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MERCURY PLANETARY ORBITER (MPO)

SIXS Experiment-to-Archive ICD (EAICD)

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1 INTRODUCTION

1.1 Purpose and scope

This document describes the format and the content of the Solar Intensity X-ray and particle Spectrometer (SIXS) data as archived in the European Space Agency (ESA) Planetary Science Archive (PSA). It includes detailed descriptions of the data products and associated metadata, as well as the data generation, calibration, validation and analysis processes.

This EAICD is intended to provide enough information to enable users to understand the SIXS data and their organization. The users for whom this is intended are the scientists who will process and analyse the SIXS data.

The specifications described in this document apply to all SIXS products submitted to the archive, for all phases of the BepiColombo mission (i.e. near-earth commissioning, cruise, mercury commissioning and science phases). This document is expected to evolve throughout the mission lifetime.

1.2 Experiment-to-Archive ICD Schedule

This is version 1.9 of the SIXS EAICD. This document is expected to evolve throughout the mission lifetime. The schedule and scope of the pre-Launch versions of this document is as follows:

Issue/Revision	Date	Scope
D.1	25/07/2017	This draft is a very preliminary version of the document, produced by the SGS. It is mainly intended as a template to capture the archive data organisation and the list of science products as the pipeline is developed, for discussion and consolidation. Most sections are incomplete, with references to other documents until the details are consolidated. Details will be added as available/necessary. PDS label templates (in Excel and/or XML format) are used to document the format and content of the data products during the development phase; once consolidated, the information will be captured in this document. PDS label templates are developed and maintained by the Instrument Team with support from the SGS under the SGS version control system.
D.2		This version will include a complete description of the archive data organisation with detailed descriptions of all science products and associated information (i.e. calibration files, documentation, etc.) that will be generated and archived during the Cruise phase as well as their generation process. On-ground calibration activities and resulting data will be also described.
D.3		Minor updates to the previous draft, after consolidation of the data processing specifications and implementation. This version will include a list and detailed description of all “browse” products that will be generated during the Cruise phase.

Table 1: Experiment-to-Archive ICD (EAICD) Schedule

1.3 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] BC-SGS-PL-014, BepiColombo Science Data Generation, Validation and Archiving Plan
[AD.02] BC-SGS-TN-026, BepiColombo Archiving Guide
[AD.03] PDS4 Standards Reference (SR)
[AD.04] PDS4 Data Dictionary (DDDB)
[AD.05] PDS4 Information Model Specification (IM)

1.4 Reference Documents

[RD.01] BC-SGS-LI-014, SGS Glossary
[RD.02] PDS4 website: http://pds.nasa.gov/pds4/
[RD.03] BC-SGS-TN-042, BepiColombo Data Handling and Archiving Concept
[RD.04] BC-SGS-ICD-023, SIXS Pipeline Description Document
[RD.05] BC-SIX-UM-00001, SIXS User Manual (UM)
[RD.06] Huovelin et al. (2010), Planetary and Space Science, 58(1-2), 96-107, http://www.sciencedirect.com/science/article/pii/S0032063308004017
[RD.07] BC-SIX-PL-00014, BepiColombo SIXS Ground calibration plan of SIXS FM and FS X-ray detectors
[RD.08] BC-SIX-RP-00008, SIXS FM X-ray detector calibration report
[RD.09] Lehtolainen et al. (2014), Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 735, 496-511, https://www.sciencedirect.com/science/article/pii/S016890021301320X
[RD.10] BC-SIX-RP-00007, SIXS FS X-ray detector calibration report
[RD.11] BC-SIX-TN-00002, SIXS Radiation Sensitivity and Tolerance Analysis
[RD.12] BC-SIX-TR-02049, SIXS FS SU Electron Measurement Calibration
[RD.13] BC-SIX-TR-02050, SIXS FS SU Proton Measurement Calibration
[RD.14] Agostinelli et al. (2003), Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 506, 250-303, https://www.sciencedirect.com/science/article/pii/S0168900203013688
[RD.15] Arnaud et al. (2018), XSPEC - An X-Ray Spectral Fitting Package - Users' Guide, https://heasarc.gsfc.nasa.gov/xanadu/xspec/manual/manual.html
[RD.16] OGIP Calibration Memo CAL/GEN/92-002, The Calibration Requirements for Spectral Analysis (Definition of RMF and ARF file formats), 2007 Nov 1
[RD.17] OGIP Calibration Memo CAL/GEN/92-002a, The Calibration Requirements for Spectral Analysis Addendum: Changes log, 1998 Dec 21
[RD.18] OGIP Memo OGIP/92-007, The OGIP Spectral File Format, 2009 May 6
[RD.19] Heino (2016), Calibration and simulations of SIXS-P's response to energetic particles, Master's Thesis, University of Turku, Department of Physics and Astronomy

1.5 Abbreviations and Acronyms

Acronym	Explanation
AD	Analog-to-Digital
ARF	Ancillary Response File
ASW	Application SoftWare
BKG	BacKGround

Acronym	Explanation
BOA	BepiColombo Operational Archive
DN	Digital Number
DPU	Digital Processing Unit
EDDS	EGOS Data Dissemination System
EGOS	ESA Ground Operation System
ESA	European Space Agency
FDIR	Failure Detection Isolation and Recovery
FWHM	Full Width at Half Maximum
FM	Flight Model
FoV	Field-of-View
FS	Flight Spare
GF	Geometric Factor
GFTS	Generic File Transfer Service
HEASARC	High Energy Astrophysics Science Archive Research Center
HK	HouseKeeping
ICP	Interplanetary Cruise Phase
LID	Logical IDentifier
MCP	Mercury Commissioning Phase
MSP	Mercury Science Nominal and Extended Phase
MEB	MIXS Electronics Box
MIB	Mission Information Base
MIXS	Mercury Imaging X-ray Spectrometer
MPO	Mercury Planetary Orbiter
NASA	National Aeronautics and Space Administration
NECP	Near Earth Commissioning Phase
OGS	Operational Ground Segment
PDS	Planetary Data System
PI	Principal Investigator
PIN	Positive-Intrinsic-Negative diode
PSA	Planetary Science Archive
PSU	Power Supply Unit

Acronym	Explanation
QE	Quantum Efficiency
RF	Radio Frequency
RMF	Redistribution Matrix File
SGS	Science Ground Segment
SIXS	Solar Intensity X-ray and particle Spectrometer
SU	Sensor Unit
TC	TeleCommand

Table 2: Acronyms

See also BepiColombo Acronyms and Definitions, [RD.01].

2 INSTRUMENT DESCRIPTION

This section contains a high-level description of the SIXS instrument and its science objectives. Detailed description can be found in the referenced papers.

2.1 Mission and Instrument Overview

The Solar Intensity X-ray and particle Spectrometer (SIXS) on the BepiColombo Mercury Planetary Orbiter (MPO) will investigate the direct solar X-rays, and energetic protons and electrons which pass the Spacecraft on their way to the surface of Mercury.

SIXS consists of two detector subsystems. The X-ray detector system includes three identical detectors which measure the solar spectrum at 1–20 keV energy range, and their combined Field-of-View (FoV) covers 1/4 of the whole sky.

A major task for the SIXS instrument is the measurement of solar X-rays on the dayside of Mercury's surface to enable modelling of X-ray fluorescence and scattering on the planet's surface.

2.2 Science Objectives

The SIXS (**S**olar **I**ntensity **X**-ray and particle **S**pectrometer) experiment will monitor solar X-rays (SIXS-X) and energetic particles (SIXS-P). The X-ray data are mandatory for a fluorescence analysis of MIXS (**M**ercury **I**maging **X**-ray **S**pectrometer) spectra. Because the intensity and energy spectrum of both X-rays and energetic particles are highly variable, simultaneous operations of SIXS and MIXS is a strong requirement.

Scientific objectives for SIXS-X are to monitor the solar X-ray corona and solar flares, and to determine their temporal variability and spectral classification. Therefore, SIXS-X needs a clear view to the Sun as continuously as possible, whatever the spacecraft attitude is. The sensor contains three detectors, each having about 100° FoV and covering a spectral range of 1-20 keV with about 300 eV resolution. SIXS-P will monitor solar energetic electron and proton fluxes and their variability. The key scientific objective is to study the interaction of this radiation with Mercury's exosphere, magnetosphere and surface.

SIXS is a very important supporting instrument to MIXS, but SIXS can also be operated independently of MIXS (while the opposite is not true) as its observations will be desirable for other investigations where the observation of solar X-rays and energetic particles are important/necessary inputs. They include exospheric studies with SERENA and PHEBUS on MPO and most studies with the MMO payload. In addition, it is worth noting that the far-side X-ray observations of the Sun by SIXS can be useful to space weather studies at the Earth. For more details, see Huovelin et al. (2010) [RD.06].

2.3 Instrument Description

SIXS consists of two independent subsystems, SIXS-X and SIXS-P, packaged into a single sensor unit housing. The sensor unit is connected with serial data and power cables to the MIXS Electronics Box (MEB) that contains the digital processing unit and power supply interfaces to both MIXS and SIXS sensor units.

SIXS-X is the X-ray detector system. It includes three high-purity Si Positive-Intrinsic-Negative diode (PIN) detectors, which measure the X-ray flux and spectrum at 1-20 keV energy range. Their combined field of view covers about ¼ of the whole sky. Each detector's photodiode is hermetically packaged together with a thermistor and preamplifier front-end components as well as a thermoelectric Peltier cooler inside a steel cover with a Be entrance window as an X-ray filter. Each detector's effective area is limited with a gold aperture placed in front of the PIN inside the detector package. The detectors are multiplexed and only one detector is operated at a time.

SIXS-P is the particle detector system. It is a compact assembly of a cube shaped CsI(Tl) scintillator covered on five sides with thin Si PIN detectors. The sixth side of the scintillator is coupled to a Si PIN photodiode read-out. The system detects electrons in the range 50 keV to 3 MeV and protons in the range 0.33 to 30 MeV. The separate Si PIN detectors allow for a rough angular resolution over the combined field of view that covers about ½ of the whole sky. The scintillator and the surrounding Si detectors work in coincidence using the ΔE/E principle for particle identification. The detector assembly is covered with a collimator structure that determines the view cones of the detector system. It consists of alternating rings of Al and W over each Si PIN detector as well as thin foils of Be and Kapton that shield the detectors from thermal and electromagnetic environment as well as optical light.

More detailed technical description of SIXS is provided in Huovelin et al. (2010) [RD.06].

2.4 Operational Modes

System level

At system level, there are four different modes:

1. **System Off**

The Digital Processing Unit (DPU) box is not powered and all sensors are off. The instrument DPU can be switched on in all cases. After switch on, the instrument performs a boot phase and enters into a System Standby mode.

Data volume: 0

Power consumed: 0 W (max 9.8 W for non-op heaters)

2. **System Standby**

All sensors are in their respective Off modes. The DPU is on. This mode enables the Failure Detection Isolation and Recovery (FDIR) settings to be modified for other system modes. Parameters for the sensors cannot be updated. The FDIR is disabled in this mode so that the instrument can be started even in case of failure in the FDIR system.

Data volume: 10.5 bits/s

Power consumed: 7.7 W

3. **System Operational**

This mode allows the instrument operations by commanding the sensor sub-modes. The four different sensors (SIXS-X, SIXS-P, MIXS-T, MIXS-C) have each an independent set of sub-modes, which can be commanded. The FDIR is enabled according to the FDIR settings.

Data volume: Varies by each sensor sub-mode, in addition to the 10.5 bits/s generated by the DPU

Power consumed: Varies by each sensor sub-mode, in addition to the 7.7 W consumed by the MEB

4. **System Safe**

This mode is entered after DPU or PSU temperature anomaly detected by FDIR. The mode can be activated also with a telecommand (TC). All sensors are in their respective Off modes. FDIR is disabled.

Data volume: 0

Power consumed: 7.7 W

SIXS-X

SIXS-X application software (ASW) has five operating modes:

1. **SIXS-X ASW Off**

SIXS-X sensor unit (SU) is not powered.

Data volume: 0 bits/s

Power consumed: 0 W

2. **SIXS-X ASW Standby**

SIXS-X SU is powered. A detector firmware is not running. Only housekeeping (HK) data is transmitted. FDIR is enabled in this mode.

Data volume: 4.25 bits/s

Power consumed: 1.3-1.9 W

3. **SIXS-X ASW Annealing**

SIXS-X SU is annealing. Equal to Standby mode except that the annealing voltage is on. FDIR is enabled.

Data volume: 4.25 bits/s

Power consumed: 2.7-3.3 W

4. **SIXS-X ASW Science**

This is the normal operating mode of the SIXS-X SU. A detector firmware is running. Science and HK data are transmitted. FDIR is enabled.

Data volume: 293.35 bits/s

Power consumed: 1.3-3.3 W

5. **SIXS-X ASW Safe**

SIXS-X SU is switched off. In this mode only a restricted set of mode transitions (e.g. to Off mode) are allowed, but the set of allowed TCs is extended to cover also the low level TCs to allow debugging. FDIR is disabled.

Data volume: 4.25 bits/s

Power: 0 W

SIXS-P

SIXS-P application software (ASW) has seven operating modes:

1. **SIXS-P ASW Off**

SIXS-X SU is not powered.

Data volume: 0 bits/s

Power consumed: 0 W

2. **SIXS-P ASW Standby**

SIXS-P SU is powered, but not configured. Bias voltage is switched on. HK data is transmitted. FDIR is enabled.

Data volume: 8 bits/s

Power consumed: 1.3 W

3. **SIXS-P ASW Science 1**

This is the normal science operating mode in such a case when selective downlink data is disabled. Sensor unit hardware is configured to science mode. Science and HK data are transmitted. FDIR is enabled.

Data volume: 262.25 bits/s

Power consumed: 1.9-2.5 W

4. **SIXS-P ASW Science 2**

This is the normal science operating mode in such a case when selective downlink data is enabled. Sensor unit hardware is configured to science mode. Science data is transmitted in two packets. Selective downlink support data is similar to Science 1 mode data packet. Selective downlink data is an additional packet of spectrum data with higher sampling rate. HK data is transmitted. FDIR is enabled.

Data volume: 262.25 bits/s (SIXS-P selective downlink support data + HK)

1214.4 bits/s (SIXS-P selective downlink data)

Power consumed: 2.0-2.6 W

5. **SIXS-P ASW Diagnostic**

Used for monitoring the health, and especially the stability of the parameters of the amplification chains of the detectors. Sensor unit hardware is configured with the same parameters as in Science modes. Instead of normal science data, raw event samples are transmitted. HK data is transmitted. FDIR is enabled.

Data volume: ~587.0 bits/s

Power consumed: 2.0 W

6. **SIXS-P ASW Calibration**

Used for quick health checks of the detectors, when there is no time to gather statistics from real particle events. Sensor unit hardware is configured to the calibration mode. Test pulser is active. Raw event samples are transmitted instead of normal science data as in Diagnostic mode. HK data is transmitted. FDIR is enabled.

Data volume: ~587.0 bits/s

Power consumed: 2.0 W

7. **SIXS-P ASW Safe**

SIXS-P SU is switched off. In this mode only a restricted set of mode transitions (e.g. to Off mode) are allowed, but the set of allowed TCs is extended to cover also the low level TCs to allow debugging. FDIR is disabled.

Data volume: 8 bits/s

Power: 0 W

2.5 Calibration

2.5.1 On-ground Calibration

X-ray detectors

On-ground calibration of SIXS-X included the following tasks: determination of each detector’s energy resolution as a function of photon energy at different operation temperatures, determination of each detector’s sensitivity within the Field-of-View, characterization of each detectors’ dynamical range by measuring their effective areas and by analysis of the pile-up effect, measurements of the low energy thresholds of the detectors energy scales, a comparison calibration of the fluorescence line fluxes with the SMART-1 XSM flight spare (FS) detector, and the determination of the effects of temperature on each detector’s energy scale. The on-ground calibration plan is presented in BC-SIX-PL-00014 [RD.07]. The detailed description of the on-ground calibration procedures and results for the SIXS-X flight model (FM) detectors is provided in BC-SIX-RP-00008 [RD.08] and in Lehtolainen et al. (2014) [RD.08]. The on-ground calibration of the SIXS-X FS detectors followed the same procedure and the results are provided in BC-SIX-RP-00007 [RD.10].

The detectors beginning-of-life energy resolutions were determined by illuminating fluorescence sources with an X-ray beam and measuring the Full Width at Half Maximum (FWHM) of the spectral lines of the secondary radiation. The results were ~160 eV at 6 keV and about 195 eV at 10 keV for all X-ray detectors in both FM and FS sensor units. The spectral resolution of SIXS is therefore much better than the scientific requirement, which is 250 eV at 6 keV and 300 eV at 10 keV. The detectors are also expected to fulfil the scientific requirements on spectral resolution at the end of the mission based on the analysis of radiation effects on them (BC-SIX-TN-00002 [RD.11]).

The detectors sensitivities within their Field-of-View were determined by measuring the physical sizes of their apertures, by theoretical calculations about attenuation of X-ray radiation in the detector diodes and the X-ray filters, and by measuring the relative reduction of the signal from different viewing directions compared to the direction of the detectors optical axes. The data was compiled into 3D Field-of-View sensitivity maps of each detectors' effective area as functions of off-axis and roll angles as well as the photon energy. The effective areas also show that the detectors fulfil the scientific requirements on sensitivity. The upper limit of the dynamical range of SIXS-X is dictated by the pile-up. It is estimated by the detector sensitivity that maximum count rate encountered by SIXS-X during intense X-level flares is ~20000 cps. The pile-up effect of SIXS-X detectors was characterized by measuring a known signal at different intensities and calculating the pile-up fraction. It was shown that the amount of pile-up at 20000 cps is slightly below 4% in all SIXS-X detectors, which is estimated to be the practical upper limit of pile-up for reliable spectral analysis. The SIXS-X detectors therefore fulfil the scientific requirements on dynamical range.

The low energy thresholds of the detector's energy scales are determined by an adjustable software parameter. Its purpose is to filter out the low energy noise that is a feature of all semiconductor detectors. The lowest value of the low energy threshold with which the low energy noise is non-existent was found to be 0.3 – 0.5 keV depending on the detector and the temperature. The low energy noise therefore does not affect the science because the lower limit of the energy range of SIXS-X is 1 keV. SIXS-X detectors' energy scales are known to depend on the temperature of the read-out electronics. This effect was characterized during the on-ground calibration by observing the position of the spectral lines from the detectors' internal calibration sources at different temperatures (Lehtolainen et al., 2014) [RD.09]. The obtained data will be useful in interpolating the detectors' response functions during observations where the temperature is not stable.

As a conclusion the on-ground calibrations of the X-ray detectors of both SIXS FM and FS were completed successfully, and it was shown that the detectors fulfil their scientific performance requirements. The calibration data was compiled into 3D Field-of-View sensitivity arrays (off-axis angle, roll angle, energy), which together with the in-flight calibration data, housekeeping data from the SIXS instrument, and the position of the Sun in the Field-of-View enable generation of the redistribution matrix and ancillary response files, and the spectral analysis of the scientific data from SIXS-X.

Particle detector

On-ground calibrations of the particle detector were carried out at particle accelerator facilities in Finland and Germany [RD.19]. The calibration measurements were made separately for higher and lower energy protons and electrons. The SIXS-P on-ground calibration process and results are presented in detail in BC-SIX-TR-02049 [RD.12] for electrons and BC-SIX-TR-02050 [RD.13] for protons.

SIXS-P detector was irradiated from each side with monoenergetic beam of protons or electrons and the resulting energy loss of the particles to the side detectors and the core detector were recorded. This process was repeated with several beam energies. The effects of the beam incident angle and intensity to the recorded energy loss of the particles was also studied. The on-ground calibration results were compiled into a 2D look-up table, which is used to identify the particle species and energy for each event based on the energy loss into the side and core detectors.

In addition, the low energy noise thresholds, responses to temperatures of the read-out electronics and the detectors themselves, and the differences of the amplifiers of each detector were also characterized. This information was compiled into correction tables, which include correction factors and offsets to the AD conversion values. These offsets and factors are taken into account before conversion of the AD conversion values to the energy losses in each detector.

The SIXS-P on-ground calibration results were also compared with Geant4 [RD.14] simulations. The simulation model was validated with the on-ground calibration results. The simulation results were used to further clarify the effects of incident directions on the energy loss of particles in the detectors. This information was used to fine tune the edges of the particle species and energy channels in the look-up table.

2.5.2 In-flight Calibration

X-ray detectors

Each X-ray detector of SIXS contains an internal Ti coated ^{55}Fe calibration source to enable repeated characterization between and during the observations. This is necessary because the variation of the signal due to the variability of the environmental conditions and the gradual degradation of the detectors over time is of the same order of magnitude as the instrument's energy resolution. The calibration sources are located inside the detector casings, and therefore the calibration signal is visible at all times. It must therefore be reduced from the measured spectra during scientific observations. The calibration signal consists of the fluorescence lines of Mn (5.89 keV and 6.49 keV) and Ti (4.51 keV and 4.93 keV). With the planned launch date at the end of 2018 the activity of the calibration sources is such that the count rate of the strongest fluorescence line in the calibration spectrum will be ~20 cps at the end of the planned mission, which is sufficient for accurate determination of the energy scale and the energy resolution.

Each observation with SIXS-X begins and ends with an in-flight calibration period, which is a few minute measurement of the calibration spectrum when the Sun is not in the instrument's field-of-view. The positions of these spectral lines are used to determine the energy scale for each detector during that observation. In addition, the energy resolutions of the detectors are determined by fitting Gaussian functions to these spectral lines. This information is used to construct the redistribution matrices for that observation. The in-flight calibration data along with the field-of-view sensitivity information and the position of the Sun in the Field-of-View therefore contains all required information spectral analysis of the X-ray data from SIXS-X.

Both the energy scale and the energy resolution depend on environmental conditions. If these conditions were not stable during an observation, the energy scales and redistribution matrices are interpolated. The interpolation of the energy scales can be made more accurate with the ground calibration data on the effects of temperature on the energy scales.

Particle detector

The variation of the SIXS-P signal due to the environmental conditions is expected to be much smaller than the instrument's energy resolution. There is therefore no need for an in-flight calibration sources for SIXS-P. However, the amplifier chain of SIXS-P may degrade gradually over time during the mission, resulting in changes in the AD conversion values for a given signal. To correct these changes, SIXS-P contains a test pulser, which will insert a known signal into the amplifier chain, allowing updates to the side detectors' and the core detector's energy scales possible as needed. This in-flight calibration sequence will be performed as needed.

3 DATA GENERATION AND ARCHIVING PROCESS

The SIXS science products are produced under the responsibility of the SIXS Instrument Team in cooperation with the BepiColombo MPO Science Ground Segment (SGS). The data generation, analysis and archiving processes are described in this section.

Science data resulting from the SIXS instrument are made available to the scientific community through ESA´s Planetary Science Archive (PSA) following the policies described in the BepiColombo Archiving Plan [AD.01].

3.1 Overview of the Science Data Flow

This section provides an overview of the data flow for the SIXS data, from on-board acquisition by the SIXS instrument through to ingestion into the ESA's Planetary Science Archive (PSA).

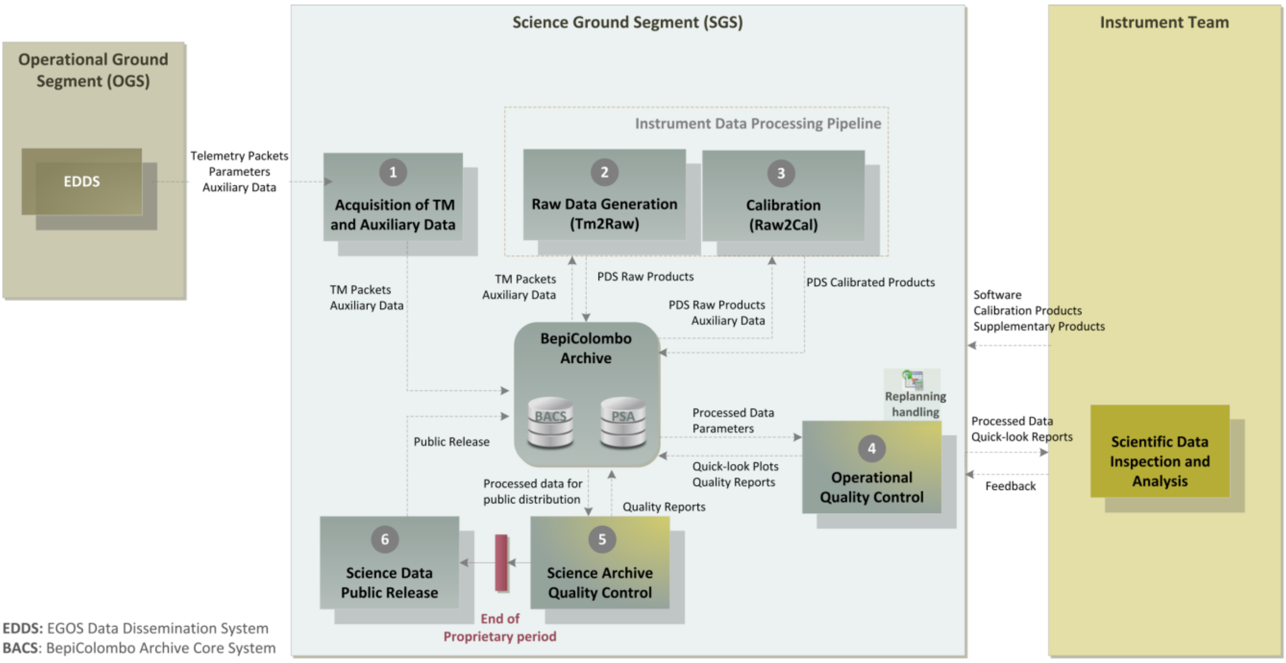

Figure 1: Science Data Flow

1) *Acquisition of Telemetry and Auxiliary Data.* Real-time telemetry received on-ground from the MPO spacecraft is relayed from the ground stations to the Operational Ground Segment (OGS) at ESOC during ground station contacts. The MPO spacecraft has two radio-frequency (RF) bands for downlink (X-band and Ka-band). The X-band channel is used to return near real-time non-science telemetry, mostly for spacecraft health, as well as high-priority science data; telemetry is transmitted packet-by-packet. The Ka-band channel is used to return nominal science data; telemetry is transmitted as a file, using the Generic File Transfer Service (GFTS).

   During each ground station contact, the OGS processes all telemetry frames acquired via X-band into packets, containing instrument and spacecraft data as originally generated on-board, and stores all science telemetry files received via Ka-band as files. Telemetry packets and files are made available in the EGOS Data Dissemination System (EDDS) (EGOS: ESA Ground Operation System) along with status and auxiliary information generated on-ground by the OGS.

Immediately after the data becomes available in the EDDS, telemetry packets, Ka-band telemetry files, housekeeping parameters and any additional information relevant for data processing and analysis (e.g. spacecraft trajectory, attitude and time correlation packets) are retrieved by the Science Ground Segment (SGS) via the EDDS and stored in the BepiColombo Operational Archive (BOA), for further processing and long-term preservation. Ka-band telemetry files are decomposed into packets as part of this process.

2) *Raw Data Generation*. Telemetry packets resulting from all instruments are systematically converted into Planetary Data System (PDS) raw data products (un-calibrated) by the SGS. Additionally, PDS raw products may be converted to partially processed products (e.g. converted to physical/engineering units) by either the principal investigator (PI) teams or by the SGS. For the SIXS instrument, the TM2RAW pipeline is run by SGS and performs the data conversion up to engineering units (equivalent of TM2RAW + RAW2ENG usual pipeline split).

3) *Calibrated Data Generation*. PDS calibrated products are generated based on the best current calibration factors and analysis routines, and using as input the PDS raw products generated in the previous step. This is done by either the SGS (for data from SIXS, ISA, SIMBIO-SYS and the radiation monitor, BERM) or by the PI team, with a prime-redundant configuration, i.e. the prime calibration runs at the PI team site while the SGS hosts a backup of the calibration software (for redundancy). When generated by the PI team, calibrated products are routinely delivered to the SGS for ingestion into the archive. Delivery packages are prepared with a software tool provided by the SGS that runs a basic validation on the products to check their compliance with PDS4.

4) *Higher-level Data Generation*. Derived data products are generated by the PI teams, and delivered to the SGS only when the scientific processing is complete.

   All science archive products resulting from BepiColombo comply with version 4 of the Planetary Data System (PDS) standards, a.k.a. PDS4, as specified in the BepiColombo Archiving Guide [AD.02]. An overview of the SIXS archive products can be found in section 3.2.

   A detailed description of the data generation, calibration and analysis process for the SIXS data can be found in section 3.3.

5) *Data transfer to the Archive*. All PDS products generated by the SGS or delivered by the PI teams to the SGS are validated for PDS4 compliance (using the NASA's PDS4 validate tool). Once validated, the products are packaged into a delivery package and transferred to the ESA's Planetary Science Archive (PSA) for ingestion.

   As part of the PSA ingestion process, science products are automatically organised into the so-called PDS4 bundles. For BepiColombo, there is one mission bundle and eleven instrument bundles, one per MPO instrument. Bundles grow incrementally as new (or updated) products are delivered to the PSA.

   The mission bundle contains products generated and maintained by the SGS with information of the BepiColombo mission. This includes all mission level supplementary products required in the instrument bundles to comply with PDS4 (e.g. context products, XML schemas, SPICE kernels).

   Instrument bundles contain science data along with supplementary information specific to an instrument. All bundles are sub-divided into collections. There is one collection for each data processing level plus supplementary collections for calibration, browse, schema, context, documentation etc.

6) *Operational Quality Control*. Science quick-look products are generated from the PDS4 raw, partially calibrated and calibrated products, and are made available through a dedicated web-based interface. Using this interface, SGS and PI teams monitor the deviations between the planned and the executed observations, check the instrument and spacecraft health, provide a first assessment of the generated science data products. The interface is also aimed at defining reduced data sets to be downlinked via the Selective Downlink if applicable. PI teams feedback the result of this analysis to the SGS. In addition, SGS performs regular completeness and integrity checks on the data.

7) *Science Data Quality Control*. Archive products are validated through routine use. PI teams routinely assess archive products as part of the operational quality control. In addition, PI teams use archive products for their analysis throughout the mission lifetime. This enables rapid detection and correction of issues in the archive data. In addition, and prior to the release of the data to the public, formal science reviews are organised by the SGS, in coordination with the Project Scientist.

8) *Science Data Public Release*. All science data resulting from BepiColombo is subject to a maximum proprietary period of six months after which the data is made publicly available through the PSA. In routine operations it is expected that PDS4 data processed at least up to calibrated level will be available to the public after the six-month period. Explicit permission may be given by a PI to reduce this period.

3.2 Overview of the SIXS Archive Products

The SIXS archive products consist of housekeeping data, SIXS-X science data and SIXS-P science data. Housekeeping data product contains MIXS/SIXS DPU housekeeping, SIXS-X housekeeping and SIXS-P housekeeping data. SIXS-X science data contains spectra and flux data as well as the ancillary response file (ARF), redistribution matrix file (RMF) and background (BKG) data necessary for spectrum fitting using the XSPEC software [RD.15]. SIXS-P science data contains electron and proton spectra, as well as Pulse height and Counting Rate data.

3.3 Data Generation, Calibration and Analysis

The housekeeping data is calibrated when the telemetry data is converted from binary to FITS format. The numerical and textual calibrations used in the Mission Information Base (MIB) are used. The cap.dat and txp.dat files containing the calibrations are included in the pipeline.

SIXS-X data are analysed with the XSPEC spectral fitting software. XSPEC is part of National Aeronautics and Space Administration's (NASA) High Energy Astrophysics Science Archive Research Center (HEASARC) software collection and is available at https://heasarc.gsfc.nasa.gov/docs/xanadu/xspec/. The inputs needed by the software are the spectrum, instrument response (ARF+RMF), background (BKG) and a model. The SIXS pipeline produces all inputs except the model. Model selection is done by the scientist doing the spectrum fitting. The XSPEC manual available at https://heasarc.gsfc.nasa.gov/xanadu/xspec/manual/XspecManual.html provides instructions and examples of the use of the software package.

Calibration spectra are recorded on the night side for five minutes for each detector before and after recording solar spectra on the day side. Based on these calibration spectra, energy range and resolution can be calculated.

Energy range and resolution of calibration spectra is calculated by fitting Gaussians on the peaks generated by the calibration sources in the detectors. The energies of these calibration peaks are known and the energy range is calculated from the positions of the fitted Gaussians. The energy resolution is calculated from the width of the fitted Gaussians.

The instrument response consists of ancillary response (ARF) and redistribution matrix (RMF). The ancillary response (section 4.2.3) contains the effective area of the detector for each spectrum as a function of energy. The effective area depends on the detectors quantum efficiency (QE), the photon energy and the position of the target in the detector Field-of-View.

The quantum efficiency of the detectors as a function of energy was calculated based on the instrument dimensions and materials. The on-axis sensitive area of each detector was measured from scanning electron microscope images and the detectors Field-of-View sensitivity was measured during ground calibrations. These were combined to produce the effective area curves. The resulting tables containing the curves as functions of roll and off axis angles are included in the pipeline. The correct curve is selected from the table based on the off-axis and roll angles and rebinned to fit the spectrums energy range. While the ancillary response depends on the detector, the ARF file contains the response for each separate spectra allowing the responses of all detectors to be included in a single file.

The redistribution matrix (section 4.2.3) contains the probabilities at which incoming photons of given energy will be detected in a certain spectrum channel. The redistribution matrix is calculated based on the energy resolution of the spectrum. The energy resolution is slightly different for each detector and slowly gets worse as the detectors age. The RMF file contains the redistribution for each detector channel and the file format is fixed and does not allow for including multiple detectors in a single file which is why separate files are produced for each detector.

The background (BKG) (section 4.2.3) is the calibration peaks which need to be removed from the solar spectra. Like the ARF the BKG file contains the background for each separate spectra allowing the backgrounds of all detectors to be included in a single file.

For the particle data, offset, temperature and amplification correction is done on board. It is possible to update the FPGA tables controlling these corrections, but this requires patching of the SIXS on-board software.

Calibration inputs for SIXS-P used in the pipeline are the geometric factor which is derived from Geant4 [RD.14] simulations and the energy ranges which are derived from ground calibrations (section 2.5.1). Both inputs are hard coded in the pipeline.

It is possible to adjust the energy ranges of both electron and proton spectra during flight by updating the SIXS-P look up table that controls the population of the spectra. This requires patching the SIXS on-board software.

For the particle spectra the differential flux is calculated for all spectrum channels. The differential flux is calculated by first dividing the counts per channel with the integration time. The resulting counting rate is then divided by the product of the geometric factor and the nominal width of the energy channel in question.

3.4 Science Data Quality Control

This section describes the different processes by which the archive data products are validated.

3.4.1 Validation

Prior to the delivery of the data to the archive, every data product is validated to check that it conforms to a basic set of requirements, as defined in the BepiColombo Archiving Guide [AD.02]. This is done using the NASA's PDS4 validate tool, and a set of XML Schema and Schematron files.

In addition, the SGS performs completeness and integrity checks on the SIXS science data to ensure that they comply with the specifications described in this EAICD. Visual inspection is used as necessary to check the content.

3.4.2 Instrument Team Validation

In parallel to SGS archive validation activities, PI teams routinely assess archive products as part of the operational quality control. In addition, PI teams use archive products for their analysis throughout the mission lifetime. This enables rapid detection and correction of issues in the archive data.

3.4.3 Science Reviews

Formal science reviews of the data will be organised by the SGS, in coordination with the Project Scientist. These are the so-called Peer Reviews. The Peer Review committee will include independent planetary scientists knowledgeable in each discipline to assess the quality of the data against well-defined scientific criteria. A preliminary schedule of the reviews can be found in the BepiColombo Archiving Plan [AD.01]. Additional review will be organised as necessary.

There will be a preliminary review approximately 2 months before Launch and 2 months prior to the start of the science phase. This review will contain sample data and documentation in the format of the final archived data set. The sample data will be produced using datasets from the flight instrument checkout activities that differ from the final data set only in specific values and sizes. Data formats and data processing and archiving methods are identical.

4 DATA ORGANISATION AND CONTENTS

4.1 Format and Conventions

SIXS science data are compatible with version 4 of the NASAs Planetary Data System (PDS) standards, so-called PDS4 [RD.02], and follow the organisation, format, content and documentation requirements described in the BepiColombo Archiving Guide [AD.02].

All data from the SIXS instrument for the entire mission is stored in a top-level structure (root directory) called bundle. This bundle is stored in the PSA as a single entity.

The bundle is subdivided into a set of collections (sub-directories) aiming to separate different types of data and information into an easy-to-navigate manner, so the bundle contains separate collections for instrument science data, calibration products, documentation, etc. For the instrument science data, there are separate collections for each processing level and this is standardised by PDS4 to four levels: raw, partially processed, calibrated and derived.

The structure of the bundle is outlined in Figure 2.

Details of the structure and content of the SIXS bundle are provided in the following sections.

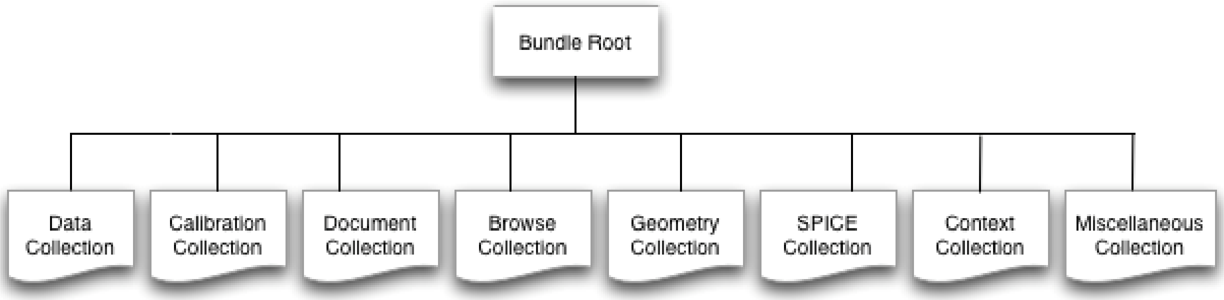

Figure 2: PDS4 bundle structure

4.1.1 Logical Identifiers Formation

Bundle and collection logical identifiers are as indicated in Table **6** and Table 7. General conventions can be found in section 3 of the BepiColombo Archiving Guide [AD.02].

In addition to the general conventions SIXS uses the following logical identifier (LID) **<descriptor>** definitions:

Descriptor	***Description***
arf	SIXS-X ancillary response file data
bkg	SIXS-X background data
rmf1	SIXS-X detector 1 redistribution matrix file data
rmf2	SIXS-X detector 2 redistribution matrix file data
rfm3	SIXS-X detector 2 redistribution matrix file data
spectra	SIXS-X and SIXS-P spectrum data

Descriptor	*Description*
hrspectra	SIXS-P high time resolution spectrum data
diagnostic	SIXS-P diagnostic data
ground	ground calibration data

Table 3: SIXS LID descriptors

4.1.2 Data Directory Naming Convention

General conventions can be found in section 3.2 of the BepiColombo Archiving Guide [AD.02].

In addition to the general conventions SIXS uses the following directory names:

Directory	*Description*
hk	Housekeeping data; DPU, SIXS-P and SIXS-X
sixs-x	Other SIXS-X data
sixs-p	Other SIXS-P data

Table 4: SIXS directory names

4.1.3 File Naming Convention

General conventions can be found in section 3.3 of the BepiColombo Archiving Guide [AD.02].

In addition to the general conventions SIXS uses the following file name **<descriptor>** definitions:

Descriptor	*Description*
arf	SIXS-X ancillary response file data
bkg	SIXS-X background data
rmf1	SIXS-X detector 1 redistribution matrix file data
rmf2	SIXS-X detector 2 redistribution matrix file data
rfm3	SIXS-X detector 2 redistribution matrix file data
spectra	SIXS-X and SIXS-P spectrum data
hrspectra	SIXS-P high time resolution spectrum data
diagnostic	SIXS-P diagnostic data
ground	ground calibration data

Table 5: SIXS file name descriptors

4.2 Bundle Content and Structure

The complete set of SIXS data is archived in one single instrument bundle (root directory). A top-level description of the bundle is provided below. A more detailed description of its contents and format is provided in the following sub-sections.

Bundle Title	***Bundle Logical Identifier (LID)***	***Description***
SIXS instrument bundle	urn:esa:psa:bc_mpo_sixs	This bundle contains the data collected by the Solar Intensity X-ray and particle Spectrometer (SIXS) instrument on-board the BepiColombo Mercury Planetary Orbiter (MPO) spacecraft, along with the documents and other information necessary for the interpretation of the data.

Table 6: SIXS instrument bundle

The following files are contained in the root directory of the bundle:

- bundle_bc_mpo_sixs.xml (*this is an inventory file for the bundle)*
- readme_bc_mpo_sixs.txt *(this is a README file for the bundle; it contains a table of contents)*

Inside the bundle, the data are organised in a directory structure as follows:

Directory Name	***Collection Logical Identifier (LID)***	***Description***
data_raw	urn:esa:psa:bc_mpo_sixs:data_raw	SIXS-X and SIXS-P spectrum and housekeeping products; units are digital numbers (DNs), no conversion applied. Products are FITS files with corresponding XML label. See section 4.2.1.
data_calibrated	urn:esa:psa:bc_mpo_sixs:data_calibrated	SIXS-X and SIXS-P spectra and housekeeping products, in engineering/physical units. Products are FITS files with corresponding XML label. See section 4.2.2.
calibration_partially _processed	urn:esa:psa:bc_mpo_sixs:calibration_partially _processed	SIXS-X calibration files (Calibration spectra, Ancillary Response Files (ARF), Redistribution Matrix Files (RMF) and Background spectra. Calibration files are compatible with XSPEC. SIXS-P calibration mode spectra. See section 4.2.3.
browse_calibrated	urn:esa:psa:bc_mpo_sixs:browse_calibrated	Browse products are generated for Calibrated SIXS-X and SIXS-P spectrum product. See section 4.2.5.
document	urn:esa:psa:bc_mpo_sixs:document	Documents related to the bundle; necessary for the use and interpretation of the data. See section 4.2.6.

Directory Name	***Collection Logical Identifier (LID)***	***Description***
context (S)	urn:esa:psa:bc:context	Text files describing the agency, mission, spacecraft, instrument and targets. These files refer to the full descriptions in the document collection.
spice_kernels (S)	urn:esa:psa:bc:spice_kernels	SPICE kernels
xml_schema (S)	urn:esa:psa:bc:xml_schema	XML Schemas used in the bundle.

Table 7: SIXS collections

(S) This is a "secondary member" collection i.e. this is a collection associated to the bundle by reference to a collection in the mission bundle (see Mission Bundle details in [AD.02]). Products inside this collection are prepared and maintained by the SGS, and are not part of instrument data deliveries to the SGS. For completeness, this collection is included in the instrument bundle when accessed and downloaded from the PSA.

4.2.1 Raw Data directory (data_raw)

The structure of the raw data collection is as follows:

data_raw/
- collection_data_raw.xml
- collection_data_raw.csv
- <mission_phase>/
    - hk/
    - sixs-p/
    - sixs-x/

Where <mission_phase> is:
- near-earth: Near Earth Commissioning Phase (NECP)
- cruise: Interplanetary Cruise phase (ICP)
    - vgaN: Venus Gravity Assist, with N=1-2
    - mgaN: Mercury Gravity Assist, with N=1-6
- commissioning: Mercury Commissioning Phase (MCP)
- science: Mercury Science Nominal and Extended Phase (MSP)

The sixs-x, sixs-p and hk directories are further sub-divided in months or range of orbits:
- <YYYYMM>/ (during NEC, Cruise and Mercury commissioning phases)
- <ORBIT_NNNNN_MMMMM>/ (used during the Mercury Science Phase)

Where YYYYMM is year and month, NNNNN start orbit and MMMMM end orbit.

The lowest level sub-directories contain the following types of data products:

Directory Name	***File Naming Convention***	***Description***
hk	six_raw_hk_<YYYYMMDD>.xml/.fits six_raw_hk_<NNNNN>.xml/.fits six_raw_hk_sixs-p_<YYYYMMDD>.xml/.fits six_raw_hk_sixs-p_<NNNNN>.xml/.fits six_raw_hk_sixs-x_<YYYYMMDD>.xml/.fits six_raw_hk_sixs-x_<NNNNN>.xml/.fits	Housekeeping data products; DPU, SIXS-P and SIXS-X housekeeping parameters See sections 5.2.1 - 5.2.3
sixs-p	six_raw_sc_sixs-p_spectra_<YYYYMMDD>.xml/.fits six_raw_sc_sixs-p_spectra_<NNNNN>.xml/.fits six_raw_sc_sixs-p_hrspectra_<YYYYMMDD>.xml/.fits six_raw_sc_sixs-p_hrspectra_<NNNNN>.xml/.fits six_raw_sc_sixs-p_diagnostic_<YYYYMMDD>.xml/.fits six_raw_sc_sixs-p_diagnostic_<NNNNN>.xml/.fits	SIXS-P nominal, high-resolution (hr) and diagnostic spectrum, flux, pulse height and counting rate data (raw); Include geometry, UTC timestamps and relevant HK. See sections 5.2.4 - 5.2.6.
sixs-x	six_raw_sc_sixs-x_spectra_<YYYYMMDD>.xml/.fits six_raw_sc_sixs-x_spectra_<NNNNN>.xml/.fits	SIXS-X spectrum and flux data (raw); Include geometry, UTC timestamps and relevant HK. See section 5.2.7.

Table 8: SIXS raw data product types

Where:

<YYYYMMDD>: date of the measurements in the product (used during NEC and Cruise)
<NNNNN>: orbit number of the first measurement in the product (used at Mercury)

4.2.2 Calibrated Data directory (data_calibrated)

The structure of the calibrated data collection is as follows:

data_calibrated/
- collection_data_calibrated.xml
- collection_data_calibrated.csv
- <mission_phase>/
  - hk/
  - sixs-p/
  - sixs-x/

Where <mission_phase> is defined as in section 4.2.1.

The sixs-x, sixs-p and hk directories are further sub-divided in months or range of orbits as follows:
- <YYYYMM>/ (during NEC, Cruise and Mercury commissioning phases)
- <ORBIT_NNNNN_MMMMM>/ (used during the Mercury Science Phase)

Where YYYYMM is year and month, NNNNN start orbit and MMMMM end orbit.

The lowest level sub-directories contain the following types of data products:

Directory Name	*File Naming Convention*	*Description*
hk	six_cal_hk_<YYYYMMDD>.xml/.fits six_cal_hk_<NNNNN>.xml/.fits six_cal_hk_sixs-p_<YYYYMMDD>.xml/.fits six_cal_hk_sixs-p_<NNNNN>.xml/.fits six_cal_hk_sixs-x_<YYYYMMDD>.xml/.fits six_cal_hk_sixs-x_<NNNNN>.xml/.fits	Housekeeping data products; DPU, SIXS-P and SIXS-X housekeeping parameters See sections 5.3.1 - 5.3.3
sixs-p	six_cal_sc_sixs-p_spectra_<YYYYMMDD>.xml/.fits six_cal_sc_sixs-p_spectra_<NNNNN>.xml/.fits six_cal_sc_sixs-p_hrspectra_<YYYYMMDD>.xml/.fits six_cal_sc_sixs-p_hrspectra_<NNNNN>.xml/.fits six_cal_sc_sixs-p_diagnostic_<YYYYMMDD>.xml/.fits six_cal_sc_sixs-p_diagnostic_<NNNNN>.xml/.fits	SIXS-P nominal and high-resolution (hr) and diagnostic spectrum, flux, pulse height and science mode count rates data (calibrated); Include geometry, UTC timestamps and relevant HK See sections 5.3.4 - 5.3.6
sixs-x	six_cal_sc_sixs-x_spectra_<YYYYMMDD>.xml/.fits six_cal_sc_sixs-x_spectra_<NNNNN>.xml/.fits	SIXS-X spectrum and flux data (calibrated); Include geometry, UTC timestamps and relevant HK See section 5.3.7

Table 9: SIXS calibrated data products

Where:

<YYYYMMDD>: date of the measurements in the product (used during NEC and Cruise)
<NNNNN>: orbit number of the first measurement in the product (used at Mercury)

4.2.3 Calibration directory (calibration_partially_processed)

The structure of the calibration collection is as follows:

calibration_partially_processed/
- collection_calibration_partially_processed.xml
- collection_calibration_partially_processed.csv
- <mission_phase>/
  - sixs-p/
  - sixs-x/

Where <mission_phase> is defined as in section 4.2.1.

The sixs-p and sixs-x directories are further sub-divided in months or range of orbits as follows:
- <YYYYMM>/ (during NEC, Cruise and Mercury commissioning phases)
- <ORBIT_NNNNN_MMMMM>/ (used during the Mercury Science Phase)

Where YYYYMM is year and month, NNNNN start orbit and MMMMM end orbit.

The lowest level sub-directories contain the following types of data products:

Directory Name	***File Naming Convention***	***Description***
sixs-p	six_calib_sixs-p_spectra_<YYYYMMDD>.xml/.fits six_calib_sixs-p_spectra_<NNNNN>.xml/.fits	Calibration spectra contain spectra recorded in Calibration mode See section 5.4.1
sixs-x	six_calib_sixs-x_arf_<YYYYMMDD>.xml/.fits six_calib_sixs-x_arf_<NNNNN>.xml/.fits six_calib_sixs-x_bkg_<YYYYMMDD>.xml/.fits six_calib_sixs-x_bkg_<NNNNN>.xml/.fits six_calib_sixs-x_rmf[1-3]_<YYYYMMDD>.xml/.fits six_calib_sixs-x_rmf[1-3]_<NNNNN>.xml/.fits six_calib_sixs-x_spectra_<YYYYMMDD>.xml/.fits six_calib_sixs-x_spectra_<NNNNN>.xml/.fits	Ancillary Response Files (ARF) contain effective area Background files contain model of the instrument background generated by the calibration sources Redistribution Matrix Files (RMF) contain photon energy redistribution probabilities for each SIXS-X detector (1-3) Calibration spectra contain calibration spectra recorded when the Sun is outside the field of view of the instrument See sections 5.4.2 - 5.4.5

Table 10: SIXS calibration data products

Where:

<YYYYMMDD>: date of the measurements in the product (used during NEC and Cruise)
<NNNNN>: orbit number of the first measurement in the product (used at Mercury)

4.2.4 Ground calibration directory (calibration_files)

SIXS ground calibration products have not been generated at this time. The following products are planned to be made based on the ground calibrations done with the SIXS instrument [RD.09] [RD.19].

The structure of the calibration collection is as follows:

calibration_files/
- collection_calibration_files.xml
- collection_calibration_files.csv
- sixs-x/

The lowest level sub-directories contain the following types of data products:

Directory Name	*File Naming Convention*	*Description*
sixs-x	six_calib_ground.xml/.fits	SIXS-X ground calibration scans for field-of-view sensitivity with different off-axis and roll angles using an X-ray tube source.
sixs-x	six_calib_ground_reference.xml/.fits	SIXS-X reference spectra without X-ray tube source only containing the signal from the internal calibration source.

Table 11: SIXS ground calibration data products

4.2.5 Browse directory (browse_calibrated)

The structure of the browse collection maps the structure of the data collections:

browse_calibrated/

- collection_browse_calibrated.xml
- collection_browse_calibrated.csv
- <mission_phase>/
  - sixs-p/
  - sixs-x/

Where <mission_phase> is defined as in section 4.2.1.

The sixs-p and sixs-x directories are further sub-divided in months or range of orbits as follows:

- <YYYYMM>/ (during NEC, Cruise and Mercury commissioning phases)
- <ORBIT_NNNNN_MMMMM>/ (used during the Mercury Science Phase)

Where YYYYMM is year and month, NNNNN start orbit and MMMMM end orbit.

These lowest level sub-directories contain the following types of data products:

Directory Name	***File Naming Convention***	***Description***
sixs-p	six_cal_browse_sixs-p_spectra_<YYYYMMDD>.xml/.jpg six_cal_browse_sixs-p_spectra_<NNNNN>.xml/.jpg six_cal_browse_sixs-p_hrspectra_<YYYYMMDD>.xml/.jpg six_cal_browse_sixs-p_hrspectra_<NNNNN>.xml/.jpg six_cal_browse_sixs-p_diagnostic_<YYYYMMDD>.xml/.jpg six_cal_browse_sixs-p_diagnostic_<NNNNN>.xml/.jpg	Plots showing total electron and proton counts for spectra over the observation period and proton and electron fluxes for the spectrum with the highest total counts.
sixs-x	six_cal_browse_sixs-x_spectra_<YYYYMMDD>.xml/.jpg six_cal_browse_sixs-x_spectra_<NNNNN>.xml/.jpg	Plot showing total counts and off-axis angle for spectra over the observation period and the raw spectrum with the highest total counts.

Table 12: SIXS browse products

Where:

<YYYYMMDD>: date of the measurements in the product (used during NEC and Cruise)
<NNNNN>: orbit number of the first measurement in the product (used at Mercury)

4.2.6 Document directory (document)

The structure of the raw data collection is as follows:

document/
- collection_document.xml
- collection_document.csv
- < Documents; see table below >

Document	***Description***
BC-SIX-IF-00003_SIXS_EAICD.pdf/.xml	This document
BC-SIX-RP-00007.pdf/.xml	SIXS FS X-ray Detector Calibration Report
BC-SIX-RP-00008.pdf/.xml	SIXS FM X-ray Detector Calibration Report
BC-SIX-TN-02047.pdf/.xml	Simulations of SIXS-P FM model
Heino_2016.pdf/.xml	Heino, E., 2016, "Calibration and simulations of SIXS-P's response to energetic particles", Master's Thesis, University of Turku, http://www.doria.fi/handle/10024/125471
Huovelin_2005.pdf/.xml	Huovelin, J., Grande, M., Fraser, G., et al., 2005,"SIXS, the Solar Intensity X-ray and particle Spectrometer for BepiColombo", EGU05-A-08003; PS1.6-1MO4O-001, p. 109, also ISSN: 1029-7006 (CD-ROM)
Vainio_2005.pdf/.xml	Vainio, R., Huovelin, J., Grande, M., Fraser, G., et al., 2005,"Energetic charged particle measurements by SIXS on-board BepiColombo MPO", EGU05-A-06714; PS1.6-1TU1P-0495, p. 202, also ISSN: 1029-7006 (CD-ROM)
Ahoranta_2009.pdf/.xml	J. Ahoranta, M. Uunila, J. Huovelin, H. Andersson, R. Vainio, A. Virtanen and H. Kettunen, Radiation hardness studies of CdTe and HgI2 for the SIXS particle detector on-board the BepiColombo spacecraft, 2009, Nuclear Inst. and Methods in Physics Research, A 605 (2009), pp. 344-349
Huovelin_2010.pdf/.xml	Huovelin, J., Vainio, R., Andersson, H., Valtonen, E., Alha, L., Mälkki, A., Grande, M., Fraser, G.W.. Kato, M., Koskinen, H., Muinonen, K., Näränen, J., Schmidt, W., Syrjäsuo, M., Anttila, M., Vihavainen, T., Kiuru, E., Roos, M., Peltonen, J.. Lehti, J., Talvioja, M., Portin, P., Prydderch, M., 2010, Solar Intensity X-ray and particle Spectrometer (SIXS), Planetary and Space Science, Vol. 58,Iss. 1-2, p. 96-107, doi: 10.1016/j.pss.2008.11.007
Lehtolainen_2011.pdf/.xml	Lehtolainen, A., Huovelin, J., Alha, L., Tikkanen, T., 2011, Estimates of in-flight calibration source activities for the SIXS X-ray detectors on board BepiColombo, Nuclear Instruments & Methods in Physics Research. Section A, Volume 636, Issue1, p. 48-60, DOI: 10.1016/j.nima.2011.01.026
Huovelin_2011.pdf/.xml	Huovelin, J., Genzer Maria, and the SIXS team, 2011, An Introduction to Solar Intensity and particle Spectrometer (SIXS) for BepiColombo, Geophysical Research Abstracts, Vol. 13, EGU2011-14094

Document	***Description***
Andersson_2013.pdf/.xml	H. Andersson, K. Kuparinen, J. Lehti, J. Saari, E. Valtonen, A. Lehtolainen, L. Alha, J. Huovelin, R. Vainio, 2013, Detector developments for the SIXS instrument on BepiColombo, NP02-119, Poster presented at the 2013 IEEE Nuclear Science Symposium, Seoul, Korea.
Lehtolainen_2014.pdf/.xml	Lehtolainen, A., Alha, L., Huovelin, J., Moissl, R., Korpela, S., Andersson, H., Kuparinen, K., 2014, Ground calibrations of the Solar Intensity X-ray Spectrometer (SIXS) on board BepiColombo, Nuclear Instruments & Methods in Physics Research A, 735 (2014), 496-511, DOI: 10.1016/j.nima.2013.10.006

Table 13: SIXS documents

5 DATA PRODUCT FORMATS

PDS label templates (in Excel and/or XML format) are used to document the format and content of the data products during the development phase; once consolidated, the information will be captured in this section.

PDS label templates are developed and maintained by the Instrument Team with support from the SGS under the SGS version control system; see SIXS PDS4 repository:

- gitolite@scigit02.esac.esa.int:bepi.pds4.six.git

5.1 Label Format and Content

XML Declaration and Schema Reference Information

<Product Type>
- **<Identification Area>**
  - <Alias_List>
  - <Citation_Information>
  - <Modification_History >
- **<Observation_Area>**
  - <Time_Coordinates>
  - <Primary_Result_Summary>
  - <Investigation_Area>
  - <Observing_System>
  - <Target_Identification>
- **<Mission_Area>**
- **<Discipline_Area>**
- **<Reference_List>**
  - <External_Reference>
  - <Internal_Reference>
- **<File_Area_Observational>**
  - <File>
  - <Data Structure(s)>
- **<File_Area_Observational_Supplemental>**
  - <File>
  - <Data Structure(s)>

</Product Type>

Figure 3: Simplified PDS4 label example

Label examples will be included as Annex in a future version of the document.

5.2 Raw Data Products

5.2.1 *Raw SIXS DPU Housekeeping*

Raw SIXS DPU Housekeeping product is a FITS file composed of a primary header and one binary table extension. The binary table contains SIXS DPU housekeeping parameters.

5.2.2 *Raw SIXS-P Housekeeping*

Raw SIXS-P Housekeeping product is a FITS file composed of a primary header and one binary table extension. The binary table contains SIXS-P housekeeping parameters.

5.2.3 *Raw SIXS-X Housekeeping*

Raw SIXS-X Housekeeping product is a FITS file composed of a primary header and one binary table extension. The binary table contains SIXS-X housekeeping parameters.

5.2.4 *Raw SIXS-P Spectra*

Raw SIXS-P spectra product contains science data collected when SIXS-P is in Science 1 mode. It is a FITS file composed of a primary header and three binary table extensions:

- Spectra table
- Counting Rate table
- Pulse Height table

The spectra table contains the raw proton and electron spectra and fluxes recorded by the instrument. The instrument records electron and proton spectra from five directions. Spectra are integrated over a period of eight seconds. For each integration period the table contains five electron spectra with seven energy channels and five proton spectra with nine energy channels.

The counting rate table contain instrument dead time, throughput and omnidirectional flux data. In science mode the time resolution is 1 second.

Pulse height data consist of a sample of 16 particle events transmitted as raw pulse heights from the detector elements. The interval for pulse height data collection is 64 seconds.

5.2.5 *Raw SIXS-P High-resolution Spectra*

Raw SIXS-P high-resolution spectra product contains science data collected when SIXS-P is in Science 2 mode. It is a FITS file with same structure as the raw SIXS-P spectra product.

Spectra are integrated over a period of one second.

Counting rate and pulse height data is identical to raw SIXS-P science spectra product.

5.2.6 *Raw SIXS-P Diagnostic Spectra*

Raw SIXS-P diagnostic spectra product contains science data collected when SIXS-P is in Diagnostic mode. It is a FITS file with same structure as the raw SIXS-P spectra product.

Spectra are integrated over a period of 640 seconds.

Counting rate data time resolution is 64 seconds.

Pulse height data collection interval is 1 second.

5.2.7 *Raw SIXS-X Spectra*

Raw SIXS-X science product contains data collected when SIXS-X is in Science mode. It is a FITS file composed of a primary header and two binary table extensions:

- Spectra table
- Flux table

The spectra table contains the raw spectra recorded by SIXS-X. The nominal integration time of a spectrum is 16 seconds. The spectra have 512 energy channels. The spectra table include both calibration and solar spectra. The calibration spectra are recorded when the instrument is pointing to empty sky and consist of four distinct spectral lines produced by the calibration sources in the instrument. The energy of an X-Ray hitting the detector is measured and the result analog-to-digital (AD) converted and added to the spectrum. If an additional X-ray or X-rays hit the detector during the energy measurement the energy cannot be measured and no AD conversion is made. In such cases the number of events is recorded instead. The spectra contain all events that were AD converted by the instrument. Both AD converted and non-AD converted events are included in the flux table.

The flux table contains the raw flux recorded by the instrument. The flux is integrated over one second intervals and contains all events detected by the instrument. This includes the AD converted events whose energy is measured and non-AD converted events whose energy is not measured. The energy of an event can't be measured when an event occurs before the pulse height measurement of the previous event is complete. In these pile-up events the pulse height measured is proportional to the total energy of the events.

5.3 Calibrated Data Products

5.3.1 *Calibrated SIXS DPU Housekeeping*

Calibrated SIXS DPU Housekeeping product is a FITS file composed of a primary header and one binary table extension. The binary table contains SIXS DPU housekeeping parameters.

5.3.2 *Calibrated SIXS-P Housekeeping*

Calibrated SIXS-P Housekeeping product is a FITS file composed of a primary header and one binary table extension. The binary table contains SIXS-P housekeeping parameters.

5.3.3 *Calibrated SIXS-X Housekeeping*

Calibrated SIXS-X Housekeeping product is a FITS file composed of a primary header and one binary table extension. The binary table contains SIXS-X housekeeping parameters.

5.3.4 *Calibrated SIXS-P Spectra*

SIXS-P calibrated spectra format is similar to the raw spectra format. The spectra table contains additional columns for relevant calibrated HK parameters and calibrated proton and electron spectra.

5.3.5 *Calibrated SIXS-P High-resolution Spectra*

SIXS-P calibrated spectra format is similar to the raw high-resolution spectra format. The spectra table contains additional columns for relevant calibrated HK parameters and calibrated proton and electron spectra.

5.3.6 *Calibrated SIXS-P Diagnostic Spectra*

SIXS-P calibrated spectra format is similar to the raw diagnostic spectra format. The spectra table contains additional columns for relevant calibrated HK parameters and calibrated proton and electron spectra.

5.3.7 Calibrated SIXS-X Spectra

SIXS-P calibrated spectra format is similar to the raw spectra format. The spectra table contains additional columns for relevant calibrated HK parameters, energy range and energy resolution.

5.4 Calibration Data Products

5.4.1 SIXS-P Calibration Spectra

SIXS-P calibration spectra product contains data collected when SIXS-P is in Calibration mode. It is a FITS file with same structure as the SIXS-P diagnostic spectra product.

Spectra are integrated over a period of 640 seconds.

Counting rate data time resolution is 64 seconds.

Pulse height data collection interval is 1 second.

The data in calibration product is not collected from the detectors but generated by an internal test pulser.

5.4.2 SIXS-X Ancillary Response File (ARF)

SIXS-X Detector effective area for each spectrum. Used in spectrum fitting with XSPEC. Format defined in [RD.16] and [RD.17].

5.4.3 SIXS-X Redistribution Matrix File (RMF)

Photon energy redistribution probabilities for each SIXS-X detector. Used in spectrum fitting with XSPEC. Format defined in [RD.16] and [RD.17]

5.4.4 SIXS-X Background (BKG)

Background spectra containing a model of the spectrum produced by the in-flight calibration sources. Subtracted from solar spectra during spectral fitting with XSPEC. Format defined in [RD.18].

5.4.5 SIXS-X Calibration Spectra

Spectra integrated when the Sun is outside the instrument field of view containing only the spectrum produced by the in-flight calibration sources. Used for determination of energy range and resolution.

5.5 Ground Calibration Data Products

SIXS ground calibration products have not been generated at this time. The following products are planned to be made based on the ground calibrations done with the SIXS instrument [RD.09] [RD.19].

5.5.1 SIXS-X Detector Off-axis Sensitivity Scans

Spectra and corresponding housekeeping data from ground calibration off-axis sensitivity scans. Spectra with different off-axis and roll angles with X-ray tube source and reference spectra without X-ray tube source.

5.6 Browse Products

Currently browse products are generated for calibrated spectra products.

5.6.1 Calibrated SIXS-P Spectra Browse Product

Plots showing total electron and proton counts for spectra over the observation period and proton and electron fluxes for the spectrum with the highest total counts.

5.6.2 Calibrated SIXS-P High-resolution Spectra Browse Product

Plots showing total electron and proton counts for spectra over the observation period and proton and electron fluxes for the spectrum with the highest total counts.

5.6.3 Calibrated SIXS-P Diagnostic Spectra Browse Product

Plots showing total electron and proton counts for spectra over the observation period and proton and electron fluxes for the spectrum with the highest total counts.

5.6.4 Calibrated SIXS-X Spectra Browse Product

Plot showing total counts and off-axis angle for spectra over the observation period and the raw spectrum with the highest total counts.

5.7 Document Products

Document products have not been generated at this time. The products listed in table Table 13: SIXS documents in section 4.2.6 are planned to be made.

ANNEX A DATA DELIVERY SCHEDULE

To be included in a future version of the document.

END OF DOCUMENT