ORGANICAM: A LIGHTWEIGHT TIME-RESOLVED FLUORESCENCE IMAGER AND RAMAN SPECTROMETER FOR ICY WORLD ORGANIC DETECTION AND CHARACTERIZATION.

R. C. Wiens[1], P. J. Gasda[1], A. K. Misra[2], T. E. Acosta-Maeda[2], S. K. Sharma[2], H. Quinn[1], K. Ganguly[1], S. P. Love[1], A. Nelson[1], R. Newell[1], S. Clegg[1], S. Maurice[3], C. Virmontois[4]; [1]LANL Los Alamos; [2]U. Hawaii; [3]IRAP, Toulouse; [4]CNES, Toulouse

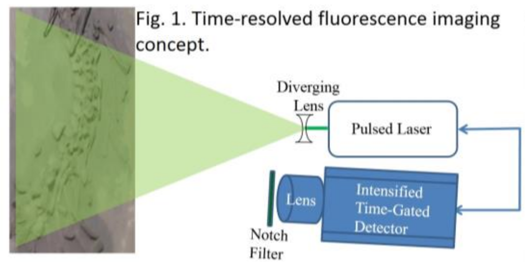
Introduction: The search for life elsewhere in the solar system is focused on habitable environments. These include oceans that exist below the icy crusts of bodies such as Europa, Enceladus, and possibly Ceres. High-mass organic molecules have been observed within plumes emanating from Enceladus [1], and there is evidence of plumes from Europa [2]. Because plumes are believed to deliver fresh material from the sub-surface oceans to the surfaces, a lander may be able to detect and characterize the organic materials that originated in the ocean to search for signs of biological activity. NASA has made plans to develop a Europa lander for this purpose [3]. The lander would have a single arm that would acquire samples within a work zone next to the lander and deliver them to the in-situ instruments for analysis.

The surface of Europa is inhospitable due to the cold temperatures, low solar illumination, long distance from Earth, and intense radiation field within the Jovian magnetosphere. Because of these factors, the landed mission is expected to be relatively short in duration (480 hours), have relatively low data volume, and will be limited to relatively simple operations (e.g., 5 sampling cycles) [3]. The surface of Europa is likely a complex mixture of exogenous materials from comets and meteorite impacts, materials altered by radiation, endogenous salts and inorganic materials embedded in the ice, and likely organics from the ocean [4].

Given these very few opportunities to sample the surface and the potential complexity of surface materials, it is of utmost importance to select sampling locations within the arm work space that are most likely to contain organic materials. We are developing a simple "OrganiCam" instrument to exclusively detect and image organic materials within the work zone and around the lander using time-resolved fluorescence and then identify these materials with Raman and fluorescence spectroscopy. OrganiCam will enable mission success in selection of organic-rich sampling locations.

Time-Resolved Laser-Induced Fluorescence. OrganiCam operates on the simple principle that biomaterials on Earth have characteristically short fluorescence lifetimes (~10 ns [5]) that clearly distinguish them from inorganic mineral phosphorescence (1 µs to several ms). A simple way to image the time-domain fluorescence is by exciting the targets with a pulsed laser (e.g., 5 ns duration), using a diffusing lens to project over a wide area, and imaging the sample area using a laser notch filter and a camera with a fast time-gated intensified detector (Fig. 1). This has been demonstrated by the Biofinder prototype instrument, built with COTS parts at U. Hawaii [6]. As described in [6], the set-up shown in Fig. 1 provides rapid imaging, distinguishing bio-materials from fluorescing minerals (Fig. 2).

Fig. 1. Time-resolved fluorescence imaging concept.



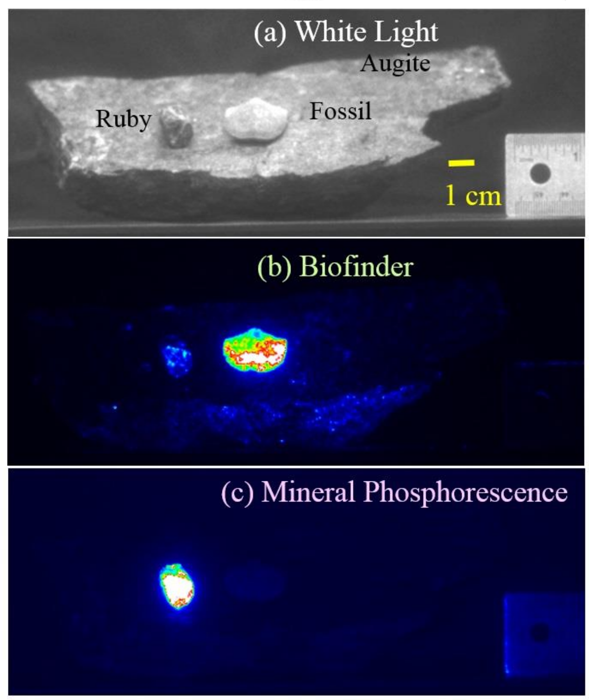


Fig. 2. Time-resolved fluorescence Biofinder results at 2 m distance [6]. Biological (b) and mineral fluorescence (c) are clearly distinguished, as is needed on Europa.

OrganiCam Requirements and Concept. OrganiCam responds to the requirements of the planned Europa Lander mission, fitting well within the mission energy, operations, and data-volume constraints. In addition to time-resolved fluorescence imaging, a fluorescence spectrum will be obtained as well. Once the panoramic organic imaging is completed, OrganiCam can take Raman spectra of selected locations. The basic OrganiCam requirements are as follows:

- Resolve objects < 1 mm within Lander work zone (SDT requirement; [3]), e.g., up to 2 m away, using biofluorescence imaging.
- Take a complete bio-fluorescence panorama to 2 m from the lander; greater distances are bonus science.
- Distinguish bio-fluorescence from mineral fluorescence via time gating of the detector (100 ns).
- Perform Raman spectroscopy of selected targets.
- Spectral range 535–650 nm.
- Spectral resolution < 30 cm^{-1}.
- Extend detection below the surface of the ice.
- Bio-fluorescence detection: low ppm to ppb range.
- Accomplish science goals within the 20 day mission.
- Survive environmental requirements. Europa has an integrated proton spectrum of 10^6 $cm^{-2}s^{-1}$ and an integrated electron environment of 10^8 $cm^{-2}s^{-1}$ [7]. Portion inside vault designed for 300 krads, outside portions designed for 2 Mrads and survival heat.

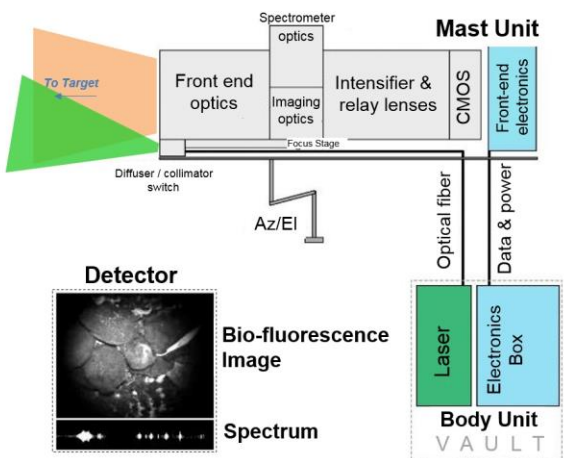


Fig. 3. Block diagram of OrganiCam shown set for fluorescence mode. Raman mode is enabled by removing the diffusing lens from the beam path.

An instrument schematic diagram is shown in Fig. 3. The laser and electronics are housed in the Lander Vault. Laser light is transmitted via an optical fiber to the mast unit. The diffuser is removed from the beam path for Raman mode, providing ~3.5 orders of magnitude higher illumination on a small spot in this mode, needed to obtain the weaker Raman signals. The mast-unit 'receive' optics contain a camera section and a spectrometer section, both of which focus simultaneously on separate portions of the intensified detector (Fig. 3, inset). The ground footprint of the spectrum is displaced laterally from the image; the locations of the two are reconstructed once the mosaic is complete. The intensified detector section has heritage from the Mars2020 SuperCam instrument, but must be qualified for Europa.

Design and Current State of Development. The design of the prototype camera and spectrometer sections are shown in Fig. 4. We are using radiation-hardened optics to build the camera and spectrometer sections. A spare SuperCam intensifier is being used, and we are building a SuperCam-based time-gated high-voltage power supply to operate it. Readout for the detector has already been developed.

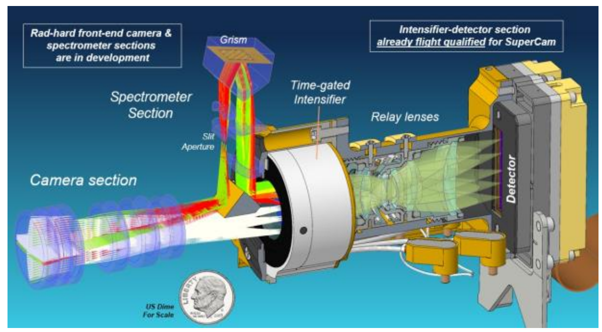


Fig. 4. OrganiCam prototype camera, spectrometer, and detector-system design.

Irradiation of Biological Samples. We have begun conducting radiation tests on biological samples to understand the effects of radiation on bio-materials that may be found on the Europa surface. Bio-fluorescence remains strong and relatively unchanged in two types of bacteria tested to 20 Gy [8], but tests must be scaled to the much higher radiation doses typical of Europa. Note that OrganiCam can detect materials slightly below the surface of the ice, where radiation is lower.

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References: [1] Postberg F., et al. (2018) Nature 558, 564. [2] Jia X., et al. (2018) Nature Astronomy 2, 459. [3] Hand K.P., et al. (2017) Report of the Europa Lander Science Definition team, posted February, 2017. [4] Carlson, R. W., et al. (2009) Europa's Surface Composition in *Europa*, U. of AZ Press: Tucson, pp 283–328. [5] Brody S.S. and Rabinowitch E. (1957) Science 125, 555. [6] Misra A.K., et al. (2016) Astrobiology 16, 715-729, doi:10.1089/ast.2015.1400. [7] Paranicas, C., et al. (2009) Europa's Radiation Environment and Its Effects on the Surface in *Europa*, U. of AZ Press: Tucson, pp 529–544. [8] Ganguly K., et al. (2018) Survival, genetic modification, and time-resolved laser-induced fluorescence analysis of bacterial exposed to high-dose radiation simulating Europa's surface. Europa deep Dive 2 Meeting, LPI, Houston, 10/9-11.