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Introduction: Knowledge of the surface mineralogy of a planet, planetesimal or moon can lend insight into its origin, conditions of formation, processing history, and so forth. In landed missions, X-ray diffraction (XRD) is the best technique for identifying complex mineralogy. XRD is included in the science payloads of Mars Science Laboratory (MSL '11) [1] and ExoMars. However, both of these instruments require relatively intensive sample processing prior to sample analysis.

We are developing ultra-compact and lightweight XRD/XRF instruments for planetary mineralogical analysis. The Extraterrestrial Regolith Analyzer (XTRA) is a reflection geometry instrument for quantitative mineralogical analysis of fines in surface regolith samples. Fine-grained regolith is quite common on airless bodies in the solar system, and because this fraction is often comminuted from the rocky regolith, it can often be used as a proxy for the surface as a whole.

Applications: Quantitative XRD (QXRD) is useful for characterizing the mineralogy and mineral abundances of a variety of airless bodies. Some examples include:

Lunar surface: Some lunar pyroclastic deposits have primitive igneous compositions, providing valuable clues to mantle composition, and their glass/crystal ratios provide information about magma migration and eruption mechanisms. The mineralogy of regions with high contents of incompatible elements (identified from orbit by their high Th concentrations) contain important information about the extremes of lunar igneous fractionation. Particularly interesting targets include silicic volcanic constructs [2] and highly mafic rock outcrops in places on the Moon [3], which could be mantle rock or crustal cumulates.

Mercury: Recent results from the MESSENGER mission show that Mercury has a diverse surface in which the relative abundances of oxides and silicates vary [4]. Some ambiguity exists in the identification of the oxide phases [5], which could be eliminated by QXRD analyses of surface materials. Such missions are obviously challenging, but the unambiguous identification of major mineralogy is essential to fully understanding the evolution of the Mercurian crust.

Carbonaceous asteroids: Asteroids with compositions resembling carbonaceous chondrites can be characterized through mineralogical analyses [6]. Those retaining hydrous minerals, such as CI and CM chondrites, contain serpentine, interlayered saponite-serpentine, and ferrihydrite, in addition to high-temperature silicates (olivine, pyroxene), sulfides, and magnetite. The ratio of serpentine/olivine varies in the CI chondrite Orgueil, a potential mapping tool for an *in situ* exploration mission; both minerals are easily measured by XTRA. The lack of hydrous, layered silicates can distinguish such meteorites from other types of carbonaceous chondrites such as CV and CO.

Anhydrous asteroids: XRD is capable of distinguishing among asteroids with compositions of the numerous types of anhydrous chondritic and differentiated meteorites on the basis of olivine/pyroxene and silicate/metal ratios [7-10]. Such studies can provide ground truth for remote sensing observations and allow detailed characterization, including compositional variations across an asteroid's surface, and provide insight into the processes that operated in the bodies.

Technology: The technology is inherited from CheMin (MSL XRD): 1- the sample is illuminated by a miniature X-ray beam produced by a microfocused X-ray tube combined with a collimator; 2- XRD and XRF signals are collected in parallel by a CCD detector in direct illumination.

Several subsystems are being developed to high Technical Readiness Level (TRL) with the objectives of mass, cost and risk reduction, including miniature microfocused X-ray source, CCD detector, CCD control and data-processing electronics.

The flight qualifiable X-ray source, developed in collaboration with Battel Engineering (Phoenix, AZ), combines a 25kV-5W microfocused X-ray tube and an efficient power supply. The X-ray spot size can be reduced to <50µm. The source weighs less than 1kg.

The CCD is a commercial detector installed in a space-qualified package with embedded Peltier cooler. This sensor was chosen over the development of a dedicated CCD for cost saving and our broad experience with this detector in commercial and prototype instruments.

The CCD control electronics, developed in collaboration with Baja Technologies (Tucson, AZ), uses a Field Programmable Gate Array (FPGA) to drive the CCD and process data, and a Correlated Double Sampler (CDS) for fast CCD readout. Prototypes achieved a resolution of <200eV (Mn Kα) at 500MHz readout.

These subsystems can be arranged in different configurations. Transmission geometry would provide similar performance as Terra (inXitu Inc.), the commercial derivative of CheMin. While offering a substantially lower mass and volume than the MSL instrument, it would still require sample processing (drilling or grinding) that will not be available on missions with limited payload capacity.

XTRA is an instrument configuration specifically developed for mineralogiocal analysis of regolith when no sample preparation is available. XTRA uses a reflection geometry to analyze the fines of regolith samples "as received" from a sample acquisition scoop. It will weigh about 4kg and require 25W during operation.

XTRA breadboard: A breadboard instrument was developed to evaluate the capabilities of XTRA (Figure 1). It is based on commercial-grade components of Duetto (commercial reflection XRD/XRF instrument for non-destructive analysis of works of art) interfaced to a small vacuum chamber hosting the sample in reflection mode (2θ range of 8-55°) under vacuum (<10^{-5}mb). Since the entire X-ray beam path is under vacuum, the system allows testing X-ray performance under extant conditions on air-less bodies such as the moon, mercury, asteroids, etc. Powdered samples were sieved to <45μm and loaded manually in the shallow well of a sample holder plate and leveled using a glass slide.

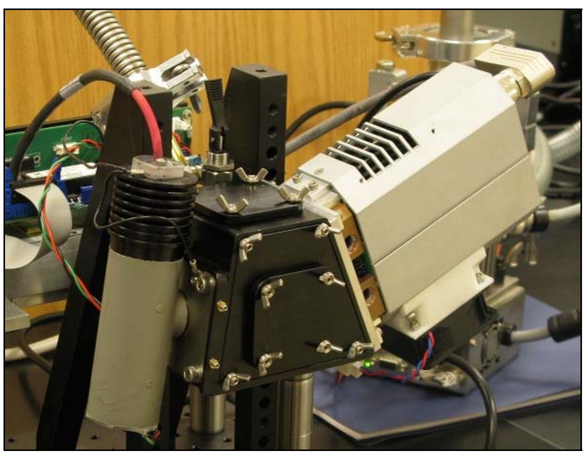

Figure 1. XTRA breadboard built with commercial components to test the geometry and operation under vacuum. Left to right: X-ray tube, vacuum chamber, CCD camera.

The breadboard was tested with a number of samples including three lunar soils. An example of lunar soil data is shown in Figure 2 compared with data from Terra. In addition to the difference in geometry (reflection vs. transmission), the instruments differ in how sample are handled during analysis (fixed in the XTRA breadboard, vibrated for granular convection in Terra [11]). Good quality data were obtained with the breadboard instrument, yielding accurate quantitative results when fine samples (<45μm) were used.

Although simple and convenient for a breadboard test, the loading process would be difficult to implement for robotic operation. A reversed geometry, with the X-ray measurement made through an X-ray transparent window at the bottom of a sample cup, would provide an easier robotic deployment.

The breadboard shows a higher sensitivity than Terra to the presence of coarse grains, due to the lack of sample motion from a vibrator. A sample vibrator will be developed for XTRA to improve the instrument tolerance to coarse-grained materials. The instrument would then analyze samples as delivered by a sampling scoop. A small carousel hosting a number of vibrated sample cups could be integrated into the XTRA design.

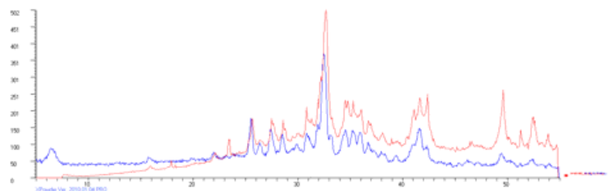

Figure 2. Comparison of XRD data from Terra (blue) and XTRA (red) using a Lunar soil (#14163). Differences in peak relative intensities are due to the sensitivity to grain size with the XTRA breadboard.

Discussion: XTRA is an XRD/XRF instrument for mineralogiocal analysis of regolith on air-less bodies. Very compact and light weight, it will be suitable for missions to the Moon, Mercury, or asteroids on landers fitted with basic sample acquisition capabilities. The instrument utilizes a reflection geometry for ease of sample preparation and delivery. All major subsystems are being developed as flight qualifiable components. Tests of a breadboard instrument show the validity of the general design and point to possible areas of improvement in the sample loading and handling system.

References: [1] http://msl-scicorner.jpl.nasa.gov/Instruments/CheMin/ [2] Glotch, T.D. et al. (2010) *Science* **329**, 1510-1513 [3] Yamamoto, S. et al. (2010) *Nature Geoscience* **3**, 533-536 [4] Denevi, B. W. et al. (2009) *Science* **324**, 613-618 [5] Riner, M.A., McCubbin, F.M., Lucey, P.G., Taylor, G.J., and Gillis-Davis, J.J. (2010) *Icarus* **209**, 301-313 [6] Bland, P.A., Cressey, G., and Menzies, O.N. (2004) *Meteor. Planet. Sci.* **39**, 3-16 [7] Dunn, T.L. et al. (2010a) *Meteor. Planet. Sci.* **45**, 123-134 [8] Dunn, T.L. et al. (2010a) *Meteor. Planet. Sci.* **45**, 135-156 [9] Howard, K.T. et al. (2010) *Geochim. Cosmochim. Acta* **74**, 5084-5097 [10] Izawa, M. R. M. (2010) *J. Geophys. Res.* **115** [11] Sarrazin, P. et al, (2004) *LPS XXXV,abstract #1794*