ORGANICAM: FIRST-LIGHT RESULTS FROM A COMPACT TIME-RESOLVED LASER-INDUCED FLUORESCENCE IMAGER AND RAMAN SPECTROMETER WITH FLIGHT QUALIFIED PARTS

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Introduction: The focus of NASA's robotic exploration is shifting from finding habitable environments (last 2 decades) to characterizing organic materials and searching for biosignatures in the places where they may be found (Mars, icy worlds, comets, meteorites, possibly Venus' atmosphere). These are challenging tasks in the inhospitable conditions in space and with the low organic abundances in many of the most accessible locations (ppb to possibly low ppm on Mars' surface; unknown abundances on Europa's surface). There are many techniques to detect organic materials in situ. However, relatively few techniques can detect organics or positively distinguish them at remote or stand-off distances. Among these, fluorescence can be the most sensitive technique, especially with strong stimuli such as from a laser. Fluorescence from organic materials including biomaterials is non-specific in that minerals also luminesce. A key feature of organic fluorescence is its rapid timescale, on the order of ps to ns, which is much more rapid than mineral luminescence [1]. Therefore, time-resolved observations at ns scales can uniquely distinguish organics from inorganic background signals.

While organic fluorescence is highly sensitive, it lacks specificity because the fluorescence is generally broadband. Raman spectroscopy, on the other hand, offers the ability to identify specific molecular bonds, clearly distinguishing different types of bio-molecules. On the other hand, Raman spectroscopy is far less sensitive than fluorescence spectroscopy.

We have used flight heritage parts to build a compact instrument [2] to image at stand-off surfaces in laser-induced time-resolved fluorescence, and to take spectra of the most promising locations within the field of view. These observations can be made rapidly from a distance of several meters above the surface. Applications could be to explore a Mars lava-tube cave by rotorcraft [3] or to observe organics around a Europa lander [4]. For the latter, an organic-sensing instrument is highly important to guide the sampling arm to the most organic-rich location within the work space.

Time-Resolved Laser-Induced Fluorescence: OrganiCam operates on the simple principle that biomaterials on Earth have characteristically short fluorescence lifetimes (~10 ns) that clearly distinguish them from inorganic mineral phosphorescence (1 µs to several ms). Time-domain fluorescence can be imaged 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 [5].

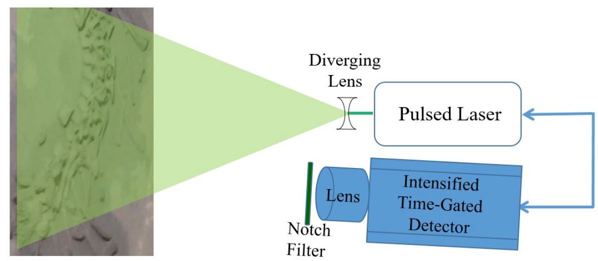

Figure 1. Laser-induced time-resolved fluorescence imaging concept employed by both the Biofinder [5] and OrganiCam.

OrganiCam Requirements and Concept: In addition to time-resolved fluorescence imaging, a fluorescence spectrum is obtained. Once organic-sensing imaging is completed, OrganiCam takes Raman spectra of selected locations. The basic OrganiCam requirements are as follows:

- Resolve objects < 1 mm at 2 m distance, using biofluorescence imaging.
- Distinguish bio-fluorescence from mineral fluorescence via detector time gating (100 ns).
- Obtain Raman spectra of selected targets.
- Spectral range 535–650 nm.
- Spectral resolution < 30 cm^{-1}.
- Bio-fluorescence detection: low ppm to ppb, broadly comparable to the concentration of organic materials observed by SAM on Mars [6].

An instrument schematic diagram is shown in Fig. 2. Laser light is diffused over the entire field of view of the imager in Imaging Mode. The diffuser can be removed from the beam path for Targeted Mode (not shown), providing ~3.5 orders of magnitude higher illumination on a small spot, giving orders of magnitude higher fluorescence detection, and also giving the fluence needed to obtain the weaker Raman signals. The sensor head contains a camera section and a spectrometer section, both of which focus simultaneously on separate portions of the intensified detector (Fig. 2, inset). The ground footprint of the spectrum is displaced laterally from the image; the locations of the two are reconstructed in post processing.

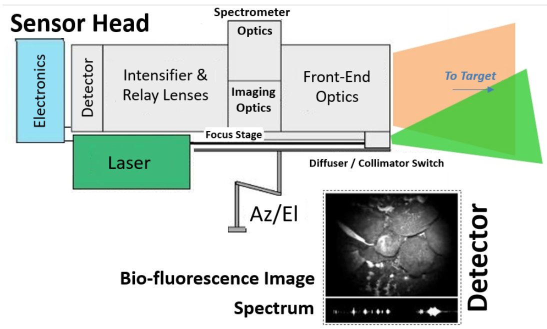

Fig. 2. OrganiCam schematic diagram set for Imaging Mode. Targeted Mode is enabled by removing the diffusing lens from the beam path, providing much higher sensitivity for a small spot. Inset illustrates simultaneous spectrum & image collected on the same detector.

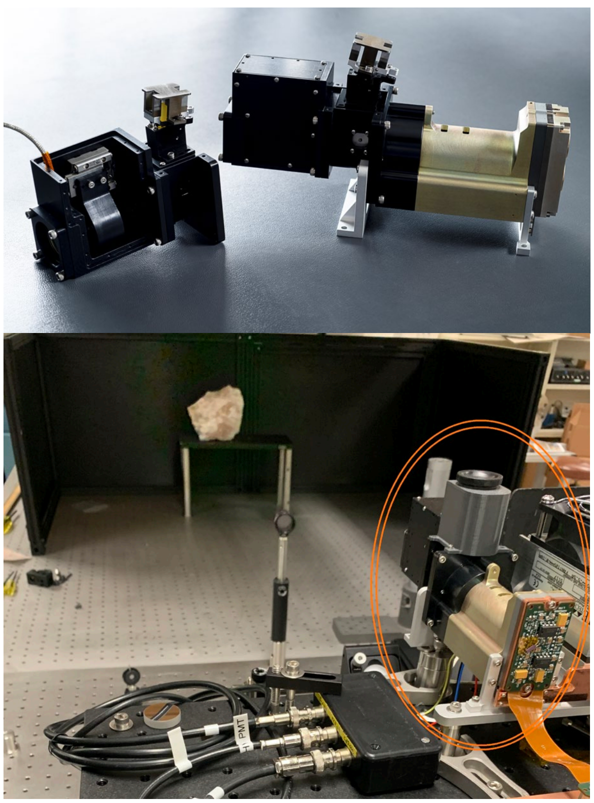

Fig. 3. OrganiCam prototype camera, spectrometer, and detector system (top). The unit is 19.1 cm in length and weighs 692 g (not yet optimized). Lab set-up (bottom) with OrganiCam circled. Target is 1.5 m away.

An image of OrganiCam is shown in Fig. 3. The intensified detector section has heritage from the Mars 2020 SuperCam instrument [7,8]. The camera lenses are radiation hardened to survive a Europa surface mission. Detection limits for some species are projected at ~5 ppm for organic fluorescence in Imaging Mode at 2 m with 12° FOV; in Targeted Mode the fluorescence detection limit is projected in the low ppb range, with a Raman detection limit of a few wt. %, all using comparable laser intensities to that on SuperCam [7,8].

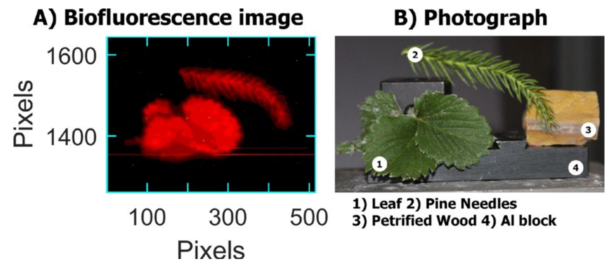

Fig. 4. OrganiCam first results with time-resolved fluorescence imaging at 1.5 m distance. Organic materials are illuminated to the exclusion of inorganic materials (A). Photograph of organic and inorganic materials (B).

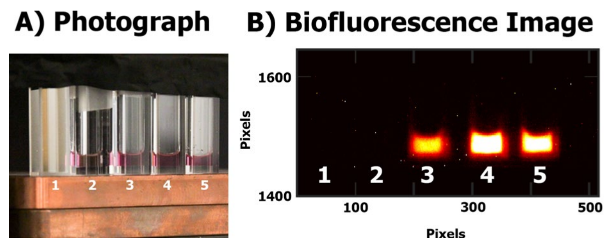

Fig. 5. First detection-limit tests, dye-stained live cells. Blanks are included.

First Results: Initial results have validated the exclusivity of the fluorescence images from biomaterials (Fig. 4) and demonstrated the spectral resolution (not shown). Targets are also being analyzed to benchmark detection limits, in progress (Fig. 5).

Acknowledgements: OrganiCam development at LANL is funded by LDRD 20180244ER.

References: [1] Gaft M. et al. (2015) *Modern Luminescence Spectroscopy of Minerals and Materials*, Springer. [2] Wiens R.C. et al. (2020) LPSC 51, 1780; Gasda P et al. Manuscript in prep. [3] Wiens R.C. et al. (2020) Airborne reconnaissance mission concept for organics in a Martian cave. 3rd Int'l. Planetary Caves Conf., #1063, San Antonio, TX, LPI. [4] Hand K.P. et al. (2017) Report of the Europa Lander Science Definition Team. [5] Misra A. et al. (2016) Astrobio. doi:10.1089/ast.2015.1400. [6] Eigenbrode J.L. et al. (2018) Science 360, 1096. [7] Wiens R.C. et al. (2020) Spa. Sci. Rev. 10.1007/s11214-020-00777-5. [8] Maurice S. et a. (2020) Spa. Sci. Rev. SPAC-D-20-00069R1.