BepiColombo Mission – Brief description and overview

Document in support of the Announcement of Opportunity for Interdisciplinary Scientists and Guest Investigators in the BepiColombo mission (13 May 2019)

1. Introduction

This document presents a brief summary of the BepiColombo mission and its two major elements, the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MMO). The BepiColombo scientific investigations are summarised and a top-level description of the instrumentation is given. More up to date information is available on the ESA websites: http://sci.esa.int/bepicolombo and https://cosmos.esa.int/bepicolombo. It is not intended to update this document after this first issue.

2. The BepiColombo mission

The BepiColombo mission has four main components (see Figure 1 and Figure 2): Mercury Transfer Module (MTM), Mercury Planetary Orbiter (MPO), Mercury Magnetospheric Orbiter (MMO), and MMO Sunshield and Interface Structure (MOSIF). During the launch and the cruise phase, these components fly in a 'stack' configuration and only separate at arrival at Mercury in December 2025.

The scope of the instrumentation onboard MPO and MMO is to perform a full interdisciplinary study of the interior, surface, composition, magnetosphere, and exosphere of Mercury. During the cruise phase, instrument operations are limited by two main constraints: First, no instrument operations are foreseen during the firing of the Solar Electric Propulsion System (SEPS), both for MPO and MMO instrumentation; Second, the MPO observation deck — providing the mounting/viewing location for most remote sensing instruments — faces the MTM and, as a consequence, the field-of-view of most instruments is blocked during the cruise phase. The MMO is protected by the MOSIF and it is not possible to deploy any boom until arrival at Mercury. The MMO detectors are thus not directly exposed to the solar wind or the spacecraft environment during the cruise phase.

Figure 1. The BepiColombo spacecraft stack before the transfer to the final assembly building. Credit: ESA/CNES/CSG, S. Martin

Figure 2. Artist's impression of the BepiColombo spacecraft stack during the cruise phase. Credit: ESA/ATG medialab

3. BepiColombo mission objectives

The BepiColombo mission will study the composition, geophysics, atmosphere, magnetosphere, and history of Mercury. In particular, the mission objectives are:

- To understand why Mercury's uncompressed density is markedly higher than that of all other terrestrial planets, and of the Moon;
- To understand and determine the nature of the core of Mercury;

- To understand the origin of the intrinsic magnetic field and investigate Mercury's magnetised environment;
- To investigate if the permanently shadowed craters of the polar regions contain sulphur and/or water ice;
- To study Mercury’s composition and unravel the question of missing iron;
- To obtain global and high-resolution compositional information of Mercury’s surface;
- To study the production mechanisms of the exosphere and to understand the interaction between the planetary magnetic field and the solar wind in the absence of an ionosphere;
- To obtain new clues about the composition of the primordial solar nebula and about the formation of the Solar System;
- To test general relativity with improved accuracy, taking advantage of the proximity of the Sun.

In addition, the BepiColombo mission will provide a unique opportunity to collect multi-point measurements in a planetary environment, and thus support the solar wind and exosphere-related science objectives. This will be particularly important at Mercury because of the short temporal and spatial scales of the environmental effects. The baseline for the MPO and MMO orbits will ensure that there are several close encounters (a few 100 km or less) throughout the mission. Such intervals are very important for the inter-calibration of similar instruments on the two spacecraft.

During the cruise phase, before the arrival at Mercury in December 2025, some BepiColombo science could be possible:

- To execute the solar conjunction experiment with the radio science experiment;
- To obtain in-situ solar wind observations in the inner Solar System;
- To observe Venus and Mercury during flybys;
- To study the plasma composition, the ion flux and density, and the magnetic field of Venus and Mercury during flybys;
- To support coordinated science observations with other spacecraft in Earth orbit and in the inner Solar System, e.g., Akatsuki, Parker Solar Probe, SDO, Proba-2, Hisaki, and Solar Orbiter.

4. Mission Phases and Mission Calendar

The present section provides an overview of the BepiColombo mission cruise and nominal operations while orbiting Mercury.

BepiColombo was successfully launched on 20 October 2018 from the European spaceport in Kourou, French Guiana. The spacecraft will arrive at Mercury in December 2025, the MMO will be transferred into its orbit in late December 2025, and the MPO in March 2026. The cruise phase foresees flybys of Earth, Venus, and Mercury, as detailed in Table 1 and Figure 3.

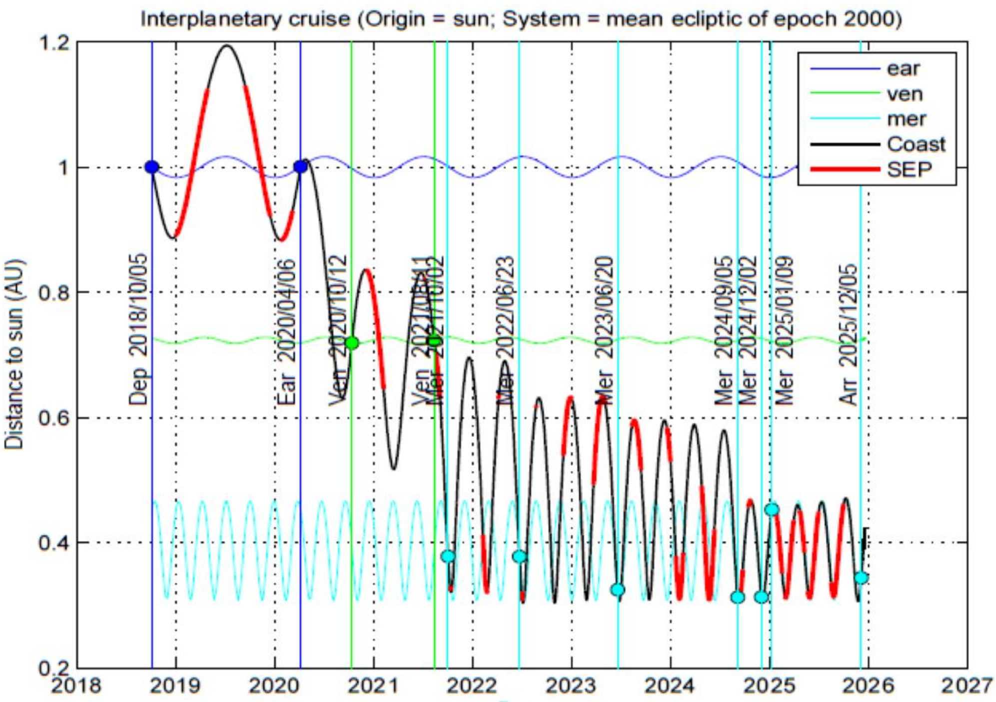
The operation of MPO and MMO instruments was originally scheduled with short check-out periods every six months. Following the successful launch, it was agreed that instrument operations are allowed in non-SEPS periods, on a best-effort basis. The SEPS periods are listed in Table 2.

The Mercury Radio Science Experiment (MORE) is scheduled for nominal operations already during the solar superior conjunction periods during the cruise phase. The periods of the solar superior conjunction are given in Table 3 for critical Sun-Earth-spacecraft angles of 5.0° for the cruise and nominal mission.

Table 1. BepiColombo flybys during cruise phase[1]

	Earth	Venus 1	Venus 2	Mercury 1	Mercury 2	Mercury 3	Mercury 4	Mercury 5	Mercury 6
Flyby Date	13-4-2020	16-10-2020	11-8-2021	2-10-2021	23-6-2022	20-6-2023	5-9-2024	2-12-2024	9-1-2025
Solar Longitude	-156.5°	107.7°	-131.7°	-18.1°	-17.6°	30.6°	50.3°	48.9°	-132.0°
Flyby Velocity	3.92 km/s	7.94 km/s	8.09 km/s	6.57 km/s	6.37 km/s	3.63 km/s	2.78 km/s	2.65 km/s	1.84 km/s
Flyby altitude	11264 km	10907 km	1007 km	200 km	200 km	200 km	200 km	40000 km	345 km

Figure 3. Distances and events during the interplanetary cruise phase.
Credit: ESA/ESOC, M. Khan



[1] All dates and derived geometrical parameters depend on spacecraft orbit manoeuvres. Listed values reflect the current baseline.

Table 2. SEPS operation periods

	Duration [days]	Start Time	End Time
EP1	66	16-12-2018	19-02-2019
EP2	60	22-09-2019	20-11-2019
EP3	5	12-02-2020	16-02-2020
EP4	17	18-06-2021	04-07-2021
EP5	8	18-08-2021	25-08-2021
EP6	5	09-10-2021	13-10-2021
EP7	6	06-12-2021	11-12-2021
EP8	22	05-02-2022	26-02-2022
EP9	6	30-06-2022	05-07-2022
EP10	5	21-08-2022	25-08-2022
EP11	34	01-12-2022	03-01-2023
EP12	46	23-03-2023	07-05-2023
EP13	34	12-08-2023	14-09-2023
EP14	16	18-12-2023	02-01-2024
EP15	29	21-01-2024	18-02-2024
EP16	48	25-04-2024	11-06-2024
EP17	12	12-09-2024	23-09-2024
EP18	11	14-10-2024	24-10-2024
EP19	29	19-01-2025	16-02-2025
EP20	35	26-02-2025	01-04-2025
EP21	70	24-04-2025	02-07-2025
EP22	44	15-08-2025	27-09-2025

Table 3. Periods of solar superior conjunctions

5.0° Entry	Duration (days)	Electric Propulsion
Interplanetary Cruise		
11-03-2021	14	No
29-01-2022	12	Partial
10-07-2022	8	No
28-01-2023	13	No
26-06-2023	7	No
30-11-2023	31	Partial
17-05-2024	7	Yes
24-09-2024	12	No
01-02-2025	11	Yes
23-05-2025	8	Yes
07-09-2025	11	Yes
Mercury		
15-01-2026	14	
11-05-2025	9	
24-08-2026	10	
25-23-2026	17	
25-04-2027	10	
08-08-2027	9	
03-23-2027	19	
03-12-2027	10	

The MMO and MPO nominal mission at Mercury will start after a period of instrument checkouts, not later than 16 April 2026. The nominal mission will last for one year (about 4 Mercury years, or 2 Mercury solar days). Orbit maintenance is not required over the planned operational lifetimes of the MPO and MMO.

For MPO, a polar orbit at 480 km × 1500 km altitude with a 2.3 h period was selected with its apoapsis at the equator on the dayside when Mercury is at perihelion to obtain full high-resolution mapping coverage of the planet. Half a Mercury year later, at aphelion, the sub-solar point occurs when the spacecraft is at its minimum distance to the planet.

For the MMO, a highly eccentric orbit at 590 km × 11 640 km altitude with a 9.3 h period, co-planar with the MPO orbit, was selected to allow mapping of the magnetic field and study of the magnetosphere, including the bow shock, magnetotail, and magnetopause.

5. The Mercury Planetary Orbiter

The BepiColombo MPO accommodates 11 scientific instruments (Figure 4 and Table 4) and has a box-like shape with a size of 3.7 m × 2.2 m × 1.7 m. The MPO accounts for 1230 kg of dry mass, including 85 kg of science payload. The MPO is designed to take scientific measurements in all parts of the orbit throughout the Mercury year, implying that most of the apertures of the remote sensing instruments are continuously nadir pointing.

Communication with Earth is ensured via a high-gain antenna, a medium-gain antenna, and two low-gain antennas. The medium-gain antenna is mounted on a boom and provides global coverage, ensuring that contact is maximised with respect to spacecraft attitude and Earth position. The high-gain antenna provides a link with a high data rate for science data transmission and is the basis for the MORE radio science experiment. This link is achieved using X-band uplink for commanding, both Ka and X-band for data downlink, and both Ka and X-band uplink and downlink for radio science. Over one Earth year in Mercury orbit, about 1550 Gbit will be downlinked to Earth. Precise range and range rate (Doppler) measurements are enabled by the dual-frequency uplink and downlink, allowing accurate orbit determination.

5.1 Instruments on the Mercury Planetary Orbiter

5.1.1 BELA

The BepiColombo Laser Altimeter (BELA) (Gunderson and Thomas, 2010) will characterise and measure the figure, topography, and surface morphology of Mercury. It will provide absolute topographic height and position with respect to a Mercury-centred coordinate system. This information will be used to create a digital terrain model that allows quantitative exploration of the planet’s geology and tectonics. In synergy with the stereo camera, BELA will improve knowledge of Mercury’s geology, geomorphology, tectonics, volcanism, and the evolution of the planet.

BELA uses a classic approach to laser altimetry. A Nd:YAG laser produces a 50 mJ pulse at 1064 nm wavelength with a duration of 5–8 ns. This beam produces a 60-μrad footprint (20–50 m) on the surface of the planet. The laser light is reflected from the surface, received with a telescope and fed into the pulse discrimination electronics, which determines the time of flight, the integrated pulse intensity, and the pulse width. Onboard data compression and data storage are essential. BELA requires significant baffling and thermal control and can operate over the dayside and nightside hemispheres, allowing optimum data acquisition. Performance estimates show that data return is expected at altitudes up to 1050 km above the surface with very low probabilities of false detections. Samples will be acquired every 250 m along ground tracks that will be separated by 25 km at the equator. The experiment will provide return pulse intensity and width information, allowing an assessment of surface reflectance and roughness.

The BELA laser will not be scientifically operated before Mercury orbit insertion.

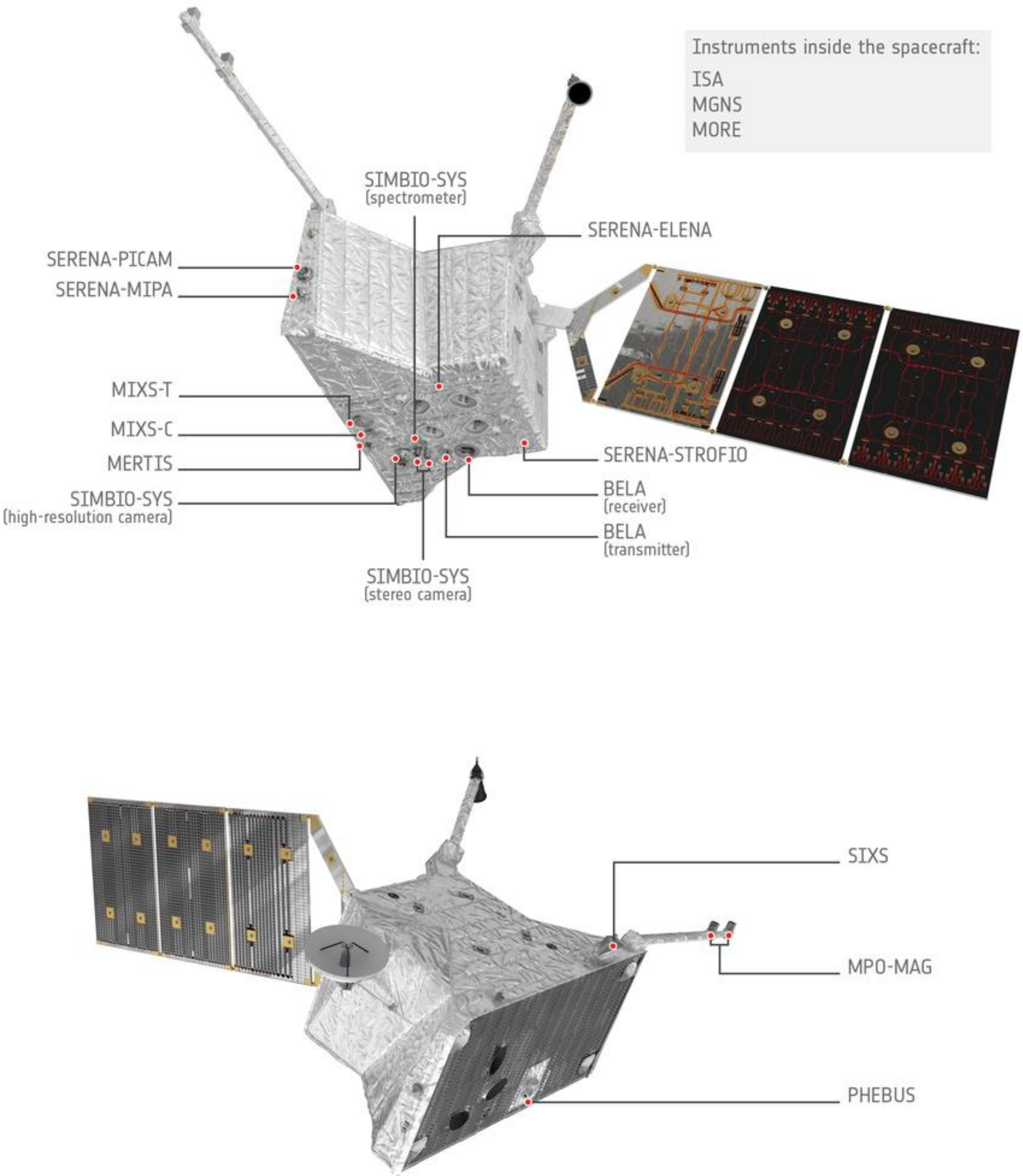


Figure 4. The Mercury Planetary Orbiter and its instruments. Credit: ESA/ATG medialab

Table 4. MPO Instrument Overview

Instrument	Main objective	Principal Investigator (Country)
BELA: BepiColombo Laser Altimeter	Characterize the topography and surface morphology of Mercury.	Hauke Hussmann (Germany) Nicolas Thomas (Switzerland)
MORE: Mercury Orbiter Radio Science Experiment	Determine Mercury's gravity field as well as the size and physical state of its core.	Luciano Less (Italy)
ISA: Italian Spring Accelerometer	Study Mercury's interior structure and test Einstein's theory of relativity.	Valerio Iafolla (Italy)
MPO-MAG: Mercury Magnetometer	Describe Mercury's magnetic field and its source.	Daniel Heyner (Germany)
MERTIS: Mercury Radiometer and Thermal Imaging Spectrometer	Determine Mercury's mineralogical composition and obtain a global map of the surface temperature.	Harald Hiesinger (Germany)
MGNS: Mercury Gamma-ray and Neutron Spectrometer	Determine the elemental composition of Mercury's surface distribution of volatiles in the polar areas.	Igor Mitrofanov (Russia)
MIXS: Mercury Imaging X-ray Spectrometer	Obtain a global map of the surface atomic composition.	Emma Bunce (United Kingdom)
PHEBUS: Probing of Hermean Exosphere by Ultraviolet Spectroscopy	Characterize the composition and dynamics of Mercury's exosphere.	Eric Quémerais (France)
SERENA: Search for Exosphere Refilling and Emitted Neutral Abundances	Study the interactions among the surface, exosphere, magnetosphere, and the solar wind.	Stefano Orsini (Italy)
SIMBIO-SYS: Spectrometers and Imagers for MPO BepiColombo Integrated Observatory System	Provide global, high-resolution, and infrared imaging of the surface.	Gabriele Cremonese (Italy)
SIXS: Solar Intensity X-ray and particle Spectrometer	Perform measurements of solar X-rays and energetic particles at high time resolution.	Juhani Huovelin (Finland)

5.1.2 ISA

The Italian Spring Accelerometer (ISA) (Iafolla et al., 2010) is a three-axis, high-sensitivity accelerometer devoted to measurement of the acceleration related to the non-gravitational perturbations (NGPs) acting on the surface of the MPO spacecraft. The three sensitive elements are based on a mechanical harmonic oscillator with a resonance frequency of 3.5 Hz. The weakest accelerations that ISA is able to measure cause a displacement of the proof masses of about 2×10^{-11} m. These displacements are detected by means of a capacitive pick-up system in a bridge configuration. The NGPs in Mercury orbit are mainly due to the incoming solar visible radiation and visible and infrared radiation from the planet. The scientific objectives of ISA are strongly related to the BepiColombo Radio Science Experiment (RSE) of MORE. ISA's key role is to remove the NGPs from the list of unknowns in the MPO equation of motion in the precise orbit determination that is the core of the RSE. As a "by-product" ISA will deliver a characterisation of the MPO dynamics at low frequencies. The ISA accelerometer is able to measure variable accelerations in the frequency band 3×10^{-5} to 0.1 Hz with a sensitivity of 10^{-8} m/s^{2}Hz$^{0.5}$.

The ISA instrument was fully commissioning in November 2018 and it can be operated during cruise on a best effort basis.

5.1.3 MPO-MAG

The primary objective of the MPO Magnetometer (MPO-MAG) (Glassmeier et al., 2010) is to collect magnetic field measurements to describe Mercury's planetary magnetic field and its source in great detail. These measurements will improve understanding of the origin, evolution, and current state of the planetary interior. The requirement is to determine all the terms associated with the internal field up to octupole components with high accuracy, using accurate magnetic field measurements on the low portions of the MPO orbit. This campaign will be supported by similar measurements to be made by MMO, to distinguish the effects of the magnetospheric currents on the MPO measurements and to use the MMO measurements directly to augment the database for the determination of the internal field.

The secondary objectives of MPO-MAG are related to the interaction of the solar wind with Mercury's magnetic field and the planet itself. This interaction leads to the formation of highly dynamic global magnetospheric current systems. In particular, measurements close to the planet will allow a determination of the conditions for access of the solar wind to the planetary surface and an assessment of the role and importance of different current systems, including subsurface induction currents sensitive to the conductivity of the interior. These objectives will again be assisted by the planned close association with the magnetic field investigation on the MMO.

The MPO-MAG experiment consists of a dual fluxgate magnetometer system that will measure vector magnetic fields from direct current (DC) to 128 Hz frequency within ±2048 nT with a digital resolution better than 60 pT. In order to determine and remove magnetic contamination (alternating current and DC) from the spacecraft, MPO-MAG consists of two sensors, an inboard sensor and an outboard sensor, mounted on a 2.8-m-long boom and separated by 50 cm.

The MPO-MAG boom was deployed shortly after launch and fully commissioned. The MPO-MAG can be operated also during cruise on a best effort basis.

5.1.4 MERTIS

The goal of the Mercury Radiometer and Thermal Imaging Spectrometer (MERTIS) instrument (Hiesinger et al., 2010) is to provide detailed information about the mineralogical composition of Mercury's surface material by globally mapping spectral emittance at high spectral resolution. MERTIS will cover a wavelength range from 7 to 14 μm with a spectral resolution of 90 nm, although some binning will be needed to improve the signal-to-noise ratio for identifying subtle spectral features at lower spectral resolution. This resolution will allow the detection and identification of the characteristic features of surface minerals in this spectral region, such as the Christiansen frequencies, Reststrahlen bands, and transparency features. In addition, MERTIS will be able to measure thermophysical properties of the surface, such as thermal inertia and surface texture. MERTIS is an infrared imaging spectrometer and will make use of micro-bolometer technology for which no cooling is required. MERTIS will globally map the planet with a spatial resolution of 500 m. To allow the observation of calibration targets, the instrument is equipped with two telescopes/baffles: a space baffle and a planet baffle. The planet baffle is mounted on the nadir deck of the MPO, whereas the space baffle is pointing through the radiator shield, and thus always directed opposite to the direction of the Sun.

MERTIS underwent commissioning after launch, and thus MERTIS — via the space baffle — can be used to obtain scientific observations on a best effort basis during the cruise phase.

5.1.5 MGNS

The scientific goal of the Mercury Gamma-ray and Neutron Spectrometer (MGNS) (Mitrofanov et al., 2010) is to measure the elemental surface and sub-surface composition for distinguishable regions over the entire surface of Mercury by measuring (a) the nuclear lines of major elements in Mercury surface material (Na, Fe, Ti, Al, Mg, Si, Ca, O, K, U, and Th), (b) the leakage flux of neutrons, and (c) the lines of naturally radioactive elements, including U, Th, and K. It will also determine the regional distribution of volatile deposits in permanently shadowed polar areas of Mercury and provide a map of column density of these deposits with an accuracy of 0.1 g/cm^2 and a surface resolution of about 400 km.

The MGNS is mounted inside MPO and does not depend on any viewports. The MGNS underwent commissioning after launch and can be operated also during the cruise phase on a best effort basis.

5.1.6 MIXS

The Mercury Imaging X-ray Spectrometer (MIXS) (Fraser et al., 2010) will measure the planetary X-ray flux from Mercury, stimulated by high-energy solar X-rays and charged particle interactions with the surface of the planet. This information, in combination with simultaneous measurements of the solar X-ray flux with the Solar Intensity X-ray and particle Spectrometer (see Section 5.1.11), will allow measurements at high spectral and spatial resolution of the planetary surface composition. In order to achieve its science objectives, MIXS consists of two channels: MIXS-C, a collimator providing efficient flux collection over a broad range of energies with a wide field of view for global planetary mapping, and MIXS-T, an imaging telescope with a narrow field of view for high-resolution measurements of the surface.

By use of the X-ray fluorescence technique, MIXS will provide a global view of Mercury's surface composition in both hemispheres. It is expected that MIXS will obtain global elemental abundance maps of key rock-forming elements (e.g., Na, Mg, Al, Si, S, K, Ca, Ti, and Fe) to an accuracy of 10–20 %. MIXS will also obtain high-spatial-resolution measurements of the distribution of chemical elements on the local scale. These measurements will enable the composition determination of small surface features (down to the ~few-kilometre scale) during periods of high solar activity. In addition, the MIXS dataset will allow the study of complex interactions among Mercury's surface, its local environment, and the solar wind, via remote sensing of the energetic electrons and particles that are known to precipitate to the surface and produce X-ray emission (Starr et al., 2012).

The MIXS instrument will not be scientifically operated before Mercury orbit insertion.

5.1.7 MORE

The Mercury Orbiter Radio Science Experiment (MORE) addresses scientific goals in geodesy, geophysics, and fundamental physics. It will help to determine the gravity field of Mercury as well as the size and physical state of its core. It will provide crucial experimental constraints to model the planet's internal structure and test theories of gravity with unprecedented accuracy. MORE will also measure the gravitational oblateness of the Sun and test and characterise the most advanced interplanetary tracking system ever built. Finally, it will assess the performance of the novel tracking system for precise orbit determination and space navigation. These scientific goals will be achieved by means of several data types, generated by MORE itself at the ground station, other onboard instruments (BELA, ISA, and SIMBIO-SYS), and the onboard attitude determination and control system. MORE will also contribute to the determination of Mercury's obliquity (i.e., the angle that the spin axis makes to the normal to the orbital plane) and the amplitude of its 88-day physical libration in longitude. These two quantities, together with the coefficients of the second-degree harmonics of the gravity field, will more precisely constrain the outer radius of the planet's molten core.

The MORE solar superior conjunction experiment will be executed during the cruise phase (see Table 2).

5.1.8 PHEBUS

The Probing of Hermean Exosphere by Ultraviolet Spectroscopy (PHEBUS) experiment (Chassefière et al., 2010) is an ultraviolet spectrometer devoted to the characterisation (structure, composition, and dynamics) of Mercury's exosphere and to the understanding of the coupled surface–exosphere–magnetosphere system. The spectral range of PHEBUS spans the major resonance lines of most detected or expected species. One of the key objectives is to produce an average exosphere characterisation, i.e., the altitude profile of density for key atmospheric species at different distances from the Sun, and to further quantify north–south and east–west asymmetries (Sprague et al., 1997; Potter et al., 1999). An aim of the experiment is to produce such maps every one-eighth of a Mercury year, that is, on a time scale of 10 Earth days. Mercury's exosphere is expected to vary rapidly in response to solar wind variations, and therefore it is important to provide partial maps of the exosphere on time scales of less than a few hours. The polar orbit of the spacecraft will allow the exosphere to be monitored at all latitudes but only within a narrow longitudinal region along the orbit, with the restriction that only regions of the exosphere illuminated by the Sun may be observed.

The spectral range of PHEBUS is covered by three instruments: an extreme ultraviolet detector (EUV), a far-ultraviolet detector (FUV), and a near-ultraviolet spectrometer (NUV). The EUV detector covers emission lines at 25–155 nm, and the FUV detector does the same at 145–315 nm. The FUV detector is protected by a vacuum cover consisting of a sealed MgF2 window that is transparent above 115 nm, allowing FUV to cover the wavelength range 145–422 nm. The EUV detector must respond to wavelengths shorter than the MgF2 window cut-off, so it has a cover that is opened in flight. The NUV spectrometer monitors the spectrum out to > 425 nm to observe exospheric Ca and K emissions at 404 nm and 422 nm, respectively. The wavelength resolution of all observations will be better than 1 nm. A vertical scanning system covers the altitude range 0–1500 km, with a vertical resolution of about 20 km.

The PHEBUS baffle has a full 360 degree of freedom and is already commissioned, thus scientific operations can be obtained also during the cruise phase on a best effort basis.

5.1.9 SERENA

The Search for Exosphere Refilling and Emitted Neutral Abundances (SERENA) experiment (Orsini et al., 2010) will provide information about the global surface–exosphere–magnetosphere system and its interaction with the solar wind. The experiment consists of four sensors that can be operated individually: (1) Emitted Low-Energy Neutral Atoms (ELENA) is a 4° × 76° one-dimensional imager (the spacecraft track will provide the second dimension) of energetic neutral particles emitted from the surface of Mercury (with energies from about 50 eV up to 5 keV); (2) STROFIO is a mass spectrograph that determines particle mass per charge (mass resolution $m/\Delta m \geq 60$) by a time-of-flight technique; (3) Miniature Ion Precipitation Analyser (MIPA) is an ion mass analyser with a hemispheric field of view for the energy range 10 eV – 15 keV and a time cadence of 22 s per full distribution function to measure ions that precipitate toward the surface; and (4) Planetary Ion Camera (PICAM) is an ion mass spectrometer (mass resolution $m/\Delta m$ about 50) with a field of view of 0.4 π sr, in the energy range from the spacecraft potential up to ~3 keV with 32 energy channels.

SERENA will measure in-situ both neutral species and ions and, in addition to investigating the planetary response to external forcing, it will complement the MMO for magnetospheric dynamics investigations. The key scientific objectives of SERENA include the identification and localisation of source and sink processes of neutral and charged particles as well as estimates of their relative efficiencies. The latter depend on surface composition and external forcing such as solar irradiance, plasma, precipitation, or micrometeoroid impact, and both spatial and temporal variability are expected. Measurement objectives further include the composition and altitude profile of neutral particles and ions in the exosphere for all species, including their energy spectra and spatial distributions. The dynamics of the neutral and ionized exosphere, e.g., circulation from day to night and active to inactive regions, will be investigated as well as atmosphere–magnetosphere exchange and transport processes.

ELENA and STROFIO are mounted on the nadir deck of the MPO, and scientific operations are foreseen after Mercury orbit insertion.

MIPA and PICAM are mounted on the side panel of the MPO radiator. Both detectors were already commissioned and can be operated also during cruise phase on a best effort basis.

5.1.10 SIMBIO-SYS

The Spectrometers and Imagers for MPO BepiColombo Integrated Observatory System (SIMBIO-SYS) instrument suite is an integrated package for imaging and spectroscopic investigation of the surface of Mercury (Flamini et al., 2010). The science goals of SIMBIO-SYS are to examine the surface geology (stratigraphy, geomorphology), volcanism (lava plain emplacement, volcano identification), global tectonics (structural geology, mechanical properties of the lithosphere), surface age (crater population and morphometry, degradation processes), surface composition (maturity and crustal differentiation, weathering, rock-forming mineral abundance determination), and geophysics (libration measurements, internal planet dynamics) of Mercury. It incorporates capabilities to perform global mapping at medium spatial resolution in stereo and colour imaging using two pan-chromatic and four broad-band filters, respectively, as well as high-spatial-resolution imaging with pan-chromatic and three broad-band filters and imaging spectroscopy at visible to near-infrared wavelengths.

The instrument suite consists of three units: (a) The Stereo Channel (STC) will provide global colour coverage of the surface in full stereo at 60 m/pixel resolution with the aim of defining the main geological units, large-scale tectonic features, impact crater population, and volcanic edifices. The STC design, composed of two "sub-channels" that utilise the same detector and based on a push-frame acquisition mode, yields stereo images. (b) The High-Resolution Imaging Channel (HRIC) will characterise surface targets with high-resolution images at ground pixel sizes of about 6 m/pixel from 480 km altitude in four different bands. (c) The Visible Infrared Hyperspectral Imager Channel (VIHI) is a hyper spectral imager in the visible to near-infrared wavelength range (400–2000 nm) that will map the planet to provide the global mineralogical composition of the surface at a spectral resolution of 6.25 nm and at 500 m/pixel size, plus coverage of selected areas with a resolution as good as 125 m.

All detector baffles are directed towards the nadir and thus covered by the MTM during the cruise phase. Scientific operations are foreseen to be executed after the Mercury orbit insertion.

5.1.11 SIXS

The Solar Intensity X-ray and particle Spectrometer (SIXS) experiment (Huovelin et al., 2010) will monitor solar X-rays (SIXS-X) and energetic particles (SIXS-P). The X-ray data are required for a fluorescence analysis of MIXS spectra. Because the intensity and energy spectrum of both X-rays and energetic particles emitted by the Sun are highly variable, simultaneous operations of SIXS and MIXS is a strong requirement. Scientific objectives for SIXS-X are to monitor the solar X-ray corona and solar flares and to determine their temporal variability and spectral classification. Therefore, SIXS-X needs a clear view to the Sun as continuously as possible. The sensor contains three detectors, each having about a 100º-wide field of view and covering a spectral range of 1–20 keV with about 300 eV resolution. SIXS-P will monitor solar energetic electron and proton fluxes and their variations. The key scientific objective is to study the interaction of this radiation with Mercury’s exosphere, magnetosphere, and surface.

SIXS will work in synergy with MIXS, but SIXS can also be operated independently of MIXS as its observations will be desirable for other investigations for which the measurements of solar X-rays and energetic particles are important or necessary inputs. These investigations include exospheric studies with SERENA and PHEBUS on MPO and most studies with the

MMO payload. In addition, X-ray observations by SIXS on the side of the Sun not visible to instruments near Earth can be useful for Earth space weather studies.

Both SIXS-X and SIXS-P are mounted on the MPO radiator. Due to geometrical constraints, the SIXS-X channels will not be illuminated by the Sun during the cruise phase, and dedicated spacecraft pointing might be extremely difficult to achieve. The SIXS-P channel is fully calibrated and can be operated also during the cruise phase on a best effort basis.

6. The Mercury Magnetospheric Orbiter

The BepiColombo MMO will be a spin-stabilised spacecraft once it has separated from the MPO following Mercury orbit insertion. The MMO is optimised for in-situ measurements of plasma and electromagnetic fields and waves in orbit about Mercury. The nominal spin rate is 15 rpm (or a spin period of 4 s) to meet the scientific requirements. The spin axis will be pointed nearly perpendicular to the Mercury orbital plane. The total MMO mass is 255 kg, including 45 kg for the science payload and N2 gas for attitude control after separation. The MMO main structure consists of two decks (upper and lower). Most of the scientific instruments (e.g., the particle sensors) are mounted on the upper side of the bottom deck, whereas the four deployment units of the electric probe antennas for the Plasma Wave Instrument (PWI) are installed on the lower side of the bottom deck (see Table 5 and Figure 5).

During the interplanetary cruise phase the MMO is shielded and thus cannot produce its own power. Therefore, the BepiColombo MPO provides heater power and energy for regular status checks. The booms will be deployed after Mercury orbit insertion, and the whole MMO will be shielded by the MOSIF during cruise. As a consequence, direct observations of the solar wind during cruise will not be possible. Data acquisition of the detectors of MPPE, MMO-MAG, and PWI are however foreseen also during cruise on a best effort basis.

The 80-cm-diameter High Gain Antenna (HGA) is used for the high-rate X-band telemetry (TLM) command (CM) and ranging link, with the use of a 20 W power amplifier. The MMO HGA is pointed toward Earth with the antenna despun motor and antenna pointing mechanism to control elevation angle between -90° and +15°, depending on the positions of Mercury and Earth. A Medium Gain Antenna (MGA) is accommodated for emergency TLM/CM link. The MGA is installed on the lower surface of the MMO and will be deployed after MMO separation. In orbit about Mercury, the MMO telemetry rate will change as a function of the distance from Earth. The average data rate of the HGA is 16 kbps, which in turn translates into 40 MB/day given a 6-h pass in view of a radio antenna on Earth.

6.1 Instruments on the Mercury Magnetospheric Orbiter

6.1.1 MDM

The main objective of the Mercury Dust Monitor (MDM) (Nogami et al., 2010) is to measure the dust environment at Mercury's region of the Solar System (0.31–0.47 AU). The impact of micrometeoroids may provide an important source process for the planet’s exosphere. At Mercury's orbit, the main dust components are Keplerian dust particles and beta-meteoroid particles. The Keplerian dust particles are interplanetary dust particles (IDPs) that originate from asteroids or comets and gradually decrease their solar-centric distance by the Poynting-Robertson effect, whereas beta-meteoroids are dust particles that are on unbound orbits from the direction of the Sun. The MDM system is composed of a 64 cm^2 piezoelectric lead zirconate titanate (PZT) sensor unit (MDM-S) attached to the outside of the side panel and the electronics unit (MDM-E) installed inside the spacecraft. This instrument can detect impact momentum, crude direction, and the number density of dust particles in the local environment. The viewing direction covers nearly a hemisphere. The PZT can withstand high temperatures (about 230 °C) and does not need any bias voltage or high voltage for operation.

Table 5. MMO Instrument Overview

Instrument	**Observational Objective**	**Principal Investigator (Country)**
MMO-MAG: Mercury Magnetometer	Provide a detailed description of Mercury's magnetosphere and of its interaction with the planetary magnetic field and the solar wind.	Wolfgang Baumjohann (Austria)
MPPE: Mercury Plasma Particle Experiment	Study low- and high-energy particles in the magnetosphere.	Yoshifumi Saito (Japan)
PWI: Plasma Wave Instrument	Make a detailed analysis of the structure and dynamics of the magnetosphere.	Yasumasa Kasaba (Japan)
MSASI: Mercury Sodium Atmospheric Spectral Imager	Measure the abundance, distribution, and dynamics of sodium in Mercury's exosphere.	Ichiro Yoshikawa (Japan)
MDM: Mercury Dust Monitor	Study the distribution of interplanetary dust in the orbit of Mercury.	Masanori Kobayashi (Japan)

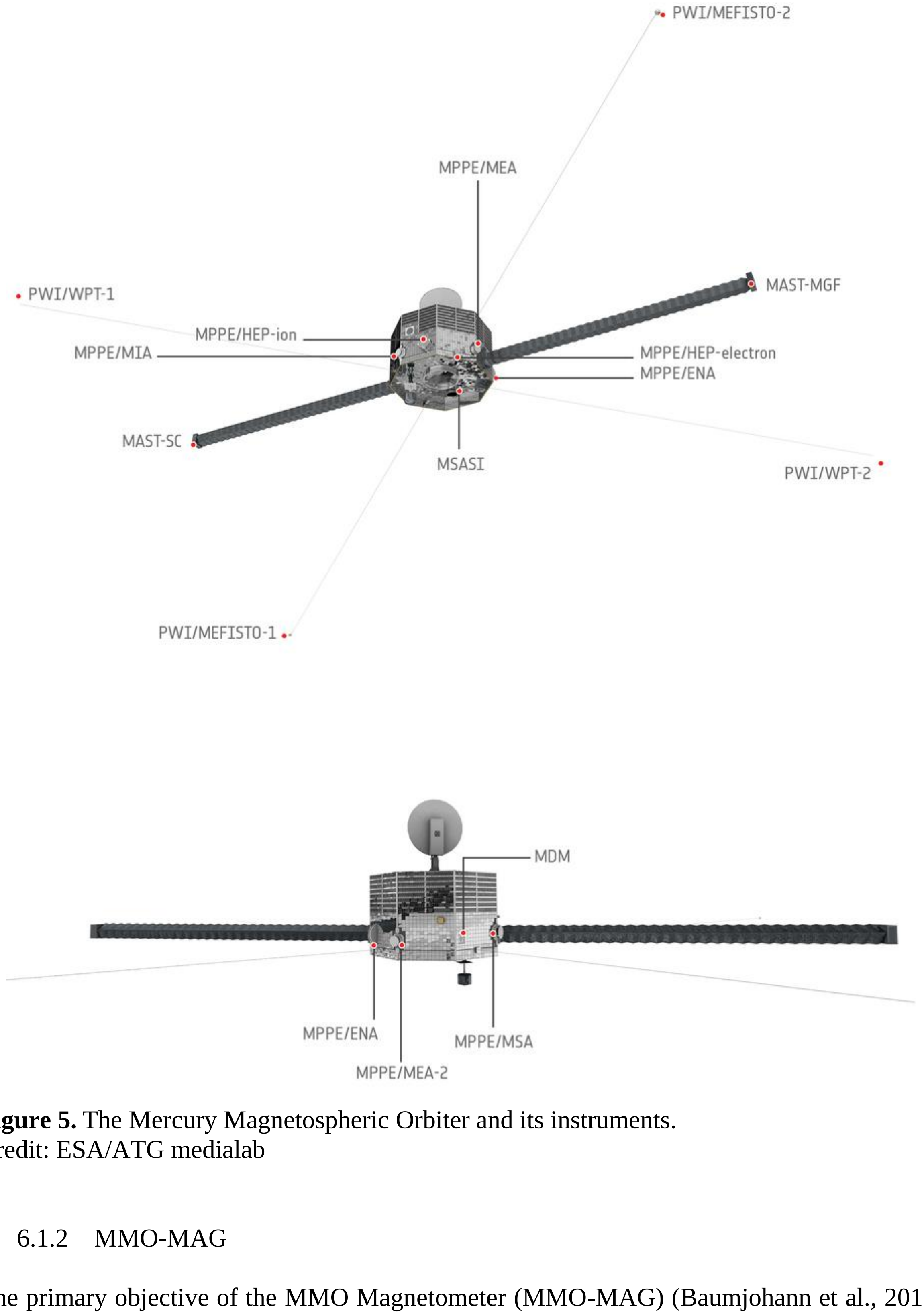


Figure 5. The Mercury Magnetospheric Orbiter and its instruments.
Credit: ESA/ATG medialab

6.1.2 MMO-MAG

The primary objective of the MMO Magnetometer (MMO-MAG) (Baumjohann et al., 2010) is to collect magnetic field measurements to study the variability of Mercury's magnetosphere and probe the planetary interior. The MMO-MAG consists of fluxgate magnetometers, an outer sensor that is a so-called digital type and an inner sensor that is a traditional analog type. Both have their own electronics boards, and both are mounted on a 4.4-m-long boom. The outer sensor is mounted on the tip of the boom, and the inner sensor is mounted 1.6 m from the boom tip. The instrument is designed to measure magnetic fields with an accuracy of about 10 pT, a dynamic range of ±2048 nT, and a sampling rate of up to 128 Hz. The sampling rate of the data transmitted to Earth is flexible and adapted to study each particular process in the different regions of observation.

6.1.3 MPPE

The Mercury Plasma Particle Experiment (MPPE) was designed to investigate the plasma and particle environment around the planet (Saito et al., 2010). MPPE is a comprehensive instrument suite for measurements of plasma, high-energy particles, and energetic neutral atoms. It consists of seven sensors: two Mercury Electron Analyzers (MEA1 and MEA2), the Mercury Ion Analyzer (MIA), the Mercury mass Spectrum Analyzer (MSA), the High Energy Particle instrument for electrons (HEP-ele), the High Energy Particle instrument for ions (HEP-ion), and the Energetic Neutrals Analyzer (ENA). The first six sensors perform in-situ observations and cover the range of particle species and energy of interest from the perspective of space plasma physics. MEA will provide fast electron measurements at Mercury's orbit, MIA will provide precise measurements of both solar wind ions and Mercury magnetospheric ions, MSA will provide plasma composition information with high mass resolution, HEP-ele will measure the energy and angular distributions of electrons in the energy range 30–700 keV, and HEP-ion will provide the energy or velocity distribution of ions in the energy range 30–1500 keV. ENA will image Mercury's magnetosphere in energetic neutrals created via charge-exchange on the Mercury exosphere and map the plasma precipitation via backscattered neutral particles to investigate the global dynamics of the Mercury magnetosphere and exosphere–magnetosphere interactions.

6.1.4 MSASI

Direct exposure of Mercury's rocky surface to the space environment gives the planet distinct characteristics in its atmospheric composition. Its tenuous atmosphere is known to have a substantial sodium component. The Mercury Sodium Atmospheric Spectral Imager (MSASI) (Yoshikawa et al., 2010) is a high-dispersion visible spectrometer working in the spectral range around the wavelength of the sodium D2 emission (589 nm). A Fabry-Perot etalon is used to achieve a compact design. A one-degree-of-freedom scanning mirror is employed to obtain full-disk images of the planet. A radiation-tolerant complementary metal-oxide semiconductor (CMOS) device with an image intensifier is used as a photon detector. The Fabry-Perot interferometer comprises two parallel, flat, transparent plates coated with a film of high reflectivity. Its principal advantage is that its throughput is much higher than that of a prism or grating spectrometer. MSASI will be the first use of such a device for a planetary mission. The combination of Fabry-Perot etalon and filter accommodates the mass and power limitations on the instrument and provides high sensitivity (16 counts/2 ms/bin/10 kR, achieving a signal-to-noise ratio of 4) and spectral resolution (0.009 nm or better).

6.1.5 PWI

The Plasma Wave Instrument (PWI) on MMO (Kasaba et al., 2010) will provide the first electric field, plasma wave, and radio wave data from the Mercury plasma environment. It will give important information regarding energy exchange processes in the small magnetosphere, where the role of microphysics is particularly important for global dynamics. The PWI consists of three sets of receivers connected to two sets of electric field sensors and two magnetic field sensors. The receivers include an Electric Field Detector (EFD), WaveForm Capture (WFC), and Onboard Frequency Analyzer (OFA); a Spectroscopic Ondes Radio & Bruit

Electrostatique Thermique (SORBET), and the Active Measurement of Mercury’s Plasma (AM2P). The electric field sensors are the Mercury Electric Field In-Situ TOol (MEFISTO) and Wire-Probe anTenna (WPT). The magnetic field sensors are the Low-Frequency Search Coil (LF-SC) and Dual-Band Search Coil (DB-SC). The PWI will observe both waveforms and spectra in the frequency range from DC to 10 MHz for the electric field and from 0.1 Hz to 640 kHz for the magnetic field.

ANNEX – ACRONYMS

AM2P	Active Measurement of Mercury’s Plasma
AU	Astronomical Unit
BELA	BepiColombo Laser Altimeter
CMOS	Complementary Metal-Oxide Semiconductor
CNES	Centre National D’Études Spatiale
CSG	Guiana Space Centre
DB-SC	Dual-band Search Coil
DC	Direct Current
EFD	Electric Field Detector
ELENA	Emitted Low-Energy Neutral Atoms
ENA	Energetic Neutrals Analyzer
EP	Electric Propulsion
ESA	European Space Agency
EUV	Extreme ultraviolet
FUV	Far-ultraviolet
HEP	High Energy Particle
HGA	High Gain Antenna
HRIC	High-Resolution Imaging Channel
IDP	Interplanetary Dust Particle
ISA	Italian Spring Accelerometer
JAXA	Japan Aerospace Exploration Agency
kbps	kilobits per second
LF-SC	Low-Frequency Search Coil
MB	Megabyte
MDM	Mercury Dust Monitor
MEA	Mercury Electron Analyzer
MEFISTO	Mercury Electric Field In-situ TOol
MERTIS	Mercury Radiometer and Thermal Imaging Spectrometer
MGA	Medium Gain Antenna
MGNS	Mercury Gamma-ray and Neutron Spectrometer
MIA	Mercury Ion Analyzer
MIPA	Miniature Ion Precipitation Analyser
MIXS	Mercury Imaging X-ray Spectrometer

MORE	Mercury Orbiter Radio Science Experiment
MOSIF	MMO Sunshield and Interface Structure
MMO	BepiColombo Mercury Magnetospheric Orbiter
MMO-MAG	MMO-Mercury Magnetometer
MPO	BepiColombo Mercury Planetary Orbiter
MPO-MAG	MPO-Mercury Magnetometer
MPPE	Mercury Plasma Particle Experiment
MSA	Mercury mass Spectrum Analyzer
MSASI	Mercury Sodium Atmospheric Spectral Imager
MTM	BepiColombo Mercury Transfer Module
Nd:YAG	Neodymium-doped yttrium aluminium garnet
NGP	Non-gravitational perturbation
NUV	Near-ultraviolet
OFA	On-board Frequency Analyzer
PHEBUS	Probing of Hermean Exosphere by Ultraviolet Spectroscopy
PICAM	Planetary Ion CAMera
PWI	Plasma Wave Instrument
PZT	Piezoelectric lead zirconate titanate
RSE	Radio Science Experiment
SDO	Solar Dynamics Observatory
SEPS	Solar Electric Propulsion System
SERENA	Search for Exosphere Refilling and Emitted Neutral Abundances
SIMBIO-SYS	Spectrometers and Imagers for MPO BepiColombo Integrated Observatory System
SIXS	Solar Intensity X-ray and particle Spectrometer
SORBET	Spectroscopic Ondes Radio & Bruit Electrostatique Thermique
STROFIO	STart from a ROtating Field mass spectrOmeter
STC	STereo Channel
TLM/CM	Telemetry/Command
VIHI	Visible Infrared Hyperspectral Imager
WFC	WaveForm Capture
WPT	Wire-Probe anTenna

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