ORGANICAM: A LIGHTWEIGHT TIME-RESOLVED FLUORESCENCE IMAGER AND RAMAN SPECTROMETER FOR MARS CAVE OR ICY-WORLD SURFACE ORGANIC CHARACTERIZATION.

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Introduction: The search for life elsewhere in the solar system is focused on habitable environments. These include underground Mars or oceans that exist below the icy crusts of outer solar-system bodies. High-mass organic molecules have been observed within 4 cm of the surface of Mars [1] as well as within plumes emanating from Enceladus [2]. There is evidence of plumes from Europa [3], suggesting the possibility of organic molecules on its surface, originating from the ocean below. Attempts to search for evidence of life in these ocean worlds would start with observations at their surfaces. These are inhospitable places where the first observations would be made by a relatively small, simple-to-operate payload package. Likewise, accessing Mars' deep underground is a daunting task. The easiest access is via a large cave. Most known caves on Mars are lava tubes with at least one skylight opening to the sky. While it is difficult to know the depths of these caves, some are estimated to descend at least 1/3 km, i.e., deep underground; many have openings > 100 m diameter [4, 5], Fig. 1. Caves provide shelter from both radiation and thermal extremes of the surface, and for these reasons, they are also appealing for the human Mars program [e.g., 6].

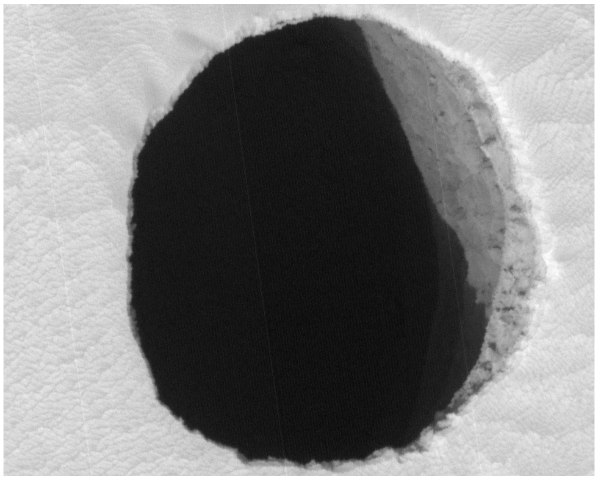

Fig. 1. Arsia Mons cave: ~150 m dia. opening by at least 175 m deep. PSP_004847_1745.

We are developing a simple "OrganiCam" instrument to exclusively detect and image organic materials using time-resolved fluorescence and then characterize these materials with Raman and fluorescence spectroscopy. These observations can be made rapidly from a distance of several meters above the surface, either from a hovering vehicle, i.e., in a cave, or from a lander (e.g., Europa).

Time-Resolved Laser-Induced Fluorescence. OrganiCam operates on the simple principle that biomaterials on Earth have characteristically short fluorescence lifetimes (~10 ns [7]) 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. 2). This has been demonstrated by the Biofinder prototype instrument, built with COTS parts at U. Hawaii [8]. The set-up shown in Fig. 2 provides rapid imaging, distinguishing biomaterials from fluorescing minerals (Fig. 3).

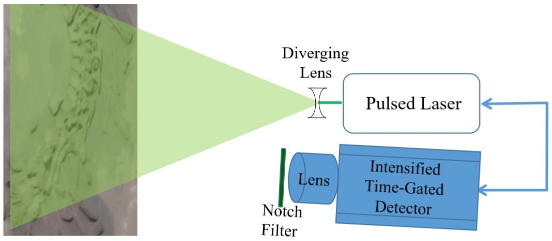

Fig. 2. Time-resolved fluorescence imaging concept.

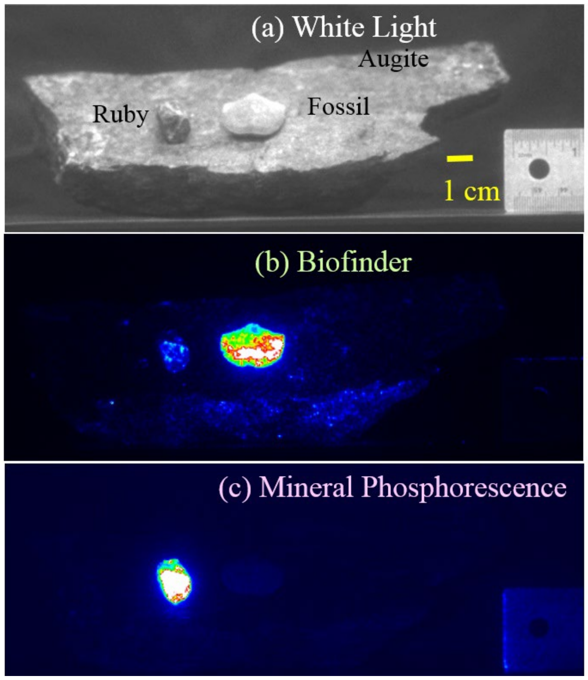

Fig. 3. Time-resolved fluorescence Biofinder results at 2 m distance [8]. Biological (b) and mineral fluorescence (c) are clearly distinguished.

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 bio-fluorescence imaging.
- 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}.
- Bio-fluorescence detection: low ppm to ppb range, broadly comparable to the concentration of organic materials observed by SAM on Mars [9].

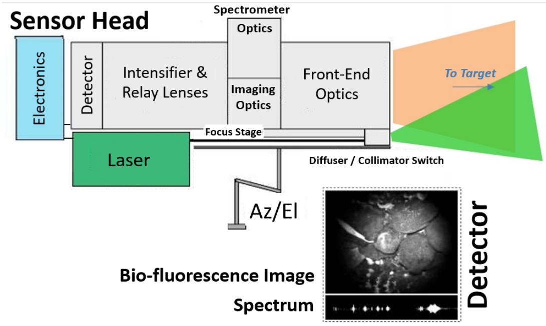

Fig. 4. Schematic diagram of OrganiCam shown set for fluorescence mode. Raman mode is enabled by removing the diffusing lens from the beam path. Lower inset illustrates simultaneous spectrum and image collected on the same detector.

An instrument schematic diagram is shown in Fig. 4. Laser light (green) is expanded through a diffuser for fluorescence mode. The diffuser is removed from the beam path for Raman mode, providing ~3.5 orders of magnitude higher illumination on a small spot, 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. 4, inset). The ground footprint of the spectrum is displaced laterally from the image; the locations of the two are reconstructed on the ground. The intensified detector section has heritage from the Mars2020 SuperCam instrument. The camera optics are radiation hardened to survive a Europa surface mission.

Status and Test Plans. The design of the prototype camera and spectrometer sections are shown in Fig. 5. As of early 2020, the design is complete and assembly has begun. We plan to have initial performance results in time for the meeting. Further testing in the spring of 2020 should validate the requirements. Some of the testing will involve organic materials that have been irradiated, similar to the surfaces of Mars and Europa. Our preliminary experiment with micro-Raman revealed interesting spectral signatures of Gamma-irradiated DNA and bacteria.

Missions. OrganiCam will be highly useful as a reconnaissance instrument for organics on other bodies of the solar system. These include ocean worlds as well as other environments, such as comet surfaces or caves on Mars. OrganiCam is one of the main instruments in the LIFE COVE mission concept that was submitted in to MEPAG. That mission accesses organics, potentially in a large (~200 m deep) skylight cave via a rotorcraft using technology from the Mars 2020 helicopter. The mission provides extensive reconnaissance of a cave, including imaging, organic, and atmospheric characterization over many flights without the need for a (risky!) landing in the cave [10]. The carrier spacecraft first lands on Mars and the helicopter traverses to near the cave entrance (e.g., Fig. 1) using multiple flights. The helicopter initially hovers over the opening to sample gases and test airflow in/out of the cave. Then, on successive missions, it robotically flies deeper in the cave, reconnoitering surfaces with its imager and OrganiCam, always exiting the cave to recharge and communicate at the end of each flight.

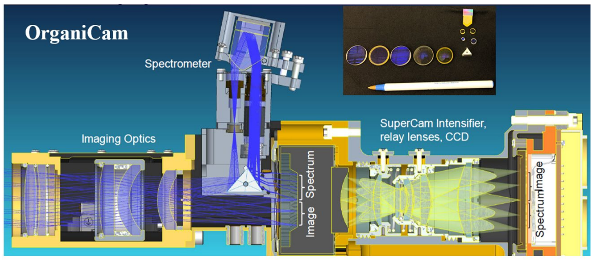

Fig. 5. OrganiCam prototype camera, spectrometer, and detector system. The time-resolving image intensifier is at the center. A single intensified detector system records both the image and the spectrum simultaneously on separate areas. The entire right side of the instrument is direct Mars 2020 / SuperCam heritage. Inset shows lenses with a pen for scale.

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References: [1] Freissinet C. et al. (2019) Mars 9, 6123. [2] Postberg F., et al. (2018) Nature 558, 564. [3] Jia X., et al. (2018) Nature Astronomy 2, 459. [4] Cushing G. (2017) AbSciCon 3708. [5] Cushing G.E. et al. (2015) JGR doi:10.1002/2014JE004735. [6] Boston P.J. et al. (2003) Grav. Spa. Bio. Bull. 16, 121. [7] Brody S.S. and Rabinowitch E. (1957) Science 125, 555. [8] Misra A.K., et al. (2016) Astrobiology 16, 715-729, doi:10.1089/ast.2015.1400. [9] Eigenbrode J. et al. (2018) Science 360, 1096. [10] Wiens R.C. et al. (2020) Airborne reconnaissance mission concept for organics in a martian cave. 3rd Int'l. Planetary Caves Conference #1063, San Antonio, TX.