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BEPICOLOMBO

MERCURY PLANETARY ORBITER (MPO)

MPO-MAG 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 MPO Mercury Magnetometer (MPO-MAG) data as archived in the 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 provides enough information to enable users to understand the MPO-MAG data and their organization. The users for whom this information is intended are the scientists who will process and analyze the MPO-MAG data.

The specifications described in this document apply to all MPO-MAG 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 1.4 of the MPO-MAG EAICD, significantly updated by the MPO-MAG team from the base version produced by the SGS for the SGS Launch Implementation Review. Further updates might be required throughout the mission lifetime once new data products were defined. The schedule and scope of the pre-Launch versions of this document is as follows:

Issue/Revision	Date	Scope
D.1	15/02/2016	Current version. 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 organization 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	18/11/2016	This version will include a complete description of the archive data organization 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	05/05/2017	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.
1.0	28/11/2017	Version of the document ready for the first Science Review.
1.1	13/03/2019	Content changed + added , all sections, IR
1.2	31/01/2020	Derived Data added, calibration description expanded, products updated, minor changes, RAW2CAL Description, IR
1.3	13/05/2020	META_DATA added, Position Label description in e2k data updated, Derived data filename convention, Temperature calibration added

Issue/Revision	Date	Scope
1.4	19/06/2020	Update due to comments of MB. Figure 5 updated. Partially processed data added
1.5	20/01/2021	Update due to Archive Review Autumn 2020

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]	ESDC-PSA-TN-0002 Iss2Rel5-5, 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-TN-043, Annex to Archiving Guide
[RD.05]	BC-SGS-ICD-019, MPO-MAG Pipeline Description Document
[RD.06]	BC-MAG-UM-00002, MERMAG User Manual (UM)
[RD.07]	Glassmeier et al., The fluxgate magnetometer of the BepiColombo Mercury Planetary Orbiter, Planetary and Space Science 58 (2010) 287–299, doi:10.1016/j.pss.2008.06.018
[RD.08]	Baumjohann et al., Magnetic field investigation of Mercury's magnetosphere and the inner heliosphere by MMO/MGF, Planetary and Space Science 58 (2010) 279–286, doi:10.1016/j.pss.2008.05.019
[RD.09]	Benkhoff et al., BepiColombo—Comprehensive exploration of Mercury: Mission overview and science goals, Planetary and Space Science 58 (2010) 2–20, doi:10.1016/j.pss.2009.09.020
[RD.10]	Richter I., FLUXGATE MAGNETOMETER CALIBRATION FOR BEPICOLOMBO, BC-MAG-TR-0085, Protocol and Analysis of the BepiColombo MPO Calibration for Sensor BS 10 & BS 11 connected to the FM 1 Electronics, IGEP, TU-Braunschweig, 2013
[RD.11]	BepiColombo Acronyms and Abbreviations Directory: http://emits.sso.esa.int/emits-doc/ASTRIUMLIM/BepiColombo_LVA_Structure/BC.ASD.LI.00003.Issue.2.pdf
[RD.12]	BC-EST-RS-01140, Experiment Interface Document – Part A,Iss2, Rev4, 2014
[RD.13]	SPICE for celestial coordinate transformations, https://naif.jpl.nasa.gov/naif/toolkit.html
[RD.14]	SPICE Kernels for BepiColombo, https://repos.cosmos.esa.int/socci/projects/SPICE_KERNELS/repos/bepicolombo/browse

[RD.15] Leinweber et al. (2008). An advanced approach to finding magnetometer zero levels in the interplanetary magnetic field. Measurement Science and Technology, 19(5), 055104. https://doi.org/10.1088/0957-0233/19/5/055104

[RD.16] Murakami, G., Hayakawa, H., Ogawa, H. *et al.* Mio—First Comprehensive Exploration of Mercury's Space Environment: Mission Overview. *Space Sci Rev* **216,** 113 (2020). https://doi.org/10.1007/s11214-020-00733-3

[RD.17] Anderson, B. J., et al. A magnetic disturbance index for Mercury's magnetic field derived from MESSENGER Magnetometer data. *Geochemistry, Geophysics, Geosystems*, *14*(9), 3875–3886, 2013

1.5 Abbreviations and Acronyms

General Acronyms: see BepiColombo Acronyms and Definitions, [RD.01] and [RD.11].

MPO-MAG specific acronyms:

ADC	Analog to digital Converter
BOA	BepiColombo Operational Archive
CoC	Center of Coilsystem
CVP	Commissioning and Verification Phase
DAC	Digital to Analog Converter
EDDS	EGOS Data Dissemination System
EGOS	ESA Ground Operation System
E2K	ECLIPJ2000, Ecliptic J2000 Coordinates
FM	Flight Model
FPGA	Field Programmable Gate Array
HK	Housekeeping Parameter
IB	Inboard Sensor
ICP	Interplanetary Cruise Phase
IGEP	Institute for Geophysics and Extraterrestrial Physics, Braunschweig
Ka-Band	Communication Band at 26.5–40 GHz
MCF	Magnetic Coil Facility
MEPS	MTM Electric Propulsion System
MERMAG,MPOMAG,MPO-MAG	Fluxgate Magnetometer onboard MPO
MPO	Mercury Planetary Orbiter
MSE	Mercury Centered Solar Ecliptical Coordinates
MSEQ	Mercury Centered Solar Equatorial Coordinates
NECP	Near Earth and Commissioning Phase
nT	Nanotesla
MMO	Mercury Magnetospheric Orbiter
MMO-MGF	Mercury Magnetospheric Orbiter – Magnetic Field Sensor

MOC	Mission Operation Centre
MTM	Mercury Transfer Module
OB	Outboard Sensor
OBT	Onboard Time
OGS	Operation Ground Segment
PDS	Planetary Data System
PID	Process Identifier
PSA	Planetary Science Archive
P/L	Payload instrument
RW	Reaction Wheel
S/A	Solar Array
S/C	Spacecraft
SCET	Spacecraft Elapsed Time
SCF	Spacecraft Coordinate Frame
SEPS	Solar Electric Propulsion Phase
SGS	Science Ground Segment
SPICE	An Observation Geometry System for Space Science Missions
S/W	Software
TC	Telecommand
TM	Telemetry
URF	Unit Reference Frame, Instrument Coordinates
UTC	Universal Time Coordinated
X-Band	Communication Band at 8.0 – 12.0 GHz

2 INSTRUMENT DESCRIPTION

A detailed technical description of the MPO-MAG instrument can be found in [RD.06]. A scientific and technical overview about the MPO-MAG magnetometer is given in [RD.06]. The link to the MMO-MGF instrument and magnetic field measurements in Mercury's magnetosphere is presented in [RD.07].

2.1 Mission and Instrument Overview

The BepiColombo Mission is a scientific enterprise aiming to Mercury, the innermost planet of our Solar System. It is jointly conducted by the European Space Agency (ESA) and the Japanese Aerospace Exploration Agency (JAXA). There are two spacecraft, the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MMO), which will fly together until reaching Mercury after a seven year cruise phase. The launch took place on October 20, 2018 at 01:45:28 UTC. Several swing-bys of Earth,Venus and Mercury will be flown in order to decelerate the s/c for a successful insertion into Mercury's orbit in 2025. For details about the mission, refer to [RD.08].

Besides a broad suite of scientific instruments, both s/c are carrying dual sensor magnetometers, the MMO/MGF instrument on the Magnetospheric orbiter and the MPO-MAG instrument on the Planetary Orbiter, which is subject of the present EAICD.

Magnetometer operation takes place as often and as long as possible - also during the cruise phase. This requirement results from the lessons learned by ROSETTA. The long cruise phase including the swing-bys provide the unique opportunity to gain detailed knowledge about the instrument and any s/c-interference in order to be well prepared when arriving at planet Mercury. We also aim for instrument operations during the phases of electric propulsion (SEPS), in order to reveal as many as possible "spacecraft secrets" and to support the MOC in understanding the MEPS related effects, although magnetic disturbances will diminish the quality of the magnetic field data during these phases.

MPO-MAG is an instrument collecting time series of magnetic field data – these times series should be as long and complete as possible. Therefore, a quasi permanent operation is highly desired by the instrument team and should be granted if not inhibited by any s/c operational reasons.

2.2 Science Objectives

The primary objective of the **MPO MAG**netometer (MPO-MAG) is to collect magnetic field measurements in order to describe Mercury's planetary magnetic field and its source in great detail. This will help us understand the origin, evolution and current state of the planetary interior. The requirement is to determine all the terms associated with the internal field up to the octopole with high accuracy, using accurate magnetic field measurements on the low orbit of MPO. The instrument can be operated in various measurement ranges and rates as listed in **Table 4** to guarantee the performance needed in specific mission phases.

The MPO-MAG observations will be supported by similar measurements made on MMO, in order to distinguish the effects of the magnetospheric currents on the MPO measurements and to use the MMO measurements directly to augment the database for the determination of the internal terms.

The secondary objectives of MPO-MAG are related to the interaction of the solar wind with Mercury's magnetic field and the planet itself. This interaction will lead to the formation of the global magnetospheric current systems that are highly dynamic. In particular, measurements close to the planet will allow the determination of the conditions for access of the solar wind to the planetary surface. Furthermore, the role and importance of different current systems with respect to subsurface induction and the determination of the regolith conductivity will be addressed. These objectives will be assisted by the planned joint magnetic field investigations onboard the MMO.

General Instrument Operations in Mercury Phase

Figure 1 shows the orbits of the BepiColombo probes with respect to the planet and its magnetopause. Most of the time MPO will be located inside the magnetosphere. Only at perihelion, with MPO's apocenter towards the Sun, it is expected that MPO-MAG will probe the magnetosheath region. At the same time, MMO will serve as upstream solar wind monitor, such that magnetospheric dynamics can be correlated with upstream solar wind data. At aphelion, MMO can record events like depolarization fronts before MPO. Thus, this will allow us to study their evolution. On other events, MMO and MPO will be on the same flux tube. This situation will allow us to study e.g. field-aligned currents. This is only an abbreviated list of the advantages to have two probes in the system.

Orbital evolution will modify this picture only marginally. Selective downlink will allow us to keep the scientific planning effort small. However, it has to be decided at what sampling rate data will be stored in the selective downlink package stores. This will be decided by the probe's location with respect to the magnetosphere.

Figure 2 shows the magnetic fluctuations recorded by the MESSENGER probe and **Figure 3** visualizes the general selective data production scheme for MPO-MAG. The assumed weekly threshold for data production and downlink was 2 Gbit/week.

Figure 4 shows a configuration that fulfils this requirement.

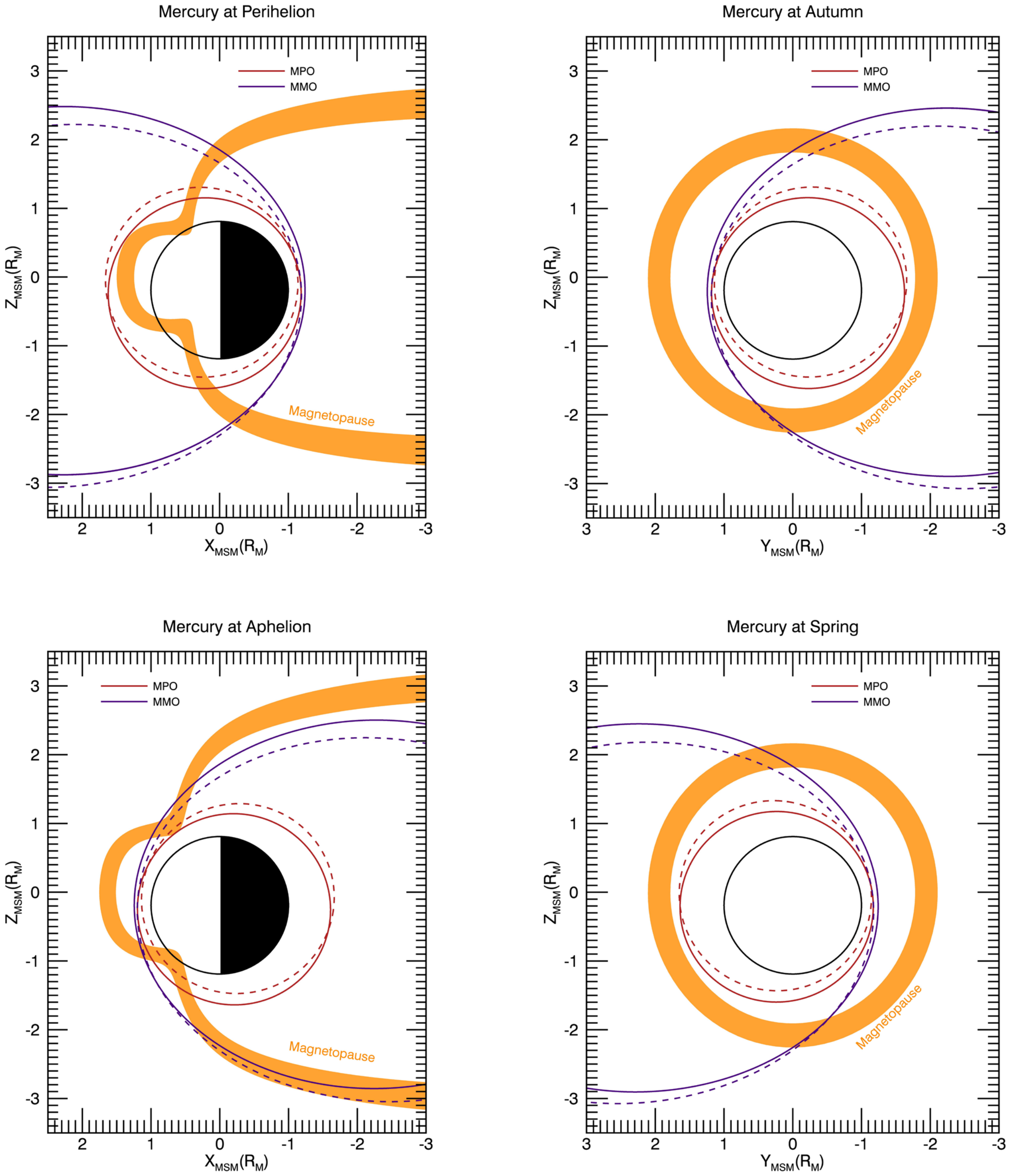

Figure 1: The initial orbits of BepiColombo probes MPO (red) and MMO (blue) w.r.t. the planet (circle) and the magnetopause (orange, 1σ environment) at different heliocentric distances (see graphic title). The dashed line shows the orbits after one Mercury year [TBC].

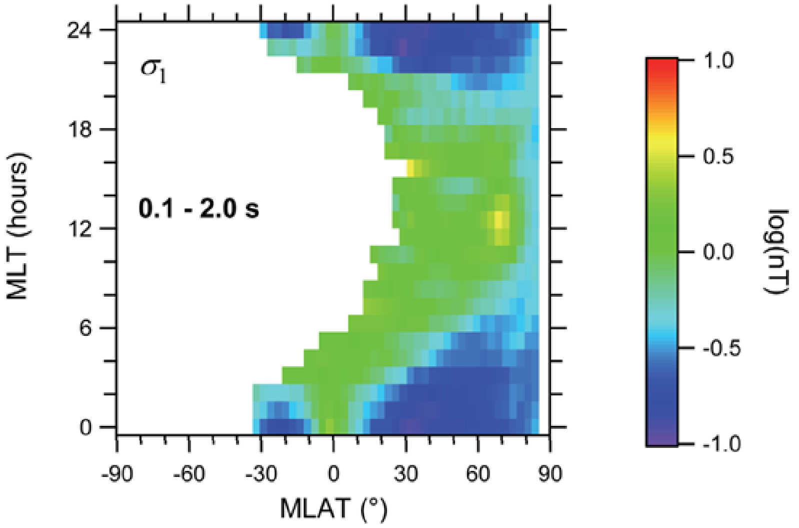

Figure 2: Recorded magnetic fluctuations in the 0.5-10 Hz frequency band binned to Magnetic Local Time (MLT) and Magnetic Latitude (MLAT) from MESSENGER observations from [RD.17].

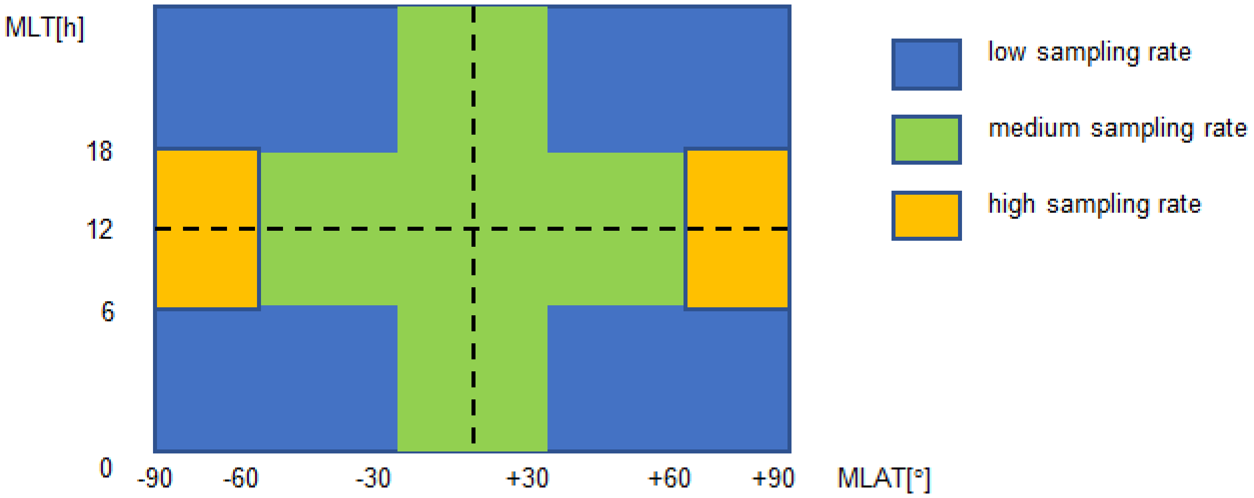

Figure 3: General scheme for MPO-MAG sampling frequency for selective downlink data.

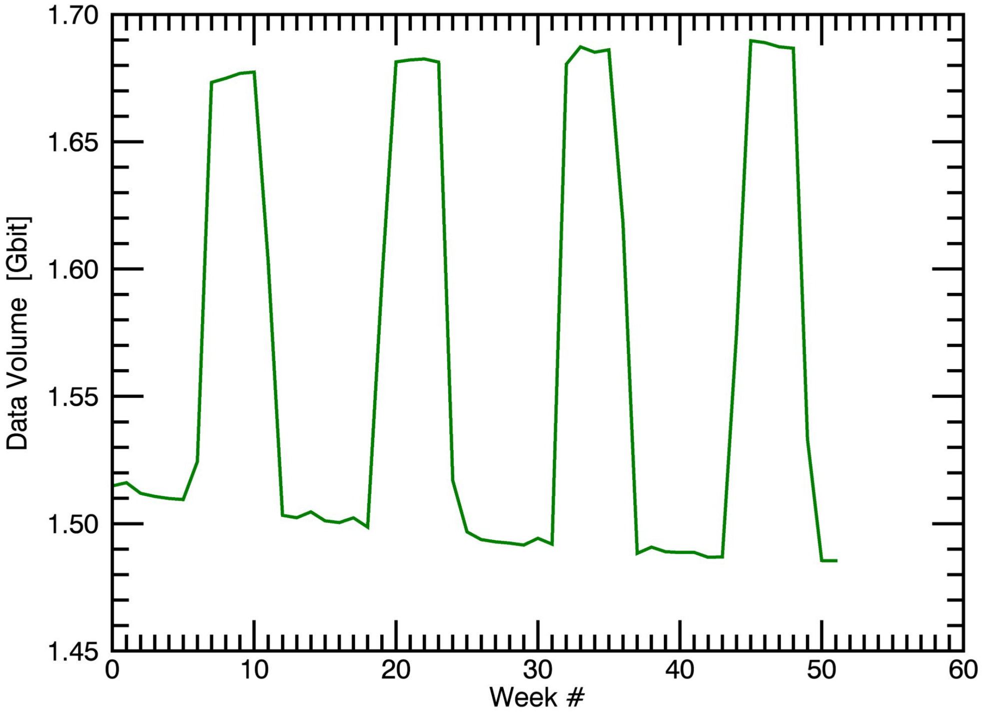

Figure 4 : Simulated data production for low=16 Hz, medium=32 Hz, high=64Hz. The assumed data rates are: 16Hz → 0.41kb/s, 32 Hz→1.62kb/s, 64 Hz→3.24 kb/s. These rates depend on the data compression.

Boundary Layer Operations

There will be many occasions when MPO crosses plasma boundaries such as the magnetopause or the bow shock. During these phases, the magnetometer needs to be operated in its highest time resolution mode. The details of this mode may depend on the actual situation encountered in the mainly unknown Hermean magnetosphere.

2.3 Instrument Description

The MPO-MAG experiment consists of a dual fluxgate magnetometer system that measures the 3 components of the magnetic field vectors from DC up to 128 Hz. In order to determine magnetic contamination (AC and DC) from the spacecraft, MPO-MAG consists of two sensors, an inboard (IB) and an outboard (OB) sensor, mounted on a 2.8 m long boom and separated by 50 cm.

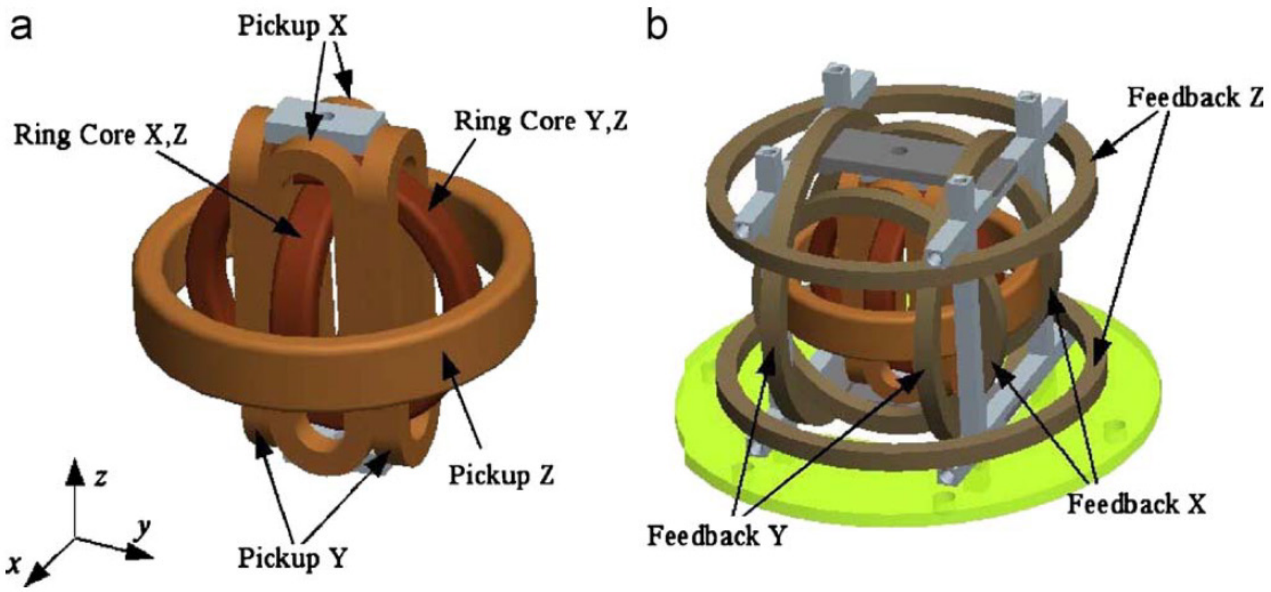

Figure 5: MPO-MAG Sensor-design (from RD [.07])

Figure 5 reveals details of the sensor. In the left part the two ring cores including excitation coils can be seen. They are located inside the pickup coil, where the magnetic field signal is taken and fed into the subsequent electronics. As displayed in the right sketch the 3 outmost coils build a Helmholtz-compensation system, which is fed by a feedback current in order to operate the sensor in zero-field conditions.

The magnetometer is a digital fluxgate type instrument. A coarse block diagram of the electronics is presented in Figure 6. This electronics chain is duplicate, one for the OB and one for the IB part.

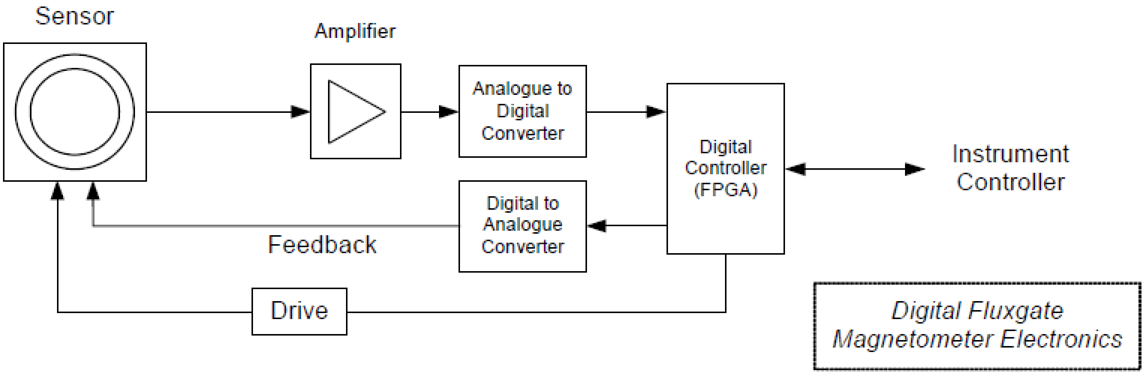

Figure 6: MPO-MAG, Block Diagram of Sensor Electronics (from RD [.07])

The magnetic field signal measured by the sensor is amplified and immediately converted into a digital word, which acts as input to a FPGA. This device generates a dynamic digital feedback signal, which is converted into an analogue feedback signal and connected to the sensor's feedback coil. Additionally the FPGA generates the excitation signal that is conditioned by the drive electronics before injection to the excitation coil. On the other hand, the FPGA is connected to the Instrument Controller, which collects the magnetic field data and controls the magnetometer.

The fundamental parameters of the MPO-MAG instrument are summarized in Table 2.

PARAMETER		VALUE
Instrument Type		Tri-axial vector-compensated dual sensor ringcore FGM with digital signal processing
Mass	Total	2530 g
	Sensor	2 x 270 g
	Harness	720 g
	Electronics	1270 g
Dimension	Sensor	82.4mm x 82.4mm x 122.7mm
	E-Box	162mm x 169mm x 96.6 mm
Average Power consumption	Heaters off	5.0 W
	Heaters on	5.75 W
Sample Rates		0.5 - 128 vec/s
Data Volume /Orbit		3 Mbit
Range	dynamic	+-2048 nT
	compensation	+-5000 nT
Resolution	21 Bit	1.96 pT
Data Reduction	16 bit selected out of 21bit for TX	6 ranges
Noise		10 pT/ √Hz @1 Hz
Temperature	Sensor- operating	-120 °C - +180°C
	Sensor - non operating	-155 °C - +180°C
	Electronics	-55°C - +80°C
Offset		< 6 nT
Offset Stability		
	vs. time	< 0.5 nT / 100h
	vs. T_sens	< 50 pT /K
	vs. T_elec	< 50 pT /K
Axis Alignment	Mechanical Tolerance	< 1°
	Knowledge of axes dir.	< 0.1°
	Stability of axes dir.	<0.1°
Scale factor Linearity error		< 0.052 %

Table 2: MPO-MAG, Summary Table

Data Averaging and filtering

The processing chain **inside the instrument** comprises various steps:

i. The sensor is excited at an excitation frequency of f_e = 9.6 kHz. According to the fluxgate principle the information about the ambient magnetic field is proportional to the amplitude of the signal at 2 f_e. In order to be properly compliant to the Nyquist theorem this primary sensor signal is sampled at 4 f_e at the correct phase (tested and set during dedicated calibration campaigns at ground or CVP) at the times where the amplitude reaches its extrema. Therefore , two maximum and two minimum values are obtained during one excitation period. Thus, a first average at f_e can be computed by adding these values : AVG = (Max1 –Min1 +Max2 –Min2) /4

ii. As the nominal intrinsic sampling frequency of the instrument is f_s = 128 Hz , 9600/128 = 75 averages have to be summed up (and scaled) to generate the nominal magnetic field values at f_s.

iii. This signal acts as input of the digital filter inside the DPU generating the averaged magnetic field values at the specific measurement rates of 64, 32 ,16… 0.5 Hz using selected modes (see next subsection). The implemented digital filter is a cascaded multistage sinc halfband FIR lowpass filter with 17 coefficients as listed in **Table 3**.

Filter coefficient	**Value**
a0 = a16	0
a1 = a15	-0.00531893983961
a2 = a14	0
a3 = a13	0.02629639672517
a4 = a12	0
a5 = a11	-0.07956381221274
a6 = a10	0
a7 = a9	0.30864305659745
a8	0.49988659745946

Table 3: FIR coefficients

For each frequency reduction by a factor of 2 one filter stage is used. The occurring group delay is compensated by delaying the related time stamps accordingly. The design of the filter guarantees a linear phase behavior in the pass band.

The data are generated in this way are the so called instrument raw data.

During the data processing **on ground** specific averaged data can be generated:

Concerning timing there is no difference between raw and calibrated data. “Averaged calibrated data”, however, which are one possible derived data product, are processed in an additional step.
Averaged data will be provided for a specific average time interval. Our standard value is t_{avg}= 1 s.

This averaging is done by just taking all data available in the given interval of (t- t_{avg} /2 , t+ t_{avg} /2) and using the IDL function *mean(x)*, which just computes the arithmetic mean value . The new time stamp to is set to t. The next value will be computed for t+ t_{avg} , and so on.

Remark: The positions listed in the data tables are recomputed at the new times t , (t + t_{avg}), (t +2* t_{avg}), ... by use of the SPICE kernels and of course not by just averaging the original positions. The temperatures in the data tables, however, are averaged in the same way as the magnetic fields.

Operational Modes

The MPO-MAG instrument can be operated with various sampling rates listed in Table 4. The stated "Sampling Rate Index" is also part of the science data filenames, used as *s<sampling_rate_index>,* in order to get the sampling rate information of the obtained data already in the filename.

Sampling Rate Index	**Measurement Rate**	**Packet Rate**
0		Standby
1	0.5 Hz	256 sec
2	1 Hz	128 sec
3	2 Hz	64 sec
4	4 Hz	32 sec
5	8 Hz	16 sec
6	16 Hz	8 sec
7	32 Hz	4 sec
8	64 Hz	2 sec
9	128 Hz	1 sec

Table 4: Measurement Rates

For the MPO-MAG instrument two general observation strategies are used:

1. Standard Measurement Mode:
   This is the general observation mode for times where no TM restrictions occur. The measurement rate will just be set to the desired value and observation are made permanently. Mode used e.g during cruise and flyby phases. Data will be downlinked with the current sampling rate only.

2. Selective Downlink:
   In time where TM restrict apply (Mercury orbit) it is not possible to generate data permanently at a sufficiently high sampling rate. Therefore, the so called selective downlink strategy will be used: Observations are made permanently using a high sampling rate (128 Hz). These data are only written to a ring buffer (capacity ~ 4 weeks) on the s/c and not immediately transmitted to Earth. Instead data

are averaged to 1 Hz, and sent to Earth as “normal science”. These data will be analyzed just in time. In case of occurrence of “interesting” structures, the selective downlink will be triggered, high resolution data of the interesting time interval will be fetched from the ring buffer and sent down (selective science packets) to Earth. Using this strategy TM can be minimized to the benefit of other P/L.

Besides the sampling rate the compression mode and the used transmission band characterize the measurement mode. The following list gives an overview about the possible modes:

Mode ID	Science Mode	Transmission Band	Compression State	Description
3	Normal Science	X	Uncompressed, Compressed, Dual compressed	This is the normal mode of science operation. Data volume is dependent on sensor activation state (inboard/outboard), data rate and compression mode/activation.
4	Normal Science	Ka	Uncompressed, Compressed, Dual compressed	Science mode. Data volume is dependent on sensor activation state (inboard/outboard), data rate and compression mode/activation.
5	Selective Science	X & Ka	Uncompressed, Compressed, Dual compressed	This mode is used for selective downlink. 2 data products (selection support data and high rate selective data) are generated. Data volume is dependent on sensor activation state (inboard/outboard), data rate and compression mode/activation.
6	Science Standby	-	-	In this mode science data, output is disabled, but sensor housekeeping data is still available.
9	Calibration Science	X	compression not available	Provide calibration possibilities for the sensors. Data volume is dependent on sensor activation state (inboard/outboard), and data rate.

Table 5: MPO-MAG Standard Measurement Modes

If the measurement mode is set to 9, the instrument is operated in calibration mode, where various functionalities can be tested. These test options are identified by the CALIBRATION MODE ID. Table 6 lists all possible calibration modes.

Value	Calibration Mode ID	Explanation
0	Normal	Normal Operation for comparison purposes.
1	Calibration 1	The feedback DAC is operated using a step function.
2	Calibration 2	The sensor counts up in the data values. Used for filter verification.
3	Calibration 3	ADC measurement and feedback DAC Values are sent separately. To keep frame generation rate constant, each second ADC vector is replaced by the DAC value of the first vector.
4	Calibration 4	The magnetometer is operated in open loop, the feedback DAC is set to 0 by default and can be changed via TC.
5	Calibration 5	Meander Macro using Feedback DAC. The magnetometer is operated in open loop, feedback and compensation DAC values are changed every 10 seconds using a lookup table.
6	Calibration 6	Meander Macro using Compensation DAC. The magnetometer is operated in open loop, feedback and compensation DAC values are changed every 10 seconds using a lookup table.
7	Calibration 7	Find phase Macro using Feedback DAC. The magnetometer is operated in open loop, the feedback DAC and phase values are changed in adjustable steps and time.
8	Calibration 8	Find phase Macro using Compensation DAC. The magnetometer is operated in open loop, the feedback DAC and phase values are changed in adjustable steps and time.
Others	Invalid	

Table 6: Calibration Modes

For reason of completeness, the following Table 7 has been affiliated. It lists the possible Process Identifiers (PID), used to distinguish all TM packets. The PIDs are defined by the operational modes, which initiate the related instrument processes. Not every process and its related housekeeping data is available in every operational mode (e.g. sensor science and housekeeping data is not available during boot or maintenance).

Process ID	**Process & Transmission Band**	**Available in Measurement**
85	Traditional science or support science (X-band)	3
86	Traditional science (Ka-band)	4
87	Selective high rate science (Ka-band)	5
89	Instrument Management, Sensor Control and Housekeeping	1,3,4,5,6,7,9

Table 7: PID Allocation

A complete summary of obtained data volume at specific data rates and measurement modes, coming down in the s/c telemetry stream, is presented in Table 8.

TM Rate Overview

Sampling Rate	Rate [bps]					
	Normal Science		Selective data product		Calibration	
	Active Sensors		Active Sensors		Active Sensors	
	Single	Both	Single	Both	Single	Both
128	6352	12704	6352	12704	6384	12768
64	3176	6352	3176	6352	3192	6384
32	1588	3176	1588	3176	1596	3192
16	794	1588	794	1588	798	1596
8	397	794	397	794	399	798
4	198.5	397	198.5	397	199.5	399
2	99.25	198.5	99.25	198.5	99.75	199.5
1	49.625	99.25	49.625	99.25	49.875	99.75
0.5	24.8125	49.625	24.8125	49.625	24.9375	49.875

Table 8: TM Rate Overview Table

In case of selective Science mode both the normal science and the selective data product are generated with individually selected rates.

Due to the very limited power resources aboard BepiColombo MPO, the MAG instruments implements a reduced power mode. In reduced power mode only one sensor is operated, the other one is disabled. Most likely, the inboard sensor will be deactivated, only in case the outboard sensor is nonfunctional, this one will be deactivated. Generally, this means that the science data rates are reduced to the one for a single mode; also housekeeping will be available only for one sensor. In terms of power, excitation and heating of one sensor is deactivated.

Since operating the instrument in reduced power mode means also reduced science, this mode is only used in mission cases where the power budget is very narrow.

For further details of the experiment, see [RD.06].

Remark1:

It shall be noted here, that the different possible modes and transmission channels are not reflected in the archived data filenames. Only the sensor name and the sample rate index is used in the data filenames to guarantee a proper distinction between the data streams available. The transmission band does not play any role for the data user as the data of different channels are processed automatically and stored in the right files. Furthermore, the calibration mode is used only internally for tests during the commissioning phase and will not be used for scientific data.

Remark2:

After instrument switch on it will normally be rebooted using the standard procedure AMEF003A which sets MPO-MAG to the following default values:

Parameter	Description	Value	Type	Unit	Radix
XF003A01	Science Mode	Science X	Eng		Decimal
XF003A02	Sensor ID	Both Sensors	Eng		Decimal
XF003A03	AutoRange ENBL	Off	Eng		Decimal
XF003A04	Meas RNG	128	Eng	nT	Decimal
XF003A05	PID	Science X	Eng		Decimal
XF003A06	RATE	16	Eng	Hz	Decimal
XF003A07	K1X IB	23236	Raw		Decimal
XF003A08	K1Y IB	13137	Raw		Decimal
XF003A09	K1Z IB	55570	Raw		Decimal
XF003A10	K1X OB	39323	Raw		Decimal
XF003A11	K1Y OB	21907	Raw		Decimal
XF003A12	K1Z OB	55160	Raw		Decimal
XF003A13	Phase	159	Eng	deg	Decimal
XF003A14	ENBL DUAL COMP	On	Eng		Decimal
XF003A15	24 BIT	Off	Eng		Decimal
XF003A16	COMPRESSION	On	Eng		Decimal

Table 9 : Default Boot Parameter according to AMEF0003A

Details on Time Tagging

All data measured on the spacecraft are tagged by a timestamp in the related instrument packet header. This timestamp refers to the OBT, the onboard time, which is derived from a common s/c-clock. For the downlink process these packets are wrapped in transfer frames an transmitted to Earth in specific virtual channels. At reception on Earth an UTC timestamp is added to the packet, indicating the Earth reception time (ERT). The time correlation between OBT and UTC (at time of measuring the data , not ERT) is carried out later in the downlink procedures at ESA's ground facilities using so called time correlation packets. These take into account

- the delay between the reception time at the antenna and the time of stamping the data with the ERT tag,
- the propagation delay or one way light time (OWLT),
- and the processing delay onboard the s/c.

As result all TM/raw data will be stamped by proper UTC (at time of measuring) and corresponding OBT tags.

[RD.04] contains a section of detailed information about the generation, correlation and conversion of OBT and UTC timestamps onboard as well as its reprocessing after reception on ground. According to [RD.12] the correlation between OBT and UTC is guaranteed to be better than 1 ms.

Format of UTC time stamps in data files:

According to the PDS time standard UTC timestamps are formatted in the following format:
YYYY-MM-DDThh:mm:ss.ffffffZ
Each format represents a concatenation of the conventional date and time expressions with the two parts separated by the letter T:
YYYY year (0000-9999)
MM month (01-12)
DD day of month (01-31)
T date/time separator
hh hour (00-23)
mm minute (00-59)
ss second (00-59)
ffffff fractions of second (000000-999999)

Note:

- "Z" is appended to the expression to indicate Z-time = UTC.
- In the *start_day_time* and *stop_date_time* keyword stated in the xml labels the resolution is only given in milliseconds, thus the format here is YYYY-MM-DDThh:mm:ss.fffZ

Format of SPACECRAFT CLOCK and OBT tags:

The PDS format of the *spacecraft_clock_start_count* , *spacecraft_clock_stop_count* and the related onboard time (OBT) differs significantly from the UTC format.
The header of the experiment TM source packets contains the data acquisition start time in OBT as 32 bit of unit seconds followed by 16 bit of fractional seconds. The time resolution is 2^{-16} s = 1.53×10^{-5} s.
OBT= 0 is at 1999-08-22-T00:00:00 UTC.
The OBT is represented in the following format: "<reset number>/<unit seconds>.<fractional seconds>"
The unit seconds and the fractional seconds are separated by the full stop character.
Note that this is not a decimal point. The fractional seconds are expressed as multiples of 2^{-16} s and count from 0 to 2^{16} -1 = 65535.
The spacecraft clock could be reset during the mission (although this is not planned). This would imply a change of the zero point. The zero point of the OBT will be indicated by prepending the reset number (integer starting at 1) and a slash to the unit seconds, i.e. "1/".

Usage of Timetags in RAW, CALIBRATED and DERIVED Data Products

Raw data are tagged by UTC and OBT timestamps corrected and correlated as written above. In the process of generating higher level CALIBRATED data products the original timing is kept as neither averaging nor resampling is necessary in this step.
For the generation of averaged data (DERIVED data products) the timing has to be adjusted to the chosen average interval t_{avg}. For all data in averaged over a specific average interval ($t- t_{avg}/2 \ : \ t+ t_{avg}/2$) the new timestamp will be set to t. This adjustment is done for the UTC as well as the OBT tag.

Thus all data in every data product are stamped by the right timetags indicating the time of observation.

2.4 Calibration

2.4.1 On-ground Calibration

The description and the results of the Ground calibration conducted in Magnetsrode at TU Braunschweig in May 2013 are presented in [RD.09]. This report will be added to the archive. That calibration is related to the sensors #10 and #11 connected to the FM1 electronics, finally flown on BepiColombo.

The basic mathematical principle of the Ground Calibration is summarized in the following paragraph.

2.4.1.1 Mathematical Description of the Calibration

The Magnetsrode Coil Facility (MCF) generates an artificial magnetic field $\underline{\boldsymbol{B}}^{\mathrm{FLD}}$ that can be considered as a calibrated, orthogonal magnetic reference field[*] defined in coil system coordinates. For the calibration, analysis this ideal coil system field is rotated to ideal orthogonal sensor coordinates using a nominal rotation matrix $\underline{\underline{\boldsymbol{R}}}_{\mathrm{nom}}$ at the first step. Nominal means that only rotations of ±90° or ±180° at any axis are considered here to get a coarse alignment of the applied field with the sensor-axes.

$$\underline{\boldsymbol{B}}^{\mathrm{c}} = \underline{\underline{\mathbf{R}}}_{\mathrm{nom}}\ \underline{\boldsymbol{B}}^{\mathrm{FLD}}$$

For a standard calibration the matrix $\underline{\underline{\boldsymbol{R}}}_{\mathrm{nom}}$ is just an $\underline{\underline{\boldsymbol{I}}}$-matrix; sensor coordinates and coil system coordinates have roughly the same direction. If the sensor coordinates are left-handed or the sensor is turned by about ±90° or ±180° at any axis, $\underline{\underline{\boldsymbol{R}}}_{\mathrm{nom}}$ will contain ±1-elements or 0-elements at any place. The rotated coil system field $\underline{\boldsymbol{B}}^{\mathrm{c}}$ is the used reference field for the following analysis.

The magnetometer under test at the center of the coil system (CoC) generates magnetic raw data $\underline{\boldsymbol{B}}^{\mathrm{r}}$. These data include an eventually existing residual field of the coil system $\underline{\boldsymbol{B}}^{\mathrm{res}}$ and the magnetometer offset $\underline{\boldsymbol{B}}^{\mathrm{off}}$.
Both entities are combined in the offset & residual field $\underline{\boldsymbol{B}}^{\mathrm{or}}$:

$$\underline{\boldsymbol{B}}^{\mathrm{or}} = \underline{\boldsymbol{B}}^{\mathrm{off}} + \underline{\boldsymbol{B}}^{\mathrm{res}}$$

---

[*] During the calibration the temperature dependent sensitivity of the coil system is calculated every 3 minutes and taken into account as well as the static misalignment of the coil system to produce orthogonal, known fields.

Therefore, the second step of the calibration is the generation of offset and residual field corrected measured field data $\underline{\boldsymbol{B}}^{\mathrm{m}}$:

$$\underline{\boldsymbol{B}}^{\mathrm{m}} = \underline{\boldsymbol{B}}^{\mathrm{r}} - \underline{\boldsymbol{B}}^{\mathrm{or}}$$

The actual offset and residual field is automatically taken into account during the calibration analysis. Either a constant field or - if needed - a linear trend of $\underline{\boldsymbol{B}}^{\mathrm{or}}$ is subtracted from the raw data.

The relation between the calibration field and the magnetometer data is then defined by

$$\underline{\boldsymbol{B}}^{\mathrm{c}} = \underline{\underline{\boldsymbol{\Phi}}}\,\underline{\boldsymbol{B}}^{\mathrm{m}}$$

where $\underline{\underline{\boldsymbol{\Phi}}}$ is the complete calibration transfer matrix, defined by

$$\underline{\underline{\boldsymbol{\Phi}}} = \underline{\underline{\boldsymbol{R}}}_{\mathrm{nom}}\ \underline{\underline{\boldsymbol{\rho}}}\,\underline{\underline{\boldsymbol{\omega}}}\,\underline{\underline{\boldsymbol{\sigma}}}.$$

$\underline{\underline{\boldsymbol{\sigma}}}(T)$ represents the temperature dependent sensitivity.

$\underline{\underline{\boldsymbol{\omega}}}(T)$ describes the temperature dependent internal sensor misalignment (orthogonalization matrix).
$\underline{\underline{\boldsymbol{\rho}}}\,(T)$ describes the real rotation of the sensor against the coil axes[†].

Thus, the calibration algorithms have to solve the following problem:

$$\underline{\boldsymbol{B}}^{\mathrm{c}} = \underline{\underline{\boldsymbol{\Phi}}}\,\underline{\boldsymbol{B}}^{\mathrm{m}} \qquad (1)$$

[†] Also the rotation matrix is regarded as temperature dependent being able to consider any thermal setup inadequacies causing fractional rotations.

$$= \underline{\underline{\boldsymbol{R}}}_{\text{nom}}\ \underline{\underline{\boldsymbol{\rho}}}\ \underline{\underline{\boldsymbol{\omega}}}\ \underline{\underline{\boldsymbol{\sigma}}}\ \underline{\boldsymbol{B}}^{\text{m}}$$

The separation into these submatrices and evaluation of their elements is done in subsequent steps:

- Calculation of the Sensitivity matrix $\underline{\underline{\boldsymbol{\sigma}}}$

  The sensitivity matrix shall contain the on-axis sensitivity coefficients of the sensors. Therefore, $\underline{\underline{\boldsymbol{\sigma}}}$ has to be a diagonal matrix of the following kind:

$$\underline{\underline{\boldsymbol{\sigma}}} = \begin{pmatrix} \sigma 1 & 0 & 0 \\ 0 & \sigma 2 & 0 \\ 0 & 0 & \sigma 3 \end{pmatrix}$$

  The separation of matrix $\underline{\underline{\boldsymbol{\sigma}}}$ *from* the transfer function $\underline{\underline{\boldsymbol{\Phi}}}$ *yields*

$$\underline{\underline{\boldsymbol{\Phi}}} = \begin{pmatrix} \Phi 11/\sigma 1 & \Phi 12/\sigma 2 & \Phi 13/\sigma 3 \\ \Phi 21/\sigma 1 & \Phi 22/\sigma 2 & \Phi 23/\sigma 3 \\ \Phi 31/\sigma 1 & \Phi 32/\sigma 2 & \Phi 33/\sigma 3 \end{pmatrix} \begin{pmatrix} \sigma 1 & 0 & 0 \\ 0 & \sigma 2 & 0 \\ 0 & 0 & \sigma 3 \end{pmatrix} := \underline{\underline{\boldsymbol{\Phi}}}\hat{}\ \underline{\underline{\boldsymbol{\sigma}}}$$

  For the computation of the sensitivity coefficients σ_i the transformation of the base-vectors has to be considered. Equation (1) transforms the components of the fields, whereas

$$\underline{\boldsymbol{e}}^{\text{c}} = (\underline{\underline{\boldsymbol{\Phi}}}^{T})^{-1}\ \underline{\boldsymbol{e}}^{\text{m}} \ := \underline{\underline{\boldsymbol{\Psi}}}\ \underline{\boldsymbol{e}}^{\text{m}}$$

  has to be used for the contragredient base-vector transformation of the skew sensor system Σ^{m} into the orthonormal coil system Σ^{c}. The length of the column vectors of $\underline{\underline{\boldsymbol{\Psi}}}$ define the sensitivity coefficients σ_i:

$$\sigma_1 = \frac{1}{\sqrt{(\psi 11)^2 + (\psi 21)^2 + (\psi 31)^2}}$$

$$\sigma_2 = \frac{1}{\sqrt{(\psi 12)^2 + (\psi 22)^2 + (\psi 32)^2}}$$

$$\sigma_3 = \frac{1}{\sqrt{(\psi 13)^2 + (\psi 23)^2 + (\psi 33)^2}}$$

- Calculation of the Sensitivity matrix $\underline{\underline{\boldsymbol{\omega}}}$

  After the separation of $\underline{\underline{\boldsymbol{\sigma}}}$ the reduced transfer function $\underline{\underline{\boldsymbol{\Phi}}}$^ contains only the misalignment and the real sensor rotation. The misalignment angles $\xi_{xy}, \xi_{xz}, \xi_{yz}$, hence the angles between the base-vectors of the affine sensor system Σ^m, can be evaluated from the scalar products of all these base-vectors. The base unit-vectors are defined by the inverse transposed matrix of the reduced transfer function:

$$(\underline{\boldsymbol{e}}^{\mathrm{m}})_{\mathrm{x}} := ((\underline{\underline{\boldsymbol{\Phi}}}\,\hat{}\,)^{T})^{-1} \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$$

$$(\underline{\boldsymbol{e}}^{\mathrm{m}})_{\mathrm{y}} := ((\underline{\underline{\boldsymbol{\Phi}}}\,\hat{}\,)^{T})^{-1} \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$$

$$(\underline{\boldsymbol{e}}^{\mathrm{m}})_{\mathrm{z}} := ((\underline{\underline{\boldsymbol{\Phi}}}\,\hat{}\,)^{T})^{-1} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

  The misalignment angles can be derived from the scalar products:

$$\xi_{xy} = arccos\,(\ (\underline{\boldsymbol{e}}^{\mathrm{m}})_{\mathrm{x}} \cdot (\underline{\boldsymbol{e}}^{\mathrm{m}})_{\mathrm{y}}\ )$$

$$\xi_{xz} = arccos\,(\ (\underline{\boldsymbol{e}}^{\mathrm{m}})_{\mathrm{x}} \cdot (\underline{\boldsymbol{e}}^{\mathrm{m}})_{\mathrm{z}}\ )$$

$$\xi_{yz} = arccos\,(\ (\underline{\boldsymbol{e}}^{\mathrm{m}})_{\mathrm{y}} \cdot (\underline{\boldsymbol{e}}^{\mathrm{m}})_{\mathrm{z}}\ )$$

Let us assume that the x-axis of the reference system $(\underline{\boldsymbol{e}}^{\mathrm{c}})_{\mathrm{x}}$ is identical to the $(\underline{\boldsymbol{e}}^{\mathrm{m}})_{\mathrm{x}}$-axis of the sensor system. The angle between $(\underline{\boldsymbol{e}}^{\mathrm{c}})_{\mathrm{x}}$ and $(\underline{\boldsymbol{e}}^{\mathrm{m}})_{\mathrm{y}}$ is β (rotation angle around the $(\underline{\boldsymbol{e}}^{\mathrm{c}})_{\mathrm{z}}$-axis). In addition, the sensor $(\underline{\boldsymbol{e}}^{\mathrm{m}})_{\mathrm{z}}$-axis can be constructed by a rotation of η in the $(\underline{\boldsymbol{e}}^{\mathrm{c}})_{\mathrm{x}}$, $(\underline{\boldsymbol{e}}^{\mathrm{c}})_{\mathrm{y}}$-plane and a second rotation of γ out of this plane. Then this misalignment of the base vectors is given by

$$\underline{\underline{\boldsymbol{O}}} = \begin{pmatrix} 1 & \sin\beta & \sin\gamma \\ 0 & \cos\beta & \cos\gamma\,\sin\eta \\ 0 & 0 & \cos\gamma\,\cos\eta \end{pmatrix} \tag{2}$$

By comparison of the angles β, η, γ with misalignment angles $\xi_{xy}, \xi_{xz}, \xi_{yz}$ the misalignment matrix (2) can be written in the following shape:

$$\underline{\underline{\boldsymbol{O}}} = \begin{pmatrix} 1 & \cos\xi xy & \cos\xi xz \\ 0 & \sin\xi xy & \dfrac{\cos\xi yz - \cos\xi xy\,\cos\xi xz}{\sin\xi xy} \\ 0 & 0 & \sqrt{sin^2\xi xz - \dfrac{(\cos\xi yz - \cos\xi xy\,\cos\xi xz)^2}{sin^2\xi xy}} \end{pmatrix}$$

$\underline{\underline{\boldsymbol{O}}}$ transforms the base vectors. To achieve the transformation between the field components the transposed, inverse matrix of $\underline{\underline{\boldsymbol{O}}}$ has to be calculated as the final misalignment matrix:

$$\underline{\underline{\boldsymbol{\omega}}} \;\; = (\underline{\underline{\boldsymbol{O}}}^{T})^{-1}$$

- Calculation of the Rotation matrix $\underline{\underline{\boldsymbol{\rho}}}$

  With the knowledge of ω and the nominal Setup matrix $\underline{\underline{\boldsymbol{R}}}_{\mathrm{nom}}$ the rotation matrix $\underline{\underline{\boldsymbol{\rho}}}$ can be evaluated:

$$\underline{\underline{\boldsymbol{\rho}\;}} = (\underline{\underline{\boldsymbol{R}}}_{\mathrm{nom}}\,)^{-1}\;\; \underline{\underline{\boldsymbol{\Phi}}}\hat{}\;\; (\underline{\underline{\boldsymbol{\omega}}})^{-1}$$

  From this rotation matrix, the actual rotation angles of the sensor w.r.t. the coil system can be calculated using again the scalar product:

$$\lambda := \arccos\left(\left[\boldsymbol{\rho}\begin{bmatrix}1\\0\\0\end{bmatrix}\right]\cdot\begin{bmatrix}1\\0\\0\end{bmatrix}\right)$$

$$\mu := \arccos\left(\left[\boldsymbol{\rho}\begin{bmatrix}1\\0\\0\end{bmatrix}\right]\cdot\begin{bmatrix}1\\0\\0\end{bmatrix}\right)$$

$$\nu := \arccos\left(\left[\boldsymbol{\rho}\begin{bmatrix}1\\0\\0\end{bmatrix}\right]\cdot\begin{bmatrix}1\\0\\0\end{bmatrix}\right)$$

  The rotation matrix $\underline{\underline{\boldsymbol{\rho}}}$ and the rotation angles λ, μ, ν are of interest only for the calibration to determine the right magnetometer parameters.

The transfer function for the normal use of the magnetometer is just given by

$$\underline{\underline{\boldsymbol{\Phi}}}^{\sim} = \underline{\underline{\boldsymbol{\omega}}}\;\underline{\underline{\boldsymbol{\sigma}}}$$

2.4.2 In-flight Calibration

The in-flight calibration of magnetometers is a challenging problem, particularly on three axes stabilized spacecraft. A spacecraft-induced magnetic background can be seen at the location of the MPO-MAG sensors. This is the primary and crucially important reason that the MPO-MAG instrument has two boom-mounted sensors.

The objective of the in-flight calibration is

(a) to determine and monitor the actual spacecraft-induced magnetic background at the magnetometer sensors

(b) to verify to what extent the ground calibration remains valid

(c) to monitor and quantify any changes in the calibration parameters.

(d) to generate a “magnetic field data product” cleaned and treated on best effort base.

The standard calibration parameters achieved during the ground calibration are a good proxy for the situation on board. Especially sensitivity and misalignment have probably not to be changed anymore. In contrast, the absolute value of the magnetic field will definitely be different from the ideal ones identified during the ground calibration under ideal conditions.
The absolute value of the field is determined by the sum of the instrument offset and the s/c-magnetic field.
The instrument offset, including its temperature behavior, is most likely sufficiently known from the ground calibration – far better than 1 nT. Nevertheless, this will be checked by suitable means as aging processes might play a role here.

The s/c-magnetic field, however, will vary with time and is still unknown, although the MPO-MAG sensors are located on a relatively long boom. Especially all the various s/c-state changes will have huge impact on this entity.

Already from the first weeks of data from the commissioning slot during NECP and the first months of the cruise phase we could learn a lot. In that s/c- configuration - MAG boom deployed, MTM and MMO attached to MPO - we can clearly see a dependence of the

- MTM Solar Array rotation angle to the s/c-magnetic field in the order of about 30 nT.
- Reaction wheel rotation rate to the AC s/c-magnetic field.
- Current flowing through the SEPS and generating a field of roughly 30 nT.
- Slow varying offset/spacecraft magnetic field over weeks in dependence of temperature

From ROSETTA we know that

- Thruster activities can cause significant magnetic field DC- as well as AC-disturbances in wide frequency ranges.
- Currents flowing on the s/c and ground loops can generate peculiar disturbance pattern.
- P/L can cause magnetic distortions due to currents and switched magnets.
- Activation of heaters, which are either operated in a pulse width modulated way or just in a conventional on/off mode, can be visible in the magnetic field.

Therefore, further investigations will be conducted permanently during the long cruise phase in order to be able to characterize the spacecraft-payload-system in more details. Data cleaning/flagging algorithms will be developed or adapted from the ROSETTA experience accordingly. One of the major topics is the creation of a temperature dependent inflight model of the s/c disturbance & sensor offset.

We propose to use the dual-magnetometer technique for in-flight calibration. This technique was first developed by Ness et al., 1970 with the purpose of correcting magnetic field measurements on a spacecraft that produced a significant magnetic disturbance at the location of the magnetometer sensors. The technique has been rarely used in practice as most spacecraft either achieved an adequately high level of magnetic cleanliness or had a long enough boom. In other cases when a single magnetic sensor was used, a significant uncertainty remained concerning the absolute accuracy of the measurements. The dual magnetometer technique has been successfully applied recently to the CSSAR/ESA Double Star spacecraft. Due to inadequate compensation of the currents generated by the spacecraft, a significant magnetic disturbance was found after launch at the location of the two magnetometer sensors. The dual magnetometer technique has been applied to the data. The disturbance field due to the spacecraft has been identified and quantified and the ensuing in-flight calibration algorithm and procedure ensured that the measurements could be used to generate scientifically usable data.

In addition to the dual magnetometer technique, more standard calibration procedures will be used through a built-in calibration mode and by the use of the statistical properties of the magnetic field data when the MPO is operated in the solar wind.

From the experience of the first year of magnetic field observations during the cruise phase we learned two things:

1) The deviation of the magnetic field readings to the real absolute value of the external magnetic field components can be minimized if a certain offset is added to the components. This shift is considered to be constant for each individual switch-on/switch-off interval of the instrument. Thus it is varying in the frame of months. It will be recalculated after such a phase and the original calibrated data (which have not been published in the archive at that stage) will be reprocessed and thus now taking into account the new offset. At the time of writing this paragraph (December 2020) these new data are the “calibrated data” being published. The current offsets including timestamps are written into so called “static offset calibration files”, which are read by the pipeline s/w and are also being published in the archive.
   The offset adjustment at the times of every switch on/reboot event only has the advantage that artificial jumps inside gapless time series can be avoided.

2) Additionally we learned that the temperature variation over months, due to varying sun –s/c distance, causes varying s/c- magnetic disturbing fields. A polynomial model of the field versus temperature will be calculated and used to minimize the temperature effects to the data. The polynomial coefficients will be written to the temperature calibration file and read by the raw2cal pipeline for a coarse data temperature correction. This process still under development and currently (December 2020) not applied to the data (polynomials are already existing, but coefficients are still set to zero). In the unlikely case that not only one but various time dependent temperature polynomials would have to be used, we will apply the corrections that way that no artificial jumps but smooth transition between the segments will occur by choosing suitable coefficients.

These two effects are purely spacecraft related and could therefore not be assessed during the ground calibration. Thus they are listed here in the “inflight calibration” section. Nevertheless, these two corrections can be applied automatically once understood completely and coded into the pipeline s/w. Therefore, already the “calibrated data” could benefit much from these corrections and thus we decided to apply these automatically running improvement algorithms already to the “calibrated data” and not only to “inflight calibrated” data. The generation of “inflight calibrated” data needs more manual work and more auxiliary information about P/L and S/C systems which will take much more time for preparation.

As a general rule we can state that the “calibrated data” will contain all possible corrections available during the time of observation (e.g. ground calibration results, long term inflight offset and temperature models) and that the “inflight calibrated data” will be generated using more specific, highly variable disturbance sources requiring longer development and processing times.

2.4.3 Known Instrument Shortcomings

At the time of writing this document, the following malfunctions are known:

- The temperature sensor #2 of the MPO-MAG IB-Sensor has a loose contact and should therefore not be used. This thermistor is located close to the heater of the IB-Sensor. The behavior will be flagged in the related data labels.

3 DATA GENERATION AND ARCHIVING PROCESS

The MPO-MAG science products are produced under the responsibility of the MPO-MAG 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 MPO-MAG 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 MPO-MAG data, from on-board acquisition by the MPO-MAG instrument through to ingestion into the ESA's Planetary Science Archive (PSA).

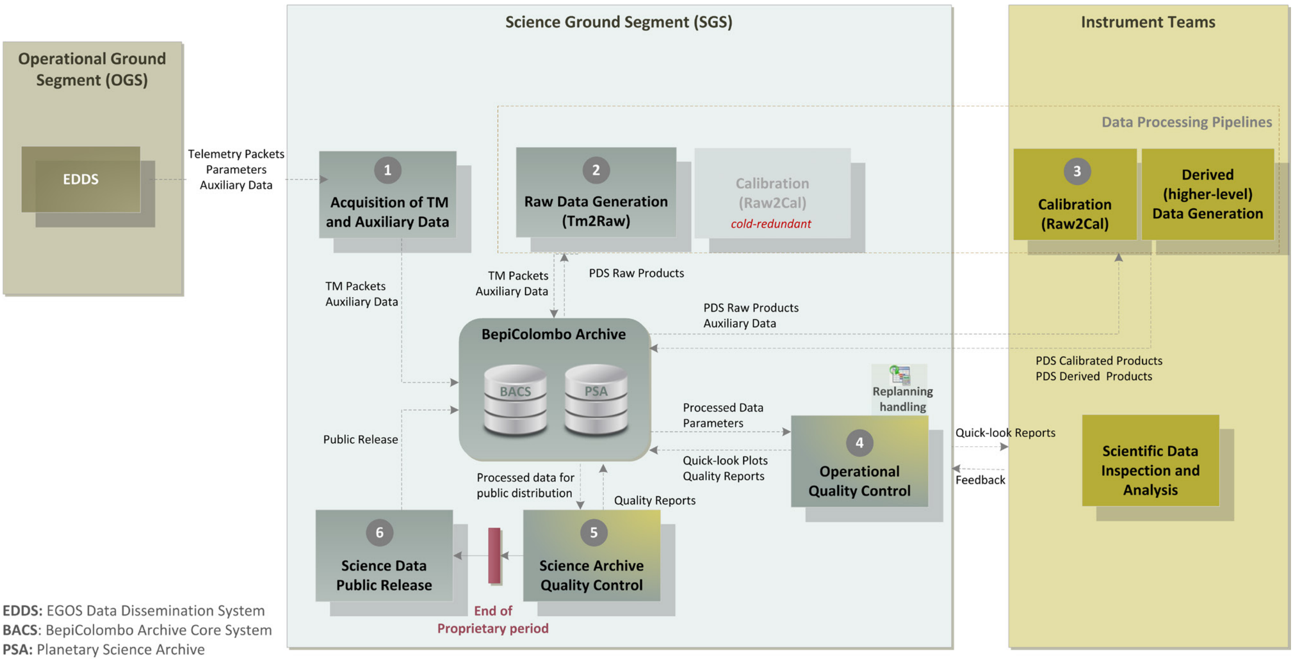

Figure 7: Science Data Flow

i. *Acquisition of Telemetry and Auxiliary Data. (1)* 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 File Transfer Service (FTS).

   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) 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 operational archive (a.k.a. BOA), for further processing and long-term preservation. Ka-band telemetry files are decomposed into packets as part of this process.

ii. *Raw Data Generation.* (2) Telemetry packets resulting from all instruments are systematically converted into PDS raw data products (un-calibrated) by the SGS. These data are available in the PSA as RAW products. Additionally, PDS raw science products are converted always to partially processed products (PAR, still in counts) which are acting as input files for the *raw2cal* pipeline software for the generation of calibrated data. These science PAR files contain the magnetic field data from the science raw files and the temperatures, compensation values, range and clipping information from the HK files. This additional information is essential for the generation of proper calibrated data.

iii. *Calibrated Data Generation.* (3) PDS calibrated products are generated based on the best current calibration factors (obtained from ground calibration) and analysis routines, and using as input the PDS raw products generated in the previous step. This is done by the PI team, with a prime-redundant configuration i.e. the prime calibration runs at the PI team site while the SGS might host a backup of the calibration software (for redundancy). Still TBC. 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.

iv. *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 MPO-MAG archive products can be found in section 3.2.

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

v. *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 organized into the so-called PDS4 bundles. For BepiColombo, there is one mission bundle and eleven instrument bundles, one per 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.

vi. *Operational Quality Control.* (4) Science quick-look products are generated from the raw and calibrated products, and are made available through a dedicated web-based interface. Using this interface, PI teams monitor the deviations between the planned and the executed science observations and provide a first assessment of the quality of the generated science data products. PI teams feedback the result of this analysis to the SGS. In addition, SGS performs regular completeness and integrity checks on the data.

vii. *Science Archive Quality Control.* (5) 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 organized by the SGS, in coordination with the Project Scientist.

viii. *Science Data Public Release.* (6) All science data resulting from BepiColombo is subject to a maximum proprietary period of six months after which the data will be made publicly available through the PSA. In routine operations it is expected that 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 MPO-MAG Archive Products

WARNING!

Magnetic field observations onboard satellites are subject to various disturbances like e.g. thruster activities, solar array rotations, temperature effects, P/L-mode switches, electric current flow, reaction wheel operations, heater switches, etc. Although the data are processed very thoroughly it cannot be ruled out that these effects pretend to appear as scientifically interesting structures in the data, which are, however, purely based on the mentionend artificial disturbance effects. Therefore, the data should be used very carefully when utilized for scientific analyses. In the final state of the archive quality flags used for derived data will indicate disturbance problems on best effort base - but a remaining risk will definitely persist. Therefore:

In any doubt, please contact the PI team for further advice!

The primary data products of the MPO-MAG instrument are times series of the magnetic field measured during the BepiColombo mission. Additionally the instrument housekeeping values like e.g. measured instrument supply voltages will be ingested into the archive. Furthermore, the required documentation like e.g. this EAICD will be published with the data. The used parameters from the ground calibration and the sophisticated inflight calibration will be provided as well.

The magnetic field data will be available at different processing levels and various coordinate systems.

Processing levels are

- **Raw data: (RAW)**

This type of data contain directly to ASCII converted TM data without any further processing. Data are just given in counts. The TM data are sorted by HK and science data. The science data are stored in separate files for each sensor at each available sampling rate, individual for each day.

- **Partially processed data: (PAR)**

This type of data contain directly to ASCII converted TM data without any further processing. Data are just given in counts. In contrast to RAW data, the PAR data files contain combined data streams of SCIENCE and HK data, in order to have all important information in one file. Thus magnetic field vectors and temperatures are compiled here.

- **Calibrated data: (CAL)**

The next level of data are raw data which have been fed into standard calibration algorithm taking into account the temperature dependent sensitivity, misalignment and sensor offset. As result ground calibrated data, still separate for OB and IB sensor, are written to the "data calibrated" directory. At this level, neither any s/c influence nor possibly occurring aging effects of the instrument are taken into account.

However, the long term temperature effect minimization and a coarse long term offset/disturbance field correction are taken into account during data generation.

Thus the ground calibrated data will most likely not have the exact right absolute value and will contain lots of s/c signatures like e.g. Solar array rotations, electric propulsion impacts, AC reaction wheel disturbances etc. Data are given in nanotesla.

Therefore, calibrated data have to be used very carefully when utilized for scientific analyses, as sometimes occurring pattern might pretend interesting new science although it just might be a signature of s/c disturbance fields. In any doubt, please contact the PI team for further advice!

- **Derived data: (DER)**

We distinguish different kind of Derived Data:

- ➢ Averaged Calibrated Data: These data are just calibrated data which have been averaged to a certain time interval, indicated in the file names. The standard interval is one second. Data are provided in celestial coordinates only.
- ➢ Inflight Calibrated Data: These data will finally be the real "magnetic field data product". Only one time series, derived from the OB and IB sensor – using the dual magnetometer technique – will be generated. Disturbances will be eliminated on best effort base and data will be flagged according to the various disturbance sources. Data units are nanotesla. The major actual calibration parameters will be written to a calibration file.
- ➢ Averaged Inflight Calibrated Data: These data are averaged inflight calibrated data as just described. Standard average interval is again one second.

Details concerning the data files are described in section 4.2.

3.3 Data Generation, Calibration and Analysis

The data generation and calibration is a complex chain of tasks being briefly displayed in **Figure** 7.

The chain starts with magnetic field observations onboard the BepiColombo MPO spacecraft using the MPO-MAG magnetometer. Data are measured using two sensors, the OB and the IB sensor. Additional instrument HK data are measured. All these data are converted into various TM packets compliant to the ESA TM data structure according to the definitions in the EID-A. The TM stream is transmitted to Earth, where the data will be received using the deep space antennas. The received data are sent to ESOC where all the binary data are stored in the EDDS.

In the next step, SGS retrieves the relevant MAG TM packets (Standard science and HK) from the EDDS and converts the binary data to ASCII data using the SGS software *tm2raw*. The output of this software is manifold:

- ASCII HK raw data will be generated for each day and sensor and stored in individual files
- ASCII Science raw data will be generated for each day, sensor and each sampling mode at that day and stored as well in individual files. These files also contain the actual compensation values, clipping information and of course the sensor temperatures.

For format details, refer to section 4.2.1.

In the following step, these raw data in counts will be converted to ground calibrated data in physical units, taking into account all information available from the ground calibration. This RAW2CAL process is described in the schematic software overview depicted in **Figure 8**.

The conversion of HK raw data to calibrated HK data is done using linear transformations obtained from the HK coefficients files

- `calibration_files\mag_calib_hk_coefficients.asc`

These coefficients were directly derived from the datasheets of the electronics manufacturer.

The conversion of the magnetic field science raw data in URF coordinates to calibrated science data in URF coordinates is done using the algorithm described in section 2.4.1.1. The necessary input parameter from the ground calibration is taken from the calibration files

- `calibration_files\mag_calib_gnd_fm1_s10_ib_cal0.asc`
- `calibration_files\mag_calib_gnd_fm1_s10_ob_cal0.asc`

These files contain the calibration parameters obtained from the Magnetsrode calibration analysis S/W.

From the experiences of the first months of MPO-MAG operation we concluded that the data can be improved if a specific offset and S/C magnetic field value is added to the data for certain intervals. These values are determined after a certain time period has elapsed. A value will be changed only after the instrument has been switched off/switched on again in order to avoid artificial jumps in the time series. The additional shift values, which have been applied to the data after reprocessing can be found in the STATIC OFFSET files

- `calibration_files\mag_calib_static_offset_ib.asc`
- `calibration_files\mag_calib_static_offset_ob asc`

These files contain four columns: a time column indicating a start time for the actual shift values and the 3 shift components (x,y,z) in URF coordinates. The values are called static offsets, because they are changed only in the cadence of several months.

Note on the determination of these static offsets:

> The magnetic s/c-disturbances are varying over various timescales and different amplitudes due to manifold s/c-operations. As it will probably not be feasible to relate all occurring disturbances to definite sources on the s/c a statistical approach has to be applied. A view to the data reveals that a coarse stepwise offset adjustment, specific for each switch on/switch off phase, could already improve the data quality significantly. A fine tuning, accounting for temperature dependences and distinct switch processes, will be done later.
>
> Thus we developed a method that just calculates the longterm static offsets of all measured magnetic field components using the intrinsic properties of the solar wind. As the solar wind fluctuations are primarily changes in direction rather than changes in magnitude, the magnitude is more constant than any of its components; the Alfvenic fluctuations provide a proven means to estimate the unknown offsets. The algorithm is based on the Davis-Smith method [RD.15] which obtains the zero values by minimizing the variance of the squared magnetic field magnitude over many data intervals. Data are taken on six minute windows which are shifted by ten seconds over the complete measurement phase. The statistical distribution of the calculated offsets is then characterized by a Kernel Density Estimator yielding in the most probable offsets for the given time interval.

The second experience during the first months of the mission regards the long term temperature effects. It turned out that the varying temperature due to changing s/c- sun distance, causes the s/c-magnetic disturbing field to change. Therefore, a polynomial temperature model will been created to minimize this effect. The polynomial coefficients will be stored in the temperature calibration files

- `calibration_files\mag_calib_temperature_offset_ib.asc`
- `calibration_files\mag_calib_temperature_offset_ob asc`

These files will contain individual temperature polynomial coefficients for each magnetic field component. The value of the polynomial at the current temperature is subtracted from the magnetic field data by the raw2cal software.

Note on the temperature correction:

> At the time of writing this paragraph (December 2020) details on the temperature correction are still unknown. Although a strong evidence for temperature depending zero levels of the magnetic field readings is present, the source is still unknown. The temperature dependence is roughly ten times higher than the pure sensor offset drift observed and calculated during the ground calibration. This definitely proofs that external (S/C or P/L) temperature dependent magnetic field sources diminish the quality of the magnetic field measurements. The problem is to find the right temperature sensor on the s/c that reflects this behavior in the best way. We also have the guess that the rotating solar arrays in conjunction with varying illumination condition are causing time, temperature and current depending impacts on our measurements, which should somehow be incorporated in this correction. Therefore, lots of investigations are necessary until the final correction polynomials are found.

At a further step, the science data in URF coordinates are transformed to S/C-coordinates (scf folder) and suitable celestial coordinates using SPICE routines. The coordinates are e.g. ECLIPJ2000 (E2K folder) during cruise or convenient Mercury frames (MSE, MSEQ,..)

For format details, refer to section 4.2.3. and **Table 11**.

These calibrated data do only take into account the temperature dependent sensor parameters, namely sensitivity matric, misalignment matrix and the offset vector.

All the s/c influence and disturbance like e.g. dynamic reaction wheel disturbance, S/A currents and rotations, navigation thruster activity, SEPS operations, and impact of other P/L instrument are ignored at this calibration level as a complete automatic pipeline until this step was intended to be executed.

All the latter magnetic field impacting entities will be considered at the later stage of the generation derived data and lead to so called inflight calibrated data. Here we distinguish between data provided at the original sample rate (inflight_cal_sc) and averaged data (avg_inflight_sc) at a standard average rate of one second. Further details are still TBD.

For format details of the derived data, refer to section 4.2.4.

Figure 8 gives an overview about the internal structure of the Raw2Cal software. “Green” files are input data, “yellow” files are PDS4 compliant output data.

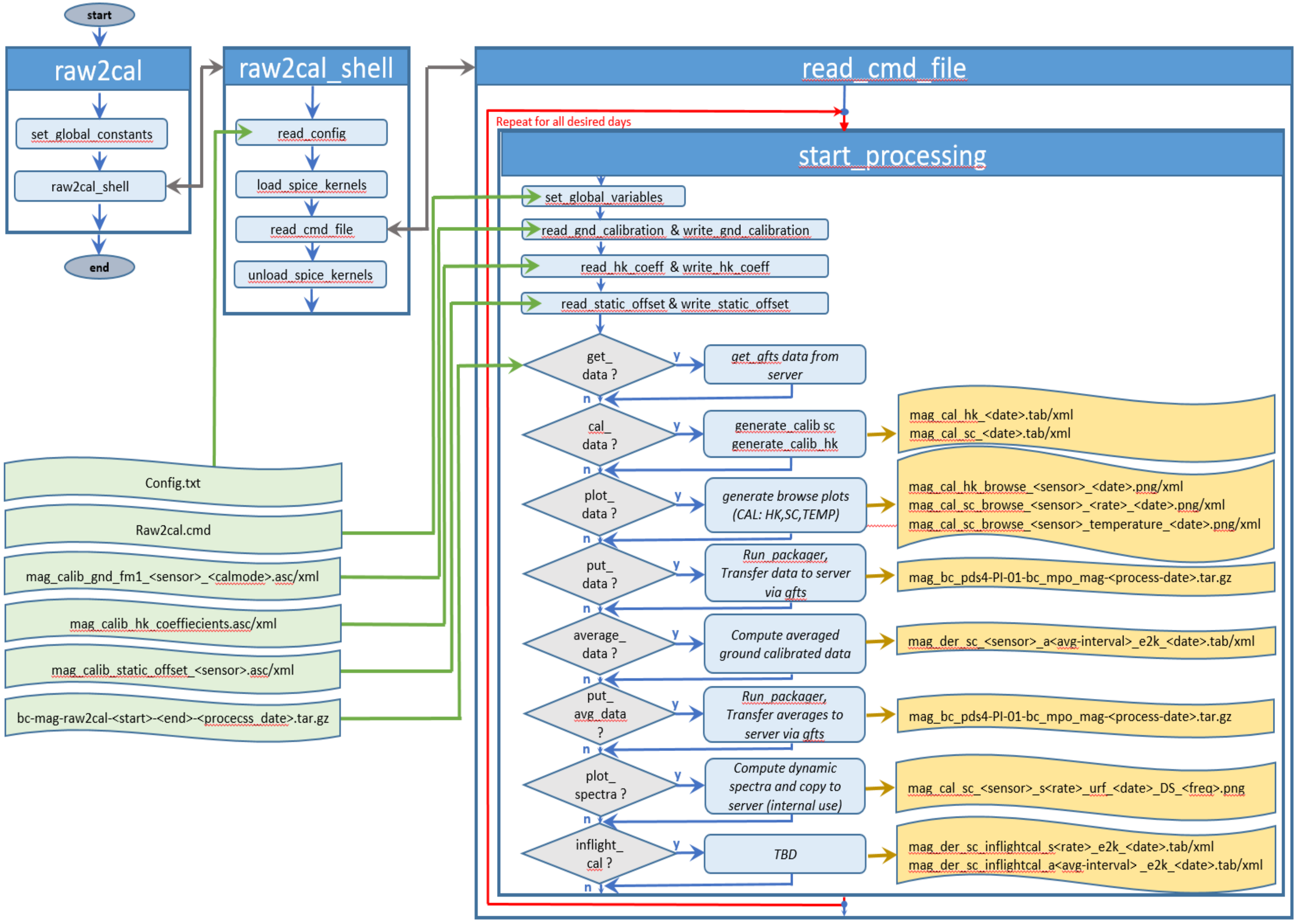

Figure 8: RAW2CAL – Generation of Calibrated Data

The processes running in this s/w are controlled by the command input file *Raw2Cal.cmd*. It consists of a sequence of day-based text blocks built by statements of a simple but powerful meta-language like shown below:

```
START:
 DAY= 2020-02-02
 REFERENCE_BODY= SUN                      ; or EARTH, VENUS, MERCURY …..
 CELESTIAL_COORDSYS= ECLIPJ2000           ; or BC_MSO, BC_GSE, BC_VSO….
 RESAMPLED_AVERAGE= 1                     ; Resampling interval in seconds
 GET_DATA=  Y                             ; Y/ N  - retrieve data from server (Y) or use local data  (N)
 CAL_DATA=  Y                             ; Y/N Run calibration (Y) or use already existing data (N)
 GEN_PLOTS= Y                             ;Y/N Generate Browse plots (Y) or use already existing plots (N)
 GEN_AVG_CAL_SC_DATA_CELESTIAL= Y         ;Y/N Generate averaged data (Y) or use already exisiting data (N)
 GEN_DYNSPEC_PLOTS= Y                     ;Y/N Generate dynamic spectra (Y) or use already exisiting spectra (N)
 PUT_CAL_DATA=  Y                         ;Y/N run packager and transfer GFTS file to server
 PUT_DER_AVG_DATA= Y                      ;Y/N run packager and transfer GFTS file with averaged data to server
 ACTION:                                  ; start processing
END:
```

Each command between START: and STOP: will be parsed and used by the pipeline s/w. The real processing of the stated DAY starts after the recognition of the command ACTION: defining all the processing this way allows it to reprocess the data as often as required.

All these control words are used to select the related program blocks (grey rhombical decision fields) and to process the data of the desired day in a specific, reproducible way.

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 MPO-MAG 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.

The validation of the data is an easy task, which is conducted quasi-automatically, as the MAG team uses the archive data files for all the scientific investigations. No second set of differently formatted data will be generated. Therefore, all science output is based on the official archive files and all MAG team members will reveal any significant error in these files during the extensively scientific usage of the archived files.

3.4.3 Science Reviews

Formal science reviews of the data will be organized 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 reviews will be organized as necessary.

Such a review will contain sample data and documentation in the format of the final archived data set. The sample data will be produced using real flight datasets that may differ from the final data set only in specific values and sizes. Data formats, data processing, and archiving methods are identical.

4 DATA ORGANISATION AND CONTENTS

4.1 Format and Conventions

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

All data from the MPO-MAG 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 standardized by PDS4 to four levels: raw, partially processed, calibrated and derived.

The structure of the bundle is outlined in **Figure 9**.

Details of the structure and content of the MPO-MAG bundle are provided in the following sections.

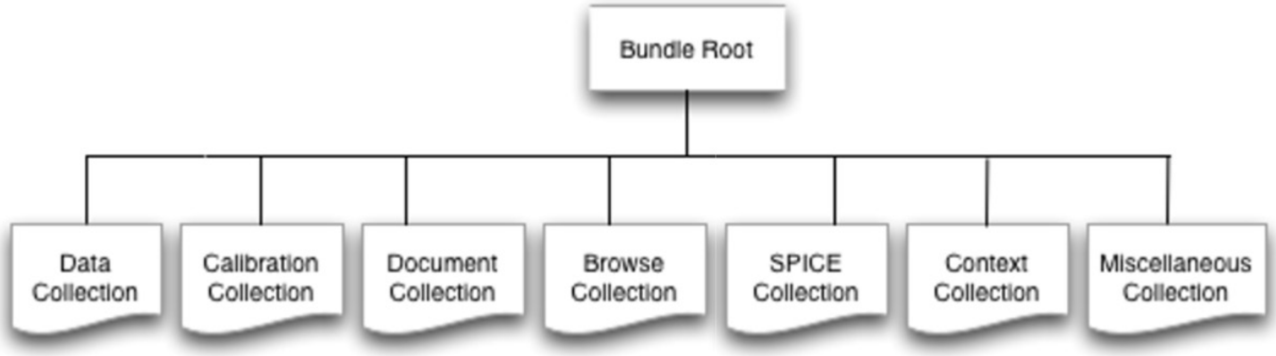

Figure 9: PDS4 bundle structure

4.1.1 *Logical Identifiers Formation*

Bundle and collection logical identifiers are as indicated in **Table 12** and **Table 13** . General conventions can be found in section 3 of the BepiColombo Archiving Guide [AD.02].

4.1.2 Data Directory Naming Convention

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

For details see sections 4.2.x of the present document.

The following tree reveals the structure and used names of the used MPO-MAG archive :

Archive Structure	Description
+---**browse_calibrated**	used for browse plots
+---near_earth_commissioning	mission phase name, here: Near Earth Commissioning
+---hk	housekeeping data
+---ib	inboard sensor
+---ob	outboard sensor
+---sc	science data
+---ib	inboard sensor
+---<celestial_coords>	Celestial-coordinates
+---scf	S/C-coordinates
+---temperature	Temperature data
+---urf	Instrument-coordinates (unit reference frame)
+---ob	outboard sensor
+---<celestial_coords>	Celestial-coordinates
+---scf	S/C-coordinates
+---temperature	Temperature data
+---urf	Instrument-coordinates (unit reference frame)
+---cruise	mission phase name, here: Cruise Phase
+---hk	housekeeping data
+---ib	inboard sensor
+---ob	outboard sensor
+---sc	science data
+---ib	inboard sensor
+---<celestial_coords>	Celestial-coordinates
+---scf	S/C-coordinates
+---temperature	Temperature data
+---urf	Instrument-coordinates (unit reference frame)
+---ob	outboard sensor
+---<celestial_coords>	Celestial-coordinates
+---scf	S/C-coordinates
+---temperature	Temperature data
+---urf	Instrument-coordinates (unit reference frame)
+---**calibration_files**	needed files for calibration

+---**data_calibrated**	Ground calibrated data
+--- near_earth_commissioning	mission phase name, here: Near Earth Commissioning
+---hk	housekeeping data
+---ib	inboard sensor
+---ob	outboard sensor
+---sc	science data
+---ib	inboard sensor
+---<celestial_coords>	Celestial-coordinates
+---scf	S/C-coordinates
+---urf	Instrument-coordinates (unit reference frame)
+---ob	outboard sensor
+---<celestial_coords>	Celestial-coordinates
+---scf	S/C-coordinates
+---urf	Instrument-coordinates (unit reference frame)
+---cruise	mission phase name , here: Cruise Phase
+---hk	housekeeping data
+---ib	inboard sensor
+---ob	outboard sensor
+---sc	science data
+---ib	inboard sensor
+---<celestial_coords>	Celestial-coordinates
+---scf	S/C-coordinates
+---urf	Instrument-coordinates (unit reference frame)
+---ob	outboard sensor
+---<celestial_coords>	Celestial-coordinates
+---scf	S/C-coordinates
+---urf	Instrument-coordinates (unit reference frame)
+---***data_derived***	Derived Data
+---avg_cal_sc	Averaged calibrated science data
+--- near_earth_commissioning	mission phase name, here: Near Earth Commissioning
+---ib	inboard sensor
+---<celestial_coords>	Celestial-coordinates
+---ob	outboard sensor
+---<celestial_coords>	Celestial-coordinates
+---cruise	mission phase name, here: Cruise Phase
+---ib	inboard sensor
+---<celestial_coords>	Celestial-coordinates
+---ob	outboard sensor
+---<celestial_coords>	Celestial-coordinates
+---inflightcal_sc	Inflight calibrated & best effort disturbance eliminated data
+--- near_earth_commissioning	mission phase name, here: Near Earth commissioning
+---<celestial_coords>	Celestial-coordinates
+---cruise	mission phase name, here: Cruise Phase
+---<celestial_coords>	Celestial-coordinates

+---avg_inflightcal_sc	Averaged Inflight calibrated & best effort disturbance eliminated data
+--- near_earth_commissioning	mission phase name, here: Near Earth commissioning
+---<celestial_coords>	Celestial-coordinates
+---cruise	mission phase name, here: Cruise Phase
+---<celestial_coords>	Celestial-coordinates
+---***data_raw***	Instrument raw data in Counts
+--- near_earth_commissioning	mission phase name, here: Near Earth commissioning
+---hk	housekeeping data
+---ib	inboard sensor
+---ob	outboard sensor
+---sc	science data
+---ib	inboard sensor
+---urf	Instrument-coordinates (unit reference frame)
+---ob	outboard sensor
+---urf	Instrument-coordinates (unit reference frame)
+---cruise	mission phase name, here: Cruise Phase
+---hk	housekeeping data
+---ib	inboard sensor
+---ob	outboard sensor
+---sc	science data
+---ib	inboard sensor
+---urf	Instrument-coordinates (unit reference frame)
+---ob	outboard sensor
+---urf	Instrument-coordinates (unit reference frame)
+---***data_partially_processed***	Partially processed raw data in Counts
+--- near_earth_commissioning	mission phase name, here: Near Earth commissioning
+---hk	housekeeping data
+---ib	inboard sensor
+---ob	outboard sensor
+---sc	science data
+---ib	inboard sensor
+---urf	Instrument-coordinates (unit reference frame)
+---ob	outboard sensor
+---urf	Instrument-coordinates (unit reference frame)
+---cruise	mission phase name, here: Cruise Phase
+---hk	housekeeping data
+---ib	inboard sensor
+---ob	outboard sensor
+---sc	science data
+---ib	inboard sensor
+---urf	Instrument-coordinates (unit reference frame)
+---ob	outboard sensor
+---urf	Instrument-coordinates (unit reference frame)
+---***document***	Useful documents

Table 10: MPO-MAG Archive Structure

REMARKS to the *document* directory:

The *document directory* will be populated with suitable sub-directories if this would improve the archive usability. It will contain useful information needed to understand and work successfully with the MPO-MAG data.

REMARKS to <CELESTIAL>-Coordinates:

The raw2cal pipeline by default generates data in Instrument-Coordinates (urf, unit reference frame) and S/C-coordinates (scf). Data are also provided in our standard celestial frame ECLIPJ2000 (e2k) by default. This default can be changed if another celestial frame is more convenient for the current observation situation.

The generation of data is dependent of the availability of the specific frame inside the SPICE kernel system. From the calibration pipeline point of view data can be rotated to any desired frame available in the SPICE kernels.

A list of currently implemented and meaningful frames is listed in **Table 11**. We do not intend to provide data on daily bases in all possible frames as this would definitely overstrain the available resources. However, provision of specific data on request can be negotiated.

DATA_REFERENCE_SPICE_FRAME	DATA_REFERENCE_FRAME_ACRONYM (used in filenames and folders)	DESCRIPTION
'MPO_MPO-MAG_IBS'	'urf'	MPO-MAG inboard-sensor unit reference frame
'MPO_MPO-MAG_OBS'	'urf'	MPO-MAG outboard-sensor unit reference frame
'MPO_SPACECRAFT'	'scf'	MPO spacecraft frame
'ECLIPJ2000'	'e2k'	Ecliptic frame of Jan 1, 2000. X points from the Sun to the vernal equinox, Y is in the ecliptic plane pointing against the orbital motion of the Earth and Z completes the right-handed coordinate system.
'BC_MBF'	'mbf'	Mercury Body Fixed
'BC_MSO'	‘mso'	Mercury-Centric Solar Orbital
'BC_MSM'	'msm'	Mercury-Centric Solar Magnetospheric
'BC_MME_IAU2009_OF_DATE'	'mme'	Mean Mercury Equator and IAU vector of date using IAU 2009 Mercury rotation constants
'BC_MPO_RTN'	'rtn'	MPO Radial-Tangential-Normal Heliocentric
'BC_GSE'	'gse'	Geocentric Solar Ecliptic
'BC_GSM'	'gsm'	Geocentric Solar Magnetospheric
'BC_VSO'	'vso'	Venus Solar Orbital

'IAU_MERCURY'	'mer'	predefined Mercury Body Fixed PCK frame
'IAU_VENUS'	'ven	predefined Venus Body Fixed PCK frame
'IAU_EARTH'	'ear'	predefined Earth Body Fixed PCK frame

Table 11: Implemented Celestial Coordinate Systems

NOTE on celestial coordinate transformations:

All transformations between the different coordinate system can preferably be accomplished using the SPICE system [RD.13]. The names of the frames to be used are listed in the first column of **Table 11.** In order to avoid any miscalculations and problems the current metakernels (*bc_ops.tm* for operation and *bc_plan.tm* for planning), officially provided by ESA, should be used. The kernels are distributed via a git system and can be accessed by [RD.14]. Using self constructed sub-lists of kernels as well as home-designed transformation routines could show odd effects, therefore the use of the official metakernels and SPICE routines is strongly recommended.

4.1.3 File Naming Convention

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

The following sections illustrate the file naming convention used for the MPO-MAG archive.

4.1.3.1 Raw Housekeeping data

All files are twofold, one for each sensor. For each data table file (*.tab) a related xml label file (*.xml) exists.

General Filename:

mag_raw_hk_<sensor>_<type>_<orbitnumber>_<date>***.tab***
mag_raw_hk_<sensor>_<type>_<orbitnumber>_<date>***.xml***

Mnemonics:	<sensor>	= ***ib*** | ***ob***	; inboard or outboard sensor
	<type>	= ***sensor*** | ***temperature***	; sensor for general K values,

; temperature of temperature HK values

<orbitnumber> = nnnnn ; 5 digit integer orbit number,
set to 00000 before Mercury orbit insertion

<date> = yyyymmdd ; 4 digits year, 2 digits month, 2 digits day

Example:

mag_raw_hk_ib_temperature_00012_20250302.tab

mag_raw_hk_ib_temperature_00012_20250302.xml

mag_raw_hk_ob_sensor_00000_20190307.tab

mag_raw_hk_ob_sensor_00000_20190307.xml

4.1.3.2 Partially Processed Science data

All files are twofold, one for each sensor. For each data table file (*.tab) a related xml label file (*.xml) exists.

General Filename:

mag_par_sc_<sensor>***_s***<rate>_<coordinates>_<orbitnumber>_<date>***.tab***
mag_par_sc_<sensor>***_s***<rate>_<coordinates>_<orbitnumber>_<date>***.xml***

Mnemonics: <sensor> = ***ib | ob*** ; inboard or outboard sensor
<rate> = ***0..9*** ; sampling rate index according to **Table 4**.
<coordinates> = ***urf*** ; unit reference frame

<orbitnumber> = nnnnn ; 5 digit integer orbit number,
set to 00000 before Mercury orbit insertion
<date> = yyyymmdd ; 4 digits year, 2 digits month, 2 digits day

Example:
mag_par_sc_ib_s2_urf_00012_20250302.tab
mag_par_sc_ib_s2_urf_00012_20250302.xml

4.1.3.3 Calibrated Housekeeping data

All files are twofold, one for each sensor. For each data table file (*.tab) a related xml label file (*.xml) exists.

General Filename:

mag_cal_hk_<sensor>_<orbitnumber>_<date>***.tab***

mag_cal_hk_<sensor>_<orbitnumber>_<date>***.xml***

Mnemonics:			
	<sensor>	= ***ib*** | ***ob***	; inboard or outboard sensor
	<orbitnumber>	= nnnnn	; 5 digit integer orbit number, set to 00000 before Mercury orbit insertion
	<date>	= yyyymmdd	; 4 digits year, 2 digits month, 2 digits day

Example:

mag_cal_hk_ib_00012_20250302.tab

mag_cal_hk_ib_00012_20250302.xml

mag_cal_hk_ob_00000_20190307.tab

mag_cal_hk_ob_00000_20190307.xml

4.1.3.4 Calibrated Science data

All files are twofold, one for each sensor. For each data table file (*.tab) a related xml label file (*.xml) exists.

General Filename:

mag_cal_sc_<sensor>_***s***<rate>_<coordinates>_<orbitnumber>_<date>***.tab***
mag_cal_sc_<sensor>_***s***<rate>_<coordinates>_<orbitnumber>_<date>***.xml***

Mnemonics: <sensor> = ***ib | ob*** ; inboard or outboard sensor
<rate> = ***0..9*** ; sampling rate index according to **Table 4**.
<coordinates> = ***urf | scf | e2k …*** ; unit reference frame, s/c-coordinates, celestial coordinate reference frame acronym according to **Table 11**
<orbitnumber> = nnnnn ; 5 digit integer orbit number, set to 00000 before Mercury orbit insertion
<date> = yyyymmdd ; 4 digits year, 2 digits month, 2 digits day

Example:

mag_cal_sc_ib_s2_e2k_00012_20250302.tab
mag_cal_sc_ib_s2_e2k_00012_20250302.xml

mag_cal_sc_ob_s0_scf_00000_20190307.tab
mag_cal_sc_ob_s0_scf_00000_20190307.xml

4.1.3.5 Derived Science data

For each data table file (*.tab) a related xml label file (*.xml) exists.

Derived science data contain calibrated data, which have initially passed the ground calibration pipeline and were treated in different ways afterwards according to the descriptions in the next 3 paragraphs:

4.1.3.5.1 Averaged Calibrated Science data

Averaged calibrated science data are data, which have been derived directly from calibrated data by averaging to a certain interval. The standard average time interval is one second, but longer time intervals from 1 s up to 999 s are in principle possible. Data are provided for both, OB and IB sensor, but only in celestial coordinates.

Top level location for these data is the .*data_derived**avg_cal_sc*\ folder.

<u>General Filename:</u>

mag_der_sc_<sensor>***_a***<average_interval>_<coordinates>_<orbitnumber>_<date>***.tab***

mag_der_sc_<sensor>***_a***<average_interval>_<coordinates>_<orbitnumber>_<date>***.xml***

<u>Mnemonics:</u> <sensor> = ***ib*** | ***ob*** ; inboard or outboard sensor
<average_interval> = nnn ; seconds of average period (1…999)
<coordinates> = coord acronym ; celestial coordinate reference frame acronym according to **Table 11**

<orbitnumber> = nnnnn ; 5 digit integer orbit number, set to 00000 before Mercury orbit insertion
<date> = yyyymmdd ; 4 digits year, 2 digits month, 2 digits day

<u>Example:</u>

mag_der_sc_ib_a001_e2k_00012_20250302.tab

mag_der_sc_ib_a001_e2k_00012_20250302.xml

mag_der_sc_ob_a001_e2k_00012_20250302.tab

mag_der_sc_ob_a001_e2k_00012_20250302.xml

4.1.3.5.2 Inflight Calibrated Science data

Inflight calibrated science data are data which have been derived initially from calibrated data. Then corrections in order to minimize the s/c disturbance influence using combined and weighted IB and OB data have been made. Furthermore, suitable DC level shift, Reaction Wheel corrections have been applied and suitable data quality flags have been added. Thus there is only one data product available as a combination of OB and IB timeseries. Data are provided at the original sampling rate but in celestial coordinates only.

Top level location for these data is the .*data_derived**inflightcal_sc*\ folder.

General Filename:

mag_der_sc_inflightcal_s<rate>_<coordinates>_<orbitnumber>_<date>***.tab***

mag_der_sc_inflightcal_s<rate>_<coordinates>_<orbitnumber>_<date>***.tab***

Mnemonics:	<rate>	= ***0..9***	; sampling rate index according to **Table 4**.
	<coordinates>	= coord acronym	; celestial coordinate reference frame acronym according to **Table 11**
	<orbitnumber>	= nnnnn	; 5 digit integer orbit number, set to 00000 before Mercury orbit insertion
	<date>	= yyyymmdd	; 4 digits year, 2 digits month, 2 digits day

Example:

mag_der_sc_inflightcal_s2_e2k_00012_20241213.tab

mag_der_sc_inflightcal_s2_e2k_00012_20241213.xml

mag_der_sc_inflightcal_s6_e2k_00134_20210528.tab

mag_der_sc_inflightcal_s6_e2k_00134_20210528.xml

4.1.3.5.3 Averaged Inflight Calibrated Science data

Averaged inflight calibrated science data are data which have been derived directly from derived inflight calibrated data by averaging to a certain interval. The standard average time interval is one second. Data are provided only in celestial coordinates. No distinction between sensors is made.

Top level location for these data is the .*data_derived**avg_inflight_sc*\ folder.

General Filename:

mag_der_sc_inflightcal_a< average_interval >_<coordinates>_<orbitnumber>_<date>***.tab***

mag_der_sc_inflightcal_a< average_interval >_<coordinates>_<orbitnumber>_<date>***.xml***

Mnemonics: <average_interval> = nnn ; seconds of average period
<coordinates> = coord acronym ; celestial coordinate reference frame acronym according to **Table 11**
<orbitnumber> = nnnnn ; 5 digit integer orbit number, set to 00000 before Mercury orbit insertion
<date> = yyyymmdd ; 4 digits year, 2 digits month, 2 digits day

Example:

mag_der_sc_inflightcal_a001_e2k_00012_20241213.tab
mag_der_sc_inflightcal_a001_e2k_00012_20241213.xml

mag_der_sc_inflightcal_a001_e2k_00134_20210528.tab
mag_der_sc_inflightcal_a001_e2k_00134_20210528.xml

4.1.3.6 Calibration Files

All files are twofold, one for each sensor. For each calibration parameter file (*.asc) a related xml label file (*.xml) exists.

4.1.3.6.1 Ground Calibration Files

Ground Calibration Files contain all information necessary to convert instrument raw counts into physical usable entities (ADCcounts → nanotesla). These files are the result of the ground calibration conducted specifically for each sensor and each DPU.

General Filename:

mag_calib_<cal_type>_<unit>_**s**<sensor_number>_<sensor>_<calmode>***.asc***

mag_calib_<cal_type>_<unit>_**s**<sensor_number>_<sensor>_<calmode>***.xml***

Mnemonics: <cal_type> = ***gnd*** ; for ground calibration files
<unit> = ***fm1*** ; constant, for Flight model FM1
<sensor_number>= 10 |11 ; sensor manufacturing serial number [‡]
<sensor> = ***ib*** | ***ob*** ; inboard or outboard sensor
<calmode> = ***cal0*** | ***cal4*** ; Calibration mode 0 or 4

Example:

mag_calib_gnd_fm1_s10_ib_cal4.asc

mag_calib_gnd_fm1_s10_ib_cal4.xml

[‡] The manufacturing serial number was a number being used during the development phase of the sensors. At that time many individual sensors were produced and tested. As it was not clear at that time which sensors will be flown as real FM consecutive numbers were used for distinction. The best sensors were finally flown. These are IB = 10 and OB = 11.

4.1.3.6.2 Housekeeping Value Conversion Files

The Housekeeping Value Conversion Files contain all information to convert the housekeeping raw counts into physical usable values like Voltages or currents. The file comprises offset and scale values for all instrument HK parameters available

Files:

mag_calib_hk_coefficients.asc

mag_calib_hk_coefficients.xml

4.1.3.6.3 Static Offset Calibration Files

The Static Offset Calibration Files contain the "static" offset + s/c disturbance field, specific for each switch on period of the instrument. The values have been determined from observations over several month using the Hedgecock method and reflect an average value of the s/c-disturbance field. For each interval the file contains the start time of the actual shift values and the 3 components accordingly. These files are used for the automatic generation of calibrated data. New files will be ingested in the archive immediately once available.

General Filename:

mag_calib_static_offset_<sensor>***.asc***

mag_calib_static_offset_<sensor>***.xml***

Mnemonics: <sensor> = ***ib* | *ob*** ; inboard or outboard sensor

Files:

mag_calib_static_offset_ib.asc

mag_calib_static_offset_ib.xml

mag_calib_static_offset_ob.asc

mag_calib_static_offset_ob.xml

4.1.3.6.4 Inflight Calibration Files

Although the inflight calibration is still under development, we already have setup structural requirements in order to tackle any corrections. Any short term s/c disturbance field and offsets jumps will be adjusted using special inflight calibration files. These files will contain the actual shift values for the magnetic field in order to minimize s/c-disturbance jumps and temperature drifts. Each row of the file will consist the start time of the actual correction values and the 3 components accordingly. These files are intended to be used for the generation of derived inflight calibrated data.

The generation of derived data is still under development.

General Filename:

mag_calib_inflight_offset_<sensor>***.asc***

mag_calib_inflight_offset_<sensor>***.xml***

Mnemonics: <sensor> = ***ib*** | ***ob*** ; inboard or outboard sensor

Files:

mag_calib_inflight_offset_ib.asc

mag_calib_inflight_offset_ib.xml

mag_calib_inflight_offset_ob.asc

mag_calib_inflight_offset_ob.xml

4.1.3.7 Browse plots

All files are twofold. For each picture/plot file (*.png) a related xml label file (*.xml) exists.

Browse plots are generated for calibrated data only as a simple mean for quick look and diagnostic purposes.

General Filename:

mag_cal_<data_type>***_browse_***<sensor>_<type>_<rate_coordinates>_<orbitnumber>_<date>***.asc***

mag_cal_<data_type>***_browse_***<sensor>_<type>_<rate_coordinates>_<orbitnumber>_<date>***.xml***

Mnemonics:	<data_type>	=	***hk*** | ***sc***	; housekeeping or science data
	<sensor>	=	***ib*** | ***ob***	; inboard or outboard sensor
	<type>	=	""	; empty string for HK plots
		=	""	; empty string for magnetic field plots
		=	temperature	; for temperature plots
	<rate_coordinates>	=	""	; empty string for HK plots
		=	s<n>	; sampling rate n for temperature plots
		=	s<n>_<coords>	; sampling rate n and coordinates <coords> for magnetic field science plots
	<n>	=	0..9	; sampling rate index according to **Table 4**
	<coords>	=	***urf*** | ***scf*** | ***e2k..***	; unit reference frame, s/c-coordinates, ; celestial coordinate reference frame acronym according to **Table 11**
	<orbitnumber>	=	nnnnn	; 5 digit integer orbit number

<data> = yyyymmdd ; 4 digits year, 2 digits month, 2 digits day

Example:

mag_cal_hk_browse_ob_00000_20181104.png

mag_cal_hk_browse_ob_00000_20181104.xml

mag_cal_sc_browse_ib_s2_e2k_00012_20250302.png

mag_cal_sc_browse_ib_s2_e2k_00012_20250302.xml

mag_cal_sc_browse_ob_temperature_00012_20250302.png

mag_cal_sc_browse_ob_temperature_00012_20250302.xml

4.2 Bundle Content and Structure

The complete set of MPO-MAG 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***
MPO-MAG instrument bundle	urn:esa:psa:bc_mpo_mag	This bundle contains the data collected by the MPO-Mercury Magnetometer (MPO-MAG) instrument on-board the BepiColombo Mercury Planetary Orbiter (MPO), along with documents and other information necessary for the data interpretation.

Table 12: MPO-MAG instrument bundle

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

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

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

Directory Name	***Collection Logical Identifier (LID)***	***Description***
data_raw	urn:esa:psa:bc_mpo_mag:data_raw	Contains MPO-MAG raw data products, see section 4.2.1.
data_partially_processed	urn:esa:psa:bc_mpo_mag:data_partially_processed	Contains MPO-MAG partially processed_raw data products, see section 4.2.2.
data_calibrated	urn:esa:psa:bc_mpo_mag:data_calibrated	Contains MPO-MAG ground calibrated data products, see section 4.2.3.
data_derived	urn:esa:psa:bc_mpo_mag:data_derived	Contains MPO-MAG averaged ground calibrated and inflight calibrated, cleaned data products, see section 4.2.4 .
calibration_files	urn:esa:psa:bc_mpo_mag:calibration_files	Contains MPO-MAG ground calibration inputs, see section 4.2.5.
browse_calibrated	urn:esa:psa:bc_mpo_mag:browse	Science overview and quick-look analysis plots of the data products. See section 4.2.6.
document	urn:esa:psa:bc_mpo_mag:document	Documents related to the bundle; necessary for the use and interpretation of the MPO-MAG data. See section 4.2.7.
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 13: MPO-MAG 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_mpo_mag_data_raw.xml

- collection_mpo_mag_data_raw.csv
- <mission_phase>/
    - **hk** ; for housekeeping data
        - ib |ob
    - **sc** ; for science data
        - ib |ob

Where <mission_phase> is:

near_earth_commissioning	: Near Earth Commissioning Phase (NECP)
cruise	: Interplanetary Cruise phase (ICP)
flybys/earth_flyby	: Earth Gravity Assist
flybys/venus_flyby_n	: Venus Gravity Assist N, with N=1-2
flybys/mercury_flyby_n	: Mercury Gravity Assist N, with N=1-6
mercury_commissioning	: Mercury Orbit Commissioning Phase
mercury_science_orbit	: Mercury Science Phase

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

1) **MPO-MAG raw sensor housekeeping data**
Description:

The raw sensor housekeeping data contain time series of all relevant supply voltages and currents of the MPO-MAG instrument represented by raw ADC-counts. Individual files exist separately for the ib and ob sensor. Furthermore, heater data and status information is provided here. Additionally usage of the feedback relays and the clock source and also various internal status flags are listed in the hk data for diagnoses purposes.

Format and content details: Section 5.2.2.

2) **MPO-MAG raw temperature housekeeping data**
Description:

The raw temperature housekeeping data contain the sensor and electronics temperatures of the actual magnetic field sensor as well as the related sensor heater status. Data are raw values represented in ADC-counts.

Format and content details: Section 5.2.3.

3) **MPO-MAG raw science data**
Description:
The raw science data contain the time series of magnetic fields represented by raw ADC-counts converted to ASCII-values of a single sensor (ob | ib). Additionally the actual measurement range, clipping information indicating any over ranging, the coded sample rate, the offset compensation values and a quality bit derived from the vector checksum complete every data vector.

Format and content details: Section 5.2.1.

Directory Name	***File Naming Convention***	***Type***
hk	***mag_raw_hk_***<sensor>***_temperature_***<NNNNN>_<YYYYMMDD>**.xml/.tab**	1
hk	***mag_raw_hk_***<sensor>***_sensor_***<NNNNN>_< YYYYMMDD>**.xml/.tab**	2
sc	***mag_raw_sc_***<sensor>***_s***<rate>***_urf_***<NNNNN>_< YYYYMMDD>**.xml/.tab**	3

Table 14: MPO-MAG raw data product types

Where:

<sensor>: ib | ob
<rate>: measurement rate index according to ***Table 4.***
<NNNNN>: orbit number of the first measurement in the product (only used at Mercury)
<YYYYMMDD>: date of the measurements in the product

4.2.2 Partially Processed Data directory (data_partially_processed)

The structure of the partially processed raw data collection is as follows:

data_partially_processed/

- collection_mpo_mag_data_par.xml
- collection_mpo_mag_data_par.csv
- <mission_phase>/
    - **hk** ; for housekeeping data
        - ib |ob
    - **sc** ; for science data
        - ib |ob

Where <mission_phase> is:

- near_earth_commissioning : Near Earth Commissioning Phase (NECP)
- cruise : Interplanetary Cruise phase (ICP)
- flybys/earth_flyby : Earth Gravity Assist
- flybys/venus_flyby_n : Venus Gravity Assist N, with N=1-2
- flybys/mercury_flyby_n : Mercury Gravity Assist N, with N=1-6
- mercury_commissioning : Mercury Orbit Commissioning Phase
- mercury_science_orbit : Mercury Science Phase

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

1) MPO-MAG par science data

Description:

The partially calibrated science data contain the time series of magnetic fields represented by raw ADC-counts converted to ASCII-values of a single sensor (ob | ib). Furthermore, the raw sensor and electronics temperature values are included. Additionally clipping information indicating any over ranging, the coded sample rate, the offset compensation values and a quality bit derived from the vector checksum complete every data vector.

Format and content details: Section 5.2.4.

Directory Name	***File Naming Convention***	***Type***
sc	***mag_par_sc_***<sensor>***_s***<rate>***_urf_***<NNNNN>_< YYYYMMDD>**.xml/.tab**	3

Table 15: MPO-MAG partially processed raw data product types

Where:

<sensor>: ib | ob

<rate>: measurement rate index according to ***Table 4.***

<NNNNN>: orbit number of the first measurement in the product (only used at Mercury)

<YYYYMMDD>: date of the measurements in the product

4.2.3 Calibrated Data directory (data_calibrated)

The structure of the calibrated data collection is as follows:

data_calibrated/

- collection_mpo_mag_data_calibrated.xml
- collection_mpo_mag_data_calibrated.csv
- <mission_phase>/
    - **hk** ; for housekeeping data
        - ib
        - ob
    - **sc** ; for science data
        - ib
            - <coordinate-system>
        - ob
            - <coordinate-system>

Where <mission_phase> is:

- near_earth_commissioning : Near Earth Commissioning Phase (NECP)
- cruise : Interplanetary Cruise phase (ICP)
- flybys/earth_flyby : Earth Gravity Assist
- flybys/venus_flyby_n : Venus Gravity Assist N, with N=1-2
- flybys/mercury_flyby_n : Mercury Gravity Assist N, with N=1-6
- mercury_commissioning : Mercury Orbit Commissioning Phase
- mercury_science_orbit : Mercury Science Phase

<coordinate-system> assigns the actual used reference frame for the data, which could be e.g.

- urf ; unit reference frame = instrument coordinates
- scf ; spacecraft coordinates
- e2k ; ECLIPJ2000 frame
- other celestial frames …

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

1) MPO-MAG ground calibrated Housekeeping data

Description:
MPO-MAG ground calibrated housekeeping data contain time series of all relevant supply voltages and currents of the MPO-MAG instrument represented by their ground calibrated physical units. Individual files exist separately for the ib and ob sensor. Furthermore, heater data and status information is provided here. Additionally the usage of the feedback relays and the clock source and also various internal status flags are listed in the hk data for diagnoses purposes.

Format and content details: Section 5.3.1.

2) MPO-MAG ground calibrated magnetic field science data

Description:
The ground calibrated magnetic field science data contain the time series of magnetic fields represented by ground calibrated nanotesla values for a single sensor (ob | ib). Furthermore, the calibrated sensor and electronics temperature values are included. The data in celestial coordinates also contain the actual position vector in each data row.

All values have been shifted to nominal offsets using the specific compensation values and the static shift values obtained from the actual switch instrument switch on phase. Data with wrong checksums (e.g. TM error) are NOT included in the calibrated data, they are only present in RAW data.

Format and content details: Section 5.3.2.

Remark: The thermistor (NME02215) located at the IB-sensor heater had already a loose contact at launch time. Therefore, the data of this thermistor are flagged as 'bad' in the xml label files.

4.2.4 Derived Data directory (data_derived)

The structure of the calibrated data collection is as follows:

data_derived/

- collection_mpo_mag_data_derived.xml
- collection_mpo_mag_data_derived.csv
- **avg_cal_sc/** ; averaged ground calibrated data
  <mission_phase>/
    - ib
        - <celestial_coordinate system>
    - ob
        - <celestial_coordinate system>

- **inflightcal_sc/** ; inflight calibrated data
  <mission_phase>/
    - <celestial_coordinate system>

- **avg_inflightcal_sc/** ; averaged inflight calibrated data
  <mission_phase>/
    - <celestial_coordinate system>

Where <mission_phase> is:

- near_earth_commissioning : Near Earth Commissioning Phase (NECP)
- cruise : Interplanetary Cruise phase (ICP)
- flybys/earth_flyby : Earth Gravity Assist
- flybys/venus_flyby_n : Venus Gravity Assist N, with N=1-2
- flybys/mercury_flyby_n : Mercury Gravity Assist N, with N=1-6
- mercury_commissioning : Mercury Orbit Commissioning Phase
- mercury_science_orbit : Mercury Science Phase

<celestial coordinate-system> assigns the actual used reference frame for the data, which could be e.g.

- e2k ; ECLIPJ2000 frame
- other celestial frames …

The second level sub-directories contain the following data products:

MPO-MAG derived averaged ground calibrated magnetic field science data

Description:
The averaged ground calibrated magnetic field science data contain the time series of magnetic fields derived directly from the calibrated data. Data are available for IB and OB sensor, but only in a suitable celestial coordinate system. For the NECP and cruise phases this is the ECLIPJ2000 frame. For the planetary swing-by phases and the Mercury science phase this will be a convenient planetary specific reference frame. Besides the magnetic field vector the data tables contain the actual position, and sensor and electronics temperature values. All data are averaged to a certain time interval, the standard averaging period is one second. No further data treatment than that applied to the ground calibrated data has been performed.
Format and content details: Section 5.4.1.

MPO-MAG derived inflight calibrated magnetic field science data

Description:
The derived inflight calibrated magnetic field science data contain the time series of magnetic fields derived initially from the calibrated data. Only one data product is available, no distinction between IB and OB sensor is made anymore, as the data disturbance cleaning algorithm combines the IB and OB data stream in order to minimize s/c-disturbance (dual magnetometer method). Data are provided in a suitable celestial coordinate system only. For the NECP and cruise phases this is the ECLIPJ2000 frame. For the planetary swing-by phases and the Mercury science phase this will be a convenient planetary specific reference frame. Besides the magnetic field vector the data tables contain the actual position, and sensor and electronics temperature values. Data quality flags are added with respect to the estimated quality and the cleaning algorithms applied to the specific data.

All magnetic field values have been shifted by best effort means to the best achievable offset components using the specific inflight calibration procedures. If any clipping has occurred, a quality string bit labels the saturation. Data with wrong checksums (e.g. TM error) are NOT included in the derived inflight calibrated data, they are only present in RAW data.
Format and content details: Section 0.

MPO-MAG derived averaged inflight calibrated magnetic field science data

Description:
The averaged inflight calibrated magnetic field science data contain the time series of magnetic fields derived directly from the derived inflight calibrated data. Only one data product is available, no distinction between IB and OB sensor is made. Data are provided in a suitable celestial coordinate system only. For the NECP and cruise phases this is the ECLIPJ2000 frame. For the planetary swing-by phases and the Mercury science phase this will be a convenient planetary specific reference frame. Besides the magnetic field vector the data tables contain the actual position, and sensor and electronics temperature values. All data are averaged to a certain time interval, the standard averaging period is one second. No further data treatment than that applied to the inflight calibrated data has been performed. Data quality flags are added accordingly.
Format and content details: Section 5.4.3.

4.2.5 *Calibration directory (calibration_files)*

The structure of the calibration collection is as follows:

calibration_files/
- collection_mpo_mag_calibration.xml
- collection_mpo_mag_calibration.csv

The calibration file directory contains the parameter files needed for the conversion from ADC-counts to physical values, provides the ground calibration parameters needed to obtain proper calibrated magnetic fields in “nanotesla” and comprises the inflight calibration parameter files needed for the final generation of derived inflight calibrated data.

1) HK conversion files

mag_calib_hk_coefficients.asc	; ASCII table
mag_calib_hk_coefficients.xml	; XML label file

These files contain the conversion factors and offsets needed to convert the ADC-counts to physical values for all HK data available.
Usage: Physical value = Scale_factor *ADC-counts + Offset

The files has the following content:

```
#*** FILE : MAG_CALIB_HK_COEFF.asc *******
#
CALP8VOLTAGE_SCALE_OB        =   0.0001525824
CALP8VOLTAGE_OFFSET_OB       =   0.0
CALP8CURRENT_SCALE_OB        =   0.0598400567
CALP8CURRENT_OFFSET_OB       =   -0.200
CALN8VOLTAGE_SCALE_OB        =   0.0004577473
CALN8VOLTAGE_OFFSET_OB       =   -25.029
CALN8CURRENT_SCALE_OB        =   0.1795087266
CALN8CURRENT_OFFSET_OB       =   -0.05
CALP5VOLTAGE_SCALE_OB        =   0.0000994098
CALP5VOLTAGE_OFFSET_OB       =   0.0
CALP5CURRENT_SCALE_OB        =   0.0389865303
CALP5CURRENT_OFFSET_OB       =   -0.116
CALP3V3VOLTAGE_SCALE_OB      =   0.0000763421
CALP3V3VOLTAGE_OFFSET_OB     =   0.0
CALP1V8VOLTAGE_SCALE_OB      =   0.0000763421
CALP1V8VOLTAGE_OFFSET_OB     =   0.0
CALP2V5VOLTAGE_SCALE_OB      =   0.0000762912
CALP2V5VOLTAGE_OFFSET_OB     =   0.0
CALP2V5CURRENT_SCALE_OB      =   0.0953640110
CALP2V5CURRENT_OFFSET_OB     =   0.0
CALSENSORTEMP1_SCALE_OB      =   0.0047596731
CALSENSORTEMP1_OFFSET_OB     =   -65.87
CALSENSORTEMP2_SCALE_OB      =   0.0047587109
CALSENSORTEMP2_OFFSET_OB     =   -65.67
CALELECTRONICSTEMP_SCALE_OB  =   0.0019810836
CALELECTRONICSTEMP_OFFSET_OB =   -46.72
CALP8VOLTAGE_SCALE_IB        =   0.0001525824
CALP8VOLTAGE_OFFSET_IB       =   0.0
CALP8CURRENT_SCALE_IB        =   0.0598400567
CALP8CURRENT_OFFSET_IB       =   -0.200
CALN8VOLTAGE_SCALE_IB        =   0.0004577473
CALN8VOLTAGE_OFFSET_IB       =   -25.029
```

```
CALN8CURRENT_SCALE_IB        =   0.1795087266
CALN8CURRENT_OFFSET_IB       =   -0.05
CALP5VOLTAGE_SCALE_IB        =   0.0000994098
CALP5VOLTAGE_OFFSET_IB       =   0.0
CALP5CURRENT_SCALE_IB        =   0.0389865303
CALP5CURRENT_OFFSET_IB       =   -0.116
CALP3V3VOLTAGE_SCALE_IB      =   0.0000763421
CALP3V3VOLTAGE_OFFSET_IB     =   0.0
CALP1V8VOLTAGE_SCALE_IB      =   0.0000763421
CALP1V8VOLTAGE_OFFSET_IB     =   0.0
CALP2V5VOLTAGE_SCALE_IB      =   0.0000762912
CALP2V5VOLTAGE_OFFSET_IB     =   0.0
CALP2V5CURRENT_SCALE_IB      =   0.0953640110
CALP2V5CURRENT_OFFSET_IB     =   0.0
CALSENSORTEMP1_SCALE_IB      =   0.0047596731
CALSENSORTEMP1_OFFSET_IB     =   -65.87
CALSENSORTEMP2_SCALE_IB      =   0.0047587109
CALSENSORTEMP2_OFFSET_IB     =   -65.67
CALELECTRONICSTEMP_SCALE_IB  =   0.0019810836
CALELECTRONICSTEMP_OFFSET_IB =   -46.72
```

2) Ground calibration files for magnetic fields

mag_calib_gnd_fm1_s10_ib_calo0.asc	; ASCII table	- Ground Calibration file for FM1, ib-sensor, calibration mode 0
mag_calib_gnd_fm1_s10_ib_calo0.xml	; XML label file	
mag_calib_gnd_fm1_s11_ob_calo0.asc	; ASCII table	- Ground Calibration file for FM1, ob-sensor, calibration mode 0
mag_calib_gnd_fm1_s11_ob_calo0.xml	; XML label file	
mag_calib_gnd_fm1_s10_ib_calo4.asc	; ASCII table	- Ground Calibration file for FM1, ib-sensor, calibration mode 4
mag_calib_gnd_fm1_s10_ib_calo4.xml	; XML label file	
mag_calib_gnd_fm1_s11_ob_calo4.asc	; ASCII table	- Ground Calibration file for FM1, ob-sensor, calibration mode 4
mag_calib_gnd_fm1_s11_ob_calo4.xml	; XML label file	

These files contain all ground calibration parameters for the ground calibration described in section 2.4.1 and have a content like this:

```
#***** File MAG_CALIB_GND_FM1_S10_IB_CAL0.ASC ****
#
# File manually generated; init  2017-08-24 IR
# SourceS: THERMAL_MODEL__13-04-09-09-52-27_IB_MODE_0.TEX
#          THERMAL_OFF_MODEL__13-04-09-11-14-46_IB_MODE_0.TEX
# Final Calibration Coefficients for
# DPU: FM1
# SENSOR: FM IB
# CALMODE: 0
# OFFSET COEFFICIENTS - GND
OFF_0   -2.92971E-1    -1.05443E+0    1.46463E-1
OFF_1   -3.69506E-3    -1.72164E-3    3.34259E-3
OFF_2    4.77003E-5     1.51567E-5   -2.31102E-5
#
#
# SENSITIVITY COEFFICIENTS
SIGMA_0    9.75788E-1    9.88057E-1    9.85916E-1
SIGMA_1   -1.59695E-5   -1.44024E-5   -1.77112E-5
#
#
# ALIGNMENT COEFFICIENTS
#
XI_0   8.9575E+1   8.9942E+1   9.0345E+1
XI_1   5.8946E-5   4.1061E-5  -1.6514E-5
#
#
```

The OFF_n parameters contain 3 polynomial coefficients (2nd order polynomial) for the temperature correction of the three magnetic field offset components.

The SIGMA_n parameters contain 2 polynomial coefficients (linear polynomial) for the temperature correction of the three magnetic field sensitivities.

The XI_n parameters contain 2 polynomial coefficients (linear polynomial) for the temperature correction of the three sensor misalignment angles.

3) Static Offset calibration files for calibrated magnetic field data

The files contain the needed parameters for the coarse shift of the magnetic field data according to the long time offset and s/c-disturbance field level. The actual levels are calculated with the Hedgecock method and are valid specifically for individual switch on /switch off phases of the magnetometer. All preliminary calibrated data are reprocessed once new shift values are available.
The files contain start times and the three component of the sum of the actual s/c-disturbance field and the instrument offset in URF coordinates in nanotesla:

```
# ***** File MAG_CALIB_STATIC_OFFSET_OB.ASC ****
#
# File manually generated; V2.5 2021-01-20 IR
# Values valid until 2021-01-06
# V2.4 changes for 2020-10-26 -- 2020-12-17
# V2.5 changes for 2020-12-17 -- 2021-01-06
# Values calculated by Johannes Mieth
# Initial Static Calibration Coefficients for
# DPU: FM1
# SENSOR: FM OB
#
# URF COORDINATES
# OFFSET VALID AFTER ASSIGNED DATE/TIME
# VALUES in nT
# USE = B_real =B_raw -B_Off
#
# MEANING:          Time   Offset X   Offset Y   Offset Z
# FORMAT:           27s     11.3f      11.3f      11.3f
#                    nT        nT         nT
2018-11-01T00:00:00.000000Z     7.490    -4.930    12.040
2018-11-29T17:31:16.798000Z     9.250    -4.380    12.210
2019-03-06T19:31:16.741000Z     9.280    -3.860    11.540
2019-05-24T07:11:55.673000Z     9.610    -3.030    10.610
2019-06-19T12:10:00.000000Z     8.860    -2.930    10.860
2019-07-18T22:49:00.000000Z     8.560    -2.780    10.910
2019-08-09T16:46:00.000000Z     8.460    -2.930    11.060
2019-11-13T13:40:14.014000Z     9.510    -4.330    12.060
2019-11-14T06:00:00.000000Z     8.260    -4.080    13.460
2020-02-26T00:00:00.000000Z     8.710    -3.680    12.710
2020-04-04T09:36:05.000000Z    11.860     6.720    21.210
2020-04-04T21:28:50.000000Z    13.260     7.220    20.910
2020-04-08T04:56:00.000000Z    11.860     6.320    20.810
2020-04-08T16:25:00.000000Z     0.210    -1.380    -1.140
2020-04-08T19:34:00.000000Z    11.810     6.070    20.910
2020-04-09T01:24:55.000000Z    15.460    -4.280    22.010
2020-04-09T05:01:55.000000Z    12.860     1.120    22.010
2020-04-10T17:10:05.000000Z     8.210     9.770    17.010
2020-04-11T14:25:00.000000Z    12.210     6.770    17.810
2020-04-12T04:25:15.000000Z     8.460    -3.730    10.360
2020-04-24T18:00:00.000000Z     8.460    -3.730    10.310
2020-06-18T09:00:00.000000Z     7.660    -3.630    12.760
```

```
2020-08-03T14:30:00.000000Z    4.060   -3.930   14.260
2020-10-14T03:00:00.000000Z    5.310   -5.130   11.010
2020-10-26T17:00:00.000000Z    7.510   -3.380   10.260
2020-12-17T00:00:00.000000Z    7.610   -3.430   10.510
2020-12-20T02:47:00.000000Z    8.560   -5.030    8.360
2020-12-22T15:50:00.000000Z    7.210   -3.180   10.110
2050-12-31T00:00:00.000000Z    0.000    0.000    0.000
#
```

4) Temperature calibration files for calibrated magnetic field data

The two files contain the needed polynomial coefficients for the minimization of the long term temperature effects of the spacecraft disturbance field.
The T_OFF_n parameters contain 4 polynomial coefficients (3rd order polynomial) for the temperature correction of the three magnetic field offset components.

```
#***** File MAG_CALIB_TEMPERATURE_OFFSET_IB.ASC ****
#
# File manually generated; init  2020-05-13 IR
#
# TEMPERATURE POLYNOMIAL COEFFICIENTS
#              X    Y    Z
# P(T) =    T_OFF_0  +  T_OFF_1 *T  +  T_OFF_2 * T*T  +    T_OFF_3 * T*T*T
#
T_OFF_0   0    0   0
T_OFF_1   0    0   0
T_OFF_2   0    0   0
T_OFF_3   0    0   0
```

At the time of writing the model is still under development.

5) Inflight calibration files for derived magnetic field data

The files will contain the needed parameters for the inflight calibration described in section 2.4.2.
The format of the files will most likely be the same or as the static offset calibration files, only the entries will reflect a higher frequent disturbance characterization in the order of minutes to hours.

Details are still TBD as the inflight calibration is currently under development.

4.2.6 Browse directory (browse_calibrated)

The structure of the browse collection maps roughly the structure of the calibrated data collection:

Browse_calibrated/

- collection_mpo_mag_data_calibrated.xml
- collection_mpo_mag_data_calibrated.csv
- <mission_phase>/
    - hk ; for housekeeping data
        - ib
        - ob
    - sc ; for science data
        - ib
            - <coordinate-system>
            - temperature
        - ob
            - <coordinate-system>
            - temperature

Where <mission_phase> is:

- near_earth_commissioning : Near Earth Commissioning Phase (NECP)
- cruise : Interplanetary Cruise phase (ICP)
- flybys/earth_flyby : Earth Gravity Assist
- flybys/venus_flyby_n : Venus Gravity Assist N, with N=1-2
- flybys/mercury_flyby_n : Mercury Gravity Assist N, with N=1-6
- mercury_commissioning : Mercury Orbit Commissioning Phase
- mercury_science_orbit : Mercury Science Phase

<coordinate-system> assigns the actual used reference frame for the data, which could be e.g.

- urf ; unit reference frame = instrument coordinates
- scf ; spacecraft coordinates
- e2k ; ECLIPJ2000 frame
- ...

The ***temperature*** folder assigns the sub directory for all the temperature plots.

In the filenames listed below, the assignment is as follows:

<sensor>: ib | ob
<rate>: measurement rate index according to *Table 4*.
<nnnn>: orbit number of the first measurement in the product (only used at Mercury)
<yyyymmdd>: date of the measurements in the product

1) Housekeeping data browse plots

mag_cal_hk_browse_<sensor>*_<nnnnn>_<yyyymmdd>**.png***
mag_cal_hk_browse_<sensor>*_<nnnnn>_<yyyymmdd>**.xml***

The HK browse plots depict all instrument supply voltages and instrument current on daily base.

2) Magnetic field science data browse plots

mag_cal_sc_browse_<sensor>***_s****<rate>_<coords>_<nnnnn>_<yyyymmdd>**.png***
mag_cal_sc_browse_<sensor>***_ s****<rate>_<coords>_<nnnnn>_<yyyymmdd>**.xml***

The magnetic field science browse plots show the ground calibrated magnetic field data of the assigned sensor in the assigned coordinate system for the given day. The plots display 3 three field components and the field magnitude on daily base. One plot will be generated for each available sampling rate at the given day.

3) Temperature science data browse plots

mag_cal_sc_browse_<sensor>***_temperature_****<nnnnn>_<yyyymmdd>**.png***
mag_cal_sc_browse_<sensor>***_temperature_****<nnnnn>_<yyyymmdd>**.xml***

The temperature plots display the calibrated sensor and the electronics temperature of the stated sensor at the given day on daily base.

Remark: The thermistor (NME02215) located at the IB-sensor heater had already a loose contact at launch time. Therefore, the data of this thermistor are flagged as ‘bad’ in the browse plots.

4.2.7 Document directory (document)

The structure of the document collection is as follows:

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

Document	***Description***
BC-MAG-ICD-001_MPO-MAG_EAICD.pdf/.xml	This document;
BC-MAG-TR-0085-CALIBRATION_REPORT.pdf/.xml	Protocol and Analysis of the BepiColombo MPO Calibration for Sensor BS_10 & BS_11 connected to the FM1 Electronics
BC-MAG-TR-00120-FM_Commissioning.pdf/.xml	Commissioning Report, Time Period 25.10.2018 – 6.12.2018
BC-MAG-Instrumentpaper.pdf/.xml	Instrument Paper
LOGBOOK_<mission_phase>_<start>_<end>.asc/.xml	MPOMAG related chronological command & Event list
BC-IGEP-TRxxxx_<mission_phase>_AVAILABILITY.pdf/.xml	Overview of available MPO-MAG data and list of s/c-events important for MPO-MAG.

Table 16: MPO-MAG documents

5 DATA PRODUCT FORMATS

This section will provide details on the format and content of each of the products included in the MPO-MAG science data. Some information on the format of the products has been included in this version as templates.

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 MAG PDS4 repository:

- https://repos.cosmos.esa.int/bepicolombo/projects/PDS4XML/repos/bepi.pds4.mag

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 10: 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 *MPO-MAG Raw Science data*

ASCII table (Table Character) with the format specified in the table below.

MPO-MAG Raw Science Data Table

#	*Name*	*Start Byte*	*Data Type*	*Unit*	*Description*
1	TIME_UTC	1	ASCII_Date_Time_YMD_UTC		UTC TIME OF OBSERVATION: YYYY-MM-DDT HH:MM:SS.SSSSSSZ
2	TIME_OBT	29	ASCII_String		S/C-CLOCK AT OBSERVATION TIME: P/SSSSSSSSSS.FFFFF, P: PARTITION OF THE S/C-CLOCK, SSSSSSSSSS: RELATIVE SECONDS AFTER T0, FFFFF: FRACTIONAL NON DECIMAL SECONDS RUNNING UNTIL 65535
3	MEASUREMENT_RANGE	48	ASCII_NonNegative_Integer		MEASUREMENT RANGE INDEX IN DN
4	FieldValX	51	ASCII_Integer	Counts	MAGNETIC FIELD X COMPONENT, UNCALIBRATED RAW DATA, INSTRUMENT COORDINATES, IB/OB SENSOR.
5	FieldValY	63	ASCII_Integer	Counts	MAGNETIC FIELD Y COMPONENT, UNCALIBRATED RAW DATA, INSTRUMENT COORDINATES, IB/OB SENSOR.
6	FieldValZ	75	ASCII_Integer	Counts	MAGNETIC FIELD Z COMPONENT, UNCALIBRATED RAW DATA, INSTRUMENT COORDINATES, IB/OB SENSOR.
7	Clipping	87	ASCII_NonNegative_Integer		THE CLIPPING BIT PROVIDES INFORMATION ABOUT ANY OVERANGE EVENT OF THE SENSOR. VALUE IS GIVEN AS BINARY FLAG:

MPO-MAG Raw Science Data Table					
#	**Name**	**Start Byte**	**Data Type**	**Unit**	**Description**
					0: NORMAL OPERATION, 1: SENSOR IS OVERRANGED
8	CompensationValueX	89	ASCII_Integer	Counts	THIS VARIABLE PROVIDES INFORMATION ABOUT THE FIELD COMPENSATION SHIFT OF THE MAGNETIC FIELD X COMPONENT. VALUE IS GIVEN IN ADCCOUNTS.
9	CompensationValueY	97	ASCII_Integer	Counts	THIS VARIABLE PROVIDES INFORMATION ABOUT THE FIELD COMPENSATION SHIFT OF THE MAGNETIC FIELD Y COMPONENT. VALUE IS GIVEN IN ADCCOUNTS.
10	CompensationValueZ	105	ASCII_Integer	Counts	THIS VARIABLE PROVIDES INFORMATION ABOUT THE FIELD COMPENSATION SHIFT OF THE MAGNETIC FIELD Z COMPONENT. VALUE IS GIVEN IN ADCCOUNTS.
11	QualityFlag	113	ASCII_Integer		THIS COLUMN CONTAINS A BASIC QUALITY ASSESSMENT: 0: PACKET OK; 1: PACKET CORRUPTED; 2: PACKET SENT TWICE WITH IDENTICAL OBT; 3: COMPRESSION ERROR;

Table 17: MPO-MAG Raw Science Data

5.2.2 MPO-MAG Raw Housekeeping Data

ASCII table (Table Character) with the format specified in the table below.

MPO-MAG Raw Housekeeping Data Table

#	Name	Start Byte	Data Type	Unit	Description
1	TIME_UTC	1	ASCII_Date_Time_YMD_UTC		UTC TIME OF OBSERVATION: YYYY-MM-DDT HH:MM:SS.SSSSSSZ
2	TIME_OBT	29	ASCII_String		S/C-CLOCK AT OBSERVATION TIME: P/SSSSSSSSSS.FFFFF, P: PARTITION OF THE S/C-CLOCK, SSSSSSSSSS: RELATIVE SECONDS AFTER T0, FFFFF: FRACTIONAL NON DECIMAL SECONDS RUNNING UNTIL 65535
3	Sensor_Heater_Value	48	ASCII_NonNegative_Integer	Counts	HEATER POWER DUTY CYCLE (0-128)
4	Sensor_p8_Voltage	54	ASCII_NonNegative_Integer	Counts	+8V SUPPLY VOLTAGE
5	Sensor_p8_Current	60	ASCII_Integer	Counts	CURRENT OF +8V LINE
6	Sensor_m8_Voltage	66	ASCII_NonNegative_Integer	Counts	-8V SUPPLY VOLTAGE
7	Sensor_m8_Current	72	ASCII_Integer	Counts	CURRENT OF-8V LINE
8	Sensor_p5_Voltage	78	ASCII_NonNegative_Integer	Counts	+5V SUPPLY VOLTAGE
9	Sensor_p5_Current	84	ASCII_Integer	Counts	CURRENT OF +5V LINE
10	Sensor_p3.3_Voltage	90	ASCII_NonNegative_Integer	Counts	+3.3V SUPPLY VOLTAGE
11	Sensor_p1.8_Voltage	96	ASCII_NonNegative_Integer	Counts	+1.8V SUPPLY VOLTAGE
12	Sensor_p2.5_Voltage	102	ASCII_NonNegative_Integer	Counts	+2.5V SUPPLY VOLTAGE
13	Sensor_p2.5_Current	108	ASCII_Integer	Counts	CURRENT OF +2.5V LINE
14	SensLatchADCX	114	ASCII_NonNegative_Integer		SENSOR X LATCHUP DETECTION: 0= NORMAL OPERATION, 1= LATCHUP DETECTED

MPO-MAG Raw Housekeeping Data Table					
#	***Name***	***Start Byte***	***Data Type***	***Unit***	***Description***
15	SensLatchADCY	116	ASCII_NonNegative_Integer		SENSOR Y LATCHUP DETECTION: 0= NORMAL OPERATION, 1= LATCHUP DETECTED
16	SensLatchADCZ	118	ASCII_NonNegative_Integer		SENSOR Z LATCHUP DETECTION: 0= NORMAL OPERATION, 1= LATCHUP DETECTED
17	HeatEmergency	120	ASCII_NonNegative_Integer		HEATER STATUS: 0= NORMAL OPERATION , 1= HEATER TEMPERATURE EXCEEDS THRESHOLD (HEATER EMERGENCY OFF)
18	SensSyncSelect	122	ASCII_NonNegative_Integer		DEFINES SYNC SIGNAL SOURCE: 0: USE EXTERNAL SYNC OF ICU , 1: EXTERNAL SYNC SWITCHED OFF ; USE SYNC OF SENSOR ELECTRONICS
19	SensSyncUsed	124	ASCII_NonNegative_Integer		SYNC SIGNAL SELECTION: 0= SIGNAL N/A OR NOT VALID , 1= SYNC SIGNAL VALID
20	SensClkSelect	126	ASCII_NonNegative_Integer		MASTER CLOCK SELECTION: 0= USE ICU GENERATED CLOCK, 1= FORCE USE OF SENSOR ELECTRONICS GENERATED CLOCK
21	SensClkUsed	128	ASCII_NonNegative_Integer		CLOCK USAGE: 0= ICU GENERATED CLOCK N/A , 1= ICU GENERATED CLOCK AVAILABLE
22	SensRelais1	130	ASCII_NonNegative_Integer		ACTUAL STATUS OF FEEDBACK RELAIS: 0= RELAIS OPEN , 1= RELAIS CLOSED

MPO-MAG Raw Housekeeping Data Table					
#	**Name**	**Start Byte**	**Data Type**	**Unit**	**Description**
23	SensFBRelais	132	ASCII_NonNegative_Integer		NOMINAL STATUS OF FEEDBACK RELAIS: 0= RELAIS OPEN , 1= RELAIS CLOSED
24	SensExcitation	134	ASCII_NonNegative_Integer		SENSOR EXCITATION STATUS: 0= EXCITATION OFF , 1= EXCITATION ON
25	SensCalBits	136	ASCII_NonNegative_Integer		SENSOR ELECTRONICS CALIBRATION MODE: 0= STANDARD MODE 1= CAL1 (OPEN LOOP) 2= CAL2 (ADC + DAC TRANS.) 3= CAL3 (STEP FUNCTION)
26	SensElecID	138	ASCII_NonNegative_Integer		SENSOR ELECTRONIC BOARD IDENTIFIER: VALID VALUES= 0,1,2

Table 18: MPO-MAG Raw Housekeeping Data

5.2.3 *MPO-MAG Raw Sensor Temperature Data*

ASCII table (Table_Character) with the format specified in the table below.

MPO-MAG Raw Temperature Data Table					
#	***Name***	***Start Byte***	***Data Type***	***Unit***	***Description***
1	TIME_UTC	1	ASCII_Date_Time_YMD_UTC		UTC TIME OF OBSERVATION: YYYY-MM-DDTHH:MM:SS.SSSSSSZ
2	TIME_OBT	29	ASCII_String		S/C-CLOCK AT OBSERVATION TIME: P/SSSSSSSSSS.FFFFF, P: PARTITION OF THE S/C-CLOCK, SSSSSSSSSS: RELATIVE SECONDS AFTER T0, FFFFF: FRACTIONAL NON DECIMAL SECONDS RUNNING UNTIL 65535
3	Sensor_Heater_Value	48	ASCII_NonNegative_Integer	Counts	HEATER POWER DUTY CYCLE (0-128)
4	Sensor_Temp1	54	ASCII_NonNegative_Integer	Counts	TEMPERATURE OF THE MAGNETIC FIELD SENSOR MEASURED BY TEMPERATURE SENSOR T1.
5	Sensor_Temp2	60	ASCII_NonNegative_Integer	Counts	TEMPERATURE OF THE MAGNETIC FIELD SENSOR MEASURED BY TEMPERATURE SENSOR T2.
6	Electronics_Temp	66	ASCII_NonNegative_Integer	Counts	TEMPERATURE OF THE MPO-MAG ELECTRONICS MEASURED BY TEMPERATURE SENSOR T_ELEC.

Table 19: MPO-MAG Raw Sensor Temperature Data

5.2.4 MPO-MAG Partially Processed Science data

ASCII table (Table Character) with the format specified in the table below.

MPO-MAG Raw Science Data Table					
#	***Name***	***Start Byte***	***Data Type***	***Unit***	***Description***
1	TIME_UTC	1	ASCII_Date_Time_YMD_UTC		UTC TIME OF OBSERVATION: YYYY-MM-DDT HH:MM:SS.SSSSSSZ
2	TIME_OBT	29	ASCII_String		S/C-CLOCK AT OBSERVATION TIME: P/SSSSSSSSSS.FFFFF, P: PARTITION OF THE S/C-CLOCK, SSSSSSSSSS: RELATIVE SECONDS AFTER T0, FFFFF: FRACTIONAL NON DECIMAL SECONDS RUNNING UNTIL 65535
3	MEASUREMENT_RANGE	48	ASCII_NonNegative_Integer		MEASUREMENT RANGE INDEX IN DN
4	FieldValX	51	ASCII_Integer	Counts	MAGNETIC FIELD X COMPONENT, UNCALIBRATED RAW DATA, INSTRUMENT COORDINATES, IB/OB SENSOR.
5	FieldValY	63	ASCII_Integer	Counts	MAGNETIC FIELD Y COMPONENT, UNCALIBRATED RAW DATA, INSTRUMENT COORDINATES, IB/OB SENSOR.
6	FieldValZ	75	ASCII_Integer	Counts	MAGNETIC FIELD Z COMPONENT, UNCALIBRATED RAW DATA, INSTRUMENT COORDINATES, IB/OB SENSOR.
7	Sensor_Temp1	87	ASCII_NonNegative_Integer	Counts	TEMPERATURE OF THE MAGNETIC FIELD SENSOR MEASURED BY TEMPERATURE SENSOR T1.
8	Sensor_Temp2	93	ASCII_NonNegative_Integer	Counts	TEMPERATURE OF THE MAGNETIC FIELD SENSOR MEASURED BY TEMPERATURE SENSOR T2.

MPO-MAG Raw Science Data Table					
#	***Name***	***Start Byte***	***Data Type***	***Unit***	***Description***
9	Electronics_Temp	99	ASCII_NonNegative_Integer	Counts	TEMPERATURE OF THE MPO-MAG ELECTRONICS MEASURED BY TEMPERATURE SENSOR T_ELEC.
10	Clipping	105	ASCII_NonNegative_Integer		BINARY CLIPPING FLAG INDICATING SENSOR SATURATION, 0: NORMAL OPERATION, 1: SENSOR IS OVERRANGED
11	CompensationValueX	107	ASCII_Integer	Counts	SHIFT VALUE OF MAGNETIC FIELD X COMPONENT
12	CompensationValueY	115	ASCII_Integer	Counts	SHIFT VALUE OF MAGNETIC FIELD Y COMPONENT.
13	CompensationValueZ	123	ASCII_Integer	Counts	SHIFT VALUE OF MAGNETIC FIELD Z COMPONENT.
14	QualityFlag	131	ASCII_Integer		BASIC QUALITY ASSESSMENT DERIVED FROM THE PACKET CHECKSUM. CODING: 0: PACKET OK; 1: PACKET CORRUPTED; 2: PACKET SENT TWICE WITH IDENTICAL OBT; 3: COMPRESSION ERROR;

Table 20: MPO-MAG Partially Processed Science Data

5.3 Calibrated Data Science Products

5.3.1 MPO-MAG Calibrated Housekeeping data

ASCII table (Table Character) with the format specified in the table below.

MPO-MAG Calibrated Housekeeping Data Table

#	*Name*	*Start Byte*	*Data Type*	*Unit*	*Description*
1	TIME_UTC	1	ASCII_Date_Time_YMD_UTC		UTC TIME OF OBSERVATION: YYYY-MM-DDT HH:MM:SS.SSSSSSZ
2	TIME_OBT	29	ASCII_Sring		S/C-CLOCK AT OBSERVATION TIME: P/SSSSSSSSSS.FFFFF, P: PARTITION OF THE S/C-CLOCK, SSSSSSSSSS: RELATIVE SECONDS AFTER T0, FFFFF: FRACTIONAL NON DECIMAL SECONDS RUNNING UNTIL 65535
3	Sensor_Heater_Value	48	ASCII_NonNegative_Integer	%	HEATER POWER DUTY CYCLE (0-100)
4	Sensor_p8_Voltage	52	ASCII_Real	V	+8V SUPPLY VOLTAGE
5	Sensor_p8_Current	63	ASCII_Real	mA	CURRENT OF +8V LINE
6	Sensor_m8_Voltage	74	ASCII_Real	V	-8V SUPPLY VOLTAGE
7	Sensor_m8_Current	85	ASCII_Real	mA	CURRENT OF -8V LINE
8	Sensor_p5_Voltage	96	ASCII_Real	V	+5V SUPPLY VOLTAGE
9	Sensor_p5_Current	107	ASCII_Real	mA	CURRENT OF +5V LINE
10	Sensor_p3.3_Voltage	118	ASCII_Real	V	+3.3V SUPPLY VOLTAGE
11	Sensor_p1.8_Voltage	129	ASCII_Real	V	+1.8V SUPPLY VOLTAGE
12	Sensor_p2.5_Voltage	140	ASCII_Real	V	+2.5V SUPPLY VOLTAGE
13	Sensor_p2.5_Current	151	ASCII_Real	mA	CURRENT OF +2.5V LINE

MPO-MAG Calibrated Housekeeping Data Table					
#	**Name**	**Start Byte**	**Data Type**	**Unit**	**Description**
14	SensLatchADCX	162	ASCII_NonNegative_Integer		SENSOR X LATCHUP DETECTION: 0= NORMAL OPERATION, 1= LATCHUP DETECTED
15	SensLatchADCY	164	ASCII_NonNegative_Integer		SENSOR Y LATCHUP DETECTION: 0= NORMAL OPERATION, 1= LATCHUP DETECTED
16	SensLatchADCZ	166	ASCII_NonNegative_Integer		SENSOR Z LATCHUP DETECTION: 0= NORMAL OPERATION, 1= LATCHUP DETECTED
17	HeatEmergency	168	ASCII_NonNegative_Integer		HEATER STATUS: 0= NORMAL OPERATION , 1= HEATER TEMPERATURE EXCEEDS THRESHOLD (HEATER EMERGENCY OFF)
18	SensSyncSelect	170	ASCII_NonNegative_Integer		DEFINES SYNC SIGNAL SOURCE: 0: USE EXTERNAL SYNC OF ICU, 1: EXTERNAL SYNC SWITCHED OFF ; USE SYNC OF SENSOR ELECTRONICS
19	SensSyncUsed	172	ASCII_NonNegative_Integer		SYNC SIGNAL SELECTION: 0= SIGNAL N/A OR NOT VALID, 1= SYNC SIGNAL VALID
20	SensClkSelect	174	ASCII_NonNegative_Integer		MASTER CLOCK SELECTION: 0= USE ICU GENERATED CLOCK, 1= FORCE USE OF SENSOR ELECTRONICS GENERATED CLOCK
21	SensClkUsed	176	ASCII_NonNegative_Integer		CLOCK USAGE: 0= ICU GENERATED CLOCK N/A , 1= ICU GENERATED CLOCK AVAILABLE

MPO-MAG Calibrated Housekeeping Data Table					
#	***Name***	***Start Byte***	***Data Type***	***Unit***	***Description***
22	SensRelay	178	ASCII_NonNegative_Integer		ACTUAL STATUS OF FEEDBACK RELAIS: 0= RELAIS OPEN, 1= RELAIS CLOSED
23	SensFBRelay	180	ASCII_NonNegative_Integer		NOMINAL STATUS OF FEEDBACK RELAIS: 0= RELAIS OPEN, 1= RELAIS CLOSED
24	SensExcitation	182	ASCII_NonNegative_Integer		SENSOR EXCITATION STATUS: 0= EXCITATION OFF , 1= EXCITATION ON
25	SensCalBits	184	ASCII_NonNegative_Integer		SENSOR ELECTRONICS CALIBRATION MODE: 0= STANDARD MODE 1= CAL1 (OPEN LOOP) 2= CAL2 (ADC + DAC TRANS.) 3= CAL3 (STEP FUNCTION)
26	SensElecID	186	ASCII_NonNegative_Integer		SENSOR ELECTRONIC BOARD IDENTIFIER: VALID VALUES= 0,1,2

Table 21: MPO-MAG Calibrated Housekeeping Data

5.3.2 MPO-MAG Calibrated Magnetic Field Science data

5.3.2.1 MPO-MAG Calibrated Magnetic Field Science data in URF or SCF coordinates

ASCII table (Table Character) with the format specified in the table below.

MPO-MAG Calibrated Science Data Table : URF or SCF Coordinates					
#	***Name***	***Start Byte***	***Data Type***	***Unit***	***Description***
1	TIME_UTC	1	ASCII_Date_Time_YMD_UTC		UTC TIME OF OBSERVATION: YYYY-MM-DDT HH:MM:SS.SSSSSSZ
2	TIME_OBT	29	ASCII_String		S/C-CLOCK AT OBSERVATION TIME: P/SSSSSSSSSS.FFFFF, P: PARTITION OF THE S/C-CLOCK, SSSSSSSSSS: RELATIVE SECONDS AFTER T0, FFFFF: FRACTIONAL NON DECIMAL SECONDS RUNNING UNTIL 65535
3	FieldValX	48	ASCII_Real	nT	MAGNETIC FIELD X COMPONENT, CALIBRATED DATA, INSTRUMENT COORDINATES, INBOARD SENSOR SENSOR.
4	FieldValY	60	ASCII_Real	nT	MAGNETIC FIELD Y COMPONENT, CALIBRATED DATA, INSTRUMENT COORDINATES, INBOARD SENSOR SENSOR.
5	FieldValZ	72	ASCII_Real	nT	MAGNETIC FIELD Z COMPONENT, CALIBRATED DATA, INSTRUMENT COORDINATES, INBOARD SENSOR SENSOR.
6	Sensor_Temp1	84	ASCII_Real	°C	TEMPERATURE OF THE MAGNETIC FIELD

MPO-MAG Calibrated Science Data Table : URF or SCF Coordinates					
#	**Name**	**Start Byte**	**Data Type**	**Unit**	**Description**
					SENSOR MEASURED BY TEMPERATURE SENSOR T1.
7	Sensor_Temp2	93	ASCII_Real	°C	TEMPERATURE OF THE MAGNETIC FIELD SENSOR MEASURED BY TEMPERATURE SENSOR T2, LOCATED AT THE SENSOR HEATER. [§]
8	ElecTemp	102	ASCII_Real	°C	TEMPERATURE OF THE MPO-MAG ELECTRONICS MEASURED BY TEMPERATURE SENSOR T_ELEC.

Table 22: MPO-MAG Ground Calibrated Science Data in URF or SCF Coordinates

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[§] OB: ok; IB : the value is corrupted due to a loose contact, do not use!

5.3.2.2 MPO-MAG Calibrated Magnetic Field Science data in Celestial Coordinates

ASCII table (Table Character) with the format specified in the table below. This example shows data rotated to ECLIPJ2000 coordinates as celestial frame.

MPO-MAG Calibrated Science Data Table : Celestial Coordinates

#	Name	Start Byte	Data Type	Unit	Description
1	TIME_UTC	1	ASCII_Date_Time_YMD_UTC		UTC TIME OF OBSERVATION: YYYY-MM-DDT HH:MM:SS.SSSSSSZ
2	TIME_OBT	29	ASCII_String		S/C-CLOCK AT OBSERVATION TIME: P/SSSSSSSSSS.FFFFF, P: PARTITION OF THE S/C-CLOCK, SSSSSSSSSS: RELATIVE SECONDS AFTER T0, FFFFF: FRACTIONAL NON DECIMAL SECONDS RUNNING UNTIL 65535
3	PosX	48	ASCII_Real	km	SC POSITION X COMPONENT, ECLIPJ2000 COORDINATES. DISTANCE RELATIVE TO STATED BODY
4	PosY	63	ASCII_Real	km	SC POSITION Y COMPONENT, ECLIPJ2000 COORDINATES. DISTANCE RELATIVE TO STATED BODY
5	PosZ	78	ASCII_Real	km	SC POSITION Z COMPONENT, ECLIPJ2000 COORDINATES. DISTANCE RELATIVE TO STATED BODY
6	FieldValX	93	ASCII_Real	nT	MAGNETIC FIELD X COMPONENT, CALIBRATED DATA, ECLIPJ2000 COORDINATES.

MPO-MAG Calibrated Science Data Table : Celestial Coordinates					
#	***Name***	***Start Byte***	***Data Type***	***Unit***	***Description***
7	FieldValY	105	ASCII_Real	nT	MAGNETIC FIELD Y COMPONENT, CALIBRATED DATA, ECLIPJ2000 COORDINATES.
8	FieldValZ	117	ASCII_Real	nT	MAGNETIC FIELD Z COMPONENT, CALIBRATED DATA, ECLIPJ2000 COORDINATES.
9	Sensor_Temp1	129	ASCII_Real	°C	TEMPERATURE OF THE MAGNETIC FIELD SENSOR MEASURED BY TEMPERATURE SENSOR T1.
10	Sensor_Temp2	138	ASCII_Real	°C	TEMPERATURE OF THE MAGNETIC FIELD SENSOR MEASURED BY TEMPERATURE SENSOR T2, LOCATED AT THE SENSOR HEATER. [**]
11	ElecTemp	147	ASCII_Real	°C	TEMPERATURE OF THE MPO-MAG ELECTRONICS MEASURED BY TEMPERATURE SENSOR T_ELEC.

Table 23: MPO-MAG Ground Calibrated Science Data in ECLIPJ2000 Coordinates

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[**] OB: ok; IB : the value is corrupted due to a loose contact, do not use!

5.4 Derived Data Science Products

5.4.1 MPO-MAG Derived Averaged Ground Calibrated Science Data

ASCII table (Table Character) with the format specified in the table below.

MPO-MAG Derived Averaged Calibrated Science Data Table

#	**Name**	**Start Byte**	**Data Type**	**Unit**	**Description**
1	TIME_UTC	1	ASCII_Date_Time_YMD_UTC		UTC TIME OF OBSERVATION: YYYY-MM-DDT HH:MM:SS.SSSSSSZ
2	TIME_OBT	29	ASCII_String		S/C-CLOCK AT OBSERVATION TIME: P/SSSSSSSSSS.FFFFF, P: PARTITION OF THE S/C-CLOCK, SSSSSSSSSS: RELATIVE SECONDS AFTER T0, FFFFF: FRACTIONAL NON DECIMAL SECONDS RUNNING UNTIL 65535
3	PosX	48	ASCII_Real	km	SC POSITION X COMPONENT, ECLIPJ2000 COORDINATES. DISTANCE RELATIVE TO STATED BODY
4	PosY	63	ASCII_Real	km	SC POSITION Y COMPONENT, ECLIPJ2000 COORDINATES. DISTANCE RELATIVE TO STATED BODY
5	PosZ	78	ASCII_Real	km	SC POSITION Z COMPONENT, ECLIPJ2000 COORDINATES. DISTANCE RELATIVE TO STATED BODY
6	FieldValX	93	ASCII_Real	nT	MAGNETIC FIELD X COMPONENT, 1-SECOND-AVERAGED CALIBRATED DATA, ECLIPJ2000 COORDINATES.
7	FieldValY	105	ASCII_Real	nT	MAGNETIC FIELD Y COMPONENT, 1-SECOND-AVERAGED CALIBRATED DATA, ECLIPJ2000 COORDINATES.
8	FieldValZ	117	ASCII_Real	nT	MAGNETIC FIELD Z COMPONENT, 1-SECOND-AVERAGED CALIBRATED DATA, ECLIPJ2000 COORDINATES.

MPO-MAG Derived Averaged Calibrated Science Data Table					
#	***Name***	***Start Byte***	***Data Type***	***Unit***	***Description***
9	Sensor_Temp1	129	ASCII_Real	°C	TEMPERATURE OF THE MAGNETIC FIELD SENSOR MEASURED BY TEMPERATURE SENSOR T1. VALUE IS AVERAGED TO A 1-SECOND-MEAN VALUE
10	Sensor_Temp2	138	ASCII_Real	°C	TEMPERATURE OF THE MAGNETIC FIELD SENSOR MEASURED BY TEMPERATURE SENSOR T2, LOCATED AT THE SENSOR HEATER. VALUE IS AVERAGED TO A 1-SECOND-MEAN VALUE [††]
11	ElecTemp	147	ASCII_Real	°C	TEMPERATURE OF THE MPO-MAG ELECTRONICS MEASURED BY TEMPERATURE SENSOR T_ELEC. VALUE IS AVERAGED TO A 1-SECOND-MEAN VALUE

Table 24: MPO-MAG Derived Averaged Ground Calibrated Science Data

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[††] OB: ok; IB : the value is corrupted due to a loose contact, do not use!

5.4.2 MPO-MAG Derived Inflight Calibrated Science Data

ASCII table (Table Character) with the format specified in the table below. Exact Format still TBD/TBC

MPO-MAG Derived Averaged Calibrated Science Data Table

#	Name	Start Byte	Data Type	Unit	Description
1	TIME_UTC	1	ASCII_Date_Time_YMD_UTC		UTC TIME OF OBSERVATION: YYYY-MM-DDT HH:MM:SS.SSSSSSZ
2	TIME_OBT	29	ASCII_String		S/C-CLOCK AT OBSERVATION TIME: P/SSSSSSSSSS.FFFFF, P: PARTITION OF THE S/C-CLOCK, SSSSSSSSSS: RELATIVE SECONDS AFTER T0, FFFFF: FRACTIONAL NON DECIMAL SECONDS RUNNING UNTIL 65535
3	PosX	48	ASCII_Real	km	SC POSITION X COMPONENT, ECLIPJ2000 COORDINATES. DISTANCE RELATIVE TO STATED BODY
4	PosY	63	ASCII_Real	km	SC POSITION Y COMPONENT, ECLIPJ2000 COORDINATES. DISTANCE RELATIVE TO STATED BODY
5	PosZ	78	ASCII_Real	km	SC POSITION Z COMPONENT, ECLIPJ2000 COORDINATES. DISTANCE RELATIVE TO STATED BODY
6	FieldValX	93	ASCII_Real	nT	MAGNETIC FIELD X COMPONENT, CALIBRATED AND CLEANED ON BEST EFFORT BASE, ECLIPJ2000 COORDINATES.

MPO-MAG Derived Averaged Calibrated Science Data Table					
#	***Name***	***Start Byte***	***Data Type***	***Unit***	***Description***
7	FieldValY	105	ASCII_Real	nT	MAGNETIC FIELD Y COMPONENT, CALIBRATED AND CLEANED ON BEST EFFORT BASE, ECLIPJ2000 COORDINATES.
8	FieldValZ	117	ASCII_Real	nT	MAGNETIC FIELD Z COMPONENT, CALIBRATED AND CLEANED ON BEST EFFORT BASE, ECLIPJ2000 COORDINATES.
9	Quality_Flags	129	ASCII_String		QUALITY FLAGS DESCRIBING THE DATA QUALITY. Format still TBD.

Table 25: MPO-MAG Derived Inflight Calibrated Science Data

5.4.3 MPO-MAG Derived Averaged Inflight Calibrated Science data

ASCII table (Table Character) with the format specified in the table below. Exact Format still TBD/TBC

MPO-MAG Derived Averaged Calibrated Science Data Table

#	Name	Start Byte	Data Type	Unit	Description
1	TIME_UTC	1	ASCII_Date_Time_YMD_UTC		UTC TIME OF OBSERVATION: YYYY-MM-DDT HH:MM:SS.SSSSSSZ
2	TIME_OBT	29	ASCII_String		S/C-CLOCK AT OBSERVATION TIME: P/SSSSSSSSSS.FFFFF, P: PARTITION OF THE S/C-CLOCK, SSSSSSSSSS: RELATIVE SECONDS AFTER T0, FFFFF: FRACTIONAL NON DECIMAL SECONDS RUNNING UNTIL 65535
3	PosX	48	ASCII_Real	km	SC POSITION X COMPONENT, ECLIPJ2000 COORDINATES. DISTANCE RELATIVE TO STATED BODY
4	PosY	63	ASCII_Real	km	SC POSITION Y COMPONENT, ECLIPJ2000 COORDINATES. DISTANCE RELATIVE TO STATED BODY
5	PosZ	78	ASCII_Real	km	SC POSITION Z COMPONENT, ECLIPJ2000 COORDINATES. DISTANCE RELATIVE TO STATED BODY
6	FieldValX	93	ASCII_Real	nT	MAGNETIC FIELD X COMPONENT, CALIBRATED AND CLEANED ON BEST EFFORT BASE,

MPO-MAG Derived Averaged Calibrated Science Data Table					
#	**Name**	**Start Byte**	**Data Type**	**Unit**	**Description**
					ECLIPJ2000 COORDINATES. 1-SECOND-AVERAGED DATA
7	FieldValY	105	ASCII_Real	nT	MAGNETIC FIELD Y COMPONENT, CALIBRATED AND CLEANED ON BEST EFFORT BASE, ECLIPJ2000 COORDINATES. 1-SECOND-AVERAGED DATA
8	FieldValZ	117	ASCII_Real	nT	MAGNETIC FIELD Z COMPONENT, CALIBRATED AND CLEANED ON BEST EFFORT BASE, ECLIPJ2000 COORDINATES. 1-SECOND-AVERAGED DATA
9	Quality_Flags	129	ASCII_String		QUALITY FLAGS DESCRIBING THE DATA QUALITY. Format still TBD.

Table 26: MPO-MAG Derived Averaged Inflight Calibrated Science Data

6 ANNEX

6.1 Meta-Data

In order to support the user of the data with auxiliary information so called meta-data have been added to the label files. The meta-data describe the instrument conditions of the current observations. Furthermore, the used coordinate system is listed. Also information about the calibration type and the used sampling rate or averaging interval is provided by the meta data.

A complete overview about the meta-data can be obtained from **Table 27**.

NAME	RANGE / VALUE LIST	UNIT	CLASS	DESCRIPTION
sample_rate	0.5, 1, 2, 4, 8, 16, 32, 64, 128	Hz	Data	Describes the sample rate of the measurements in Hertz.
mpomag_boom_status	'stowed' 'deployment ongoing' 'deployed'	N/A	Instrument_Status	Describes the actual status of the MAG boom.
mpo_status	'MPO free flying' 'MPO attached to MTM and MMO' 'MPO attached to MTM' 'MPO attached to MMO'	N/A	Instrument_Status	Describes the actual status of the MPO s/c wrt. the other BepiColombo components. Could be interesting for any disturbance analysis.
measurement_range_index	0 ... 9, multiple values allowed	N/A	Data	Lists the measurement range indices in the given product, to allow easy filtering of data in different range indices. Measurement range index and measurement range correspond to each other.
measurement_range	2048 1024 512 256 128 64 32 16 8	nT	Data	Lists the measurement ranges in the given product, to allow easy filtering of data in different ranges. Measurement range index and measurement range correspond to each other. Range 9 and range 0 represent both 2048 nT ranges, range 9 is 24 bit wide and range 0 is 16 bit wide (standard).
data_reference_frame_acronym	'urf' 'scf' 'e2k' 'mbf' 'mso' 'msm' 'mme' 'rtn' 'gse' 'gsm' 'vso' 'mer' 'ven' 'ear'		Data	The short reference of the coordinate frame in which the magnetic field vectors have been projected.

data_reference_ spice_frame	'MPO_MPO-MAG_IBS' 'MPO_MPO-MAG_OBS' 'MPO_SPACECRAFT' 'ECLIPJ2000''BC_MBF' 'BC_MSO''BC_MSM' 'BC_MME_IAU2009_OF_DATE' 'BC_MPO_RTN' 'BC_GSE' 'BC_GSM' 'BC_VSO' 'IAU_MERCURY' 'IAU_VENUS' 'IAU_EARTH'		Data	The SPICE coordinate frame in which the magnetic field vectors have been projected.
calibration_type	'none' 'ground' 'inflight'	N/A	Data	Describes the calibration performed on the data. This is * none -- for raw and partially processed data, * ground -- for calibrated and averaged derived data using pre-launch ground based calibration results and longterm corrections from inflight observations. *inflight -- for derived data using special results obtained by in-flight measurement techniques.
averaging_ interval	N/A	s	Data	The interval over which data have been averaged (in seconds). This is only used in derived data and not being included into other products.

Table 27 : MPO_MAG Meta Data

END OF DOCUMENT