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The OMEGA Instrument on board Mars Express: First Results

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Abstract. OMEGA (Observatoire pour la Mineralogie, l'Eau, le Glace e l'Activité) is a visible and near infrared mapping spectrometer, operating in the spectral range (0.35 - 5.1 μm). Combining imagery and spectrometry, OMEGA is designed to provide the mineralogical and molecular composition of the surface and atmosphere of Mars through the spectral analysis of the diffused solar light and surface thermal emission. OMEGA will provide a global coverage at medium resolution (2 to 5 km) of the entire surface of Mars from altitudes 1500 to 4000 km, and high resolution (< 400 m) spectral images of selected areas, amounting to a few percents of the surface, when observed close to periapsis (< 300 km altitude). OMEGA will address major questions associated to internal structure, geologic and chemical evolution, past activity and present surface variegation. It will greatly contribute to the understanding of the evolution of Mars from geological time scales to seasonal variations. It will in particular give unique clues for understanding the H_2O and CO_2 cycles over the Mars history. It will play a major role in identifying areas of interest for the future martian in situ explorations. OMEGA is an international collaboration between France, Italy and Russia, involving the following Institutions: IAS (Institut d'Astrophysique Spatiale, Orsay, France), DESPA (Dpartement de Recherches Spatiales, Observatoire de Paris/Meudon, France), IFSI (Istituto di Fisica dello Spazio Interplanetario, Rome, Italy) and IKI (Institute for Space Research, Moscow, Russia). In this paper we present the first results after few months from starting of its observations.

Key words. Spectroscopy – Mars – Remote Sensing

1. Introduction

A new generation of instruments for planetary remote sensing includes imaging spectrometers. These couple imaging capabilities together with the spectroscopy potential, that is, the possibility to identify the mineralogical composition of a soil/rock. In general terms, spectral remote sensing is based on the results of the interactions of the electromagnetic radiation with the minerals making up the surface of the object being sensed. In addition, as the human eye always does, it is possible to distinguish features on a picture by their shape and size as well as their color. As solar radiation interacts with a solid surface, the intensity and the spectral distribution of the reflected ra-

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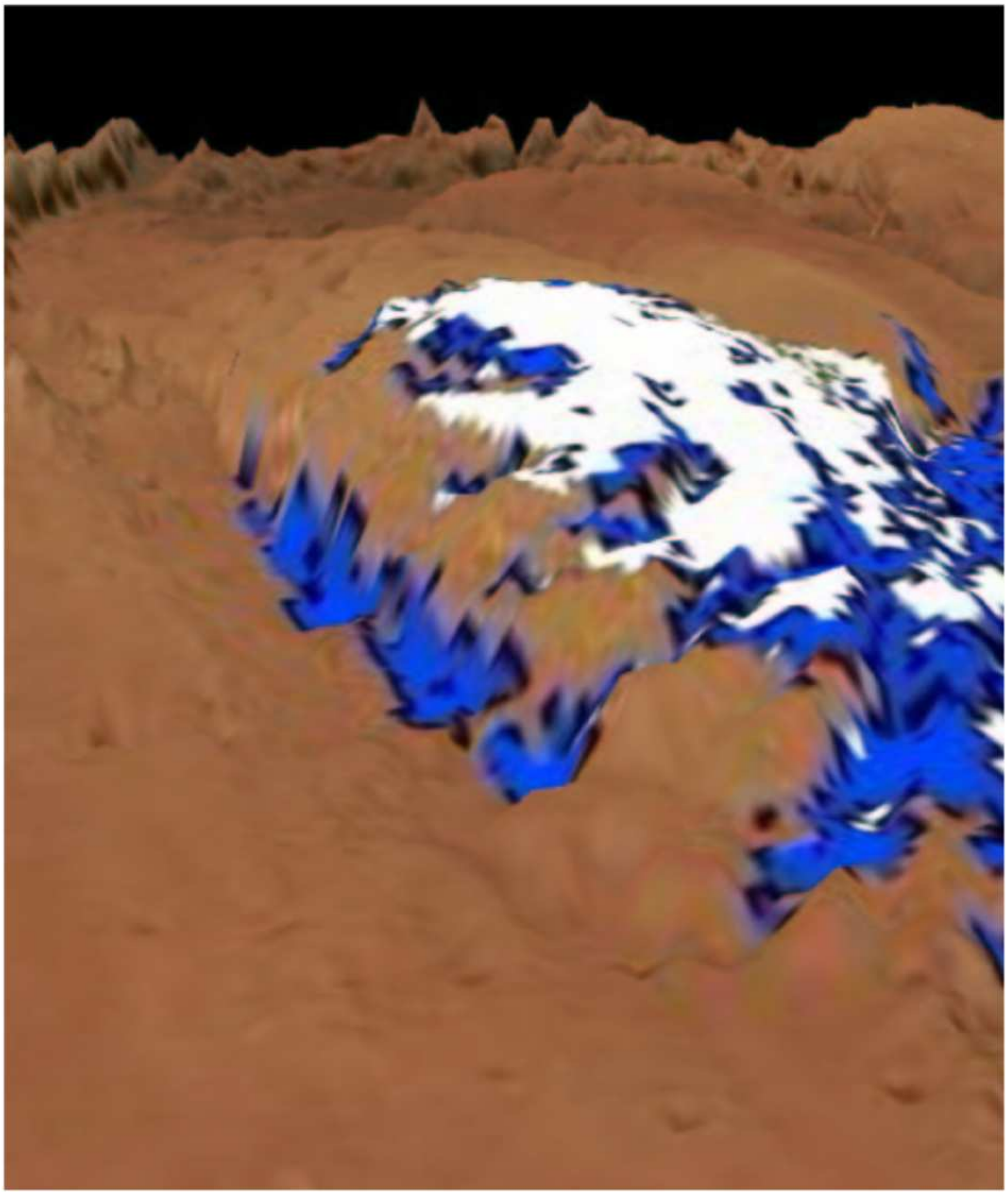

Fig. 1. Tridimentional view of the south polar cap of Mars. The white color shows the CO_2 ices while in blue the water ices terrains are shown

diation will be determined by the composition of the soil, and by its physical properties such as porosity, roughness, grain size distribution. The spectral features of minerals, rocks and soils are produced by either electronic or vibrational processes Burns (1993). Electronic transitions require more energy than vibrational processes and most of these spectral features are located in the ultraviolet and visible range with only a few features, mainly due to iron, extending in the infrared. Electronic transitions produce spectral absorptions which are usually very broad. Fundamental vibrational processes give rise to much narrower spectral features in the middle and far infrared regions (above 2.5 μm). In the visible region of the spectrum, the spectral signatures of silicate minerals like olivines and pyroxenes and of silicate bearing rocks like basalts are approximately localized in the range 0.8 - 1.1 μm. This range is diagnostic of the presence of ferric oxides resulting from the alteration of mafic (magnesium iron rich) rocks in the material making up the surface under study. The infrared domain is diagnostic of pyroxene composition, water H_2O-OH bound in minerals, H_2O-CO_2 ice in the soils, carbonate and sulphate minerals. From the precedent discussion follows that an instrument capable of combining high spectral and high spatial resolution would greatly enhance the amount of information that can be extracted from an image of a planetary surface.

2. Scientific Objectives

The OMEGA instrument is the imaging spectrometer on board the European mission Mars Express. The orbit of Mars Express has been chosen highly inclined and eccentric so as to allow a variable ground track spatial sampling and a latitude drift of the periapsis leading to an almost complete planetary coverage. Consequently, given the downlink constraints and capability of the mission, it will be possible for OMEGA to achieve a global coverage, at medium resolution, from medium altitudes, and to acquire high resolution spectral images, for a fraction of the surface, with full selection flexibility, when operating close to periapsis. More specifically, with its instantaneous field of view (IFOV) of 4.1 arcminutes (1.2 mrad), the global coverage should be completed, in one martian year, at 2 to 5 km resolution, from altitudes 1500 to 4000 km, while the periapsis high resolution should reach a few hundreds meters. The scientific objectives of OMEGA are:

1. Mineralogy. OMEGA will map the surface of Mars in order to identify the minerals of the major geological units. The goal is to monitor the past and present evolution of Mars induced by internal activity, meteoritic impacts, and the interaction with the atmosphere. A global mapping of Mars will be achieved with a resolution of a few kilometers. Indeed, the Viking and MGS1 orbiter images indicate strong albedo variations down to sub kilometer scales. ISM/Phobos spectral images in the near IR also exhibit large compositional variations at kilometer scales. Moreover, this investigation demonstrated that although large amounts of transported soil with uniform properties cover parts of the surface, all geological units exhibit part of their uncovered bedrock at these scales. Therefore, OMEGA should identify the diversity of the global Martian surface, inferring compositional variations directly related to planetary evolution. In addition, OMEGA will benefit from observations close to periapsis to significantly improve the resolution for at least a few percents of the Martian surface. This should in particular permit to: - increase the sensitivity for detecting constituents with restricted geographical extension. For example, the present failure of detection of carbonates might be directly linked to limited instrumental resolution. High resolution snapshots of areas more likely to have accumulated sedimentary carbonates might lead to a positive detection of fundamental value; - map mineralogical boundaries between geological units, in particular recent plains and older regions with high density of impact craters, thus helping understanding the hemispheric Martian asymmetry; - identify the composition of deposits and observe possible gradients in the hydration minerals near features associated with fossil water flows; - monitor features associated with wind transportation. As for the spectral range and spectral sampling, OMEGA will operate from 0.35 to 5.1 μm in 352 contiguous spectral elements (spectels), 7 nm to 20 nm large. It will identify, through their diagnostic spectral features, the major classes of silicates and other important minerals (such as carbonates), oxides and hydrates. Moreover, OMEGA will be capable of monitoring the content of OH radicals within the surface soil and rocks, so as to identify possible genetic relationships of hydrated miner-

als with major structural units such as volcanoes or canyons. In addition, the presence of fluidized ejecta around impact craters is likely to indicate that the underlying bedrock contains ice mixed with rocks. It is then plausible that ejecta experienced hydration. The spectral features of hydrated minerals (clays) are readily observable in the near IR. Alteration processes transformed Martian mafic rocks into ferric-bearing minerals. In order to understand when this process took place (via volcanic activity, interaction with the atmosphere or flooding water), it is essential to relate these minerals with geological structures. OMEGA will detect these altered minerals through their signatures between 0.5 and 0.8 μm. It is plausible that the CO_2 Martian reservoir is dominantly in the form of carbonates. The detection and localization of theses minerals would be of key importance for understanding the past activity of the planet: OMEGA should unambiguously detect them, even at very low concentrations, through their absorption features between 3.4 and 4.0 μm.

2. Polar caps and frosts. OMEGA will determine the spatial evolution of the two polar caps, by the observation of both CO_2 and H_2O, and the layered deposits. It will enable to discriminate between the permanent (residual) ice, at both poles, and the seasonal frosts. OMEGA will thus monitor the cycle of sublimation/condensation, and identify the relative contributions of the two major atmospheric constituents as a function of time and location. OMEGA will also identify dust within the polar ices; its composition indicates where it originated from, thus allowing to follow the transportation processes. At lower latitudes, the condensation of frost will be mapped over time, for both CO_2 and H_2O. In addition, OMEGA will be capable of detecting minor species containing either carbon or nitrogen: no such molecules have been observed yet, and their discovery would be of major interest for the understanding of the overall chemical evolution. If permafrosts layers do exist, they may appear at the very surface in a few regions. OMEGA would then detect such icy-rich rocky sites. From the identification of the borders of the underlying permafrost layers, one should be able to evaluate the global distribution of ice within the Martian crust, thus complementing the MARSIS radar subsurface sounding. It is a major goal to try to identify the sites and phases where most of the water resides, in particular when searching for the most favorable sites for a possible past organic activity, and assessing water resources for future exploration.

3. Atmospheric evolutionary processes. The OMEGA instrument is be well suited for monitoring some of the parameters of the Martian atmosphere, which play a key role in the Martian meteorology: total pressure, column densities of the minor constituents H_2O and CO, content of aerosols, and, in some cases, vertical temperature distribution. OMEGA should thus efficiently complement the PFS and SPICAM investigations, with a lower spectral sampling but at a much higher spatial resolution. The ISM/Phobos imaging spectrometer, which mapped part of the Martian surface in February-March 1989, has demonstrated the ability of infrared spectroscopy, even at low (21 km) spatial sampling, to accurately retrieve the altimetry of Mars (100 m vertical resolution). The observations of CO_2 absorption bands with OMEGA will give, as from ISM/Phobos, a measurement of the ground pressure. As the altimetry on Mars will be better known, at time of Mars Express observations, after the MOLA/MGS measurements, OMEGA will study local pressure variations, as induced by baroclinic wave pattern at mid-latitudes by passing over the same regions at different times. Expected variations of a few percent of the atmospheric pressure will be easily measured with OMEGA (design goal is 1% in accuracy, in the absence of global dust storms).

3. Instrument Performances

The OMEGA imaging spectrometer acquires 352 monochromatic images of the Martian surface in the 0.36 - 5.1 μm spectral range. It is composed of two bore-sighted spectrometers covering, respectively, the 0.36 - 1.05 μm (VIS) and 0.89 - 5.1 μm (IR) spectral ranges. This wavelength domain is diagnostic of iron mineralogy, pyroxene composition, water H_2O-

OH bound in minerals, H_2O-CO_2 ice in the soils and water vapour in the atmosphere. The OMEGA nominal spectral resolution is 7.5 nm in the visual, 15 nm in the near infrared and 20 nm in the infrared. The instrument has imaging capabilities, providing spectral images at a nominal angular resolution of 1.2 mrad/pixel and a maximum field of view of 8.8°, giving a swath of 128 pixels. This large field of view will allow to map the entire Mars surface by operating at distances greater than ~ 2000 km. Other operation modes are also possible which allow to work at closer distances, up to pericenter (~280 km). These modes include the 4.4°, 2.2° and 1.1° field of view, corresponding, respectively, to 64, 32, and 16 pixels swath. The 16 pixels swath is routinely used at pericenter. Different exposure times are also used: the visual channel can operate at 50, 100 and 200 ms, while the infrared channel at 2.5 and 5 ms. OMEGA works as a pushbroom imager in the VIS and as a whiskbroom imager in the IR. At a given instant, the VIS spectrometer records a so-called slice that is, all the spectra belonging to a strip perpendicular to the velocity vector. As far as the spacecraft proceeds in its orbit, the image cube is built up, by staking together all the acquired strips. The IR channels operates differently. While the VIS has a 2D detector, the IR has a linear detector which records, at a given instant, only one spectrum at the time. The IR spectrometer needs then a scanner to acquire the same strip acquired by the VIS. Briefly, the OMEGA visual channel (henceforth VNIR) is composed by a lens telescope focusing the light onto a slit and by a grating spectrometer which disperses light along each column of a 2D CCD detector. The image of the slit at each wavelength is thus registered on a detector row. Spatial and spectral summing (3x3) of detector elements provide a final matrix of 128 spatial pixels by 96 spectral elements. We call this basic data unit, slice. The summing reduces the data volume provided by VNIR but, on the other hand, increases the signal/noise ratio of each spectrum. By acquiring consecutive slices along the orbit, we can reconstruct a 2D image of the surface at each wavelength. VNIR has been developed by IFSI-Rome under an ASI contract. A complete description of the instrument can be found in Bellucci et al. (1998) and Bibring et al. (2004b).

4. First Results

A few initial observations have been performed soon after Mars Orbit Insertion, in particular while the spacecraft was over flying the South polar areas. The altitude of observation ranged from ~1500 km to ~2000 km, providing an OMEGA surface sampling of ~2 km. OMEGA thus mapped a large fraction of the South polar regions, along 4 distinct orbits, from January 18th, till February 11th, 2004 (Ls=335° to 348°), that is about one month prior to the Mars Southern Fall equinox. At the time of the observations, the Sun elevation was very low (< 10°); however, given the very high performances of OMEGA, several tens of thousands of spectra were acquired with SNR > 100 over the entire spectral domain. From the acquired spectra, one can derive coupled maps of a variety of parameters and properties: in particular, the major icy constituents, CO_2 and H_2O, have several unambiguous diagnostic spectral signatures enabling to map their respective distribution over the imaged areas (figure 2). The OMEGA optical images exhibit the well-characterized high albedo perennial polar ice patterns. From their near infrared spectrum, we can assert that these bright areas are those where CO_2 ice is highly concentrated Bibring et al. (2004a) (figure 1).

A crucial finding is the identification of H_2O ice, with a varying concentration over a much larger area (figure 1 and 2). H_2O ice is found in three distinct units: 1- on the bright cap. In this unit, water ice is mixed with large concentrations of CO_2 ice. This makes its spectral identification more difficult than in the two other units, since CO_2 ice exhibits spectral features in the same spectral domain. It requires a careful analysis, illustrated in figure 2 (right panel) where a typical OMEGA spectrum of a pixel located in this CO_2 ice cap is compared to modelled spectra obtained with either pure CO_2 ice or a mixture of H_2O ice and CO_2 ice. It is shown that pure CO_2 ice cannot account for the observed spectra: the presence of H_2O ice

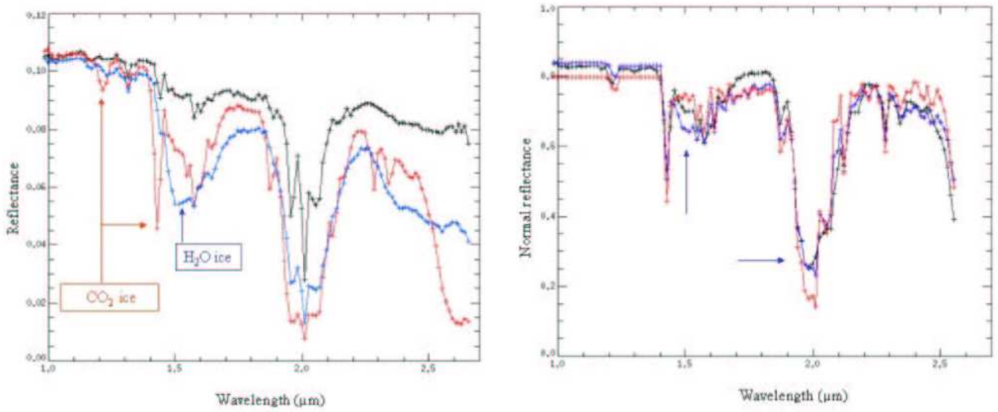

Fig. 2. Left panel: Spectra of the CO_2 ice (red), water ice (blue) and normal terrains (black) as measured by OMEGA on the Martian south pole. Right panel: the previous spectra modelled with a varying abundance of CO_2 and H_2O

is required. The best fit is obtained with a mixture of 15% in weight of H_2O ice, in the form of an intimate molecular mixture, rather than a simple geometrical mixture of two pure components; 2- on the scarps around the residual cap. This H_2O ice is almost completely CO_2 ice-free, and appears darker than the surrounding bright CO_2 ice-rich cap; there is a correlation between the albedo, the H_2O and CO_2 content of the ice: the darker the ice, the richer it is in H_2O, the more depleted in CO_2; 3- along vast zones expanding down slope in stratified terrains, tens of km wide, and tens of km away from the CO_2 ice-rich perennial caps. These water ice rich areas are CO_2 free: they appear much darker than the bright CO_2 ice-rich cap, both in the visible and the near infrared, which reflects their high dust concentration, and would confirm the scenarios where H_2O precipitates together with dust. The OMEGA processed data show that the H_2O to dust ratio varies, with no clear correlation with the local topography or relief (Sun illumination angle).

5. Conclusions

The OMEGA instrument is currently operating nominally. Its unprecedent performances will surely provide a new picture of Mars mineralogy and of its thermal and climatic history.

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