

**Laser Induced Thermal Desorption Measurements of Volatiles on Lunar Soils.** J. L. McLain<sup>1</sup>, M. Sarantos<sup>2</sup>, N. M. Johnson<sup>2</sup>, J. W. Keller<sup>2</sup> and W. M. Farrell<sup>2</sup>, <sup>1</sup>University of Maryland/GSFC/CRESST2 (College Park, MD 20742. jason.l.mclain@nasa.gov), <sup>2</sup>NASA Goddard Space Flight Center (8800 Greenbelt Rd. Greenbelt, MD 20771).

**Introduction:** The literature on the distribution of surface binding sites for water desorption has been shown to greatly affect the dynamics of the lunar exosphere [1, 2]. Nonetheless, only water adsorption/desorption experiments have been performed on different lunar soil types, i.e., mare vs. highlands [1]. As new space-based exospheric observations from future and ongoing missions continue to accumulate new exospheric species, we are able to better constrain exospheric volatile abundances. Measurements of microphysical parameters of several compounds on lunar samples are entirely missing from the literature.

Thermal desorption is usually described in terms of an Arrhenius expression, often called the Polanyi-Wigner equation,  $r(\theta) = -d\theta/dt = v(\theta) \theta_n \exp[-E(\theta)/RT]$ , where the rate of desorption is  $r$ , the adsorbate coverage,  $\theta$ , time,  $t$ , pre-exponential or prefactor,  $v$ , desorption order,  $n$ , and the activation energy for desorption,  $E$ . The total abundance of a species in the exosphere and the resulting local time dependence is a function of this temperature dependent desorption rate. In these LITD experiments; activation energy for desorption, prefactor, and desorption order can be determined as a function of coverage as described by [4].

Methane in the Moon's exosphere peaks at 7 AM [3], which would imply  $\sim 0.8$  eV binding energy even for one of the most volatile species. To fit the Ar observations by LADEE, specifically how slowly the Ar density dropped off from dawn, [8] had to assume that the activation energy for desorption is temperature-dependent, and that on the dayside they bind more strongly. Our LITD experiments will provide binding distributions with coverage and temperature that will allow us to test these modeled inferences.

A large set of applications for our data and models include the H and H<sub>2</sub> measurements at the Moon [5], H measurements at Mercury [6, 7], the detection of Argon [8, 9], Neon [7], and CH<sub>4</sub> on the Moon [3], and detections of water group ions reported during MESSENGER flybys [10].

**Experimental:** Two lunar soil types will be compared in this presentation. An Apollo 15 (15271) mature soil sample, Is/FeO = 63, with 42% agglutinate content, and an Apollo 17 (73131) very immature soil clod, Is/FeO = 16 (Morris 1978). The main technique used for these experiments is Laser Induced Thermal Desorption (LITD). The LITD utilizes a 10.6 micron CO<sub>2</sub> laser. The laser beam enters the vacuum chamber

through a ZnS window, and illuminates the soil samples. The laser pulse and power have been optimized to remove only adsorbates on the soil surface and not from the sample holder. A closed-cycle helium cold-finger is attached to the sample holder and incorporates an internal 20 W cartridge heater to provide a broad sample temperature range from 10 K to 400 K. Our lunar sample request was granted Nov. 2015 to study various lunar soil types.

A quadrupole mass spectrometer collects molecular specific data at an  $\sim 20$  ms data rate. During a steady-state isothermal desorption analysis, a small amount of a volatile gas is leaked into the chamber at a constant rate, typically  $\leq 1 \times 10^{13}$  molecules/cm<sup>2</sup>·s. This presentation will focus on the kinetics of CO<sub>2</sub>, Argon and CH<sub>4</sub>. At a specific leak rate, the accumulation time is varied while the laser pulses any adsorbed volatile back into the vacuum. This impulse of gas can be directly related to the amount of gas adsorbed on the soil at a particular sample temperature, and converted into a steady-state isothermal desorption curve, Figure 1.

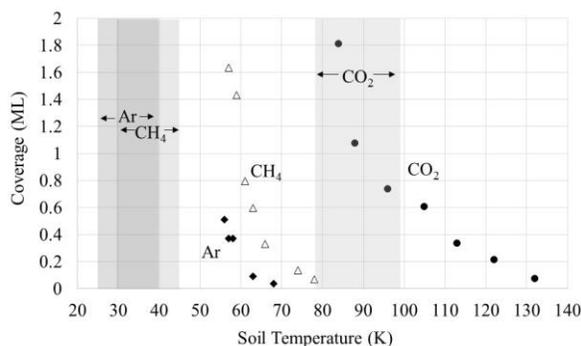


Figure 1. Isothermal desorption/adsorption equilibrium coverages of Ar, CH<sub>4</sub>, and CO<sub>2</sub> on Apollo soil 15271 at various temperatures. The constant flux of the gases was  $\sim 10^{13}$  molecules/cm<sup>2</sup>·s. The coverage was determined by the LITD signal. For comparison, the range of adsorption temperatures are given on amorphous solid water ice (ASW) is presented in the shaded regions.

**Results:** For this presentation, the plan is to present the temperature and/or coverage dependent activation energies for desorption for the three gases in Figure 1, and compare those values to other Apollo soil types. In Figure 1, as the coverages approach 1 ML, the desorption kinetics change from adsorbate-soil interac-

tions to adsorbate-adsorbate interactions (formation of multilayer ices). As seen in Figure 1, the range of the absorption temperatures varies from those on ASW. For Ar, CH<sub>4</sub> and CO<sub>2</sub>, the range in adsorption temperatures in high vacuum on ASW is centered at 31, 39 and 90 K, respectively [11, 12].

For the kinetic analysis, a steady state coverage on the Apollo soils versus pressure (or flux) under equilibrium conditions can be used to determine the desorption rate at different soil temperatures. These data can then be fit by the Arrhenius expression to obtain the kinetic parameters  $E$  and  $\nu$ . This analysis is shown in Figure 2 for CO<sub>2</sub>. The desorption energy was determined to be  $E = 7.3 \pm 0.05$  kcal/mol, with a prefactor =  $10^{13}$  and desorption order = 0.7. We plan to perform a detailed statistical fitting analysis for all species studied. The spread in these data represents  $dE$  or width in activation energy that is expected to depend on the gas type interaction with the soil grain adsorption sites.

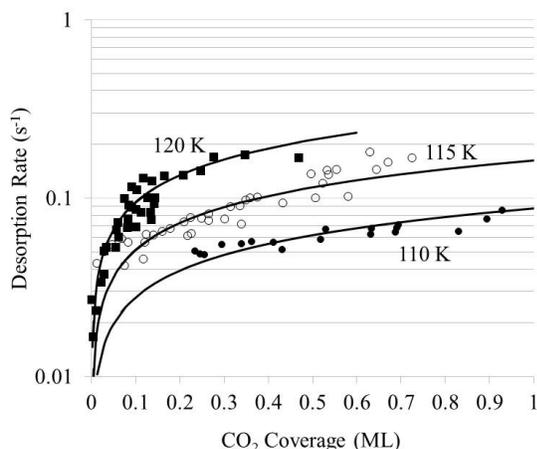


Figure 2. Isothermal CO<sub>2</sub> desorption rates on Apollo soil 15271 versus CO<sub>2</sub> coverages at various soil temperatures. The solid lines are the Arrhenius expression fits.

With this new data set, our Monte Carlo model can simulate residence times on the surface and losses to Permanently Shadowed Regions (PSRs). We can simulate exospheric migration and adsorption into craters, with each  $0.5^\circ \times 0.5^\circ$  surface pixel experiencing a realistic monthly temperature cycle. The code now adopts a different binding energy per surface pixel and can account for a surface-coverage dependence of the desorption energy.

**Summary:** The plan is to continue adsorption-desorption experiments of CO<sub>2</sub>, Ar, Ne, H<sub>2</sub>O, N<sub>2</sub>, O<sub>2</sub>, etc., on the various Apollo soils. Additional experiments will include lab-grown silicate condensates, ini-

tially exposed to air. If these results prove promising, then the vacuum load-lock will be used to transfer them into the LITD apparatus. Then we can run the new modeling code with lab-measured binding energy per molecule per surface pixel and apply them to various astronomical targets.

#### References:

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