

**A MINIATURIZED XRF FOR IN SITU PLANETARY EXPLORATION - AXRS.** A. W. Beck, P. N. Peplowski, and Z. W. Yokley, Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, email: andrew.beck@jhuapl.edu

**Introduction:** X-ray fluorescence spectroscopy (XRF) is a fundamental tool for measuring the elemental composition of planetary surfaces. *In situ* x-ray spectroscopy has primarily utilized passive, radioactive sources to fluoresce characteristic x-rays in target samples (e.g. alpha particle x-ray spectrometers (APXS) on Pathfinder, MER, MSL) [1]. An alternate approach involves using (active) x-ray sources (e.g. x-ray tubes, pyroelectric crystals) to produce x-rays at tunable energies and intensities. Active x-ray spectroscopy can provide similar results as APXS, but with shorter acquisition times and without a radioactive source. Recent advancements in active x-ray XRF (i.e. traditional “XRF” in terrestrial geology) technology miniaturization [2] and x-ray detector resolution (i.e. silicon drift detectors, SDD) suggests active XRF-type instruments may become increasingly utilized in future planetary missions, as evidenced by the recent selection of an active XRF-based instrument (PIXL) on Mars 2020 [3].

Here we present initial results from the development of a miniaturized active XRF instrument for planetary exploration, the Active X-Ray Spectrometer (AXRS). Unlike PIXL, which measures the elemental composition of individual grains via x-ray focusing optics, AXRS is designed to measure bulk composition within a small (~1 cm) spot through a low resource (<5 W, <1 kg) implementation that does not require precision in positioning.

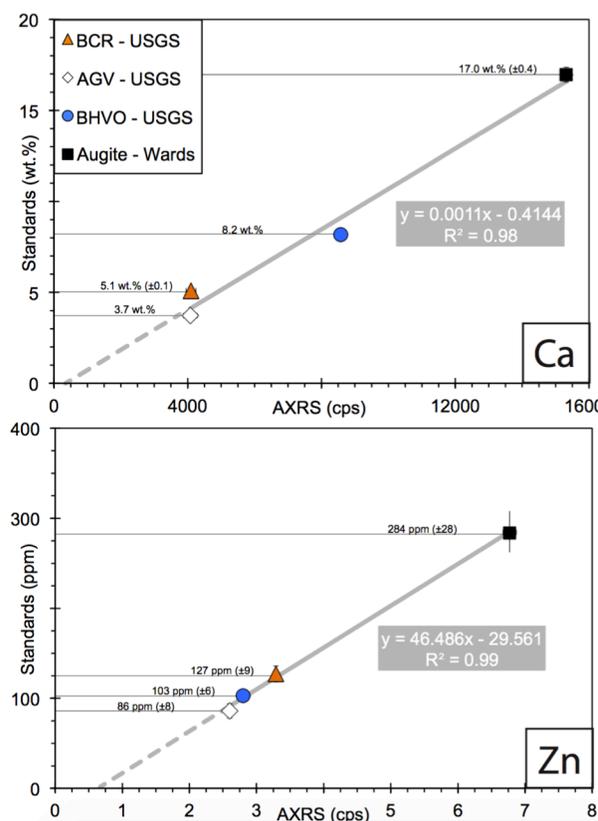
**Instrument design:** AXRS was designed to have comparable performance as APXS. This includes having sensitivity to the elements Na (Z=11) though Zn (Z=30), which requires maximum operating voltages of 12–15 kV. We also desired rapid (~5 min) measurement times, which sets the operating current at 20–100 μA. Our prototype AXRS was based on consumer off-the-shelf components from Amptek (Fig. 1), and we are currently assembling a TRL-5 version of the instrument using components suitable for spaceflight thermal and vibration environments.



**Fig. 1 - AXRS setup.** Mini-X x-ray generator (left) and detector (right). Image width ~15 cm

**Results:** Several USGS standards, Allende (CV chondrite) and an augite standard were selected for instrument testing of AXRS accuracy and precision. These tests were conducted using conditions and measurement geometries described above. Precision tests were conducted in vacuum; however, accuracy measurements were not (they were conducted at atmosphere). We anticipate accuracy tests to have been conducted in vacuum by the time this abstract is presented.

AXRS has excellent accuracy for major (e.g. Ca, Fig. 2 top) and trace (e.g. Zn, Fig. 2 bottom) elements, both across a range of concentrations (3.7-17.0 wt.% and 86-284 ppm, respectively). Some calibration curves (i.e. regression of AXRS vs. standards) divert from a y-intercept at the origin (e.g. Fig 1, bottom). This occurrence will likely be rectified with the inclu-



**Fig. 2 - AXRS accuracy.** Comparison of standards to AXRS-measured counts per second. AXRS shows strong accuracy in major (top) and minor/trace (bottom) elements. Regressions reverse-projected (dashed) to show relation to origin. Standard concentrations and standard deviation (where reported) shown as tie lines

sion of more reference materials (only four standards analyzed for accuracy testing thus far). As can be seen in the Zn plot, AXRS can resolve concentrations as low as 86 ppm, and discern concentrations within  $\pm \sim 10$  ppm at that concentration level (i.e. BCR, AGV and BHVO resolvable in AXRS cps, Fig. 1 bottom). From the Ca data displayed here, AXRS accuracy appears to decrease for very small variations ( $< \sim 1$ wt%) of major elements at low concentrations ( $< \sim 4$  wt%; i.e. Fig. 2 top). However, we note that element-by-element sensitivity is also affected by the locations and intensities of neighboring, partially overlapping x-ray peaks.

We anticipate accuracy of measurements of low concentrations of Ca and other major elements will be improved as we: 1) repeat the accuracy tests in vacuum and/or 2) improve the energy resolution of the system through the incorporation of a silicon drift detector.

AXRS measurement repeatability (precision) is high (see Table 1), as displayed by the  $< 10\%$   $1\sigma$  deviation from the mean in all major element concentrations for the three standards examined. Note, mafic element (Fe, Mg) concentrations are low in felsic samples, thus a large  $1\sigma$  for those elements is to be expected (i.e. lower concentration = lower precision).

**Discussion:** Several planetary materials were examined to gauge the ability of AXRS to test potential planetary missions hypotheses. In those data (Fig. 3), the relatively FeNi metal- and sulfide-rich chondritic meteorites display noticeably larger S, and Ni peaks than the diogenite meteorites (achondrites), which are

Table 1. AXRS precision

Standard	Dunite (DTS-2b)						mafic ↓ felsic
Element	Al	Ca	Fe	K	Mg	Si	
$1\sigma$ (relative)	-	-	9%	-	2%	3%	
Standard	Granodiorite (GSP-2)						
Element	Al	Ca	Fe	K	Mg	Si	
$1\sigma$	3%	9%	8%	10%	-	4%	
Standard	Andesite (AGV-2)						
Element	Al	Ca	Fe	K	Mg	Si	
$1\sigma$	1%	9%	25%	12%	13%	4%	

Concentrations: [crustal.usgs.gov/geochemical\\_reference\\_standards/](http://crustal.usgs.gov/geochemical_reference_standards/)

essentially metal and sulfide-free. Within the two diogenite meteorites examined, PCA 02008 (enriched in Ca-rich pyroxene and plagioclase [4]) has a noticeably higher Ca peak than the more mafic, olivine-rich MIL 07001 diogenite [5]. From this qualitative assessment, AXRS appears to be able to test broad scientific questions, such as: “is a landed object chondritic or achondritic?” and finer petrologic questions, like: “Is the material more mafic (opx, olivine-rich) or felsic (cpx, plagioclase-rich)?”

We are currently conducting measurements to test the ability of AXRS to resolve carbonaceous chondrite subgroups by examining variations in lithophile volatile vs. lithophile refractory element concentrations, and we anticipate displaying those results in the conference presentation.

References: [1] Gellert et al. (2009) LPSC #2364, [2] Ribbing et al. 2003, Review of Scientific Instruments, 74(7), [3] Allwood et al. 2015, IEEE Aero. Conf. Proc. 2015, [4] Beck and McSween 2010, Meteoritics and Planetary Science 45(5) 850-872, [5] Mittlefehldt et al. (2014) LPSC #1613.

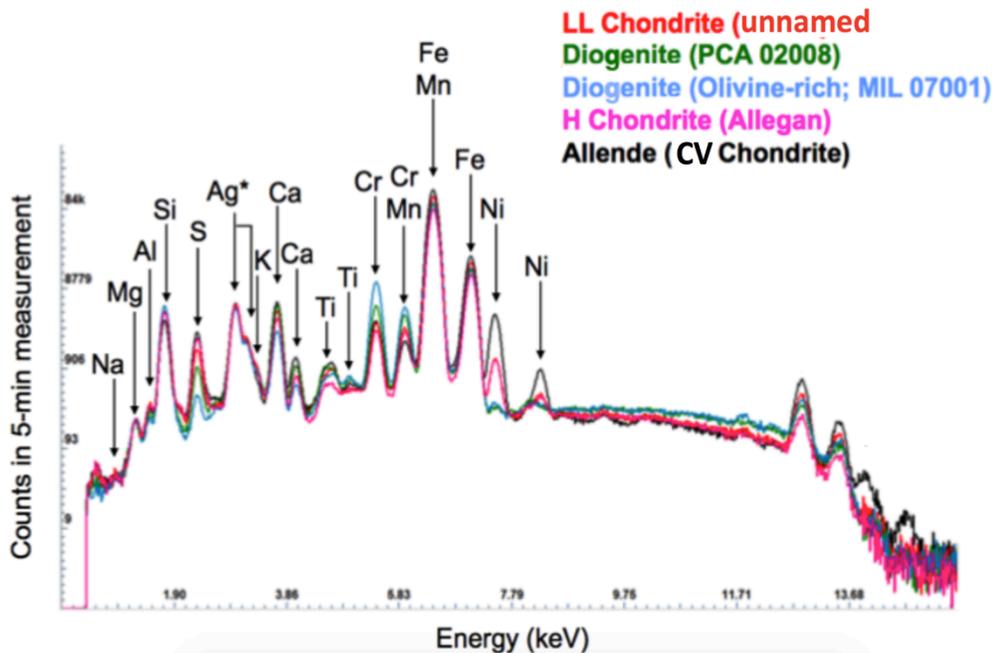


Fig. 3 – AXRS analysis of chondritic and achondritic meteorites. The presence of Ag is a background associated the production of the incident x-rays. See text for discussion of the samples.