MICROGRAVITY TEST PLAN FOR A FULLY INTEGRATED PROGRAMMABLE MICROFLUIDIC ORGANIC ANALYZER. Z. Estlack[1], A. L. Butterworth[2], M. Golozar[2], N. Parsley[2], R. A. Mathies[2], J. Kim[1], [1]The University of Utah, [2] Space Sciences Laboratory, University of California Berkeley, Berkeley, CA 94720

Introduction: Microfluidics have begun to be utilized for space exploration to enable micro-to-nanoliter scale volume manipulation without any sensitivity trade-off when measuring biological and chemical compounds [1]. However, most microfluidic devices are designed for single tasks so they perform limited sample handling functions. In contrast, Berkeley microfluidic organic analyzers [2] are fabricated using a programmable microvalve array (PMA) integrated directly with a glass microchannel for integrated capillary electrophoresis (μCE). PMAs consist of networks of pneumatic microvalve arrays that can perform a wide variety of sample preparation and analysis steps using nanoliter to microliter scale volumes of sample or fluid. Like a programming logic circuit, the PMA can activate any fluidic path by switching each microvalve status in the valve network. With this liquid processor, target samples are mixed with labeling dye, incubated in a storage reservoir, and then transferred to the sample reservoir of the μCE channel for analysis. The Berkeley analyzers all demonstrate quantitative compositional analysis with nM limits-of-detection for amino acids, aldehydes, ketones, and carboxylic acids.

The Enceladus Organic Analyzer (EOA) [3-5] has made a major development step toward space flight for the PMA-μCE incorporating aerospace engineering to provide a low-power, low-mass pneumatic manifold and latched switching valves, environmental pressure chamber, gas and fluid storage, sample capture chamber, and miniature confocal Laser–Induced Fluorescence (LIF) detection system with 405 nm excitation, demonstrated to 60 picomolar limit of detection for amino acid [6].

The same compact core analyzer is deployed in the Microfluidic Organic Analyzer for Biosignatures (MOAB), optimized with sample handling for a Europa Lander. The manifold design and its driver electronics and microprocessor control accommodates a PMA-μCE device allowing for PMA design modifications for mission science optimization with minimal software changes. The PMA thus provides a universal microfluidic platform providing a programmable, flexible fluid processor desirable for organic chemical analytical applications in space exploration.

The next major step in preparing a PMA-μCE for spaceflight is environmental testing, in particular microgravity testing. To achieve this goal multiple ZeroG parabolic flights are planned to create a challenging microgravity environment that varies from +2g to weightless. The evaluation of microfluidic functions during this range of environmental challenges and the performance of a variety of chemical assays during flight will be an important TRL advancement of this technology.

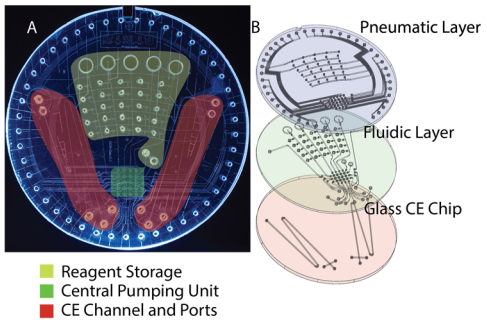

Figure 1: View of a programmable microfluidic chip and the necessary features for analysis use. A) The assembled chip with specific regions highlighted. B) An exploded view of the chip showing the multilayer approach.

Flight-like Instrument Development:

Programmable microvalve array (PMA) chip development. The initial Berkeley microfluidic chip design was based on expected requirements for trace amino acids analysis. Thus, the chip, shown in **Figure 1**, has a reagent storage region for access to the necessary chemicals, a central pumping unit to move fluid around the chip, and an integrated glass capillary electrophoresis chip to separate the organic molecules [7]. The resulting chip has been characterized in multiple ways. First, the pumping capabilities of the chip were verified with respect to theory and fluidic resistance on-chip. **Figure 2A** shows the pumping profile of the central pumping unit and 894 nL/cycle of pumping capability was achieved. Next, the mixing capabilities of the chip were tested using a fluorophore and fluorescence microscope. In addition to characterization, pumping and actuation sequences were written to accomplish the required tasks for autonomous deployment. Of particular interest was a sequence to fill and degas the main pumping section of the chip. The chip will need to remain dry during launch and a multi-year journey to planetary destination, followed by remote, autonomous start-up and aliveness testing and mission function of the instrument.

Integrated PMA-μCE performance. The MOAB instrument with integrated PMA-μCE chip successfully completed an automated, integrated amino acid mixture test experiment in the lab: This involved automatically

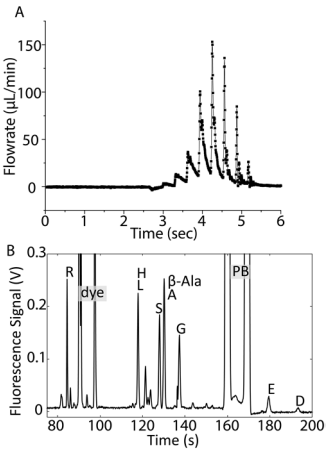

Figure 2: Characterization results for the PMA. A) Lab based flowrate profile for the chip. This will be compared with data under microgravity conditions B) Capillary electrophoresis results from samples labeled and separated in the PMA.

filling a dry chip, mixing amino acids and a fluorophore (Pacific Blue) in pH 9 buffer, incubating to label, delivering the labeled sample to the detector after dilution, running high resolution CE separation and detection of nanomolar amino acids with the integral flight-like LIF detector shown in **Figure 2B**.

Support hardware and software development. A support system has been built for the pneumatic manifold chip interface and a second miniature confocal LIF detector has been fabricated with 532 nm laser to enable other dye assays to be utilized. An enclosure was designed and fitted with a sensor suite containing g-force, atmospheric pressure and temperature, pneumatic pressure and vacuum, and a flowrate monitor. In addition, a separate box was designed to provide power and pneumatics to the main instrument enclosure. **Figure 3** shows the current designs with a chip inside ready for microgravity environmental testing. Other planned environmental tests include vibration, thermal and vacuum testing of at Space Sciences Lab (SSL) and field testing to verify the remote analysis outside laboratory conditions, providing foundational steps to a full autonomous system. Software for controlling the microfluidic chip was developed to aid in prototyping and running the microfluidic chip. This software (Python) generates fluidic sequences, which allows for modular analytical experiments to be loaded onto the control microprocessor from a simple to use spreadsheet format, and this has been integrated with a real-time data analysis system in LabVIEW for use during the validation process.

Field and Flight testing: We aim to complete two primary tests of PMA function both in challenging mobile and field environments and in varying g-load environments including zero-g.

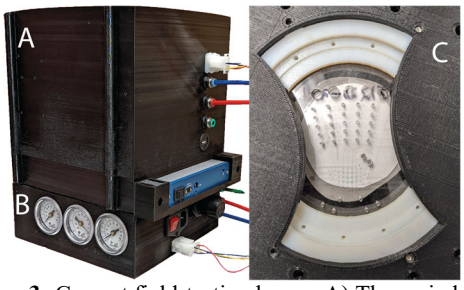

Figure 3: Current field-testing boxes. A) The main box for the PMA chip, sensor suite, optical setup, and high voltage supply. B) The supporting box for power and pneumatic sources. C) Top view of the main box showing a chip mounted for visibility.

Ground-based testing. The field-ready platform will be used for automated trace organic analysis field tests on challenging analog samples. This will involve taking the MOAB system into the field and running real-world samples through the analyzer. We are planning tests at a variety of hot sping sites for example. Field operation can be challenging because the instrument must be fully capable of remote function and it must survive the transit, assembly, and operation in sites with widely varying environments.

Microgravity PMA tests. During the microgravity environment of a parabolic flight, the MOA sensor suite will monitor chip functions and experiments: Performance of the PMA valve membranes; Chip flow-rate and pumping efficiency; the LIF detector will measure accuracy of mixing ratios and results from mock assays run on-chip. Contemporaneous gravitational force and atmospheric sensor measurements will be correlated with chip performance and analytical results. While we expect there to be no difference to ground-based results due to underlying physics at play in microfluidics, this is an important step in the verification of a microfluidic system destined for use in space.

The resulting experiments accomplish two major milestones. First, the MOA is field-tested in a variety of different challenging environments, and second, the PMA is tested with real-world samples, which are essential to refine the instrument system-level science operations and autonomous decision points.

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