DUST REMOVAL ON MARS USING LASER-INDUCED BREAKDOWN SPECTROSCOPY. T. G. Graff [1], R. V. Morris[2], S. M. Clegg[3], R. C. Wiens[3] and R. B. Anderson[4], [1]Jacobs Technology ESCG, 2224 Bay Area Blvd. Houston, TX 77258, Mail Code JE23 (*trevor.g.graff@nasa.gov*), [2]NASA-JSC, ARES, Houston, TX, [3]Los Alamos National Laboratory, Los Alamos, NM, [4]Cornell University, Department of Astronomy, Ithaca, NY.

Introduction: Dust coatings on the surface of Mars complicate and, if sufficiently thick, mask the spectral characteristics and compositional determination of underlying material from *in situ* and remote sensing instrumentation. The Laser-Induced Breakdown Spectroscopy (LIBS) portion of the Chemistry & Camera (ChemCam) instrument, aboard the Mars Science Laboratory (MSL) rover, will be the first active remote sensing technique deployed on Mars able to remove dust. ChemCam utilizes a 5 ns pulsed 1067 nm high-powered laser focused to <400 µm diameter on targets at distances up to 7 m [1,2]. With multiple laser pulses, dust and weathering coatings can be remotely analyzed and potentially removed using this technique [2,3]. A typical LIBS measurement during MSL surface operations is planned to consist of 50 laser pulses at ~14 mJ, with the first 5 to 10 pulses used to analyze as well as remove any surface coating. Additionally, ChemCam's Remote Micro-Imager (RMI) is capable of resolving 200 µm details at a distance of 2 m, or 1 mm at 10 m [1,4].

In this study, we report on initial laboratory experiments conducted to characterize the removal of dust coatings using similar LIBS parameters as ChemCam under Mars-like conditions. These experiments serve to better understand the removal of surface dust using LIBS and to facilitate the analysis of ChemCam LIBS spectral data and RMI images.

LIBS Instrumentation: A new LIBS instrument has been setup at the Johnson Space Center (JSC) as part of the Astromaterials Research and Exploration Science (ARES) Spectroscopy and Magnetics Laboratory (Figure 1). The excitation source for this system is a Tempest solid-state neodymium doped yttrium aluminum garnet (Nd:YAG) high-energy laser operating at a wavelength of 1064 nm. The pulsed laser system is capable of a maximum of ~200 mJ and has a variable repetition rate up to 10 Hz, with a pulse width of 3 to 5 ns. The detector array consists of three high-speed fiber optic spectrometers, covering a spectral range from 224 to 932 nm.

The JSC LIBS system includes an environmental sample chamber, with a volume of ~230 liters, vacuum certified from 760 Torr (1 atm) to 10^{-9} Torr. Samples are placed in the chamber on a horizontal 40 cm diameter circular stage, which is rotated through the beam path. Sample positioning is controlled via a precision rotary feed-through. Other flanges and feed-throughs are utilized for chamber access, sample viewing and pressure monitoring.

Samples and Methods: The substrate material used in these experiments consisted of aphanitic basalt slabs from the Columbia River Basalt Group (Figure 2a). The slabs, measuring ~13 x 5 cm, were prepared with 60-grit sand paper to achieve flat uniform surfaces.

A dust deposition chamber was used to deposit uniform coatings of air-fall material. This is accomplished by mechanically agitating a selected starting material in order to extract, suspend, and settle the fine-grained component [5,6]. Palagonitic tephra (HWMK919), sieved to <1 mm, was used as the source for the dust in these experiments [7]. The mean diameter of discrete particles of air-fall material that settled on the substrate was <10 µm, as estimated by binocular microscopic examination. Progressively thicker dust coatings were applied with multiple runs until the desired coating thickness was achieved (Figure 2b through 2g). The thickness of the dust layer was measured both with a vertically-calibrated microscope (geometric thickness in microns) and by weighing the mass of dust for a known surface area (mass thickness in mg/cm^2) [6]. The average density for the air-fall dust coatings was 0.11 g/cm^3.

The dust coated samples were placed on the circular stage within the JSC LIBS environmental chamber. The chamber was then pumped down and maintained at 7 Torr of CO_2, to produce a Mars-like environment. For these experiments the laser power was set at ~17 mJ with a repetition rate of 3 Hz, to approximately replicate ChemCam operating conditions. The six dust coated slabs were rotated into the beam path and four sets of laser pulses were conducted on each slab. The laser pulse sets consisted of 1, 5, 20 and 50 pulse(s) per slab. Digital photographs were taken of the slabs after they were removed from the chamber with an 8.0 megapixel camera in macro mode, providing an image resolution of ~200 µm.

Results and Application: Figure 2 displays the resulting features of the four sets of laser pulses on dust coatings of increasing thickness. In all cases dust is removed from the surface exposing the basaltic substrate. With 50 pulses at ~17 mJ the largest area of partially uncovered substrate was ~21.5 mm in diameter.

The dust removed from a single pulse tends to grow in size with increasing coating thickness, from ~1 mm diameter spot with an 11 µm coat to ~4.5 mm diameter spot with a 304 µm thick dust coating. This is likely a result of the plasma, produced from the initial laser pulse, forming deeper beneath the surface of the dust and therefore ejecting material further from the center.

Displayed prominently starting at 5 laser pulses, a distinctive ring appears around the central pit (best displayed in Figure 2c, 2d and 2e). These rings persist with increasing laser pulses even as additional dust is removed outward. We attribute this feature to sintered palagonite material that lightly adheres to the basaltic substrate, and remains even when the surrounding dust coating is blown away. The 209 µm and 304 µm coatings do not display this central ring as the coatings are sufficiently thick to prevent the energy from the initial laser pulses from adhering material directly to the substrate. For these thicker coatings at 50 pulses, the total area cleared of dust starts to diminish as more energy is required to move the additional material outward (Figure 2f and 2g).

These results support the LIBS remote dust cleaning capability as discussed by [2,3,9], and represent a series of realistic air-fall dust coating conditions that are likely to be encountered by MSL and ChemCam on Mars (e.g. the various dust coatings observed on Adirondack by Spirit as depicted in Figure 3) [8]. The overall observations of this study will also facilitate the analysis of potential features in RMI images. Results with the ChemCam flight model gave a much smaller cleaned diameter of only 2.4 mm in one test [9], corresponding more to the central cleaned feature in these results. [9] used 10 mJ laser energy (vs. 14 mJ for flight and 17 mJ for our results) at nearly 3 m distance. In addition to the difference in laser energy, the target distance, beam diameter, material particle size and deposition methods may account for the variation in the overall cleaned diameters between these tests.

References: [1] Wiens et al. (2010) *41st LPSC,* Abstract #2205. [2] Wiens et al. (2009) *40th LPSC,* Abstract #1461. [3] Wiens et al. (2005) *36st LPSC,* Abstract #1580. [4] Maurice et al. (2009) *40th LPSC,* Abstract #1864. [5] Graff et al. (2001) *32nd LPSC,* Abstract #1899. [6] Morris et al. (2001) *32nd LPSC,* Abstract #1912. [7] Morris et al. (2001) *JGR*, 106, E3. [8] Spirit at Gusev Crater: Plates (2004) *Science,* 305, 811. [9] Wiens et al. (2011) this meeting.

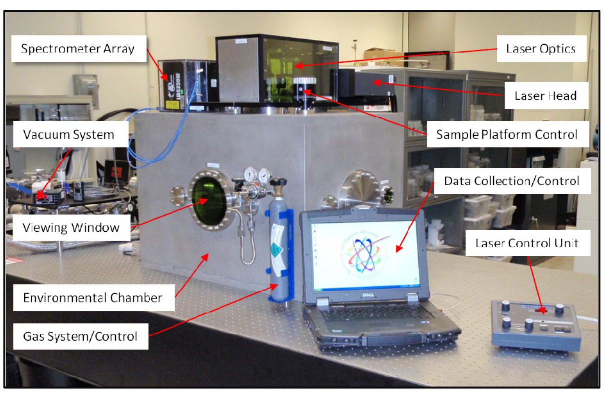

Figure 1: LIBS setup in the JSC Spectroscopy and Magnetics Lab.

Figure 3: Pancam image of Adirondack in Gusev Crater, Mars displaying an increasingly thicker dust coating from top to bottom [8].

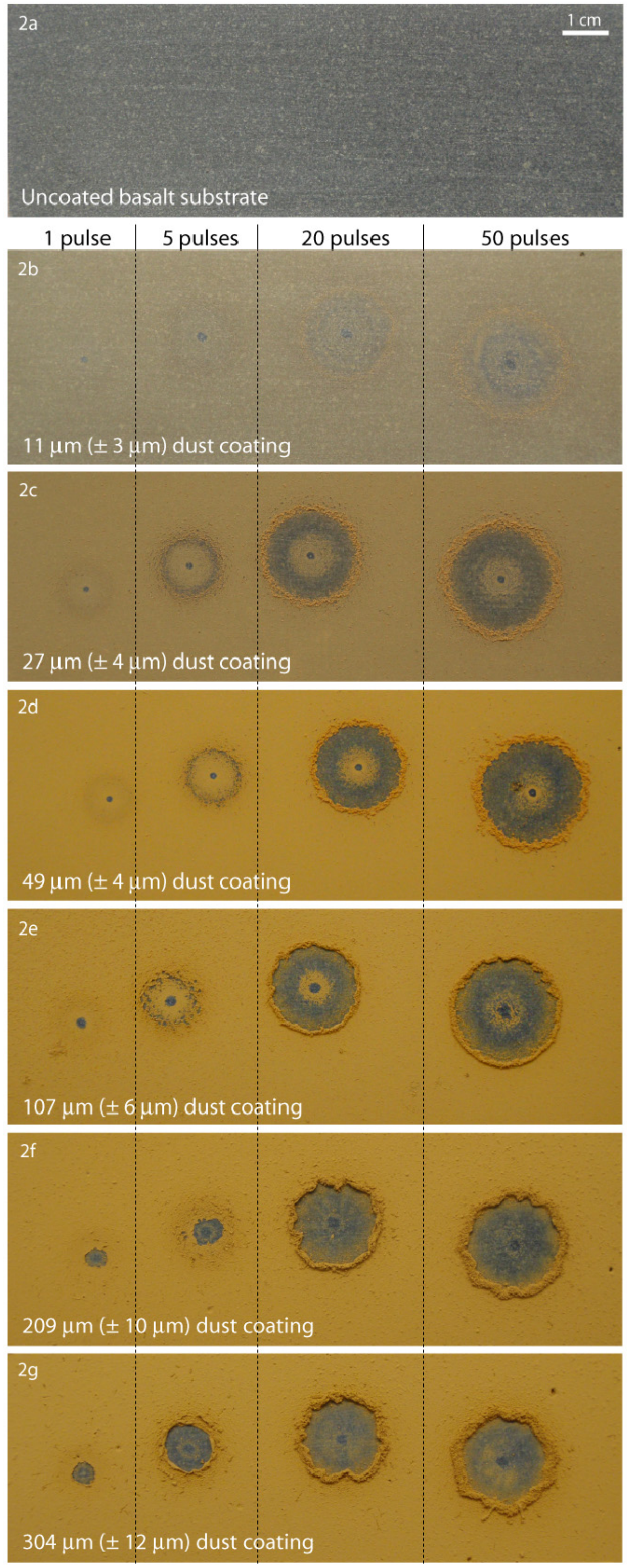

Figure 2: Resulting features from ~17 mJ laser pulses on progressively thicker dust coatings. Coating thickness is given in the lower left of each image with increasing number of laser pulses (1, 5, 20, and 50) from left to right. Average dust coating density was calculated at 0.11 g/cm^3. Uncoated basaltic substrate and the image scale are displayed at the top.