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Mars Express: From the Launch Pad to a 20-Year Success Record at Mars

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Abstract
Mars Express was conceived and built by ESA as a successor of the unsuccessful Russian Mars-96 mission. It was planned from the onset as an orbiter and lander mission to be able to carry out long-term, remote sensing and in-situ scientific investigations of the planet Mars and its environment. As an exceptionally successful workhorse and a backbone of the Agency's Science Programme in operation at Mars since end December 2003, Mars Express has proven to be a highly productive mission returning excellent scientific value for the investments made by ESA and its Member States. This paper is intended as the introduction to the series of papers that make this special collection. It briefly reviews the history of the mission, its science goals, its uniqueness while establishing its complementarity with other Mars missions in a collaborative context. It also lists the teams and operational aspects and innovations that made this mission a success. Then the paper highlights Mars Express's scientific achievements throughout its 20-year lifetime. Mars Express results and discoveries continue playing an essential role in understanding the geological, atmospheric and climate evolution of the Red Planet and determining its potential past habitability. To conclude, a preview of the science and other topics covered by this collection is given. Mars Express, a pioneering mission for Europe at Mars, is currently continuing on its long scientific journey around the Red Planet.

1 A Brief History of Mars Express

A mission to Mars was always present in the planning of the Scientific Programme of ESA, and in particular as one of the priorities of the Horizon 2000 Plus plan in 1995. Following the footprints of past missions to Mars, from Mariner then Viking in the 1970s to more recent mostly NASA-led orbiter missions, and to fill the programmatic and scientific vacuum left by the non-selected Intermarsnet mission, Mars Express was conceived and built by ESA as a successor of the unsuccessful Russian Mars-96 mission, inheriting much of its payload (e.g., Bibring et al. 2025, this collection; Chicarro et al. 2004). Mars Express became the first de facto fast and flexible planetary mission project of ESA's Science Directorate in 1997, slated for launch in 2003.

Mars Express was planned from the onset as an orbiter and lander mission to be able to carry out long-term, remote sensing and in-situ scientific investigations of the planet and its

Extended author information available on the last page of the article

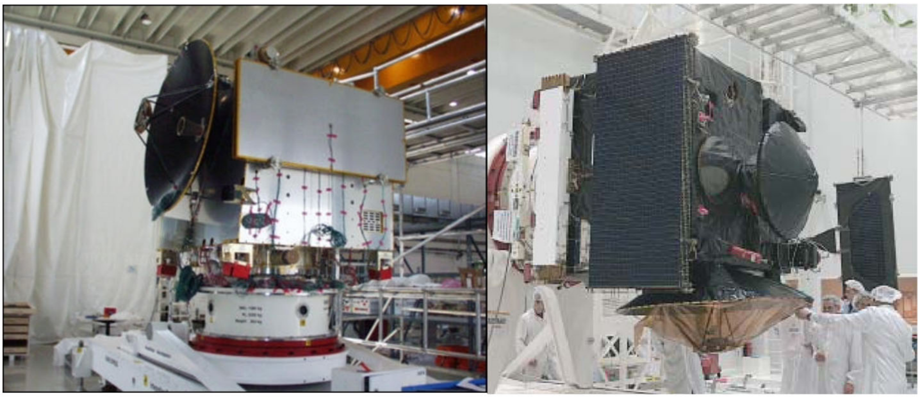

Fig. 1 Left: Structural model of Mars Express in Intespace, Toulouse, in 2001 for testing prior to further testing and integration by the Prime contractor (Astrium, now Airbus). Right: Mars Express in launch configuration in Baikonur, 2003

environment. From the established scientific requirements was derived a nominal mission of one Martian year (687 Earth days). The orbiter spacecraft (Fig. 1) was developed and is operated and fully funded by ESA except for the scientific instruments. At the time of selection, Mars Express was characterised as a unique, low cost, low risk, opportunity for Europe to join the other major space faring nations in the scientific exploration of Mars, the most Earth-like planet in our Solar System.

Mars Express was designed with a set of scientific payloads on the orbiter and also included a small UK-built, 60-kg lander, Beagle-2. ESA was responsible for the overall orbiter spacecraft and mission design, orbiter procurement, orbiter payload integration, lander module integration into the orbiter, system testing, orbiter operations, acquisition and distribution of the science data, and preparation of the Mars Express legacy data archive. The lander module Beagle-2 and the MELACOM equipment for communications between the orbiter and the lander, were provided by the UK. All scientific investigations on the Mars Express orbiter are nationally funded by ESA Member States or international partners through an agency, institute or through an international consortium.

With its initial complement of seven instruments (ASPERA-3, HRSC, MaRS, MARSIS, OMEGA, PFS, SPICAM; see Table 1), the Mars Express orbiter was designed to study all aspects of the Red Planet, including its plasma environment, atmosphere and climate, the mineralogy and geology of its surface, and its subsurface. The later conversion into scientific payload of the VMC camera for wide-angle imaging and of the MELACOM communications package for radio occultations with the ExoMars Trace Gas Orbiter (TGO) contributed to enhance the mission's scientific performance. The payload and its evolution are detailed in Wilson et al. (2025, this collection), this collection, and the initial payload described in Wilson and Chicarro (2004).

The spacecraft was built and launched in record time and at a much lower cost than previous, similar deep space missions. Following this fast-track development phase, Mars Express began its journey to Mars at 17:45 UT with the successful launch of a Soyuz-Fregat rocket from the Baikonur Cosmodrome in Kazakhstan on 2 June 2003 (Fig. 2), for a ∼7-month cruise phase prior to Mars Orbit Insertion on 25 December 2003. The Beagle-2 lander was released on 19 December 2003, six days before Mars Express braked into orbit around Mars, but most probably failed to communicate after incomplete deployment of its solar

Table 1 The Mars Express scientific payload, with their initial PIs and participating countries

Experiment Acronym	Instrument Type	Principal Investigator (PI)	Participating Countries
HRSC	Super/High Resolution Stereo Colour Imager	G. Neukum (DLR/FU Berlin, D)	D, F, RU, US, FIN, I, UK
OMEGA	IR Mineralogical Mapping Spectrometer	J.-P. Bibring (IAS, Orsay, F)	F, I, RU
PFS	Atmospheric Fourier Spectrometer	V. Formisano (CNR, Frascati, I)	I, RU, PL, D, F, E, US
MARSIS	Subsurface-Sounding Radar/Altimeter	G. Picardi (Univ. Rome, I) & J. Plaut (NASA/JPL, US)	I, US, D, CH, UK, DK, F, RU
ASPERA-3	Energetic Neutral Atoms Analyzer, Electron Spectrometer, Ion Mass Analyzer	R. Lundin & S. Barabash (RFI, Kiruna, S)	S, D, UK, F, FIN, I, US, RU
SPICAM	UV and IR Atmospheric Spectrometer	J.-L. Bertaux (CNRS, Verrières, F)	F, B, RU, US
MaRS	Radio Science Experiment	M. Paetzold (Univ. Köln, D)	D, F, US, A
Beagle-2 (Lander)	Suite of imaging instruments, organic and inorganic chemical analysis, robotic sampling devices and meteo sensors	C. Pillinger (Open Univ., UK) & M. Sims (Leicester Univ., UK)	UK, D, US, F, CH, RU, PRC, A, E

panels (as revealed in Mars Reconnaissance Orbiter images acquired in 2015, disproving possible failure scenarios laid out by the inquiry report). Orbiter mission operations are run from ESOC in Germany and science operations and archiving are carried out from ESAC in Spain (Cardesín-Moinelo et al. 2024, this collection).

A more comprehensive recap of the history of the mission, from its original conception to its contemporaneous state, is detailed in Bibring et al. (2025, this collection). The authors translate the genesis of the Mars Express mission into its system design, the payload selected, and the operation strategy. They conclude that Mars Express achieved unprecedented objectives, including coupled analyses of all Mars envelopes, i.e. from the planet's exosphere and upper and lower atmosphere to the surface and subsurface characterisation. They also declare that based on Mars Express, the first ever European Mars mission, the Agency, the European space industry and the science community have built excellence and opened strong cooperative partnerships (Bibring et al. 2025, this collection).

Mars Express was the only mission to Mars in the ESA Directorate of Science's Horizon 2000 programme, but became an essential precursor to other European missions flown in subsequent Science Programme phases (Cosmic Vision and Voyage 2050), and in the Exploration Programme executed by ESA's Directorate of Human and Robotic Exploration (HRE). The next sections give further overview of the mission's goals, evolution through its operational years and highlights of its achievements.

2 Mission Science Goals

In the broad context of planetary science, Mars represents an important transition between the outer volatile-rich, more oxidised outskirts of the accretion zone of the terrestrial bodies (asteroid belt) and the inner, rocky, more refractory and less oxidised regions from which the Earth, Venus and Mercury accreted.

Fig. 2 Mars Express, launched on 2 June 2003, at 23:45 (local time) on board a Soyuz-Fregat rocket from the Baikonur Cosmodrome in Kazakhstan. ESA/STARSEM-S. CORVAJA 2003

This special position of Mars and its traditional character is also manifested by its size, the degree of internal activity, the age of its surface features, and the density of its atmosphere. These properties are intermediate between those of the large terrestrial planets (Earth, Venus) and the smaller planetary bodies (Mercury, the Moon, the asteroids). The exploration of Mars is therefore crucial for a better understanding of the Earth from the perspective of comparative planetology. It is also worth noting that Mars is a remarkable planet due to its habitability potential, with prospects of finding evidence of present or extinct life.

It is through an international strategy developed via the International Mars Exploration Working Group (IMEWG) that the key scientific goals of Mars Express were set, largely with the aim of recovering part of the lost objectives from the ill-fated Mars-96. Hence, the Mars Express mission was established as a survey mission to address a wide range of Mars science, from the planet's interior to its plasma environment.

With the addition of a small lander, Mars Express' initial science goals were distributed into orbiter and lander goals, summarised here from Mars's subsurface to its exosphere and moons:

Mars Express orbiter science goals:

- Global high-resolution photogeology (incl. topography, morphology, paleoclimatology) at up to 10 m/pixel resolution
- Super-resolution photogeology of selected areas of the planet (2 m/pixel)
- Global high spatial resolution mineralogical mapping of the Martian surface at kilometre scale down to several 100 m/pixel resolution
- Subsurface structure characterisation at kilometre scale down to several km depth
- Structure of the interior

- Global characterisation of the atmospheric structure and circulation, and mapping of the atmospheric composition (and its variability)
- Surface-atmosphere interaction
- Aeronomy and structure of the ionosphere and its variability
- Interaction of the atmosphere with the interplanetary medium (including escape processes and couplings between observed atmosphere layers)
- Phobos, and to a lesser extent Deimos, properties

Beagle-2 lander science goals (not achieved due to incomplete landing success):

- Internal structure and dynamic activity
- Meteorology and climatology
- Landing site geology, mineralogy and geochemistry
- Physical properties of atmosphere and surface layers
- Exobiology (i.e., search for signatures of life)

While the above listed goals have largely been achieved during over twenty years in Martian orbit and nine extensions of the orbiter mission, they have also evolved - been expanded and complemented with each new scientific discovery and each new question raised. The evolution of the scientific objectives has been made possible through new discoveries, accumulated time coverage of instrument observations, or payload or spacecraft capability enhancements. A detailed review of the payload and science goals and their evolution is established in Wilson et al. (2025, this collection).

As an exceptionally successful workhorse and a backbone of the Agency's Science Programme in operation at Mars since end December 2003, Mars Express has proven to be a highly productive mission returning excellent scientific value for the investments made by ESA and its Member States. The science performance, measured in terms of executed science observations versus the observation plan, remains steadily close to 99%. The mission capability was enhanced through its lifetime by introducing a new science instrument (Visual Monitoring Camera, VMC) and observation modes (e.g., new MARSIS Phobos and surface modes, MEX-TGO radio science, ASPERA-3 – MARSIS active sounding of the plasma environment), enhancing downlink capabilities and establishing new collaborations. Deep Space Network (DSN) support also contributed to enhancing the science return of the mission (see Cardesín-Moinelo et al. 2024, this collection). The number of peer-reviewed papers based on the Mars Express data has exceeded 2000 with no sign of decline of the annual publication rate.

3 Uniqueness and Major Features of Mars Express

This section summarises how this first European Mars mission is unique in its configuration, parameters and major features, all of which have allowed it to achieve those scientific successes highlighted in this collection. Although there have been around a dozen spacecraft operating at Mars over the past couple decades, Mars Express is at time of writing one of the oldest of the still operating orbiters at the Red Planet and still possesses important unique features:

(1) This is a multi-disciplinary mission whose investigations cover a broad spectrum of Mars science topics, from the subsurface to the upper atmosphere and plasma environment, as well as its moons. It provides global context and reference data for other, more focused missions such as, for instance, MAVEN (aeronomy and evolution) or the ExoMars Trace Gas

Orbiter (atmospheric composition and chemistry). Mars Express' interdisciplinary science serves as a cohesive common ground unifying the wider Martian community in Europe.

(2) The non-Sun-synchronous elliptical orbit (300-10000 km) allows the spacecraft to observe the planet at all local times, to regularly perform close Phobos flybys, to cross magnetospheric boundaries, and enables complete ionospheric and atmospheric sounding at all times of day over a large range of viewing geometries.

(3) The Mars Express payload (Wilson et al. 2025, this collection) has occupied an important niche in the realm of other sophisticated and powerful instruments operating at Mars. Examples of unique mission capabilities at the onset of the MEX mission were:

- Building global Digital Elevation Models (DEM) with $\sim$50 m/px horizontal and $<$10 m vertical resolution that are of particular importance for co-registration of different Mars Express instruments and also are used as geodetic reference for other Mars missions;
- Characterisation of the regional-scale geology, supporting landing site selection;
- Investigation of glacial and fluvial processes indicative of major climate changes;
- Characterisation by the OMEGA near-infrared hyperspectral imager of the composition (mineralogical and molecular) of the surface and atmosphere. Such results, in particular with respect to hydrated minerals (e.g., phyllosilicates, sulfates), among the top ten of the mission, paved the revisiting of Mars's history, on which subsequent Mars missions have been built (e.g., where to land to access potential "habitable" sites);
- Simultaneous monitoring of temperature and composition of the lower atmosphere, H_2O and CO_2 in the upper atmosphere (complementing TGO in polar regions);
- Sounding of the structure of the entire ionosphere and ion population.

Since 2003 subsequent missions have of course covered such topics, but Mars Express remains unique in that MARSIS is the first subsurface sounder at Mars and still the only one capable of measuring features down to kilometres below the surface.

(4) Mars Express continues building the longest record of climatological and ionospheric parameters that is essential for the understanding of the meteorology, climate and evolution of the planet.

(5) Mars Express is the only spacecraft that has performed near-continuous plasma environment observations over more than one solar cycle. Since MAVEN lowered its orbital apoapsis altitude in 2019, Mars Express remains the main spacecraft to monitor the solar wind parameters. The Tianwen-1 orbiter may offer similar capabilities, but with an unknown performance to date.

(6) Mars Express, together with NASA's MAVEN spacecraft and CNSA's Tianwen-1 spacecraft, can provide multi-point plasma measurements for the first time at another planet.

(7) Together with the data delivered by Venus Express, Mars Express significantly contributes to the field of comparative planetology of terrestrial planets.

4 Mission Complementarity and Collaborations

Mars Express is a major, indispensable element of the international Mars exploration and one which played a crucial role in setting up ESA's Mars exploration programme. The main synergies and complementarities with the other Mars missions are outlined below.

Complementarity with TGO/ExoMars: Mars Express has played a "pathfinder" role for the ExoMars Programme in Europe, whose science objectives were to a great extent set based on the Mars Express findings. The collaborations between MEX and TGO, in particular between the HRSC and CaSSIS cameras but also between the SPICAM, PFS, OMEGA and NOMAD and ACS spectrometers, are well established and summarised in Cardesín-Moinelo et al. (2021). Synergies between the MEX and TGO missions can be summarised as follows: (1) monitoring of the lower atmosphere (<20 km) by Mars Express complemented by observations of the middle and upper atmosphere by TGO, enabling a study of the couplings between atmospheric layers; (2) cross-link MEX-TGO UHF radio occultations providing almost unconstrained (all latitudes, longitudes and local times at any time in the mission) sounding of the ionosphere and neutral atmosphere (Parrott et al. 2024); (3) provision of context imaging and DEMs which also serve as geodetic reference datasets for co-registering and analysis of data from instruments on other missions, e.g. CTX, HiRISE, CaSSIS, SHARAD; (4) MEX complementary coverage of the polar regions (>75°) which are not accessible by TGO; (5) coordinated MEX-TGO observations to separate spatial and temporal effects; (6) cross-calibration of the instruments and retrieval techniques; (7) complementarity of ASPERA solar wind / ionosphere measurements with TGO FREND radiation measurements, for characterisation of the radiation environment in low Mars orbit.

Complementarity with other Mars missions: The exemplary collaboration with NASA's Mars Reconnaissance Orbiter (MRO) exploits the complementarity of the payloads on both orbiters and is especially advanced in geological investigations, surface mineralogical mapping and subsurface sounding. MRO collaboration has especially been instrumental in supporting the OMEGA results regarding the era during which abundant water did leach the surface minerals (Carter et al. 2025, this collection). The well-established collaboration between Mars Express and NASA's MAVEN mission is continuing. This includes cross-calibration of the instruments, monitoring of the solar wind, two-point plasma observations at Mars, coordinated observations and joint data analysis. Both missions will also benefit from the complementarity of the MEX sounding of the lower and middle atmosphere and MAVEN investigations of the upper atmosphere, thus enabling the characterization of complex couplings between atmospheric layers. In particular, the transfer to the upper atmosphere of hydrogen atoms from water vapour in the lower and middle atmosphere, a central question for water escape (Fedorova et al. 2021), is addressed in a complementary manner. After lowering of the MAVEN orbit in 2019, Mars Express provides a vital support to other missions and science investigations by monitoring the upstream solar wind parameters. HRSC images and DEMs and OMEGA mineralogy maps as well as the teams' expertise were used to characterise the Mars-2020, ExoMars, InSight and Zhurong landing sites (Kirk et al. 2020). The Mars Express DEMs are critical for precise co-registering of the other spatial and spectral datasets on the surface of Mars. Atmospheric science benefits from new Mars Express collaboration with Tianwen-1 (China) and Hope (United Arab Emirates) orbiter missions that is being currently established. Of high value is regular monitoring of the atmospheric conditions and minor species by PFS over Gale crater where NASA's *Curiosity* rover conducts in-situ measurements (Giuranna et al. 2019). ASPERA-3 supports Suzaku X-ray telescope observations of Mars by solar wind measurements. VMC collaborated with the MOM mission of ISRO (India). Mars Express is also involved in joint campaigns with *ground-based observatories* for the characterisation of minor species, CO_2 isotopes and dust. Mars Express supports JAXA's Martian Moons eXploration (MMX) project by regular observations of Phobos and Deimos, creation of a global shape model, improving the ephemerides of the moons as well as sharing data and expertise. The extensive and evolving Mars Express database is crucial to MMX in defining its science objectives, mission planning and selecting sample return sites on Phobos. On MMX arrival at Mars, both missions will conduct coordinated observations of Mars and its moons. A collaboration with the Chinese Tianwen-1 mission is expected to build up and include geology and surface science, subsurface radar sounding, ionospheric and plasma investigations.

5 Mars Express: A Long History of Teamwork

Europe waited a long time for the opportunity to mount its own mission to Mars and that dream became a reality with the launch of Mars Express in June 2003. This mission marked the opening of a new era for Europe in planetary exploration, through an ESA project which was the start of an innovative way of organising the building blocks that form European space missions nowadays.

In addition to fast-track development and integration, the spacecraft and its instruments represent a truly international endeavour and collaboration (see Table 1 and Table 3) – among them a stereoscopic camera from Germany, a mineralogical mapping device from France and atmospheric sounders from Italy and France. The radar instrument, to probe for water at depths of a few kilometres below the surface, was built jointly between Italy and the Jet Propulsion Laboratory in California. The Beagle-2 landing craft was designed and built in the UK. As well as the remote observation payload, the orbiter carries a lander communications package, MELACOM, that supports relay with various international Mars lander missions since 2003.

Regarding the personnel involved, this mission has obviously been, over nearly 30 years of development, implementation and operations, evolving from the initial ESA, industrial and scientific teams and collaborators to the current groups of people.

During the development phase, the project is led by a Project Manager (see Table 7). Once the mission has been launched and the in-orbit commissioning review has taken place, the Project Manager hands over the mission responsibility to a Mission Manager for the remaining phases of the mission, including its post-operations. In the operational phase, the Science Ground Segment Team is led by a Mission Manager, a Project Scientist and a Science Operations Coordinator, whose roles have been held by several individuals through the 20 years of mission, as careers have evolved and people retired. Similarly, due to the long running operational phase, the Science Ground Segment team (originally at ESTEC, then moved to ESAC) has seen a significant turnover of expertise (Table 2). Note: from 2004 to 2008 the science operations of the mission were run from an external Payload Operations Service team located at Rutherford Appleton Laboratory, UK, before science operations were centralised at ESAC in Spain.

The external part of the Science Ground Segment team is formed by the Principal Investigators (PIs) of the mission and their team, distributed across Europe with some overseas team members as well. Table 3 lists the Mars Express scientific payload past and present Principal Investigators or Team Leads.

Interdisciplinary Scientists (IDSs; listed in Table 4), nominated by ESA, form another important element of the Science Working Team (SWT) of the mission. IDSs support the scientific process by bridging investigations along dedicated science themes chosen to enhance and optimise the mission legacy. Two new atmospheric IDSs were nominated in 2016 and one of their missions was to initiate the MEX Legacy Archive as part of the Planetary Science Archive, containing high-level datasets produced using MEX data and published in the peer-reviewed journals.

The Operations Ground Segment Team, or Mission Operations Centre (MOC) team, is located at the European Space Operations Centre (ESOC) in Darmstadt, Germany. In the list below, FCT is the Flight Control Team, FD is Flight Dynamics, ESTRACK is the Ground Station Network team and MCS is the Mission Control Systems team. The composition of the MOC team is as follows (Table 5).

Table 2 Mission management and science ground segment team (past and present)

Mission Role	Name	Affiliation
Mission Managers (MM)	Fred Jansen (former MM; 2004-2013; retired)	ESTEC, The Netherlands
	Patrick Martin (current MM; 2013-Present)	ESAC, Madrid, Spain
Project Scientists (PS)	Agustin Chicarro (1997-2009; retired)	ESTEC
	Olivier Witasse (2009-2014)	
	Hakan Svedhem (2014-2015; retired)	
	Dmitrij Titov (2015-2022; retired)	
	Colin Wilson (2022-Present)	
Science Operations Coordination	Rene Pischel (2002-2007)	ESTEC
	Patrick Martin (2008-2013)	ESAC
	Alejandro Cardesín-Moinelo (2014-Present)	ESAC
Science Operations Engineers and Scientists	At ESAC or ESTEC: Nicolas Altobelli, Michel Breitfellner, Isabel Caballero, Manuel Castillo, Marian Cuevas, Alfredo Escalante, Pilar Esquej, Bernhard Geiger, Sergio Ibarmia, Arnaud Mahieux, Julia Marin Yaseli de la Parra, Donald R. Merritt, Carlos Muniz, Federico Nespoli, Fran Raga, Eleni Ravanis, Lucie Riu, Mar Sierra, Ricardo Valles, Jim Volp, Pablo Pardo Voss, Tanja Zegers	ESAC, ESTEC, RAL
	At RAL (2003-2008): Anne Chadwick, Patrick Chaizy, Mila de Vere, Trevor Dimbylow, Matt Dunckley, Mike Hapgood, Gerard Hutchinson, Monica Kendall, Andrew McDermott, Dave Neudegg, Martin Ricketts, Helen Walker	
Archive Scientists	- Emmanuel Grotheer (2014-Present), Michel Breitfellner (2021- Present)	ESAC or ESTEC
	- Nicolas Manaud (2006-2014)	
	- David Heather (2003-2012), Marek Szumlas (2008-2010), Jose-Luis Vazquez (2008)	
	- Joe Zender (1999-2003)	

To complement ESTRACK and provide other project support as part of international collaboration, NASA personnel listed in Table 6 contributed extensively to the science return of the mission via technical and management support from its JPL and Headquarters centres.

Up to early 2004 the Mars Express Project team was located at ESA/ESTEC in the Netherlands and was in charge of developing, building, launching and commissioning the spacecraft before the Mission Manager took over the responsibility. The Project team (listed in Table 7), led by the ESA Project Manager, interfaced with Industry, i.e. the Prime Contractor who built the satellite and integrated the payload, and with the instrument builders via the Science Working Team chaired by the Project Scientist.

Astrium SAS of Toulouse, France, was the prime contractor for Mars Express, leading a consortium of 24 companies from 14 European countries and the US. Table 8 lists the Astrium team members who built Mars Express. In addition, Matt Cosby provided Industry support related to the MELACOM telecommunications package from QinetiQ, UK.

Table 3 Past and present Principal Investigators (PI) of the Mars Express mission

Instrument/Experiment	Acronym	Principal Investigator or Team Lead
High-Resolution Stereo Camera	**HRSC**	Daniela Tirsch, Institute of Planetary Research, German Aerospace Center (DLR), Germany Former PIs: Gerhard Neukum, Ralf Jaumann, Thomas Roatsch
Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité	**OMEGA**	John Carter, LAM, Marseille, France Former PI: Jean-Pierre Bibring, Institut d'Astrophysique Spatiale - IAS Orsay, France
Planetary Fourier Spectrometer	**PFS**	Marco Giuranna, Istituto Nazionale di Astrofisica, Rome, Italy Former PIs: Vittorio Formisano, Davide Grassi
Analyser of Space Plasma and Energetic Atoms	**ASPERA-3**	Mats Holmström, Swedish Institute of Space Physics, Sweden Former PIs: Rickard Lundin, Stas Barabash
Mars Radio Science Experiment	**MaRS**	Kerstin Peter, Rheinishes Institut für Umweltforschung, Köln Universität, Germany Former PI: Martin Pätzold
Spectroscopy for the Investigation of the Characteristics of the Atmosphere of Mars	**SPICAM**	Franck Montmessin, Laboratoire Atmosphères, Milieux, Observations spatiales (LATMOS), France Former PI: Jean-Loup Bertaux, retired from LATMOS
Mars Advanced Radar for Subsurface and Ionospheric Sounding	**MARSIS**	Andrea Cicchetti, Istituto di Astrofisica e Planetologia Spaziali, Italy. Jeff Plaut, Jet Propulsion Laboratory, USA Former PIs: Giovanni Picardi, Roberto Orosei
Visual Monitoring Camera	**VMC**	Team Lead: A. Sánchez-Lavega, University of the Basque Country, Bilbao, Spain

Table 4 Mars Express Interdisciplinary Scientists (IDS)

IDS	Topic	Affiliation
R. Amils	Astrobiology; Beagle-2	IDS until 2015; Centro de Astrobiologia, Madrid, Spain
E. Gibson	Exobiology; Beagle-2	IDS until 2015; NASA Johnson Space Center, Houston, USA
K. Maezawa	Space environment	IDS until 2015; JAXA-ISAS, Japan
G. G. Ori	Geological evolution	IDS until 2015; IRSPS, Pescara, Italy
T. Duxbury	Phobos, Deimos and small bodies investigations, Mars geodesy and cartography	IDS until 2019; George Mason University, Fairfax, USA (formerly at JPL)
F. Forget	Atmosphere and surface-atmosphere interactions	Laboratoire de Météorologie Dynamique/CNRS, Sorbonne Université, Paris, France
A. Määttänen	Climatology	IDS since 2016; LATMOS, Sorbonne Université, UVSQ Université Paris-Saclay, CNRS, Paris, France
F. González-Galindo	Aeronomy	IDS since 2016; Instituto de Astrofísica de Andalucía, CSIC, Granada, Spain

Table 5 Mars Express mission operations team at MOC, ESOC, Darmstadt, Germany

Name	MOC Team	Role
James Godfrey	FCT	Spacecraft Operations Manager (2015-present)
Michel Denis		Former Spacecraft Operations Manager (1999-2015)
Michael McKay		Former Ground Segment Manager
Alan Smith		Former Flight Operations Director
Alastair MacDonald Chiara Gobbi Francesco De Vita Joachim Hahn Luke Lucas Simon Wood Vittorio Pistone	FCT	Spacecraft Operations Engineers
Alan Moorhouse, Alexandros Minogiannis, Andrew David Johnstone, Caglayan Guerbuez, Daniel Lakey, Dave Turner, Duc Tran, Erhard Rabenau, Gianaldo Mantovani, Hannes Griebel, Joerg Fischer, Johannes Bauer, Jonas Marie, Jonathan Schulster, Juergen Fay, Isabelle Dauvin, Kees Van der Pols, Marco Bruno, Martin Shaw, Massimiliano Ladovaz, Oliver Page, Olivier Reboud, Pattam Jayaraman, Peter Schmitz, Pierre Choukroun, Rick Blake, Roberto Ferretti, Roberto Porta, Ruben Solaz, Sibylle Peschke, Thomas Dressler, Thomas Ormston, Thomas Soumeillan, Zeina Mounzer	FCT	Former Spacecraft Operations Engineers / Graduate Interns
Peter Wright Guillem Antoja Lleonart Carina Rufas Talamas Rudy Ciarletta Todor Toshev Arampan Rijiranuwat Roberto Parmegiani Palmieri Glenn Hurrel	FCT	Former Data Analysts
Jesus Amo Navarro, Robin Drevet, Giuseppe Enricomaria Esposito, Cristiano Garino, Federico Giannetto, Hamza Nachett El Bakkai, Carina Rufas Talamas, Francesco Salmaso, Maarten Van Nistelrooij	FCT	Spacecraft Controllers (“Spacons”)
Felix Romero Gomez Dario di Francesco Carmine Formisano		JUICE/Cluster Spacons

Table 5 (*Continued*)

Name	MOC Team	Role
Chiara Gobbi, Vittorio Pistone, Anna Schiavo, Aniris Inojosa, Thomas Dressler, Jan Maass, Guillem Antoja Lleonart, Corentin Guemene, Anton Michallek, Stephen Stewart, Roland Koehler, Joerg Kistner, Darrell Barrowman, Ralf Wichary, Alice Crowe, Andrei Buzila, Steve Jefferys, Achim Zschaege, Elena Ancona, Eleonora Bassi, Ian Shazell, Todor Toshev, Frederik Braeuer, Dieter Rossin, Michael Rhodes, Ulrich Kaiser, Freya Sice, Scott Selby, Rainer Wagner		Former Spacons
Sylvain Damiani	Flight Dynamics	Flight Dynamics Manager
Michael Mueller Vicente Companys Trevor Morley Johannes Schoenmaekers	Flight Dynamics	Former Flight Dynamics Managers
Martin Hechler	Mission Analysis	Former Mission Analysis Manager
Michael Khan Arturo Yáñez Ruaraidh Mackenzie	Mission Analysis	Former Mission Analysis Engineers
Gabriela Ravera	ESTRACK	Ground Operations Manager
J. Howard		Ground Operations Engineer
Marco Lanucara		Former Ground Operations Manager
John Reynolds		Former Ground Operations Engineer
Gianluca Gaudenzi	Mission Data Systems	Data Systems Manager
Erik Sorensen Andrzej Olchawa		Former Data Systems Managers
Alessandro Ercolani Fabienne Delhaise		Former Data Systems Development Managers
Adam Williams	Simulator System	Former Sims Officer
Kim Neergard David Verrier		Former Sims Development Managers
Stefano Scaglioni Michel Frantz Luca Paita Jana Mulacova Federica Pireddu	Ops Quality	Product Assurance / Quality Assurance Representative

As seen from the below map in Fig. 3, Mars Express exemplified and contributed to the genesis of European industrial cooperation (as well as scientific) on planetary exploration missions in Europe and beyond.

Table 6 NASA Project and DSN representatives at JPL/HQ in the USA

Name	JPL/HQ Role
Tommy Thompson	Project/DSN Representative
Freia Weisner	
Laif Swanson	
Padma Varanasi	
Roy Gladden	
Amanda Kniepkamp	
Sami Asmar	
Kris Angkasa	
Chad Edwards	
Sue Kirtik	
Dwight Holmes	
Richard Horttor	

Table 7 Mars Express Project team at ESTEC, Noordwijk, The Netherlands

Name	Project Team Role
Rudolf Schmidt	Project Manager
Hans Eggel	Payload Manager
John Reddy	Power / Data Handling Engineer
John Bennett	Quality Engineer
Ared Schnork	Structure / Thermal Propulsion Engineer
Don McCoy	System Integration Manager
Joe Pereira	System Integration Engineer
Piet Witteven	AOCS Engineer
Alistair Winton	TTC Engineer
Michael Witting	Beagle-2 Lander Engineer
Con McCarthy	Beagle-2 Lander Engineer
Thorsten Siwitza	Project Controller
Roy Gouka	Schedule Officer and Documentalist
Geoff Dudley	Post-2005 - Head of Battery Section

Evidently, Mars Express would not have been without a number of pioneering people. Among them are those who, following the outcome and recommendation from the 1996 International Mars Exploration Working Group (IMEWG) meeting, proposed and designed at fast pace an orbiter recovery mission after the Mars-96 launch failure. They are Josette Runavot, Richard Bonneville, Jean-Pierre Bibring, then Roger Bonnet, Marcello Coradini and Yves Langevin (see Bibring et al. 2025, this collection).

All personnel involved, from the pioneering people of this mission to the current operations teams and generations of scientists and students performing research based on Mars Express data, and including those possibly not listed above, have and still are demonstrating a team spirit and dedication without which this mission would not have collected so many successes.

Table 8 Mars Express Prime Contractor team at Astrium SAS, Toulouse, France

Name	Prime Contractor Team Role
Vincent Poinsignon	Project Manager
Alain Clochet	Payload Manager
Georges Noyer	Payload Architect
Frédéric Faye	System Manager
Christian Lebranchu	Mechanical Architect
Michel Feuillatre	Thermal Architect
Patrice Riant	AOCS Architect
Eric Ecale	AOCS Studies Manager, then AOCS Architect and MEX Technical Coordinator
Dieter Kolbe	Electrical Architect
Philippe Humbert	DMS & S/W Architect
Jérôme Lebrédonchel	SSMM Procurement Manager
Jacques Borde	Operations Manager
Raoul Caspar	Database Manager
Eric Orsoni	DMS & AOCMS Software Project Manager
Richard Langevin	Product Assurance Manager
Michel Pendaries	Procurement and AIV Manager
Olivier Bonnamy	MEX Technical Coordinator
Philippe Tatry	MEX Technical Coordinator

6 Mars Express: A Well-Built, Resilient and Innovative Spacecraft and Operations System

Although the mission was originally designed for a nominal mission lifetime of one Martian year, it has now operated successfully for over eleven Martian years (∼21 Earth years). Both the overall status and prognosis of the spacecraft, payload and ground segment continue to be robust and healthy. Key to continued successful science data acquisition are gyroless attitude and attitude rate estimator operations, running stably since their implementation in the spring of 2018. In combination with an Inertial Measurement Unit (IMU, including the gyros) duty cycle as low as 5% over the past year, these gyroless operations are likely to render the mission robust against IMU issues until about 2029 (worst case). Lifetime estimations for all other platform functions extend well beyond 2028 and pose no concern for a future extension interval beyond 2026. See Cardesín-Moinelo et al. (2024, this collection) for details on technical and operational status and challenges.

The technical status of the payload of Mars Express is overall very good to excellent, and the ensemble of instruments maintains its nearly full technical capability to continue their regular usage for the scientific mission (as per the applicable, regularly updated science plan) and maintains unique capabilities to provide data of the highest scientific relevance. It is noted, for example, that the High-Resolution Stereo Camera (HRSC) on Mars Express remains a unique instrument for provision of context information for in-situ and localised measurements on and in orbit around Mars, as well as its two main moons (e.g., Jaumann et al. 2007). Mars Express is, for example, the only mission making regular close flybys of Phobos so it provides a unique capability for high-resolution imaging of the future landing site of JAXA's Martian Moons eXploration (MMX) mission to Phobos.

The extensive operational experience and search for ways to optimise the mission has also resulted in several ground-breaking new possibilities of operations which demonstrate

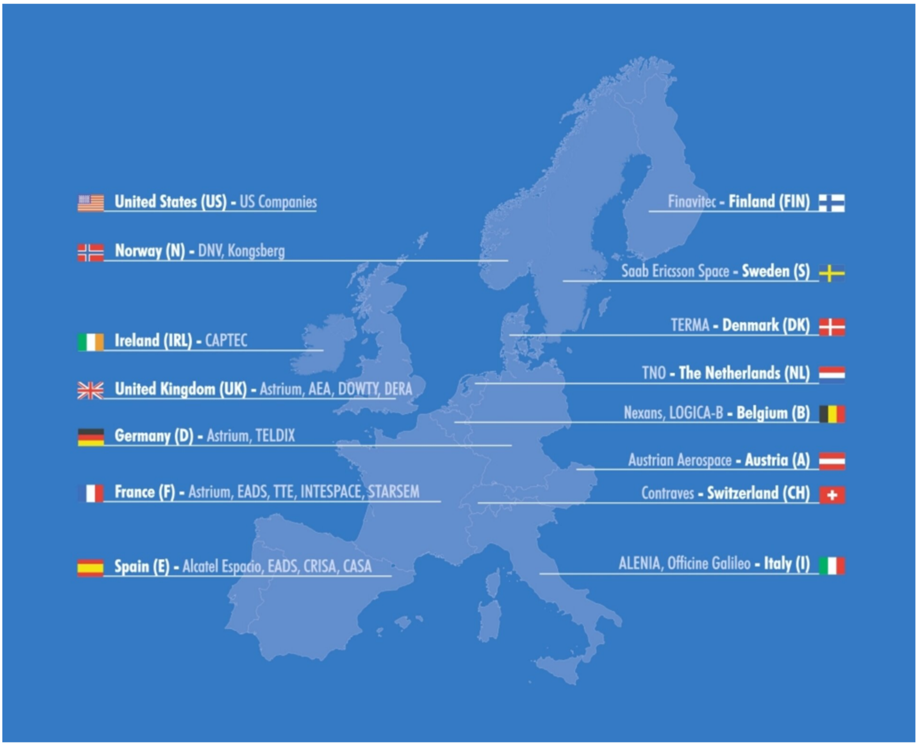

Fig. 3 Initial industrial partners in the 15 countries that contributed to the Mars Express mission. Illustration credit: Medialab/ESA 2001

that innovation still takes place on this ageing mission, for example: Use of the Visual Monitoring Camera, initially developed for engineering purposes, for science (Hernández-Bernal et al. 2024), inter-satellite radio science (Parrott et al. 2024), new MARSIS modes for liquid water detection and Phobos measurements (Cicchetti et al. 2023), and ASPERA-MARSIS first ever active sounding of plasma environment at another planet (Voshchepynets et al. 2018). The only major recent issue on the payload side regards the Planetary Fourier Spectrometer (PFS) which is believed to suffer from the reference laser diode ageing, which in turn causes intermittent data loss for a significant fraction of the observing time. Root cause analysis and mitigation actions are being worked on by the instrument and ESA operations teams. Details on the Mars Express payload, its evolution over the course of the mission and operational status are available in Wilson et al. (2025, this collection).

The Science Ground Segment continues running very smoothly, supporting and providing mission and science operations as well as archiving of primary and high-level science products. The monthly mission performance (planned vs. executed/recovered science observations) hovers regularly above 99%, and the daily total science data return is typically stable around or above 1.5 Gbit. Mars Express has since 2004 accumulated well over 9.5 TB of science data. Communications with the spacecraft and data downlink via ESA's ESTRACK ground station network, with support from NASA's DSN network, is running smoothly. Measures are in place to ensure nominal, routine operations through the 2024-2026 interval and beyond, in close collaboration with TGO science operations also conducted from

ESAC. For details on Mars Express science operations and archiving, see Cardesín-Moinelo et al. (2024, this collection).

All ground systems are deemed fully capable to sustain long-term operations beyond 2026. Finally, it is noted that the meanwhile standard use of multiple spacecraft per aperture (MSPA, for downlink), and multiple uplinks per aperture (MUPA, for uplink) greatly increases the efficiency of the ground resources used for missions at Mars, in our case MEX and TGO.

The lander backup relay capabilities of Mars Express are highly valued and will be used in even more significant ways over the coming years, in support of ESA or international surface elements, with the relevant agreements in place to provide emergency relay support when requested.

The overall status, performance and stability of all Mars Express spacecraft elements are examined at each extension opportunity (Mission Extension Operations Review or MEOR). Until now, through 9 mission extensions, the Review Board has confirmed that Mars Express could technically deliver the data to achieve the expected science return as presented in each science case. Considering that Mars Express has been in orbit around Mars for over twenty years, the spacecraft platform and payload status is very good, with no failure of any lifetime-critical element of the mission since Launch. The next technical review is expected by the end of 2025.

7 Highlighting the Mission's Scientific Achievements

Mars Express has acquired a wealth of scientifically rich data in the course of its 20 years of operations at Mars, some constituting breakthrough discoveries which led to a profound revisiting of Mars's properties and history, at all timescales. They built new paradigms that paved the way to most subsequent Mars exploration missions.

Mars Express continues to produce major scientific advances to the understanding of the planet and its system. Most of the mission's initial results were compiled in Fletcher and Witasse (2009). Titov et al. (2025, this collection) summarised the mission science highlights in more detail, while the full spectrum of Mars Express scientific achievements and discoveries is exposed throughout this entire collection by topical papers.

Most achievements originate from the pioneer capability to couple the analyses of Mars envelopes, with a new generation of instruments, some never flown on planetary missions at the time. For the sub-surface and surface investigations, they also became possible due to (1) the elliptical polar orbit of Mars Express with a pericentre at 250-300 km that naturally drifted in the North-South direction thus continuously covering all latitudes and (2) the non-sun-synchronous orbit that allowed pericentre observations in turn on both day and night sides that correspondingly favoured imaging by HRSC and OMEGA as well as MARSIS subsurface sounding, respectively. Furthermore, full planet coverage would not be possible without such a long mission duration.

The first subsurface radar sounding ever at another planet provided the third dimension to the surface investigations. The MARSIS radar has characterised the structure of the polar caps down to the depth of several kilometres and determined that the volume of water ice they contain is a couple of millions cubic kilometres, that is equivalent to Greenland ice sheet. The sounding revealed vast plains of permafrost at different latitudes, and potentially found pockets of liquid water underneath the Southern polar cap (Orosei et al. 2018, 2025, this collection). Noticeably though, the total budget of surface and trapped water ice has been evaluated to less than 100 m global equivalent layer, a tiny volume fraction of the Earth surface oceans and glaciers, pleading for an ancient Mars atmospheric loss.

This conclusion also derived from the global surface hyperspectral imaging by OMEGA, at near-infrared wavelengths, over large temporal and spatial domains. These data revealed the surface composition and mineralogy at sub-kilometre resolution which, together with the visible high-resolution stereoscopic mapping by HRSC, allowed the reconstruction of the regional geology and history of the planet (Bibring et al. 2006; Jaumann et al. 2024, this collection; Jaumann et al. 2015). A seminal discovery has been that of sequences of hydrated minerals, starting with that of phyllosilicates, followed by sulphates and a wide variety of altered minerals, tracing an ancient era during which Mars likely harboured stable liquid water at either or both its surface and subsurface (Carter et al. 2025, this collection). These discoveries opened a new pathway to the study of Mars's potential past "habitability", in particular by identifying and locating the most favourable sites having preserved such early enabling properties. This era transited to a dry period, with only transient "wet" episodes, through a global climatic change during which most atmospheric species escaped. Noticeably, the highly depleted resulting atmosphere, as compared to that of Venus, has a similar N_2/CO_2 ratio: it contrasts with that of Earth, for which most atmospheric CO_2 ended trapped into carbonates by reaction within stable oceans.

The identification by OMEGA of distinct silicate families, primarily of high and low calcium pyroxenes, as well as of plagioclase, put in their geological context by their coupling to the HRSC high-resolution camera images, has been essential to build a consolidated Mars geological history. HRSC has sent back thousands of stunning, 3D views of the planet's surface, spanning from immense volcanoes and steep-walled canyons to dry river valleys, ancient impact craters and evolving polar ice caps (Gwinner et al. 2016; Jaumann et al. 2024, this collection). Their interpretation, in particular through an accurate dating derived from impact craters densities, has led to ground-breaking outcomes, in terms of Mars volcanic and geological evolution.

SPICAM and PFS dedicated instruments have provided the longest so far (more than 10 Martian years) record of atmospheric parameters, including temperature structure, abundance of minor species and their variability (Montmessin et al. 2017; Giuranna et al. 2021; Montmessin et al. 2024, this collection; Giuranna et al. 2025, this collection). They led to a major improvement of chemical, meteorological and climate models at various scales; the discovery and monitoring of the ozone content and of its recurrent annual evolution by SPICAM is exemplary. Mars Express paved the way for, and has been coupled to, more accurate and sensitive investigations of the atmospheric composition by the TGO orbiter (Vandaele et al. 2024, this collection). Climatologies of gases, dust and clouds, as well of ices, derived from the Mars Express observations encompass annual cycles, diurnal and spatial variations; it also includes the evolution of dust storms and optical properties (Määttänen et al. 2024, this collection). The long duration of the mission and non-sun-synchronous orbit were essential for the study of the variability of meteorological parameters and rare transient events as well as diurnal changes.

As a pioneer discovery, the planet's carbon-dioxide-rich atmosphere and its low temperature result, in addition to clouds primarily made of water ice, in the formation of carbon dioxide (CO_2) clouds. Mars Express has detected these very unique clouds in the mesosphere, at altitudes well above 40 km (Montmessin et al. 2006b; Määttänen et al. 2010; Scholten et al. 2010). Remarkable was the discovery of a fleeting layer of such clouds at altitudes of up to 100 km — the highest clouds ever seen above any planetary surface (Montmessin et al. 2006a). They translate the occurrence of a highly specific microphysics of cloud nucleation.

The mission covered consecutive solar minima 23/24 and 24/25, enabling complete characterisation of the topology and variability of the ionospheric and magnetospheric boundaries at Mars (Hall et al. 2019). The long-term series of observations by the MARSIS ionospheric radar, the MaRS radio-occultation experiment, and the ASPERA-3 plasma package revealed a variability of the ionospheric structure and total electron content with solar zenith angle and Sun-Mars distance, the role of the crustal magnetic field and atmospheric cycles (Peter et al. 2024, this collection). Mars Express opened a new field of research on Mars with the discovery of aurorae on the planet (Bertaux et al. 2005; González-Galindo et al. 2024, this collection) and a previously unobserved ionospheric layer first identified as a new "meteoric" layer created by fast-moving cosmic dust which burns up as it hits the atmosphere (Pätzold et al. 2005; Peter et al. 2024, this collection). The mission also investigated couplings between atmospheric layers. In particular, it revealed the role of dust storms that significantly enhance the variability of the upper atmosphere and the ionosphere (Peter et al. 2024, this collection). In an endeavour to discover why the atmosphere is so thin and dry today, Mars Express has studied the upper atmosphere and ionosphere, detecting hydrogen and oxygen ions escaping into space (Montmessin et al. 2024, this collection; Barabash et al. 2025, this collection). Water vapour supersaturation was observed in the middle atmosphere, providing a piece in the puzzle of the atmospheric escape to space (Maltagliati et al. 2011). The achievements in aeronomy and plasma observations also strongly benefited from the long mission duration and non-sun-synchronous orbit. Furthermore, the elongated orbit enabled sounding of the plasma environment from the upstream solar wind to the inner regions of the induced magnetosphere.

Its highly elliptical orbit has enabled the spacecraft to look far beyond Mars, in order to survey its two moons, particularly the innermost satellite Phobos, which has been studied in unprecedented detail (Pätzold et al. 2025, this collection). Regular encounters with Phobos significantly contributed to the characterisation of the moon and its ephemeris as preparation for MMX and other future in-situ missions, with flybys from less than 100 km uniquely made possible. The revised mass and density data have opened up the possibility that the interior of Phobos exhibits a high degree of porosity (Pätzold et al. 2025, this collection). Surface structure and composition have been drastically refined, offering the MMX JAXA mission, planned to land on Phobos in order to collect and return samples back to Earth, a set of key reference data. As for the origin of Phobos and Deimos, an accretion in Mars debris following a giant impact (Craddock 2011; Rosenblatt and Charnoz 2012), similar to the Earth's moon proposed formation, will be addressed as a prime MMX scientific goal, in parallel to the scenario favouring a capture during a close encounter billions of years ago.

Finally, images from the Visual Monitoring Camera, initially intended to monitor the lander ejection, have provided mission scientists with new science-bearing output to monitor atmospheric dynamics at regional and global scale (Sánchez-Lavega et al. 2024, this collection).

As a summary, Mars Express results and discoveries continue playing an essential role in understanding the geological, atmospheric and climate evolution of the Red Planet and determining its potential past habitability. Those results also contributed to enhance Mars Express's role as a key player in the field of comparative planetology. Together with Venus Express, for instance, Mars Express brought about significant progress in the study of terrestrial planets.

8 A Strong Focus on International Collaboration

Throughout the 20+ years of its lifetime around Mars, Mars Express has carried out its own science data acquisition for the purpose of achieving the goals specified at the onset of the mission. But the very setup of the mission, built in an international context, has paved the way for not only inter-instrument and inter-institute science collaborations, but also for scientific and technical collaborations across domains (e.g., relay, lander activities, data models, spacecraft technology lessons learned) and international partners.

While addressing its science objectives, Mars Express has also provided relay communication services between the Earth and various landers deployed on the surface by other nations, thus playing an important role in international relay cooperation at Mars (Cardesín-Moinelo et al. 2024, this collection).

The mission has opened the path for European exploration efforts including the ExoMars programme as well as other current and future landing and mobile missions (Titov et al. 2025, this collection). Its results significantly helped in the characterization and selection of landing sites. Mars Express continues to foster a strong planetary science community in Europe that carries forward new missions to Mars and other planetary bodies. It has maintained through the years its recognised status as a reliable partner in fruitful collaborations with international scientists, as a relay orbiter supporting ESA's and other agencies' missions, and as an enabling element for landing site selections on Mars and Phobos.

In the most recent years, new collaboration opportunities have appeared as new mission arrivals at Mars were made by the EMM-Hope (United Arab Emirates) and Tianwen-1 (China) orbiters, the InSight lander and the Mars2020 Perseverance rover mission. These were opportunities for joint science campaigns but also which allowed Mars Express to provide relay passes in support of the CNSA and NASA missions.

As an upcoming collaboration opportunity, and one of the main focuses of the indicative extension in 2027-28, Mars Express is expected to conduct both joint science at Phobos with JAXA's Martian Moons eXploration (MMX) sample return mission while supporting that mission with its characterisation of the moon and landing site selection.

We should mention here that the European planetary community grew up with Mars Express. More than 170 PhD theses based on analysis of MEX observations have been successfully prepared and defended. More detail can be found here: https://www.esa.int/ESA_Multimedia/Images/2023/05/20_years_and_counting_Mars_Express_in_numbers; https://www.cosmos.esa.int/web/mars-express/phd-theses.

9 European Science at Mars

Although this paper collection is focused on Mars Express achievements, ExoMars Trace Gas Orbiter (TGO) results are highlighted as well in order to emphasise the long European presence at Mars. Furthermore, expected results from currently planned European scientific involvement at Mars are briefly described below.

The Trace Gas Orbiter, the first mission of ESA's ExoMars program, was launched in March 2016. It has a crucial relay capability designed to sustain the ExoMars rover mission. In addition, as it embarked a strong scientific payload package consisting of 4 instruments (ACS (Korablev et al. 2018), CaSSiS (Thomas et al. 2017), FREND (Mitrofanov et al. 2018) and NOMAD (Vandaele et al. 2018)), its main science goal is to investigate the Martian atmosphere, particularly the presence and distribution of trace gases such as water vapour, carbon monoxide, methane and other organic compounds, which may indicate biological or geological processes occurring on Mars (Vago et al. 2015).

The most notable science results and findings from the TGO mission can be summarised as follows: TGO has established an upper level for methane of only 20 parts per trillion throughout its mission (Korablev et al. 2019; Montmessin et al. 2021). The apparent discrepancy between this absence of methane at altitudes several kilometres up in the atmosphere, where TGO is at its most sensitive, and the reported detections of methane at the surface by mass spectroscopy by MSL/SAM, is a conundrum which is spurring a great deal of research. TGO has discovered the first halogen-containing species in the Martian atmosphere: hydrogen chloride (HCl), and revealed it to be highly variable, and thus a useful tracer of processes involving surface-atmosphere exchange, dust, and water cycle (Korablev et al. 2021). In addition to HCl, TGO has identified and measured abundance of other trace gases such as water vapour (H_2O), carbon monoxide (CO), hydrogen chloride (HCl), ozone (O_3) and isotope ratios, contributing to our understanding of Mars's atmospheric chemistry and evolution (Vandaele et al. 2024, this collection).

TGO has also greatly complemented Mars Express surface investigations by the study of seasonal processes continuously altering the topography (Thomas et al. 2025, this collection) and mapping distribution of hydrogen-bearing species in the shallow (1–2 m) subsurface (Orosei et al. 2025, this collection; Mitrofanov et al. 2022). TGO data has been further used to search for signs of ongoing geological activity on Mars, such as gas emissions from the planet's crust, and have contributed to create more accurate models of the Martian atmosphere and its dynamics, helping scientists understand the transport and distribution of trace gases. The detection of certain gases, particularly in conjunction with methane, has implications for the potential past habitability of Mars, driving further questions about the planet's environment and history.

Throughout the spacecraft's over 8 years at the Red Planet to date, TGO findings have enhanced our understanding of Mars' atmosphere and have implications for future exploration, including the search for life. TGO continues to operate and collect data, and its results are regularly updated as analyses progress.

Following in the footsteps of TGO, the ExoMars Rosalind Franklin Mission (RFM) is expected to bring Europe to the surface of Mars, with a launch planned in 2028. The Rosalind Franklin rover will explore the planet's surface at the selected landing site, Oxia Planum (Quantin-Nataf et al. 2021; Fawdon et al. 2024). The unique capabilities of the Rosalind Franklin rover include its mobility, drill, and suite of survey and analytical instruments in the Pasteur Payload (Vago et al. 2017). Drilled samples from depths reaching 2 m will undergo mineralogical and molecular analyses in the on-board Analytical Laboratory Drawer (ALD), to accompany interpretations of geologic context from surface and sub-surface measurements. The Rosalind Franklin Mission provides the most compelling and soonest opportunity to search for signs of life from the surface of Mars.

The Mars Sample Return Campaign is a sequence of missions led jointly by NASA and ESA partners (McCubbin et al. 2025). NASA's Perseverance rover in the Mars2020 mission is collecting suites of samples of rock cores, loose material and atmospheric gas at Jezero crater, a site hosting a delta formation and a diverse range of sedimentary and igneous rocks (Czaja et al. 2023; Herd et al. 2025). European involvement in Mars Sample Return includes balanced scientific participation from across ESA states, provision of the Earth Return Orbiter (ERO) which will perform the round-trip to Mars, and ground-based activities to support the Sample Receiving Project (SRP), including development of double-walled isolator cabinets, and management of an Analogue Sample Library (ASL) (Thorpe et al. 2024).

The Japanese Space Agency (JAXA), partnering with ESA, NASA, CNES and DLR, is leading the Martian Moons eXploration mission (MMX) (Kuramoto et al. 2022), which is slated for launch in 2026 and has objectives to resolve the origin of Phobos and Deimos and study the cis-Mars environment. MMX shall return $\geq$10 g of material for study on Earth, via core- (Sawada et al. 2021) and pneumatic-sampling (Zacny et al. 2020) at two locations on Phobos (Nakamura et al. 2021). European scientists are involved in teams of contributed elements such as the IDEFIX rover (Michel et al. 2022) and MMX Infrared Spectrometer (MIRS) (Barucci et al. 2021), and as ESA-appointed members of the MMX Science Board, and Science Strategy Teams (SSTs). The unique characteristics of Mars Express' orbit allow regular flybys of Phobos, leading to a wealth of observations of Phobos to support MMX mission planning and science (e.g. Witasse et al. 2014), and a wide range of opportunities for future supporting and coordinated observations.

Furthermore, ESA is also proposing a new programme of Lightship orbiters dedicated to weather monitoring in view of preparing future European landing missions (see Titov et al. 2025, this collection and references therein).

10 Outline of Science Topics from This Collection

The present collection of papers should not be considered as a comprehensive review of the Martian science. It rather aims at summarising and highlighting the successes of the Mars Express mission across a broad palette of topics and disciplines, with a particular focus on the 20 years of scientific achievements. Some observations of the successor mission, ExoMars 2016, as well as results of supporting modelling are also included where relevant.

Section 7 above summarised the major achievements of the Mars Express mission. Those span many scientific disciplines and discovery topics, which the following collection of papers covers and classifies into selected historical, scientific or learning domains. From each of those, and here to give the reader a preview of this collection to navigate through, a brief abstract is listed below. The collection will be preceded by a historical recap of the mission's genesis by Bibring et al. (2025) and be concluded by Titov et al. (2025, this collection) who describe the science highlights, the mission's lessons learned and future Mars exploration in more detail.

Cardesín-Moinelo et al. (2024, this collection) describe the operations, science planning and data archiving systems and processes. The paper also outlines major challenges, surmounted by the operations teams, and the evolution of the ground and space segment operations to provide new capabilities not envisaged before launch, whilst simultaneously maintaining and even increasing the quality and quantity of scientific data. The science payload and its evolution over the past 20 years is presented in Wilson et al. (2025, this collection).

Several papers highlight major Mars Express results in the field of geology and surface processes. Jaumann et al. (2024, this collection) summarises Mars Express observations and results that revealed geological and water-related processes on the surface of Mars. Both quantifying the geological processes and age determination put constraints on the evolution of water-related activities in space and time and suggested episodicity in the geological activity and accumulation of fluvial, glacial, and lacustrine deposits. This demonstrated close correlation between individual surface processes and endogenic activity, orbit variations and changing climate conditions.

Thomas et al. (2025, this collection) focused on the progress in our knowledge of seasonal processes on Mars thanks to the continued operation of Mars Express, Mars Reconnaissance Orbiter, and the ExoMars Trace Gas Orbiter. The most apparent evidence of the importance of seasons on Mars on a large scale is annual variation in the sizes of the Martian polar caps. However, high-resolution imaging has also shown that seasonal forcing can lead to small-scale phenomena that are continuously changing the topography. These phenomena often have no terrestrial analogue and involve complex interactions between seasonal ices, atmosphere, and substrate. Jaumann et al. (2015) discuss the Mars Express achievements in the investigation of volcanic and tectonic processes on Mars based on almost complete surface coverage by stereo and colour imaging by the HRSC camera. In particular, the mission contributed essentially to our understanding of the formation scenarios for Nili Fossae, Arabia Terra, the Olympus Mons vicinity and other regions. Carter et al. (2025, this collection) describe the surface composition and mineralogy derived from the global mapping at sub-kilometre resolution by the OMEGA imaging spectrometer. These results together with the HRSC imaging allowed reconstruction of the regional geology and history of the planet (Bibring et al. 2006; Jaumann et al. 2024, this collection). The subsurface sounding by the penetrating radar MARSIS provided the third dimension to the surface investigations, revealing buried subsurface structures down to several kilometres in depth (Orosei et al. 2025, this collection). Of special interest was the characterisation of the Polar Layered Deposits (PLD) and the discovery of multiple subglacial water bodies underneath the southern PLD.

Several papers of the present topical collection describe the science highlights of the atmospheric investigations. Giuranna et al. (2025, this collection) describe the Mars Express monitoring of the atmospheric temperature field and its variations, in particular in the vicinity of Martian volcanoes as well as changes related to dust storms. Vandaele et al. (2024, this collection) focused on the rich harvest of results in the field of atmospheric composition and chemistry delivered by Mars Express and its successor Trace Gas Orbiter. More detailed discussion of the water cycle peculiarities and variations and, in particular, its role in the atmospheric chemistry and escape can be found in the paper by Montmessin et al. (2024, this collection). Observations of dust, water ice and CO_2 ice clouds on Mars as observed by MEX and complemented by Trace Gas Orbiter and other missions are reviewed by Määttänen et al. (2024, this collection). The paper presents a complete picture of the climatologies of dust and clouds and, in particular, unique views on the processes leading to dust lifting and cloud formation. Sánchez-Lavega et al. (2024, this collection) describe the dynamic phenomena in the atmosphere of Mars from the images taken by the VMC and HRSC cameras and the properties of atmospheric features traced by aerosols covering a large range of spatial and temporal scales, including dynamical interpretations and modelling when available, with their geographic distribution and the daily and seasonal cycles.

Three papers of the topical collection present the major results in the field of aeronomy, plasma environment and escape. Peter et al. (2024, this collection) present the long-term series of observations by MARSIS ionospheric radar, MaRS radio-occultation experiment, and ASPERA-3 plasma package. They revealed variability of the ionospheric structure and total electron content with solar zenith angle and Sun-Mars distance, as well as the influence of the crustal magnetic field and atmospheric cycles on the upper atmosphere. González-Galindo et al. (2024, this collection) summarise the most relevant information obtained by the analysis of atmospheric emissions data from Mars Express and TGO, about the temperature and density structure, the atmospheric dynamics, the chemistry and the atmospheric escape to space. The paper includes in particular the most outstanding results collected by Mars Express about airglow and aurorae. Barabash et al. (2025, this collection) summarise pioneering and fundamental contributions of Mars Express to the understanding of the interaction of the solar wind with Mars, the ion escape at Mars and its role in the atmospheric evolution.

Pätzold et al. (2025, this collection) present investigations of Mars' moon Phobos by Mars Express. This paper describes the planning of the flybys and execution of the remote sensing observations, including high-resolution images of the surface. The scientific analysis covers different areas, from the determination of the Phobos ephemeris, to the surface geology, its three-dimensional shape and rotation, insights into Phobos' interior geophysical bulk parameters, mass, density and gravity field, and the study of the interactions between Phobos and the space environment.

To conclude, Titov et al. (2025, this collection) summarise science highlights of the Mars Express mission, list important lessons that can be learned from its mission design, operations and management, and describe how it functions as an effective bridge for the future science and exploration of the Red Planet.

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Declarations

Competing Interests The authors declare that they have no conflicting interests.

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