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Mars Miniature Science Instruments

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Abstract— For robotic Mars missions, all the science information is gathered through on-board miniature instruments that have been developed through many years of R&D. Compared to laboratory counterparts, the rover instruments require miniaturization, such as low mass (1-2 kg), low power (> 10 W) and compact (1-2 liter), yet with comparable sensitivity. Since early 1990's, NASA recognized the need for the miniature instruments and launched several instrument R&D programs, e.g., PIDDP (Planetary Instrument Definition and Development). However, until 1998, most of the instrument R&D programs supported only up to a breadboard level (TRL 3, 4) and there is a need to carry such instruments to flight qualifiable status (TRL 5, 6) to respond to flight AOs (Announcement of Opportunity). Most of flight AOs have only limited time and financial resources, and can not afford such instrument development processes. To bridge the gap between instrument R&D programs and the flight instrument needs, NASA's Mars Technology Program (MTP) created advanced instrumentation program, Mars Instrument Development Project (MIDP). MIDP candidate instruments are selected through NASA Research Announcement (NRA) process [1]. For example, MIDP I (1998-2000) selected and developed 10 instruments, MIDP II (2003-2005) 16 instruments, and MIDP III (2004-2006) 11 instruments. Working with PIs, JPL has been managing the MIDP tasks since September 1998. All the instruments being developed under MIDP have been selected through a highly competitive NRA process, and employ state-of-the-art technology. So far, four MIDP funded instruments have been selected by two Mars missions (these instruments have further been discussed in this paper).

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1. Introduction

NASA's robotic Mars missions require many new instruments for in-situ and remote sensing as prioritized by the Mars Exploration Program Analysis Group (MEPAG, [2]). AOs (announcements of Opportunities) provide limited time and funding of new instruments to developed and inserted to flight projects. NASA's well established Planetary Instrument Definition and Development Program (PIDDP) supports development of new instruments only up to a breadboard level demonstration and there is a crucial gap between this R&D phase and flight hardware construction. Such a gap in development increases mission risk. In order to bridge the gap, MIDP (Mars Instrument Development Project) was initiated in 1998 to support further development of promising instruments from the breadboard or laboratory-demonstration phase (Technology Readiness Level, TRL 3, 4) to a point where they can be tested in systems-level simulated rover operations or under similar realistic (e.g., environmental) conditions (TRL 5, 6) [1]. This means that instruments proposed for funding by MIDP should be at a moderately advanced ("breadboard") stage of development, e.g., previously or currently developed under PIDDP, Sensor and Instruments Technology Development Program, Small Business Innovative Research (SBIR), or other research and development support.

To be compatible with Mars missions, MIDP requires miniaturization of instruments and their supporting electronics to be low-volume (typically less than 1000 cm^3), low-mass (on the order of <1 kg), and low-power (on the order of 5 W or less). So far, the main emphasis of MIDP has been for in-situ investigations, i.e., limited to instruments/systems that would be deployed on the surface or subsurface of Mars. Orbital instruments may be the subject of a future MIDP solicitation.

2. Science Focus of MIDP Instruments

MIDP instruments are selected with relevance to upcoming Mars missions, instruments that address the science

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2. SCIENCE FOCUS OF MIDP INSTRUMENTS

MIDP instruments are selected with relevance to upcoming Mars missions, instruments that address the science objectives of particular missions. Thus, it is emphasized that any instrument developed under MIDP must be justified by the type(s) of science investigations that could be carried out should the instrument be eventually selected for flight.

For example, MIDP I (NRA 97-OSS-16) was aimed for development of instruments for Mars '03 and '05 mission objectives. Target issues include, characterizing the Martian surface from a lander or rover, conducting detailed studies of specific samples, or mechanically acquiring (grabbing, coring, chipping) samples for analysis and/or caching. The following are the instrument list stated in the NRA [1]:

(a) High-resolution imaging from a lander or rover, which may include stereo imaging systems, multispectral cameras, imaging spectrometers, or "hand-lens" microscopes.

(b) Surface soil and rock bulk composition and mineralogy, which include, but are not limited to, point spectrometers, Alpha-Proton X-ray Spectrometer or X-ray diffraction instruments, thermal evolved gas sensors, mass spectrometers, Raman spectrometers, and Mossbauer spectrometers.

(c) Subsurface ice and water characterization, the techniques for which may include microwave probes, magnetic resonance sensors, resistivity experiments, or other geophysical methods.

(d) Exobiology assessment of surface materials, which include, but are not limited to, gas chromatography experiments, mass spectrometers, amino acid detectors, and Raman spectrometers.

(e) Surface radiometric age dating.

(f) Sample preparation and retrieval, which includes devices to be mounted at the end of a rover-mounted or lander-mounted manipulator that drill, core, or chip a rock sample to expose interior layers for study or caching.

(g) Proposals that seek to combine existing instruments into architectures that lead to an overall reduction in size, mass, or power may also be considered for funding.

For MIDP II (NRA-02-OSS-01-MIDP) and III (NRA-03-OSS-01-MIDP) [1], requirements were for the development of instruments that addressed the science objectives of the Mars Science Laboratory (MSL, 2009) and/or Mars Scout missions. The science objectives , as stated in the NRAs, were:

(1) To improve our understanding of the Mars climate through analysis of in situ materials;

(2) To increase our understanding of the availability and amount of water on Mars;

(3) To identify areas and materials of possible interest for future scientific exploration (both *in situ* and via sample return);

(4) To determine the nature of surface geological processes from surface morphology and chemistry, including the characteristics of sub-micrometer scale features;

(5) To determine the spatial distribution and composition of minerals, rocks, soils, and ices on and within the accessible Martian surface;

(6) To investigate properties of the Martian near subsurface; and

(7) To improve our knowledge of the deep Martian interior.

To achieve the science objectives, in addition to the list described under (a), (b), (c) and (d) of MIDP I NRA, the following list of measurements and ***in-situ instruments*** were given as a guide:

(e) Environmental measurements, including atmospheric temperature, pressure, density, and humidity; wind velocity; and surface temperature; dust loading; solar and thermal fluxes;

(f) Weather phenomena monitoring including long-duration water vapor flux and atmospheric isotopic distribution;

(g) Subsurface sounding, which may include low and high frequency ground penetrating radar and/or electromagnetic sounding;

(h) High-resolution microscopy from a lander or rover, especially in the submicron range, including instrument systems that incorporate autonomous detection of biostructures in rock, and rock abrasion devices (up to 10 cm deep);

(i) Heat flow calibration below the annual seasonal wave, and seismic activity monitoring;

(j) Organic molecule detection, oxidation boundary determination, and mineralogical assessment from an in situ drilling platform (particularly encouraged); and

(k) Remote elemental analysis methods such as Laser Induced Breakdown Spectroscopy (LIBS), or other approaches that do not require contact to sense the materials in question.

The ability to acquire and deliver surface and subsurface samples to scientific instruments on the primary payload is of particular importance for missions in the 2007 to 2011 time frame (MSL, Mars Scouts, and MSR) and devices that provide for ***sample acquisition and handling mechanisms*** or instrument suites that can perform one or more of the following tasks were also considered:

(l) Acquire a 1 cm^3 sample of surface soil or rock from a lander or rover platform;

(m) Acquire a 1 cm^3 sample of subsurface material from a borehole with maximum depth of 15 m and a maximum diameter of 7 cm (may be designed as part of a drilling package);

(n) Deploy instruments or instrument sensing heads within a borehole (as defined in the second objective above) to permit measurement-while-drilling or measurement-after-drilling data collection;

(o) Deliver a 1 cm^3 sample of soil or rock from the sample acquisition mechanism (drill, sampling arm, core drill, etc.) to a series of instruments on board the lander or rover platform for analysis;

(p) Create a smooth measurement surface for XRD and other analysis techniques; and/or

(q) Volatilize a sample for mass spectrometry and other analysis techniques.

3. MIDP Instrument Selection Criteria

MIDP proposals are evaluated on the basis of their (1) Intrinsic science and technical merit, (2) Relevance to NASA objectives, (3) Realistic and reasonable cost, and (4) Educational/Public Outreach component. Intrinsic merit is weighted more heavily than relevance and cost, which have approximately equal weight. Evaluation of Criteria (4) may be used as an additional factor in selecting among otherwise equal proposals [1].

4. Selected MIDP Instruments

Selected MIDP instruments since the start of the program are summarized in Table 1 by PI institutions, and Table 2,

Table 1. MIDP Participation by PI institution.

	MIDP I 1998-2001	MIDP II 2003-2005	MIDP III 2004-2006
University	3	4	3
Industry	2	3	2
Government	2	1	1
NASA Centers	3	8	5
Total	10	16	11
Total Funding	$7M	$17M	$10M

Table 2. MIDP Instruments by science category

Instrument Science Category	MIDP I 1998-2001	MIDP II 2003-2005	MIDP III 2004-2006
Characterization of Martian Atmosphere	0	3	2
Elemental Anaysis	1	0	2
Characterization of Martian Surface Materials	2	2	0
Imaging Spectrometer	1	1	0
Age Dating Surface Materials	0	1	0
Mineralogy	2	3	1
Water Detection	0	2	1
Imager/Camera	2	0	0
Rock Surface Preparation	1		
Subsurface Geology	0	2	1
Subsurface Access with Integrated Instrument	1	1	4
Integrated Instrument Package	0	1	0
Total Instruments	10	16	11

by instrument science categories. As shown in Table 2, the selected instruments pretty much follow the science objectives of the NRAs. By the science categories, a brief description of individual instruments are listed. For the characterization of Martian atmosphere, MIDP instruments include:

(1) Particle Charge Spectrometer (PI, Stephen Fuerstenau, JPL) measures electrostatic charge and size of individual airborne dust grains (up to 200 particles per second) in the Martian atmosphere.

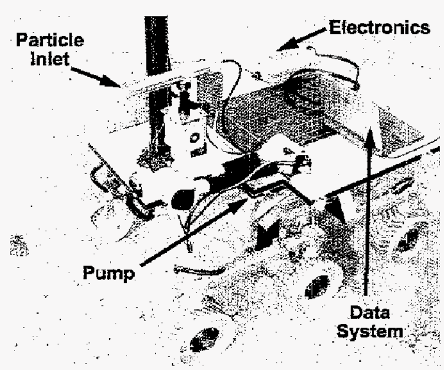

Figure 1 - Field testing of PCS instrument integrated with Rocky 8 rover. PCS prototype sampled wind driven particles at three arm elevations during a rover traverse and proved it is robust and compatible with a rover-based deployment

(2) Characterization of Mars Atmosphere (CMAD PI, Phillip Jenkins, OAI) measures dust settling rate, microscopic imagery of dust and offers spectroscopy of both atmospheric and settled dust in the visible/near-IR range [3]. The instrument shown in Figure 2 is developed from the microscope and spectrometers of flight DART (Dust Accumulation and Removal Test) and MATE (Mars Array Technology Experiment). MATE characterizes the solar energy reaching the surface of Mars, and measures the performance and degradation of solar cells under Martian conditions. DART characterizes the dust environment of Mars, measures the effect of settled dust on solar arrays and investigates methods to mitigate power loss due to dust accumulation.

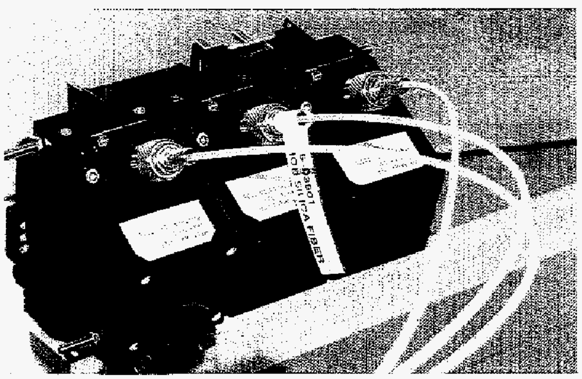

Figure 2 - Miniature Visible/Near IR/Shortwave IR spectrometer of CMAD

(3) Tunable Laser Spectrometer (TLS, PI, Christopher Webster, JPL) for detection and measurement of atmospheric gases in the atmosphere and evolved from soil samples [4,5]. The TLS spectrometer, shown in Figure 3 is recently selected as part of the SAM instrument suite on the 2009 Mars Science Laboratory (MSL) Mission, is a multi-channel instrument that measures water and its isotopes (D/H, $^{18}O/^{17}O/^{16}O$), methane and its isotopes ($^{13}C/^{12}C$), carbon dioxide and its isotopes ($^{13}C/^{12}C$, $^{18}O/^{17}O/^{16}O$), hydrogen peroxide and nitrous oxide. TLS can provide high sensitivity, fast response, and direct, non-invasive measurements of several key species that cannot be measured using conventional Gas Chromatograph/ Mass Spectrometry.

(4) Modular Autonomous Meteorology Station (MarMet, PI, Mark Richardson, Caltech) is to reduce the total resource footprint (compact, modular and low power) of an existing meteorological station design, such as Meteorology station (MET) of the Mars Polar Lander. The MarMet will be capable of performing semi-autonomous and adaptable observations so that it may be accommodated with reduced risk and cost with increased science return for future Mars Exploration Program.

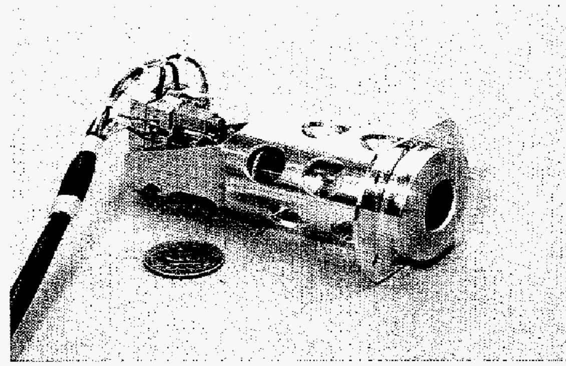

Figure 3 - Optical head of a single laser-detector multi pass cell. The tunable diode laser and detector are both mounted on a single thermoelectric cooler [4].

(5) Mars Atmosphere Temperature and Humidity Sounder (MATHS, PI, Michael Janssen, JPL) shown in Figure 4 is a submillimeter wave (557 GHz) upward-looking radiometer prototype that simultaneously measure temperature and humidity profiles through the Mars boundary layer on time intervals to capture significant weather variations, and obtain self calibrated data under Martian conditions.

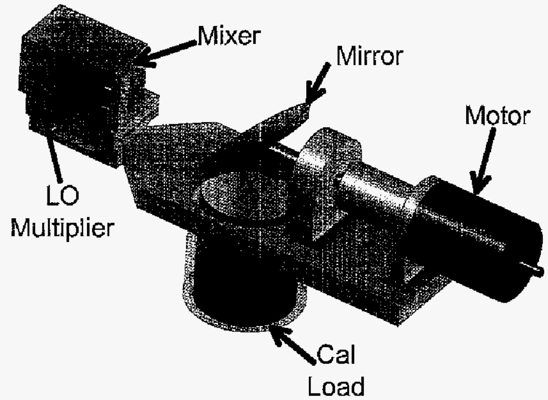

Figure 4 - The Mars Atmosphere Temperature and Humidity Sounder (MATHS) Instrument. A rotating 3-cm mirror shapes and directs the beam from the sky or the calibration load located under the mirror) into the feed horn of the 557 GHz heterodyne receiver front end.

MIDP instruments for the elemental Analysis include:

(6) Laser Induced Breakdown Spectrometer (MIDP I, PI David Cremers and MIDP III, PI Roger Wiens, LANL) is for qualitative as well as quantitative elemental analysis of geological samples, ices and ice dust mixtures at a stand off distances of up to 19 meters [6]. It utilizes a state-of-the-art echelle spectrograph integrated with a state-of-the-art CCD detector as well as specially designed compact cassegrain telescope system for focusing laser pulses on target and collection of plasma light from the samples.

(7) Atmospheric Electron X-Ray Spectrometer for Elemental Analysis (AEXS, PI, Jaroslava Wilcox, JPL) is a miniature X-ray fluorescence (XRF) instrument with short (minuite) spectrum acquisition times and variable spatial resolution (from several cm to sub mm-size) [7]. The key feature of AEXS is the ability to excite XRF from samples in the ambient atmosphere using a high intensity focused electron beam source as shown in Figure 5. This eliminates the need for an evacuated chamber for sample testing.

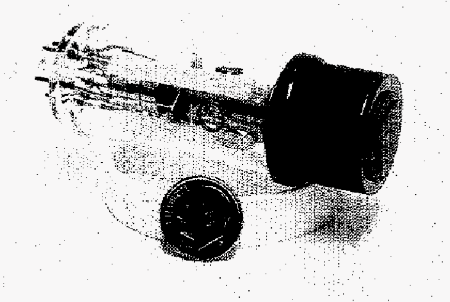

Figure 5 - Vacuum isolated electron source using a thin electron transmissive membrane

Characterization of Martian Surface Chemistry instruments include:

(8) Mars Organic Detector (PI, Jeffrey Bada, UCSD) is for the detection of amino acids, amines and polyaromatic hydrocarbons in Martian surface samples with 100 times the sensitivity of Viking. It also combines a Tunable Diode Laser spectrometers for detection of water and carbonate mineral contents of surface samples.

(9) Mars Oxidant Instrument (MOI, PI, Aaron Zent, NASA/ARC) is for characterization / identification of Martian oxidants and oxidation mechanisms by monitoring the change of resistivity of well characterized arrays of films when in contact with Martian soil samples [8]. This is a variation of MOx (Mars 96).

(10) Mars Oxidant and Radical Detector (MORD, PI, Albert Yen, JPL)xx is based on a miniature electron paramagnetic resonance (EPR) spectrometer for detection of Martian oxidants (superoxide radical anions, $O2^-$) and other radical species in soil, rock samples [9].

(11) Electrospray Ionization/Ion Mobility Spectrometer (PI, Isik Kanik, JPL) for detection of organic molecules including organic acids, amino acids, amines, nitriles and aldehydes [10]. It detects organics by dissolution of samples in water, and the extracted solution is sprayed into the spectrometer. Unlike conventional mass spectrometers, this instrument will be able to perform under ambient Martian atmosphere without need for vacuum pumps.

Imaging Spectrometers include:

(12) Acousto-Optic Imaging Spectrometer (AImS, PI, David Glenar, NASA/GSFC) shown in Figure 6 is a two-channel, tunable imaging spectrometer designed for mineralogical and geological mapping of surface soils, rocks, ices and dusts, at visible and near-IR wavelengths [11]. Tuning is electronic (no moving parts), using RF-driven acousto-optic tunable filters (AOTF's) as the spectral tuning elements.

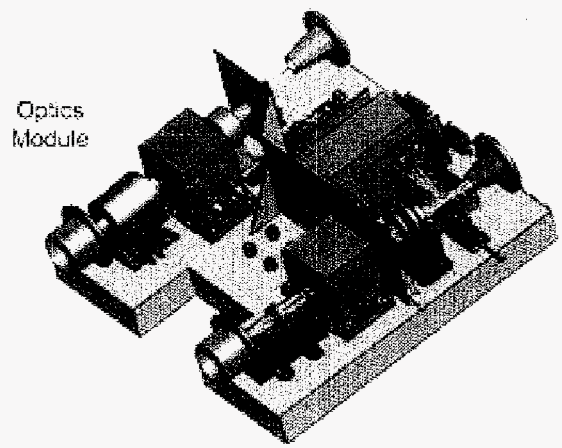

Figure 6 – Optics module of Acousto-Optic Imaging Spectrometer

(13) Mars Alteration Hyperspectral Imager (MAHI, PI, Paul Lucey, U of Hawaii, Honolulu) shown in Figure 7 is a mineral mapping spectrometer utilizing 1.8-2.5 micron wavelength region. This wavelength region is uniquely suited to unambiguous characterization of water-related minerals such as clays, sulfates and carbonates, and relatively insensitive to the presence of igneous rock-forming minerals.

Age-Dating surface Materials:

(14) Argon Geochronology Experiment (AGE, PI, Timothy Swindle, U of Arizona, Tucson) is an in-situ geochronology instrument based on potassium-argon (K-Ar) dating and cosmic ray exposure (CRE) ages using powdered rock samples. The instrument is composed of LIBS and noble gas mass-spectrometer.

Mineralogy instruments include:

(15) Three Raman spectrometers, Fiber Optic Raman Spectrometer (PI, Christian Schoen, Detection Limit),

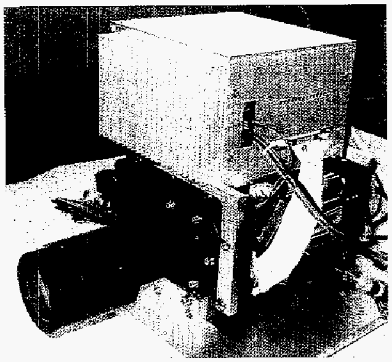

Figure 7 - Mars Alteration Hyperspectral Imager (MAHI) is a 1-2.5 micron imaging spectrometer using an Offner spectrograph and a 320x256 HgCdTe array housed in microdewar cooled with a 4 stage thermoelectric cooler to 195K

Raman Spectroscopy System for Mars Surface Studies (PI, Bruce McIntosh, Hamilton Sundstrand) for mineralogy of rock, soil samples and HYDRA, Mars Raman Instrumentation (PI, Arthur L. Lane, JPL) with emphasis on detection of water bearing minerals.

(16) Two XRD/XRF spectrometers; Mineral Idenfification & Composition Analyzer (MICA, PI, John Marshall, SETI) and CheMin (PI, David Blake, NASA/ARC) . Both instruments are for elemental analysis (XRF) and mineralogic structural data (XRD) of soil, rock samples. MICA obtains the data by scanning a probe over sample surfaces, whereas CheMin requires powder samples inside a sample chamber. CheMin is selected as one of the MSL payload instrument.

(17) Regolith Evolved Gas Analyzer (REGA, PI, John Hoffman, U of Texas, Dallas) is for characterization of Martian mineralogy by mass-spectroscopic analysis of gases and vapors released from programmed heating of soil samples; Obtain atmospheric composition by long term monitoring of Martian atmosphere. A version of REGA was selected as one of the instrument for Phoenix Scout Mission (2007).

Water detection instruments include:

(18) Two neutrion spectrometers: Miniature Hydrate Sensor (PI, Richard Elphic, LANL, shown in Figure 8) and Neutron Detector (PI, Jeffrey Moersch, U of Tennessee, Knoxville) for detection of protons up to 1 m depth.

(19) A Rugged Miniature Mass-Spectrometer (PI, Scott Anderson, U of Hawaii, Honolulu) for measuring aqueous geochemistry of Mars. It is based on Fig. XX Left, Sensor module of the Miniature Hydrate Sensor, Right, Assembled HYDRA neutron spectrometer (LANL).a rotating field mass-spectrometer derived from in-situ deep ocean applications.

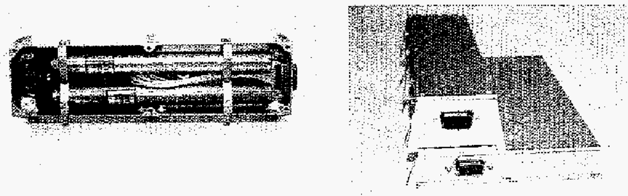

Figure 8 - Left, Sensor module of the Miniature Hydrate Sensor, Right, Assembled HYDRA neutron spectrometer (LANL)

Imager/Cameras include:

(20) Camera Hand Lens Microscope (CHAMP, PI, George Lawrence, U of Colorado, Boulder, Figure 9) is a simple, low mass imager based on Infiniprobe microscope (Infinity Photo-Optical Co., Boulder, CO) and RGB color camera. CHAMP can offer a continuous autofocus 9 mm to infinity, better than 10X hand lens at close ups, and extended depth of field to help identify minerals and mineral structures [12].

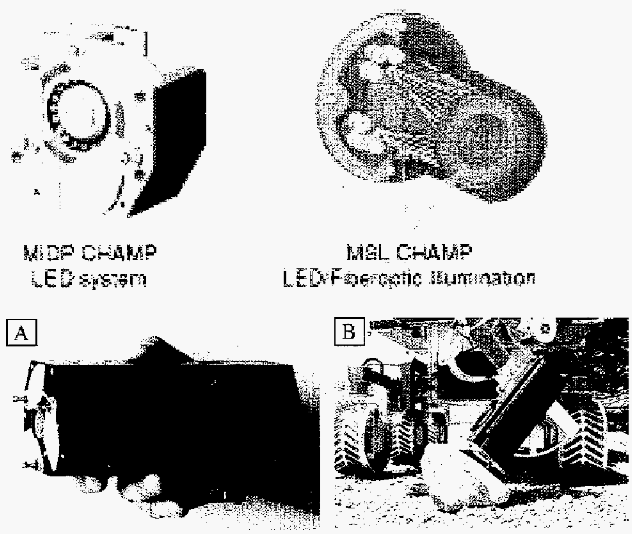

Figure 9 -Top, CHAMP Illumination system design, bottom, (A) the assembled CHAMP instrument, (B) deployed on NASA K9 rover for a field testing

(21) Panoramic Stereo Multicolor Camera (PANCAM, PI, Alan Delamere, Ball Aerospace) is for a high resolution (0.28 milli-radians/pixel), panoramic (365° by 75° field of view), stereo (two cameras at 23 cm separation) multi-spectral imaging (3 color channels/head) of Martian surface and sky.

Rock Surface Preparation includes:

(22) Abrasive Rock Polisher (PI, Stephen Fuersteanu, JPL) is a miniature sand blaster using compressed gas (e..g., propane) to accelerate powder particles (e.g, silicone

carbide) and expose fresh rock surfaces for spectroscopic examination on Mars.

Subsurface Geology instruments include:

(23) Two Ground penetrating radar instruments for Martian subsurface stratigraphy; Mars Ground Penetrating Radar (PI, Soon Sam Kim, JPL) is for deeper penetration (80 MHz center frequency, 10-50 m depth) at moderate resolution (0.5 m). Rover GPR for MSL (PI, John Grant, Smithsonian) [13, 14] is for shallower penetration (400/900 MHz center frequencies, 10-15 m depths) at higher resolution.

(24) Deployable instruments (PI, Gregory Delory, U of California, Berkeley, Figure 10) is composed of a subsurface electromagnetic (EM) sounder for detection of water and a standalone electro-meteorology station.

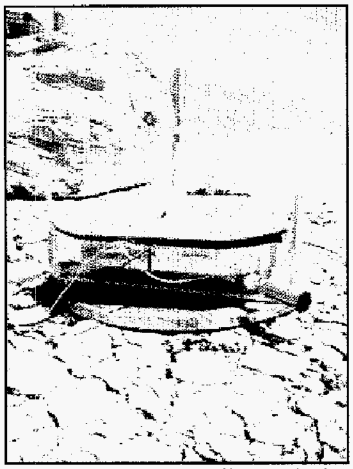

Figure 10 - Prototype EM sounding unit developed by QUASAR Inc. in cooperation with the UC Berkeley Space Sciences Laboratory

Subsurface Access/ Integrated Instruments include:

(25) Subsurface Sampling Tool (PI, Hans Hamacher, DLR) is a self-penetrating tool with internal hammer and designed to collect subsurface soil samples (0.5 cm^3) up to a depth of 1 m. This task was participation only, no NASA funding was involved.

(26) Mars Underground Mole (MUM, PI, Carol Stoker, NASA/ARC) utilizes a mole (ESA Beagle-2, modified version of the Subsurface Sampling Tool, DLR) connected to ground based infrared reflectance and Raman spectrometers through optical fibers for determining subsurface mineralogy, stratigraphy and detection of hydrate minerals.

(27) Drill Integrated Neutron Spectrometer (PI, Steven Gorevan, Honeybee Robotics) utilizes a compact neutron spectrometer (Co-I, Richard Elphic, LANL) configured inside a drill segment for detection of subsurface proton source, and Mars Borehole Spectrometer (PI, William Smythe, JPL) incorporated a small solid state IR spectrometer to monitor wall structure as well as subsurface H_2O and CO_2 contents during the drilling process.

(28) Drill Automation for Mars Exploration (DAME, PI, Brian Glass, NASA/ARC) is for the development of generic drill automation software system with diagnosis and control technology.

(29) Low-Force Sample Acquisition System (LSAS, PI, Scott Stanley, Alliance Spacesystems) is a hammer drill equipped with a sample acquisition system capable of retrieving a subsurface sample (1 cm^3) of soil, rock, or ice that can be used for analytical instruments.

Integrated Instrument Package:

(30) Sample Analysis at Mars (SAM, PI, Paul Mahaffy, NASA/GSFC) is an integrated instrument package with a quadrupole mass spectrometer, a gas chromatography, laser desorption mass spectrometer and tunable laser spectrometer. It is for characterization of organics, elemental and mineralogical analysis and isotopic analysis for atmospheric as well as solid samples.

5. Rover Integration Field Testing

As a test of compatibility, the MIDP instruments developed were field tested with available rovers such as JPL Rocky-7, Rocky-8 and NASA Ames K-9.

For example, Roger Wiens (LANL) and David Cremers (LANL) have developed a portable LIBS spectrometer (MIDP I, 3 kg, 5 W, 2000 cm^3), and field tested the prototype with K-9 rover in FY2000 at Ely, NV. (Figure 11). The instrument is to obtain elemental analysis at a stand-off distance of up to 6 m from geological samples (rocks and soils) in the open air. The rock samples used in the test and a LIBS spectrum is shown in Figure 12.

Abrasive Jet Polisher (MIDP I, PI, Stephen Fuerstenau, JPL) was field tested at JPL's Mars Yard integrated with Rock-7. Figure 13 shows the nozzle of the prototype on the rover arm, aimed at a rock surface and exposed a fresh surface of the rock (5 mm dia.).

6. Scout Phoenix MIDP Instrument

REGA developed under MIDP I was selected as one Peter Smith, U of Arizona, launch in August 2007).

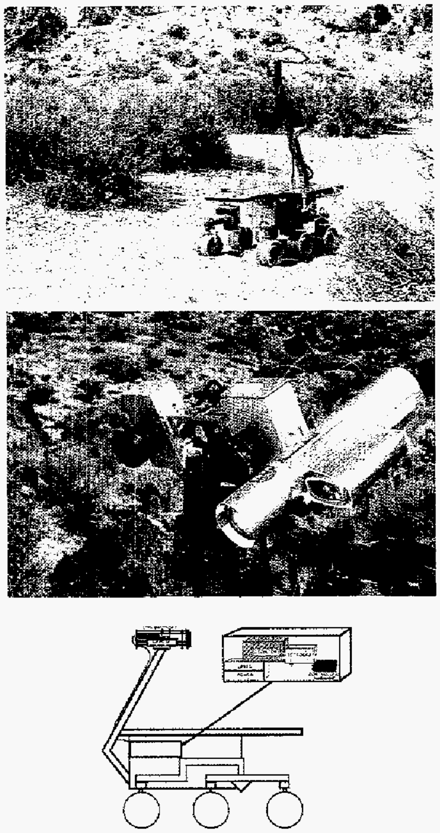

Figure 11 - Top, Field testing of LIBS mounted on the K-9 rover in Ely, Nevada site. Middle, Close up of LIBS on the K-9 mast. Bottom, Schematic for LIBS integration with the K-9 rover.

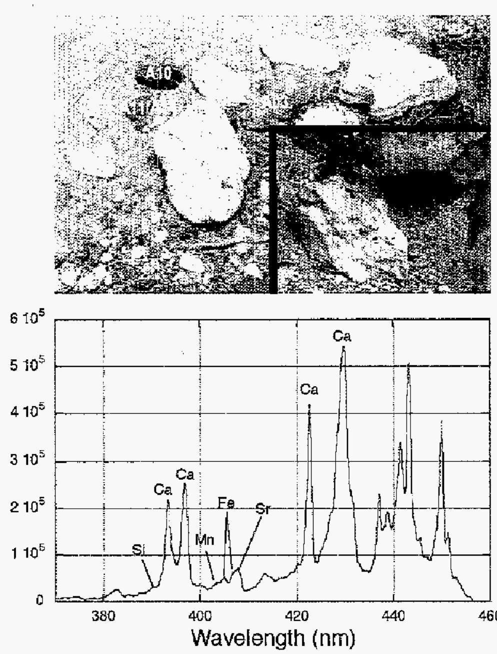

Figure 12 - Top, Rock samples measured in conjuction with the field test, Ely, NV. Bottom, A portion of the spectrum of basalt rock recorded by the LIBS.

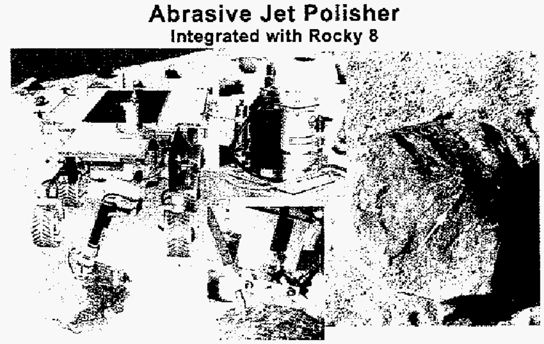

Figure 13 – Integration field testing of Abrasive Jet Polisher with Rocky-7.

The goal of the mission is to land the spacecraft in the northern region of the planet, above the arctic circle, where an abundance of hydrogen has been detected. It is presumed to exist in the from of ice very near the surface. The lander has an arm with a scoop that will dig a trench up to 1 meter deep in search for the ice. The discovery of water, the analysis of the subsurface materials and the search for hydrocarbons are principal goals.

One of the 6 science instruments on the spacecraft is TEGA (Thermal Evolved Gas Analyzer). Its purpose is to analyze soil and ice samples from the trench. It consists of a set of 8 small ovens (Thermal Analyzer, Co-I, W. Boynton) into which samples from the trench will be deposited. The ovens will heat the samples to, first melt any ice, then, heat the residue up to 1000°C to decompose the minerals. The evolved gases from the ovens are transported to a mass spectrometer (a variation of REGA, Co-I, J. Hoffman) for analysis. The MS will identify the gas species and measure the isotopic ratios of the principal components. When the mass spectrometer is not involved in analyzing the effluents from the ovens, it will analyze samples of the martial atmosphere for composition and isotopic ratios of the dominant gases, CO_2, N_2, and argon. The instrument contains a gas enrichment cell that will remove the active gases from an atmospheric sample thereby enriching the noble gas concentrations in order to measure the isotopic ratios of the minor noble gases. TEGA is a joint project of the University of Arizona, the ovens, and the University of Texas at Dallas, the mass spectrometer.

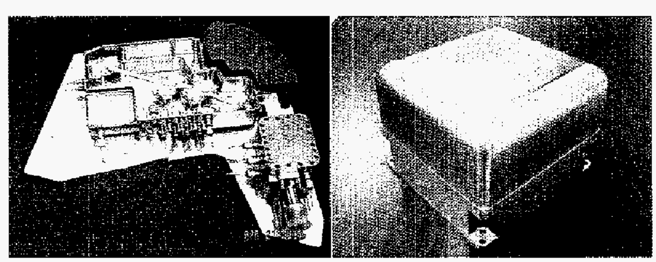

Figure 14 – Left, REGA mass analyzer and right, assembled mass spectrometer package with electronics. Package dimensions are 23 cm x 24 cm x 19 cm.

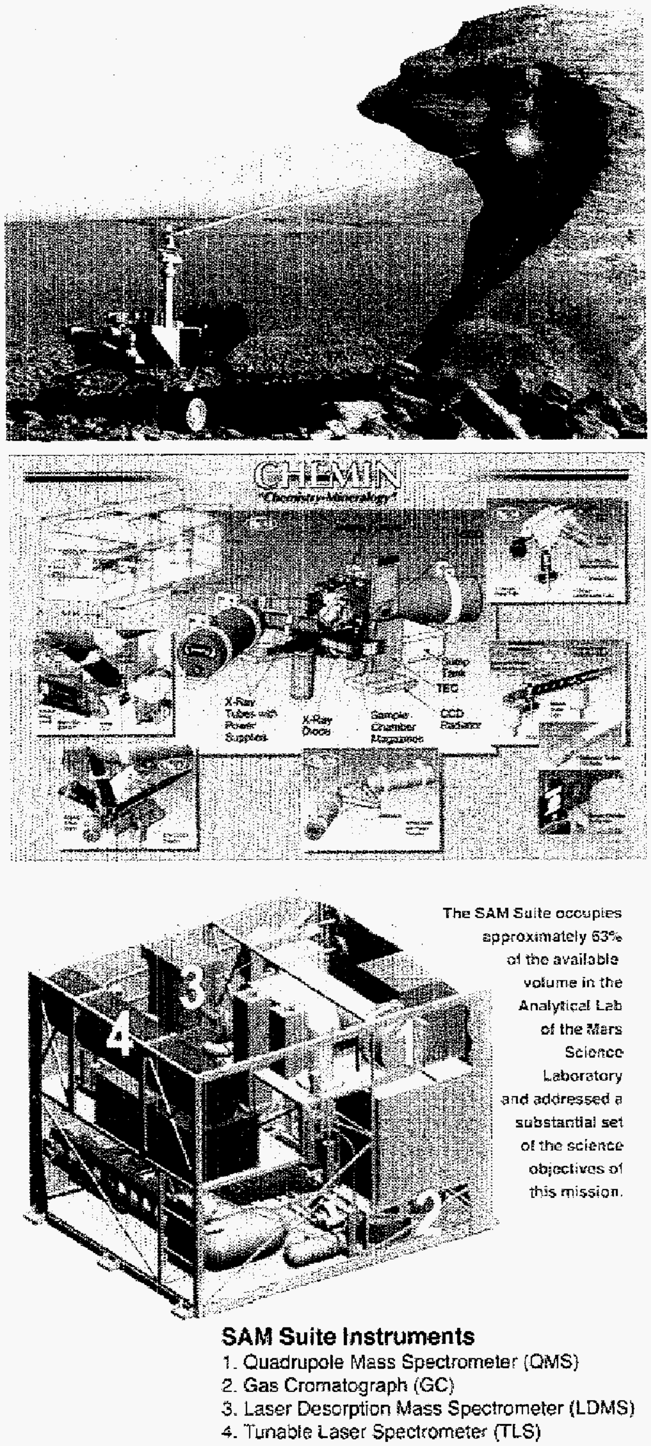

Figure 15 - Selected MSL instruments developed under MIDP, top, ChemCam (MIDP, Laser Induced Breakdwon Spectrometer), Middle, CheMin and Bottom, Sample Analysis at Mars (SAM).

7. MSL Selection of 3 MIDP Instruments

In April 2004, Mars Science Laboratory (MSL) project announced solicitation for science instruments to explore and quantitatively assess a potential habitat on Mars. Eight instruments were selected by NASA (December 14, 2004). Three of the instruments (see Figure 15) were developed by the Mars Technology Program's MIDP funding.

They are: (1) "ChemCam: Laser Induced Remote Sensing for Chemistry and Micro-Imaging," Roger Wiens, Los Alamos National Laboratory, Los Alamos, N.M. ChemCam will ablate surface coatings from materials at standoff distances of up to 10 meters and measure elemental composition of underlying rocks and soils. (2) "CheMin: An X-ray Diffraction/X-ray Fluorescence (XRD/XRF) instrument for definitive mineralogical analysis in the Analytical Laboratory of MSL," David Blake, NASA's Ames Research Center, Moffett Field, Calif. CheMin, will identify and quantify all minerals in complex natural samples such as basalts, evaporites and soils, one of the principle objectives of Mars Science Laboratory. (3) "Sample Analysis at Mars (SAM) with an integrated suite consisting of a gas chromatograph mass spectrometer, and a tunable laser spectrometer," Paul Mahaffy, NASA's Goddard Space Flight Center, Greenbelt, Md. SAM will perform mineral and atmospheric analyses, detect a wide range of organic compounds and perform stable isotope analyses of organics and noble gases.

Conclusions

As demonstrated in the MSL instrument selection, MIDP has produced state-of-the-art miniature in-situ instruments, and contributed toward the Mars missions. This is the program essential for bridging the gap between the instrument R&D programs and construction of flight instruments. Many future Mars missions will benefit through the MIDP program as a source of space-qualifiable in-situ instruments.

Acknowledgement

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http://research.hq.nasa.gov

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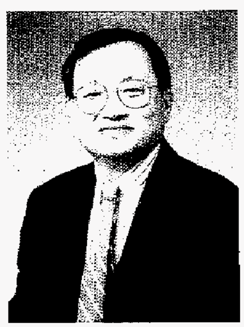
Biography



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