Photoelectrochemical investigation of cyanobacteria coated electrodes under cosmic radiation

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1 Project description

The conversion of sunlight to usable energy is realized in nature by photosynthesis e.g. in plants and cyanobacteria via the oxidation of water and is known as "primary production" (of biomass), while in technologies making use of photoelectrodes, it is known as electricity generation through solar (photovoltaic) cells. A shortcoming of solar cells is that the electricity obtained this way cannot be easily stored. Production of easily stored and transported synthetic fuels, such as hydrogen, by sunlight can be done by (i) a combination of solar cells and an electrolyzer, or (ii) photoelectrochemical cells (Braun 2019, 2020). A novel approach is to functionalize photoelectrodes with components from the photosynthetic apparatus, such as light harvesting proteins (Bora et al. 2012, 2013), or even with live cyanobacteria or microalgae (Braun et al. 2015; Ryzhkov, Colson, Ahmed, Pobedinskas, Haenen, and Braun 2024; Ryzhkov, Colson, Ahmed, Pobedinskas, Haenen, Janssen, et al. 2024). Cyanobacteria and microalgae are considered as the primary natural food or oxygen supply for life support systems in space missions and space exploration (Fahrion et al. 2021; Mapstone et al. 2022). We extend the range of application of such organisms to the continuous production of solar fuel in space missions, instead of just using them as biomass, i.e. as supplementary food. One critical aspect for bringing animate and inanimate matter into space is that it will be subjected to elevated levels of cosmic radiation and hence may become damaged, directly or indirectly (genetically). This is why astronauts, for example, must wear space suits as radiation shields. Our partners at the Belgian Nuclear Research Center (SCK CEN), Mol, Belgium previously tested the survival of the cyanobacterium *Limnospira indica* PCC 8005 when subjected to acute and chronic doses of ionizing radiation e.g. ^{60}Co gamma rays (Badri et al. 2015; Yadav et al. 2021) and are now in the process of testing this strain's survivability and unaltered ability to produce oxygen and biomass under real space conditions at the International Space Station in frame of the September 2024 ArtEMISS space flight experiment (Fahrion et al. 2024). Empa and SCK CEN teamed up to study bio-photoelectrochemical cells functionalized with *Limnospira indica* PCC 8005, funded by the Swiss National Science Foundation and the Flemish Science Foundation (Braun et al. 2020).

The HFSJG with an altitude of 3570 m is a natural radiation source which we exploit for long term radiation exposure. *Limnospira indica* PCC 8005 cells were coated as a thin film on fluorine-doped tin oxide coated glass substrates, which serve as mechanical support and electric current collectors. They were contacted in an electrochemical cell (Braun et al. 2013) from acryl glass in a three-electrode configuration with a Pt counter electrode and a Ag/AgCl reference electrode, using phosphate buffered saline (PBS) as electrolyte. Two such cells were prepared and one mounted at the Sphinx platform outside, i.e. exposed to the weather elements and high-altitude environment. The other was kept inside the hutch. Both cells were operated independently by two potentiostat type IVIUM Vertex 100 and run under chronoamperometry conditions at −200 mV vs. Ag/AgCl reference. Figure 1 shows how the cell is mounted (Braun et al. 2024) and contacted outside at the Sphinx platform from 14 to 15 August 2024 during day and night.

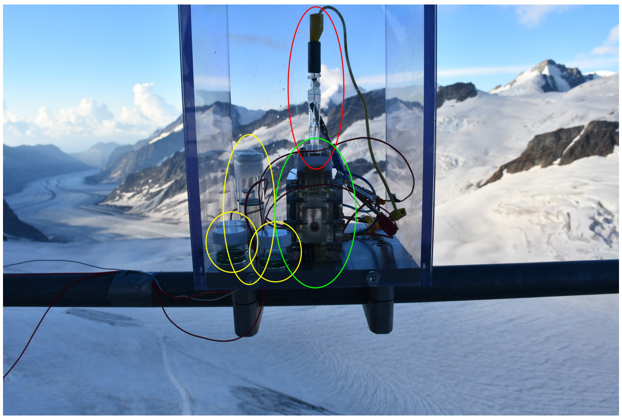

Figure 1: Photoelectrochemical cell (green ellipse) housed in a polycarbonate container and mounted at the rails of the Sphinx platform, facing the Aletschgletscher. The cell contains an FTO electrode coated with arthrospira platensis cyanobacteria, immersed in PBS as electrolyte. Red ellipse shows reference electrode. Yellow ellipses point to extra containers with cyanobacteria dispersions. The wires lead to potentiostat, which is inside the hutch in the research station. 14 August 2024, 06:58 am.

Figure 2 shows the raw data of the current transients over the cyanobacterial photoelectrode inside the hutch (orange

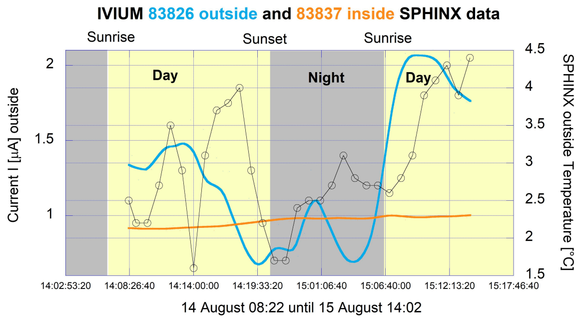

Figure 2: Preliminary electric current data (left abscissa) measured from the photoelectrode outside (blue) and inside (orange) the Sphinx-observatory from 14 August 08:22 am until 15 August 14:02 pm, 2024. The grey panel and yellow panel denote day and night phases, with sunset/sunrise given by the vertical borders. The right abscissa denotes the temperature at the Sphinx platform outside, indicated by the dashed line with open symbols.

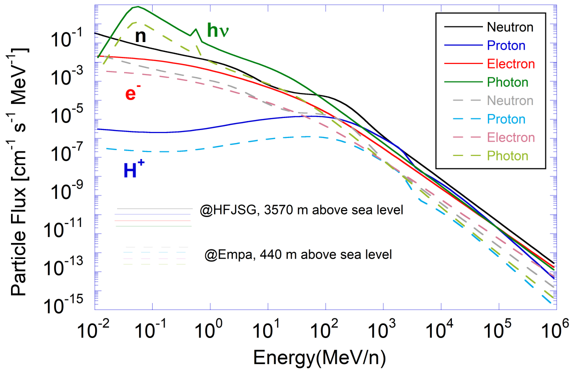

Figure 3: Comparison of the flux of cosmic rays at 440 m and 3570 m above sea level classified as in the legend including neutrons, protons, electrons, photons, as determined from database values and the PARMA model and exercised in the EXPACS package developed by Sato (Sato 2015).

curve) and outside on the Sphinx platform (blue curve). The current ranges from 0 to 2 µA; this is the variation of the current for the experiment done outside. The behaviour of the current of the photoelectrode inside the hutch is much more stable. On the right abscissa, the temperature at the platform is given, which was between 1.5 and 4.5 °C during our campaign. The current of the photoelectrode outside is higher during daytime and lower at night, when it was dark. Hence, we do see a variation of the current with the available daylight outside. There is also a slight correlation between current and temperature outside. We do not observe such correlation for the photoelectrode inside, because the temperature in the hutch was stable ambient between 17.5 °C and 19.5 °C. The reason for enhanced current can thus not be the enhanced temperature outside during daytime. In addition, samples with cyanobacteria dispersions in small vials (see orange ellipses in Figure 1) were brought to the Sphinx platform and kept next to the photoelectrochemical cell. Every 8 hours, one of the vials was removed and brought into the tunnel in the rocks 112 m underneath the Sphinx research station to preserve it from further exposure to cosmic radiation. For example, the neutron flux (corrected for efficiency) during our measurements was 361.5 cts/sec according to the JUNG1 monitor. In parallel, aliquots of the vials were kept inside the hutch and removed at the same time as the aforementioned ones. Thus, we have a set of cyanobacteria in its natural state, exposed to cosmic radiation for 8 hours or more, inside the hutch and outside on the Sphinx platform.

Data analysis and peripheral experiments are in progress and will be communicated later. This will include the assessment of the radiation influence, which we base on computational methods from the EXPACS package (Sato 2015, 2016; Sato et al. 2006, 2008), as produced in Figure 3.

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