NASA’s Next Rover:
The 2009 Mars Science Laboratory

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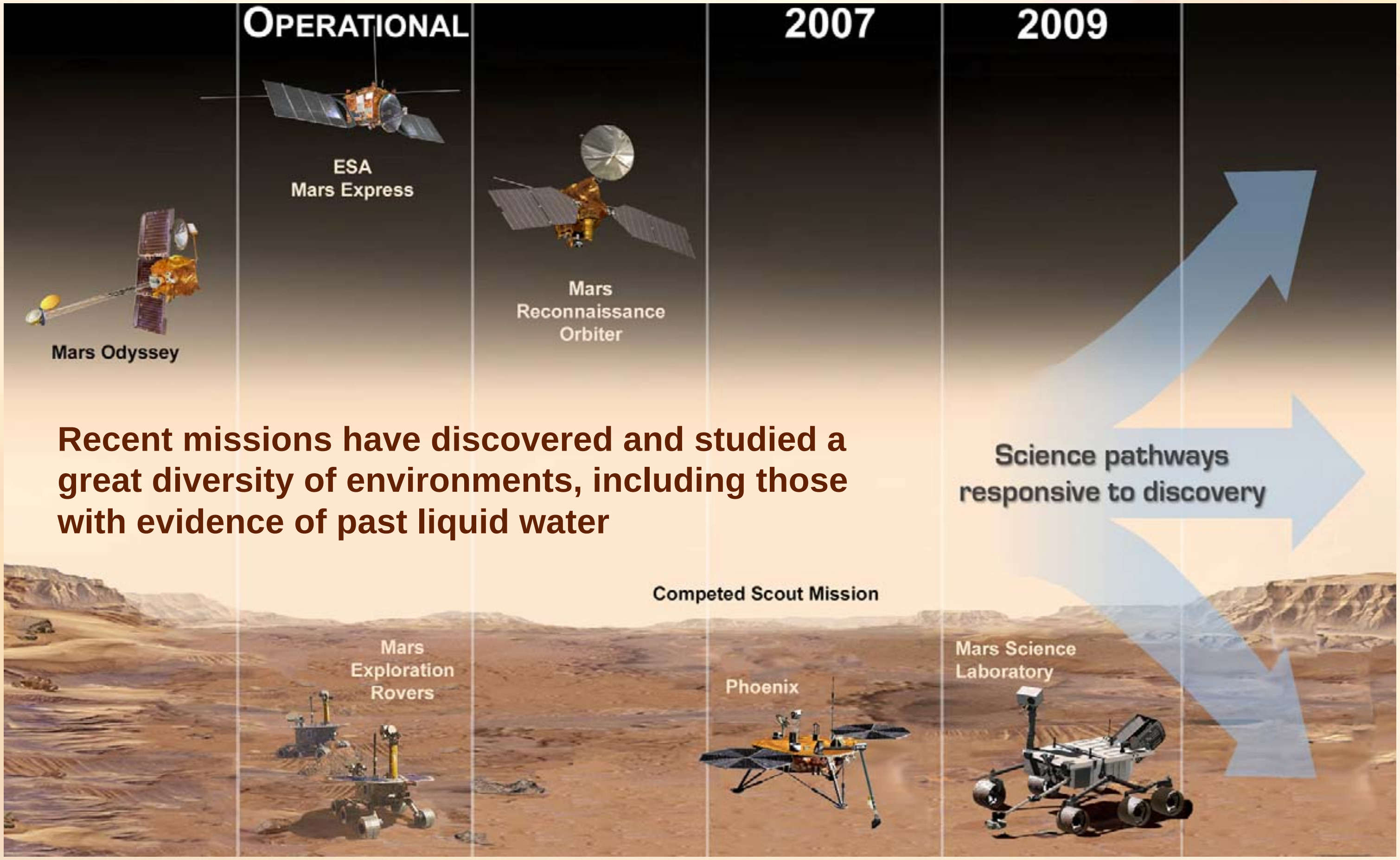
NASA's Mars Exploration Program



- **Future missions are likely to be focused on returning samples or detecting extant life**
- **The Mars Science Laboratory extends past investigations and enables future missions by characterizing the *habitability* of a site, i.e., its potential to support microbial life**

Scientific Objectives for MSL

Explore and quantitatively assess a local region on Mars' surface as a potential habitat for life, past or present.

A. Assess the biological potential of at least one target environment.
   1. Determine the nature and inventory of organic carbon compounds.
   2. Inventory the chemical building blocks of life (C, H, N, O, P, S).
   3. Identify features that may represent the effects of biological processes.

B. Characterize the geology and geochemistry of the landing region at all appropriate spatial scales (i.e., ranging from micrometers to meters).
   1. Investigate the chemical, isotopic, and mineralogical composition of martian surface and near-surface geological materials.
   2. Interpret the processes that have formed and modified rocks and regolith.

C. Investigate planetary processes of relevance to past habitability, including the role of water.
   1. Assess long-timescale (i.e., 4-billion-year) atmospheric evolution processes.
   2. Determine present state, distribution, and cycling of water and CO_2.

D. Characterize the broad spectrum of surface radiation, including galactic cosmic radiation, solar proton events, and secondary neutrons.

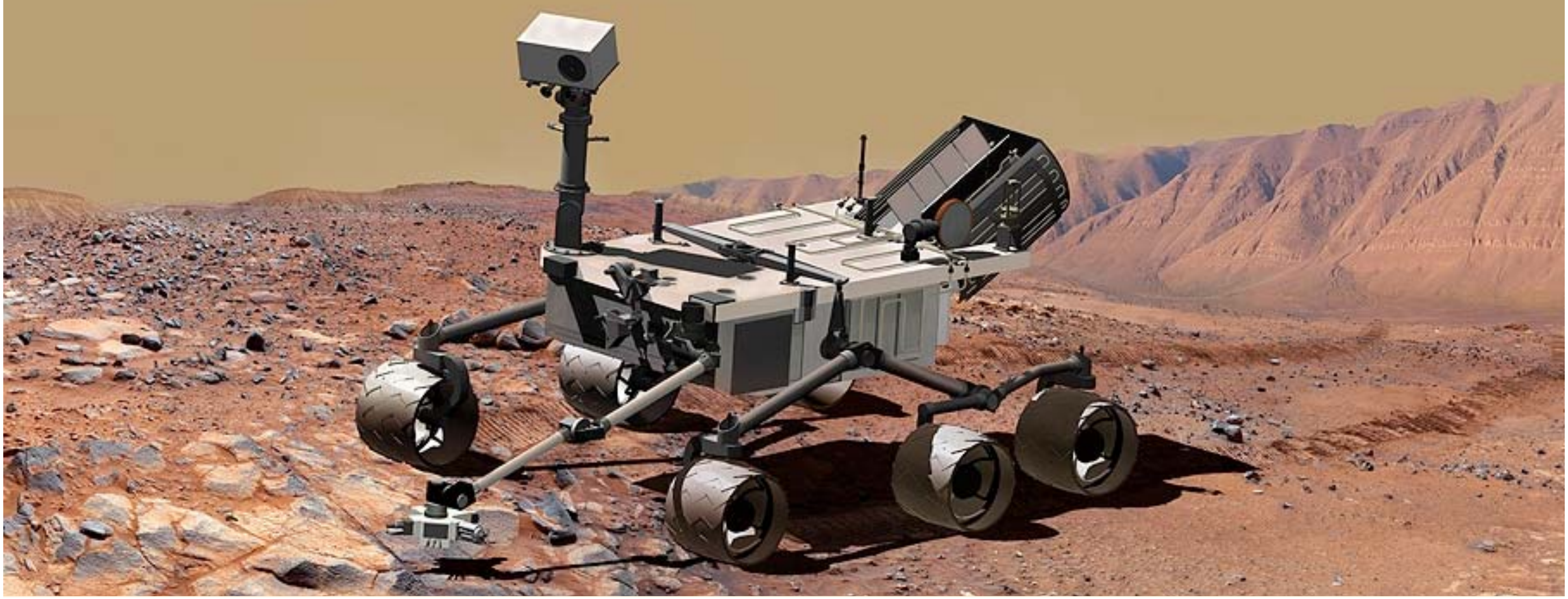
Scientific Objectives for MSL

Explore and quantitatively assess a local region on Mars' surface as a potential habitat for life, past or present.

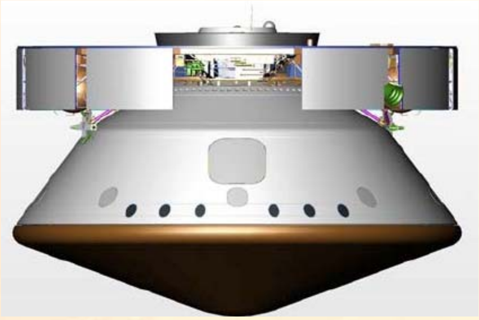
- Assessment of present habitability requires:
  - An evaluation of the characteristics of the environment and the processes that influence it from microscopic to regional scales.
  - A comparison of these characteristics with what is known about the capacity of life as we know it to exist in such environments.
- Determination of past habitability has the added requirement of inferring environments and processes in the past from observation in the present.
- Such assessments require integration of a wide variety of chemical, physical, and geological observations.

Needed Capabilities

- A long-lived, roving, robotic laboratory capable of visiting many sites
- Access to a wide range of candidate landing sites assessed by orbiting spacecraft
- A broad and flexible payload including advanced geochemical instruments used in Earth labs
- A system to acquire and process dozens of rock and soil samples
- An integrated science team and operations strategy



MSL Mission Overview

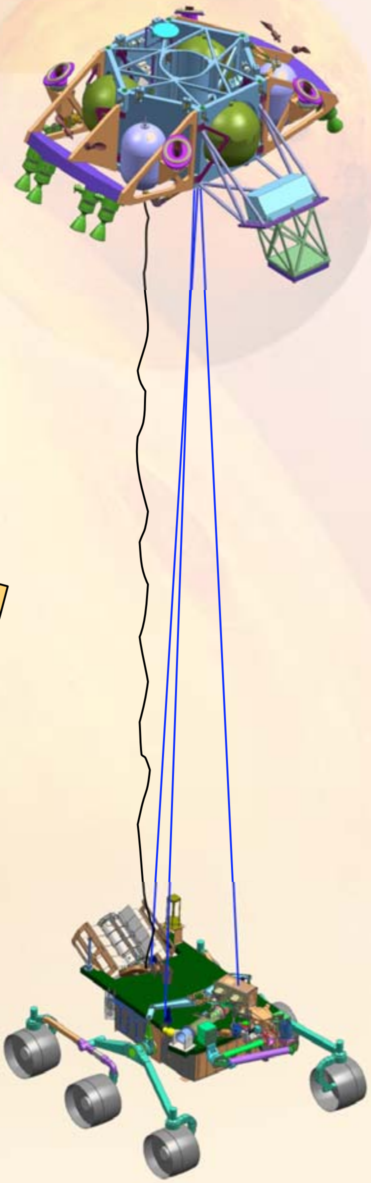


CRUISE/APPROACH

- 10-11 month cruise
- Spinning cruise stage
- Arrive N. hemisphere summer

ENTRY, DESCENT, LANDING

- Guided entry and controlled, powered "sky crane" descent
- 20-km diameter landing ellipse
- Discovery responsive for landing sites ±45º latitude, <+1 km elevation
- 900-kg landed mass



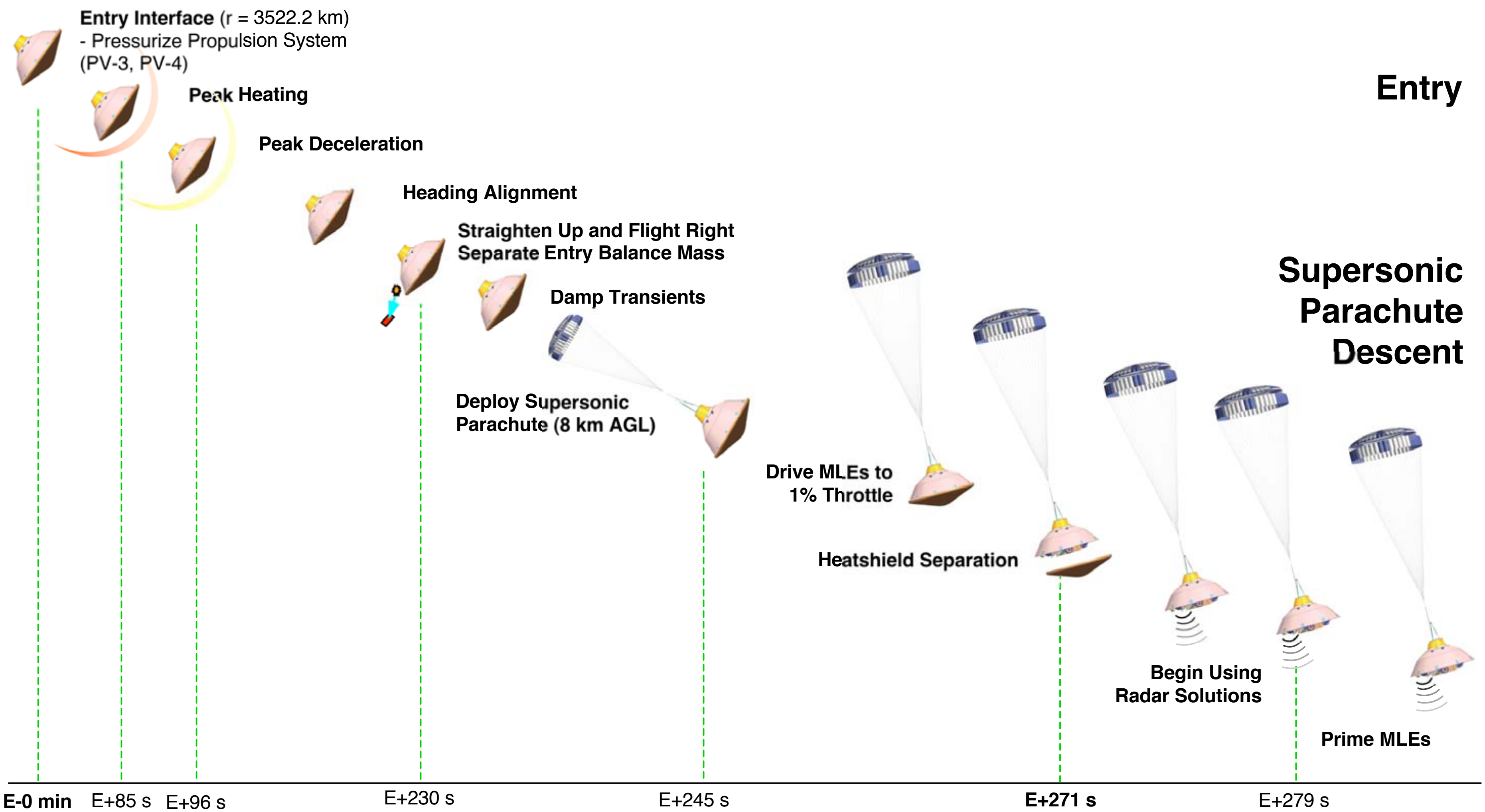
LAUNCH

- Sept. or Oct. 2009
- Atlas V (541)

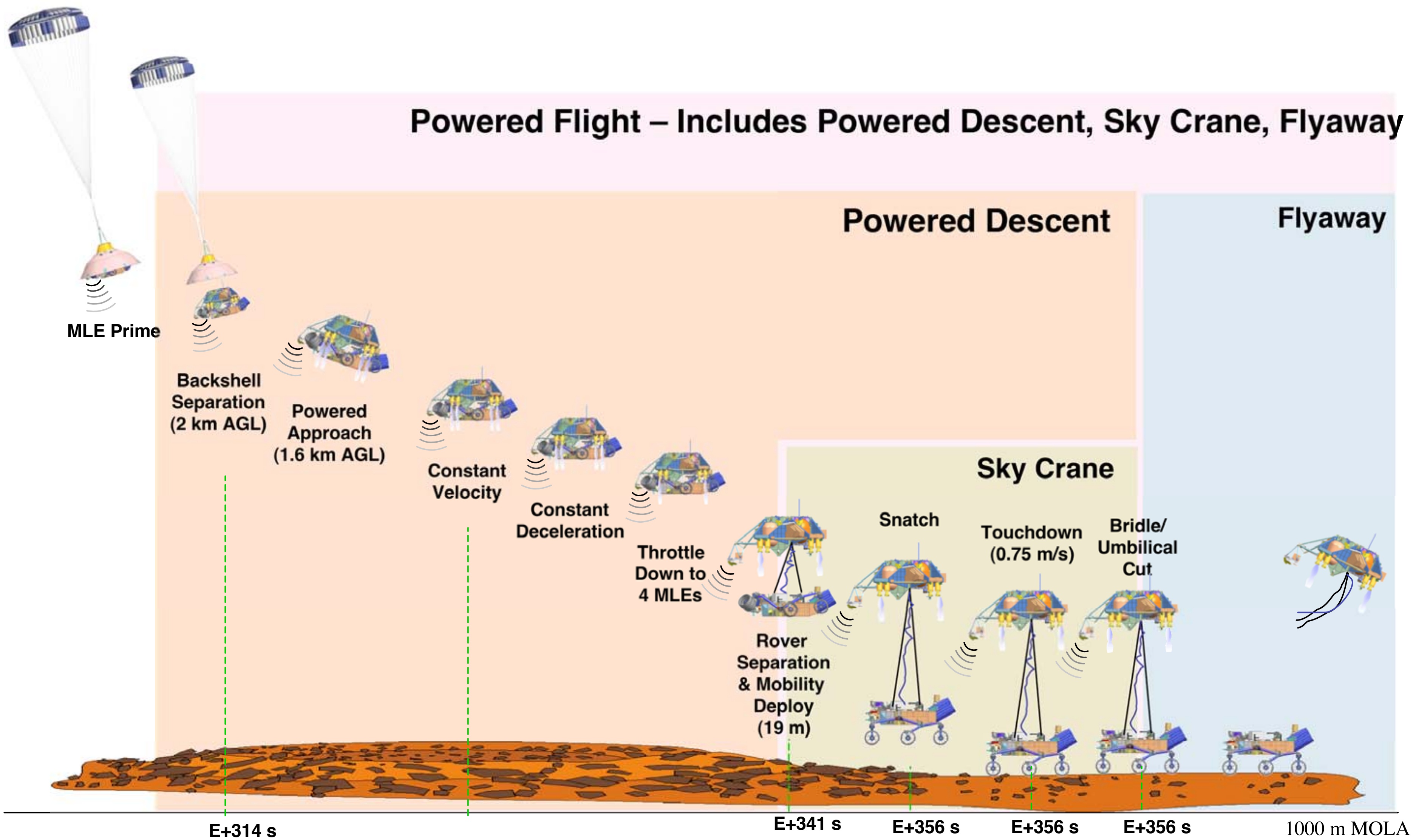
SURFACE MISSION

- Prime mission is one Mars year
- Latitude-independent and long-lived power source, pending approval
- 20-km range
- 80 kg of science payload
- Acquire and analyze samples of rock/regolith
- Large rover, high clearance; greater mobility than previous rovers (MPF, MER)

EDL Timeline (1 of 2)



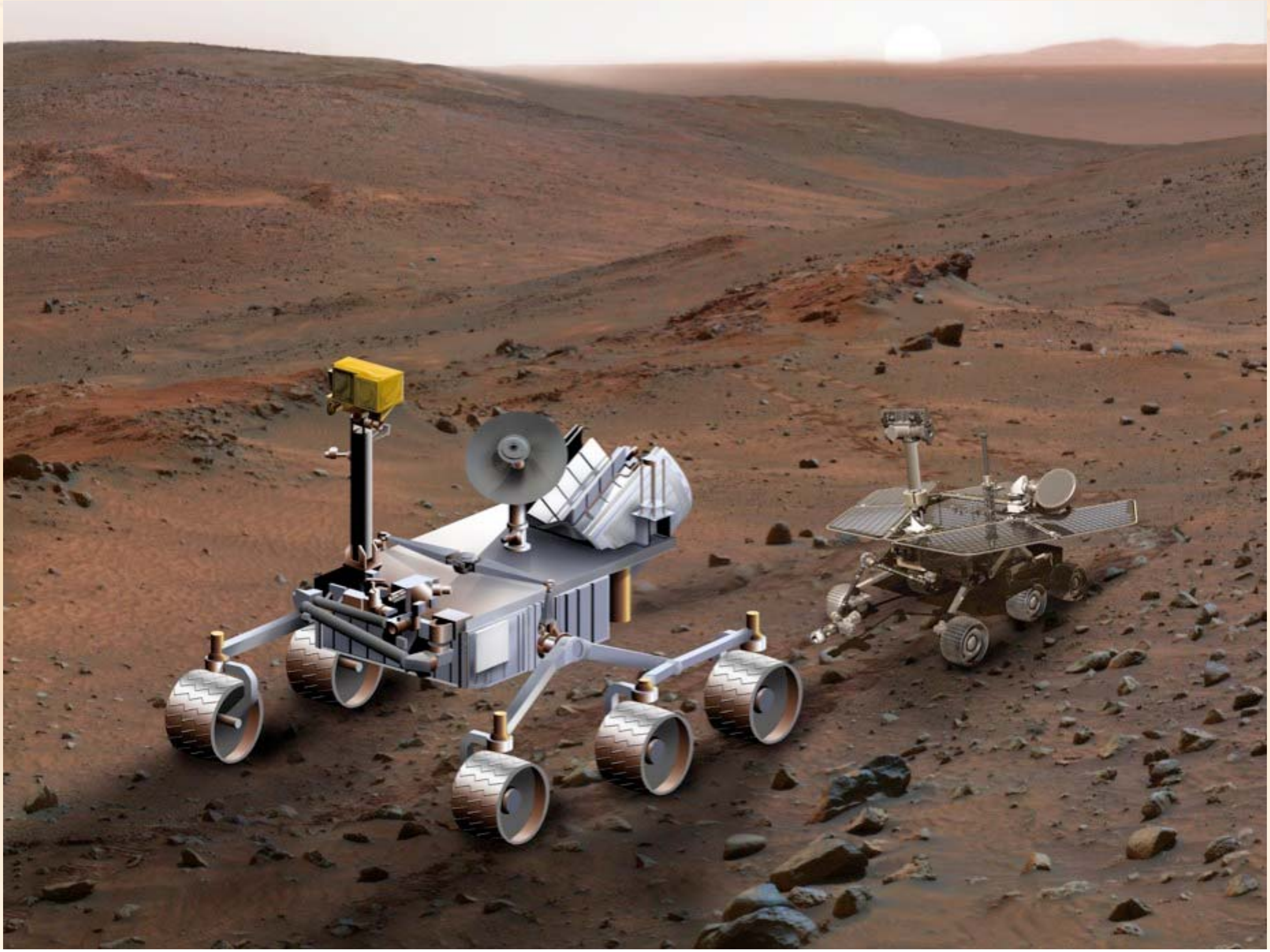
EDL Timeline (2 of 2)



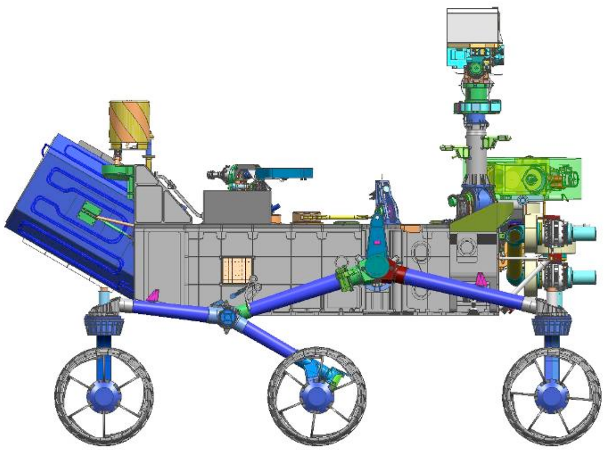
MSL - MER Comparison

	MSL	MER
LV/Launch Mass	Atlas V/4000 kg	Delta II/1050 kg
Prime Mission	1 yr. cruise/2 yrs. surface	7 mo. cruise/3 mo. surface
Redundancy	Dual string, some exceptions	Selective/Dual Mission
Payload	10 instruments (80 kg)	5 instruments (~5 kg)
EDL System	Guided entry + skycrane	MPF Heritage/Airbags
Heatshield Diam.	4.5 m	2.65 m
EDL Comm.	UHF or DTE	DTE + Partial UHF
Surface Power	2500 W-hr/sol	<900 W-hr/sol
Surface Comm.	Orbiter Relay (+ DTE)	Orbiter Relay (+ DTE)
Rover Mass	900 kg (allocation)	170 kg (actual)
Rover Range	>20 km	>600 m (few km actual)
Landing Ellipse Size	20-km diameter circle	80 × 10-km ellipse (final)
Accessible Latitudes	45ºS to 45ºN	15ºS to 10ºN
Accessible Altitudes	< +1 km MOLA	< -1.3 km MOLA

MSL - MER Comparison



Size Comparison



JPL 2009 MSL Rover

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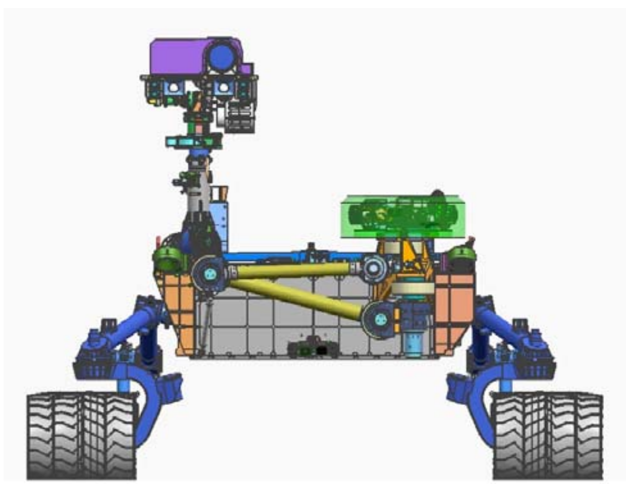
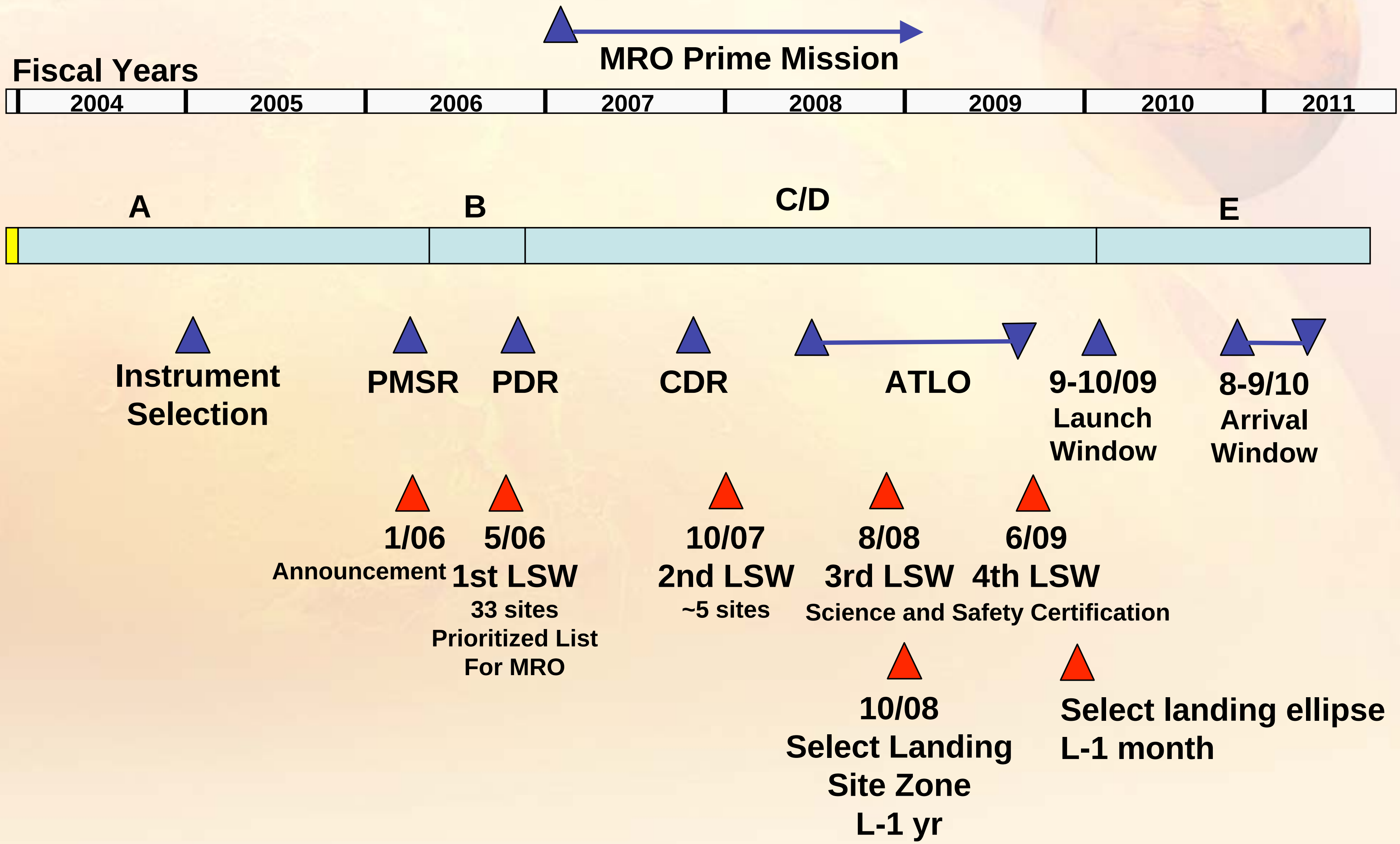
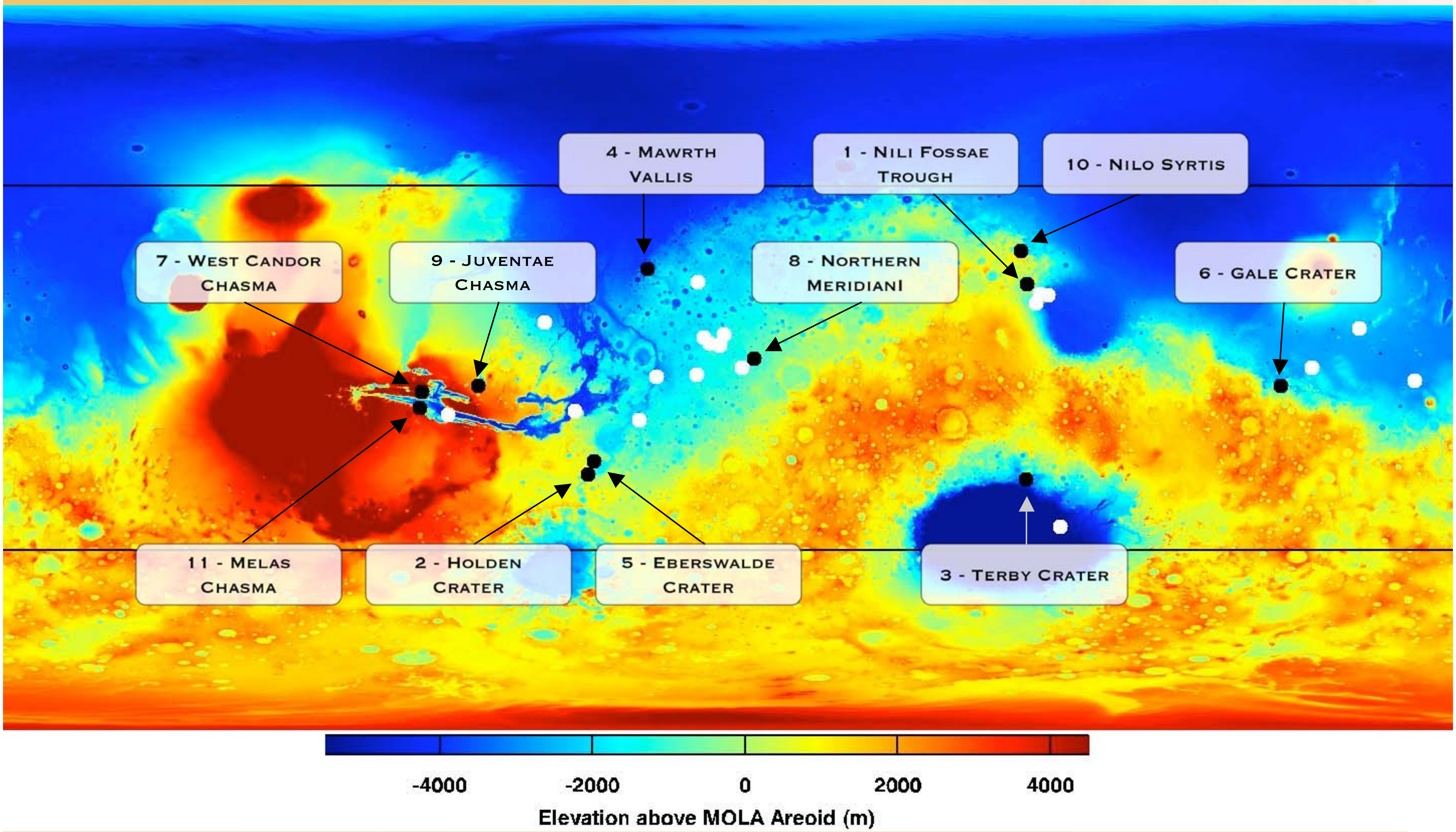


Project and Landing Site Milestones

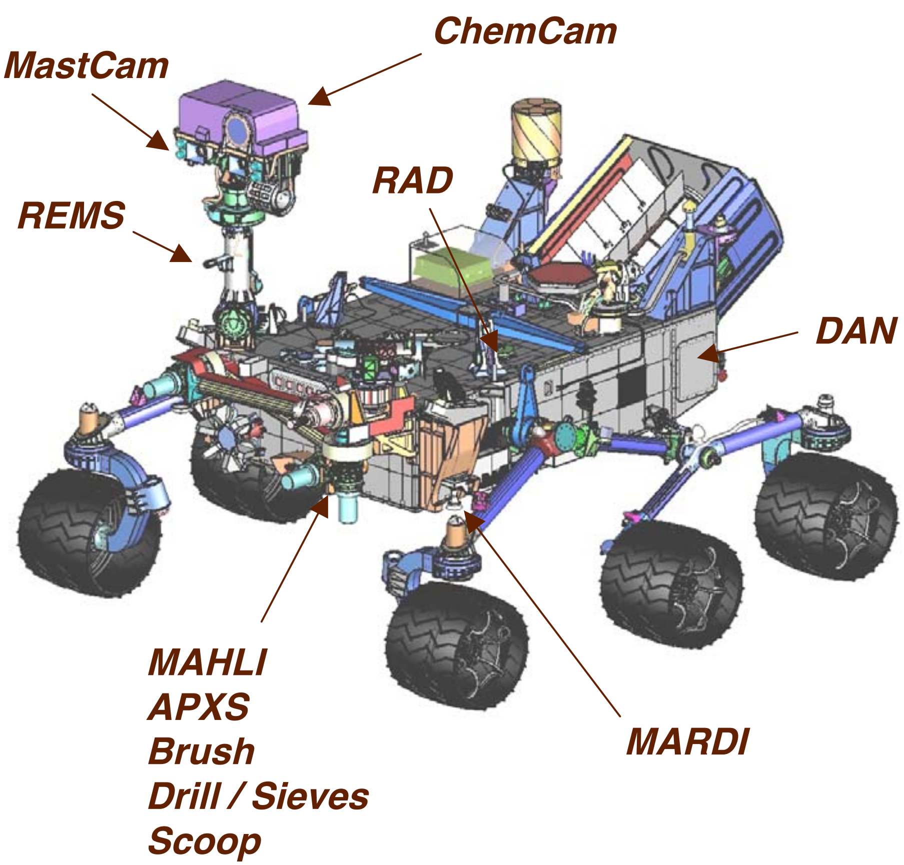


MSL Candidate Landing Sites



Higher-priority sites are black, others are white. Black lines show ±45° latitude.

MSL Payload



Wheel Base:	**2.2 m**
Height of Deck:	**1.1 m**
Height of Mast:	**2.2 m**

REMOTE SENSING

MastCam (M. Malin, MSSS) - Color stereo imaging, atmospheric opacity

ChemCam (R. Wiens, LANL/CNES) – Chemical composition; remote micro-imaging

CONTACT INSTRUMENTS (ARM)

MAHLI (K. Edgett, MSSS) - Microscopic 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

DAN (I. Mitrofanov, IKI, Russia) - Subsurface hydrogen

MARDI (M. Malin, MSSS) - Descent imagery

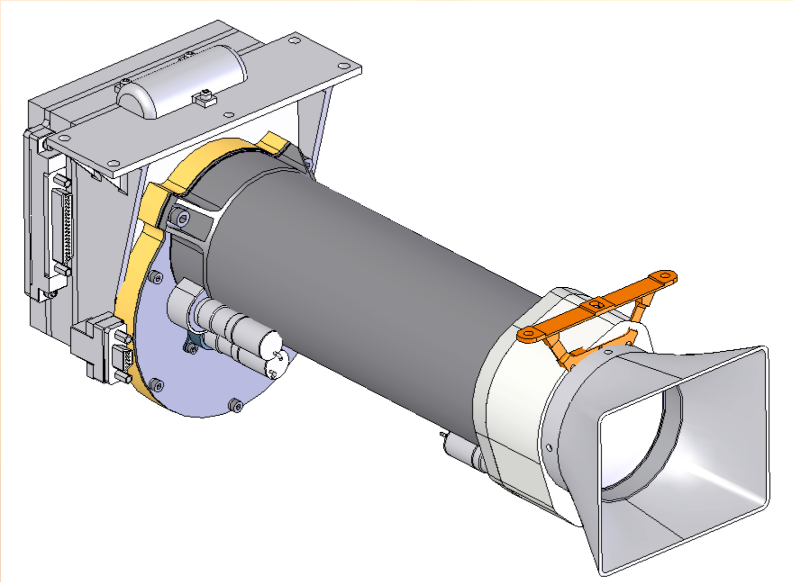
REMS (J. Gómez-Elvira, CAB, Spain) - Meteorology/UV

RAD (D. Hassler, SwRI) - High-energy radiation

Mast Camera (MastCam)

Principal Investigator: Michael Malin

Malin Space Science Systems



MastCam observes the geological structures and features within the vicinity of the rover

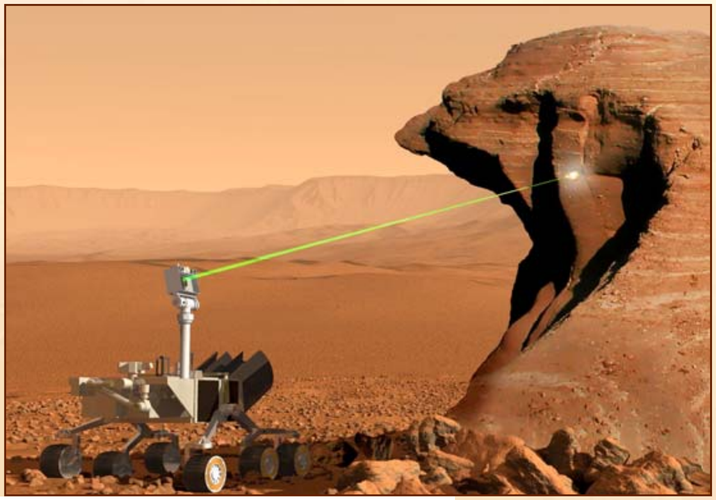
- Studies of landscape, rocks, fines, frost/ice, and atmospheric features
- Stereo, 15:1 zoom/telephoto lens, from 90° to 6° FOV
- Bayer pattern filter design for natural color plus narrow-band filters for scientific color
- High spatial resolution: 1200×1200 pixels (0.2 mm/pixel at 2 m, 8 cm/pixel at 1 km)
- High-definition video at 5-10 FPS, 1280×720 pixels
- Large internal storage: 256 MByte SRAM, 8 GByte flash

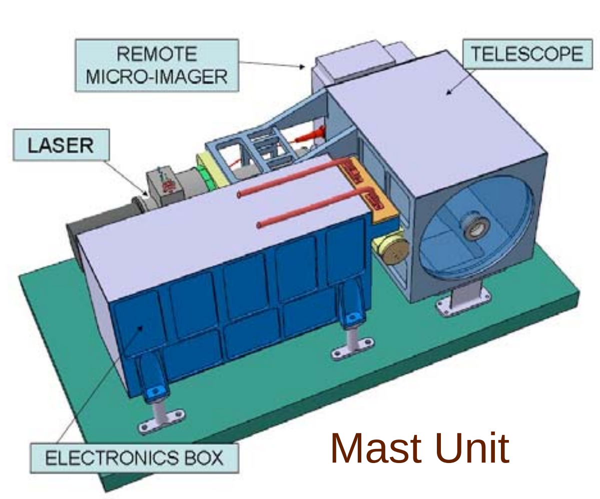
Chemistry & Micro-Imaging (ChemCam)

Principal Investigator: Roger Wiens

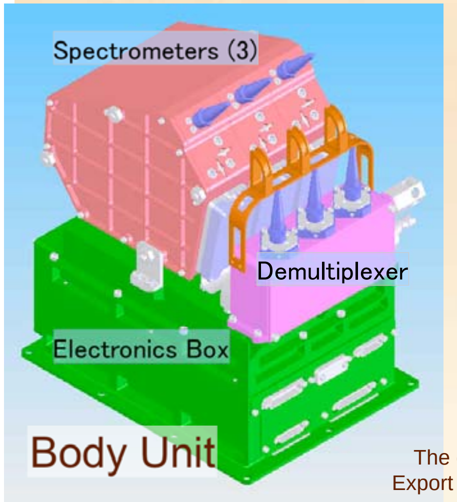
Los Alamos National Laboratory

Centre d'Etude Spatiale des Rayonnements





Mast Unit



Body Unit

ChemCam performs elemental analyses through laser-induced breakdown spectroscopy

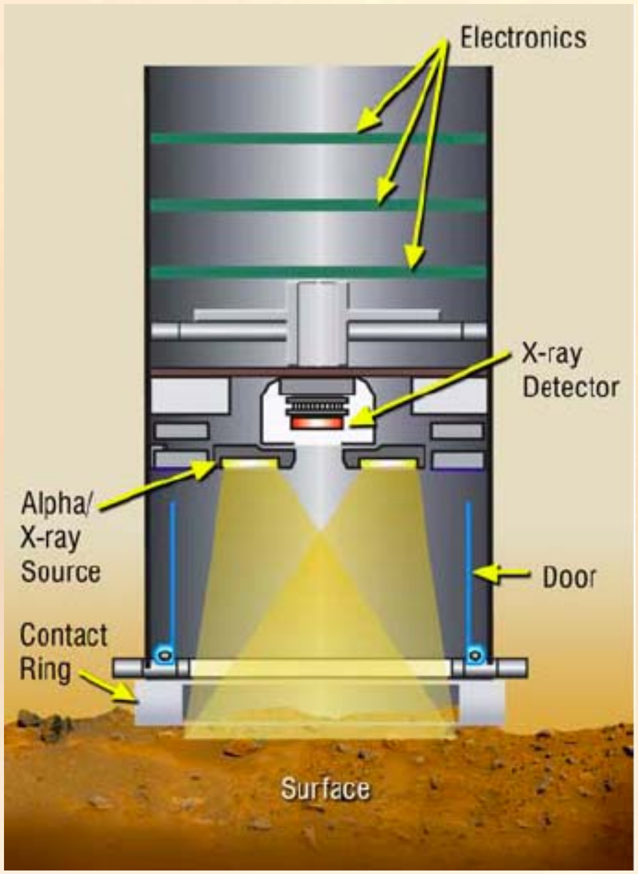
- Rapid characterization of rocks and soils from a distance of up to 9 meters
- 240-800 nm spectral range
- Dust removal over a ~1-cm region; depth profiling within a ~1-mm spot
- Helps classify hydrated minerals, ices, organic molecules, and weathering rinds
- High-resolution context imaging (resolves ~0.8 mm at 10 m)

Alpha Particle X-Ray Spectrometer (APXS)

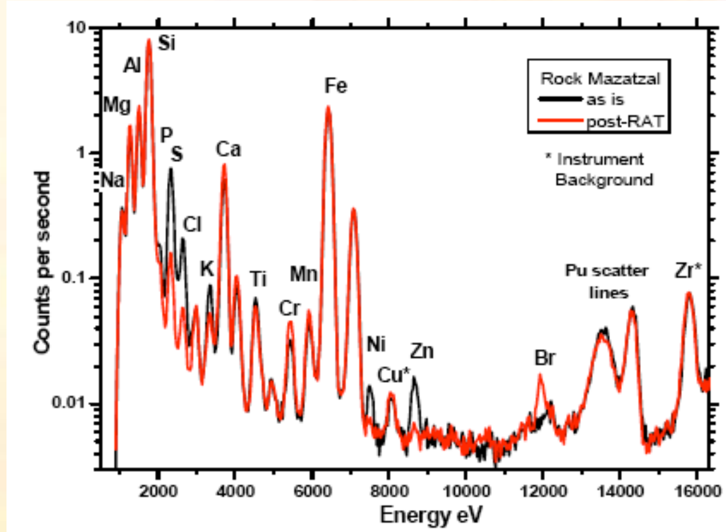
Principal Investigator: Ralf Gellert

University of Guelph, Ontario, Canada

Canadian Space Agency



Heritage: Pathfinder, MER



APXS determines the chemical composition of rocks, soils, and processed samples

- Combination of particle-induced X-ray emission and X-ray fluorescence using a ^{244}Cm source
- Rock-forming elements from Na to Br and beyond
- Useful for lateral / vertical variability, surface alteration, detection of salt-forming elements
- Factor ~3 increased sensitivity, daytime operation compared with MER

Mars Hand Lens Imager (MAHLI)

Principal Investigator: Kenneth Edgett

Malin Space Science Systems

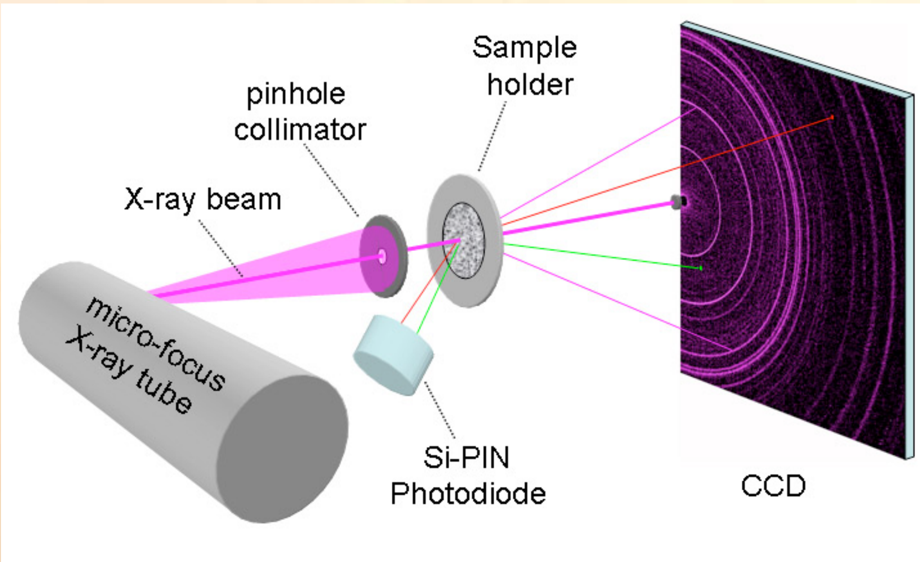
MAHLI characterizes the history and processes recorded in geologic materials encountered by MSL

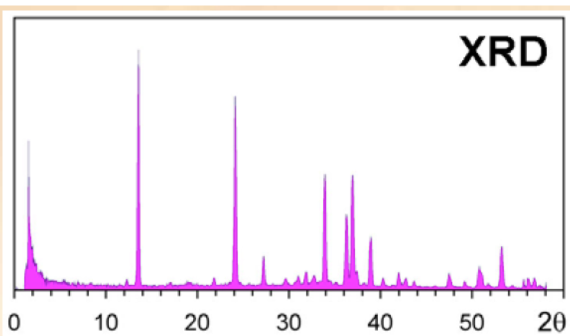
- Examines the structure and texture of rocks, fines, and frost/ice at micrometer to centimeter scale
- Returns color images like those of typical digital cameras; synthesizes best-focus images and depth-of-field range maps
- Wide range of spatial resolutions; can focus at infinity; highest spatial resolution possible is ~9 μm/pixel
- White light and UV LEDs for controlled illumination, fluorescence

Chemistry & Mineralogy (CheMin)

Principal Investigator: David Blake

NASA Ames Research Center





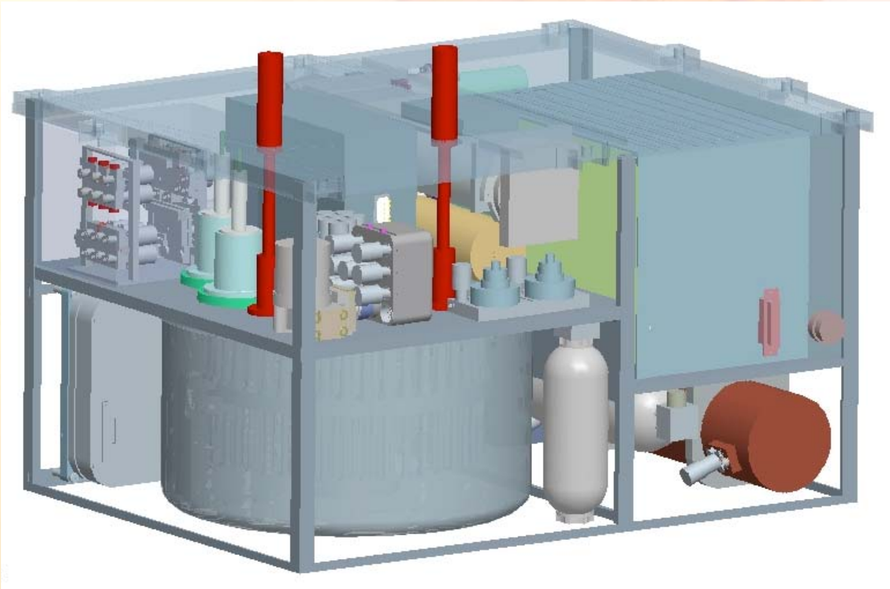
CheMin derives definitive mineralogy

- X-ray diffraction (XRD); standard technique for laboratory analysis
- Identification and quantification of minerals in geologic materials (e.g., basalts, evaporites, soils)

Sample Analysis at Mars (SAM)

Principal Investigator: Paul Mahaffy

NASA Goddard Space Flight Center



SAM Suite Instruments

Quadrupole Mass Spectrometer (QMS)
Gas Chromatograph (GC)
Tunable Laser Spectrometer (TLS)

- Search for organic compounds of biotic and prebiotic relevance, including methane, and explore sources and destruction paths for carbon compounds
- Reveal chemical state of other light elements that are important for life as we know it on Earth
- Study the habitability of Mars by measuring oxidants such as hydrogen peroxide
- Investigate atmospheric and climate evolution through isotope measurements of noble gases and light elements

- **QMS:** molecular and isotopic composition in the 2-535 Dalton mass range for atmospheric and evolved gas samples
- **GC:** resolves complex mixtures of organics into separate components
- **TLS:** abundance and precision (<10 per mil) isotopic composition of CH_4, CO_2

Dynamic Albedo of Neutrons (DAN)

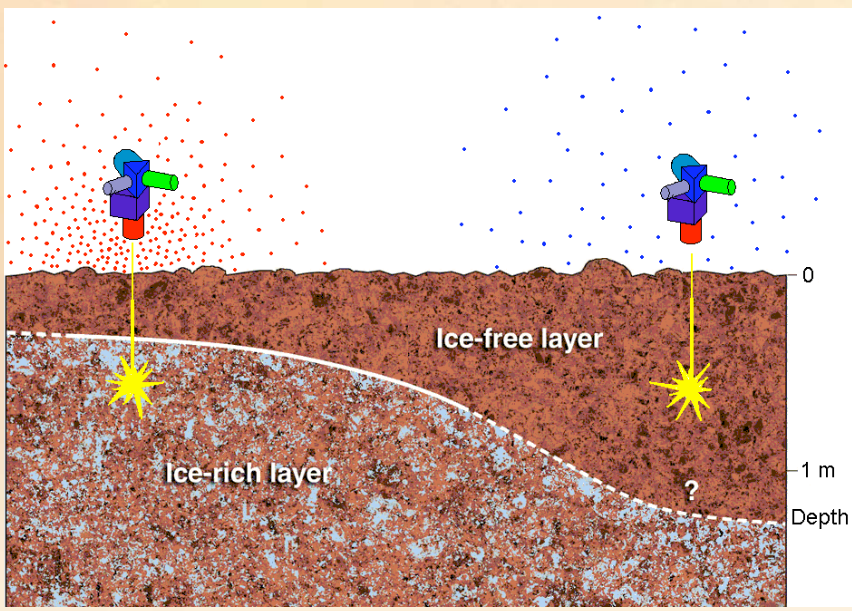
Principal Investigator: Igor Mitrofanov

Space Research Institute (IKI), Russia

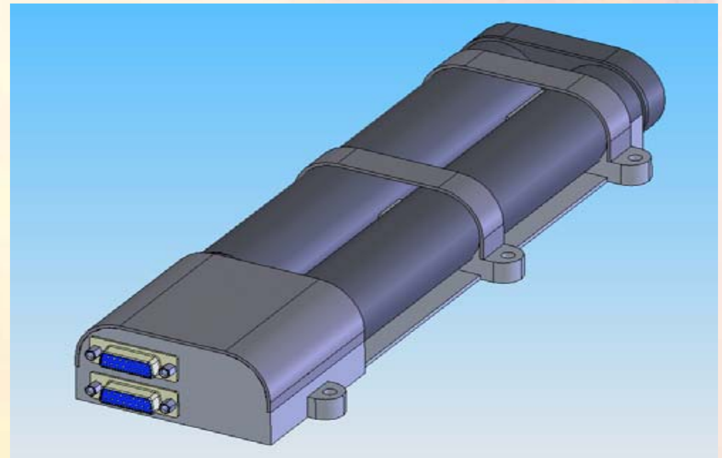
DAN measures the abundance of hydrogen (e.g., in water or hydrated minerals) within one meter of the surface

Large albedo flux of thermal neutrons

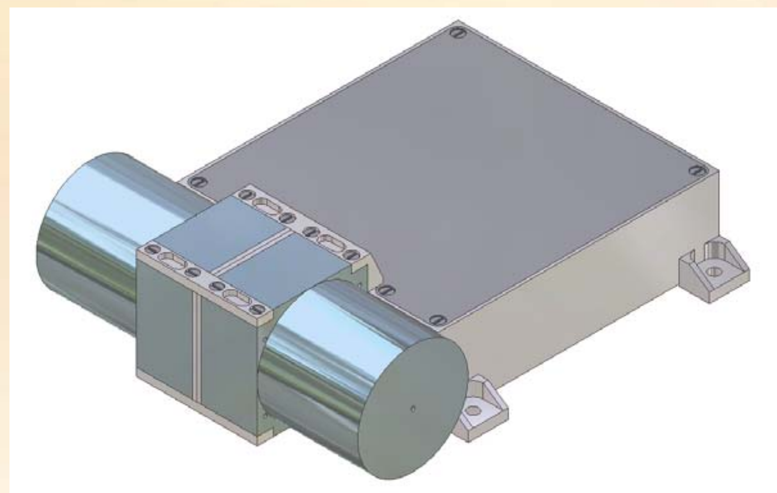
Small albedo flux of thermal neutrons



Pulsing Neutron Generator



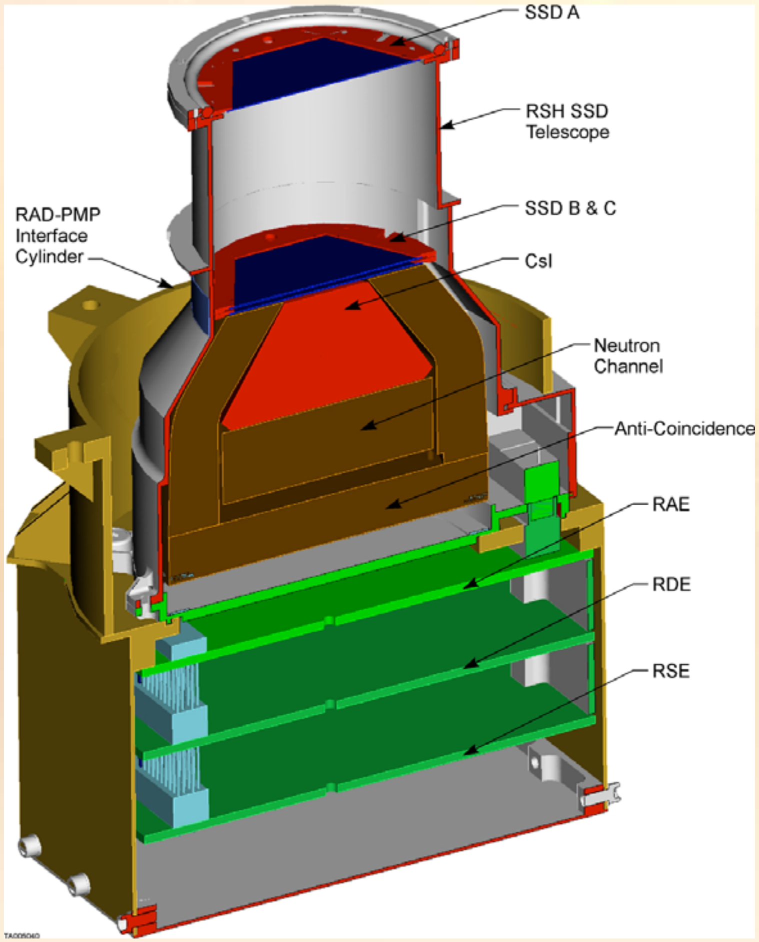
Thermal & Epithermal Neutron Detectors



Radiation Assessment Detector (RAD)

Principal Investigator: Donald M. Hassler

Southwest Research Institute



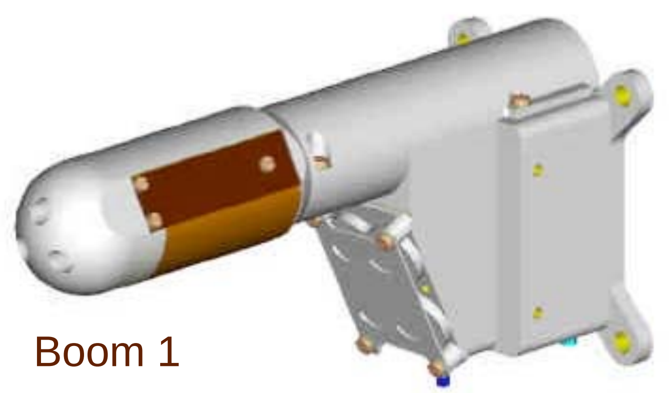
RAD characterizes the radiation environment on the surface of Mars

- Measures galactic cosmic ray and solar energetic particle radiation, including secondary neutrons and other particles created in the atmosphere and regolith
- Determines human dose rate, validates transmission/transport codes, assesses hazard to life, studies the chemical and isotopic effects on Mars' surface and atmosphere
- Solid state detector telescope and CsI calorimeter. Zenith pointed with 65º FOV
- Detects energetic charged particles (Z=1-26), neutrons, gamma-rays, and electrons

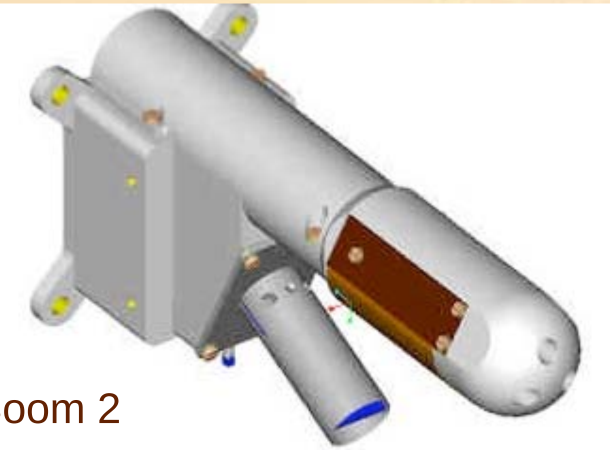
Rover Environmental Monitoring Station (REMS)

Principal Investigator: Javier Gómez-Elvira

Centro de Astrobiología (CAB), Spain



Boom 1



Boom 2

REMS measures the meteorological and UV radiation environments

- Two 3-D wind sensors
- Ground and air temperature sensors
- Pressure sensor
- Humidity sensor
- UV radiation detector (200 to 400 nm)
- 1-Hz sampling for 5 minutes each hour

Mars Descent Imager (MARDI)

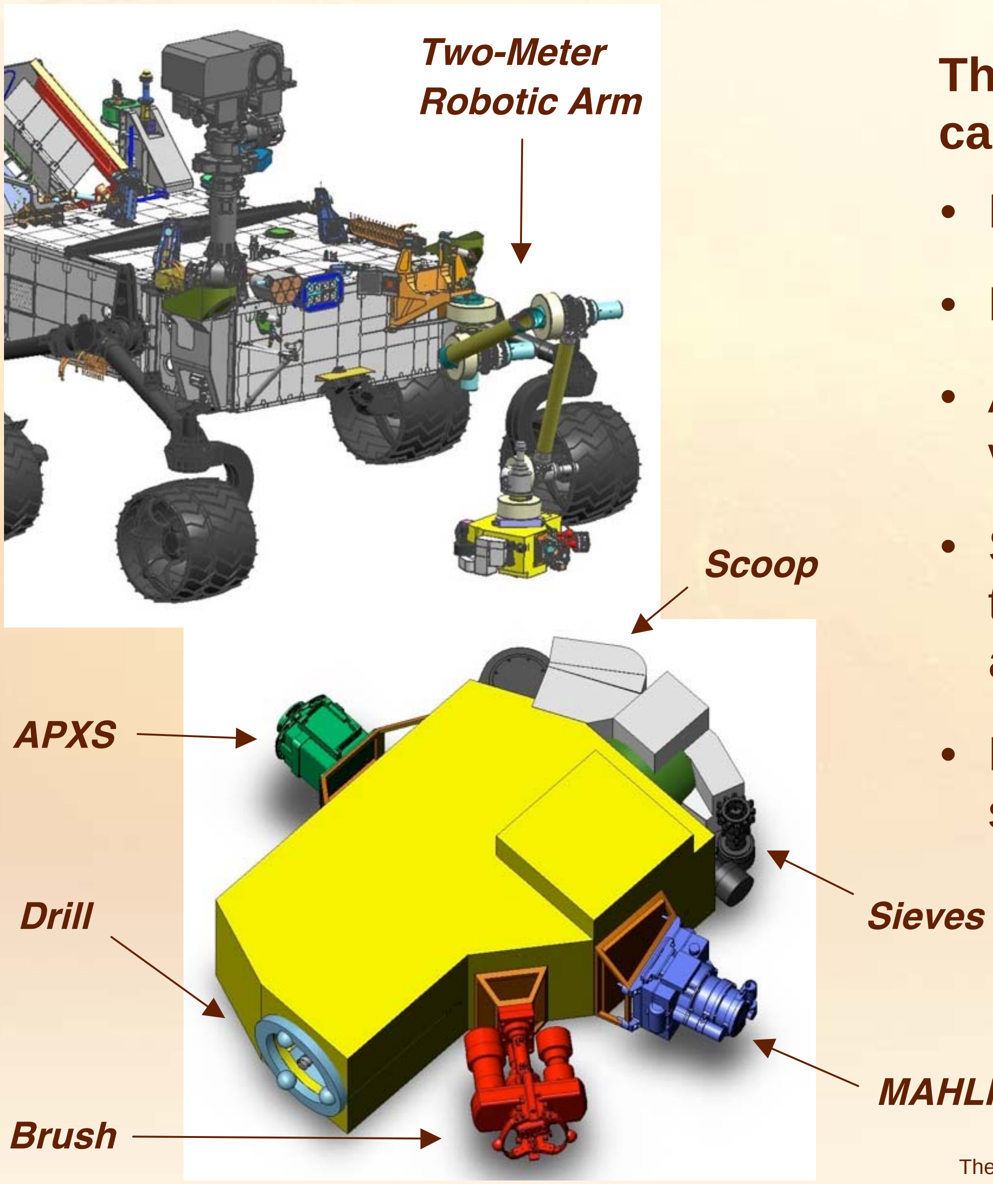
Principal Investigator: Michael Malin

Malin Space Science Systems

MARDI provides detailed imagery of the MSL landing region

- Provides images over three orders of magnitude in scale, tying post-landing surface images to pre-landing orbital images
- Bayer pattern filter for natural color
- Short exposure time to reduce image blurring from spacecraft motion
- High-definition, video-like data acquisition (1600×1200 pixels, 5 frames/sec)
- Large internal storage: 256 MByte SRAM, 8 GByte flash

Sample Acquisition, Processing, & Handling



The SA/SPaH has the following capabilities:

- Brush rock surfaces
- Place and hold contact instruments
- Acquire samples of rock or regolith via powdering drill and scoop
- Sieve samples into fines and deliver the processed material to the analytical lab instruments
- Provide the opportunity to observe sieved samples

Summary: Investigations vs. Objectives

Objective:	Mast-Cam	Chem-Cam	MAHLI	APXS	SAM	Che-Min	MARDI	DAN	REMS	RAD
Determine the nature and inventory of organic carbon compounds.		+			++					
Inventory the chemical building blocks of life (C, H, N, O, P, S).		++		++	++	+		+		
Identify features that may represent the effects of biological processes.		+	++	+	++	+				
Investigate the chemical, isotopic, and mineralogical composition of the Martian surface and near-surface geologic materials.	+	++	+	++	++	++		+		
Interpret the processes that have formed and modified rocks and regolith.	++	+	++	+	+	++	+		+	+
Assess long-time scale atmospheric evolution processes.	+	+		+	+	+	+			
Determine present state, distribution, and cycling of water and CO_2.	+	+	+		+			++	++	+
Characterize the broad spectrum of surface radiation, including galactic cosmic radiation, solar proton events, and secondary neutrons.								+	+	++

- Each objective addressed by multiple investigations; each investigation addresses multiple objectives; provides robustness and reduces risk.

A Typical Payload Operations Scenario

- The MSL science objectives and mission capabilities suggest a natural flow of operations focused primarily toward acquiring samples, punctuated with fixed "decision points" for the science and engineering teams.
- Each decision involves contributions from multiple payload elements. Ideally the pace of science operations would be limited only by these decisions.

Action on Mars
Traverse, remote sensing
Approach target; remote sensing
Contact science, rock brushing
Acquire sample; more imaging and contact science
Process sample in analytical laboratory

4-decision sampling sequence

Subsequent Decision on Earth
Is there an interesting target?
Is there a target in the workspace worth examining further?
Is the target worth sampling?
Is the sample worth analyzing?
Drive away from target site?

Management of Science Operations

- Achieving MSL's science objectives requires an integrated and interdependent set of investigations, accomplished through an integrated set of operations on the rover
- These interdependencies imply that:
  - resources such as time, energy, data volume, and consumables be managed at the group level
  - tactical and strategic decisions are made by the science team in an efficient, coordinated fashion
  - sharing of data between investigations be immediate and complete
- Development of plans for tactical and strategic processes in science operations is underway, following an approach based on the successful Pathfinder and MER models

Typical Instrument Activities vs. Sol Type

	DAN	MastCam	ChemCam	MAHLI	APXS	SAM	CheMin
Traverse / Recon	***hydrogen survey (active)***	***panoramic imaging***	***LIBS / imaging untargeted and targeted***	*soil and rock survey*	*soil and rock survey*		
Approach	***hydrogen measurement (active)***	***workspace imaging***	***LIBS / imaging of target; workspace***	*soil and rock survey*	*soil and rock survey*		
Contact	*hydrogen measurement (passive)*	***multispectral imaging, pre- and post-brushing***	***LIBS / imaging of workspace***	***hand-lens imaging***	***elemental analysis, pre- and post-brushing***		
Sampling	*hydrogen measurement (passive)*						***XRD quick-look analysis***
Analysis	*hydrogen measurement (passive)*		*LIBS / imaging of powdered sample*	*hand-lens imaging of powdered sample*	*elemental analysis of powdered sample*	***GCMS / TLS analysis of sample***	***XRD analysis of sample***
Additional Science Campaigns	*intensive hydrogen survey*	*geological investigations*	*geological / geochemical investigations*	*geological investigations*	*geochemical investigations*	*atmospheric analyses*	*Long integrations*

- RAD and REMS perform regular observations throughout the mission.
- Multiple payload elements provide decision-critical data (shaded) on each sol.

Mars Community Involvement in MSL

- Over 130 PIs, Co-Is, and collaborators
- The Mars science community is invited to participate in the selection and certification of the MSL landing site. The first workshop was held in June 2006. The next workshop is scheduled for October 23-25, 2007, in Pasadena. Scientists can also provide scientific and safety analyses through the Critical Data Products and Mars Data Analysis programs.
- NASA has appointed a Landing Site Selection Steering Committee co-chaired by John Grant (Smithsonian Inst.) and Matt Golombek (JPL).
- NASA plans to call for MSL Participating Scientists. Selected scientists would join the Project several months before launch and participate in operational readiness tests.