Virtual Research Presentation Conference

A Pyroelectric Instrument for X-ray Lithochemistry

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Tutorial Introduction

Abstract

X-ray Fluorescence (XRF) spectroscopy is a very reliable means for in situ exploration of planetary bodies. We harness existing pyroelectric X-ray source technology to generate a form of spacecraft X-ray source (PyroXRS) that is of small and simple design, requires minimal power and is inexpensive to fabricate.

Our instrument consists of a lithium tantalate pyroelectric crystal (Fig. 1) which generates an electric field between the crystal and a thin copper foil separated by a small gap. An induced cycling of heating and cooling via thermal electric cooler applied to the crystal generates an alternating polarity electric field between the crystal and an opposite facing thin copper foil. This gives rise to repeat electron charging then discharging across their gap which in turns produces the X-ray flux needed for XRF in situ analysis.

We aim to optimize our instrument's X-ray flux, demonstrate elemental quantification capabilities, develop supporting chamber automation and XRF quantification software and characterize flux stability, power consumption and general suitability for space application.

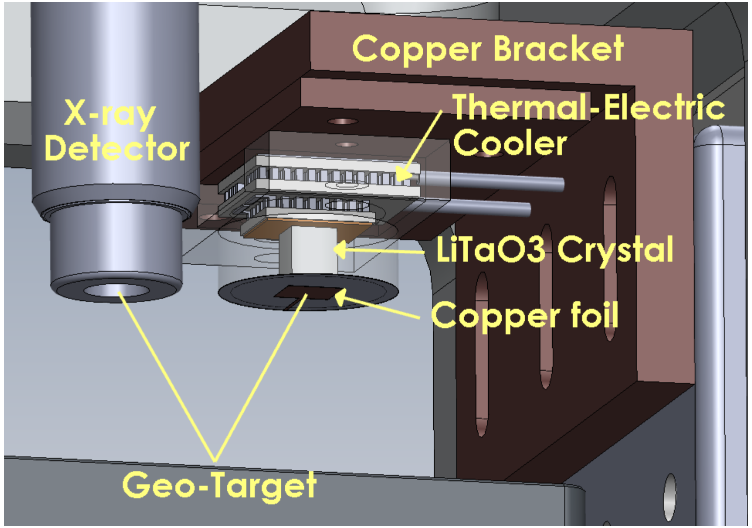


Figure 1: Single crystal and copper film schematic of 1-crystal pyroelectric instrument design planned for development in the forthcoming year. Instrument testbed key components include 1-crystal source and Amptek XR-100SDD detector and Amptek PX5 Digital Pulse Processor.

Problem Description

a) **Context**
XRF geochemical analysis (Z ≥ 11): e.g. Na, Mg, Al, Si, K, Ca, Ti, Mn, Fe, Ni, Cu, Sr, Zr helps investigate a planet's geological evolution and can support the search for past potential habitability.

b) **SOA Comparison**
Leading high fidelity spacecraft XRF instruments include the **alpha-particle X-ray Spectrometer (APXS)** – Fig. 2, on the Mars Science Laboratory Curiosity Rover and the **Planetary Instrument for X-ray Lithochemistry (PIXL)** – Fig. 3, on Perseverance Rover.

APXS – compact, minimal power (10 W), non-trivial procurement of radioactive materials.
PIXL – High flux and analytical capabilities, large, complex power supplies and tube, power ~50 W.

PyroXRS – compact, minimal power (~10 W), simple components, inexpensive, APXS-like flux.

c) **Relevance to NASA and JPL**
In response to NASA's Science Mission Directorate's (SMD) endorsing in the development of instrumentation and technology that are simple, cost-sensitive, and highly relevant to smaller scale missions, **PyroXRS** has great potential to fly on future small in situ lander or rover missions.

PyroXRS

Relevance	→ inner planets, outer planet moons **especially Earth's moon**.
Craft utilization	→ surface sensor – lander/rover, helicopter sensor, borehole spectrometer
Relevant calls	→ PICASSO or Commercial Lunar Payload Services (CLPS)
	→ Development and Advancement of Lunar Instrumentation Program (DALI) or MatISSE

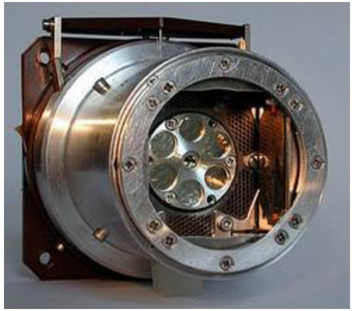


Figure 2: Mars Science Laboratory Alpha-Particle X-ray Spectrometer (APXS). Source: https://mars.nasa.gov/msl/spacecraft/instruments/apxs/

Figure 3: Planetary Instrument for X-ray Lithochemistry (PIXL) flown on the Mars 2020 Perseverance Rover.

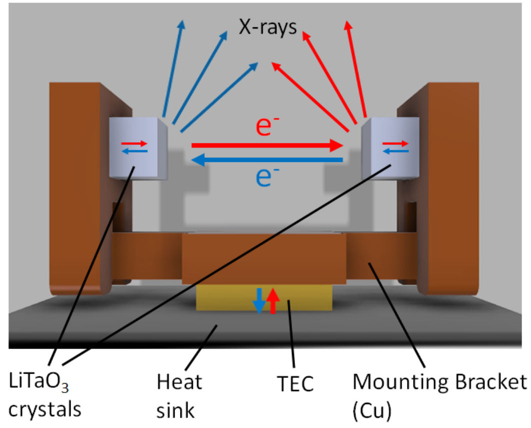
Methodology (Goals)

a) **2-crystal bracket re-design** (Fig. 4) **–** original too much material/heat capacity, reduce Copper wt.

b) **1-crystal testbed design** – Replace 2-crystal design with 1-crystal setup (recall Fig. 1)

c) **Testbed automation software** – manual operation cumbersome – develop LabVIEW GUI to control all
   a) Temperature setpoints (e.g. 20 – 80 C), TEC current driving, repeat temperature cycling
   b) Start/stop spectra and housekeeping data acquisition
   c) Time and housekeeping data

Figure 4: Early generation pyroelectric source 2-crystal design.



d) **Elemental Quantification** – convert pyro-source measurement of targets into element wt% using **Pyro-Q** Quant. Code
pyPenelope Monte Carlo → Analytical model → integrated in Pyro-Q → validated with measurements

e) **Geological material measurement** – Assess general instrument capabilities and software fidelity – iterate development

f) **Thermal-Vacuum testing** – demonstrate functionality in relevant environment: thin atmosphere, other gases, cold (-80 C)

Results

a) Accomplishments versus goals:

- a) 2- crystal brackets fabricated but not tested – geometry issues – sample needs to be very close (mm's)
- b) Good progress in 1-crystal design, fabrication and integration (Fig. 5 – on going) – **data taking still needed**
- c) LabVIEW automation software – completed, software-hardware communicates, but needs testing
- d) Elemental quantification – validated use of Monte Carlo code (Fig. 6) and incorporation of multi-element material crystals in **Pyro-Q** physics-geometry description
- e) Sample measurement – partial progress – obtained vacuum safe sample stage, chamber design for measurement, needs 1-crystal holder integrated to take data
- f) Thermal – Vac Expt. – has not commenced

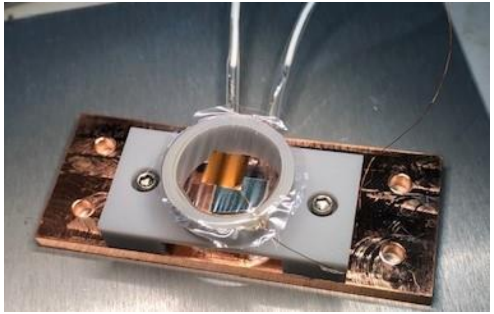
b) Significance

- a) progress in, or completion of, most goals, almost ready to take lots of data
- b) decent standing for
  proposal to PICASSO call, some additional data needed

c) Next steps

- a) Assemble remaining 1-crystal components and take data (FY'20)
- b) Respond to PICASSO proposal
- c) Continued development in FY'21 via RTD 6-mos. pandemic carry-over?

Figure 5: Assembled 1-crystal source holder and copper film. (missing – crystal)



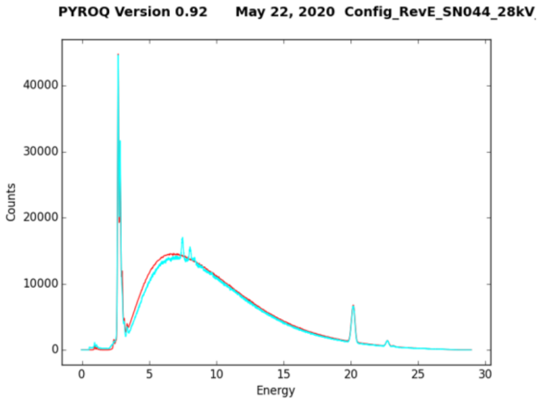


Figure 6: pyPenelope MC calculation (red) for PIXL flight measurement of Teflon compared to PIXL Teflon data (cyan).

Subject Matter References

- Brownridge, J. D. and Raboy, S., Investigations of pyroelectric generation of x rays. Journal of Applied Physics 86 (1999) 640 – 647.
- Geuther, J. A. and Danon, Y., High-energy x-ray production with pyroelectric crystals. Journal of Applied Physics 97 (2005) 104916.
- Kawai, J. et al., X-ray fluorescence analysis with a pyroelectric x-ray generator. X-ray Spectrometry 34 (2005) 521 – 524.
- Kim, K.J. et al., An Active X-Ray Spectrometer for the SELENE-2 Rover. Trans. JSASS Aerospace Tech. Japan 12 (2014) 35 – 42.
- Lang, S. B., Pyroelectricity: From ancient curiosity to modern imaging tool. Physics Today 58 (2005) 31 – 36.

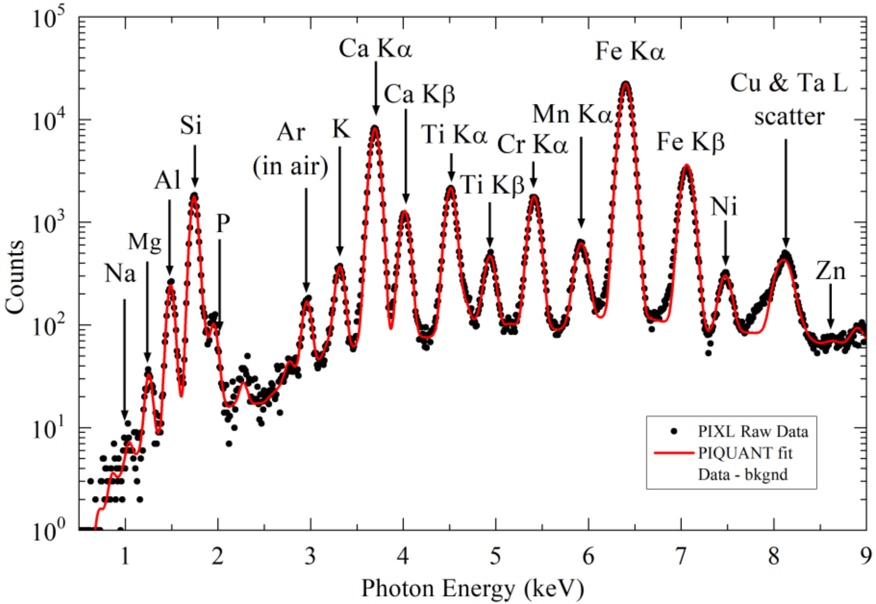


Figure 7: Histogram of geological reference material BHVO2 powder measured using Amptek Cool-X in helium environment for 75 minute equivalent single detector integration. Major and minor elements in sample identified in 0 – 9 keV range.