

# Photosynthetic eukaryotes at the extremes: adaptations of glacier ice algae to life on the Greenland Ice Sheet

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Pigmented glacier ice algae of the genus *Ancylonema* live on glaciers globally, including the Greenland Ice Sheet. These algal species can bloom despite harsh environmental conditions, such as low temperatures, very high light intensities, and low nutrient availability. In polar regions, the long polar night also imposes additional abiotic stressors, which the algae must survive in order to bloom during the following summer months. *Ancylonema* species are the dominant eukaryotes in ice surface microbiomes and do not bloom in other environments, suggesting they have unique and specific adaptations to life on glaciers. However, the cellular mechanisms responsible for *Ancylonema*'s resistance and adaptation to these extreme conditions are unknown. To identify what survival strategies *Ancylonema* species use to thrive in these conditions, we investigated the functional responses of an *Ancylonema*-dominated microbiome to high light stress and prolonged darkness. We used a microbial sample collected directly from the surface of the Greenland Ice Sheet, undertook a 12-day incubation in *in-situ* light conditions and constant darkness, and quantified functional responses using metatranscriptomics and metaproteomics. The microbial community composition was not substantially altered during the 12 days of incubation; however, the heterotrophic community members became more transcriptionally active in the dark. We identified an extremely stable algal transcriptome in the light despite daily weather fluctuations, suggesting possible gene expression stability supporting algal survival. We found a transcriptional downregulation of genes linked to the methyl cycle in the dark, hypothesising a potential role for methylation in the maintenance of stable transcriptomes in high light conditions. After 12 days of darkness, the algae also downregulated the expression of enzymes linked to the production of photoprotective phenolic pigments and proteins linked to oxidative stress, consistent with a loss of light stress. Transcriptional reprogramming linked to sugar uptake and phytohormone signalling was also identified in the dark, providing an insight into the first steps towards algal cell survival through the polar night. With this study, we provide essential