MAPX-PIXE: A Full Field Micro X-Ray Fluorescence Imager for Astrobiology Applications on Ocean Worlds. R. C. Walroth,[1] D.F. Blake,[1] P. Sarrazin,[2] K. Thompson[2] and S. A. Meursing[1] [1]Exobiology Branch, MS 239-4, NASA Ames Research Center, Moffett Field, CA 94035 (richard.c.walroth@nasa.gov), [2]SETI Institute, Mountain View, CA 94043.

Introduction: Investigations of Ocean Worlds and other bodies as potential habitats for life require a knowledge of the mineralogy and elemental chemistry at the surface [1]. APXS, currently deployed on MSL, obtains compositional information from X-ray fluorescence (XRF) spectra with a spot size 1.6 cm in diameter [2]. However, the information on bulk samples leaves out spatial information which can reveal traces of physical, chemical, and biological processes. The Mapping X-ray Fluorescence Spectrometer (MapX) employs XRF at the micrometer scale (μXRF) to obtain such information [3]. MapX-PIXE has been designed for use with radioisotope sources that will emit both α and γ radiation. The γ radiation will induce XRF from heavy elements, while α particles will be able to induce XRF from lighter elements *via* particle induced X-ray emission (PIXE). Thus, MapX-PIXE will be capable of imaging both heavy elements for mineralogical characterization and light elements for possible identification of biological material.

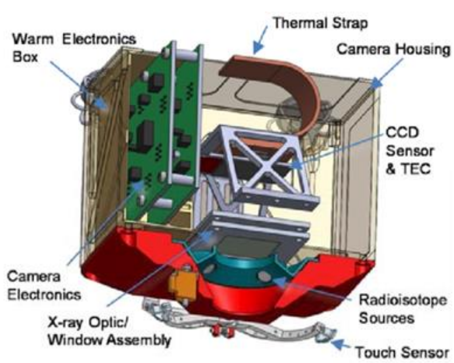

Figure 1. Proposed design for a MapX-PIXE instrument.

MapX Prototypes to Date: MapX is a full-field XRF imager which employs a CCD detector operated in single photon counting mode. The number of electron hole pairs created by an incident photon is energy dependent, and by summing multiple frames it is possible to produce XRF spectra for each pixel of the CCD. If a photon lands near the boundary of a pixel, it is possible for the resulting charge to diffuse into adjacent pixels in what is known as a split pixel event. Such split pixel events are filtered as part of initial data processing. The same technology is employed in the CheMin instrument on MSL, which provides qualitative bulk compositional information as well as spatially-resolved diffraction information for mineral identification. MapX combines this CCD with a micro-pore optic (MPO) which focuses X-rays 1:1 onto the CCD. The resulting instrument is capable of producing μXRF maps with a resolution of ~100 μm. Data is currently being collected using two prototypes employing X-ray tube sources, MapX-II and MapX-III, which are at TRL3 and TRL4 respectively.

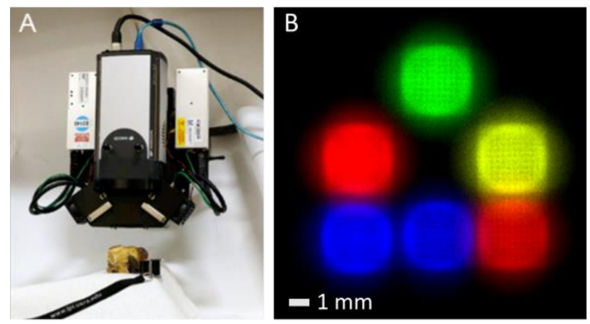

Figure 2. A) MapX-II prototype employing two X-ray tubes and a commercial CCD. B) Mesh grid targets demonstrating spatial resolution and sensitivity to element identity. Cu in red, Ti in blue, Fe in green, and Ni in yellow.

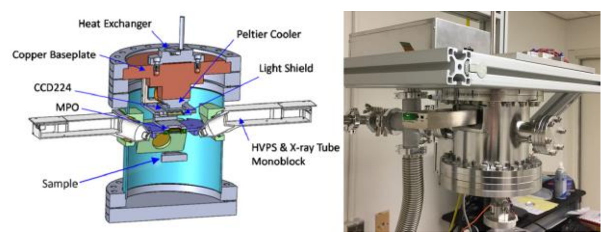

Figure 3. MapX-III prototype assembled using a legacy CCD224 imager from CheMin. Sample, MPO and CCD are in vacuum to allow detection and imaging of low-Z elements.

The MPO employed has a distinctive cross-shaped point spread function (PSF). This PSF was characterized using a micro focused X-ray spot on an Fe foil at the Stanford Synchrotron Radiation Light Source. Using this PSF along with dedicated deconvolution code inspired by the AIDA package developed by Hom *et al.* it is possible to recover resolution lost due to the PSF. The MPO/CCD geometry has significant advantages over other μXRF systems. MapX has no moving parts. Further, the MPO provides a greater depth of field than instruments which employ polycapillary optics. MapX has a measured depth of field of approximately 10 mm, which means that rough, unprepared surfaces can be imaged with minimal loss of resolution.

Employing Radioisotope Sources: So far, MapX has been developed with X-ray tube sources which efficiently excite elements heavier than Ne. Using fundamental parameters methods it is possible to calculate the overall composition in terms of weight percent for heavy elements without directly measuring the light elements. However, detecting life or its precursors on Ocean Worlds will require the detection and mapping of C and N on the surface. To this end, MapX-PIXE will employ ^{244}Cm which emits 14 keV and 18 keV γ-rays as well as 5.8 MeV α-particles [4]. The γ-rays efficiently excite heavy elements (20 < Z < 30) similarly to X-ray tubes, while α-particles excite lighter elements (~6 < Z < 19) *via* PIXE. GEANT4 simulations show the increased signal from light elements when using ^{244}Cm compared to X-ray tubes [5]. A ^{244}Cm equipped MapX-PIXE instrument will be smaller, less complex and more robust than an X-ray tube based instrument. Radioisotope-based XRF instruments have been employed on the MER and MSL rovers, demonstrating their feasibility in flight [2].

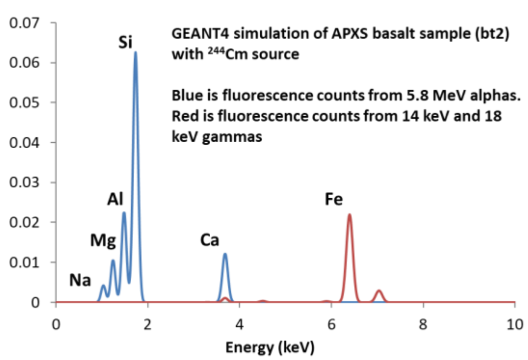

Figure 4. GEANT4 simulation of γ-ray (red) and α-particle (blue) induced fluorescence demonstrating more efficient excitation of lighter elements by α-particle induced fluorescence.

Applications to Ocean Worlds: MapX-PIXE will be well suited to answer a range of scientific questions on Ocean Worlds. Designed to be included in the instrument vault of a Europa lander, it will be able to map and quantitatively analyze as-received ice fragments. It will be able to determine the ion content of the ice at the surface as well as quantify the amount of dissolved C and N. It will be able to distinguish endogenous from exogenous salts as dissolved salts will present a more uniform background compared to deposited salts.

For Ocean Worlds such as Europa, the surface is expected to contain micro-meteorites which have "gardened" the surface to a depth of 2 cm [6]. This rough material can be imaged without sample preparation, and MapX will be able to characterize embedded meteorites in the immediate sub-surface. While α-particles will only induce emission at the surface, the 14 and 18 keV γ-rays are expected to penetrate to a depth of 3.5 and 6.5 mm respectively with only 50% loss of intensity. This will render elements heavier than Fe detectable at depths ranging from 1 to 2 mm in the ice based on the energy of the XRF lines.

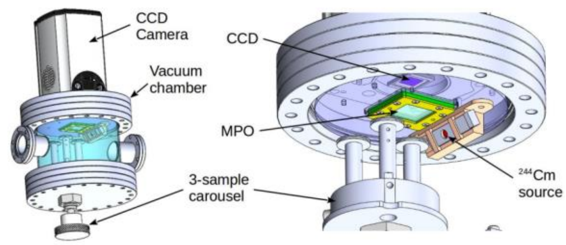

Figure 5. Proposed prototype of MapX-PIXE. Geometry is similar to MapX-III, but will employ radioisotopes and a CCD designed for improved detection of soft X-rays.

Data Processing: The full x, y, energy data cube produced by MapX and MapX-PIXE will be too large to send back from space; algorithms are in development to automate the selection of regions of interest (ROI). The XRF spectra from these autonomously selected ROIs can be sent back in addition to element maps. The summed spectra will be processed on the ground for element quantification which will then be used to constrain possible minerals present in the analyzed material based on the RRUFF database [7].

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