SAMPLE PROCESSOR FOR LIFE ON ICY WORLDS (SPLIce):
DESIGN AND TEST RESULTS
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ABSTRACT
We report the design, development, and testing of the Sample Processor for Life on Icy Worlds (SPLIce) system, a microfluidic sample processor to enable autonomous detection of signatures of life and measurements of habitability parameters in Ocean Worlds. This monolithic fluid processing-and-handling system (mass ~ 0.5 kg) retrieves a 50-µL-volume sample and prepares it to supply a suite of detection instruments, each with unique preparation needs. SPLIce has potential applications in orbiter missions that sample ocean plumes, such as found in Saturn’s icy moon Enceladus, or landed missions on the surface of icy satellites, such as Jupiter’s moon Europa.

KEYWORDS: life detection; micro fluidics; icy worlds; ocean worlds; fluidic processor; sample processor

INTRODUCTION
Answering the question “Are we alone in the universe?” is captivating and exceptionally challenging. Even general criteria that define life very broadly include a significant role for water [1,2]. Searches for extinct or extant life therefore prioritize locations of abundant water whether in ancient (Mars), or present (Europa and Enceladus) times. Only two previous planetary missions had onboard fluid processing: the Viking Biology Experiments [3] and Phoenix’s Wet Chemistry Laboratory (WCL) [4]. SPLIce differs crucially from those systems, including its capability to process and distribute µL-volume samples and the integration/autonomous control of a wide range of fluidic functions, including: 1) retrieval of fluid samples from an evacuated sample chamber; 2) onboard multi-year storage of dehydrated reagents; 3) integrated pressure, pH, and conductivity measurement; 4) filtration and retention of insoluble particles for microscopy; 5) dilution or vacuum-driven concentration of samples to accommodate instrument working ranges; 6) removal of gas bubbles from sample aliquots; 7) unidirectional flow (check valves); 8) active flow-path selection (solenoid-actuated valves); 9) metered pumping in 100 nL volume increments.

EXPERIMENTAL
The SPLIce manifold, made of three thermally fused layers of precision-machined cyclo-olefin polymer, supports all fluidic components (Figure 1 and 2) and integrated microchannels (125 x 250 µm). Fluid is pumped by a stepper-motor-driven pump (Lee Co.). The functionality of the integrated MEMS pressure sensor (Honeywell) and passive check valves (Figure 3) were tested in conjunction with our newly designed integral bubble traps (Figure 4) and a hydrophobic, PTFE membrane (0.2 µm pores)-based vacuum-driven concentrator (Figure 5.)
RESULTS AND DISCUSSION

The integrated concentrator has demonstrated as much as 120-fold vacuum-evaporative concentration with an 8.4 mm² PTFE membrane surface area and 7.4 µL working volume. Polyethylene fused bead beds (PEFBBs; ~50% porosity) are used to store dry/lyophilized buffers, calibrants, and fluorescent dyes, and also to promote mixing of sample with calibrant, dye, or H₂O. Software-controlled automated tests demonstrated successful 1) fluid delivery to each component 2) valve and pump synchronization 3) sample aliquot delivery to instrument interface ports, and 4) rehydration of vacuum-dried fluorescent dye. In Figure 6, fluorescein on PEFBBs was rehydrated for 15 min using a pump-delivered water aliquot; it is displaced as H₂O enters the bottom of the channel and pushes the dye into a check valve.

CONCLUSION

Ultimately, SPLIce will fluorescently label amino acids in the sample for microchip-based electrophoretic (MCE) chiral separation and detection to seek and quantify key organic biosignatures [5]; it will also deliver sample to a microfluidic WCL (“mWCL”) to measure soluble ions, pH, and redox-active species.

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REFERENCES


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Sample Processor for Life on Icy Worlds (SPLIce) system: a microfluidic sample processor to enable autonomous detection of signatures of life and measurements of habitability parameters in Ocean Worlds.

- Monolithic fluid processing-and-handling system
- Prepares sample for a suite of detection instruments, each with unique preparation needs

Potential applications:
- Orbiter missions that sample frozen plumes, such as found above Saturn’s icy moon Enceladus
- Landed missions on the surface of icy satellites, such as Jupiter’s moon Europa.

SPLIce differs crucially from previous onboard fluidic systems, including its capability to process and distribute µL-volume samples and the integration/autonomous control of a wide range of fluidic functions:
1. Retrieval of 50-µL fluid samples from an evacuated sample chamber
2. Onboard multi-year storage of dehydrated reagents
3. Integrated pressure, pH, and conductivity measurements
4. Filtration and retention of insoluble particles for microscopy
5. Dilution or vacuum-driven concentration of samples to accommodate instrument working ranges
6. Removal of gas bubbles from sample aliquots
7. Unidirectional flow (check valves)
8. Active flow-path selection (solenoid-actuated valves)
9. Metered pumping in 100 nL volume increments

SPLIce will fluorescently label amino acids and amines for microchip-based electrophoretic (MCE) chiral separation and laser-induced fluorescence detection to identify and quantify key organic biosignatures.

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