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SIMBIO-SYS Near Earth Commissioning Phase: A step forward toward Mercury

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ABSTRACT

On December 2018, the Near Earth Commissioning Phase (NECP) has been place forSIMBIO-SYS (Spectrometers and Imagers for MPO BepiColombo Integrated Observatory – SYStem), the suite part of the scientific payload of the BepiColombo ESA-JAXA mission. SIMBIO-SYS is composed of three channels: the high resolution camera (HRIC), the stereo camera (STC) and the Vis/NIR spectrometer (VIHI) . During the NECP the three channels have been operated properly. For the three channels were checked the operativity and the performance. The commanded operations allowed to verify all the instrument functionalities demonstrating that all SIMBIO-SYS channels and subsystems work nominally. During this phase we also validated the Ground Segment Equipment (GSE) and the data analysis tools developed by the team.

Keywords: Space instrumentation, Imaging, Spectrometer, Commissioning, Calibration, Ground Segment ….

INTRODUCTION

After launch, occurred on October 20th 2018, during November/December 2018 the BepiColombo spacecraft underwent to the initial commissioning phase during which the health status and the monitoring of the expected performance of the spacecraft systems and scientific payload have been verified. During this phase the SIMBIO-SYS instrument, the imaging and VIS-NIR spectral suite, has taken advantage of a 3-day window to be switched on and operated for the first time after the launch.

The three channels of SIMBIO-SYS [1] the high resolution camera (HRIC), the stereo camera (STC) and the Vis/NIR spectrometer (VIHI) have validated their functioning through two kinds of tests: a) SIMBIO-SYS health has been checked after the demanding launch phase; b) a long sequence of performance checks and measurements has been performed (considering the available resources) to integrate and confirm the on-ground data. In addition, the instrument was commanded to execute timelines simulating all the operational modes that will be performed during the scientific phase of the mission. In these simulations both single channel operations and/or simultaneous use of all the three ones have been tested. The tests have also allowed the validation of the Ground Segment Equipment (GSE) and data tools developed by the team for the conversion and visualization of the scientific and House Keepings (HK) data.

In this paper, we describe the tests executed and the results obtained during the commissioning. In particular, after a short introduction to the instrument (Section 2), are reported the activities done for HRIC (Section 3). STC (Section 4) and VIHI (Section 5). In Section 6, the inter-channel activities are described and discussed; Section 7 introduces the SIMBIO-SYS GSE and in Section 8 some conclusions are reported.

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SIMBIOSYS

BepiColombo is composed by two different modules: the JAXA-led Mercury Magnetospheric Orbiter (MMO) and ESA-led Mercury Planetary Orbiter (MPO). The mission has been approved at the end of 2000 as part of the Cosmic Vision programme.

After a 7-year interplanetary cruise using electric propulsion and nine gravity assists, with Earth, Venus and Mercury itself, the spacecraft will be captured into Mercury orbit in December 2025 and starts its scientific activities in March 2026.

The main aims of MPO are the study of Mercury, as end-member of the Solar System, and the high accuracy measurement of some General Relativity parameters, while the MMO will study the Mercury environment, as magnetosphere and exosphere, and the interplanetary medium.

The MPO spacecraft is a three-axis stabilized, and the orbit is polar and fixed to maintain the subsolar point on the orbital plane at aphelion and perihelion. This permits the instrument to perform global mapping for all the latitudes working for the part of the orbit around the periherm and to take advantage of Mercury revolution and rotation for longitude coverage.

Half of the Data Volume (DV) of MPO mission will be allocated to the Spectrometer and Imagers for MPO Bepicolombo Integrated Observatory SYStem (SIMBIO-SYS) which is the visible and infrared imaging eye of the 5th ESA Cornerstone Mission. The three optical channels of SIMBIOSYS are: STC (Stereo Imaging Channel), VIHI (Visual and near-Infrared Hyper-spectral Imaging channel) and HRIC (High-Resolution Imaging Channel).

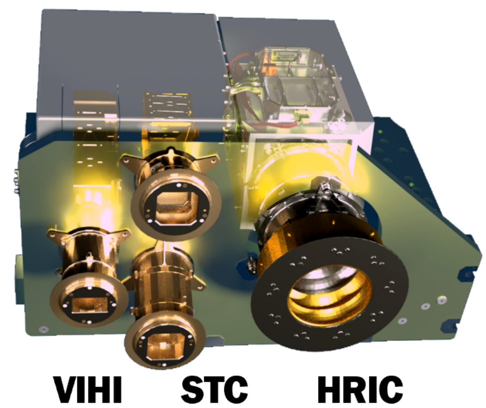

Figure 1: SIMBIOSYS three channels

HRIC will provide images at unprecedented level of details (i.e., < 10 m/pxl) of key superficial features in the visible range in grey scale (Pan Filter 400-900 nm) and color (3 Broad Band filters centered at 880 nm, 750 nm, 550nm).

VIHI, with imaging and spectroscopic capabilities will produce the hyper spectral global mapping of the surface in the 400-2000 nm spectral range.

Finally, STC will generate the 3D global mapping of all the planet surface (600-800 nm) and color images of specific regions in 4 selected wavelength bands in the range 420 and 920 nm.

HRIC CHANNEL

HRIC performed several image acquisitions during the NECP with the aim of checking the channel performances and to confirm the calibration measurements performed on ground during the AIT-AIV phase. Due to the spacecraft (S/C) configuration HRIC was unable to take images of light sources, thus only performance parameters that can be retrieved with dark acquisitions have been measured: the ReadOut Noise (RON), the Fixed Pattern Noise (FPN), and the Dark Current (DC). In addition to these tests we acquired similar images, i.e. having the same windows dimensions and integration times, at different compression ratio in order to check the impact of the compression on images characteristics; we also performed a specific “test reset” to investigate if the detector is affected by a noise drift between 2 acquisition.We investigated this possible effect in an acquisition sequence where we modified time between two subsequent acquisition maintaining the detector switched on.

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In the following we will present all the measures and the obtained results:

- Data compression test:

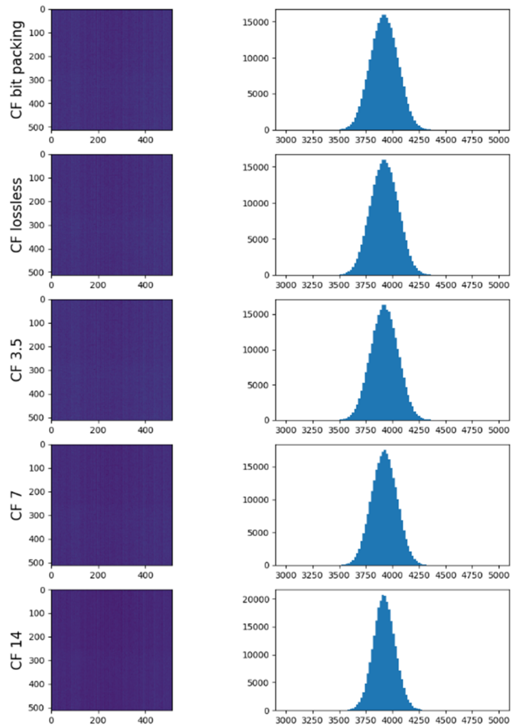

Figure 2: Frames acquired during the compression test: on the left column the frames acquired with different Compression Factors (CF), on the right column the corresponding histograms.

During this test the detector was acquired using the same integration time (96 ms) and 5 different values of the compression acted by the Main Electronic unit. The compression is defined by the parameter IBR (Inverse Bit Rate) commanded to be 0, 1, 16, 32, 56 corresponding respectively to the following compression levels: bit packing, lossless, 14, 7, 3.5 (see Figure 2). The differences in the average and the standard deviation of the pixel values for each acquisition are negligible for the acquired scene, which is an almost uniform dark image.

- Dark current measurements:

During dark test/measurement, the areas of the detector corresponding to the Panchromatic (PAN), and to the three Broad Band (BB) filters have been acquired with different integration times starting from the minimal, 400 ns in the configuration used for the ROIC(Read Out Integrated Circuit), up to about 6 seconds. The values of the average of the acquired PAN frames are reported in Figure 3. The trend shown in the plot is compatible with the trends measured during the calibration campaign on ground and reported in [2].

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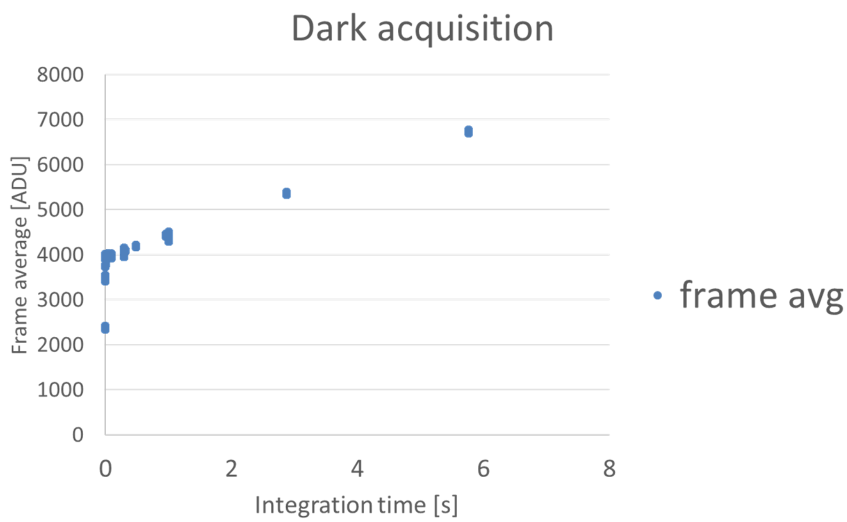

Figure 3: Panchromatic channel Dark Current trend. The plot shows the average value of the frames acquired at different integration times.

Using the data collected during the DC measurements also the FPN and the RON of the detector have been checked with respect to the values obtained during the calibration campaign. The values obtained for both FPN and RON are in good agreement with the values obtained in [2] (Figure 4).

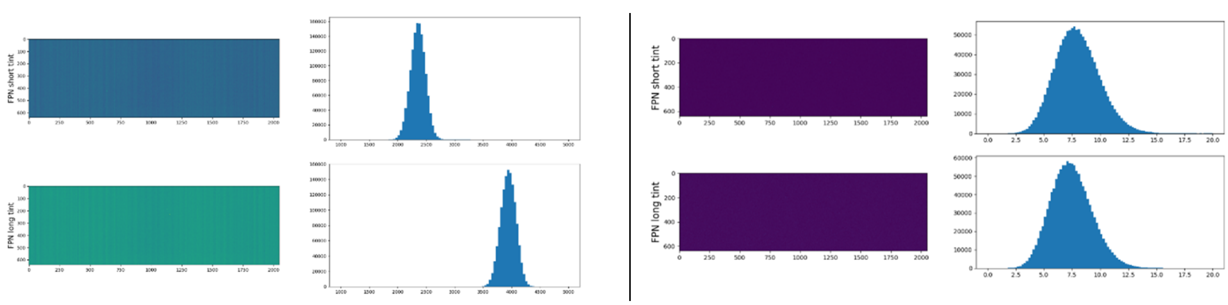

Figure 4: The FPN (left side) and the RON (right side) frame at short integration time. Data come from the average of 10 acquisitions at minimum integration time (upper side) and 48 microseconds (lower side).

- Test detector reset

  The pixel values in the frames acquired for this test are quite stable the only difference between the series is due to the DC behavior. As checked before the launch, no reset issue is present on the HRIC detector (within the RON of the detector).

STC CHANNEL

During NECP phase, STC performed different tests to confirm the calibration measurements executed on ground. The tests included the measurement of the FPN, DSNU and RON for different acquisition modes among which the nominal ones: Global Mapping and Color Mode (CM).

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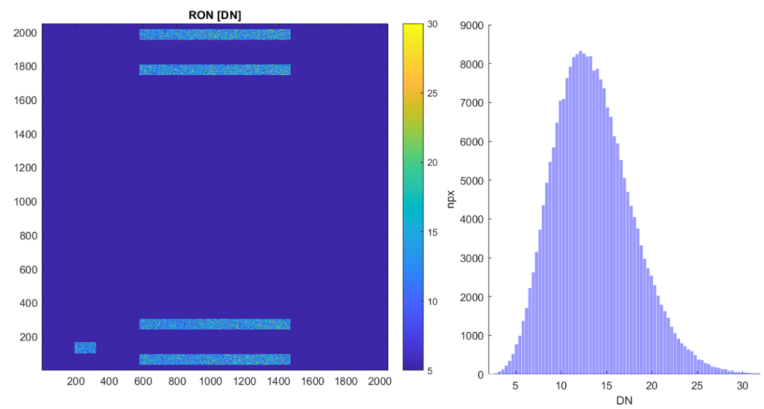
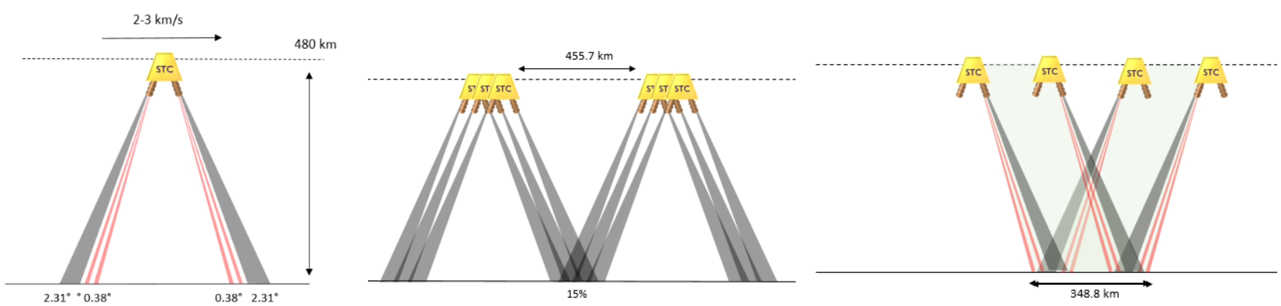


Figure 5 First image acquired during the functional tests. The windows acquired are the 4 broadband filters and the smaller mitigation window. Repetition Time (RT) is 400 ms, integration time (IT) is 38.4 microsec. Left image shows the distribution (uniform) of the RON on the detector. On the right the distribution of the RON.

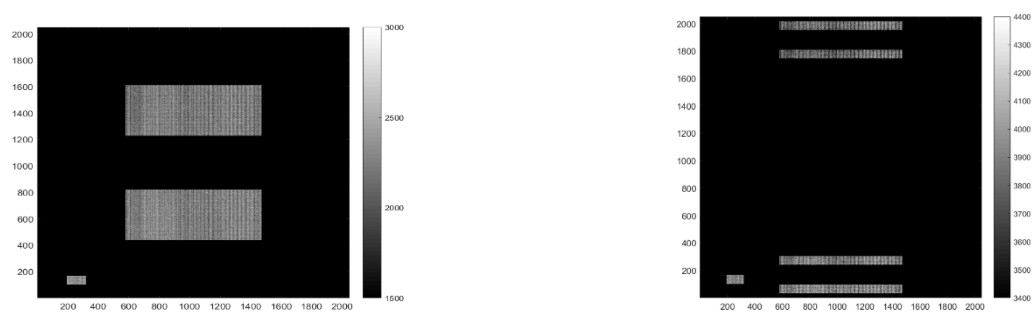
The two modes considered have reproduced the acquisitions foreseen by the two main strategies of STC: the Global Mapping and the Color Mode. (see Figure 6).



(a) (b) (c)

Figure 6: The main acquisition strategies of STC [3]. In (a) the nominal on ground FoV with the external Panchromatic filters and the internal BB filters. In (b) a schematic representation of the Stereo Mapping operative sub mode adopted for Global Mapping. In (c) a schematic representation of the Color Mode or the Target Stereo Mapping.

An example of the images acquired during the two acquisition modes is shown in Figure 7.



(a) (b)

Figure 7 These two figures show the dark signal distribution on the STC-FPA for Global Mapping mode (a) and Color Mode (b).

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The DSNU is limited to 135 DN as predicted by the on-ground calibration measurements. The Read-out Noise, for the nominal integration times, has an upper limit of 15 DN. The images were compared with the data acquired on ground during the dark current campaign considering the sensor temperatures provided by instrumental HKs.

In particular, we tested the Integration Times (IT) between 0 and 5 seconds from the acquisitions of the surface with panchromatic filters to the stellar acquisitions during the inflight calibration. The test considers IT<2 ms (0.4 ms in mean) and 7s<RT<15s to simulate the Global Mapping case while IT<30 ms (4 ms in mean) and 1s<RT<4s to simulate the Color Mode.

The ITs have been calculated using the SIMBIO-SYS simulator [4] which takes into account the Hapke reflectance model [5] with the parameters calculated by [6] for Mercury surface.

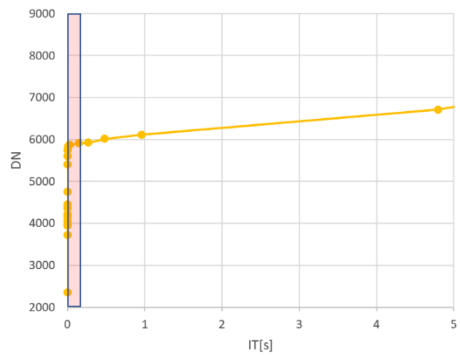

Figure 8: This figure shows the dark current curve of STC panchromatic filter as function of the integration time. The ITs have been chosen to simulate the acquisition strategy foreseen at periherm.

VIHI CHANNEL

The VIHI spectrometer performed several measurements to confirm after launch its performance with respect to the Dark Current values and the internal calibration sources signals (i.e., Lamp and LED) as measured during pre-launch calibrations. For this verification the following tests were performed:

- VIHI Calibration
  This test was the first in flight run of the calibration routine using the internal sources, lamp and LED.
  The in-flight calibration signal of the Lamp source is shown in Figure 9. The spectrum shows the reference absorption bands introduced with the Didymium filter used to verify the spectrometer's spectral response.

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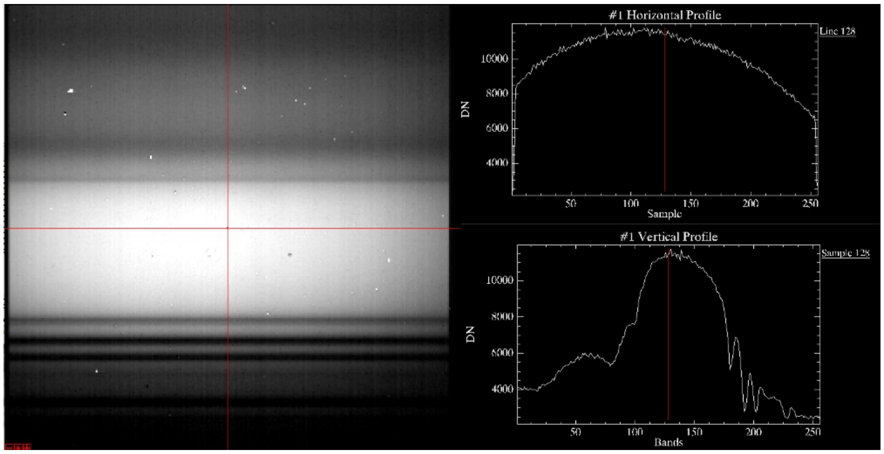

Figure 9: VIHI internal calibration lamp signal. On the left the image of the Focal Plane showing spectral information in the vertical direction and spatial information in the horizontal direction. On the right two profiles which show spatial variability (top right) across the FOV and the spectrum (bottom right) from 400nm (band 255) and 2000nm (band 0).

Commissioning measurements have shown a discrepancy of the signal measured during pre-launch tests [8]; the signal measured in flight is about 30% higher than the one on ground at parity of integration time and lamp's current. This ratio is approximately constant within the full FOV for a given wavelength. This effect is currently under investigation and seems to be caused by the different configuration of VIHI aperture between on ground tests and cruise spacecraft configuration. VIHI internal calibration unit uses a particular optical configuration in which a beam splitter placed at telescope's entrance is used to inject about 10% of the calibration sources fluxes towards the spectrometer while the remaining 90% is ejected towards the outside [9]. During the on ground tests the instrument's baffle housing the internal calibration unit was unobstructed allowing the dispersion of the 90% fraction of the flux outside the instrument. But in the current inflight configuration the baffle is closed by a cover necessary to protect the telescope's aperture from the nearby propulsion module to which MPO is stacked together during the cruise closes VIHI's baffle. Internal reflections of the lamp flux on this cover are the probable cause of the observed signal increment.

Conversely, the reference spectral absorptions of the lamp's Didymium filter are stable on the same bands, an indication that VIHI spectral response has not changed after the launch (see Figure 10).

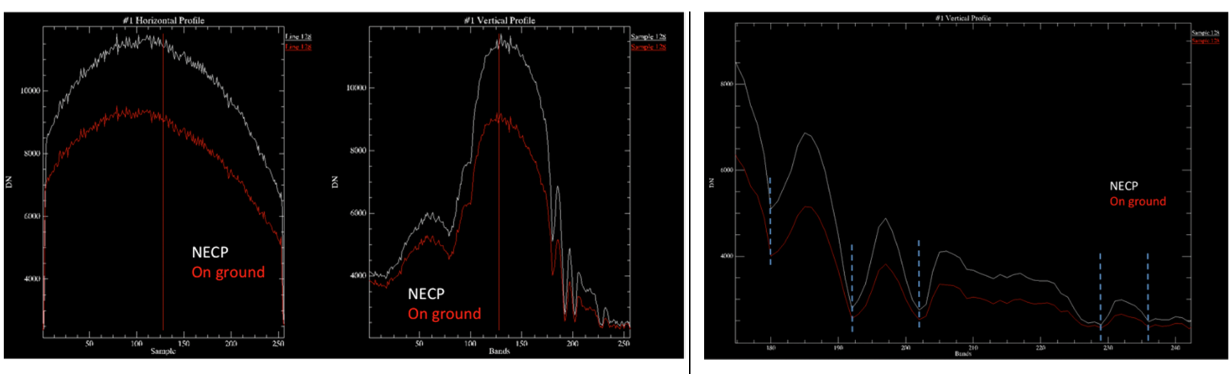

Figure 10: VIHI spectral response verification: on the left and central panels are shown the comparisons between the NECP tests (white curves) and the on ground ones (red curves). The two profiles show spatial variability (left) across the FOV and the spectrum (centre) from 400nm (band 255) and 2000nm (band 0). On the right panel, it is shown a spectral profile zoom above the constant position of the Dydymium filter absorption bands before and after launch.

A similar comparison has been performed also on the LED source signal (Figure 11 and Figure 12). In this case the on ground and in flight performances are fairly similar, including the spectral position of the narrow emission peak at 450 nm.

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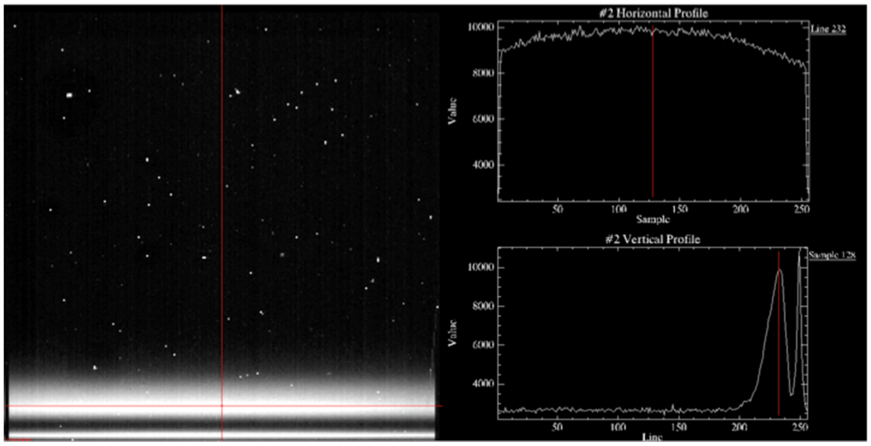

Figure 11: VIHI internal calibration LED source signal measured during commissioning: On the left panel is shown the signal on the detector frame (spectral information along the vertical direction and spatial information along the horizontal direction). On the right panel spatial variability (top right) across the FOV and the spectrum (bottom right) from 400 nm (band 255) and 2000 nm (band 0) are shown.

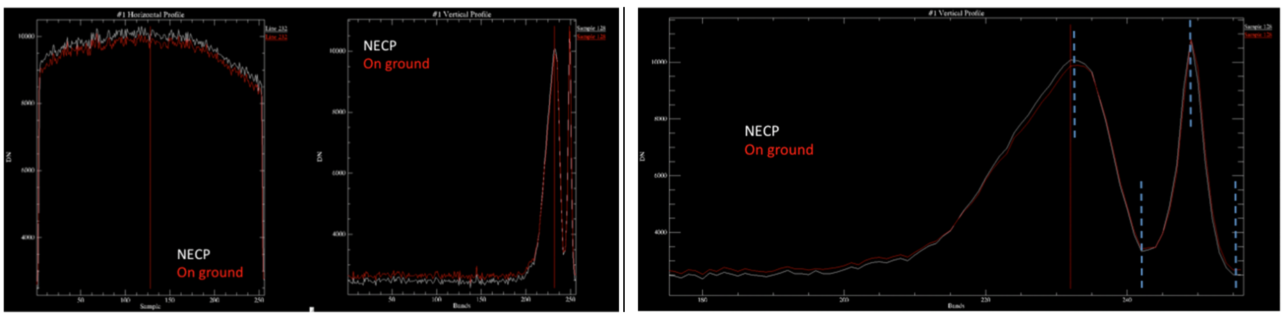

Figure 12: Comparison between VIHI internal calibration LED source signal measured during commissioning (white curves) and on ground tests (red curves). Spatial variability across the FOV and the spectrum from 400 nm (band 255) and 2000 nm (band 0) are shown in the left and central panels, respectively. On the right panel, it is shown a spectral profile zoom above the constant position of the Dydymium filter absorption bands before and after launch.

- VIHI compression and binning test

The goal of this test was to verify several instrument operative modes to verify the operability of the various compression levels and binning capabilities of the VIHI Channel.

The binning was correctly performed.

Two runs of scientific acquisitions were performed by acquiring dark current frames: the first with the shutter closed (Dark) and the second with the shutter opened (Background). Normally dark and background not necessarily return the same signal as the shutter limits the input flux to the spectrometer. However, as VIHI FOV is obstructed by the presence of the BepiColombo spacecraft module, the two observations are indeed identical. The analysis of the dark signal is shown in Figure 13 (Background: left panel; Dark current: right panel). The mean signal on the detector shows the effect of the noise with fluctuations increasing with integration time. The angular coefficients of the best (linear) fits representing the dark current signal rate for a given operating temperature of the detector are shown.

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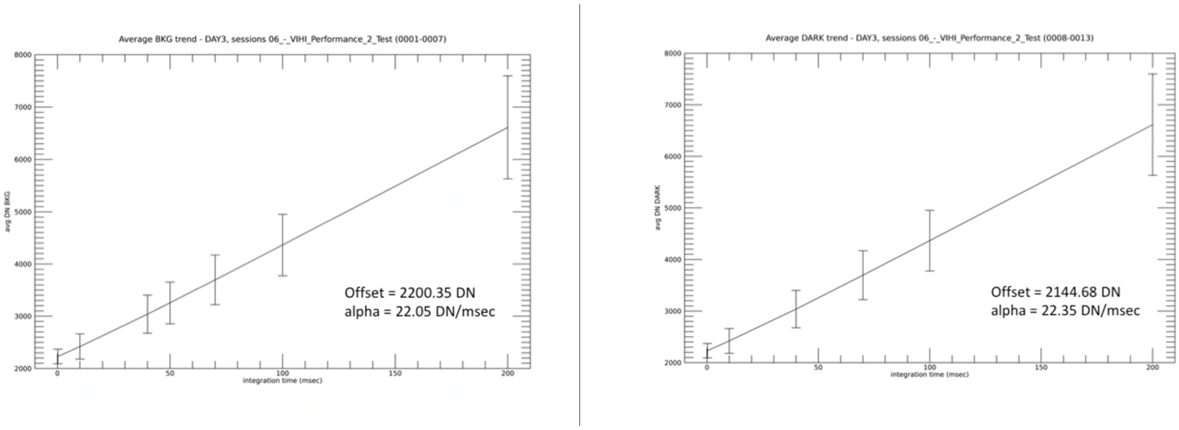

Figure 13: Trend of the background signal (left side) and of the dark signal (right side) with respect to the integration times (i.e., 0.2,10,40,50,70,100,200 ms) and FPA temperature 215K, Spectrometer temperature 225K, PE Temperature 284-286K.

The value found in flight is perfectly in agreement with on-ground measurements [7].

SIMBIOSYS INTERCHANNEL TEST

Three specific simulations were planned to verify the interoperability of the three channels:

- MAX Stress test: the aim of this test is to command in science mode all the three channels of SIMBIO-SYS in a configuration that stresses at maximum (in terms of computation and data throughput) all the units (i.e., Proximity Electronics and Main Electronics) involved during acquisitions. In particular:
    - HRIC: acquisition of an area of 512x512 pixels with 8x8 binning, Compression Factor (CF)=3.9375 and Repetition Time (RT) 0.5s
    - STC: acquisitions in CM with CF=3.9375 and RT 0.2s
    - VIHI: full frame acquisition with dark subtraction and RT 0.04s

  The test was executed with no evidence of errors indicating that the system (i.e., SIMBIO-SYS ME) is capable to manage the operability of all the channels even in such a stressing configuration.
- MAX Data-Rate test: the aim of this test is to command in science mode all the three channels of SIMBIO-SYS conveniently configured to evaluate ME behaviour during acquisitions at maximum Data Rate. In particular:
    - HRIC: PAN acquisition with, CF=3.9375 and RT 1.115s
    - STC: acquisitions in CM with CF=3.9375 and RT 0.2s
    - VIHI: full frame acquisition with CF=1 and RT 0.04s

  The test was executed with no evidence of errors indicating that the system is capable to manage the operability of all the channels when producing their maximum data rate.
- Orbit test: the aim of this test is to simulate a nominal operation phase during an orbit of Mercury commanding in science mode all the three channels of SIMBIO-SYS configured in the primary operation mode of Global Mapping Phase. During this phase STC and VIHI will operate continuously to cover all the surface of the planet in stereo acquisition mode and to generate a full mineralogical map of the surface, respectively. In addition, HRIC will operate in spot mode observing specific targets along the orbit. In particular:
    - HRIC acquired images simulating the acquisition of a selected region of the surface with PAN filter in lossy (CF=7) compression.
    - STC acquired images continuously changing integration time, repetition time and cross track dimension for 9 different orbit arcs. It acquired in Global Mapping mode lossy (CF=7) changing its cross track window size from 128 px to 640 px.
    - VIHI acquired images continuously changing integration time and repetition time for 8 different orbit arcs.

  The test was executed with no evidence of errors indicating that the system is capable to operate in its primary operative mode.

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GSE PERFORMANCE

The NECP test was planned on three days.

Date	Spacecraft Visib. Start	End	Start Test	Activity	Dur.[h]	Outpass	Outpass Activity	Dur.[h]
10/12/18	07:56:53	19:06:32	Start +2h	P45 ME Functional Checkout	0.50	End+2h	P42 HRIC Commissioning Performance test	4.00
				P42 HRIC Com. Main	2.30			
				P43 STC Com. Main	2.30			
				P44 VIHI Com. Main	2.30			
11/12/18	07:53:57	19:02:42	Start +8h	P42 HRIC Com. Red.	0.60	End +2h	P43 STC Commissioning Performance test	9,00
				P43 STC Com. Red.	1.00			
				P44 VIHI Com. Red.	0.60			
12/12/18	07:51:04	19:02:56	Start +1h	P45 SIMBIO Performance Tests – Max Stress / Max DR				
			Start +3h	P45 SIMBIO Performance Tests - Orbit Simulation	1.50			
			Start +4.5 h	P44 VIHI Commissioning Performance test	1.30			

For each test the GSE is capable to automatically produce a report structured in the following sections:

- a summary of all the data produced in that test. The output are two different types of CSV files (one for the diagnostic housekeeping and one with all the housekeeping parameters related to a single image) and a file containing the image in binary format. All the data are in PDS4 format, that means that they include an XML file with all the parameters of each acquisition, both considering as source the instrument or the spacecraft. For each image is present an extra file in PNG format as quick preview.
- a report for the events acknowledgments. In the event checks are reported:
  - all the negative telecommand acknowledgments
  - the rejected telecommands
  - the failed telecommands

  For each rejected or failed telecommand, the event is reported a sheet with all the information about the telecommand, mnemonic name, description, time of execution and all the parameters.
  For each event is reported a list for the low, medium and high severity errors with a description of the event.
- a report of the Proximity Electronic (PE) events. From an automatic analysis of the diagnostic HK, a list of the negative event alerts, sent by the PE, is created. Each alert is reported with the decimal ID and with the complete description.
- a check on the lost packets. The automatic check on the lost packets is performed using the Packet Sequence Control number which is a progressive number associated to the TM packets and follows a different enumeration for different telemetry packet type.

The report includes also two sections where the TC history is compared to the actual activities performed, giving evidence to any issues or discrepancies identified

CONCLUSIONS

In this work, we presented the activities performed during the commissioning of SIMBIO-SYS aboard the BepiColombo mission after the October 2018 launch.
In particular, we described the performed measurements with the aim of:

- verify the health status of the instrument;
- check its performances and the compliance with the expected one derived from on-ground calibration campaign.

During the NECP activity the three channels of the instrument demonstrated their functionalities individually and the first inter-channel test was performed simulating the operations of SIMBIO-SYS during a foreseen typical orbit of Bepicolombo S/C around Mercury planet during the Science Phase.

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The obtained results, a part from an unexpected spacecraft issue, for the instrument suite and for each channel, confirm the SIMBIO-SYS operability and capability in an operative scenario.

The allowed checks on the channel scientific and acquisition performances confirm the data obtained during the on-ground calibration, small discrepancies found could be due mainly to the different observation conditions with respect to the on-ground calibrations.

The performed operations and data acquisition allowed also to validate the on-ground processing pipeline of the SIMBIO-SYS GSE.

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