US Participation in Mars Express

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This paper describes US participation in the Mars Express mission, in which NASA is a supporting partner.

1. Introduction

In December 1997, ESA issued an Announcement of Opportunity for experiments to be included in the Mars Express mission. Mars Express is flying refurbished European instruments developed for the Russian-led Mars-96 mission, plus an advanced radar sounder capable of characterising the martian subsurface to a depth of several kilometres. US scientists who had been appointed Mars-96 Participating Scientists by NASA were invited to propose as instrument Co-Investigators (Co-Is). NASA and the Italian Space Agency (ASI) submitted a joint experiment proposal for the subsurface sounder: the Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS).

NASA Headquarters was represented in the ESA selection process. Eleven US proposers were selected by ESA as instrument Co-Is. The selected investigators subsequently submitted proposals and proposed budgets to NASA and were appointed by NASA. The NASA/ASI MARSIS sounder was selected over a competing proposal prepared by a German-led consortium. J. Plaut, of the Jet Propulsion Laboratory (JPL), is the MARSIS Co-Principal Investigator (Co-PI) and W.T.K. Johnson was named as Instrument Manager. NASA is also funding hardware development, data reduction and archiving tasks for the Analyser of Space Plasma and Energetic Atoms (ASPERA-3) instrument via the agency's Discovery Mission of Opportunity. Two of ASPERA-3's four data-gathering sensors, the Electron Spectrometer and the Ion Mass Analyser, were built by the Southwest Research Institute (SwRI).

Table 1 lists the Mars Express experiments and their US Investigators. Table 2 lists the key US personnel.

2. US Participation

US participation primarily consists of the Mars Express/NASA Project, managed by JPL. The contribution to ASPERA-3 is supported by the Discovery Program, managed by the NASA Management Office, also located in Pasadena.

2.1 Mars Express/NASA Project

The structure of the Mars Express/NASA Project is shown in Fig. 1. It includes the US role in MARSIS, support for the US investigators and a Telecommunications and Interoperability Task to study communications between elements of Mars Express and US assets at Mars. In addition, the Deep Space Network (DSN) will provide tracking support.

Table 1. US participation in Mars Express instruments.

Country	*Instrument*	*PI*	*US Hardware*	*US Co-Is*
I/US	MARSIS	G. Picardi, Univ. of Rome Co-PI, J.J. Plaut	W.T.K. Johnson, JPL/ D. Gurnett, Univ. of Iowa RF subsystems and Sounder antenna	J. Plaut, JPL D. Gurnett, Univ. of Iowa E. Stofan, Proxemy Research Inc
I	PFS	V. Formisano, Instituto Fisica Spazio Interplanetario		S. Atreya, Univ of Michigan
D	HRSC	C.G. Neukum, DLR Institut für Planetenerjundung		M. Carr, USGS R. Kirk, US Geological Survey T. Duxbury, JPL R. Greeley, Univ. of Arizona J. Head, Brown Univ. T. McCord, Univ. of Hawaii S. Squyres, Cornell Univ.
D	MaRS	M. Paetzold, Univ. of Cologne		L. Tyler, Stanford Univ.
F	SPICAM	J.L. Bertaux, Service d'Aéronomie, Verrières-le-Buisson		W. Sandel, Univ. of Arizona A. Stern, SwRI
F	OMEGA	J.P. Bibring, Institut d'Astrophysique Spatiale		
S	ASPERA-3	R. Lundin, Swedish Institute of Space Physics	D. Winningham, SwRI Electron Spectrometer and portions of the Ion Mass Analyser	C. Curtis, Univ. of Arizona K.C. Hsieh, Univ. of Arizona J. Kozyra, Univ. of Michigan J. Luhmann, Univ. of California E. Roelof, Johns Hopkins Univ. B. Sandel, Univ. of Arizona J. Sharber, SwRI R. Frahm, SwRI D. Williams, Johns Hopkins Univ.
UK	Beagle 2	C. Pillinger, Open Univ.		M. Sinha, JPL

Table 2. Key US Mars Express personnel.

Mars Express/NASA Project Manager: Richard L. Horttor *(richard.l.horttor@jpl.nasa.gov)*

Mars Express/NASA Project Science Manager: Thomas W. Thompson *(thomas.thompson@jpl.nasa.gov)*

MARSIS Instrument Manager: William T.K. Johnson *(wtk.johnson@jpl.nasa.gov)*

Mars Express/NASA Project Telecommunications and Interoperability Task Manager: Stanley A. Butman *(stanley.butman@jpl.nasa.gov)*

MARSIS Co-PI: Jeffrey J. Plaut *(plaut@jpl.nasa.gov)*

ASPERA-3 ELS PI: J. David Winningham *(david@cluster.space.swri.edu)*

Discovery Program Manager: John B. McNamee *(john.b.mcnamee@jpl.nasa.gov)*

NASA Headquarters Program Executive: David Lavery *(dave.lavery@hq.nasa.gov)*

NASA Headquarters Program Scientist: Catherine Weitz *(cweitz@hq.nasa.gov)*

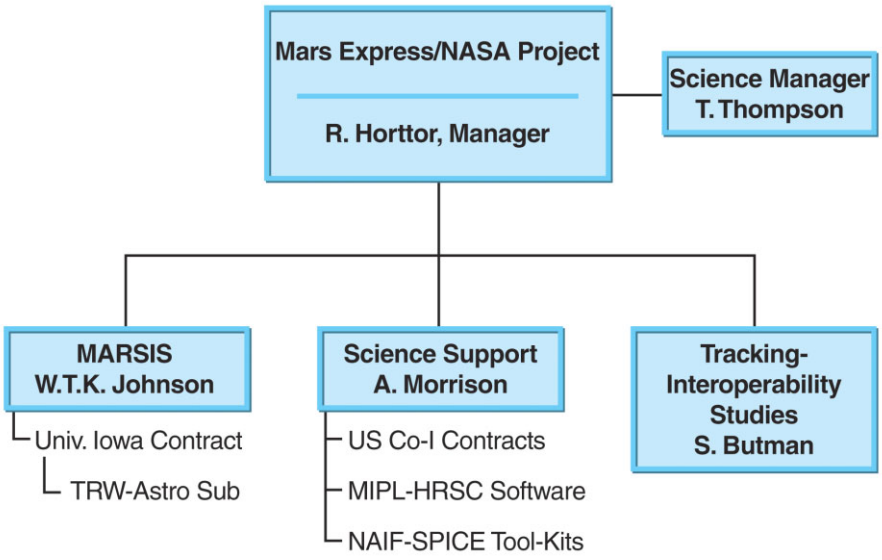

Fig. 1. The structure of the Mars Express/NASA Project.

Specific goals of the Mars Express/NASA Project are:

— to support the science objectives of HRSC (High Resolution Stereo Camera), OMEGA (IR mapping spectrometer), MaRS (Mars Radio Science), PFS (Planetary Fourier Spectrometer), SPICAM (UV atmospheric spectrometer), ASPERA-3 and MARSIS instruments by providing US Co-I support;
— to provide information and advice on navigation and mission operations that could be used by Mars Express;
— to provide the Radio Frequency (RF) subsystem for MARSIS, including the integrated transmitter, antenna and receiver;
— to plan for relaying communications to and from Beagle-2 and any potential European 2005 landers using NASA and ESA orbital assets;
— to coordinate US planning inputs to Mars Express orbiter observations and secure support from JPL's Telecommunications and Mission Operations Directorate for tracking and navigation support for Mars orbit insertion;
— to archive a copy of the science investigation data in a Planetary Data System (PDS)-compatible format, as specified in the international agreements;
— to support the HRSC investigation with adaptation of NASA/JPL image processing software;
— to deploy the Spacecraft, Planet, Instrument, C-matrix, Events (SPICE) ancillary information system.

The Mars Express/NASA Project completed the transition from Phase-B (Planning) into Phase-C/D (Implementation) in September 2000. Launch initiated mission operations.

2.2 MARSIS

The MARSIS Program is funded by both NASA and ASI. ASI maintains the science leadership through the Principal Investigator (PI), Giovanni Picardi of the INFOCOM Department of the University of Rome, while NASA maintains the instrument leadership through JPL. The US MARSIS Team provided the antennas and the receiver and transmitter subsystems; Alenia Spazio, Rome had responsibility for the digital subsystem and instrument integration and test, under direction of the JPL Instrument Manager. The Co-PI serves as the lead scientist for the NASA side of the joint experiment.

The University of Iowa, under contract to JPL, constructed the antenna subsystem,

working with their subcontractor, TRW-Astro, Inc., of Carpenteria, CA. The University of Iowa, under contract to JPL, built the transmitter subsystem; JPL built the receiver subsystem. JPL integrated the antenna, transmitter and receiver subsystems into a single RF subsystem that was delivered to Alenia Spazio, who integrated it with their digital electronic system and delivered an integrated MARSIS instrument to ESA (Astrium) for mating to the spacecraft.

2.3 Science Support Task

The Science Support Task (SST) comprises three Sub-Tasks: the Co-I Sub-Task, the HRSC-Multimission Image Processing Laboratory (MIPL) Sub-Task, the Navigation and Ancillary Information Facility (NAIF)-SPICE Sub-Task and several ancillary activities, including possible US navigation contributions to the mission.

The Co-I support activity funds and manages the Co-PI and Co-Is. With the exception of OMEGA, all Orbiter instruments have one or more US Co-Is. The SST will support OMEGA Co-Is, once selected. The MARSIS Co-PI is also supported by the SST.

US Co-Investigators will provide instrument calibration, data validation and data archiving support to their respective Instrument PIs and Teams to help ensure that the data products meet the objectives of the mission. Co-Investigators are expected to publish the results of their scientific analysis and provide their data products to the PDS. Interdisciplinary and Participating Scientists, when selected, will also be supported by the Co-I support activity.

The Co-I activity also supports obtaining DSN tracking and data communication through Mars Express Project Service Level Agreements (PSLAs), approved Letters of Agreement (LOAs) and Memoranda of Understanding (MOUs), allowing technical exchange between the US Co-Is and their European colleagues and JPL navigation support to the mission.

The HRSC/MIPL telemetry software development activity is similar to that for Mars-96. The basic HRSC instrument is the same except that the wide-angle camera was deleted and a Super-Resolution Channel (SRC) added. With those exceptions, the instrument formats are the same, including the data compression. The spacecraft is completely different, as are the telemetry systems.

MIPL developed the HRSC telemetry processing software. This will convert the HRSC data as they are received in Berlin (D) from ESA into a format compatible with existing image processing software for further processing. The telemetry processing includes a telemetry processor and data-merge and decompression programs.

After using the telemetry processor on its data, DLR will distribute this processed imagery daily to its Co-Is, so that the US HRSC Co-Is can support Mars Express mission operations, as well as meet their individual commitments as described in their proposals. As part of this distribution activity, MIPL will receive these processed data electronically on behalf of the HRSC Co-Is and then distribute them directly to the US Co-Is.

MIPL will maintain approximately 60 days of the most current HRSC Mars Express data online, with the remainder held in an offline store. The data will be provided to the US HRSC Co-Is automatically through a subscription service or on a request basis. They will have access to the data in level 1 or 2 format, such as the decompressed version of the level 0 image product, or the radiometrically corrected version of level 1. The radiometric correction software and calibration files will be provided to MIPL by DLR.

MIPL will also develop PDS generation and validation software to convert the HRSC processed imagery into a PDS-compatible format. DLR will then use this software to place its HRSC data on archive volumes for delivery to the PDS imaging node at JPL. There will also be sustaining support for the JPL-developed software for the first 6 months after orbital insertion.

NASA's SPICE system was conceived to provide planetary scientists with a standard, flexible and proven method of obtaining and properly using the suite of

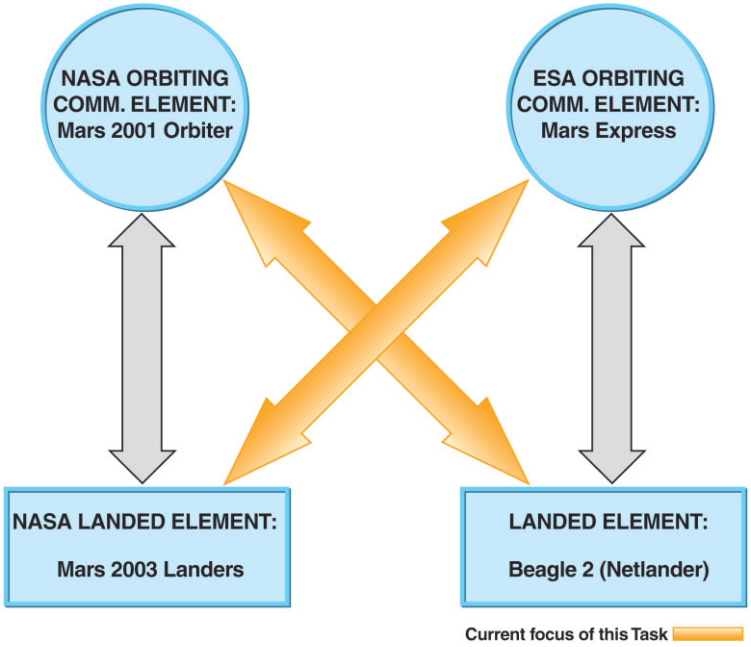

Fig. 2. Mars telecommunications interoperability.

ancillary and engineering data needed for conceptualising and evaluating mission designs, planning scientific observations, analysing scientific data and comparing results obtained from multiple instruments and multiple spacecraft. To this end, SPICE is used – or being adapted for use – on all NASA planetary missions, including the full suite of JPL's Mars Exploration Program missions. NASA's SPICE system will be deployed to support the US Co-Is, the HRSC team operations, and the other instrument teams as interested. SPICE was developed and is maintained by JPL's NAIF.

In particular, JPL provided the SPICE Tool Kit software and documentation to ESTEC and Mars Express PI and Co-I teams and team members who will be involved in producing and using SPICE data components. The latest versions were delivered in November 2000, June 2001 and June 2002. In conducting its work, the SPICE Sub-Task is striving to achieve as much commonality as possible with the use of SPICE by NASA Mars missions.

2.4 Relay communications and tracking interoperability

Another ESA-NASA area of cooperation involves tracking and telecommunication interoperability. NASA is supporting efforts to establish and demonstrate communications and tracking interoperability between the various orbiting and landing elements of NASA and ESA. Starting with the Mars 2001 Orbiter and the 2003 Landers, NASA plans to launch a series of orbiting and landing/roving elements, with the eventual goal of returning rock and soil samples to Earth. With all these assets, including Mars Express, in Mars orbit and on the surface, it is desirable to provide communication and navigation cross-support between the NASA and ESA elements. This support may be highly desirable during certain critical mission events such as orbit insertion or landing. Fig. 2 shows the potential combinations of cross-support at Mars for Mars Express and other elements in the 2001-2005 time frame.

Achieving interoperability requires several steps:

— determine the interface characteristics of each pair of elements;
— if compatible, proceed to write the Interface Control Documents (ICDs);
— if not compatible, propose design changes to one or both elements;
— write ICD to define interface to be tested;

— write test plan and schedule test;
— perform interface test and document results.

2.5 Navigation and orbit insertion

When the Mars Express spacecraft arrives at Mars, it will deliver the Beagle-2 lander and brake into an elliptical orbit about the planet. Achieving the operational orbit might involve aerobraking. Coordination between the ESA/ESOC Flight Dynamics Division and the NASA/JPL Navigation Section will improve understanding of the mission constraints and risks. This follows the path pioneered by previous joint ESA-NASA missions such as Giotto, Ulysses and Mars Pathfinder. Comparison of navigation results from techniques and procedures developed by each agency is the primary objective of a series of workshops starting in September 2000 on navigation collaboration for Mars Express.

2.6 The Discovery Program and ASPERA-3

NASA's Discovery Program is supporting ASPERA-3 as a Discovery Mission of Opportunity, which is not a complete Discovery Mission but rather a portion of a larger mission. In this case, it gives the US scientific community the chance to participate in a mission of a non-US government agency. For ASPERA-3, the Discovery Program is funding both hardware development and data reduction, and the PDS archiving tasks being performed by the SwRI.

The Swedish Institute of Space Physics headed the development of ASPERA-3. The instrument has four sensors, along with the data processing unit and the scanning platform. Two of the sensors, the Electron Spectrometer (ELS) and the Ion Mass Analyser (IMA), are funded by NASA as a Discovery Mission of Opportunity. ELS and IMA were built by SwRI, led by D. Winningham as PI and J. Scherrer as Project Manager. The instrument was built by an international team of 15 groups from 10 countries.

ASPERA-3's scientific objectives are to study the interaction between the solar wind and the atmosphere of Mars and to characterise the plasma and neutral gas environment in near-Mars space. It uses Energetic Neutral Atom (ENA) imaging to visualise the charged and neutral gas environments around Mars. ASPERA-3 will make the first ever ENA measurements at another planet. These studies will address the fundamental question of how strongly interplanetary plasma and electromagnetic fields affect the martian atmosphere, which is directly related to the many questions about water on Mars.

Acknowledgement

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