International Conference on Space Optics—ICSO 2018

Chania, Greece

9–12 October 2018

Edited by Zoran Sodnik, Nikos Karafolas, and Bruno Cugny

The hyperspectral instrument onboard EnMAP: overview and current status

Manuela Sornig

Sebastian Fischer

Christian Chlebek

Martin Muecke

et al.

International Conference on Space Optics — ICSO 2018, edited by Zoran Sodnik, Nikos Karafolas, Bruno Cugny, Proc. of SPIE Vol. 11180, 1118007 · © 2018 ESA and CNES · CCC code: 0277-786X/18/$18 · doi: 10.1117/12.2535926

The Hyperspectral Instrument Onboard EnMAP, Overview and Current Status

Manuela Sornig*[a], Sebastian Fischer[a], Christian Chlebek[a], Martin Muecke[b], Hans-Peter Honold[b], Brian Heider[b]
[a]German Aerospace Center, Space Administration, Koenigswinterer Str. 522-524, 53227 Bonn, Germany; [b]OHB System AG, Manfred-Fuchs-Strasse 1, 82234 Wessling, Germany

ABSTRACT

The Environmental Mapping and Analysis Program (EnMAP) is a German spaceborne science mission that aims at characterizing the Earth's environment on a global scale. The single payload of the satellite is the hyperspectral imager (HSI). It is capable of measuring the solar radiance reflected from the Earth's surface as a continuous spectrum in the spectral range of 420nm to 2450nm, with a spectral sampling of 6.5nm (VNIR) and 10nm (SWIR). The EnMAP on ground swath of 30km is sampled with 30m.

The instrument features a telescope with a 18cm aperture. A double-slit splits the field of view into the two separate fields for VNIR and SWIR. Two spectrometers disperse the light using large, curved prisms and collect the light in an Offner configuration onto the VNIR and the SWIR detector. In addition, the instrument features calibration capabilities using a deployable, full aperture solar diffuser in front of the telescope and on-board calibration sources that can be fed into the spectrometers. The instruments demanding requirements on thermal stability are covered by an active thermal control of the whole instrument using loop-heat pipes.

In this proceeding, we give a short overview on the design, application and current integration status of the mission, which is currently in Phase D. The focus is on the important steps recently accomplished or currently ongoing, specific on the:

- completion of the telescope setup
- assembly of the spectrometers with the optical components of both spectrometer paths already in place, aligned and successfully characterized
- setup and characterization of the on-board calibration source OBCA
- integration of the calibration chain including the above mentioned OBCA into the spectrometer
- implementation of the first of the two front end devices, the VNIR camera and the SWIR camera
- assembly of the platform

The present situation suggests an EnMAP launch by the end of 2020.

Keywords: EnMAP, Hyperspectral, Spectrometer, Earth Observation,

1. INTRODUCTION

The scientific topics addressed by EnMAP cover a broad application range, from climate change impacts, land cover changes, biodiversity processes, and natural resources, to geohazard and risk assessment [1]. With a substantial improvement in terms of signal-to-noise over hyperspectral missions such as Hyperion, it fills an important gap to allow measurements and quantification of key science parameters of the earth only possible with EnMAP. In addition, it will complement multispectral missions such as Sentinel 2.

DLR space agency has contracted OHB System AG in Oberpfaffenhofen as prime for the space segment (see Figure 1). The spacecraft bus has initial been assembled at OHB Bremen and was transferred to OHB Oberpfaffenhofen in May 2017. The instrument design and construction is in full responsibility of OHB System AG.

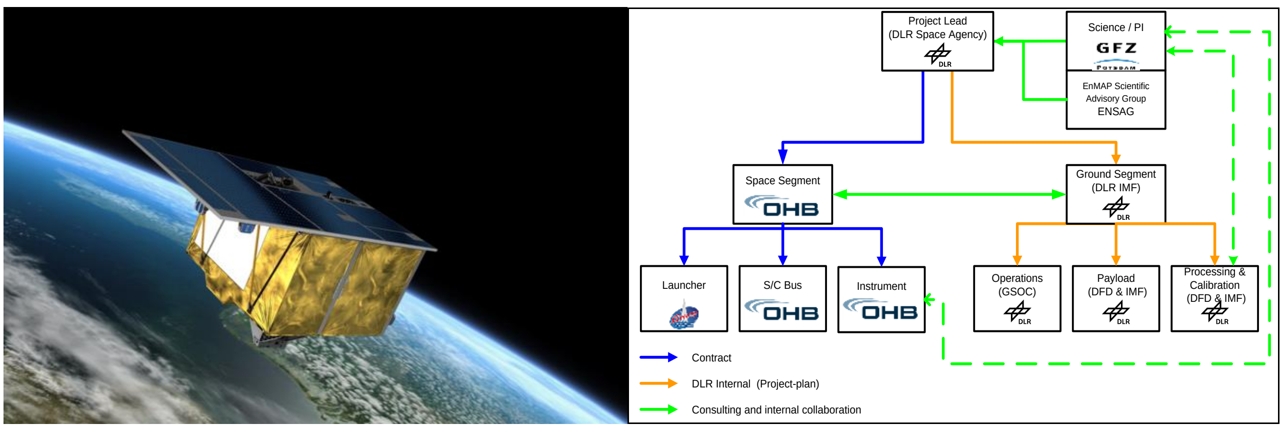

Figure 1. The EnMAP satellite is pictured at the left and at the right an overview on the project structure is given.

The satellite is a push-broom earth observation satellite. With dimensions of 3 x 2 x 1 m and a mass of one ton, it will orbit earth in a sun-synchronous, low earth orbit of 650km. Crucial for the scientific aims of EnMAP are the target revisit time of 27 days (VZA<5°) respectively 4days (VZA<30°). The launch of the satellite is slated for 2020, with a design mission lifetime of 5 years.

The single payload of the satellite is the hyperspectral imager (HIS). It is capable of measuring the solar radiance reflected from the Earth's surface as a continuous spectrum in the spectral range of 420nm to 2450nm. An overview of the performance characteristics of the HIS is given in Table 1.

Table 1. Important performance parameters of the hyperspectral instrument on EnMAP.

	VNIR	*SWIR*
Spectral range	420 - 1000 nm	900 - 2450 nm
Number of bands	88	154
Spectral sampling interval	6.5 nm	10 nm
Spectral bandwidth (FWHM)	8.1 ± 1.0 nm	12.5 ± 1.5 nm
Signal-to-noise ratio (SNR)	> 400:1 @495 nm	> 170:1@2200 nm
Spectral calibration accuracy	0.5 nm	1 nm
Ground sampling distance	30 m x 30 m (at nadir; sea level)	
Swath width	30 km (field-of-view = 2.63°across track)	
Swath length	1000 km/orbit - 5000 km/day	

The important optical units of the HIS are the telescope, the VNIR spectrometer, the SWIR spectrometer and the calibration units. The two spectrometers have a distinct on-ground FOV, with the VNIR spectrometer FOV following the SWIR spectrometer FOV by about 600m on-ground. The calibration units allow a spectral and radiometric on-board calibration. The OBCA (on-board calibration assembly) allows spectral and relative radiometric calibration by means of two calibration spheres. One of them is furnished with a rare earth-doped diffuser which provides a stable and typical spectrum. The absolute radiometric calibration is accomplished by the FADA (Full Aperture Diffuser Assembly), a spectralon which is illuminated by the sun.

In order to compensate the thermal external environment which is changing over the orbit, active mini-loop-heat pipes are thermally stabilizing the two spectrometer line-of-sight to each other. In addition, the platforms' star trackers are directly connected to the IOU in order to optimize the stability of the pointing knowledge [2].

2. CURRENT STATUS OF THE INSTRUMENT & PLATFORM

2.1 Completion and Characterization of the telescope setup

The instrument optical unit (IOU) of EnMAP consists of two parts, the instrument spectrometer unit (ISU) and the telescope assembly (TA). The telescope design is a TMA with a 18cm entrance aperture and includes one additional fold mirror. While the ISU assembly is still ongoing the TA has passed all integration steps. A last assessment regarding light tightness has been recently successful accomplished. The three pictures in Figure 2 show the TA from different perspectives during this activity in the ISO5 room at OHB in Oberpfaffenhofen.

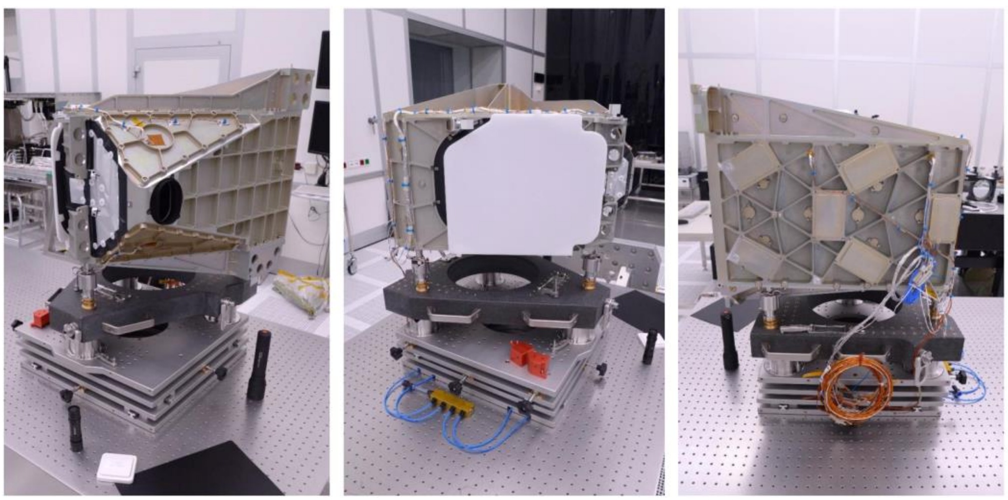

Figure 2. EnMAPs telescope assembly (TA) from different views during the light tightness check.

Having a fully assembled telescope assembly gives way to mount the TA to the spectrometer unit. The first iteration of placement and alignement is done. Currently the final flight hardware shims necessary for a precicse positioning of the TA in respect to the ISU are in manifacturing. Figer 3 shows the ISU with the spectrometer compartments already closed (black covers) and the TA (the telescope is indicated with the blue circle) assembled together. This is one of the first pictures of the full instrument optical unit.

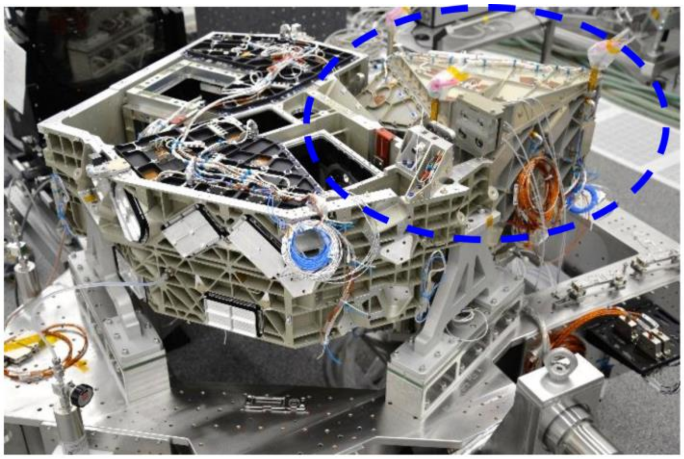

Figure 3. The picture shows the instrument optical unit (IOU) of EnMAP including the telescope assembly (TA) and the instrument spectrometer unit (ISU). The blue circle indicates the TA.

2.2 Assembly of the spectrometers

The optical dispersion within EnMAP is achieved by a number of large prisms made of fused silica and SF6 respectively. The prims together with reflective mirrors are arranged in a monolithic aluminum compartment providing two spectral channels (VNIR, SWIR). A huge step forward in the overall AIT process has been achieved recently by placing and aligning all optical flight components of the two spectrometers [3]. Figure 4 shows the compartment of the VNIR channel within the aluminum structure. On the left side the frame of the four VNIR prisms are visible form bird's-eye view, on the right side the compartment is already closed.

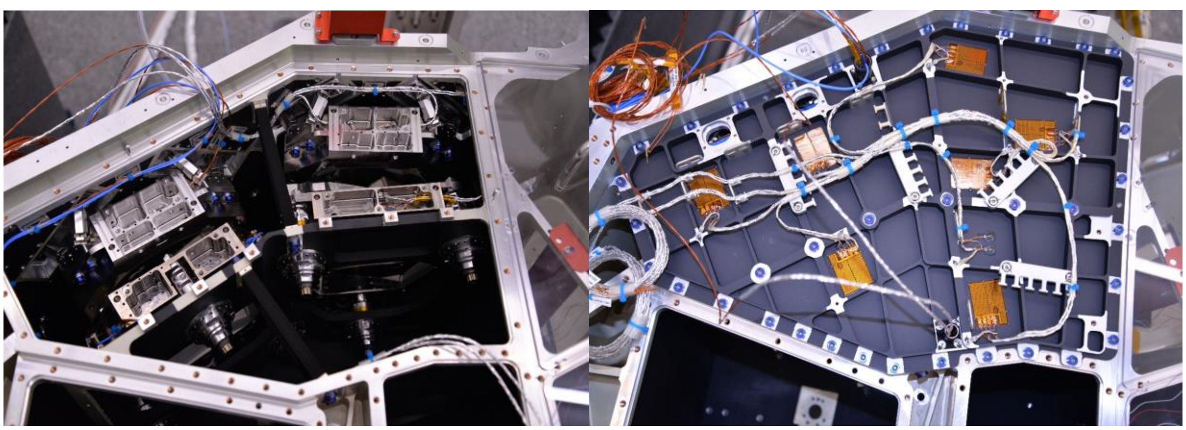

Figure 4. VNIR channel compartment of EnMAPs instrument spectrometer unit (ISU). At the left the frames of the four VNIR prisms can be seen from bird's-eye view At the right the compartment is already closed by a black cover.

Placement and alignment has taken place. The characterization of the spectrometer units requests a complex setup of optical ground support equipment. Measurements have been accomplished and show satisfactory results. For the SWIR channel the wavefront error (WFE) in single pass is found to be between 34 and 243 nm RMS. A result that has been achieved by only one single alignment correction iteration. Table 2 gives a comprehensive overview of the WFE results for measurements at two different wavelengths and five position symmetric to the center of the slit.

Table 2. Overview on RMS wavefront errors of the SWIR spectrometer measured at 5 different positions symmetric from the center at 940nm and 1550nm.

RMS WFE [nm]	940 nm	1550 nm
+12 mm	120	159 / 166
+8.4 mm	39	- / 94
0 mm	93	84 / 85
-8.4 mm	59	- / 128
-12 mm	78	161 / 177

Similar straight forward the alignment of the VINR path resulted in a RMS wave front errors between 79 nm and 235 nm. More detail on the spectrometer characterization is given in table 3, where the RMS wavefront errors at 450nm, 659nm and 940nm are summarized. Measurements have been collected at symmetric position from the center of the slit.

Table 3. Overview on RMS wavefront errors of the VNIR spectrometer measured at 5 different positions symmetric from the center and at three different wavelength: 450nm, 659nm and 940nm

RMS WFE [nm]	450 nm	659 nm	940 nm
+12 mm	87.4 ± 6.5	79.8 ± 0.8	78.6 ± 0.5
+8.4 mm	125.9 ± 10.4	118.4 ± 1.1	95.1 ± 0.4
0 mm	152.6 ± 10.9	147.5 ± 0.9	119.2 ± 0.3
-8.4 mm	155.4 ± 9.4	141.9 ± 0.6	162.7 ± 0.7
-12 mm	213.0 ± 11.1	203.5 ± 0.9	235.1 ± 0.7

As an example Figure 5 shows the wave front error measurement of the VNIR spectrometer at 660 nm at the center of the slit (x= 0mm). It gives an impression of the relative wave front error still containing the well defined contribution from the measuring device (SpecSid) itself. For absolute WFEs the SpecSid contribution is eliminated and results are given in table 2 and 3.

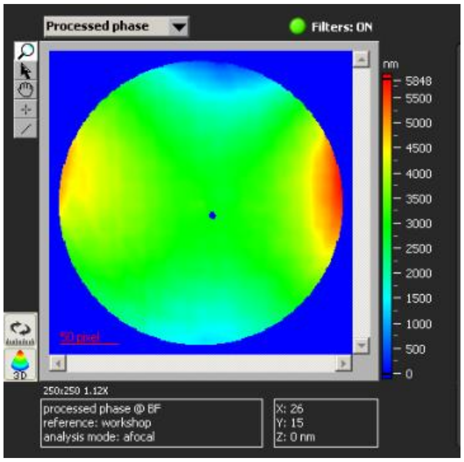

Figure 5. Wave front error of VNIR spectrometer at the center position measured at wavelength of 660nm.

The left over WFE for both spectrometers is within the budged and meets the requirements demanded, resulting in a successful characterization of the SWIR and VNIR spectrometer.

2.3 Setup and characterization of the on-board calibration source OBCA

EnMAP possesses an on-orbit calibration assembly (OBCA) to pursue the spectral and radiometric behavior of the instrument during in-orbit operation. The spectral calibration sphere with a rare earth-doped diffuser provides a stable and well defined spectrum. An Ulbricht integrating sphere serves as homogeneous source for radiometric calibration. A compact overview of the entire on-board calibration approach is given in the companioning paper by M.Muecke in chapter three [3]. The flight model of the OBCA is assembled and has recently gone through the ground based calibration campaign at PTB (Physikalisch-Technische Bundesanstalt) yielding a positive result regarding the spectral stability of the system. Figure 6 shows the spectrum of the OBCA using the different lamps [3].

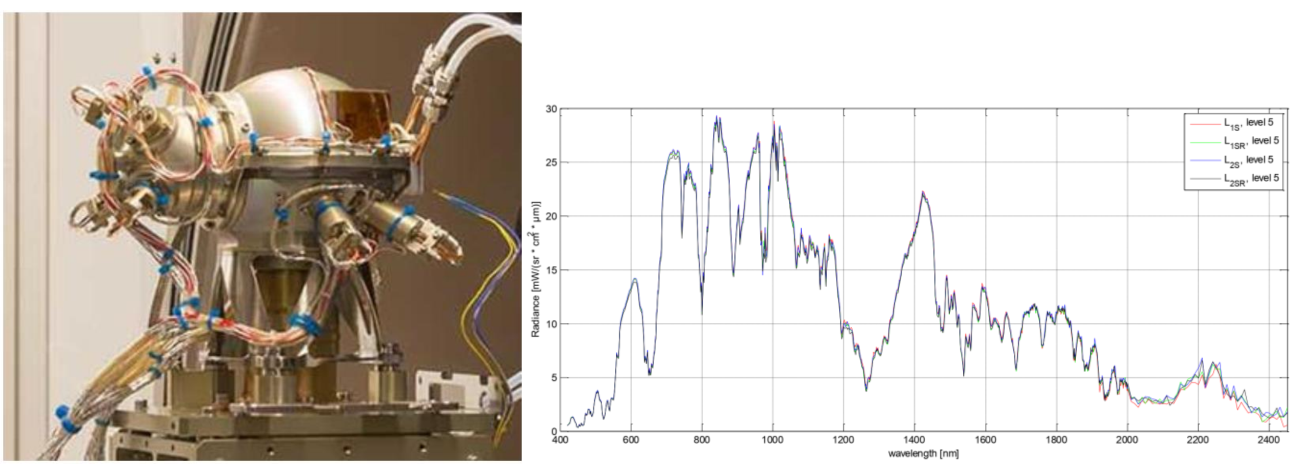

Figure 6. The picture shows flight model of EnMAPs on-board calibration assembly (OBCA) and the diagram gives the spectral radiance used for spectral stability measurements. The different colors show results of the two different lamps and their redundancies.

2.4 Implementation of the two front end devices: VNIR-CAM & SWIR-CAM

The two spectrometer channels need their focal plane. The VNIR camera is a 1056x256 pixel CMOS imager. The pixel size is 24x24µm. It is actively cooled by a TEC (thermo-electric cooler) and operates at 21°C. The columns contain the spectral information, whereas the lines collect the spatial data for the bush-broom operating satellite. The VNIR camera is provided by DLR-OS and the flight model has undergone the full acceptance testing and has already been delivered to the prime OHB System AG, where the camera is currently integrated in the instrument optical unit. A picture short before integration is given on the left side in Figure 7.

The SWIR camera is a MCT detector with a dimension of 1024x256 pixel. The pixel size is 24x32µm. It is actively cooled by a pulse tube cooler and operated at 160K. Like the VNIR-CAM the columns contain the spectral information, whereas the lines collect the spatial data for the bush-broom operating satellite. The SWIR camera, a picture of the qualification model is shown in Figure 7 at the right side, is a delivery item of AIM Infrarot-Module GmbH. The first flight model has been delivered for pre-assembly to OHB. Acceptance testing will be accomplished after the pre-assembling and followed by the integration into the instrument optical unit in the first half of the year 2019.

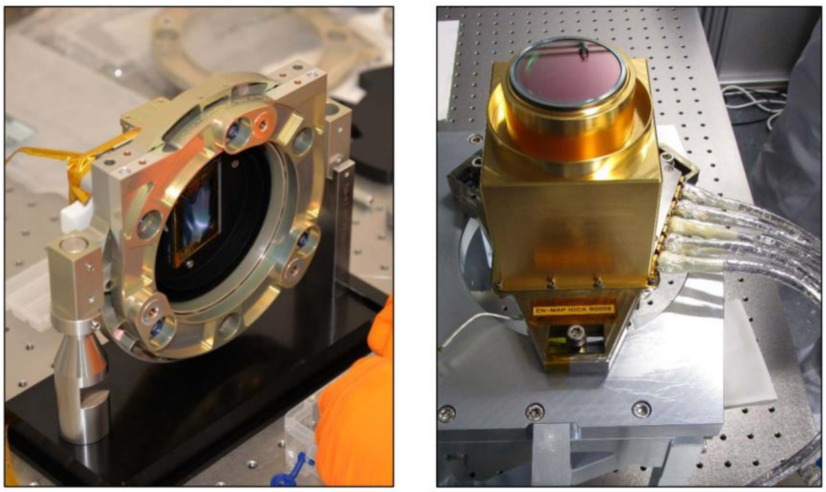

Figure 7. The left picture shows the VNIR detector assembly ready to be integrated into the instrument optics unit. At the right side the qualification model of the SWIR focal plane is pictured.

2.5 Integration of the calibration chain

Currently the calibration chain integration is work in process. The main component is the above described OBCA. It is assembled and characterize and therefore ready for implementation (see chapter 2.3).

Beside the OBCA the "calibration source optics assembly" CSOA, the "shutter/calibration mechanism assembly" SCMA and the "field splitter slit assembly" FSSA are part of the calibration chain. The FSSA is a double slit of two times 24µm x 24mm separated by 480µm providing the two entrance slits for the two spectrometer channels (VNIR,SWIR). It is made out of a silicium waver and the slit opening is micro machined. A detailed description of the slit assembly can be found in [4]. The slit is assembled, measured and the flight model is integrated in the ISU. The SCMA serves to select between different sources. A wheel allows to choose between the nominal Earth observation, the calibration source (OBCA), a dark calibration with a closed port and a fail save position. The last part of the calibration chain, the CSOA is the optical assembly to image the radiation from the OBCA via the SCM mirror onto the FSSA. SCMA as well as CSOA are ready for integration, which will start after completion of the VNIR-CAM integration. Therefore a VNIR spectrum of the calibration source is expected in near future.

2.6 Assembly of the platform

The mechanical integration of the bus is largely completed, with the procurement of units with a planned delivery at a later stage of the project ongoing. In May 2017, the EnMAP platform was transferred from OHB Bremen to the system prime in Oberpfaffenhofen.

Currently, the platform's electrical integration and preparation of bus functional and acceptance tests planned for 2019 are being performed in the ISO8 cleanroom at OHB System AG. Figure 8 shows the current status of the platform. The physical S-band and X-band up- and downlink IFs have been successfully tested in 2016 and platform and system level interface tests with the ground segment are in preparation.

To complement the platform two additional components are needed but the due date is short before launch. Nevertheless activities have been started to get them ready in time. One is the battery/power subsystem which passed the critical design review in the first half of 2018. The second one is the solar generator which has to go through the critical design review in near future.

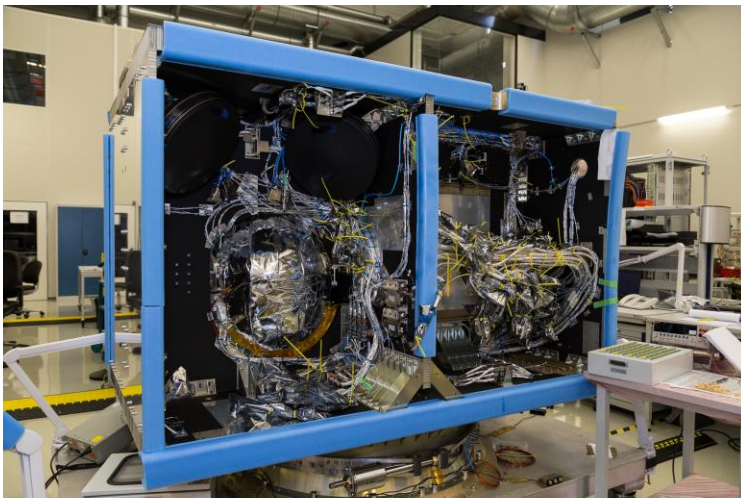

Figure 8. EnMAPs platform during electrical integration activities at OHB in Oberpfaffenhofen

3. CONLUSION & OUTLOOK

At this time most of the sub-systems of the instrument are assembled and ready for integration, hence the setup of the instrument optical unit IOU is advancing. The optical elements of the two spectrometer channels are successfully placed and the spectrometers are aligned and characterized. The focal plane of the VNIR channel placement is currently ongoing, followed by the implementation of the calibration chain. At that point the first on-ground spectra of EnMAP is expected, containing the information about the spectral calibration sphere from the OBCA in the VNIR wavelength range. The next important steps are the environmental test campaign of the instrument optical unit IOU by the beginning of 2019 and a comprehensive on ground calibration of the instrument [5]. After joining the platform, which is currently in its electrical integration and testing phase, the satellite shall be ready for launch at the end of 2020.

ACKNOWLEDGEMENTS

The work presented in this paper was performed on behalf of the German Space Agency DLR with funds of the German Federal Ministry of Economic Affairs and Technology under the grant No. 50 EP 0801. The authors are responsible for the contents of this publication.

REFERENCES

[1] Guanter, L., Kaufmann, H., Segl, K., Foerster, S., Rogass, C., Chabrillat, S., Kuester, T., Hollstein, A., Rossner, G., Chlebek, C., Straif, C., Fischer, S., Schrader, S., Storch, T., Heiden, U., Mueller, A., Bachmann, M., Mühle, H., Müller, R., Habermeyer, M., Ohndorf, A., Hill, J., Buddenbaum, H., Hostert, P., van der Linden, S., Leitão, P., Rabe, A., Doerffer, R., Krasemann, H., Xi, H., Mauser, W., Hank, T., Locherer, M., Rast, M., Staenz, K. and Sang, B., "The EnMAP Spaceborne Imaging Spectroscopy Mission for Earth Observation", *Remote Sensing*, vol. 7, issue 7, pp. 8830-8857, (2015).

[2] Fischer, F., Sang, B., Heider, B., Erhard, M., Betz, M., Honold, H-P., Sornig M., Straif, C. and Chlebek, C., "The Hyperspectral Instrument on-board EnMAP, Overview and Current Status", SPIE 10562, 191 ICSO (2016)

[3] Muecke, M., Sang, B., Heider, B., Honold, H.-P., Sornig, M., Fischer, S., "EnMAP-Hyperspectral Imager (HIS) for Earth Observation: Current Status", ICSO 2018, unpublished

[4] Huber, G., Sang, B., Erhard, M., Staton, G. Honold, H.-P., Schmitt, S., Zauner, C., Sornig, M., Fischer, S., „ An all-silicon, hight precision double-slit device for hyperspectral imager EnMAP, ICSO 2018, unpublished

[5] Lettner, M., Lamour, T., Polz, L., Glastre, W., Compain, E., Fischer, S.,"Versatile full Aperture Illumination OGSE Setup for Alignment and End-to-End Calibration of the EnMAP Hyperspectral Imager, ICSO 2018, unpublished