XTRA: An ExtraTerrestrial Regolith Analyzer for Lunar Soil

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The Importance of Mineralogy to Lunar Science and Technology

The mineralogy of lunar soil can be used to elucidate its petrogenesis as well as subsequent impact gardening.

In-situ mineralogical analysis can be also used to (for example):

- evaluate potential In Situ Resource Utilization (ISRU) processes such as the production of water or oxygen, metallic Fe or Al, or of ceramic building materials.
- discover ore deposits useful for Rare Earth Element extraction.

Mineralogical analysis using X-ray Diffraction (XRD) and X-ray Fluorescence (XRF):

XRD is the only *in-situ* technique able to definitively identify, quantify and determine the average composition of minerals present in lunar regolith. XRD can also determine the quantity of X-ray amorphous material present in a regolith sample, and when combined with XRF, the elemental composition of the amorphous component(s).

XRD Analysis of Apollo Soils

Taylor et al. [1] report the mineralogy of 118 Apollo regolith samples in the <150 µm grain-size range analyzed by Terra, a commercialized version of the CheMin instrument (e.g., Fig. 1-2). Sun et al [2] report XRD-based ground-truth mineralogy of the Apollo 17 landing site. All XRD patterns and mineral abundances are available on the Open Data Repository: https://odr.io/lunar-regolith-xrd

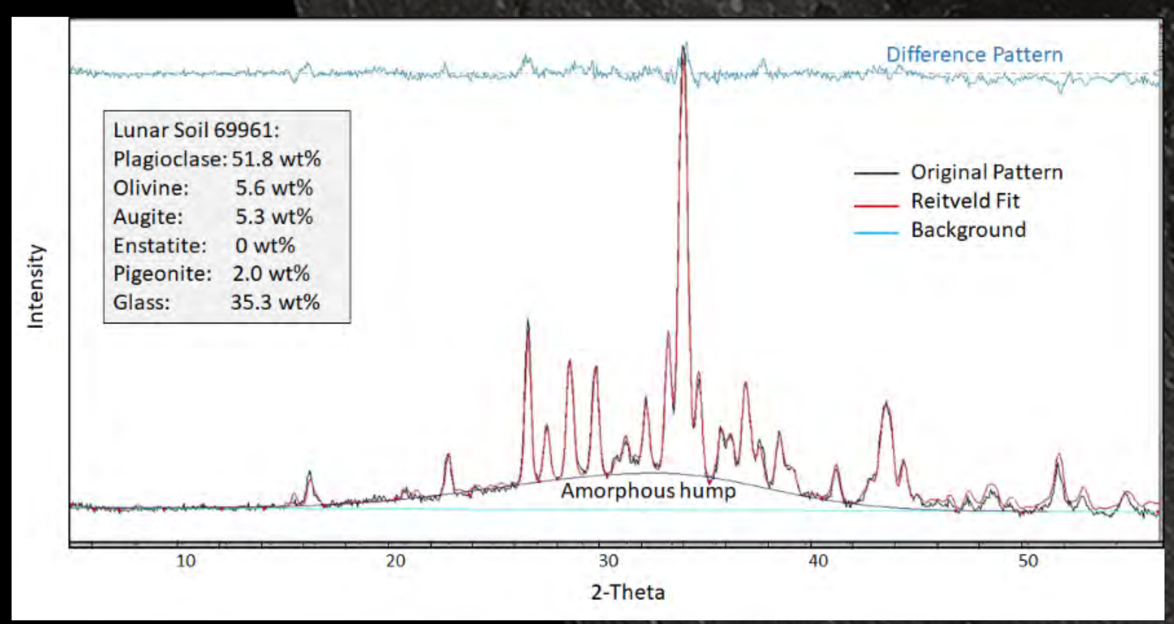


Fig. 1: XRD pattern of Apollo 16 soil (analyzed in the Terra XRD).

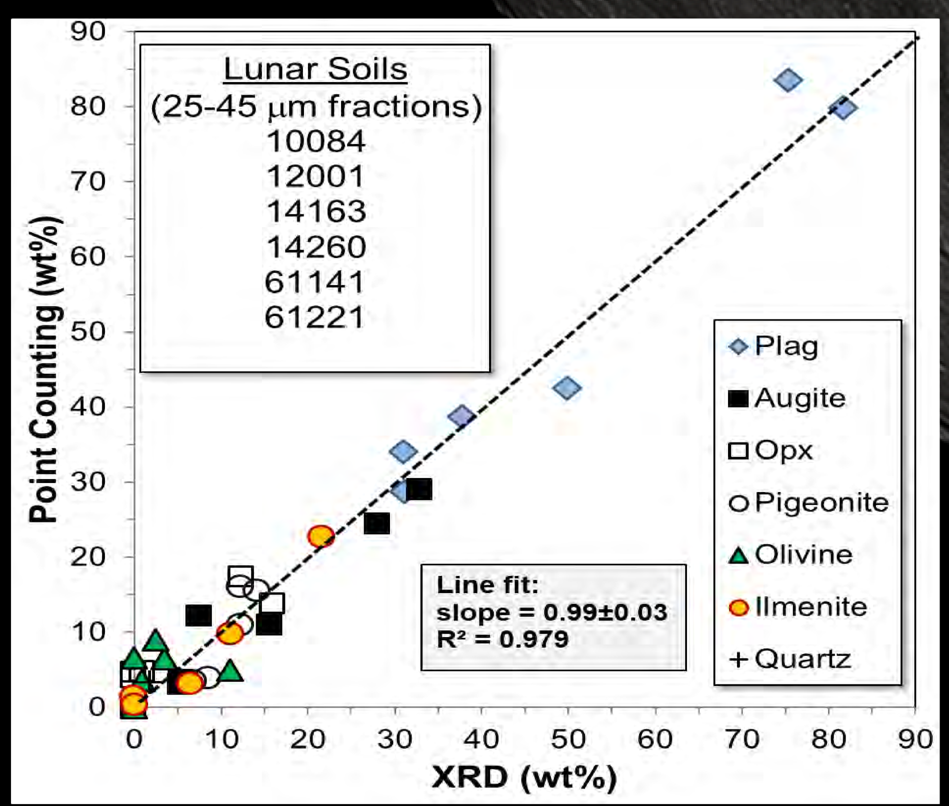


Fig 2: XRD modal abundances compared to those determined by SEM point counting [3-4].

ISRU: Generation of H_2O from Mauna Kea Soil

Fig. 3 shows example XRD results from an ISRU test during the 2007 Scarab-RESOLVE field demonstration [5].

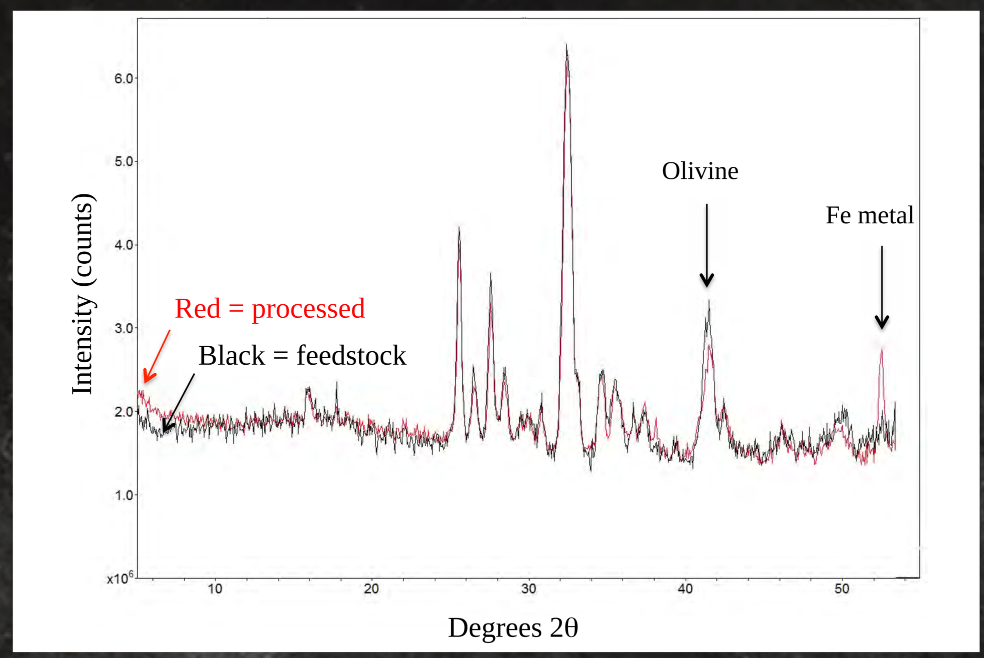


Fig. 3: XRD patterns of as-received Mauna Kea soil (black) and after heating in a hydrogen atmosphere (red). Olivine is consumed during the production of Fe metal and water.

XRD with Limited Sample Preparation:

XTRA is intended to analyze fines in as-delivered surface regolith, without sample preparation [6]. XTRA is configured in reflection geometry using vibrated cells for as-delivered powders, allowing direct analysis of materials scooped at the surface.

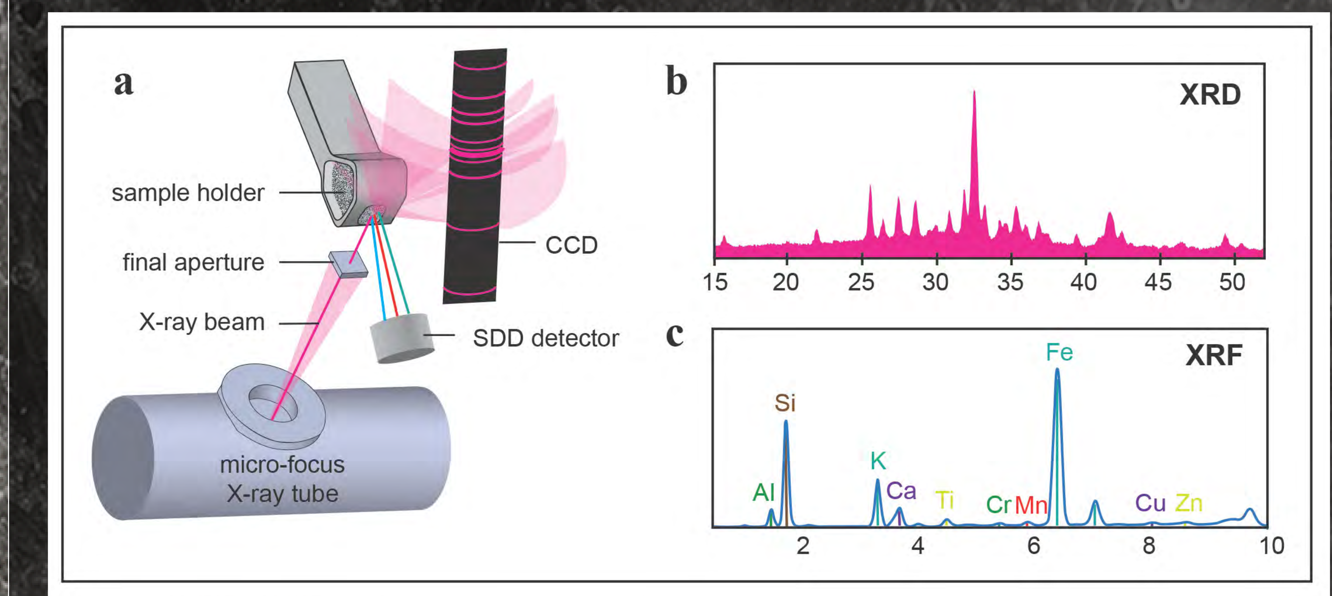


Fig. 4: (a), schematic diagram of XTRA diffraction and fluorescence geometry. Primary beam characteristic X-rays (magenta) are identified by their energy. A 2-D image of these constitutes the diffraction pattern. (b), the 2-D pattern (magenta in (a)) is summed radially about the central beam along each arc to yield a 1-D diffractogram. (c), Fluorescence X-rays from the sample (multicolored in (a)) are detected by an SDD detector and summed into a histgram of energy vs. number of counts. This histogram is the XRF spectrum of the sample.

Sample Acquisition and Delivery to XTRA

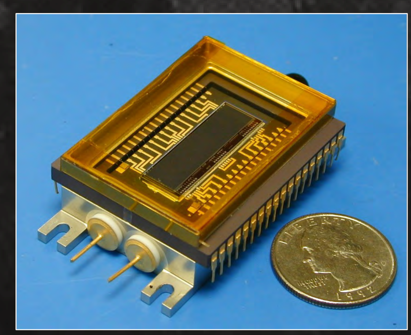
XTRA will be integrated with a sample collection/delivery system developed by Honeybee Robotics. The system is based on HBR's PlanetVac system in which sample acquisition is achieved through a pnuematic system attached to the footpad of the lander.

XTRA's initial deployment will be as a proof-of-concept instrument on early commercially launched landers. Instruments with carousels and multiple sample analysis capability are being designed for follow-on rover missions.

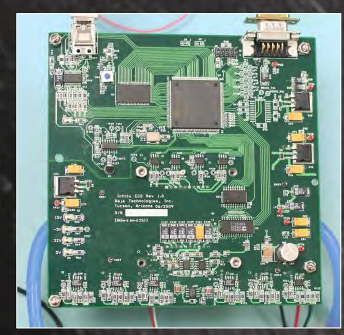
Development of high TRL components

We have partnered with industry leaders to develop high-TRL systems for XRD flight instruments.

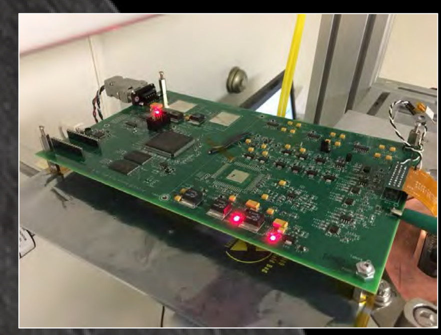
- CCD detectors (e2v)
- CCD electronics (Baja Technologies)
- X-ray tubes (RTW)
- High voltage power supplies (Battel Engineering)



Low-cost X-ray CCD in flight qualified package with internal Peltier cooler (e2v)

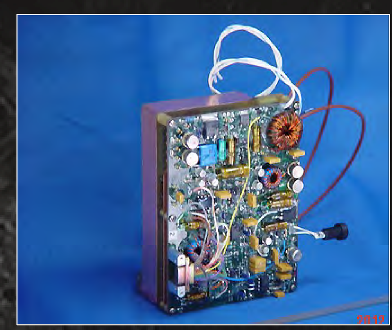


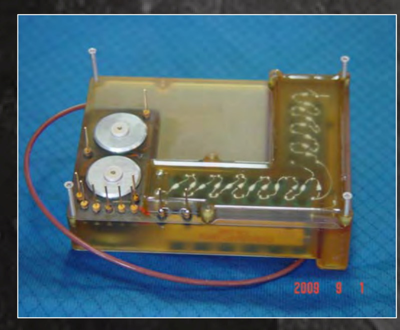
Full-frame CCD driver



Frame transfer CCD driver

Custom flight CCD electronics (Baja Technology)





Flight X-ray tube power module for grounded cathode X-ray tube (Battel Engineering)

10 W microfocused X-ray tube (RTW)

The XTRA instrument proposed for Lunar applications:

- TRL 5-6
- Reflection geometry - as-received regolith can be analyzed
- 2θ range 15-55° (Cobalt radiation)
- Vibrated sample cells to enable analysis of coarse powders
- Improved XRF performance using SDD in reflection geometry
- 4.5 kg, 4.5 liters, ~100 watt hrs.
- 240 X 150 X 130 mm, excluding cyclone funnel

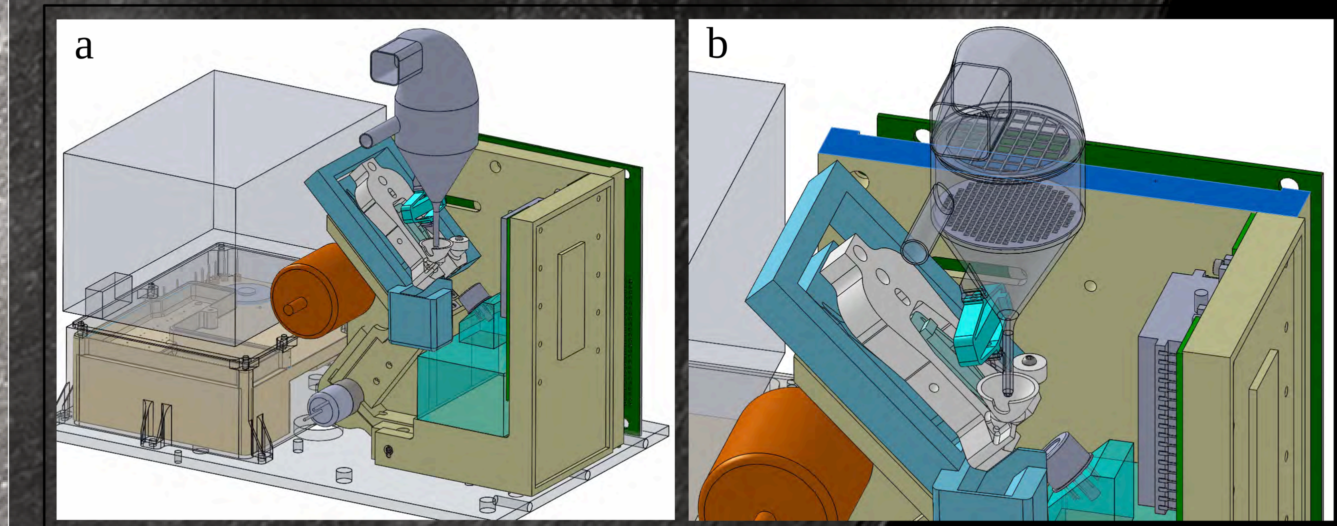


Fig. 5: Solidworks model of proposed flight instrument. a), overall view of instrument, b), closeup of cyclone and sample cell system.

References:

[1] Taylor, G.J., et al. (2012), LPSC 43 #2313; Taylor et al., (2019), GCA, submitted; [2] Sun, et al. (2018), LPSC 49, #1693. [3] Taylor L.A. et al. (2001). Icarus 124, 500-512. [4] Taylor, L.A. et al., (2001). J. Geophys. Res., 106 27985-27999. [5] Blake , D.F. et al.,(2008), NLSI Lunar Science Conference, Abstr. #2041. [6] Blake et al. (2012), IEEE Aerospace Conf. Big Sky, MO Paper #2.0905.

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