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MA_MISS: MARS MULTISPECTRAL IMAGER FOR SUBSURFACE STUDIES

A. Coradini[1], G. Piccioni[1], S. Amici[1], R. Bianchi[1], F. Capaccioni[1], M. T. Capria[1], M.C. De Sanctis[1], A. M. Di Lellis[1], S. Espinasse[1], C. Federico[2], S. Fonti[3], G. Arnold[4], S. K. Atreya[5], T. Owen[6], M. Blecka[7], A. Bini[8], M. Cosi[8], S. Pieri[8], and M. Tacconi[8]

[1]Istituto di Astrofisica Spaziale, CNR – ARTOV, Via del Fosso del Cavaliere 100, 00185 Roma – Italy
[2]Dipartimento di Scienze della Terra dell'Università degli Studi di Perugia, Perugia, Italy
[3]Dipartimernto di Fisica dell' Università di Lecce, Lecce, Italy
[4]DLR Institut für Planetenerkundung, Rutherfordstrasse, 2 12489 Berlin – Germany
[5]Dep. Atmosferic,Oceanic,and Space Science, Univ. of Michigan, 2455 Hayward Street, Ann Arbor, MI, USA
[6]Hawaii Institute of Geophysics and Planetology, 2525 Correa Road, Honolulu, HI 96822, USA
[7]Space Research Center, PAS, Bartycka 18A,00-716 Warszawa, Poland
[8]Alenia Difesa, Officine Galileo,.via A. Einstein 35, 50013 Campi Bisenzio, Firenze, Italy

ABSTRACT

The Italian drill "DEEDRI" is going to be the lander based sample acquisition system for the Mars Surveyor Program of the Mars Sample Return mission. DEEDRI is capable to collect core/sand sample of the martian soil down to 50 cm in depth. The MA_MISS experiment belongs to the DEEDRI system and it will be dedicated to observe the wall of the excavated hole in terms of infrared spectral reflectance in the range 0.8-2.8 μm. The spectral sampling is about 20 nm while the spatial sampling is 100 μm over the target. The optical window of MA_MISS is placed very close to the drill tip so that the target view to be observed can span from the soil down to 50 cm. The proximity optics and electronics of MA_MISS have to be very miniaturized since they will be collocated inside the drill tool in a very limited volume of about 25 mm in diameter. On the other side the main electronics will be on the lander and it will communicate through an interface based on slip rings devices. MA_MISS can acquire in different observation modes. The images are scanned by moving the DEEDRI itself. One image ring is built up by acquiring contiguous images of the MA_MISS slit. The study of the Martian subsurface will provide important constraints on the nature, timing and duration of alteration and sedimentation processes on Mars, as well as on the complex interactions between the surface and the atmosphere. This study will permit to infer the history of erosion, transport and deposition of loose material. Alteration processes can dominate the mineralogy of the Martian surface: it will be essential to study the mineralogy of deeper layers, where a more limited alteration took place. MA_MISS can provide very important scientific return from the subsurface of Mars along with a selection criteria for the samples collection.

INTRODUCTION

The MA_MISS (Mars Multispectral Imager for Subsurface Studies) instrument is a miniaturized imaging spectrometer designed to provide imaging and spectra by reflectance in the near-infrared (0.8-2.8μm) wavelength region. A version of the instrument for the visible range has been studied for the Mars Surveyor Program 2003 lander in order to decrease the procurement time of the detector. MA_MISS will be integrated in the drill that the Italian Space Agency will provide to NASA, as part of the sample acquisition system of the Mars Surveyor Program lander. MA_MISS will be operated periodically during the pauses of the drilling activity and will be able to provide an image of the hole wall. MA_MISS multispectral images will be essential also to document the sample acquisition for MAV (Mars Ascent Vehicle) and the selection of particularly significant samples to be given to IPSE (Italian Package for Scientific Experiments) for further in-situ analysis.

The Mars exploration asks for a detailed in-situ investigation of the Martian surface and sub-surface. At present, only the Viking 1-2 missions and the Pathfinder ones succeeded in obtaining information on the composition of the Martian surface. In fact the in-situ analysis is needed in order to improve our knowledge on the following topics: identify the presence biological history of Mars and search for possible indicators of life; constrain the amount of water on the planet and put it in relation with the present and past geologic and climatic history of Mars, at least at local scale; determine the nature of local geology, chemistry and mineralogy; study the Mars environment in terms of human survival on the surface. We intend to study the previously described objectives by means of a small imaging spectrometer put inside a drill tool that will be able to perforate the first meters of the Martian surface.

MARTIAN MATERIALS

The Mars Global Surveyor (MGS) Thermal Emission Spectrometer data from low-albedo regions on Mars have identified basaltic and andesitic global surface compositions (Bandfield et al., 2000, Christensen et al., 2000): the detection of two distinct volcanic rock types, interpreted to be mostly sand-sized particles, on the martian surface is generally consistent with basaltic SNC meteorites and andesitic rocks measured by the Mars Pathfinder (MP) APXS. TES measurements of the MP landing site confirm the Mars Pathfinder observations that this region is largely covered by fine-grained dust. TES have shown that the most common surface component is basaltic materials in low albedo surfaces. These spectra are best fit by a combination of pyroxene, plagioclase, and olivine. The most striking result is the definitive identification of crystalline hematite within a localized zone approximately 300 km in diameter centred near the equator at ~5° W. The TES results indicate that the hematite occurs within a localized region with sharp boundaries. Crystalline hematite has been previously reported using telescopic visible/near-IR observations, and nanophase hematite is widely thought to be an important component of the materials that give Mars its red color (Singer, 1982; Morris et al., 1989; Bell et al., 1990). The crystalline hematite discovered by the TES most likely did not form by weathering processes, but may have formed by crystal growth from hot, iron-rich fluids, due to hydrothermal alteration.

The two Viking landers have collected basically four different types of surface materials: rocks, drift, crusty-to-cloddy, and blocky. The compositions of the two landing sites are extremely similar which may be due to homogenizing global processes such as global dust storms or volcanic processes. These materials have been studied by remote sensing observations and in-situ measurements from landed spacecraft. The data acquired have shown that a large variety of surface materials exist, but that most of the Mars surface can be characterized by four units (Christensen and Moore, 1992). Unit 1 is composed of fine and bright dust, with only few rocks exposed. Radar observations suggest that a rough surface is buried beneath several meters of fine dust. Unit 2 is characterized by a dark, coarse grained surface with abundant rocks. Unit 3 has been interpreted to be a rough and indurated surface. Finally, Unit 4 (that contains the two Viking landing site) is characterized by a thin dust layer accumulated on the surface. It has been estimated in various ways that a global blanket 2km thick, composed of impact ejecta, may exist, overlying a heavily fractured basement. This layer, called megaregolith, could be interbedded with volcanic flows, weathering products and sedimentary deposits. We briefly describe here some properties of this materials.

Palagonite

The visible and infrared spectra of Martian dust present some problems for interpretation. In this spectral range, most crystalline minerals show features that should have been identified, if these materials were abundant. The alternative is that the form of these minerals is not crystalline but amorphous (or poorly crystalline), as palagonites or altered volcanic glasses. Palagonite is an amorphous, or poor crystalline, ferric iron silica gel, formed by volcanic eruptions of basalt in water rich environments or by alteration of basaltic ash. This material shows absorption bands at 1.4 and 1.9μm due to embedded water.

Igneous materials

Low albedo materials on Mars are considered related to the crustal rocks. The spectra between 0.35 –1.1μm of the dark regions are consistent with terrestrial olivine basalt oxidized in laboratory. Ground based observations show that the lowest albedo regions have indications of significant oxidation or contamination with oxidized materials. The spectra of these dark regions have a negative IR slope. Singer and McCoord (1979) showed that this negative slope in the IR and the Fe2+ absorption near 1 μm is associated with the dark materials themselves and that the Fe3+ bearing materials are also associated with this dark materials (as coating or mixed). Singer (1982) has shown that a thin Fe3+ rich layer coating a dark substrate can reproduce the spectra of the Mars dark areas without masking the NIR features of the substrate.

Olivine and pyroxene

The spectra of the dark regions of Mars show features near 1μm and more tentative features (due to the strong CO_2 absorption in the Martian atmosphere) near 2μm. The exact position of the 1μm band is very sensitive to the Ca+ content, in the case of clinopyroxene, and to Fe2+, in the case of orthopyroxene. The position of this signature changes among different dark regions from 0.93 to 1.05μm and may be completely absent in some areas. Analyzing the available spectra of the dark regions, Singer (1982) indicated that olivine is not the dominant mafic component. Olivine should be a dominant mineral of the Martian upper mantle, as on the Earth. Since almost all the boulders observed on the surface of Mars are made of volcanic ejecta, it is probable that aeolian erosion and meteoric ablation pulverize them. Thus, fractions of olivine can appear in the regolith. MA_MISS will help in solving this problem by analyzing samples of "protected layers". The signature near 2μm and those around 0.96μm suggest the presence of pyroxenes, probably augite or pigeonite.

Clays

The presence of bound water in some form in Mars soil materials, from the 3μm signature and from the evidence for alteration and weathering products, suggests clay minerals. The diagnostic features seen below 2.6μm include moderately strong features near 1.4μm and 1.9μm, and some weaker bands near 2.1 and 2.5μm. The presence, positions and strength of these bands give information about mineralogy and H_2O content. O-H stretch of OH- and H_2O contribute to the 1.4μm signature, while the 1.9μm band is due to H-O-H bend overtones and is an indicator of absorbed or bound molecular H_2O in a mineral. The 1.4 and 1.9μm signatures are difficult to observe from ground for the interference of Earth and Mars atmospheres. Large amount of crystalline aluminous clays (as kaolinite or montmorillonite) should have signatures at about 2.2µm that were not observed in Mars spectra.

Scapolite

The spectra in the 2-2.5µm range, exhibit a series of narrow spectral features that can be due to scapolite. On Earth this is a metamorphic mineral that can be formed with processes involving basaltic magmas intruding into carbonate deposits or in presence of CO_2-rich gas or liquid. From spectral data the scapolite abundance is variable on regional scale. These signatures might be also due to the atmospheric CO.

Carbonates and sulfates

The spectra of carbonates show different features between 2 and 5µm. From spectral data, carbonate abundance seems to be limited to a few percent (less than 5%). From the ISM spectra Bibring et al. (1990) suggested that a feature near 2.5µm can be assigned to carbonate. The Viking Lander detected sulfate in soil in an abundance of 5-10%. Sulfates also exhibit an absorption near 4.5µm: Blaney and McCord (1990) have identified this feature in spectra of different Martian regions. They noted a large spatial variability in the strength of this signature that can be due to a different sulfate content. Difficulties in the detection of carbonates may lie in the fact that these materials can be destroyed by the solar UV. This problem is still discussed but it may appear that the search for carbonates should be carried out in the deep layers, as MA_MISS will do.

Water

Water ice has fundamental bands near 3.2 and 6.1µm, with overtones at 1.5 and 2µm. Weaker signatures are near 1.26, 1.04µm and shorter wavelengths. Additional weaker overtones are observed at 1.26, 1.04 and shorter wavelengths. The near IR bands (2µm and shorter), being weaker, are less likely to be saturated and can provide more useful information on the amount and physical status of the ices. These ice bands have positions, widths and shapes that are different from those of molecular H_2O and OH-. Spectroscopic observations of Mars show a strong absorption feature in the 3µm region that is attributed to H_2O in some form. From the data of Mariner 6 and 7, Pimentel et al. (1974) interpreted this signature to water of hydration and/or ice. More recently, the Infrared Imaging Spectrometer (ISM) on Phobos 2 has been used to spectrally map the mid and equatorial regions of Mars, at 25Km of resolution. The spectra acquired suggested that the abundance of water in volcanic and canyon terrain varies by as much as 20% (Bibring et al., 1990),in agreement with Mariner 6 and 7.

MARS SUBSURFACE PROPERTIES

From radio and radar observations, providing information on the upper 0.1 to 10m of the Martian crust, we know that subsurface properties seem to be slightly different from those at the surface, suggesting subsurface layering in many places. In the first meters of the soil, the following characteristics are expected: bulk soil porosity of 50%, thermal conductivity of 2 W m^{-1} K^{-1} (±1) (Christiansen and Moore, 1992), a density between 1 and 1.6g cm^{-3} for the dry particulate material dominating the surface. The active layer of the cryolithosphere (determined by the diurnal skin depth) is expected to be partly desiccated. Older models predict that near the equator the regolith has been probably desiccated to a depth of several hundred meters. Geological evidence indicates that there are, or were, great quantities of water close to the Martian surface. If the planet has retained a significant amount of water, it could be hidden in the terrain, as ground water or ground ice, and be not directly observable. The stability of ice in ground is controlled by the atmospheric pressure and the ground temperature. Several models have been developed to asses the stability of water ice under the present Martian conditions. Farmer and Doms (1979), assuming a well-mixed atmosphere and average Martian albedo and thermal inertia, found three stability regions. At low latitudes the ice is permanently unstable at all depths below the surface. At all high latitudes the ice is stable at about 1m below the surface, and, at a depth less than about 1m only during part of the year. This scenario has been revised by Paige (1992) and Mellon and Jakosky (1993). Paige stresses that Mars has a large range of albedo values and that the atmosphere may not be well-mixed. Thus, water ice can be stable also at lower latitudes in the low thermal inertia regions. The presence of ice will increase the thermal inertia below the surface. At latitudes higher than ±30°, ice is present near the surface, thoroughly comminuted materials, and terrain softening can take place. At lower latitudes, ice only persists in deep heavily fractured bedrocks, still allowing rampart craters to form for large impacts but preventing terrain softening.

OBJECTIVES OF MA_MISS

The goal of this experiment is to study the Martian subsurface layer structure by means of a multispectral camera named MA_MISS. The upper few meters of the surface materials on Mars play a crucial role in its geological history, providing important constraints on the rate of Mars surface modification. These materials can give information on the evolution of surface sediments (erosion, transport, deposition), on the relation between sediments and bedrock, on the relation between environmental conditions and surface processes. Martian regolith is a product of intensive impact bombardment coupled with volcanic and weathering activity. In the regolith various salts should exist, most likely NaCl brines, forming the so-called duricrust. The MA_MISS experiment can help us to understand these processes by means of the following main scientific objectives:

- Image the structure of the stratigraphyc column drilled by DEEDRI
- Identify the existence of "lateral anisotropies" in the sample.
- Detect the presence of layers containing clays, carbonates and alteration products.

- Identify the granulometry at different depths along the walls of the excavated hole.
- Study the mineralogy of single grains through their NIR spectrum between 0.8 and 2.5μm.
- Identify the presence of volatiles mixed with siliceous materials.
- Detect how deeply condensation of CO_2 and H_2O ice is possible.
- Study, if the DEEDRI operations will allow it, the variation of recondensation phenomena.

The previous scientific goals are achievable provided that the following requirements are achieved:

- Spatial sampling: 100μm
- Spectral sampling: 20nm
- Spectral range: 0.8-2.8μm
- Signal to Noise ratio better than 100

INSTRUMENT DESCRIPTION

The data are acquired through a flat optical window on the drill wall. Through this window the inner surface of the hole is illuminated by means of a tungsten lamp. The image is acquired by an array of optical fibres simulating a slit. An optical system situated inside the drill will permit to observe details from few tenths of microns to hundreds of microns and to perform low resolution spectroscopy in the range 0.8-2.8μm. The linear array of optical fibres mimics the slit. The focal plane is a two-dimensional matrix of HgCdTe or PbS of 32 (or 64) pixels in the spatial direction by 25 (or 256) pixels in the spectral direction. Both the focal plane arrays can work at ambient temperature (up to 300K). The pixel dimension is of the order of 80μm, dimension that matches the minimum optical fibre dimension. As in other imaging spectrometers, MA_MISS images are obtained using the relative motion of the slit in respect to the wall generated by the drill rotational motion, or, if the drill is not moving, by scanning the window by means of the shutter, designed as linear scanner as well. The main function of the shutter is to protect and clean the optical window of MA_MISS before each session. We propose to acquire data during each coring activity, not contemporarily with the drill sampling operations. Once a sample is acquired, before storing it in the MAV, a detailed analysis of the walls is performed. The reduced volumes and the drill particular architecture, lead to consider as image transport system an optical fibres coherent bundle. This implies two other design solutions: the target lighting, which is done by means of a dedicated optical fibre bundle (independent but integrated with the image transport bundle) and the imaging relay (magnification 1x) concept to image the target on the fibre optics bundle optical plane.

MA_MISS is a very flexible experiment therefore the observation strategy can be adjusted to the available resources of mass memory and telemetry. MA_MISS can acquire in different observation modes, the high-level ones being the "ring mode" and the "column" mode, see Figure 1. One image ring and one column in high spectral and spatial resolution requires about 50Mbits and 7.6Mbits, respectively. If all the hole wall is observed, the required data volume is extremely high, so that a reasonable observation strategy shall be devised. A typical acquisition is composed by 3 rings and 10 columns corresponding to 220Mbits uncompressed. Obviously, depending on the situation, much less expensive operative modes can be foreseen, for example by reducing the spectral sampling. The main characteristics of the near infrared instrument are shown in Table 1.

Table 1. Main parameters of MA_MISS

Spectral range	0.8-2.8μm
Spectral sampling	20nm
Spatial sampling	<0.1mm
Window dimensions	2.4 x 1.8mm
Typical Signal to Noise Ratio	~ 100

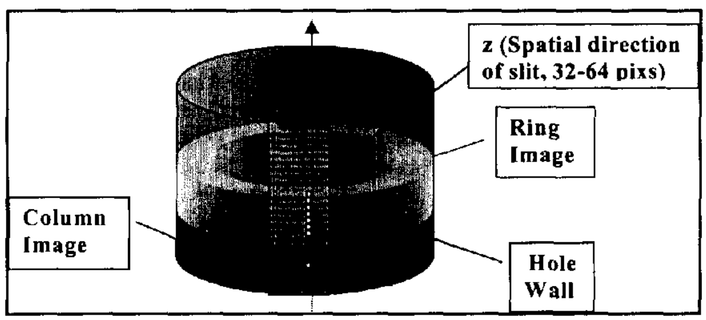

Fig. 1. Sketched description of the column and ring mode of MA_MISS

THE MA_MISS ARCHITECTURE

The most hard problem in the design was the accommodation inside the drill tip, due of course to the small available space for the proximity optics and electronics. The following instrument concept fulfils, in principle, the requirements above mentioned. The concept described in Figure 2 foresees a polychromatic illuminating system that uses a dedicated incoherent bundle of optical fibres. The image of a line of the target is kept throughout the imaging relay on a coherent linear array of optical fibres. On the opposite bundle end, the coherent linear array of optical fibres is the incoming slit of a spectrometer system which produce the dispersion on the detector, perpendicularly to the slit itself. The detector dimension will be chosen in order to obtain the maximum possible spectral resolution. The whole 2D-target image is obtained scanning the image by either translating the optical head perpendicularly to the array or using DEEDRI as scanning system.

The Imaging relay on the optical head must focus the target image on the optical fibres bundle plane. To optimise its efficiency, on the whole spectral range, an approach of a completely catotrics design has been considered. By the way, this allows to eventually extend the spectral range, in the future, if it will be necessary. The aperture of the optical system should be

F/# = 10. This should allow a field deep of about ±1mm, which could be sufficient to avoid focusing problem due to irregularities of the target. In any case, with a simple linear actuator (e.g. a solenoid around the bundle end), it should be possible to change the distance between the bundle itself and the imaging relay. The lighting of the target is done throughout an incoherent bundle of optical fibres, which can be integral part of the image transport bundle, and which transport the light from the source (a miniaturized lamp) to the target. The lighting bundle end (at the target side) is divided by two (or more) branches in order to improve the light distribution of the sample. A preliminary investigation has been done on the various solutions of the spectrometer. Because of the lack of the available volume and its particular shape, the choice has been reduced to few systems. Among them, the most attractive is a grating spectrometer system based on the Dyson modified concept.

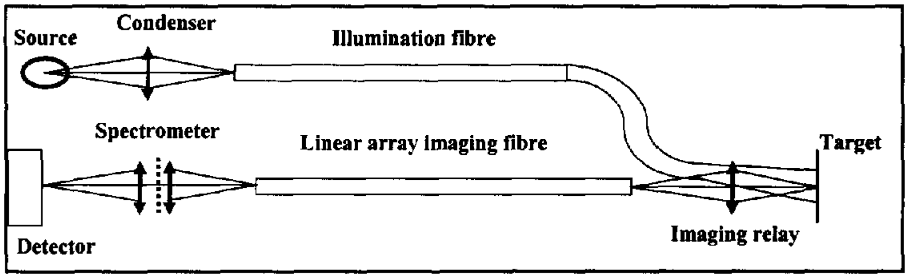

Fig. 2. Simultaneous spectral detection spectrometer concept.

Signal to Noise ratio performances

A radiometric model of the instrument has been used to evaluate the signal to noise ratio in a typical condition having various materials as target. In Figure 3 is the result of the expected signal to noise ratio. The calculation was done considering a detector a full well capacity of 10^8 electrons and a quantum efficiency > 60%. The illuminating tungsten lamp (2-4 watt). The evaluation of the signal to noise normalising the laboratory spectra to an average albedo of 0.4.

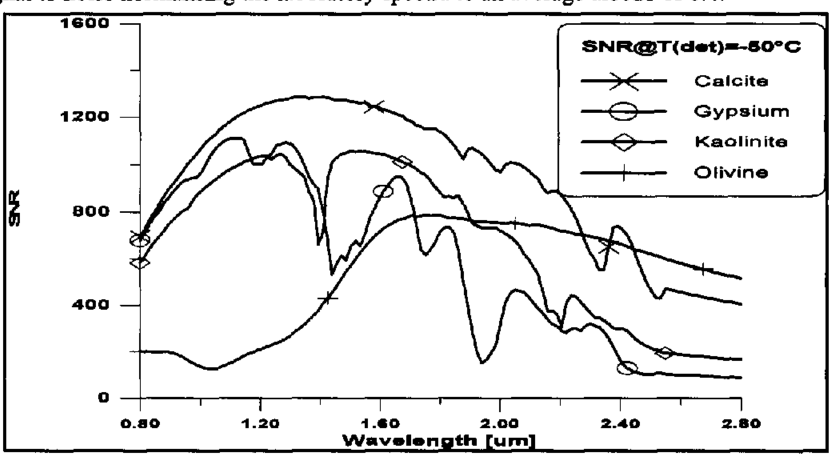

Fig. 3. Signal to noise ratio in the typical Martian environment condition

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