EPSC Abstracts
Vol. 11, EPSC2017-822, 2017
European Planetary Science Congress 2017
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Observations of Lunar Exospheric Helium with LAMP UV Spectrograph onboard the Lunar Reconnaissance Orbiter

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Abstract

We present results from a dedicated campaign of the Lyman Alpha Mapping Project (LAMP) UV imaging spectrograph onboard the Lunar Reconnaissance Orbiter (LRO) to detect the 58.4 nm emission line of helium (^{4}He) atoms resonantly scattering sunlight. We compare LAMP line-of-sight column densities to: 1) those predicted by an exospheric model, to highlight regions of discrepancy; 2) solar wind alpha particles' flux measured by ARTEMIS, to constrain the source rate of lunar endogenic helium (i.e. coming from the interior of the Moon); 3) helium density measured in situ by LADEE's Neutral Mass Spectrometer (NMS), when possible, to map the latitudinal distribution of helium. Such campaign therefore yields a comprehensive picture of the extension of the lunar helium exosphere (in altitude, latitude, local time, and longitude).

1. Introduction

Helium is one of the main constituents of the lunar exosphere, with densities of ~10^4 cm^{-3} measured at the surface by the mass spectrometer LACE (Lunar Atmosphere Composition Experiment) deployed during the Apollo 17 mission. The lunar He density correlates with the solar wind [1,24], meaning that the source of lunar helium as the solar wind alpha particles, which get neutralized upon impact on the lunar surface and become part of the lunar helium exosphere. Whenever the Moon is in the Earth's magnetotail (± 2 days from full moon), the solar wind is turned off, and the helium population decreases due to gravitational escape, with a decay time constant of 4.5 days [2]. Interestingly, a recent campaign by LAMP itself provided evidence of enhancements of lunar exospheric helium uncorrelated with meteoroid streams or solar wind [3]. This supports the hypothesis that part of the lunar helium comes from the interior of the Moon. This ^{4}He population is produced by radioactive decay of ^{232}Th and ^{238}U, is trapped in micropores and cracks, and then released into the exosphere following shallow moonquakes (and hence opening of such voids), a mechanism which has been proposed for argon too [4]. One of the motivations behind the current paper is to constrain the endogenic source rate of helium, which currently ranges between 15% [2] and 30-40 % [5,6] of the solar wind, and to identify the regions where such outgassing occurs.

2. Observations

The spacecraft was pitched along the direction of motion. This allowed LAMP to look through a longer illumined column of gas, compared to the usual nadir-looking mode, and therefore enhancing the brightness of the 58.4 nm emission line. The lines of sight of the observations spanned a variety of local times, latitudes, longitudes, and altitudes.

3. Data-model comparison

To interpret the data, we use a Monte Carlo code of the lunar exosphere [5], scaled to the variation of the ARTEMIS solar wind alpha particles flux with respect to its median value during the period of interest (2013-2016). In this way we take into account the variability in the solar wind (and hence of the helium source rate). For each point along the LOS we computed the column density predicted by the model and we compare it to LAMP brightness, converted in column density. In Figure 1 we plot the model/LAMP ratio vs latitude of the shadow point, i.e. the point where the LOS encounters the shadow (LAMP is pointing at the night side surface). In this case, the model is predicting less helium than what is being observed by LAMP at lower latitudes, which also correspond to lower altitudes since LRO has its periapsis at the lunar south pole. In Figure 2 we report the 3D geometry of the same maneuver.

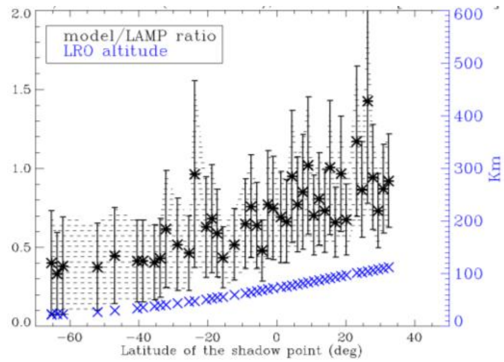

Figure 1: model/data ratio (black) and altitude of the spacecraft (blue).

The Moon is depicted (with a LOLA topography map) as viewed from Earth's northern hemisphere, with darker hemisphere illustrating night side. This observation was performed at post-dusk, and the model/data ratio progressively decreases towards the lunar south pole. Finally, Figure 3 shows the 3D geometry of two maneuvers taken at different days, at very similar local times (around 6:30 pm) but at different longitudes.

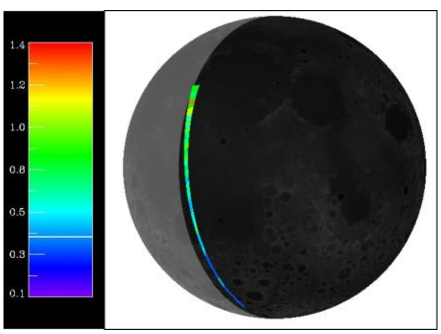

Figure 2: The model/data ratio in the LAMP LOS is colored according to the model/data ratio (see color bar on the left).

4. Discussion

These plots allow us to identify regions of discrepancy between the observations and the model both in local time and in longitude. The discrepancy highlighted in Figure 2 might be related to the scale height (which measures how rapidly an exosphere decreases its density by a factor of *e*) used in the model. The fact that we might need to revise it could mean that we need to revise our understanding of the interaction between the solar wind and the Moon. Alternatively, the discrepancy could be due to deviations from a steady state exosphere which come from time variability of the source, as well as variability in the spatial distribution of the source. Moreover, by comparing observations taken at the same local time but at different longitudes, like those in Figure 3, we can identify regions of possible outgassing of ^{4}He. In this case, there seems to be an excess of helium compared to the model above the Western Maria, close to where LADEE's NMS detected an enhancement in exospheric argon-40 [2]. However, the above-mentioned discrepancy must be fixed, to constrain the source rate of endogenic helium.

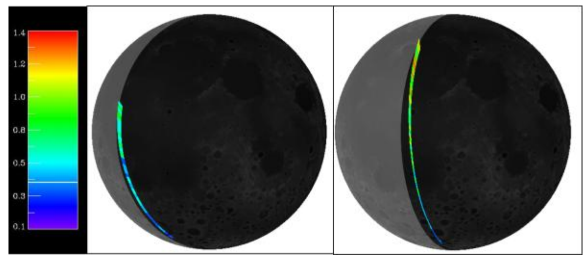

Figure 3: model/data ratio in 3D on two different observations with similar coverage in local time but different coverage in longitude.

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