OBSERVATIONS OF LUNAR EXOSPHERIC HELIUM WITH LRO/LAMP. C. Grava[1], D. M. Hurley[2], K. D. Retherford[1], G. R. Gladstone[1], P. D. Feldman[3], W. R. Pryor[4], T. K. Greathouse[1], and K. E. Mandt[2]. [1]Southwest Research Institute, 6220 Culebra Road, San Antonio, TX, 78238, USA (cgrava@swri.edu), [2]Johns Hopkins University, Applied Physics Laboratory, Laurel, MD, USA, [3]Johns Hopkins University, Department of Physics and Astronomy, Baltimore, MD, USA, [4]Central Arizona College, Coolidge, AZ, USA.

Introduction: The Lyman-Alpha Mapping Project (LAMP) Ultra-Violet (UV) spectrograph [1] on board the Lunar Reconnaissance Orbiter (LRO) [2] carried out a campaign to constrain the spatial and temporal distribution of helium in the lunar exosphere. Helium has its main origin in the neutralization, upon impact, of the solar wind alpha particles [3]. Being a noble gas, helium interacts weakly with the lunar surface, such that its density n is inversely proportional to the surface temperature T: $n \sim T^{-5/2}$ [4]. This means that helium density depends on the Local Time (LT). However, a small but non-negligible fraction, between ~15% [5] and ~40% [6], of the lunar helium outgasses from the interior of the Moon, as the radioactive daughter of ^{232}Th and ^{238}U [7]. Moreover, previous LAMP observations detected enhancements in the lunar He density uncorrelated with either local time or solar alpha particle flux [8].

We present here almost 150 observations performed by LAMP between 2013 and 2016, along with their interpretation by means of an exospheric model [9]. The data-model comparison yields physical parameters of interest such as the source rate and the thermal accommodation with the lunar surface.

Observations: LAMP can detect the feeble emission lines of the tenuous lunar exosphere by pointing at the nightside, thus considerably suppressing the background, when the spacecraft is illuminated, and gases along the line of sight (LOS) resonantly scatter solar photons. By tilting LRO along its direction of motion (pitch maneuvers), it is possible to considerably increase the illuminated LOS compared to the nominal, nadir mode, and hence to increase the brightness of emission lines seen by LAMP. Of these, helium is by far the brightest, and its resonance line at 58.4 nm can be detected in a single orbit, allowing a study of the latitudinal distribution to be made. Furthermore, by repeating these pitch maneuvers over multiple orbits, it is possible to study the dependence of lunar helium density on local time and selenographic longitude. The dependence of the helium density with local time, and hence on lunar surface temperature, allows to study the accommodation (and thus the interaction) of helium with the lunar surface temperature. The dependence of the helium density with selenographic longitude yields information on the possible locations of helium outgassing. LAMP count rates are converted first to brightness by applying the instrument calibration factor obtained by looking at interstellar helium [10], then to column density using daily averages of solar irradiance at 58.4 nm measured by the Solar Dynamic Observatory's Extreme ultraviolet Variability Experiment [11].

Data-model comparison: Line of sight column densities are finally compared with a Monte Carlo code of the lunar exosphere [9], which predicts the density of helium as a function of latitude, solar time, and altitude. The model is scaled to the solar wind alpha particles flux measured by the ARTEMIS twin spacecraft [12] during the period of interest to take into account the variability in the solar alpha particles flux (and hence of the helium source rate). For each point along the LAMP LOS we compute the column density predicted by the model and the relative brightness, using the same irradiance used to convert the LAMP brightness in column density. We divided the region around the Moon in bins of 15° in latitude, 15° (= 1 hr) in local time, and 10 km in altitude (from 0 to 190 km). For each observation, we multiply the ratio of the data/model derived column densities by the model density maps. We then take the average of these "volume rates" in all our 24x12x19 cells to obtain a 3D model of lunar exospheric helium weighted by LAMP measurements.

Results: Fig. 1 shows the density of helium in our 3D grid. Shown here is the average of all the observations around 6 pm ± 2 hrs (left half) and 6 am ± 2 hrs (right half) LT, regardless of selenographic longitude. It appears that helium is more concentrated at southern latitudes and around dawn. While the dawn/dusk distribution is understandable in terms of lunar surface being colder at dawn (thus helium density being greater) than at dusk, the latitudinal distribution is puzzling. Fig. 2 shows a similar density map, but now cells at dawn are restricted to longitudes 135° East ± 30° (right half), while cells at dusk are restricted to longitudes 45° West ± 30° (left half). The region of 45° West ± 30° is of special interest because it includes the Oceanus Procellarum, a mare above which the LADEE lunar orbiter detected an enhancement of ^{40}Ar density, possibly indicating active outgassing of volatiles [5]. Finally, Fig. 3 shows a 3D density map similar to the one on Fig. 2, but with the local times inverted: dawn is now at 45° West ± 30° (left half) and dusk at 135° East ± 30° (right half).

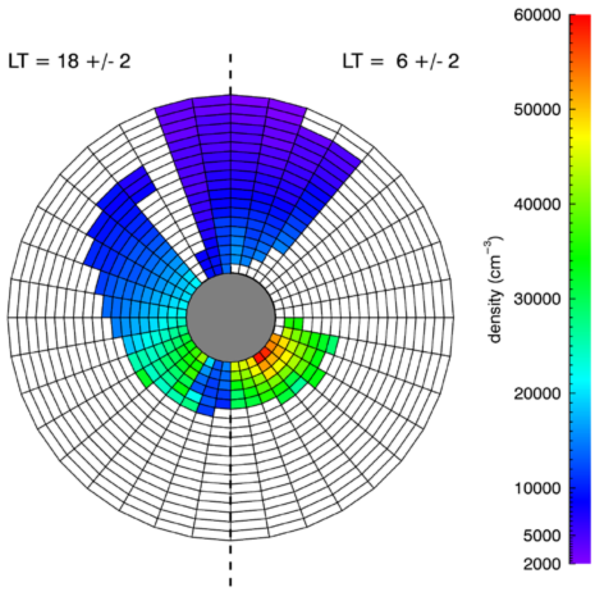

Figure 1 Derived helium density based on LAMP-model comparison, around 6 pm ± 2 hrs (left half) and 6 am ± 2 hrs (right half) LT, regardless of longitude. White cells have not been traversed by any LAMP LOS. Radial and azimuthal directions indicate altitude and latitude, respectively.

Fig. 3 shows that the enhancements in southern latitudes persists for meridians within 60° degrees from the sub-Earth point.

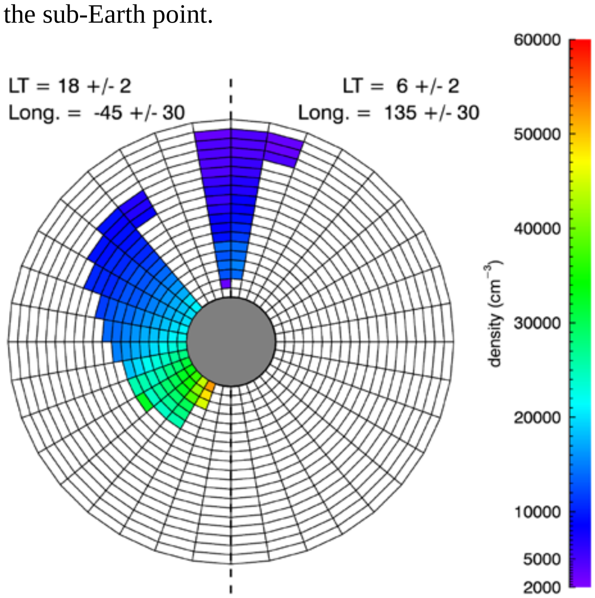

Figure 2 Same as Fig. 1 but with dawn cells (right) restricted within 60° longitude from the 135° East meridian, and dusk cells (left) restricted within 60° longitude from the 45° West meridian, encompassing the Oceanus Procellarum.

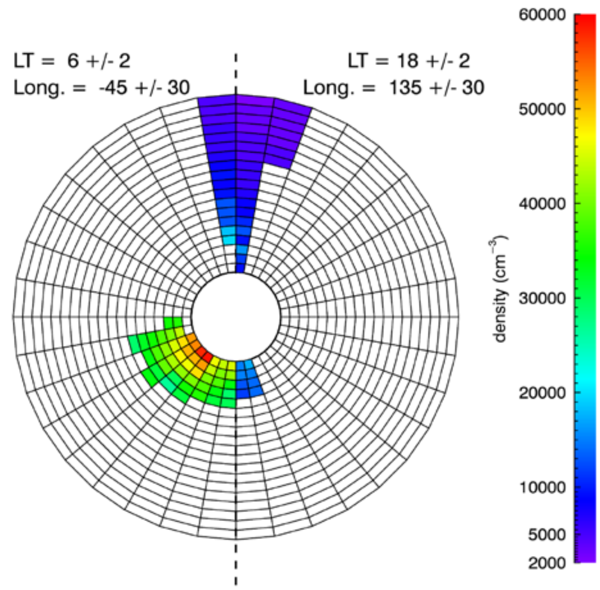

Figure 3 Same as Fig. 2 but with local time inverted.

Discussion: Figs. 1-3 are only a handful of 3D density maps of the lunar exospheric helium weighted by LAMP observations. Comparison between Fig. 2 and 3 suggests a stronger dependence of helium density on local time than on selenographic longitude. On the other hand, the general greater densities in the southern latitudes could be due to a combined effect of accommodation coefficient (scale height) and orbital geometry. LRO is in polar orbit with apoapsis at the North Pole (~150 km) and periapsis at the South Pole (~30 km). Therefore, LAMP's LOS around the North Pole includes atoms at higher altitudes than around the South Pole. A model with a smaller scale height would decrease the discrepancy in the southern hemisphere more than at the northern one. Ongoing analysis is focusing on adjusting the model's scale height to match the observations. A smaller scale height might indicate that the noble gas helium has a stronger interaction with the lunar surface than previously thought.

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