OMEGA: Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité

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The OMEGA visible and near-IR mapping spectrometer will reveal 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. It will provide global coverage at medium resolution (2-5 km) for altitudes from 1500 km to 4000 km, and high-resolution (< 350 m) spectral images of selected areas.

1. Introduction

OMEGA (Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité) is a visible and near-IR mapping spectrometer, operating in the spectral range 0.38-5.1 µm. Combining imaging and spectrometry, it will study 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 global coverage at medium-resolution (2-5 km) for altitudes from 1500 km to 4000 km, and high-resolution (< 350 m) spectral images of selected areas, amounting to a few percent of the surface, when observed from near-periapsis (< 300 km altitude). OMEGA will:

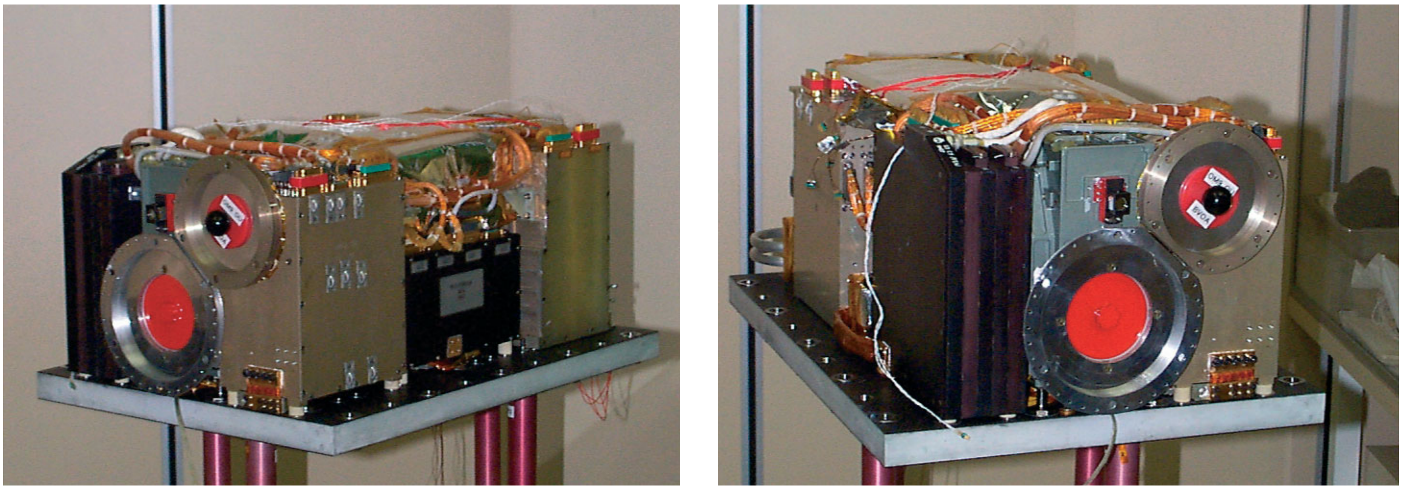


Fig. 1. The Flight Model of OMEGA.

- characterise the composition of surface materials, identifying the composition and the spatial and temporal distributions of the various classes of silicates, hydrated minerals, oxides and carbonates in soils and rocks, and of ices and frosts;
- study the spatial and temporal distributions of atmospheric CO_2, CO, H_2O and aerosols.

OMEGA will therefore address major questions concerning internal structure, geological and chemical evolution, past activity and present surface variegation. It will greatly contribute to understanding the evolution of Mars, ranging from geological timescales to seasonal variations. In particular, it will provide unique clues for understanding the H_2O and CO_2 cycles over martian history. It will play a major role in identifying areas of interest for future *in situ* exploration.

OMEGA was developed for the Russian Mars-96 mission. A spare unit was fully integrated and calibrated for that mission, and served as the basis for the Mars Express flight unit (Fig. 1). The major change was the complete redesign of the Main Electronics. OMEGA is managed as it was for Mars-96, between France, Italy and Russia, involving the following Institutions: IAS (Institut d'Astrophysique Spatiale, Orsay, France), LESIA (Laboratoire d'Etudes Spatiales et d'Instrumentation en Astrophysique, Observatoire de Paris/Meudon, France), IFSI (Istituto di Fisica dello Spazio Interplanetario, Rome, Italy) and IKI (Institute for Space Research, Moscow, Russia). The Principal Investigator and the Experiment Manager are both from IAS.

2. Scientific Objectives

The highly inclined (86°) and eccentric (0.6) orbit of Mars Express offers variable ground-track spatial sampling and latitude drift of the periapsis to produce near-global coverage. Consequently, OMEGA will achieve global coverage at medium resolution from medium altitudes, and will acquire high-resolution spectral images, for a fraction of the surface, with full selection flexibility, when operating close to periapsis. With its instantaneous field of view (IFOV) of 4.1 arcmin (1.2 mrad), global coverage should be attained in one martian year, at 2-5 km resolution, from altitudes of 1500-4000 km, while the highest resolution at periapsis should reach a few hundred metres.

2.1 Mineralogy

OMEGA will map the surface in order to identify the minerals of the major geological units. The goal is to study the evolution of Mars caused by internal activity, meteoritic impacts and interaction with the atmosphere.

Viking Orbiter and Mars Global Surveyor images indicate strong albedo variations down to subkilometre scales. Spectral images from the ISM mapping spectrometer on the Phobos mission in the near-IR also show large compositional variations at kilometre scales. 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. OMEGA should therefore reveal the diversity of the global surface, inferring compositional variations directly related to planetary evolution.

In addition, OMEGA's high-resolution observations close to periapsis will:

— increase the sensitivity for detecting constituents with restricted geographical extension. For example, the continuing failure to detect 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 a high density of impact craters, thus helping to understand Mars' hemispherical asymmetry;
— identify the composition of deposits and reveal 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 within 0.38-5.1 µm using 352 contiguous spectral elements (spectels), 7-20 nm wide. 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 is capable of measuring the content of OH radicals within the surface soil and rocks, so as to identify possible genetic relationships of hydrated minerals with major structural units such as volcanoes or canyons. In addition, fluidised 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 at 0.5-0.8 µm.

It is plausible that the martian CO_2 reservoir is dominated by carbonates. The detection and localisation of these 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 at 3.4-4.0 µm.

2.2 Polar caps and frosts

OMEGA will determine the spatial evolution of the two polar caps, by observing CO_2 and H_2O, and the layered deposits. It will enable discrimination between the permanent (residual) ice, at both poles, and the seasonal frosts. It 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 its origin and thus reveals 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 is capable of detecting minor species containing carbon or nitrogen; no such molecules have yet been observed, and their discovery would be of major interest for understanding the overall chemical evolution.

If there are permafrost layers, they may appear at the surface in a few regions. OMEGA would detect such icy-rich rocky sites. By identifying the borders of these underlying permafrost layers, the global distribution of ice within the crust can be evaluated, complementing the subsurface sounding by the MARSIS radar instrument of Mars Express. Identification of the sites and phases where most of the water resides is a major goal, in particular when searching for the most favorable sites for possible past organic activity, and assessing water resources for future exploration.

2.3 Atmospheric evolutionary processes

OMEGA is well-suited for monitoring some of the atmospheric parameters with key roles in martian meteorology: total pressure, column densities of the H_2O and CO minor constituents, content of aerosols, and, in some cases, vertical temperature distribution. It complements the PFS and SPICAM investigations, with lower spectral sampling but at much higher spatial resolution. The ISM/Phobos imaging spectrometer, which mapped part of the martian surface in February-March 1989, demonstrated the ability of IR spectroscopy, even at low spatial sampling (21 km), to retrieve the altimetry of Mars (100 m vertical resolution) accurately. The observations of CO_2 absorption bands with OMEGA will provide, as did ISM/Phobos, a measurement of the ground pressure. As the altimetry of Mars is now of higher quality, thanks to continuing MOLA/Mars Global Surveyor 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. The expected variations of a few percent in atmospheric pressure will be measured easily by OMEGA (the design goal is 1% in accuracy), in the absence of global dust storms.

OMEGA will monitor the CO and H_2O partial pressure for each resolved pixel. The spatial distribution of these minor constituents is still a field of great interest, following the ISM/Phobos discoveries of unexpected variations in their mixing ratios from volcano areas and surrounding plains.

OMEGA has four major advantages over ISM/Phobos for atmospheric studies:

— about double the spectral resolving power. This is important for improved retrieval of the H_2O and CO total column densities;
— extension of the spectral range up to 5.1 µm. The 3.2-5.1 µm range accesses the thermal emission of the martian disc for most of the dayside regions (surface temperature higher than about 240K). It will be possible to infer the thermal profile from the inversion of the strong CO_2 ν_2 band at 4.3 µm. In addition, new information, complementing that obtained from the diffuse solar spectrum, will be obtained on the CO abundance from its absorption bands at 4.7 µm;
— an IFOV 2.9 times higher, leading to a spatial sampling 70 times higher at periapsis;
— greatly extended planetary coverage, because of the near-polar orbit instead of the equatorial orbit of the Phobos mission.

Another important atmospheric parameter is the aerosol content. It has a key role in the general circulation, because the dust modifies the radiative properties of the atmosphere through its heating and cooling rates. As the atmospheric dust content shows very strong variations, both on a local scale and over a seasonal cycle, continuous monitoring is as necessary as knowing the local thermal profile. The analysis of ISM/Phobos data has shown that the aerosol abundance can be estimated from the slope of the reflected component of the spectrum. The same information will be derived by OMEGA over the whole martian disc. Moreover, OMEGA will be able to identify the aerosols through their composition (silicate and/or icy-rich particles), and assess their distribution with altitude and time, in addition to their optical properties. In particular, these measurements can be correlated with surface and climatic seasonal properties, towards an integrated (surface, atmosphere, aerosols) database of unique meteorological value.

Observations by the Short Wavelength Spectrometer (SWS) of ESA's Infrared Space Observatory (ISO) provided a high-quality IR spectrum of Mars, which is helping to prepare for OMEGA observations. In particular, it demonstrated the feasibility of retrieving dust opacity from the strong 2.7 µm CO_2 band. The detection of faint fluorescence emission in CO_2 at 4.3 µm by ISO provides another objective: OMEGA will confirm and study the spatial variation of these emissions, which give information on the highest part of the stratosphere.

3. OMEGA Performance

The capabilities of OMEGA can be summarised as:

— imaging: 128 contiguous IFOVs of 1.2 mrad (4.1 arcmin) each, corresponding to < 350 m surface sampling at periapsis;
— spectral: 352 (or 400, depending on the summing mode chosen for the visible channel) contiguous spectels to acquire the spectral range 0.38-5.1 µm for each resolved pixel, with 96 (or 144) spectels to cover the 0.38-1.05 µm range, with a spectral sampling of 7 nm (or 4.5 nm), 128 spectels to cover 0.93-2.73 µm, with 13 nm spectral sampling, and 128 spectels to cover 2.55-5.1 µm, with 20 nm sampling;
— photometric: S/N > 100 over the full spectral range, allowing the identification of absorptions and thermal variations to the percent-level.

The high sensitivity of OMEGA and its high spectral and spatial sampling capabilities should allow the unambiguous detection and compositional identification, on each resolved pixel, of the surface minerals and their OH/H_2O content, the atmospheric major and minor constituents, and the aerosols. For example, if there are carbonates at concentrations of a few percent, they should be readily detected. At the same spatial scale of a few hundred metres, the surface temperature will be mapped with an accuracy of better than 1K.

Such performance will provide an unprecedented harvest of results in a wide variety of Mars and planetary science fields such as: geology, tectonic and chemical planetary evolution, climatology and meteorology, atmospheric processes and exobiology.

4. Instrument Description

4.1 Instrument concept

OMEGA is a mapping spectrometer, with coaligned channels working in the 0.38-1.05 µm visible and near-IR range (VNIR channel) and in the 0.93-5.1 µm short wavelength IR range (SWIR channel). The data products constitute three-dimensional (x, y, λ) ‘image-cubes’, with two spatial and one spectral dimensions.

The VNIR channel uses a bi-dimensional CCD detector, operating in a pushbroom mode. The telescope’s focal plane provides one cross-track line corresponding to the entire 8.8° FOV, defined by an entrance slit; the second dimension of the image is provided by the motion of the spacecraft. Each line is spectrally dispersed along the columns of the array, the slit being imaged through a concave holographic grating.

The SWIR channel operates in the whiskbroom mode. Each imaged pixel is focused by an IR telescope on a slit, followed by a collimator. The beam is then split towards two separated spectrometers, to acquire the IR spectrum of each resolved pixel on to two InSb linear arrays of 128 spectels each, working at 0.93-2.73 µm and 2.55-5.1 µm. A scanning mirror in front of the telescope provides cross-track swaths 16-128 pixels wide, for a maximum FOV of 8.8° (matching the VNIR FOV). The spacecraft motion provides the second spatial dimension. The images are built as shown in Fig. 5. Each array is cooled to 70K by a dedicated cryocooler, while the entire spectrometer is cooled to 190K by a conductive link to a passive radiator.

The typical IR integration time, defined by the spacecraft ground-track velocity and the spatial sampling chosen, is 2.5 ms or 5 ms. The corresponding VNIR integration times are 50-200 ms, depending on the swath width (and hence the altitude). With such integration times, an S/R of > 100 is specified over the entire spectral range.

OMEGA comprises two distinct units, coupled by a 0.7 kg electrical harness:

— a Camera unit (OMEga Camera, or OMEC), carrying the VNIR and SWIR

Fig. 2. VNIR optical layout.

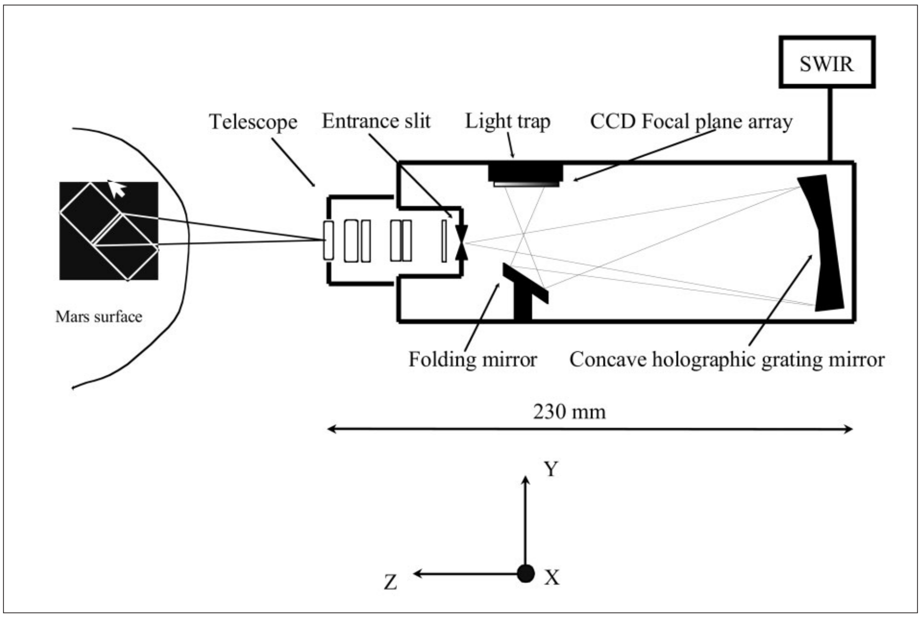
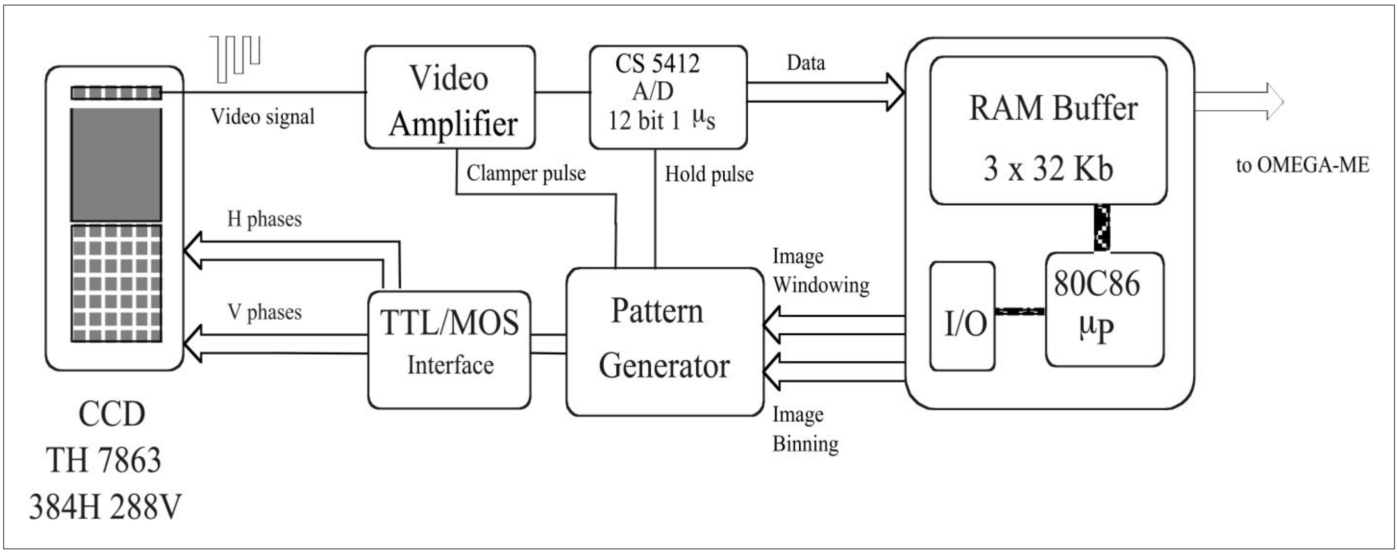


Fig. 3. VNIR electronics.



spectrographs, their associated electrical devices, and an electronics assembly for controlling the camera. All units are integrated on a common baseplate. The mass and size of OMEC are, respectively, 23.5 kg, and 290x180x150 mm;

— a Main Electronics module (OMEga-Me, or OMEM), for the data processing and the general management of the instrument. Mass is 4.6 kg.

OMEGA's power requirement is 27.4 W during the ~2 h cooling of the focal planes, and 47.6 W peak power during observation.

4.2 VNIR

VNIR comprises two optical subsystems: a focusing telescope with its focal plane on a slit, and a spectrometer to spread the slit image in the spectral dimension. It provides image data in the spectral range 0.38-1.05 µm, achieving a maximum spatial sampling of 0.4 mrad and a maximum spectral sampling of 50 Å.

The optical layout and major components of VNIR are summarised in Fig. 2 and

Table 1. OMEGA's VNIR characteristics.

Element/Parameter	*Description/value*
Telescope	Double Gauss objective
Field of view	8.8°
Spectrometer	concave holographic grating mirror
Detector	CCD Thomson TH 7863 384×288 pixels
Detector size	8.8×6.6 mm
Pixel size	23×23 µm
Spectral range	0.38-1.05 µm
Spectral resolution	70-200 $\lambda/\Delta\lambda$
Dynamics	12-bit

Table 2. VNIR telescope and spectrometer optical parameters.

Aperture	15.6 mm
Focal length	57.6 mm
Field of view	8.8°
F number	3.7
Scale factor	1°/ mm
Entrance slit width	50 µm
Grating type	concave holographic grating mirror
Grooves/mm	65
Dispersion	1071Å/mm
Wavelength range	0.38-1.05 µm
Grating size	40 x 10 mm
Material	Silica
Manufacturer	Jobin Yvon

Table 1. A refractive telescope focuses the image on to a slit placed on the Rowland circle of an aberration-corrected concave holographic grating mirror. This element reflects and disperses the light on a CCD detector tangent to the Rowland circle. The detector used is the TH7863 frame-transfer CCD produced by Thomson. The grating mirror creates a flat image at the focal plane, matching the flat detector matrix to the grating without other optical components. Each row of the CCD frame contains an image of the slit at a given wavelength, while each column contains the spectrum of a point along the slit. The bi-dimensional image of the surface is obtained by the pushbroom technique, in which the spacecraft's movement along its orbit scans the slit across the planetary surface. The electrical signal from the detector is amplified and then digitised by a fast 12-bit analogue/digital converter (ADC). Following conversion, all data are processed within the OMEGA Main Electronics module.

In order to decrease the detector noise, the VNIR channel is cooled to 190K by conduction to the SWIR mechanical unit.

Refractive optics are preferred over reflective because of the large (8.8°) field of view requirement. The telescope has a 6-element objective similar to that of a modern commercial photographic camera. The shape of the elements and the types of optical glass were chosen to obtain the best chromatic aberration corrections over the entire spectral range. The last element serves as a field lens which matches the entire objective with the grating to avoid light losses. To avoid stress in the lenses at the working temperature, the two doublets are not cemented. The two glasses, FK54 and fused silica, have very different expansion coefficients of 8×10^{-6} K^{-1} and 0.55×10^{-6} K^{-1} at room temperature. The entrance aperture of 15.6 mm is defined by a diaphragm between the two doublets.

An aberration-corrected concave holographic grating is placed 142.7 mm from the entrance slit (which is in the focal plane of the telescope). The grating is tilted to form the spectrum at an angle of roughly 6° from the optical axis. This angle does not allow CCD insertion near the entrance without beam obscuration, so a folding mirror deflects the beam toward the side of the assembly, where the CCD can be mounted with ample clearance. The zero-order spectrum, at 4.5° from the folded optical axis (lying in the y-z plane), is directed into a light trap to prevent degradation of the image. The first-order spectrum ranges in angle from 6° at 0.35 µm to 10° at 1.05 µm. The second- and higher order spectra can, in principle, also degrade the data. Their contributions depend both on the grating efficiency and the spectral distribution of the incident radiation. For this reason, a dedicated filter is mounted in front of the detector. The concave, spherical, holographic grating in a Rowland mounting – where the entrance slit and the spectrum are on radii of curvature of the grating – makes the spectrometer compact, light and simple. In fact, no collimator or camera lens is required and the spectrometer has only one element. Moreover, the focal plane image is flat, matching the planar CCD sensors. Since the concave holographic grating is obtained by recording a perfect optical pattern with groove spacing absolutely constant, it has no ghosts. Stray light is also at a much lower level than the best ruled gratings. Therefore, concave holographic gratings generally have a much higher signal to noise ratio than classically ruled gratings.

The optical performances were computed by ray tracing. In the focal plane, the spot diagram is about the pixel size (23×23 µm). For off-axis propagation (4.4°), the total spot size is about 2 pixels in the sagittal direction (the z direction, see Fig. 2). More precisely, on axis and at 0.7 µm, 98.8% of the energy falls within a 23×23 µm pixel; at 4.4° off-axis and 0.4 µm, 74% of the energy falls within a CCD element. When the light propagates off-axis, the spot size is smaller for the shorter wavelengths.

The block diagram of the VNIR electronics is shown in Fig. 3. The Pattern Generator (PG) determines the CCD integration time, and generates the timing signals necessary to transfer an image from the light-sensitive area to the masked zone and then to the output shift register of the CCD. The output of the CCD is then amplified and converted by a fast 12-bit ADC under control of the PG.

The timing of the instrument imposes a relatively high frequency for CCD operation. In fact, depending on the distance from the planet and hence on the spacecraft speed, the time T_R between consecutive frames can be chosen as: 50, 100, 200, 400 or 800 ms. During the T_R period the integration, readout and data transmission processes must occur. To save time, integration and transmission of the previous frame are overlapped. Because the maximum data value that can be transmitted during T_R is limited to 12 288 bytes, it is not possible to read the total frame of 384×288 pixels, corresponding to 110 592 bytes. We are forced to read only a subframe, or to reduce the number of pixels by summing them on chip. The combination of different scientific requirements, integration times and hardware limitations led us to the definition of 40 operation modes, which can be selected through commands sent to the spacecraft, ranging from the nominal (spatial × spectral) mode (128×96 with summation of 3×3 pixels), to the high spectral resolution mode (64×144), to the high-speed mode (16×96). Summation along columns and rows decreases the spatial and spectral resolution, but increases signal-to-noise ratio considerably. The implementation of mode 16×74 is the most critical owing to the short time available to complete all the operations (T_R = 100 ms). For this reason, the Pattern Generator provides two values for the pixel readout frequency: f_{slow} = 500 kHz when the pixel voltage has to be digitised and f_{fast} = 4 MHz when the pixel is simply read from the CCD output register without any digital conversion.

4.3 SWIR

The SWIR channel consists of a telescope and its fore-optics, a beam splitter and two spectrometers, each with its detector array actively cooled (Fig. 4).

The telescope is a Cassegrain of 200 mm focal length, an f/4 aperture, leading to a 1.2 mrad (4.1 arcmin) IFOV and a 15 arcmin free FOV (including the positioning tolerances). The distance between the primary and secondary mirrors is 51 mm; between the secondary mirror and the image plane is 82 mm.

In front of the telescope, a fore-optics system has the primary goal of providing a cross-track scanning of the IFOV. It includes two mirrors, moving and fixed. The total scanning angle is ±4.4° (FOV = 128 IFOV), and is adjusted to the OMEGA viewing direction. The control of the scanning mechanism is performed by a dedicated FPGA-based electronic subsystem.

Focused by the telescope on an entrance slit, through a shutter, the beam is first collimated, then separated, by a dichroic filter with its cut-off wavelength at 2.7 µm towards two spectrometers, operating at 0.93-2.73 µm and 2.55-5.1 µm. Each spectrometer includes a blazed grating working at its first order, and an optical

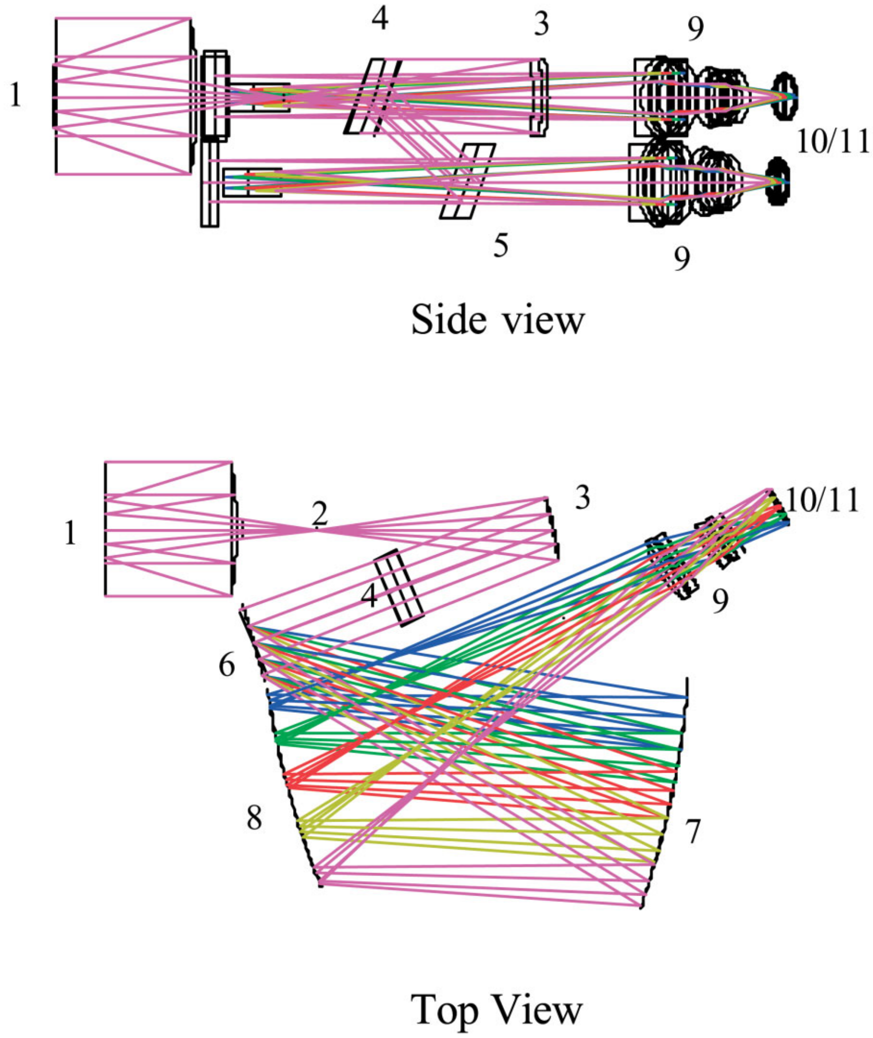


Fig. 4. SWIR channel optical layout.

1: Cassegrain telescope of 200 mm focal length, f/4 aperture, 4 arcmin IFOV and 15 arcmin free FOV (including the positioning tolerances).
2: entrance slit 800 µm high (spatial dimension).
3: collimator (off-axis parabolic mirror R = 192.85 mm, offset 37.14 mm) to collimate the beam from the slit to the dichroic and the gratings.
4: dichroic filter, separates the two channels (short wavelength is reflected; long wavelength is transmitted).
5: folding mirror, reflects the short wavelength channel to the grating.
6: blazed flat gratings working in the first order. Short wavelength: groove density 180/mm, incidence angle –6.5° and blazed wavelength 1.7 µm; long wavelength: groove density 120/mm, incidence angle –10.6° and blazed wavelength 3.8 µm.
7: spherical collector mirrors (R = 378.49 mm), re-image the diffracted image of the slit near the field mirrors.
8: spherical field mirrors (R = 378.49 mm), image the grating inside the objective.
9: objectives, four spherical ZnSe lenses, re-image the diffracted image of the slit.
10: sets of filters in front the detector.
11: InSb detector linear arrays (128 pixels of 90x120 µm photosensitive area and pitch of 120 µm.)

reflective system, then a field mirror and a refractive refocusing system that gives a large aperture on the detection block (f/1.6). It images the spectrum on to a 128-element InSb linear array, cooled to < 80K, and multiplexed by a charge transfer device. Sets of filters are implemented in front of the detector to reject the contribution of other orders from the grating.

The InSb photodiodes were manufactured by SAT (F). The dimensions of each photosensitive element is 90×120 µm, with a pitch of 120 µm. All elements of the focal planes are hybridised on a ceramic with two electric circuit layers to connect the elements. The ceramic is glued to a titanium baseplate and covered by a titanium frame that holds the filters.

An internal calibration source controls potential shifts of the overall spectrometer transmission and calibrates the relative response of each pixel. The tungsten lamp, operated as a black body, is heated to different temperatures. The calibration beam is reflected towards the spectrometer by diffusion on the back side of the entrance slit.

SWIR requires accurate thermal control, at three levels:

— the electronics and the cryocoolers heads are internally linked by heat pipes and coupled to a 280K radiator.

Table 3. Typical OMEGA observing sessions.

Maximum altitude (km)	300	1500	4000
True anomaly	0	60	95
Pixel size	< 360 m	< 1.8 km	< 4.8 km
Track width (px)	16	64	128
Track width (km)	5-7	60-120	300-600
Track length (px)	~ 7500	~ 2000	~ 1000
Track length (km)	~ 3000	~ 3000	~ 3000
Session duration (min)	~ 12	~ 12	~ 24
Data volume (Mbit)	~ 200	~ 200	~ 200

Table 4. OMEGA total data budget.

Investigation	*Global Mapping (100% coverage)*	*High-Resolution (5% coverage)*	*Seasonal Variation (5% coverage)*
Required number of non-overlapping contiguous sessions	250	500	500
Total data volume	~ 50 Gbit	~ 100 Gbit	~ 100 Gbit

— the spectrometer must be cooled to ≤ 190K, to minimise the thermal background and to enable the detectors to reach their operational temperature (< 80K). This is achieved by copper links to a spacecraft radiator;
— the IR detectors must be cooled to < 80K, controlled with an accuracy of better than 0.1K. This is done by using copper heat links to two cryocoolers, one for each array: Inframetrics 13000-series integral Stirling cycle coolers controlled by dedicated electronics. Their guaranteed lifetimes are > 2500 h;

4.4. OMEGA Main Electronics

The main electronics power and control the instrument, acquire and compress all scientific data on-line, and interface with the spacecraft telecommand/telemetry system. The entire system is cold-redundant. Within OMEga-Me, the Command and Data Processing Unit (CDPU) has the following tasks:

— acquisition of all scientific data from VNIR and SWIR;
— formatting for realtime data compression;
— wavelet-based data compression, followed by formatting of processed data;
— reception and formatting of housekeeping data;
— forwarding of all data to the spacecraft telemetry system.

The CDPU is based on a TSC21020 Temic processor, and integrated, together with a 6 Mbyte SRAM, into a 3D-packaged highly miniaturised cube, inherited from the ÇIVA instrument aboard the Rosetta mission.

5. Ground Calibration

OMEGA was fully calibrated before its delivery and integration with the spacecraft. The calibration plan included spectral, geometric, photometric, sample and functional tests, with the following goals:

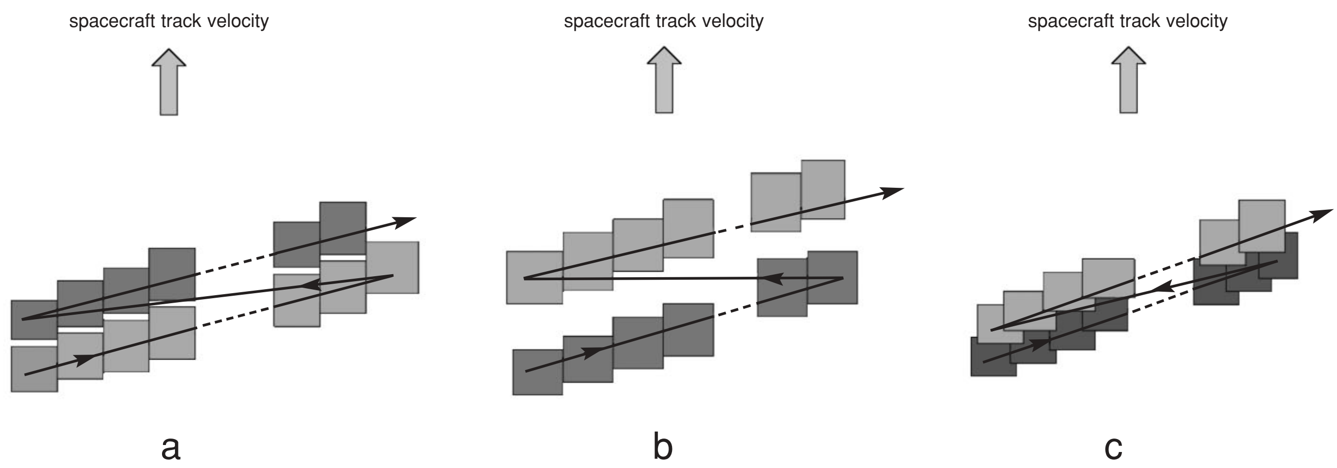


Fig. 5. Whiskbroom building of the IR image, with contiguous swaths (a), undersampling (b) and oversampling (c).

- spectral calibration: determination of the spectral centre position and width of each spectel, with an accuracy of better than 1/5 of the spectel width, within the entire FOV;
- photometric calibration: determination of the Data Number (DN) value of each spectel for a given incident power. Accuracy: better than 1% spectel-to-spectel (relative) and better than 20% in absolute terms;
- geometric calibration: determination of the IFOV and FOV of each channel, their spatial response in azimuth and declination, and their relative coalignment;
- sample calibration: determination of the actual response of OMEGA when imaging targets with minerals and mixtures of known composition;
- functional calibration: determination of the instrumental response for all programmable parameters and modes.

A dedicated calibration facility was built at IAS, comprising two major components:

- an ultra-clean vacuum chamber, where OMEGA was installed on a stage remotely movable in two angular directions around the entrance pupil of the instrument. The chamber's thermal screens and regulated platforms cool the spectrometers to any temperature within the range 300-150K, while maintaining OMEga-Me at a different and higher temperature. The incident beam, from the optical bench, passes through a large sapphire window to illuminate OMEGA;
- an optical bench, purged with dry nitrogen, containing a 4 m focal length and 400 mm-diameter collimator, imaging one of the following four sources on to OMEGA: a monochromator, a black body with temperature stabilised up to 1200°C, a point source (1/3-pixel) illuminated by a high-temperature (2500°C) ribbon black body, and a cold black body (down to 70K).

During calibration, OMEGA was operated through its Electrical Ground Support Equipment (EGSE) and spacecraft simulator, while the facility (vacuum chamber and optical bench) was controlled by a dedicated computer, acquiring all relevant parameters (monochromator wavelength, angular positions of the moving stage, temperatures), and acting as the slave in a master/slave configuration with the EGSE, ensuring synchronous acquisition with OMEGA scientific data.

6. Operations

Given the global Mars Express orbital and downlink constraints within the nominal (one martian year) duration of operations, the OMEGA science goal of complete planetary coverage cannot be achieved at the highest possible resolution, obtained close to periapsis. Thus, the OMEGA investigation is divided into three global modes:

- global (100% complete) coverage at 2-5 km spatial resolution, acquired from altitudes of 1500-4000 km;
- high-resolution (< 350 m) coverage of a fraction (> 5%) of the surface, with high flexibility of site selection (longitude and latitude), acquired close to periapsis;
- seasonal monitoring of surface and atmospheric composition at given locations, with wide flexibility of site selection (longitude and latitude).

These investigations will be conducted using different operational and instrumental modes. With a fixed IFOV, OMEGA has the flexibility to accommodate operations from a variety of altitudes, through a number of acquisition times, swath widths and data compression modes. As the IR maps will be built by contiguous cross-track swaths (Fig. 5) in a wiskbroom mode, the displacement of the spacecraft track during the acquisition of a swath should be as close as possible to the pixel size (5a) in order to avoid both undersampling (5b) and oversampling (5c).

At periapsis, where the orbital ground velocity is about 4 km s^{-1}, the nadir track shifts by one IFOV in less than 100 ms. This duration corresponds to acquiring cross-track swaths 16 pixels wide, with a nominal integration time of 5 ms. Thus, the nominal OMEGA high-resolution mode, operated from altitudes of < 350 km, will build maps 16 pixels wide. For medium-resolution modes, 32-pixel swaths will be chosen when operating from altitudes of 350-700 km, and 64 pixels from altitudes up to about 1500 km. From 1500 km to 4000 km, OMEGA will provide global coverage: it will use the full 128-pixel FOV, for which one swath is acquired, with nominal integration time, in 640 ms. However, at these altitudes, the ground-track velocity is less than 2 km s^{-1}, and the spacecraft ground-track shifts by one pixel (one IFOV) in 1-2.5 s. In order to avoid oversampling, OMEGA will sum several (up to 4) contiguous swaths. This is illustrated in Table 3, indicating three typical session sizes, with the assumption of a (pessimistic) compression factor of 3, and spatial summing of two contiguous swaths for the global coverage mode. The non-overlapping sessions required to achieve the three objectives quoted above are covered in Table 4. These budgets are based on building maps with non-overlapping sessions and performing limb observations. These require the availability of dedicated spacecraft pointing modes:

- nadir pointing, either along the track, or with a constant off-track angle (up to 30°), for all surface mappings;
- 3-axis inertial pointing, for a few atmospheric studies and some specific surface observations.

The data, as soon as they are received at ESOC on the Data Distribution System (DDS) are transferred to IAS, on a dedicated server, where they are decompressed, PDS formatted and archived. Each cube of data is submitted to a quick-look analysis (for both scientific data and housekeeping) to validate its completeness and the quality of the downloaded data. In parallel, orbital and spacecraft attitude parameters are received from ESOC via ESTEC, out of which geometric cubes are built, first as predicted values and then after proper reconstruction. These cubes are in-house PDS-formatted in a manner identical to the scientific ones, to enable a reconstruction of the mapped areas on the martian surface.

The entire OMEGA team has direct, full and protected access to the data server at IAS, on which a variety of auxiliary files (such as calibration files) are available. In accordance with ESA policy, the data processing is restricted to the team during the proprietary period.

For the distribution and archiving strategy after this period, OMEGA will comply with the overall ESA scientific data policy. The goal is to prepare a final level of data set, constituting: the raw compressed data, the decompression procedures, the decalibrated data for each pixel at the surface of Mars, referred to a (latitude, longitude) frame, and the complete spectrum from 0.38 µm to 5.1 µm, in physical units. This geometric reconstruction will include the instrumental and spacecraft corrections, thus allowing image-cubes to be generated. These calibrated image-cubes will be formatted according to the Planetary Data System (PDS) standard for distribution and archiving, through the ESA Planetary Science Archive. The actual storage medium will depend on availability at the time of operations; at present, erasable/rewritable CD-ROMs and DVDs are being considered.