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BepiColombo SGS

Science Data Generation, Validation and Archiving Plan

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1 INTRODUCTION

1.1 Purpose and Scope

The purpose of this document is to describe the plan for producing, validating, archiving and disseminating all science data from the BepiColombo mission with special emphasis on the data from the MPO instruments.

This document also provides an overview of the science data products resulting from BepiColombo observations, along with the roles and responsibilities of all parties involved in the data generation process, the schedule for the delivery of the data to the archive and associated policies for the release and distribution of the science data within the BepiColombo project and to the scientific community and general public through the BepiColombo archive.

This document is based on the BepiColombo Data Handling and Archiving Concept [RD.02] and is prepared with contributions from the ESA Project Scientist, the MPO Instrument Teams, the Science Archives Team (SAT) and the Planetary Science Archive (PSA) team.

Due to the long mission lifetime, it is expected that this document will be revisited and, if necessary, updated after arrival at Mercury in order to incorporate relevant changes.

1.2 Applicable Documents

The following documents, of the exact issue shown, form part of this document to the extent specified herein. They are referenced in this document in the form [AD.XX]:

[AD.01] ESA/SPC (2004)9, BepiColombo Science Management Plan (SMP), January 2004.
[AD.02] BC-EST-RS-02531, Science Implementation Requirements Document (SIRD), v2.0.
[AD.03] BepiColombo ESA/JAXA MOU, Draft 6 bis, 12 April 2006.
[AD.04] StdRef_4.0.8_130219, Planetary Data System Standards Reference, version 4.1.

1.3 Reference Documents

The following documents, although not part of this document, amplify or clarify its contents. They are referenced in this document in the form [RD.XX]:

[RD.01] BC-SGS-PL-009, BepiColombo SGS Concept.
[RD.02] BC-SGS-TN-042, v1.4, BepiColombo DHA Concept, 11 November 2013.
[RD.03] BC-SGS-TN-026, BepiColombo Archiving Guide.
[RD.04] Volume 58/1–2 (2010), Comprehensive Science Investigations of Mercury.
[RD.05] BC-SGS-PL-008, BepiColombo Science Activity Plan (SAP).
[RD.06] BC-EST-PL-xxx, BepiColombo Data Sharing Agreements.
[RD.07] BC-SGS-ICD-[002-012], BepiColombo Data Processing Agreements.
[RD.08] BC-EST-RS-01140, BepiColombo EID-A.

[RD.09] BC-EST-RS, BepiColombo MPO Payload EID-Bs.
[RD.10] BC-SGS-ICD-026, BepiColombo MPO PIs – SGS ICD.
[RD.11] BC-SGS-ICD-001, MMO SSOC – MPO SGS ICD.
[RD.12] BC-SGS-PL-006, BepiColombo SGS Development Management Plan (DMP).
[RD.13] SAT_BACS_TN-0.1_04, BACS Architecture Concept Document.
[RD.14] BC-SGS-RS-006, BACS User Requirements Document (URD).
[RD.15] BACS Development Plan.
[RD.16] BC-ESC-IF-05011, BepiColombo Data Delivery ICD (DDID).
[RD.17] BC-SGS-TN-023, Software Engineering Guidelines for External Users (SEGU).
[RD.18] SOP-RSSD-PR-004, PSA Review Procedure.
[RD.19] BC-SGS-TN-022, BepiColombo SGS Documentation Tree.
[RD.20] BC-SGS-LI-014, SGS Glossary

1.4 Abbreviations and Acronyms

See BepiColombo online Glossary [RD.20].

2 MISSION OVERVIEW

BepiColombo is Europe's first mission to Mercury. It has been defined as a collaboration between ESA and the Japan Aerospace Exploration Agency (JAXA), executed under ESA leadership. The mission comprises two spacecraft: the Mercury Planetary Orbiter (MPO), built by ESA, and the Mercury Magnetospheric Orbiter (MMO), built by JAXA, which are dedicated to the detailed study of the planet and its magnetosphere respectively. Their orbits have therefore been optimised accordingly.

The MPO is a three-axis-stabilized and nadir-pointing spacecraft designed for an operational lifetime of one Earth year (with a possible extension of one year). The MPO orbit will be placed in an inertially fixed polar orbit; the spacecraft has one axis aligned with the nadir direction to allow continuous nadir observation of the planet. The MPO's 2.3-hour low-eccentricity orbit will provide excellent spatial resolution over the entire planet's surface. The MPO science payload will investigate Mercury's interior, surface composition and morphology, intrinsic magnetic field, the composition of the exosphere and the coupling between all of these aspects. MPO scientific instruments are detailed in Section 2.2.1.

The MMO is a spin-stabilized spacecraft to be placed in a high-eccentricity polar orbit with its spin-axis perpendicular to Mercury's equator. MMO operational lifetime will be at least one Earth year. The MMO accommodates 5 instruments/instrument packages dedicated to the study of fields, waves and particles in the Mercury environment. MMO scientific instruments are detailed in Section 2.2.2.

The launch of the MPO-MMO composite is planned for 2016 on an Ariane 5 from Kourou. Approximately 7.5 years later, after one Earth, two Venus and four Mercury flybys, the spacecraft will perform its final approach to Mercury. BepiColombo will arrive at Mercury in 2024, and gather data during a 1-year nominal mission, with a possible 1-year extension.

2.1 Scientific Objectives

The scientific objectives of the BepiColombo mission are set out in the BepiColombo Science Management Plan [AD.01] and are summarised in Chapter 2 of the Science Activity Plan [RD.05], grouped by major topical areas (Physical Characterisation of Mercury, Surface and Composition and Mercury's Environment).

The main scientific objectives of the mission are:

- High resolution exploration of Mercury
- Investigation of the geological evolution of the planet
- Understanding the origin of Mercury's high density
- Analysis of the planet's internal structure and search for the possible existence of a liquid outer core
- Investigation of the origin of Mercury's magnetic field

- Study of the planet's magnetic field interaction with the solar wind
- Characterisation of the composition of the planet's surface
- Identification of the composition of the radar bright spots in the Polar Regions
- Determination of the global surface temperature
- Determination of the composition of Mercury's vestigial atmosphere (exosphere)
- Determination of the source/sink processes of the exosphere
- Determination of the exosphere and magnetosphere structures
- Study of particle energisation mechanisms in Mercury's environment
- Fundamental physics: verification of Einstein's theory of gravity

2.1.1 Cooperation with MESSENGER

MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) is a NASA Discovery Program mission orbiting Mercury that was launched in August 2004 and entered Mercury orbit in 2011. Being the first spacecraft ever to orbit Mercury, MESSENGER ended its 1-year nominal mission in March 2012 and its extended mission in March 2013. A second extension proposal for another two years, until March 2015, is under review.

As mentioned in the BepiColombo Science Management Plan [AD.01], representatives of BepiColombo and MESSENGER meet regularly to (1) maintain open communication for optimising the implementation and scientific returns of both missions, and (2) identify areas of possible coordination.

MESSENGER and BepiColombo science goals and requirements reflect partly their order of arrival at Mercury. The BepiColombo orbiters (MPO and MMO), in orbits complementary to that of MESSENGER, will extend geochemical, spectral, and photometric mapping of the planet. With its factor-of-ten larger downlink, BepiColombo will follow on the intensive study of Mercury begun with the exploration by MESSENGER.

The scientific objectives and requirements set for BepiColombo reflect the more demanding role played by this mission to resolve the many outstanding questions related to the origin, evolution, structure and environment of Mercury.

2.2 Science Instruments

2.2.1 MPO Science Instruments

The Mercury Planetary Orbiter (MPO) will carry a highly sophisticated suite of eleven scientific instruments, ten of which will be provided by Principal Investigators through national funding by ESA Member States and one from Russia. A detailed description of the MPO instruments can be found in [RD.04].

Instrument	*Science Objectives*
BELA (BepiColombo Laser Altimeter)	Characterise the topography and surface morphology of Mercury.
ISA (Italian Spring Accelerometer)	Non-gravitational accelerations of MPO. The objectives of ISA are strongly connected with those of the MORE experiment. Together the experiments can give information on Mercury's interior structure as well as test Einstein's theory of the General Relativity.
MPO/MAG (MPO Magnetic Field Investigation)	Detailed description of Mercury's planetary magnetic field and its source, to better understand the origin, evolution and current state of the planetary interior, as well as the interaction between Mercury's magnetosphere with the planet's magnetic field and with the solar wind.
MERTIS Mercury Radiometer and Thermal Imaging Spectrometer	Detailed information about the mineralogical composition of Mercury's surface layer. Global mapping of surface temperature and thermal inertia.
MGNS Mercury Gamma-Ray and Neutron Spectrometer	Determine the elemental compositions of the surface and subsurface of Mercury, and will determine the regional distribution of volatile depositions on the polar areas which are permanently shadowed from the Sun.
MIXS Mercury Imaging X-ray Spectrometer	Use X-ray fluorescence analysis method to produce a global map of the surface atomic composition at high spatial resolution.
MORE Mercury Orbiter Radio Science Experiment	Determine the gravity field of Mercury as well as the size and physical state of its core.
PHEBUS (Probing of Hermean Exosphere by UV Spectroscopy)	The spectrometer is devoted to the characterisation of Mercury's exosphere composition and dynamics. It will also search for surface ice layers in permanently shadowed regions of high-latitude craters.
SERENA Search for Exospheric Refilling and Emitted Natural Abundances	Study the gaseous interaction between surface, exosphere, magnetosphere and solar wind.
SIMBIO-SYS (Spectrometers and Imagers for MPO BepiColombo Integrated Observatory)	Global, high resolution, and IR imaging of the surface. Examine the surface geology, volcanism, global tectonics, surface age and composition, and geophysics.

SIXS Solar Intensity X-ray and particle Spectrometer	Measurements of X-rays and particles of solar origin at high time resolution and a very wide field of view.

Table 1: MPO Instruments Description

In addition to the science instruments listed above, the MPO spacecraft will carry a radiation monitor (BERM), a resource efficient spectrometer that will be used to monitor the radiation environment around the Mercury planet and during cruise in order to issue an alarm to switch off other instruments to prevent its damage. Data resulting from the BERM instrument will follow the generation, validation and archiving plan described in this document.

2.2.2 MMO Science Instruments

The Mercury Magnetospheric Orbiter (MMO) will carry five advanced scientific experiments provided by nationally funded Principal Investigators (PIs), one European and four from Japan. A detailed description of the MMO instruments can be found in [RD.04].

Instrument	*Science Objectives*
MSASI Mercury Sodium Atmospheric Spectral Imager	Measure the abundance, distribution, and dynamics of sodium in Mercury's exosphere.
PWI Mercury Plasma Wave Instrument	Detailed analysis of the structure and dynamics of the magnetosphere.
MMO/MAG (MGF) MMO Magnetic Field Investigation	Provide a detailed description of Mercury's magnetosphere and of its interaction with the planetary magnetic field and the solar wind.
MPPE Mercury Plasma Particle Experiment	Study low- and high-energetic particles in the magnetosphere.
MDM Mercury Dust Monitor	Study the distribution of interplanetary dust in the orbit of Mercury.

Table 2: MMO Instruments Description

2.3 Mission Profile

The mission profile defines the different spacecraft and payload operations required per phase to prepare the spacecraft for Mercury operational orbit acquisition, science data acquisition and transmission.

The following mission phases are defined for achieving the scientific mission objectives:

Mission Phase	**Description**	**Planned Operations**
Launch and Early Orbit Phase (LEOP)	This phase lasts from the removal of the vehicle umbilical connector until the achievement of a stable spacecraft configuration. It includes the deployment of solar arrays and appendages, the initial attitude acquisition and the injection error correction manoeuvre.	During this phase all instruments are switched off.
Near Earth Commissioning Phase (NECP)	This phase extends until the end of commissioning. It includes the commissioning of the spacecraft and the initial check-out of the payload (wherever possible).	The MPO payloads and the MMO system are checked out one at a time as far as the system configuration allows. Final commissioning of payloads and MMO takes place after Mercury Orbit Insertion (MOI).
Interplanetary Cruise Phase (ICP)	This phase lasts until the beginning of the Mercury Approach Phase, at about 3 months before the Mercury Capture Manoeuvre.	MPO and MMO instruments are nominally switched off, but regular health checks will be planned. The Superior Conjunction Experiment will take place during this phase.
Separation and Mercury Orbit Insertion Phase (MOI)	This phase lasts until the beginning of the MPO commissioning in its operational orbit. It includes all the orbit injection and correction manoeuvres and all the separation manoeuvres.	During this phase all instruments are switched off.
Mercury Commissioning Phase (MC)	After the MPO orbit injection, an engineering commissioning followed by a scientific performance verification phase will take place, which will verify the actual performance capabilities of the payload complement.	This phase lasts nominally one month.
Mercury Science Phase (MSP)	Routine operations start with the completion of the MPO instruments commissioning.	Routine operations during the Mercury Orbit Phase (MOP) follow the science operations strategy described in the Science Activity Plan [RD.05].

		This phase lasts nominally one Earth year with a possible extension of another year.

Table 3: BepiColombo Mission Phases

The Science Activity Plan [RD.05] describes in detail the scientific observations to be carried out by the instruments on-board the MPO spacecraft to facilitate the achievement of the scientific goals of all BepiColombo MPO science instruments by the most efficient means possible.

Geometric environmental conditions (e.g. Earth Occultations, Solar Occultations, Inferior and Superior Conjunctions) and instrument operational constraints (e.g. mission profiles for data volume downlink, limitations of the SSMM and pointing constraints) determine which observations should and can be carried out in each part of the Mercurial year.

For the purpose of structuring the science operations planning, routine operations are divided into seasons. Seasons are defined by dividing the Mercury orbit around the Sun (which takes about 88 days) into four major seasons (Aphelion, Perihelion, and the Terminator seasons in between), depending on the distance of Mercury to the Sun and whether the Sun goes into the shadow of Mercury.

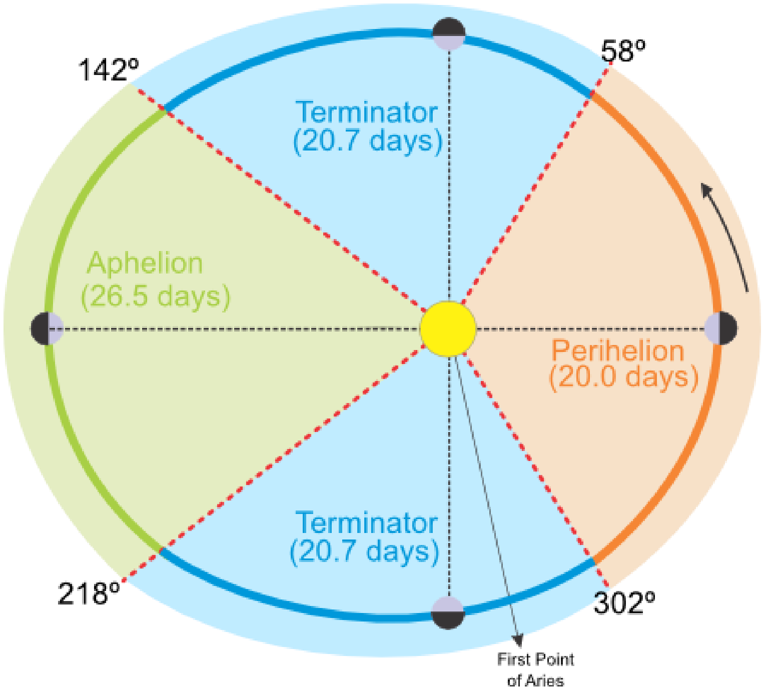

Figure 1: MPO orbit around the Sun as split in seasons. Eclipses during seasons are indicated.

While the terminator seasons can be treated quite similar, the observing and resource conditions of the Perihelion and Aphelion seasons differ significantly. Since Mercury is in a 3:2 resonance with respect to the Sun it will be possible to observe almost the whole planet in each of the seasons. As a result, global remote sensing coverage of the surface can be obtained, in an ideal scenario, within two Mercury years. Thus allowing recovery of missed opportunities in later seasons making the best use of available resources.

2.4 Mission Operations

The BepiColombo ground segment, provided by ESA and JAXA, is responsible for spacecraft operations, telemetry acquisition, and data processing, archiving and dissemination of all BepiColombo science data.

Within the overall Ground Segment, **ESA's Ground Segment** is made up of the following components:

- The ***Operational Ground Segment (OGS)***, located at the European Space Operations Centre (ESOC) in Germany, composed of the Mission Operations Centre (MOC) and the Ground Stations and Communications Network.
- The ***Science Ground Segment (SGS)***, located at the European Space Astronomy Centre (ESAC) in Spain.
- The ***Instrument Teams***, located at different institutes.

An equivalent **JAXA Ground Segment** has been established by JAXA, with the operational and science ground segments located in ***JAXA/ISAS Sagamihara Space Operations Centre (SSOC)***.

The OGS is responsible for all mission operations planning and execution from launch until end of mission, which includes: operations of the composite spacecraft (MMO+MPO) until MMO separation and operations of the MPO in Mercury orbit.

During the Mercury Orbit Phase, MPO science operations will be coordinated and planned by the Science Ground Segment (SGS), in close collaboration with the Operational Ground Segment (OGS), the Project Scientist and the Instrument Teams, whilst MMO will be controlled and operated by the JAXA Ground Segment.

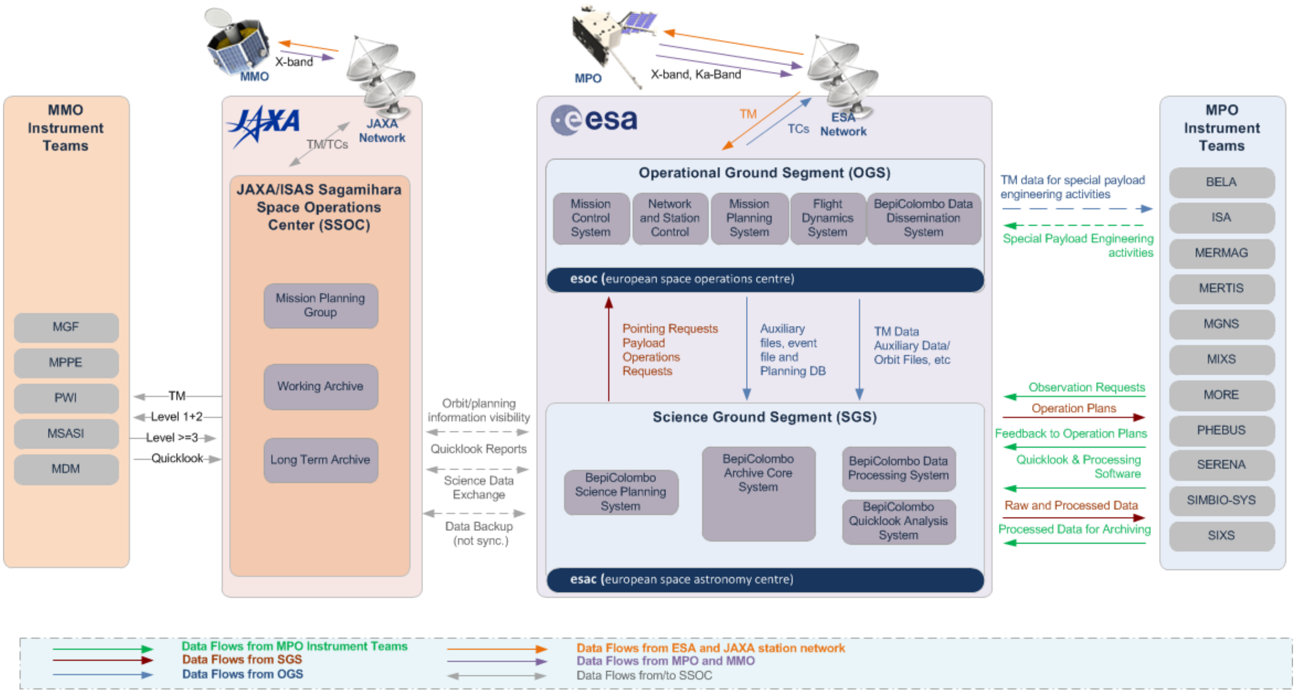

Figure 2: Overview of the BepiColombo Ground Segment and their interfaces.

The activities of the Science Ground Segment (SGS) encompass science operations planning of the MPO instruments as well as all data handling and archiving tasks, from retrieval of telemetry and auxiliary data from the EGOS Data Dissemination System (EDDS), under OGS responsibility, to all subsequent processing into higher data levels in collaboration with the Instrument Teams, including quick look checks of the performed observations. Data archiving is performed at different levels of the data processing chain.

As part of these tasks, the SGS will maintain an archive of all mission data, and will provide the BepiColombo science team with direct access to the data throughout the entire lifetime of the mission. This archive is the part of the BepiColombo archive under ESA´s responsibility, and is implemented by the SGS under the responsibility of the Project Scientist (for all science aspects) and in close collaboration with JAXA's Ground Segment. A conceptual description of the overall BepiColombo archive is provided in Section 4.1.

The overall science operations concept of the BepiColombo SGS is described in [RD.01].

3 SCIENCE DATA

This section provides a definition of the science data deliverables, along with some fundamental content and structure requirements based on the BepiColombo Science Management Plan [AD.01]. Additionally, a high-level description of all data deliverables resulting from the BepiColombo mission is provided in Section 3.3.2.

Table 4 provides a summary of the science data acquisition periods per mission phase.

Mission Phase Name	Science Data Acquisition
Launch and Early Orbit Phase (LEOP)	No science data acquisition expected during this phase.
Near Earth Commissioning Phase (NECP)	No science data acquisition expected during this phase.
Interplanetary Cruise Phase (ICP)	No science operations are planned with the exception of: • The Superior Conjunction Experiment (SCE) performed by the ISA and MORE instruments. • Periodic functional instrument checkouts and calibration exercises (if feasible).
Separation and Mercury Orbit Insertion Phase (MOI)	No science data acquisition expected during this phase.
Mercury Commissioning Phase (MC)	No science data acquisition currently expected during this phase.
Mercury Science Phase (MSP)	All scientific observations carried out by the instruments on-board the MPO spacecraft as planned in the Science Activity Plan [RD.05], including data resulting from commissioning.

Table 4: Overview of science data acquisition per Mission Phase

In addition to the science data acquired during these periods, telemetry data from the MPO spacecraft acquired throughout all mission phases will be processed and archived.

Other data, resulting from on-ground calibration campaigns and laboratory measurements will be also archived if considered relevant for the analysis and interpretation of the science observations.

3.1 Definition of Science Data Deliverables

BepiColombo science data deliverables are divided into Primary products and Supplementary products as defined in the following sections. Data processing level identifiers (when applicable) are as defined in Annex A.

Instrument teams (in consultation with the SGS) will select the most appropriate classification for the data from their instrument according to the definitions in this section, and will provide a detailed description of the type of products and processing applied in accompanying documentation.

3.1.1 Primary Products

Primary products contain the scientific data resulting from BepiColombo observations, including housekeeping and calibration data if applicable. Primary products are classified according to the level of processing applied as follows:

Primary Data	
Processing Level	*Description*
Telemetry	Original binary stream as produced by the corresponding instrument or spacecraft subsystem on-board encoded in telemetry packets.
Raw	Unprocessed instrument-count data extracted from telemetry packets and formatted in one of the PDS allowed formats for observational data, with the corresponding PDS label. In those cases where on-board compression has been applied, raw products contain the decompressed version of the data.
Partially Processed	Raw products processed beyond the raw stage but which have not yet reached calibrated status i.e. some processing has been applied to the data.
Calibrated	Raw or partially processed products converted to physical units where all of the calibration based on the instrument has been applied.
Derived	Results that have been generated from one or more calibrated products (for example: mosaics, maps, resampled data, fits to data models, temperature profiles, gravity or magnetic fields, or ring particle size distributions).

Table 5: Primary Data Classification

Further classification of the science products, based on instrument specific criteria, is outlined in Section 3.3.2.

Relevant engineering and housekeeping information needed for further processing and analysis of the science products, as well as observing parameters, can either (1) be recorded in the metadata (labels) of the primary products or (2) compiled in separate products, which then can be classified as primary or supplementary products (see Sections 3.1.1 and 3.1.2) depending on the content and purpose of the data.

3.1.2 Supplementary Products

Supplementary products include all BepiColombo non-observational data required directly or indirectly in the processing and analysis of the primary data.

BepiColombo supplementary products are broadly grouped into the following categories:

Supplementary Data	
Type	*Description*
Calibration	Calibration products include all data used at any stage of the calibration process. They can include, for example, observations of an on-board hardware calibrator or an external target used for calibration, or instrument response curves and bad pixel maps.
Geometry	Geometry products include pointing, orientation and positioning information. Geometry information can be provided in two formats (1) as calculated values (e.g. pixel-by-pixel geometry parameters computed for each image/product in the data set), and (2) as SPICE kernels, which can be used with the NAIF SPICE software toolkit to calculate the appropriate values.
Browse	Browse products are browse representations (thumbnails) or quick-look plots/reports of the observational products.
Document	Document products include all documentation or supporting information to assist in understanding and using the Primary Products. The Experiment to Archive Interface Control Document (EAICD), see Section 5.1.2, is a required document product.
Miscellaneous	Miscellaneous products include any additional information and documentation products generated (e.g. tables to track planned and executed observations, spacecraft manoeuvres, pointing modes, ground-station communication passes, target identification, spacecraft and hardware anomalies), if not easily classified as one of the above-described supplementary products. Anything that might affect, influence or offer an insight into the interpretation or understanding of the science data can be included in the archive.
Context	Context products include descriptions of the mission, spacecraft, instrumentation and targets in sufficient detail to give the user an insight into the nature of the data returned and the calibration processes used.

Table 6: Supplementary Data Classification

In addition to the instrument data processing and quick-look analysis software that will be integrated as part of the SGS system (following the Data Processing Agreements [RD.07]), Instrument Teams are encouraged to deliver any additional software products for data visualisation and analysis that are considered useful for the end-users. These software products will be made available to the scientific community through the BepiColombo archive along with the science data.

3.2 Science Data Contents and Structure Requirements

All BepiColombo science data must be compatible with NASA's Planetary Data System (PDS) standards and must follow the organisation, format, content and documentation requirements described in the BepiColombo Archiving Guide [RD.03]. This is key to guarantee usability and long-term preservation, and ensures compatibility with other PDS compliant data (like MESSENGER data; see Section 2.1.1).

Version 4 of the PDS standards (also known as PDS4) will be used as the archiving standard for all BepiColombo science data. The exact release of the PDS4 standards applicable to BepiColombo will be the release in place 2 months before the first science data are acquired. Changes to the applicable release of the PDS4 standards, if required during the mission, will be discussed in the DHAWG and documented in the BepiColombo Archiving Guide [RD.03].

The overall content and organisation of the science data must be comprehensible and stored in formats that the science community will find easy to use (simple and self-explanatory).

The main objective is to use formats that are familiar to and convenient for the scientific communities that the BepiColombo program will serve, as well as compliant with the PDS requirements for long-term preservation (e.g. ASCII tables, FITS, ISIS and including a simplified CDF format for MMO science data).

The selected data formats and accompanying information must facilitate searches, supporting science across missions and disciplines.

It shall be possible to use standard PDS software to visualise and manipulate the data. It shall be possible to write customised software based on the supporting documentation describing the formats and organisation of the data.

BepiColombo science data must include raw products and science-ready calibrated products in physical units from each instrument for all observations. In addition, science data may include laboratory measurements, on-ground calibration data, auxiliary data and any planning data useful to understand and analyse the content of the observational products.

It is expected that derived (higher-level) products (i.e. mosaics, maps, resampled data, fits to data models), developed by the Instrument Teams in the course of doing their data analysis, be delivered to the archive. The SGS will work closely with the data producers to facilitate the generation of these products in PDS compliant formats, thereby minimising the additional effort required for this activity.

The availability of higher-level data in the public archive will greatly contribute to maximising the usability and science return of the BepiColombo mission. Derived data will be released to the science community only after exploitation by the Instrument Teams. Public release of derived products requires explicit approval from the Instrument Team (see Data Rights and Release Policy in Chapter 8).

Supplementary products must provide sufficient information of the mission, the instruments and the operations and calibration procedures necessary for members of the current and future science community to effectively use and, if appropriate, recalibrate the data. This includes complete information about the geometry relevant to the observations.

Instruments will be obtaining on-ground and in-flight calibration measurements that will be part of the science data. These calibration measurements will characterise the performance and capabilities of each instrument and will be used to derive the calibration algorithms and tables needed to interpret the scientific measurements made during the mission. It is expected that details of the calibration data, algorithms and results from each instrument be documented in a Calibration Plan (or equivalent document).

3.3 Description of Science Products

This section provides a high-level description of the types of products resulting from each BepiColombo science instrument, including further classification of the products according to instrument-specific criteria e.g. instrument mode, data type, processing methods applied.

3.3.1 Telemetry Data

MPO telemetry frames received from the spacecraft through the ground stations are processed by the OGS into telemetry packets (as originally produced on-board) and stored on-ground by the OGS (up to the end of the mission post-operations phase).

Throughout the mission, telemetry data are made available to the SGS for further processing through the EGOS Data Dissemination System (EDDS) in the form of telemetry files. Telemetry files consist of a stream of encoded packets as produced by the corresponding instrument or spacecraft subsystem on-board.

Telemetry files are systematically retrieved and processed by the SGS. To ensure long-term preservation of all telemetry data, telemetry files are labelled with a PDS compatible label and stored in the archive as telemetry products.

Telemetry products include housekeeping and science packets generated by the different instruments on-board the MPO spacecraft as well as engineering data regarding spacecraft behaviour and status. Both types of telemetry data are stored and preserved by the SGS.

Telemetry products should be properly documented to allow for decoding of the telemetry packets. The generic structure of a telemetry packet is specified in the EID-A [RD.08], and is based on the Consultative Committee for Space Data Systems (CCSDS) recommended standards on telemetry and space data link protocols. Within this generic packet structure, there is an instrument-specific data field that constitutes the variable part of the packet (specific for each instrument or subsystem and for each packet structure type) and is defined in the instrument EID-B(s) [RD.09], instrument's User Manuals or equivalent documentation.

In addition to the telemetry files, telemetry parameters (calibrated if applicable) extracted from the housekeeping and science packets that are deemed to be essential for the reconstruction of the spacecraft state vector and for processing of the scientific data and their correct interpretation will be stored by the SGS in the archive.

3.3.2 MPO Science Data

Please note that this section contains a preliminary description of the science products resulting from the MPO instruments based on the inputs from the Instrument Teams. Further iteration with the Instrument Teams is expected to complete and consolidate this section. Once the iterations with the teams are completed, this section will be updated to ensure descriptions, language and terminology are homogeneous and inline with the rest of the document.

3.3.2.1 BELA

Primary Data	
Processing Level	***Description***
Raw	BELA raw data products are intended to store BELA measurement data in a form close to the telemetry data received from the spacecraft. BELA raw data files include all of the telemetry data items needed to analyse the instrument data. Units are not converted, no ancillary calibration data and no data resampling is applied. BELA raw data are stored in table format. Different types of binary and ASCII-encoded tables are produced depending on the instrument operation mode (pulse, sensor and albedo) and corresponding contents of the telemetry data: • PDI table (ASCII), including science-related housekeeping and a standard set of pulse detection and intensity parameters. • PCO table (binary), including pulse-fitting coefficients. • SMP (binary), including raw pulse intensity samples. • HST (binary), including range tracking histogram data. • HK (ASCII), including housekeeping parameters provided by the Range Finder Module (RFM). All tables are organized on a "per shot" basis, i.e. data related to one laser shot (or reflectance measurement in "albedo" mode) are reported on a single row. The only exception from this is "pulse" mode housekeeping data tables, which are transferred once per science telemetry packet instead of once per shot.

Partially Processed	Not applicable.
Calibrated	BELA calibrated data products will contain calibrated timing information and all relevant parameters of the raw data product converted to physical units and commonly used scientific number formats and time standards. Calibrated timing information will include the coarse time-of-flight (CoarseToF) parameters for up to four alternative returned pulse candidates. BELA calibrated data are stored in table format. Different types of binary and ASCII-encoded tables are produced depending on the instrument operation mode (pulse, sensor and albedo). Calibrated product types follow the same definitions (PDI, PCO, SMP, HST and HK) described for the raw products (see above).
Derived	BELA derived products comprise e.g. Digital Terrain Models, which can be composed of the BELA altitude profiles and camera-derived surface maps (SIMBIO-SYS). Other derived products will be added later.
Supplementary Data	
Type	***Description***
Others	*Under definition.*

Table 7: BELA Science Products

3.3.2.2 BERM

Primary Data	
Processing Level	***Description***
Raw	BERM raw data products will mainly consist of energy histograms of electrons, protons and heavy ions with a time resolution of 30s, and particle count rates. Energy ranges and energy bins are respectively: 0,3 to 10MeV (5 bins), 1 to 200MeV (8 bins) and 1 to 50MeV/mg/cm2 (5 bins).
Partially Processed	Not applicable.
Calibrated	Calibrated histograms in physical units, with associated geometry and housekeeping information.
Derived	
Supplementary Data	
Type	***Description***
Others	*Under definition.*

Table 8: BERM Science Products

3.3.2.3 ISA

Primary Data	
Processing Level	***Description***
Raw	ISA raw data products are in the form of ASCII tables containing time versus voltage (acceleration) per sensor and all housekeeping parameters needed for data analysis and validation. A separate housekeeping ASCII table contains all other housekeeping parameters not included in the science raw products. The data will be divided into blocks based on the ISA operative modes.
Partially Processed	ISA partially processed data products are derived from raw data (except ISA housekeeping) and in flight calibration output, in order to have files suitable for following analyses. The data will be divided into sub-blocks, in order to have homogeneous data sets to be further processed.
Calibrated	ISA calibrated data products are derived from the partially processed data, by applying the ISA calibration parameters and geometry corrections. These products are referred to as ISA “reduced” products.
Derived	ISA derived products are obtained from the calibrated data by selecting, reformatting and integrating the data with the quality parameters. These products are referred to as ISA “post-processed” products.
Supplementary Data	
Type	***Description***
Calibration	ISA on ground calibration products include all ISA parameters from instrument on-ground and in-flight calibration and characterization needed for data analysis and validation.
Others	*Under definition.*

Table 9: ISA Science Products

3.3.2.4 MERTIS

Primary Data	
Processing Level	***Description***
Raw	The MERTIS raw products consist of packet of Digital Units from the Image Spectrometer (TIS) and Radiometer (TIR) channel. Data are acquired on a spectral basis for TIR and on hyper-spectral image basis for TIS (push-broom

	imaging mode). Data packets contain all the relative acquisition ancillary data. The raw products for each type are self contained, independent records. Supplementary data associated with these products include the calibration coefficients derived during the on-ground calibration in the form of calibration matrices.
Partially Processed	Not applicable.
Calibrated	All raw spectra are a vector of values (spectral channels), where the values correspond to data numbers (DNs). MERTIS calibrated products are produced by first decompressing the raw products using algorithms incorporating the appropriate compression tables and/or compression algorithms. Raw spectra DNs are converted to radiance values by applying calibration algorithms based on calibration parameters derived from on-ground instrument calibration measurements and in-flight calibration. Different types of calibrated products are produced: • Radiometrically and geometrically corrected data by applying on-ground calibration data. • Geometrically registered products, using MPO attitude data.
Derived	Surface temperatures, thermal inertia and emissivity maps are the first-order DAPs. From this first order DAPs MERTIS shall identify the following mineral phases and their correlation to surface features: Christiansen features and Reststrahlen bands of proposed surface minerals, Differentiation of end-member of plagioclase group, Pyroxenes, Elemental sulphur, Representation of complex mineral spectra (e.g. sulphates). Spatial coverage and resolution will depend on altitude and orbit. The delivered derived products will include interpolated maps of key wavelengths, temperatures, thermal inertia and emissivity.
Supplementary Data	
Type	***Description***
Calibration	• On-ground Calibration measurements. • PEL/PSSL Laboratory measurements.
Others	*Under definition.*

Table 10: MERTIS Science Data

3.3.2.5 MGNS

Primary Data	
Processing Level	***Description***
Raw	MGNS raw data products will have no processing applied to them. MGNS generates two parallel time series of data: Main and Selective (higher time resolution and is mainly intended to be used for Solar events monitoring). Time series contain spectra (of counts per energy channel) for all five sensors (SD2, SD1, MD, SCD/N and SCD/G), only for the Gamma-ray sensor (SCD/G) and only for the Neutron sensors (SD2, SD1, MD, SCD/N). The integration interval can be set between 1s - 131071s (standard: 20s/low-res and 2s/high-res). A separate housekeeping table is produced.
Partially Processed	MGNS partially processed products are derived from raw data products by applying the conversion to engineering units with time units appended (spacecraft clock units converted to UTC time stamps) and spatial information appended. No scientific data has been altered yet. This is also the highest data level for MGNS housekeeping data product.
Calibrated	MGNS calibrated data are science time series corrected for instrument and environment effects. Inputs are partially processed products (main and selective). These time series will be corrected to account for detectors efficiency, temperature drifts, Solar events (that must be excluded from the data sets) and other engineering parameters that can affect detectors count rate. The result is data time series that can be used for mapping (Science Main) or Solar events analysis (Science Selective). This is the highest data level for MGNS selective data type.
Derived	These are the main products of MGNS investigation. Derived products include Mercury maps of counts in each detector, over a certain pixel, over a defined time period. These products are derived from the MGNS calibration products (main science data products only). Unlike all the previous data products, these maps need to be updated regularly (semi-yearly or yearly) to add maps with higher accumulated statistics over the previous periods.
Supplementary Data	
Type	***Description***
Others	*Under definition.*

Table 11: MGNS Science Products

3.3.2.6 MIXS

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 planetary mapping.
- **MIXS-T**, an imaging telescope with a narrow field for high resolution measurements of the surface.

Primary Data	
Processing Level	**Description**
Raw	All MIXS science and engineering telemetry are decoded and re-assembled into HK reports (DPU, FPA-T and FPA-C) and self-contained (re-packed and complete) pixel lists (MIXS-T, MIXS-C), histograms (MIXS-C) and detector images (MIXS-T, MIXS-C). Each ground contact comprises a SET of these product types. Product SETS make up a COLLECTION which represents a period when the DPU (at least) is switched on. Depending on the status of MIXS-T and MIXS-C, a SET will include science data or just HK reports. Each SET will have associated metadata that links the data products together (i.e. time window). For each ground contact SET the following products are available: • HK report (DPU) • HK report (FPA-T) • HK report (FPA-C) • MIXS-T pixel list of amplitudes (in detector coordinates) • MIXS-C pixel list of amplitudes (in detector coordinates) • MIXS-C histograms • MIXS-T detector image (for diagnostics) • MIXS-C detector image (for diagnostics) • Other (TBD)
Partially Processed	For each ground contact SET, all HK and science products are organised into OBSERVATIONS, the definition of which is currently TBD. All HK reports are merged into a single HK report for DPU, FPA-T and FPA-C for each OBSERVATION. Incomplete MIXS-C histograms that straddle an OBSERVATION start boundary are ignored and incorporated into the next OBSERVATION. All pixel list and histogram data are converted from amplitude to energy and optionally corrected for gain and black level using ground reference data. For each OBSERVATION the following products are available:- • HK report (incorporating DPU, MIXS-T and MIXS-C) • MIXS-T pixel list array of energies (in detector coordinates) • MIXS-C histograms • Other (TBD)
Calibrated	For each OBSERVATION, all data products are organised into SEGMENTS that represent regions of the Mercury surface. OBSERVATION context is preserved as

	metadata for each SEGMENT. All detector coordinates are converted to Mercury surface coordinates expressed as a FOV footprint of TBD size and shape dependent on the instrument FOV (square or round) and the presence of the planetary rim or terminator within its FOV. A vignetting function is applied to all pixel lists. Solar and geometric corrections are applied to all pixel lists and MIXS-C histograms. For each SEGMENT the following products are available: • HK report (incorporating DPU, MIXS-T and MIXS-C) • Calibrated MIXS-T pixel list array of energies (in Mercury surface coordinates) • Calibrated MIXS-C histograms • Other (TBD)
Derived	For each SEGMENT all data products are organised into GROUND PIXELS that represent areas of the Mercury surface that can be used to construct a spectral image cube. For each GROUND PIXEL MIXS-T and MIXS-C science data are converted to spectra. Contiguous GROUND PIXEL data produce maps in the form of IMAGE CUBES in either high-resolution (MIXS-T) or low resolution (MIXS-C). HK from calibrated reports and science data packets are merged as metadata for the image cubes. For each IMAGE CUBE the following products are available: • Report (HK and other contextual metadata) • Image cube (low resolution using MIXS-T data) • Image cube (low resolution using MIXS-C data) • Other (TBD)
Supplementary Data	
Type	**Description**
On-ground calibration	On-ground calibration measurements.
Others	*Under definition.*

Table 12: MIXS Science Products

3.3.2.7 MORE

Primary Data	
Processing Level	***Description***
Raw	The estimation of physical quantities of interest will be based almost entirely upon range and range-rate observables obtained by exploiting the microwave link

	between the spacecraft and the Earth. All measurements are carried out in a coherent two-way mode, in which the frequency reference is generated at the ground station and all on-board transponders (KaT and DST) are commanded in a coherent mode. The key aspect is the implementation of a multi-frequency link. In this configuration, two uplink and three downlink carriers are simultaneously used: • A X-band downlink (X, at 8.4 GHz) coherent with an X-band uplink (at 7.2 GHz) • A Ka-band downlink (Ka1, at about 32 GHz) coherent with the same X-band uplink • A Ka-band downlink (Ka2, at about 32 GHz) coherent with a Ka-band uplink (at about 34 GHz) The Ka2 link will be the primary link for the radio science experiment. The DST (part of the spacecraft TT&C subsystem) receives the uplink X-band signal and generates the coherent X and Ka1 downlink carriers. All DST carriers will be phase modulated by a PN ranging code at 3 Mcps. In addition, the primary radio science link (Ka2) will support a high precision ranging channel, also referred as the wide band ranging system (WBRS), used for precision measurements (crucial for all fundamental physics tests). The WBRS will be implemented by a regenerative PN ranging scheme, with a clock component at 12 MHz modulated by a 24 Mcps PN code for highly accurate measurements. The WBRS PN regenerative channel is the baseline configuration that will be implemented in the KaT. NASA's DSN Goldstone DSS-25 ground station is currently the only one fully supporting the multi-frequency link, as it is equipped with Ka-band uplink instrumentation. Both ESA and NASA make use of meteo data and GNSS-based calibrations for the troposphere path delay. In order to ensure a calibration of the absolute wet path delay at a level of 10%, MORE requires the use of Water Vapour Radiometers (WVR) at the ground station. At the moment, NASA is employing Advanced Water Vapour Radiometers (AWVR) capable of accuracies of 5%. In order to achieve the desired accuracy and reliability of the results, the on-board accelerometer instrument (ISA) must measure the non-gravitational perturbations with a relative accuracy of the order of 10^{-6}cm/s^2. Finally, support from the ACS subsystem for attitude reconstruction, from the on board high- resolution camera (SIMBIO-SYS) for the determination of Mercury's rotational state (libration experiment) and from the on board laser altimeter (BELA) for the geodesy experiment are requested.
Partially Processed	Not applicable.
Calibrated	The raw products represent what in Orbit Determination (OD) processes are called "observed observables". They are fitted, in the OD codes, to the so-called "computed observables", which represent the prediction of the observed

	observables, obtained through mathematical models. Calibration data are added to the computed observables to minimise their difference (in a least- square sense) with respect to the "observed observables". The MORE team can provide the methods used for calibration and the corresponding calibration products (troposphere, ionosphere and plasma, KaT delays, maneuvers, etc.). The simultaneous operation of all three links leads to a complete plasma cancellation for SEP angles up to at least 2 degrees (8 solar radii impact parameter). The plasma cancellation method based upon a multi-frequency link provides range and range rate observables virtually independent of the SPE angle and solar wind conditions. The so-called "plasma-free" (non- dispersive) sky frequency (for example at X-band) is obtained as a linear combination of the three X/X, X/Ka and Ka/Ka observables. *This is the only pre-processing calibration carried out on the observed observables.* The physical parameters of interest will be estimated using the OD code developed by the MORE team. While being processed by the software, the range and range-rate computed observables will need to be corrected to account for several delays and delay variations introduced into the signal path (e.g. troposphere and ionosphere, KaT delays, etc). The effects of non-gravitational accelerations on the spacecraft dynamics (quite large in the harsh hermean environment) will be removed to a large extent thanks to the ISA accelerometer. These instrument readouts will be sent to ground in the telemetry stream and referenced to the phase center of the high gain antenna. The OD code will then use a smoothed version of the accelerometer measurements to integrate the equation of motion, effectively realizing a software version of a drag-free system. A crucial aspect of the radio science experiment is the referencing of the range rate to the fiducial point of the accelerometer. Effectively this requires the knowledge of the vector between the location of the reference point of the accelerometer and the antenna phase center (Schulte vector). Due to the motion of the antenna, this vector changes with time (both in the inertial and the body frame). Therefore a data product containing this vector at any time with adequate accuracy and density has to be generated. The TDM+ (Tracking Data Message) is an enhanced TDM format that allows customizing the standard TDM in order to increase the capabilities of exchange data among the involved teams and the Agencies. The open loop, standard TDM and ancillary data are pre-processed and generate an enhanced TDM and a Quality File to be used in the orbit determination process. The data flow from the agencies is divided as follows: • JPL/RSR and ESA/IFMS open loop data • Closed loop tracking data (TDM format) • Meteo/Media data from JPL

	The closed loop tracking data can also be generated from RSR data with a Ranging & DPLL algorithm developed by the MORE team. Other ancillary information is exchanged using JPL proprietary format.
Derived	Most MORE data products are derived and in combination with the on-board accelerometer (ISA), high- resolution camera (SIMBIO-SYS/HRIC) and laser altimeter (BELA), the following quantities will be provided, which can be viewed as derived products: • Spherical harmonics coefficients of the Mercury's gravity field up to degree and order 25 • Love number k_2 • Obliquity of the planet • Amplitude of physical librations in longitude • Ratio between mantle and planet moment of inertia • Post Newtonian parameters • Time variation of the gravitational constant • Gravitational oblateness of the Sun • Spacecraft trajectory reconstruction Concerning the last point, the MORE team will deliver the spacecraft reconstructed trajectory to the SGS for distribution to the BepiColombo science team on a weekly basis, with a two-week delay (SPICE kernels of state vectors and covariance matrices) and Solar System Ephemeris (to be incorporated to NAIF ephemeris).
Supplementary Data	
Type	***Description***
Others	*Under definition.*

Table 13: MORE Science Products

3.3.2.8 MPO-MAG

Primary Data	
Processing Level	***Description***
Raw	MPO-MAG raw products consist of time-ordered series of counts of the X, Y, and Z components of the magnetic field at the location of the sensors (inboard and outboard). Raw products are in the form of ASCII tables. The raw data files will contain the sensor temperatures as well, as these are needed to calculate the real magnetic field. Raw data are quality flagged.

Partially Processed	Not applicable.
Calibrated	MPO-MAG calibrated products contain data in physical units like Nanotesla and Kelvin. This means, that the results of the ground calibration or inflight calibration have been applied to the data. Different types of calibrated products are produced: • Data in instrument coordinates including also sensor temperatures. Spacecraft generated noise and residual fields are not taken into account. • Data in spacecraft coordinates including temperatures as well. S/C generated noise and residual field are not taken into account. • Data are data in celestial coordinates. Nominal s/c position and attitude have been considered during the evaluation. s/c generated noise and residual fields are not taken into account. Data contain s/c positions as well. The spacecraft generated residual fields and the structures arising from the s/c noise are not removed in these data. The elimination of these effects is under development and will lead to derived data products.
Derived	The MPO-MAG derived products can be: • Resampled products: Derived from the calibrated data by averaging to a specified average period, e.g. 1 second or 1 minute or correcting specific disturbance sources by application of special filters (e.g. elimination of a heater influence). Different types of resampled products will be produced. • Correlated and uncorrelated derived products: These data have been processed using a principal component analysis (PCA). The correlated data are the data that are supposed to represent the solar wind magnetic field. The uncorrelated (IB, OB) data represent the spacecraft noise.
Supplementary Data	
Type	**Description**
Others	*Under definition.*

Table 14: MPO-MAG Science Products

3.3.2.9 PHEBUS

The PHEBUS instrument is composed of two Ultra-Violet spectrophotometers (EUV and FUV) and one scanning mirror.

Primary Data	
Processing Level	***Description***
Raw	PHEBUS raw products correspond to split or decommuted telemetry derived from unprocessed raw science and housekeeping data. Data are also tagged with time and location of acquisition geometry metadata.

	Science and housekeeping data products are derived from the instrument telemetry data. After an observation session reconstruction, data are decompressed (if the data were compressed on-board, optional) and session sliced (one set of files for each individual observation), sorted by instrument data types and instrument modes. Data will be stored as detector images or individual spectra. This data will be still un-calibrated (in digital numbers) with minimal processing applied for identifying and filling gaps with no data values and for detecting unusable pixels (e.g. defective pixels or saturated pixels, or pixels affected by a cosmic ray). PHEBUS raw data products will be under FITS (Flexible Image Transport System) format and conform to the requirements of the FITS standard. A raw data FITS file will be made of two 2D array data blocks: one for the data image and one for the data quality. Instrument housekeeping data time series (temperatures, voltages, scanner position, etc.) will be stored in a separated ASCII table as FITS file and PDS4 formatted.
Partially Processed	PHEBUS partially processed data products are data corrected from instrumental effects (removal of dark current, electronic noise, stray light, etc.). These data will be still in instrument units (in digital numbers or counts). Data uncertainty will be computed accordingly to correction made on the data. PHEBUS partially processed data products will be made of three image data blocks: the first one for corrected data image, the second one for data quality flag, and the last one for data uncertainty.
Calibrated	PHEBUS calibrated data products are derived from the corrected (partially processed) data by applying the PHEBUS in flight calibration output. Data will be converted to physical units. PHEBUS calibrated data files will have the same structure as PHEBUS corrected data files. The first image data block will now correspond to the calibrated data.
Derived	Not applicable.
Calibration Data	
Type	*Description*
In-flight Calibration Products	Dark current model, flat field, calibration factors, effective area as a function of time. Calibration plans: Stellar observations, 1 per day (TBC). Used to correct for sensitivity degradation.
Others	*Under definition.*

Table 15: PHEBUS Science Products

3.3.2.10 SERENA

The SERENA experiment is a Neutral Particle Analyser and Ion Spectrometer particle suite that consists of four spectrometers and one system control unit:

- ELENA (Emitted Low-Energy Neutral Atoms), a neutral particle camera.
- STROFIO (Start from a Rotating Field mass Spectrometer), a neutral particle spectrometer.
- MIPA (Miniature Ion Precipitation Analyser), an ion monitor.
- PICAM (Planetary Ion CAMera), an ion mass spectrometer operating as an all-sky camera for charged particles.

A preliminary description of the SERENA data products is available and is currently being consolidated among the SERENA team. This description will be incorporated in a future version of this document.

Primary Data	
Processing Level	***Description***
Raw	*Under definition.*
Partially Processed	
Calibrated	
Derived	
Supplementary Data	
Type	***Description***
Others	*Under definition.*

Table 16: SERENA Science Products

3.3.2.11 SIMBIO-SYS

SIMBIO-SYS consists of 3 channels: (1) STC, a Stereo Channel (2) HRIC, a High spatial Resolution Imaging Channel (3) VIHI, a Visible Infrared Hyperspectral Imager Channel.

Due to the nature of the channels, this instrument generates data in different formats:

- Hyper-spectral cubes, for VIHI
- Matrices of pixels with different dimensions and number of filters, for STC and HRIC.

Primary Data	
Processing Level	***Description***
Raw	Raw data products are organised as follows: • VIHI: Image cubes (spatial and spectral pixels) • STC and HRIC: Image matrices (only spatial)

	Supplementary data associated with these products includes: • All spacecraft and instrument kernels useful for the further processing activities are archived along with the raw products (for all channels) – SPICE Products. • All housekeeping parameters translated into physical units associated to each image cube/matrix - Primary Data Products. • Geometric information associated to each spatial pixel in the image cube/matrix, at least for VIHI (TBD for STC and HRIC) – Geometry products.
Partially Processed	As the three channels of SIMBIO-SYS can operate independently from each other, the partially processed products are partially overlapped in terms of format and type. In addition, at this stage, new data coming from other instruments (i.e., MORE) could be available to produce more accurate geometrical information to include in SIMBIO-SYS partially processed dataset. SIMBIO-SYS partially processed products will include scientific data organized as image matrices (only spatial) for STC and HRIC. Supplementary data associated with these products includes: • All housekeeping parameters translated into physical units associated to each image cube/matrix - Primary Data Products. • Geometric information associated to each spatial pixel in the image cube/matrix – Geometry products.
Calibrated	Calibrated products are also partially overlapped in terms of format and type. For the time being, the SIMBIO-SYS calibration data products will include: • VIHI: Image cubes calibrated to radiance (in physical units) and reflectance. • STC and HRIC: Image matrix calibrated to radiance (TBC). Supplementary data associated with these products includes: • Data Quality Information: For each image frame we shall record the location of the defective pixels (hot and dead), the calculated Signal to Noise Ratio. • All housekeeping parameters translated into physical units associated to each image cube/matrix - Primary Data Products. • Geometric information associated to each spatial pixel in the image cube, at least for VIHI (TBD for STC and HRIC). For STC and HRIC the way to handle geometric information associated to each image is still under discussion. In any case, either the geometry associated to each pixel or a means to derive this information will be part of the data products.
Derived	

Supplementary Data	
Type	***Description***
In-Flight Calibration	SIMBIO-SYS in-flight calibration products will include: • Scientific observations (Mercury/Venus and proper star fields). These observations will be treated as normal scientific data products and will follow the same processes used for raw and calibrated data. • VIHI: Internal calibration. These products shall be archived as normal raw data products and consequently will follow the same processing pipeline adopted for the scientific raw data except for the derivation of geometric information.
Others	*Under definition.*

Table 17: SIMBIO-SYS Science Products

3.3.2.12 SIXS

The SIXS instrument consists of two detector systems (SIXS-X and SIXS-P), sharing the Data Processing Unit and Power Supply Unit with the MIXS instrument.

- SIXS-X is an X-ray detector system that consists of three X-ray detectors with 512-channels, with only one detector operating at a time. The detectors are identical, and the only difference is the optical axis direction of each detector. The target energy range of each X-ray detector is 1-20 keV.
- SIXS-P is a proton and electron sensitive detector system, with 5 apertures, all operating simultaneously. With the SIXS-P system, measurements of the particle energy, particle type and directional information are obtained in all parts of the orbit. The energy ranges covered for electrons and protons are 0.1-3 and 1-30 MeV, respectively.

Primary Data	
Processing Level	***Description***
Raw	The raw data products for the SIXS-X detector system include X-ray energy spectra and flux data (counts/s) collected at one-second resolution over the full energy range. To reduce the amount of data transferred to ground, the 512-channel spectrum produced by the sensor is binned into a 265-channel spectrum. The nominal integration time for a spectrum is 16 seconds. Each SIXS-X raw energy spectra data product consists of a table (in FITS format) with the 265-channel histograms expanded back to 512 channels, each of which is designated as a single X-ray energy spectrum. Calibration spectra are taken at the beginning and end of each observation, and stored at the beginning and end of the table. Each SIXS-X raw flux data product consists of a table (in FITS format) containing

	the total count rate (counts/s). Each row in the table contains the number of counts for each second of integration collected during 64 s. The raw data products for the SIXS-P system include energy spectra of protons and electrons and flux data at one-second resolution. The nominal integration time for a spectrum is 8 seconds. Each SIXS-P raw energy spectra data product consists of a table (in FITS format) with 9 and 7 differential logarithmically spaced energy channels histograms, recorded separately in the five different viewing directions of the detector system. Each SIXS-P raw flux data product consists of a table (in FITS format) containing the total count rate (counts/s) of protons and electrons at two wide energy channels (protons: 1-4.3 MeV and 4.3-30 MeV; electrons: 0.1-0.3 MeV and 0.3-3 MeV). Each row in the table contains the number of counts for each second of integration and energy channel collected during 64 s. Each SIXS-P raw pulse height data products consists of samples of particle events recorded as raw pulse heights as received from the detector elements. Each record contains 16 samples (pulse heights). The nominal interval for this type of data is 64 s.
Partially Processed	Above mentioned raw data products with relevant calibrated housekeeping parameters, instrument and spacecraft geometry parameters included.
Calibrated	Spectral data converted to physical units and calibrated using the calibration algorithms based on in-flight and on-ground instrument calibration measurements. The calibration inputs and the algorithms to do the conversions are supplied as Supplementary products (e.g. sensitivity of the detectors, energy resolution and energy scale). Note that SIXS-X in-flight calibration files (background calibration spectra) are included as part of the raw products. Calibration process consists of finding the instrument response, effective area and background and applying them to the spectra. Instrument response (energy range and resolution) is derived from in flight calibration spectra. Effective area is derived from the position of the Sun in the field of view and ground calibration data. Background is derived from in flight calibration spectra.
Derived	
Supplementary Data	
Type	**Description**
Calibration	Detector effective area maps from ground calibrations.
Others	Under definition.

Table 18: SIXS Science Products

3.3.3 MMO Science Data

An overview of the MMO science data products will be added in this section when available.

3.3.4 Auxiliary Data

This section describes the auxiliary data that will be archived as part of the MPO science data (and therefore in PDS compliant format). Auxiliary data includes:

- A complete set of instrument and spacecraft geometry information (e.g. SPICE kernels, observation footprints) for the whole mission. *Additional formats will be considered based on the needs from the Instrument Teams.*
- Others (e.g. platform housekeeping, science planning information and other context information). *Additional auxiliary data collections are under definition.*

4 OVERVIEW OF THE SCIENCE DATA FLOW

Real-time telemetry received on-ground from the MPO spacecraft will be relayed from the ground stations to the Operational Ground Segment (OGS) during ground station contacts, including both instrument and spacecraft recorded telemetry frames.

During each ground station contact, the OGS will process the recorded telemetry frames into packets containing instrument and spacecraft data as originally generated on-board, and will make packet sets available in the EGOS Data Dissemination System (EDDS) along with status and ancillary information. The OGS will also extract and calibrate a set of key housekeeping parameters from telemetry packets and make them available through the same dissemination system.

Immediately after the data becomes available in the EDDS, telemetry packets, housekeeping parameters and any additional information relevant for data processing and analysis (in particular spacecraft trajectory, attitude and time correlation packets) are retrieved by the SGS through the EDDS and stored in a mission centralised archive.

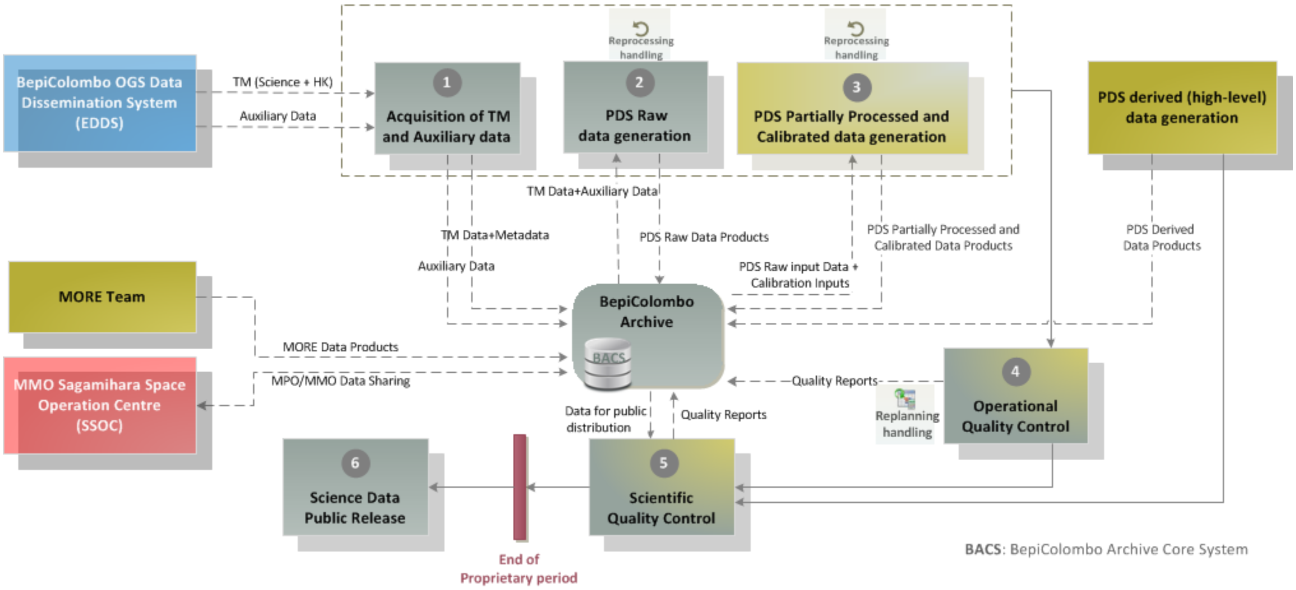

Figure 3: Overview of the Data Handling and Archiving processes and data flow.

Grey boxes indicate processes performed by the SGS, while yellow boxes indicate processes performed by the Instrument Teams. Mixed grey-yellow boxes are performed in collaboration.

The raw data processing (from telemetry through to un-calibrated science data) is centralised at the SGS. Raw data products will be systematically generated by the SGS every time new telemetry data is available in the archive (within 4 hours after availability of new telemetry in the EDDS). This step relies on inputs delivered by the teams, either in the form of ready-to-use processing software (under version control between the SGS and the Instrument Team institution) or in the form of algorithms and input/output definitions, depending on the agreement with each team (see Data Processing Agreements [RD.07]).

Raw data products generated by the SGS (in PDS4 compliant format) will be stored in the archive for subsequent processing and analysis waiting for verification by the relevant Instrument Team. Instrument Teams are required to review the products within a few days (typically one day; the exact period of time will be decided and adapted to each team, depending on the complexity of the products).

Orbit, attitude and time correlation files (and other relevant spacecraft telemetry e.g. solar array motion and high-gain antenna orientation) are also converted into SPICE kernels by the SGS and made available in the archive.

Each Instrument Team is then responsible for generating calibrated and derived data products based on the best current calibration factors and analysis routines.

Two options are foreseen for the generation of the calibrated products. The Instrument Team can choose to have the calibration step either (1) located at the SGS with software provided by the Instrument Team (to take advantage of the reprocessing capabilities and resources that the SGS can offer) or (2) located at the Instrument Team institution, based on a prime-redundant configuration i.e. the prime calibration process runs at the Instrument Team site while the SGS hosts a backup of this processing step. The exact configuration of the calibration step will be adapted to each team, depending on the complexity of the software.

Independently of the option that is chosen, the calibration process must take as input the raw data in PDS4 format as generated in the previous step.

Instrument Teams (when applicable) will routinely deliver calibrated data products to the SGS within 1 week of receipt of raw data and associated SPICE kernels.

The generation of high-level (derived) products is the responsibility of the Instrument Team and follows the general requirements for science data formats (PDS4). The schedule for delivery is however, driven by a case-by-case agreement.

The SGS will provide to the Instrument Teams software to assist them in the delivery and validation of the generated products. All supplementary products must be delivered by the Instrument Teams to the SGS and archived as PDS4 products.

Based on the available raw and calibrated products, the SGS together with the Instrument Teams will monitor deviations between the planned and the executed science observations and, when possible, feed back the result of this analysis into the different cycles of the science planning, as well as flag significant issues to the Instrument Teams. This activity is referred to as Operational Quality

Control (or quick-look analysis), and will be used to assess instrument performance, support operations, identify times/regions of scientific interest and provide a first view of MPO science measurements and Mercury´s environment.

As the Instrument Teams are responsible for producing valid science data, they will define (and if necessary modify) the procedures and parameters/values to be checked to assess the success of execution of an observation. The SGS will support the Instrument Teams in the application of these procedures on a mutually agreed basis and will report to the Instrument Teams on the results. The result of the quick-look analysis (generated by the SGS) will be provided to the Instrument Teams in the form of automatic quick-look reports containing plots (designed in collaboration with the Instrument Teams) and any additional information relevant for the interpretation and assessment of the results.

In addition to raw and calibrated products, the SGS will extract a set of key parameters from science telemetry packets that, together with the housekeeping parameters retrieved from the OGS, can be also used for quick-look and monitoring purposes.

The frequency of the acknowledgement/feedback by each Instrument Team to the operational quality control reports generated by the SGS will be discussed and adapted to each Instrument Team. Instrument Teams will be able to respond in a flexible way to specific events and findings.

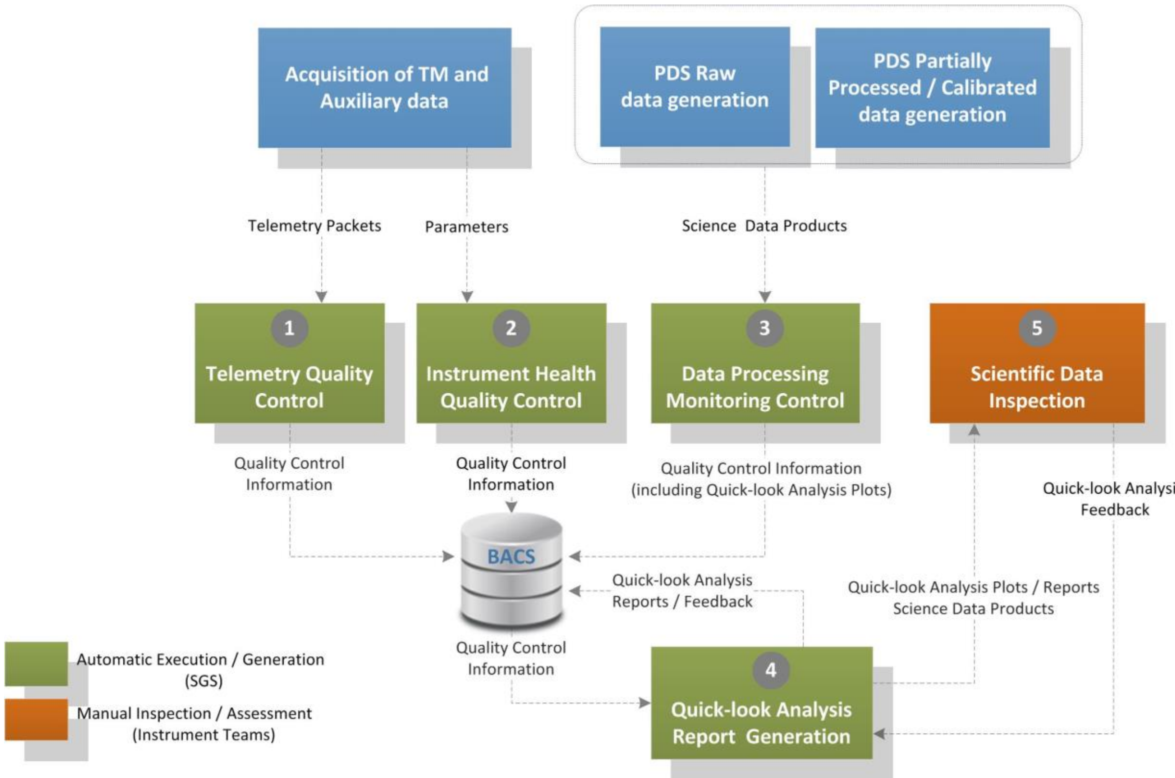

Figure 4: Operational Quality Control Processes

After the Instrument Team's acknowledgement of the report content, and of the need or not to attempt re-planning, the information can be fed back into the relevant planning cycle. Quick-look products and associated information will be archived, along with the science data.

Data products resulting from the raw and calibration processing steps, once validated by the relevant Instrument Teams, are made available by the SGS in the archive to other teams, within the rules agreed upon in the Data Sharing Agreements [RD.06]. The content of the data sharing agreements (defining how different teams can exchange data of interest to support their own science investigations) will be defined and agreed by the Science Working Team (SWT).

Updates to calibrations, algorithms, and/or processing software are expected to occur regularly, resulting in appropriate production system updates followed by reprocessing of science data products by Instrument Teams and SGS accordingly. Systems at the SGS and Instrument Teams will be designed to handle these periodic version changes and updates.

An exception to the described data flow is the handling of the radio science data resulting from the MORE instrument. Radio science data are not telemetry data, but individual files acquired at the ground station. The radio science team will take the data directly from ESA and NASA's DSN ground stations. The MORE team will provide radio science raw and calibrated data products to the SGS for ingestion into the archive in batches of 1 week. These data will be available in the archive within a maximum of 2 weeks from acquisition, including relevant supplementary data.

Following the six month proprietary period, and after feedback from the Instrument Teams has been received, raw and calibrated data available in the archive are routinely released to the public, with the exception of derived products that will require explicit approval from the Instrument Team. Public release of raw and calibrated data will be done on a regular basis in batches of 1-week for raw data and 1-month for calibrated data.

Responsibilities for data product generation, validation and dissemination are discussed in Chapter 6. The timeline and schedule for production and availability of the BepiColombo science data products is shown in Chapters 7 and 8.

4.1 BepiColombo Archive

Throughout this document, the term archive refers to the part of the BepiColombo archive under ESA's responsibility (also named BepiColombo Archive Core System in the SGS system context).

The BepiColombo archive is a joint ESA-JAXA international effort bringing together MPO and MMO science data holdings and associated services into one logical entity. This entity is composed of two interoperable archive systems: the BepiColombo MPO archive (provided by ESA) and the BepiColombo MMO archive (provided by JAXA).

The main goal of the BepiColombo archive is to maximise the scientific exploitation of the data by making all mission science data globally accessible to the science team and to the scientific community at large through both archive systems via a range of access mechanisms.

By using interoperability protocols and common data standards, the exchange of information between both archives will be possible in a completely transparent way to the end-users. Access to the data during the proprietary period will follow the Data Sharing Agreements [RD.06] defined at Science Working Team (SWT) level.

As mentioned in previous sections of this document, the BepiColombo MPO archive (the part of the BepiColombo archive under ESA's responsibility) is based on a single archive approach that will provide access to all BepiColombo scientific and operational data throughout the different phases of the mission (from early development to operations, post-operations and science exploitation-legacy phases).

In addition, science data available through the BepiColombo archive will be made accessible through the ESA's Planetary Science Archive (PSA). PSA is a multi-mission archive for all scientific and engineering data returned by ESA's planetary missions, including data from Smart-1, Mars Express, Venus Express and Rosetta. With a primary focus on scientifically related data sets, PSA provides a range of cross-mission and cross-instrument search and download services centralising data access and resources for users wishing to use planetary data.

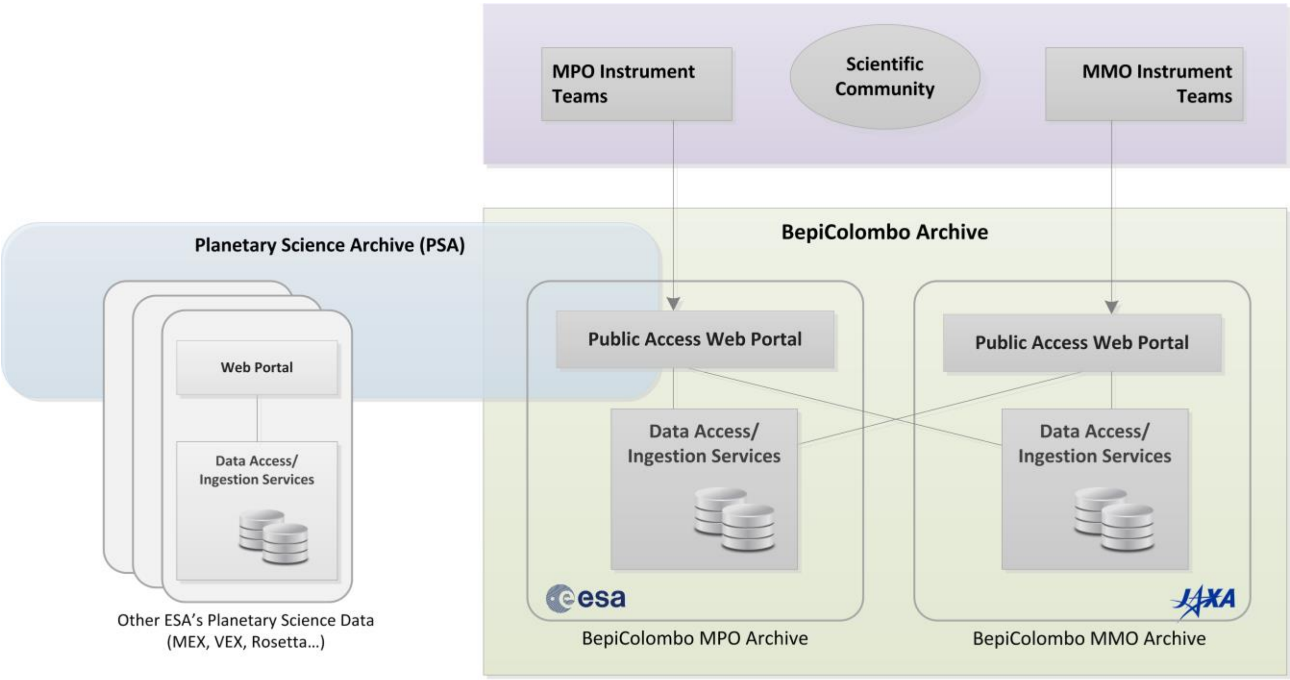

Figure 5:Conceptual diagram of the BepiColombo Archive.

The BepiColombo MPO archive and the other SGS systems will be integrated to build a unique SGS system covering all data handling and archiving needs.

The archive is required early on in the mission to support pipeline development and ingestion of on-ground calibration data and laboratory measurements relevant for the interpretation of the science data from the MPO instruments. An initial version of the archive will be ready at launch with some essential functionality (in addition to the above) to support the processing, ingestion and distribution of telemetry and auxiliary data acquired during the Near Earth Commissioning and Cruise phases, including all data required and resulting from the demonstrable pipelines (see Section 5.1.3).

After that, the archive will evolve through the different phases of the mission (up to the end of the post-operations phase and the transition to the legacy phase) until all expected functionalities for the search and retrieval of all science data are implemented.

Details of the BepiColombo archive, its data access interfaces and associated services, and the development approach will be described in separate documents (see BACS Architecture Concept [RD.13]).

5 SCIENCE DATA HANDLING AND ARCHIVING PROCESS

5.1 Pre-Launch Preparation

5.1.1 Planning Phase

The two steps of the BepiColombo science data handling and archiving process described in this section were completed before the preparation of the present document.

- Definition of a *Data Handling and Archiving Concept [RD.01]*. The archiving process starts by collecting all the requirements from the mission and from the Instrument Teams and documenting the overall concept for the generation, validation, transfer and distribution of the science data.

- Set up of a *Data Handling and Archiving Working Group (DHAWG)*. This working group is the forum for discussion and agreement on activities related to science data processing and archiving, including associated services. The Project Scientist, supported by the SGS, chairs this working group and coordinates its activities. In addition to the chairs, this working group includes representatives from all MPO Instrument Teams, the JAXA MMO archive and PSA and SAT representatives.

Interactions with the Instrument Teams are required throughout the mission, via the Data Handling and Archiving Working Group (DHAWG), for discussion and agreement on all aspects related to the science data handling and archiving, including the development of the BepiColombo archive.

The Data Handling and Archiving Concept defined in [RD.01] was discussed and agreed in the DHAWG before the preparation of the present document started.

5.1.2 Design Phase

The objective of this phase is the definition of the contents and structure requirements related to science data and the identification of the products that will result from the BepiColombo mission. The initial agreement towards a common archiving standard was made in the BepiColombo Science Management Plan [AD.01]. Based on that, the following activities take place during this phase.

a) Preparation of the *Science Data Generation, Validation and Archiving Plan* (this document). The so-called Archive Plan is one common document for all science data that describes the science data contents, organisation, structure and applicable standards as well as the plan and schedule for the generation, validation and archiving of the science data. It gives references to relevant documents, defines responsibilities and provides a brief description of the different data types and the corresponding data volume.

This document is prepared by the SGS and the Project Scientist (with contributions from all the involved parties). Instrument Teams contribute to this document by:

- Identifying the products to be delivered to the archive in order to fulfil the requirements in the BepiColombo Science Management Plan [AD.01], summarised in Section 3.2 of this document, including an estimation of the data volume of those products.
- Contribute to the defined process, requirements and recommendations with their expertise and experience.

This document is approved and signed by all MPO Instrument Teams, the Project Scientist and the PSA and SAT coordinators, and authorised by the SGS Development Manager.

The archive plan (this document) is complemented by a set of rules, common terminologies and conventions that all BepiColombo Instrument Teams (or other data providers) shall follow when generating and submitting their science data and associated products to SGS for archiving This set of rules and conventions is documented in the BepiColombo Archiving Guide [RD.03]. This guide is a living document that may be edited and updated throughout the mission to cover arising needs and requirements.

b) Preparation of the Experiment to Archive Interface Control Documents (EAICD). The EAICDs are separate documents to be delivered by each Instrument Team and shall include detailed information about the data resulting from their instrument. These documents are intended to provide enough information to enable users to understand the science data products and their organisation. The EAICDs define the PDS data types used for the data products, the naming conventions and the contents of the directories. These documents shall contain information on all data deliverables, including the data flow, data processing and analysis system, and any software algorithms for generating the data. Instrument teams shall follow the EAICD template provided in Annex F of this document.

Before the mission is launched, EAICDs should be progressed so far that they cover at least generation and archiving of the raw and calibration products. EAICDs should be finalised before arrival at Mercury. Each EAICD document is the responsibility of the corresponding Instrument Team.

For the preparation of the EAICDs, Instrument Teams will work with the SGS in order to ensure consistency of the content, formats and structures used across all science data. During this preparation, the SGS will assist Instrument Teams in developing PDS-compliant labels for all identified products (see Section 3.3.2) that will be maintained under version control. See Section 5.2.3 for the review of the EAICD.

5.1.3 Development Phase

This phase includes the development of the SGS systems needed to cover all data handling and archiving needs, including the development or adaptation of Instrument Teams pipelines to generate the PDS-compliant data deliverables listed in Section 3.3.2.

The Science Archives Team (SAT), located at ESAC, is responsible for the implementation of the BepiColombo MPO archive (so-called BepiColombo Archive Core System), based on the requirements provided by the SGS. An initial plan for the development of the archive is provided in the overall SGS Development Plan [RD.12]. A more detailed development plan will be defined in a separate document [RD.15], including a reference to the applicable configuration control practices. Development, integration and testing of data processing pipelines is a collaborative effort between the SGS and the Instrument Teams, following the decisions agreed upon in the Data Processing Agreements [RD.07]. A set of guidelines and recommendations to ensure consistency and quality of all software systems forming part of the SGS are described in the Software Engineering Guidelines for External Users (SEGU) [RD.17]. Instrument teams are expected to consider (as much as possible) these guidelines for the development of their data processing and quick-look software (when applicable) in order to facilitate the integration into the SGS system.

As indicated in the Science Implementation Requirements Document (SIRD) [AD.02], an early version of the SGS system (including the archive and a limited set of processing pipelines) is required by launch. This initial version is intended to:

- Support early instrument pipeline development activities and ingestion of data resulting from on-ground calibration campaigns and laboratory measurements.
- Provide a proof of concept of the designed systems. This will help to better understand the expectations of the Instrument Teams on the data processing and operational quality control (quick-look) systems, allowing the SGS to improve the relevant systems for the Mercury orbit phase.

The set of instruments for which initial versions of the processing pipelines (so-called "demonstrable" pipelines) will be developed and integrated within the SGS system by launch include ISA, MERTIS, MPO-MAG and SIXS. Additionally, processing pipelines for other instruments will be integrated into the SGS system during the Cruise phase on a best effort basis.

The instruments listed above were chosen based on different criteria (namely availability of instrument developed software by launch and scientific interest during the Cruise phase, including the usefulness of the corresponding pipeline and quick-look system from launch).

Validation of sample products generated with the developing pipelines and iterations between the Instrument Teams and the SGS throughout this phase are key to ensure compatibility.

5.2 Routine Operations

This phase entails running the data processing pipelines, validating the products and delivering the products to the SGS (when applicable) for ingestion into the archive, following the strategy described in the Data Handling and Archiving Concept [RD.01] and summarised in Chapter 0 of this document.

During operations (starting already at launch), the archive will be the central point of data exchange between all SGS subsystems and between the SGS and the other external parties (mainly the Instrument Teams and the scientific community).

5.2.1 Data Delivery and Validation

Following the delivery schedule defined in Chapter 7, Instrument Teams collect raw data from the SGS, analyse and process their data into higher levels in collection periods (see Chapter 8). After the collection period, Instrument Teams prepare their data for delivery to the SGS.

A basic set of requirements that any science data set must comply with in order to be archived is defined in the BepiColombo Archiving Guide [RD.03]. These are the constraints to be checked before the data deliverables (see Section 3.1) are archived. The SGS will provide to the Instrument Teams software to assist them in the delivery and validation of the generated products to assure data deliverables are compatible with these basic requirements.

Details of the delivery mechanisms and specific formats will be documented in the SGS-PI Interface Control Document [RD.10].

5.2.2 Operational Quality Control

Operational quality control (quick-look analysis) is a key aspect of the science operations of BepiColombo. Details of the Operational Quality Control are provided in the Data Handling and Archiving Concept [RD.01] and are subject to the agreement between the SGS and each Instrument Team.

The results of the operational quality control will be provided to the Instrument Teams in the form of automatic quick-look reports through a web interface that will allow recording and tracking of feedback provided by the Instrument Teams. Quality control information (including the quick-look reports) will be stored in the archive along with the science data, and will be made available to the end-users.

One of the primary objectives of the Operational Quality Control is to support the Instrument Teams in the assessment of the results of the executed observations and the generated science data products. Efforts required from the Instruments Teams related to providing feedback on the analysis of these results to the SGS should be minimized.

5.2.3 Science Archive Quality Control

In addition to the operational quality control, formal reviews of the science data ingested in the archive will be organised by the SGS, in coordination with the Project Scientist.

A description of the review procedure followed by all ESA's planetary missions can be found in the PSA Review Procedure [RD.18]. A summary of this procedure is given below.

The review is a three-step process consisting of:

1) Review of the Science Data Generation, Validation and Archiving Plan (this document) and the individual Experiment-to-Archive Interface Control Documents (EAICDs), including (if possible) sample data and processing pipelines documentation (Archiving Documentation Review).
2) Review of the first data delivery (Initial Peer Review).
3) Review of all data together after the final delivery (Final Peer Review).

Additional reviews may be organised as deemed necessary.

Some additional details of the Peer-Review procedure are provided below.

The SGS team, in coordination with the Project Scientist, is responsible for organising these reviews. The objective of the review is to ask independent planetary scientists knowledgeable in each discipline to assess the quality of the data against well-defined scientific criteria. The external review team members and the review chairperson will be agreed between the Project Scientist and the SGS team. The SWT will be informed about the composition of the review team.

The Peer Review team verifies the data and documents. The tasks of the team can be best compared to the tasks of a referee for a paper to be published in a scientific journal.

The Instrument Teams and the SGS will resolve arising problems. Data sets where Review Item Discrepancy Reports (RIDs) occurred and on which the Peer Review team proposed clear solutions, do not have to undergo an additional Peer Review. In case of more serious RIDs, revision and reviewing of the data sets will be iterated.

Science data in the archive will be flagged indicating the status of the data as "pending peer review", "successfully peer reviewed" or "failed peer review". At the conclusion of each review step all data should be certified and clearly flagged in the archive as "successfully peer reviewed".

The results of the scientific quality control will be recorded and tracked through a web interface allowing Instrument Teams to provide feedback when needed. Scientific quality control results will be stored in the archive along with the science data, and will be made available to the end-users.

5.2.4 Data Access and Exploitation

To help ensure that the most recent data and software are easily available, data access for external users (in general Instrument Teams and the scientific community) is centralised at the SGS through the BepiColombo archive (see Section 4.1).

The archive will provide different data access mechanisms, with the Public Access Portal (web interface) being the main entry point to the archived data and all associated services.

Data resulting from both MPO and MMO instrument observations, as indicated in Section 4.1, will be made available through the archive, following the rules agreed upon in the Data Sharing Agreements [RD.06] between the MMO and MPO Instrument Teams, defined at Science Working Team (SWT) level. Authentication and authorisation services will be implemented in the archive to fulfil this requirement.

ESA and JAXA will establish a range of data exchange mechanisms (e.g. science data exchange based on the IPDA Planetary Data Access Protocol – PDAP) to cover all requirements and needs gathered from the Instrument Teams during the different phases of the mission. Details of the data exchange mechanisms between MPO and MMO will be documented separately see [RD.11].

Following the agreed strategy for the public release of the science data (see Chapter 8), the scientific community outside the BepiColombo team will have timely access to scientifically useful and well-validated products through the BepiColombo archive.

The archive, including its associated data access services, will be developed ensuring that the needs of the Instrument Teams and the scientific community are fully met. The development will be driven by the implementation of science use-cases, gathered by the SGS from the science team and the scientific community through the DHAWG, under the responsibility of the Project Scientist. Functionalities will evolve in time according to the different requirements during the different phases of the BepiColombo mission. Archive user requirements will be documented in the BACS User Requirements Document [RD.14].

Additionally, the SGS will support the development of visualisation tools to aid in data access and analysis of the archived data and will maintain a help-desk service to provide answers to technical and scientific questions.

In cooperation with the Instrument Teams, the SGS will organise data workshops in the form of hands-on lessons, with expert members of the Instrument Teams providing direct support on the best ways in which to calibrate and use their data for science. The SGS will also support Instrument Teams in the creation of data tutorials to help end users in their data exploitation activities.

Feedback on the data access and exploitation services related to BepiColombo science data will be continuously collected through dedicated user groups, resulting in regular user feedback reports including recommendations on some possible improvements.

5.3 Post-Operations and Legacy

As defined in the Science Implementation Requirements Document (SIRD) [AD.02], the post-operations phase starts at the end of the routine operations and has a total duration of 1.5 years.

SGS resources will be gradually reduced during this phase although archiving support will be maintained and guaranteed.

Archiving resources during this phase will be devoted to the consolidation of the archive with the following main objectives:

- Ensure that the best data products attainable are archived.
- Ensure that data and supplementary information (including data processing, visualisation and analysis tools) are properly documented and successfully peer-reviewed (including the final review as indicated in Section 5.2.3).
- Maintain a high level support to the scientific user community for the exploitation of the archived data.

Bulk reprocessing campaigns may be needed during this phase as better calibrations become available.

After the conclusion of the post-operations phase, the BepiColombo mission ends formally with specific funding and dedicated resources no longer available. The BepiColombo archive will then enter the legacy phase becoming the long-term archive.

According to the Science Implementation Requirements Document (SIRD) [AD.02], ESA is required to preserve the BepiColombo archive for at least 10 years after the end of the post-operations phase. However, current ESA strategy envisages ensuring long-term preservation of all ESA space science data holdings for an even longer period (with the limitations that this may impose).

Preservation responsibilities related to the BepiColombo archive during the legacy phase are limited to maintenance, technology upgrades (foreseen every ~5 years), help-desk support and ingestion of improved data and new products (on a best effort basis).

6 ROLES AND RESPONSIBILITIES

This section describes the roles and responsibilities of the personnel and organisations involved in generating, validating, transferring, distributing and maintaining the BepiColombo archive.

6.1 Project Scientist

- Represent the science community needs.
- Monitor the state of implementation and readiness of the instrument operations and data processing infrastructure.
- Coordinate the creation of the scientific products, their archiving and distribution to the scientific community.

- Define and follow the implementation of an efficient and cost-effective science operations centre, also responsible for scientific data handling and archiving.
- Consolidation of data processing approach.
- Transform knowledge of instrument science performance, instrument operations and science data products into requirements for the SGS.
- Support the creation of the scientific data deliverables, their archiving and distribution to the scientific community.
- Coordinate and host (being the responsible author of) the Data Sharing Agreements Document [RD.06].

6.2 Science Ground Segment (SGS)

- Integration of the instrument pipelines in the SGS (telemetry-to-raw; raw-to-calibrated only if agreed with the corresponding Instrument Teams).
- Retrieval of telemetry products from the OGS.
- Generation of raw products and distribution of these products to the Instrument Teams.
- Support the generation of the data deliverables by advising the Instrument Teams.
- Validation of all data deliverables from the Instrument Teams to ensure their compliance with a minimum set of requirements (i.e. PDS compliance).
- Coordinating any data deliverables containing data from several instruments, if no coordination undertaken by an experiment team.
- Convert the spacecraft orbit and attitude data from the OGS into SPICE kernels.
- Convert all agreed auxiliary data from the OGS to PDS formatted products.
- Dissemination of all required data available in the mission archive to the Instrument Teams.
- Dissemination of data archived in the BepiColombo archive to the scientific community and general public.
- Coordination of the formal peer-reviews of the archive and contents as described in Section 5.2.3.
- Ensuring long-term preservation of all data deliverables mentioned in Chapter 3.
- Overall coordination of the system specification, design and development.
- Overall coordination of the archive specification, design and development.
- Overall coordination of the definition and implementation of the MPO-MPO interface, including definition of data formats, exchange mechanisms and backup policies as agreed with JAXA/ISAS SSOC.
- Advise Instrument Teams on data processing and archiving related issues.
- Ensure that the archive meets PDS standards (data validation).
- Ensure the quality, usability, completeness and integrity of the archived data through formal peer-reviews.

6.3 Instrument Teams

- Contribute to the definition of the science operations and data handling concept.

- Exploit the scientific results of the mission and assure their diffusion as widely as possible.
- Provide software required by the SGS to decode telemetry into PDS raw products following the requirements specified in [RD.01].
- Maintain all instrument team provided software until the end of the mission.
- Provide all required calibration data (see Chapter 3) to the SGS along with a full instrument technical and science user manual for use by the general science user community.
- Definition of data quality assessment criteria (in particular automatic checks that would allow SGS to implement their operational quality control requirements).
- Retrieval of science PDS raw products and supplementary data from the SGS (via the mission archive).
- Generation of calibrated and derived products (and corresponding validation) using as inputs the PDS raw data retrieved from the SGS and any additional data required.
- Delivery of calibrated and derived products (including supplementary products) to the SGS following the requirements specified in [RD.01].
- Scientific analysis of the data.
- Science quality assessment (operational quality control) on the retrieved data including feedback to the SGS for re-planning.
- Deliver updated science data products (when applicable) according to the peer-review results.

6.4 Operational Ground Segment (OGS)

- Make available to the SGS (through the EDDS):
    - Up-to-date information on the orbital position and attitude of the spacecraft at the time of all observations by any instrument, including retroactive updates of the position whenever the precision is significantly improved.
    - Time correlation information whenever the accuracy is worse than the precision required by the mission.
    - All spacecraft ancillary data and any other non-spacecraft ancillary data, e.g. event files, the mission command database, the list of executed commands needed by the SGS.
- Make available to the SGS and to the Instrument Teams (through the EDDS) all instrument telemetry data.

6.5 Science Archives Team (SAT)

- Development and implementation of the part of the BepiColombo archive under ESA's responsibility, according to the requirements provided by the SGS.
- Development and implementation of the integration of the BepiColombo archive into the Planetary Science Archive (PSA), in coordination with the PSA team.
- Maintenance of the archive infrastructure.

6.6 Planetary Science Archive (PSA) Team

- Advise SGS in all aspects related to the archiving of BepiColombo data, including suitability of documentation, data formats, content, structures and procedures.
- Coordinate the integration of the BepiColombo archive into the Planetary Science Archive.
- Provide support to SPICE activities.

6.7 JAXA/ISAS Sagamihara Space Operations Centre (SSOC)

- Overall coordination of the definition and implementation of the MPO-MMO interface, including definition of data formats, exchange mechanisms and backup policies as agreed with the MPO Science Ground Segment (SGS).

6.8 Interdisciplinary Scientists (IDSs)

To be written by the Project Scientist when details available.

7 DATA DELIVERY SCHEDULE

This section outlines the nominal data product generation and delivery schedule, including the availability of these products at the SGS.

The data delivery schedule defined below will allow for timely availability of data products:

- For exchange of data during the proprietary period, as agreed in the Data Sharing Agreements [RD.06] at SWT level.
- For the Operational Quality Control and re-planning purposes, due to the need for rapid feedback within the operations and planning cycle.

Deliverables	Schedule	Provider
Telemetry Products	Available in the archive immediately after retrieval from the EDDS (OGS).	SGS
Raw Products	Available in the archive within ***4h*** after telemetry products are received from the EDDS (OGS).	SGS
Partially Processed and Calibrated Products (1)	Generated by the Instrument Teams from the raw products, and delivered to the SGS within ***1 week*** after the raw products are available in the archive. When not delivered in the defined period, and only if agreed with the corresponding PI in the *Data Processing Agreements [RD.07]*, the SGS will generate preliminary calibrated products for science health monitoring and re-planning purposes, using the latest calibration information available.	Instrument Team
Derived Products	Delivered as soon as they are generated and validated.	Instrument Team
Supplementary Products	Delivered as soon as they are generated and validated. When needed for a specific release/purpose, detailed delivery dates will be defined (e.g. on-ground calibration products, preliminary calibration inputs, EAICD).	Instrument Team / SGS

Table 19: List of deliverables with corresponding delivery schedule (to SGS)

(1) For some instruments, the calibration process will need to be consolidated during the first few months, affecting the delivery schedule. Whenever possible, a reference calibration (to produce preliminary calibrated products) will be used until the calibration process is consolidated.

An exception to the delivery schedule described in Table 19 is MORE: MORE raw and calibrated data will be delivered to the SGS within a maximum of 2 weeks from acquisition (including all supporting information). In addition, a MPO reconstructed trajectory will be produced on a weekly basis by MORE and delivered to the SGS with a 2 weeks delay (best-effort basis).

In addition, within 12 months after the end of the BepiColombo mission, all data recalibrated or reprocessed since launch not available in the archive shall be delivered by the Instrument Teams to the SGS.

8 DATA RIGHTS AND RELEASE POLICY

Due to the expected scientific interest and the strong commitment to releasing data on a timely basis, it is important to establish a clear policy for data dissemination to both the scientific community and the general public.

In accordance with the BepiColombo Science Management Plan [AD.01], exclusive data rights reside with the Instrument Team for the analysis and exploitation of their products for a maximum of 6 months (proprietary period) from receipt of the original science telemetry. After this time, science data will be made available to the scientific community at large through the BepiColombo archive.

To facilitate the public release of the data, a data collection period is defined depending on the data product type.

Deliverables (1)	Producer	Responsible	Release Policy (2)
Raw Products	SGS	PI(s)	Immediately after proprietary period. Prior confirmation from the PI is required. Data collection period: 1 month.
Partially Processed and Calibrated Products	Instrument Team	PI(s)	Immediately after proprietary period. Prior confirmation from the PI is required. Data collection period: 1 month.
Derived Products	Instrument Team	PI(s)	Derived data will be released to the science community only after exploitation by the Instrument Teams. Public release of derived products requires explicit approval from the PI. Data collection period will depend on the type of product, to be defined on individual basis.

Table 20:List of data deliverables with corresponding policy for public release

(2) Including all Supplementary products needed for the interpretation and use of the data. Content requirements will be provided in the BepiColombo Archiving Guide [RD.03].
(3) Updated versions of already released products will be delivered and released as soon as they are generated and validated.

The first BepiColombo public data release during the Mercury Orbit Phase will occur six months (proprietary period) after acquisition of data starts and will consist of data acquired during the first month (accumulation period for raw and calibrated data). Thereafter, public data releases will occur every month for raw and calibrated data products, including data acquired during the corresponding accumulation period. This is illustrated in the following figure.

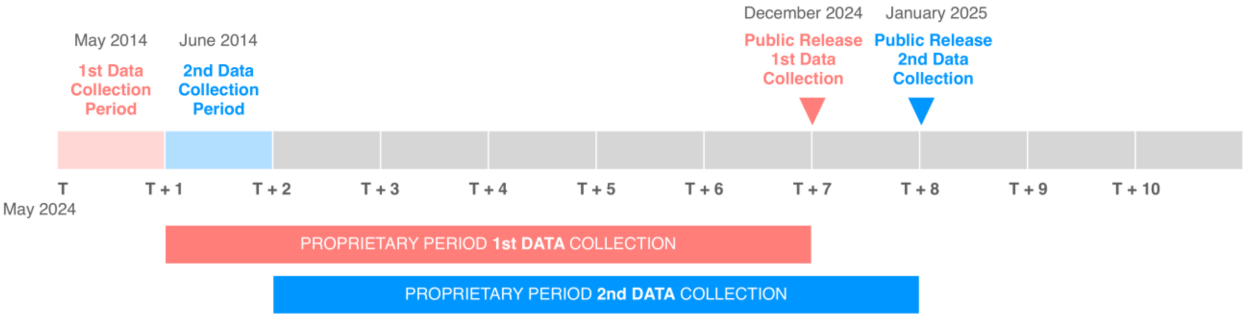

Figure 6: Public releases of science data (based on the data collection and proprietary periods)

ANNEX A DEFINITION OF DATA PROCESSING LEVELS

BepiColombo has adopted the following terms for broadly classifying science data products in the archive according to their level of processing. This classification is based on the PDS policy on Data Processing Levels.

Data Processing Level	Definition
Telemetry	Original binary stream from an instrument encoded in telemetry packets.
Raw	Original data from an instrument. If compression, reformatting, packetization, or other translation has been applied to facilitate data transmission or storage, those processes will be reversed so that the archived data are in a PDS approved archive format.
Partially Processed	Data that have been processed beyond the raw stage but which have not yet reached calibrated status.
Calibrated	Data converted to physical units where all of the calibration based on the instrument has been done.
Derived	Results that have been distilled from one or more calibrated data products (for example, maps, gravity or magnetic fields, or ring particle size distributions). Supplementary data, such as calibration tables or tables of viewing geometry, used to interpret observational data should also be classified as 'derived' data if not easily matched to one of the other three categories. Navigation products (including SPICE kernels) will be classified as Derived data.

Table 21: Definition of Data Processing Levels for BepiColombo

When defining the classification of the science data products, MPO Instrument Teams (in consultation with the SGS) will select the most appropriate term and will provide a detailed description of the processing in accompanying documentation.

ANNEX B OVERALL SCHEDULE AND MILESTONES

Mission Phase	Milestone / Activity	Date
Before Launch	Archiving Plan (signed version of the present document)	SGS-LaS-RR
	EAICD (draft; ready for peer-review)	SGS-LaS-RR
	Peer-review of available documentation, data samples and pipelines	Launch – 2 months
	Ingestion of all on-ground calibration and laboratory measurements	Launch
Launch		July 2016
Launch - MOI	EAICD (final version; ready for peer-review)	SGS-MeS-RR
	First data delivery (and ingestion in the archive)	*TBC*
	First raw data public release during Cruise phase	*TBC*
	First calibrated data public release during Cruise phase	*TBC*
	Peer-review of documentation, data samples and pipelines	MOI – 2 months
Mercury Orbit Insertion (MOI)		January 2024
Start of Science Operations		June 2024
Mercury Science Phase	First data delivery (and ingestion in the archive)	June 2024
	Peer-review of the first data delivery	September 2024
	First raw data public release during Nominal phase	December 2024
	First calibrated data public release during Nominal phase	December 2024
EOM		November 2027
Post-Operations Phase	Final data delivery	EOM + 6 months
	Peer-review after the final data delivery	EOM + 6 months
	Archive transfer to Legacy Phase	EOM + 1.5 years

SGS-LaS-RR: SGS Launch System Readiness Review
SGS-MeS-RR: SGS Mercury System Readiness Review
MOI: Mercury Orbit Insertion
EOM: End of Mission

Table 22: Overall Schedule and Milestones

ANNEX C BEPICOLOMBO DHA KEY PERSONNEL

DHA Key Contact		***Email Address***
MPO Project Scientist	Johannes Benkhoff	Johannes.Benkhoff@esa.int
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ISA	Francesco Santoli Roberto Peron Carmelo Magnafico	francesco.santoli@iaps.inaf.it roberto.peron@iaps.inaf.it carmelo.magnafico@iaps.inaf.it
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PHEBUS	Aurelie Reberac	aurelie.reberac@latmos.ipsl.fr
SERENA	Francesco Lazzarotto	francesco.lazzarotto@iaps.inaf.it
SIXS	Eero Esko	eero.esko@helsinki.fi
SIMBIO-SYS	Maria Teresa Capria Michele Zusi	mariateresa.capria@iaps.inaf.it zusi@na.astro.it
Science Ground Segment (SGS)	Mauro Casale Fernando Perez-Lopez Santa Martinez	Mauro.Casale@esa.int Fernando.Perez.Lopez@esa.int Santa.Martinez@esa.int
Science Archives Team (SAT)	Pedro Osuna Alan Macfarlane	Pedro.Osuna@esa.int Alan.Macfarlane@esa.int
Planetary Science Archive (PSA)	David Heather	David.Heather@esa.int
JAXA/ISAS SSOC	Iku Shinohara	iku@stp.isas.jaxa.jp

Table 23: BepiColombo Data Handling and Archiving Key Personnel

ANNEX D SUMMARY OF SCIENCE DATA PRODUCTS

A complete list of the science data products will be included in the table below once the descriptions in Chapter 3 are complete and consolidated.

Product Type	***Short Description***	***Data Producer***

Table 24: List of science data products

European Space Agency
Agence spatiale européenne

ANNEX E DATA VOLUME ESTIMATIONS

The data volume estimations will be included in the table below once the descriptions of the MPO science data products (section 3.3.2) are complete and consolidated.

Instrument	*Processing Level(s)*	*Estimated Data Volume*
BELA		
BERM		
ISA		
MERTIS		
MGNS		
MIXS		
MORE		
MPO-MAG		
PHEBUS		
SERENA		
SIMBIO-SYS		
SIXS		

Table 25: Science data volume estimations

ANNEX F DOCUMENTATION ROADMAP

The following figure illustrates all BepiColombo documents relevant for science data generation, validation and archiving activities. Documents have been grouped according to the SGS phases/activities.

For the complete list of SGS documentation, please see SGS Documentation Tree [RD.19].

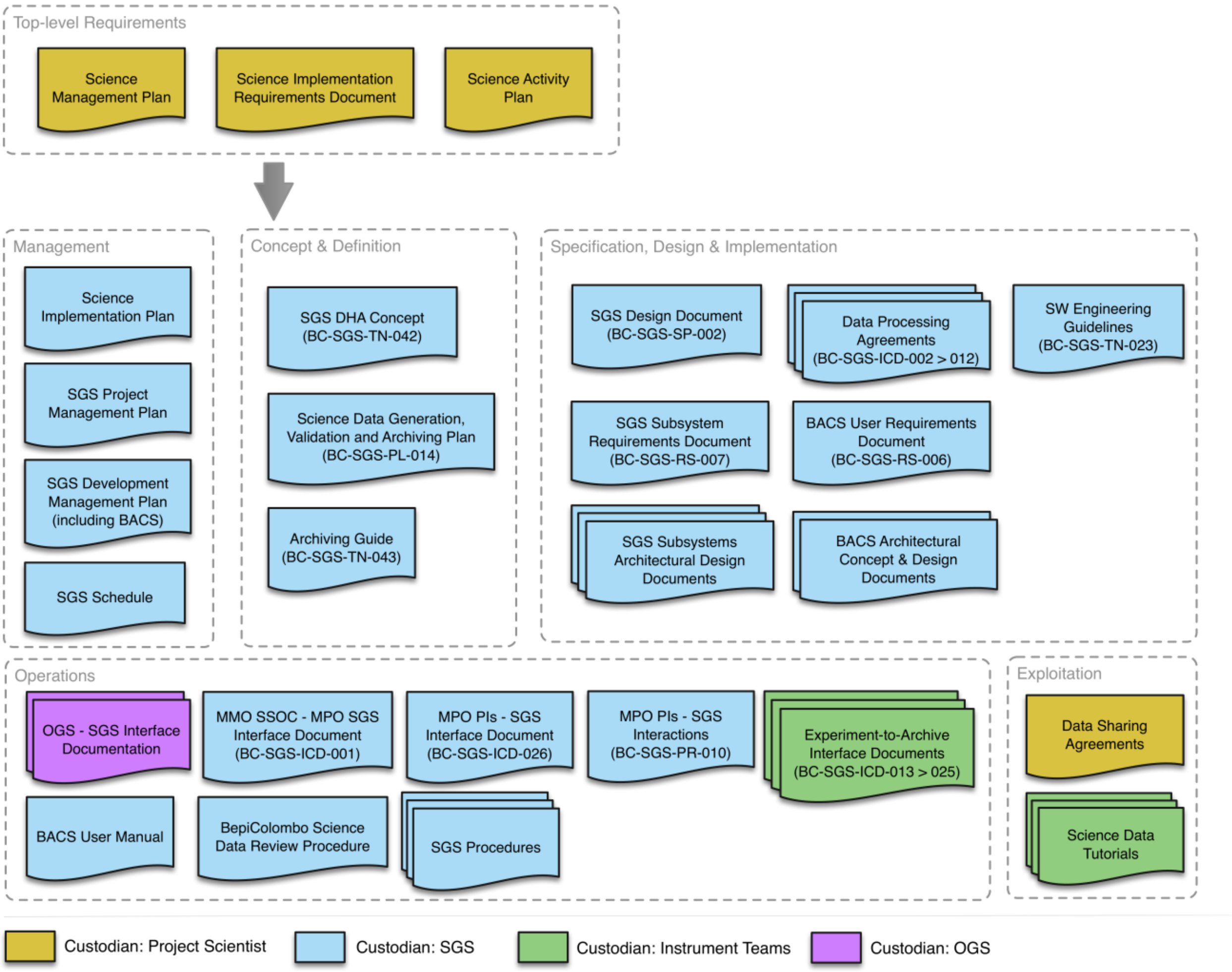

Figure 7: Documentation Roadmap

ANNEX G EAICD TEMPLATE

A template for the Experiment-to-Archive Interface Control Document (EAICD) is provided in a separate document, see “Annex F: BepiColombo EAICD Template” (with ref. BC-SGS-TPL-013). All BepiColombo EAICDs must follow this template.

END OF DOCUMENT