National Aeronautics and Space Administration

FY24 Strategic Initiatives Research and Technology Development (SRTD)

SCHAN: Analysis of biomolecules from resilient microorganisms using supercritical CO_2 and subcritical H_2O

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Strategic Focus Area: In-Situ Extant Life Detection Technology **| Strategic Initiative Leader:** Victor S Abrahamsson

Objectives: The Supercritical CO_2 and Subcritical H_2O Analysis (SCHAN) instrument uses supercritical CO_2 to analyze organic biosignatures at parts-per-trillion (ppt) concentration levels (Fig. 1). The operational steps of the SCHAN instrument are as follows: 1) load sample and capture any microbes or other particulates on a filter, 2) perform cell lysis with supercritical CO_2 (22 MPa, ≤250 °C), 3) extract, preconcentrate, separate, and detect organic biosignatures. The overall goal in FY24 was to develop and validate a TRL 5 version of SCHAN (Task 1, Fig. 2). To achieve this, and prepare for environmental and TVAC testing, several parts of SCHAN needed to be modified or redesigned, including the overall design of the enclosure and lab bench. The SCHAN instrument demonstration included an ice/liquid handling and delivery subsystem and mass spectrometer subsystem demonstrated in an end-to-end configuration.

Background: Life-detection missions to Enceladus and Mars have been identified as two of the top priorities for the upcoming decade by the Decadal Strategy for Planetary Science and Astrobiology 2023-2032. New technologies, and sensitive and versatile instruments such as SCHAN are needed to fulfill stringent mission concept measurement requirements. SCHAN offers several advantages over its competitors in sensitivity, simplicity, and gentleness of approach (no harsh chemicals or very high temperatures that are commonly used by other instruments). The instrument's design offers unprecedented sensitivity in lipid detection, with detection limits almost 1,000,000 times more sensitive than current gas chromatography-mass spectrometry (GC-MS) systems.

The SCHAN instrument is capable of analyzing both solid samples (Mars) and liquid samples (melted ice from Enceladus). The work in FY22 focused on developing methods for an Enceladus scenario, FY23 on hardware development to bring SCHAN from TRL 4 to 5, and FY24 on demonstration of TRL 5 through environmental tests.

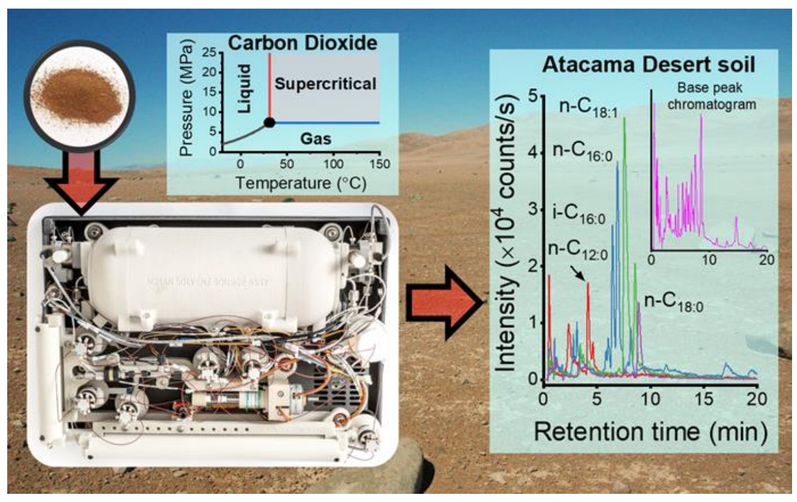

Figure 1. SCHAN: The TRL 5 instrument developed through this effort uses supercritical CO_2 for lysing microbes to analyze biosignatures at parts-per-trillion (ppt) concentration levels.

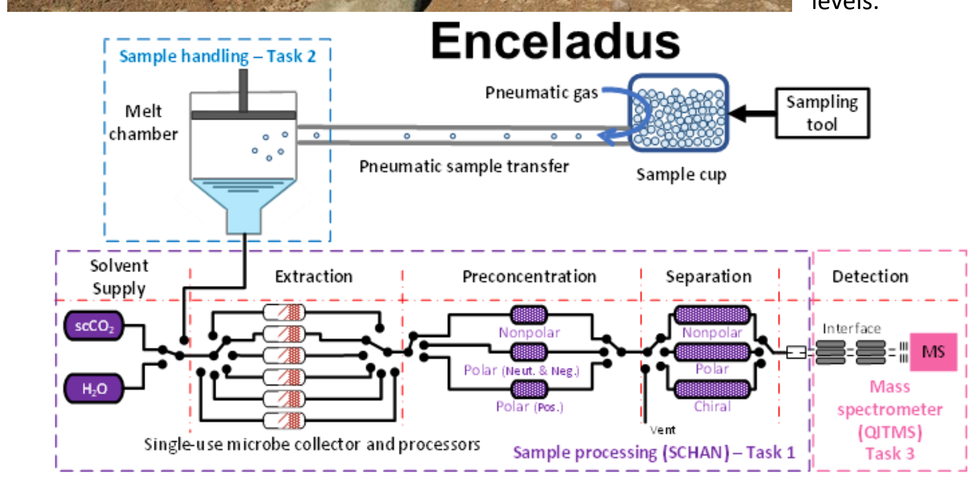

Figure 2. The goal of this Strategic Initiative was to deliver an instrument for in situ life detection and chemical analysis for both Mars (TRL 4) and Ocean Worlds (TRL 5).

Approach and Results: Our environmental testing requirements were: demonstrate survival of all components except the solvent supply down to -55 °C, demonstrate operation under vacuum at temperatures from 0 °C to 55 °C, demonstrate vibration from 20-2000 Hz in the z and xy directions at a Grms of 6.8, and demonstrate that our components can withstand Enceladus mission-relevant radiation doses. We set an Enceladus-relevant total ionizing dose requirement of 100 krad (Si) behind 100 mils of aluminum, which is the same radiation requirement as in the Enceladus Orbilander Planetary Mission Concept Study, and which exceeds typical exposures for Mars missions. The lipid and chiral columns, trap column, and valve assemblies were consecutively vibration, thermal/vacuum (TVAC), and radiation tested, with performance tests conducted after each step. In all cases, the components were demonstrated to be highly stable across the full battery of tests. No notable changes in separation performance were recorded following the environmental tests (see Fig. 3). The valve assembly performance was confirmed through actuation and pressurization / leak tests. The PEEK tubing used in SCHAN was also tested to 100 krad (Si), and found to maintain its flexibility and pressurizability with no brittleness. End-to-end TVAC tests demonstrating SHaD/SCHAN have been completed (Fig. 4) using Ocean World analogs (seawater and frozen seawater from the Pacific Ocean). The analysis of ~2 g of liquid or solid sample was completely automated once the sample was scooped or poured into the SHaD chamber. Multiple fatty acids were detected at parts-per-billion level or lower.

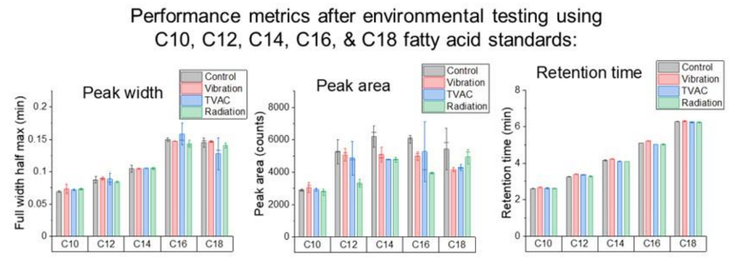

Figure 3. Coupling of SHaD (sample handling, Task 2) and SCHAN (analysis, Task 1) subsystems was successfully demonstrated with a seawater (blue trace) and sea ice (red trace) Ocean World analog sample from the Pacific Ocean. Analysis revealed several fatty acids, in addition to many other organics. No other instrument is capable of detecting fatty acids at the parts-per-trillion level, showing that SCHAN is uniquely capable of detecting extant life at these low concentrations.

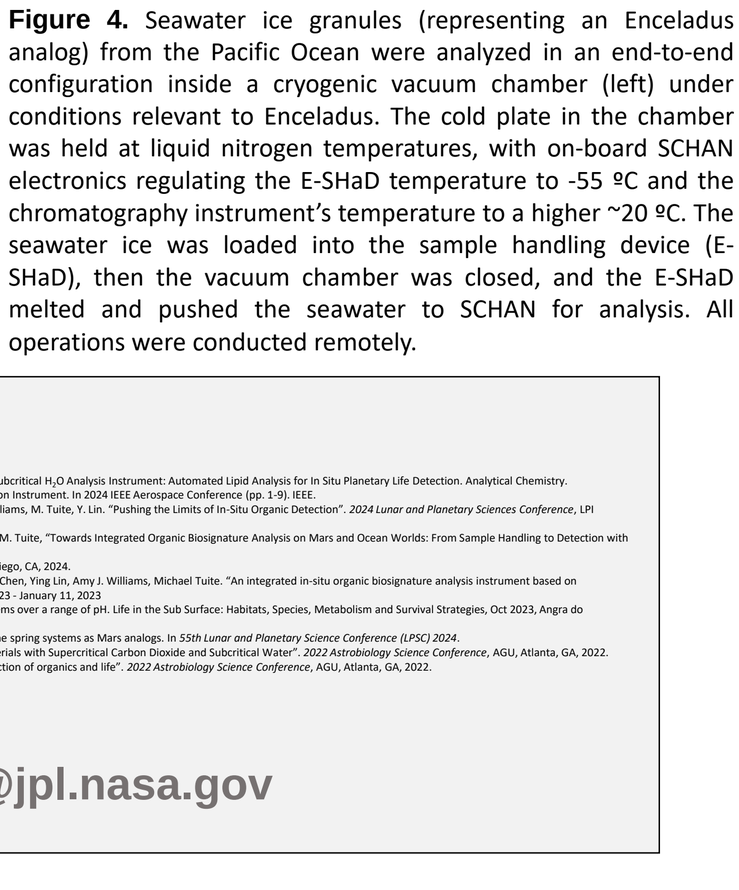

Figure 4. Seawater ice granules (representing an Enceladus analog) from the Pacific Ocean were analyzed in an end-to-end configuration inside a cryogenic vacuum chamber (left) under conditions relevant to Enceladus. The cold plate in the chamber was held at liquid nitrogen temperatures, with on-board SCHAN electronics regulating the E-SHaD temperature to -55 ºC and the chromatography instrument's temperature to a higher ~20 ºC. The seawater ice was loaded into the sample handling device (E-SHaD), then the vacuum chamber was closed, and the E-SHaD melted and pushed the seawater to SCHAN for analysis. All operations were conducted remotely.

Significance/Benefits to JPL and NASA: We have developed an integrated, high-fidelity TRL 5 package. It:

- Is the first and only instrument demonstrating end-to-end analysis of lipids and fatty acids – an important group of molecules for life detection and the main focus area for Mars
- Delivers unprecedented detection limits (as required by mission concepts)
- Provides a unique approach to circumvent known problems related to derivatization, experienced by for example Sample Analysis at Mars, and emphasized as an area of concern by MEPAG.
- Is ready for infusion into mission proposals to Ocean Worlds, or with some further (minor) support, for Mars.

In this work, we have found that SCHAN's performance is so far unmatched by any other technology. In particular, it could revolutionize science return for Mars in-situ lipid applications, as it is the most sensitive instrument in the world for these high priority organic biosignatures that have extreme longevity. Adding to the uniqueness, SCHAN's integrated sample processing for microbe lysis is capable of detecting $<1\times10^4$ cells/mL – the lowest so far reported for a separation instrument (e.g. gas chromatography or capillary electrophoresis).

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Publications:

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