THE MAP-X μ-XRF IMAGING SPECTROMETER. P. Sarrazin[1], D. Blake[2], K. Thompson[1], M. Gailhanou[3], J. Chen[4] and T. Bristow[2], [1] SETI Institute, Mountain View, CA 94043 (psarrazin@seti.org), [2] Exobiology Branch, NASA Ames Research Center, Moffett Field, CA 94035, [3] CNRS, IM2NP UMR, Marseille, France, [4] Baja Technology, Tempe, AZ

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 ("Map-X") is intended to provide elemental imaging at ≤100μm spatial resolution, yielding elemental chemistry at or below the scale length where many relict physical, chemical, and biological features can be imaged and interpreted in ancient rocks.

Map-X: Map-X is an arm-based instrument placed directly on the surface of an object to be analyzed and held in registry with it through the use of touch sensors that physically contact the surface. During an analysis, either an x-ray tube or a radioisotope source bombards the sample surface with x-rays (tube source) or α-particles and γ-rays (radioisotope source), resulting in x-ray fluorescence from the sample. Fluoresced x-rays emitted in the direction of an x-ray sensitive CCD imager pass through an x-ray 1:1 focusing lens that projects a spatially resolved image of the x-rays generated from the sample surface onto the CCD. The CCD is read at several frames per second so that in the majority of cases, no more than one photon strikes an individual pixel between read cycles. In this way, the energies and positions of individual X-ray photons are recorded. The images are stored in memory and processed using algorithms parameterized from the ground. In a single analysis, several thousand frames are both stored and processed in real-time. The MapX concept is illustrated in fig. 1.

Higher level data products that can be obtained from the raw images include single-element maps for elements of interest with a lateral spatial resolution of ≤ 100 μm and XRF spectra from selected Regions of Interest (ROIs). XRF spectra from ROIs are processed on the ground to determine quantitative elemental compositions. Quantitative compositions from ROIs are compared with known rock and mineral compositions to extrapolate the data to rock types and putative mineralogies. A single Map-X experiment provides elemental and compositional maps and XRF spectra having a spatial resolution of ≤ 100 μm, commensurate with other imaging instruments.

Proof of concept prototype: An earlier prototype [1,2] was constructed to show the utility of the Map-X concept, but lacked some of the specific hardware and software necessary for proper testing and evaluation of the concept. A second prototype was custom built from commercial components and specialized software (fig. 2). A commercial camera with 1024x1024 back illuminated deep depletion CCD, under vacuum with a 200 μm Be window was used for the new prototype instrument (Andor iKon M). Two 40kV-4W Au target transmission window x-ray tubes (Moxtek) illuminate the sample from opposite sides of the camera to limit topographic contrast. An MPO x-ray focusing lens (PHOTONIS) is placed equidistant between the sample location and the CCD. This reflective lens derives from "lobster-eye" multichannel optics used for X-ray astronomy [3]. It is implemented here in a flat geometry for 1:1 focusing. This lens provides a much improved aperture when compared to pin-hole camera optics having similar spatial resolution, and true focusing when compared to polycapillary collimating optics also used for X-ray mapping. The camera is driven at up to 3 frames per second, and the x-ray sources are shuttered during read cycles.

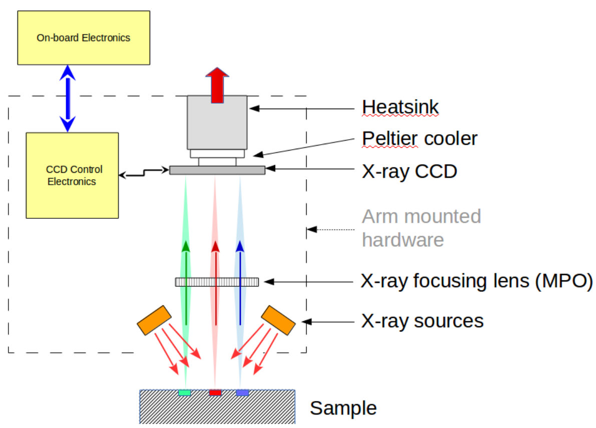

Fig. 1: Schematic drawing of the Map-X concept.

Other work in progress: Other parts of the instrument development are being pursued in parallel with the proof of concept evaluation.

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 of the prototypes. This code includes background correction, split charge removal, and optional binning features. Resulting X-Y-energy data cubes are stored in HDF5 format and analyzed using PyMca [4] for quantitative analysis with fundamental parameter methods. Limited bandwidth of planetary missions will require additional on-board processing to further reduce data into alternative products such as XRD spectra of spatial regions of interest, or X, Y maps of spectral regions of interest.

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. The PSF varies with signal energy and with X-Y position due morphological or stacking defects of the micro-channels. Dedicated equipment is being built to characterize the lens PSF and software is being developed to deconvolve the PSF from the data. Ray-tracing models of the MPO have been developed in parallel to evaluate the effects of various types of defects on the PSF and to assist in the development of PSF deconvolution algorithms.

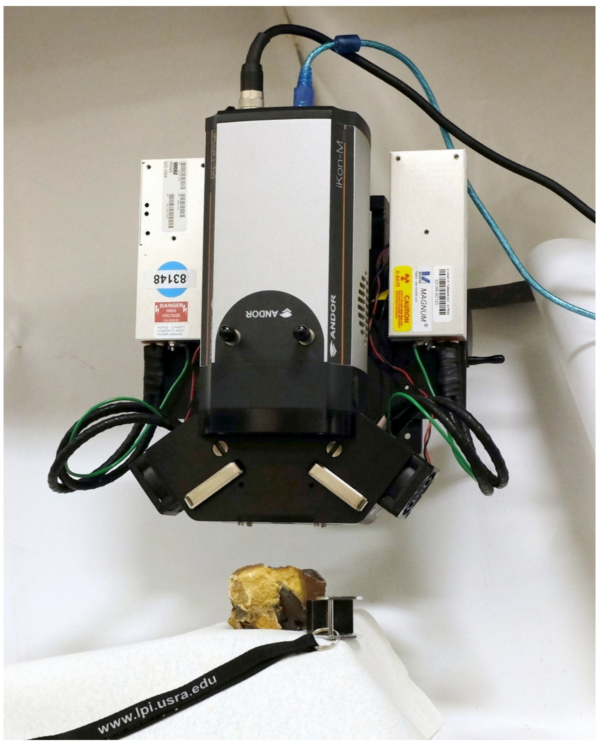

Fig. 2: 2nd generation prototype instrument based on commercial components; center: CCD camera, sides: X-ray tubes; 25 mm working distance.

Development of high-TRL Map-X components. In parallel with the method development and laboratory and field prototype refinement, engineering efforts are being pursued to increase the TRL of the instrument. The main effort is the development of a Peltier cooled CCD X-ray camera using the E2V frame transfer CCD used in the MSL CheMin XRD/XRF instrument. Dedicated CCD electronics using flight design standards are being developed and a breadboard is currently being tested. The new camera prototype will demonstrate the basic architecture of a flight camera for an arm mounted instrument and will serve a base for an in-vacuum Map-X prototype to characterize the system capabilities at the low X-ray energies (e.g., Kα lines for Na-K) that are absorbed in the in-air current prototypes.

Flow-down of science requirements. Instrument models are being developed for the X-ray source emission, fluorescence response of the sample, MPO transmission and CCD signal collection to provide critical tools in the flow-down of system requirements. Initial results of this effort are presented in [5].

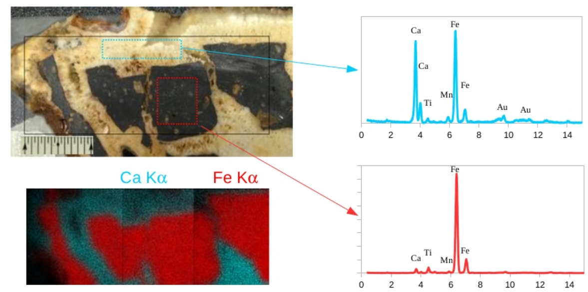

Fig 3: Example of data output with the 2nd generation instrument. Top left: optical image of sample composed of breccia fragments and light-toned cement. , scale is in mm; bottom left: Fe K_α and Ca K_α maps obtained by tiling 3 analyses of 1000s integration. Right: XRF spectra of two regions of interest chosen in the MapX data.

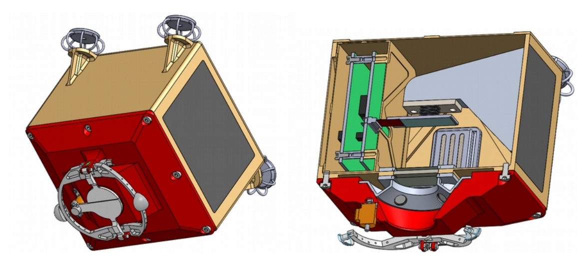

Fig 4: Preliminary design of a MapX planetary arm instrument. The arm unit connects to a control unit (not shown) installed in the rover/lander. The front end features a passive sample interface mechanism and one time actuation protective door.

References:

[1] D.F. Blake et al. (2014) IPM-2014, #1080 [2] D.F. Blake et al. (2015) LPSC XLVI #2274. [3] G. W. Fraser et al. (2010) Planet. Space Sci. 58(1-2), 79–95. [4] V.A. Solé, et al. (2007) Spectrochim. Acta B 62 63-68. [5] K. A. Thompson, et al. (2016) this conference.

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