ORGANICAM: A TIME-RESOLVED LASER FLUORESCENCE IMAGER AND SPECTROMETER FOR BIO-ORGANIC DETECTION ON OCEAN WORLDS.

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Introduction: A major goal of NASA is to explore the Solar System looking for signs of past and present habitable environments and life [**1**]. Ocean worlds are possible places to search for life because they have long-term liquid water and energy sources, typically below a surface of ice. Identified ocean worlds include Europa, Enceladus, and Ceres, but there are likely others. Geological activity, e.g., impacts, cryovolcanism, and tectonics allow materials from the subsurface oceans of these worlds to reach the surface, giving us the opportunity to sample the ocean and determine its potential to harbor life. Over the next decade, NASA plans to send two missions, first an orbiter and then a lander, to the ocean world of Europa to confirm the presence of an ocean beneath the moon’s icy surface and study whether life might exist there. Future flyby or landed missions may be sent to Ceres or Enceladus. Since Europa is most likely NASA’s next target for a lander, and Europa has the added difficulty of being situated in Jupiter’s extreme radiation environment, it is important to begin the development of instruments and strategies to characterize potential biological materials on Europa.

We suggest a strategy of using a mast-mounted fluorescence imaging instrument to survey the area, including locations for drilling/scooping with an arm for more detailed analysis by internal instruments. A laser-induced time-resolved fluorescence imager can quickly survey the area and identify organic materials of biological origin. When using a pulsed laser or LED light source and an electronically gated spectrometer, a fluorescence imager can often discriminate between bio-organic, non-biological organic, and inorganic materials based on fluorescence lifetime, a significant advantage over the typical infrared or Raman spectrometers. And, if a spectroscopy capability is included, then the fluorescence wavelength signature of the materials in the ice can also be collected.

The challenge of sending an imager to Europa will be the extreme radiation environment: As much as ~2 Mrad of Total Ionizing Dose (TID) is expected during the course of the mission [**2**], with more than half of that radiation occurring after Europa orbit insertion and during the 20–30 day mission [**3**]. As light is collected and read out of a detector, there is high potential that data will become corrupted by the ionizing radiation environment. Detector dark current also rises with increasing radiation exposure [**4**]. Electronics and memory are subject to faults caused by radiation [e.g., **5,6**], and collection optics can be darkened [e.g., **7,8**]. Hence, we are designing both instrument hardware and software with the extreme radiation of Europa in mind.

Time-Resolved Laser-Induced Fluorescence (TR-LIF) Spectroscopy: Fluorescence is extremely sensitive to fluorescent materials; up to ~10% of the excitation photons produce a fluorescence signal. Fluorescence signal emission lifetimes depend on the materials being sampled. Large organic biological molecules have very short fluorescence lifetimes (1 ps–100 ns) because they have many decay pathways, while inorganic materials have lifetimes of 0.5–10 μs because of the greater stability of metal ion triplet states. Nonbiological organic molecules, e.g., PAHs found in carbonaceous meteorites, have intermediate fluorescence lifetimes (~500 ns) [**10,11**]. Thus, time-resolved fluorescence can be used to distinguish between biological and background non-biological organic and inorganic fluorescent materials. Fluorescence spectral signatures of organics do not have a high degree of specificity, but spectra can still allow us to understand the characteristics of different materials sampled if they have similar fluorescence lifetimes.

Instrument Concept: Based on the ‘BioFinder’ instrument built from COTS parts [**9**], we are developing a prototype fluorescence imager called ‘OrganiCam’ using flight-qualified hardware and radiation-hardened optics. The instrument (**Fig 1**) consists of a pulsed laser with a dispersed beam to cover a ~20 cm^2 region, and collection optics that focus most of the light to a gated intensifier and CCD (**Fig 2**). In addition, a narrow strip of the incoming light is redirected through a slit and into a folded spectrometer. The spectrometer will redirect the dispersed light onto a strip on the top portion of the detector. Thus, OrganiCam improves on previous fluorescence imagers by adding a spectrometer that collects a spectrum on the same detector (**Fig 1**). The detector package—CCD, intensifier, and high voltage power supply—was developed and flight qualified by LANL for M2020/SuperCam. Modeling and experiments will demonstrate OrganiCam’s radiation hardness.

Operational Concept: During the 20–30 day primary mission of a Europa lander, we expect that the first round of instrument activities will be preprogrammed. There may be time for 1–2 sets of follow-on, ground-in-the-loop activities. The OrganiCam imager would build a panorama starting immediately upon landing and deploying the mast/antenna. The instrument would first collect images in the arm workspace to characterize fluorescent materials that are accessible to the arm. Then images would be collected over progressively wider and longer ranges. By overlapping many images, both fluorescence images and spectral information can be collected for the entire area surrounding the lander. Thus, our instrument would provide a rich dataset of fluorescence information in Europa's ice.

Expected Results and Future Experiments: Provided that biological materials are present in Europa's ice, we have high confidence that a TR-LIF instrument will detect them. Studies of detection limits have already been carried out with the BioFinder instrument, showing the capability to detect ~10 ppm of biological material in water (e.g., bacterial cells), and that sensitivity could increase by accumulating and averaging many images of the same area. And while it is difficult to imagine many organics or life surviving in the Europa ice due to cold and high radiation, [**12**] shows that radio-resistant bacterium such as *D. radiodurans* can withstand the radiation beneath just ~1 mm of ice on Europa. Lasers and generated fluorescence signals can easily penetrate the first few cm of ice or other light dispersing materials to sample materials within [**13**]. We plan to test this concept by measuring fluorescence signals of bacteria in pure and contaminated ice before and after exposure to radiation.

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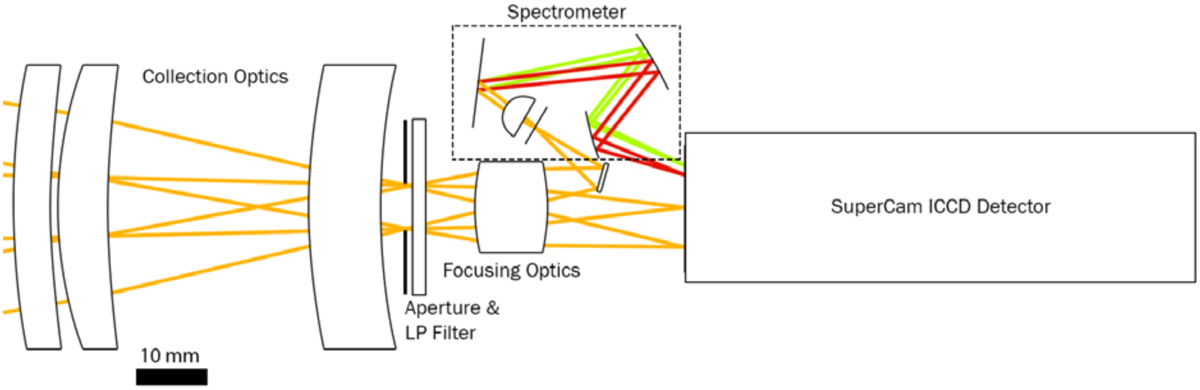

Figure 1: A schematic of the OrganiCam front end optics (excitation source not shown for clarity; intensifier, optics, and CCD are shown in **Fig 2**). The light is collected from the scene with fixed lenses and focused through an aperture. A longpass (LP) filter removes light at and below the excitation wavelength. A moveable triplet lens is used to focus the light onto the image plane and the spectrometer slit. A small mirror picks off the upper third of the image coming from the focusing optics and redirects it into the spectrometer through a slit. The light from the slit is collimated, a diffraction grating splits the light, and two mirrors then direct the diffracted light back onto the same detector used for imaging.

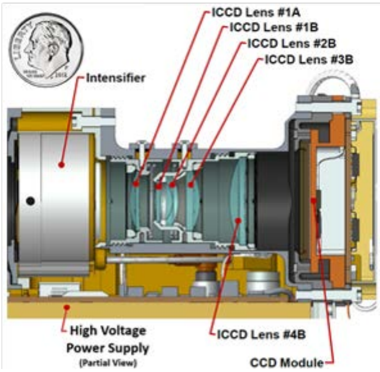

Figure 2: The SuperCam intensifier, relay optics, CCD and high voltage power supply with a dime for scale.