***IN-SITU* MINERALOGICAL ANALYSIS OF MERCURIAN REGOLITH USING X-RAY DIFFRACTION AND X-RAY FLUORESCENCE.** D.F. Blake[1], F.M. McCubbin[2], P. Sarrazin[3], T.S. Bristow[1], R. Downs[4], A. Yen[5], D. Bergman[6] and K. Zacny[6]. [1]MS 239-4 NASA Ames Research Center, Moffett Field, CA 94035, david.blake@nasa.gov; [2]NASA Johnson Space Center, Houston, TX; [3]SETI Institute, Mountain View, CA; [4]University of Ariz., Tucson, AZ; [5]Jet Propulsion Laboratory, Pasadena, CA; [6]Honeybee Robotics, Pasadena, CA.

Introduction: The MESSENGER mission revealed that Mercury is a geochemical end-member among the terrestrial planets, and as such, an *in-situ* surface investigation of its mineralogy and chemistry will greatly aid our understanding of planet formation and planetary evolution. Mercury is the most chemically reduced of the terrestrial planets, diverse in terms of surface compositions, and volatile rich [1, and refs. therein]. Upcoming orbital observations by BepiColombo will reveal its surface composition and other features in much greater detail [2]. However, the mercurian surface lacks diagnostic spectral absorption features in the UV-VIS region, so the mineralogy of Mercury has only been inferred through normative calculations based on surface compositions, and uncertainties in the oxygen content of the surface result in a large range of possible minerals that could be present [3-5].

Spacecraft-Capable Quantitative Mineralogy: With regard to mineralogical analysis, the CheMin instrument on Mars Science Laboratory [6] is the first spacecraft-capable instrument to provide definitive mineral identification and quantification using X-ray Diffraction, the "gold standard" of mineralogical techniques. CheMin-V, a next-generation XRD/XRF instrument proposed for Venus [7] and Mercury [8] benefits from a further decade of instrument R&D, resulting in reduced mass and complexity coupled with improved performance. When integrated with Honeybee Robotics PlanetVac system [9] (Fig. 1), surface regolith samples can be pneumatically collected and delivered to CheMin-V without a sampling arm or complicated mechanical movements.

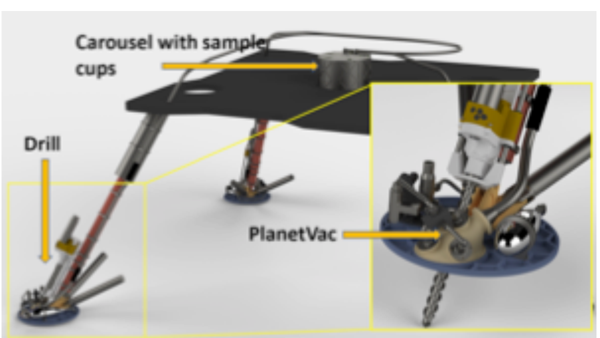

Fig. 1: PlanetVac moves a regolith sample from a lander footpad to instruments inside the lander pneumatically, with no requirement for an arm or complicated moving parts.

CheMin-V: CheMin-V is a transmission geometry XRD instrument similar to the CheMin XRD on MSL. CheMin-V requires a ~100 mg powder sample having a particle size <150 µm. Particle sizes in this range are routinely produced by percussion drills such as the Honeybee Robotics Venus drill and the MSL drill without sieving or other post-processing.

Fig. 2 illustrates the CheMin-V XRD/XRF geometry. A single X-ray source emits a cone of CoKα radiation intercepted by two pinhole collimators. The two collimators produce ~70 µm diameter beams of X-rays directed at the centers of two sample cells. The direct beams from the source/collimators strike beam stops at opposite ends of a 256X1024 pixel CCD, and the diffracted beams from each sample are detected by the CCD along its long dimension. The CCD is split into two halves longitudinally, yielding two separate 128X1024 pixel detectors, each recording an XRD pattern (Fig. 3). Silicon Drift Diode detectors (SDD) are placed on the X-ray entrance side of each sample cell, recording their XRF spectra.

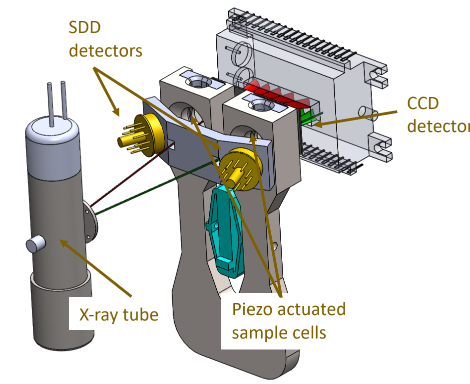

Fig. 2: Geometry of the CheMin-V instrument. A single X-ray tube illuminates two samples of powdered regolith. Two diffraction patterns are recorded by the same CCD imager, while individual XRF spectra are recorded with SDD detectors.

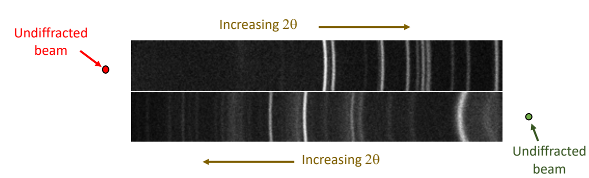

Fig. 3: Example diffraction patterns collected on a 256X1024 CCD imager (simulated).

The Terra XRD/XRF Instrument, a Prototype for CheMin-V: A powdered basalt sample from Hawai'i was analyzed in a Terra XRD/XRF instrument (a commercial spin-off of CheMin having the same XRD geometry as CheMin-V) for 15 minutes, then reanalyzed for 8 hours in a Rigaku laboratory X-ray Diffractometer. Table 1 shows the resulting Rietveld refinement and quantitative analysis from Terra, compared to that from the Rigaku XRD. Individual mineral compositions are derived from the refined lattice parameters [10] for andesine, augite, pigeonite and forsterite from the Terra instrument.

Table 1. Quantitative analysis of a basalt cobble

Phase	Formula	Terra 15 minutes Wt %	Rigaku 8 hours Wt %
Andesine	$Ca_{0.24}Na_{0.26}(Al_{0.735}Si_{3.265})O_8$	34.9	27.9
Augite	$Mg_{0.82}Fe_{0.52}Ca_{0.66}Si_2O_6$	15.4	19.9
Pigeonite	$(Mg_{0.54}Fe_{0.46})SiO_3$	10.8	13.3
Forsterite	$(Mg_{0.69}Fe_{0.31})SiO_4$	7.3	7.5
Ilmenite	$FeTiO_3$	0.8	1.5
Hematite	Fe_2O_3	0.3	0.4
Magnetite	Fe_3O_4	ND	1.1
Cristobalite	SiO_2	5.1	2.6
Palag./Allophane		20.3	20.9
Nontronite 10.0		4.4	4.0
Total		99.3	99.1

CheMin-V can return quantitative mineralogical results from two different samples in ~15 minutes. Two (or more) additional samples can be analyzed with a second sample cell pair, rotated into position by a single actuator (not shown). Additional analyses are possible by emptying and refilling cells (as is done in the CheMin instrument).

Table 2. CheMin-V Proposed Analytical Parameters

Parameter	Baseline
Number of Analyses	2 (4 or more possible)
Mineral Detect / Quantify	Detection ≥ 1%, quantification ≥ 3%.
Mineral Composition	Oxide wt% for all major elements, ± 5%
Element Quantification	10<Z<35 to ±10% of amount present
Element Detection	10<Z<35 if present at >100 ppm.
Amorphous Material Quant.	Quantification ± 10%.
Amorphous Composition	Oxide wt. %, to ±10% of amount present

Table 2 lists the proposed analytical capabilities of the CheMin-V instrument. Fig. 4 shows a 3-D model of CheMin-V. Estimated dimensions of the instrument are 27 X 18 X 15 cm with a mass of 4 kg.

XRD/XRF analyses provide the most diagnostic and complete mineralogical characterization of rocks and soil possible by any spacecraft-capable technique, improved upon only by sample return and analysis in terrestrial laboratories. Two (or more) quantitative XRD analyses of mercurian regolith would revolutionize our understanding of the early history and evolution of Mercury, and greatly improve our understanding of comparative terrestrial planetology.

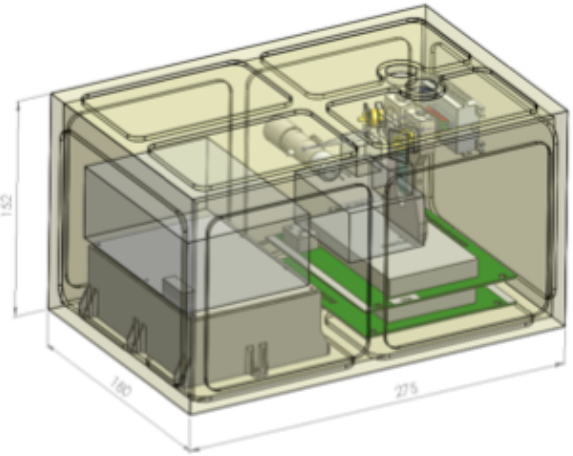

Fig. 4: 3-D model of the CheMin-V instrument.

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References: [1]. Armytage, et al., (2018), https://www.researchgate.net/publication/329504378. [2]. Benkhoff et al., (2010), DOI: 10.1016/j.pss.2009.09.020. [3]. Vander Kaaden, K.E., et al., (2017), Icarus 285, 155-168. [4]. McCubbin, F.M., et al., (2017), J.G. Planets 122, 2053-2076. [5]. Namur, O. and Charlier, B., (2017), Nature Geosci. 10, 9-13. [6]. Blake, D., Vaniman, D., Achilles, C. et al. Space Sci Rev (2012), 170: 341; All CheMin data & pubs downloadable from: http://odr.io/CheMin. [7]. Blake, D. F. et al., (2019), LPSC50 abstr. #1144; Blake, D.F. et al., (2019), EPSC-DPS2019 abstr. #858 Joint Meeting 2019. [8]. Blake, D.F. et al (2019), AGU Fall Meeting, abstr. # P13C-3523. [9]. Zacny, K. and A. Garcia, (2014). IEEE Aerospace Conference, 3-7 March 2014, Big Sky MT. [10]. Morrison et al., (2018), http://dx/doi/org/10.2138/am-2018-6123.