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The mercury radiometer and thermal infrared imaging spectrometer (MERTIS) onboard Bepi Colombo: first inflight calibration results

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ABSTRACT

The MErcury Radiometer and Thermal Infrared Spectrometer (MERTIS) is an instrument to study the mineralogy and temperature distribution of Mercury's surface in unprecedented detail. MERTIS was proposed in 2003 as payload of the Mercury Planetary Orbiter spacecraft of ESA-JAXA BepiColombo mission and will reach Mercury in 2025. MERTIS will map the whole surface at 500 m scale, combining a push-broom IR grating spectrometer (TIS) with a radiometer (TIR) sharing the same optics, instrument electronics and in-flight calibration components for the whole wavelength range of 7-14µm (TIS) and 7-40µm (TIR). MERTIS successfully completed its planned tests of the Near-Earth Commissioning Phase (NECP) between 13 and 14 November, collecting thousands of measurements of its internal calibration bodies and deep space. The data collected during NECP, are being used to verify the operational performances of onboard sub-modules, in particular the spectrometer and radiometer sensor sensitivity. A preliminary look at calibrated data shows a performance comparable with ground-based measurements and no appreciable performance loss or misalignment. The next important dates for MERTIS are the Earth/Moon flyby on 6 April 2020 and the first Venus flyby on 12 October 2020. Both those encounters will be important both for further instrument calibration refinement and for possible unprecedented measurement in the thermal infrared of the Moon and Venus.

Keywords: Mercury, spectroscopy, spectrometer, bolometer, mineralogy, surface.

1. INTRODUCTION

1.1 BepiColombo Mission

BepiColombo is a dual spacecraft mission to Mercury to be launched in October 2018 and carried out jointly between the European Space Agency (ESA) and the Japanese Aerospace Exploration Agency (JAXA). The spacecraft comprises two separate orbiters: the Mercury Planetary Orbiter (MPO), which have a suite of instruments dedicated to complement the NASA/MESSENGER observations of the surface and internal composition, the Mercury Magnetospheric Orbiter (MMO) which will study the particle science in the extreme thermal environment. The ESA is responsible for the development of the MPO and the Institute of Space and Astronautical Science (ISAS) of the JAXA is the developer of the MMO. These instruments onboard the MPO include a laser altimeter (BELA), an accelerometer (ISA), a magnetometer (MERMAG), a gamma-ray and neutron spectrometer (MGNS), an imaging X-ray spectrometer (MIXS), a radio science experiment (MORE), an ultraviolet spectrometer to probe the Mercurian exosphere (PHEBUS), a neutral and ionized particle analyzer (SERENA), high-resolution stereo cameras and visual and NIR spectrometers (SIMBIO-SYS), a solar intensity X-ray spectrometer (SIXS), and the Mercury Radiometer and Thermal Infrared Spectrometer (MERTIS). In addition to a complementary suite of instruments, BepiColombo will be able to observe both the northern and southern hemispheres at high resolution. The orbiters will be contained in Mercury Composite Spacecraft (MCS). The MCS will also house the Mercury Transfer Module (MTM). MTM is present mainly to provide propulsion for orbital transfers, braking during final arrival at Mercury and will be separated from the other spacecraft before orbit injection at Mercury. Along with these, there is a sunshield component called the Magnetospheric Orbiter Sunshield and Interface Structure (MOSIF). Both MTM and MOSIF are built by ESA. Both of the orbiters host multiple instruments to achieve the scientific objectives of the mission. MERTIS is one of the instruments in MPO's suite of instruments. BepiColombo uses a solar electric propulsion system and its trajectory towards Mercury is a combination of low-thrust arcs and flybys at Earth, Venus, and Mercury and will be used to reach Mercury with low relative velocity. The mission was launched successfully on an Ariane 5 from the European Spaceport in Kourou on October 22, 2018.

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1.2 MERTIS Instrument

The MERTIS instrument is an innovative and compact spectrometer, that combines a push-broom IR grating spectrometer (TIS) with a radiometer (TIR) in around 3Kg of mass and an average ~10 W power consumption[1,2]. TIS operates between 7 and 14 µm and will record the day-side emissivity spectra from Mercury, whereas TIR is going to measure the surface temperature at day- and night side in spectral range from 7-40 µm corresponding to temperatures from 80- 700 K. TIR has an in-plane separation arrangement, while TIS is an imaging spectrometer with an uncooled micro-bolometer array. The optical design of MERTIS combines a three mirror anastigmatic lens (TMA) with a modified Offner grating spectrometer[1]. A pointing device allows viewing the planet (planet-baffle), deep space (space-baffle), and two black bodies at 300 K and 700 K temperature, respectively.

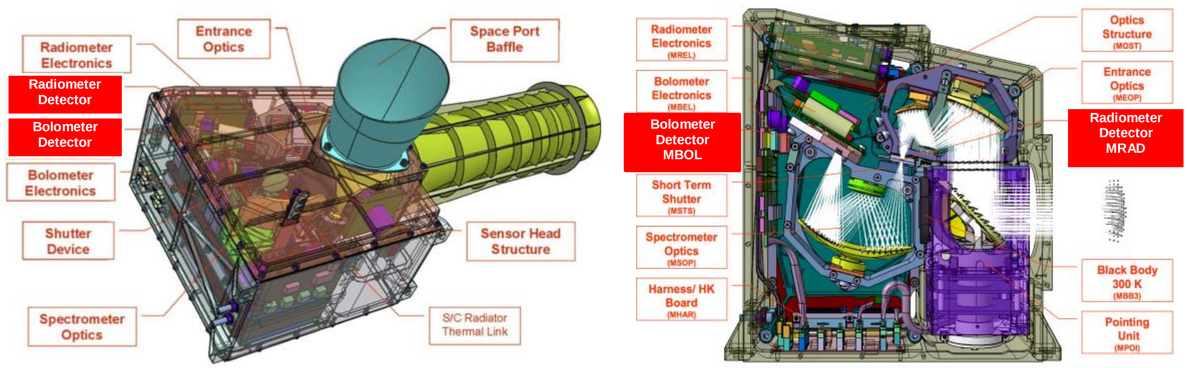

Figure 1 Schematic view of the MERTIS instrument. left: semi-transparent view from deep space view side. Right: exploded view from the same side. Clearly visible is the planet baffle (yellowish–greenish), the space port baffle (bluish–greenish) and the housing structure. Dimensions of the instrument are approximately 180   180   130 mm3. The external baffles are 200 and 90 mm long, the diameter is 75 mm. Total mass is on the order of 3.4 kg. Figure adapted from H. Hiesinger and J. Helbert[4].

MERTIS was developed at DLR IN collaboration WITH the University of Munster. MERTIS scientific objectives are based around four specific goals: 1. Study of Mercury's surface composition, 2. Identification of rock-forming minerals, 3. Mapping of surface mineralogy and 4. Study of surface temperature and thermal inertia. MERTIS is essentially a combination of a spectrometer and a radiometer working with a push-broom configuration. The spectrometer aims to capture data on the mineralogy whereas the radiometer surveys the thermal inertia of the planet5. The incoming radiation is guided via a baffle7 which can be seen in the Figure 1, protruding from the instrument. The radiation is then fed to the spectrometer and bolometer in the instrument. Thermal instability can cause highly inaccurate readings; hence MERTIS's mode of operation is designed to avoid this.

The chosen orbit for MPO of 2.3 hours with a low eccentricity allows MERTIS to achieve its 500 meters global mapping scientific goal. MERTIS's design and performance drivers have been fine-tuned and with the data obtained from the Planetary Emissivity Laboratory and subsequently checked against the result from the NASA MESSENGER mission. One of the main conclusions was the most useful wavelength to image Mercury. While the visible and near-infrared wavelength range covered by NASA MESSENGER showed no clear bands which would allow to identify minerals due to the lack of iron on the surface of Mercury, the thermal infrared which is mainly sensitive to silicates is not hindered by a lack of iron. With its high Signal-to-Noise ratio (SNR), MERTIS will be able to identify the likely surface mineralogy of Mercury - mainly feldspar - due to their characteristic spectral features in TIS channel spectral range 7-14 µm [5,6].

MERTIS's Instrument Controller Unit contains a SpaceWire controller and processor core on which the on-board software runs. The software design implements the concept of having separated code module and configuration file which is referenced by the code. For the sake of redundancy, backup software is also included. The main function of the software is to control the sub-systems the TIS and TIR, data handling, pointing, black bodies, thermal systems and all other subsystems. Also, there are many modes of operation for MERTIS which is managed by the on-board software. MERTIS operations are grouped in operation modes, listed in [7] and distributed with the data archive, each one is activated by specific telecommands. In case of failure, the instrument stays in this safe mode after power-on. However, for normal operation state, after power-on MERTIS will be in StandBy mode waiting for upcoming commands[8]. Diagnostic, Calibration and Science modes are normal functional modes which can only be activated only after the instrument is in WarmUp mode to ensure it is thermally stable, the most critical for a correct calibration. Test mode can be achieved directly after StandBy mode. Science mode has further sub-modes that are related to different functions of calibration and operations. The science data can be lossless compressed up to factor of two to reduce the data size. The compression is configurable by telecommand as necessary. There are two channels of scientific data from MERTIS; one acquired from the spectrometer and other from the radiometer. The spectrometer data is from the bolometer array and the radiometer data is obtained from the thermopiles. The on-board software will process the data for transmission. Along with the data the software also transmits the essential metadata that is necessary to decode the data on-ground[8].

2. NEAR EARTH COMMISSIONING PHASE OPERATIONS

BepiColompbo started the payload NECP a few weeks after launch, first commissioning all the spacecraft modules and then the scientific instruments.

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 days 05:55.

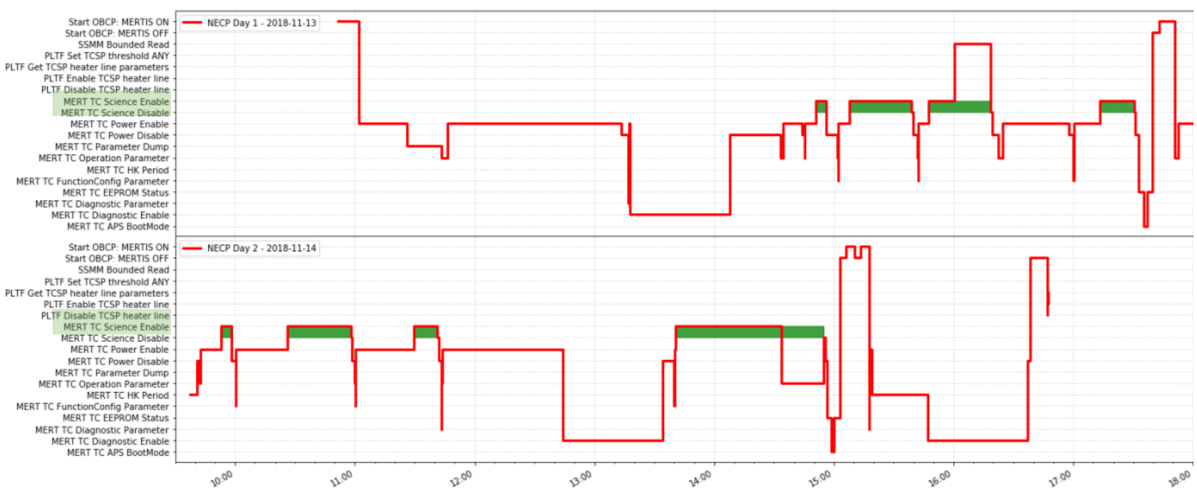

Figure 2: List of Telecommand sent to MERTIS instrument in the two commissioning days (top/bottom panel) versus UTC time. The solid green area is the timeframe of actual data acquisition. The green area is where MERTIS actually acquired data, between Science Enable/Disable commands.

The night between the 13th and 14th 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. Effective operation time was or ~7:45 hours on the first day and ~7 hours on the second day. The operation plan developed for the NECP was aiming to verify the operational performances of all the instrument sub-modules, in particular the spectrometer and radiometer sensor sensitivities, the pointing unit (MPOI), and the thermal stability of the whole instrument. Figure 2 shows the actual list of Telecommands (TCs) sent to the MERTIS instrument on day 1 and 2. Almost half of the first day was used to set and check the thermal stability of the instrument, sending TC and dumping housekeeping (HK) parameters. This allow a short feedback cycle to perform onboard parameters adjustments, needed to reach a thermal environment suited for instrument operations.

Once the instrument thermal environment reached a status in the nominal range, the Science Mode was enabled at 14:16 to 14:56, 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 normal operation/calibration cycle of 60 seconds:

- Cold 300K Blackbody
- Hot 700K Blackbody
- Deep space
- Planet View

The latter position is currently obstructed by the MTM structure and will be freed after Mercury orbit insertion. Those measurements will be used as further calibration, after the temperature of the facing MTM portion will be accurately modeled: there is no thermal sensor directly in the MERTIS Planet View field of view, so the closest spacecraft data should be collected and interpolated. In each measurement session a TIS acquisition took 100 milliseconds, plus the time to rotate the MPOI to different positions. The instrument was left on at the end of first day session and in thermally stable condition during the night to start with highly stable thermal condition on the 2nd day. The second day had 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. The MERTIS Team is currently analyzing those data to develop and test a complete ingestion, calibration and transformation pipeline for MERTIS data, from raw telemetry level data to calibrated products and higher-level derived products [5].

3. NEAR EARTH COMMISSIONING PHASE RESULTS

3.1 TIS Spectrometer

The grating spectrometer differential (scene – dark scene) images acquired at different MPOI position are shown in Figure 3 (top). The unmasked part of the CCD is the central one, where the 'frames' pixels only show signal due to the thermal noise. The average value of all frames pixels is called Macropixel and is an important indicator of the thermal state of the CCD 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. The sequence shows a normal behavior, with less signal coming from cold Space View source, slightly higher signal from Planet View, that has around the same environmental temperature as the spacecraft and the higher signal form the cold 300K Blackbody temperature at 9.09°C.

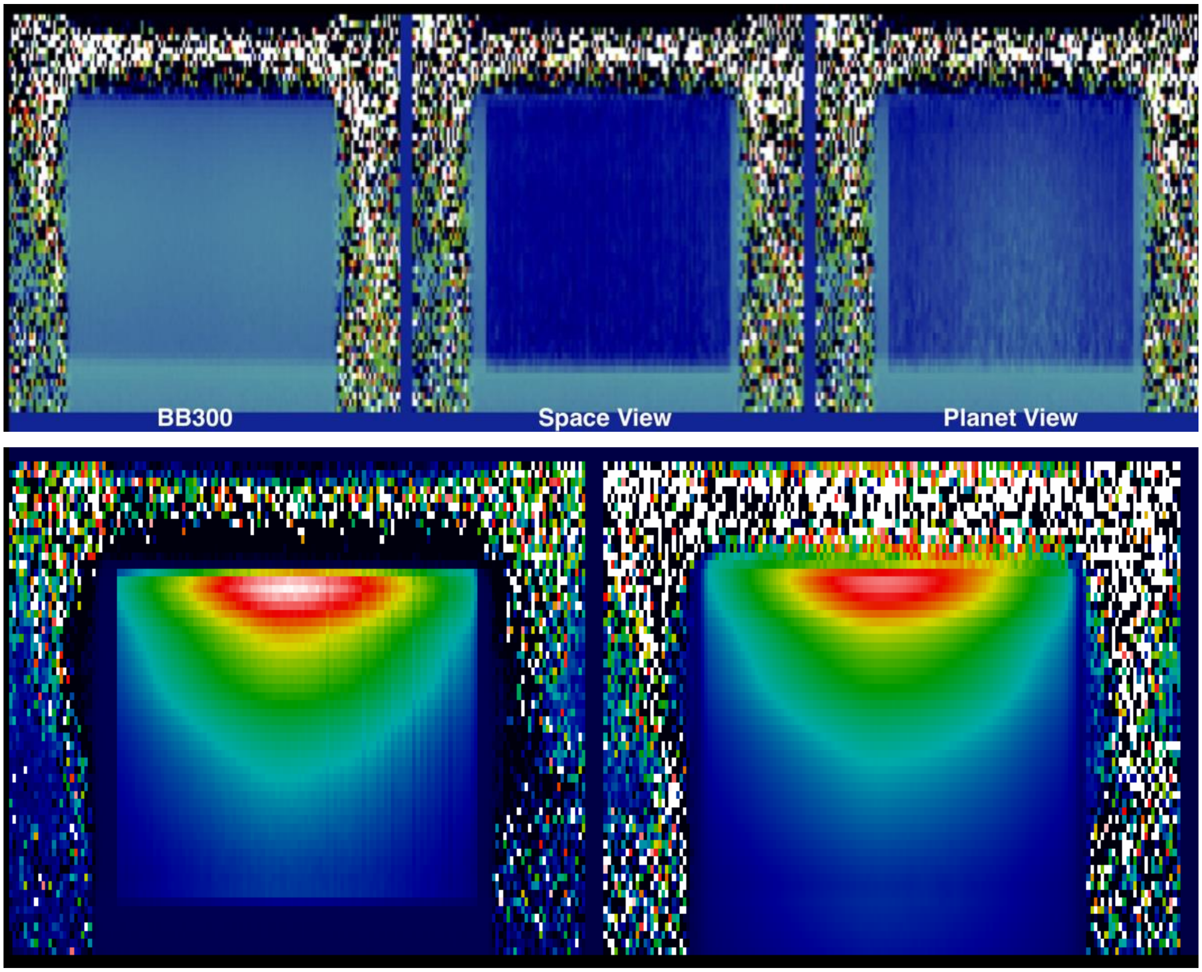

Figure 3: *Top panel*: Radiance Values from different MPOI position, part of a typical science observation sequence. Colors [Blue, Red]: [-1.38, 5.46] W/m²/sr. *Bottom panel*: Radiance Values from 700K hot blackbody inflight (right) and on-ground (left) [Blue, Red]: [-3.63, 41.56] W/m²/sr

Figure 4 top panel shows the BB700 image barycenter shift. Temperature conditions on base plate were very similar: Inflight 9.85°C vs On-ground: 9.48°C. Identical Detector Operational Settings of Voltage and Bolometer temperature. Inflight images were binned onboard to [spatial x spectral]: [1 x 2] and „unbinned" before calculations, i.e. oversampled to [1 x 1], laboratory images were acquired unbinned. Barycenter calculations over whole scene window with threshold selection of 30 % highest signal values. Inflight measurements seem to have less noise (probably due to low image offsets, edge of linear region). Very little image shift of half a pixel [dx , dy] = [0.47 , 0.49]

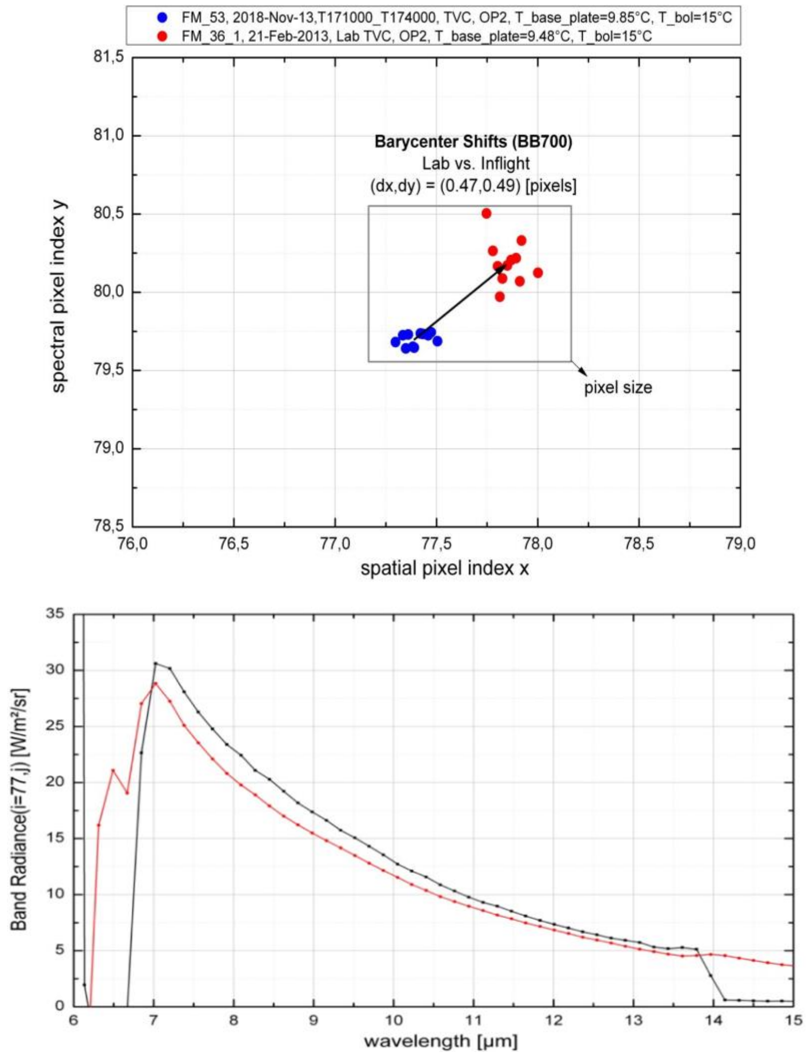

Figure 4: Top panel : barycenter shift between NECP data (blue) and Laboratory, taken on 21 Feb 2013 in Thermo Vacuum Chamber. The total shift is sub-pixel. Bottom panel: BB700 TIS on-ground / space spectral comparison.

Figure 4 bottom panel shows a spectral curve extracted from the center of BB700 image. The spectral response is slightly lower for inflight image, even for higher target temperature.

3.2 TIR Radiometer

The TIR radiometer was fully functional after launch. Only a slight sensitivity decreases of broadband channel by B (5-40 µm) 12% already observed on-ground before launch. In Figure 5 a summary of TIR observations : panel a. shows the TIR channel A between on-ground and NECP measurement, panel b. for broad channel B. Both panels show BB700 differential measurement to space view. Panel c. and d. show the BB300 differential measurement to space view, in space and on-ground respectively.

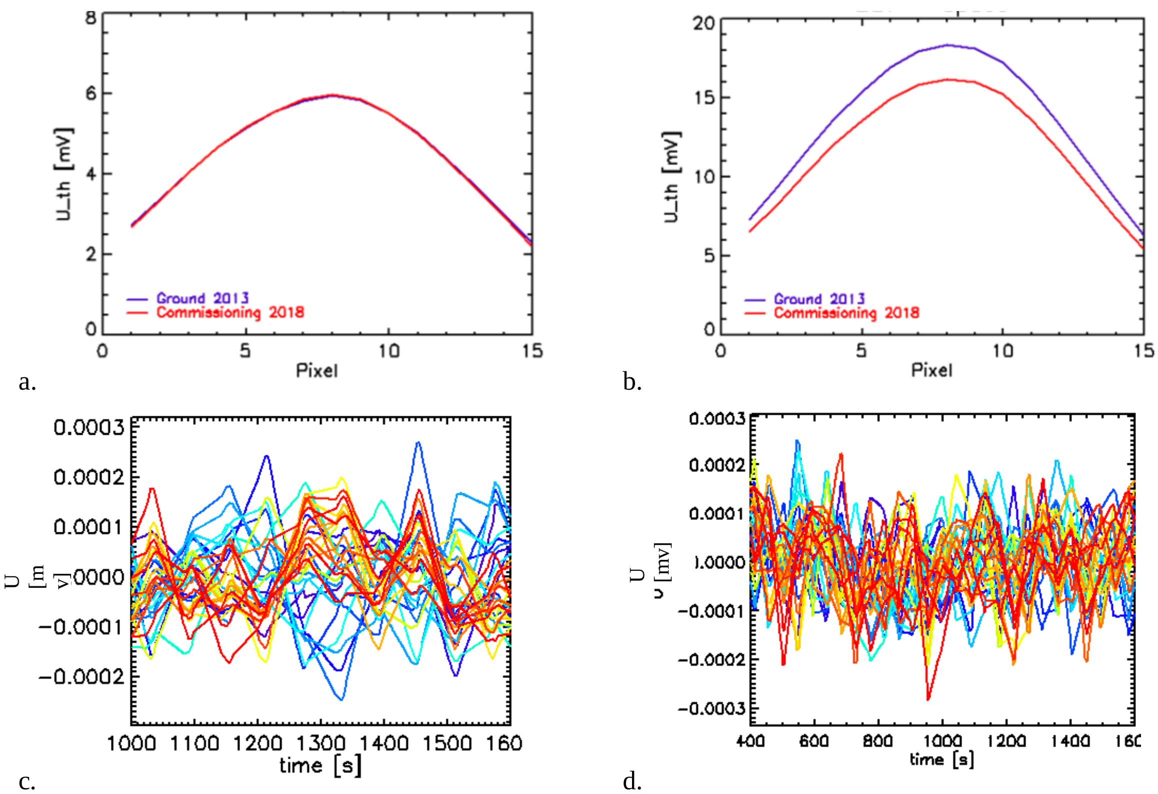

Figure 5: **a.** BB700 – Space [IR-A 8-14 µm] **b.** BB700 – Space [IR-B 5-40 µm] **c.** BB300 – Space (NECP) **d.** BB300 – Space (on-ground acquisition on 12/01/2013)

4. CONCLUSIONS

MERTIS completed NECP tests between 13 and 14 November, collecting measurements of its internal calibration bodies and deep space. The data collected are shown in this work to address the instrumental performance variation after launch. In conclusion , NECP was successful performed, with both channels fully operational. The spectrometer shows performance comparable with the on-ground testing and some finer adjustments of working points is recommended to optimize performance. The radiometer shows a slight degradation of performance for the long wavelength channel, but this was already observed on-ground. Monitoring of the behavior both channels during cruise is recommended.

The MERTIS TIS spectrometer channel is fully functional after launch. Performance is comparable with last measurements on-ground with a very small image shift after launch (less than 0.5 pixel). Slight change in the parameters for the ADC were observed, so adjustments of working points is being performed. An onboard review will be performed during next check out.

The MERTIS TIR radiometer channel is fully functional after launch, with noise performance unchanged. Noise is determined from standard deviation of difference between BB3 and space view and contains electronics + thermal noise. Noise is dominated by electronics noise. Thermopile noise < 100 nV and Pt-1000 noise < 2 mK. Inflight calibration of MERTIS provides a means for finer sensitivity correction.

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