Laser illuminates life in ice

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Laser-induced fluorescence emission techniques enable ground and remote sensing of photosynthetic microorganisms living in the snow and ice.

Polar and alpine snow, glaciers, and lake ice caps are home to rich microbial communities including photosynthetic cyanobacteria that are capable of significantly altering the Earth’s carbon budget. Advances in laser-induced fluorescence emission (LIFE) imaging and spectroscopy make it possible to detect these microbes and may one day provide a methodology to search for life in the icy world of Europa, the poles of Mars, and the frozen regions of exoplanets in distant star systems.

Since life needs liquid water, how could life exist in the frozen wastelands covering a planet’s cryosphere? In fact, Earth’s cryosphere contains rich microbe-dominated food webs\(^1, 2\) that are so highly sensitive to environmental change they serve as proxies of planetary-scale stress. Photosynthetic microorganisms ride the winds and even the icy clouds of our planet\(^3\) often on dust rich in organic material. The grains land on the ice, solar energy absorbed by the dark dust melts the underlying ice, and the assemblage sinks.\(^4\) Liquid melt water covers the dust and soon freezes, but solar photons pass easily through the clear ice, continue to warm the dust, and produce a thin layer of liquid water around the grains. The combination of dust, water, photosynthetic microbes, and sunlight constitute sufficient conditions for a tiny ecosystem deriving both liquid water and useable energy from the sun.

Unfortunately, the fragility of both the life and their icy world makes studying these systems difficult. Until now, samples were cored, transported to a distant laboratory, and melted. Such protocols produce physiochemical changes to microbes and environments. Eliciting fluorescence in specific microbial chemicals and then photographing the fluorescence response is a technique used for decades in microbiology laboratories. Such systems are expensive, fragile, heavy, and use power-hungry illumination. We speculated that recent advances in laser and camera technology would make it possible to use an inexpensive, robust, macroscopic field LIFE imaging system capable of detecting cyanobacteria communities living in ice. We found that 532nm green lasers excite critical photopigments in cyanobacteria and produce multiple fluorescence signatures between 550nm and 750nm (depending on bacterial species and metabolic state).

The Foveon Fx17-78-F13 CMOS sensor in a Sigma DS14 DSLR camera provides an inexpensive UV/visible/near-IR recorder for LIFE. The sensor generates true three-band color images without filters.\(^5\) A silicon sensor absorbs different wavelengths of light at different depths.\(^6\) Foveon detectors use sensors embedded at 0.2mm (blue), 0.8mm (green), and 3.0mm (red) depths. The sensors form a stable three-component signal for each individual pixel without Bayer inter-pixel interpolation.\(^7\) The camera contains an easily removable IR sensor cover, transforming it into an efficient IR detector.

During the Tawani Foundation 2008 Antarctic Expedition to the dry valleys of Schirmacher Oasis and Lake Untersee (see Figure 1A and 1B), a perennially ice-covered lake in Dronning Maud Land, Antarctica, we produced the first LIFE in situ images for photosynthetic cyanobacteria using 532nm laser excitation. In situ illumination of the dust grains in the clear translucent ice (see Figure 1C) excited multiple photosynthetic pigments to produce a fluorescence image (see Figure 1D). In May 2009, we produced the first airborne LIFE signatures from snow (see Figure 2) in an arctic meadow near Manley Hot Springs, Alaska. Signatures from ice coverings of multiple frozen rivers and lakes were easily obtained at altitudes between 7 and 30 meters using a 5mw 532nm laser.

Cryosphere photosynthetic microbial communities contribute significantly to the annual availability of new organic carbon, which in turn supports higher forms of life.\(^8\) Deploying inexpensive, non-destructive, field survey technology is important if we are to monitor the impact of shrinking ice sheets and re-treating glaciers during periods of global climate change. Laser wavelengths at 220–250nm excite nucleic and amino acids, and LIFE techniques at these wavelengths found life 1.3 kilometers below Mauna Kea, a dormant volcano in Hawaii.\(^9\)

A LIFE system using a 375nm laser produces fluorescence in the blue and green portion of the spectrum from critical metabolites found in all life as well as in small prebiotic interstellar polycyclic aromatic hydrocarbons (PAHs). We have proposed LIFE as a technique of choice to search for life on Mars\(^10\) and to search Continued on next page
Figure 1. (A) Ice covered Lake Untersee in Dronning Mauds Land, Antarctica is the site of the (B) 2008 Tawani Foundation Antarctic Expedition. (C) Laser excitation of cyanobacteria produces a fluorescence signal (D) in the photosynthetic pigments.

Figure 2. Predicted (+) and measured (o) red (R) - blue (B) band response for more than 22000 pixels as a function of the intensity of green (532nm) laser excitation. Excitation strength is measured in the camera’s green (G) band. The difference between the predicted and measured response is due to laser-induced orange-to-red fluorescence of photo-pigments in photosynthetic microorganisms living in the snow.

for PAHs beneath the regolith,\textsuperscript{11,12} especially because it does not require sample preparation or destruction, and it uses limited consumable resources.

We expect that the laser techniques currently employed on the ground to illuminate millimeter scale targets will evolve first into airborne and then orbital systems. For example, we are now preparing to mount a LIFE system on a Cessna 185 to survey sea ice during a solo flight to the North Pole by veteran aviator and polar explorer Art Mortvedt.

With continued global warming, the ability to monitor carbon availability and quantify cryosphere microbial growth will be of critical importance. If orbital deployment of LIFE technology is feasible, the technique could open the way to remotely search for life in the icy poles of Mars or terrestrial exoplanets orbiting nearby star systems.

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Michael Storrie-Lombardi received his undergraduate degree in physics from Florida State University in 1964, and his doctorate in medicine from the University of Florida in 1968. He is participating scientist on the ExoMars PanCam and produced the first UV fluorescence images and Raman spectra of microbial life 1.3km below Hilo Bay. He was expedition physician, diving medical officer, and participating scientist for the Tawani 2008 International Expedition to Dronning Maud Land, Antarctica.

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Brigit Sattler received her PhD in microbiology and limnology. Her research focus is the cryosphere of the Alps, high Arctic, and Antarctica dry valleys. She produced the first evidence microbial life grows in the ice of cloud droplets, for which she received the 2008 Wings World Quest 2008 Air & Space Award. She devotes time to ‘Sparkling Science’ a program initiated by Austria’s Ministry of Science and Education to introduce children to polar and alpine research on climate change.

References