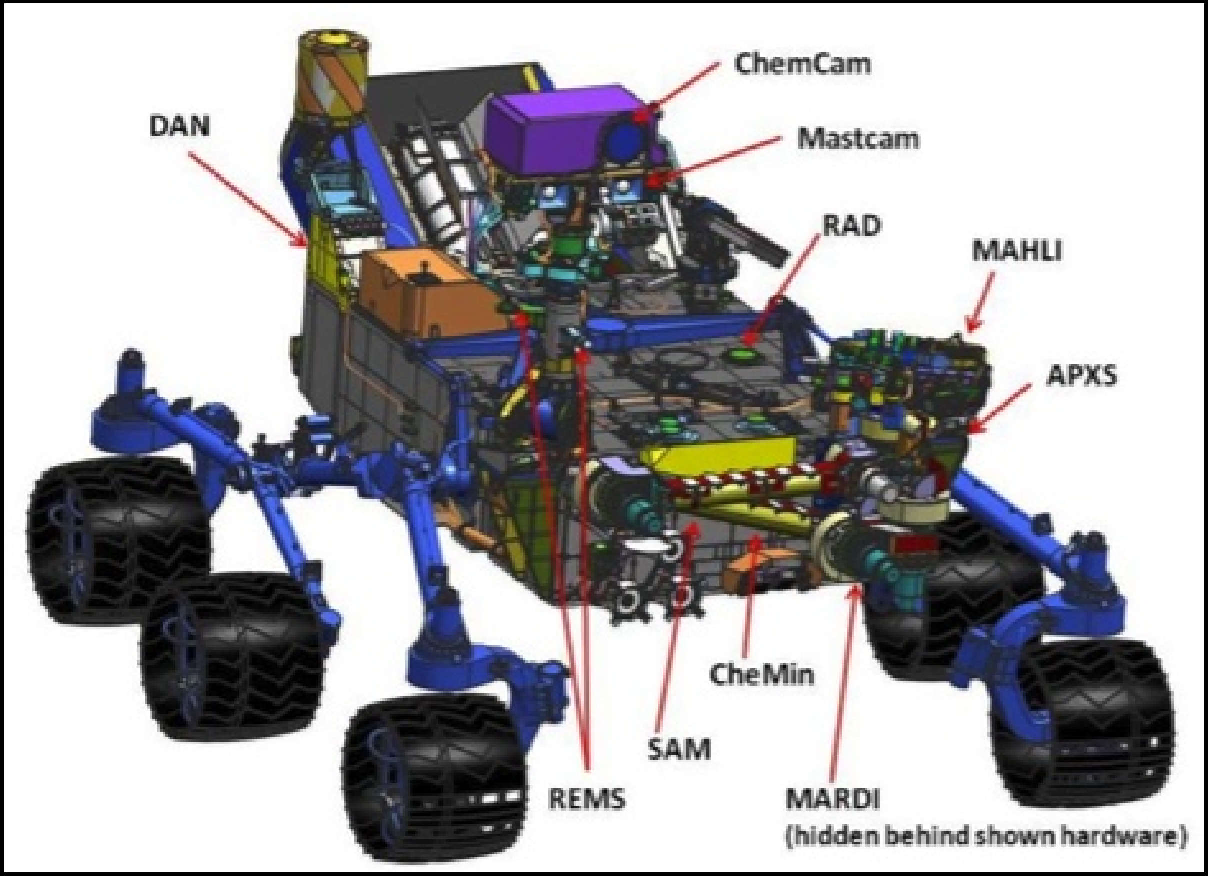
- Many unknowns
  - Atmospheric conditions
  - Surface conditions
  - Winds
  - Location of hazards

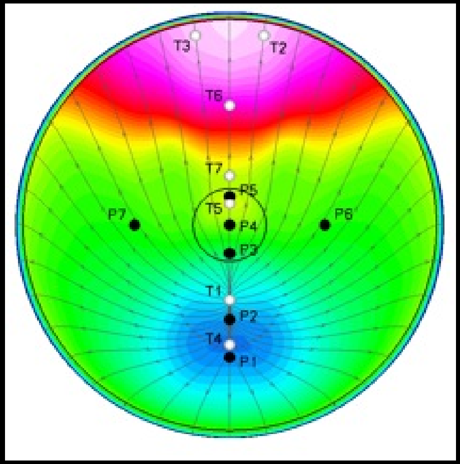
Past, Present and Future Rovers



(Photo: NASA/JPL/Thomas “Dutch” Slager)

Mars Science Laboratory (MSL)



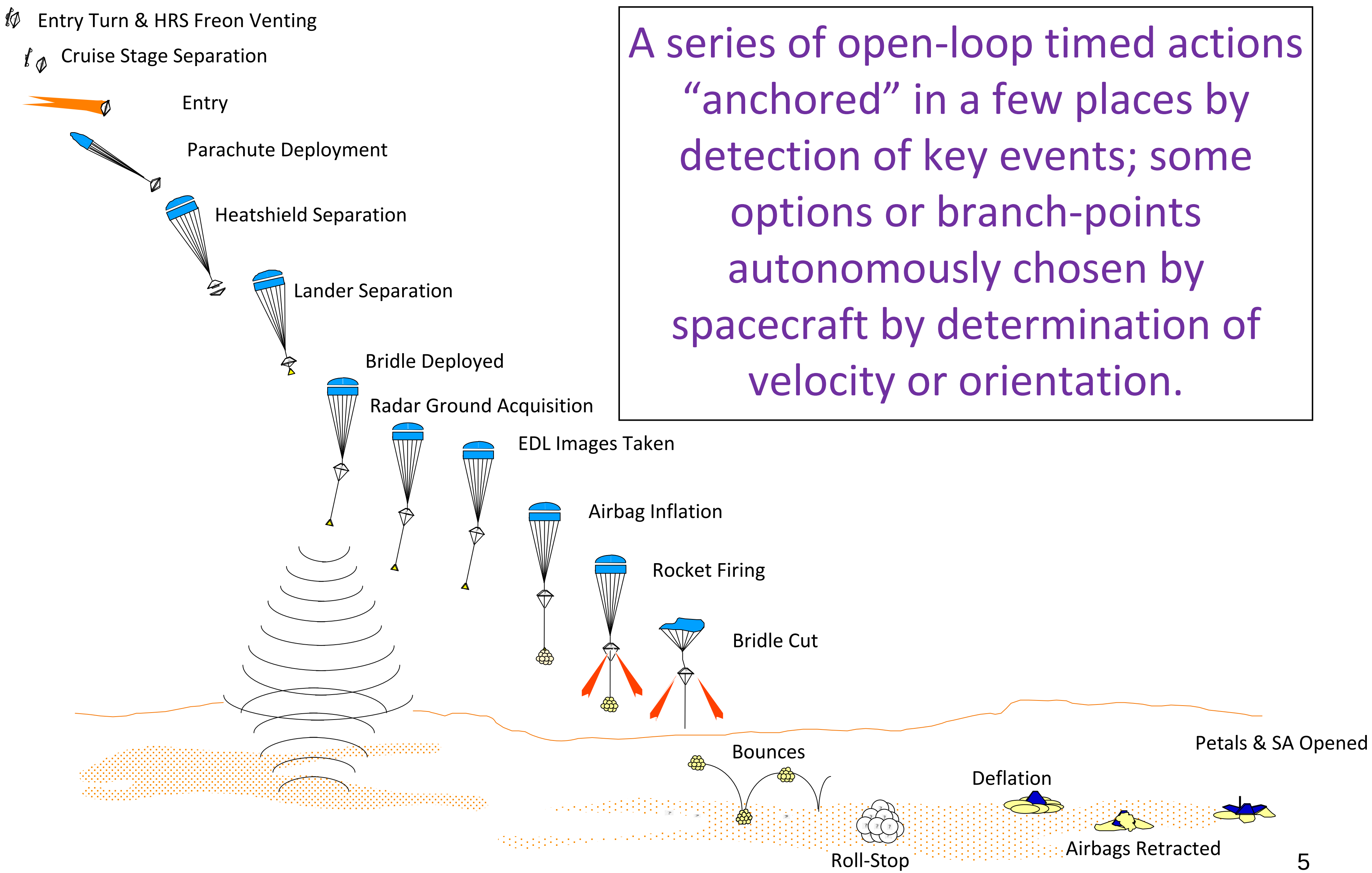


Predicted heat flux during EDL

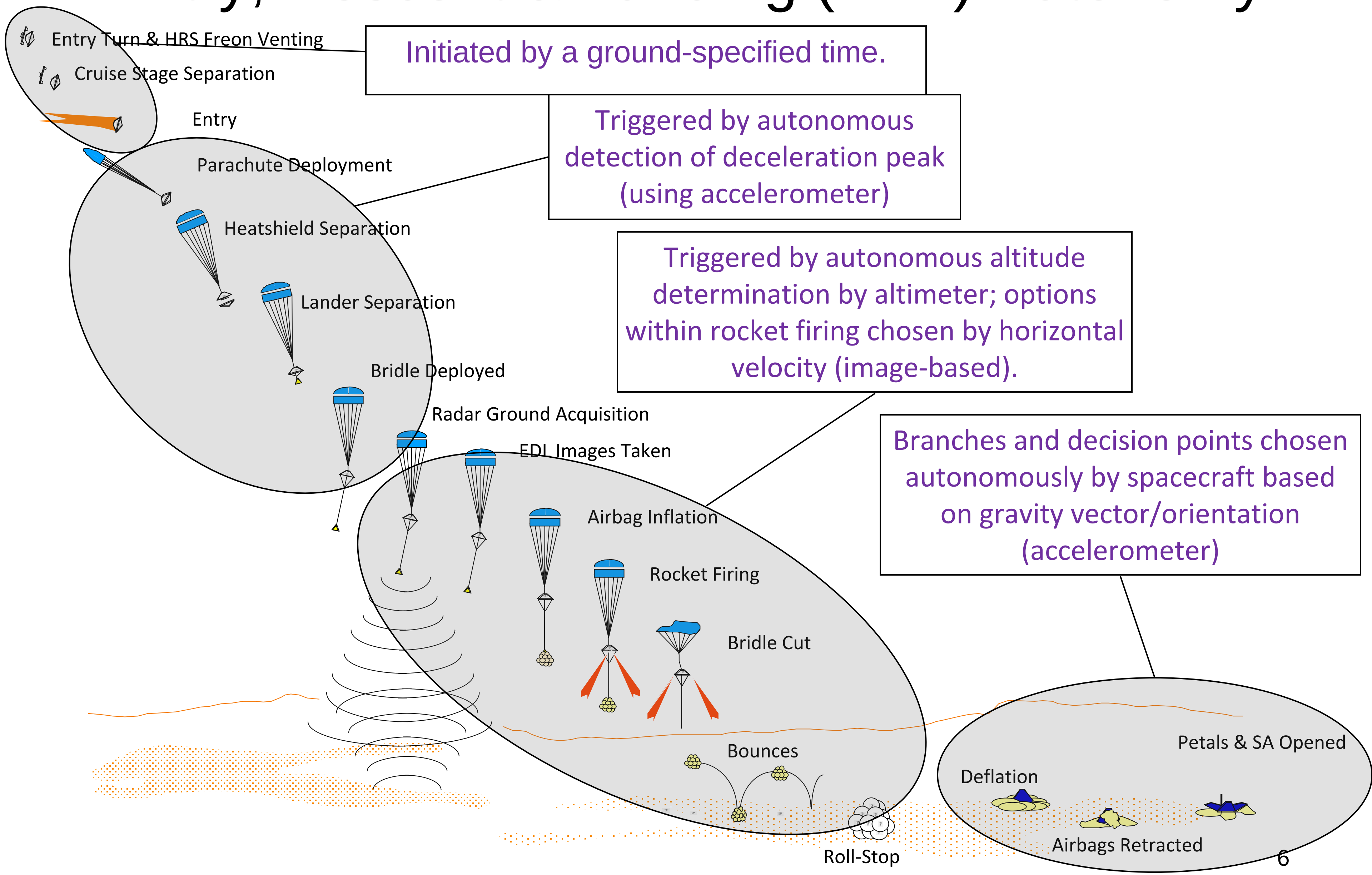
Mars Descent Imager (MARDI)

Mars Exploration Rovers (MER)
Entry, Descent & Landing (EDL) Autonomy

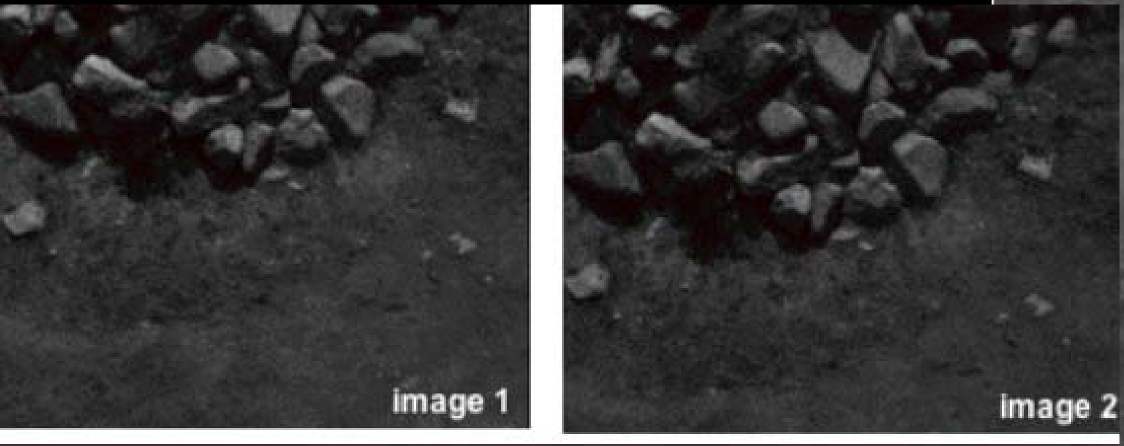
A series of open-loop timed actions "anchored" in a few places by detection of key events; some options or branch-points autonomously chosen by spacecraft by determination of velocity or orientation.

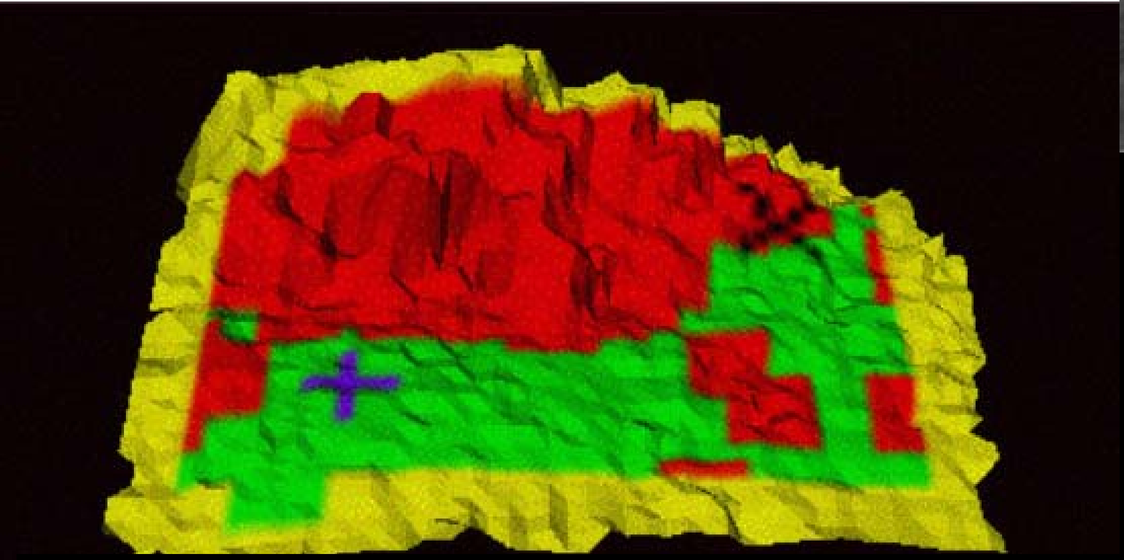


Mars Exploration Rovers (MER)
Entry, Descent & Landing (EDL) Autonomy

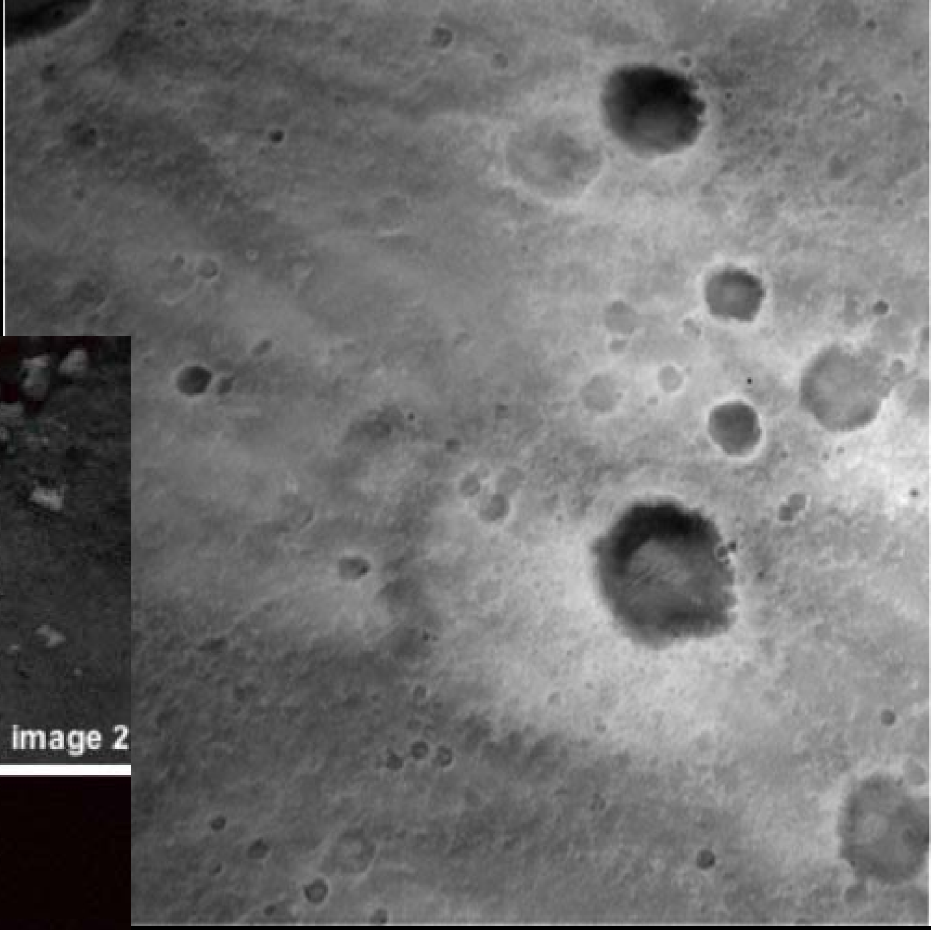


MER Entry, Descent, & Landing





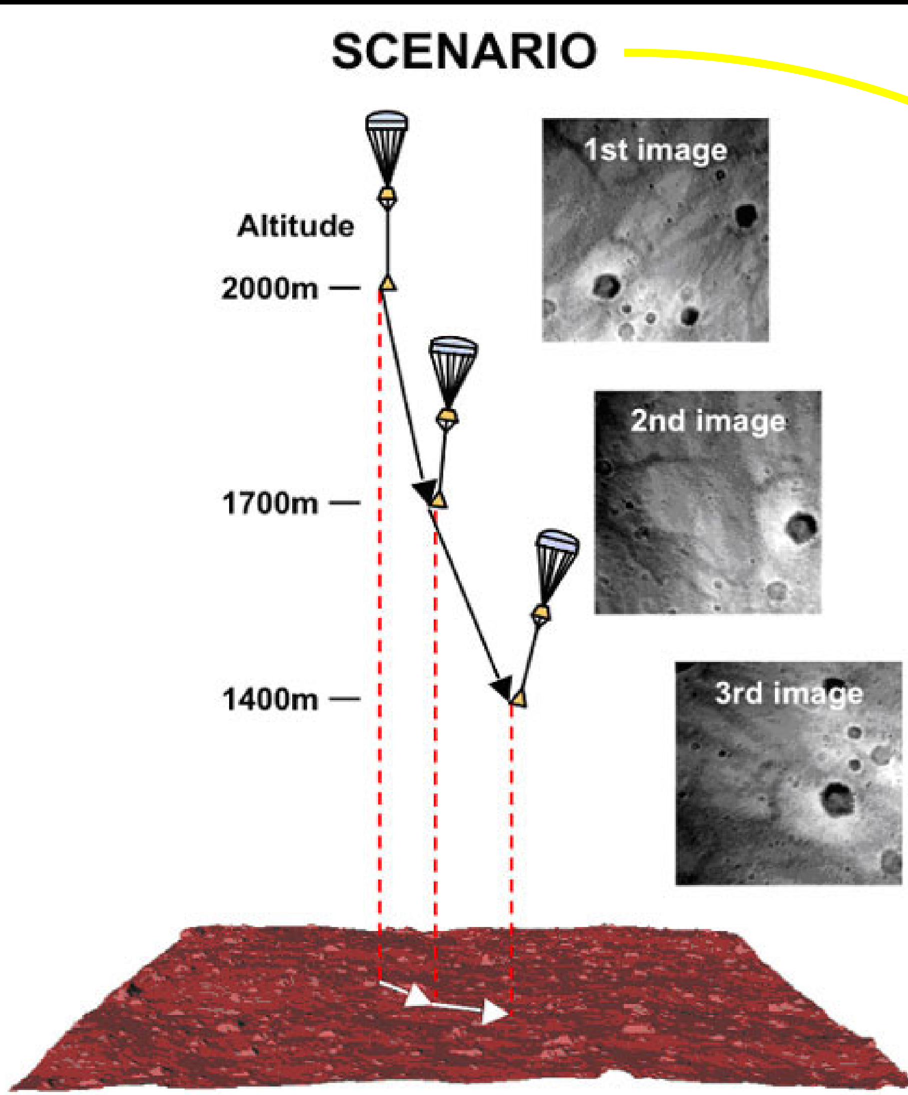
Safe landing map on terrain



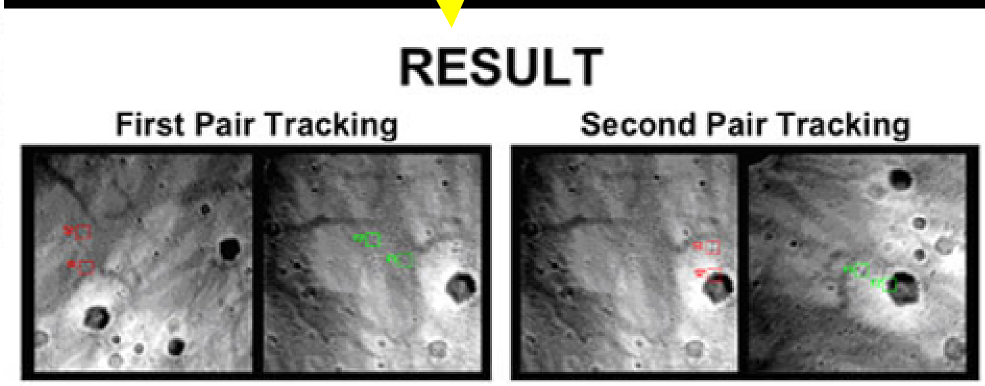
Descent image motion estimation subsystem (DIMES)

MER Entry, Descent, and Landing 1

Entire EDL system is autonomous.



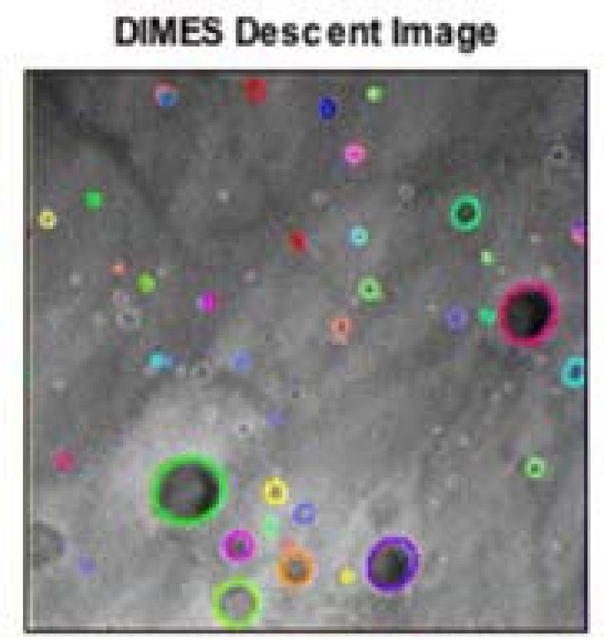
Descent image motion estimation subsystem (DIMES)

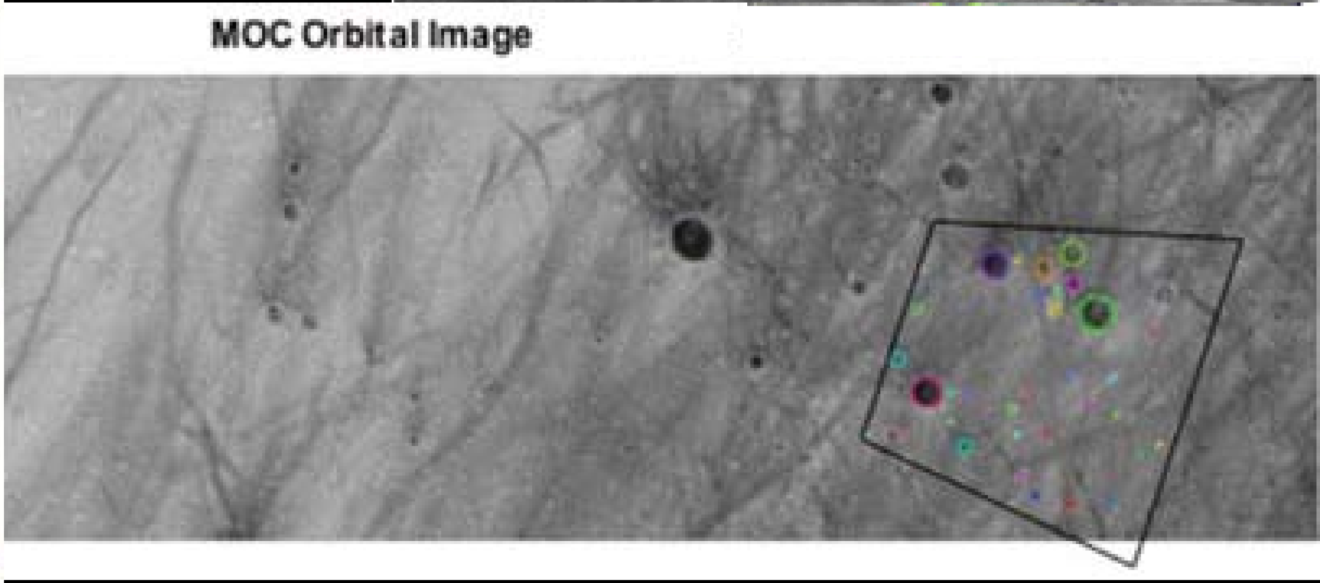


MER-A/Spirit, Gusev Crater, January 4th, 2004

MER Entry, Descent, and Landing 2

Descent image motion estimation subsystem (DIMES)

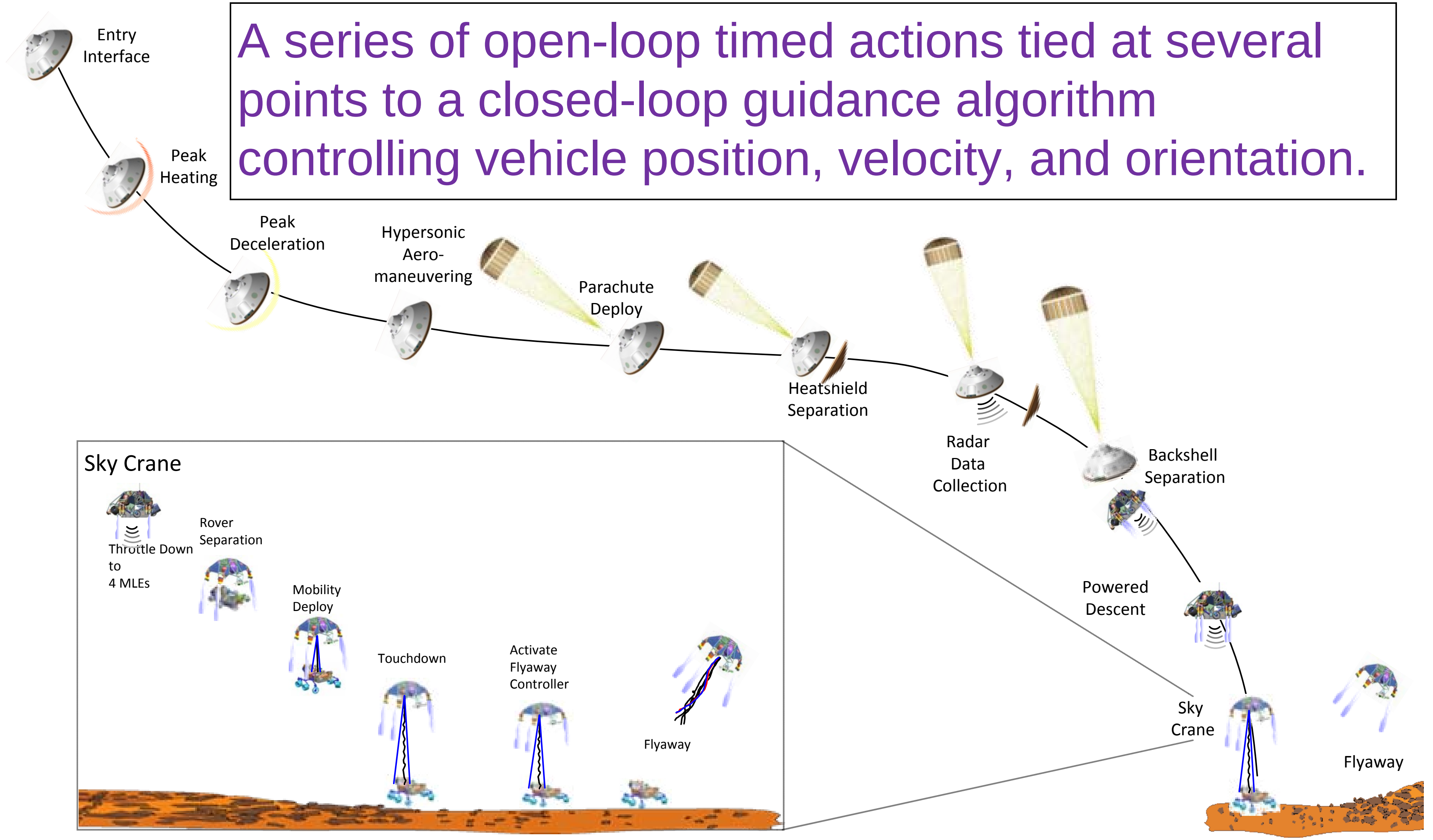




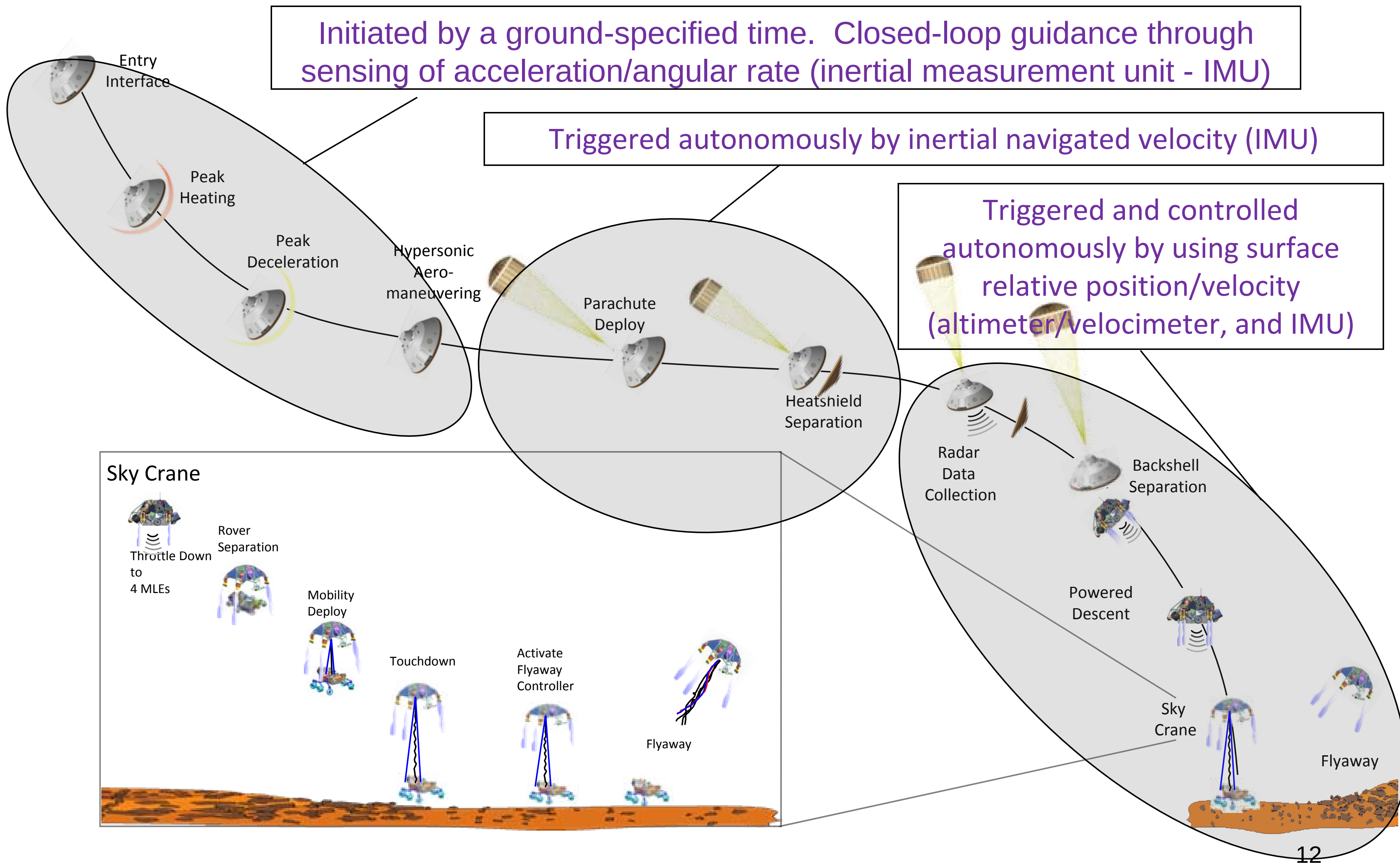
Phoenix on the Chute

Mars Science Laboratory (MSL) Entry, Descent & Landing (EDL) Autonomy

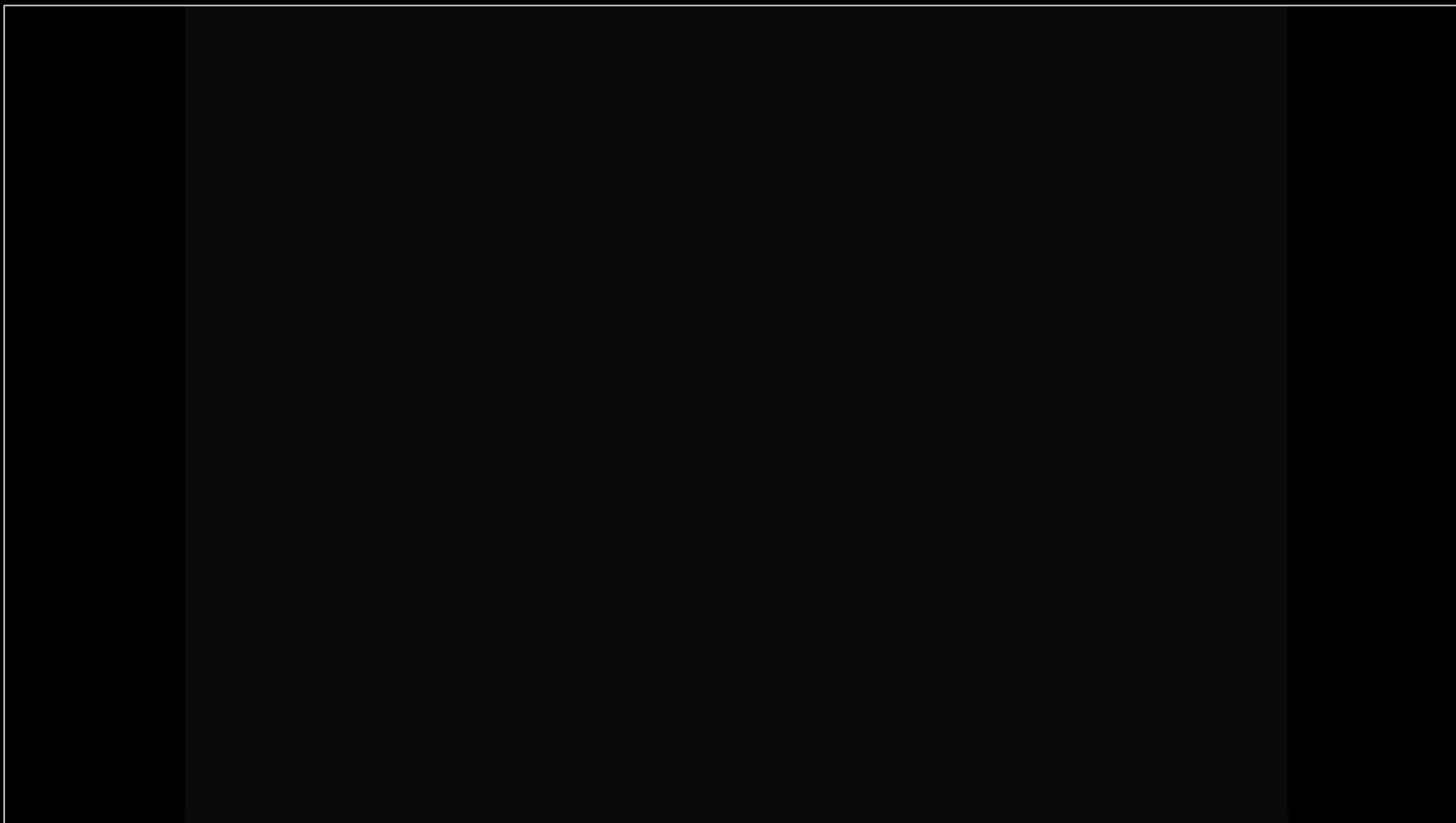
A series of open-loop timed actions tied at several points to a closed-loop guidance algorithm controlling vehicle position, velocity, and orientation.



Mars Science Laboratory (MSL) Entry, Descent & Landing (EDL) Autonomy



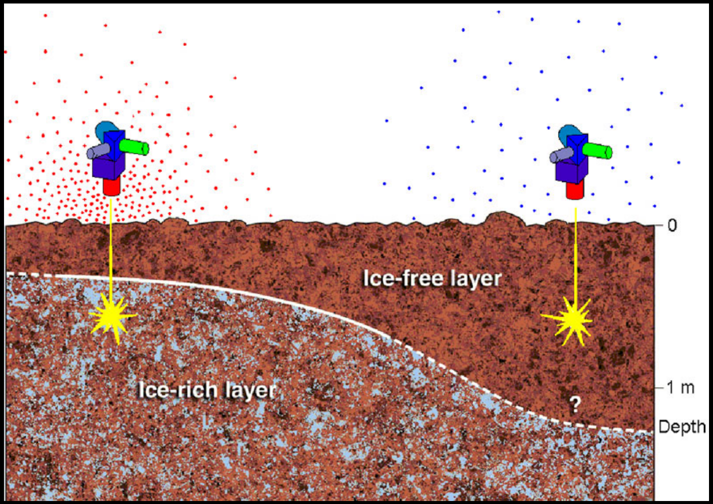
MER Entry, Descent & Landing



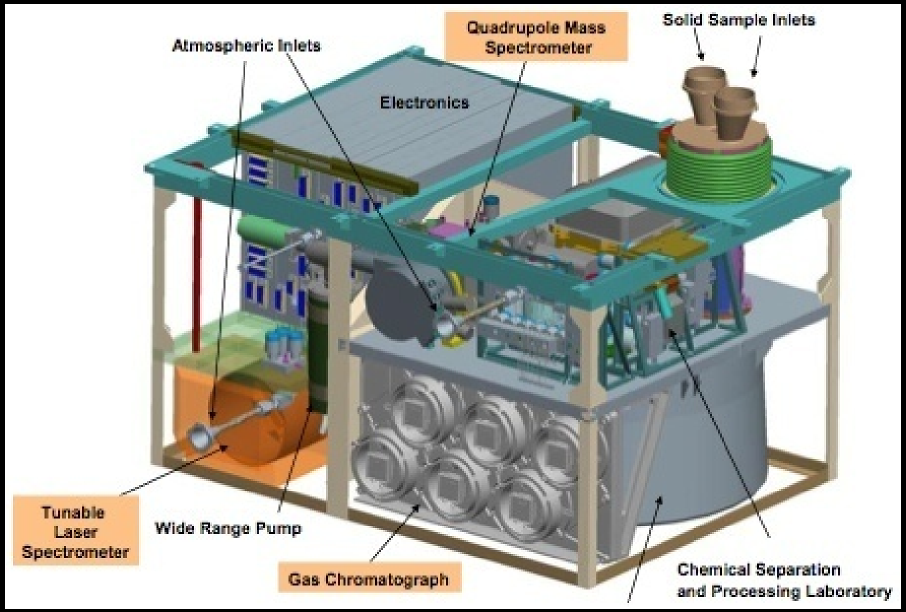
MSL Entry, Descent & Landing

MSL Ground Robotic Science

Dynamic Albedo of Neutrons (DAN)

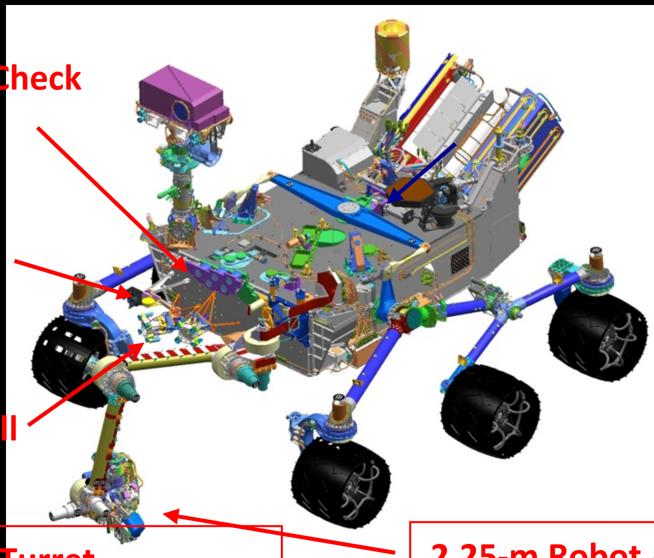


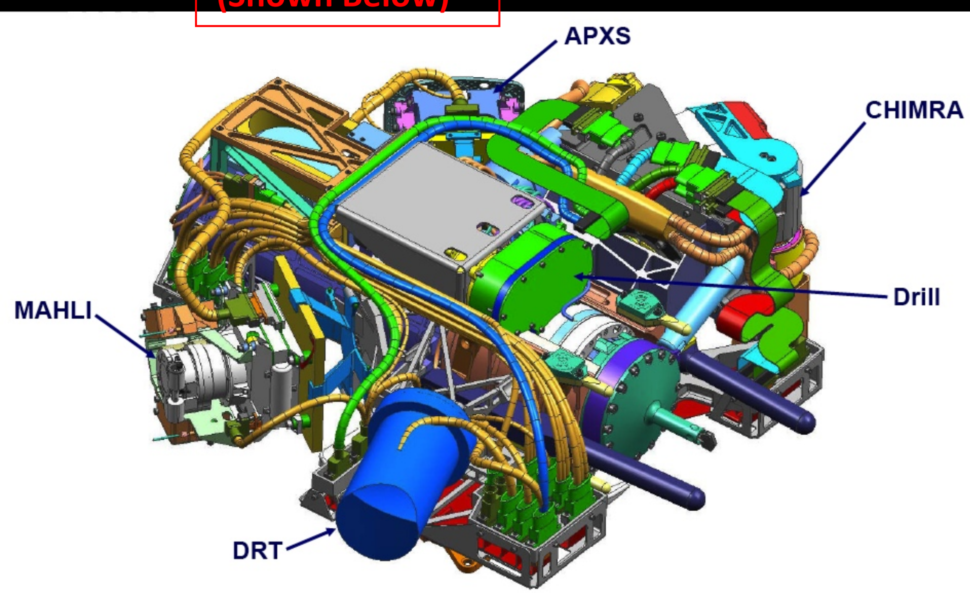
Alpha Particle X-ray Spectrometer (APXS)



Sample Analysis at Mars (SAM)

Sample Acquisition, Processing, and Handling





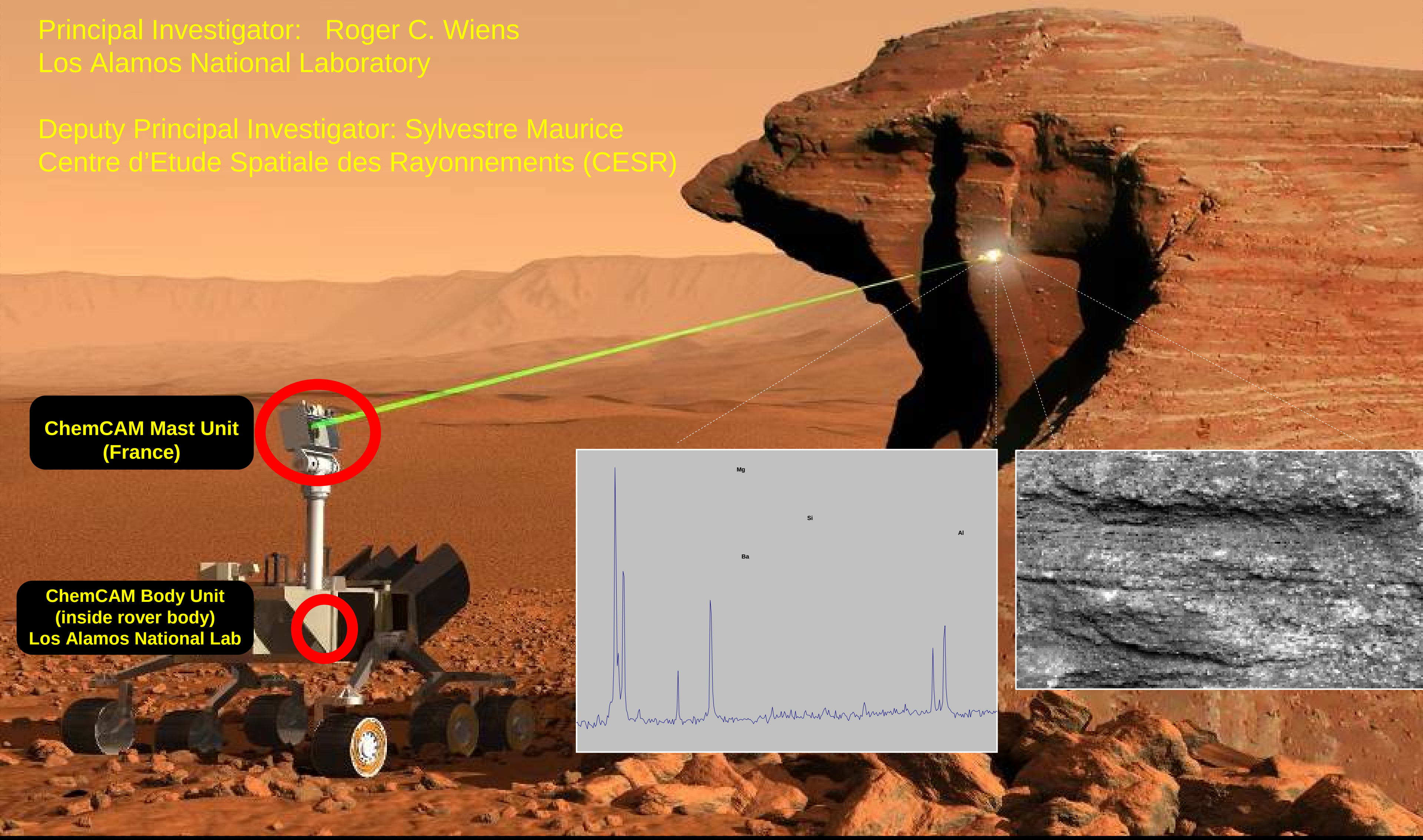
MSL's sampling system can:

- Clean rock surfaces with a brush
- Place and hold the instruments on the arm (APXS and MAHLI)
- Acquire samples of rock or soil with a powdering drill or scoop
- Sieve the samples and deliver them to SAM, CheMin, or a tray for observation
- Exchange spare drill bits

ChemCam is a Laser Induced Breakdown Spectroscopy (LIBS) Instrument with Remote Macroscopic Imaging (RMI) capability.

Principal Investigator: Roger C. Wiens
Los Alamos National Laboratory

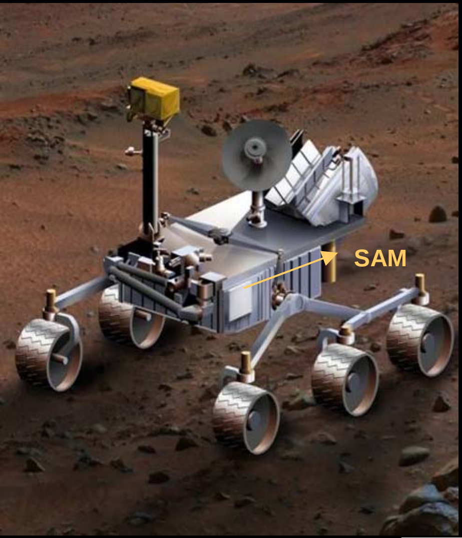
Deputy Principal Investigator: Sylvestre Maurice
Centre d'Etude Spatiale des Rayonnements (CESR)



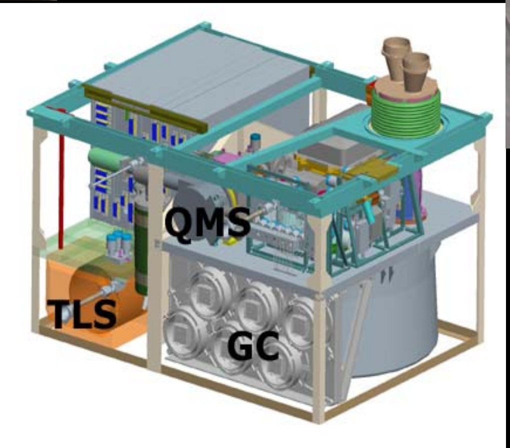
Sample Analysis at Mars (SAM) gas chromatograph can detect organic compounds

Gas Chromatograph (GC)

The GC columns can separate out individual gases from a complex mixture into molecular components for Quadrupole Mass Spectrometer and stand alone GC-mass spectrometry (GC-MS) analysis. A wide range of organic compounds including some of those relevant to life (amino acids, nucleobases, carboxylic acids, amines) can be detected by GC-MS.

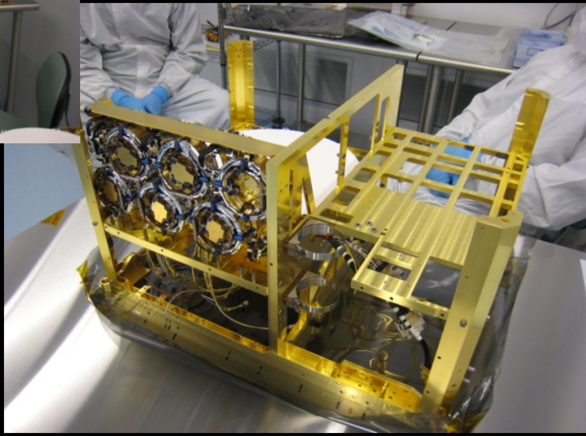


Location of SAM on Mars Science Laboratory rover



SAM configuration

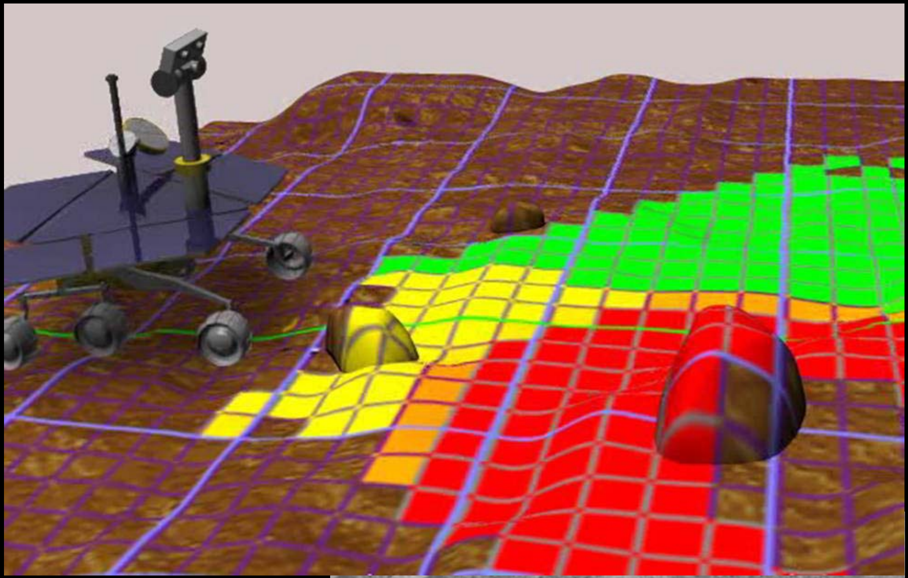
SAM engineers holding GC



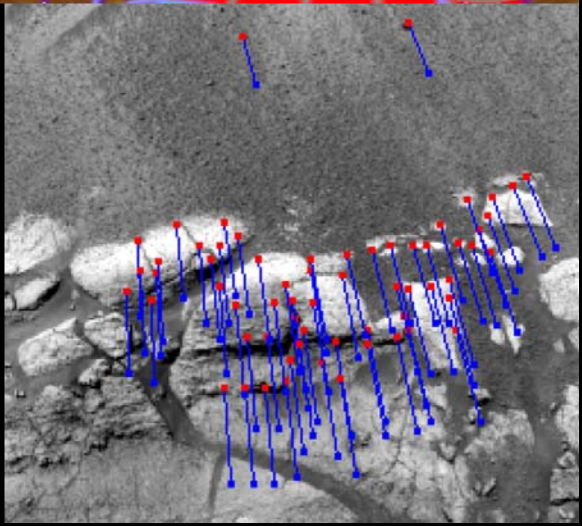
GC integrated onto SAM flight hardware

MER Driving Autonomy

- Terrain assessment (predictive hazard detection)
- Path selection
- Visual pose update (visual odometry)

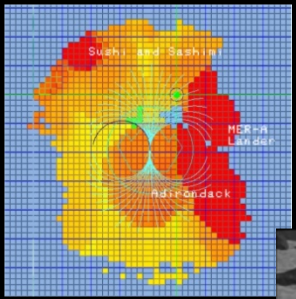


GESTALT Navigation



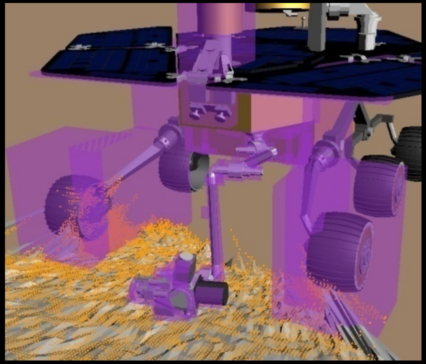
Visual Odometry

Autonomous Rover Surface Operations

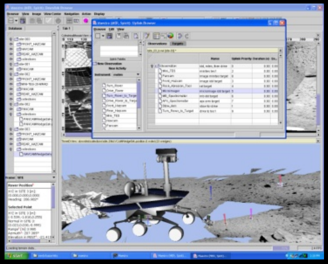


Actual map built from MER Spirit imagery

Visual Odometry



Simulation of autonomous instrument placement



Remote Science Operations

Key capabilities that provide autonomous operation of rovers millions of miles away

•Autonomous rover navigation

•Autonomous driving capability using stereo images for hazard detection and avoidance. The onboard software performs traversability analysis on 3-D range data to predict vehicle safety at all nearby locations; robust to partial sensor data and imprecise position estimation

•Visual odometry

•Capability to autonomously measure the progress of the rover traverse by imaging the surrounding area and comparing the successive images to provide an independent odometry from what is measured by the rotation of wheels to account for wheel slippage

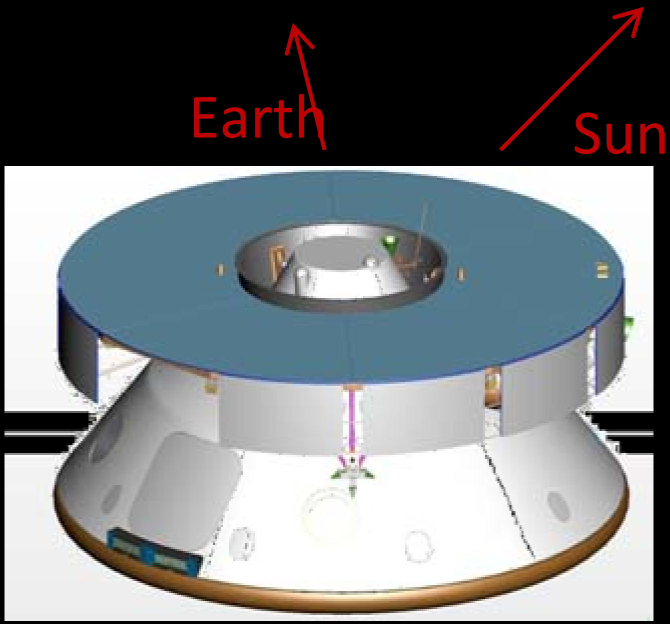
•Instrument placement

•Capability to autonomously traverse ~10 meters towards a rock designated by scientists and orienting the rover such that an instrument can be placed on the rock with ~1 cm accuracy. The onboard software uses visual tracking of the designated rock and autonomously drives the rover towards the rock while avoiding hazards and computes a feasible rover orientation so that its manipulator can place the instrument on the rock.

•Remote science operations

•Provides downlink data visualization, science activity planning, merging of science plans from multiple scientists and develops plans for autonomous science operations by the rover and its science instruments

General Spacecraft Autonomy and Fault Protection



- The spacecraft independently monitors its state and acts to maintain critical resources and capabilities:
  - Attitude (e.g. knowledge with respect to sun or stars, control based on available actuators)
  - Power (e.g. solar cell orientation to sun, power states)
  - Thermal (e.g. body orientation to sun, state of heaters, power states)
  - Communications (e.g. antenna orientation to Earth, configuration of radios)

- Onboard systems generally execute sequences of timed activities to control the spacecraft.
- Activities may include critical events like propulsive maneuvers with state monitors and decision-making. For example:
  - Inertial measurement of accumulated Delta-V
  - Monitoring for failed hardware and trigger of autonomous recovery.

Autonomous Underwater Vehicle

Environmentally
Non-Disturbing
Under-ice Robotic
Antarctic Explorer
(ENDURANCE)

Possible future submersible seeking liquid water on Europa or Enceladus