LunaPIX & MapX: Particle Induced X-Ray Emission – X-Ray Fluorescence (PIXE-XRF) Instruments for Lunar and Planetary Science

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Introduction: APXS (also called PIXE-XRF) instruments have returned nearly all *in-situ* elemental information from Mars and the Earth's moon [1-3]. When compared to X-ray Fluorescence instruments such as PiXL [4], PIXE-XRF instruments do not require X-ray tubes, High Voltage Power Supplies or complex mechanical movements. Measurements are made of ~2 cm areas of regolith simply by pressing the contact plate of the instrument onto the surface to be analyzed.

PIXE-XRF instruments are listed in the payloads of four missions identified in the Planetary Science Decadal Survey [5]: Lunar Intrepid, Endurance-A, Endurance-R, and the Mars Life Explorer.

Two PIXE-XRF instruments are in development by our group: 1). *LunaPIX* utilizes a Silicon Drift Detector (SDD) to collect an elemental analysis of a 2 cm diameter area; 2). *MapX* simultaneously collects X-rays from a 2-D area of the regolith and images them onto a CCD detector.

LunaPIX: LunaPIX is a robotic arm-deployed instrument that is held on the surface or hovered just above the surface of the regolith to be analyzed (Fig. 1).

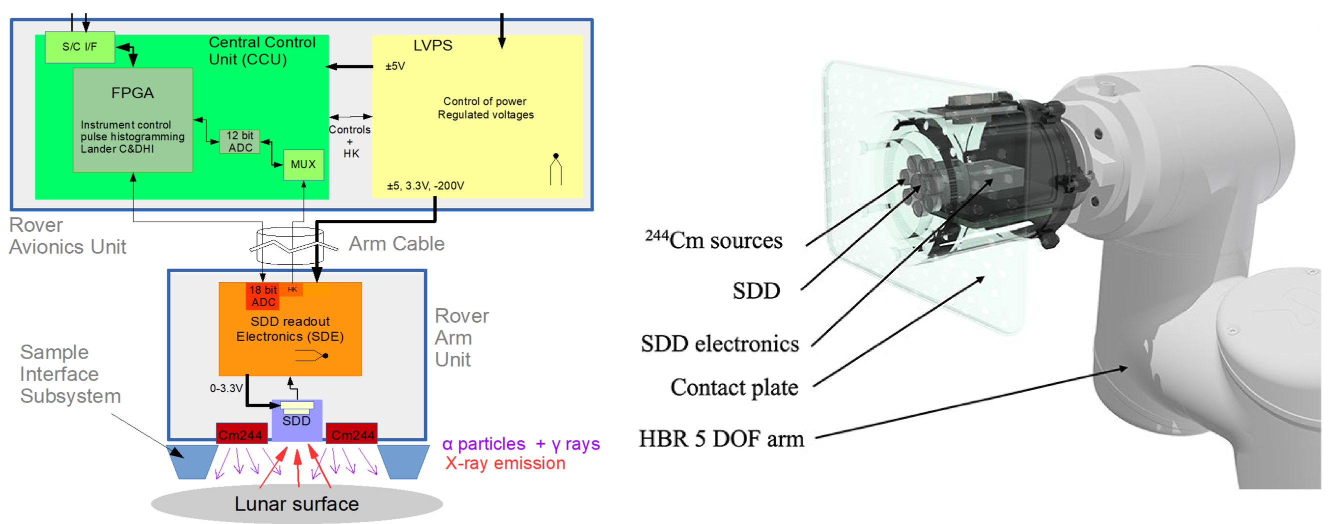

Fig. 1: LunaPIX Arm Unit attached to the HoneyBee Robotics robotic arm. During an analyses, a contact plate (translucent in this image) is pressed onto the regolith. An SDD and six ^{244}Cm sources can be seen recessed from the contact plate.

MapX: MapX is a native full-frame elemental imager that utilizes an X-ray Micro-Pore Optic (MPO) lens to directly focus X-rays fluoresced from the sample onto an energy-discriminating Charge-Coupled Device (CCD) detector. (Fig. 2).

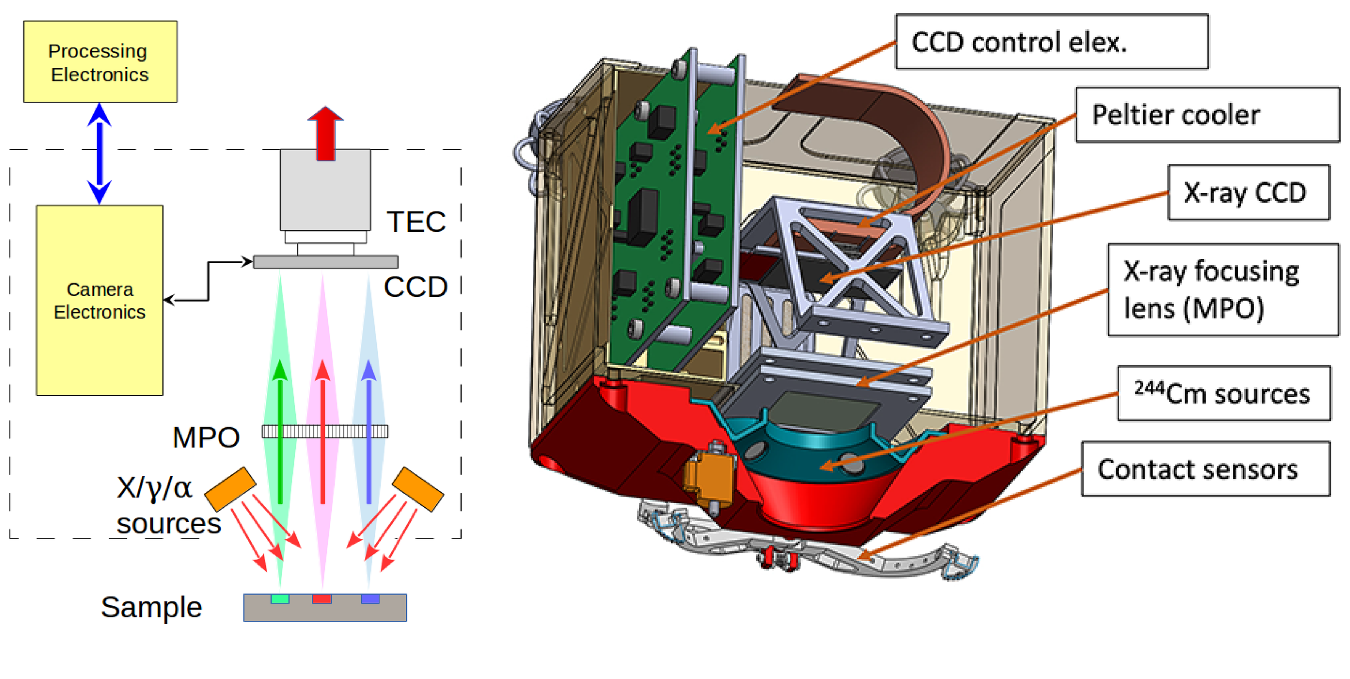

Fig. 2: (left) Fluoresced photons from the sample that are emitted in the direction of a CCD imager are focused by an X-ray lens called an X-ray Micro Pore Optic (MPO) onto the CCD, resulting in a 1:1 image of the sample in its elements. (right) cross-section of the MapX flight instrument.

Source Requirements for LunaPIX: ^{244}Curium radioisotope sources are uniquely suited to fluorescing the elements of geological and biological interest since they emit γ-rays of 14 and 18 KeV that efficiently fluoresce $19<Z<40$ and α-particles of 5.8 MeV that efficiently fluoresce $5<Z<20$ (Fig. 3).

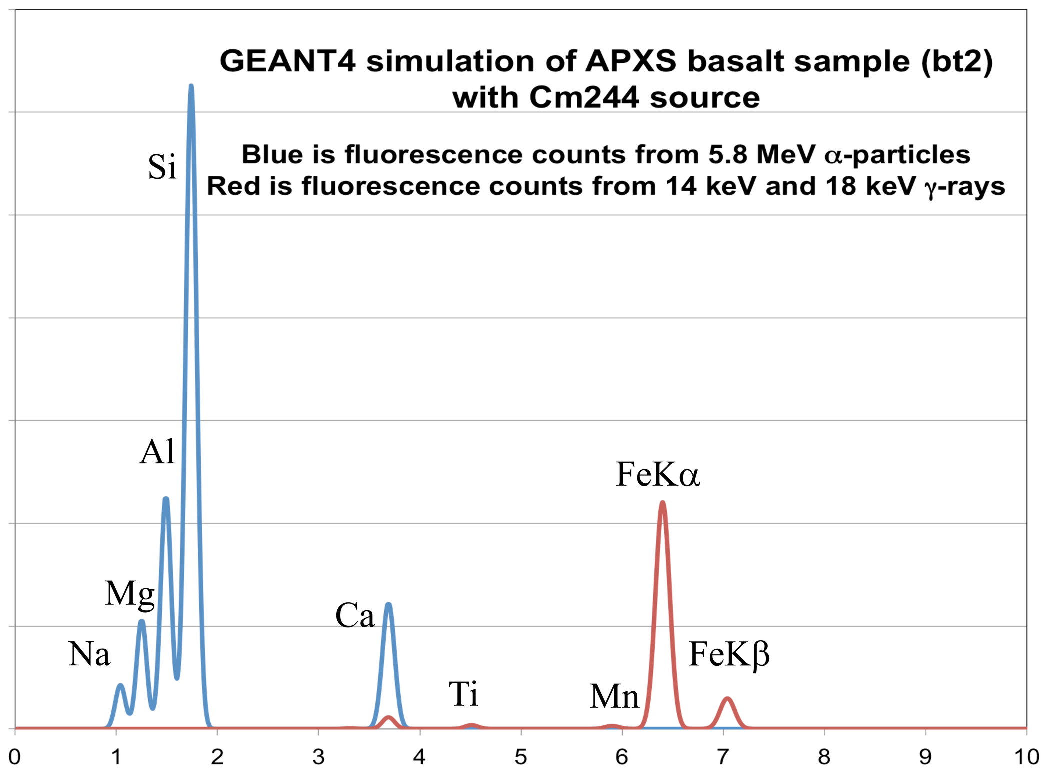

Fig. 3: Simulated spectrum of APXS basalt sample bt2, calculated using GEANT4 and a Fundamental Parameters model of LunaPIX. Red spectrum = γ-ray fluorescence, blue spectrum = α-particle fluorescence (30 mCi ^{244}Cm).

LunaPIX detection and quantification limits are in-family with APXS instruments flown previously. Namely, for a 10^4 sec. acquisition using 30 mCi ^{244}Cm, detection of $10<Z<40$ @ ~500 ppm, and quantification @ ~1500 ppm. In vacuum, C, N and O can be measured as well. Analyses are possible in 10-30 minutes with reduced accuracy. Source strength can be adjusted to suit the science objectives of a particular mission.

MapX: X-ray photons are summed into an HDF-5 data cube that contains an XRF spectrum for each x,y position on the sample. Data products include element maps and Regions of Interest (ROI) with common compositions that are identified using principal components analysis. ROI are returned along with quantifiable XRF spectra for each. Fig. 4 shows a partial dataset from a 10-minute "touch-and-go" analysis collected in a MapX prototype.

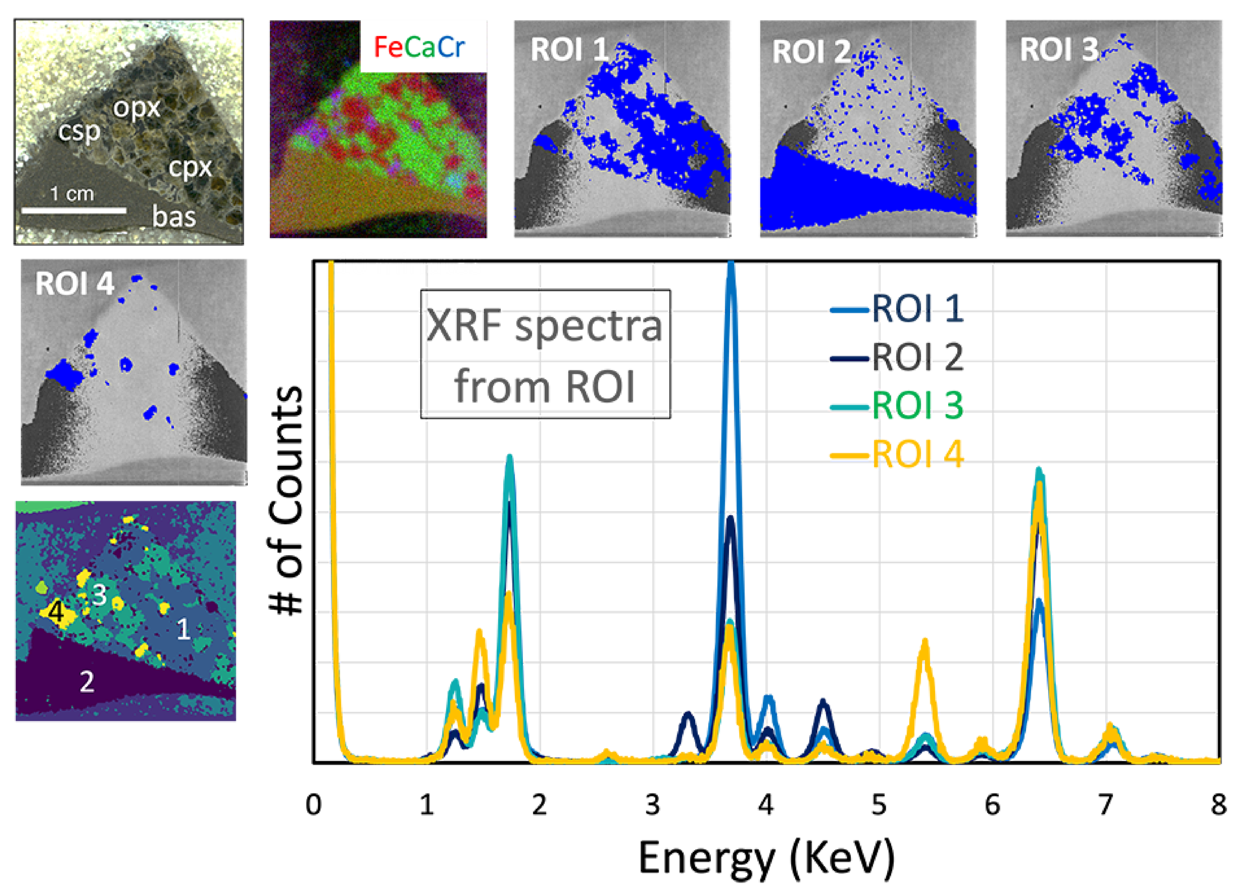

Fig. 4: MapX-III prototype partial dataset from a sample containing basalt (bas), orthopyroxene (opx), clinopyroxene (cpx) and chrome spinel (csp). Optical image (1 cm scale bar), 3-color FeCaCr map, and ROI 1-4 chosen from the HDF-5 data cube by a machine learning algorithm. Returned spectra are from the 3 identified minerals plus basalt. 10-minute analysis.

The X-ray optical characteristics of MapX were determined by ray-tracing [6] and direct measurement on SSRL Beam Line 2-3 [7]. Elemental images have a FWHM resolution of 100 µm at focus with a degradation to 200 µm over a ±5 mm depth of field. This result demonstrates that rough, unprepared regolith surfaces can be imaged with minimal loss of spatial resolution.

Fabrication of ^{244}Cm sources: To date, all APXS instruments have been provided to NASA from foreign countries, using ^{244}Cm provided by Russia. We are working with Oak Ridge National Laboratory and Lawrence Livermore National Laboratory to develop a domestic capability to fabricate and characterize ^{244}Cm sources for spaceflight. Curium will be procured from ORNL and sources will be prepared at LLNL (Fig. 5). Thin metal coatings will be evaporated onto the sources to reduce or eliminate "self-transfer," a process that can contaminate samples with Cm fragments during analysis. This will be particularly important for Endurance-A, in which astronauts will collect and return analyzed samples.

The flight prototype instruments will be transferred to LLNL for testing with these sources and a final flow-down of source requirements will be made based on the science goals and measurement objectives of a particular mission.

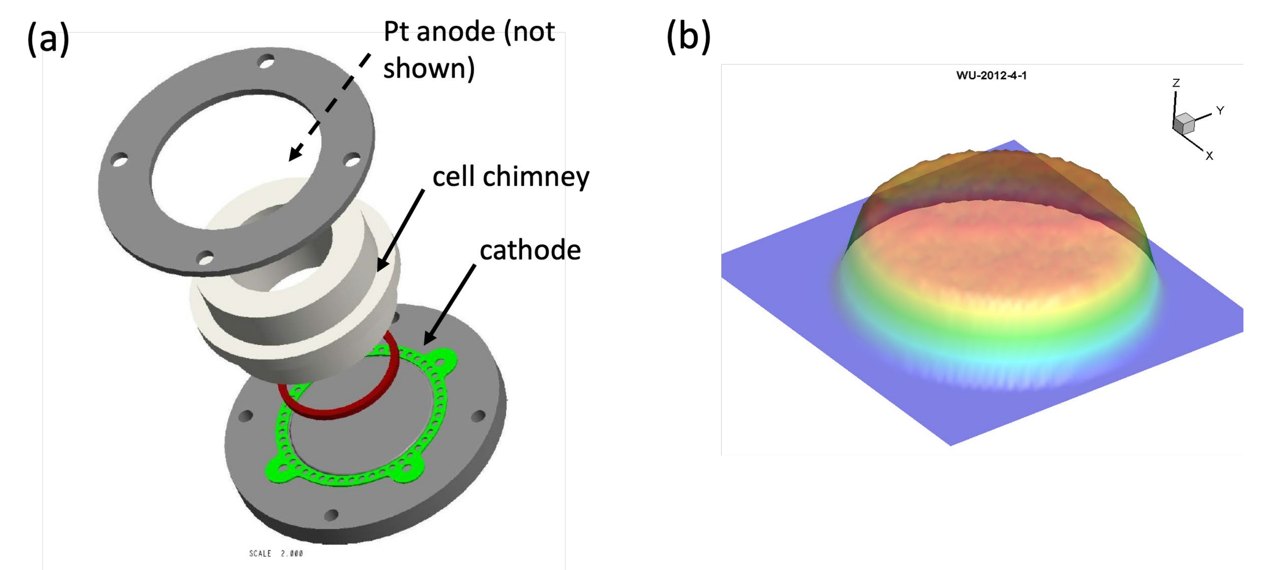

Fig. 5: (a). Exploded view of electroplating cell. The plating substrate is attached to the green ring. ^{244}Cm is electroplated onto the substrate from a dilute solution of Cm in isopropanol. (b). Source Intensity ¾ view, showing the uniformity of the radioisotope deposition.

All components of LunaPIX and MapX (with the exception of the ^{244}Cm sources) are being developed to TRL-6 in MatISSE and DALI programs.

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