Japan Aerospace Exploration Agency

Institute of Space and Astronautical Science

# BepiColombo
# An Interdisciplinary Mission to Mercury

# Mercury Magnetospheric Orbiter [MMO]

# SCIENCE MANAGEMENT PLAN

**Institute of Space and Astronautical Science (ISAS)**
**Japan Aerospace Exploration Agency (JAXA)**

**(JX-MMO-0002)**

**14 April 2004**

| **BepiColombo Mission Summary** | | |
|---|---|---|
| **Scientific Objectives** | • Origin and evolution of a planet close to the parent star<br>• Mercury as a planet: form, interior, structure, geology, composition and craters<br>• Mercury's vestigial atmosphere (exosphere): composition and dynamics<br>• Mercury's magnetized envelope (magnetosphere): structure and dynamics<br>• Origin of Mercury's magnetic field<br>• Test of Einstein's theory of general relativity | |
| **Reference Payloads -** | • **Mercury Planetary Orbiter (MPO):** cameras, spectrometers (IR, UV, X-ray, γ-ray, neutron), radiometer, laser altimeter, magnetometer, particle analyser, Ka-band transponder, accelerometer.<br>• **Mercury Magnetospheric Orbiter (MMO):** low-energy plasma analysers (electron/ion), high-energy particle detectors (electron/ion), energetic neutral atom imager, magnetometer, plasma wave analyser, dust monitor, and imager. | |
| **Transfer to Mercury** | • MPO and MMO launched together on one Soyuz-Fregat 2-1B<br>• Interplanetary cruise with Solar Electric Propulsion Module (SEPM) and gravity assists of the Moon, Venus and Mercury; SEPM jettisoned upon arrival at Mercury.<br>• Mercury capture with Chemical Propulsion Module (CPM), jettisoned after insertion in polar orbit. | |
| **Spacecraft Module** | **MPO** | **MMO** |
| **Stabilisation** | 3-axis | 15 rpm spin |
| **Orientation** | Nadir | Spin at ~90° to Sun |
| **TM band** | X/Ka | X |
| **Deployment** | 400 km x 1500 km | 400 km x 12000 km |
| **Operational lifetime** | > 1 year | > 1 year |
| **Data volume** | 1550 Gb/year | 160 Gb/year |
| **Equivalent average bit rate** | 50 kb/s | 5 kb/s |
| **Launch vehicle** | Soyuz-Fregat 2-1B | |
| **Launch date** | mid-2012 | |
| **Cruise duration** | 3.9-4.2 years | |
| **Ground TM station** | Cebreros (Spain), 35 m Antenna, 8 hours/day | Usuda (Japan) 64m Antenna 6-8 h/day |
| **Programmatic** | • ESA is responsible for MPO, SEPM, CPM, launch, transfer to Mercury, spacecraft deployment and MPO operations.<br>• JAXA procures MMO and ensures its operation.<br>• BepiColombo is the first ESA mission in close cooperation with Japan. | |

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# 1 SUMMARY AND SCOPE

BepiColombo is the planetary mission of the reconstructed Cosmic Vision Programme of the European Space Agency (ESA). The mission is devoted to the thorough exploration of Mercury and its environment with the aim to understand the process of planetary formation and evolution in the hottest part of the proto-planetary nebula as well as to understand similarities and differences between the magnetospheres of Mercury and Earth.

The mission will be carried out as a joint project between ESA and JAXA (Japanese Aerospace Exploration Agency).

The BepiColombo baseline mission consists of two spacecraft: the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MMO). The orbiters will be launched together on one Soyuz-Fregat 2-1B. ESA is responsible for MPO and JAXA is responsible for the MMO. ESA will also provide the Solar Electric Propulsion Module (SEPM) and the Chemical Propulsion Module (CPM) for the transport of the two spacecraft to Mercury and the insertion into their dedicated orbits and subsequent MPO operations, as well as the launcher and the ground segment.

This document, MMO Science Management Plan (MMO-SMP), deals with the scheme that will be implemented up to and including the post operational phase, to ensure the fulfilment of the scientific objectives of the BepiColombo MMO mission and to optimise its scientific return, with special emphasis on payload procurement, science operation and data management.

The MMO-SMP first recapitulates the main aspects of the mission, including the international relationship between ESA and JAXA. The MMO-SMP then explains how the scientific community will be associated across the full mission to the exploration of the planet Mercury. There will be a separate payload selection procedure for the MPO and the MMO whereby the responsibility for the MPO lies with ESA and the MMO payload selection is under the responsibility of JAXA.

The MMO-SMP deals, in particular, with the selection of the instruments, which will constitute the MMO scientific payload. The plan outlines the payload configuration and the JAXA science management tasks from instrument selection to data distribution and archiving. The SMP also addresses the duties and rights of the MMO investigators, as well as their interaction with the MPO science group.

The SMP for MPO, which is compatible with this document, is issued separately by ESA.

# 2 MISSION OVERVIEW

## 2.1 Introduction

BepiColombo is an interdisciplinary mission to the planet Mercury. It has been defined as collaboration between ESA and JAXA. It consists of two orbiters, the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MMO), which are dedicated to the detailed study of the planet and its magnetosphere. Their orbits have therefore been optimized accordingly. The MPO is three-axis-stabilized and nadir pointing, whereas the MMO is a spinning spacecraft. The launch of the MPO/MMO complement is planned for 2012. Solar electric propulsion will be used for the journey to Mercury and chemical propulsion for the insertion of the spacecraft into their dedicated orbits.

JAXA will be responsible for the development of the MMO and part of its scientific payload. In order to maximize science return with minimum resources, the instruments of the MMO payload share common functions and resources. JAXA will also be responsible for the integration of the scientific payload into the MMO and for the MMO mission operations (uplink commanding and downlink data acquisition) and data distribution to the MMO PIs.

ESA will be responsible for the following tasks: 1) mission design, 2) spacecraft composite, the MPO procurement (without instrument front ends), 3) integration of the scientific payload into the MPO, 4) integration of the Japanese contributions into the composite, 5) system testing, 6) MPO mission operations, 7) MPO data acquisition and distribution to the PIs.

## 2.2 Historical Background

Since the flyby observations by Mariner 10 in 1974-1975, the planet Mercury has long been one of the most important objects in space physics and planetary explorations. Mission definition and technical feasibility have been studied extensively in Europe, Japan and America. Their results have been presented in international conferences, and the possibility of international collaborations has been discussed.

In ESA, a mission to Mercury was selected as a cornerstone candidate in the Horizons 2000 scientific programme of the Agency in 1996. On 15 October 2000, ESA's Science Programme Committee (SPC) approved BepiColombo (MPO, MMO, MSE) as ESA's 5th Cornerstone mission. Then the collaborative framework with the Japanese Institute of Space and Astronautical Science (ISAS) was formed for the MMO to be provided by Japan. Between October 2002 and June 2003, BepiColombo went through a reassessment process with the aim to maximise the scientific performance, through the optimisation of the payload complement, while attempting to reduce costs and programmatic risk. The preferred mission scenario that emerged from the reassessment was to launch the MPO and MMO together on a single launcher (Soyuz Fregat 2-1B) in mid 2012, leaving the second launcher for the MSE. On 6 November 2003 the SPC approved the BepiColombo mission with the MPO/MMO complement as a part of the reconstructed Cosmic Vision Programme. The Payload Selection Procedure for the MPO payload as outlined in ESA/SPC 2003(41) was unanimously approved.

In Japan, the Mercury Exploration Working Group (MEWG) was formed in June 1997 under the Steering Committee for Space Science (SCSS) of ISAS to investigate a mission to Mercury. In 1998, the MEWG published the Japanese plan based on a spinning Mercury orbiter with chemical propulsion and multiple Venus and Mercury flybys. The possibility of collaboration with the ESA BepiColombo mission was discussed at the time of Inter-Agency Consultative Group (IACG) in November 1999, and stated in a letter from the Director-General of ISAS to the Directorate of Science Programme of ESA, dated 31 July 2000. According to the approval of BepiColombo as the 5th Cornerstone of ESA, the MEWG was re-formed for the investigation of MMO for the BepiColombo mission. The international Mercury exploration mission with BepiColombo was approved by the SCSS of ISAS in January 2002, followed by the formal approval by the Space Activities Commission in June 2003. It is noted that Japan Aerospace Exploration Agency (JAXA) was formed in October 2003 as merger of ISAS, National Space Development Agency (NASDA) and National Aerospace Laboratory (NAL).

## 2.3 Scientific Objectives

Mercury is an extreme of our planetary system. Since its formation, it has been subjected to the highest temperature and has experienced the largest diurnal temperature variation of any object in the Solar System. It is the closest planet to the Sun and has the highest uncompressed density of all planets. Solar tides have influenced its rotational state. Its surface has been altered during the initial cooling phase and its chemical composition may have been modified by bombardment in its early history. Mercury therefore plays an important role in constraining and testing dynamical and compositional theories of planetary system formation.

Only the American probe Mariner 10 has returned data from Mercury. The spacecraft made three flybys of Mercury in 1974-1975; it obtained images of somewhat less than half of the planet's surface and discovered its unexpected magnetic field that is, though weak, strong enough to stand off the solar wind and form the magnetosphere. Although these data have been fully exploited, a lot of gross features remain unexplained. Many conclusions are still speculative and have evoked a great number of new questions.

The main objectives of BepiColombo can be summarised as follows:

- **Origin and evolution of a planet close to the parent star**
  - Understanding the origin of Mercury's high density
  - Investigation on the geological evolution of the planet
- **Mercury's surface: geology and composition**
  - Exploration of Mercury's unknown hemisphere
  - Characterisation of the composition of the planet's surface
  - Identification of the composition of the radar bright spots in the Polar Regions
- **Mercury's interior: structure and magnetic field**
  - Analysis of the planet's internal structure
  - Mercury's magnetic field and its origin
  - Search for the possible existence of a liquid outer core
- **Mercury's Exosphere: dynamics, composition, and process**
  - The structure, variation, and composition of Mercury's exosphere
  - The generation and loss processes of the exosphere
  - Interaction between Surface, Exosphere, and Magnetosphere
- **Mercury's Magnetosphere: structure, dynamics, and process**

Comparative magnetospheres between Mercury and Earth
Unique Magnetosphere: without Ionosphere and large "sink" planet
Mechanisms of energetic particle accelerations

- **Environment of Mercury: Inner solar system**
  Solar wind and interplanetary shocks in 0.3-0.5AU
  Interplanetary / interstellar dust in the inner solar system
- **Fundamental physics**
  Test of Einstein's theory of general relativity

With the complexity of these fundamental objectives, the BepiColombo mission consists of two spacecraft, MPO and MMO. The MMO main scientific targets are:

1) Structure, dynamics, and physical processes of Mercury's magnetosphere
2) Structure and origin of Mercury's magnetic field
3) Structure, variation, and origin of Mercury's exosphere
4) Physical environment of inner solar system

Required investigations to achieve the scientific objectives and resulting performance requirements of individual instruments for the MMO mission are summarized in the MMO Science Requirement Document (MMO-SciRD). The MPO-SciRD is issued separately by ESA.

## 2.4 Mission Description

### 2.4.1 TRANSFER TO MERCURY AND TASK DISTRIBUTION

In the baseline scenario, MPO and MMO are launched together on a single Soyuz-Fregat 2-1B in mid 2012. The transfer to Mercury will be based on Solar Electric Propulsion with an approximate travel time of 4.2 years. Upon arrival the Solar Electric Propulsion Module (SEPM) will be jettisoned and the Chemical Propulsion Module will provide the required thrust for Mercury capture and orbit insertion.

ESA will be responsible, among other tasks, for (1) the cruise operations up to the delivery of the orbiters at their destinations and (2) the MPO operations and data acquisition. JAXA will be responsible for the MMO operation around Mercury.

### 2.4.2 MERCURY MAGNETOSPHERIC ORBITER (MMO)

MMO is a spinning spacecraft to be placed in a 400 x 12000 km altitude polar orbit, with an operational lifetime of at least one Earth year.

MMO will accommodate instruments mostly dedicated to the study of fields, waves and particles in the environment of the planet. The MMO spacecraft is spin stabilised at 15 rpm, which facilitates the azimuth scan of the particle detectors and the deployment of wire electric antennas. The MMO spin axis will be nearly perpendicular to the equator. The orbit is polar and highly elliptic; its major axis lies in the equatorial plane to permit a global exploration of the magnetosphere up to a distance of nearly 6 planetary radii from the planet's centre.

The MMO science requirements along with the model payload (see also Table 1 of Annex) are outlined separately in the MMO Science Requirement Document (MMO-SciRD). In

order to maximize science return with minimum resources, the instruments are planned to share Payload Common System (PCS) which consists of Data Processing Unit (DPU) and Power Supply Unit (PSU) [Cf. MMO-SciRD A2.1].

### 2.4.3 MERCURY PLANETARY ORBITER (MPO)

The MPO is a three-axis-stabilized and nadir-pointing module with an operational lifetime of at least one Earth year. It has one axis aligned with the nadir direction for a continuous observation of the planet. Its low-eccentricity polar orbit (400 x 1500 km altitude) will provide excellent spatial resolution over the entire planet surface.

The reference payload was established from the analysis of the science objectives and the scientific measurements required to achieve these objectives. The scientific requirements outlined in the MPO-SciRD have been translated into the MPO reference payload as defined in the MPO Payload Definition Document, MPO-PSD V4.0 (see also Table 2 of the Annex). The reference payload of the MPO does not consist of a number of self standing instruments, each with their own supporting subsystems, but rather of the scientific sensors (instrument front ends, IFE's) which share common functions and resources for their back ends.

## 2.5 Cooperation with Messenger

Messenger is a NASA Discovery Program mission to Mercury. ESA representatives of BepiColombo and members of the Messenger Team met on 10 September 1999. They recommended that ESA and NASA establish a framework within which regular meetings will occur to (1) maintain open communication for optimizing the implementation and scientific returns of both missions, and (2) identify areas of possible coordination.

The first such meeting among ESA, JAXA and NASA shall be scheduled after the launch of the Messenger.

# 3 PROGRAMME PARTICIPATION

## 3.1 Payload Configuration and PI-Responsible Instruments

The MMO model payload has been studied to fulfil the MMO science requirements by science teams consisting of Japanese and European scientists in collaboration with the JAXA/BepiColombo study team. Figure 1 shows a schematic diagram of the model payload configuration. However, it is by no means exclusive, and the actual instrument complement will be selected on the basis of the responses to the Announcement of Opportunity, with a view to optimizing the overall scientific return. To this effect, a proposal may be amended after discussions between its author and the MMO Payload Review Committee.

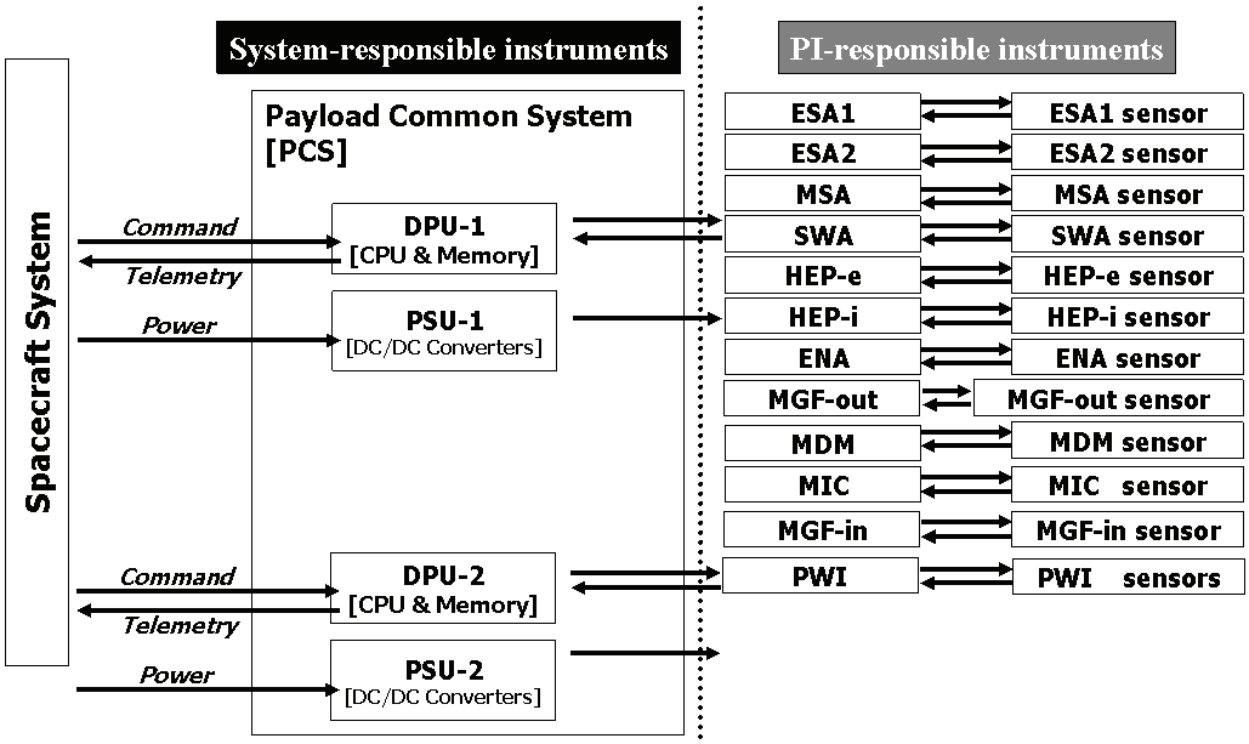


**Figure 1. Functional diagram of the MMO model payload package**
(Cf. Appendix in MMO-SciRD)

Although the definitive configuration will be determined according to selected sets of instruments, it is the baseline that scientific instruments share Payload Common System (PCS), which consists of Data Processing Unit (DPU) and Power Supply Unit (PSU) [Cf. MMO-SciRD A2.1], in order to maximize science return with minimum resources. The common hardware will be procured under the responsibility of the JAXA/BepiColombo Project Office, while the instrument front ends (on the right hand side of the dotted line) are to be developed under the responsibility of consortia headed by Principal Investigators (PI's). The PI-responsible software to be executed in the PCS/DPU should be developed in cooperation with a PCS/DPU task team to be organized by the JAXA/BepiColombo Project Office and PI teams.

For the MMO payload, JAXA will issue an Announcement of Opportunity (AO) to call for proposals of the PI-responsible instruments. Each proposing group shall be headed by a single person, designated as the Principal Investigator (PI). The other members of the group shall participate as Co-Investigators (Co-Is), but a Co-Principal Investigator (Co-PI) may be appointed if a major development is carried out in a country/institution different from the one of the PI. A Co-PI will have similar rights as a PI, but the PI will remain the formal interface to the JAXA/BepiColombo Project Office (see section 3.2.2).

The proposal must show that the PI can exert adequate control over all aspects of the programme. In the case of a consortium proposal, the Co-PI has a well-defined responsibility and relationship with the PI. All responses should be accompanied by draft letters of the responsible funding agencies for the endorsement of the PI's and all Co-I's. Note that the funding of Japanese investigators for their activities approved by JAXA/BepiColombo Project Office will be supported by ISAS/JAXA. Any change shall be agreed between the PI (if necessary, the funding institution) and the JAXA/BepiColombo Project Office.

For the MPO payload, ESA has issued a Request for Proposals (RFP) separately. Both the ESA RFP and JAXA AO are open to European and Japanese scientists and to other scientific communities with which reciprocity or specific agreements exist. The selection processes for MPO and MMO may not be simultaneous due to the different schedules for the ESA and JAXA budgetary approvals. However, the two agencies will continuously exchange information and coordinate their actions.

Announcement of Opportunity (AO) for participation as IDS will be issued after the payload selection is completed. AOs for Guest Investigators will be staged after launch.

## 3.2 Modes of Participation

The possible modes of participation to the BepiColombo programme are:

(1) Principal Investigator (PI), heading an instrument consortium providing a PI-responsible instrument (see section 3.2.1);

(2) Co-Principal Investigator (Co-PI) may be appointed if a major development is carried out in a country/institution different from the one of the PI; A Co-PI will have similar rights as a PI, but the PI will remain the formal interface to the Project Office (see section 3.2.2);

(3) Co-Investigator (Co-I), a member of an instrument consortium providing a PI-responsible instrument (see section 3.2.3);

(4) Interdisciplinary Scientist (IDS), an expert in specific science themes connected with Mercury (see sections 3.2.4);

(5) Guest Investigator (GI), by participating in the data collection and analysis of one or more instruments (see sections 3.2.5).

### 3.2.1 PRINCIPAL INVESTIGATOR

The PI will have the following responsibilities:

*(1) Management*

(i) Nominate an Experiment Manager with appropriate hardware, software and procurement expertise, and establish with him an efficient and effective managerial scheme, which will be used for all aspects and through all phases of her/his instrument programme, in cooperation with the JAXA/BepiColombo Project Office.

(ii) Organise the efforts, assign tasks and guide other members of the instrument consortium.

(iii) Ensure that plans are established, implemented and analysed such that the status reporting complies with the requirements of the JAXA/BepiColombo Project Office.

(iv) Provide the formal managerial and technical interface of the instrument to the JAXA/BepiColombo Project Office.

(v) Support JAXA/BepiColombo management requirements (e.g. investigation progress reviews, programme reviews, change procedures, product assurance, etc.) outlined in the MMO Instrument Requirement Document (MMO-I-IRD).

*(2) Science*

(i) Provide the formal scientific interface of the instrument consortium with the JAXA/BepiColombo Project Office.

(ii) Attend meetings of the Science Working Team and MMO Science Working Group meetings, as appropriate; report on instrument development, and take a full and active part in their work.

(iii) Monitor the compliance of the instrument design to fulfil the scientific requirements.

(iv) Ensure adequate calibration of all parts of the instrument, both on the ground and in space. This includes the provision of all required calibration data along with a full instrument science and technical user manual.

(v) Participate in the definition of the science operations and data handling, and support the JAXA/BepiColombo Project Office.

(vi) Exploit the scientific results of the mission and assure their diffusion as widely as possible.

(vii) Provide the scientific data (raw data, calibrated data, and higher level data), including relevant calibration products, to the BepiColombo ESA-JAXA archive in a format that will be agreed with the ESA SOC and the JAXA/BepiColombo Project Office for use by the general science community.

*(3) Hardware*

(i) Define the functional requirements of the instrument and auxiliary test equipment (e.g. MGSE, EGSE, CGSE, etc.).

(ii) Ensure the development, construction, testing and delivery of the instrument. This shall be performed in accordance with the technical and programmatic requirements

outlined in the MMO AO including its annexes such as the MMO-I-IRD, and subsequently reflected in the PI response, MMO-I-ICD.

(iii) Ensure that the instrument is to a standard that is appropriate to the objectives and lifetime of the mission, and to the environmental and interface constraints under which it must operate.

(iv) Deliver adequate instrument verification models (EM, STM, etc.) of the instrument to the JAXA/BepiColombo Project Office, as required to verify system interfaces. The envelope of this delivery is ruled by the MMO-I-IRD, in accordance with technical programme needs.

(v) Deliver an instrument Flight Model in accordance with the technical requirements defined in the MMO-I-IRD, together with the relevant Ground Support Equipment. Flight spares must be prepared for critical elements.

(vi) Support the system level integration and test activities related to and involving the instrument.

(vii) Provide the necessary equipment to process their data as agreed with the JAXA/BepiColombo Project Office and specified in the MMO-I-IRD.

(viii) Provide the overall documentation during the project, as defined in the MMO-I-IRD.

Note that JAXA-funded hardware is to be developed, constructed and tested in cooperation with the JAXA/BepiColombo Project Office.

(4) *Software*

(i) Ensure the development, testing and documenting of all software necessary for the control, monitoring and testing of the instrument. The on-board software to be executed in the PCS/DPU should be developed in cooperation with the PCS/DPU task team to be organized by the JAXA/BepiColombo Project Office and PI teams.

(ii) Specify and then support the development, testing and documenting of all software necessary for the testing, operation and data reduction/analysis of those parts of the instrument under the ISAS/JAXA responsibility.

(iii) Ensure the delivery to the JAXA/BepiColombo Project Office of any instrument specific software which is required for testing or operations, in accordance with JAXA/BepiColombo Project guidelines, procedures and schedules. This includes the provision of software required in the JAXA/BepiColombo Project Office as agreed in the MMO Science Operations Requirements Document.

(iv) Maintain and update all PI-responsible instrument software and its documentation until the end of the mission.

*(5) Product Assurance*

Provide product assurance functions in compliance with MMO-I-IRD. As for JAXA-funded hardware/software, the JAXA/BepiColombo Project Office is responsible for providing product assurance functions with support of PI teams.

*(6) Operations*

Provide support for preparation and implementation of the mission and science operations up to the end of the mission including delivery of a user manual and data base inputs in accordance to the MMO-I-IRD requirements.

*(7) Financial*

Funding for all participants in the proposal team shall be provided by their own national funding agencies and/or institutions, but the Lead Funding Agency will be considered responsible for all what concerns financial matters related to the selected investigations. Co-I teams are required via their national funding agencies to seek agreement with the Lead Funding Agency.

As for the Japanese contributions to the MMO and MPO payloads, JAXA (ISAS) must approve all financial engagements.

*(8) Communications and Public Relations*

Support ESA and JAXA science communications and public relations activities, and provide suitable information and data in a timely manner, as outlined in the Science Communication Plan (see section 6.4.2).

### 3.2.2 CO-PRINCIPAL INVESTIGATORS

A Co-Principal Investigator (Co-PI) may be appointed if a major development is carried out in a country/institution different from the one of the PI. Note that the single point interface to the JAXA/BepiColombo Project Office will remain the PI.

Co-PIs are responsible for their own funding which is guaranteed via their national funding agencies and must be underwritten by formal interagency agreements with the Lead Funding Agency, representing the PI and which holds overall fiscal responsibility with respect to the instrument development and delivery to the JAXA/BepiColombo Project Office. As for the Japanese contributions, see section 3.2.1 (7).

### 3.2.3 CO-INVESTIGATORS

Members of each PI-led instrument consortium may be proposed out as Co-Investigators. Each Co-I should have a well-defined role either with regard to hardware/software delivery or with regard to scientific support of the investigations within the instrument consortium. The PI-led instrument consortium may review the status of its members regularly and implement changes if required.

Co-Is are responsible for their own funding which is guaranteed via their national funding agencies and must be underwritten by formal interagency agreements with the Lead Funding Agency, representing the PI and which holds overall fiscal responsibility with respect to the instrument development and delivery to the JAXA/BepiColombo Project Office. As for the Japanese contributions, see section 3.2.1 (7).

### 3.2.4 INTERDISCIPLINARY SCIENTISTS

To ensure a solid top-level oversight of the mission science it is proposed that a number of interdisciplinary scientists (IDS) are selected through an open AO process. These IDS's should not reflect instrument specific domains but cover specific science themes, such as planetary interior, surface morphology, mineralogy, exosphere, magnetosphere, and inner heliosphere. An IDS may also wish to undertake specific and time-limited tasks in areas such as modelling, mission and science operation planning, hazard assessment and similar activities that may be required during the course of the mission. The appointment of one or more IDS's may also be considered for the coordination of MPO-MMO science. Interdisciplinary Scientists (IDS's) will take part in the analysis of data from different instruments onboard one or more elements of the mission. They have the same data rights as the members of the PI-led instrument consortia.

The proposals submitted by IDS individuals must describe clearly their scientific case, the relevance of their contribution to the mission and the instrument data sets needed to carry out their research programme. Financial endorsement by the national funding agencies, should they require funds for their activity, is also required. The IDS's, like the PI's, are expected to provide adequate support to the communications activities of ESA and JAXA.

ESA and JAXA may jointly release additional AOs at a later stage for specific mission phases and interdisciplinary studies related to Mercury.

### 3.2.5 GUEST INVESTIGATORS

Guest Investigators (GI's) are individual scientists who wish to make use of the data collected by a single instrument. Their proposals shall be submitted to the PI's heading the instrument consortia with a copy to the JAXA/BepiColombo Project Office. Their tasks shall be agreed with the PI's, with concurrence of the JAXA/MMO Project Scientist.

Guest Investigators will be selected after launch.

# 4 SELECTION PROCESS

The PI-responsible instruments will be selected based on evaluation of an MMO Payload Review Committee of proposals to be submitted in response to the Announcement of Opportunity (AO). The submission of proposals is open to the Japanese and European scientists and to other scientific communities with which reciprocity or specific agreements exist. It is expected that consortia will be formed to propose a highly integrated payload to maximize science return with minimum resources, and that potential PI's of consortia will submit Letters of Intent before submission of actual proposals. Then, if required, the JAXA/BepiColombo Project Office will work in support of the definition of each instrument consortium as well as the definition of technical and financial risks.

The timetable of events leading to the determination of the payload is as follows:

- 15 April 2004: Issue of the JAXA/MMO AO.
- 15 May 2004: Receipt of Letter of Intent.
- 15 July 2004: Receipt of PI-led proposals.
- August – September 2004: Peer Review of all instrument proposals.
- October – December 2004: Status report on the MMO definitive payload and its endorsement in the Steering Committee for Space Science of ISAS/JAXA.
- January – February 2005: Preliminary Requirement Review
- March 2005: Final approval by the Executive Director of ISAS/JAXA for BepiColombo/MMO to enter the implementation phase (Phase-B).

## 4.1 Instrument Selection

### 4.1.1 PAYLOAD REVIEW COMMITTEE

An MMO Payload Review Committee (MMO-PRC) will evaluate all proposals for the PI-responsible instruments. This selection committee will consist of 9 voting members. On the advice of the Steering Committee for Space Science, the Executive Director of ISAS/JAXA will nominate two thirds of the MMO-PRC members including the chairperson, while one third will be appointed by ESA. The MMO-PRC will also include non-voting ISAS/JAXA and ESA Executives or their representative.

For technical reviews, the PRC is supported by the JAXA/BepiColombo Project Office and its contractors as well as invited specialists. The JAXA/BepiColombo Project Office will also help the assessment in financial and programmatic areas.

The "No Conflict of Interest" rule will apply; i.e., no potential PI can be a member of the MMO-PRC. Proposing Co-Is may be accepted as MMO-PRC members, if strictly necessary, but they will have no voting right for their own investigation and other competing investigations.

### 4.1.2 EVALUATION CRITERIA AND SELECTION PRINCIPLES

The instrument proposals will be evaluated by the PRC, individually, on the basis of the AO with the following preliminary criteria:

- Relevance of the scientific objectives and their compatibility with the global objectives of the whole mission;
- Adequacy of the measurements to fulfil the stated objectives and capability of the instrument to perform the required measurements as indicated in the MMO Sci-RD;
- Feasibility and heritage of the proposed technical solutions;
- Development status of the instrument;
- Instrument development plan including test and validation programme;
- Availability of relevant technologies forming part of the instrument and the need for the development of new technologies. The development status of such "new" technologies should also be evaluated based on the AO response.
- Compliance with the interfaces specified through the MMO-I-IRD;
- Compatibility of the instrument component with the Mercury environment, spacecraft resources and mission constraints;
- Operational complexity;
- Management plan and its adequacy with the instrument complexity; this specifically includes the complexity of the management interfaces within an instrument consortium.
- Adequacy of human and institutional resources to ensure a timely execution of the instrument development, calibration and associated tasks, and to support post launch operation and data analysis.
- Competence and experience of the team in all relevant areas (science, technology, software development and management);
- Compliance with ISAS/JAXA/BepiColombo applicable management, engineering, reporting and product assurance requirements and standards;
- Possible financial impact of the proposed instrument upon ISAS/JAXA;
- Commitment of all the national funding agencies to provide the correct level of support to member institutes within the consortium under the overall responsibility of the Lead Funding Agency which represents at a minimum the PI-institutes participation in the instrument consortium.

The composition of the overall payload carried by MMO will take into account the following criteria:

- Evaluation of individual instrument proposals (see above);
- Potential scientific achievement within the global mission objective;
- Synergy with the MPO payload and redundancy;
- Compatibility with system resources, mission and programme constraints, and financial envelope imposed by national agencies.

### 4.1.3 SELECTION PROCESS

The instrument proposal evaluation and selection for the MMO will be made in four steps:

- Scientific evaluation;
- Technical, managerial and financial evaluation;
- Payload/Spacecraft compatibility evaluation;
- Final recommendation.

***(1) Scientific evaluation***

The MMO-PRC will evaluate the merits of each instrument proposal from a scientific point of view. Specifically its validity with respect to the mission science objectives and its compliance with the science requirements will be assessed. Not only the scientific value, but also the complementary character of the scientific research, will be assessed. The predicted performance of the instruments and their capability to achieve the mission objectives will also be scrutinized. The feasibility of the instrument meeting its requirements within the resource and schedule constraints will also be assessed.

Candidate PI's with relevant Co-PIs/Co-Is may be invited to clarification meetings, individually or collectively, to discuss critical issues and possible areas of overlap or complementarities.

***(2) Technical, managerial and financial evaluation***

The JAXA/BepiColombo Project Office will form a technical review team to evaluate all instrument proposals for their managerial and technical compliance with the mission requirements. The instrument concept, feasibility, management scheme and funding will be assessed.

In the frame of the selection process, potential PI's, with the relevant Co-PIs/Co-Is and technical support personnel may be invited to attend meetings at ISAS/JAXA to clarify details on technical, managerial or financial issues.

***(3) Payload/Spacecraft Compatibility Evaluation***

Based on the technical and scientific assessments, the PRC will recommend the configuration of the payload complement which would satisfy the mission science objectives. The JAXA/BepiColombo Project team and its contractors will then study further the accommodation of this payload complement on the MMO. The goals of this exercise are:

- To analyse the detailed requirements of the selected instruments to identify potential problem areas.
- To analyse the impact of the proposed instruments on the spacecraft design and payload complement in order to keep the mission cost within the financial envelope.

The PRC might recommend upgrading, descoping or merging of instrument proposals, during the whole selection process based on the science objectives, technical feasibility, programmatic and financial situation.

***(4) Final Recommendation***

The final recommendation will be subject to the Preliminary Requirement Review, and finally submitted to the Executive Director of ISAS/JAXA for approval of the implementation.

## 4.2 Selection of Interdisciplinary Scientists

Interdisciplinary Scientists (IDS) will be selected through an open AO process (see 3.2.4). The proposals will be evaluated through an independent Peer Review. Each IDS will be selected on the basis of the scientific quality and value of the investigation proposed. The proposed research shall not require additional resources or any redesign of the definitive payload. The selection will take place after the completion of the MPO and MMO payload confirmation procedure.

## 4.3 Selection of Guest Investigators

The selection criteria for Guest Investigators (GI's) will be established later, at the discretion of the instrument teams, in consultation with the SWT (see 3.2.5 and 5.2). The formal appointment will be made for the MMO by the JAXA/BepiColombo Project Office.

# 5 SCIENCE AND PROJECT MANAGEMENT

## 5.1 The JAXA/BepiColombo Project Office

JAXA, via the JAXA/BepiColombo Project Manager, will retain overall responsibility for the MMO mission through all phases. ISAS/JAXA has established the JAXA/BepiColombo Project Office, headed by Dr. Hiroshi Yamakawa, Project Manager, which will fulfil its function until the completion of the MMO mission operations.

The JAXA/BepiColombo Project Manager will periodically (nominally a few times per year) call Project Reviews, which will include all aspects of the MMO mission, and which will be carried out at MMO Design Meetings in ISAS/JAXA. The JAXA/BepiColombo Project Team will cooperate with the ESA BepiColombo Project Office for compliance with schedule, resources, interfaces, safety and any other relevant aspect of the MMO implementation.

JAXA nominates the MMO Project Scientist (MMO-PS) who is the interface of ISAS/JAXA with the Principal Investigators and the scientific community for scientific matters. The MMO-PS will chair the MMO Science Working Group and coordinate its activities.

During all phases of the MMO mission, the MMO Project Scientist will be responsible for all scientific issues within the JAXA/BepiColombo Project. The MMO-PS will advise the JAXA/BepiColombo Project Manager on technical matters affecting scientific performance, and will monitor the state of implementation and readiness of the MMO instrument operations and data processing infrastructure. The MMO-PS will also have overall responsibility for coordination of the MMO science operations and delivery of the scientific output of the MMO mission as approved within assigned constraints. The MMO-PS will coordinate the creation of the MMO scientific products, their archiving and distribution to the scientific community. A small team will support the MMO-PS in the above-mentioned tasks.

## 5.2 The ESA/BepiColombo Project Scientist

ESA nominates the BepiColombo Project Scientist (PS). The PS is located at ESTEC within the Planetary Missions Division within RSSD and is the ESA's interface with the Principal Investigators for scientific matters. The PS will chair the Science Working Team (SWT), and coordinate its activities.

During all phases of the mission, i.e. implementation phase until the end of the exploitation phase, the BepiColombo Project Scientist will be responsible for all scientific issues within the Project. During the development phase, the PS will advise the ESA Project Manager (SCI-P) on technical matters affecting scientific performance and will be supported by the Science Payloads and Advanced Concepts Office (SCI-A) as required. The PS will monitor the state of implementation and readiness of the MPO instrument operations and data processing infrastructure. A small team will support the PS in the above-mentioned tasks. The Science Operations and Data System Division of ESA's Research and Scientific Support Department (RSSD) will provide support on science operations and archiving.

After the in-flight commissioning phase, the Mission Manager within RSSD takes over the responsibility for the mission throughout the exploitation phase. The Mission Manager will

have overall responsibility for the delivery of the scientific output of the MPO mission as approved within assigned constraints. The PS will continue his/her activity as the main interface with the scientific community and will coordinate the MPO science operations with the Mission Operations Manager at ESOC. The PS will coordinate the creation of the scientific products, their archiving and distribution to the scientific community.

## 5.3 Science Working Team

The BepiColombo Science Working Team (SWT) will consist of all PI's/Co-PIs and IDS's. The ESA/BepiColombo Project Scientist will chair the SWT with the JAXA MMO Project Scientist as the Co-Chairperson.

The SWT will monitor and advise ESA and JAXA on all aspects of the BepiColombo mission that will affect its scientific performance. It will assist the PS in maximising the overall scientific return of the mission within the established boundary conditions. It will advise on aspects of science coordination between ESA and JAXA. It will act as a focus for the interests of the scientific community in BepiColombo.

In order to increase the working effectiveness, a Science Working Team sub-group (SWG) will be formed for each of the spacecraft elements. The MPO-SWG and MMO-SWG report to the SWT. The respective PS of ESA and JAXA will chair them.

An ESA MMO Science Coordinator will work within the ESA PS team and report to the PS. He/She will be the JAXA/MMO Project Scientist representative in Europe. Similarly, a JAXA MPO Science Coordinator will work within the JAXA/BepiColombo Project Scientist team and report to it. He/she will be the ESA Project Scientist representative in Japan for MPO matters. The same individual may fulfil "Project Scientist" and "Science Coordinator" functions.

The SWT, MPO-SWG and MMO-SWG meetings may take place at different times and venues, in order to improve flexibility and minimize travel costs. The norm to be sought is that out of 3 SWT meetings, 2 will take place in Europe and 1 in Japan.

In order to account for the multidisciplinary aspects of this mission, the SWT may delegate tasks to scientific subgroups. These subgroups will focus on specific topics of research and on issues related to the spacecraft element they are associated with. One member of the SWT, preferably an IDS, will lead each scientific subgroup.

Participation of individual scientists to activities of several subgroups is possible and even recommended. The ESA and JAXA Project Scientist Teams, through SWT scientific meetings, will insure the coordination between these subgroups.

## 5.4 Monitoring of Instrument Development

The JAXA/BepiColombo Project Office, in close coordination with the MMO Project Scientist, will monitor the progress of the design, development and verification of the MMO instruments. The instrument consortia will have to demonstrate to the JAXA/BepiColombo Project Office, in regular reports and during formal reviews, compliance with the scientific mission goals, the spacecraft system constraints, the spacecraft interfaces and the programme schedule as defined in the mutually agreed MMO Instrument Interface Control Document (MMO-I-ICD).

# 6 SCIENCE OPERATIONS AND DATA

## 6.1 BepiColombo Operations Concept

ESA will be responsible for the launch and operations/checkout of the composite spacecraft (MMO+MPO) into Mercury orbit. After separation of the spacecraft, ESA will retain responsibility for operations, including data acquisition, transmission and distribution for MPO, whilst JAXA will provide these services for MMO.

ESA will establish the BepiColombo Mission Operations Centre (MOC), located at the European Space Operations Centre (ESOC). The MOC will be responsible for the operation and control of the spacecraft composite during the transfer phase as well as MPO and MMO orbit insertion. ESA will also establish a Science Operation Centre (SOC). The SOC will be responsible for the science operations of MPO and coordinate its actions with the MMO science operations conducted by JAXA. After MMO separation from the stack controlled by the ESA MOC, it is the responsibility of the JAXA/BepiColombo Project Office to perform Mercury in-orbit commissioning and support the MMO science operations.

## 6.2 MMO Mission and Science Operations

After separation from the stack, the MMO will be controlled and operated by JAXA at the Sagamihara Operation Centre (SSOC) under the responsibility of the JAXA/BepiColombo Project Office, while the ESA MOC will continue to be responsible for the operation and control of the MPO.

ESA and JAXA will establish a data link between the European and Japanese centres to support the mission and the scientific data distribution, as part of the programme implementation.

The JAXA/BepiColombo Project Office will establish an efficient and effective scheme in close cooperation with the MMO-Science Working Group (MMO-SWG) for the MMO mission and science operations. As for the mission operations, the JAXA/BepiColombo Project Office will, in particular, be responsible for the following tasks, relevant to science operations of MMO:

- Overall mission planning of MMO
- Supplying, in near real time, the MMO Principal Investigators with raw data from their instrument, and spacecraft housekeeping and auxiliary data in an agreed format;
  Providing and monitoring the data lines within Japan and between the European and Japanese centres as mutually agreed;
- Performing anomaly (out of limit) checks on a set of payload parameters in near real time for MMO;
- Notifying payload anomalies to the MMO PI's.

Science operations will be conducted in close coordination between ESA, JAXA and the PI teams. Key science operations responsibilities and functions include:

- Optimisation of the science return from the BepiColombo mission by defining and implementing an efficient and cost-effective science ground system and operational scheme for all mission phases;

- Preparation of the long-term and short-term payload operations plan, to be implemented by the Mission Operations Centre and the JAXA/BepiColombo Project Office (for in-orbit operations of the MMO);
- Preparation of guidelines supported by the PI teams, to create the BepiColombo ESA-JAXA science data archive.

The specific responsibilities of the JAXA/BepiColombo Project Office for the science operations, in coordination with the ESA Science Operations Centre, are:

- Definition and implementation of efficient and cost-effective science operations planning, data handling and archiving concepts in close coordination with the MMO-SWG;
- Support of instrument operations;
- Coordination of the science planning;
- Consolidation of the instrument operation timelines before their execution;
- Harmonisation of the science operations plans of MPO and MMO;
- Preparation with the MMO investigators of summaries of scientific results at regular intervals and for mission highlights;
- Preparation of guidelines for science data archiving and creation of the BepiColombo ESA-JAXA scientific data archive for MPO and MMO;
- Support to Public Relations activities;
- Ensure the Knowledge Management over the long mission duration;
- Provide software support to the PI teams for payload operations;
- Archiving of non-scientific data needed for instrument calibration, e.g. from check-outs during cruise phase;
- Distribute pre-processed instrument data and supporting information
- Analysis (with the MMO Science Working Group support) of critical science data required for MMO science operations;

The specific responsibilities of the MMO PI's are:

- Support the definition of the science operations;
- Provision of inputs for the definition and implementation of the science operations planning, and data handling and archiving concepts;
- Preparation of the instrument operation timelines;
- Provide expert support at the JAXA SSOC during payload commissioning and critical operations;
- Provision of support members required by the JAXA/BepiColombo Project Office for the MMO mission and science operations at the JAXA SSOC;
- Support of the definition and implementation of the BepiColombo ESA-JAXA scientific data archive, as part of the pre-launch tasks;
- Monitoring and optimisation of instrument performance;
- Deliver raw, calibrated, and high level data, including relevant calibration products, to the BepiColombo ESA-JAXA scientific archive, at the end of the proprietary period;
- Provision to ESA and JAXA with electronic access to all processed and analysed data for public relation purposes;
- Provision of summaries of the main scientific results at regular intervals.

A coherent science operations programme for all spacecraft shall be endorsed by the SWT and will be conducted by the MPO and MMO Science Working Groups, under the overall responsibility of the BepiColombo Project Scientist. The MPO-SWG and MMO-SWG will be charged with the definition of dedicated campaigns of observations, in compliance with their respective resource allocations and overall constraints.

The science operations will be implemented in a cost-effective manner making use of facilities like Internet, electronic communications, video conferencing etc. In order to fulfil from the start their assignments for science operations, the PI's will require adequate support from their funding agencies.

## 6.3 Data Rights

The MMO data sets will be made available in compliance with decisions made by the MMO Science Working Group, while the MPO data will be made available in compliance with the established ESA rules concerning information and data rights and release policy. Reduction of science data is under the responsibility of PI teams. Exclusive data rights reside with the PI team for a maximum of 6 months from receipt of the original science telemetry and auxiliary orbit, attitude and spacecraft status information. After this time, data will be made available by PI's to the scientific community at large through the ESA-JAXA science data archive. The exclusive data rights will only commence once the instrument in-orbit commissioning has been completed.

The PI teams will also be required to share data with the IDS's and GI's so as to enhance the scientific return from the mission, in accordance with procedures to be agreed and formalised within the SWT.

The PI teams will provide records of processed data with all relevant information on calibration and instrument properties to the ESA-JAXA science data archive. The data format for the two spacecraft shall be compatible with those defined for the ESA-JAXA science data archive. The ESA-JAXA science data archive will be the repository of all mission products (MPO and MMO). ESA and JAXA will collaborate in ensuring a mission system view is achieved for data products from the BepiColombo mission. The ESA-JAXA science data archive, which will be based on and part of the Planetary Science Archive (PSA) of ESA, will be compatible with the Planetary Data System (PDS).

Scientific results from the missions will be published, in a timely manner, in appropriate scientific and technical journals. Proper acknowledgement of the services supplied by ESA and JAXA shall be made.

The MMO-PI teams will provide JAXA with processed and useable data for Science Communication purposes as soon as possible after their receipt. The PI teams will also engage in supporting a Science Communication Plan that will be prepared by ESA and JAXA in due time.

## 6.4 Communication and Public Outreach

### 6.4.1 PUBLIC OUTREACH

The BepiColombo mission is expected to attract much public interest. Hence, the mission will be given proper importance and exposure within the framework of the ESA and JAXA communication activities. Each MPO/MMO Investigator must provide material and information for Public Relations to ESA and JAXA.

For the MPO ESA is the overall responsible for planning and coordinating with national agencies such an activity around the mission, while JAXA will have similar responsibilities for the MMO.

During the development phase of the mission, ESA and JAXA will set up web pages on the BepiColombo mission as an information tool for the general public and the media. With the progress of the mission the web pages will be enriched with more material and features related to the mission.

All communication plans concerning the mission will be generated and implemented when appropriate under the responsibility of the ESA Science Programme Communication Service, in coordination with JAXA. This Service will work in full coordination with the scientific individuals responsible for the mission (Project Manager, Project Scientist, Principal Investigators, etc.).

The active cooperation of all scientists involved in the BepiColombo mission in providing relevant information and results is expected for the success of the related communication activities.

ESA and JAXA will coordinate their Public Outreach activities.

### 6.4.2 SCIENCE COMMUNICATION

ESA will have the overall responsibilities for planning and carrying out science communication on BepiColombo. JAXA will retain responsibility for the MMO. A general outline of these activities will be provided under the form of a Communication Plan. This plan must be formally agreed - and adhered to - by the PI's.

The MMO Project Scientist will initiate and publish MMO-related progress reports and scientific results. Articles suitable for release will be provided by the members of the MMO-SWG, upon their own initiative or upon request from the MMO Project Scientist, at any time during the development, operational and post-operational phases of the MMO mission.

ESA and JAXA will inform each other about their science communication.

# ACRONYMS

| | |
|---|---|
| AO | Announcement of Opportunity |
| Co-I | Co-Investigator |
| Co-PI | Co-Principal Investigator |
| CGSE | Calibration Ground Support Equipment |
| EGSE | Electrical Ground Support Equipment |
| EM | Engineering Model |
| ESA | European Space Agency |
| ESTEC | European Space Research and Technology Centre [ESA] |
| FM | Flight Model |
| GI | Guest Investigator |
| GSE | Ground Support Equipment |
| IDS | Inter-Disciplinary Scientist |
| JAXA | Japanese Aerospace Exploration Agency |
| MGSE | Mechanical Ground Support Equipment |
| MMO | Mercury Magnetospheric Orbiter |
| MMO-I-IRD | MMO Instrument Interface Requirement Document |
| MMO-I-ICD | MMO Instrument Interface Control Document |
| MMO-SMP | MMO Science Management Plan |
| MMO-SWG | MMO-Science Working Group |
| MPO | Mercury Planetary Orbiter |
| MPO-PSD | MPO Payload Study Document |
| MPO-SWG | MPO-Science Working Group |
| PI | Principal Investigator |
| PRC | Payload Review Committee |
| RSSD | Research and Scientific Support Department [ESA] |
| SOC | Science Operation Centre [ESA] |
| SPC | Science Programme Committee [ESA] |
| SSOC | Sagamihara Spacecraft Operation Centre [ISAS/JAXA] |
| SWG | Science Working Group |
| SWT | Science Working Team |

# ANNEX MODEL/REFERENCE PAYLOAD

## Table 1: BepiColombo/MMO model payload

| | |
|---|---|
| Electron Spectrum Analyser (ESA) [x2] | Low energy electrons |
| Mass Spectrum Analyser (MSA) | Low energy ions (in magnetosphere) |
| Solar Wind Analyser (SWA) | Low energy ions (in solar wind) |
| High Energy Particle (HEP-e, HEP-i) | High energy electrons and ions |
| Energetic Neutral Atoms (ENA) | Energetic neutral atoms (imaging) |
| Magnetic Field Sensor (MGF) [x2] | DC magnetic field |
| Plasma Wave Instrument (PWI) | DC electric field, Plasma waves, radio waves |
| Mercury Dust Monitor (MDM) | Dust |
| Mercury Imaging Camera (MIC) | Na and K atmosphere, and global surface imaging |

## Table 2: BepiColomo/MPO Reference payload

- High Resolution Colour Camera
- Stereo Camera
- Limb Pointing Camera
- Visible-Near-IR Mapping Spectrometer
- Thermal IR Spectrometer/Radiometer
- Laser Altimeter
- Ultraviolet Spectrometer
- X-Ray Spectrometer
- Solar X-Ray Monitor
- Gamma-Ray-Neutron Spectrometer
- Radio Science Experiment Accelerometer
- Magnetometer
- Neutral Particle Analyser
- Miniature Plasma Analyser
- Planetary Ion Camera