

**PLANETARY ORGANIC ANALYZERS: INSTRUMENTATION AND METHODS FOR DETECTING TRACE ORGANIC MOLECULES ON ICY MOONS SUCH AS ENCELADUS.** A. M. Stockton<sup>1</sup>, Z. Duca<sup>1</sup>, G. Tan<sup>1</sup>, J. Kim<sup>2</sup>, A. Butterworth<sup>3</sup>, P. Turin<sup>3</sup>, M. Ludlam<sup>3</sup>, M. Diaz-Aguado<sup>3</sup>, P. A. Willis<sup>4</sup>, and R. A. Mathies<sup>5\*</sup> <sup>1</sup>Georgia Institute of Technology, Atlanta, GA. <sup>2</sup>Texas Tech University, Lubbock, TX. <sup>3</sup>University of California Berkeley Space Sciences Laboratory, Berkeley, CA. <sup>4</sup>Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA. <sup>5</sup>University of California, Berkeley, CA. \*Corresponding author: Richard A. Mathies, College of Chemistry, University of California, Berkeley, CA.

**Introduction:** *In situ* organic analysis has been proven to be a powerful and cost effective approach for detecting molecules of relevance for chemical evolution in our solar system. As miniaturized analytical systems become even more powerful, these capabilities and accomplishments will surely expand our knowledge of the chemistry and perhaps biochemistry of our solar system even further. Many missions, especially to exciting outer Solar System targets like the icy moons of Saturn and Jupiter are best approached with *in situ* instruments because of the formidable risks and costs of sample return.

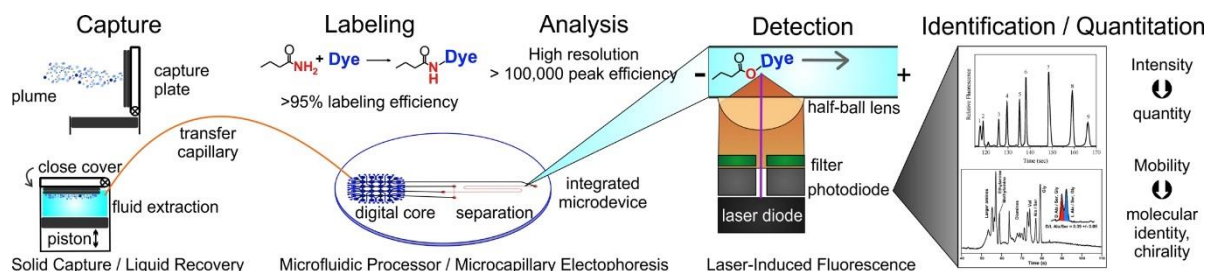
The Enceladus Organic Analyzer (EOA), developed as a Discovery Mission proposed Technology Demonstration Option, was designed to demonstrate *in situ* organic analysis capability by characterizing the organic content of Enceladus plume samples. The identity and concentration of organic molecules including amines, amino acids, and their chirality in extraterrestrial samples can be determined with sub-part-per-billion sensitivity using the EOA. An overview of the EOA operational scheme is shown in Figure 1.

**EOA Instrumentation:** Extensive instrument and method development and field testing has been used to develop the basic EOA capabilities. First, sub-part-per-billion sensitivity is achieved with an integrated instrument that first efficiently extracts organic molecules from captured material using aqueous extraction. The molecular extracts are passed to a multilayer integrated microdevice that consists of a Programmable Microfluidic Analyzer or PMA and a microfabricated capillary

electrophoresis ( $\mu$ CE) device. In the PMA, the organic compounds are automatically labeled with an amine-specific fluorescent reagent. The labeled molecules are then passed to the  $\mu$ CE system for high-resolution electrophoretic separation followed by highly sensitive laser-induced fluorescence detection. Finally, the dye-labeled organics are identified by their electrophoretic mobility. The coupling of efficient non-perturbative aqueous extraction, high efficiency labeling and sensitive detection results in sub-part-per-billion detection limits that dramatically enhance our ability to perform *in situ* detection and characterization of organic molecules the plume of Enceladus and other solar system bodies including moons and comets.

**Heritage and Recent Developments:** The instrumental concepts and technologies described here are based on over 15 years of development work at UC Berkeley and JPL [1-3]. Portable prototypes have been field tested in the Panoche Valley, CA and in the Atacama Desert in Chile, where amino biomarkers of ancient life were detected and dated based on their chiral ratios [1]. Recent effort has been targeted towards demonstrating survivability of the microdevice and reagents upon storage. Solid storage of all reagents has been demonstrated, as has microvalve functionality after 10+ years in storage.

**References:** [1] Skelley A.M. *et al.*, (2005) *PNAS USA*, 102, 1041-1046. [2] Kim J. *et al.*, (2013) *Anal. Chem.*, 85, 7682-7688. [3] Mora M.F., Stockton A.M., Willis P.A. (2012) *Electrophoresis*, 33, 2624-2638.



**Figure 1:** Enceladus Organic Analyzer (EOA) investigational schematic. The EOA captures plume particles using a specially engineered capture door during the fly through. After closing the capture door to form a fluid extraction chamber, the target molecules are dissolved in an aqueous extraction solvent. The extract is passed to the Programmable Microfluidic Analyzer (PMA) where it is labeled with an amine-specific fluorescent dye, separated based on size and charge in the capillary electrophoresis system, and detected by laser-induced fluorescence. The fluorescence intensity vs. time provides quantitative compositional and chirality information.