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SPECTROModule: A modular *in-situ* spectroscopy platform for Exobiology and Space Sciences

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Abstract

The evolution of the solar system and the origin of life remain some of the most intriguing questions for humankind. Addressing these questions experimentally is challenging due to the difficulty to mimic environmental conditions representative for Early Earth and/or space conditions in general in ground based laboratories. Performing experiments directly in space offers the great chance to overcome some of these obstacles and to possibly find answers to these questions. Exposure platforms in Low Earth Orbit (LEO) with the possibility for long-duration solar exposure are ideal for investigating the effects of solar and cosmic radiation on various biological and non-biological samples. Up to now, the exobiology and space science research community has successfully made use of the International Space Station (ISS) via the EXPOSE facility to expose samples to the space environment with subsequent analyses after return to earth. The emerging small and nanosatellite market represents another opportunity for astrobiology research as proven by the O/OREOS mission, where samples were analyzed in-situ. In this framework, the European Space Agency is planning the development of a novel Exobiology facility outside the ISS. The new platform, which can host up to seven different experiments, will combine the advantages of the ISS (long-term exposure, sample return capability) with near-real time in-situ monitoring of the chemical/biological evolution in space. In particular, ultraviolet-visible (UV-VIS) and infrared (IR) spectroscopy have been considered as key non-invasive methods to analyze the samples in-situ. Changes in the absorption spectra of the samples developing over time will reveal the chemical consequences of exposure to solar radiation. Simultaneously, spectroscopy provides information on the growth rate or metabolic activities of biological cultures. The first four selected experiments to be performed on-board are IceCold and OREOcube, Exocube-bio and -chem. To prepare for the development of the Exobiology facility, ground units of the UV-VIS and IR spectrometers have been studied, manufactured and tested as precursors of the flight units. The activity led to a modular in–situ spectroscopy platform able to perform different measurements (e.g. absorbance, optical density, fluorescence measurements) at the same time on different samples. The paper will describe the main features of the platform installed under a solar simulator, the verification steps and approach followed in the customization of components –off-the shelf (COTS) to make them suitable for the space environment. The ground platform supports the establishment of analogue research capabilities able to address the long-term objectives beyond the current application.

Keywords: Exobiology, Spectroscopy, In-situ monitoring, Low Earth Orbit, International Space Station

Acronyms/Abbreviations

International Space Station (ISS), components –off-the shelf (COTS), ultraviolet-visible (UV-VIS), infrared (IR), Low Earth Orbit (LEO), Fourier-transform infrared spectroscopy (FTIR), Ground Model (GM), European Space Agency (ESA), Planetary and Space Simulation (PSI), Optical Density (OD), light-emitting diode (LED), Scientific Module (SM).

1. Introduction

Since the early 1990's there is a long heritage of ESA Exobiology flight experiments, initially using the EURECA facility, deployed and retrieved by the Space Shuttle. Multi-users platform as "BIOPAN" (short-term) and the EXPOSE (outside ISS up to 1 year), refer to Figure 1, have allowed exposing samples to the effect of the space environment [1]. These missions provided an unique set of data to understand the influence of UV, cosmic radiation, vacuum, weightlessness, thermal excursions on several organic and life forms. The main limitation of these facilities' generation was the unavailability to perform in-situ measurements with subsequent analyses after return to earth.

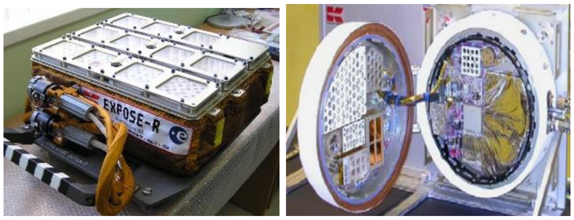

Figure 1 : EXPOSE-R Facility (on the left) and BIOPAN Faciliy (on the right)

The advantage of long-term exposure and mainly sample return, is fostering the development of new platforms (commercial and institutional) to provide more locations and opportunities for accommodation of exposed payloads. Examples for ISS are [2]:

- Nano Racks External Platform NREP
- IVA-replaceable Small Exposed Experiment Platform i-SEEP

Another platform, which can be installed on Exposed Logistic Carriers (ELC-2), is:

- Materials International Space Station Experiment MISSE-X [3]

The emerging small and nanosatellite market represents another opportunity for astrobiology research as proven by the O/OREOS mission [4], where samples were analyzed in-situ; but with the limitation and sample number and no option to return the samples to Earth.

In this framework, the European Space Agency is planning the development of a novel Exobiology facility outside the ISS. As outcome of the ILSRA 2014 exercise, seven experiments, namely BIOSIGN, MASE-in-Space, IceCold, RISE, GENESISS, EXOcube and OREOcube, have been selected for implementation on this Facility. Therefore, the platform design is based on a modular approach to accommodate the needs of all the seven experiments, and it will be equipped with an array of instruments to fulfil their different requirements.

More in detail, the experiments GENESISS, Exocube, IceCold and OREOcube will require in-situ measurement. In particular, IceCold and OREOcube will require the use of an UV-VIS Spectrometer, and Exocube will require the use of both a UV-VIS Spectrometer and of an IR-spectrometer.

1.1 SPECTROModule project objectives

To prepare for the development of the EXOBIOLOGY facility, ground units of the UV-VIS and of IR spectrometer have been studied, manufactured and tested as precursor of the flight units. The spectrometers represent the core instrumentation for the samples in-situ measurements. The instruments, in order to fulfil the acquisition, will be coupled with the "samples handling mechanisms", which describes the system/ subsystem allowing the acquisition of data by bringing the samples in contact with the measurement systems. The elaborated spectrometer and the sample acquisition system (called SPECTROModule GM) design, has been used as input to define the interfaces and specification of the new facility as well as the software specification to fulfil the experiments execution and scientific data handling. The Exobiology Facility will be accommodated outside Columbus (currently on the upcoming Bartolomeo Platform [5]).

The Ground model has a double purpose:

a) The spectrometer and sample acquisition system (SPECTROModule) have to be a proof of concept of the proposed technical solution for the flight unit, hence it has to be representative of the flight design solution. The system has to be validated and tested to assess the compliance to the ISS environment and assure to perform as planned.

b) The SPECTROModule and the Ground Support Equipment (GSE) delivered in the frame of the project have been used also as Science Reference Module (SRM) by the scientists to test the system performances and the experiments protocols. Therefore, the GM system has to be flexible and reconfigurable to serve different setups to support the scientific teams in identifying the suitable experimental protocols and potential improvement areas.

The paper reports the main outcomes of the SPECTROModule project focused on the activities performed for ground model of the UV-VIS spectrometer, samples acquisition system and FTIR spectrometers.

2. Experiments Definition for the first mission

2.1 First Mission Overview

The EXOBIOLOGY facility will be a multi-users platform. Therefore the utilization concept is based on the development of a "Common Module", which will represent a fixed interface to the exchangeable Scientific Modules (SM1 & SM2) uploading a different set of experiments. Considering the scientific requirements of the experiments and of the necessary instruments, the first group accommodated on the SM1 will consist in OREOCube, IceCold and Exocube. It can be envisaged that the facility will first be deployed for about 1 year to perform the mentioned 3 experiments, then retrieved inside the ISS for reconfiguration for the remaining 4 experiments, and then redeployed outside the ISS for about 1 year.

2.2 IceCold

The icy moons of the outer solar system, in particular Europa and Enceladus, are part of the few possibly habitable places in our solar system. Though the moon´s surfaces are too hostile to expect any life, the liquid water oceans beneath the water ice surfaces may provide the necessary environment to support life similar to Earth´s deep oceans. Recent evidence of possible very-near surface water (brine) together with the geological youthfulness of the linea features and observed plumes support the idea of a possible extant habitat. Life existing near the surface – even if transient - may interact with surface electromagnetic and particle radiation. Short wavelength solar UV and – in case of Europa - Jupiter´s radiation might penetrate into the ice shield and brines, challenging possible life to evolve protection mechanisms. The IceCold experiment tests the hypothesis that selected extremophile microorganisms, representing the 3 domains of life on Earth, survive and multiply in a periodically cold (below 0°C), salty, liquid environment, even when exposed to low extra-terrestrial short wavelength UV and ionizing radiation, in space on an outside exposure platform of the ISS. The candidate test organisms *Halorubrum lacusprofundi* (archaeon, 1), *Rhodococcus JG-3* (bacterium,) and *Rhodotorula JG-1b* isolated from Antarctica grow at low temperatures in salty liquid media. They are complimented by the bacteria *Deinococcus radiodurans*, *Bacillus subtilis* and the archaeon *Halobacterium salinarum*. The set of microorganisms will be uploaded in a metabolically passive, dried form. When installed on the expected destination Bartolomeo outside of the ISS, the metabolism and growth of the cultures is started by the addition of medium, marking also the start of the experiment. The cultures growth will be monitored by automated repeated measurements of the optical density (OD). Increasing OD of the cultures indicates growth of the microorganisms while no OD increase indicates microorganisms that are not multiplying. The in-flight control set of samples will remain in the dark during the whole mission while the test set is covered with MgF_2 windows and shutters for defined irradiations with extra-terrestrial short wavelength solar radiation.

The cell growth of 36 samples (18 sun irradiated, 18 in the dark) is monitored via OD measurement. Considering that the culturing medium by itself can contribute to the OD and to change thereof, three sun exposed and three dark culture-free cuvettes will be accommodated and optically measured. The following optical measurements will be performed, refer to the Figure 2:

- OD of each culture (Sun irradiated and in the dark)
- OD measurements of the cuvette filled by medium only, will provide the light absorption caused by the medium itself that has to be subtracted. This value is understood to be the reference measurement (blank)
- Measurement of the solar spectrum behind the optical window (attenuated) to give information about transmissivity of the window.
- Solar spectrum not attenuated by any window.
- Measurement of the dark spectrum, which should be subtracted from both sample and reference spectra.

IceCold will not be temperature controlled and hence oscillate with the LEO temperature at the exposure platform. Incident extra-terrestrial solar UV will be measured by the experiments common spectroradiometer.

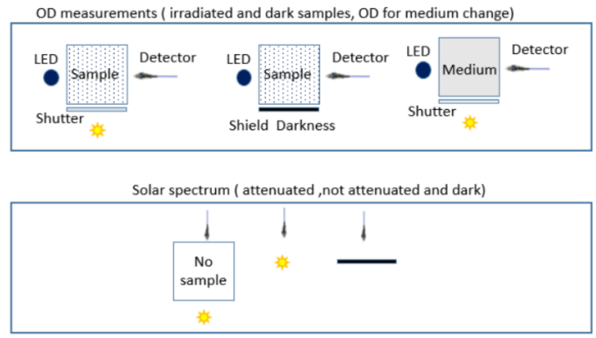

Figure 2 : IceCold OD and spectra measurements

All obtained science (OD) and environmental (temperature, UV spectra) data will be transmitted to Earth for analysis regularly together with housekeeping/health data. The overall mission exposure time is expected to be approximately 6 months. After exposure, the samples will be returned to Earth for additional investigations. A flight identical ground reference experiment will be performed in parallel to the mission according to the mission data in the Planetary and Space Simulation facilities at DLR Cologne as far as possible.

The psychrophilic organisms proposed for the space experiment here are representatives of very important groups of microorganisms on Earth. The experiment will increase our knowledge on the limits of life and serve as demonstrator for free flying experiment in higher radiation orbits.

2.3 OREOcube

Current and upcoming planetary exploration missions such as Curiosity [6] from NASA or ExoMars [7] from ESA fuel our pursuit of tracing life's origin on Earth and possibly beyond. The stability of molecules indicative for life, so called biomarkers, is a prime objective of OREOcube. Studying the stability of astrochemically relevant organic molecules when exposed to photons, electrons and heavier particles has a long history in ground based experiments [8]. Numerous facilities and laboratories worldwide are capable of exposing samples to selected or extended parts of the electromagnetic spectrum, electrons and/or heavier particles such as atoms or ions. However, to date, it is technically and experimentally extremely challenging, and economically unfeasible, to reproduce solar radiation levels faithfully in ground based laboratories [9]. In the last decades, experiments on the ISS provided valuable data on the effect of the outer space environment in low Earth orbit on organic and biological samples [10]. Until recently, most of these studies relied on the characterisation of the organic material prior and after their exposure period in space. However, real kinetic information cannot be obtained with this approach. Attempts to equip space exposure platforms with in situ measurement capabilities have been successfully accomplished by NASA in the form of free-flying nanosatellites. A recent example is the O/OREOS satellite [11]. Similarly, with its in situ spectroscopic capability, OREOcube will measure changes in organic samples when in contact with inorganic surfaces and provide insights into the kinetic details of photochemical reactions in order to study radiation-induced modifications of astrochemically relevant organics and inorganics. In addition to the in situ capabilities, OREOcube samples will be returned to Earth to allow further sophisticated analysis in ground based laboratories. Potential candidates of organic compounds and inorganic substrates for the OREOcube project were selected based on recent findings and observations in the fields of astronomy, astrophysics, meteoritics and planetary sciences.

The OREOcube experiment requires the acquisition of different spectra of organic compounds and some samples mixed with inorganic substances. The photochemical changes will be acquired by the UV-VIS spectrometer. Four different measurements are performed in-situ, as shown in the Figure 3:

- Sample cells spectra
- Sample free-cells are used as reference spectrum to normalize the measurement
- Dark spectra with the Sun, blocked off, and without cuvette to determine signal level changes and to correct for baseline offset and fixed pattern noise
- Direct Solar Spectrum

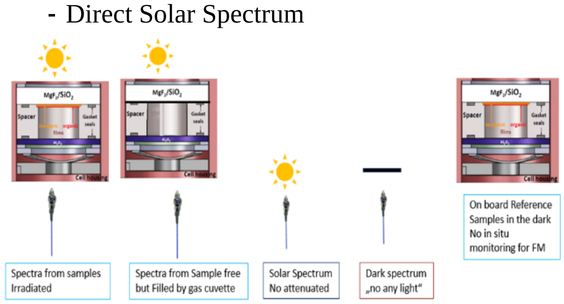

Figure 3: OREOCube samples measurements' set

2.4 Exocube

The interaction of solar and cosmic radiation with organic molecules and biological systems is of great importance in space science and in particular for astrobiology [12] and astrochemistry [13]. How does life at different stages of complexity respond to, and evolve in, space and planetary conditions? During such processes, what biomolecular mechanisms come into play at the interfaces between biology, chemistry, and physics? Exocube is aiming to address these questions with far-reaching implications for the interpretation of the results of past and upcoming planetary exploration missions.

With its heritage from the NASA O/OREOS mission [4], Exocube represents a new generation of space exposure platforms based on miniaturized in-situ analytical instrumentation. Infrared spectroscopy as well as fluorescence and colorimetric measurements will allow monitoring radiation effects on biological molecules and organisms. According to the type of samples, a short name has been assigned: ExocubeChem ('chemistry', i.e. non-living samples) and ExocubeBio ('biology', i.e. (mostly) living samples). Exocube will couple the capability of in-situ online monitoring of organism responses to the spaceflight environment with detailed post-flight sample analyses on the ground.

The ExocubeBio experiment aims, using an UV-VIS spectrometer, to acquire the OD (Optical Density) and fluorescence signal as indication of biological and metabolic activities. The ExocubeChem experiment requires the use of FTIR spectrometer for the acquisition of different spectra of biological membranes samples directly deposit as thin film on the exposure window. In this way, we can investigate (i) the response of life at different stages of complexity to space conditions and (ii) the role of membranes and membrane components as the interface between life and the physical environment.

The Exocube experiment will expose protocells, prokaryotes and eukaryotic cells to space radiation in low Earth orbit and microgravity and measure in-situ their biological response via reporter dyes. This, together with further sophisticated ground-based post-flight analysis, will allow us to study in detail the bio-molecular pathways triggered by radiation events and microgravity. It will also help to identify key molecules and membrane components that are involved in the adaptation of these organisms to space conditions.

3. SPECTROModule Project

The project has been executed on four main phases, as illustrated in the Figure 4.

The Phase I activities included a market survey to identify off-the-shelf (OTS) instruments which can be used for the Exobiology Facility Spectrometer and consolidate the instruments specifications considering performances as well as the environment in which the instrument will work and the need to be integrated into the Exobiology facility. The Phase II led to a design and customization of the identified instruments, sample handling system and Ground Model platform. Later in the Phase III, the main Manufacturing, Assembly, Integration and Testing (MAIT) activities have been performed on the Ground Models. It is worthwhile to clarify that for the UV-VIS SPECTROModule GM hardware two models of the spectrometer and sample handling were released (GM#1 and GM#2) considering the challenging schedule over 1 year Developing two models allowed decoupling environmental tests from the scientific test campaign at scientists' site, performed in the Phase IV.

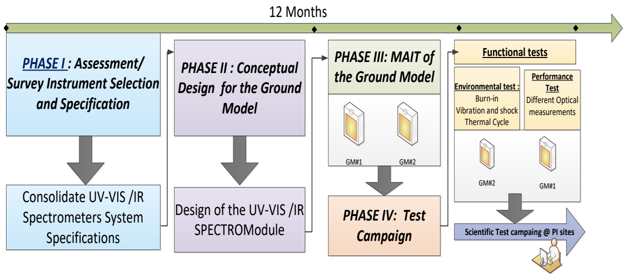

Figure 4. SPECTROModule project phases

3.1 System description

SPECTROModule consists of two different hardware setups. The first setup includes an UV-VIS spectrometer for servicing the experiments OREOCube, ExocubeBio, and IceCold. The second setup uses a FTIR spectrometer for the experiment ExocubeChem. The spectrometers have been selected to fulfil the scientific requirements defined for each experiment, as well as technical constraints related to operating environment (outside ISS) and available budgets. The following main points have been used to screening the market for the most promising ones:

- Spectrometer with high optical performance: wavelength range 200-1000nm, spectral resolution of 2 nm, Absorbance Unit accuracy of 0.03 and Signal-to-noise ratio (SNR) 250:1
- Compliance with power budget (5W) and dimensions (10x10x10 cm^3)
- Independent interfaces cuvette/spectrometer for sample removal
- Space Application heritage

The key point, mainly for the UV-VIS architectural design, has been identified in the Sample Handling system. It represents the "method/technique" selected to bring all the samples of the 3 experiments to be observed by one spectrometer. In total, about 120 sample measurements need to be performed for the Flight Model using one spectrometer and the minimum number of samples for ExocubeBio. The approach used is based on a trade-off analysis considering the reliability and robustness as selection criterion. Moreover, the selected solution will have impact on the sample removal operational concept for the return to Earth, due to that; the Sample Handling represents the direct interface with the cuvette.

Two reconfigurable Ground Model Platforms have been design and manufactured for each optical set-up based on the conceptual layout and future interfaces with the Exobiology Facility, as displayed in the Figure 5.

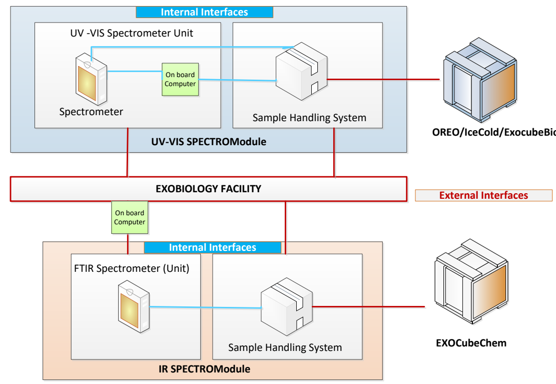

Figure 5: SPECTROModule system concept and interface

3.2 COTS optical instrument: selection, ruggedization and testing

The remainder of this chapter describes how the hardware has been selected and how critical COTS components were ruggedized and tested for use in space.

3.2.1 UV-VIS spectrometer and Samples handling

The UV-VIS spectrometer market survey provided a short list of top candidates' instruments able to fulfil the requested performances. The OEM-Embed 2000 from Ocean Optics was selected as final choice, as shown in Figure 6. This spectrometer can measure spectra from 200 nm to 1000 nm with a spectral resolution better than 2 nm. The OEM version allows developing a dedicated interface for power and software implementation and allow testing of own software code instead of the COTS software from Ocean Optics. One of the main goal of the project was to assess the possibility to use one spectrometer to serve 3 experiments at the same time on the future Exobiology Facility. For the Ground Model two possibilities to perform the acquisition selection between the different samples were presented and compared. They are called "Cell switch", "Fiber switch". Cell switch is a mechanism such as a carousel, which drives the cuvettes under the optical fiber tip for the measurement.

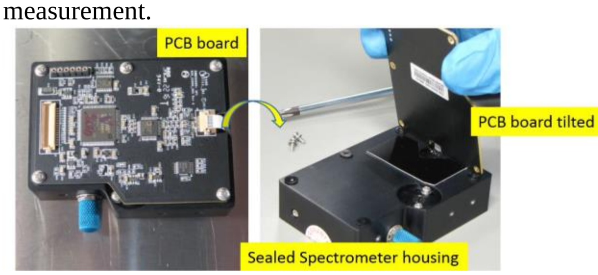

Figure 6: UV-VIS Spectrometer system

While, in the fiber switch concept, each cell is associated to its own dedicated multimode optical fiber. A switch unit is used to select the fiber that is measured by the spectrometer. Due to the strong differences among the experiments in terms of protocols and subsystem (e.g. pumps, reservoirs, several LEDs type); it was agreed in testing the optical fiber switch technology to allow a higher flexibility in sample handling in a compact size. The spectrometer is connected via a customized 48-channel fibre switch from Agiltron (Figure 7) to the experiment cuvettes of IceCold and ExocubeBio and to the OREOCube cartridges. The model Light Bend Mini was the baseline option due to the large wavelength bandwidth, epoxy –free optical path, customization for high amount of ports and small size (4x4x10cm3) and power (1W).

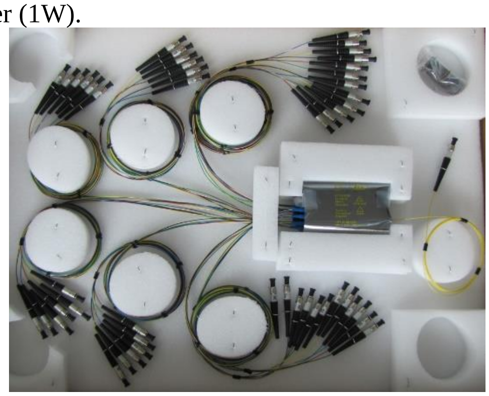

Figure 7: Optical Fiber Switch 1x48 channels

The IceCold and ExocubeBio cuvettes have several LEDs on the opposite sides of the fibres for optical density measurement and LEDs perpendicular to them to perform fluorescence measurements. LEDs with different wavelengths are used for the different biological samples of IceCold and ExocubeBio. The OREOcube samples are directly exposed on one side to a light source, which simulates the Sun. The glass fibre for measurement in the UV-VIS spectrometer collects the transmitted light from the Sun. Figure 8 shows the accommodation of all the experiments on one optical bench.

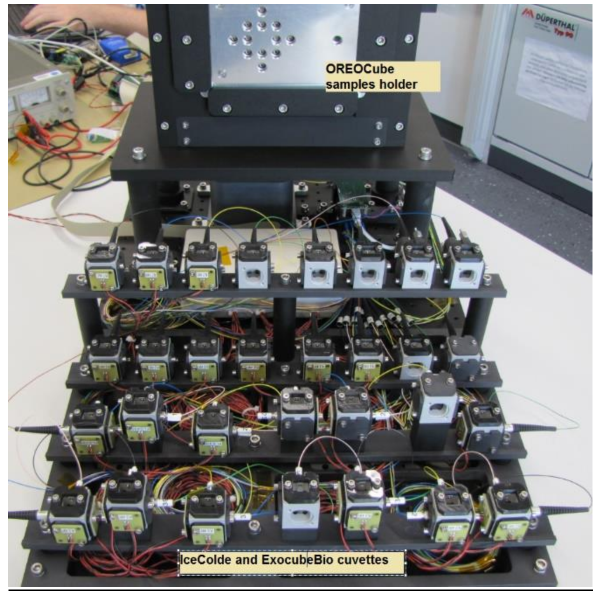

Figure 8 : SPECTROModule for UV-VIS applications

3.2.2 *FTIR spectrometer hardware*

The FTIR spectrometer hardware is required for the ExocubeChem experiment, because these samples show spectral features in the wavenumber range from 1000 cm^{-1} to 4000 cm^{-1}.

A Fourier transform spectrometer has a radically different measuring concept than a grating spectrometer (used for IceCold, OREO and ExocubeBio). In the FTIR spectrometer for ExocubeChem, a collimated light beam from the light source is split via a beam splitter into two light beams. The beams are retroreflected by corner cubes that are mounted on a common pendulum axis. After reflection, the light beams combine and exit the interferometer to be measured with a detector. Due to the oscillation of the pendulum, a time-dependent interference pattern can be recorded at the detector. Following a Fourier-transformation, the interferogram is converted to a spectrum.. In the infrared band, Fourier transform spectrometers have advantages:

- Better signal-to-noise ratio
- Higher spectral resolution
- Flexibility in the spectral resolution

The disadvantage is that they usually are not so compact and require a controlled thermal condition for the quality of the measurements. The market survey lead to the selection of the original equipment manufacturer (OEM) version spectrometer from Arcoptix that consist of a light source, the actual interferometer and a Peltier-cooled detector, refer to Figure 9. High and low power IR lamp sources, have been procured for scientific tests supporting the elaboration of a trade-off assessment between the performances achieved and the thermal and power budgets.

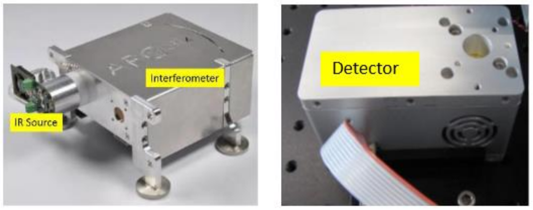

Figure 9: FTIR spectrometers components

The Ground Model platform for the FTIR, refer to Figure 10, has been derived from the optical path design needed to place the ExocubeChem samples under observation, using a linear stage mechanism. The platform is an optical bench allowing adjusting the configuration or including future new items (e.g. second detector). Twelve (12) exposed samples cartridges and twelve (12) dark cartridges can be hosted on the GM Sampling system in total for the test. Two different configurations have been provided to the scientist as transmission and transflection set-up.

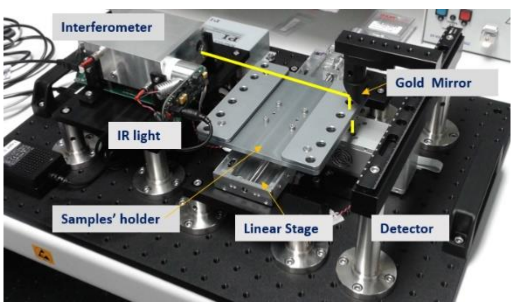

Figure 10 : FTIR GM platform - trasmission set-up

In the transmission set-up, the collimated light beam leaves the spectrometer, which is then directed with a 45° flat mirror through the ExocubeChem sample to the detector, as shown in the yellow light path in the Figure 10. The idea behind the focused transflection setup is to use a mirror and lens in a cats-eye configuration, where the sample is between mirror and lens. Thus, a small aperture of the sample does not reduce the intensity and a double pass through the sample increases the measurement sensitivity (Figure 11). However, the design becomes more complex including more optical components and has increased alignment requirements.

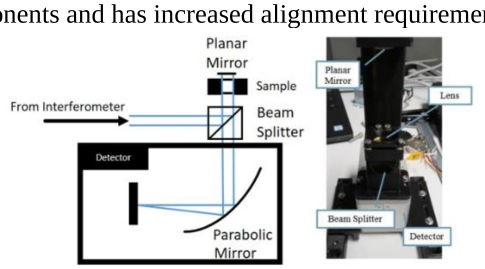

Figure 11: FTIR GM platform - transflection set-up elements

3.2.3 *COTS Ruggedization and Environmental Tests*

The COTS evaluation program for SPECTROModule started with a critical incoming inspection. Components have been evaluated to understand their suitability for use in space outside the ISS, for example if forbidden components are used that outgas; it will compromise the optical components. Afterwards, an environmental test campaign has been performed to evaluate whether critical components can survive the launch and the space environment. The UV-VIS spectrometer and the fibre switch have undergone vibration and shock testing and well as a thermal-vacuum chamber test.

The UV-VIS spectrometer and the fibre switch have been placed in a 0.5 Cargo Transportation Bag (CTB), which was then mounted onto the respective test benches. Figure12 shows the layout of the fiber switch and spectrometer inside the Cargo Transfer Bag. The 48 cables have been fixated in two separate layers on the foam. The UV-VIS spectrometer was placed under these layers. The vibration test was successfully performed at the ZARM, Bremen, and the shock test at the DLR Raumfahrtsysteme in Bremen; considering Protoflight approach. Optical performance measurements have been conducted before and after the tests.

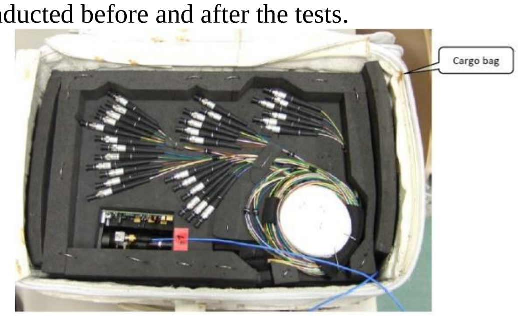

Figure 12: UV-VIS and fiber Switch in 0.5 CTB for vibration and shock tests

The thermal test was performed in-house at OHB Oberpfaffenhofen. The test setup is shown in Figure 13. The fibre-switch with its fibres was directly exposed to vacuum, but the UV-VIS spectrometer was placed in an airtight nitrogen compartment, because the used version was not designed for vacuum.

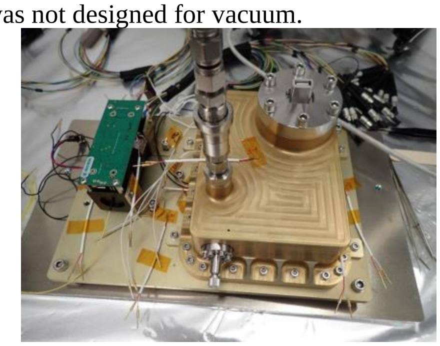

Figure 13 : UV-VIS and fiber Switch Set-up for thermal vacuum test

The setup was connected electrically and optically to equipment outside the chamber to verify the system performance during the test. Overall, eight cycles between -25°C and 60°C were performed. Performance was measured at the extreme temperatures. Interestingly, the spectrometer showed very low values, when close to the upper operational limit declared by the manufacturer. It shows that the UV-VIS spectrometer cannot operate at all beyond its operational limit. However, once the temperature falls again, the spectrometer operates normally. Therefore, a thermal control needed to be implemented in the EXOBIOLOGY Facility.

A total ionizing dose (TID) test was also performed for the fibre switch (without fibres) and the FTIR spectrometer. A Co-60 ELDORADO Source at the Helmholtz Zentrum München (HZM), ISS Institute of Radiation Protection has been used to irradiate the components with a total dose of 1800 rad. The source has a mean gamma energy of 1.25MeV and 0,27Gy/min in 1 m distance, Figure 14. Both the fibre-switch and the FTIR spectrometer have been operating during the test. No anomalies were detected, confirming the promising implementation for LEO applications.

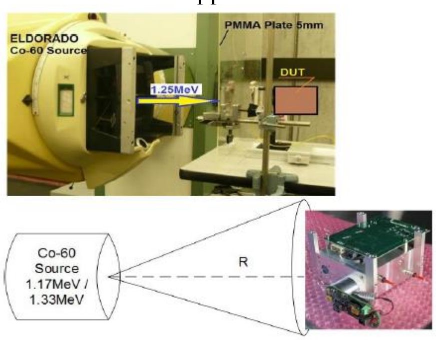

Figure 14 : TID test set-up at HZM

Finally the FTIR spectrometer underwent also a thermal test, where it was successfully cycled eight times from -20°C to +40°C. Customization was implemented, as the removal of the fan from the detector, to simulate the heat exchange outside ISS and 10 layers of MLI, Figure 15, covered detector and interferometer.

FTIR was operated during the cycles, where a constant performance could be monitored, showing no degradation in performances.

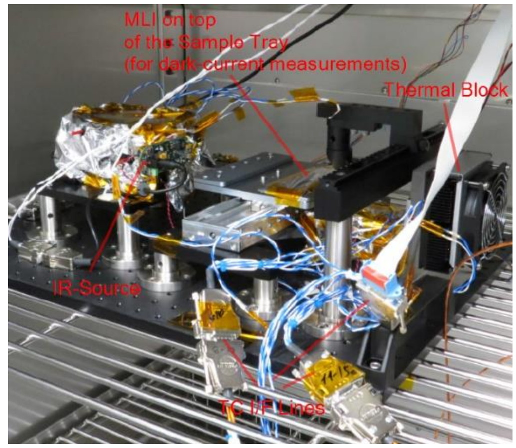

Figure 15 : FTIR Set-up for thermal test

The results of the COTS evaluation program are being used to ruggedize these components for use outside the ISS and dedicated development is on-going with the instruments' manufacturers.

4. Results and Discussion

The performance tests were validated by using a ground model platform, mainly needed for the OREOcube, IceCold experiments which required the Sun as source of light for their measurements. While for the ExocubeChem, the integrated IR source in the system make it testable in normal environmental conditions.

The Ground model platform and the cell holder to keep in place the scientific samples under the observation field have been designed considering as main design driver the capability to place all experiment samples under the irradiation source at same time for the test execution. The DLR Planetary and Space Simulation (PSI) facilities in Cologne has been used and modified to accommodate the platform with all samples or only a portion of it, according to the needs. A dedicated rack has been manufactured to host the SOL2 (solar simulator) lamp with a shutter, while the experiments platform is mounted on the slide table, which allows testing different irradiated positions, as shown in the Fig 16.

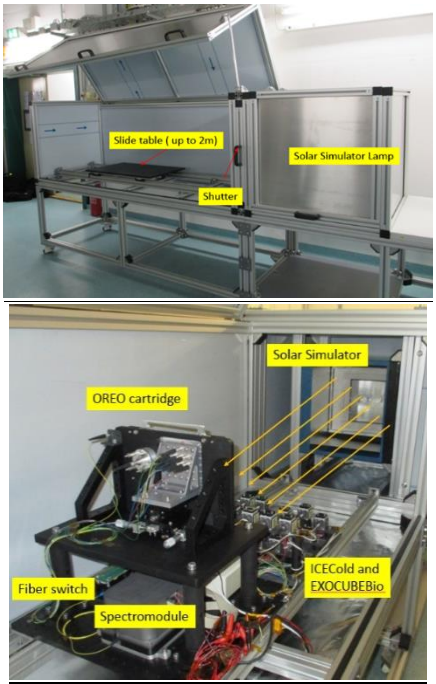

Figure 16: Ground Model Platform: Rack (top) and main plate with experiments Interfaces (bottom) at DLR

The spectrometer with fibre switch port #43 was calibrated using the Bentham calibration lamp. The fibre tip was positioned at a specified distance of 200 mm in front of the glass window of the calibration lamp. Then a validation of the calibration curves was performed using a UVC 254 as source and compare to the value between the Bentham and Spectromodule with different integration times, Fig.17. Further correction measurements are necessary in particular for the short wavelength region below 250 nm and for tor the peak irradiance measurements but overall, the GM#1 accurately follows the wavelengths distribution, with a maximum measured at 254 ± 1 nm.

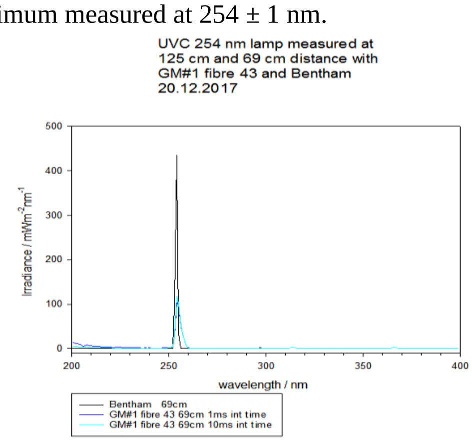

Figure 17: Comparison of Bentham and GM#1 measurements of the UVC mercury low-pressure lamp at 69 cm distance

Tests, performed with the solar simulator at two different distance from the sources, shown a good correlation as reported in the Figure 18

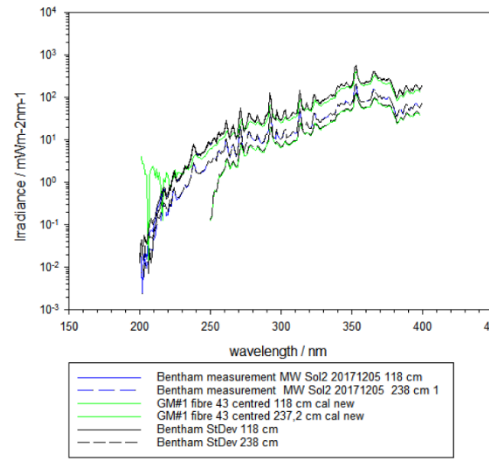

Figure 18. Comparison of Bentham and GM#1 measurements of the SOL2 at 118 cm distance, linear presentation

Several tests were performed with the spectrometers configuration also for the OD and fluorescence measurements using calibrated solutions. The fluorescence reference standard have been used to benchmark SPECTROModule against a bench-top Agilent Eclipse fluorescence spectrophotometer. The results, in combination with LED excitation at 420 and 535nm, revealed a very good agreement, as shown in the Figure 19.

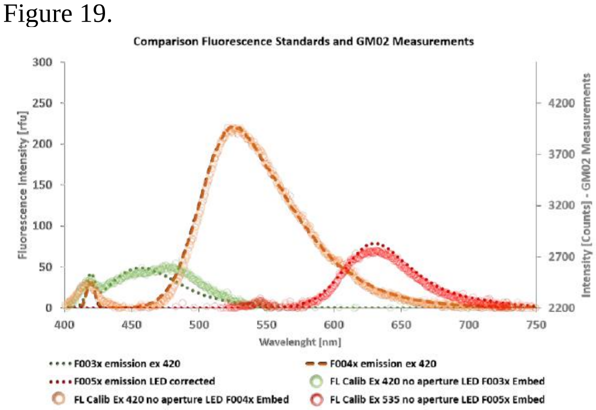

Figure 19: Fluorescent intensity comparisons with fluorescent standards by taking into account differences in LED intensity levels.

5. Conclusions

The SPECTROModule GM platforms are a useful test-bench to prove the suitability of the instruments and experiments 'executions and to prove the expected results. Moreover, the utilization of one spectrometer to serve three experiments in parallel has been revealed

quite challenging with the scheduled operation on board, as well as complex in case of accommodation of more samples. Therefore, the main outcome of the project is the utilization of LEDs and photodiodes to measure OD and fluorescence at fixed wavelength ranges.
The spectrometer and the optical fiber switch will be mainly used for the OREOcube experiment, allowing for a fine-tuning in the ultraviolet region of interest.

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