

LUNAR EXOSPHERIC ARGON MODELING. Cesare Grava¹, J.-Y. Chaufray², K. D. Retherford¹, G. R. Gladstone¹, D. Hurley³, R. R. Hodges⁴, ¹Southwest Research Institute, 6220 Culebra Road, San Antonio, TX, 78238 USA (cgrava@swri.org), ²LATMOS-IPSL, CNES, Paris, France, ³Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA, ⁴Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO, USA.

Introduction: The isotope of ⁴⁰Ar was first detected by the Apollo 17 surface-based mass spectrometer LACE, along with Ne and He [1]. Its measured atmospheric density at the surface of $\sim 10^4$ atoms cm^{-3} is similar to that of He and makes them the most abundant gases in the lunar exosphere.

Contrary to helium, argon is a truly native element in the lunar environment, resulting from the decay of ⁴⁰K within the lunar crust. The Apollo data, obtained during 9 lunations in 1973, showed a diurnal pattern typical of a condensable gas at the cold nightside surface temperature and an apparently cyclical variation of ⁴⁰Ar density, with maximum to minimum abundance ratio of 2. This requires a presently active mechanism for transient venting of gas from deep within the Moon [2].

Besides its importance for sounding the lunar interior, argon's behavior as a condensable gas might resemble that of other volatiles (e.g. water vapor) that can be stored in permanently shadowed regions (PSR) of the Moon for >1 billion years. The study of reflectance from these shadowed regions is the main objective of the LAMP instrument onboard the LRO spacecraft and a detailed model of argon transport at the lunar surface has thus been developed.

Details of the Model: Our Monte Carlo simulation follows the fate of argon atoms from their creation to annihilation or implantation on the surface. Particles are emitted throughout the lunar surface with a Maxwell-Boltzmann flux distribution [3] and their trajectories are computed using a Runge-Kutta algorithm. Once a particle impacts the regolith, it resides for certain residence time, defined by the formula:

$$t = \frac{C}{T^2} \exp\left(\frac{Q}{RT}\right)$$

Where C is a constant, Q is the activation energy, R is the gas constant and T is the surface temperature. We used $C = 10^{-10} \text{ sK}^2$ and $Q = 6485.1 \text{ cal/mole}$, following [4]. For the surface temperature, we use LRO/Diviner maps. Fundamental parameters such as position, velocity, distribution of energy and velocity are stored at regular time steps.

Early results: Our preliminary results (Figure 1) show a satisfactory agreement with portions of the measurements of the Apollo mass spectrometer (which were performed only at night). The decreasing trend from the sunset to the sunrise is consistent with the decrease of Ar in the lunar exosphere due to increasing adsorption at the surface. The peaks at sunrise and sun-

set represent lateral migration of Ar from the subsolar point to the nightside, due to the $T^{5/2}$ for a non-condensable gas at the hot dayside surface temperature [5]. The model results showed no appreciable difference if we take into account saturation pressure due to resonant scattering of sunlight, a mechanism which is responsible for the creation of an anti-sunward tail of lunar sodium atoms [6]. The low efficiency of this process is due to the extremely low *g-value* (resonant scattering coefficient) for Ar compared to that for Na ($\sim 6 \times 10^{-8} \text{ s}^{-1}$ and $\sim 0.8 \text{ s}^{-1}$ at 1 AU, respectively).

Further improvements and applications: We will further refine the model to include photo-ionization, in order to explain the decrease in exospheric argon within 6-7 months. More applicable Diviner temperature maps will be used to model the diurnal behavior. A predicted Ar-1048 Å emission line intensity will then be derived and compared with upper limits being provided by the LRO/LAMP UV spectrograph, which is currently mapping the polar regions of the Moon and exploring the lunar exosphere [7, 8, 9].

Finally, this model will be modified to study the evolution of other volatiles, such as Hg and molecular hydrogen.

References: [1] Hoffman, J.H. et al. (1973), *Proc. 4th Lun. Sci. Conf.*, Vol 3, pp. 2865-2875. [2] Hodges Jr., R.R. and Hoffman, J.H. (1974), *Proc. 5th Lun. Sci. Conf.*, Vol 3, pp. 2955-2961. [3] Hodges Jr., R.R. (1980) *JGR* 85, A1. [4] Hodges, Jr., R.R. (1982) *LPI XIII*. [5] Hodges, Jr., R.R. and Johnson, F.S., (1968), *JGR* 73, 23. [6] Matta, M. et al. (2009) *Icarus* 204, 409-417. [7] Gladstone, G. R. et al. (2010), *Science* 330, 472. [8] Stern, S. A. et al. (2012), *GRL*. [9] Cook, J. C., et al. (2013), submitted to *Icarus*.

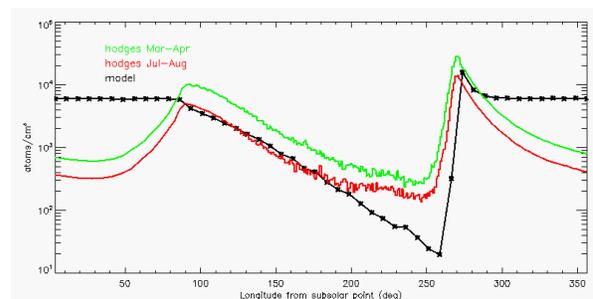


Figure 1 Modeled argon density (black asterisks) overlaid on Apollo 17 measurements. Longitudes are here expressed in degrees from subsolar point, with sunset at 90 deg and sunrise at 270 deg. Our modeled density extends below the LACE sensitivity of ~ 100 atoms cm^{-3} .