Progress in the Development of MapX, a Full-Frame Imaging X-ray Spectrometer for *in situ* Analysis of Planetary Surfaces

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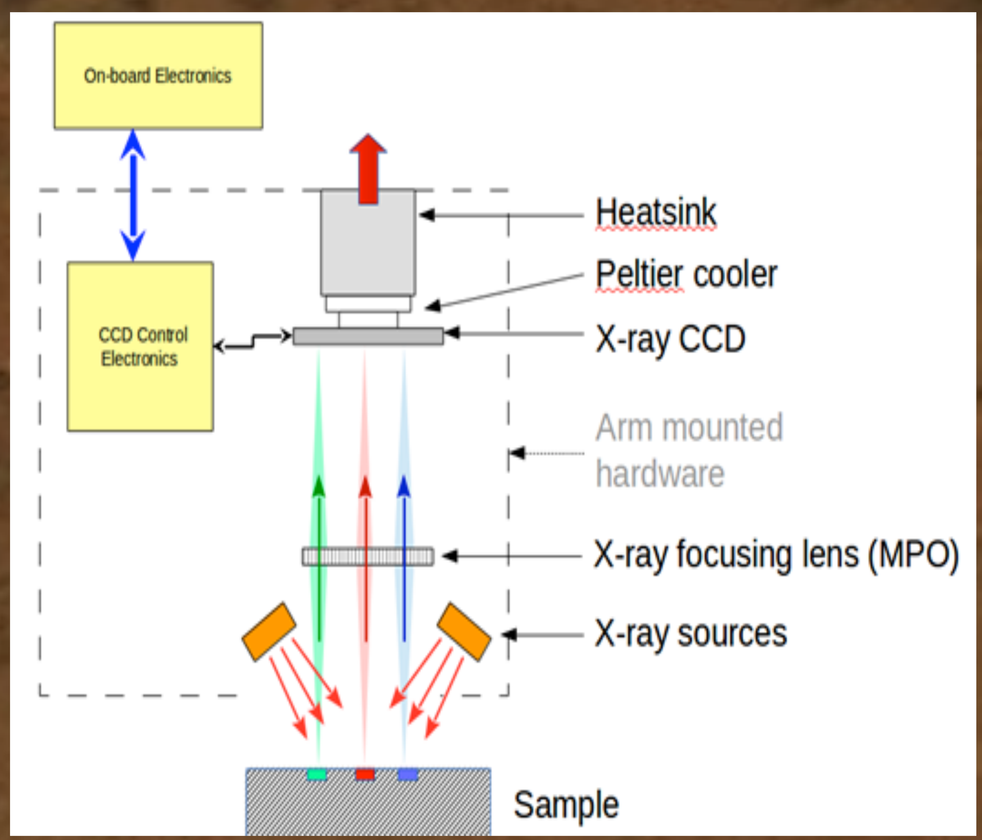
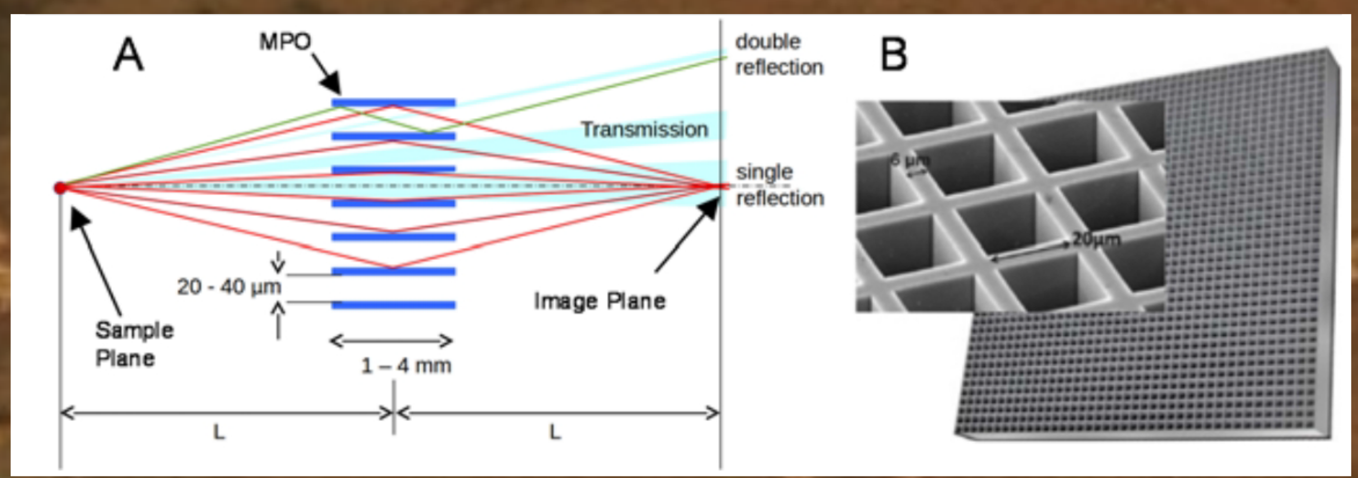
Introduction:

MapX will provide elemental imaging of 2.5 X 2.5 cm areas at ≤100µm spatial resolution, a scale where many relict physical, chemical, or biological features can be imaged and interpreted in ancient rocks on Mars or on the surfaces of other planetary bodies/planetesimals.



How MapX works:

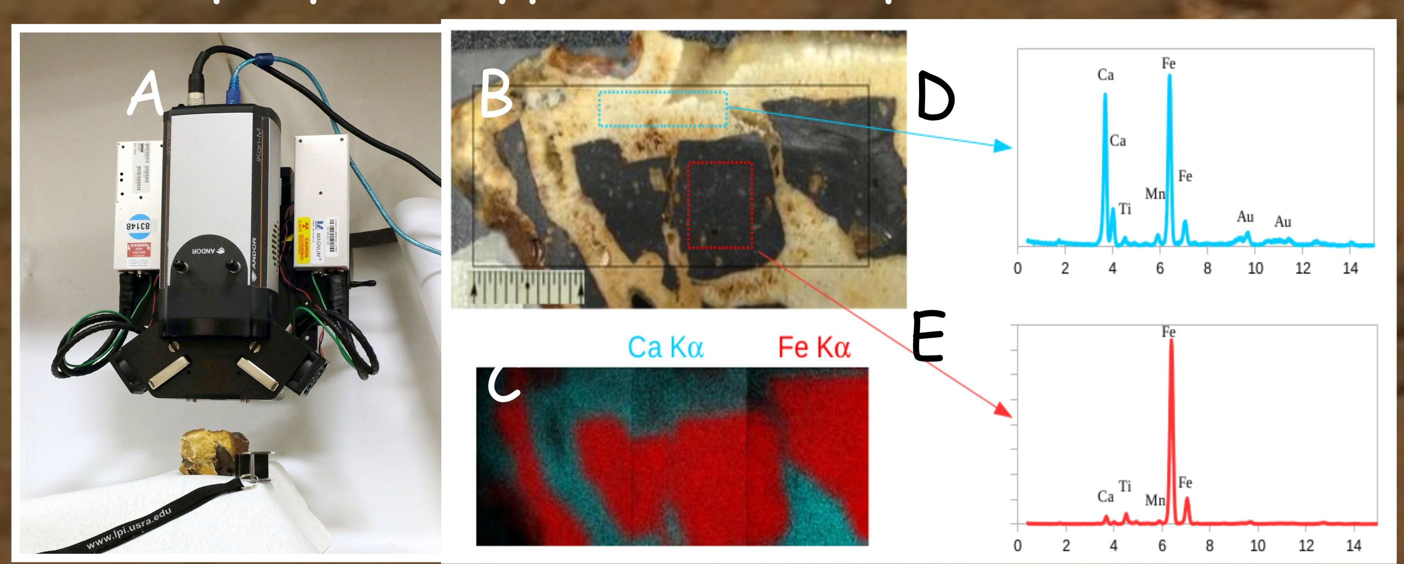
MapX is placed directly on or over a surface to be analyzed. A source fluoresces the sample with X-rays or α-particles / γ-rays, producing sample X-ray Fluorescence (XRF/PIXE). X-rays pass through a 1:1 focusing lens (X-ray µ-pore Optic (MPO)) that projects the X-rays onto an energy-discriminating X-ray sensitive CCD. The CCD is operated in single photon counting mode so that the energies and positions of individual X-ray photons are recorded. In a single analysis, several thousand frames are stored and processed in real-time.



X-ray µ-Pore Optic (MPO)

How it works: Total reflection of X-rays on channel walls collected under the critical angle. The MPO lens derives from "lobster-eye" multichannel optics used for X-ray astronomy [1], here implemented in a 1:1 flat geometry.

MapX prototype and example dataset:

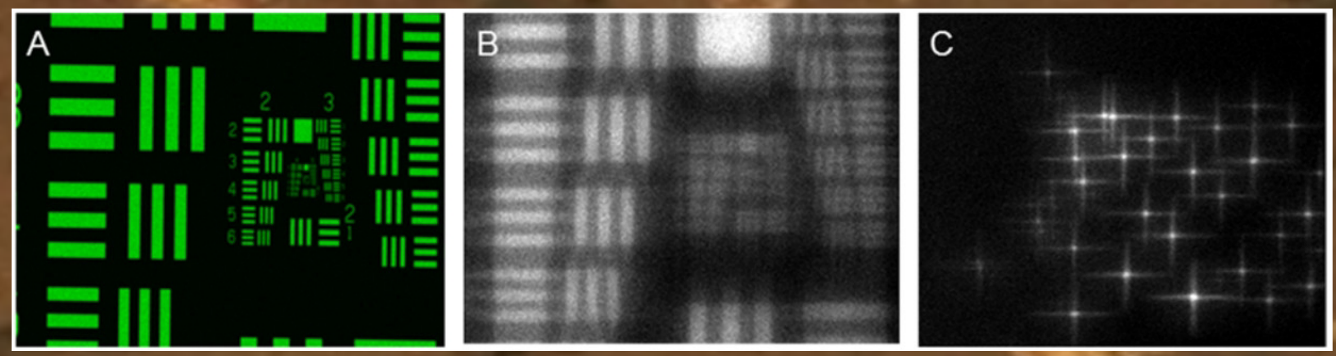


A: MapX-II prototype. B: Optical image of sample composed of basalt breccia fragments and light-toned carbonate cement (scale in mm); C: FeKα (red) & CaKα (blue) map obtained by tiling 3 analyses of 1000s integration. D: XRF spectrum from Ca-rich Region of Interest (ROI); E: XRF spectrum of Fe-rich ROI.

Development of data processing software

The instrument collects a large number of short acquisitions that are combined into X-Y-time data cubes. Python code was developed for processing raw CCD data from the prototypes. The resulting X-Y-energy data cubes are stored in HDF5 format and quantified with PyMca [2] using fundamental parameters methods.

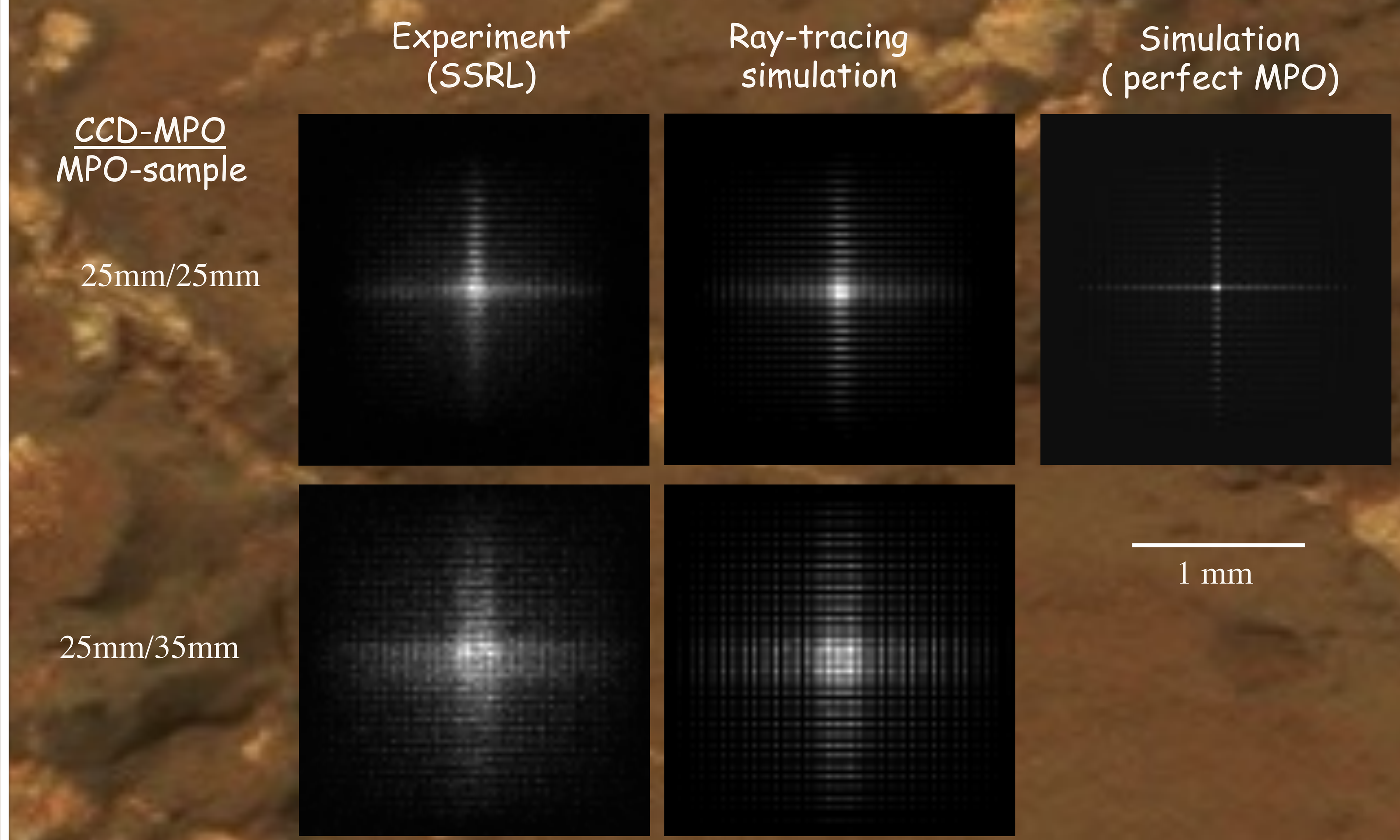
Images and Image Simulation:



Resolution test of MapX-II. USAF 1951 imaging standard, Cr on Glass. A) Cr map obtained in an EDAX Orbis PC instrument with a 30 µm polycapillary optic (~80 µm resolution). B) Cr map measured with MapX-II. Resolution is decreased as a result of non-optimal geometry and the MPO lens Point Spread Function (PSF). C) Fe map of 60 µm iron particles obtained with MapX-II. Fe particles appear as crosses; photon intensity is spread away from the source particles in x and y directions. This is the PSF of the lens.

Experiments were performed at Stanford SSRL beam line 2-3 to characterize the PSF, and ray-tracing simulations of the MPO were performed for comparison. The figures below show results of empirical tests at SSRL compared to ray-tracing simulations.

Point Spread Function

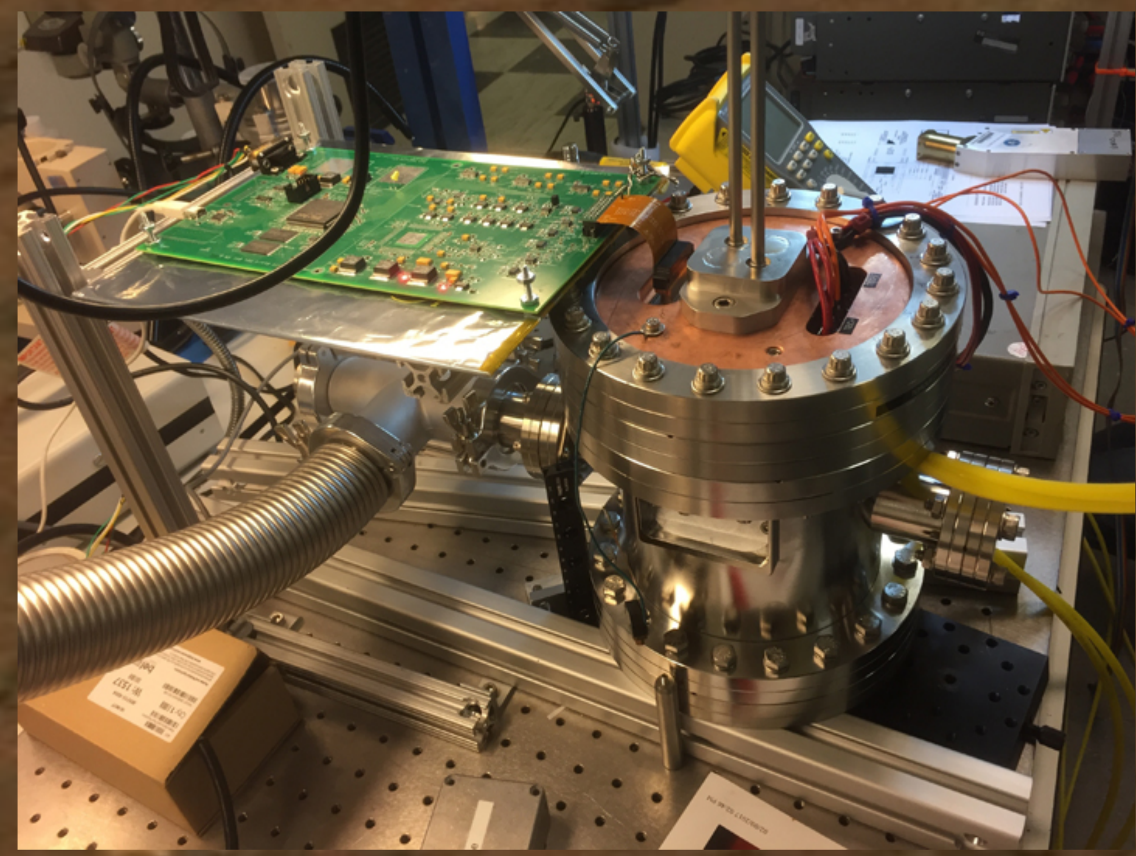


Comparison of MPO PSF data collected at SSRL BL2-3 with ray tracing simulations. Upper: sample in focus (25mm-25mm); Lower: sample out of focus by 10mm (25mm-35mm). A 10 mm defocus condition results in a point resolution decrease of ~100 µm. This result demonstrates that the MapX geometry is relatively indifferent to surface roughness ≤ 1-2 cm.

MapX PSF Deconvolution (1951 USAF resolution standard, Cr on glass). A) Original image. CrKa, taken with MapX-II (MPO-CCD, MPO-Target = 50 mm). The resolution of this image is estimated to be 200µm. B) Measured PSF from the SLAC experiment (FWHM ~165µm). C) AIDA [3] deconvolution with automatized cost function parameters (resolution ~160 µm).

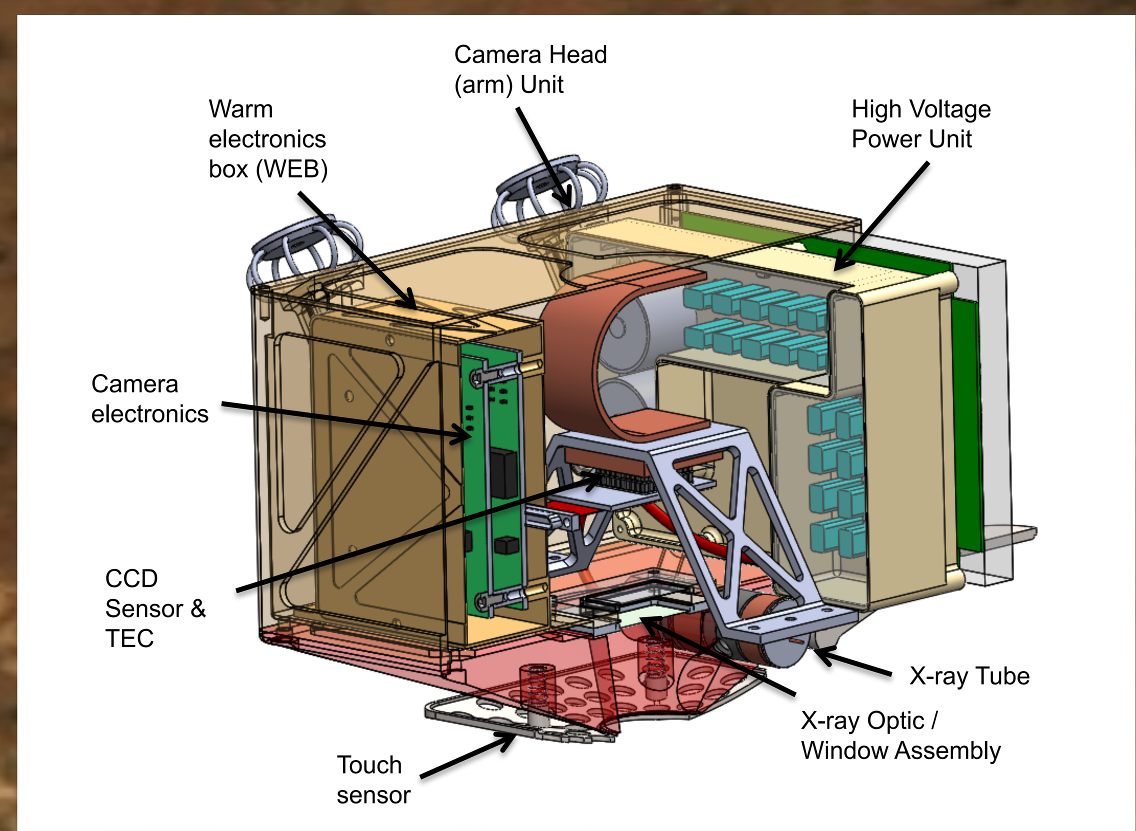
Flight-like MapX prototypes:

MapX-III (below) is a TRL4+ prototype with commercial X-ray tube sources, MSL CheMin heritage CCD224 CCD package, flight qualifiable frame transfer CCD camera design, exchangeable MPO and modifiable geometry. MapX-III is being used as a trial-horse for MPO testing, geometry refinement and development of the flow-down of science requirements.



Flight instrument concept:

Conceptual illustration of an arm-deployed MapX instrument. Est. mass 3.2 kg, est. pwr. 44W. Replacing X-ray sources with radioisotope sources would reduce the mass by 1 kg. and the power by 10W. Not shown is a Control and Processing Unit (CPE).



Source Requirements for MapX

Source requirements for MapX are determined through Monte Carlo modeling and experiment to determine detection limits and accuracy/precision for elements of interest. Preliminary results indicate that either a 3W X-ray tube source, or a 30mCi ^{244}Cm radioisotope source (as carried on the APXS instruments) will be sufficient to meet MapX science objectives [4].

Please see Thompson et al. # 1602 in this poster session for a flow-down of science requirements for MapX [4].

References:

[1] G. W. Fraser et al. (2010) Planet. Space Sci. 58 (1-2), 79–95. [2] V.A. Solé, et al. (2007) Spectrochim. Acta B 62 63-68. [3] Hom, E.F.Y. et al. (2007) *J. Opt. Soc. of America. A*, 24(6), pp. 580–600. [4] Thompson, et al. (2017) LPSC XLVIII, #1602.

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