PROGRESS IN THE DEVELOPMENT OF MAPX, A FULL-FRAME IMAGING X-RAY SPECTROMETER FOR *IN SITU* ANALYSIS OF PLANETARY SURFACES. D.F. Blake[1], P. Sarrazin[2], T. Bristow[1], R. Downs[3], M. Gailhanou[4], F. Marchis[2], D. Ming[5], R. Morris[5], V. A. Solé[6], K. Thompson[2], P. Walter[7], M. Wilson[1], A. Yen[8] and S. Webb[9], [1]NASA Ames Research Center, Moffett Field, CA - david.blake@nasa.gov, [2]SETI Institute, Mountain View, CA, [3]Univ. of Arizona, Tucson AZ, [4]IM2NP, Université Paul Cézanne, Marseille, France, [5]NASA Johnson Space Center, Houston, TX, [6]ESRF, Grenoble, Fr, [7]Université Pierre et Marie Curie, Paris, Fr., [8]JPL, Pasadena, CA, 9SLAC, Stanford, CA.

Introduction: Many planetary surface processes leave traces of their actions as features in the size range 10s to 100s of μm. The Mapping X-ray Fluorescence Spectrometer (MapX) will provide elemental imaging at ≤100μm spatial resolution, yielding elemental chemistry at 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.

MapX: MapX is an arm-based instrument positioned on soil or regolith with touch sensors. The MapX concept is illustrated in Fig. 1. A source bombards the sample with X-rays or α-particles / γ-rays, resulting in sample X-ray Fluorescence (XRF). X-rays emitted in the direction of an X-ray sensitive CCD imager pass through a 1:1 focusing lens (X-ray μ-pore Optic (MPO)) that projects a spatially resolved image of the X-rays onto the CCD. The MPO lens derives from "lobster-eye" multichannel optics used for X-ray astronomy [1], here implemented in a 1:1 flat geometry. 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 1-3 hour analysis, several thousand frames are both stored and processed in real time. Higher level data products include single-element maps with a lateral spatial resolution of ≤ 100 μm and quantitative XRF spectra from ground- or instrument- selected Regions of Interest (ROI).

MapX is a native full-frame imager; a complete X-ray map of the sample is obtained each time a frame is collected; counting statistics improve as frames are summed. Element line scans and quantifiable XRF spectra from multiple and/or randomly shaped ROIs, etc. can be obtained after data collection by reprocessing the raw frames stored in the instrument. Earlier prototypes [2-4] demonstrated proof-of-concept using COTS components. Fig. 2 shows the MapX-II prototype along with an example dataset.

Work in progress:

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. This code includes background correction, split charge removal and optional binning features. The resulting X-Y-energy data cubes are stored in HDF5 format and quantified with PyMca [5] using fundamental parameters methods.

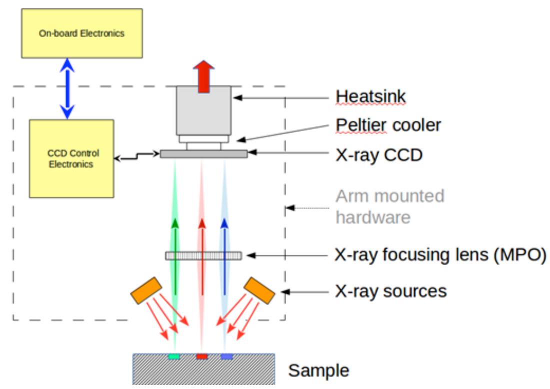

Fig. 1: Schematic drawing of the MapX concept.

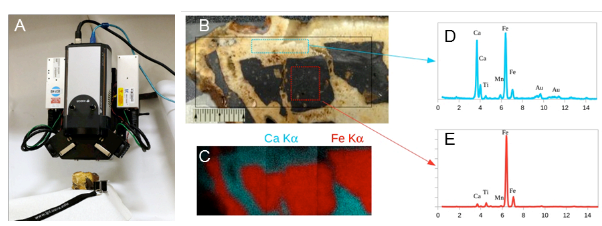

Fig. 2: MapX-II Prototype. A) MapX-II in position to analyze a rock sample. B) Optical image of sample composed of basalt fragments and light-toned cement (scale in mm). C) FeKα /CaKα map obtained by tiling 3 analyses of 1000s integration. D-E) XRF spectra of ROI chosen from the MapX-II image shown in "C."

Characterization and correction of the MPO Point Spread Function (PSF). The MPO lens causes a signal spread on the detector that must be corrected for optimum spatial resolution. Experiments were performed at the Stanford SSRL to characterize the PSF, and ray-tracing models of the MPO were developed in parallel to assist in the development of PSF deconvolution algorithms [6] (e.g., Fig. 3). Figure 4 shows results in which a deconvolution algorithm based on an observed PSF was applied to data from an imaging standard.

X-ray and γ-ray/α-particle radioisotope source requirements. Source requirements for MapX are determined through Monte Carlo modeling and experiment. XMIMSIM [7], GEANT4 [8] and PyMca [5] are being used along with a dedicated XRF test fixture 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 [9].

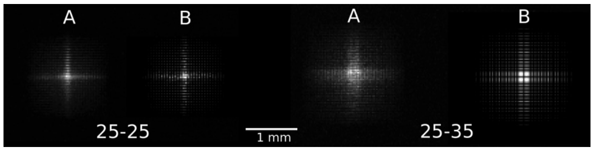

Fig. 3. Comparison of MPO PSF data (A) collected at SSRL BL2-3 and (B) obtained by ray tracing simulations at a nominal CCD-MPO distance of 25mm. Left: sample in focus (25-25); Right: sample out of focus by 10mm (25-35). A 10 mm defocus condition results in a point resolution decrease of ~100 µm. This result demonstrates that the MapX design is relatively indifferent to surface roughness ≤ 1-2 cm.

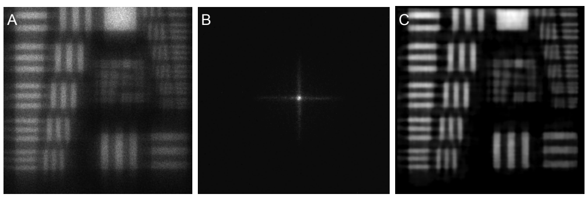

Fig. 4. MapX PSF Deconvolution Example (1951 USAF resolution standard, Cr on glass). A) Original image. CrKα, taken with MapX-II (MPO-CCD, MPO-Target = 50 mm). The resolution of this image is estimated to be 200µm. B) Measured PSF from the SLAC experiment (FWHM ~165µm). C) AIDA [6] deconvolution with automatized cost function parameters (resolution ~160 µm).

Development of high-TRL MapX components. MapX-III (Figs. 5-6) is being built with a CCD224 imager (MSL CheMin heritage) driven by dedicated CCD electronics using flight design standards. The new camera prototype will demonstrate the basic architecture of a flight camera for an arm mounted instrument and will serve to characterize the system capabilities at the low X-ray energies (e.g., Kα lines for Na) that are absorbed in the in-air current prototypes.

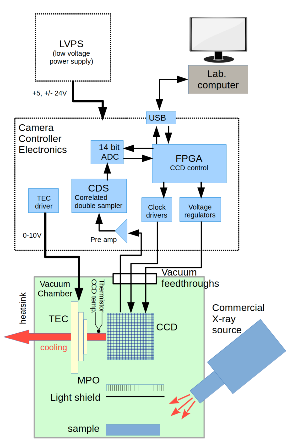

Fig. 5: Schematic of MapX-III prototype with in-vacuum flight qualifiable CCD camera and adjustable optics.

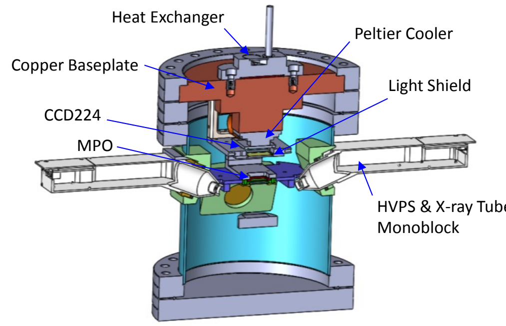

Fig. 6. TRL-4+ MapX-III prototype with X-ray tube sources, MSL CheMin heritage CCD224 CCD package, exchangeable MPO and modifiable geometry.

Flight instrument concept: Fig. 7 shows a conceptual illustration of an arm-deployed MapX instrument (with X-ray tube sources). Replacing X-ray sources with radioisotope sources would reduce the mass by 1 kg. and the power by 10W. Not shown is a Rover Avionics Mounting Platform (RAMP) unit that houses the Control and Processing Electronics (CPE).

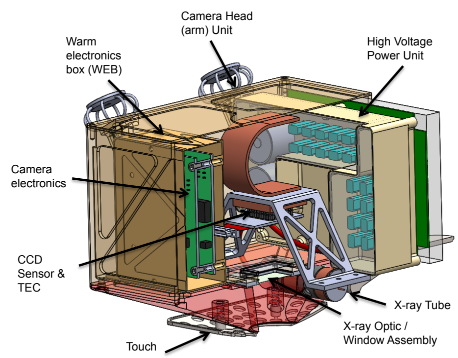

Fig. 7. Notional Flight configuration of MapX Arm Unit (X-ray tube version) enclosing the Camera Head Electronics (CPE).

References: [1] G. W. Fraser et al. (2010) Planet. Space Sci. 58 (1-2), 79–95. [2] P. Sarrazin et al. (2016) LPSC XLVII #2883. [3] D.F. Blake et al. (2016) IPM2016 #4006. [4] P. Sarrazin et al. Proc. ICSO 2016. [5] V.A. Solé, et al. (2007) Spectrochim. Acta B 62 63-68. [6] Hom, E.F.Y. et al. (2007) *J. Opt. Soc. of America. A,* 24(6), pp. 580–600. [7] Schoonjans T. et al. (2012) *Spectrachim. Acta Part B, 70*, 10-23. [8] Agostinelli, S. et al. (2003) *Nucl. Instr. and Methods in Phys. Res. A*, **506**, 250-303. [9] Thompson, et al. (2017) LPSC XLVIII.

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