CONTINUOUS MEASUREMENT OF THE BIOLOGICAL EFFECTS OF STRATOSPHERIC UV RADIATION – BIODOS EXPERIMENT, BEXUS-15

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ABSTRACT

Solar light and especially the ultraviolet (UV) range of the electromagnetic spectrum is an essential environmental factor for life on Earth, for its effects on living systems can be both beneficial and harmful. Studying the effect and the dynamics of solar UV radiation damage on model biomolecules and organisms can contribute to our knowledge on the evolution and survival of life in harsh environments. In order to assess the biological damage caused by stratospheric UV radiation, the experiment presented here tested a new, continuous biodosimetric measurement method on board a BEXUS balloon.

1. INTRODUCTION

The harmful effects of ultraviolet radiation on living organisms are based on the molecular changes introduced mostly in DNA. The DNA chain consists of a sugar-phosphate backbone and purin and pyrimidine organic bases. UV radiation induces the dimerisation of adjacent pyrimidine bases (Fig 1) and leads to the formation of photoproducts such as cyclobutane dimers and 6-4 bipyrimidines [1-3].

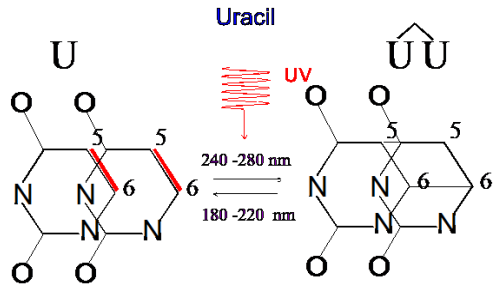

Figure 1. Pyrimidine (uracil) dimerisation due to ultraviolet radiation.

Dimers present in the DNA chain impair the replication mechanism, resulting in mutations or cell death. The ultraviolet spectrum can be divided into four wavelength ranges: UVA (315-400nm); UVB (280-315nm); UVC (200-280nm) and vacuum UV (VUV) (100-200nm). The dimerisation of pyrimidine bases can mainly be attributed to UVB radiation, while shorter wavelengths (UVC) revert this and cause monomerisation [2-3;5]. In polychromatic UV environment, the two processes run parallel and the overall effect reflects the dominant range of radiation. Several biochemical models containing pyrimidine bases are available for studying pyrimidine dimerisation, such as polycrystalline uracil thin layers, bacterial spores and the T7 bacteriophage [4]. The measurement method for the study of UV damage is based on the change in one of the optical attributes of the pyrimidine sample called optical density (OD), which is the logarithmic ratio of radiation falling on a material (I_0) to the radiation transmitted through it (I_t).

$$OD = \log\left(\frac{I_0}{I_t}\right) \qquad (1)$$

Due to the dimerisation of pyrimidine molecules caused by UV exposure, the optical density of the sample (OD) decreases. The OD decrease caused by dimerisation is most prominent in a 50nm wide range of the absorbance spectrum of a pyrimidine base (~250-300nm). The OD change on the outlying ranges cannot be precisely attributed to pyrimidine dimerisation (Fig 2).

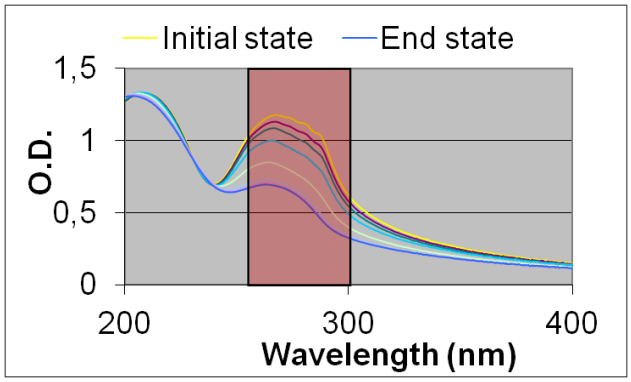

Figure 2. Decrease of optical density of uracil in the UV range. The red rectangle highlights the range of OD change associated with dimerisation

The optical density can be measured by ultraviolet-visible (UV-VIS) spectrophotometry and is usually used to register the initial and final OD of an exposed pyrimidine sample. The UV-VIS method can only produce limited data points from a measurement, and the removal of the sample from the experimental environment is always needed. As the data gained from a spectrophotometric measurement can only enable a

crude assessment on the changes in the behaviour of the irradiated samples with time, the precise analysis of the dynamics of the dimerisation processes requires a continuous measurement. This is particularly important in space applications, for example on satellite platforms where retrieving the sample material can be impossible.

2. EXPERIMENT SETUP

During the course of the BEXUS BioDos project, a continuous OD measurement method was designed and tested onboard the gondola of a stratospheric balloon. According to (1), OD can be calculated from intensity values measured before and behind a sample material. The relevant UV intensity can be monitored with UV sensitive silicon carbide photodetectors. For the calculation of OD, two sets of detectors were used in the experiment: a reference detector measured the unattenuated radiation intensity (I_0) and sample detectors were placed behind pyrimidine samples to measure the transmitted radiation (Fig 3) [6].

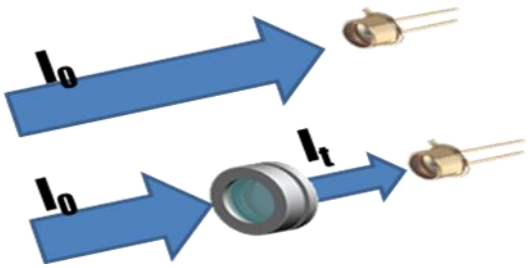

Figure 3. The scheme of OD measurement in the BioDos experiment

The voltage levels measured by the detectors correlate with the intensity (irradiance) of the UV radiation falling on them. Decreasing absorbance leads to an increase in the transmitted intensity and therefore an increase in the voltage values measured by the sample detectors. After converting the electric signals of both types of diode to irradiance values, the OD can be calculated from (1). The measurement principle was supplemented by a corresponding electrical and mechanical design which enabled the pilot flight of the experiment onboard a balloon. The experiment consisted of five separate units: four optical boxes (OB), facing towards four directions at the four sides of the gondola, and an electronics box (EB). The OBs contained the reference and sample detectors as well as the pyrimidine samples. For the purposes of the experiment, polycrystalline uracil thin layers (UD) were chosen as the model system and function as passive detectors by changing their respective absorbance values. The photodiode detectors (PD) were UV broadband sensors with their maximum sensitivity in the UVB range. Six UDs were enclosed in each Optical Box: four of them were irradiated during flight, and two served as dark samples. The latter were used to determine possible non-UV caused damage. In each OB, one of the sample holders was empty (i.e. did not contain uracil sample) and the PD placed behind it served as the reference diode.

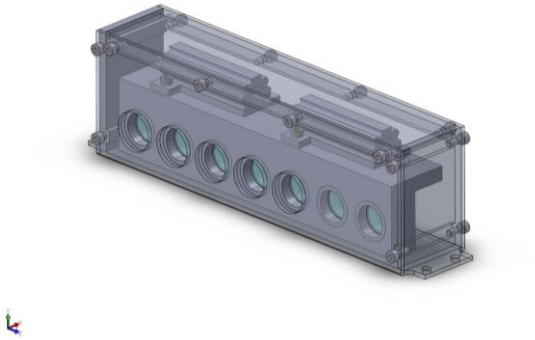

Figure 4. An Optical Box.

All Optical Boxes and sample holders were eloxated in order to minimize the noise in the intensity measurement caused by reflections on the metal surface. The OBs were designed to have thermal insulation (multi layer insulation [MLI]) and automatic heating switching on if the outside temperature dropped below -20°C.

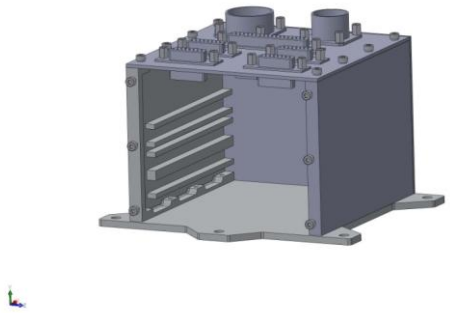

Figure 5. The Electronic Box without the printed circuit boards.

The EB (Fig 5) provided onboard data handling, telemetry, power supply, power distribution and temperature control functions. It contained four printed circuit boards (PCBs): one motherboard, an OBDH board for the digital electronics, a Power Supply (PS) board and an AUX board with the heater control and supplementary electronics. Data and control signals between the OBs and the EB were carried through 15-wire cables. The measured data was stored and transmitted to the Earth Ground Support Equipment

(EGSE) via the Esrange Airborne Data Link (E-Link) telemetry system. The EGSE continuously received the telemetry and measurement data and was used to send telecommands controlling sampling frequency and general experiment behaviour. The experiment boxes were mounted on base plates (Fig 6) and placed in the opposite corners of the gondola (Fig 7). The experiment weight was ~10 kilograms.

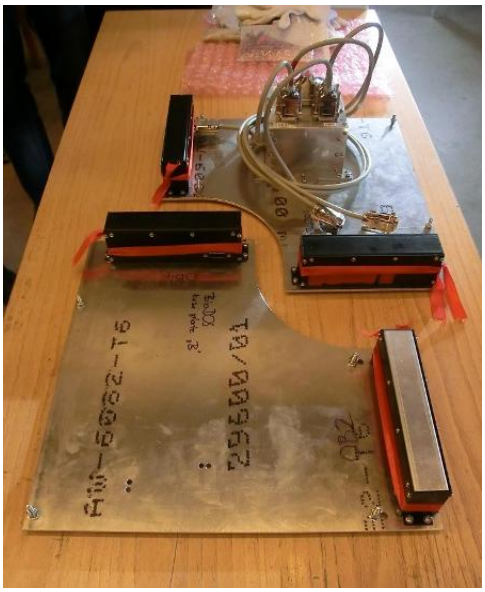

Figure 6. Experiment units: four optical boxes and the electronics box mounted on the base plates

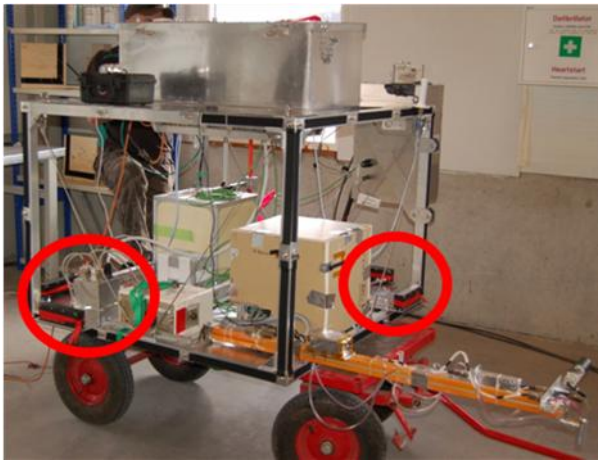

Figure 7. Experiment placement on the gondola

3. THE BEXUS PLATFORM

The BEXUS (Balloon-borne Experiments for University Students) programme offers flight opportunities to student experiments onboard a stratospheric balloon. The choice of vehicle for the BioDos experiment was based on several scientific and technical observations regarding the dimerisation process. As the main scientific objective of the experiment is the assessment of solar UV radiation, the Sun was required as the UV source. The radiation range necessary to pyrimidine dimerisation and monomerisation (UVB and UVC) is not present at ground level. This can be attributed to the stratospheric ozone layer which filters out the lower wavelengths of UV radiation. The higher wavelengths (UVA) reaching the surface cannot cause the expected photoreaction. Ground level testing of the proposed measurement method is therefore impossible. The BEXUS balloons have a minimum flight altitude of 25 kilometers. Even though the concentration of ozone at the specified height is still high, at 25-30 kilometers of altitude the UVB and UVC components of solar radiation appear in the electromagnetic spectrum, enabling the intended measurement. It should also be mentioned that a balloon flight has the necessary float time duration of at least one hour for the detectable photoreaction to take place in the sample. As the experiment is intended as a pilot project for later satellite or ISS experiments, the likeness of the stratosphere to the Low Earth Orbit (in terms of environmental factors) is beneficial for testing the overall idea.

4. LAUNCH

The experiment was assigned to the BEXUS-15 balloon which was launched on 25 September 2012 at 10:18 UTC from the Esrange Space Center, Kiruna, Sweden. During the Launch Campaign, the student team performed the necessary testing (functional and communication tests) of the experiment. Telemetry data show that the experiment operation was nominal during the flight. Voltage and current telemetries were constant. The thermal behaviour of the optical boxes is shown on Fig 8.

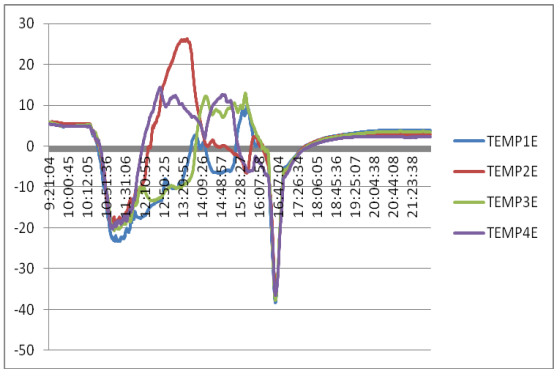

Figure 8. Thermal behaviour of the four optical boxes Temperature shown was measured outside the MLI foil.

After 6h 10 minutes of flight time the balloon was cut down and landed in Finland. The gondola and the experiment was recovered and delivered back to Esrange a few days later. The student team confirmed that the experiment sustained no damage during landing. The experiment was dismounted from the gondola and transported back to Budapest.

5. RESULTS

Data analysis and evaluation was done at the premises of the two universities cooperating in the BioDos experiment: Semmelweis University (Research Group for Biophysics) and Budapest Universiy of Technology and Economics (Space Research Group).

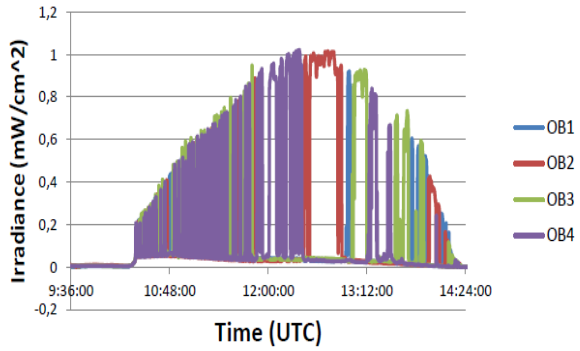

Figure 9. UV irradiance values during the flight

Fig 9 shows the UV irradiance values measured by the four reference detectors during flight. Irradiance values show sudden drops to zero – this can be attributed to the gondola turning away from the Sun, which also affected the irradiation times of the samples. From Fig 9 it can also be concluded that the gondola's rotation slowed down in time. During the ascent phase, the rotation was rapid, but by the time of the float phase (maximum altitude) it slowed down. This led to two of the optical boxes getting most of the UV-radiation during the flight (OB2 and OB4), while OB1 and OB3 were irradiated mostly during the ascent and descent phases.

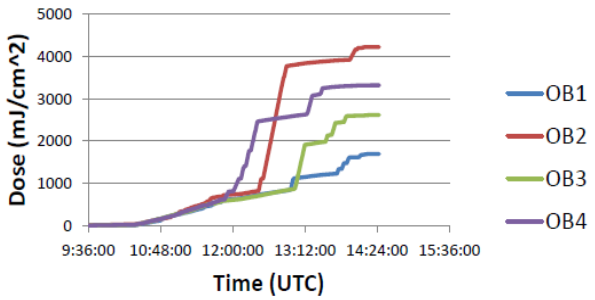

Figure 10. UV dose received by the samples

The optical densities of the samples were determined by UV-VIS spectrophotometry and by calculation from the signals of the UV diodes. Spectrophotometric measurements showed small or no decrease in OD (Fig 11).

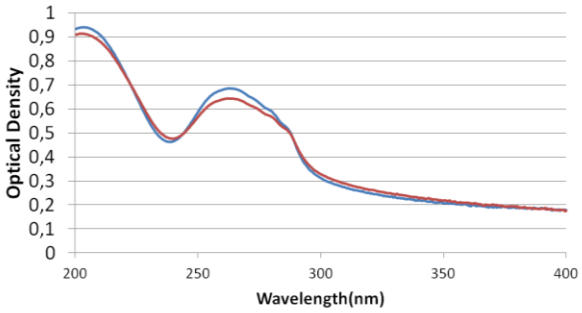

Figure 11. Example of the OD decrease of an uracil sample. Blue: before flight, red: after flight data

There were anomalous measurement data regarding the behaviour of the samples. In a significant amount of samples the OD increased instead of decreasing. The most likely explanation is a change in the crystalline structure of the sample; the exact reason is still under investigation however.

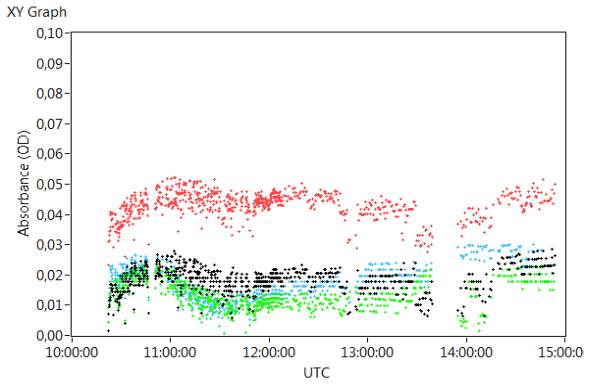

Figure 12. Result of the continuous measurement of the OD of the samples in OB1. Different colours mark the four different samples.

Fig 12 shows the calculated OD of the samples in Optical Box 1. The optical density is expectedly constant during the measurement as the broadband sensors are not specific enough to detect the small decrease in OD shown in Fig 11. There were some anomalies however in the calculated data. A significant amount of data points had negative values of OD which would mean that the unattenuated irradiance is lower than the attenuated. These kinds of readings are scientifically impossible and therefore have to be corrected during further investigations into the measurement method. The most likely explanation for the experienced anomaly is the usage of broadband sensors. Even though the sensitivity of the detectors was at the maximum in the relevant wavelength range (~280nm), the sensitivity was still high enough in the

UVA and UVC ranges to cause a very high level of "noise" in the experiment as the behaviour of the samples in these respective ranges is not as predictable and understood as in the 50nm wide range specified before. This can cause nonsensical data during evaluation.

6. CONCLUSIONS

The BioDos mission objectives were centered around the development of a continuous measurement platform for biodosimetric purposes. As it was mentioned in the introduction, an application like this counts as a pioneer in this field of study, as former experiments were carried out without complex measurement electronics. Continuous measurements require the system to collect and send the measurement data in real time to the Groud Station. This requires a custom design Data Collecting/Processing circuit. The flight results show that the Data Handler was working as intended during the mission and there were no instances of data loss. Despite the completely newly-made design, the experiment worked nominally during the flight of the balloon. Therefore, future modifications will target changes specific to the intended application rather than the experiment setup as a whole. The fulfilment of the scientific objectives depended on environmental factors rather than technological prowess. Even the anomalies described earlier can be used to improve the experiment design. As the main problem of the electrical measurement was the usage of the non-specific broadband sensors, the measurement can be improved by using UVB and UVC sensors. These detectors have a thinner sensitivity spectrum which can be beneficial twofold: first the calculation of the UV dose received by the samples can be more precise as with the usage of an UVB sensor the calculation of the useful dose would be possible. Second, the noise caused by the presence of the UVA/UVC range of radiation during the OD measurement can be eliminated this way. The possible improvements will be realized by the student team in the next cycle of the BEXUS programme. After the successful application and selection in December 2012, a follow-up experiment called Daemon will have a flight opportunity on board the BEXUS 16/17 balloon in October 2013. The data gained in the future experiment may also be used to correct the broadband data of BioDos.

7. REFERENCES

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