# Limits of surface life under extreme ionizing radiation: insights from desert lichens

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## Overview and objectives

My NASA Astrobiology Early Career Collaboration Award (ECCA) supported a 10-day research visit to work with Mr. Taylor Wilson, CEO and nuclear physicist at Prometheus Industries in Reno, to understand the ionizing radiation tolerance limits of photosynthetic life (Figure 1). The project broadly helps us understand the resilience of surface and near-surface photosynthetic life in extreme radiation environments. Specifically, we measured oxygen output, a potent biosignature gas whose production depends on both survival and metabolic rate, in lichens under radiation stress.

The main objective was to quantify how the photosynthetic and respiratory apparatus of two lichen types, green-algal lichen (eukaryotic photobiont) and a cyanolichen (prokaryotic photobiont), respond to acute X-ray exposure across a dose range of approximately 0.8–9.6 kGy. The intent in choosing this range was twofold. First, it spans well beyond terrestrial background levels and into the range relevant to surface radiation environments on bodies lacking a substantial atmosphere or magnetosphere. Second, pushing toward the higher end of the dose range also allows us to determine the maximum limits of tolerance.

## Background

Lichens are among the most radiation- and desiccation-tolerant organisms known and have long served as astrobiological analogs for the limits of habitability, having survived direct exposure to simulated Mars and space conditions during orbital exposure experiments (Singh et al., 2024). However, unlike UV radiation, ionizing radiation is not blocked by a lichen's pigmented cortex, so how its photosynthetic and respiratory machinery specifically responds to acute ionizing radiation is important for constraining models of surface habitability on irradiated bodies (for example, Mars, icy moon surfaces, or M-dwarf planet surfaces) and for identifying which physiological process, photosynthesis or respiration, is the more radiosensitive target.


**Figure 1.** X-ray irradiation system equipped with oxygen sensors positioned inside the irradiation chamber (right) for real-time monitoring of photosynthetic oxygen production on the computer (left) during X-ray exposure.

# Outcomes

I conducted a paired before-and-after X-ray exposure study using a PyroScience FireSting-PRO fiber-optic oxygen sensor system. Both algal lichen and cyanolichen samples were exposed to X-ray doses ranging from 0.8 to 9.6 kGy, with oxygen concentration continuously monitored before and after exposure via alternating light and dark phases to separately resolve net photosynthesis and dark respiration. For each sample, the pre-exposure (baseline) and post-exposure $O_2$ time series were segmented into light and dark intervals, and a linear regression was fit to each segment to obtain a metabolic rate (%$O_2$ per hour) (Figure 2). A subset of samples was additionally tracked continuously through repeated light/dark cycles under the X-rays (data now shown).

After excluding flagged runs, the clearest pattern to emerge was that respiration was strikingly robust, remaining clearly negative (net $O_2$ consumption) in every sample even at the maximum dose of 9.6 kGy. Photosynthesis was more radiosensitive: net light-phase $O_2$ exchange declined with dose and, in several samples, flipped from net production to net consumption as early as 6.4 kGy in one algal sample, and in most samples by 9.6 kGy. Together, this suggests respiration is the more radiation-resistant of the two processes. Direct comparison of the two lichen types was limited by sample size after quality filtering, particularly for cyanolichens, and I do not consider the current dataset sufficient to conclude whether one functional type is more radiation-resistant than the other.

Without an ECCA award, this study would not have been possible. Beyond the experimental results, this visit gave me hands-on experience with the X-ray irradiator, and the collaboration strengthened a working relationship between our two groups. I plan to conduct a few more experiments to turn this work into a publication.

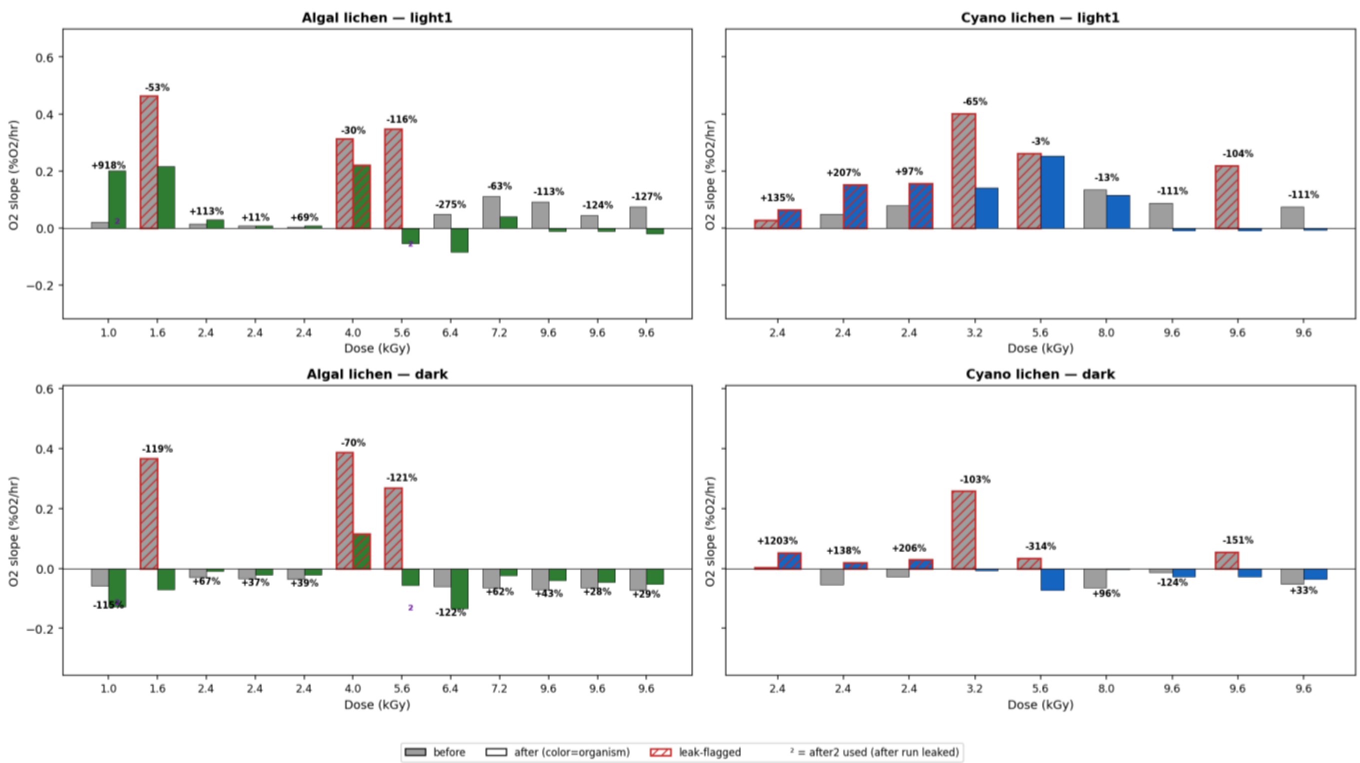


**Figure 2.** Oxygen exchange rate (%$O_2$/hr) before and after X-ray exposure, by dose, for algal lichen (left) and cyanolichen (right) samples, separated into light-phase (top) and dark-phase (bottom) measurements. Grey bars show the pre-exposure baseline; colored bars (green-algal; blue-cyano) show the post-exposure measurement. Bars outlined in red indicate a run flagged during quality control for a suspected measurement artifact.

# References:


1. Singh, T., Georgiou, C. D., Jeffrey, C. S., Tucker, M. J., Philbin, C. S., Mahmud, T., ... & Sun, H. J. (2025). UVC-Intense Exoplanets May Not Be Uninhabitable: Evidence from a Desert Lichen. Astrobiology, 25(6), 404-413.