LUNAPIX & MAPX: PARTICLE INDUCED X-RAY EMISSION – X-RAY FLUORESCENCE (PIXE-XRF) INSTRUMENTS FOR LUNAR AND PLANETARY SCIENCE. D. F. Blake[1], R.A. Henderson[2], T.F. Bristow[1], P. Sarrazin[3], P. Lucey[4], A. S. Yen[5], E.B. Rampe[6], K. Zacny[7], K. A. Thompson[8], M. Gailhanou[9] and S. Webb[10] [1]NASA Ames Research Center (david.blake@nasa.gov), [2]Lawrence Livermore National Laboratory, [3]eXaminArt LLC, [4]Univ. Hawaii, [5]JPL, [6]NASA Johnson Space Center, [7]Honeybee Robotics, [8]SETI Institute, [9]CNRS – Universite Paul Cezanne, [10]SSRL/SLAC.

Introduction: Alpha Particle X-ray Spectrometry (also called PIXE-XRF) instruments have returned nearly all *in-situ* elemental information from Mars and the Earth's moon [1-3]. The ^{244}Curium radioisotope sources used in these instruments 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 the mid-Z elements Ca-Zr and α-particles of 5.8 MeV that efficiently fluoresce the low-Z elements Na-K. 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 with a robotic arm.

PIXE-XRF (APXS) instruments are listed in the payloads of four missions identified by the recent Planetary Science Decadal Survey [5]: The lunar Intrepid mission, the Endurance-SPA missions (New Frontiers-Class Endurance-A and Flagship-Class Endurance-R), and the Mars Life Explorer mission.

Here we describe two PIXE-XRF instruments in development by our group: 1). *LunaPIX* utilizes a Silicon Drift Detector (SDD) to collect an overall analysis of a 2 cm diameter area; 2). *MapX*, a first-of its-kind *imaging* PIXE-XRF instrument, simultaneously collects X-rays from a 2-D area of the regolith and directly images them onto a 512 X 512 pixel 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).

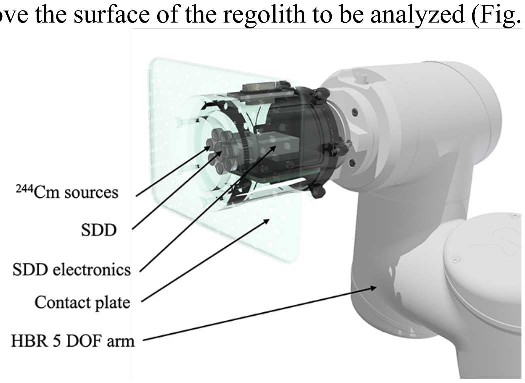

Fig. 1: LunaPIX Arm Unit attached to the HoneyBee Robotics robotic arm. During an analysis, a contact plate (translucent in this image) is pressed onto the regolith. An SDD and six ^{244}Cm sources can be seen recessed from the contact plate.

During an analysis, X-rays fluoresced from the surface are summed into a histogram of X-ray counts vs. X-ray energy that constitutes an X-ray Fluorescence Spectrum of the sample (e.g., Fig. 2).

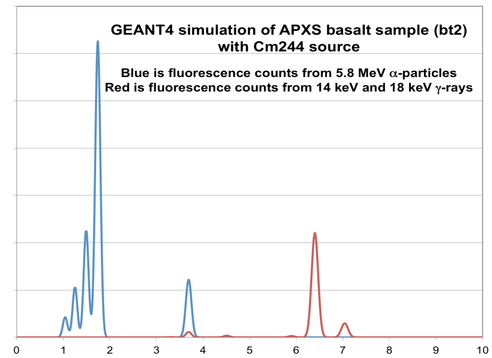

Fig. 2: Simulated spectrum of APXS basalt sample bt2, calculated using GEANT4 and a Fundamental Parameters model of LunaPIX. Red spectrum = γ-ray fluorescence, blue spectrum = α-particle fluorescence (30 mCi ^{244}Cm).

Calculated LunaPIX detection and quantification limits for a 10^4 sec. acquisition using 30 mCi ^{244}Cm are shown in Table 1. These values are in-family with those of APXS instruments flown on previous missions.

Table 1: LunaPIX detection and quantification limits for an element in a basalt matrix, 30 mCi ^{244}Cm sources, 10^4 sec.

Element	(Z)	Det. (ppm)	Quant. (ppm)
C	6	1470	3700
N	7	477	954
O*	8		
F	9	363	755
Na	11	420	1100
Mg	12	390	1100
Al*	13		
Si*	14		
P	15	310	940
S	16	210	650
Cl	17	220	690
K	19	310	980
Ca	20	540	1700
Ti	22	380	1200
V	23	290	920
Cr	24	240	760
Mn	25	280	870
Fe*	26		
Ni	28	200	610
Zr	40	50	200

*Major elements contained in the matrix are not shown.

"Touch and go" analyses are possible in 10-30 minutes with reduced accuracy. If necessary, additional ^{244}Cm sources can be added to meet the science requirements of particular missions. All components of LunaPIX (with the exception of the ^{244}Cm sources) are being developed to TRL-6 in MatISSE and DALI programs.

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. 3).

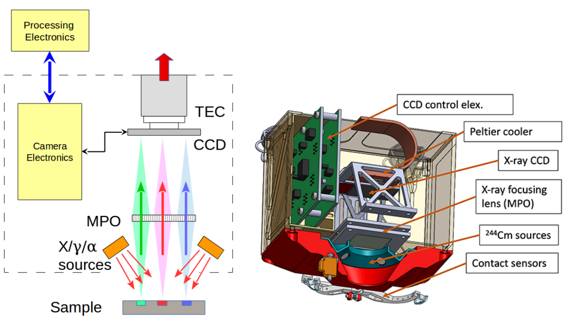

Fig. 3: (left) Fluoresced photons from the sample that are emitted in the direction of a CCD imager are focused by an X-ray lens called a MicroPore Optic (MPO) onto the CCD, resulting in a 1:1 image of the sample in its elements. (right) cross-section of the MapX flight instrument.

During an analysis, the CCD is exposed and read several times per second and the detected X-ray photons are summed into an HDF-5 data cube that contains a complete XRF spectrum for each x,y position on the sample. Reduced data products include element maps and Regions of Interest (ROI) having common compositions that are identified using principal components analysis. ROI images are returned along with quantifiable XRF spectra for each. Because MapX fluoresces the entire sample at once, it is extremely fast relative to scanned probe instruments such as PiXL. Fig. 4 shows a partial dataset from a 10-minute "touch-and-go" analysis collected in a MapX prototype. MapX analyses are stored as HDF-5 data cubes; new data products (e.g., element line scans, element correlation plots, etc.) can be generated from previous analyses as long as the data are stored on the instrument.

The X-ray optical characteristics of MapX were determined by ray-tracing simulation [6] and by direct measurement on SSRL Beam Line 2-3 [7]. MapX elemental images have a FWHM lateral spatial resolution of 100 µm at focus with a gradual degradation to 200 µm over a ±5 mm depth of field. This result suggests that rough, unprepared regolith surfaces can be imaged with minimal loss of spatial resolution and without instrument movements in x, y, or z.

Preliminary testing of instruments with ^{55}Fe: LunaPIX and MapX TRL-6 prototype instruments will be tested under flight-like conditions at NASA/ARC using ^{55}Fe sources (NASA/ARC does not have an NRC license for Cm).

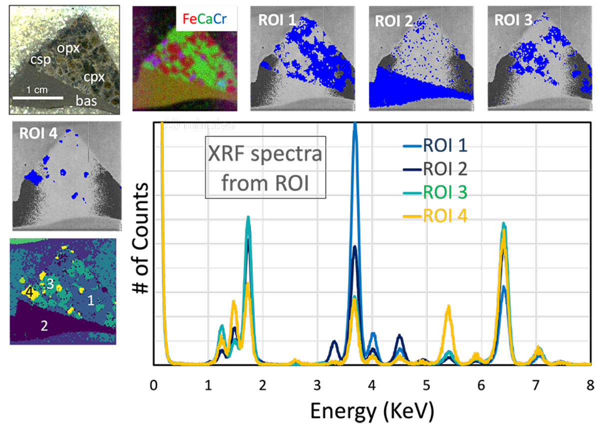

Fig. 4: MapX-III prototype partial dataset from a sample containing basalt (bas), orthopyroxene (opx), clinopyroxene (cpx) and chrome spinel (csp). Optical image (1 cm scale bar), 3-color FeCaCr map, and ROI 1-4 chosen from the HDF-5 data cube by a machine learning algorithm. Returned spectra are from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

Fabrication of ^{244}Cm sources: Future work includes the fabrication and characterization of ^{244}Cm sources at LLNL. Sources will be prepared and γ-assayed for intensity and heterogeneity. Thin metal coatings will be electroplated onto the sources to reduce or eliminate "self-transfer," a process that can contaminate samples with Cm fragments during analysis. The flight prototype instruments will be transferred to LLNL for testing with these sources and flow-down of requirements will be made based on the science goals and objectives of a particular mission.

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