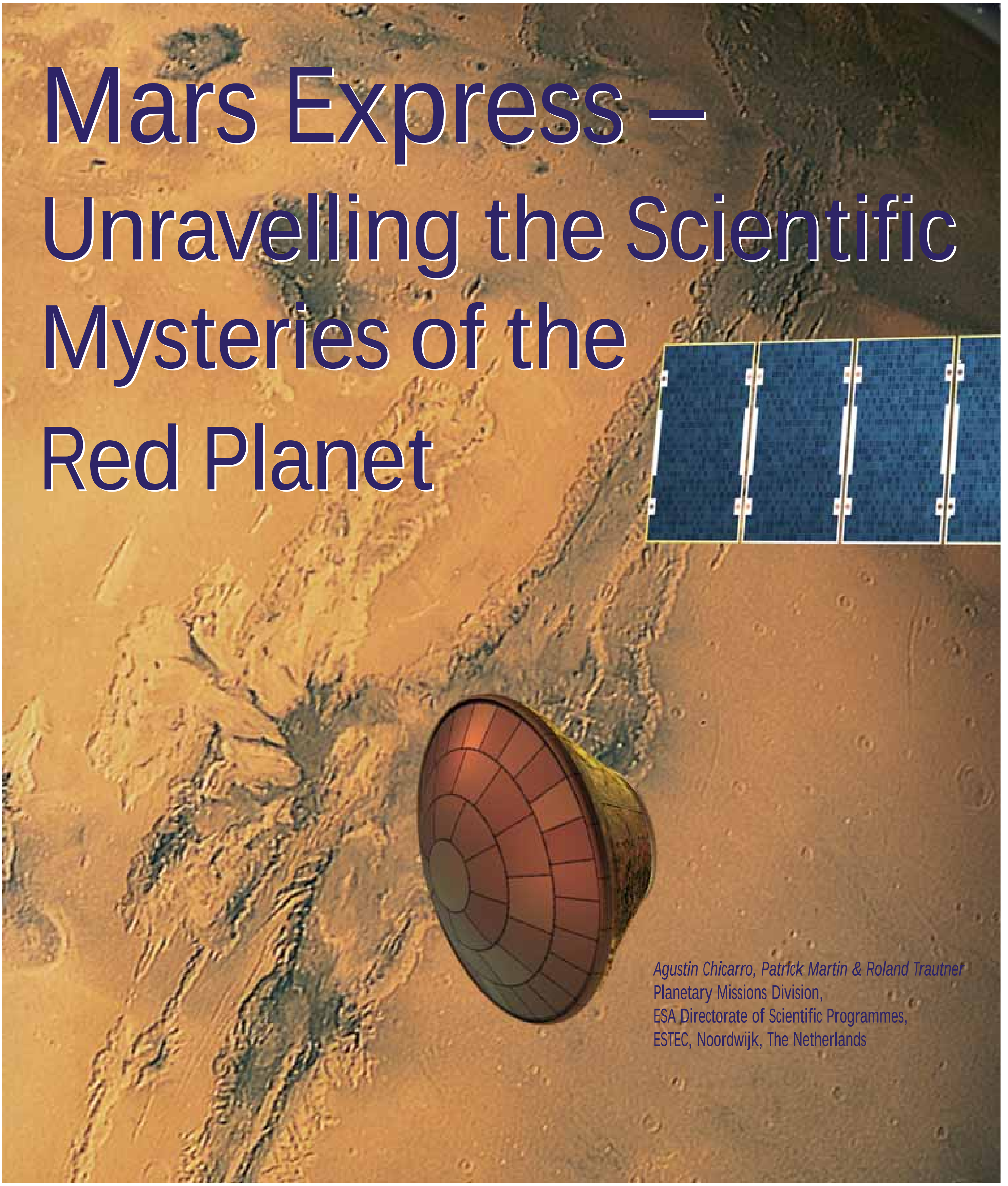

Mars Express – Unravelling the Scientific Mysteries of the Red Planet

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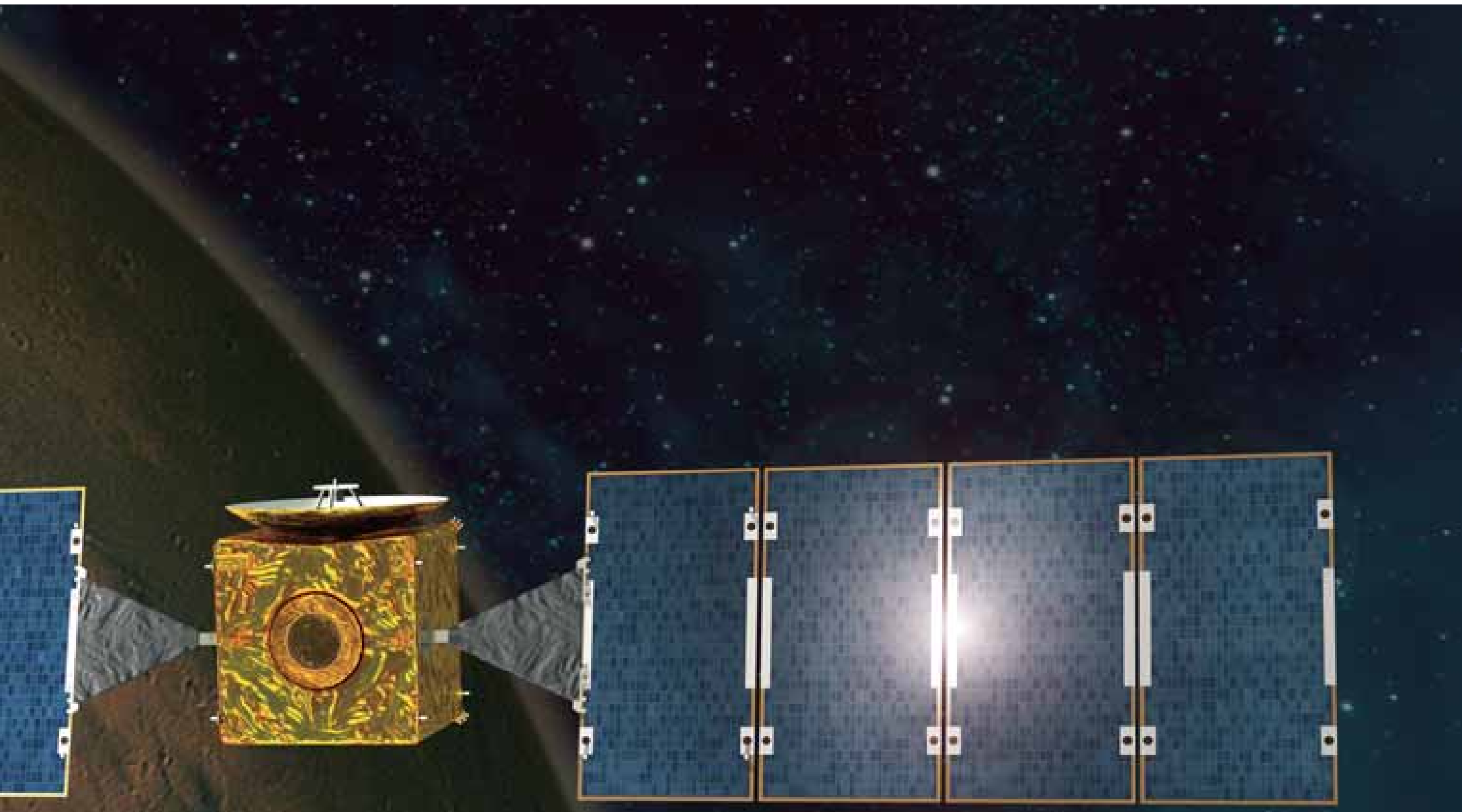


Mars Express is the first ESA mission to the Red Planet, and is in fact the first European mission to any planet. Launched on 2 June 2003, it includes both an orbiter spacecraft and a small lander, called 'Beagle 2' after Charles Darwin's sailing ship 'Beagle'. As the first 'flexi-mission' in the revised long-term ESA Cosmic Vision Science Programme, it has been developed in record time - about five years from concept to launch - and much more cheaply than any previous scientific mission to Mars

Historical Perspective

Before embarking on the Mars Express mission, ESA and the scientific community had conducted several feasibility studies of potential future European missions to the Red Planet - including Marsnet and Intermarsnet. Conducted over a period of more than ten years, those studies focussed on a network of surface stations complemented by an orbiter. The network concept was considered a high scientific priority in Europe until the demise of the Russian Mars-96 mission, which included many outstanding European scientific instruments. In addition to taking over several of the major goals that had been set for Mars-96 in terms of global study of the planet, Mars Express also addresses two major new themes: water and life.

Importantly, the scientific investigations to be conducted with Mars Express are absolutely complementary to those of recent US Mars Global Surveyor and Mars Odyssey orbital missions, as well as the Mars Exploration Rovers, have been launched this year. Very close collaboration has also been established with the Japanese Nozomi mission, the orbital characteristics and scientific objectives of which also fit well with those of Mars Express.

ESA has provided the launcher, the Mars Express orbiter, the mission operations and part of the Beagle 2 lander, the rest of the lander being funded by a UK-led consortium of space organisations. The orbiter's instruments have all been provided and funded by scientific institutions throughout the ESA Member States. Other countries, including the USA, Russia, Poland, Japan and China, are also participating in various scientific capacities. The ground segment includes the Mission Operations Centre at ESOC in Darmstadt, Germany, and ESA's new deep-space ground station at New Norcia in Western Australia. Support from NASA's Deep Space Network (DSN) will help to increase the scientific data return early in the mission. The Mars Express orbiter was built by Astrium in Toulouse (F), as Prime Contractor, and involved a large number of other European companies as subcontractors.

Artist's impression of the Mars Express spacecraft in polar orbit around the Red Planet

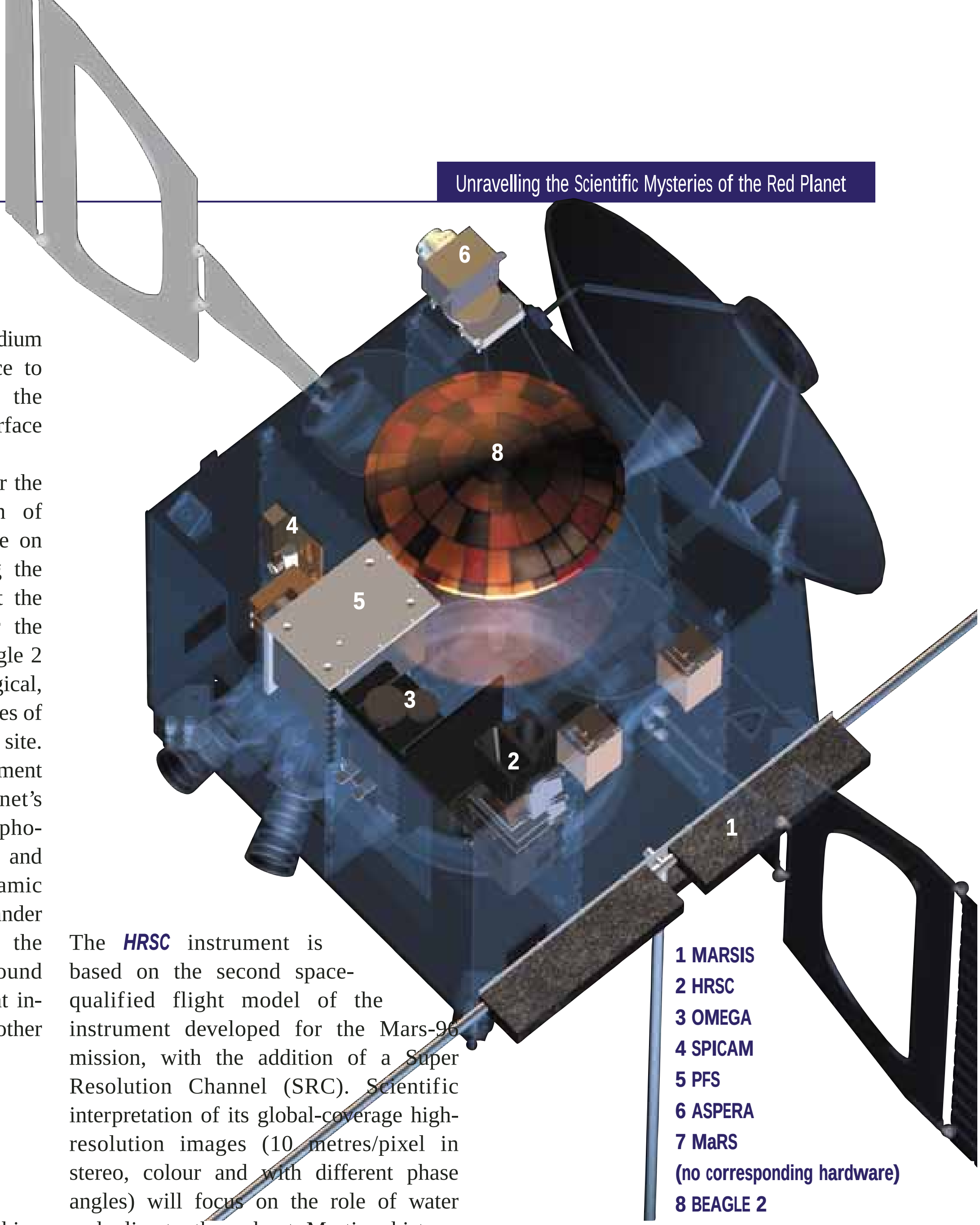
THE SCIENTIFIC PAYLOAD OF MARS EXPRESS

Acronym	Instrument	Principal Investigator	Lead Institute	Countries Participating
Orbiter				
HRSC	Super/High-Resolution Stereo Colour Imager	G. Neukum	DLR, Berlin FU Berlin	D, F, RU, USA, SF, I, UK
OMEGA	IR Mineralogical Mapping Spectrometer	J.P. Bibring	IAS, Orsay	F, I, RU
PFS	Planetary Fourier Spectrometer	V. Formisano	CNR, Frascati	I, RU, PL, D, F, E, USA
MARSIS	Subsurface-Sounding Radar/Altimeter	G. Picardi & J. Plaut	Univ. of Rome NASA/JPL	I, USA, D, CH, UK, DK, F, RU
ASPERA	Energetic Neutral Atoms Analyser	R. Lundin & S. Barabash	RFI, Kiruna	S, D, UK, F, SF, I, USA, RU
SPICAM	UV and IR Atmospheric Spectrometer	J.L. Bertaux	CNRS, Verrieres	F, B, RU, USA
MaRS	Radio Science Experiment	M. Pätzold	Univ. of Cologne	D, F, USA, A
Lander				
Beagle 2	Suite of imaging instruments, organic and inorganic chemical analysis, robotic sampling devices and meteorological sensors	C. Pillinger & M. Sims	Open Univ. Leicester Univ.	UK, D, USA, F, CH, RU, PRC, A, E

The Scientific Goals

The Mars Express orbiter spacecraft represents the core of the mission, providing unprecedented global data on the planet, and its surface, subsurface and atmosphere in particular. The Beagle 2 lander was selected on the basis of its innovative scientific goals and very challenging payload. The resulting orbiter-lander combination constitutes a very powerful tool with which to focus on two largely related issues, namely the current inventory of ice and/or liquid water, and possible traces of past or present biological activity on the planet.

The broad scientific objectives of the orbiter are: global colour and stereo high-resolution imaging with 10 m resolution and imaging of selected areas at 2 metres per pixel, global mineralogical mapping of the surface in the infrared, radar sounding of the subsurface structure down to the permafrost, global atmospheric composition and circulation studies, study of



atmosphere/surface/interplanetary medium interactions, as well as radio science to derive critical information about the planet's atmosphere, ionosphere, surface and interior.

The ultimate scientific objective for the Beagle 2 lander is the detection of evidence of extinct and/or extant life on Mars, a more attainable goal being the assessment of whether conditions at the landing site were ever suitable for the emergence and evolution of life. Beagle 2 will therefore perform in-situ geological, mineralogical and geochemical analyses of selected rocks and soils at the landing site. It will also study the Martian environment via chemical analysis of the planet's atmosphere, via localised geomorphological studies of the landing site, and via the investigation of dynamic environmental processes. Further lander studies will include analysis of the subsurface regime using a ground penetration tool and a first attempt at in-situ isotopic dating of rocks on another planet.

The Science Instruments

On the Orbiter

The orbiter's scientific payload, weighing about 116 kg, consists of six instruments, in addition to a radio-science experiment that does not involve any hardware. The six instruments fall into two catagories: those dealing primarily with the solid planet by observing its surface and subsurface – namely the Super/High-Resolution Stereo Colour Imager (HRSC), the Infrared Mineralogical Mapping Spectrometer (OMEGA) and the Subsurface-Sounding Radar Altimeter (MARSIS) – and those studying the Martian atmosphere and environment – namely the Planetary Fourier Spectrometer (PFS), the Ultraviolet and Infrared Atmospheric Spectrometer (SPICAM) and the Energetic Neutral Atoms Analyser (ASPERA). The Radio-Science Experiment (MaRS) will provide insights into the planet's internal structure, surface roughness, neutral atmosphere and ionosphere.

The ***HRSC*** instrument is based on the second space-qualified flight model of the instrument developed for the Mars-96 mission, with the addition of a Super Resolution Channel (SRC). Scientific interpretation of its global-coverage high-resolution images (10 metres/pixel in stereo, colour and with different phase angles) will focus on the role of water and climate throughout Martian history, the temporal evolution of volcanism and tectonics, the surface/atmosphere interactions, the establishment of an accurate chronology, and observations of the planet's moons Phobos and Deimos.

OMEGA is a visible and near-infrared mapping spectrometer derived from the spare model built for the Mars-96 mission. Operating at wavelengths between 0.38 and 5.1 µm, it will provide global coverage of Mars with 1 to 5 km resolution from orbital altitudes of between 1000 and 4000 km, and higher-resolution (few hundred metres) snapshots of selected areas of the surface. OMEGA will characterise the composition of surface materials, study the temporal and spatial distribution of atmospheric carbon dioxide, carbon monoxide and water vapour, identify the aerosols and dust particles in the atmosphere, and monitor the processes transporting surface dust. It will contribute to our understanding of the planet's evolution on seasonal to geological time scales and provide unique clues for understanding the water and carbon-dioxide cycles throughout Mars' evolution.

MARSIS is a low-frequency radar sounder and altimeter with ground-penetrating capabilities. It uses synthetic-aperture techniques, two 20 m booms and a secondary receiving antenna to isolate subsurface reflections, and will be the first radar sounder to investigate both the surface and subsurface of Mars. Its primary objective is to map the distribution of water, both liquid and solid, in the upper portions of the Martian crust to a depth of 3 to 5 km. Detection of such water reservoirs addresses key issues in the geological, hydrological, climatic and possibly biological evolution of the planet. Secondary objectives for MARSIS include subsurface geological probing, surface-roughness and topography characterisation on scales ranging from tens of metres to kilometres, and ionospheric sounding to characterise the interactions of the solar wind with the ionosphere and the upper Martian atmosphere.

PFS is an infrared spectrometer optimised for atmospheric studies. Also derived from a similar instrument developed for the Mars-96 mission, it is able to cover the wavelength ranges of 1.2 to 5 µm and 5 to 45 µm with a spectral resolution of 2 cm^{-1} and a spatial resolution of 10 to 20 km. Its main scientific objectives are global long-term three-dimensional monitoring of the temperature field in the lower Martian atmosphere, measurement of the variations in water vapour and carbon monoxide, determination of the size distribution, chemical composition and optical properties of the atmospheric aerosols, dust clouds, ice clouds and hazes, and study of their global circulations and dynamics. PFS will also determine the daily temperature variations (thermal inertia) of the planet's surface and the nature of the surface condensate and the seasonal variations in its composition, as well as studying surface-atmosphere exchange processes.

SPICAM is an ultraviolet and infrared spectrometer devoted to studying the Martian atmosphere, including its photochemistry, density/temperature structure (from 0 to 150 km), upper-atmosphere/ionosphere escape processes, and interaction with the solar wind. The infrared sensor will be used to determine column abundances and the water, carbon dioxide and ozone cycles. SPICAM's measurements, which will complement those of PFS, will therefore address key questions regarding the present state of the atmosphere of Mars, its climate and evolution. SPICAM can also perform nadir viewing measurements of the atmosphere, and uses limb viewing and stellar occultation to infer atmospheric parameters.

The Issue of Water

Today, liquid water cannot exist on the surface of Mars due to the low density of its atmosphere (6 mbar). There is, however, ample evidence to suggest that during the planet's early history liquid water flowed freely, such as the dry riverbeds in the heavily cratered Southern Highlands. The early climate of Mars appears to have been warm and wet until about 3.8 billion years ago, much like the Earth's at about the time when life appeared on our planet. It therefore seems reasonable to hope that biological activity flourished on Mars also! Soon afterwards, however, surface conditions on Mars changed dramatically, turning it into the cold, dry place that it is today, as the modest erosion rates found at the Mars Pathfinder site have illustrated. There is also growing evidence that the young smooth Northern Plains were once occupied by an ocean, covering about one-third of the planet. Thus, the tantalizing question is: Where has all this water gone? Was it lost into space through natural evaporation, including atmospheric erosion through large impacts, or is it still somewhere on the planet, maybe below the surface in an icy form like the Earth's permafrost? Recent Mars Odyssey gamma-ray spectroscopy data have revealed a significant concentration of H^+ hydrogen ions adsorbed in the first few millimetres of soil in both polar areas on Mars. However, in light of similar Lunar Prospector data from the Moon - where we know from rock samples that there is no water present - these data only indicate the presence of a mechanism concentrating H^+ from the solar wind towards the poles. Hence, most of the Mars Express orbiter's instruments are directed towards settling this issue one and for all, through radar subsurface sounding (MARSIS), surface mineralogical mapping (OMEGA), the establishment of a detailed geological chronology (HRSC), the imaging of atmospheric escape (ASPERA), and study of the atmosphere's water, carbon dioxide and dust cycles (PFS and SPICAM). Never before has a mission to Mars been so focused on making a water inventory of the planet, and never has one been so well equipped to do so.

ASPERA is an energetic neutral-atom analyser with which to study plasma domains at different points on Mars Express's orbit, examine the interaction of the upper atmosphere with the interplanetary medium and the solar wind, and characterise the near-Mars plasma and neutral gas environment. It will also be used to characterise quantitatively the impact of plasma processes on atmospheric evolution, and obtain the global plasma and neutral gas distributions in the near-Mars environment. It will also make in-situ measurements of ions and electrons and provide data on the undisturbed solar wind. A similar instrument is being flown on the Japanese Nozomi mission.

The ***MaRS*** experiment, which does not involve any dedicated hardware, will make radio soundings of the Martian atmosphere and ionosphere (occultation experiment) to derive vertical density, pressure and temperature profiles and the diurnal and seasonal variations in the ionosphere. It will also determine the dielectric and scattering properties of the Martian surface in specific target areas with a bi-static radar experiment, and determine gravity anomalies for the investigation of the structure and evolution of the planet's interior. Precise determination of the mass of the Martian moon Phobos and radio sounding of the solar corona during the superior conjunction of Mars and the Sun are also among the MaRS objectives. The telemetry and telecommand subsystem links between the orbiter and Earth will be used (observing the phase, amplitude, polarisation and propagation times of the signals transmitted) for this experiment, which has a significant heritage from the one on the Rosetta mission.

Although not considered part of the scientific payload, two subsystems located on the spacecraft will particularly benefit the deployment and operations of the

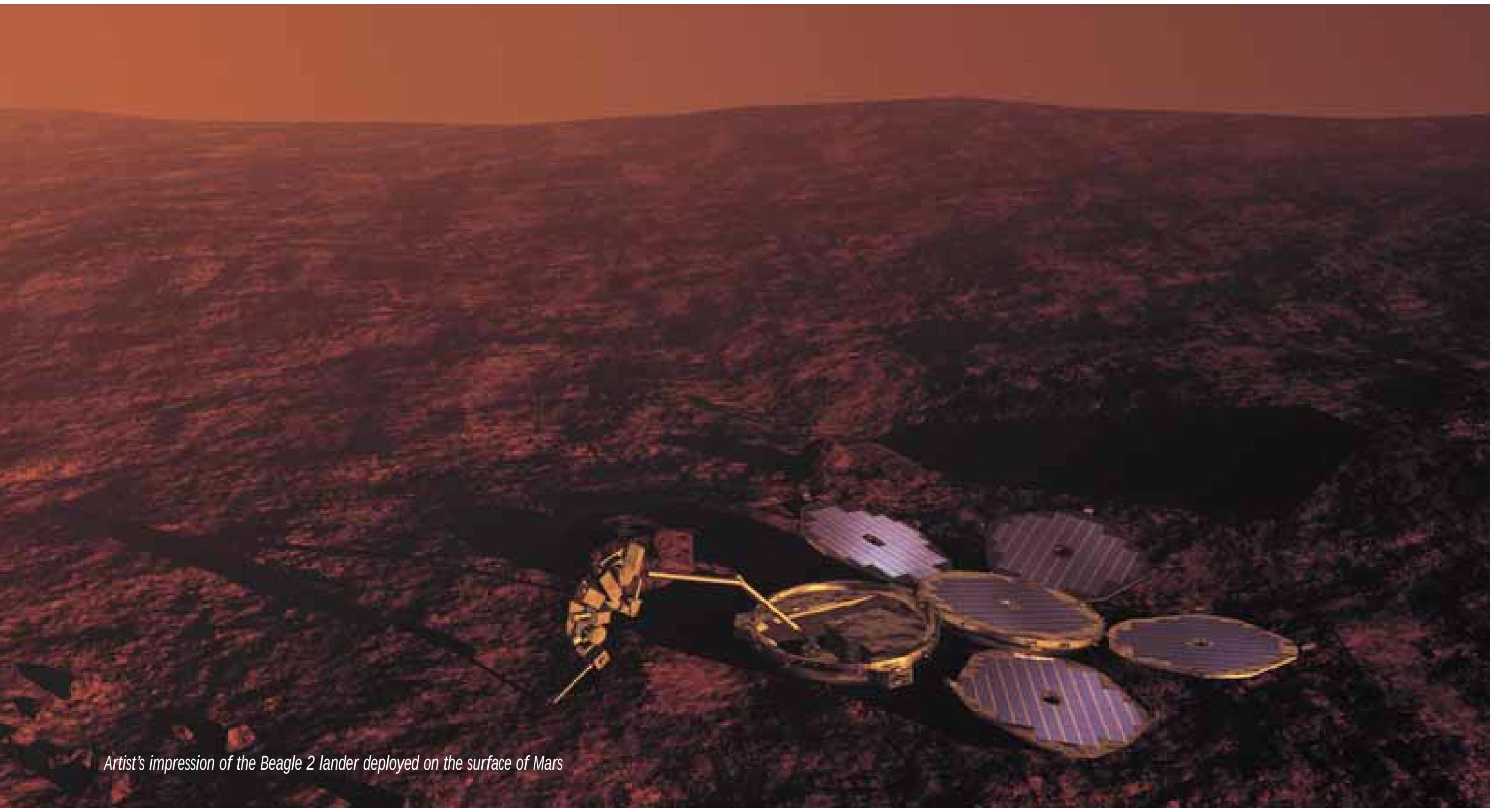
Beagle 2 lander. The Mars Express Lander Communications (MELACOM) subsystem is the radio orbiter-to-lander data-relay transponder, whose primary role is to provide data services for the lander. Mars Express will fly over the Beagle 2 landing site every 1 to 4 Martian days and will relay scientific data to the UK-based Lander Operations Centre (LOC) via ESOC. Another device attached to the spacecraft is the digital Visual Monitoring Camera (VMC), which will monitor the release and separation of Beagle 2 five days before Mars orbit insertion.

On the Lander

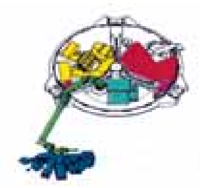
Beagle 2's scientific payload, which weighs just 10 kg, consists of six instruments and two dedicated tools with which to study the Martian surface and subsurface materials, and a robotic sampling arm with five degrees of freedom. The eight experiments can be divided into two catagories: those mounted directly on the lander platform – namely the Gas Analysis Package (GAP) and the Environmental Sensor Suite (ESS) – and those housed within an innovative structure called the Payload Adjustable Workbench (PAW) located at the end of the robotic arm – namely the Stereo Camera System (SCS), the Microscope (MIC), the X-ray Spectrometer (XRS), the Mössbauer Spectrometer (MBS), and a set of tools that includes the Rock Corer Grinder (RCG), the Planetary Underground Tool (PLUTO), and other support equipment such as a sampling spoon, a torch and a wide-angle mirror. The science-payload/landed-structure ratio is about 1:3, the highest of any planetary lander to date.

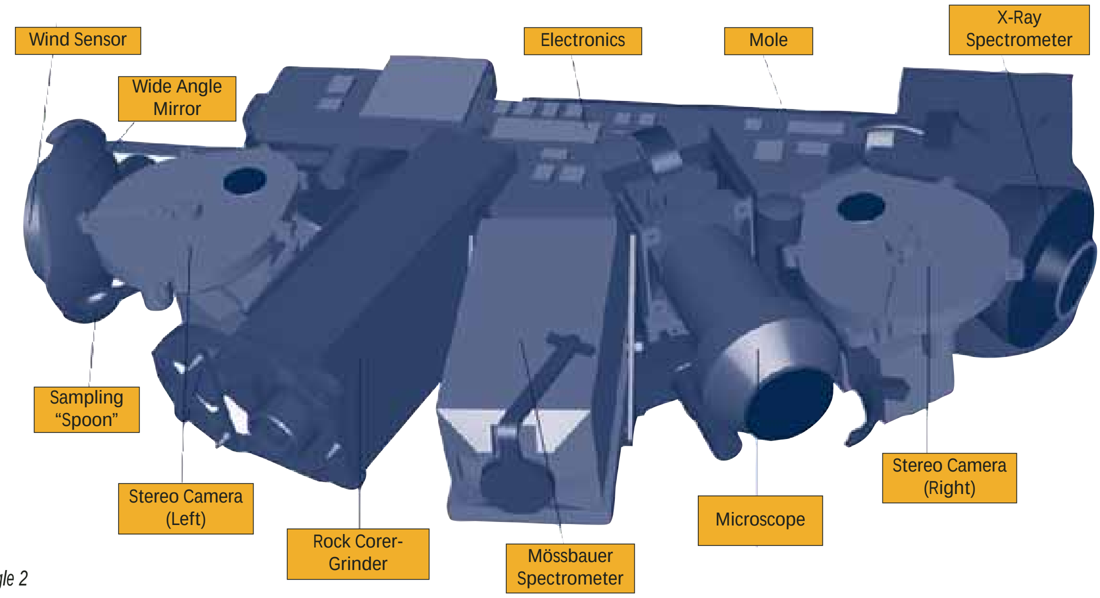
GAP, which is accommodated in the lander's base, will make both quantitative and qualitative analyses of sample composition, as well as precise isotopic measurements. It can process atmospheric samples as well as material acquired by the sampling tools in the form of soil or rock chippings, which are deposited into one of eight miniaturised ovens. Gases can be analysed directly (e.g. those present in the atmosphere), after their release from samples by heating, or as by-products of chemical processing (e.g. CO_2). GAP can therefore investigate: processes associated with atmospheric evolution, circulation and cycling, the nature of gases trapped in rocks and soils, low-temperature geochemistry, fluid processes, organic chemistry, formation temperatures and surface exposure ages, and can also assist in isotopic rock dating.

ESS will contribute to characterisation of the landing site and permit meteorological studies using the data from 11 sensors scattered throughout the lander platform and the PAW. Measurements of the ultraviolet radiation flux at the surface together with the oxidising capability of the soil and air will provide insights for exo-biological investigations. Measurements of atmospheric temperature, pressure, wind speed and direction, dust saltation and angle of repose will complement the in-situ environmental experiments.



Artist's impression of the Beagle 2 lander deployed on the surface of Mars





The paw instruments on Beagle 2

SCS, which consists of two identical CCD cameras and integrated filter wheels, will be used back on Earth to construct a Digital Elevation Model (DEM) of the landing site from a series of overlapping stereo image pairs. The DEM will then be used to position the PAW with respect to promising target rocks and soils. The landing-site investigations will include panoramic 360 deg imaging, multi-spectral imaging of rocks and soils to determine mineralogy, and close-up imaging of rocks and soils to infer their texture. Observations of the day and night sky, the Sun, the stars, and the Martian moons Deimos and Phobos will allow the assessment of such atmospheric properties as optical density, aerosol properties, and water-vapour content. The observation of the lander's surfaces and atmospheric effects will allow the dust and aerosol properties of the Martian atmosphere to be assessed.

MIC will investigate the nature of Martian rocks, soils and fines on the particulate scale (few microns), providing important exobiological data in the form of direct evidence of microfossils, microtextures and mineralisations of biogenic origin if present. By identifying the physical nature and extent of the weathering rinds/coatings on rocks and soils, it will also contribute to geological characterisation of the landing site. Atmospheric and the global planetary studies will also benefit from the more detailed knowledge of dust morphology. MIC will be the first attempt to directly image and assess individual particles with sizes close to the wavelength of scattered light on another planet. The acquisition of complete sets of images for each target will allow the 3D reconstruction of sample surfaces in both the visible part of the spectrum and the ultraviolet.

The primary goal with ***XRS*** is to determine, in-situ, the elemental composition, and by inference, the geochemical composition and petrological classification, of the surface materials at the landing site. It can detect major elements (Mg, Al, Si, S, Ca, Ti, Cr, Mn and Fe) and trace elements, and uses X-ray fluorescence spectrometry to determine the elemental constituents of rocks. It can perform radiometric dating of Martian rocks in-situ.

MBS will allow a quantitative analysis of iron-bearing materials in Martian rock and soil materials. Such measurements are particularly important due to the abundance of Fe-bearing minerals on Mars and their formation being linked to the history of water on the planet. It will also provide information about rock weathering in general and oxidation in particular. The MBS-generated spectra will allow the characterisation of the mineralogical makeup of rocks and soils, and hence a petrological classification. The MBS also complements the in-situ geochemical and petrological work, and provides support for the GAP measurements.

The ***RCG***, located on the PAW, addresses the latter's need for access to 'fresh', pristine material on a suitably prepared rock surface to avoid the effects of weathering rinds and geometric effects that can seriously compromise instrument performance. It allows the removal of the altered material and produces a flat, fresh surface suitable for the spectrometer measurements. After the in-situ analyses have been completed, a ground sample will be extracted using the device's coring action, and delivered to the GAP's inlet port for further chemical analysis.

The ***PLUTO*** subsurface sampling device is another PAW tool, which can retrieve soil samples from depths down to about 1.5 m and, depending on the terrain, from under a large boulder. This capability is very important for Beagle 2's exobiological investigations because materials preserving traces of biological activity lie deep within the soil or rocks, where they are unaffected by solar-ultraviolet radiation. PLUTO will make in-situ temperature measurements as a function of time and depth as it penetrates below the surface, and will also allow the soil's mechanical properties and layering to be assessed.

The Science Operations

The Mars Express orbiter will record onboard all of the scientific data gathered by its own experiments as well as those from the lander, and then transmit them back to Earth during the periods of ground-station visibility. The volume of data being downlinked will vary throughout the year from less than 1 Gbit/day to about 6 Gbits/day.

As one of several players involved in the Mars Express science operations, the Payload Operations Service (POS) established at the Rutherford Appleton Laboratory, Chilton, UK, is supporting the Mars Express Project Scientist Team (PST), the Principal Investigators (PIs), the Mission Operations Centre (MOC) and the Lander Operations Centre (LOC). The POS has been responsible, under a contract from ESA, for the development, imple-mentation, testing, and operations of the system and tools needed to support the Mars Express science operations.

The PST and the PIs are currently compiling a Master Science Plan (MSP) scheduling the acquisition of science data by Mars Express in a way that is consistent with both the scientific objectives for the mission and the resources available during the various periods of observation. The MSP will form the basis of all payload operations timeline planning during the various phases of the mission. The high-level scientific planning is to be performed by the Science Operations Working Group, which includes representatives of all PI teams. Both the PST and POS interface with the MOC on the one side, and with the PI institutes and LOC on the other.

International Collaboration

In developing the Mars Express mission, international collaboration from beyond the ESA Member States, either through participation in instrument hardware or through scientific data analysis, has been very much valued in order to expand the scope of and enhance the scientific return from the mission. Three major partners are therefore contributing to the mission: the USA, Russia and Japan. NASA is providing a major share of the MARSIS subsurface-sounding radar, as well as supporting Co-Investigators for most of the scientific payloads. It is also making its Deep Space Network (DSN) available for increased science data downloading during the early part of the mission and when critical manoeuvres are being carried out. Russian scientists are also involved in most of the orbiter experiments, many of which were originally destined for the Mars-96 mission as joint collaborations between European and Russian institutes. Other non-ESA Member States participating in the mission include Poland and China.

Collaboration with Japan is a special case. The Mars Express and Nozomi Science Working Teams have been collaborating closely since the unfortunate malfunctioning of the ISAS Nozomi spacecraft soon after its launch in 1998, because mutual benefit can be drawn from the fact that both missions will now reach Mars at almost the same time. This collaboration includes scientific data exchange and analysis, as well as the exchange of scientists between instrument teams. The two missions are highly complementary in terms of their orbits and scientific investigations, with Nozomi focusing from its highly elliptic equatorial orbit on the Martian atmosphere and its interaction with the solar wind, while a large part of the polar-orbiting Mars Express mission is devoted to studying the planet's surface and subsurface. Never before has a planet been simultaneously observed from two different viewing geometries by two orbiters from different space agencies. This tandem exploration programme for Mars could pave the way for even closer cooperation in the future between Europe and Japan for other targets of opportunity, including all terrestrial planets.

More information about the Mars Express mission and its Beagle 2 lander can be found at:
http://sci.esa.int/marsexpress/ and
http://www.beagle2.com/

The Issue of Life

The Mars Express mission will address the issue of the emergence of life in the cosmos and in particular life signatures on Mars, both directly and indirectly. The majority of the orbiter's instruments will look for indications of conditions favorable for the existence of life, either now or during the planet's evolution. It will search in particular for traces of liquid, solid or gaseous water. Therefore, the HRSC camera will take pictures of ancient riverbeds, the OMEGA spectrometer will look for minerals with OH-radicals indicating in the presence of water, the MARSIS radar will look for subsurface ice and liquid water, the PFS and SPICAM spectrometers will analyse water vapour in the atmosphere, and finally ASPERA and MaRS will study neutral-atom escape from the atmosphere, and particularly oxygen coming from water and carbonates. The instruments on Beagle 2 will also look for water in the Martian soil, rocks and atmosphere, and in particular for traces of life with in-situ measurements. The presence of more of the lighter C^{12} isotope than heavier C^{13}, for example, would indicate the existence of extinct life, while the presence of methane (CH_4) would be indicative of extant life. Measurements from a single instrument will probably not settle the issue of life on Mars, but the sum of all of the Mars Express measurements will allow us to build up a picture pointing towards the existence of life on Mars, or not. In either case, the exo-biological implications will be far-reaching, as we will then know whether life is a common occurrence in the Universe or not. In the context of this debate, comparing the geological evolutions of Earth and Mars is obviously a potentially fruitful exercise, as both planets have seasons, polar caps, a transparent atmosphere, aeolian activity, etc. However, our other planetary neighbour Venus must not be forgotten in this respect, in view of its similarities with Earth in terms of internal activity and recent resurfacing. Comparative planetology is therefore key to our understanding the Solar System's evolution, including exo-biology. It is the first time since NASA's Viking missions in 1976 that an exhaustive search for life has been so central to a space mission to Mars.