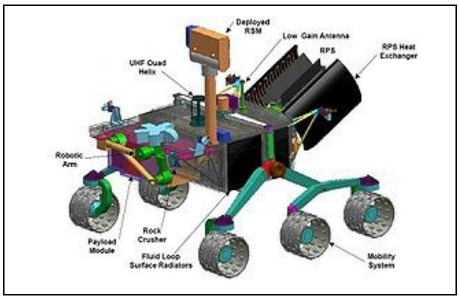
Explorador Curiosity



Espectrómetros

- **ChemCam:** ChemCam es un sistema de espectroscopia de colapso inducida por rayo láser (LIBS -siglas en inglés), el cual puede apuntar a una roca a una distancia de 13 metros, vaporizando una pequeña cantidad de los minerales subyacentes en ella y recogiendo el espectro de luz emitida por la roca vaporizada usando una cámara con una resolución angular de 80 microradianes. Está siendo desarrollada por el Laboratorio Nacional de Los Álamos y el laboratorio francés CESR (a cargo del rayo láser). Utiliza un rayo láser infrarrojo con una longitud de onda de 1067 nanómetros y un pulso de 5 nanosegundos, que enfocará en un punto de 1 GW/cm^2, depositando 30mJ de energía. La detección se logrará entre los 240 y los 800 nanómetros.[13] [14] [15] En octubre del 2007 la NASA anunció que se detenía el desarrollo del dispositivo debido a que el costo había llegado a un 70% del costo proyectado y se terminaría solo con el dinero ya proporcionado.[16] El Laboratorio Nacional de Los Álamos afirmó que el sobrecosto se debió a los requerimientos impuestos por la misión del rover y el ahorro en costos era mínimo debido a que el dinero provenía de la CNES francesa.[17]

- **Espectrómetro de rayos X por radiación alfa (APXS):** Este dispositivo irradiará muestras con partículas alfa y permitirá su análisis a partir del espectro generado por los Rayos X re-emitidos. Está siendo desarrollado por La Agencia Espacial Canadiense, para determinar la composición elemental de muestras. El sistema APXS es una forma de PIXE. Instrumentos similares fueron incluidos en la misión Mars Pathfinder y en la Mars Exploration Rovers[18]

- **CheMin:** Chemin es la abreviación usada para el Instrumento de análisis químico y minerológico a través de la difracción y fluorescencia de Rayos X, el cual cuantifica y analiza la estructura de los minerales contenidos en una muestra. Es desarrollado por el Doctor David Blake en el *NASA Ames Research Center* y el *NASA Jet Propulsion Laboratory*[19]

- **Análisis de muestras en Marte (SAM):** El instrumento así denominado, analizará muestras sólidas y gaseosas en búsqueda de compuestos orgánicos. Está siendo desarrollado por el Centro de vuelo espacial Goddard de la NASA y el Laboratoire Inter-Universitaire des Systèmes Atmosphériques (LISA) -Laboratorio Inter-Universitario de Sistemas Atmosféricos-. SAM consiste en un sistema de manipulación de muestras con 74 copas las cuales pueden ser calentadas a una temperatura de 1000 °C para enriquecer y derivar moléculas orgánicas de la muestra misma. El espectrómetro de cromatografía de gases es un espectrómetro cuadropolar con una rango de masa Dalton de 2-235 el cual obtiene información a través de las seis columnas cromatográficas de gases. El espectrómetro láser ajustable es capaz de medir radios de isotopos de carbono y oxígeno en CO_2

Detectores de radiación

- **Detector por evaluación de radiación (RAD):** Este instrumento analizará toda la gama e intensidad de radiación espacial y radiación solar que recibe la superficie de Marte, con el objetivo de diseñar protección contra la radiación para exploradores humanos. Este instrumento está financiado por la NASA y desarrollado por la universidad Southwest Research Institute (SwRI) en EE.UU. y la universidad alemana 'Christian-Albrechts-Universität zu Kiel.'

- **Albedo dinámico de Neutrones (DAN):** DAN es una fuente pulsante de neutrones la cual será utilizada para medir la concentración de hidrógeno o agua bajo la superficie cercana. Este instrumento es proporcionado por la Agencia Espacial Federal Rusa.
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Sensores medioambientales

- **Estación de monitoreo ambiental Rover (REMS):** Esta es una estación meteorológica que medirá la presión atmosférica, humedad, dirección y fuerza del viento, así como temperatura ambiental y niveles de radiación ultravioleta. El desarrollo del equipo ha sido liderado por el Centro de Astrobiología con el apoyo del Centro para el Desarrollo Tecnológico Industrial y el Ministerio de Educación y Ciencia, el Ministerio de Defensa a través del Instituto Nacional de Técnica Aeroespacial de España y con la colaboración de Finnish Metereological Institute (Vídeo oficial del aparato REMS)
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Instrumentación para el ingreso, descenso y amartizaje (MEDLI)

El objetivo del módulo MEDLI es medir la densidad de la atmósfera exterior, así como la temperatura y función del escudo térmico de la sonda durante su ingreso a la atmósfera marciana. Los datos obtenidos serán utilizados para entender y describir mejor la atmósfera marciana y ajustar los márgenes de diseño y procedimientos de entrada requeridos para las sondas futuras.

Chemistry & Camera (ChemCam)

PI: Roger C. Wiens, Los Alamos National Laboratory
Deputy PI: Sylvestre Maurice, CESR, France

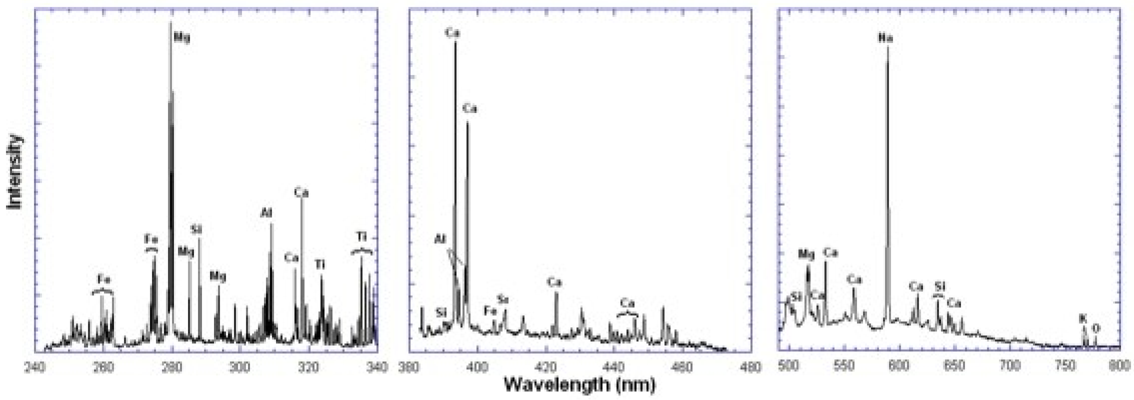
The ChemCam instrument package consists of two remote sensing instruments: the first planetary science Laser-Induced Breakdown Spectrometer (LIBS) and a Remote Micro-Imager (RMI). The LIBS provides elemental compositions, while the RMI places the LIBS analyses in their geomorphologic context. Both instruments will help determine which rock and soil targets within the vicinity of the rover are of sufficient interest to use the contact and analytical laboratory instruments for further characterization. ChemCam also can analyze a much larger number of samples than can be studied with the contact and analytical laboratory instruments. For example, the ChemCam team anticipates making daily analyses of the soil at the rover location to understand variations within the soils both locally and regionally. Furthermore, it can provide valuable analyses of samples that are inaccessible to other instruments, such as vertical outcrops where LIBS can target individual strata using its submillimeter beam diameter. ChemCam has the capability, but is not required, to provide passive spectroscopy data of rocks and soils on Mars. The spectral range covered by LIBS is not typical of passive spectroscopy instruments, making it more difficult to know what information can be useful from the spectra. However, the passive spectroscopy does not have the distance limitation that LIBS does. Additional information about ChemCam can be found in the publications listed in the “Publications” link on the web site http://libs.lanl.gov.

LIBS Instrument

The LIBS instrument uses powerful laser pulses, focused on a small spot on target rock and soil samples within 7 m of the rover, to ablate atoms and ions in electronically excited states from which they decay, producing light-emitting plasma. The power density needed for LIBS is > 10 MW/mm^2, which is produced on a spot in the range of 0.3 to 0.6 mm diameter using focused, ~14 mJ laser pulses of 5 nanoseconds duration. The plasma light is collected by a 110 mm diameter telescope and focused onto the end of a fiber optic cable. The fiber carries the light to three dispersive spectrometers which record the spectra over a range of 240 - 850 nm at resolutions from 0.09 to 0.30 nm in 6144 channels. The spectra consist of emission lines of elements present in the samples. Typical rock and soil analyses yield detectable quantities of Na, Mg, Al, Si, Ca, K, Ti, Mn, Fe, H, C, O, Li, Sr, and Ba. Other elements often seen in soils and rocks on Earth include S, N, P, Be, Ni, Zr, Zn, Cu, Rb, and Cs. It is anticipated that 50-75 laser pulses will be required achieve the desired 10% accuracy for major elements at 7 m distance.

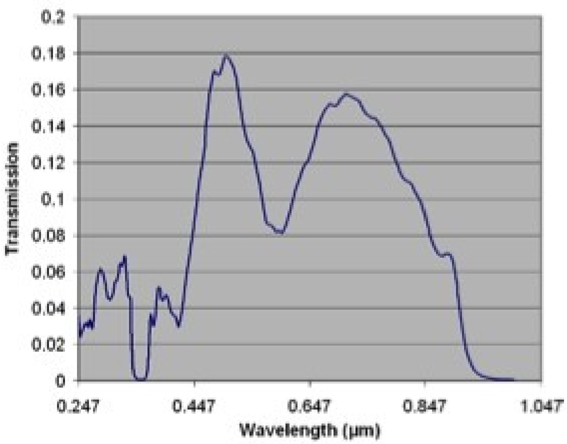
The advantages of the LIBS instrument are:

- Remote elemental analysis with no sample preparation
- Ability to remove dust and weathering layers with repeated laser pulses trained on the same spot
- Simultaneous analysis of many elements
- Low detection limits for a number of minor and trace elements, including Li, Sr, and Ba
- Rapid analysis; one laser shot can constitute an analysis, though many spectra are often averaged for better statistics, still only taking a few seconds
- Small analysis spot size of < 0.6 mm diameter
- Ability to identify water and/or hydrated minerals
- Low power consumption resulting from very short analysis times



LIBS spectrum of basalt standard GBW07105 taken with ChemCam engineering model at 5 m distance in 7 Torr (9.3 mbar) of atmosphere. The major emission lines are labeled.

RMI Instrument



The Remote Micro-Imager (RMI) is intended as a context imager for the LIBS, though unlike LIBS, it has no restrictions on the distance to the targets it images. It images through the same telescope as the LIBS, with the camera wavelength response shown in the figure at right. The detector is a 1024 x 1024 pixel CCD. The RMI has a field of view of 19 milliradians. Due to optimization of the telescope for LIBS, the RMI resolution is not pixel-limited, and is approximately 100 microradians. The RMI can clearly distinguish the submillimeter LIBS spot on a metal plate at any distance within range of the LIBS. LIBS spots on rocks are more difficult to distinguish, but will be known from the pixel mapping, so the context of the LIBS spot can be determined.

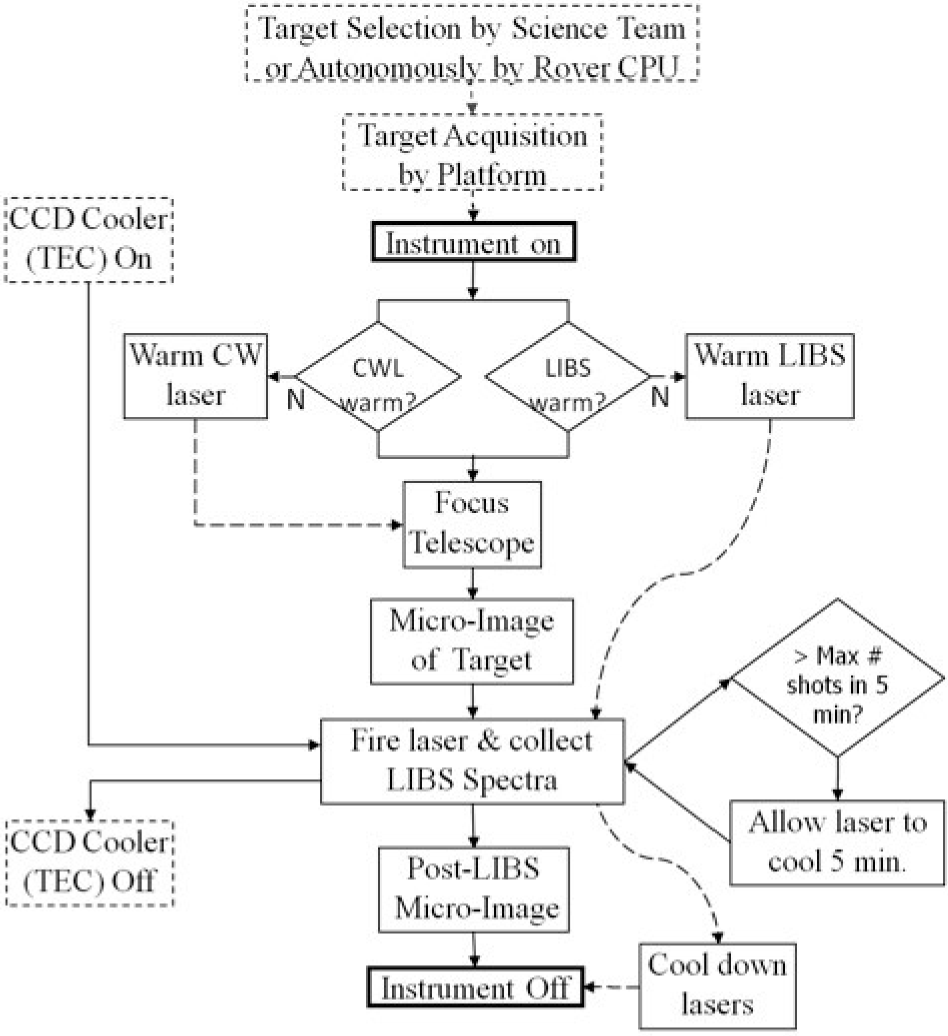
Types of Investigations

The ChemCam instrument suite will be used to pursue the following investigations:

1. Rapid remote rock identification, which will be the main method of rapidly determining whether a given sample is similar to or different from rocks already encountered during the mission, and if the latter, whether the sample warrants investigation by the analytical laboratory instruments.
2. Quantitative elemental analyses, including trace elements, to support the MSL science objectives. Whole-rock analyses will require a number of (< 1 mm diameter) analysis spots on the same rock. Quantitative analyses will rely on using both the onboard calibration standards as well as comparison with LIBS analyses of standards in terrestrial laboratories.
3. Soil and pebble composition surveys. The ChemCam team plans to make a measurement of the soil near the rover each sol to document the range of soil compositions over which the rover traverses. These measurements may signal the presence of a new geological region, and will tell about the compositional similarity of the dust from place to place on Mars. The RMI can provide documentation on soil grain sizes without the need for placement of the contact instruments.
4. Detection of hydrated minerals. LIBS sensitivity for hydrogen is unique and will be an important indicator of bound water in minerals.
5. Depth profiles of rock weathering layers. LIBS can provide weathering profiles on a fine scale for small features, a unique capability.
6. Rapid remote identification of surface ices/frosts. LIBS can unambiguously detect water ice.
7. Geomorphology and imaging science. The high resolution imaging provided by RMI will enable detailed studies of the weathering processes of surfaces, and provide opportunities to image closeup many details with comparable or slightly higher resolution than Mastcam and without the need to drive up to a sample and deploy contact instruments.
8. Complement other techniques for rock identification in cases of dust or weathering. ChemCam can use its laser to remove dust or weathering surfaces to aid other instruments in their investigations.
9. Assist with Sample Acquisition, Processing, and Handling (SA/SPaH). ChemCam analyses can guide decisions on which samples within the robotic arm workspace should be sampled for in situ instrument analyses. ChemCam can provide imaging and compositional analyses on the samples being obtained for the in situ instruments. The small analysis spot size will be important in this regard. For example, without ChemCam the connection between a given XRD pattern taken by the analytical instruments and a distinctive mineral grain seen in the images might only be inferred at best.

Analysis Sequences

A measurement with ChemCam can take many forms due to its versatility. However, for illustrative purposes, the figure at right shows a potential analysis sequence that acquires RMI images before and after the LIBS analysis. This type of sequence would be most often used for rapid rock identification. Each analysis of this type should take six minutes or less, excluding thermal delays. A thermoelectric cooler (TEC) is turned on to cool the detectors some minutes prior to instrument turn-on. The target is acquired by motion of the rover mast elevation and azimuth gimbals. The instrument is turned on, and the LIBS laser and the autofocus laser (continuous-wave, or CW laser) are warmed if needed. The telescope is focused on the target. RMI image acquisition and LIBS analyses are performed, and a background (laser-off) spectrum is taken. The mast can then acquire other targets and the focus and shoot sequence can be repeated. Other types of analyses will include:

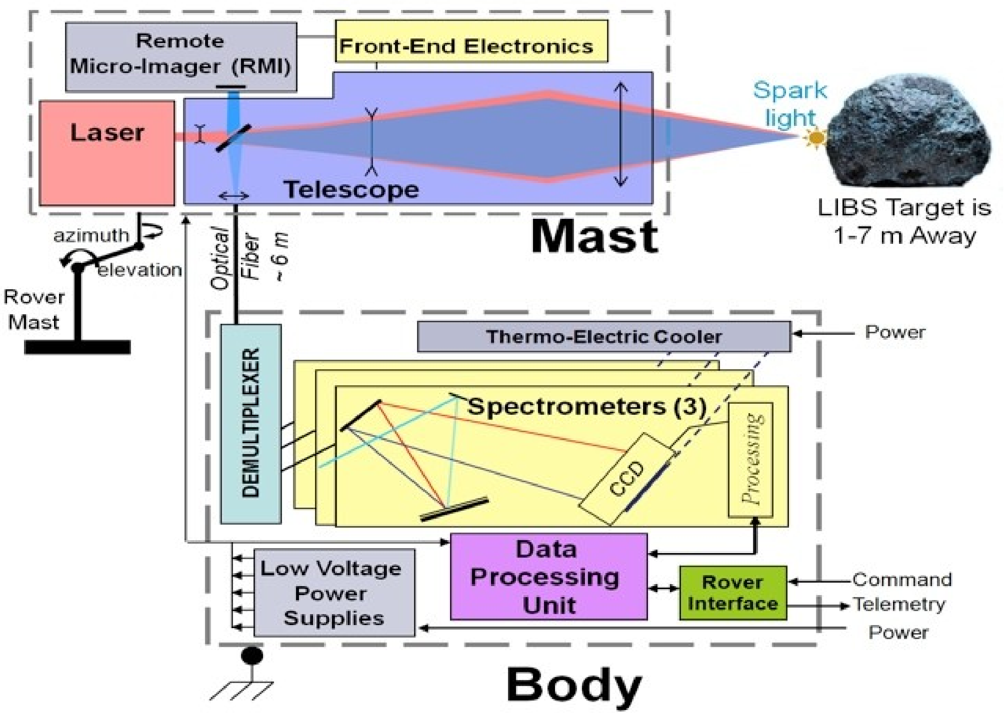


- Depth profiles > 0.5 mm, requiring > 500 laser shots on the same spot.
- Soil surveys, probably utilizing much the same analysis sequence as shown.
- Quantitative analyses, which will require a number of analysis spots on a single rock. Quantitative analyses would be carried out in conjunction with:
- Calibration targets. These are mounted on the rover and are used to calibrate the LIBS spectra.
- Miscellaneous images independent of any LIBS analyses. These will be used to characterize samples for the analytical laboratory, for general geomorphology studies, and to provide the highest resolution images of distant features.
- Passive UV-visible spectra. The LIBS spectrometers provide the opportunity for passive spectra taken using ambient sunlight and without the laser plasma.

Instrument Description

The figure and photos below show a functional block diagram of the ChemCam suite. The package consists of two separate units: “Body Unit” and “Mast Unit,” which are further broken down into modular components. The spectrometers and data processor are in the Body Unit, while the laser, imager, telescope, and focus laser are in the Mast Unit. The ChemCam Mast Unit is mounted on the rover mast just above Mastcam and Navcam. The boresight, at a height of 2.1 m above the ground, is coaligned with both Mastcam and Navcam. The Mast Unit is provided by CESR (funding from CNES), while LANL is responsible for the Body Unit. JPL is responsible for the fiber optic cable that transmits light from the telescope to the spectrometers. JPL also provided the thermoelectric cooler that cools the spectrometer

CCDs. Parts and targets for the onboard calibration target were provided by C. Fabré (Nancy), V. Sautter (MNHN, Paris), D. Vaniman (LANL), and D. Dyar (Mount Holyoke College). The onboard rover calibration targets for LIBS consist of natural and synthetic volcanic glasses (Fabré et al., 2009, 2010) and ceramics consisting of mixtures of smectite and kaolinite with anhydrite and basalt to simulate Martian sedimentary samples (Vaniman et al., 2009). Also included is a graphite disk for carbon identification and a titanium plate for general use.



Calibrations, Data, and Operations

Calibration of the LIBS data involves preflight calibrations, postlanding calibrations using the onboard targets, and comparisons with spectra obtained on Mars analogs in terrestrial laboratories. Preflight calibration targets consist of approximately seventy standards, two-thirds of which are igneous standards covering a somewhat larger range of SiO2 abundances than basalts and andesites. The preflight standards also include a range of “dirty” sulfates, and a number of sedimentary materials. “Dirty” standards that are mixtures of materials are preferred over pure minerals, as pure mineral compositions can be easily determined by the occurrence of only the elements present in the given mineral. Postlanding calibrations will be done with the onboard standards described above, and by comparison with both the preflight calibrations and with Mars analog samples analyzed in terrestrial LIBS laboratories. Comparisons between ChemCam LIBS spectra and LIBS spectra from terrestrial laboratories need to be studied, as does the effect of distance on calibrations. For example, different emission lines respond to distance differently likely based on their activation energies. We are actively studying these effects, and we expect to continue these studies into the mission phase.

Operation of the instrument is expected to be shared 50/50 between the U.S. and France. After transition to remote operations, the team will operate on a 38 day cycle during which the Mars time shifts relative to Earth time. The French team will be responsible for instrument operation during the half of the cycle in which downlinks are too late in the day in the US, while the U.S. team members will operate the instrument during times when downlinks are too late in the day in France. Staffing of science theme groups will be done by both countries regardless of who has instrument operation responsibilities at any given time, so that scientists from both countries are involved in decisions at all times.

ChemCam science team members are expected to help staff the Science Operations Working Group and ChemCam Payload Downlink Lead positions, especially given the expected frequent operation of the instrument. RMI data reduction will use JPL imaging tools. LIBS data reduction will consist of preprocessing such as background subtraction, wavelength calibration, and distance corrections. Data processing will use multivariate analysis techniques, relying heavily on comparison with spectra of high-fidelity Mars analogs analyzed in terrestrial laboratories. We envision using principal components analyses (PCA) and related techniques to classify and compare samples, while we expect to use partial least squares (PLS) to calibrate and quantitatively determine elemental compositions (e.g., Clegg et al., 2009). Payload Downlink Leads will be expected to carry out preprocessing and sample classification in order to present results to the SOWG for tactical use.

http://msl-scicorner.jpl.nasa.gov/Instruments/ChemCam/

APXS

The Alpha Particle X-Ray Spectrometer will measure the abundance of chemical elements in rocks and soils. Funded by the Canadian Space Agency, the APXS will be placed in contact with rock and soil samples on Mars and will expose the material to alpha particles and X-rays emitted during the radioactive decay of the element curium. X-rays are a type of electromagnetic radiation, like light and microwaves.

Alpha particles are helium nuclei, consisting of 2 protons and 2 neutrons. When X-rays and alpha particles interact with atoms in the surface material, they knock electrons out of their orbits, producing an energy release by emitting X-rays that can be measured with detectors. The X-ray energies enable scientists to identify all important rock-forming elements, from sodium to heavier elements.

The APXS will take measurements both day and night. Its sensor head is designed to be smaller than a soda can and will contain a highly sensitive X-ray detector in the middle of an array of curium sources. The longer the instrument is held in place on the surface of a rock or soil sample, the more clearly the signal from the sample can be determined. Most APXS measurements will take two to three hours to reveal all elements, including small amounts of trace elements. Ten minutes of operation will be sufficient for a quick look at major elements.

As a contact instrument, the APXS is designed to work in concert with other payload elements on the instrument arm and in the body of the Mars Science Laboratory rover, such as the CheMin instrument and the Dust Removal Tool (brush). Scientists will use the APXS to help characterize and select rock and soil samples and then examine the interiors of the rocks following brushing. By analyzing the elemental composition of rocks and soils, scientists will seek to understand how the material formed and if it was later altered by wind, water, or ice. The APXS on NASA's two Mars Exploration Rovers has already provided evidence that water once played a major role in Mars' geologic past.

Two earlier missions to Mars carried previous versions of the Alpha Particle X-Ray Spectrometer. The first was the Alpha Proton X-Ray Spectrometer, launched to Mars on the Pathfinder mission in late 1996. The second was the APXS, on board both the Mars Exploration Rovers that arrived on the red planet in January, 2004.

In addition to the Canadian Space Agency and NASA, major organizations involved in developing the APXS include the University of Guelph; MDA Space Missions; the University of California, San Diego; and Cornell University.

http://mars.jpl.nasa.gov/msl/mission/instruments/spectrometers/apxs/

CheMin

The Chemistry and Mineralogy instrument, or CheMin for short, will identify and measure the abundances of various minerals on Mars. Examples of minerals found on Mars so far are olivine, pyroxenes, hematite, goethite, and magnetite.

Minerals are indicative of environmental conditions that existed when they formed. For example, olivine and pyroxene, two primary minerals in basalt, form when lava solidifies. Jarosite, found in sedimentary rocks by NASA's Opportunity rover on Mars, precipitates out of water.

Using CheMin, scientists will be able to study further the role that water, an essential ingredient for life as we know it, played in forming minerals on Mars. For example, gypsum is a mineral that contains calcium, sulfur, and water. Anhydrite is a calcium and sulfur mineral with no water in its crystal structure. CheMin will be able to distinguish the two. Different minerals are linked to certain kinds of environments. Scientists will use CheMin to search for mineral clues indicative of a past Martian environment that might have supported life.

To prepare rock samples for analysis, the rover will be able to drill into rocks, collect the resulting fine powder, sieve it, and deliver it to a sample holder. It will use a scoop for collecting soil.

CheMin will then direct a beam of X-rays as fine as a human hair through the powdered material. X-rays, like visible light, are a form of electromagnetic radiation. They have a much shorter wavelength that cannot be seen with the naked eye. When the X-ray beam interacts with the rock or soil sample, some of the X-rays will be absorbed by atoms in the sample and re-emitted or fluoresced at energies that are characteristic of the particular atoms present.

In X-ray diffraction, some X-rays bounce away at the same angle from the internal crystal structure in the sample. When this happens, they mutually reinforce each other and produce a distinctive signal. Scientists can measure the angle at which X-rays are diffracted toward the detector and use that to identify minerals. For example, if the mineral halite (common table salt, or NaCl), were placed in CheMin, the instrument would produce a specific diffraction pattern that would identify the structure of halite.

Because all minerals diffract X-rays in a chacteristic pattern and all elements emit X-rays with a unique set of energy levels, scientists will use the information from X-ray diffraction to identify the crystalline structure of materials the rover encounters on Mars. A Charge-Coupled Device (CCD) will collect both diffraction and fluorescence information.

http://mars.jpl.nasa.gov/msl/mission/instruments/spectrometers/chemin/

SAM

The Sample Analysis at Mars instrument suite takes up more than half the science payload on board the Mars Science Laboratory rover and features chemical equipment found in many scientific laboratories on Earth. Provided by NASA's Goddard Space Flight Center, Sample Analysis at Mars will search for compounds of the element carbon, including methane, that are associated with life and explore ways in which they are generated and destroyed in the martian ecosphere.

Actually a suite of three instruments, including a mass spectrometer, gas chromatograph, and tunable laser spectrometer, Sample Analysis at Mars will also look for and measure the abundances of other light elements, such as hydrogen, oxygen, and nitrogen, associated with life.

The mass spectrometer will separate elements and compounds by mass for identification and measurement. The gas chromatograph will heat soil and rock samples until they vaporize, and will then separate the resulting gases into various components for analysis. The laser spectrometer will measure the abundance of various isotopes of carbon, hydrogen, and oxygen in atmospheric gases such as methane, water vapor, and carbon dioxide. These measurements will be accurate to within 10 parts per thousand.

Because these compounds are essential to life as we know it, their relative abundances will be an essential piece of information for evaluating whether Mars could have supported life in the past or present.