SIMULATION OF LUNAR EXOSPHERIC ARGON: INSIGHTS ON LOSS PROCESSES, COLD-TRAPPING, AND SUDDEN RELEASE EVENTS.

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Introduction: A Monte Carlo simulation of argon in the lunar exosphere has been developed in order to explain the measurements of the Lunar Atmosphere Composition Experiment (LACE) mass spectrometer deployed at the lunar surface during the Apollo 17 mission [1].

Argon-40 is one of the few truly native elements in the lunar exosphere, coming from the radioactive decay of Potassium-40 present within the crust. Besides its importance in sounding the lunar interior, its behavior as a condensable gas might reflect that of other volatiles (e.g. water) that can be stored in the Permanently Shadowed Regions (PSRs) of the Moon for billions of years and are among the main targets of the Lyman Alpha Mapping Project (LAMP) UV spectrograph [2] onboard the Lunar Reconnaissance Orbiter (LRO).

In particular, we aim to reproduce the observed global decrease in argon density recorded by LACE over a time span of four lunations [3], or 120 days, to test the importance of the cold-trapping in the PSRs as a loss process for argon, in addition to the main loss process which is solar photoionization.

Model: In our Monte Carlo simulation, we launch test particles across the whole lunar surface. The energy of the particles is determined by the regolith temperature assuming a Maxwell-Boltzmann flux distribution [4] and an accommodation factor of 1 [5].

Residence time. In order to properly treat the exosphere-surface interaction, we take into account the residence time, or the time an atom spends adsorbed in the lunar surface [6].

Soil temperature. To describe the surface temperature we use a temperature map derived from a one-orbit observation of the LRO/Diviner radiometer. Figure 1 illustrates our model superimposed to the maximum argon density measured by LACE (digitized from [3]) at the Apollo 17 landing site.

Loss by solar processes alone. Photoionization and charge-exchange with solar protons (a much less important loss process) are both treated with a probabilistic approach, starting with the photoionization lifetime for a quiet Sun [7]. We also include recycling of 10% of photo-ions that hit the surface, as suggested by [8].

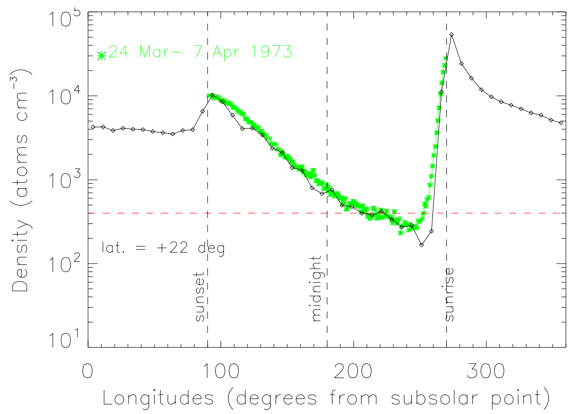

Figure 1 Maximum argon density as measured by LACE (green) and our model (black).

Cold-trapping by PSRs. We also introduced cold-trapping in a probabilistic approach based on a fractional area of PSRs that are cold enough to trap argon.

Results: At first, we ran the simulation with only solar losses. We found that they are not enough to deplete argon in only 120 days to the extent measured with LACE (see Figure 2). An additional loss process is clearly required, and we next modeled the loss due to cold trapping of argon in the Permanently Shaded Regions.

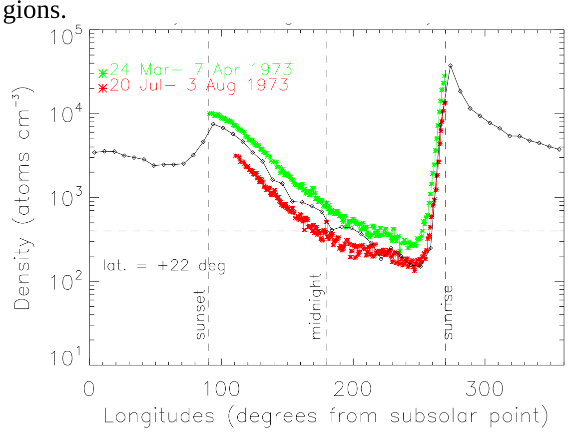

Figure 2 As Figure 1, except that the model now represents the density after 120 days. The red points are LACE observations 120 days after the maximum density (green points).

As an initial estimate of the surface area of PSRs in each polar cap, we first used the values published in [9], but this resulted in too much loss. Reducing the trapping area to 10% of the PSR area, we find good agreement with the decrease in argon observed by LACE (see Figure 3). The total extent of the PSRs contributing to argon cold-trapping is 0.007% of the lunar surface.

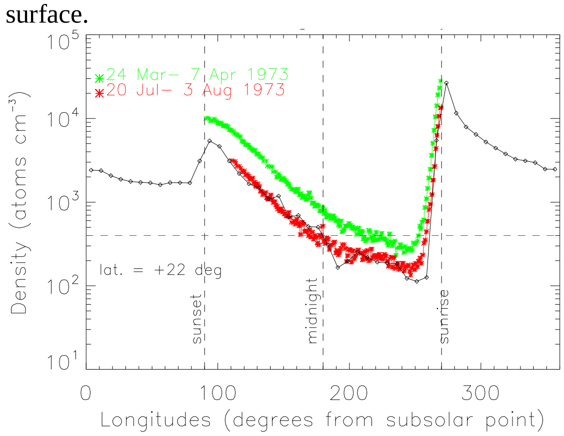

Figure 3 As in Figure 3 but with the addition of cold trapping in the PSRs.

Discussion:

The initial population. In order to match the maximum density recorded by LACE we find that an initial exosphere of 1.2×10^{29} argon atoms is required, or, equivalently, a release of 1.4×10^{28} argon atoms on top of a pre-existing argon exosphere. This is in good agreement with the expected amount of argon that can be released during a moonquake [10].

The amount of argon trapped at the PSRs. Of the initially released amount of argon, 30%, or ~2 tons, must be trapped in the PSRs to account for the decrease in density observed by LACE. A first rough estimate of the soil temperature corresponding to the surface area contributing to this percentage is 41 K (Figure 4). This temperature, while lower than the condensation temperature for argon on clean rocks (~70 K), is in good agreement with the condensation temperature for argon in the presence of water [11]. Our results are therefore consistent with the presence of adsorbed water at the lunar PSRs.

A localized release of argon. We also released argon in a location very close to LACE, to test the consequences of a localized release of argon. We report that a global release of argon, rather than a localized surface-ejection, such as a source close to the LACE mass spectrometer, is the most tenable explanation for the LACE observations, on the basis of the simulation results.

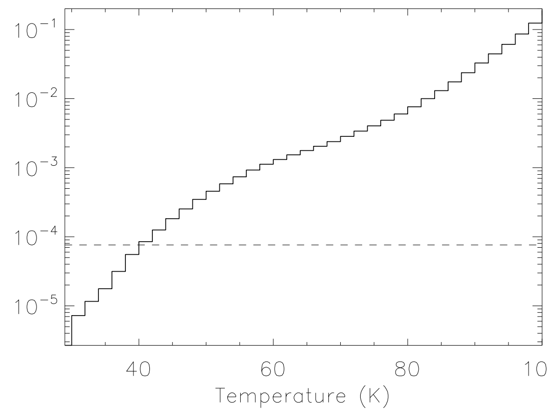

Figure 4 Cumulative distribution of area of lunar surface below a certain temperature (x axis). The histogram is normalized to the total lunar surface area. The horizontal dashed line is the fraction of argon-trapping PSRs compared to the lunar surface area.

Future work: Future implementations of the code will include a more rigorous treatment of the exosphere-surface interaction, of the lunar topography, and of the interaction with the plasma environment. Analysis of LRO/LAMP observations of LCROSS impact plume [12] will be performed to search for argon emissions, after improvement in the instrument calibration.

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