



MERTIS DATA USER GUIDE

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1. INTRODUCTION

The aim of this document is to describe the archival data produced by the Mercury Radiometer and Thermal Imaging Spectrometer (MERTIS) as archived in the ESA Planetary Science Archive (PSA), their calibration, usage and any caveats in their use.

It includes detailed descriptions of the data products and associated metadata, as well as the data generation, calibration, validation and analysis processes.

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

The specifications described in this document apply to all MERTIS 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.

1.1. Related documentation

1.1.1. Applicable Documents

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

- [AD.01] BC-SGS-PL-014, BepiColombo Science Data Generation, Validation and Archiving Plan
- [AD.02] BC-SGS-TN-026, BepiColombo Archiving Guide
- [AD.03] [PDS4 Standards Reference](#) (SR)
- [AD.04] [PDS4 Data Dictionary](#) (DDDB)
- [AD.05] [PDS4 Information Model Specification](#) (IM)

1.2. Reference Documents

- [RD.01] MER-DLR-MA-001, Instrument User Manual
- [RD.02] MER-DLR-TR-035, FM Spectrometer Optical Performance Report
- [RD.03] MER-DLR-RP-057, MERTIS-FM Spectrometer Radiometric Calibration Report
- [RD.04] Hiesinger, H., 2020, Space Sci Rev 216, 110. <https://doi.org/10/ghbnfm>
- [RD.05] MER-DLR-TR-042 – Science Performance Document 2026
- [RD.06] BC-MER-TR-TAR-2320 MERTIS Target Strategy Document

The documents described above can all be found in the instrument or mission archive document collection, or otherwise made available in an accessible long-term repository. This could include, but is not limited to:

- Instrument User Manual
- Pipeline description/user manual
- Calibration reports, or similar
- Performance reports, or similar
- Operations logs or timeline
- Key instrument or calibration paper(s)

All necessary information to calibrate and interpret the data should be made available in the archive itself.

1.3. Abbreviations and Acronyms

BB3	Blackbody 300 K (internal MERTIS calibration target, passive, floating)
BB7	Blackbody 700 K (internal MERTIS calibration target, actively controlled)
CF	Christiansen feature
DOI	Digital Object Identifier

DLR	Deutsches Zentrum für Luft- und Raumfahrt
FM	Flight Model
ICU	Instrument Controller Unit
MERTIS	Mercury Radiometer and Thermal Imaging Spectrometer
MLI	Multi-Layer Insulation
MPO	BepiColombo Mercury Planetary Orbiter
MPOI	MERTIS Pointing unit
NEDT	Noise Equivalent Temperature Difference
PI	Principal Investigator
PSA	Planetary Science Archive
PSU	Power Supply Unit
QM	Qualification Model
RB	Reststrahlen bands
S/C	Spacecraft
SHH	Sensor Head Heater
TEC	Thermal Electrical Cooler
TF	Transparency feature
TIR	MERTIS Thermal Infrared Radiometer
TIS	MERTIS Thermal Infrared Spectrometer
TRP	Temperature reference point

1.4. Citation and license information

Information on how to cite MERTIS data products is given below and is also contained in the MERTIS PDS4 Bundle itself (see PDS label bundle_bc_mpo_mertis.lblx).

The Mercury Radiometer and Thermal Infrared Spectrometer (MERTIS) consists of a push-broom IR-spectrometer (TIS) and a radiometer (TIR), which operate in the wavelength regions of 7-14 μm and 7-40 μm , respectively. This wavelength region is characterized by several diagnostic spectral signatures: the Christiansen feature (CF), Reststrahlen bands (RB), and the Transparency feature (TF), which will allow us to identify and map rock-forming silicates, sulfides as well as other minerals. Thus, the instrument is particularly well-suited to study the mineralogy and composition of the hermean surface at a spatial resolution of about 500 m globally and better than 500 m for approximately 5-10% of the surface.

Reference to instrument design, performance and scientific objectives of MERTIS can be made in scientific contexts by citing [RD.04] :

Hiesinger, H. et al, Team, 2020. Studying the Composition and Mineralogy of the Hermean Surface with the **ME**rcury **R**adiometer and **T**hermal **I**nfrared **S**pectrometer (MERTIS) for the BepiColombo Mission: An Update. Space Sci Rev 216, 110, <https://doi.org/10.1007/s11214-020-00780-w>

MERTIS on board the European Space Agency's BepiColombo Mercury Planetary Orbiter (MPO) is a joint project with PI teams at University of Münster (PI Harald Hiesinger) and

German Aerospace Center (DLR, Co-PI Solmaz Adeli). MERTIS Raw, Calibrated and Derived data products and archiving pipeline are produced by the MERTIS Instrument Team at DLR in cooperation with the BepiColombo Science Ground Segment at ESA.

MERTIS PDS4 data products are made available through the Planetary Science Archive of ESA and will be provided with a Digital Object Identifier (DOI) applicable to the data collection. The data products themselves can be referenced using the following information:

D'Amore, M., Adeli, S, Hiesinger, H, : BepiColombo MPO MERTIS bundle, PSA, DOI.

1.5. Data availability

All public data observational collections are available in the ESA Planetary Science Archive (PSA):

- Raw Data Collection (data_raw)
 - urn:esa:psa:bc_mpo_mertis:data_raw.
- Partially Processed Data Collection (data_partially_processed)
 - urn:esa:psa:bc_mpo_mertis:data_partially_processed.
- Calibrated Data Collection (data_calibrated)
 - urn:esa:psa:bc_mpo_mertis:data_calibrated.

More detailed description of the levels content is given in Section 5.

2. INSTRUMENT DESCRIPTION

2.1. Science objectives

Among the terrestrial planets, Mercury plays a special role. It is the smallest planet, the densest, the one with the probably oldest surface heavily gardened by space weathering, and it shows large daily surface temperature variations. Understanding Mercury is crucial to develop a better understanding of the early processes in the inner Solar System, of how our Earth formed, how it evolved, and how it interacts with the Sun.

The primary goal of the MERTIS instrument is to provide detailed information about the mineralogical composition of Mercury's surface layer by globally mapping thermal infrared spectral range with high spectral resolution. MERTIS plays a crucial role in the BepiColombo mission by helping to constrain models of the formation and evolution of the densest terrestrial planet.

The scientific objectives of MERTIS are categorized into four major goals, which are achieved through the synergistic use of its two measurement channels:

1. Study of Mercury's surface composition.
2. Identification of rock-forming minerals.
3. Mapping of the surface mineralogy.
4. Study of surface temperature and thermal inertia.

Here is a quick overview of the mapping techniques and channels to meet MERTIS scientific objectives, more details in [RD.04].

To fulfil these objectives, MERTIS utilizes two distinct but integrated sensors sharing the same optics and calibration components:

- Thermal Infrared Spectrometer (TIS):
 - Technique: Push-broom imaging spectroscopy in the 7–14 μm wavelength range.
 - Target: This channel is responsible for the identification and mapping of minerals (Objectives 1, 2, and 3).
 - Diagnostic Features: TIS identifies minerals by resolving specific emissivity features including the Christiansen feature (CF), Reststrahlen bands (RB), and the Transparency feature (TF). These features allow the discrimination of silicate groups (e.g., plagioclase feldspars, pyroxenes, olivines) and the detection of elements like sulfur or complex minerals like sulfides and sulfates.
 - Spatial Resolution: TIS provides global mapping at a maximum scale of 500 m, with limited observations at better than 500m.
- Thermal Infrared Radiometer (TIR):
 - Technique: Radiometric measurements using two distinct thermopile channels, Channel A (7–14 μm) and Channel B (7–40 μm), to provide independent and high-precision surface temperature measurements over Mercury's extreme diurnal range. Channel A is optimized for the higher daytime temperatures and provides a direct radiometric cross-check for the TIS spectrometer (which also operates in the 7–14 μm range), the much broader Channel B is essential for capturing the long-wavelength emissions of the cold nightside. By resolving the integrated energy across these two bands, MERTIS can independently derive brightness temperatures with a Noise Equivalent Temperature Difference (NETD) of less than 1 K at 100 K, effectively removing emissivity ambiguities and ensuring accurate mineralogical interpretations of the spectral data.
 - Target: This channel is dedicated to the characterization of surface temperature and thermophysical properties (Objective 4).

- **Diagnostic Capabilities:** TIR measures the full diurnal temperature cycle of Mercury, from roughly 100 K to 700 K. These measurements are used to determine the thermal inertia and surface texture of the regolith.
- **Synergy:** Radiometric temperature data from TIR are essential for removing emissivity ambiguities in TIS spectral retrievals, ensuring accurate mineralogical interpretations.

By combining these channels, MERTIS provides a comprehensive dataset to study the interplay between Mercury's surface composition, its extreme thermal environment, and the effects of space weathering.

2.2. Instrument design

The high surface temperature and the general notion that the surface of Mercury might be rich in feldspars was the driver for the development of MERTIS. Because the surface of Mercury is hot and there is no molecular atmosphere with rotational absorption bands, Mercury is an ideal target for mid-infrared emission spectroscopy.

The scientific requirements are discussed in detail in Error: Reference source not found and [RD.04], here only a summary is given to understand the instrument design philosophy.

The design of the MERTIS instrument is driven by the requirement to identify key mineralogic and compositional components of the Hermean surface. The instrument's spectral and radiometric performance is specifically optimized to resolve the following:

- **Primary Diagnostic Spectral Signatures:**
 - Christiansen Feature (CF): Emissivity maximum used to determine the bulk silicate composition.
 - Reststrahlen Bands (RB): Fundamental Si-O vibration bands used to identify specific silicate structures.
 - Transparency Feature (TF): Diagnostic for very fine-grained regolith (<25µm).
- **Targeted Mineral Groups and Materials:**
 - Rock-forming Silicates: Identification and differentiation of end-members of the plagioclase group, pyroxenes, and olivines.
 - Volatiles and Complex Minerals: Detection of elemental sulfur and representation of complex spectra such as sulfides and sulfates.

The surface temperature of Mercury has the largest diurnal variations of all terrestrial planets. While the daytime temperature can reach up to 700K, the night-time temperature can drop below 100K. While the spectrometer part of MERTIS (Thermal Infrared Spectrometer, TIS) allows a measurement of temperature down to about 300K, with the addition of the radiometer channel MERTIS (Thermal Infrared Radiometer, TIR) can measure temperatures over the whole diurnal cycle with a high resolution. To determine the thermal inertia and related thermo-physical properties the night side temperature of Mercury has to be measured

down to a temperature of 100K with a Noise Equivalent Temperature Difference (NETD) of less than 1 K.

Based on an initial instrument design the scientific performance was simulated to iterate the necessary parameters. It was performed by a computer program, allowing the simulation of spectral signal and noise values depending on Mercury surface and instrument parameters. That program allows quantitative and visual assessments of simulated spectra in order to optimize the instrument parameters and to predict the quality of future measurements.

The performance requirements for MERTIS are in general characterized by:

ID	Channel	Subject	Desired performance	Minimal performance
1	TIS	Spectral range	7 - 14 μm	7.2 - 13 μm
2	TIS	Spectral resolution	90 nm	200 nm
3	TIS	S/N ratio 500 K	>200	>100
4	TIS	Spatial resolution at 400 km	$\leq 300\text{m}$	$\leq 500\text{m}$
5	TIS	Spatial resolution for Global Mapping	<500m	500m
6	TIS	Coverage with 500-1000m resolution	100%	95%
7	TIS	Coverage with better than 500m resolution	10%	5%
8	TIR	NETD at 100K surface temperature	$\leq 1\text{K}$	$\leq 3\text{K}$
9	TIR	Spatial resolution at 400 km	$\leq 2000\text{m}$	$\leq 5000\text{m}$

Table 1: General MERTIS performance requirements

pointing unit which orients the optical path to incoming radiation sequentially from Mercury view, free deep-space and the two black body devices emitting at 300 K and 700 K as calibration targets (BB3 and BB7, respectively).

Passing through an highly reflective planet baffle in front of the instrument, the IR radiation is guided via the pointing mirror through an IR-window (filter) to the entrance optics. This part ends up with a slit at the intermediate focus which is the interface to the spectrometer optics. The intermediate focus is used to place the radiometer detector which also incorporates the slit for the following spectrometer optics. Diffracted by a curved grating the beam is focused onto the spectrometer sensor, the un-cooled bolometer which is thermally stabilized by a TEC. All proximity electronics are contained within the Sensor Head. A critical issue is the thermal design of this unit because high changes in temperature would cause significant misinterpretation of science data measurements. Thermal links to the dedicated MERTIS radiator as well as specific thermal couplings are foreseen to minimise the temperature

fluctuations during the calibration cycle of the instrument. This cycle corresponds to a 270° revolution of the pointing unit.

There are two on-board calibration devices, the BB3 and BB7 with their analogue control electronics. BB3 represents room temperature (near 300 K) and is a passive device with an Acktar-black coating to achieve a high optical emissivity. BB7 represents high Mercury temperatures (near 700 K) and is an actively powered micro IR emitter including its own optics. BB3 and BB7 illumination will be periodically measured (in addition to the Space view) within the in-flight calibration cycle.

Several temperature sensors are installed measuring the temperature at special locations distributed inside the housing, optics and electronics units.

In summary, MERTIS consists of several sub-systems with dedicated functions as described in full detail in [RD.01]. An overview of the modules involved is given below in Figure 1.

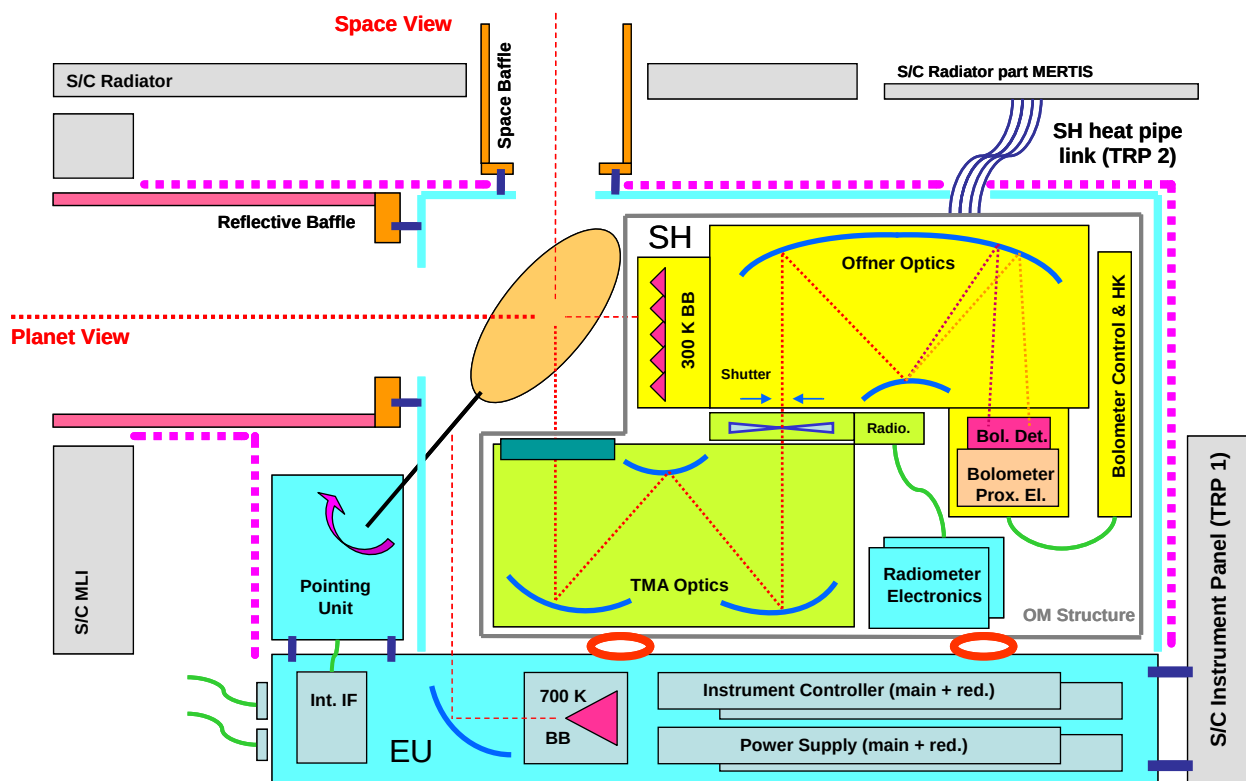


Figure 1: MERTIS Functional Block Diagram

2.3. Operational Modes

MERTIS is operated in several modes. A mode is defined for the below cases:

- Science mode where MERTIS performs the science data acquisition. This requires different S/C resources (power, data rate). These operational modes are technically adjusted by a set of parameters, so-called Operation Parameters
- A special mode is the safe mode which is entered when MERTIS detects a severe failure
- Diagnostic mode where MERTIS needs to be tested (e.g. test or diagnostic mode)

The complete list of all MERTIS modes is shown in [RD.01] chapter 5.

The active MERTIS mode can be obtained by the parameter HK_STAT_MERTIS_MODE stored in mer_XXX_hk_default data. The user should take care that this parameter indicates the modes read at HK acquisition time, and that acquisition frequency differs from TIR/TIS (typically 20 secs for HK and < 800 ms for TIS/TIR). This implies one cannot correlate perfectly this HK to the mode of individual TIS/TIR acquisitions.

Each mode transition is initiated by a dedicated telecommand or automatically in case of failure detection/termination of sequence. This mode transition is notified by sending of a progress event TM_Event_Progress (Mode Transition), that is not archived but available only during TM processing.

After **Power-On** MERTIS performs the primary and secondary boot process, initializes the ICU as well as the aPSU hardware and goes nominally in the **Stand-by** mode without any telecommanding. In case that a failure is detected MERTIS stays in **Safe** mode where all sub-systems are at power-off and MERTIS sends a small set of housekeeping parameters showing the operational status and temperatures of the ICU and PSU. The main purpose of the **Safe** mode is to perform the memory management service, i.e. uploading the Application Software in EEPROM or checking/downloading the memory in general.

In order to enter the **Science**, **Diagnostic** and **Calibration** modes it is nominally needed to get to the **WarmUp** mode before by [TC_Power_Enable](#). This is foreseen to ensure that the thermal stabilization of the instrument is reached before starting to acquire science data. The time where MERTIS remains in **WarmUp** mode depends on the thermal environmental conditions and purpose of operation. The **Science** and **Diagnostic** modes can be entered from **WarmUp** mode by telecommands [TC_Science_Enable](#), [TC_Calibration_Enable](#) and [TC_Diagnostic_Enable](#).

The **Test** mode (foreseen mainly for ground operation) is entered directly from the **StandBy** mode by [TC_Test_Enable](#). Dedicated disable commands are used to leave the mode (e.g. [TC_Test_Disable](#)).

The **Science** mode has 10 nominal “sub-modes” and 15 additional sub-modes for exceptional operational cases. The science sub-mode which is reached after [TC_Science_Enable](#) depends on the operation parameter configuration (e.g. which sub-system is switched-on).

See [RD.01] for more information and the complete list of all MERTIS modes is provided also in Appendix 8 of this document.

The observation strategy for MERTIS is described in [RD.01].

The following modes are used to perform science data acquisition with radiometer (TIR) and spectrometer/bolometer (TIS).

Each mode defines a specific resolution (High/Med/Low) where TIS binning and TIS and TIR repetition rate are different.

2.4. Instrument performance

The MERTIS instrument was designed to meet a rigorous set of scientific performance requirements derived from its primary objectives: mapping Mercury's mineralogy and characterizing its thermophysical properties. Data collected during the Near-Earth Commissioning Phase (NECP), routine cruise check-outs (CO), and planetary flybys demonstrate that MERTIS is fully functional and meets or exceeds all scientific requirements. [RD.05] describes the science performance analysis performed during the BepiColombo cruise phase.

Based on in-flight measurements and scaling of flyby data (e.g., MSB5 and ESB), the following table summarizes the compliance of MERTIS with its design specifications:

ID	Subject	Minimal Required Performance	In-Flight Status	Verification Source
1	TIS Spectral Range	7.2 – 13 μm	Compliant (7–14 μm)	MSB5
2	TIS Spectral Res.	200 nm	Compliant (90 nm)	NECP
3	TIS S/N Ratio	>100 at 500 K	Compliant (>200)	NECP
4	TIS Spatial Res.	≤ 500 m at 400 km	Compliant (~ 290 m)	ESB Scaling
8	TIR NETD	≤ 3 K at 100 K	Compliant (≤ 1 K)	NECP / CO-14
9	TIR Spatial Res.	≤ 5000 m at 400 km	Compliant	MSB5

Table 2: MERTIS Science requirements verification

Measured Detector Performance and Stability

- TIS Spectrometer:** The TIS channel has shown exceptional stability over the 12-year period from ground calibration (2013) to the latest in-flight check-outs (2025). Post-launch, a minor image shift of less than 0.5 pixels was observed, which has no impact on scientific return. While early in-flight images exhibited "stripe" artifacts, these were successfully mitigated through the **VSKIM bias recalibration** (which TIS detector Voltage Skim belong to each Operation Point of TIS working range, stored in TIS metadata as `HK_STAT_BOL_BIAS_VOLT_ACTIVE_PARAM_SET`) and subsequent software updates.
- TIR Radiometer:** The radiometer is fully operational with stable noise characteristics (<100 nV). A 12–13% sensitivity decrease in the long-wavelength channel (TIR-B) was identified during ground testing due to terrestrial atmospheric effects; however, this

degradation **stopped immediately upon launch** (vacuum conditions), and sensitivity has remained constant since NECP.

2.4.1. Performance Event Timeline

The following events represent significant milestones or updates that influenced the instrument's operational performance during the cruise phase:

Event	Date	Impact on Performance
NECP	Nov 2018	First in-flight verification; confirmed nominal health of all subsystems.
CO-4 / CO-5	2020–2021	VSKIM Bias Calibration: Identified the offset needed to remove stripe artifacts and restore linearity.
CO-9	Mar 2023	Space Port Swap: Successfully demonstrated optimized science acquisition through the space baffle.
SW Update #1	July 2025	Permanently integrated VSKIM correction and retuned the SHH thermal controller , reducing TIR noise by an order of magnitude.
MSB5	Dec 2024	First Mercury observations; verified spatial resolution and confirmed high radiometric quality.
SW Update #2	May 2026	Enabled Inverted Cycle mode , allowing for gap filling without thermal perturbations or noise from power cycling.

To maximize SNR, MERTIS acquires multiple sub-acquisitions within a single repetition period and transmits the averaged image. The number of oversamplings performed is recorded in the metadata attributes TIS_NUM_OVERSAMP and TIR_NUM_OVERSAMP within each science product

2.4.2. Known Performance Constraints and Caveats

- **100 ms Repetition Limit:** Full detector observations with a 100ms TIS repetition rate were found to cause occasional frame drops. Consequently, this configuration is now **automatically rejected** by the onboard software to preserve data integrity. Full detector observations will be performed with an 800 ms TIS repetition rate.
- **TIR Minimum Repetition:** The TIR radiometer is now restricted to a minimum repetition period of **800 ms** to ensure stable radiometric conditions and complete readout of all channels.
- **Straylight in Space Port:** Data acquired via the space port during flybys (e.g., MSB5) contains up to **10% straylight contamination** from, most probably, spacecraft radiator reflections. This effect is not expected to impact nominal orbital operations, which will utilize the specifically designed Planet port.

- **Thermal Environment:** Deterioration of the spacecraft Multi-Layer Insulation (MLI) may cause MERTIS temperatures to reach 50.6°C near perihelion. To ensure instrument safety, MERTIS may enter **Safe Mode** if the Temperature Reference Point (TRP-1) exceeds 45°C during the most extreme thermal phases.

2.5. Science operations planning strategy

The primary planning objective of MERTIS is the global mineralogical mapping of Mercury's surface at a pixel scale of 500 m or better. The operation strategy utilizes a mapping and calibration scheme designed to maximize scientific return within the extreme thermal environment of Mercury. Because the calibration cycle introduces regular data gaps, >80% coverage is achieved only after four Mercury years.

The nominal MERTIS observation cycle consists of **16 seconds of calibration** target observations (Planet, BB700, BB300, and Deep Space) followed by **124 seconds of planet observation**. This cycle introduces periodic gaps in spatial coverage which are mitigated by adjusting the observation time in subsequent orbits to cover the gaps of the previous orbit (**Direct Gap Filling**), and dedicated sessions in the 2nd half of the nominal mission to ensure global mapping completeness (**Gap Filling**).

Seasonal Phase Strategy

The overall strategy is governed by Mercury's seasonal phase (Mercury True Anomaly - MTA) (Figure 2)

- **Aphelion ($135^\circ < \text{MTA} < 225^\circ$):** The spacecraft perihelion is on the dayside allowing MERTIS to map Mercury in high-resolution with pixel scales of **<500 m**. This is the primary phase for **Global Mapping (GM) in high resolution**. TIS operates at its highest spectral and spatial resolution to observe the dayside. TIR operates at dayside, accompanying the TIS observations, as well as at nightside without TIS planet observations. The operation mode used here is Science_High_Res1 (see next section). To manage data volume, a "**skipping rule**" is applied; when orbital overlap exceeds 110%, MERTIS can skip specific orbits.
 - **Direct Gap Filling (DGF):** Gaps introduced by the 16-second in-flight calibration sequences are filled by adjusting observation timing in subsequent orbits, where nominal observations are skipped because of the above-mentioned overlap, to ensure a seamless global mosaic. The mode used here is Science_High_Res1 but in the discarding variation (see next section).
 - **Gap-Filling (GF):** After two aphelia, the remaining gaps, not possible to fill with the direct gap filling strategy, are targeted in order to obtain a global coverage of the surface. The mode used here is Science_High_Res1 but in the discarding variation (see next section).

- **Terminator ($225^\circ < \text{MTA} < 315^\circ$ and $45^\circ < \text{MTA} < 135^\circ$):** Focuses on the terminator crossing and **Permanently Shadowed Regions (PSR)**. TIR observes continuously while TIS observations are focused around the crossing, in Science_High_Res1, Science_High_Res3 and Science_Med_Res3 modes (see next section). Targeted observations of high-priority regions are performed by collecting TIS data when resources allow. The strategy for targeted observations is described in RD.13.
- **Perihelion ($315^\circ < \text{MTA} < 45^\circ$):** During this phase, the perihelion is on the nightside, providing optimal conditions for radiometric (TIR) observations of surface temperature. Dayside perihelion passes during this season result in lower spatial resolution TIS data, which are used to plan subsequent high-resolution phases. So, TIS performs **Mapping**, in Science_Low_Res3 (see next section), while TIR performs high-resolution temperature mapping at night, while continuing observing at the dayside as well. Targeted observations of high-priority regions are performed by switching to higher-resolution modes when resources allow. The strategy for targeted observations is described in RD.13.

Mercury's seasons to optimize scientific return:

- **High-Resolution Mapping (Aphelion):** When the spacecraft perihelion is on the dayside, MERTIS performs high-resolution mapping at pixel scales of **<500 m**. To manage data volume, a "**skipping rule**" is applied; when orbital overlap exceeds 110%, MERTIS can skip specific orbits when overlap exceeds 80%.
- **Survey Mapping (Perihelion):** During this phase, the perihelion is on the nightside, providing optimal conditions for radiometric (TIR) observations of surface temperature. Dayside perihelion passes during this season result in lower spatial resolution TIS data, which are used to plan subsequent high-resolution phases.
- **Direct Gap Filling:** This will be executed in **Aphelion (Global Mapping)**. Gaps introduced by the 16-second in-flight calibration sequences are filled by adjusting observation timing in subsequent orbits, where nominal observations are skipped because of the above mentioned overlap, to ensure a seamless global mosaic.
- **Gap-Filling:** This will be executed in **Aphelion (Global Mapping)**. After two aphelia, the remaining gaps, not possible to fill with the direct gap filling strategy, are targeted in order to obtain a global coverage of the surface.
- **Targeted observations:** Those will be executed in **Terminator** and **Perihelion**. Targeted observations of regions identified with high scientific relevance are performed during terminator and perihelion seasons throughout the mission. The strategy for targeted observations is described in RD.13.

The MERTIS observation strategy is schematically represented in Figure 2.

Operational Flexibility

MERTIS acquisition is flexible, allowing for spectral/spatial binning and detector windowing to manage data volume. To maintain thermal stability without power-cycling the spectrometer, the instrument remains active even when scientific data is not being transmitted. This is achieved via the **Discarding Mode**, which allows MERTIS to preserve thermal equilibrium during nightside observations or gap-filling manoeuvres. Detailed technical logic for this mode is provided in Section 4.2.1

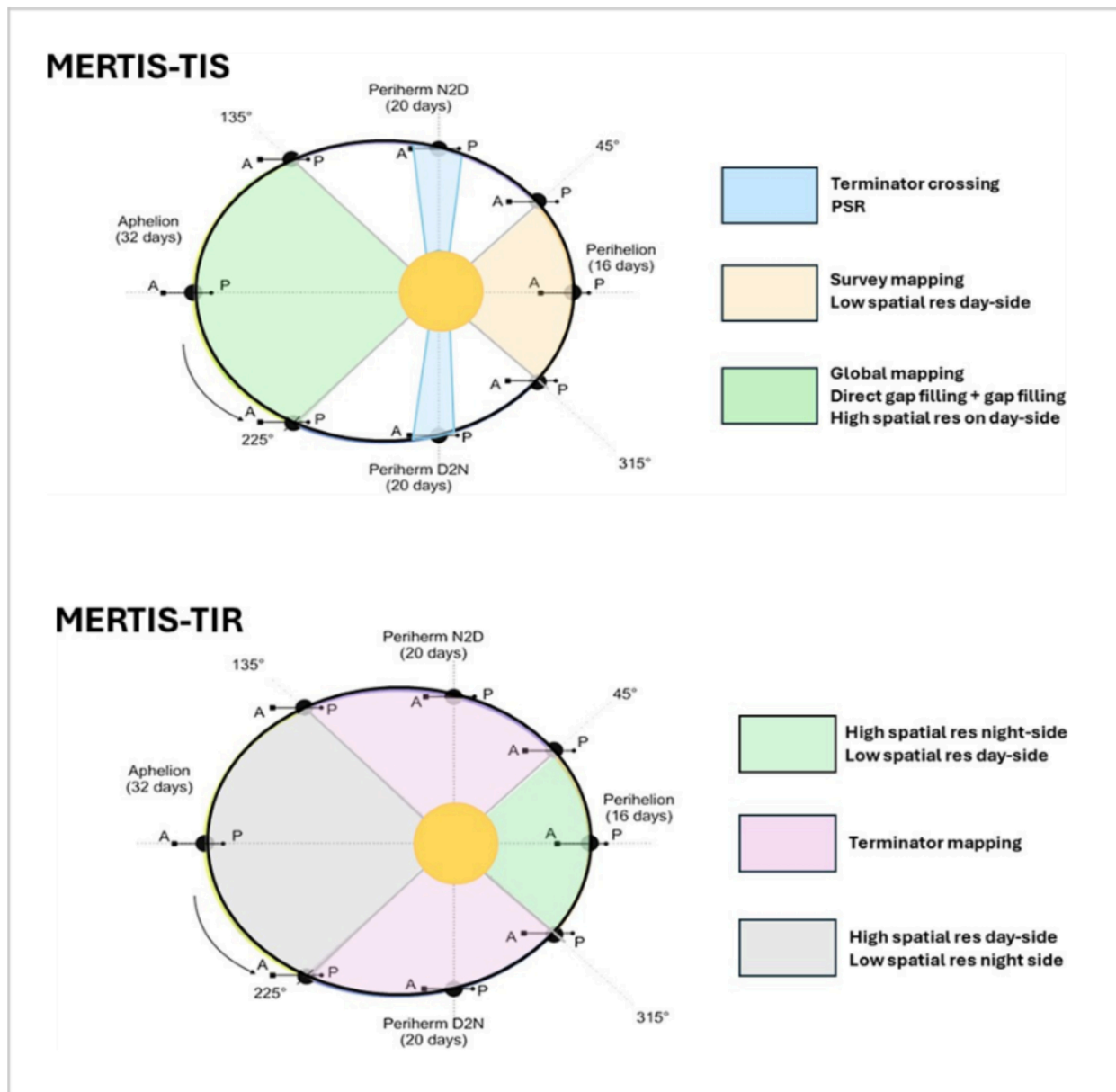


Figure 2: Overview of TIS and TIR channels observing strategy across seasonal phases of Mercury from [RD.06].

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2.5.1. Instrument Operational Modes

To accurately interpret MERTIS data and operation logs, it is essential to distinguish between high-level **Science operations planning strategy** (previous section) and low-level **Instrument operational modes**. While the science strategies define the mission's mapping

goals, the operational modes represent the highly specialized technical configurations of the instrument hardware and onboard software. In other words, the high-level strategies in the section above are technically implemented through specific Instrument Operational Modes. These configurations define the power status of sub-systems (e.g., TIS Spectrometer ON/OFF, Sensor Head Heater ON/OFF), and the specific data acquisition parameters.

Operational modes are adjusted via Operation Parameters—such as repetition rates, binning, and detector windowing—to match available spacecraft resources (power and data rate) or to respond to specific thermal environments. For instance, a high-level mapping strategy might be implemented using the `Science_High_Res1` operational mode at periapsis and switched to a windowed or binned mode as altitude increases.

The specific MERTIS operational modes, as defined in the instrument manual, are summarized here.

Mode Name	TIS	TIR	Nominal Repetition Rate (TIS / TIR)	TIS Binning (Spatial x Spectral)	TIS Window Size (Spatial x Spectral)
Safe	OFF	OFF	N/A	N/A	N/A
StandBy	OFF	OFF	N/A	N/A	N/A
WarmUp	ON	ON	N/A (Stabilization only)	N/A	N/A
Science_High_Res1	ON	ON	100 ms / 800 ms	1 x 2	100 x 80
Science_High_Res2	ON	ON	300 ms / 900 ms	1 x 2	100 x 80
Science_High_Res3	ON	ON	800 ms / 800 ms	1 x 2	100 x 80
Science_Med_Res1	ON	ON	100 ms / 800 ms	2 x 2	100 x 80
Science_Med_Res2	ON	ON	300 ms / 900 ms	2 x 2	100 x 80
Science_Med_Res3	ON	ON	800 ms / 800 ms	2 x 2	100 x 80
Science_Low_Res1	ON	ON	100 ms / 800 ms	2 x 4	100 x 80
Science_Low_Res2	ON	ON	300 ms / 900 ms	2 x 4	100 x 80
Science_Low_Res3	ON	ON	800 ms / 800 ms	2 x 4	100 x 80

Table 3: MERTIS Instrument Operational Modes used in operation planning.

Key Scientific Parameters:

- **TIR Minimum Rate:** The TIR radiometer repetition time is enforced by onboard software to a minimum of 800 ms to ensure stable radiometric conditions.
- **Binning:** Spatial binning can be used to increase the Signal-to-Noise Ratio (SNR) at the expense of spatial resolution, particularly for polar observations.
- **Data Compression:** Most science modes utilize Rice coding or differential images. Rice coding is a lossless data compression method that uses a subset of Golomb

codes, specifically designed for efficient encoding of data with small values, that explain the use of differential images. Users should note that data volumes for stable scenes (e.g., deep space) may be significantly lower than predicted due to high compression efficiency.

2.6. Data handling

This section describes the logic governing the transformation of MERTIS telemetry into archival products and the strategy for maintaining data integrity through data versioning.

2.6.1. Overall Processing and Ingestion Strategy

The MERTIS data processing pipeline is a collaborative effort between the BepiColombo **Science Ground Segment (SGS)** and the **MERTIS Instrument Team**. The workflow follows a systematic "push-pull" model:

- **Telemetry-to-Raw (Level 1):** Real-time telemetry is relayed from the Operational Ground Segment (OGS) to the SGS, where it is systematically de-packetized and reformatted into PDS4-compliant **Raw products**.
- **Calibration (Levels 2 & 3):** The MERTIS team retrieves these Raw products and applies the radiometric and geometric calibration routines (the **Raw2Cal** component) to produce **Partially Processed (par)** and **Calibrated (cal)** products.
- **Validation and Ingestion:** Prior to delivery, all products are validated using NASA's PDS4 validation tool to ensure schema and Schematron compliance. Validated products are then delivered back to the SGS via the Product Delivery Packager for ingestion into the **Planetary Science Archive (PSA)**.
- **Science Quality Control:** The Instrument Team routinely assesses archival products to enable rapid detection and correction of calibration issues, ensuring the archive remains the most scientifically accurate representation of the Hermean surface.

2.6.2. Versioning Strategy

To ensure traceability, MERTIS products follow the standard BepiColombo versioning convention. The primary version is stored in the label in and the labels in their filenames as `__V_v.ext` as convenience.

- **Minor Versions (v):** Incremented for routine pipeline updates, bug fixes in metadata, or improvements that do not fundamentally change the radiometric radiance values.
- **Major Versions (V):** Triggered by significant changes to the calibration algorithms, updates to the instrument's spectral/radiometric response models, or structural changes to the PDS4 labels. A `Modification_History` class is maintained within

each product label to document the rationale for version increments (see 10. Appendix B).

Beyond the primary versioning captured in the product filename, MERTIS tracks component-level traceability through internal metadata in TIS and TIR data for levels PAR and CAL. The `Product_Observational/File_Area_Observational/File/comment` tag within the PDS4 label contains a JSON-formatted string capturing specific software and calibration versions. This include the version of the `raw2cal` pipeline, the TIS calibration routine internally called `LibMERTISCalib`, and the `tis_calib_version` (identifying the specific TIS calibration coefficient set applied to the data).

The JSON solution is a orkwork in progress: for the final archive, these values will be moved into standard PDS4 attributes in the `Processing_Context` or `Mission_Area`.

2.6.3. Use of SPICE Kernels for Geometric Calculations

The accuracy of MERTIS's geo-location is strictly dependent on the provenance of the SPICE kernels used during processing:

- **Operational Processing:** For initial rapid delivery to the PSA (typically within a few days of acquisition), the pipeline utilizes **operational/predicted SPICE kernels**. These provide a "best-guess" geometry for immediate scientific assessment.
- **Archival Reprocessing:** Periodic updates are scheduled to ingest the **archived/reconstructed orbit and attitude data** delivered by ESA after the completion of specific mission phases or orbit ranges. All SPICE meta-kernels references will be updated to PDS4 internal references, at latest in post operations.
- **Metadata Tracking:** Every product label explicitly identifies the specific **SPICE meta-kernel** used and the **kernel provenance** (predicted, reconstructed, or mixed) in the `Discipline_Area` to allow users to evaluate the precision of the geometric metadata.

To ensure geometric consistency between different processing levels, MERTIS tracks kernel provenance across the parent-child product hierarchy. The `Product_Observational/Observation_Area/Discipline_Area/geom:Geometry` tag is used to explicitly state if the SPICE kernel version utilized for a product remains "unchanged" from its parent product. This allows users to quickly verify that geometric metadata (such as latitude and longitude layers) is consistent across RAW, PAR, and CAL levels for a given acquisition.

Near-real-time RAW/PAR/CAL products generated within days of downlink will use predicted operational meta-kernels. Once ESA releases reconstructed orbit/attitude kernels (typically post-phase or after specific orbit ranges), a scheduled reprocessing run will update the geometric backplanes (`GEOMETRY_DATA`) and metakernel references in labels. **(EDITOR COMMENT: timing is under diiscussion)**

3. CALIBRATION

The MERTIS calibration process is designed to convert raw science telemetry, measured in Digital Numbers (DN), into physically meaningful radiance values. This procedural workflow accounts for instrument-induced radiation, detector performance drifts, and the extreme thermal environment encountered at Mercury. A critical prerequisite for nominal science acquisition is the 3-hour warm-up requirement; the instrument must operate in WarmUp mode for at least 180 minutes to reach necessary thermal stability. For exhaustive technical details on spectral performance and radiometric response, users should refer to technical reports [RD.02].

3.1. Calibration strategy

The general calibration strategy relies on a frequent in-flight calibration cycle that monitors the instrument's radiometric response and internal background signal. Because MERTIS utilizes uncooled detector technologies, micro-bolometer for TIS and thermopile for TIR, the thermal state of the sensor head significantly influences science measurements. To manage this, the instrument utilizes a pointing unit MPOI that sequentially orients the optical path toward four distinct targets:

- **PlanetView:** The primary scientific target (Mercury surface).
- **BB700 (Black Body 700K):** An actively powered micro-IR emitter representing the high temperatures of Mercury's dayside. It should be noted that this technological realisation had constrain and is produces nodes not provide a flat-field illumination. Instead, it produces, but a well-known and charaterised spatio-spectral structure superimposed on top of the blackbody calibration spectrum.
- **BB300 (Black Body 300K):** A passive on-board device coated with Acktar-black representing housing/room temperature.
- **SpaceView:** A cold reference view used for noise depression and background signal subtraction.

The Pointing Unit (MPOI) typically operates in a sequential 'Move' mode to cycle between targets, but can be commanded to fixed orientations (PlanetView, BB3View) for specialized characterization sessions.

In-flight Calibration Cycle and Timing: Nominal operations follow an optimized 140-second calibration period. This duration was implemented in 2024 as the ideal trade-off between calibration stability and science observation time, replacing the earlier 20-second and 60-second cycles. Within this 140-second window, approximately 16 seconds are dedicated to calibration targets (Planet, BB700, BB300 and Space), with the remaining time allocated to PlanetView.

Cruise Phase Port Swapping: During the interplanetary cruise phase, the PLANET view is obstructed by the Mercury Transfer Module (MTM). To acquire scientific data, the team implemented a Port Swap procedure where the Space port (which is unobstructed) is used as the science view, while the calibration cycles are adjusted accordingly. The user should take care of this when looking for scientifically useful data in the cruise phase (**Editor Note: this is not marked in any way in the data, cruise operation procedures simply didn't produce any Planet observations. Each port view is always "true", the instrument really did look through it, during nominal or cruise. We may think to add a flag for this in future version of data, if useful**). The PAR level contains all the view ports acquisition, where CAL level only contains the scientifically valuable acquisitions, or the target one, in opposition to the engineering/technical one (internal black bodies, deep space). The PAR/CAL difference is valid for all phases, not only Cruise.

Radiometric and Thermal Management: The system's response to the strong flux from the instrument housing is managed through 10 defined thermal dynamic ranges. These ranges cover the full operational temperature range of -1.24°C to 39.92°C . The TIS pipeline calibration submodule selects the appropriate detector settings (specifically the VSKIM control voltage, that is stored in the TIS product as `HK_STAT_BOL_BIAS_VOLT_ACTIVE_PARAM_SET`) to keep image signals within a maximized linear response window of roughly 1450 to 12280 DN. These ranges overlap by approximately **1 K** to allow for instantaneous automatic switching as the instrument heats or cools.

3.2. On-ground calibration

The MERTIS on ground calibration performances and details can be found in [RD.02]. Here only a brief overview is given.

The initial on-ground radiometric calibration of the MERTIS Flight Model (FM) was performed under Thermal Vacuum (TVAC) conditions at the DLR IR-Lab in Berlin-Adlershof. The primary goal was to establish the digital/thermal dynamic ranges and derive the spectro-radiometric response functions across the full operational temperature range (0 to 40°C). To continuously improve dataset fidelity, the MERTIS team maintains an active laboratory calibration campaign utilizing the MERTIS Flight Spare (FS) model. The radiometric calibration concept for the MERTIS-FM TIS is divided into four parts.

1. Spectral calibration using narrow-band spectral features at multiple angular positions within the FOV
2. Adjustment of the image signal's dynamic window for a maximized linear response
3. Determination of thermal dynamic ranges
4. Radiometric response measurements under vacuum covering the whole thermal range

The radiometric calibration campaign was performed on the MERTIS FM model using measurement facilities at the DLR IR-Lab in Berlin Adlershof. In preparation of the determination of the spectro-radiometric calibration coefficients the system was optimized for a maximum signal SNR and linearity of the system response. Additionally, it has been

ensured that the instrument keeps its radiometric performance for all thermal states it will face during the operation at Mercury with respect to the large spectrometer temperature differences ranging from 0°C to 40°C. The calibration coefficients have been verified through an independent measurement in which a static scene has been recorded and the corresponding imaging data was converted to radiance values. The comparison with the theoretical values gave that there are practically no systematic errors visible. For the most basic measurement case (no averaging) the radiance images resulting from the difference images show a maximum SNR of 280 for a 700K scene. Additional averaging will even improve that result ([RD.03]).

Here the detailed results for the calibration steps are presented for the MERTIS-TIS FM.

3.3. Spectral Calibration Coefficients

3.3.1. TIS Channel

The spectral calibration of the TIS channel was performed following qualification testing by evaluating the response of a set of narrow-band infrared bandpass (BP) filters (covering 7 to 13.5 micron) across the field of view. The differences between the measured central spectral positions of the bandpass sample points on the image and the calculated dispersion plane define the spectral calibration fit error, reported as a standard deviation (σ_{fit}).

From this characterization, the spectral sampling distance (SSD), fitting coefficients (λ_0, s, t) , and the image clocking angle (Φ) are derived (summarized in Table 4). The image clocking angle (Φ) defines the rotational misalignment of the detector array within its focal plane (perpendicular to the incoming optical path) relative to the grating's dispersion axis. Because of this clocking angle, the spatial and spectral axes of the un-resampled detector grid are not perfectly parallel to the optical wavelength orientation, introducing a slight spatial-spectral tilt across pixels. This effect is preserved in PAR-level products (accompanied by a pixel-specific wavelength matrix) and is fully corrected through spectral resampling in the CAL collection.

An image showing all bandpass measurements as a sum image is given by Figure 3. The measurement data sets used for the spectral calibration / evaluation were taken in the measurement session “FM_18” on 29/January/2013. ([RD.02], [RD.03])

SSD [m]	Clocking [°]	f_0 [m]	s [m / index]	t [m / index]
8.904449×10^{-8}	7.552717×10^{-1}	1.517173×10^{-5}	-1.173749×10^{-9}	8.903675×10^{-8}

Table 4: Spectral Sampling Distance (SSD), image clocking angle Φ relative to the (almost spectral) image direction j and the spectral calibration coefficients (λ_0, s, t) .

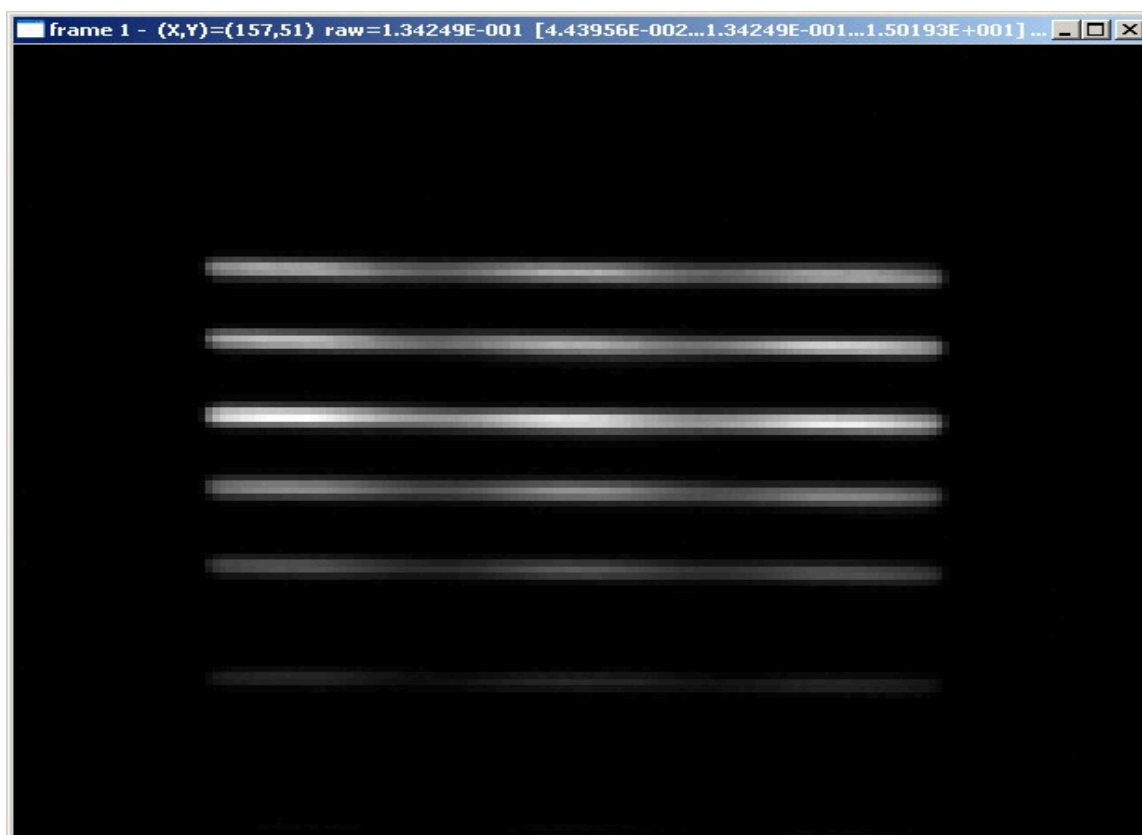


Figure 3: Figure 3: Sum of all difference images of the IR-narrow band pass filter set measured using the MERTIS-FM after vibrational tests. The set covers the spectral range between 7.5 μm and 13.5 μm . Y-axis : spectral direction, 7.5 μm on the top , x-axis : spatial direction

3.3.1.1. Image signal - dynamic window with maximized linear response

The MERTIS TIS spectrometer employs an uncooled 160x120 microbolometer array. Unlike cooled quantum detectors, microbolometers measure incident thermal radiation through the temperature-dependent change in electrical resistance of their detector elements. Because the detector operates uncooled near the instrument's ambient housing temperature (0 to 40 °C), the thermal background radiation emitted by the instrument structure itself is orders of magnitude larger than the scientific signal from the scene.

To prevent this massive, constant background flux from saturating the readout electronics and Analog-to-Digital Converters (ADCs), a voltage skimming (U^{SKIM} / VSKIM) bias is applied at the readout level. Skimming functions as an analog offset cancellation, "skimming off" the large baseline background current prior to signal amplification and digitization. Unilluminated blind/masked pixels along the outer edges of the detector (reference areas) continuously monitor the thermal dark current state. By dynamically adjusting U^{SKIM} across 10 Operational Points (OP1–OP10) as instrument temperatures shift, the remaining net signal is held within the detector's optimal linear dynamic response window (1450 to 12280 Digital Numbers CCD raw readout, see Fig. 4). The 10 Operational Points were defined to maintain an almost

linear detector response function within each temperature window by adjusting control parameters (specifically and bolometer chip temperature). The operating boundaries of adjacent points overlap, allowing for seamless, instantaneous switching between operational regimes as instrument temperatures drift

This calibration step contained two sub-steps:

- a) The detector gain U^{FID} had to be maximized. A measure for the improvement is the difference image SNR for a constant radiometric scene signal. The setup consisted of the MERTIS-FM model mounted in the thermal vacuum chamber. In front of the KRS5-chamber window a SR-20 BB radiator was set to a temperature of 800°C. For the detector gain a value of $U^{FID} = 3.972$ V has been selected for all subsequent calibration measurements and the future instrument operation.
- b) In the second step the digital dynamic range I^S as introduced was determined and giving the digital signal value bounds $\bar{S}^{low}$ and $\bar{S}^{high}$ respectively.

The measurements were done with the same setup as in step a). This time the detector gain $U^{FID} = 3.972$ V remained at a fixed value and the value U^{SKIM} was varied in a range between 4.294 V and 4.414 V. For each U^{SKIM} , a measurement has been done and the maximum signal within a difference image, image offsets, noise (from 500 samples) and the difference image SNR were calculated. All raw image data had been freed of disturbing offset components using the image reference areas.

The results can be seen in Fig. 4. The accepted digital dynamic range for MERTIS-FM is:

$$I^S = [1450 \text{ DN} \dots 12280 \text{ DN}]$$

Within the I^S DN interval, system noise, difference signal, and SNR remain stable and linear. This baseline offset window forms the operational criteria for defining the 10 Operational Points (OP1–OP10), ensuring that as the instrument temperature fluctuates in orbit, autonomous parameter adjustments keep the baseline signal centered within this linear range

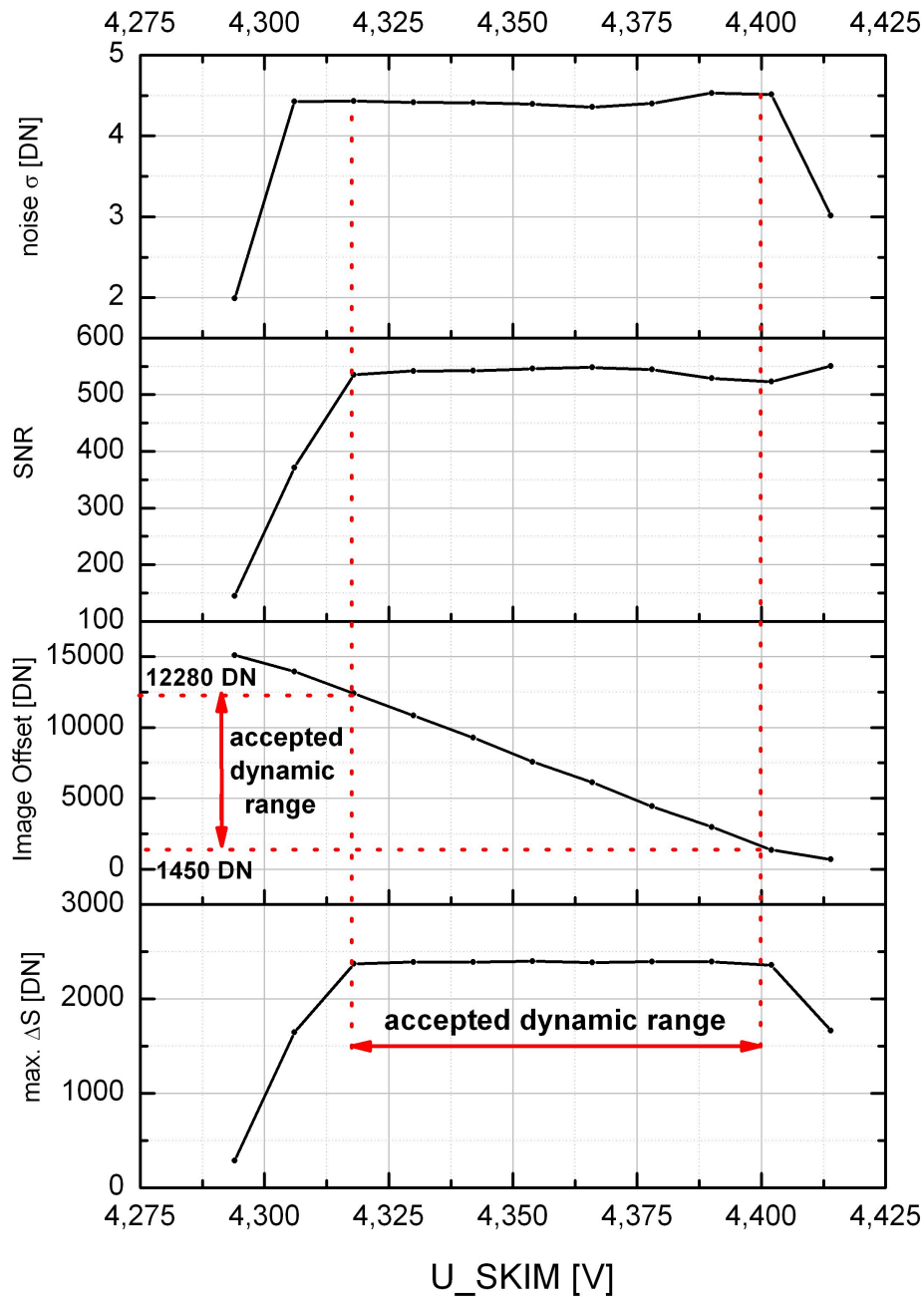


Fig. 4: Determination of an acceptable digital dynamic window avoiding a signal degradation and a non-linear system response. The measurement was taken using 11 different values of the detector's control value U^{SKIM} . In the accepted interval the max. difference signal, noise and image SNR stay nearly constant. The lower and upper bounds given define the accepted dynamic range of $I^S = [1450 \text{ DN} \dots 12280 \text{ DN}]$ related to image offsets. Note: The absolute value of the SNR is not relevant here, but only the slope.

3.3.1.1.1. Configuration of thermal dynamic ranges

With these measurements the system's response to the strong flux coming from the instrument housing and influencing the image offsets is measured and the detector's operational parameters are adjusted in order to keep the image signals within the dynamic range. The I^S result are the definitions for the thermal ranges $D_k^{thermal}$ covering the full MERTIS relevant instrument temperature range of $= I^T$ $[-1.24^\circ\text{C} \dots 39.92^\circ\text{C}]$ including the detector operational setting sets D_k and the temperature ranges and image offset intervals.

The detector settings to be found compensate the shift of the image offsets outside the dynamic range. This was achieved adapting the control voltage U_k^{skim} . Additionally, the bolometer chip temperature has been adapted so that the TEC of the detector needs to compensate only temperature differences $< 10\text{K}$.

Furthermore, the thermal range definitions are arranged with an overlap of approximately 1 K ($\pm 0.2\text{K}$) between neighboring bounds. In nominal flight operations, the MERTIS On-Board Application Software (APS) operates in automatic mode, continuously monitoring the instrument base plate temperature (HK_TEMP_OST_BASE_PLATE). When the thermal boundary is crossed, the software autonomously switches to the corresponding Operational Point (OP1–OP10). The 1K overlap provides necessary thermal hysteresis, ensuring stable operational switching without rapid toggling between ranges. The active Operational Point index is continuously reported in the housekeeping telemetry as HK_STAT_BOL_BIAS_VOLT_ACTIVE_PARAM_SET and recorded in product metadata for processing.

This ensures that the instrument can be switched to the next thermal range $D_k^{thermal}$ instantly.

The instrument was integrated into the TVC. For the control of the instrument temperature the flow-through-chiller was used. In order to emulate a cold space-view a plate connected to a Stirling cooler has been used at the chamber in front of the MERTIS space view port.

The results of that procedure are 10 thermal range sets $D_k^{thermal}$ which can be seen in Figure 5 as image offsets for Planet View and a Space View raising with the instrument temperature. The instrument temperature was represented by the temperature sensor "optics_base_plate" which is mounted in an area from which the bolometer detector chip is directly receiving radiation. The overlap of the thermal ranges is approximately 1K $\pm 0.2\text{K}$ since it is difficult and very time consuming to tune the instrument temperature more exactly. The values for the image offsets $\bar{S}_k^{low}$, $\bar{S}_k^{high}$ are referring to the reference area of the images. In Table 5 the results for thermal dynamic range sets $D_k^{thermal}$ are summarized.

Set index k	U^{FID} [V]	U_k^{SKIM} [V]	T_k^{BOL} [°C]	τ^{int} [μs]	$T_k^{BB300_low}$ [°C]	$T_k^{BB300_high}$ [°C]	$\bar{S}_k^{low}$ [DN]	$\bar{S}_k^{high}$ [DN]
1	3.971	4.397	5	123.8	-1.24	9.80	2740	10116
2	3.971	4.403	15	123.8	8.88	15.92	3685	9721
3	3.971	4.435	15	123.8	14.74	21.40	3351	9490
4	3.971	4.435	25	123.8	20.54	25.67	3422	9110
5	3.971	4.458	25	123.8	24.80	29.47	3405	8918
6	3.971	4.478	25	123.8	28.41	32.62	3556	8741
7	3.971	4.469	35	123.8	31.52	34.65	3882	8365
8	3.971	4.480	35	123.8	33.64	36.50	4037	8243
9	3.971	4.491	35	123.8	35.46	38.29	3884	8149
10	3.971	4.501	35	123.8	37.35	39.92	4147	8070

Table 5: Summary of the thermal range sets $D_k^{thermal}$ the MERTIS FM needs to be operated in

The sets include the detector's control parameter values together with the corresponding instrument temperatures and image offsets. The image offsets are related to the image reference area.

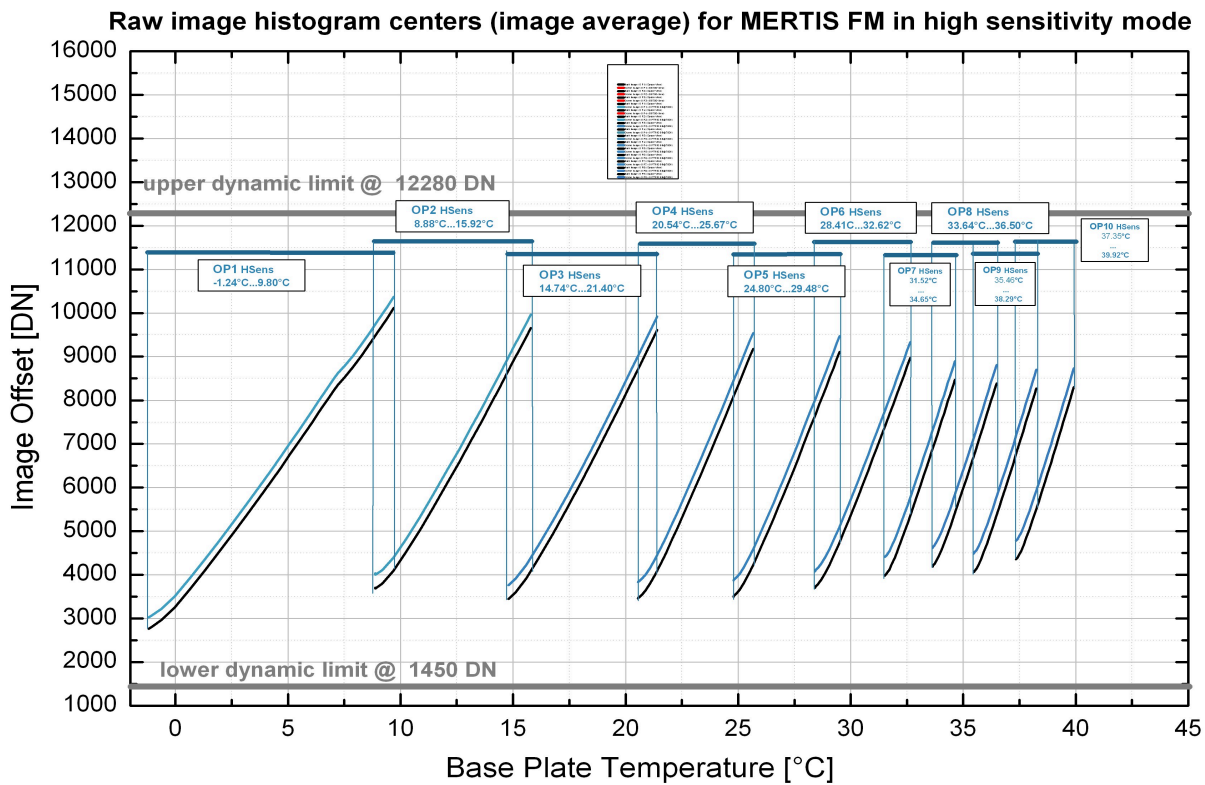


Figure 5: Image offsets for images recorded in Space-View (black) and Planet View (blue) within the different thermal dynamic ranges. The ranges overlap each other by ca. 1 K. With a growing instrument temperature also the image histogram widths grow. Since the histograms need to be kept strictly within the digital dynamic range, the image offsets are getting more distanced from the lower and upper dynamic limits. The thermal interval width is getting smaller with higher instrument temperatures because the radiant flux incident on the detector elements grows nearly with T^4 .

3.3.1.2. Spectro-Radiometric response function in TVC

Brief definition, details are in [RD.03] :

- i, j : Detector pixel indices on the 2D array, where i represents the spatial position along the Field of View (FOV) and j represents the spectral wavelength channel.
- k : The Operational Point / Thermal Dynamic Range index ($k=1,...,10$).
- $D_k^{thermal}$: The k -th Thermal Dynamic Range configuration set, specifying the instrument temperature boundaries ($T_k^{low} ... T_k^{high}$) and associated detector bias parameters (U_k^{skim}, T_k^{BOL}).
- c_{ijk}^0 : The additive offset calibration coefficient for pixel in thermal range, accounting for baseline dark signal.

- c_{ijk}^1 : The multiplicative "floating" sensitivity coefficient (gain/slope) for pixel in thermal range , calculated as a function of the thermal state .
- S_{ijk} : The baseline dark-reference signal level (measured in the unilluminated macro-pixel reference areas of the detector) at thermal state within range 3

In this step the spectro-radiometric calibration datasets $(c_{ijk}^0, c_{ijk}^1, S_{ijk})$ of the spectrometer are determined for the upper and lower bounds of each thermal range given by $D_k^{thermal}$. Additionally, the floating sensitivities $c_{ijk}^1(\bar{S}_{ijk})$ are calculated from both measurements for $D_k^{thermal}$ each .

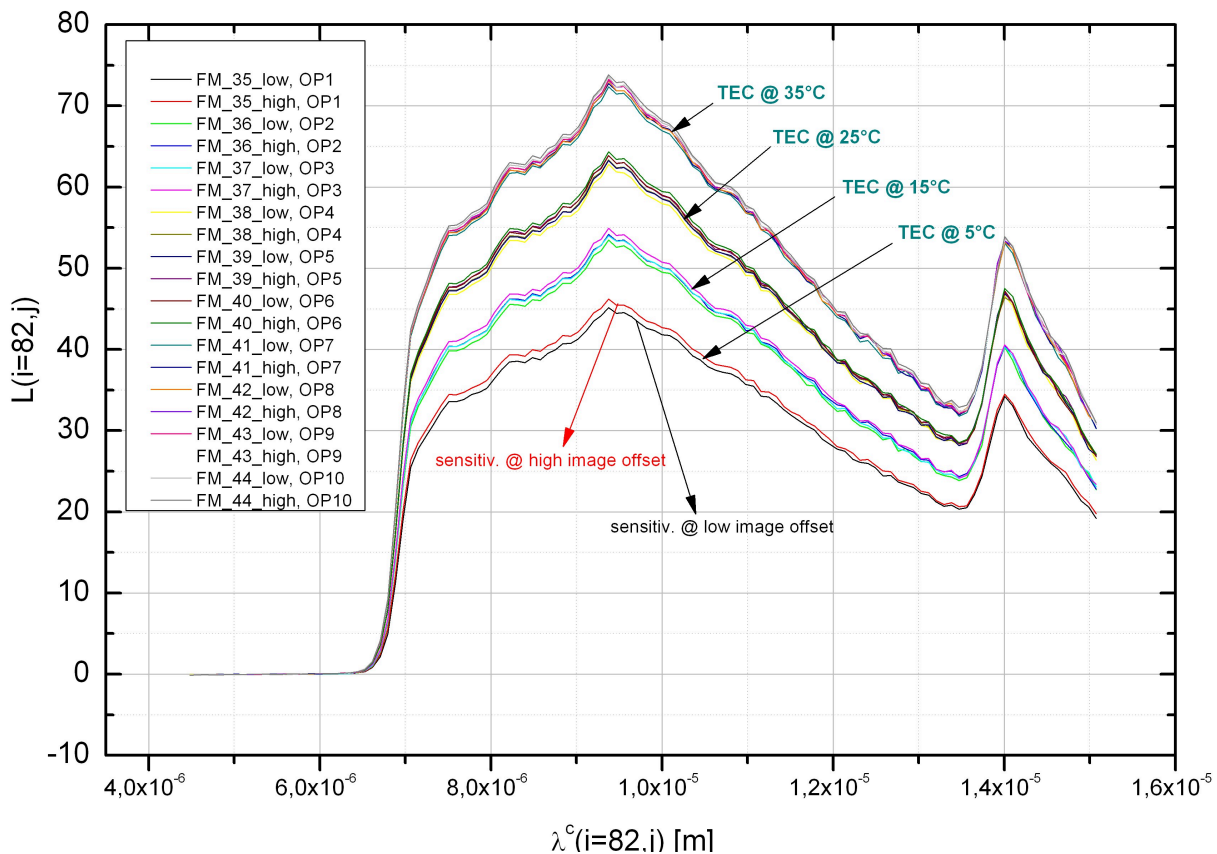


Figure 6: Spectral sensitivities for all thermal ranges and for image column 82 calculated during the radiometric response determination measurements for MERTIS FM. The sensitivity increases strongly with the bolometer chip temperature and slowly increases with a raising image offset. Both effects are regarded in the MERTIS calibration approach by calculating a floating sensitivity per thermal range k from the measurements.

3.3.1.3. Verification of spectro-radiometric calibration

In this step the calibration results are verified by doing an independent measurement of a static radiometric scene generated by the OPTRIS BB which was set to 280°C. The instrument was driven two times from 40°C down to 0°C and from 0°C up to 40°C. During the heating and cooling process images of the OPTRIS BB via the Planet View and BB3 images were taken periodically. From these datasets basic difference images (1 scene – 1 dark) were calculated and converted to radiance images using the radiometric calibration coefficients $(c_{ijk}^0, c_{ijk}^1, S_{ijk})$. For the measurement session FM_45_4 the radiances were calculated using the radiometric calibration coefficients $(c_{ijk}^0, c_{ijk}^1, S_{ijk})$. The results are shown as image profiles along the FOV (line j=64) and along the spectral direction (column i=82) in Fig.7. For that measurement the maximum temporal instrument temperature gradient was ca. 5 mK/s. All thermal ranges are covered and the calculated radiances correspond very well with to the theoretical results.

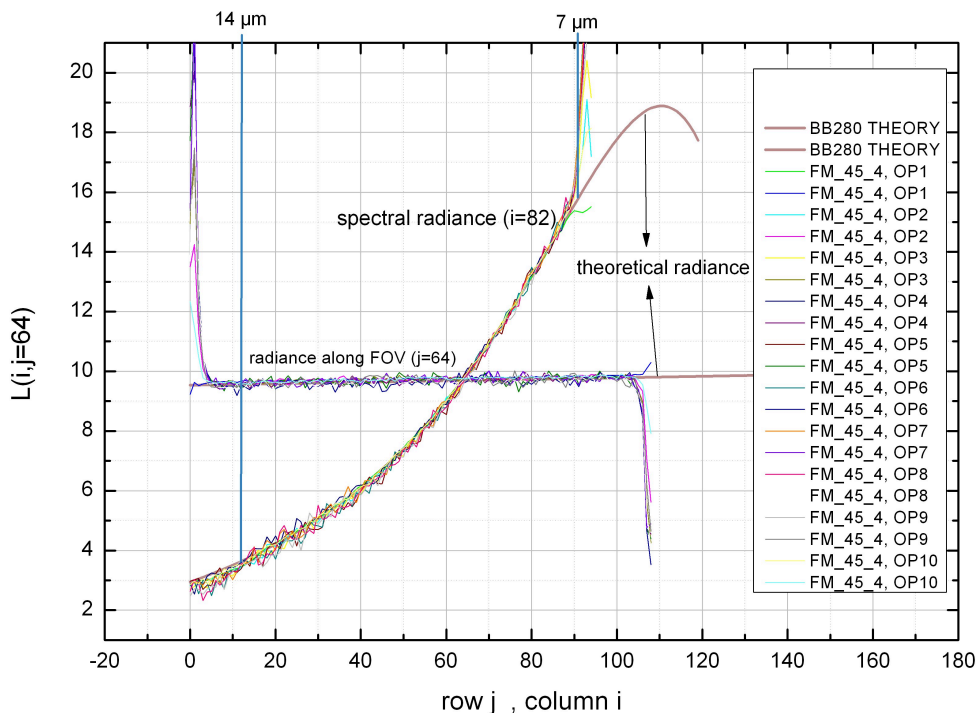


Fig.7: Radiance image profiles calculated from measurement FM_45_4 (scene at 280°C) shown for the spectral direction (column i=82) and along the FOV (j=64). All thermal ranges are covered and the profiles agree very well with the theoretical results.

3.3.2. TIR Channel

The calibration of the MERTIS Thermal Infrared Radiometer (TIR) transforms raw thermopile voltages into physically meaningful brightness temperatures. Unlike the TIS spectrometer, the TIR radiometer is not thermally stabilized and its sensitivity is dependent on the drifting temperature of the sensor head.

Radiometric Calibration Model

The TIR signal generation is based on the net radiation exchange between the pixel area and its half-space environment (target and instrument housing). To eliminate a large part of the contribution of the instrument housing the calibration is based on the difference signal computed from the actual planet port observation and the interpolated space port observations acquired in the neighbouring calibration cycles.

In order to calibrate TIR, the measured signals in digital numbers [DN] are first converted to thermopile voltages by:

$$U = \frac{DN}{c_{fac}}$$

where the conversion factor is $c_{fac} = 1.0795316 \cdot 10^9$.

The difference signal ΔU_s as function of the blackbody temperature T can then be expressed by a modified Sakuma-Hattori equation (note that the term in brackets represents an approximation of the Planck integral weighted with the instrument throughput function over the filter bandwidth):

$$\Delta U_s = \left[\frac{R_0 (1 + TCR \cdot t_{det})}{\exp\left(\frac{-c_2}{AT+B}\right) - 1} \right] + U_0 (1 + TCU \cdot t_{det})$$

with c_2 the second Planck constant and the fitting coefficients:

Responsivity R: The responsivity is temperature-dependent and exhibits an approximately linear behaviour with the detector temperature t_{det} (in °C): $R(t_{det}) \approx R_0 (1 + TCR \cdot t_{det})$, where R_0 is the responsivity at 0°C and the Temperature Coefficient of responsivity TCR is approximately **-0.5%/K**.

- 1) **Offset Voltage (U_{off}):** This term accounts for thermal gradients within the sensor head and can be expressed as $U_{off} = U_0 (1 + TCU \cdot t_{det})$. While subtraction of the **SpaceView** (cold reference) ideally removes instrumental background completely, residual offsets remain mostly due to different vignetting between the two ports and different stray light suppression by planet and space baffle. These shall be corrected using updated in-flight characterization (see [RD.03], Section 3.2 & 4.2).
- 2) The coefficient combination $A + B/T$ can be interpreted as an effective central wavelength of the instrument function.
- 3) The parameters A , B , R_0 , TCR , U_0 , and TCU were determined from the ground calibration using a least-squares fitting approach
- 4) The very high dynamic range of TIR with brightness temperatures between 90 K and 700 K makes it impossible to fit the whole range adequately with a single set of coefficients. Therefore, two sets of coefficients were determined, one for the low

temperature calibration ranging from 90-353 K and the other for the high temperature calibration covering the blackbody range 353-700 K.

The approximation of the TIR difference signal by a modified Sakuma-Hattori has the advantage that a direct inversion of the measured difference signal in brightness temperatures is possible:

$$T = \frac{c_2}{A \ln \left[\frac{R_0 (1 + TCR \ t_{det})}{\Delta U_s - U_0 (1 + TCU \ t_{det})} + 1 \right]} - \frac{B}{A}$$

The equation above for the TIR brightness temperature requires knowledge of the TIR detector temperature. To acquire this temperature each TIR channel (A and B) is equipped with a miniature Pt-1000 temperature sensor mounted directly beside the TIR thermopile chip that is supplied by a reference voltage $U_{ref} = 2.5$ V over a divider resistor $R_d = 121$ kOhms. The resistance of the temperature sensor R_t is then given by:

$$R_T = \frac{R_d U_T}{U_{ref} - U_T}$$

The Pt-1000 resistance can then be converted to the detector temperature t_{det} in [°C] (of either TIR channel A or B, respectively) by:

$$t_{det} = \frac{-c_1 R_0 \sqrt{c_1^2 R_0^2 - 4 c_2 R_0 (R_0 - R)}}{2 c_2 R_0}$$

with R_0 Ohms, $c_1 = 0.0039083$, and $c_2 = -5.775 \cdot 10^{-7}$.

Responsivity Stability and In-flight Status

- 1. Ground-to-Space Transition:** A responsivity decrease was observed between ground calibration (2013) and launch—approximately **4% for Channel A** (8–14 μm) and **12–13% for Channel B** (7–40 μm). This is attributed to terrestrial atmospheric degradation of the silver smoke absorbers of the non-hermetic thermopile sensors prior to launch.
- 2. In-flight Stability:** Since launch, the TIR degradation has stopped, and responsivity has remained exceptionally stable within $\pm 0.2\%$ across all cruise check-outs.
- 3. Noise Performance:** Following the **SW Update #1** (July 2025), which re-tuned the sensor head heater controller, TIR noise was reduced by an order of magnitude, achieving stable regulation within a few millikelvin.

Space Port Correction and Cross-Calibration

For observations acquired through the **Space Port** (e.g., Moon, Venus, and Mercury flybys), the calibration must account for different vignetting and aperture limits compared to the nominal Planet Port.

1. **Transfer Factors:** Current best practice uses transfer factors derived from the ratio of Space-to-Planet signals measured during ground TVAC tests and recent Flight Spare (FS) experiments.
2. **Vignetting:** Both TIR and TIS show similar vignetting patterns in the Space Port view due to the Pointing Unit (MPOI) internal cutouts.

4. IN-FLIGHT CALIBRATION

In-flight calibration

The MERTIS in-flight calibration scheme is designed to routinely monitor instrument induced radiation and detector performance drifts. This is achieved by periodically observing internal calibration targets and deep space to calibrate the scientific target data.

4.1. Calibration Cycle Frequency and Timing

The nominal operational cycle for MERTIS has evolved based on in-flight performance assessments:

- **Cycle Duration:** While originally designed for 20-second or 60-second cycles, the default calibration period was updated to **140 seconds** in 2024. This duration offers an optimal balance between calibration stability and science observation time.
- **Target Sequence:** A standard 140-second cycle includes approximately **16 seconds** dedicated to calibration targets: the planet, the 700K blackbody (**BB7**), the 300K blackbody (**BB3**), and **SpaceView**. The remaining 124 seconds are dedicated to the **PlanetView**.
- **Variability:** The team may periodically adjust these durations or use a "**Direct Gap Filling**" mode (inverted cycle) to cover areas previously missed during calibration sequences.

4.2. Key In-flight Performance Refinements

Several critical calibration updates implemented during the cruise phase must be accounted for by the user:

- **VSKIM Bias Correction:** To mitigate image stripes and restore linearity, the detector bias voltage was recalibrated in-flight and permanently integrated into the software via **SW Update #1**.

- **Port Swap Procedure:** During the interplanetary cruise, the PlanetView was obstructed; consequently, science data were acquired by swapping the **PLANET** and **SPACE** ports.
- **Thermal Dynamic Ranges:** MERTIS operates across 10 defined thermal ranges (OP1–OP10, defined in the calibration section 3.3.1 as index k, see Figure 5) to maintain the signal within the detector's linear response window as instrument temperatures fluctuate between -1.24°C and 39.92°C.

4.2.1. Science Mode Calibration Cycle

The MERTIS in-flight calibration is performed systematically by repeating a sequence of observations that include both the scientific target and internal reference sources. This cycle is managed by the **Pointing Unit (MPOI)**, which sequentially orients the optical mirror to four distinct targets to monitor instrument-induced radiation and detector performance drifts.

Nominal Cycle Sequence and Timing

The calibration cycle is structured into four specific target phases:

- **BB700 (Black Body 700 K):** An active, powered IR emitter representing the high temperatures of Mercury's dayside.
- **BB300 (Black Body 300 K):** A passive on-board target representing the instrument housing temperature.
- **SpaceView:** A cold reference view (+90° from the planet view) used for background signal removal. (this was used as primary scientific viewport during cruise before MTM separation).
- **PlanetView:** The primary scientific observation of the Hermean surface.

Based on in-flight performance assessments, the default **calibration period was updated to 140 seconds** in 2024 (replacing earlier 20s and 60s defaults) to facilitate operations and increase planetary coverage. In this nominal 140-second cycle, approximately **16 seconds** are dedicated to calibration targets (PlanetView, BB7, BB3, and SpaceView), while the remaining **124 seconds** are allocated to **PlanetView**. This duration represents the optimal trade-off between ensuring radiometric stability and maximizing science observation time, as frequent target switching introduces minor thermal perturbations to the sensor head.

Direct Gap Filling and the Inverted Cycle

To achieve complete global coverage, MERTIS must fill the data gaps naturally introduced by the calibration sequences. This is managed through an **Inverted Cycle (also known as "Discarding Mode")**, implemented via software update:

- **Operational Logic:** Instead of turning the TIS spectrometer OFF and ON (which adds noise and requires stabilization time), the instrument remains active. In the inverted

cycle, data are read internally from the detector but **discarded onboard** for a programmed duration before being transmitted as science TM.

- **Thermal Stability:** This approach preserves the thermal equilibrium of the instrument and avoids the risk of exceeding the MPOI motor's qualification temperature limits, which was a known risk with older "reverse cycle" strategies.
- **Implementation:** Operators explicitly set a parameter **PMR00277** to enable the inverted cycle, allowing for precise adjustment of the timing to fill gaps identified in previous orbits. This is not captured in the data, because doesn't affect the data structure.

Cruise Phase Specifics

Users should note that during the interplanetary cruise phase, the **Planet port is obstructed** by the Mercury Transfer Module (MTM). Consequently, a "port swap" procedure was implemented where the **Space port** is used for scientific observations, and the calibration cycles are adjusted accordingly. Data acquired through the Space port during flybys (e.g., MSB5) may contain approximately **10% straylight contamination** from spacecraft radiator reflections.

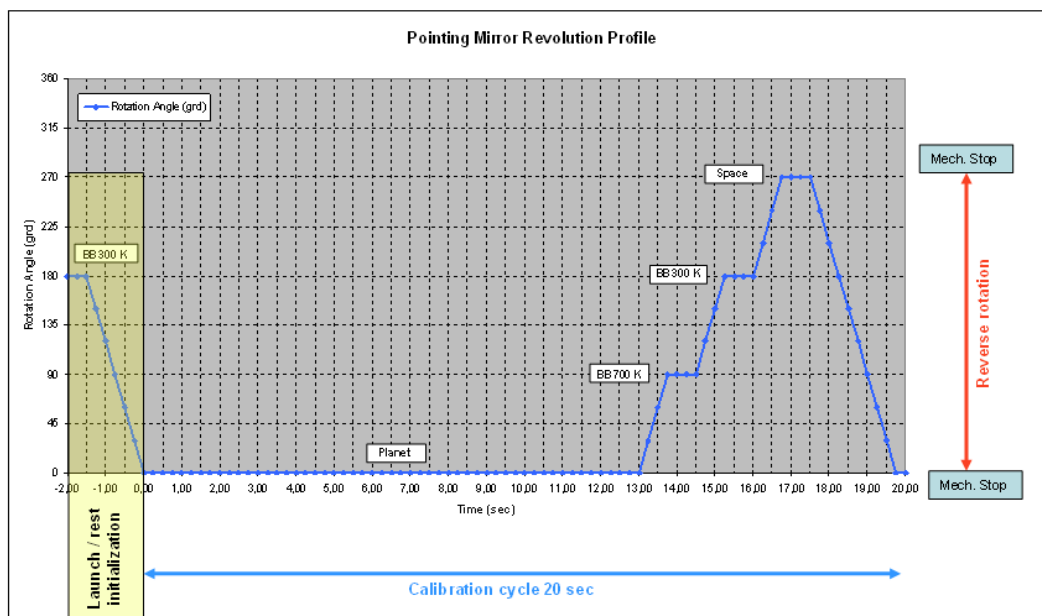


Figure 8: MERTIS in-flight calibration cycle scheme

5. DATA DESCRIPTION

MERTIS science data adopt NASAs Planetary Data System (PDS) standards version 4 (PDS4), and follow the organisation, format, content and documentation requirements described in the BepiColombo Archiving Guide[AD.02].

All data from the MERTIS 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 type of data and information into an easy to navigate manner, so the bundle contains separate collections for instrument science data, calibration products, documentation, etc. For the instrument science data, there are separate collections for each processing level and this is standardised by PDS4 to four levels: raw, partially processed, calibrated and derived.

The structure of the bundle is outlined in Figure 9.

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

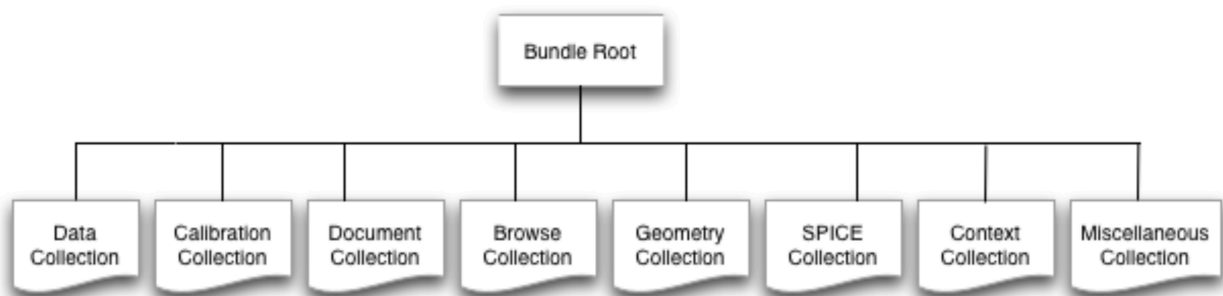


Figure 9: PDS4 bundle structure

MERTIS science data are categorized into three primary observational collections based on the PDS4 processing level standards:

- Raw Data Collection (data_raw):
 - **LID:** urn:esa:psa:bc_mpo_mertis:data_raw.
 - **Description:** Contains telemetry-to-PDS converted products. These products contain the original instrument measurements (TIS frames and TIR readings) in **Digital Numbers (DN)** with no radiometric or geometric conversions applied. MERTIS Housekeeping are converted onboard and transmitted in physical units.

- **Intended Use:** addressing technical instrument behaviour and users who want to attempt calibration.
- Partially Processed Data Collection (data_partially_processed):
 - **LID:** urn:esa:psa:bc_mpo_mertis:data_partially_processed.
 - **Description:** Product where telemetry has been converted into physical or engineering units (e.g., voltage or temperature) but still containing engineering level data (calibration targets) and TIS optical misalignment with grating introduce a wavelength shift in the CCD y direction. Data in this collection have been converted to physically meaningful radiance values by applying the in-flight calibration cycle results from the internal blackbodies (BB700, BB300) and Space View. This is not true for Cruise data, where Planet is swapped with Space View. Planet is obstructed by the transfer module. This level includes SPICE-derived geometry data as additional layer in TIR/TIS data cubes.
 - **Intended Use:** scientific analysis and cross check with technical data (internal calibration , deep space).
- Calibrated Data Collection (data_calibrated):
 - **LID:** urn:esa:psa:bc_mpo_mertis:data_calibrated.
 - **Description:** Contains radiometrically calibrated science products without engineering levels data (calibration targets) and TIS Sensor cube is re-sampled to have (spatial, spectral) channels aligned with stored data .
 - **Intended Use:** final scientific analysis.

Derived Data Collection (data_derived):

- **LID:** urn:esa:psa:bc_mpo_mertis:data_derived
- **Description:** Contains higher-level spatial, spectral, and thermophysical products synthesized from multiple calibrated (cal) observations across orbits and mission phases. These products include global and regional map grids/mosaics of surface brightness temperature, thermal inertia, spectral emissivity, Christiansen Feature (CF) position maps, and identified mineralogical phase distributions.
- **Intended Use:** High-level scientific interpretation, regional geological mapping, thermophysical regolith modeling, and cross-disciplinary studies with other BepiColombo instrument datasets (e.g., SIMBIO-SYS, MIXS, BELA)

In the MERTIS archive, raw telemetry streams are de-packetized and organized hierarchically into PDS4 products (**EDITOR COMMENT: This is still in definition**):

- **Temporal & Mission Phase Grouping:** Data are first organized by mission phase (near-earth, cruise, commissioning, science)[2]. Within each phase, products

are split into temporal sub-directories: monthly directories (YYYYMM/) during Cruise/Commissioning, or orbit-range folders (ORBIT_NNNNN_MMMMM/) during the Mercury Science Phase[3].

- **Level-Based Product Filtering:**

- **RAW (data_raw):** Contains continuous observation sequences (e.g., a full 140-second calibration + science cycle) grouped into single FITS files. Science arrays contain raw Digital Numbers (DN) for **all targets** (Planet, BB300, BB700, Space).
- **PAR (data_partially_processed):** Mirrors the RAW grouping (retaining all Planet and internal calibration target frames) but converts telemetry to engineering units, attaching 16 per-pixel geometric backplanes and wavelength matrices in native detector coordinates.
- **CAL (data_calibrated):** Science products at this level are **filtered to include only scientific targets** (PlanetView / Mercury, Venus, Moon)[10]. All internal calibration target observations (BB300, BB700) are stripped out to deliver streamlined, science-ready cubes.

LID: urn:esa:psa:bc_mpo_mertis:data_derived

- **Description:** Contains spatial, spectral, and thermophysical map products synthesized from calibrated science observations across multiple orbits.
- **Native HEALPix DGGS Framework:** To avoid spatial distortion and polar singularities, global and regional mosaics are generated natively using the HEALPix (Hierarchical Equal Area isoLatitude Pixelisation) Discrete Global Grid System. Primary archive products are stored as PDS4-compliant FITS files preserving equal-area cell indexing (, spatial resolution).
- **GIS-Ready GeoTIFF Distribution:** For direct compatibility with standard GIS software (QGIS, ArcGIS), HEALPix mosaics are resampled and exported as projected single-band or multi-band GeoTIFF map cubes (.tif) using Equirectangular (global/mid-latitude) or Polar Stereographic (high-latitude) projections.
- **Filename Examples:**
- **Native Archive:** mer_der_map_cf_mercury_healpix_n2048__1_0.fits (PDS4 XML Label: mer_der_map_cf_mercury_healpix_n2048__1_0.lblx)
- **GIS Export:** mer_der_map_cf_mercury_equirect_500m__1_0.tif (PDS4 XML Label: mer_der_map_cf_mercury_equirect_500m__1_0.lblx)

Supplemental Collections (TBD)

In addition to the observational data, the MERTIS bundle includes the following supporting collections:

- **Calibration Collection (calibration):** Contains the on-ground and in-flight calibration reference files required to process the data.
- **Document Collection (document):** Includes this Data User Guide, the EAICD, and technical reports necessary for data interpretation.
- **Browse Collection (browse):** Contains "quick-look" products and analysis plots designed to facilitate data discovery (**EDITOR COMMENT: This is in definition**)

Data product summary lists and file structure descriptions:

- **Product Structure & Multi-Extension FITS HDUs:** Science products across RAW, PAR, and CAL levels are stored as multi-extension FITS binary files paired with PDS4 XML labels (.lblx). Science arrays are contained in ImageHDU objects (Array_3D_Image for TIS, Array_2D_Image for TIR), while frame-by-frame operational telemetry is stored in a binary table (BinTableHDU / Table_Binary named MERTIS_TIS_METADATA or MERTIS_TIR_METADATA).
- **Row-to-Frame Synchronization:** The rows of the binary metadata table map **1-to-1** with Axis 1 (Time/Line or Frames) of the corresponding 3D/2D science data arrays. Row in MERTIS_TIS_METADATA directly provides the acquisition target, baseplate temperature, and active Operational Point for frame in MERTIS_TIS_*_SCIENCE_DATA.
- **Auxiliary Layers in PAR/CAL Products:** PAR and CAL level science products attach a 16-layer 3D geometry array (GEOMETRY_DATA) providing per-pixel latitude/longitude (center + 4 corners), altitude, solar incidence, emission, and phase angles. PAR level TIS products also attach a 2D center wavelength matrix (WAVELENGTH_MATRIX) in native detector coordinates to preserve grating clocking angle information prior to CAL-level resampling.

5.1. RAW collection (data_raw)

The structure of the raw data collection is as follows (detailed Data & Labels structure is in Appendix 9.1):

data_raw/

- collection_mpo_mertis_data_raw.lblx
- collection_mpo_mertis_data_raw.csv
- <mission_phase>/

Where: <mission_phase> is:

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

Each mission phase directory is further sub-divided in months or range of orbits:

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

(EDITOR COMMENT: Sub-division of this collection is under discussion and subject to change.)

Table 6: MERTIS Data Product Types Summary

Product Kind (<kind>)	Target Subsystem	File Format	Description & Scientific Contents
hk_default	Instrument Controller Unit (ICU)	ASCII Delimited fixed-width text file (.dat)	Default Housekeeping: Contains basic operational telemetry (power, ICU status, bus error counters, baseline board/PSU temperatures, and TC/TM execution counters).
hk_extended	Sensor Head & Optics	ASCII Delimited fixed-width text file(.dat)	Extended Housekeeping: Contains high-rate, detailed thermal environment telemetry (individual optical element temperatures, base plate RTDs, shutter state, and bolometer bias monitors) required for precise radiometric calibration.
sc_tir	Radiometer (TIR)	FITS (.fits)	TIR Science & Metadata: Contains 15-pixel spatial measurements for Channel A (8–14 μm) and Channel B (7–40 μm), along with associated acquisition metadata tables (target view port, integration settings, reference temperatures).
sc_tis	Spectromete r (TIS)	FITS (.fits)	TIS Science & Metadata: Contains 2D detector frames / 3D science cubes covering 7–14 μm (100 spatial x 40 spectral channels unbinned), accompanied by metadata tables (Operational Point index, acquisition target, bias configuration).

File Naming Convention and Concrete Examples

Product filenames follow the standardized BepiColombo naming convention:

- **mer**: Instrument identifier (MERTIS).
- **level**: Processing level (raw, par, cal).
- **kind**: Data type (hk_default, hk_extended, sc_tir, sc_tis).
- **YYYYMMDD**: UTC start date of the first acquisition point.
- **P-SSSSSSSSSS-FFFFF**: On-board Time (OBT) partition, ticks, and fractions⁵.
- **V_v**: Major and minor product version suffix (e.g., __0_1)(see 2.6.2).

Examples from the RAW Collection (data_raw):

- mer_raw_hk_default_20200409_1-0651130766-12538__0_1.dat (Default HK Data Table)
- mer_raw_hk_default_20200409_1-0651130766-12538__0_1.lblx (PDS4 XML Label)
- mer_raw_hk_extended_20200409_1-0651130766-12595__0_1.dat (Extended HK Data Table)
- mer_raw_sc_tir_20200409_1-0651130751-42768__0_1.fits (TIR Raw Science FITS file)
- mer_raw_sc_tis_20200409_1-0651130819-21186__0_1.fits (TIS Raw Science FITS file)

Every TIS/TIR FITS product contains two primary extensions: a binary **Metadata Table** (BinTableHDU, e.g., MERTIS_TIS_METADATA) and a multi-dimensional **Science Array** (ImageHDU, e.g., MERTIS_TIS_RAW_SCIENCE_DATA) (This is valid for PAR and CAL level too, header change only the _RAW_ in the name).

- **1-to-1 Index Matching**: The rows of the MERTIS_TIS_METADATA table map **1-to-1** with the time/acquisition dimension (Axis 1 / Line dimension) of the 3D science data cube [Acquisition_Index, Spatial_Sample, Spectral_Band]¹³¹⁵.
- **Practical Processing Workflow**: To process frame in the 3D data cube (cube[N, :, :]), the user reads row from MERTIS_TIS_METADATA¹³¹⁵. This row supplies the exact contextual parameters for that specific frame:
 1. TIME.UTC / TIME_OBT: Time stamp of frame acquisition.
 2. HK_STAT_TIS_DATA_ACQ_TARGET: Identifies whether frame is viewing Planet, BB300, BB700, or Space.
 3. HK_STAT_TIS_DATA_ACQ_TYPE: Tells the user if frame is raw DN (Sci_Raw) or onboard dark-subtracted (Sci_Subtracted_*).

4. **HK_STAT_BOL_BIAS_VOLT_ACTIVE_PARAM_SET**: Tells the user which Operational Point (OP) was active, directing them to the correct calibration sensitivity matrix.
5. **HK_TEMP_OST_BASE_PLATE**: Provides the housing temperature needed for Planck radiation calculations

N. 4 in the previous list is the main housekeeping telemetry metadata necessary for TIS calibration (Section 6.6.1 (Step 1), it reports an integer from **0 to 11**:

- **Value 0 = Manual Mode (manual)**: Indicates that automatic thermal tracking was disabled (**PAR_BOL_BIAS_VOLT_SETTING_MODE = 0**), and the bolometer bias voltages and chip temperature were explicitly commanded via fixed telecommand parameters.
- **Values 1 to 11 = Automatic Operational Points (OP1–OP10)**: When automatic mode is active (**PAR_BOL_BIAS_VOLT_SETTING_MODE = 1**), the On-Board Application Software (APS) continuously checks the optics baseplate temperature (**HK_TEMP_OST_BASE_PLATE**). The indices **1** through **11** (mapping to OP sets 1 to 10) identify which pre-calibrated parameter set (controlling VSKIM, FID bias, and TEC target temperature) was selected onboard to keep the detector response linear.

Table 7: HK_STAT_TIS_DATA_ACQ_TYPE — Enumerated values & Meanings

Enumerated Value	Name	Physical & Processing Meaning
0	Sci_Raw	Unsubtracted Raw Frame : Contains raw Digital Numbers (DN) directly from the detector. Paired with target = Planet , it represents a raw scene image acquired through the Planet port.
1	Sci_Subtracted_Raw	Onboard Differential Frame : A frame where an earlier raw reference image was subtracted onboard prior to transmission.
2	Sci_Subtracted_STS	Shutter Subtracted Frame : Frame subtracted onboard using the closed internal shutter (STS) dark reference.
3	Sci_Subtracted_BB3	BB300 Subtracted Frame : Frame subtracted onboard using the internal 300 K blackbody reference.
4	Diag_Corrected_STS	Diagnostic Shutter Corrected : Diagnostic

		mode frame corrected with shutter reference.
5	Diag_Corrected_BB3	Diagnostic BB300 Corrected: Diagnostic mode frame corrected with BB300 reference.
6	Diag_Difference	Diagnostic Differential: Diagnostic test difference pattern.
7	Sci_Subtracted_BB7	BB700 Subtracted Frame: Frame subtracted onboard using the active 700 K blackbody reference.
8	Sci_Subtracted_Space	Space Subtracted Frame: Frame subtracted onboard using the cold Deep Space reference.

Important metadata:

- **Thermal State Metadata:** HK_STAT_BOL_BIAS_VOLT_ACTIVE_PARAM_SET found in the TIS data it the primary keys for identifying which of the **10 Operational Points (OP1–OP10)** applies to the data.
- **Data Volume Caveat:** TIS data uses the Rice coding compression. Users should expect file sizes to vary significantly (e.g., 3 MB for deep space vs. 9.6 MB for planetary scenes) despite identical acquisition times.

Here some of the key metadata parameters enumerated values explicitly included in the PDS4 dictionary labels (see [RD.01] for complete packets description) :

a) HK_STAT_TIS_DATA_ACQ_TARGET (Acquisition Target)

- **0 = Planet:** Science target observation through the Planet View port.
- **1 = Space:** Deep space cold-reference observation through the Space View port.
- **2 = Background:** Internal dark measurement with shutter closed.
- **3 = BB7:** Active internal 700 K blackbody reference view.
- **4 = BB3:** Passive internal 300 K blackbody reference view.
- **8–12:** Diagnostic test patterns (Pattern Planet, Pattern Space, etc.).
- **14 = Simulation / 15 = Invalid:** Diagnostic or invalid acquisition state.

b) HK_STAT_TIS_DATA_ACQ_TYPE (Acquisition Processing Type)

- **0 = Sci_Raw:** Unsubtracted raw science frame (DN).
- **1 = Sci_Subtracted_Raw:** Onboard differential frame.

- **2 = Sci_Subtracted_STS**: Frame subtracted using internal shutter reference.
- **3 = Sci_Subtracted_BB3**: Frame subtracted using internal BB300 reference.
- **7 = Sci_Subtracted_BB7**: Frame subtracted using internal BB700 reference.
- **8 = Sci_Subtracted_Space**: Frame subtracted using cold Space reference.

c) PAR_TIS_COMP_MODE (Compression Mode)

- **0 = no compression**: Uncompressed raw science frame transmission.
- **1 = lossless**: Onboard Rice-coded compression applied to differential images.

d) PAR_TIS_BIN_MODE (TIS Spatial Spectral Binning)

- **0 = 1x1**: Full resolution (unbinned, 160 spatial 120 spectral).
- **1 = 1x2**: High resolution (1 spatial 2 spectral binning; 100 80 default).
- **2 = 2x2**: Medium resolution (2 spatial 2 spectral binning).
- **3 = 2x4**: Low resolution (2 spatial 4 spectral binning).

e) PAR_TIS_WIN_SIZE (TIS Detector Window Area)

- **0 = 100x80pixel**: Nominal science window.
- **1 = 66x80pixel**: Reduced swath window.
- **2 = 74x80pixel**: Reduced swath window.
- **3 = 160x120pixel**: Full bolometer array readout.

f) PAR_POI_MODE (Pointing Unit Mode)

- **0 = Off**: Pointing unit unpowered.
- **1 = Move**: Active stepping/scanning between targets.
- **2 = PlanetView**: Fixed pointing at Planet View port.
- **3 = BB3View**: Fixed pointing at internal 300 K blackbody.
- **4 = BB7View**: Fixed pointing at internal 700 K blackbody.
- **5 = SpaceView**: Fixed pointing at Space View port.

Table 8: Key Metadata Table

Key Metadata Field	Target Sensor	Primary Operational Role & Scientific Usage	Sections
HK_STAT_BOL_BIAS_VOLT_ACTIVE_PARAM_SET	TIS	Operational Point (OP1–OP10): Reports the active bias voltage/temperature regime (1–10; 0=manual). Serves as the primary lookup key for selecting the corresponding spectro-radiometric sensitivity calibration matrix (FM_sensitivity_coeff_images_OP[k].tdat) ⁵⁶ .	Section 6.6.1 (Step 1)
HK_STAT_TIS_DATA_ACQ_TARGET / HK_STAT_TIR_DATA_ACQ_TARGET	TIS / TIR	Observation Target Identification: Identifies whether the current acquisition frame is viewing a scientific target (Planet, Space) or an internal calibration target (BB300, BB700). Essential for background subtraction $\Delta S = S_{viewport} - S_{BB_{300}}$	Section 6.6.1 (Step 2) & Section 6.6.2 (Step 3) ²⁶
HK_STAT_TIS_DATA_ACQ_TYPE	TIS	Data Reduction Level: Indicates whether the TIS frame contains raw DN (Sci_Raw) or onboard dark-subtracted data (Sci_Subtracted_*).	Section 6.6.1 (Step 2) ⁶
HK_TEMP_OST_BASE_PLATE	TIS / TIR	Instrument Base Plate Temperature: Monitors sensor head temperature. Used to compute the theoretical Planck blackbody radiance ($L_{BB_{300}}$) and derive temperature-dependent thermopile sensitivities ($S(T)$).	Section 6.6.1 (Step 3) & Section 6.6.2 (Step 4) ⁶⁸
PAR_TIS_COMP_MODE	TIS	Onboard Compression Mode: Indicates whether Rice compression was applied (0=no compression, 1=lossless) ⁹¹⁰ . Explains file size variations between stable scenes and complex surface scenes ¹¹¹² .	Section 5.1 (Data Volume Caveat)
PAR_TIS_BIN_MODE & PAR_TIS_WIN_SIZE	TIS	Spatial/Spectral Binning & Detector Windowing: Defines the spatial/spectral binning grid and readout window size on the bolometer array.	Section 2.5 (Table 3)

5.2. PAR collection (data_partially_processed)

Contains observations converted from raw Digital Numbers (DN) into physical and engineering units (e.g., spectral radiance in $W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$, thermopile voltages, and temperatures in °C). Products at this level mirror the RAW temporal sequence and retain all acquisition targets (Planet, BB300, BB700, Space). Observations remain in native detector coordinates (un-resampled), preserving optical clocking tilt. Each science file is augmented with a 16-layer per-pixel geometry backplane array and (for TIS) a per-pixel wavelength assignment matrix (detailed Data & Labels structure is in Appendix 9.2).

Directory Structure

data_partially_processed/

- collection_mpo_mertis_data_partially_processed.lblx
- collection_mpo_mertis_data_partially_processed.csv
- <mission_phase>/ (e.g., near-earth, cruise, commissioning, science)
 - <YYYYMM>/ or <ORBIT_RANGE>/

Product File Naming Convention

Filenames follow the standardized BepiColombo naming structure with the processing level set to par :

mer_par_kind<YYYYMMDD>_<P-SSSSSSSSSS-FFFFF>_{V_v}.ext

where:

- **mer**: Instrument identifier (MERTIS).
- **level**: Processing level (raw, par, cal).
- **kind**: Data type (hk_default, hk_extended, sc_tir, sc_tis).
- **YYYYMMDD**: UTC start date of the first acquisition point.
- **P-SSSSSSSSSS-FFFFF**: On-board Time (OBT) partition, ticks, and fractions5.
- **V_v**: Major and minor product version suffix (e.g., __0_1)(see 2.6.2).

Internal Product Structures by Data Kind

1. Spectrometer Science Products (mer_par_sc_tis_*.fits / .lblx)

Delivered as multi-extension FITS binary containers described by primary PDS4 XML labels56:

- **Metadata Table (Table_Binary / MERTIS_TIS_METADATA):** Binary table containing frame-by-frame operational telemetry (UTC/OBT timestamps, acquisition target ID, active Operational Point OP1–OP10, baseplate temperature)⁶ Table rows map **1-to-1** with the time/line axis of the science array.
- **Science Data Cube (Array_3D_Image / MERTIS_TIS_PAR_SCIENCE_DATA):** 3D array of shape [Time/Line, Spatial_Sample, Spectral_Band] storing radiometrically calibrated spectral radiance in native detector coordinates⁶.
- **Geometry Backplanes (Array_3D_Image / GEOMETRY_DATA):** 16-layer 3D array of shape [Time/Line, Spatial_Sample, 16_Layers] providing per-pixel latitude and longitude (pixel center + 4 corners), altitude, spacecraft distance, local solar time, solar incidence, emission, and phase angles². (HDU 2 through 17, PDS4 array names are listed explicitly in Appendix 8.2)
- **Wavelength Matrix (Array_2D_Image / WAVELENGTH_MATRIX):** 2D array of shape [Spatial_Sample, Spectral_Band] supplying pixel-specific center wavelengths () to account for grating clocking misalignment prior to CAL-level resampling.

2. Radiometer Science Products (mer_par_sc_tir_*.fits / .lblx)

Delivered as multi-extension FITS binary containers described by primary PDS4 XML labels:

- **Metadata Table**
 - **(Table_Binary / MERTIS_TIR_METADATA):** Frame-by-frame operational telemetry table synchronized **1-to-1** with science array acquisition frames.
- **Channel A Science Array**
 - **(Array_2D_Image / MERTIS_TIR_CHANNEL_A_PAR_SCIENCE_DATA):** 2D array of shape [Time/Frames, 15_Channels] storing calibrated Channel A (8–14) thermopile voltages or temperatures.
- **Channel B Science Array**
 - **(Array_2D_Image / MERTIS_TIR_CHANNEL_B_PAR_SCIENCE_DATA):** 2D array of shape [Time/Frames, 15_Channels] storing calibrated Channel B (7–40) measurements.
- **Geometry Backplanes**
 - **(Array_3D_Image / GEOMETRY_DATA):** 16-layer 3D array providing per-pixel surface intersection and illumination geometry for the thermopile array.

3. Housekeeping Products (mer_par_hk_default_*.dat & mer_par_hk_extended_*.dat)

- **Housekeeping Tables**

- **(Table_Character/MERTIS_PAR *_HOUSEKEEPING_DATA_TABLE):** Fixed-width or delimited ASCII character tables containing ICU status, power metrics, and detailed sensor thermal environment parameters converted to physical engineering units (Volts, Amperes,)18.

Examples:

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

- mer_par_hk_default_20200409_1-0651130766-12538__0_1.dat
- mer_par_hk_default_20200409_1-0651130766-12538__0_1.lblx
- mer_par_hk_extended_20200409_1-0651130766-12595__0_1.dat
- mer_par_hk_extended_20200409_1-0651130766-12595__0_1.lblx
- mer_par_sc_tir_20200409_1-0651130751-42768__0_1.fits
- mer_par_sc_tir_20200409_1-0651130751-42768__0_1.lblx
- mer_par_sc_tis_20200409_1-0651130819-21186__0_1.fits
- mer_par_sc_tis_20200409_1-0651130819-21186__0_1.lblx

In addition to the geometric layers, users should refer to the Product_Observational/File_Area_Observational/File/comment field in the science product labels for detailed processing provenance. This field contains a JSON string identifying the specific version of the LibMERTISCalib (the TIS Calibration routine) and the tis_calib_version used to process the data. This internal metadata ensures that the specific set of TIS calibration coefficients (e.g., MERTIS-FM-RADIOMETRIC-CALIB-DATA_LAB-KRS5-Corrected...) remains traceable even if the primary product version is unchanged. **(EDITOR COMMENT: expansion of this comment string in proper PDS4 labels is in plan for the next release)**

5.3. CAL collection (data_calibrated)

The calibrated collection contains the final "science-ready" products, filtered for primary targets and corrected for instrument misalignments (detailed Data & Labels structure is in Appendix 9.3).

4Directory Structure

data_calibrated/

- collection_mpo_mertis_data_calibrated.lblx
- collection_mpo_mertis_data_calibrated.csv
- <mission_phase>/

- <YYYYMM>/ or <ORBIT_RANGE>/

Data Products The lowest level sub-directories contain filtered and resampled products:

- mer_cal_hk_default_20200409_1-0651130766-12538__0_1.dat
- mer_cal_hk_default_20200409_1-0651130766-12538__0_1.lblx
- mer_cal_hk_extended_20200409_1-0651130766-12595__0_1.dat
- mer_cal_hk_extended_20200409_1-0651130766-12595__0_1.lblx
- mer_cal_sc_tis_20200409_1-0651130819-21186__0_1.fits
- **mer_cal_sc_tis_20200409_1-0651130819-21186__0_1.lblx** (Note: Per current mission status, TIR calibration to brightness temperature (K) is integrated at this level for Mercury science phases)

File Naming Convention The naming convention follows the logic described in Section 4.1, with the level indicator updated to **cal**.

- **instrument:** mer
- **level:** cal (Fully Calibrated)
- **kind:** hk_default, hk_extended, sc_tir, sc_tis

Important Metadata and Processing Details

- **Target Filtering:** Data at this level are filtered to include only scientific targets (e.g., Mercury, Moon, Venus). Engineering target observations (BB700, BB300) are removed to streamline analysis.
- **TIS Spectral Resampling:** The TIS sensor cube is **resampled** to align spatial and spectral channels. This process corrects for the "clocking angle" between the grating and the sensor, ensuring that wavelengths are consistent across the spatial dimensions of the stored data.
- **TIR Radiometric Inversion:** For the radiometer, the science data are converted from digital numbers into **brightness temperatures (K)** using temperature-dependent sensitivity models

For fully calibrated products, the Product_Observational/File_Area_Observational/File/comment tag includes an additional parameter: wavelength_resample_kind. This field identifies the interpolation method (e.g., linear, quadratic, cubic) utilized to resample the TIS data cube. This resampling is critical for scientific analysis as it compensates for the optical- TIS detector misalignment described in Section 3.3.1, ensuring that the spectral and spatial channels are aligned to the data cube axis.

5.4. Derived Data Collection (data_derived)

The Derived Data Collection contains higher-level spatial and spectral data products produced by combining and modeling multiple calibrated science observations across orbital tracks[1][2]. While `raw`, `par`, and `cal` products represent individual observation sequences, derived products provide map-projected, seamless global and regional products designed for direct scientific exploitation and inter-disciplinary analysis.

Per the BepiColombo Science Data Generation, Validation and Archiving Plan [AD.01], derived products are generated by the MERTIS Science Team and delivered to the ESA Planetary Science Archive (PSA) following initial scientific exploitation.

Directory Structure :

`data_derived/`

└─ `collection_mpo_mertis_data_derived.lblx`

└─ `collection_mpo_mertis_data_derived.csv`

└─ `<target_body>` (eg. `mercury`, `moon`)

The derived collection encompasses two main branches of scientific deliverables: Thermophysical Map Products (derived primarily from TIR and TIS thermal observations) and Mineralogical / Compositional Map Products (derived from TIS spectral retrievals):

Table 9: Derived Product File Types

Product Kind (<kind>)	Product Description & Scientific Content	Primary Source & Wavelength	Physical Units
der_map_temp	Surface Brightness Temperature Maps: Global and regional projected maps of minimum, maximum, and diurnal surface brightness temperature.	TIR Channel A (7–14 μm) & Channel B (7–40 μm)	Kelvin (K)
der_map_inertia	Thermal Inertia & Regolith Maps: Model-derived thermal inertia grids and surface texture/grain-size characterizations derived from diurnal temperature variations ¹⁷ .	TIR + TIS Joint Inversion	$\text{J} \cdot \text{m}^{-2} \cdot \text{K}^{-1} \cdot \text{s}^{-1/2}$
der_map_emissivity	Spectral Emissivity Maps & Cubes: Map-projected spectral emissivity cubes (7–14 μm) and interpolated single-wavelength maps, corrected for thermal background and viewing geometry ¹⁷ .	TIS Spectrometer (7–14 μm)	Emissivity (0.0–1.0)
der_map_cf	Christiansen Feature (CF) Wavelength Maps: Projected maps of the emissivity maximum wavelength position (CF), serving as the primary metric for bulk silicate composition (e.g., feldspar vs.	TIS Spectrometer	Micrometers (μm)

mafic composition)1more_horiz.

der_map_mineral	Mineralogical Phase Maps: Spatial distribution maps of key diagnostic mineral groups and spectral features, including Reststrahlen band (RB) parameters, plagioclase end-members, pyroxene variations, elemental sulfur (polar deposits), and complex sulfates110.	TIS Spectrometer	Relative Abundance / Spectral Index
------------------------	--	------------------	-------------------------------------

File Formats and Spatial Projections

- **Data Arrays:** To avoid spatial distortion, pixel area variation, and polar projection singularities inherent to planar map projections, all MERTIS global and regional mosaics are generated using the HEALPix (Hierarchical Equal Area isoLatitude Pixelisation) Discrete Global Grid System (DGGS). HEALPix divides the spherical planetary surface into equal-area curvilinear quadrilaterals, providing a mathematically robust structure for multi-orbit data aggregation, spatial filtering, diurnal trend modeling, and spherical harmonic analysis.
 - **Native HEALPix FITS Archive Products:** For advanced planetary and spatial analysis, derived products are archived in their native equal-area HEALPix grid structure formatted as PDS4-compliant FITS files. These files store 1D/2D cell arrays mapping HEALPix cell indices (at a specific resolution parameter N_{side} , e.g., $N_{side} = 4096$ or 8192 (corresponding to ~ 610 and 305 m spatial resolution on mercury) directly to spectral emissivity vectors, temperature curves, or thermophysical parameters.
 - **GIS-Ready GeoTIFF Distribution Products:** To ensure seamless compatibility with standard Geographic Information Systems (GIS tools such as QGIS, ArcGIS, GDAL, and ENVI) without requiring custom spherical conversion tools, all HEALPix mosaics are resampled and projected into standardized multi-band or single-band GeoTIFF map cubes (`.tif`). GeoTIFF files embed standard geotransform matrices and spatial GeoKeys directly within the image header.
- **PDS4 Archive Compliance and Cartography Dictionary:** Each derived product (both HEALPix FITS and projected GeoTIFF) is paired with a primary PDS4 XML label (`.lblx`). The PDS4 label fully describes the data structures using Array_2D_Image / Array_3D_Image or Table_Binary classes and incorporates the PDS4 `Cartography` discipline dictionary (cart:Spatial_Domain, cart:Map_Projection, cart:Grid_System) to document geodetic parameters and grid indexing.
- **Map Projections:** Global maps use standard Equirectangular projection (centered at 0° longitude), while high-latitude and polar regions (e.g., permanently shadowed regions / polar deposits) utilize Polar Stereographic projections.

- **Metadata & Geo-referencing:** Map headers and associated PDS4 XML labels (.lblx) specify spatial bounding boxes, pixel resolution (e.g., nominal 500 m global grid or <500 m high-resolution regional grids), projection parameters, and processing provenance (including input cal product LIDs and SPICE kernel versions).

Derived products follow the standardized MERTIS filename structure with the processing level indicator set to der:

- **mer:** Instrument identifier (MERTIS).
- **der:** Processing level (Derived Data).
- **kind:** Derived product kind (map_temp, map_inertia, map_emissivity, map_cf, map_mineral).
- **target:** Target body (e.g., mercury, moon).
- **grid_or_projection:** Grid parameter or spatial map projection:
 - **Native HEALPix DGGS:** healpix_n2048 ($N_{side}=4096 \approx 500\text{ m}$, cell resolution) or healpix_n1024 ($N_{side}=1024$).
 - **Projected GIS Rasters:** equirect_500m (Equirectangular) or polar_500m (Polar Stereographic).
- **V_v:** Major and minor product version suffix separated by double underscores (e.g., __1_0).
- **ext:** Data file extension (.fits for HEALPix FITS, .tif for projected GeoTIFF), paired with PDS4 XML labels (.lblx)

Concrete Product Examples

1. Native HEALPix FITS Products (PSA Primary Archive)

These products preserve the unprojected equal-area spherical grid for mathematical integrity and quantitative spectral/thermal modeling:

- Christiansen Feature (CF) Map (FITS):
 - Data: mer_der_map_cf_mercury_healpix_n2048__1_0.fits
 - Label: mer_der_map_cf_mercury_healpix_n2048__1_0.lblx
- Multi-Channel Spectral Emissivity Cube (FITS):
 - Data: mer_der_map_emissivity_mercury_healpix_n2048__1_0.fits
 - Label: mer_der_map_emissivity_mercury_healpix_n2048__1_0.lblx

2. Projected GeoTIFF Products (GIS Ready Distribution)

These products are resampled from the native HEALPix grid into standard planar projections for direct drag-and-drop ingestion into GIS software (QGIS, ArcGIS, GDAL):

- Global Christiansen Feature (CF) Map (Equirectangular GeoTIFF):
 - Data: mer_der_map_cf_mercury_equirect_500m__1_0.tif
 - Label: mer_der_map_cf_mercury_equirect_500m__1_0.lblx
- Polar Surface Brightness Temperature Map (Polar Stereographic GeoTIFF):
 - Data: mer_der_map_temp_mercury_polar_500m__1_0.tif
 - Label: mer_der_map_temp_mercury_polar_500m__1_0.lblx
- Diurnal Thermal Inertia Map (Equirectangular GeoTIFF):
 - Data: mer_der_map_inertia_mercury_equirect_500m__1_0.tif
 - Label: mer_der_map_inertia_mercury_equirect_500m__1_0.lblx

6. SCIENCE USER GUIDE

The following guide provides scientists with the necessary context to navigate the MERTIS dataset, locate relevant observations, and interpret the multi-sensor measurements effectively.

MERTIS archival data are delivered within the PDS4 Bundle `urn:esa:psa:bc_mpo_mertis`. Observational products consist of twin files: a PDS4 XML label (`.lblx`) and a binary container (`.fits` for science, `.dat` for ASCII housekeeping).

Data Lineage and Filtering Across Processing Levels:

- **RAW (data_raw)**: Unprocessed Digital Numbers (DN) + raw housekeeping. Contains continuous observations including all calibration targets (Planet, BB300, BB700, Space).
- **PAR (data_partially_processed)**: Telemetry converted to physical units (radiances, voltages, temperatures). Attaches 16 per-pixel geometry backplanes and wavelength matrices in native detector coordinates (optical clocking tilt present). Retains all targets.
- **CAL (data_calibrated)**: Radiometrically calibrated, science-ready products. Filtered **exclusively for scientific targets** (PlanetView / flyby targets; internal blackbody frames are stripped). Resampled to rectify grating clocking tilt.

- **DERIVED (data_derived):** Map-projected spatial mosaics, thermal inertia grids, and Christiansen Feature (CF) maps on HEALPix grids and GeoTIFF cubes.

6.1. Data Packaging, Product Architecture, and Object Relationships

To effectively analyze MERTIS observations, users must understand how digital objects are organized, packaged within files, and linked across processing levels.

6.1.1. High-Level PDS4 Packaging Hierarchy

MERTIS archival data are delivered as a single PDS4 **Bundle** (urn:esa:psa:bc_mpo_mertis) stored in the ESA Planetary Science Archive (PSA):

1. **Bundle & Collections:** The bundle is subdivided into **Observational Collections** (data_raw, data_partially_processed, data_calibrated, data_derived) and **Supplemental Collections** (calibration_files, document, browse, geometry, spice).
2. **PDS4 Products (LIDVIDs):** Each logical product represents an observational sequence or housekeeping interval and consists of twin physical files:
 - **XML Label File (.lblx):** PDS4 metadata describing data structures, acquisition parameters, SPICE kernel provenance, and dictionary attributes.
 - **Binary / ASCII Data File (.fits, .dat, or .tif):** The primary container holding science measurements, housekeeping tables, or spatial grids.

6.1.2. Internal Anatomy of MERTIS Science Products

Rather than scattering associated data into separate files, MERTIS science products use multi-extension FITS files to package measurements, metadata, geometry, and calibration matrices within a single physical file:

- **Header Data Unit 0 (Primary HDU):** Global FITS and PDS4 metadata.
- **HDU 1 — Metadata Table (MERTIS_TIS_METADATA / MERTIS_TIR_METADATA):** A binary table (BinTableHDU) containing frame-by-frame operational telemetry (UTC/OBT timestamps, acquisition target, active Operational Point OP1–OP10, base plate temperatures).
- **HDU 2 — Science Data Cube/Array (MERTIS*_SCIENCE_DATA):**
 - **TIS:** A 3D array (ImageHDU) of shape [Time/Line, Spatial_Sample, Spectral_Band].

- **TIR:** 2D arrays (ImageHDU) of shape [Time/Frames, 15_Channels] for Channel A and Channel B.
- **HDU 3 — Geometry Data Cube (GEOMETRY_DATA, PAR & CAL levels only):** A 16-layer 3D array providing per-pixel surface intersection coordinates (pixel center + 4 corners longitude/latitude, spacecraft distance, incidence, emission, and phase angles).
- **HDU 4 — Wavelength Matrix (WAVELENGTH_MATRIX, PAR level only):** A 2D array supplying pixel-specific center wavelengths (m) to account for optical grating misalignment and "clocking angle" tilt prior to CAL-level resampling.

Housekeeping products (hk_default and hk_extended) are stored as fixed-width ASCII character tables (.dat) for direct inspection.

6.1.3. Relationships Between Digital Objects

1. Row-to-Frame Synchronization

Rows in the metadata binary table (HDU 1) map **1-to-1** to the first axis (Time/Line) of the science data cube (HDU 2) and geometry cube (HDU 3)⁷¹³. For instance, row in MERTIS_TIS_METADATA dictates the exact acquisition target (Planet, BB300, BB700, Space), base plate temperature, and active Operational Point for frame in the 3D science cube¹³.

2. Data Processing Lineage (RAW PAR CAL DERIVED)

Data objects evolve across processing levels while preserving structural traceability⁶:

[RAW Collection] (data_raw)

- └─ Unprocessed DN counts + Raw Housekeeping
- └─ Retains ALL targets (Planet, BB300, BB700, Space)

|



[PAR Collection] (data_partially_processed)

- └─ Telemetry converted to physical/engineering units
- └─ Attached 16-layer per-pixel Geometry Cube & 2D Wavelength Matrix
- └─ Retains native detector grid (clocking tilt present) & ALL targets

|



[CAL Collection] (data_calibrated)

- └─ Filtered EXCLUSIVELY for Science Targets (Planet View / Flyby)
- └─ Resampled to rectify clocking tilt (spatial/spectral channels aligned)

|



[DERIVED Collection] (data_derived)

└─ Multi-orbit spatial mosaics on HEALPix equal-area grids / GeoTIFFs

3. Housekeeping Linkage

Continuous default (hk_default) and extended (hk_extended) housekeeping tables provide background thermal monitoring and correlate directly with science acquisitions via On-Board Time (TIME_OBT) timestamps¹⁰.

6.2. How to approach the dataset

The MERTIS archive is designed to support investigations into Mercury's surface composition, mineralogy, and thermal properties. Users should select data based on their specific science case:

- **Mineralogical Studies:** Utilize the Thermal Infrared Spectrometer (TIS) products, which cover the 7–14 μm spectral range to identify Christiansen features and Reststrahlen bands of minerals like feldspars and pyroxenes.
- **Thermo-physical Property Studies:** Utilize the Thermal Infrared Radiometer (TIR) products, capable of measuring night-side surface temperatures down to 100K with high accuracy.
- **Data Search Strategy:** Data is organized by mission phase (e.g., Cruise, Mercury Science Phase). For specific geographic analysis, users should filter by the Orbit Number contained in the directory naming convention or the Geometry_Orbiter metadata.
- **Versioning:** Always utilize the highest version number (__V_v) found in the metadata; significant changes to calibration algorithms are reflected in a major version (V) increment.

6.3. Working with the data

MERTIS science products across all processing levels (RAW, PAR, CAL) are stored as binary arrays and binary metadata tables within multi-extension FITS files (.fits), described by PDS4 XML labels (.lblx). Fixed-width ASCII character tables (.dat) are used exclusively for Housekeeping telemetry.

Recommended PDS4 Reading Tools:

- **NASA PDS4 Viewer:** Desktop GUI for visual inspection and array display.
- **pds4_tools (Python):** Official PDS library for reading XML labels and FITS structures into NumPy arrays.

- **pdr (Planetary Data Reader):** Open-source Python tool for multi-format ingestion.
- **astropy.io.fits** : Standard Python interface for direct FITS extension reading.

Dedicated MERTIS Reader (`mertisreader`): The MERTIS team provides an open-source Python library (`mertisreader`, available at <https://github.com/mariodamore/mertisreader>). It handles all data levels (RAW to CAL), automatically binding frame metadata table attributes (`MERTIS_TIS_METADATA`) directly to 3D science data cubes, 2D TIR arrays, and geometry backplanes.

Ancillary Data: Users should utilize SPICE kernels for precise geo-location reconstruction, noting that archived/reconstructed kernels provide higher precision than predicted operational kernels.

6.4. Key data and meta-data

When filtering, assessing data quality, or setting up automated data processing pipelines, users should rely on the following key metadata attributes:

Instrument Operational Modes and Parameters:

- **Macro Mode (`HK_STAT_MERTIS_MODE`):** Recorded in default housekeeping (`hk_default`), identifying high-level modes (e.g., `Science_High_Res1`, `Diagnostic`). Because default HK is sampled at ~20-second intervals while science acquisitions run at 100 ms to 800 ms, `HK_STAT_MERTIS_MODE` provides macro context rather than frame-by-frame synchronization.
- **Frame-Level Operational Combination:** In individual frame metadata tables (`MERTIS_TIS_METADATA`), the exact operational state of each frame is defined by the combination of parameters: `PAR_REPETITION_RATE`, `PAR_TIS_BIN_MODE`, `PAR_TIS_WIN_SIZE`, and `PAR_TIS_COMP_MODE`. Mode assignment via housekeeping interpolation (used in pipeline versions) is deprecated.

Thermal State and Operational Point (OP1–OP10):

- **`HK_STAT_BOL_BIAS_VOLT_ACTIVE_PARAM_SET`:** Primary lookup key (reporting integer values 1 to 10) indicating which pre-calibrated Operational Point (OP) was active onboard⁷⁸. This key directs data users to the corresponding spectro-radiometric sensitivity calibration matrix (`FM_sensitivity_coeff_images_OP[k].tdat`).
- **`HK_TEMP_OST_BASE_PLATE`:** Monitors optics baseplate temperature, providing the essential thermal baseline required for calculating internal Planck blackbody radiation⁸⁹.

Calibration Target and Processing Type:

- **HK_STAT_TIS_DATA_ACQ_TARGET / HK_STAT_TIR_DATA_ACQ_TARGET:** Identifies the optical viewport for each frame within the 140-second calibration cycle (0 = Planet, 1 = Space, 3 = BB700, 4 = BB300).
- **HK_STAT_TIS_DATA_ACQ_TYPE:** Indicates whether the frame contains unsubtracted raw counts (0 = Sci_Raw) or onboard dark-subtracted data (1–8 = Sci_Subtracted_*).

Observational Geometry Attributes:

- **PDS4 Discipline Area (geom:Geometry):** Embedded in product XML labels (.lblx), providing summary illumination and viewing geometry calculated at periapsis.
- **Geometry Backplanes (GEOMETRY_DATA):** In PAR and CAL level science products, 16 per-pixel geometry layers supply latitude, longitude, spacecraft altitude, distance, local solar time, incidence angle, emission angle, and phase angle for pixel centers and all four pixel corners.
- **PDS4 Discipline Area (geom:Geometry / cart:Spatial_Domain)** in the XML label (.lblx), which lists the exact metakernel filename (e.g., bc_v432_20260325_001_ops.tm) and kernel provenance status (predicted, operational).

6.5. Known issues and caveats

- **Thermal Sensitivity:** Because the micro-bolometers are uncooled, measurements are highly sensitive to the sensor head's thermal state. Users should verify the Base Plate Temperature and the associated thermal dynamic range used during acquisition.
- **Calibration Overlap:** The 10 thermal dynamic ranges overlap by approximately 1K; transitions between these ranges may result in subtle shifts in image offsets.
- **Cruise Data Limitations:** Geometric metadata provided during the interplanetary cruise phase may be obsolete or inapplicable due to the extreme distance from planetary targets.
- **Sensitivity Archive Disclaimer:** Users should be aware that at the current mission stage, the standalone TIS and TIR sensitivity coefficients are not yet included as independent products in the archive. While these coefficients are utilized internally by the pipeline and are available within the pipeline code (including Python reading routines), the formal conversion and archival of these sensitivity files in a dedicated calibration collection is planned for the near future. Until this conversion is complete, users wishing to perform custom radiometric inversions should refer to the internal routine versions documented in the product metadata. **(EDITOR COMMENT: the Sensitivity are manually delivered as standalone files)**

6.6. Example analysis

To assist new users, the following analysis examples are recommended:

- **Radiance Conversion Cookbook:** A worked example of applying the in-flight calibration cycle—using SpaceView for background removal and the internal blackbodies (BB700/BB300) for radiometric response determination—to convert raw DN into radiance.
- **Performance Verification:** Reproducing radiance image profiles from static scenes (e.g., measurement FM_45_4) to verify that results match the theoretical radiometric response models documented in [RD.03].

6.6.1. TIS Radiance-to-Temperature Inversion (Cookbook)

Independent users can reproduce calibrated spectral radiance (L_{viewport}) and surface brightness temperatures (T_{br}) from raw TIS observations (data_raw) by applying the in-flight radiometric inversion pipeline (Error: Reference source not found, [RD.03]). This procedure utilizes the "Difference Principle" to subtract the large internal thermal background emitted by the uncooled instrument housing and account for detector gain variations across operational thermal states¹

Step 1: Data Identification and Operational Point (OP) Selection

1. Load the raw TIS science product (e.g., `mer_raw_sc_tis_*.fits`) and extract the measured signal in Digital Numbers (DN) from the 3D primary array `MERTIS_TIS_RAW_SCIENCE_DATA`. Inspect `MERTIS_TIS_METADATA`. Identify science observations (`HK_STAT_TIS_DATA_ACQ_TARGET` = 0 for Planet or 1 for Space) and calibration target frames (3 = BB700, 4 = BB300). Calibration cycles begin when the target transitions from science views to BB700 and BB300. Read active OP index (`HK_STAT_BOL_BIAS_VOLT_ACTIVE_PARAM_SET`) and baseplate temperature (`HK_TEMP_OST_BASE_PLATE`).

2. Inspect the frame metadata table (`MERTIS_TIS_METADATA` binary table extension) for each frame :

- **Target Identification (`HK_STAT_TIS_DATA_ACQ_TARGET`):** Identify science observation frames (0 = Planet or 1 = Space) and internal dark reference frames (4 = BB300). Calibration cycles begin when the target transitions from science views to calibration views (3 = BB700 followed by 4 = BB300) .
- **Active Operational Point (`HK_STAT_BOL_BIAS_VOLT_ACTIVE_PARAM_SET`):** Retrieve the Operational Point index k (integer 1...10) active during frame acquisition.
- **Baseplate Temperature (`HK_TEMP_OST_BASE_PLATE`):** Read the optics structure temperature (T_{baseplat} , in °C).

- **Verify Cruise Port Swapping:** Check the PDS4 label mission area (/Product_Observational/Observation_Area/Mission_Area/psa:Mission_Information/psa:Mission_Phase) to confirm if Port Swapping was active (typical for interplanetary cruise flybys where SpaceView is used as the science port) **(EDITOR COMMENT: this is not implemented yet, not yet sure if this is useful for the final user.)**

Step 2: Background Signal Removal (ΔS)

To isolate the net science signal from internal instrument background radiation and detector dark current:

1. Identify the internal Blackbody 300 K (BB300) reference frame(s) acquired within the same 140-second calibration cycle (or temporally interpolate between adjacent preceding and succeeding calibration cycles).
2. Compute the reference dark signal S_{BB300} for pixel (i,j) by taking the average DN across the BB300 acquisitions in that cycle.

(Note: The 700 K active calibration target, BB700, is intentionally excluded from background subtraction due to spatial non-uniformity across its micro-emitter aperture. BB700 is reserved for spectral barycenter verification and radiometric stability cross-checks).

3. Calculate the net difference signal for each science scene pixel:

$$\Delta S_{i,j} = S_{\text{viewport}}(i,j) - S_{BB300}(i,j)$$

Subtracting S_{BB300} removes >99% of the ambient housing background flux and mitigates detector striping artifacts.

Step 3: Radiance Conversion ($\Delta L \rightarrow L_{\text{viewport}}$)

1. **Retrieve Sensitivity Calibration Product:** Open the corresponding PDS4 calibration product from the MERTIS Calibration Collection (urn:esa:psa:bc_mpo_mertis:calibration_files):
2. Select the FITS calibration file matching the active Operational Point index identified in Step 1 (e.g., mer_cal_sensitivity_coeff_images_op[k]__1_0.fits, converted from ground .tdat characterizations).
3. **Extract Floating Sensitivity Matrix (c_{ijk}^1):** Read the 2D floating sensitivity array $c_{ijk}^1(S_{ijk})$ corresponding to OP k . The floating sensitivity accounts for detector gain variations caused by shifts in bolometer chip temperature and dark-reference offset level (S_{tk}).
4. **Compute Radiance Difference (ΔL):** Apply the sensitivity matrix to the net difference signal:

$$\Delta L_{ij} = \frac{\Delta S_{ij}}{c_{ij}^1} (S_{ijk})$$

5. **Calculate Absolute Spectral Radiance ($L_{viewport}$):** Add the theoretical Planck blackbody radiance $L_{BB300}(\lambda_j, T_{baseplate})$ of the internal 300 K reference calculated at the measured baseplate temperature ($T_{baseplate}$):

$$L_{viewport}(\lambda_j) = \Delta L_{i,j} + B(\lambda_j, T_{baseplate})$$

where $B(\lambda_j, T)$ is the Planck blackbody function evaluated at wavelength channel and temperature $T_{baseplate}$.

Step 4: Brightness Temperature Inversion (T_{br})

To convert the calibrated spectral radiance into surface brightness temperature T_{br} :

1. **Planck Curve Fitting:** Fit a Planck blackbody function $B(\lambda_j, T)$ to the measured spectral radiance $L_{viewport}$ using non-linear least-squares minimization.
2. **Spectral Windowing:** For mineralogical analysis, perform the Planck fit primarily within the $\sim 8.15 - 8.25 \mu\text{m}$ spectral window (near the Christiansen Feature), where surface emissivity approaches unity ($\epsilon \approx 1.0$) and atmospheric/calibration edge noise is minimized.

Resampling Note: If processing PAR-level data (data_partially_processed), spatial and spectral channels contain a slight optical clocking tilt. For map-projected analysis, users should use CAL-level products (data_calibrated), where spectral channels are resampled and aligned across the 3D data cube axes. This spectral tilt is the same present in the sensitivity coefficients matrix.

6.6.2. TIR Radiance-to-Temperature Inversion (Cookbook)

Independent users can convert raw MERTIS Radiometer (TIR) observations (data_raw) into calibrated thermopile voltages and surface brightness temperatures (T_{br}) by following this step-by-step procedure.

Step 1: Extract Raw Telemetry and Synchronize Metadata

1. **Load Science Arrays:** Open the raw TIR science product (file pattern mer_raw_sc_tir_*.fits). Extract Channel A (8–14 μm) and Channel B (7–40 μm) raw measurements from their respective 2D primary arrays (name:shape):
 - MERTIS_TIR_CHANNEL_A_RAW_SCIENCE_DATA : [CH_A_Frames, 15]
 - MERTIS_TIR_CHANNEL_B_RAW_SCIENCE_DATA : [CH_B_Frames, 15]

2. **Synchronize Binary Metadata Table:** Read MERTIS_TIR_METADATA324. The rows of MERTIS_TIR_METADATA map **1-to-1** with the time/acquisition dimension (Axis 1 / Frames) of the 2D science data arrays. For frame , row of MERTIS_TIR_METADATA provides:

- TIME_UTC / TIME_OBT: Timestamp of frame acquisition.
- HK_STAT_TIR_DATA_ACQ_TARGET: Identifies the target view (0 = Planet, 1 = Space, 3 = BB700, 4 = BB300).
- HK_TEMP_OST_BASE_PLATE: Optics baseplate structure temperature (t_{det} , in °C).

3. **Identify Calibration Cycle Boundaries:** Track target transitions in HK_STAT_TIR_DATA_ACQ_TARGET23. A 140-second calibration cycle begins when the acquisition target transitions from 0 (Planet) to 3 (BB700), 4 (BB300), or 1 (Space). The calibration sequence ends, and planet science observations resume, when HK_STAT_TIR_DATA_ACQ_TARGET returns to 0 (Planet).

Step 2: Convert Digital Numbers to Thermopile Voltage (U)

Raw TIR science measurements in data_raw are stored as uncalibrated Digital Numbers (DN). Convert raw DN values into thermopile voltages (in Volts) using the model conversion factor c_{fac}

$$U = \frac{DN}{c_{fac}}$$

where $c_{fac} = 1.0795316 \times 10^9$

Step 3: Background Subtraction (ΔU_s)

Calculate the net difference thermopile voltage by subtracting the internal instrument background voltage:

$$\Delta U_s = U_{viewport} - U_{background}$$

Where $U_{background}$ is the baseline background voltage obtained from deep space (SpaceView, target = 1) or internal 300 K blackbody (BB300, target = 4) frames acquired during the same 140-second calibration cycle (or linearly interpolated between neighboring cycles).

Step 4: Temperature-Dependent Sensitivity and Offset Calculation

Determine detector temperature t_{det} (in °C) using Pt-1000 temperature sensors mounted on the thermopile chip (HK_TEMP_OST_BASE_PLATE or channel reference sensors). Calculate the temperature-dependent sensitivity $S(t_{det})$ and offset voltage U_{off} :

$$S(t_{det}) = c_0 \cdot (1 + c_1 \cdot \Delta t_{det})$$

$$U_{off} = c_2 + c_3 \cdot \Delta t_{det}$$

where Δt_{det} is the temperature deviation from room reference, and c_0, c_1, c_2, c_3 are per-pixel calibration coefficients.

Step 5: Surface Brightness Temperature Inversion (T_{br})

Retrieve calibration coefficient tables and flux lookup tables from the MERTIS Calibration Collection (urn:esa:psa:bc_mpo_mertis:calibration_files):

1. Coefficient Set Selection:

- **Low Temperature Set (LT):** Use for scene temperatures between and (nightside Mercury, cold deep space, low-temperature targets; derived from FM_WSA_Calcoeff_LT.txt).
- **High Temperature Set (HT):** Use for scene temperatures between 100K and 353K (dayside Mercury, active internal BB700; derived from FM_WSA_Calcoeff_HT.txt). (Note: Both LT and HT coefficient tables are stored within the PDS4 TIR calibration product. Users should be aware of a small numerical transition artifact near ~350 K when switching coefficient regimes) **(EDITOR COMMENT: this is not yet true, planned for next release)**.

2. Radiative Flux Calculation & Lookup: Compute the net radiative scene flux 16: where is the thermopile pixel absorber area (F_{scene}), where is the thermopile pixel absorber area ($200 \mu m \times 1600 \mu m$):

$$F_{scene} = \frac{\Delta U_s - U_{off}}{S(t_{det}) \cdot A_d}$$

3. Flux Table Interpolation: Interpolate the integrated flux lookup table (IR_Flux_table.txt, packaged in the calibration collection **(EDITOR COMMENT: this is not yet true, planned for next release)**.) to add space background flux F_{space} and retrieve final surface brightness temperatures T_{br} (in Kelvin) for Channel A and Channel B. Alternatively, apply the inverted modified Sakuma-Hattori equation directly10:

7.
$$T_{br} = \frac{c_2}{A \cdot \ln \left[\frac{R_0 (1 + TCR \cdot t_{det})}{\Delta U_s - U_0 (1 + TCU \cdot t_{det})} + 1 \right]} - \frac{B}{A}$$
 INSTRUMENT MODES

The complete list of all MERTIS modes from [RD.01].

Mode	Unit					Parameter				
	Spectrometer	Radiometer	Pointing Unit (Position)	BB7	Sensor Head Heater	TIS Repetition rate	Repetition factor TIR to TIS	TIS Binning spatial x spectral	TIS Compression Spectr.	TIS WinSize Spectr. (spatial x spectral)
Safe/Idle Modes										
Safe	OFF	OFF	OFF(All)	OFF	OFF	N/A (No)	N/A	N/A	N/A	N/A
StandBy	OFF	OFF	OFF (All)	OFF	OFF	N/A (No)	N/A	N/A	N/A	N/A
WarmUp	ON	ON	ON (PlanetView or BB3View)	N/A	OFF	N/A	N/A	N/A	N/A	N/A
	ON	OFF								
	OFF	ON								
Science Modes										
Science_High_Res1(Default)	ON	ON	ON (All)	ON	OFF	100msec	8	1x2	Yes	100x80
Science_High_Res2	ON	ON	ON (All)	ON	OFF	300msec	8	1x2	Yes	100x80

Science_High_Res3	ON	ON	ON (All)	ON	OFF	800msec	8	1x2	Yes	100x80
Science_Med_Res1	ON	ON	ON (All)	ON	OFF	100msec	8	2x2	Yes	100x80
Science_Med_Res2	ON	ON	ON (All)	ON	OFF	300msec	8	2x2	Yes	100x80
Science_Med_Res3	ON	ON	ON (All)	ON	OFF	800msec	8	2x2	Yes	100x80
Science_Low_Res1	ON	ON	ON (All)	ON	OFF	100msec	8	2x4	Yes	100x80
Science_Low_Res2	ON	ON	ON (All)	ON	OFF	300msec	8	2x4	Yes	100x80
Science_Low_Res3	ON	ON	ON (All)	ON	OFF	800msec	8	2x4	Yes	100x80
Science_TIR_Only	OFF	ON	ON (All)	OFF	OFF	100msec	8	N/A	N/A	100x80
	OFF	ON	ON (All)	OFF	OFF	800msec	1	N/A	N/A	100x80
Calibration	ON	ON	ON (All)	ON	OFF	N/A	1	1x1	Yes	160x120
Exception										
WarmUp_Heated	ON	ON	ON (PlanetView or BB3View)	ON	ON	N/A	N/A	N/A	N/A	N/A
	ON	OFF								
	OFF	ON								
Pointing_BB3View	OFF	OFF	ON (BB3)	OFF	OFF	N/A	N/A	N/A	N/A	100x80
Pointing_PlanetView	OFF	OFF	ON (PlanetView)	OFF	OFF	N/A	N/A	N/A	N/A	100x80

Science_TIS_Only	ON	OFF	ON (All)	ON	OFF	100msec	N/A	1x2	Yes	100x80
Science_TIR_Only_Heated	OFF	ON	ON (All)	OFF	ON	100msec	8	N/A	N/A	100x80
	OFF	ON	ON (All)	OFF	ON	800msec	1	N/A	N/A	100x80
Science_High_Res_UnCompr	ON	ON	ON (All)	ON	ON	100msec	8	1x2	No	100x80
Science_High_Res_Heated	ON	ON	ON (All)	ON	ON	100msec	8	1x2	Yes	100x80
Science_Low_Res_Heated	ON	ON	ON (All)	ON	ON	100msec	8	2x4	Yes	100x80
Science_Raw	ON	ON	ON (All)	ON	OFF	100msec	8	1x1	No	100x80
Science_PlanetView	ON	ON	ON (PlanetView)	OFF	OFF	100msec	8	1x2	Yes	100x80
Diagnostic	OFF/ON	OFF/ON	OFF/ON (All)	OFF/ ON	OFF/ ON	>100msec	N/A	1x1, 1x2, 2x4	Yes, No	N/A
Test	OFF/ON	OFF/ON	OFF/ON (All)	OFF/ ON	OFF/ ON	>100msec	1...16	1x1, 1x2, 2x4	Yes, No	N/A
Science_Reduced_Swath1	ON	ON	ON (All)	ON	OFF	100msec	8	1x2	Yes	50x80
Science_Reduced_Swath2	ON	ON	ON (All)	ON	OFF	100msec	8	1x2	Yes	70x80
FullWin_UnCompr	ON	ON	ON (All)	ON	N/A	800msec	1	1x1	No	160x120
FullWin_Compr	ON	ON	ON (All)	ON	N/A	800msec	1	1x1	Yes	160x120
UserDefined	OFF/ON	OFF/ON	OFF/ON (All)	OFF/ ON	OFF/ ON	>100msec	1 ...16	1x1, 1x2, 2x4	Yes, No	N/A

8. APPENDIX A: TIS DATA & LABEL

8.1. TIS RAW

MERTIS TIS raw science data file structure (example):

Extension	Description
Primary FITS Header	FITS primary header
Metadata Table Header	MERTIS_TIS_METADATA FITS extension header
Metadata Table Data (BinTableHDU)	variable records × 237 bytes
Science Data Header	MERTIS_TIS_RAW_SCIENCE_DATA FITS extension header
Science Data Array (ImageHDU)	3D array of raw TIS frames

MERTIS TIS raw science label.

MERTIS_TIS_METADATA Table Structure (variable records × 24 fields, 237 bytes/record)

Field Name	Data Type	Unit	Description
TIME.UTC	ASCII_Date_Time_YMD.UTC	-	UTC time of acquisition
TIME.OBT	ASCII_String	-	OBT time of acquisition converted from UTC
TimeStamp	IEEE754MSBDouble	seconds	TimeStamp
HK_STAT_TIS_DATA_ACQ_ID	SignedMSB8	-	Acquisition number TIS, incremented

			for each data product
HK_STAT_TIS_DATA_ACQ_TYPE	ASCII_String	-	Type of TIS science data
HK_STAT_TIS_DATA_ACQ_TARGET	ASCII_String	-	Target of TIS science data acquisition
HK_STAT_BOL_BIAS_VOLT_ACTIVE_PARAM_SET	SignedMSB8	-	Currently used BIAS voltage parameter set (1...11)
HK_STAT_TIS_DATA_ACQ_TIME	IEEE754MSBDouble	seconds	TIS data time stamp at first acquisition (CUC format)
PAR_TIS_BIN_MODE	ASCII_String	-	TIS binning mode (spatial x spectral)
PAR_TIS_WIN_SIZE	ASCII_String	-	TIS window size (area on detector used for science data processing)
PAR_TIS_COMP_MODE	ASCII_String	-	TIS compression mode
HK_STAT_TIS_COMP_VERSION	SignedMSB8	-	TIS compression version number
HK_STAT_TIS_COMP_RICE_K_VALUE	SignedMSB8	-	Start value used for rice encoder/decoder of TIS compression
HK_STAT_TIS_COMP_INPUT_LENGTH	SignedMSB8	-	Length of a compression unit used for TIS compression
HK_STAT_TIS_COMP_NUM_BANDS	SignedMSB8	-	Number of sub-bands for TIS compression
HK_STAT_TIS_NUM_OVERSAMP	SignedMSB8	-	Number of oversamplings performed
HK_TEMP_BOL_CHIP	IEEE754MSBDouble	degC	Current Bolometer chip temperature (TEC controlled)
DAT_TIS_OFFSET_MACRO_PIXEL	SignedMSB8	-	Sum of selected offset pixels outside of scene area (TIS window)
HK_TEMP_BOL_HOUSING	IEEE754MSBDouble	degC	Bolometer housing temperature

HK_TEMP_OST_BASE_PLATE	IEEE754MSBDouble	degC	Optics structure / Base Plate temperature
PAR_TIS_DATA_NOISE_REDUCTION	SignedMSB8	-	Number of bits (LSB) of TIS data pixel set to value zero in order to reduce the data noise
HK_STAT_TIS_TOTAL_PACKET_NUM	SignedMSB8	-	Total number of TIS science data packets belonging to one acquisition
HK_STAT_TIS_CURRENT_PACKET_NUM	SignedMSB8	-	Current number of TIS science data packets belonging to one acquisition
HK_STAT_TIS_NUM_DATA_WORDS	SignedMSB8	-	Number of TIS science data words stored in the current packet

MERTIS_TIS_RAW_SCIENCE_DATA 3D Array

Field Name	Data Type	Unit	Description
MERTIS_TIS_RAW_SCIENCE_DATA	SignedMSB2	-	MERTIS TIS frames (raw science data)

Array Dimensions:

Axis Name	Elements	Description
Line	variable	Observations/Time dimension
Sample	100	Spatial sample dimension (no binning)
Band	40	Spectral band dimension (no binning)

Total array size: $22 \times 100 \times 40 = 88,000$ elements (176,000 bytes with 2-byte signed integers)

8.2. TIS PAR

PAR TIS file is also a FITS file, with those major changes from RAW level:

- MERTIS 3D Array is now a Radiometrically calibrated TIS science data
- Added Geometry in the Data Cube
- Added pixel wavelength matrix in the Data Cube

MERTIS TIS raw science data file structure (example):

Extension	Description
Primary FITS Header	FITS primary header
Metadata Table Header	MERTIS_TIS_METADATA FITS extension header
Metadata Table Data (BinTableHDU)	22 records × 237 bytes
Geometry Data Header	GEOENTRY DATA extension header (see below)
Geometry Data	3D array for TIS pixel geometry for each pixel corner + center (see below)
Science Data Array (ImageHDU)	3D array of raw TIS frames
Science Data Header	MERTIS_TIS_PAR_SCIENCE_DATA FITS extension header
Science Data Array (ImageHDU)	3D array of raw TIS frames

Wavelength Matrix Header	MERTIS_TIS_PAR_SCIENCE_DATA_WAVELENGTH extension header
Wavelength Matrix (ImageHDU)	.2D array of TIS frames wavelength (this contains a tilt angle due to misalignment)

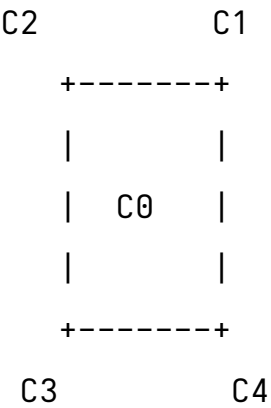
Geometry Layers :

Field Name	Data Type	Unit	Description
MERTIS_TIS_GEOMETRY_TARGET_LONGITUDE	IEEE754MSBDouble	deg	Target intersection longitude (tarlon) - planetocentric coordinates of where each pixel ray intersects the target body
MERTIS_TIS_GEOMETRY_TARGET_LATITUDE	IEEE754MSBDouble	deg	Target intersection latitude (tarlat) - planetocentric coordinates
MERTIS_TIS_GEOMETRY_SUBSPACECRAFT_LONGITUDE	IEEE754MSBDouble	deg	Subspacecraft point longitude (sublon) - point directly beneath spacecraft on target surface
MERTIS_TIS_GEOMETRY_SUBSPACECRAFT_LATITUDE	IEEE754MSBDouble	deg	Subspacecraft point latitude (sublat)
MERTIS_TIS_GEOMETRY_SUB_SUN_LONGITUDE	IEEE754MSBDouble	deg	Sub-solar point longitude (sunlon) - point where Sun is directly overhead
MERTIS_TIS_GEOMETRY_SUB_SUN_LATITUDE	IEEE754MSBDouble	deg	Sub-solar point latitude (sunlat)
MERTIS_TIS_GEOMETRY_TARGET_ALTITUDE	IEEE754MSBDouble	km	Target intersection altitude (taralt) - above reference ellipsoid (DTM)
MERTIS_TIS_GEOMETRY_SUBSPACECRAFT_ALTITUDE	IEEE754MSBDouble	km	Subspacecraft altitude (subalt)
MERTIS_TIS_GEOMETRY_SUB_SUN_ALTITUDE	IEEE754MSBDouble	km	Sub-solar altitude (sunalt)
MERTIS_TIS_GEOMETRY_TARGET_DISTANCE	IEEE754MSBDouble	km	Distance from spacecraft to target intersection point (tardis)

MERTIS_TIS_GEOMETRY_TARGET_ANGULAR_DIAMETER	IEEE754MSBDouble	deg	Angular diameter of target body as seen from spacecraft (tarang)
MERTIS_TIS_GEOMETRY_LOCAL_TIME	IEEE754MSBDouble	HH:M M:SS	Local solar time at intersection point (ltime) - derived from longitude and Sun position
MERTIS_TIS_GEOMETRY_TARGET_PHASE_ANGLE	IEEE754MSBDouble	deg	Phase angle (phase) - Sun-target-spacecraft angle
MERTIS_TIS_GEOMETRY_TARGET_EMISSION_ANGLE	IEEE754MSBDouble	deg	Emission angle (emissn) - angle between surface normal and observer direction
MERTIS_TIS_GEOMETRY_TARGET_INCIDENCE_ANGLE	IEEE754MSBDouble	deg	Incidence angle (incdnc) - angle between surface normal and Sun direction

Corner Index (5 elements):

- C0: Pixel center
- C1: Top-left vertex
- C2: Top-right vertex
- C3: Bottom-right vertex
- C4: Bottom-left vertex



MERTIS_SPACE frame (used for Earth flyby/EGA observations per the PDS4 label):

- +Z axis points along the space port boresight (co-aligned with S/C -Y axis/radiator)
- +X axis is parallel to the spatial resolution direction (along the slit), co-aligned with S/C +X
- +Y axis completes the right-hand frame (co-aligned with S/C +Z/nadir)

Directions (bottom, top, right, left) are intended looking through instrument boresight, with +X pointing right (along slit/spatial direction), +Y pointing down (along spectral/band direction), following a right-handed coordinate system where +Z is the boresight pointing outward from the instrument toward the target.

In the MERTIS_SPACE frame (used for EGA/Earth flyby observations):

- +X = S/C +X axis (spatial/sample direction, 100 pixels, no binning)
- +Y = S/C +Z axis (spectral/band direction, 40 bands, no binning)
- +Z = S/C -Y axis (boresight, pointing toward radiator/space)

In the MERTIS_PLANET frame (used for nominal Mercury science):

- +X = S/C +X axis (spatial/sample direction)
- +Y = -S/C +X axis completes right-hand frame
- +Z = S/C +Z axis (nadir/boresight, pointing toward planet)

This orientation follows the SPICE GETFOV convention where the field-of-view is defined relative to the instrument frame, with the spatial dimension (Line/samples) aligned along +X and the spectral dimension (Band) along +Y.

8.3. TIS CAL

TIS CAL level product are essentially the same as TIS PAR level, with the difference of :

- filter only observation with HK_STAT_TIS_DATA_ACQ_TARGET == scientific target (this is MERCURY in Nominal and Extended mission, MOON, VENUS or MERCURY during flyby). Operation without a defined scientific target (cruise checkout) will not have this level.
- MERTIS_TIS_PAR_SCIENCE_DATA_WAVELENGTH and MERTIS_TIS_PAR_SCIENCE_DATA FITS resampled to the rid of misalignment. Due to clocking angle between grating and sensors, MERTIS_TIS_PAR_SCIENCE_DATA_WAVELENGTH (x,y) axes are not parallel (spatial, wavelength) direction, so moving along x or y will change spatial position and wavelength.

9. APPENDIX B: TIR DATA & LABEL

9.1. TIR RAW

MERTIS TIR raw science data file structure (example):

Extension	Offset (bytes)	Size (bytes)	Description
Primary FITS Header	0	2880	FITS primary header
Metadata Table Header	2880	8640	MERTIS_TIR_METADATA FITS extension header
Metadata Table Data	11520	variable	Records $\times$ 190 bytes
Channel A Data Header	17280	5760	MERTIS_TIR_CHANNEL_A_RAW_SCIENCE_DATA header
Channel A Data	23040	variable	Frames $\times$ 15 $\times$ 8 bytes
Channel B Data Header	25920	5760	MERTIS_TIR_CHANNEL_B_RAW_SCIENCE_DATA header
Channel B Data	31680	variable	Frames $\times$ 15 $\times$ 8 bytes

MERTIS_TIR_METADATA Table Structure (variable records $\times$ 20 fields, 190 bytes/record)

Field Name	Data Type	Unit	Description
TIME.UTC	ASCII_Date_Time_YMD_UTC	-	UTC time of acquisition
TIME.OBT	ASCII_String	-	OBT time of acquisition converted from

			UTC
TimeStamp	IEEE754MSBDouble	seconds	TimeStamp
HK_STAT_TIR_DATA_ACQ_ID	SignedMSB8	-	Acquisition number TIR, incremented for each data product
HK_STAT_TIR_DATA_ACQ_TYPE	ASCII_String	-	Type of TIR science data
HK_STAT_TIR_DATA_ACQ_TARGET	ASCII_String	-	Target of TIR science data acquisition
HK_STAT_TIR_DATA_ACQ_TIME	IEEE754MSBDouble	seconds	TIR data time stamp at first acquisition (CUC format)
HK_STAT_TIR_NUM_OVERSAMP	SignedMSB8	-	Number of oversamplings performed
HK_TEMP_RAD_CHA	SignedMSB8	-	Radiometer temperature obtained by science data acquisition channel A
HK_TEMP_RAD_CHB	SignedMSB8	-	Radiometer temperature obtained by science data acquisition channel B
HK_STAT_TIR_DAT_OUT_OF_RANGE_CHA	SignedMSB8	-	TIR data channel A out of range (0=no, 1=yes)
HK_STAT_TIR_DAT_PROC_ERROR_CHA	SignedMSB8	-	TIR data channel A processing error (0=no, 1=yes)
HK_STAT_TIR_DAT_OUT_OF_RANGE_CHB	SignedMSB8	-	TIR data channel B out of range (0=no, 1=yes)
HK_STAT_TIR_DAT_PROC_ERROR_CHB	SignedMSB8	-	TIR data channel B processing error (0=no, 1=yes)
HK_TEMP_BB3_RAW	SignedMSB8	DN	BB300 temperature sensor raw value
HK_TEMP_BB3_REF_RAW	SignedMSB8	DN	BB300 reference temperature sensor raw value

HK_TEMP_BB3_OFFSET_RAW	SignedMSB8	DN	BB300 temperature sensor offset raw value
HK_TEMP_BB3_REF_OFFSET_RAW	SignedMSB8	DN	BB300 reference temperature sensor offset raw value
HK_TEMP_STS	IEEE754MSBDouble	degC	Shutter temperature
HK_TEMP_OST_BASE_PLATE	IEEE754MSBDouble	degC	Optics structure / Base Plate temperature

MERTIS_TIR_CHANNEL_A_RAW_SCIENCE_DATA 2D Array

Field Name	Data Type	Unit	Dimensions	Description
MERTIS_TIR_CHANNEL_A_RAW_SCIENCE_DATA	SignedMSB8	DN	variable × 15	TIR Channel A raw science data frames

Array Axes:

Axis Name	Elements	Description
CHANNEL_A_Frames	variable	Number of acquisition frames
CHANNEL_A_Spectral	15	Spectral channels

MERTIS_TIR_CHANNEL_B_RAW_SCIENCE_DATA 2D Array

Field Name	Data Type	Unit	Dimensions	Description
MERTIS_TIR_CHANNEL_B_RAW_SCIENCE_DATA	SignedMSB8	DN	variable × 15	TIR Channel B raw science data frames

Array Axes:

Axis Name	Elements	Description
CHANNEL_B_Frames	variable	Number of acquisition frames
CHANNEL_B_Spectral	15	Spectral channels

9.2. TIR PAR

PAR TIS file is also a FITS file, with those major changes from RAW level:

- MERTIS 2D Array is now a Radiometrically calibrated TIR A/B science data
- Added Geometry in the Data Cube
- Added pixel wavelength matrix in the Data Cube

MERTIS TIR PAR Science Data File Structure (example):

Extension	Description
Primary FITS Header	FITS primary header
Metadata Table Header	MERTIS_TIR_METADATA FITS extension header
Metadata Table Data (BinTableHDU)	19 records × 190 bytes
Geometry Data Header	GEOMETRY DATA extension header (see below)
Geometry Data	3D array for TIR pixel geometry for each pixel corner + center (see below)
Science Data Header	MERTIS_TIR_CHANNEL_X_PAR_SCIENCE_DATA FITS extension header
Science Data Array (ImageHDU)	2D array of PAR TIR frames (calibrated)

Geometry Layers (applies to both Channel A and Channel B):

Field Name	Data Type	Unit	Description
MERTIS_TIR_CHANNEL_X_GEOMETRY_TARGET_LONGITUDE	IEEE754MSBDouble	deg	Target intersection longitude (tarlon) - planetocentric coordinates of where

			each pixel ray intersects the target body
MERTIS_TIR_CHANNEL_X_GEOMETRY_TARGET_LATITUDE	IEEE754MSBDouble	deg	Target intersection latitude (tarlat) - planetocentric coordinates
MERTIS_TIR_CHANNEL_X_GEOMETRY_SUBSPACECRAFT_LONGITUDE	IEEE754MSBDouble	deg	Subspacecraft point longitude (sublon) - point directly beneath spacecraft on target surface
MERTIS_TIR_CHANNEL_X_GEOMETRY_SUBSPACECRAFT_LATITUDE	IEEE754MSBDouble	deg	Subspacecraft point latitude (sublat)
MERTIS_TIR_CHANNEL_X_GEOMETRY_SUB_SUN_LONGITUDE	IEEE754MSBDouble	deg	Sub-solar point longitude (sunlon) - point where Sun is directly overhead
MERTIS_TIR_CHANNEL_X_GEOMETRY_SUB_SUN_LATITUDE	IEEE754MSBDouble	deg	Sub-solar point latitude (sunlat)
MERTIS_TIR_CHANNEL_X_GEOMETRY_TARGET_ALTITUDE	IEEE754MSBDouble	km	Target intersection altitude (taralt) - above reference ellipsoid (DTM)
MERTIS_TIR_CHANNEL_X_GEOMETRY_SUBSPACECRAFT_ALTITUDE	IEEE754MSBDouble	km	Subspacecraft altitude (subalt)
MERTIS_TIR_CHANNEL_X_GEOMETRY_SUB_SUN_ALTITUDE	IEEE754MSBDouble	km	Sub-solar altitude (sunalt)
MERTIS_TIR_CHANNEL_X_GEOMETRY_TARGET_DISTANCE	IEEE754MSBDouble	km	Distance from spacecraft to target intersection point (tardis)
MERTIS_TIR_CHANNEL_X_GEOMETRY_TARGET_ANGULAR_DIAMETER	IEEE754MSBDouble	deg	Angular diameter of target body as seen from spacecraft (tarang)
MERTIS_TIR_CHANNEL_X_GEOMETRY_LOCAL_TIME	IEEE754MSBDouble	HH: MM: SS	Local solar time at intersection point (ltime) - derived from longitude and Sun position
MERTIS_TIR_CHANNEL_X_GEOMETRY_TARGET_PHASE_ANGLE	IEEE754MSBDouble	deg	Phase angle (phase) - Sun-target-spacecraft angle
MERTIS_TIR_CHANNEL_X_GEOMETRY_TARGET_EMISSION_ANGLE	IEEE754MSBDouble	deg	Emission angle (emissn) - angle

				between surface normal and observer direction
MERTIS_TIR_CHANNEL_X_GEOMETRY_TARGET_INCIDENCE_ANGLE	IEEE754MSBDouble	deg		Incidence angle (incdnc) - angle between surface normal and Sun direction

See geometry description in 8.2 TIS PAR for pixel corners and orientation description.

Updated Science Data Arrays

Field Name	Data Type	Unit	Dimensions	Description
MERTIS_TIR_CHANNEL_A_PAR_SCIENCE_DATA	SignedMSB8	DN	variable × 15	TIR Channel A partially processed science data (calibrated)
MERTIS_TIR_CHANNEL_B_PAR_SCIENCE_DATA	SignedMSB8	DN	variable × 15	TIR Channel B partially processed science data (calibrated)

9.3. TIR CAL

TIR CAL level product are essentially the same as TIR PAR level, with the difference of :

- filter only observation with HK_STAT_TIS_DATA_ACQ_TARGET == scientific target (this is MERCURY in Nominal and Extended mission, MOON, VENUS or MERCURY during flyby). Operation without a defined scientific target (cruise checkout) will not have this level.

9.4. DEFAULT HOUSEKEEPING

9.4.1. DEFAULT HOUSEKEEPING RAW

Attribute	Value
File Name	mer_raw_hk_default_YYYYMMDD_YYYYMMDD__0_1.dat
File Format	ASCII Delimited Text (CSV)
Field Delimiter	Comma
Record Delimiter	Carriage-Return Line-Return (CRLF)
Parsing Standard	PDS DSV 1
Records	variable
Fields per Record	36

MERTIS_RAW_DEFAULT_HOUSEKEEPING_DATA_TABLE Structure (variable records × 36 fields):

Field Name	Data Type	Unit	Description
TIME.UTC	ASCII_Date_Time_YMD_UTC	-	UTC time of acquisition
TIME_OBT	ASCII_String	-	OnBoard Time of acquisition
TimeStamp	ASCII_Real	seconds	Instrument timestamp of acquisition
HK_STAT_SID	ASCII_Integer	-	Structure Identifier for HK packets
PAD	ASCII_Integer	-	Parameter used as filling byte
HK_STAT_MERTIS_MODE	ASCII_Integer	-	MERTIS operation mode
FixVal5	ASCII_Integer	-	Fix filler dummy value
HK_STAT_EEPROM_POWER	ASCII_Integer	-	On/off status of EEPROM power
HK_STAT_EPA_POWER	ASCII_Integer	-	On/off status of Emergency

			Pointing Actuator (EPA) power
HK_STAT_HK_POWER	ASCII_Integer	-	On/off status of Housekeeping (HK) power
HK_STAT_STS_POWER	ASCII_Integer	-	On/off status of shutter (STS) power
HK_STAT_SHH_POWER	ASCII_Integer	-	On/off status of SHH power
HK_STAT_UNUSED_POWER	ASCII_Integer	-	On/off status of unused power line
HK_STAT_BB7_POWER	ASCII_Integer	-	On/off status of BB7 power
HK_STAT_TIS_POWER	ASCII_Integer	-	On/off status of TIS power
HK_STAT_TIR_POWER	ASCII_Integer	-	On/off status of TIR power
HK_STAT_TEC_POWER	ASCII_Integer	-	On/off status of TEC power
HK_STAT_POI_POWER	ASCII_Integer	-	On/off status of POI power
FixVal11	ASCII_Integer	-	Fix filler dummy value
HK_STAT_TM_BUFFER_OVERFLOW	ASCII_Integer	-	Flag for TM-Buffer overflow
HK_STAT_ICU_MAIN_RED	ASCII_Integer	-	Main/Red ICU Status, which ICU is powered
HK_STAT_WATCHDOG	ASCII_Integer	-	Status of the watchdog function (enabled/disabled)
HK_STAT_LAST_SPWLINK_ERROR	ASCII_Integer	-	Last occurred error of SpaceWire link
HK_VOLT_PSU_P34	ASCII_Integer	mV	PSU +3.4V supply digital voltage
HK_VOLT_PSU_P72	ASCII_Integer	mV	PSU +7.2V supply digital voltage
HK_TEMP_ICU	ASCII_Real	degC	ICU temperature

HK_TEMP_PSU	ASCII_Real	degC	PSU temperature
HK_STAT_LAST_ERROR_ID	ASCII_Integer	-	Identifier of the last occurred error
HK_STAT_LAST_ERROR_FREQUENCY	ASCII_Integer	-	Frequency (number of occurrences) of last error
HK_STAT_NUM_TC_RECEIVED	ASCII_Integer	-	Number of received TCs (Telecommands)
HK_STAT_NUM_TC_EXECUTED	ASCII_Integer	-	Number of executed TCs
HK_STAT_NUM_TM_SENT	ASCII_Integer	-	Number of TM packets sent (Telemetry)
HK_STAT_ICU_PROC_DUTY_CYCLE	ASCII_Integer	o/o	Duty cycle of the LEON processor (in %)
HK_STAT_ICU_NUM_AHB_ERROR	ASCII_Integer	-	Number of detected access errors on ICU AHB bus (double errors SDRAM access included)
HK_STAT_ICU_NUM_AHB_CORRECTABLE_ERROR	ASCII_Integer	-	Number of detected correctable access errors on ICU AHB bus (single errors SDRAM access)
HK_STAT_HK_NUM_LATCHUP_ERROR	ASCII_Integer	-	Number of detected HK latch-up errors

9.4.2. DEFAULT HOUSEKEEPING PAR

This level contains exactly the same data as RAW, as MERTIS delivers already calibrated sensors data. Kept for coherence between TIS/TIR corresponding products levels.

9.4.3. DEFAULT HOUSEKEEPING PAR

This level contains exactly the same data as RAW, as MERTIS delivers already calibrated sensors data. Kept for coherence between TIS/TIR corresponding products levels.

9.5. DEFAULT HOUSEKEEPING CAL

Default HK CAL level product are essentially the same as Default HK PAR level, with the difference of :

- filter only observation with HK_STAT_TIS_DATA_ACQ_TARGET == scientific target (this is MERCURY in Nominal and Extended mission, MOON, VENUS or MERCURY during flyby). Operation without a defined scientific target (cruise checkout) will not have this level.

9.6. EXTENDED HOUSEKEEPING

9.6.1. EXTENDED HOUSEKEEPING RAW

Attribute	Value
File Name	mer_raw_hk_extended_YYYYMMDD_YYYYMMDD__0_1.dat
File Format	ASCII Delimited Text (CSV)
Field Delimiter	Comma
Record Delimiter	Carriage-Return Line-Return (CRLF)
Parsing Standard	PDS DSV 1

Records	variable
Fields per Record	36

MERTIS_RAW_EXTENDED_HOUSEKEEPING_DATA_TABLE Structure (variable records × 44 fields):

Field Name	Data Type	Unit	Description	Elements
TIME.UTC	ASCII_Date_Time_YMD_UTC	None	UTC time of acquisition	1
TIME.OBT	ASCII_String	None	OnBoard Time of acquisition	1
TimeStamp	ASCII_Real	seconds	Instrument timestamp of acquisition	1
HK_STAT_SID	ASCII_Integer	none	Structure Identifier for HK packets	1
PAD	ASCII_Integer	none	Parameter is used as filling byte	1
HK_STAT_BOL_BIAS_VOLT_ACTIVE_PARAM_SET	ASCII_Integer	none	Currently used BIAS voltage parameter set (1...3)	1
HK_STAT_SH_REF_TEMP_STABLE	ASCII_Integer	none	Reference temperature for Sensor Head stable/unstable	1
HK_STAT_TIS_TEC_STABLE	ASCII_Integer	none	BOL chip temperature status (stable/unstable) controlled by TEC	1
HK_STAT_EPA_STATUS	ASCII_Integer	none	Emergency Pointing Cover Actuator status (activated/not activated)	1

FixVal12	ASCII_Integer	none	Fix filler dummy value	1
HK_STAT_POI_BB3_VIEW	ASCII_Integer	none	POI position BB3 view status (yes/no)	1
HK_STAT_POI_BB7_VIEW	ASCII_Integer	none	POI position BB7 view status (yes/no)	1
HK_STAT_POI_PLANET_VIEW	ASCII_Integer	none	POI position Planet view status (yes/no)	1
HK_STAT_POI_SPACE_VIEW	ASCII_Integer	none	POI position Space view status (yes/no)	1
HK_STAT_STS	ASCII_Integer	none	Shutter status (open/closed)	1
HK_TEMP_BB3	ASCII_Real	degC	BB300 temperature	1
HK_TEMP_BB7	ASCII_Real	degC	BB700 temperature	1
HK_TEMP_EOP_TMA	ASCII_Real	degC	Entrance Optics/TMA temperature	1
HK_TEMP_SOP_GRATING	ASCII_Real	degC	Spectrometer Optics grating temperature	1
HK_TEMP_SOP_M1	ASCII_Real	degC	Spectrometer Optics mirror M1 temperature	1
HK_TEMP_OST_BASE_PLATE	ASCII_Real	degC	Optics structure Base Plate temperature	1
HK_TEMP_BOL_CHIP	ASCII_Real	degC	Current Bolometer chip temperature (TEC controlled)	1
HK_TEMP_BOL_HOUSING	ASCII_Real	degC	Bolometer housing temperature	1
HK_TEMP_STS	ASCII_Real	degC	Shutter temperature	1

HK_TEMP_POI_MOTOR	ASCII_Real	degC	POI motor temperature	1
HK_TEMP_POI_MIRROR	ASCII_Real	degC	POI mirror temperature	1
HK_TEMP_RBA_FRONT	ASCII_Real	degC	Baffle front temperature	1
HK_TEMP_RBA_BACK	ASCII_Real	degC	Baffle back temperature	1
HK_VOLT_REF_DELTA_SINGLE_ENDED	ASCII_Real	mV	Reference HK channel delta voltage (single-ended HK channels)	1
HK_TEMP_EOP_IR_FILTER	ASCII_Real	degC	Entrance optics IR-Window temperature	1
HK_STAT_REL_NUM_LATCHUP_ERROR	ASCII_Integer	none	Number of detected Latch-Up errors of the REL ADC	1
HK_STAT_BEL_NUM_LATCHUP_ERROR	ASCII_Integer	none	Number of detected Latch-Up errors of the BEL ADC	1
HK_TEMP_BB3_REF	ASCII_Real	degC	BB300 temperature reference sensor (Pt100 compatible)	1
HK_STAT_OBTIME_SYNC_DELTA	ASCII_Integer	ms	Delta between On-Board time and last SpW time code	1
HK_STAT_NUM_SPW_ERR_CREDIT	ASCII_Integer	none	SpaceWire Credit Error count (CE)	1
HK_STAT_NUM_SPW_ERR_ESCAPE	ASCII_Integer	none	SpaceWire Escape Error count (ER)	1
HK_STAT_NUM_SPW_ERR_DISCONNECT	ASCII_Integer	none	SpaceWire Disconnect Error count (DE)	1
HK_STAT_NUM_SPW_ERR_PARITY	ASCII_Integer	none	SpaceWire Parity Error count	1

(PE)			
HK_STAT_NUM_SPW_ERR_WRITESYNC	ASCII_Integer	none	SpaceWire Write Sync Error count (WE) 1
HK_STAT_NUM_SPW_ERR_INVALIDADDRESS	ASCII_Integer	none	SpaceWire Invalid Address Error count (IA) 1
HK_STAT_NUM_SPW_ERR_EOPEEP	ASCII_Integer	none	SpaceWire Early EOP/EEP Error count (EE) 1
HK_STAT_NUM_SPW_ERR_RXAHB	ASCII_Integer	none	SpaceWire RX AHB Error count (RA) 1
HK_STAT_NUM_SPW_ERR_TXAHB	ASCII_Integer	none	SpaceWire TX AHB Error count (TA) 1
HK_STAT_NUM_SPW_ERR_TXBLOCKED	ASCII_Integer	none	SpaceWire TX Blocked Error count (TB) 1

9.6.2. EXTENDED HOUSEKEEPING PAR

This level contains exactly the same data as RAW, as MERTIS delivers already calibrated sensors data. Kept for coherence between TIS/TIR corresponding products levels.

9.6.3. EXTENDED HOUSEKEEPING CAL

Default HK CAL level product are essentially the same as Default HK PAR level, with the difference of :

- filter only observation with HK_STAT_TIS_DATA_ACQ_TARGET == scientific target (this is MERCURY in Nominal and Extended mission, MOON, VENUS or MERCURY during flyby). Operation without a defined scientific target (cruise checkout) will not have this level.

10. APPENDIX C: MODIFICATION_HISTORY CLASS

The ModificationHistory class manages product versioning and audit trails within the MERTIS data processing pipeline. It provides automated version control and guarantees full scientific and technical traceability across all data processing levels and reprocessing campaigns.

C.1. Overview and Versioning Scheme

The processing pipeline enforces a **major.minor (__V_v) versioning scheme** for all MERTIS data products²⁴:

- **Minor Version (v)**: Incremented for routine pipeline updates, metadata fixes, or processing adjustments that do not alter the underlying radiometric radiance values⁴⁶.
- **Major Version (V)**: Triggered by major updates to calibration algorithms, structural changes to PDS4 labels, or revised instrument spectral/radiometric response models⁴.

The class automatically formats and appends the version string as a filename suffix (e.g., mer_raw_hk_default_20200409__0_1.dat) to maintain consistent naming conventions across the archive³.

C.2. Backend Database Tracking

Version history and modification logs are tracked dynamically via a **SQLite3 database backend** (modificationhistory table). The schema includes the following fields⁹:

- **filename**: Name of the processed data product⁹.
- **major_version & minor_version**: Integers tracking the assigned product version⁹.
- **modification_date**: UNIX epoch timestamp of record creation/update⁹.
- **description**: Human-readable description documenting the specific rationale for the processing step or version increment².

The database supports both automated sequential version bumps (e.g., __0_1 __0_2) and explicit version assignments during major reprocessing campaigns².

C.3. PDS4 Label Generation

During product generation, the MERTIS pipeline calls extracts the complete modification record from the database and format it into **PDS4-compliant XML fragments**³. These XML fragments populate the Modification_History class in the PDS4 product label³.

C.4. Usage and Relevance for Data Users

For the scientific data user, this automated class ensures:

1. **Full Provenance & Audit Trail:** Every product label contains an embedded, human-readable modification history describing *why* and *when* a product was updated²³.
2. **Clear Distinction of Changes:** Users can quickly distinguish between minor software/metadata updates and major calibration updates by inspecting the filename suffix (__V_v) and the corresponding XML label class.
3. **Database-to-Label Consistency:** Version suffixes in filenames remain strictly synchronized with the internal PDS4 XML metadata across all observational levels (RAW, PAR, CAL)².