National Aeronautics and Space Administration

A Pyroelectric Instrument for Elemental Lithochemistry

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Program: FY21 R&TD Topics **Strategic Focus Area: Remote/In Situ/Life Detection Sensors and Instruments**

Objectives:

Characterize capabilities of our **pyroelectric X-ray fluorescence source (PyroXRS) instrument** testbed for in situ geochemical planetary exploration including:

- Flux strength and stability.
- Elemental detectability - analyze geological reference material (GRM).

Background:

Pyroelectric X-ray source technology has been investigated[1 – 5] for its properties as an X-ray source emitter, useful in materials analysis via X-ray fluorescence (XRF) spectroscopy. A primary application of interest is to use the pyroelectric source on small craft payloads for in situ lunar exploration.

Pyroelectricity –. By applying a temperature gradient (**ΔT**) across a pyroelectric crystal (e.g. $LiTaO_3$) charge collects at the +or-z crystal faces (Fig. 1). Collection leads to discharge across the gap to an opposite facing conductive material (e.g Cu film). Electron impact produces source bremsstrahlung and **characteristic X-ray** emission[1]. This emission is the primary flux of the pyroelectric X-ray source.

The JPL PyroXRS testbed and detection testbed configuration (Fig. 2) houses the 1-crysal design of Fig. 1 which is similar to a design model once commercially available[6].

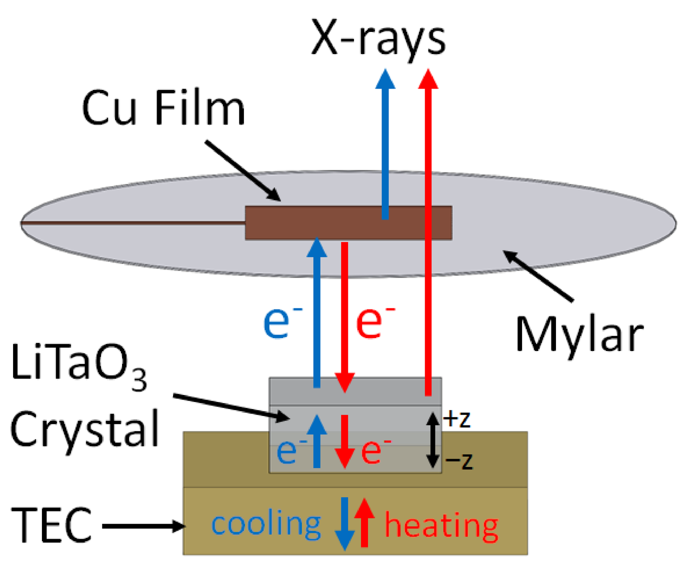

Figure 1: Schematic of the 1-crystal design showing direction of propagation of heat flow, electron discharging and X-rays emitted in the direction of the SDD.

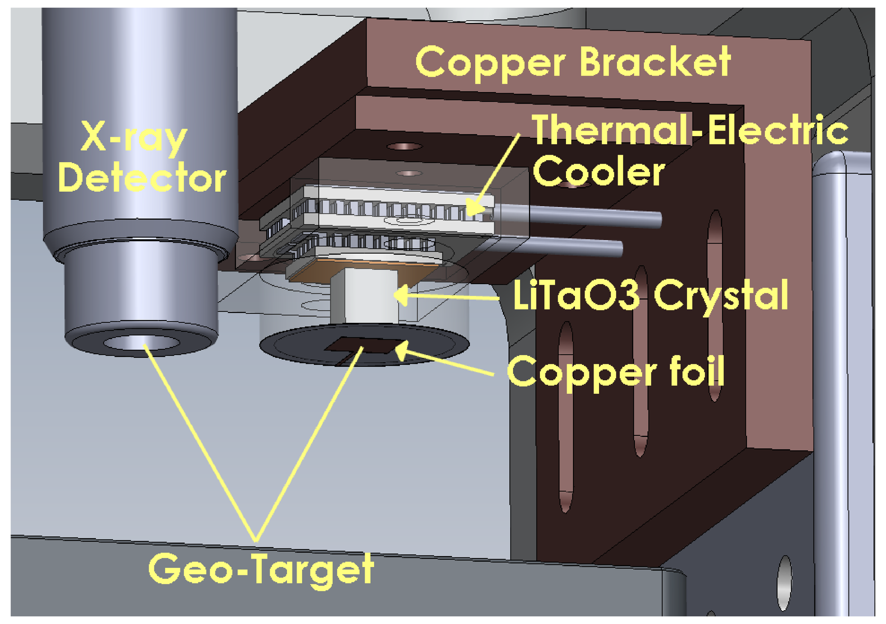

Figure 2: JPL pyroelectric instrument rendering of the 1-crystal design.

Geo-targets are measured with the source facing down. To assess **flux**, the source was rotated to face the silicon drift X-ray detector (SDD) along the same boresight.

Pyroelectric technology's inherent temporally changing flux and undefined discharge energy profile indicate that more work is needed to assess the future of pyroelectrics in in situ space exploration.

Approach And Results:

Flux examination:

Assessed: 7 experiments of 20 cycles heating-then-cooling. Spectra acquired at end of every heating or cooling cycle and results from Expt. #1 shown in Figure 3.

Heating and cooling cycles summed in Figure 4 into bulk heating (top panel) and bulk cooling (bottom panel) per experiment to assess if per-experiment flux consistency exists.

Flux results:

Flux visibly different per cycle and per experiment and likely to impact elemental quantification if used as a spectrometer. Nominal air pressure of 40 mTorr appear idea for maximizing flux output.

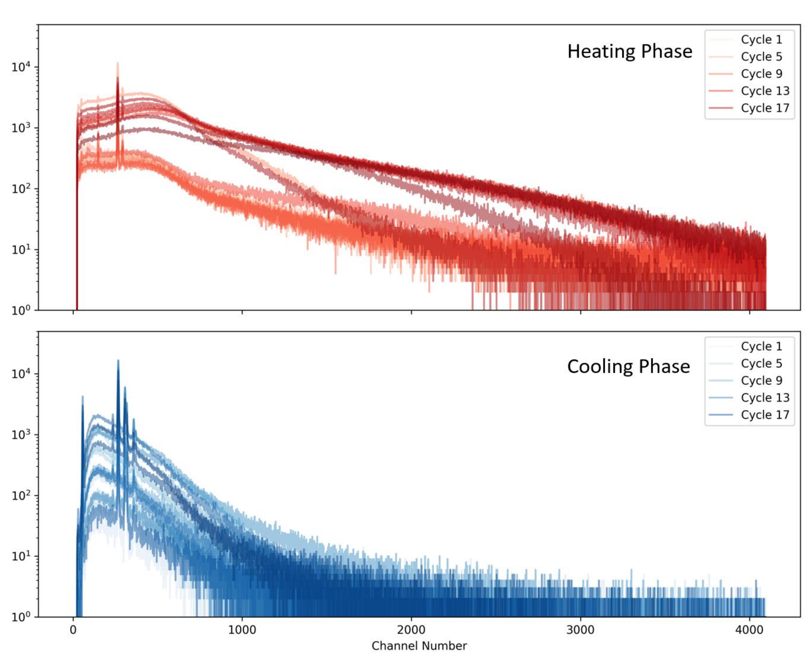

Figure 3: Results from experiment run #1 showing variations in flux observed from 20 heating (top panel data) and cooling (bottom panel data) cycles.

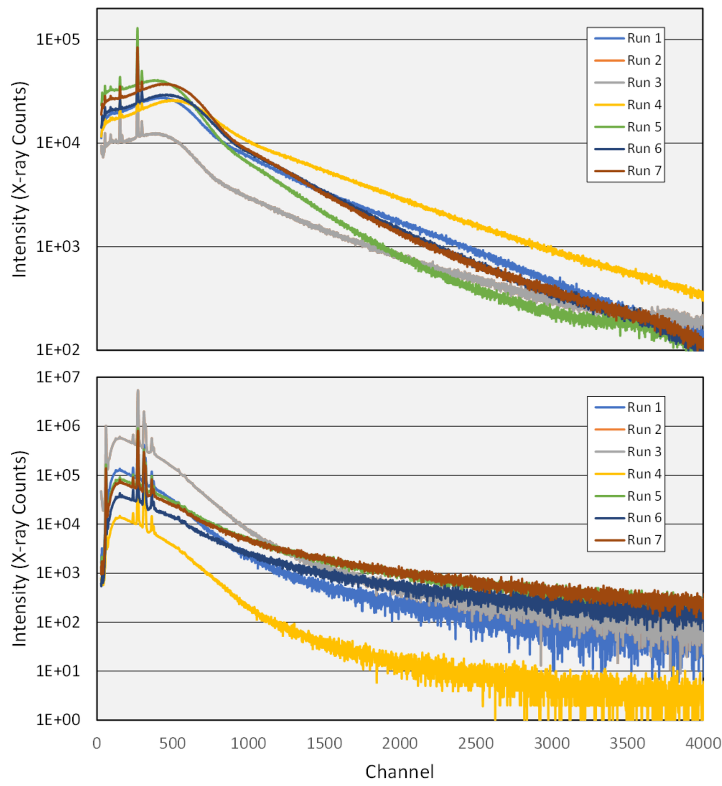

Figure 4: Bulk summed spectra from seven experiments sorted according to their acquired 20 heating twenty cycles (top panel) and twenty cooling cycles (bottom panel).

Elemental detection examination:

Using the measurement configuration (Fig. 2), a broad field powdered geological reference material of BHVO2-G (Basaltic Hawaiian Volcanic Ocean) fused glass was measured using one 20-cycle experiment run.

Elemental detection results:

- Good detection of all major elements: Z = 11 (Na) up to 26 (Fe)
- Good detectability potential for S- and Cl – salts → 2 – 3 keV region of S & Cl lines free of Rh scatter peaks as found in Rh anode tubes (e.g. PIXL)
- Poor peak to background ratio
  - Minor and trace element detectability is poor
  - Due to high Compton scatter from high excitation energies (E_{max} ~ 120 keV)
  - Must reduce E_{max} by modifying instrument geometry

Outlook – good, overall – results give insight to future design considerations to mitigate flux and detection issues. Flux instability might be compensated for using second detector counting only primary flux during measurement.

Significance and Benefits to JPL and NASA:

Benefits include furthering the development and operational understanding of the prototype PyroXRS instrument and its potential for in situ planetary exploration. We anticipate that this in situ elemental analyzer instrument, due to its overall robust design simplicity, would have utility on smaller craft missions and those in which power consumption is minimal and mission travel time is long

Showing increased instrument stability and technological readiness of an alternative X ray source has the potential both to identify future developments and provide much needed input to future PICASSO funding calls.

As a long-term benefit, continued funding to develop this instrument and characterize its operational constraints, strengths and weaknesses will help us to better match this instrument capability with mission concept.

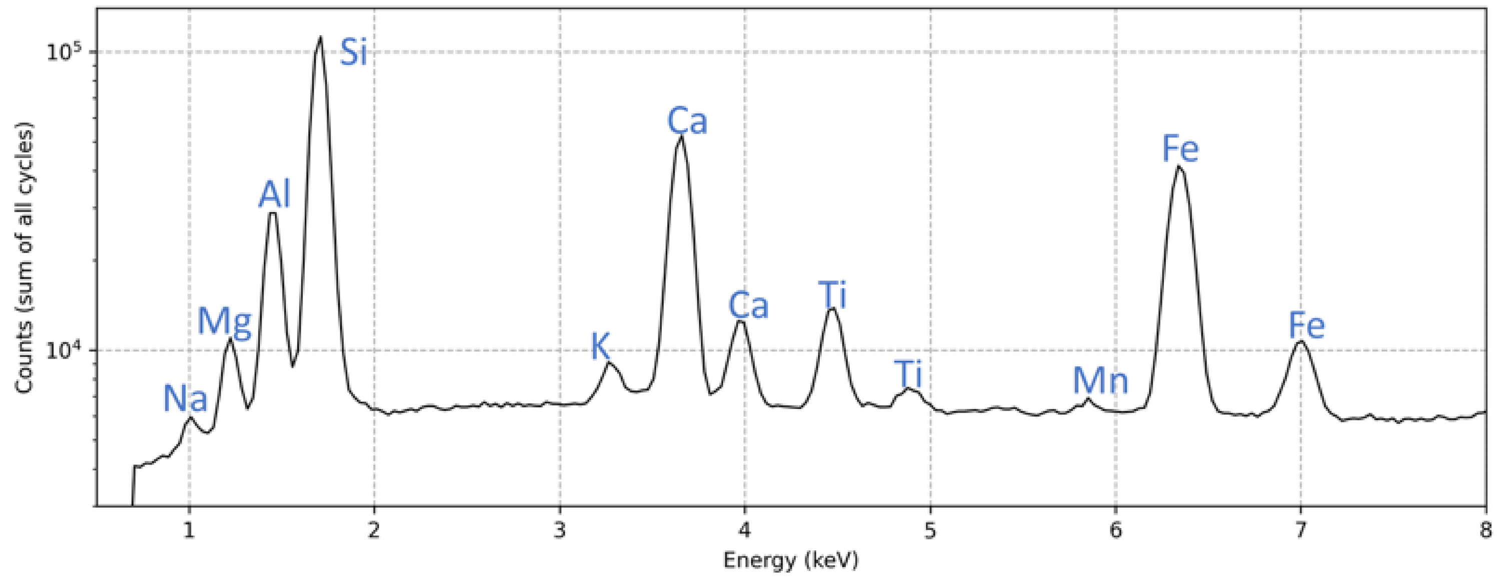

Figure 5: PyroXRS measurement of Basaltic Hawaiian Volcanic Ocean Glass (lot 2) – BHVO2-G geological reference material from the United States Geological Survey. Major and minor rock forming elemental peaks from Z = 11 (sodium) up to 26 (iron) are identified. Data for measurement was acquired using 20-cycle, 1.5 hr long, broad field (~ 4 cm diameter) excitation at 3 cm standoff from both detector and instrument face. Data were acquired in weak 40 mTorr vacuum.

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