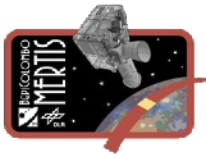




MERTIS Instrument Science Performance Review Report (draft)

Version 2.0 – 2026.04.16

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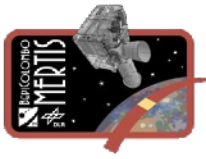
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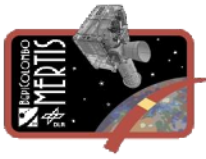


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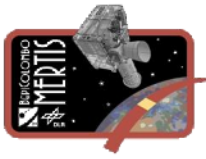
1. Introduction

1.1. Purpose

This document describes and discusses the Science Performance of the MERTIS Instrument from post launch to April 10, 2026.

1.2. Abbreviations

ADC	Analog-to-Digital Converter
APS	Application Software
BB3	Blackbody 300 K (internal MERTIS calibration target, passive, floating)
BB7	Blackbody 700 K (internal MERTIS calibration target, actively controlled)
CPPA	Common Parts Procurement Agent
CO	Check-out
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DN	Digital Number
EID	Experiment Interface Document
EMC	Electromagnetic Compatibility
EOP	Entrance optics plate
ETB	Engineering Test Bench
FEE	Front End Electronics
FM	Flight Model
FOP	Flight Operation Procedure
FOV	Field of View
FS	Flight Spare
FT	Functional Test
HK	Housekeeping
HAR	MERTIS Harness Board
ICDR	Instrument Critical Design Review
ICU	Instrument Controller Unit
IF	Interface
IR	Infrared
KT	Kayser-Threde
MERTIS	Mercury Radiometer and Thermal Imaging Spectrometer
MLI	Multi-Layer Insulation
MPOI	MERTIS Pointing unit
MSB	Mercury Swing By
MTA	Mercury True anomaly
MTM	Mercury Transfer Module
MUX	Multiplexer
NETD	Noise Equivalent Temperature Difference



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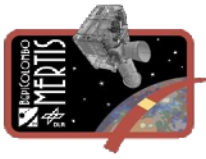
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NECP	Near Earth Commissioning Phase
OBCP	On-Board Control Procedure
OOL	Out of Limits
OP	Operation point
OSR	Oversampling ratio
PCB	Printed Circuit Board
PDOR	Payload Direct Operations Request
PSU	Power Supply Unit
QM	Qualification Model
RAD	MERTIS Radiometer Detector
REL	MERTIS Radiometer Electronics
RTD	Resistance Thermometer Device
SC	Spacecraft
SEE	Single Event Effects
SEL	Single Event Latch-up
SHH	Sensor Head Heater
SMT	Surface Mount Technology
SNR	Signal to Noise Ratio
SSD	Spectral Sampling Distance
SPI	Serial Peripheral Interface
SW	Software
T	Temperature
TC	Telecommand
TID	Total Ionising Dose
TIR	MERTIS Radiometer (5-40 μm)
TIR-A	TIR channel A (8-14 μm)
TIR-B	TIR channel B (5-40 μm)
TIS	MERTIS Spectrometer (7 -14 μm)
TM	Telemetry
TMM	Thermal Mathematical Model
TRP	Temperature Reference Point
TVAC	Thermo-Vacuum Chamber
UM	User Manual
VSKIM	Voltage Skim
VSB	Venus Swing By

1.3. Reference Documents

- MER-DLR-RS-001 MERTIS Science requirements
- MER-DLR-RP-015 Science Performance Report
- MER-DLR-TR-054 FM TBTV MERTIS Report Test Phases
- MER-DLR-RP-057 Spectrometer Radiometric Calibration Report
- MER-DLR-MA-001 issue 2.2 Instrument User Manual (FM)
- MER-DLR-MA-001 issue 2.7 Instrument User Manual (FM)
- MER-DLR-LI-019 issue 18 APS Historical Records



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- ESC_BC_SC_154_20250415_101031 BepiColombo Spacecraft Anomaly Report
- ESC_BC_SC_274_20251216_103709 BepiColombo Spacecraft Anomaly Report
- ESC_BC_SC_309_20251216_103717 BepiColombo Spacecraft Anomaly Report

1.4 MERTIS Science objectives and requirements

The scientific objectives and performance requirements of the MERTIS instrument are described in the MER-DLR-RS-001 document. However, a summary is given here.

The MERTIS instrument is designed to characterize the surface of Mercury by measuring thermal infrared radiance in the wavelength range from 7 to 40 μm . The primary objectives of MERTIS are:

- Global mapping of Mercury's surface mineralogy,
- Identification of major rock-forming minerals,
- Characterization of surface temperature and thermal inertia.

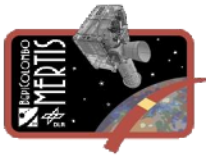
The performance requirements for the MERTIS spectrometer (TIS) are driven by the need to detect diagnostic spectral features of silicate minerals in the thermal infrared range. In particular, the instrument must resolve characteristic emissivity features such as Christiansen features (CF), Reststrahlen bands (RB), and Transparency Features (TF) of surface minerals. To enable reliable identification of mineral phases and compositional variations, the spectrometer requires sufficient spectral resolution and signal-to-noise ratio (SNR) across the full spectral range.

The requirements for the MERTIS radiometer (TIR) are defined to ensure accurate measurements of the surface brightness temperature of Mercury and to enable the derivation of thermophysical properties. The radiometer must measure surface temperatures in the range of approximately 100–700 K with a precision of about 3 K at 100 K object temperature. In addition, the instrument must provide multi-channel thermal measurements to support the determination of thermal inertia and surface roughness parameters at spatial scales of a few kilometers.

The MERTIS science requirements are listed in **Table 1**.

Table 1: MERTIS Science requirements.

ID	Channel	Subject	Desired performance	Minimal required 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%



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7	TIS	Coverage with better than 500m resolution	10%	5%
8	TIR	NETD at 100K surface temperature	≤1K	≤3K
9	TIR	Spatial resolution at 400 km	≤2000m	≤5000m

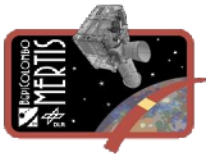
1.5 MERTIS Cruise science timeline

This document summarizes the results obtained during the cruise phase of the BepiColombo mission with the MERTIS instrument. During this period, MERTIS was periodically operated during dedicated mission events, including cruise check-outs (COs), planetary swing-bys (SBs), and software verification activities. **Table 2** provides a chronological overview of these events.

The cruise phase started with the Near-Earth Commissioning Phase (NECP) in November 2018, which marked the first in-flight commissioning and verification of the instrument after launch. The NECP results are presented in section 2 of this document. Subsequent cruise COs were used to routinely verify the health and science performance of the instrument and to perform dedicated calibration activities. The cruise phase COs were also used to investigate and optimize instrument operations, including SPACE-view observations, and SHH thermal control testing. The results of the COs are presented in section 3 of this document. Several laboratory tests were performed on the MERTIS Flight Spare during cruise to optimize the science performance verification. These are described in section 4. In addition, two onboard software updates (SW-1 and SW-2) were prepared and validated to improve instrument operations and prepare the instrument for the orbital phase at Mercury. The software updates are detailed in section 5. Finally, the Earth/Moon swing by provided the first scientific observations of MERTIS in-flight. Two Venus swing-bys in 2020 and 2021 provided new planetary observations by MERTIS, followed later by the first Mercury observations during MSB-5 in December 2024 and additional measurements under Mercury-like thermal conditions during MSB-6 in January 2025. The results of the swing bys are shown in section 7.

Table 2: Summary of MERTIS events (COs, SBs, SW updates) during the cruise phase.

Event #	Year	Month	Event name	Activity
1	2018	November	NECP	First commissioning of MERTIS in-flight
2	2019	June	CO-1	SPACE view for cruise observations #1
3	2019	December	CO-2	Standard CO
4	2020	April	Earth/Moon SB	Flyby of the Earth/Moon
5	2020	June	CO-3	Standard CO
6	2020	October	VSB-1	First Venus observations by MERTIS



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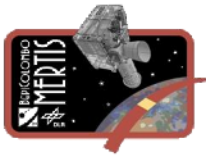
7	2020	December	CO-4	Bias Voltage calibration #1
8	2021	June	CO-5	Bias Voltage calibration #2
9	2021	August	VSB-2	Second Venus observations by MERTIS
10	2021	November	CO-6	Standard CO
11	2022	May	CO-7	Standard CO
12	2022	November	CO-8	Standard CO
13	2023	March	CO-9	SPACE view for cruise observations #2
14	2023	November	CO-10	SHH testing
15	2024	April	CO-11	SHH and direct gap-filling testing
16	2024	September	(post) MSB-4	Exceptional operation to rehears MSB-5
17	2024	December	MSB-5	First Mercury observations by MERTIS
18	2025	January	MSB-6	First observations under Mercury-like thermal environment
19	2025	April	CO-13	Detector response check
20	2025	July	SW-1	Software update #1
21	2025	July	CO-14	SW testing and MTM post-separation rehearsal
22	2026	May	SW-2	Software update #2

2. Near Earth Commissioning Phase

BepiColombo started the payload NECP a few weeks after launch, first commissioning all the spacecraft modules and then the scientific instruments. The data collected are shown in this work to address the instrumental performance variation after launch. This section describes the NECP results for the MERTIS instrument. The following subsections describe the operations, the results from both TIS and TIR channels and the conclusions for the instrument performances.

2.1 Operations

MERTIS first command was sent on the 13th Nov. 2018, 10:51:11 UTC and switched off at the end of the last ground station pass on the 14th Nov 2018 16:46:47 UTC for a total operation time of 1 day, 5 hours and 55 minutes. Effective operation time was for ~7:45 hours on the first day and ~7 hours on the second day. The night between the two days was used to reach high thermal stability and the instrument did not perform any science acquisition, because the spacecraft was out of ground station visibility. The operation plan developed for the NECP, shown in **Table 3**, was aiming to verify the operational performances of all the instrument sub-modules, in particular the spectrometer and



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radiometer sensor sensitivities, the pointing unit (MPOI), and the thermal stability of the whole instrument. **Figure 1** shows the actual list of TC sent to the MERTIS instrument on day 1 and day 2.

Table 3: MERTIS operation plan for NECP.

Step	Mode	Duration	Comment
A	Configure MERTIS Platform heaters	00:05:00	Activity performed on the first day at least 2 hour before MERTIS switch on
B	Switch on	00:05:00	
C	Perform health check	00:05:00	
D	Go to warm-up	01:00:00 to 14:00:00	Overnight until the next ground passes
E	Setup MERTIS platform heater for science	00:05:00	
F	Go to Stand by	00:01:00	
G	Diagnostic mode	00:45:00	Verify the sub-system functions in detail
H	SPACE view test	00:05:30	
I	Science mode • HK generation rate 20s • binning 1x2 • TIS 100ms • TIR 1000ms	00:32:00	
J	Go to stand by	00:32:00	
K	Set default MPOI to PLANET view	00:07:00	
L	Switch off	00:02:00	
M	Switch on	00:05:00	Quick warm up
N	Perform health check	00:05:00	
O	Diagnostic mode	00:45:00	
P	SPACE view test		



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Q	Science mode - increased HK to 1s - binning 1x2 - TIS 100ms - TIR 1000ms	00:32:00	
R	Go to stand by	00:32:00	
S	Set default MPOI to PLANET view	00:07:00	
T	Switch off	00:02:00	
U	Set default TCS control settings	00:01:00	

Almost half of the first day was used to set and check the thermal stability of the instrument, sending TCs and dumping housekeeping (HK) parameters. This allows a short feedback cycle to perform onboard parameters adjustments, needed to reach a thermal environment suited for instrument operations. Once the instrument's thermal environment reached a status in the nominal range, the Science Mode was enabled, looking at deep space, effectively acquiring the first MERTIS data ever in space. After that, another 3 data sessions were performed, changing the TIS binning and executing the nominal operation/calibration cycle of 60 seconds as follow: PLANET (1 acquisition), BB3, BB7 and SPACE. In each measurement session, TIS and TIR repetition rates were set-up to 100ms and 1000ms respectively. The second day had a similar data operation pattern, with a much higher housekeeping generation rate, each second instead each 20 seconds, as default for the nominal mission. The total amount of scientific data and housekeeping data is on the order of 1.15 GB, for a total of around 120k TIS and 15k TIR acquisitions.

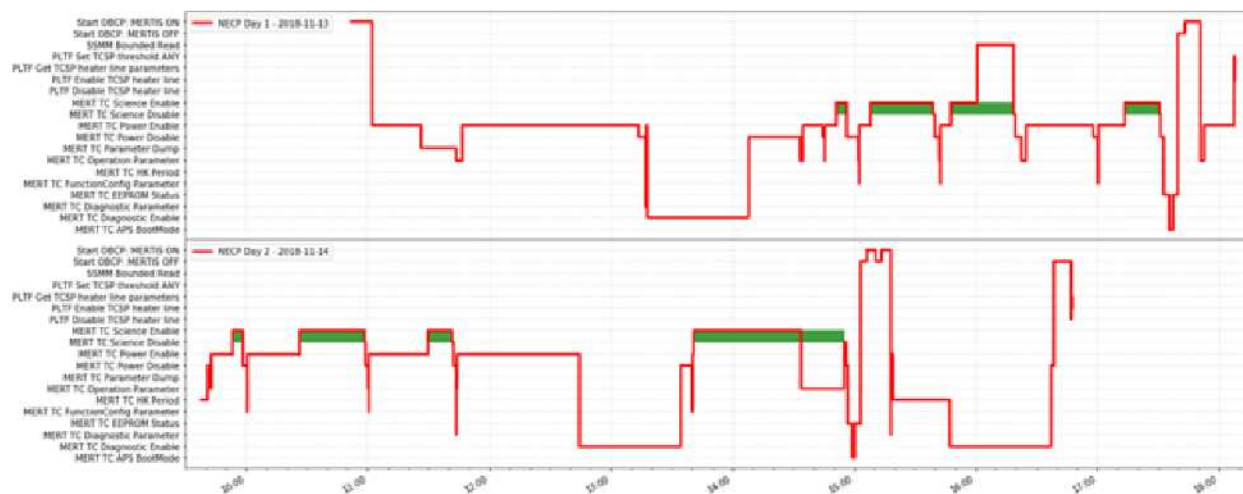


Figure 1: List of TC sent to MERTIS instrument in the first (top) and second (bottom) days of the NECP versus UTC time. The solid green area represents the time frames of actual MERTIS data acquisition.



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2.2 Results

2.2.1 MERTIS-TIS

The TIS spectrometer was fully functional during the first in-flight operations. The grating spectrometer differential (scene – dark scene) images acquired at different MPOI positions are shown in **Figure 2**. The unmasked part of the detector is the central one, where the 'frames' pixels only show signal due to the thermal noise. The average value of all frame pixels is called macropixel and is an important indicator of the thermal state of the detector itself and of the dark current generated in these specific thermal conditions. For all the images the binning was [spatial x spectral] = [1 x 2], resulting in a Spectral Sampling Distance (SSD) of 89 nm. MERTIS calibration curves have 5 different regimes, based on the total voltage read from the sensor, in this case we were in the OP-Point 2 (see user manual). The sequence shows a normal behavior, with less signal coming from the SPACE view, slightly higher signal from the PLANET view (looking at the MTM) that has around the same environmental temperature as the spacecraft and the higher signal from the BB3, with a temperature at 9.09°C (282.24K).

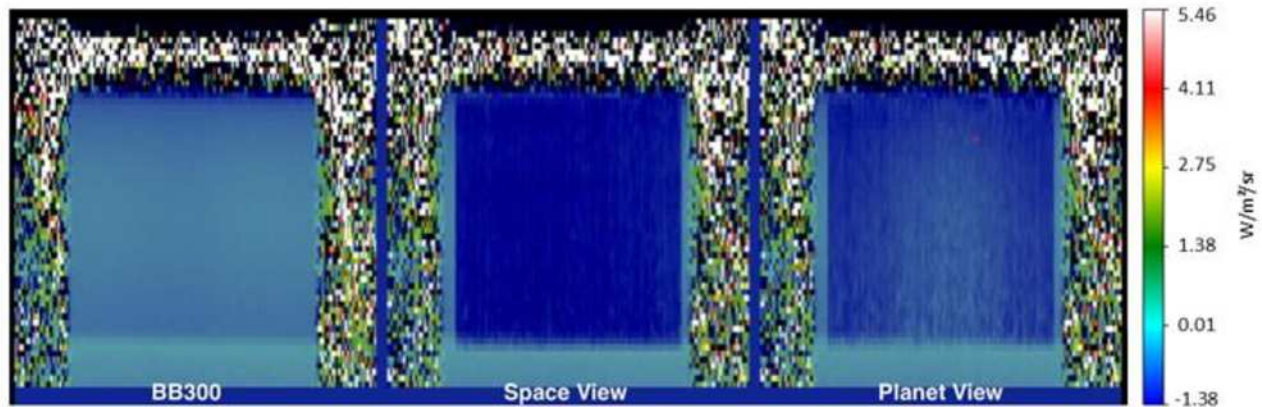


Figure 2: Grating spectrometer differential (scene – dark scene) images of the BB3 9.09°C/282.24K, SPACE view, and PLANET view - part of a typical science observation sequence of MERTIS - acquired during NECP. The color code shows the radiance level.

Figure 3 shows the BB7 images obtain during the NECP and prior to launch in the DLR Thermo-Vacuum chamber (TVAC). The thermal conditions at the base plate were nearly identical between measurements (in-flight: 9.85 °C; on-ground: 9.48 °C). Detector operational parameters were maintained consistently for both datasets, including identical bias voltage settings and bolometer operating temperature. **Figure 4** shows a spectral radiance extracted from the center of the BB7 image (pixel index=47).

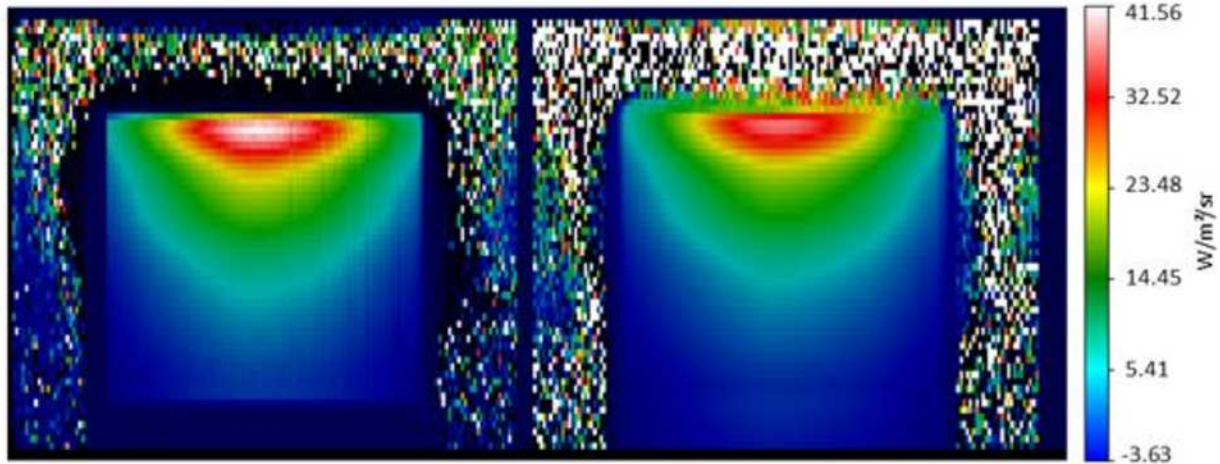


Figure 3: Grating spectrometer differential images of the BB7 during NECP at 403.20°C/676.35 K (left) and on-ground measurements in the DLR TVAC at 386.22°C/659.37K (right). The color code shows the radiance level.

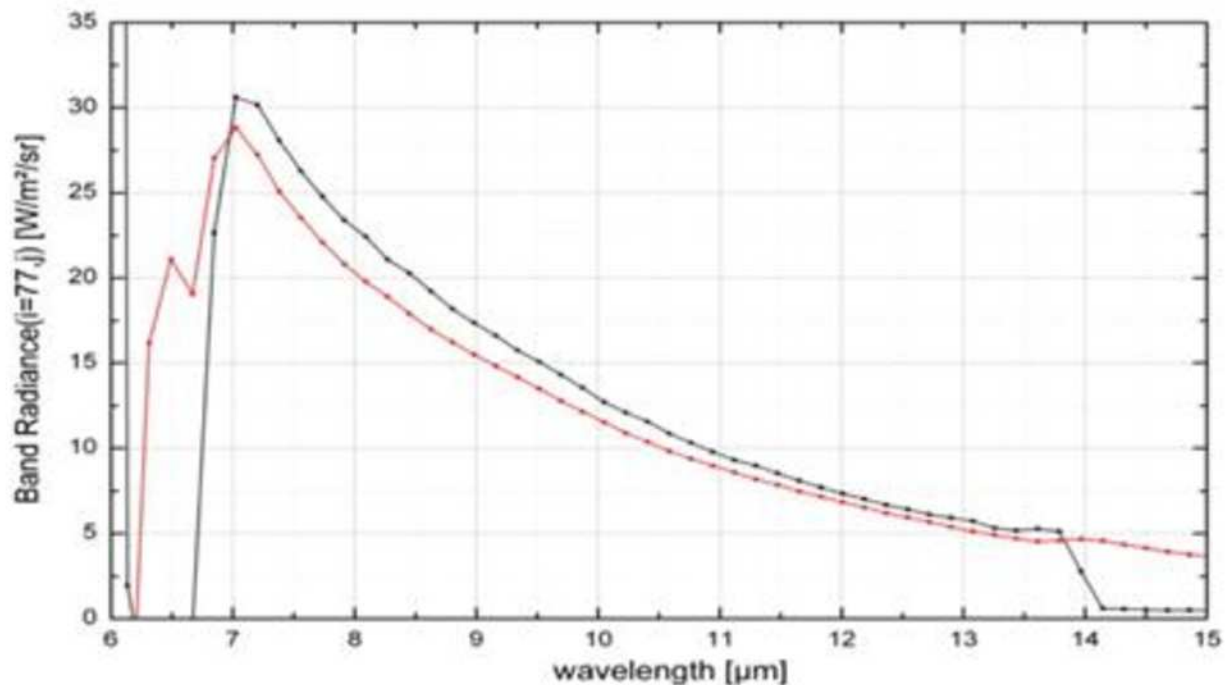


Figure 4: BB7 Radiance spectrum measured on-ground (red) and in-flight during the NECP (black) from the images shown in Figure 3.

Position of the image barycenter as been analyzed after NECP and compared with on-ground calibration measurements. Inflight images were acquired with onboard binning of [spatial x spectral]: [1 x 2] and „unbinned“ before calculations, i.e. oversampled to [1 x 1]. BB7 laboratory images were acquired unbinned on February, 2013. Barycenter positions were computed over the full scene window using a threshold mask corresponding to the top 30 % of signal values and are shown in **Figure 5**. The



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barycenter shift is minimal, corresponding to approximately half a pixel with a measured shift of $[dx, dy] = [0.47, 0.49]$. The in-flight barycenter measurements appear to exhibit lower noise, likely due to reduced image offsets placing the signal near the edge of the detector's linear response region (see MER-DLR-RP-057); these low offsets also lead to stripe patterns in the BB7 in-flight image compare to the on-ground image (**Figure 3**).

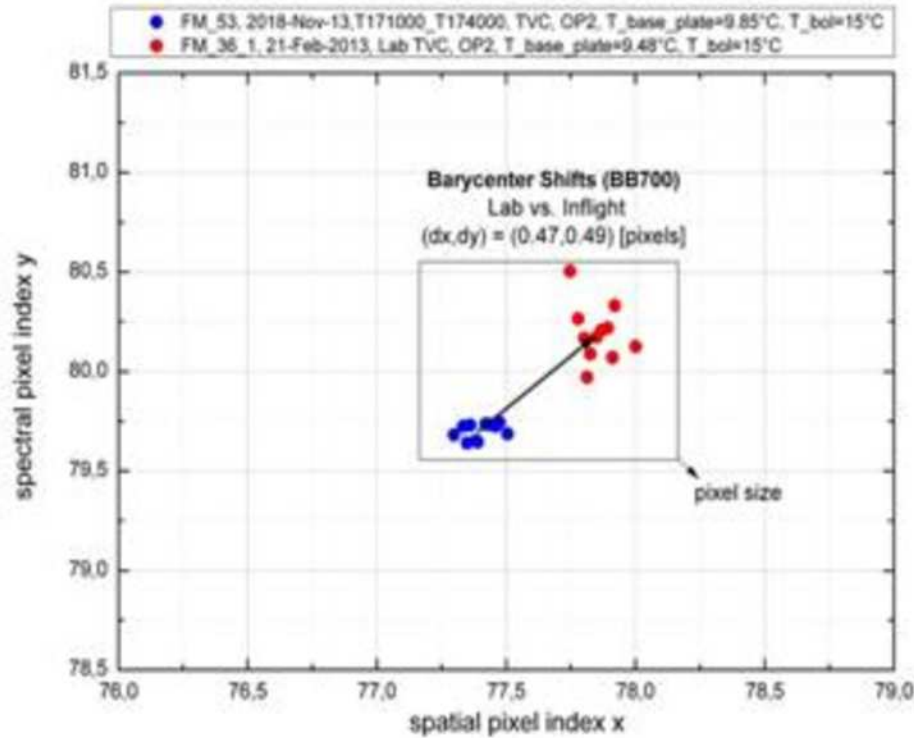
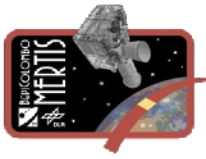


Figure 5: Comparison of the image barycenter positions between on-ground calibration measurement (red) and in-flight NECP measurements (blue) under the same thermal conditions. The barycenter shift is approximately half a pixel.

A detailed comparison of the BB3 signal levels acquired on-ground and during the NECP phase was performed (e.g. **Table 4**). The analysis indicates a decrease of approximately 2147 DN in the BB3 NECP measurements relative to the laboratory calibration measurements conducted at DLR under the same conditions. However, the detector noise, represented by the raw image non-uniformity variance (sigma), is very similar between the two measurements. The 25 DN difference is mainly due to the binning of the NECP measurements, strongly increasing the SNR (signal to noise ratio) of the measurements, as expected. The later result demonstrates the stability of the MERTIS instrument in-flight and on-ground.



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Table 4: Instrumental parameters and corresponding signal measurement (in DN) for in-flight NECP measurements and on-ground calibration laboratory measurements.

Measurements	NECP OP2	Lab - TVAC FM-36 OP2	Delta NECP – Lab
T_BOL_chip	14.996°C	15.000 °C	-0.004
T_baseplate	9.83 °C	9.48 °C	0.35 K
T_BB3	8.95°C	10.17 °C	-1.22 K
T_BB7	403.21°C	386.60 °C	16.6 K
BB3 average signal	2123 DN	4270 DN	-2147 DN
BB3 sigma	303 DN	328 DN	-25 DN

The signal level difference (-2147 DN) is consistent with observations made prior to the launch during the ESTEC TVAC test, as documented in the corresponding test report (MER-DLR-TR-054), which already shown a similar off-set in the signal compare to the calibration campaign performed at DLR. The observed difference is attributed to variations in the thermal environment between the laboratory setup and the in-flight configuration. Although the spacecraft thermal conditions were reproduced as closely as possible during the DLR TVAC campaign, the thermal interface -particularly the cooling by the TRP2- was not fully representative of the in-flight configuration.

Consequently, the NECP measurements do not indicate any in-flight degradation or change in detector performance. Instead, the observed signal offset most likely originated after instrument–spacecraft integration and was already present prior to launch.

2.2.2 MERTIS-TIR

The TIR radiometer was fully functional during the first in-flight operations. NECP observations show a slight decrease of sensitivity of broadband channel by B (5-40 μm) of 12%, already observed on-ground before launch. TIR observations of the BB7 on-ground and in-flight during the NECP is shown in **Figure 6**. TIR channel A (8-14 μm) shows the same behavior in-flight and on-ground with no alteration of the signal. TIR channel B (5-40 μm) shows a slight (12%) degradation of the detector sensitivity, already observed on-ground. This 12% decrease is mainly due to terrestrial atmospheric degradation of the sensor during the spacecraft integration and prior to launch. Therefore, there is no indication of sensitivity degradation in-flight.



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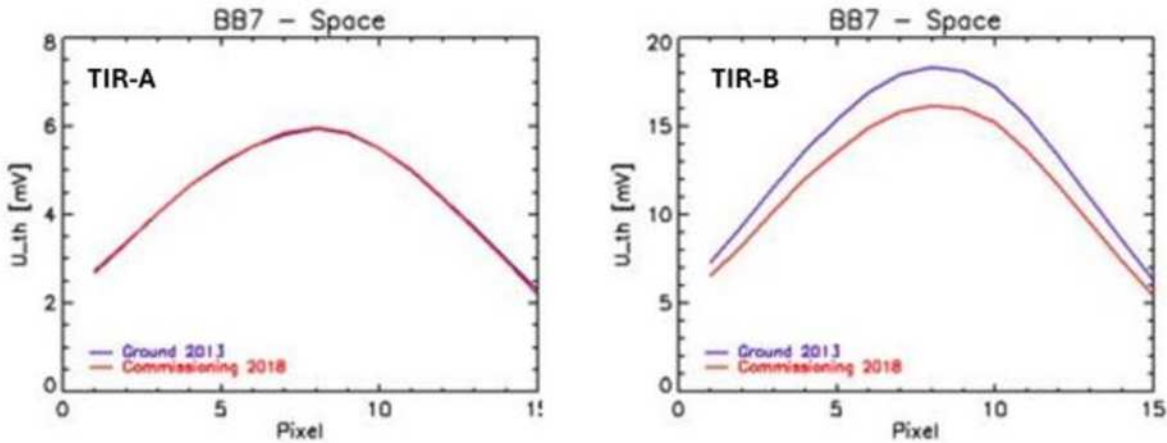


Figure 6: BB7 - SPACE measurements by the TIR radiometer channel A (left) and channel B (right) on-ground (purple) and during the NECP (red).

A detailed comparison of the BB3 noise is shown in **Figure 7**. The noise is determined from standard deviation of difference between BB3 and space view and contains both electronics and thermal noise. The thermophile noise is estimated between 72 and 63 nV for both channels on-ground and to 66 nV in-flight. The thermal noise (Pt-1000) is estimated to less than 2 mK both on-ground and in-flight for the two channels. The standard deviation of the total noise is unchanged between on-ground and NECP indicating no degradation of the signal-to-noise ratio of the TIR radiometer.

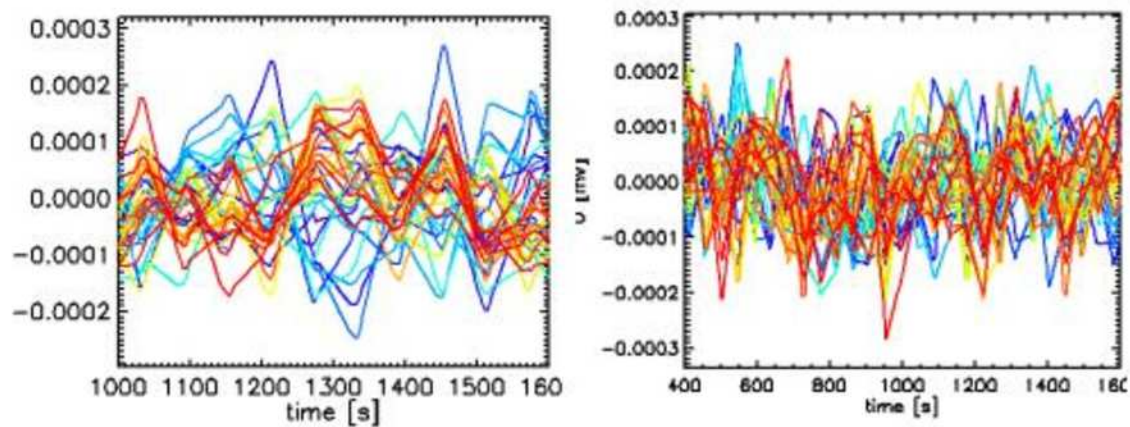
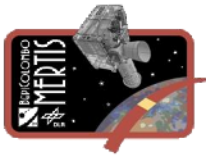


Figure 7: BB3 - Space measurements standard deviation by the TIR radiometer in-flight during the NECP (left) and on-ground (right)

2.3 Conclusions

MERTIS successfully completed its first in-flight commissioning during the NECP on November 2018. Measurements of the instrument's internal calibration targets as well as deep space were acquired. The commissioning sequence was executed fully according to the operational plan and confirmed nominal functionality of all instrument subsystems, demonstrating excellent overall instrument health.



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MERTIS TIS spectrometer exhibits performance consistent with the last on-ground testing measurements. Only a very small image shift -less than half a pixel- has been observed after launch, which has no measurable impact on the science performance of the instrument. A minor variation in signal level together with the appearance of stripes has been identified in the images; dedicated optimization activities (see CO-4 and CO-5) were performed (see next section) and allow fully recovery of the detector's nominal science performance.

MERTIS TIR radiometer is fully operational in flight. Its noise characteristics remain unchanged (<100 nV) compared with on-ground measurements, confirming the stability of the detector. A $\sim 12\%$ sensitivity decrease is observed in TIR-B (longer wavelengths); however, this effect had already been identified during ground testing and is primarily attributed to terrestrial alteration rather than any in-flight degradation.

The following instrument check-outs provided opportunities to further monitor these performances and update instrumental parameters to optimize instrument performances.

Overall, the NECP results confirm that MERTIS entered the cruise phase in excellent condition and with science performance fully consistent with expectations, providing a strong basis for high-quality thermal infrared observations during the mission.

3. Cruise check-outs

Since launch and after the NECP, the MERTIS instrument was checked regularly twice a year. The **Table 5** shows a summary of the CO performed during cruise and their main objectives following the NECP. The following sub-sections describe the operations planned, the assesement of collected data and the conclusions on the instrument performance for the individual check-outs.

Table 5: Summary of MERTIS checkouts during the cruise phase.

CO	Year	Start date	End date	Main goal
1	2019	03.06.2019	04.06.2019	Implementing a first procedure to observe cruise targets with SPACE view
2	2019	December 2019 date?	CO	Standard science mode testing
3	2020	22.06.2020	23.06.2020	Standard science mode testing
4	2020	14.12.2020	18.12.2020	BIAS Voltage calibration
5	2021	14.06.2021	18.06.2021	BIAS Voltage calibration
6	2021	23.11.2021	23-11-2021	Standard science mode testing
7	2022	18.05.2022	19.05.2022	Standard science mode testing



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8	2022	07.11.2022	08.11.2022	Standard science mode testing
9	2023	10.03.2023	12.03.2023	Standard science mode testing + new procedure for the swap to SPACE view
10	2023	06.11.2023	10.11.2023	Standard science mode testing and SHH testing
11	2024	08.04.2024	12.04.2024	SHH testing continues, science modes and reverse cycle mode testing
12	2024	04.11.2024	08.11.2024	Cancelled
13	2025	07.04.2025	11.04.2025	Testing detector response and standard science mode testing
14	2025	28.07.2025	01.08.2025	Testing new S/W version and rehearsal of MTM post-separation operations

3.1 Space view for cruise observations

In CO-1, we tested a first procedure, changing the main standard pointing from the PLANET view to the SPACE view. Since the PLANET view sight is closed by the MTM, the main view port has been swap to the SPACE port, which is free during cruise phase. This first procedure, using the so called MERTIS calibration mode, allows MERTIS to acquire relevant science observations from the SPACE view during the cruise phase which was not plan and possible before CO-1.

The calibration mode was originally a way to define free pointing sequences for ground testing. This was then used to define a sequences for BB7, BB3, and SPACE observations. The PLANET view was not used and the MPOI was not moved to this target. **Figure 8** shows a comparison between a nominal science mode and the calibration mode for the data acquisition.

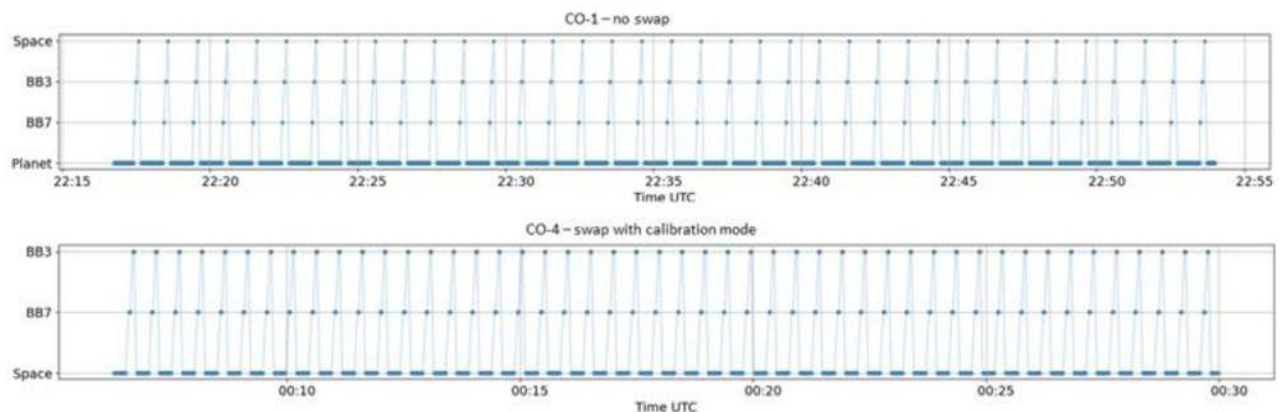
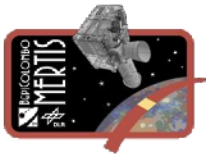


Figure 8: Result of the swap procedure implemented in CO-1, (top panel) Targets observed during CO-4 when the “Calibration mode” for the swap was not used. (bottom panel) Targets observed during CO-4 when the “Calibration mode” was implemented for the swap.



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The calibration mode was operated as a standard procedure for COs 4-5, Earth/Moon flyby and Venus flybys. The calibration mode in-flight made it possible to observe the Moon and Venus during flybys, a first with a thermal infrared spectrometer operating in the MERTIS wavelengths range.

In this configuration, several operational parameters lacked the flexibility required to reproduce the acquisition conditions implemented in the science modes, leading to noticeable variations in the BB7 calibration images.

In particular, the calibration mode did not follow the timing sequence defined for calibration target acquisitions in the nominal science modes. Reliable calibration measurements require a sufficient stabilization and acquisition period on each target. For the spectrometer TIS, target observations can be performed within less than 10 ms. In contrast, the radiometer TIR requires a significantly longer stabilization period due to its thermal response characteristics. The TIR data acquisition begins only after a stabilization time of approximately 2 s, corresponding to the thermal time constant of the detector. In addition, about 800 ms are required to read out all 32 TIR channels, including two sets of 15 pixels for TIR-A and TIR-B, plus two detector temperature readouts.

However, using the calibration mode this stabilization period was limited to only 800 ms, which is insufficient for the radiometer to reach stable conditions and acquire reliable calibration data. Furthermore, the repetition rate of both TIR and TIS acquisitions was set to 100 ms in calibration mode. While this timing is adequate for the spectrometer TIS, it is too short for the TIR radiometer, whose readout time is significantly longer (800 ms).

As a consequence, the movement of the MPOI unit becomes visible in the TIR measurements of the internal calibration targets. **Figure 9** shows the TIR channels acquisitions of the 3 calibration targets using the calibration mode (top panels) and a nominal science mode (bottom panels). After 100 ms (repetition rate) and the acquisition of 4 pixels by the TIR-A and TIR-B channels, the signal of the BB7 and BB3 start to decrease in the calibration mode, while it continues to increase in the nominal science mode acquisitions. The signal decrease is due to the slew of the MPOI to the next target. The MPOI slewing toward the next target, before the radiometer acquisition sequence has completed, results in partially corrupted calibration measurements in-flight compare to on-ground. This strongly complicates the calibration of the TIR data acquire with the calibration mode, i.e. during the Moon and the Venus flyby.



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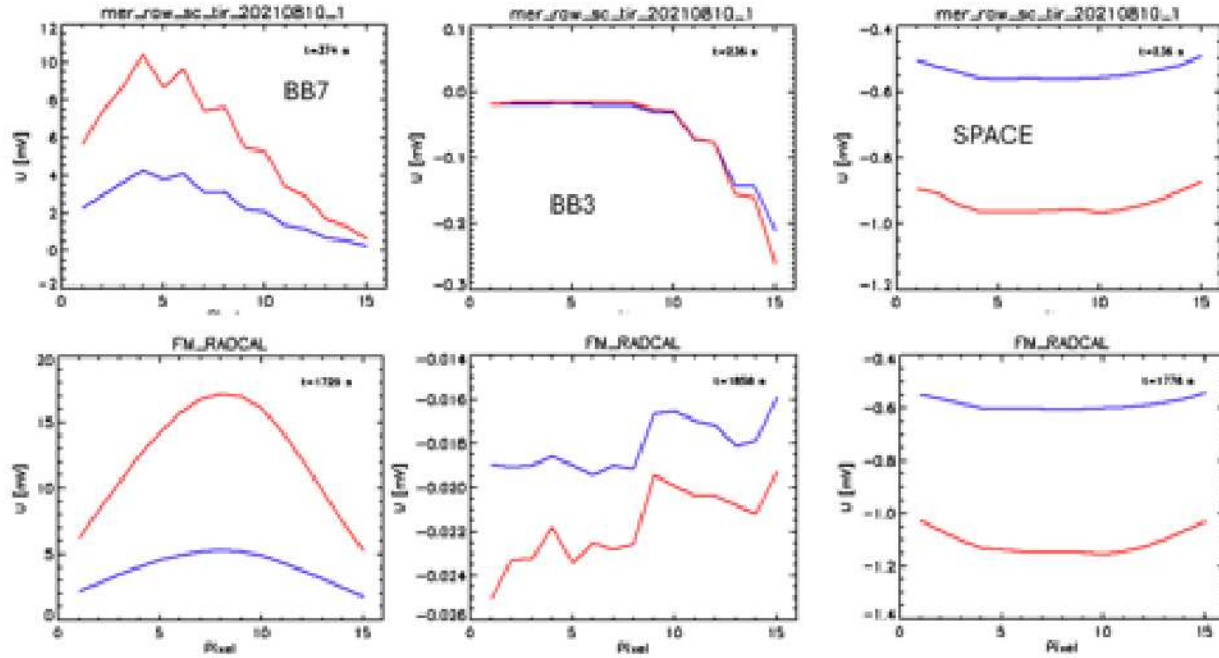


Figure 9: TIR-A (blue) and TIR-B (red) channels acquisition of calibration targets (from left to right: BB7, BB3 and SPACE) during the VSB#2 using the calibration mode (top) and the ground calibration with the nominal science mode (bottom).

In order to solve those issues, we implemented a patch using a PDOR Memory Load (OBSM) to simply swap the SPACE and PLANET views during CO-9. We tested different modes with different repetition rates to confirm the successful execution of the patch during CO-11.

The implementation of the swap patch was successful. **Figure 10** shows the targets observed during CO-9 before and after the implementation of the PDOR Memory Load (OBSM) for the swap from PLANET view to SPACE view. It was then possible to operate the instrument with the operational parameters needed and tests were made with high (100 ms) and low repetition rates (800 ms) (see **Table 6**).



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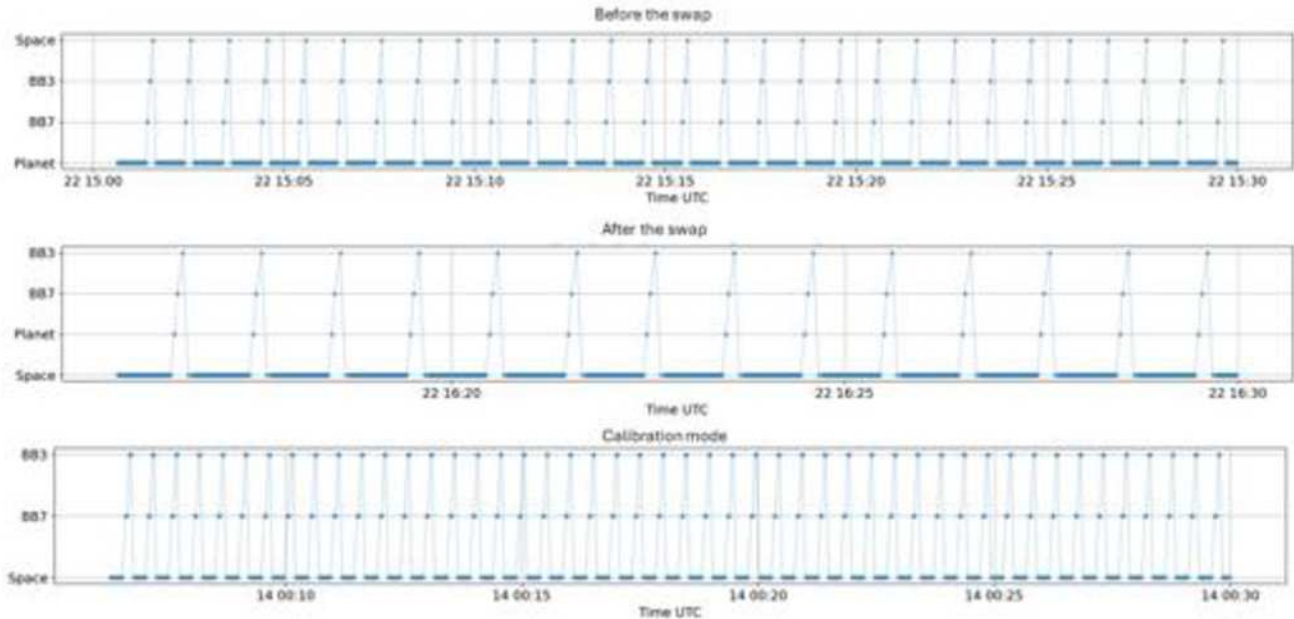


Figure 10: Result of the swap patch implemented in CO-9. The top panel shows the targets observed during 30 min Science High Resolution before the swap; the middle panel shows the targets observed during 15 min Science High Resolution 1 after the implementation of the PDOR Memory Load for the swap to SPACE view; the bottom panel shows the targets observed when using the previous method: “calibration mode” (CO-4), for comparison.

Figure 11 shows TIS images acquired from both SPACE and PLANET views before and after the swap. We can see that the MTM radiation in the PLANET image is visible before and after the swap confirming that the observations flagged as PLANET are still observing the MTM. The SPACE images continue to show low radiance level and mostly low level noise typical of deep-space observation confirming that observations flagged as SPACE before and after the swap are looking through the SPACE port.



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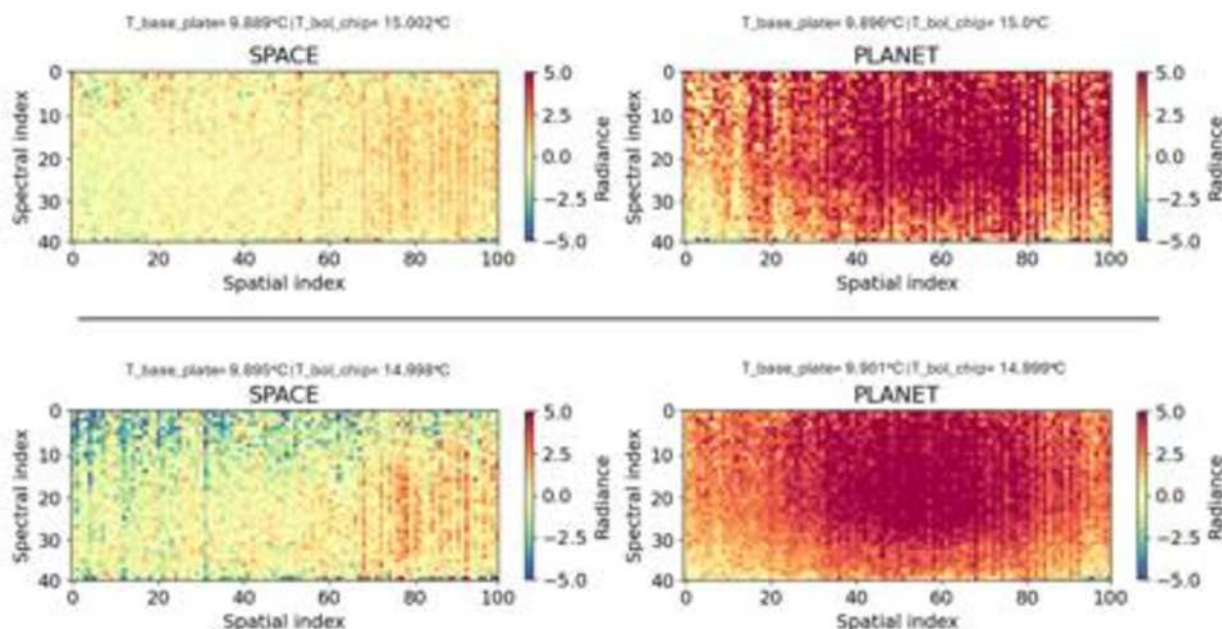


Figure 11: TIS Images of the SPACE view (left) and PLANET view (right) before (top) and after (bottom) the swap to SPACE view observed in Science High Resolution 1 mode. The thermal environment indicated by the temperature of the base plate and the bolometer chip is similar between the images.

The patch was then use in every following COs and for the Mercury flybys 5 and 6, allowing optimal instrument parameters for the scientific observations and better match with the calibration performed on-ground. In addition, the repetition time of the TIR radiometer was updated in the SW-1 release by defining a minimum default value of 800 ms (see Section 5). Following this update, repetition times below 800 ms are no longer permitted. If a lower value is specified in the operational configuration, the software automatically enforces a repetition period of 800 ms for the TIR acquisition. The TIR repetition factor will be as in the **Table 6**, depending on which TIS repetition rate has been defined. The MERTIS user manual is currently being updated with this information.

Table 6: Repetition times of TIS and TIR for the nominal science modes.

TIS Repetition time (ms)	TIR Repetition Factor	TIR Repetition time (ms)
100	8	800
300	3	900
800	1	800
2000	1	1000
10000	1	1000



3.2 Voltage calibration

3.2.1 Goals and operation

Following the NECP and the Moon flyby, our primary objective was to further optimize the science performance by mitigating the stripes observed in the images and by restoring the BB3 nominal signal level affected by low image offsets and detector non-linearity (see section 2.2.1). To address these effects, an in-flight calibration of the detector bias voltage was implemented during CO-4 and CO-5. This procedure aimed to adjust the voltage of the detector OP to a more optimal region of the response curve, thereby improving radiometric stability and reducing striping artifacts. **Figure 12** shows the response of the detector for several OP according to the temperature of the bolometer base plate. During the NECP, the instrument was operated in OP2 and base plate temperature was 9.83°C, i.e. outside the linear range of the detector/readout electronics. Each OP-point is associated to one VSKIM values. The relationship between instrument OP and voltage is described in detail in the TIS radiometric calibration report (MER-DLR-RP-057).

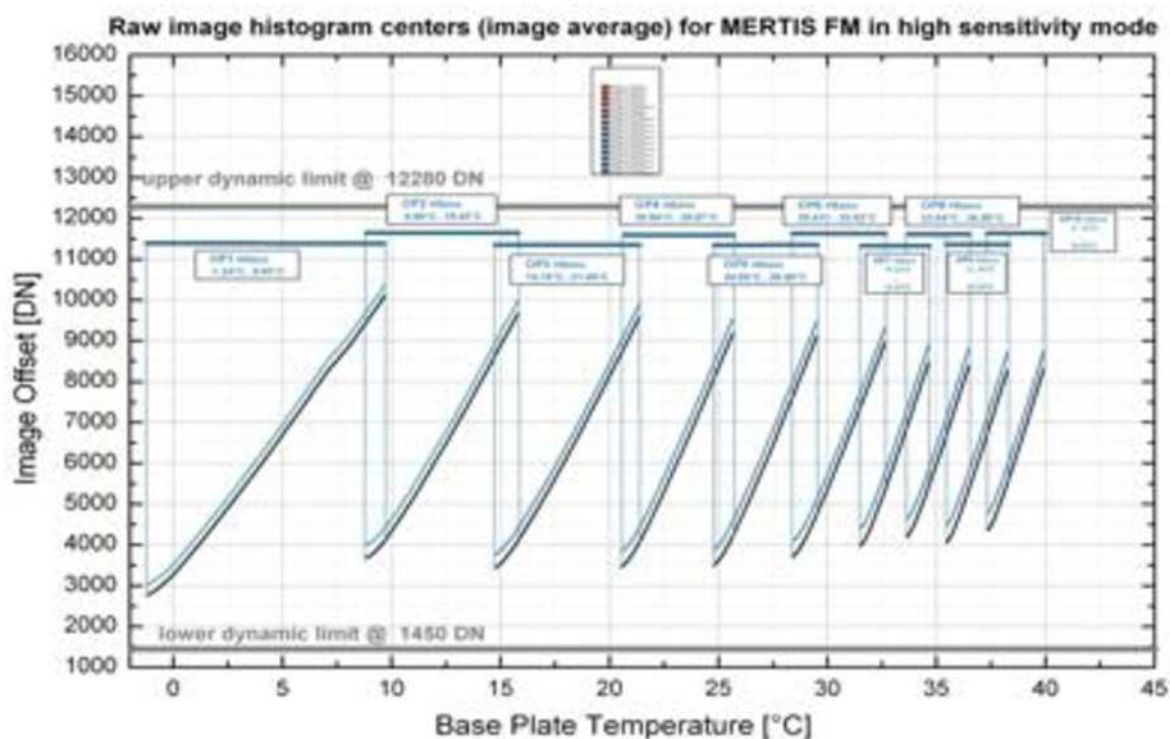
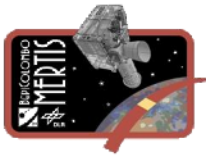


Figure 12: Image center offset for several MERTIS Operational points (OP) versus the base plate temperature of the instrument. The non-linearity of the detector is visible for each OP at low offsets.

In CO-4, we routinely operated our standard science checkout and performed the first version of our bias voltage calibration of the TIS detector. We commanded 10 hours of operations at OP 3 by changing the voltage values 144 times from 4.371 V to 4.521 V step 0.001 V around 3 optical head temperature sets. The last acquisition, with value 4.521 V was executed 2 times, one to send data on the normal Ka-band, one to test the direct down link system (X-band), leading to a total of 145 observations.



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During CO-4 several warnings occurred due to the planned high TIS repetition rate of 100ms (see next section). In CO-5, we therefore decided to optimize the timing in order to validate/reproduce the results of CO-4. The same operation plan was reproduced with modified procedures used during the first calibration test of CO-4.

3.2.2 VSKIM correction

The approach for determining the appropriate voltage (VSKIM) adjustment is based on a direct comparison between in-flight measurements and laboratory reference data acquired under equivalent detector operating conditions. The objective is to identify the bias voltage correction required to reproduce the same detector offset conditions observed during ground calibration performed at DLR.

The first step consists of finding images from both in-flight and on-ground measurements for which the BB3 image offsets (S_{ref_avg}) are equal and the base plate temperatures ($T_{baseplate}$) are equal as well. S_{ref_avg} is related to the average value of the image dark zones (no-scene) while looking at BB3.

$$T_{baseplate_inflight} = T_{baseplate_lab}$$

$$S_{ref_avg_inflight} = S_{ref_avg_lab} \text{ (related to BB300)}$$

The second step consists of calculating the correction coefficient, called the V_{skim_delta} , from the V_{skim} settings of both measurements:

$$V_{skim_inflight} - V_{skim_lab} = V_{skim_delta}.$$

It is assumed, that V_{skim} simply shifts image offsets linearly and independently from current thermal status and OP-Point of the system.

Then future measurements can be done by introducing **V_{skim_delta}** shift to the V_{skim_lab} to new $V_{skim_inflight_new}$:

$$V_{skim_inflight_new} = V_{skim_lab} + V_{skim_delta}$$

Comparison between on-ground calibration measurements and in-flight measurements performed during CO-5 is shown in **Figure 13**.

The curve of the on-ground calibration measurements cross the curve of the in-flight measurements at V_{skim} 's measurement sequence #48, which corresponds to:

$$V_{skim_inflight} = 4.371 \text{ V} + 48 \cdot 0.001 \text{ V} = 4.419 \text{ V from } 4.371 \text{ to } 4.521 \text{ step } 0.001 \text{ Volt}$$

V_{skim_delta} is then calculated as follows:

$$V_{skim_inflight} - V_{skim_lab} = 4.419 \text{ V} - 4.435 \text{ V} = -0.016 \text{ V} = V_{skim_delta}$$



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The sensitivity of the image offset related to the voltage values is ca. -129 DN/mV. Therefore, -16 mV correction corresponds to shift of ca. 2064 DN upwards, which is consistent with the image offset deviation detected at NECP (-2147 DN), see section 2.2.1. This result indicates that the image offset deviation remained essentially stable between 2018 and 2021, further confirming that no in-flight degradation of the detector has occurred.

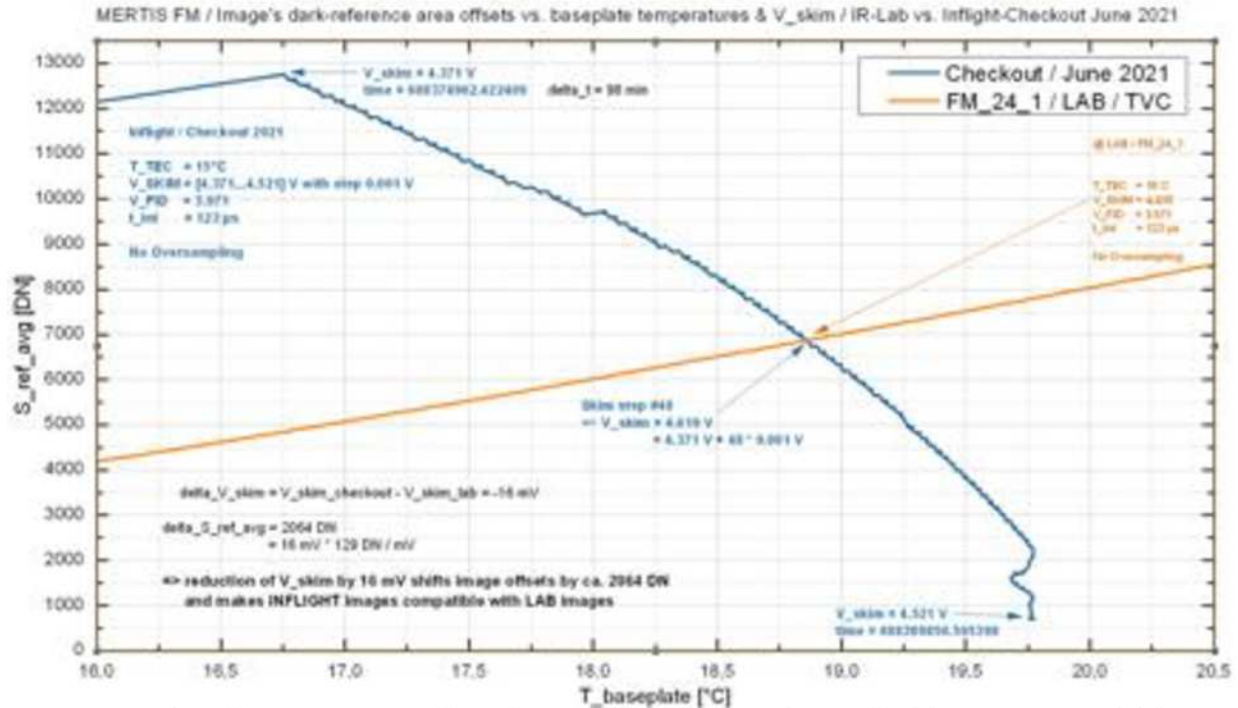


Figure 13: Graphical representation of $S_{ref_avg_inflight}(T_{baseplate_inflight})$ and $S_{avg_ref_lab}(T_{baseplate_lab})$ for OP3

After CO 5, the VSKIM offset was applied in the operation. From CO-10 the BIAS VSKIM value has been adjusted via a FOP. After the first SW update (see section 5.1), the VSKIM correction is included and no operation or parameter adjustment is needed. The FOP allowing the adjustment of the VSKIM is still available in case of any detector response change in the future (not expected).

The Moon flyby and the first Venus flyby were performed before the implementation of the VSKIM BIAS correction. The second Venus flyby performed two months after CO-5 (**Table 1**), was performed without the VSKIM correction in order to be fully comparable to the observations of the first Venus flyby. The absence of the VSKIM correction in those flyby data is not critical and the effect on the data is well understood (see section 4).

3.2.3 Results of the VSKIM correction

Several analysis were performed during the subsequent COs to assess the effect of the VSKIM correction on the science data collected by MERTIS. **Figures 14** and **15** illustrate the effect of this correction on the BB7–BB3 and BB3–SPACE differential images, respectively.



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At OP2, using the bias voltage value defined during ground calibration (VSKIM=4403 mV), the TIS differential images exhibit pronounced stripe artifacts. These artifacts are particularly evident in low-signal conditions, such as in the BB3-SPACE measurements (Figure 15). The application of the VSKIM correction derived during CO-5 effectively removes these stripe patterns, resulting in a significant improvement in image uniformity and overall data quality. This correction therefore restores the detector operating point to a regime where the detector response is linear, leading to improved radiometric stability and enhanced science performance.

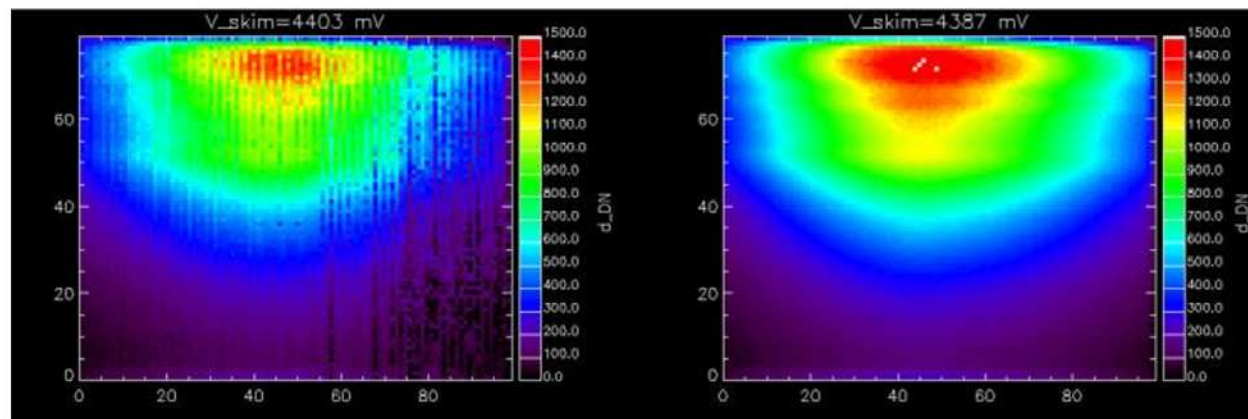


Figure 14: TIS spectrometer raw differential images of the BB7-BB3 before (left) and after (right) the VSKIM correction. The color shows the signal level difference between the two calibration targets.

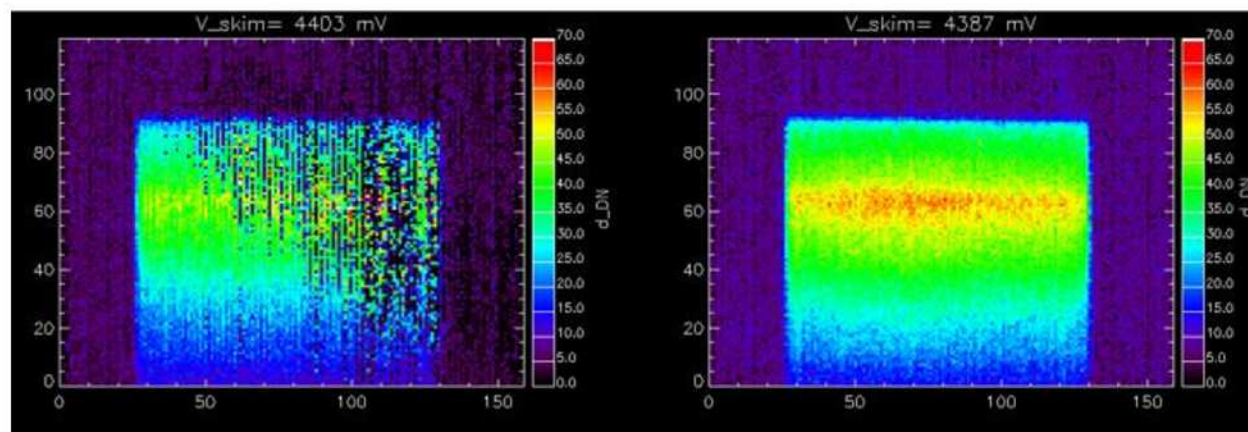


Figure 15: TIS spectrometer raw differential images of the BB3-SPACE before (left) and after (right) the VSKIM correction. The color shows the signal level difference between the two calibration targets.

3.3 Detectors sensitivity

During the whole cruise phase, the standard science CO operations implemented in most of the COs, allows us to monitor the good health of the detectors. A comparison between on-ground calibration measurements at DLR TVAC (2013) and the latest in-flight measurements (2025, CO-14) is shown in the section 3.3.1 for the TIS spectrometer. Section 3.3.2 illustrates the sensitivity of the TIR detectors



through the most recent part of the cruise phase (2023-2025) from CO-9 to CO-14 in comparison to on-ground calibration measurements and NECP.

3.3.1 MERTIS-TIS

The MERTIS spectrometer (TIS) was operated during all routine COs and its operational performance was confirmed to be nominal. The bolometer detector sensitivity shows clear constant behavior during cruise phase. The sensitivity of the TIS spectrometer is evaluated through differential images of the BB3-BB7. **Figure 16** shows a comparison of the BB7-BB3 differential images on-ground and in-flight during the most recent CO (CO-14) in 2025. The result shows a generally good agreement between the ground calibration measurements (2013) and the recent in-flight calibration data (2025). In particular, both the absolute signal level and the spectral shape—including the position of the spectral maximum—remain consistent between the two datasets. This close correspondence indicates a high degree of stability of the bolometer detector during the cruise phase and through 12 years, confirming the robustness of the instrument.

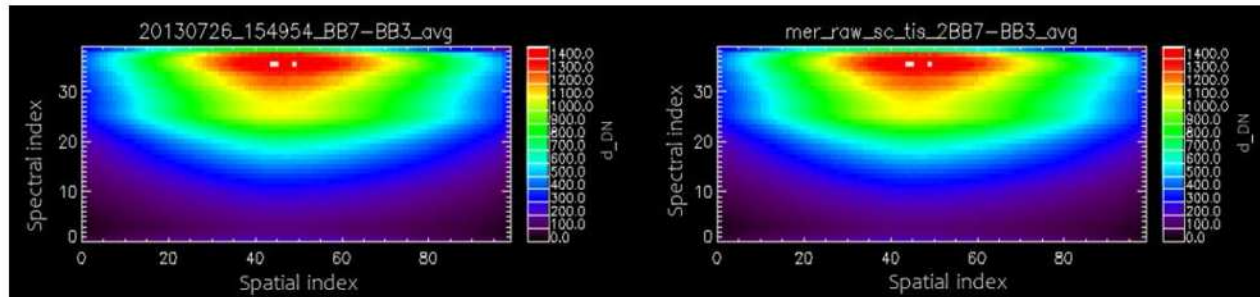


Figure 16: TIS spectrometer differential images of the BB7-BB3 on-ground (left) and in-flight (right) during the last CO in 2025. The color shows the signal level difference between the two calibration targets.

The difference between the two differential images presented in **Figure 16** is illustrated in **Figure 17**. The stretched representation of the residuals indicates a potential change in the signal structure, with relative variations reaching up to approximately 3.5% on the left side of the detector. At that stage, it remains unclear whether this structure reflects a genuine change in the instrument response or results from processing or measurement variability.

The relative differences appear to be more pronounced in regions characterized by lower signal levels, which may enhance the apparent magnitude of the variations. Further investigation is required to determine whether the observed pattern represents a physical effect within the instrument.

Several potential explanations could account for such changes. These include ageing effects of the BB7 calibration target, potentially leading to modifications in the spatial temperature distribution of the microheater, or ageing of the KRS-5 entrance window affecting the instrument transmission.

It should also be noted that absolute differences on the order of 1–2% have already been observed when comparing different ground-calibration setups, although these differences did not exhibit any noticeable spatial structure.

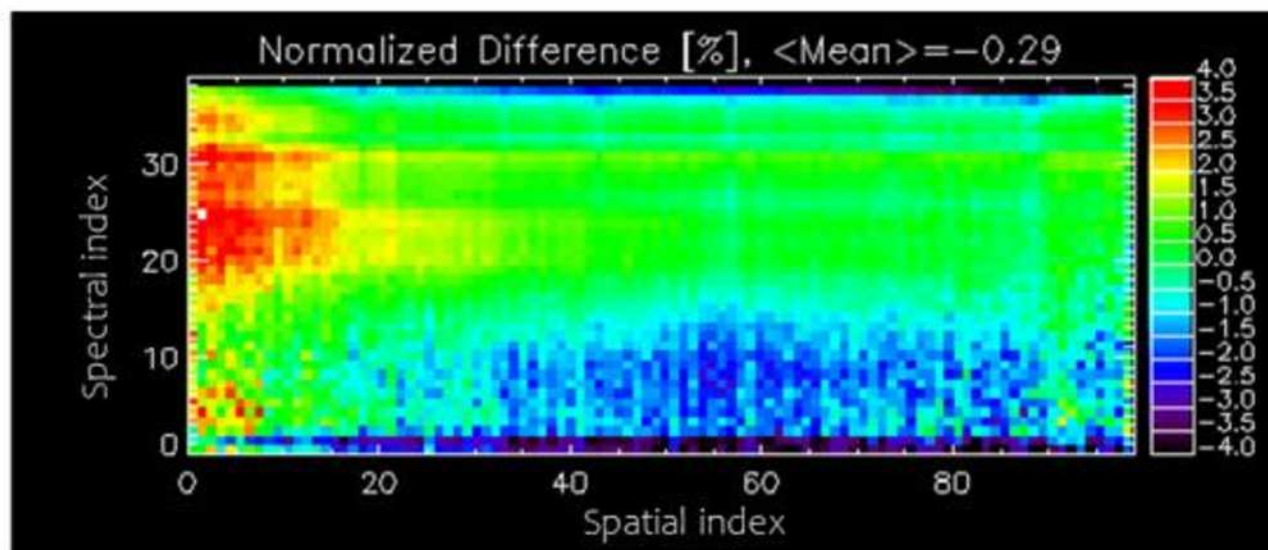


Figure 17: Difference of the differential images (BB7-BB3) shown in Figure 16 taken during on-ground calibration (2013) and in-flight during CO-14 (2025). The color code shows the percentage of difference.

3.3.2 MERTIS-TIR

The MERTIS radiometer (TIR) was operated during the reporting period in all routine COs, and its performance was verified. The science performance is assessed through the radiometric sensitivity of the infrared sensors. This is done using the in-flight calibration sequence, in which MERTIS measures the on-board calibration targets (BB7, BB3 and SPACE) at regular intervals of 20–180 seconds.

The radiometer's sensitivity is determined by calculating the difference between the measurement of the BB3 and SPACE measurement, thereby largely eliminating the instrument's variable intrinsic radiation. As these measurements were taken at various sensor head temperatures between 0°C and 12°C, and the sensitivity of the sensors exhibits an approximately linear temperature dependence, the results were all converted to sensitivity at 0°C (S_0) using the temperature coefficient ($-0.6\%/K$) of the thermopiles, whilst additionally assuming that any offset could be neglected due to the differential measurement method (2-parameter fit based solely on sensitivity at 0°C and the temperature coefficient). It had been known since commissioning that the TIR's thermopile sensors had lost sensitivity between laboratory calibration and commissioning (**Figure 6**), approximately 4% for channel A (8–14 μm) and 12–13% for channel B (7–40 μm). **Figure 18** clearly shows that the degradation of the sensors was stopped after launch (i.e. under vacuum conditions). The sensitivity values have remained constant since then; the small differences of $\pm 0.2\%$ between the CO are random and lie within the uncertainty of such a measurement.

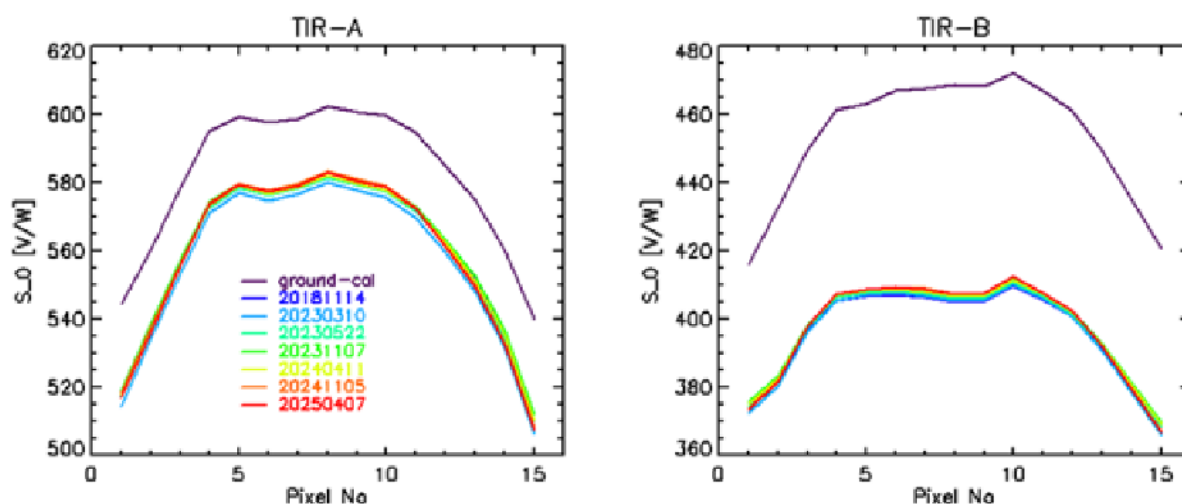
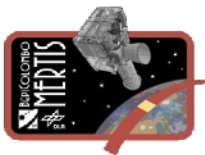
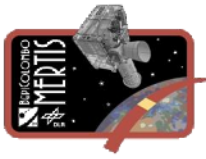


Figure 18: Sensitivity of the TIR radiometer detector channel A (left) and channel B (right) during various COs from 2023 to 2025. For comparison, the values measured immediately after launch in 2018 (NECP) and the on-ground calibration measurements are also plotted.

3.4 Sensors noise

One of the focuses of the cruise phase was to investigate the science performance of the instrument according to its thermal environment. The cruise phase reveal that the TIS spectrometer is particularly stable even during large thermal variations of the instrument's modules. In the opposite, the TIR channel is particularly sensitive to its thermal environment and in particular to the behavior of the sensor head heater (SHH). The science performance of TIR is evaluated through the characterization of the sensor noise. As already described in the section 2, showing the results of the NECP, TIR noise is determined from standard deviation of difference between BB3 and SPACE images and contains both electronics and thermal noise. **Table 7** shows the evolution of TIR noise through the cruise phase and the different tests performed.

Prior to the CO-10, COs and flybys used the SSH on with different temperature set-points ($T = 0^{\circ}\text{C}$, 10°C , 20°C or 30°C) and a proportional gain of 400. When the SSH temperature control was activated, a significant increase in noise levels was observed. The stabilization performance of the SSH was not satisfactory, as a flaw in the control algorithm resulted in an on/off-type regulation behavior rather than a stable closed-loop control. This led to pronounced thermal fluctuations that directly impacted the instrument noise. **Figure 19** illustrates the thermal oscillation of the instrument during CO-5 when the SHH was on at a set-point temperature of 10°C and gain of 400. Temperature oscillations of approximately 1 mK in the bolometer housing and the entrance optics plate (EOP) propagate through the instrument thermal sensitivity and result in an effective thermal noise level of approximately 33.43 mK in the TIR channels.



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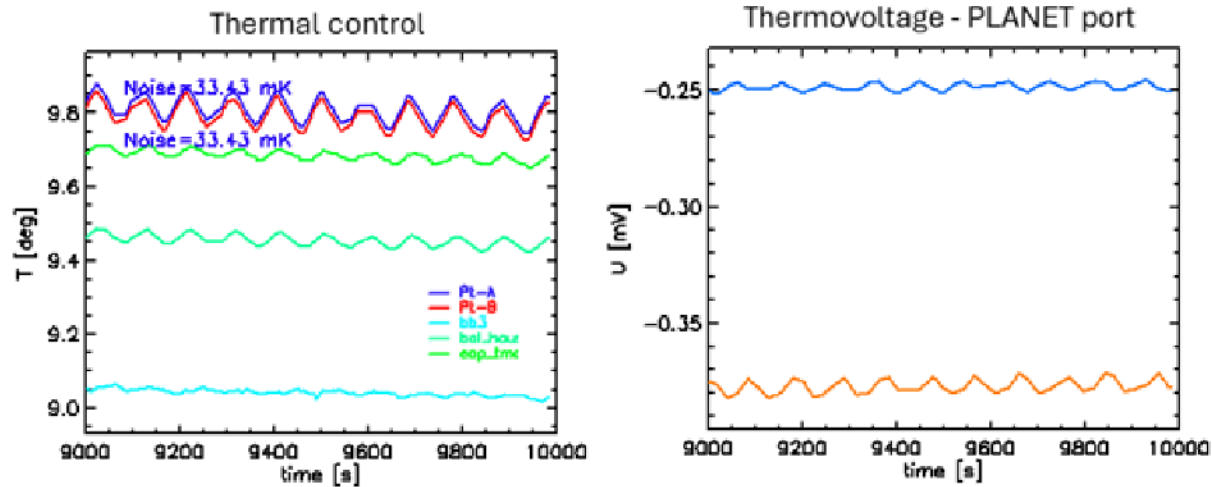
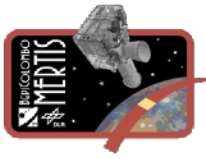


Figure 19: (left) Temperature of the BB3, bolometer housing, entrance optics and thermal noise of the TIR channels during the CO-5 (SHH T set point = 10°C, SHH gain=400). (right) Thermovoltage noise of the TIR channels (TIR-A in blue, TIR-B in red) during CO-5 from the planet port measurements.

Strong oscillations are observed in the thermopile signal when the SHH temperature control is activated. These oscillations are caused by periodic variations of the instrument and TIR detector temperature. Note that a thermopile measures, in principle, a temperature difference between the hot junction (being located under the radiation absorbing area of the pixel) and the reference junction (being located in a silicon frame acting as a heat sink). Thus, if the absorbed radiation is constant but the thermopiles temperature itself (more precisely, the temperature of the reference junction) oscillates, this is immediately seen as an oscillating signal voltage. **Figure 20** shows the resulting oscillations in the sensor noise of both TIR channels.

A portion of the SHH control-induced noise can be mitigated by a factor of 2–3 by subtracting the SPACE signal from the PLANET signal, which corresponds to the standard instrument offset correction applied during data processing. The effectiveness of this removal varies depending on the observation conditions. The example shown in **Figure 20** represents a case at the lower end of the residual noise levels observed. The resulting noise level remains approximately one order of magnitude higher than during on-ground calibration, NECP (SHH off) and in-flight COs with SHH off (**Table 7**). For reference, a noise level of 1 μ V corresponds to approximately 3.5 K in brightness temperature for an object temperature of 100 K. Therefore, during the entire cruise phase, even in the worst “SHH conditions”, TIR fully met the requirements (**Table 1**, <3K at 100K).

The issue was thought to be related to the fact that the radiator configuration was modified after the TAVC tests, while the control parameters of the temperature controller were not subsequently adapted to the new thermal conditions. As a consequence, the controller tuning is no longer optimal for the current system configuration. A re-evaluation of the SSH control algorithm was therefore planned and executed in COs 10 and 11.



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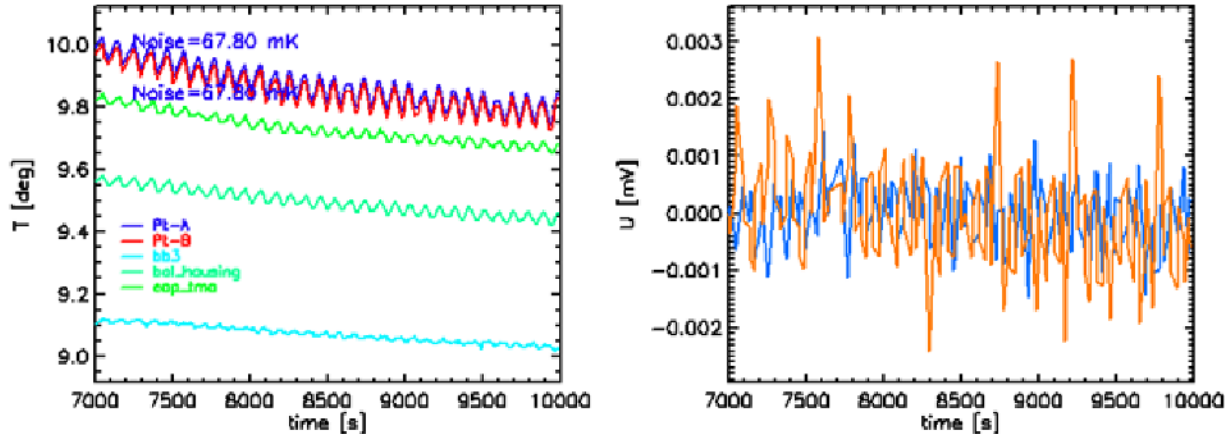


Figure 20: (left) Temperature of the BB3, bolometer housing, entrance optics and thermal noise of the TIR channels during the CO-5 (SHH T set point = 10°C , SHH gain=400). (right) BB3 - SPACE measurements standard deviation by the TIR radiometer (TIR-A in blue, TIR-B in red) during CO-5.

In CO-10, we switch on the SHH with a set-point at 10°C , resulting in a full power mode of the SSH, and then switched off to investigate the drift in temperature and analyse its effect. Further testing was done by controlling the proportional gain which controls the heater behavior when the SHH temperature derives from the set-point. During CO-11, several tests were performed with a proportional gain of 200 for the SHH. **Figure 21** shows the calculated sensor noise during CO-11 with a 200 proportional gain for the SHH. When the SHH is on during CO-11 with a gain of 200, temperature oscillations of approximately 10 mK are observed in the radiometer temperature, compared to more than 30 mK for a gain of 400 in CO-5. Although the resulting signal stability is slightly improved compared to the previous COs, where a higher control gain setting was used the residual disturbance remains substantial (**Table 7**). Therefore, updating the proportional gain settings of the SHH is only slightly improving the noise of the TIR channels due to the SHH on/off behavior. The observed still unsatisfactory TIR noise performance in CO-11 gave rise to an in-depth review of the SHH controller part of the flight software, where the not intended ON/OFF-like behavior of the controller under certain conditions was detected. This was one of the main reasons for S/W update #1.



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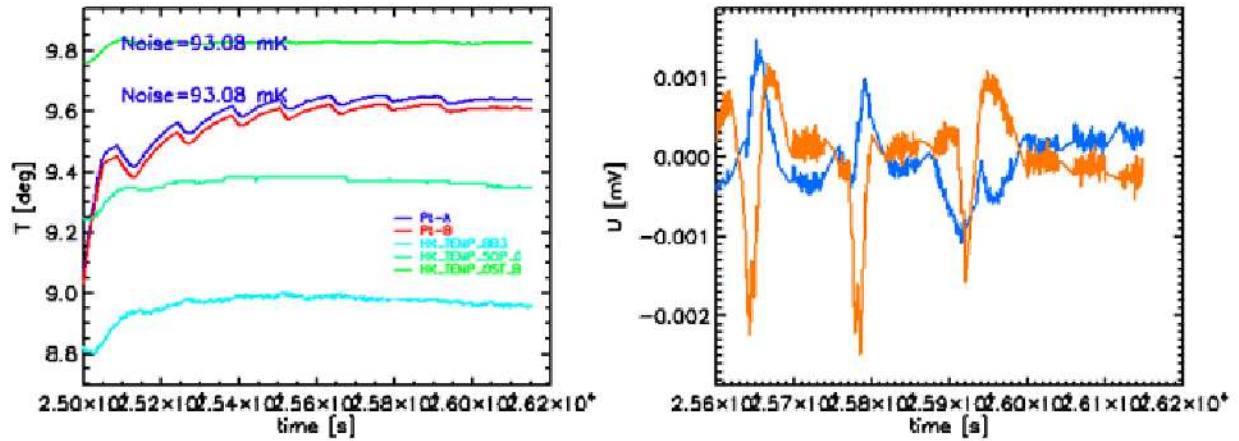


Figure 21: (left) Temperature of the BB3, bolometer housing, entrance optics and thermal noise of the TIR channels during the CO-11 (SHH T set point = 10°C, SHH gain=200). (right) BB3 - SPACE measurements standard deviation by the TIR radiometer (TIR-A in blue, TIR-B in red) during CO-5.

In depth analysis of the noise of the TIR channels has been performed with data taken with SHH off during CO-11, in order to separate the true effects of the TIR sensors and front-end electronics from the influence of control fluctuations. **Figure 22** shows the temperature of the instrument at the beginning of CO-11 observations, when the SHH was OFF, and the corresponding noise level for both TIR channels.

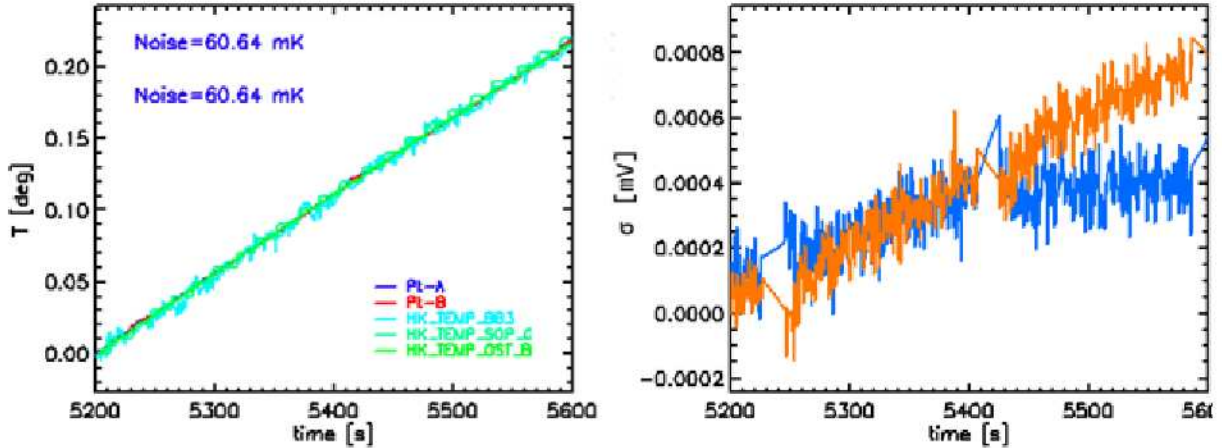


Figure 22: (left) Temperature control parameters of the instrument during the first minutes of the science observations of the CO-11, when the sensor heater was off. (right) Corresponding noise of TIR-A (blue) and TIR-B (red-orange).

The temperature of the instrument and the TIR sensors slightly increases with the observation time. This behavior is expected due to the front-end electronics of the instrument and is very low, around 0.20°C/1.5h. The standard deviation of both channels also increased with the time, in particular TIR-B which shows a similar linear trend. After corrected for the linear trend due to the electronics, the true noise of the detector including read-out electronics is compared with the NECP, in **Figure 23**. The residual small disturbances are due to the calibration cycles. The noise of both TIR channels is similar between NECP and CO-11 (SHH off), under 100 nV, showing that the science performance of TIR is stable



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after 6 years in space (**Table 7**). In addition, the noise is reduced by an order of magnitude compared to the previous COs when MERTIS operates with the SHH ON.

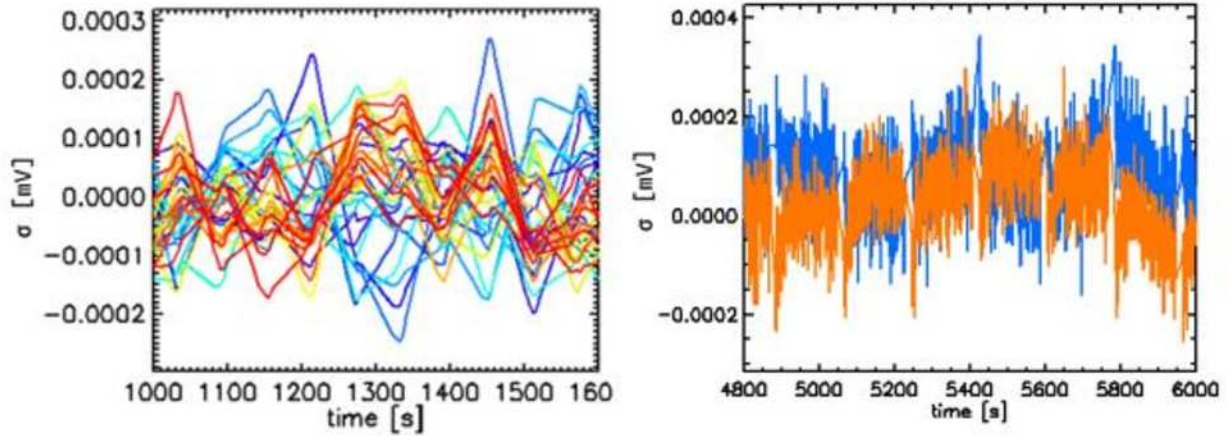


Figure 23: Noise (standard deviation of BB3-SPACE) of the TIR channels during NECP (left) and during CO-11 (right, TIR-A: blue, TIR-B: red).

To enable the possibility of performing measurements with the SHH activated during the in-orbit phase, if required, the onboard software was updated to correct the previously observed ON/OFF behavior of the SHH thermal controller (see Section 5.1 for details). This adjustment allows the instrument to operate with nominal science performance, including nominal noise levels of the TIR sensors.

The results of the verification tests performed during CO-14 after the implementation of the new software (SW-1) are shown in **Figure 24**. The heating phase toward the temperature setpoint demonstrates stable controller behavior, indicating that the selected gain parameters are appropriate. The instrument temperature increases from approximately 2 °C to the 10 °C setpoint within about 10 minutes. During this process, a small single overshoot is observed in the EOP control sensor, after which the temperature gradually approaches the setpoint from above.

Once the setpoint is reached, the temperature stabilization is maintained within a few millikelvin, confirming the effectiveness of the default temperature control parameters in achieving rapid and stable thermal regulation. Under these conditions, the TIR temperature noise is measured to be approximately 1–2 mK, with the TIR-B channel systematically showing slightly higher values. The temperature stability of the instrument remains very good, with fluctuations of approximately 4 mK for BB3 and less than 1 mK for the baseplate. The thermal oscillations due to the on/off behavior of the SHH are fully mitigated.



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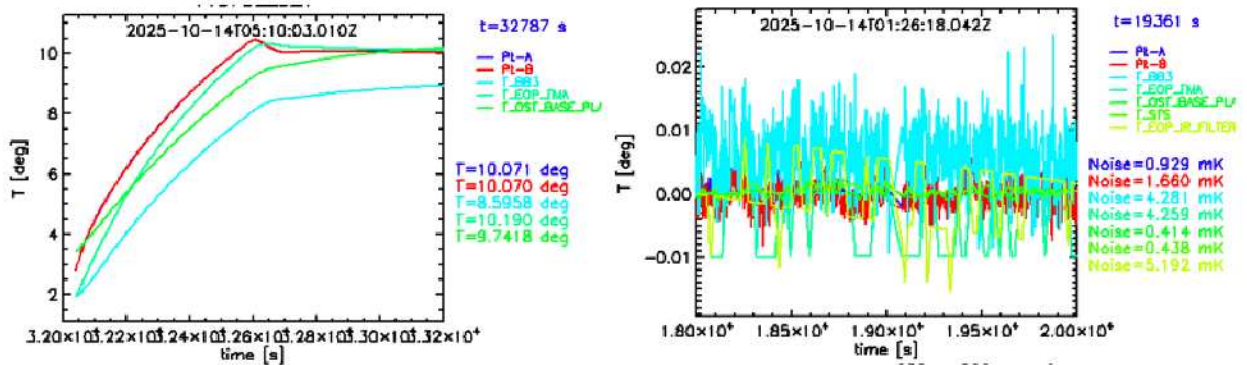


Figure 24: (left) Temperature control parameters of the instrument during the heating phase toward the temperature setpoint (10°C) and stabilization of the temperature after reaching it. (right) Linear trend removed same temperature control parameters as the left panel.

Figure 25 shows the noise of both TIR sensors after the temperature setpoint was reached and stabilized. TIR signal voltages become reasonably stable approximately 5 minutes after the temperature setpoint is reached, with the system approaching thermal equilibrium about 15 minutes after reaching the setpoint. Compared to the previous software version, the TIR noise level is improved by a factor of approximately 5–10 (see Table 7).

These results confirm that the corrected SHH control algorithm enables stable thermal regulation and supports nominal instrument science performance.

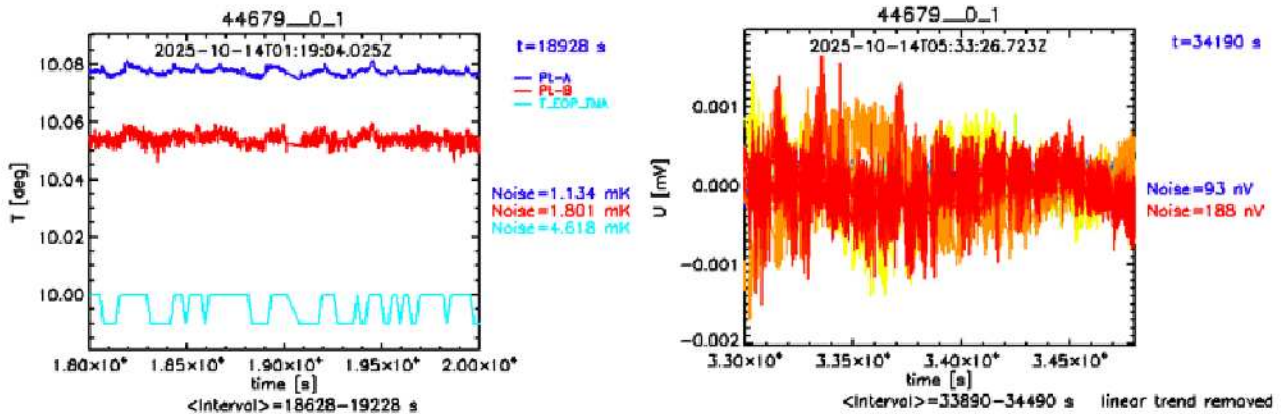
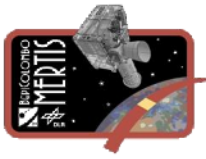


Figure 25: (left) Temperature control parameters of the instrument during the S/W test in CO-14, when the sensor heater was off. (right) Corresponding noise of TIR-A (blue) and TIR-B (red-orange).



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Table 7: Noise levels of TIR-A and TIR-B at several stages of the mission (i.e. on-ground calibration, NECP, COs) for different SHH configurations. For reference, a noise level of 1 μV corresponds to approximately 3.5 K in brightness temperature for an object temperature of 100 K.

Year	Event	SHH	TIR-A noise (nV)	TIR-B noise (nV)
2013	on-ground calibration	ON, gain=400, T setpoint=10°C	72	63
2018	NECP	OFF	66	66
2021	CO-5	ON, gain=400, T setpoint=10°C	530	922
2024	CO-11	ON, gain=200, T setpoint=10°C	428	621
2024	CO-11	OFF	82	83
2025	CO-14	ON, after S/W#1 update, T setpoint=10°C	93	188

3.5 Science modes, OBCP and reverse cycle

The mode transition duration and the reverse cycle mode was assessed during CO-11 by planning several sequences of science observations using several modes: Science High Resolution 3, Science Low resolution 3, Warmup, Warmup heated, TIR only, and Science Reverse cycle mode.

Figure 26 shows the position of the MPOI according to time during two reverse cycle testing in CO-11. The first 5 min were use to test the following stare times:

- BB7: 800 ms
- BB3: 16000 ms
- SPACE: 2400 ms

The following 5 min were use to test the following stare times:

- BB7: 2400 ms
- BB3: 16000 ms
- SPACE: 800 ms

The CO HK data show that the reverse cycle stare times implemented for the test performed well. An additional 2s is recorded for the BB3 and BB7 observations each time corresponding to the thermal stabilization needed for TIR before starting the acquisition of the target data. From an operational point of view, the reverse cycle performs well in-flight. However, from a science performance point of view, some thermal instabilities were reached during longer tests performed on-ground with the MERTIS FS (see section 4). The data obtained in-flight are not conclusive to confirm this behavior because the sequence planned was too short (2 times five minutes only).



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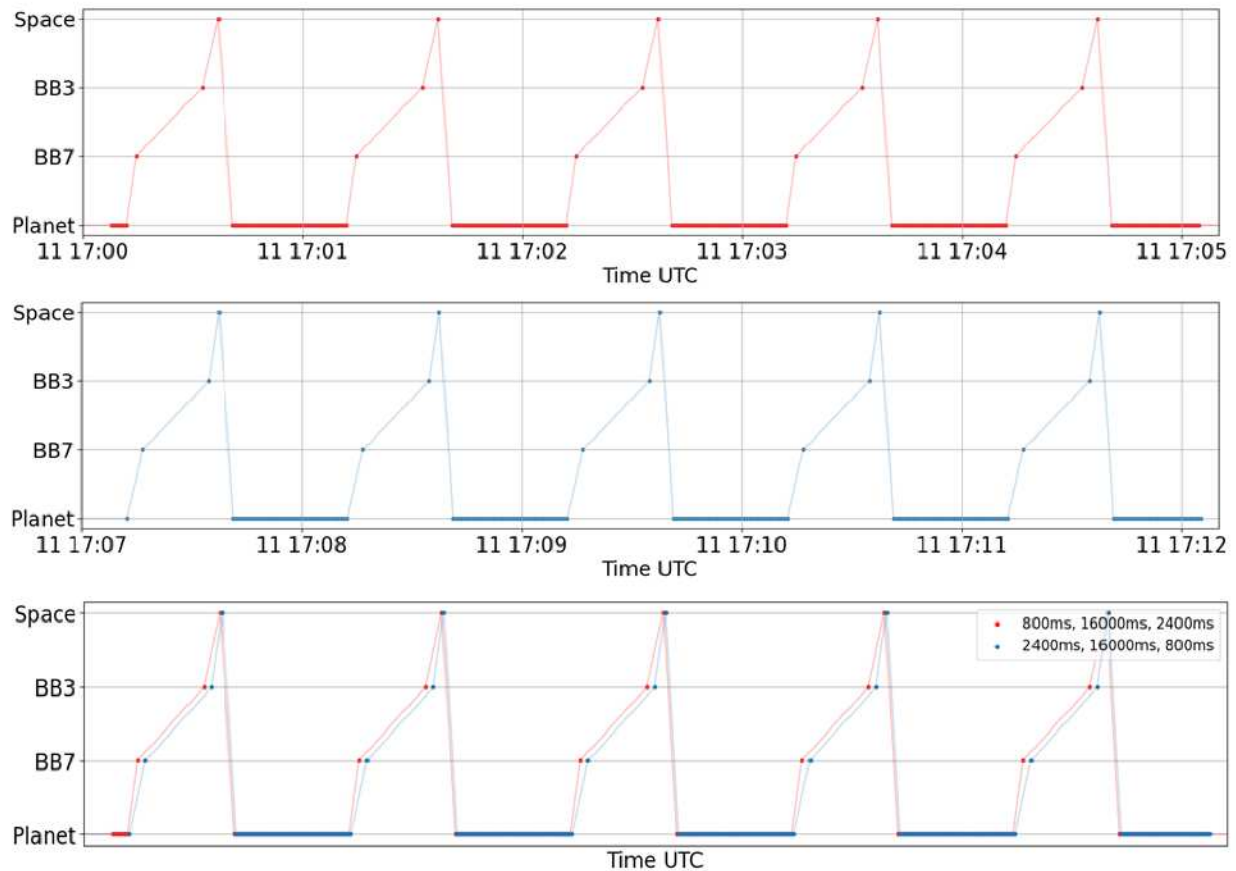


Figure 26: Two times 5 minutes of reverse cycle with different stare times on the BB7, BB3 SPACE targets compare to the nominal science cycle.

CO-11 allows us to confirm that the OBCP is performing well from an operational point of view, as well as all the MERTIS science modes. OBCP has also been use during the Mercury flyby #5 to perform the first ever Mercury's thermal infrared observations.

3.9. Anomaly reports

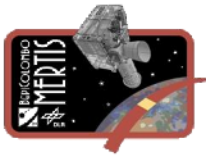
This section addresses three anomaly reports, all of which are already understood, resolved and closed:

1. Anomaly Report ID BC_SC_154, related to CO-4. This report has already been closed.

A huge number of TM(5,2) were generated, in particular the following two:

- MERT TM Warning (Bolometer -42220)
- MERT TM Warning (RAD is bus-42212)

These two events are related to full detector observations with 100ms TIS repetition rate. This repetition factor was too high and the warning refers to an occasional frame drop (missing observation). As results



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of this anomaly report, it was agreed to not to use this mode with TIS 100ms repetition rate, and a remark was added to MERTIS UM (MER-DLR-MA-001) issue 2.5. and hereafter with this information.

About future cases where this mode has been used and our approach, please see the software update #1 (see section 5.1).

2. Anomaly Report ID BC_SC_274, related to checkout #10. This had been already closed.

During MERTIS Cruise CO-10 only approximately 3 MB of data were generated when PI team was expecting 9,6 MB.

Our response to this report: MERTIS compression scheme is based on Rice coding of differential images. Because during the CO-10 the instrument was viewing a highly stable environment (deep space), the differences between consecutive frames were extremely small. This characteristic of small differences is why the compression algorithm performed with exceptional efficiency, with a compression factor of 3.4, resulting in the unexpectedly low 3 MB downlink volume. The compressed downlink volume expands upon decompression to a volume (11.212 MB) of TIS data only (plus small fractions from other components) that exceeds the 9.6 MB expected volume.

3. Anomaly Reports ID BC_SC_309 related to CO-14, and has already been closed.

During payload checkout #14, multiple issues were detected during MERTIS operations. Please note that this checkout was a very complex checkout with a new software performance test, routine operation procedure, rehearsal for the post MTM separation, testing the reverse cycle.

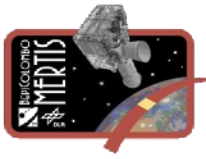
Detected unexpected OOLs:

- NMR00043 (icu proc duty cycle) with a value of 85.
- NMR00632 (diag step result) with a value of NOK.

NMR00043 (icu proc duty cycle) with a value of 85 - This OOL only occurs during diagnostic mode and it is due to the difference between the MERTIS and SC measurement intervals. The for MERTIS is the HK period. The 85% occurred during diagnosis mode. We have a lot of calculations to do during this mode.

It was agreed with OGS to agree to remove this OOL on their control system; this would not require anything on the spacecraft side. We agreed that since this monitoring was not reporting anything useful per se and was expected in the diagnostic mode then it was not needed. This means that we will still receive the parameter, it will just not raise any flags on OGS side even for high values.

NMR00632 (diag step result) with a value of NOK - The progress event reports the expected failed diagnostic for the SHH. This is related to the error 43829 (see below). The progress event TM_Event_Progress(DiagnoseStepFinished) (YMR42108) signals the end of each on-board diagnostic step and provides a summary result. Parameter HK_STAT_DIAG_STEP (NMR00631) contains the diagnostic step and parameter HK_STAT_DIAG_STEP_RESULT (NMR00632) pass (OK) or fail (NOK).



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Detected unexpected events:

- YMR42112 MERT TM Event Warning (Thermal st-42214)

This event happens when there is a significant temperature variation within the instrument. This time, this is due to the post MTM separation rehearsal, where we start science observation at a low temperature and we let the instrument to drift to higher temperature. The goal is to monitor the detector's behavior.

This event will be removed with the SW update #2, as agreed with OGS (see section 5.2).

YMR42121 MERT TM Event Error (SHH Diagnose-43829)

The OGS was informed in advance about this event. This is caused by a known issue with the sensor head heater occurring only during the diagnostic mode after the SW update #1.

Failed command:

- Command ZMR00014 (MERT TC Operation Parameter) in AMRF006A.

This command was rejected by the onboard software. This occurs when the operator plans a full detector observation with TIS repetition rate of 100ms. As known previously, this mode with this TIS rate causes problems, and we decided to add the rejection in the SW update #1 to avoid this issue.

- MERTIS off by OBCP error

This is related to KMR04021MROF. This takes longer than 1s that is stated in the state model.

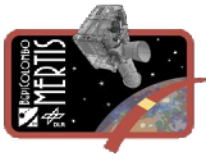
This procedure takes 110 sec and OGS agreed to update the state model to around it up to 2 min.

3.10 Conclusions

The series of instrument CO performed during the cruise phase has been very fruitful in consolidating the operational concept of MERTIS and further optimizing its science performance in preparation for in orbit observations around Mercury. Overall, the results confirm the excellent stability and robustness of the instrument.

The COs first allows to define the optimal duration for MERTIS to reach its thermal stability after switch-on: 3 hours. Therefore, MERTIS will be switch on and operate in warm-up mode for 3 hours before the start of in-orbit commissioning in March 2027.

A key outcome of the CO activities was the development and validation of an optimized procedure for in-cruise science observations through the space port developed for calibration reference measurements of deep-space. An initial method implemented during early COs relied on the instrument calibration mode. Evaluations during later COs demonstrated that this approach was not optimal. In



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particular, the calibration mode imposed limited flexibility on the repetition rates of the spectrometer and radiometer, and the resulting high acquisition cadence prevented TIR radiometer from observing the internal calibration targets long enough to reach stable radiometric conditions and perform a complete readout. An improved observation procedure, consisting of swapping space and planet port, was therefore implemented and successfully demonstrated during CO-9. This new configuration enables space port observations under fully optimized acquisition parameters and was used to acquire the first thermal infrared hyperspectral observations of Mercury with the instrument.

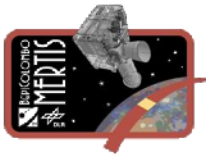
Another major achievement of the cruise phase was the in-flight recalibration of the detector bias voltage performed during CO-4 and CO-5. This activity restored the detector operating point to the nominal conditions established during laboratory calibration at TVAC-DLR. Subsequent COs clearly confirm the validity of the calculated voltage offset and demonstrate that the implemented VSKIM adjustment successfully optimizes the detector operating conditions in flight. The bias voltage correction was initially implemented through an operational patch applied during routine operations up to CO-13. Evaluation of the CO, confirms that the voltage correction applied was optimal and therefore can be integrated permanently to simplify future operations. During CO-14, the first onboard software update (SW#1) was successfully deployed, permanently integrating this correction into the instrument software and thereby simplifying in-orbit operations. During this update, an unintended modification of the onboard data compression configuration occurred, resulting in the corruption of approximately 0.001% of data packets. A subsequent software update (SW#2) is planned to fully resolve this issue and restore the nominal data handling configuration.

During CO-10 and CO-11, the science performance of MERTIS was investigated under varying thermal conditions. While the TIS spectrometer proved to be very stable, the TIR radiometer was found to be sensitive to the behavior of the SHH. When the SHH temperature control was activated with the initial settings, a flaw in the control algorithm produced an on/off-type regulation, causing thermal oscillations and significantly increased TIR sensor noise. Dedicated analyses during several COs allowed the origin of this behavior to be fully identified and characterized. Tests with the SHH switched off confirmed that the intrinsic detector noise remained stable and consistent with ground calibration over the years. The SHH control algorithm was therefore revised and implemented in the onboard software update SW#1. Verification during CO-14 demonstrated stable temperature control and nominal TIR sensor noise levels.

Throughout the cruise phase, all operational modes and onboard control procedures (OBCPs) of MERTIS were tested and validated.

Finally, the last CO was used to validate the operational strategy planned for the post-MTM separation phase of the mission. These tests allowed the operations team to refine the operational timeline, in order to better evaluate the thermal environment of the instrument on-board the spacecraft.

In summary, the cruise COs have confirmed the excellent health and performance stability of the MERTIS instrument. At the same time, they provided a unique opportunity to optimize observation strategies, onboard software, and calibration pipelines. These improvements place the instrument in a highly robust and well-characterized state, ensuring optimal readiness for the upcoming orbital science phase around Mercury.



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4. MERTIS Flight Spare laboratory test campaigns

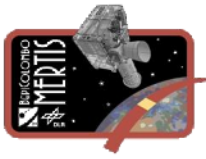
Various test campaigns have been organized by using the MERTIS FS in the laboratory at the Institute of Space Research of the DLR- Berlin. The goals are to better understand the in-flight instrument (FM) performance by running a similar commanding on the FS as in a check out; to run longer operations on FS which are not possible during CO, given the time constraints of a cruise operation. The next three sections describe the three topics tested in the laboratory and major findings.

4.1 Calibration period

The calibration period of MERTIS is defined as the period of time that the instrument needs in order to observe all four targets: Space, BB3, BB7, and Planet. Important to note that the time needed to acquire science data from the Planet are included in the calibration period. The targets BB3, BB7 and Space are known as calibration targets, and the data acquired from these three targets are used to calibrate the data acquired from the Planet, therefore the time needed to observe the calibration targets is also known as calibration cycle time by the science operation team. The time needed to collect data from the calibration targets is about 16 seconds. This time is controlled by the pointing unit and the onboard software, and had been defined in the process of on ground calibration of the instrument. Deviation from the defined view times of the calibration targets may compromise the validity of the instrument calibration.

The calibration period default value of the instrument has changed from 60 to 140 seconds in 2024 (see user manual MER-DLR-MA-001 issue 2.2 dated 2017 and MER-DLR-MA-001 issue 2.7 dated 2024) with the goal of facilitating the operation, improving the data quality and increasing the coverage. Extended calibration periods mitigate temporal and thermal perturbations in the data (see Figure 23). Viewing the internal calibration targets cold space and BB3 facilitates the removal of the varying instrument internal background radiation, a pre-requisite for a good calibration of any thermal infrared instrument, while on the other hand each calibration cycle introduces a slight thermal perturbation to the sensor head itself. Therefore, an optimal trade-off between calibration duration and science observation time is required. The decision was made to change the default value of the calibration period to 140 seconds (min 60 and max 500 sec) after various tests on the FS in a simulated Mercury environment (high vacuum and representative temperatures at TRP according to recent thermal predictions) in the laboratory showing the thermal stability of the instrument (both TIS and TIR channels) in a 140 seconds calibration period. The data analysis of these laboratory measurements is still ongoing and more tests are planned in near future. In addition, various calibration period durations have been tested on the FM and the cruise data during COs and MSB#5 shows reliable and stable science data from the FM with calibration period of 140 seconds. However, the final decision is pending and data from the instrument in thermal environment of Mercury is needed for a final determination of the optimal calibration period. This is one of the main goals of our commissioning plan: to test the 60 sec, 140 sec, and even longer periods of 280 sec and 420 sec.

The default calibration period value in the Instrument User Manual MER-DLR-MA-001 issue 2.7 dated 2024 is 120 sec, which is a mistake. This value will be updated to 140 second in the next issue, currently under preparation. The OBCP and most of the FOPs therefore have 120 seconds as default value, but for



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a few FOPs we have corrected this to 140 seconds. In any case, this parameter allows a range between 60 to 500 seconds, and therefore the operators can manually correct the value to 140 sec.

4.2 Gap Filling mode

The calibration cycle of MERTIS causes regular gaps in the planet coverage. In order to overcome this issue and to cover the gaps, the time for calibration and planet observation needs to be adjusted in a way that the instrument collects planet data when, in the previous orbit, the calibration gaps have occurred. This mode has various names, used by different teams at ESA and MERTIS. Since this is mainly required to fill the gaps, Direct Gap Filling is the term used during the Global Mapping, when some of the gaps are filled during the trailing orbit, and Gap Filling refers to filling the gaps in the second half of the nominal mission, when the remaining gaps will be filled. Other terms are: reverse cycle, inverted cycle, discarding mode. The inverted cycle also known as discarding mode uses the invert parameter in the mode we will use for the Direct Gap Filling. The necessary FOPs and procedures have already been prepared for this however the usage of this mode is dependent on the software update #2 (see section 5.2).

In the previously defined reverse cycle, the view time of BB3 had been increased with the goal of increasing the calibration cycle time from 16 seconds to e.g. 120 seconds in case of Direct Gap Filling. This would have then allowed to obtain 20 seconds of planet observation, including 4 seconds of margin. As explained in the section 5.1 changing the view time of calibration targets might compromise onground calibration, which is not optimal for the instrument. This was the motivation behind a TVAC laboratory test campaign at DLR, in July 2025.

The nominal science modes have been tested on the FS in the TVAC, in hot conditions for the TRP-1 (TRP-1 = 47.7, TRP-2=16.1). As shown in **Figure 27**, the hot spot is at the PSU at ~63°C which is within the limits for PSU operation (upper T limit at 70°C).



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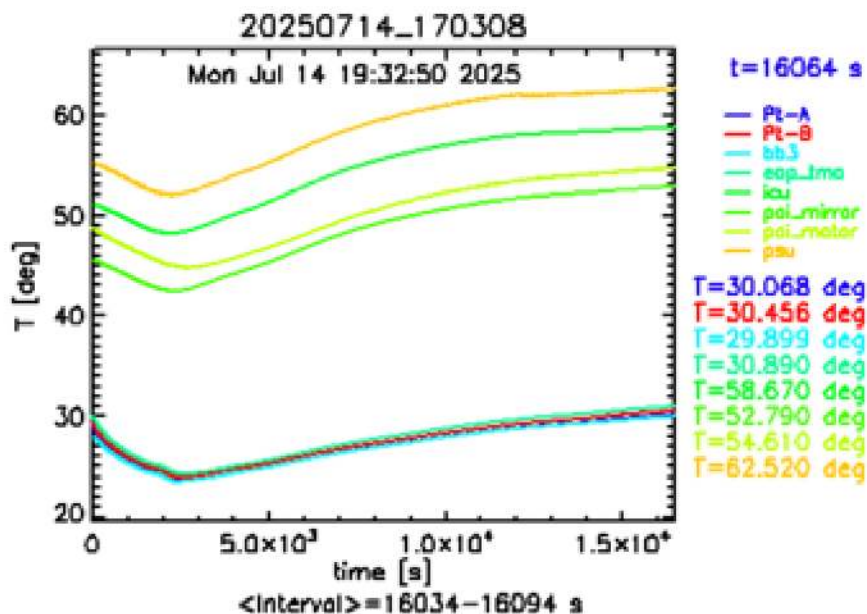


Figure 27: Instrument Thermal control parameters during MERTIS-FS in TVAC test 2025 - nominal mode for hot TRP conditions.

This test was repeated by using the reverse cycle scenario (**Figure 28**), which means changing the view time on the calibration targets in order to extend the calibration period, and to reduce the planet view time. The **Figure 28**-left panel shows the reverse cycle scenario for the calibration cycle of 60 seconds. We see that the hot spot now lies on the pointing unit motor (MPOI-motor). The hottest temperature here is 62°C which is above the qualified temperature of the MPOI motor (60°C). This is about 13°K warmer temperature for the POI-motor than in the nominal scenario. This temperature rise is caused by the additional holding current required to keep the MPOI in the BB3 position longer than what it is designed for. The right panel of **Figure 28** shows the reverse cycle scenario for the calibration cycle of 90 seconds. In this panel the temperature increase is shown as delta T. In this case the temperature increase is even higher than for the 60sec cal cycle scenario - to 20°K.

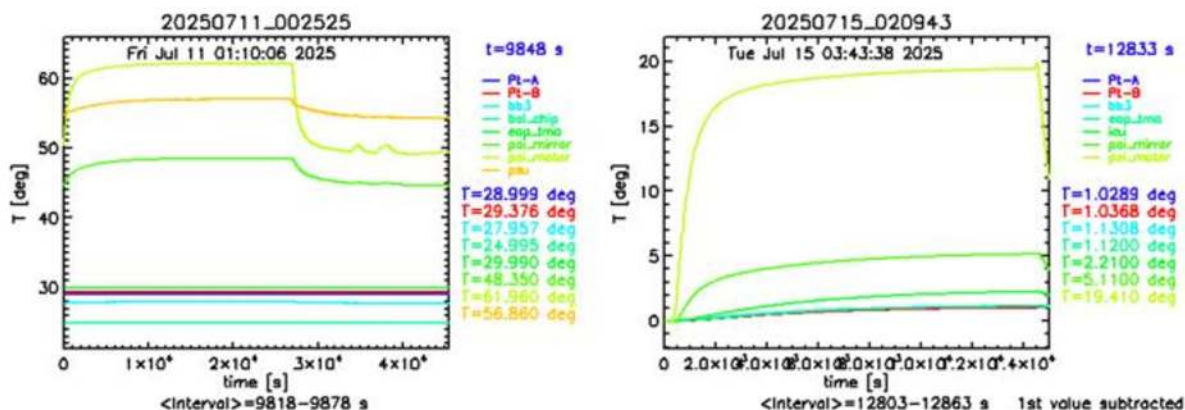


Figure 28: Instrument Thermal control parameters during MERTIS-FS in TVAC test 2025 - reverse cycle.



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The TVAC laboratory test campaign on the flight spare at DLR has shown that the reverse cycle by changing the view times on calibration targets is not compatible with the thermal qualification of MERTIS (**Figure 28**). We clearly see that out of limit temperatures are reached for TRP-1 temperature even ~5°K below the maximum temperature predicted by AIRBUS, therefore the reverse cycle does not work during operational sessions around Mercury.

This has led to exploring the MERTIS onboard software in more detail and to benefit from the invert parameter already defined in the software but so far not used in the interfaces. For more details about this, please see the section about SW update#2 (section 6.2).

4.3 Thermal predictions at Mercury

The data collected during the cruise, together with the model predictions from AIRBUS/TAS/ESA, have led to the assumption that the MLI is deteriorating (**Table 8**). For MERTIS, this means an expected rise in temperature at the TRP-1 to a maximum of 50.6°C at around MTA=0° for the worst-case scenario. During ground testing the integrated MERTIS instrument was qualified for flight operation at maximum temperatures of 45°C at TRP-1 and 20°C at TRP-2 (tested with temperatures of 50°C/25°C at TRP's during TVAC Qualification Test). Although the temperature data acquire during the FM tests and the individual design limits of critical components indicate that an increase of TRP-1 temperature to max. 50°C would be acceptable (which is further supported by tests conducted with the FS in TVAC 2025, see **Figure 29** showing the measurement campaign below), the MERTIS team has decided to keep the upper temperature limit of the instrument for TRP-1 at 45°C. This means that the MERTIS instrument may be shut down or might go to safe mode around MTA=0° (with a range less than +/- 30° MTA) at perihelion as per the predictions. We evaluate this as acceptably low impact to the MERTIS science objectives. It means science data loss during the survey mapping phase, but no impact on the global mapping. However, if during the nominal mission (during commissioning or after) we realize that the general thermal environment will be hotter than the current predictions, and that our science objectives are being impacted, then we will re-evaluate the risk imposed by the thermal conditions and their impact on the MERTIS science requirements, and possibly request an increase of the upper TRP-1 temperature limit to 50°C.

Table 8: AIRBUS prediction table for MERTIS - predicted temperature, including uncertainty.

		Maximum predicted temperature T _{p,max} in °C over 24h																			
Node	Label	BCORB001	BCORB001	BCORB002	BCORB003	BCORB003	BCORB004	BCORB005	BCORB005	BCORB007	BCORB008	BCORB009	BCORB010	BCORB011	BCORB012	BCORB013	BCORB014	BCORB015	BCORB015	BCORB215	
		MTA000	MTA000	MTA000	MTA000	MTA000	MTA030	MTA030	MTA030	MTA030	MTA045	MTA060	MTA075	MTA090	MTA090	MTA105	MTA135	MTA150	MTA180	MTA180	
		A	Full	B	C	C	A	Full	A	Full	Full	Full	Full	Full	Full	Full	Full	Full	Full	Full	
63010	MERT Housing, TRP1	38.7	50.6	43.2	40.1	41.3	38.3	44.8	36.8	40.2	41.7	41.2	26.4	15.1	14.2	24.5	38.3	33.6	30.5	31.4	
63080	MERT HP Clamp, TRP2	5.3	15.1	11.0	5.3	5.3	5.2	5.9	5.2	5.9	5.9	5.8	5.6	5.5	5.5	5.6	5.9	5.8	5.9	6.8	
03011	MLI11 Out Slugs Plate	23.3	41.1	35.5	24.0	24.4	22.5	33.1	22.5	30.0	31.7	31.0	24.5	19.5	19.0	23.0	30.2	27.0	20.2	27.4	



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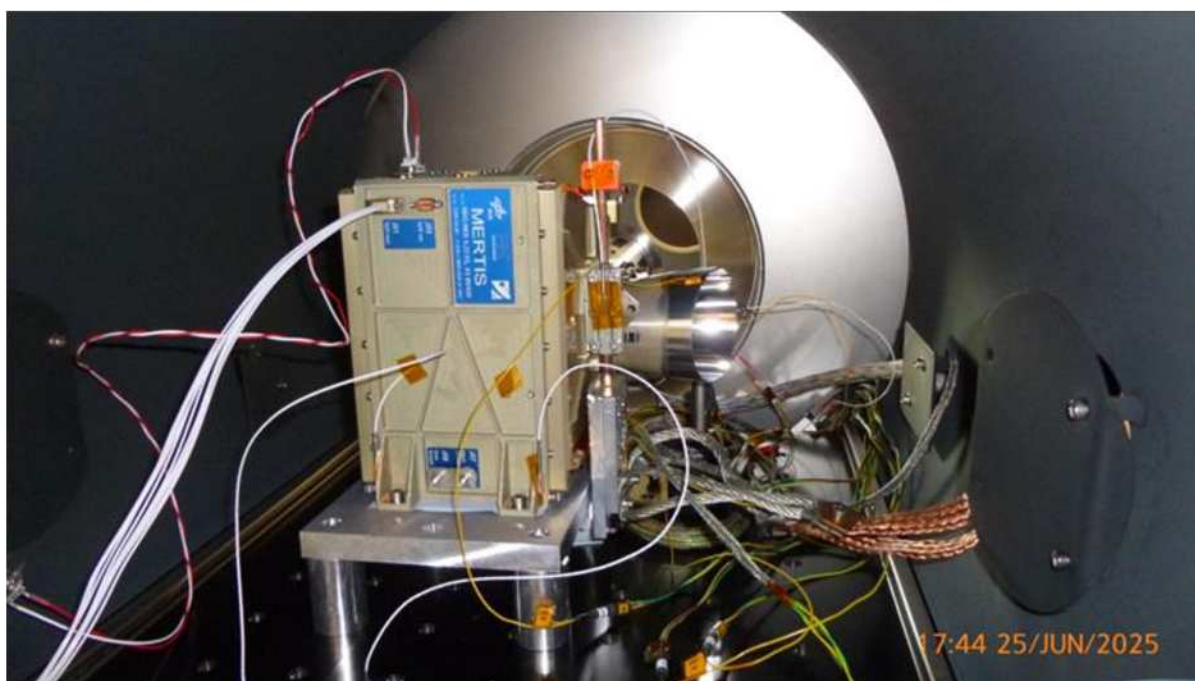
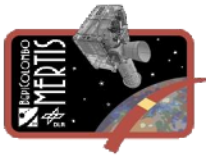


Figure 29: Laboratory measurement campaign at DLR in 2025. (top) DLR TVAC. MERTIS FS looks through an infrared transparent window on a high temperature blackbody. (bottom) MERTIS FS inside the TVAC-DLR. A support plate and thermal straps have been added to simulate the expected TRP-1/2 temperatures.



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4.4 Conclusion

Dedicated laboratory test campaigns performed with the MERTIS FS at the DLR-TVAC provided important insights into the in-flight behavior of the instrument and supported the preparation of operational strategies for the Mercury phase. These tests allowed longer and more flexible investigations than possible during COs and helped to reproduce representative commanding and thermal conditions.

The experiments confirmed that extending the calibration period to about 140 s provides a good compromise between calibration stability and science observation time, although the final optimization will be performed during commissioning at Mercury. The laboratory campaign also demonstrated that the previously proposed reverse cycle approach, based on extending the view time of calibration targets, would lead to temperatures exceeding the qualification limits of the MPOI unit and is therefore not compatible with safe instrument operations. As a result, alternative gap-filling strategies based on the onboard software invert cycle are being implemented through S/W update #2.

Finally, thermal tests helped to assess the potential impact of a warmer-than-expected thermal environment at Mercury. While current predictions suggest occasional operational constraints near perihelion for MERTIS, the expected impact on the overall science return remains limited. Overall, the laboratory investigations performed during the cruise phase significantly improved the understanding of MERTIS operational limits and contributed to the definition of safe and efficient observing strategies for the Mercury orbital phase.

5. SW Updates

5.1 SW Update #1 (V3.5.2506)

Modifications required to correct the VSKIM and the SHH non optimal functionality detected during cruise in various CO as discussed in section 3, led the team to update the S/W. The OnBoard S/W was modified and tested during the reporting period. This was the first time since the completion of the FM that an update was required, from version "REL_16/FM - APS V3.5.2394, 02/2016" to the new version "REL_17/FM - APS V3.5.2506, 07/2025". An update to this new S/W version on the FM in orbit has been executed during CO-14 in June 2025. Changes to the on-board software are documented in "MER-DLR-LI-019 APS Historical Records".

During observations, swing by tests and CO tests, various inconsistencies in MERTIS data performance were identified, which will be corrected with the aforementioned S/W update #1. This concerned the following points:

VSKIM BIAS correction

The MERTIS instrument uses different BIAS voltages settings for different temperature ranges. Following evaluation of the data, it was determined that there are acquisitions where the sensor signal was too low (see section 3.2 for detailed information). This always occurred at the transitions between



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temperature ranges. This can be compensated by a “re-calibration” of the BIAS VSKIM as described in section 3.2.2. During CO-4 and -5, data was recorded and analyzed, and the offset of the VSKIM BIAS voltage was determined to be 16 mV. This offset was implemented in an update to the software configuration and tested in the subsequent COs.

The initial assumption that the detector or the electronics were degraded was not confirmed. The test data from the spacecraft TVAC test in November 2014 at ESTEC also includes a few recordings with low detector signal. This means the detector is not degraded. The calibration setup in the DLR lab for calibrating the instrument was not perfectly representing flight conditions. The different thermal environment then lead to a low detector signal in flight at the transitions between two temperature ranges.

Sensor head temperature controller

Data recorded by the highly sensitive radiometer during the cruise revealed that the sensor head temperature controller on the FM is not optimally tuned whilst in orbit (see section 3.4); this only became apparent under very stable environmental and observational conditions.

A S/W patch for the modification was created and tested, and the control parameters P and I were redefined (see UM). Furthermore, radiometer data was recorded to better understand the thermal behavior and to compare it with previous CO data. The behavior before and after modification was replicated and tested in various measurement campaigns using the ground reference model (flight spare model) in vacuum. As a result, the modifications to the control function and the control parameters were confirmed. A change to the control parameters and the control function was implemented in the on-board software and subsequently tested in the CO-14 (**Figure 30** and **Figure 25**). This modification has successfully resulted to

- stable temperature to better than 10 mK, low noise < 2 mK,
- Resulting low noise on thermopile channels ~ 90-130 nV (~0.3 K@100 K target temperature),
- Improvement compared to previous S/W version by an order of magnitude.

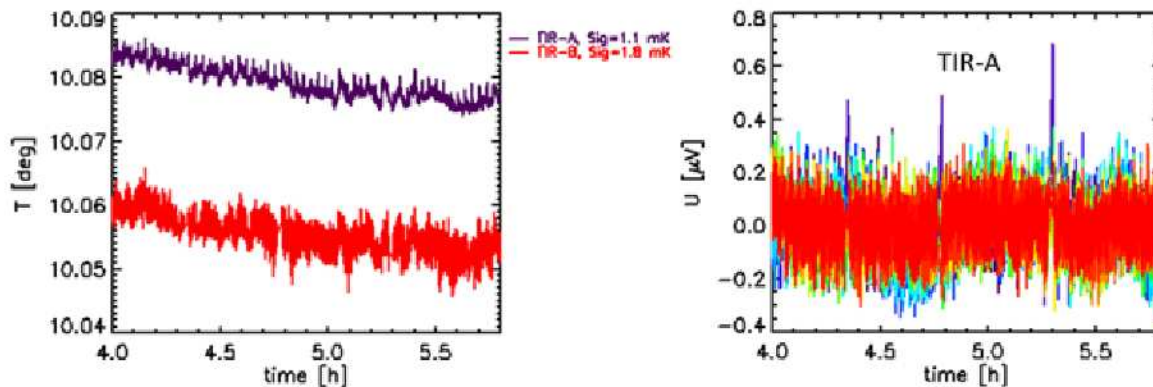
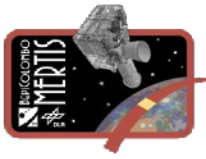


Figure 30: Thermal variations of the TIR channels (left) and the resulting TIR-A noise after the S/W update #1.



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On-board data processing modified

During measurements of various flybys and tests, it was found that improving the signal-to-noise ratio of the on-board calibration target data benefits the performance of the scientific data. Consequently, the oversampling of image data in the on-board data processing was increased, which required a S/W update.

Additional data compression mode implemented

During previous mission phases, work was carried out to optimize the on-board data compression, enabling slightly higher compression rates. This was implemented and tested as an additional compression mode in the on-board S/W.

Rejection of commanding TIS full frames with a repetition time of 100ms

If a full frame observation with TIS repetition rate of 100ms is planned by mistake in future (see section 3.9 for detailed information), this TC will be rejected by the onboard S/W. This mode with this TIS rate has been operated twice in CO-4 and CO-13.

TIR repetition rate

The repetition time of the TIR radiometer was updated in the software V3.5.2506 by defining a minimum default value of 800 ms (see Section 3.1). Following this update, repetition times below 800 ms are no longer permitted. If a lower value is specified in the operational parameter, the software automatically enforces a repetition period between 800 ms and 1000 ms for the TIR acquisition, depending on TIS repetitions rate. The TIR repetition factor will be as listed in **Table 6**, depending on which TIS repetition rate has been defined. The MERTIS user manual is currently being updated with this information.

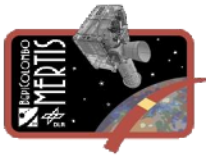
Issue with the APS v3.5.2506

The S/W APS V3.5.2506 has been tested during the CO-14 (see section 3.8). Analysing the CO-14 data which meant as a performance test to the newly updated S/W V3.5.2506, showed that 86 of the 82650 frames cannot be decompressed. The error occurs randomly, but the defective packets are always larger. They contain data from a previous, longer packet. The length information is randomly incorrect. This value comes from the compression hardware. Such sporadic error behavior is known from other projects and the root cause was always compiler errors. If the version v3.5.2506 is compiled with the recommended compiler flag “-fno-schedule-insns2”, everything works as expected and all frames are correct and can be decompressed.

5.2 SW Update #2 (V3.5.2512)

This SW update has already been successfully tested on the ETB by OGS and the S/W update on the FM is currently pending a final date. The update will address the following topics:

Gap Filling mode



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The laboratory test campaign on the flight spare at DLR (section 4.2) has shown that the reverse cycle by changing the view times on calibration targets will not allow an optimal data acquisition and may lead to a violation of the upper limit temperature of the MPOI unit. The thermal stability of the instrument would be seriously challenged, in addition, frequently turning the TIS channel ON and OFF will have a major impact on the quality of the science data and therefore on the spatial coverage and science objectives. However, the MERTIS on-board S/W has a parameter which allows inverting the cycle, without turning TIS ON and OFF, and without changing the view times on the calibration targets. This parameter, however, had remained unexplored before.

As initially planned, the TIS channel had to be regularly turned OFF and ON again which changing mode, specially from nominal science observation to TIR-only observation. This is non-optimal for the instrument, as the power consumption variation adds noise to the TIS and TIR channels. In addition, TIS channel would need some time for initiation and stabilization every time after switching ON again. This would have as well, meant compromising the science data quality and subsequently the global mapping data quality, which is one of the main science objectives of the MERTIS instrument.

The inverted cycle can be enabled using the parameter PMR00277 of the TC ZMR00014 MERT TC Operation Parameter. The data is read internally from the detector, but is not sent as a TM for the programmed time after the calibration cycle. This allows the instrument operator to perform gap filling, and the TIS and TIR channel to be always on, and therefore to increase the data quality for both channels. For science gap filling an inverted cycle shall be commanded. **Figure 31** shows the execution of a nominal science cycle of 140s. In comparison, **Figure 32** shows the execution of the inverted cycle.

Normal Cycle (e.g. calibration cycle $t_{cal} = 140s$)

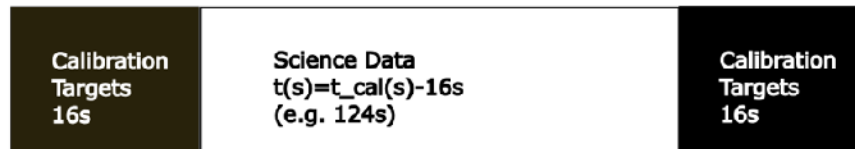


Figure 31: Execution of a nominal science cycle of 140s and the next calibration gap.

Inverted Cycle (e.g. calibration cycle $t_{cal} = 140s$ and $t_{inv} = 104s$)

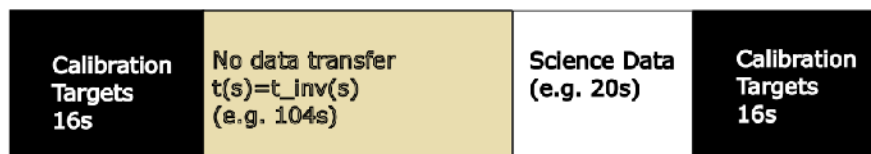
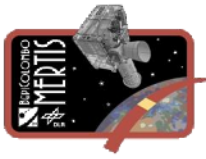


Figure 32: Execution of the inverted cycle use to fill the gaps during the direct gap filling phases and an additional calibration cycle.

For processing, we again need two calibration sets. Part of the data is only read from the detector, but not processed or transmitted. The start of the inverted cycle must be adjusted accordingly so that the data is recorded where the calibration gap was previously located. To adjust the time during which no



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data should be transmitted, parameter PAR_CALIBRATION_CYCLE_INVERT (PMR00277) can be used. This parameter already exists in the current MiB. The MiB calibration must be adjusted:

- 0 = no data transmitted (this is to match the engineering values),
- 1...254 = data is discarded onboard for 2 seconds ... 508 seconds,
- 255 = no data transmitted.

The interval between two calibration cycles can be adjusted using parameter PAR_CALIBRATION_PERIOD (PMR00130). This allows the inverted cycle to be configured within certain limits. The data at the beginning of each calibration cycle are discarded by the MERTIS APS. The timings are calculated in the software as follows:

$$\text{data_discard_time (s)} = \text{t_calibration_cycle_inverted (s)}$$

$$\text{data_keep_time (s)} = \text{calibration_period (s)} - 16\text{s} - \text{t_calibration_cycle_inverted (s)}$$

The data are discarded and transferred as shown in **Figure 33**.

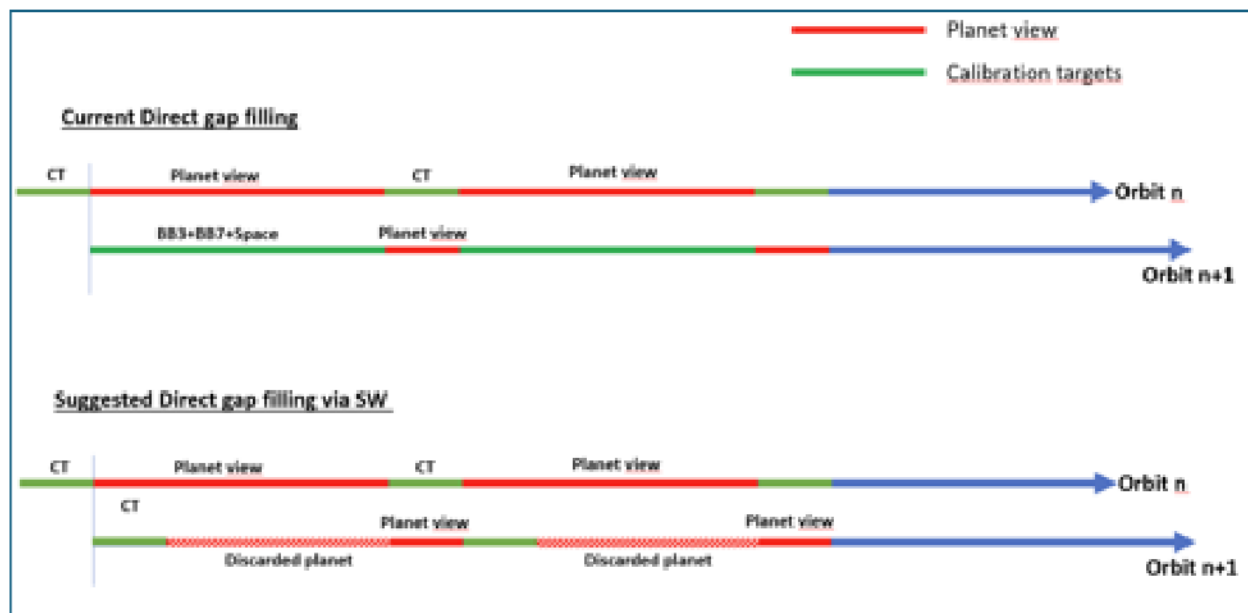
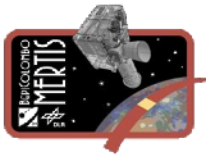


Figure 33: Description of the direct gap filling using the reserve cycle previously implemented (top) and the inverted cycle to be implemented in the S/W update #2 (bottom).

Adding the compiler flag

Update the make file and build the application software with the compiler flag “-fno-schedule-insns2” to solve the issue raised in the SW v3.5.2506.

Event 42214



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This event is issued frequently by the instrument when there are temperature variations. But there is no reaction needed from the ground segment. This event is meant as information only, therefore we decided to remove it. The event is still recorded in the extended HK and this information will be available in the downlinked data.

Quicklook

Quicklook data generation has been adopted to work with nominal and inverted cycle.

All changes to the on-board S/W are documented in “MER-DLR-LI-019 APS Historical Records”.

5.3 Conclusion

Two onboard S/W updates were developed during the cruise phase to correct performance limitations identified during in-flight operations and to improve the robustness of MERTIS science operations. SW update #1 (APS V3.5.2506) addressed several issues observed during cruise COs, including the correction of the VSKIM bias offset, the retuning of the SHH temperature controller, improvements to on-board data processing, and the implementation of an additional compression mode. These modifications significantly improved the radiometer performance, reducing thermopile noise and achieving temperature stability, representing roughly an order-of-magnitude improvement compared to the previous S/W version. Operational safeguards were also introduced, including restrictions on unsupported acquisition configurations and a minimum repetition period for the TIR radiometer.

During testing of SW update #1 in CO-14, a sporadic data decompression issue was identified and traced to a compiler optimization problem. This issue was resolved by rebuilding the software with the optimal compiler flag.

SW update #2 (APS V3.5.2512) further improves operational capabilities, most notably by enabling the gap-filling strategy through the inverted calibration cycle, which allows filling calibration gaps without modifying calibration target view times or switching the TIS channel ON and OFF. This solution preserves thermal stability and science data quality while avoiding the thermal risks identified during laboratory tests. Additional improvements include removal of non-essential instrument events, and adaptation of the quicklook for both nominal science mode and inverted cycles. Together, these updates ensure stable instrument operation and optimized science data acquisition for the Mercury orbital phase.

6. Post MTM separation

The MERTIS team has requested to collect science data during the thermal test planned for post MTM separation operation. This will be the first time that the PLANET view is uncovered, in addition the distance from the planet, offers a unique opportunity for both ports, PLANET and SPACE to be exposed to the same target, namely deep-space. Science data collected simultaneously by both ports from deep-space, allow improvement of our understanding of differences between PLANET and SPACE port for both TIS and TIR channels. Those differences can then be evaluated and quantify to drive a quantitative model for optimization of the calibration. The SPACE port observations are required for correction of



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instrument self-emission, therefore a better correction of the SPACE view port leads to a better estimation especially of the expected low nightside temperatures.

Additional objectives for this operations is to investigate and characterize the effects of vignetting by the SPACE port window; and to determine influence of MERTIS thermal state on PLANET/SPACE port observations.

In order to best prepare for this essential test, we benefited from the opportunity of the CO-14 to rehearse our operation plan. This rehearsal resulted in a better understanding of the instrument's thermal behavior and the detector's change of set points. **Figure 34** illustrate a shortened version of the planned operations post MTM separation, during CO-14, where the red frame shows the data from the rehearsal.

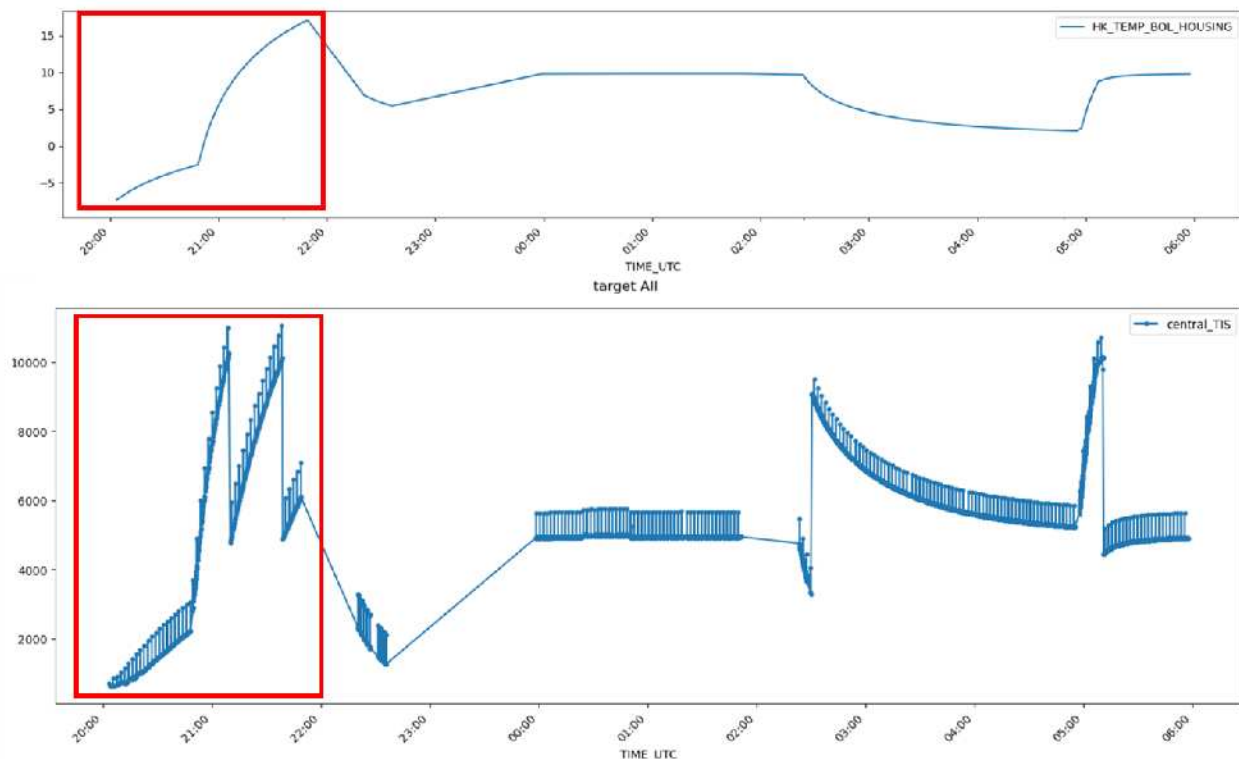
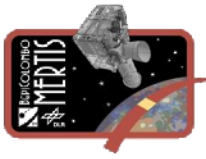


Figure 34: Rehearsal of the post-MTM separation during CO-14: nominal science mode 45 min with SHH OFF and nominal science mode 60 min with SHH ON, T set point = 35°C.

The approach is divided in two operational phases:

- Phase 1: use the full TIS resolution and operate over extended time period, starting under unstable thermal conditions. This is the first 45min operation in the rehearsal plot above. For the post-MTM operation, this phase's duration will be 20 hours. In order to keep the data volume within limits, we increase the TIS repetition period to 10 sec and TIR factor at 1.
- Phase 2: use the sensor head heater (SHH) with a higher setpoint of 35°C to heat up MERTIS for a limited duration of 60 min during the rehearsal. This part of the test is intended to provide us calibration data at different TIS operational setpoints, and further provides data to quantify the



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impact of varying thermal inhomogeneities inside the sensor head on the calibration. After analysing the rehearsal data, we noticed that 60 minutes was too short and that the sensor head has not yet reached a sufficiently stable thermal state. This led us to change the duration for the post-MTM operation to 90 minutes. The housekeeping data for phase 2 will be increased to 2 seconds to have a close monitoring of the changes of the temperature of the instrument. Besides providing unique calibration data for both MERTIS sensors this part of the test will additionally allow us to determine the thermal time constant of the sensor head under real conditions in the spacecraft which is important to optimize (if needed) the thermal control parameters of the MERTIS proportional-integral controller.

7. Flybys

TBD

8. Conclusion (TBD)

Table 9: MERTIS Science requirements. N/A for science requirements not addressed in this document. *3, 4, 5, and 9 will be addressed with the flybys.

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

References

TBD