THE MARS ORGANIC ANALYZER: INSTRUMENTATION AND METHODS FOR DETECTING TRACE ORGANIC MOLECULES IN OUR SOLAR SYSTEM

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ABSTRACT

The Mars 2020 Mission leverages Mars Science Laboratory Curiosity rover heritage to perform an investigation on Mars with objectives including: (A) Determine environmental habitability, search for regions and materials with high biosignature preservation potential, and search for evidence of past life, and (B) Scientifically select and cache well characterized samples for possible return. The Mars Organic Analyzer (MOA), developed and proposed for Mars 2020, was designed to meet these objectives by providing the mission with capability to analyze a broad range of organic molecules with sub-part-per-billion limits of detection. This analytical sensitivity is needed to characterize the habitability of environments, to characterize biosignature preservation potential, to search for evidence of past life, to characterize samples for return to Earth, and to measure and characterize any possible forward contamination.

KEYWORDS: mars organic analyzer, programmable microfluidic analyzer, biosignature, habitability

MOA SCIENCE

The MOA is capable of determining the identity and concentration of a wide range of organic molecules including amines, amino acids, aldehydes, ketones, organic acids, thiols and polycyclic aromatic hydrocarbons (PAHs) in Mar-tian samples with sub-part-per-billion sensitivity.

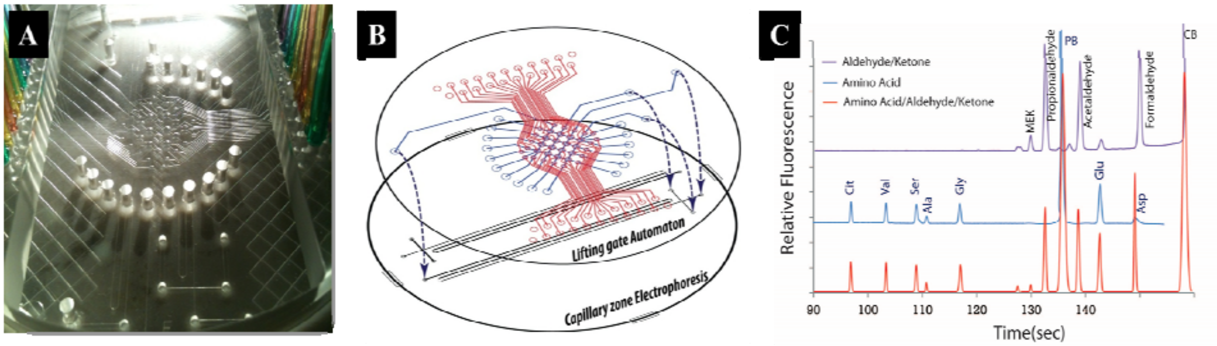

Figure 1: *(A) Actual integrated platform for universal sample processing and* µCE *detection. (B) Exploded view of the chip layout, middle: photo of a finished chip. (C) Exemplary MOA analysis of a mixture of various amino acids, aldehydes and ketones. High sensitivity labeling, CE separation and detection enables sub-part-per-billion sensitivity.*

MOA INSTRUMENT

The MOA instrument is based on extensive instrument and method development and field testing [1]. We have recently demonstrated a Programmable Microfluidic Analyzer (PMA) which includes on-chip automation of sample processing and microchip capillary electrophoresis (µCE) analysis with laser-induced fluorescence (LIF) detection (Figure 1). The microfluidic valve array is integrated to µCE via a 3-layer glass/PDMS integrated microfluidic chip. In this design, we employ the PMA as the 16-valve processing core, enabling direct integration to the µCE channel. On the perimeter of the array are 16 "stop" valves to control fluidic access from inlets/outlets into the array, enabling the processor to be cleared of contamination between operations. Four of the inlet perimeter valves have fluidic connections to the sample, waste, cathode, and anode inputs of the µCE channel. The processed sample can be loaded directly into the sample well and separated via µCE and detected with highly sensitive LIF. We have successfully demonstrated the 32-valve microfluidic processor for on-chip labeling of amino acids, carboxylic acids and aldehydes/ketones with Pacific Blue succinimidyl ester (PB) and Cascade Blue (CB) hydrazide, automatic loading for µCE, and on-chip µCE-LIF analysis. These derivatization reactions are fast (< 15 minutes) and have down to 70 pM limits of detection in µCE-LIF analysis.

With an advanced PMA in figure 2, sub-part-per-billion sensitivity is achieved with an integrated instrument that first efficiently extracts organic molecules from Martian soils and drill fines using subcritical aqueous extraction (SCAE) [2]. The molecular extracts are passed to a multilayer integrated microdevice that consists of the PMA and a microfabricated capillary electrophoresis (µCE) device. In the PMA [3], the organic compounds are autonomously labeled according to their chemical functional groups with fluorescent reagents specific for amines, aldehydes, ketones, organic acids and thiols. The labeled molecules (or naturally fluorescent PAHs) are then passed to the µCE system for high-resolution electrophoretic separation followed by high sensitivity laser-induced fluorescence detection on one of the four independent CE channels [4]. The dye-labeled organics are identified by their electrophoretic mobility and the PAHs are identified by their mobility and their fluorescence spectrum. The coupling of efficient non-perturbative SCAE, high sensitivity labeling and detection results in sub-part-per-billion detection limits that dramatically enhance our ability to perform in situ detection and characterization of organic molecules on Mars and other solar system bodies including moons and comets.

FUTURE OF MOA

The laboratory development of the extraction, labeling, processing, separation and detection methods that make the MOA instrument possible will be presented. The engineering design that integrates all of these functions for the analysis of up to 38 samples on the surface of Mars including the fiber optic coupling of the four detection systems to a single spectrograph and CCD will be presented. Overall MOA is a compact 12 kg, 5 watt, 22 x 22 x 29 cm instrument (Figure 3) that only requires 68 MB of data return for the analysis of 38 samples. While targeted for Mars, MOA could be repackaged for other planetary science missions requiring highly sensitive in situ organic analysis.

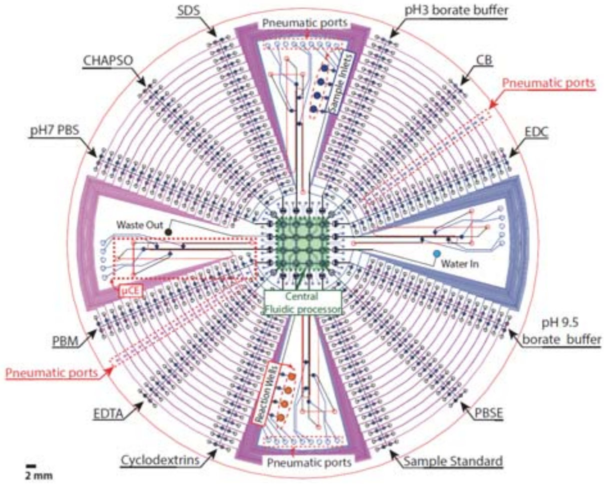

Figure 2: *MOA Programmable Microfluidic Analyzer layout. This 100-mm diameter multilayer glass-PDMS device with 516 multiplexed valves contains the dried reagents needed to perform all MOA chemical analyses upon 38 separate sample extracts on Mars.*

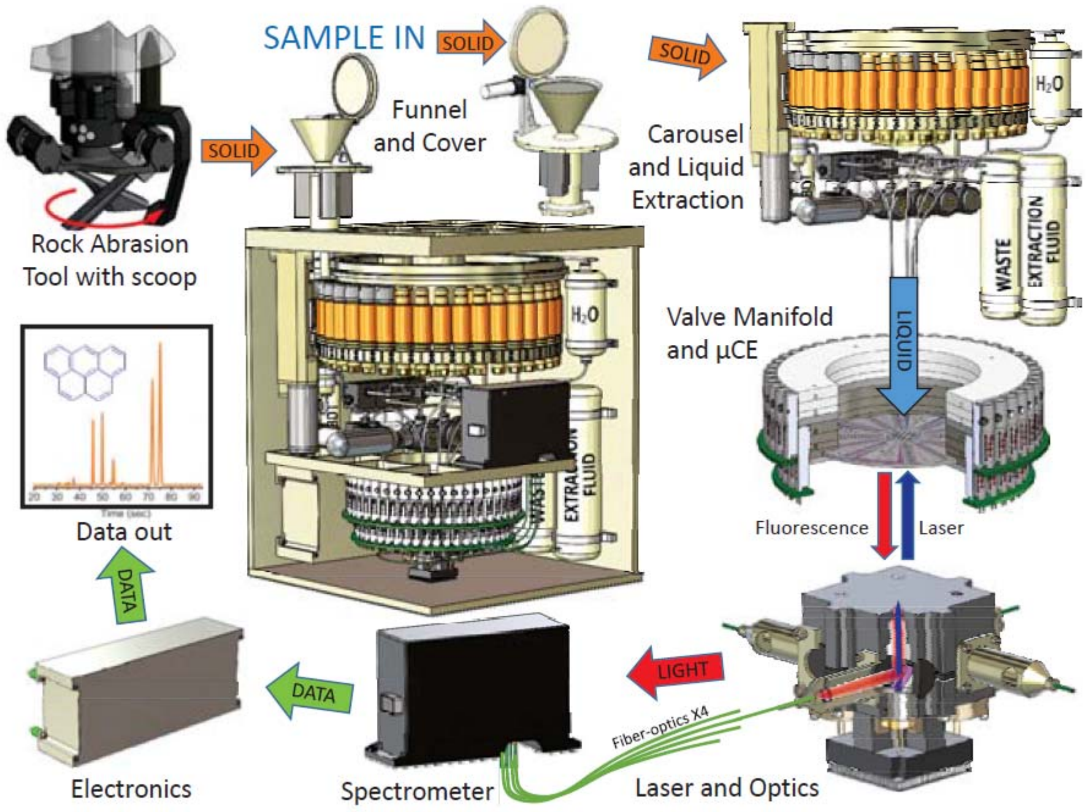

***Figure 3**: In the MOA investigation, drill fines are passed through a funnel to the extraction cup and aqueous solvent at elevated T, P is forced through the drill fines, extracting organic molecules. This extract is then transported to a programmable microfluidic sample processing system or PMA for fluorescence labeling followed by injection, separation and high sensitivity detection on a microfabricated capillary electrophoresis channel to reveal the identity and concentration of a wide variety of organic molecules.*

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