MONTE CARLO MODEL INSIGHTS INTO THE LUNAR SODIUM EXOSPHERE.

D. M. Hurley[1], R. M. Killen[2], M. Sarantos[2,3], [1]JHU Applied Physics Laboratory (dana.hurley@jhuapl.edu) , [2]NASA Goddard Space Flight Center, [3]Univ. Maryland Baltimore County.

Introduction: Sodium in the lunar exosphere is released from the lunar regolith by several mechanisms. These mechanisms include photon stimulated desorption (PSD), impact vaporization, electron stimulated desorption, and ion sputtering. Usually, PSD dominates; however, transient events can temporarily enhance other release mechanisms so that they are dominant. Examples of transient events include meteor showers and coronal mass ejections.

The interaction between sodium and the regolith is important in determining the density and spatial distribution of sodium in the lunar exosphere. The temperature at which sodium sticks to the surface is one factor. In addition, the amount of thermal accommodation during the encounter between the sodium atom and the surface affects the exospheric distribution. Finally, the fraction of particles that are stuck when the surface is cold that are rereleased when the surface warms up also affects the exospheric density.

In [1], we showed the "ambient" sodium exosphere from Monte Carlo modeling with a fixed source rate and fixed surface interaction parameters. We compared the enhancement when a CME passes the Moon to the ambient conditions. Here, we compare model results to data in order to determine the source rates and surface interaction parameters that provide the best fit of the model to the data.

Data: Observations of the lunar sodium exosphere were obtained at the McMath-Pierce solar telescope with the echelle spectrograph at high resolution during November 1998, and January and February, 1999. The slit was positioned perpendicular to the equatorial east and west limbs and the north and south poles, respectively from the surface to about a half lunar radius above the limb. The density at the surface and the scale height will be determined at these cardinal points and compared with models. These data, which have not been published previously, and additional data that are published, including a sequence in June 1998 [2], taken with the same telescope and setup, will be used to constrain models of the lunar exosphere.

Model: The Monte Carlo model follows 10^5-10^6 particles on ballistic trajectories from their points of release on the lunar surface until the particles are lost from the atmosphere using a fourth order Runge-Kutta (RK-4) algorithm [1,3]. The results presented here use the equation of motion including radiation pressure, but neglecting the effects of surface charging. The simulation space spans from the surface of the Moon to the Hill Sphere (35 R_{Moon}), where gravity from Earth begins to dominate the motion of the particles.

An input flux and spatial distribution is assigned as appropriate for the source: solar UV radiation for photon-stimulated desorption, solar particle flux for ion sputtering, and micrometeoritic or meteoritic flux for impact vaporization. At the Moon, solar wind flux dies off with solar zenith angle due to the curvature of the Moon. Micrometeorite release, in contrast, is expected to be isotropic over the surface of the Moon, at least within a factor of two.

The ejected products are assigned an initial velocity from the surface drawn from the distribution function appropriate to the release mechanism. When the particle comes back into contact with the surface, there are a variety of processes that can occur, introducing an array of interesting physics questions. These are investigated in the simulations presented here. When the atmospheric particle reencounters the planet, it may stick to the surface. It may adsorb to the surface long enough to partially or fully thermalize to the local surface temperature and then be re-emitted. Or it may rebound on contact retaining all or most of its incident energy.

The energy exchange at the surface for particles that return to the surface and are re-emitted is parameterized by a thermalization coefficient (w) and a conservation coefficient (f) that governs the energy exchange between the particle and the surface. The weights applied to v_t, a velocity from the Maxwellian distribution at the local surface temperature (thermal accommodation) and to v_i the incident particle velocity (rebound) total unity. The inbound and thermal velocities are added in quadrature with appropriate weights to compute the outbound velocity. The conservation coefficient is applied afterward to provide a separate means of damping particles. If a particle is re-emitted, the direction of release occurs with an isotropic angular distribution. However, given the microstructure of the regolith, this is a simplification. The re-emitted particle is followed on all of its ballistic hops until it is lost from the system either to sticking, escape, or photoionization.

When the particle encounters the surface, the code determines whether the particle will stick or be re-emitted depending on the sticking functions assigned to the simulation. In these simulations, sticking is applied as a temperature-based function. For each time the particle comes into contact with the surface, the

local surface temperature is queried. If the temperature is below the setting, the particle sticks. The code can immediately consider the later reemission of a stuck particle. For example, when nightside sticking is enabled, the code can assume that the particle is reemitted at the dawn terminator by a specified release process (thermal desorption or photon-stimulated desorption). This way, one can follow a particle until it is lost from the planet by escape or photoionization rather than just recycling to the regolith.

The probability of photoionization or photodissociation during a given hop is based on the photoionization time [4-5] and the time of flight in sunlight. The particle escapes the simulation when it crosses a predetermined boundary. Here, we use the Hill sphere (35 R_{Moon}) as the boundary for escape.

Conclusion: Of particular interest are the effects of sticking at the surface, thermal accommodation, temperature dependence of the yields of photon-stimulated desorption, and potential priming of the surface by magnetospheric plasma hitting the moon during plasma sheet crossings. Data from the Lunar Prospector spacecraft, which was operating at the time of these observations, will be used to determine the times of plasma sheet crossings by the moon. Temperature-based sticking in the model creates a dawn enhancement in the distribution of sodium in the atmosphere. However, compared to data, the density is too high if all of the particles that stick to the cold surfaces are released as the surface rewarms. Therefore we introduced a reemission percentage to the model. Here, we assume a portion of the sodium diffuses back into the regolith when the temperature warms, while the rest diffuses out of the regolith. This decreases the density of the sodium exosphere.

References: [1] Killen R. M. et al. (2012) *JGR 117*, 10.1029/2011JE004011 [2] Potter A. E. et al. (2000) *JGR 105*, 15073-15084 [3] Crider D. H. and Vondrak R. R. (2000) *JGR 105*, 26773-26782. [4] Huebner W. F. et al. (1992) *Astrophys. Sp. Sci. 195*, 1-294 [5] Verner D. A. et al. (1996) *Ap. J. 465*, 487.