LRO-LAMP Observations Of The Lunar Exospheric Helium Coordinated With LADEE & ARTEMIS: Analysis Of Off-Nadir Pitches. C. Grava[1*], K. D. Retherford[1], D. M. Hurley[2], P. D. Feldman[3], G. R. Gladstone[1], T. K. Greathouse[1], J. C. Cook[4], S. A. Stern[4], K. E. Mandt[1], D. E. Kaufmann[4], W. R. Pryor[5], J. S. Halekas[6].

[1]Southwest Research Institute, 6220 Culebra Road, San Antonio, TX, 78238 USA, [2]Johns Hopkins University, Applied Physics Laboratory, Laurel, MD, USA, [3]Johns Hopkins University, Baltimore, MD, USA, [4] Southwest Research Institute, Boulder, CO, USA, [5]Central Arizona College, Coolidge, AZ, USA, [6]University of Iowa, Department of Physics and Astronomy, Iowa City, IA, USA. *Corresponding author: cgrava@swri.edu

Introduction: We present results from Lunar Reconnaissance Orbiter (LRO) [1] UV spectrograph LAMP [2] campaign to study the lunar atmospheric helium. In the LAMP atmospheric campaigns, the line of sight points to the night side lunar surface (to reduce the background) while the exosphere between the spacecraft and the surface is illuminated. Two kinds of special, off-nadir maneuvers were performed. During pitch slews, the LRO spacecraft was pitched to look opposite or forward its direction of motion to a point just inside the limb in the nightside region around the polar terminator. During lateral rolls, LRO rotated sideways towards the anti-solar direction to a point nightwards of the terminator. These special maneuvers have the advantage to substantially increase the illuminated line of sight of LAMP, and hence the signal from atoms resonantly scattering the solar photons, compared to previously reported LAMP "twilight observations" with line of sight along the nadir [3-5].

Lateral Rolls: Results from the lateral roll data set [6] confirmed a positive correlation between the amount of helium in the lunar exosphere as measured by LAMP and the solar wind source rate, as derived from ARTEMIS twin spacecraft measurements of solar wind alpha particles (He^{++}) [7], but not a 1:1 relationship. Indeed, the lateral roll results point to a contribution from the interior of the Moon, consistent with other LAMP observations looking at the nadir "twilight" data set [5] and also with recent measurements from the Neutral Mass Spectrometer (NMS) on board the Lunar Atmosphere and Dust Environment Explorer (LADEE) [8].

Pitches: Here we present the results from the LAMP pitches, both forwards and backwards, and we compare them to both ARTEMIS measurements of solar wind alpha particles and LADEE/NMS in situ measurements of lunar helium. These pitches present an additional challenge in terms of data interpretation, compared to the lateral rolls, since the line of sight of LAMP traverses a greater range of local solar times, and consequently there are great variations of helium density along the line of sight. In addition to data acquired during dedicated campaigns, we also analyze LAMP observations taken during CRaTER pitches forwards and backwards to search for grazing angle albedo protons [9].

Figure 1 shows a spectrum obtained during one of these observations, while **Figure 2** displays the latitudinal variation of LAMP-derived column densities.

The CRaTER pitch slews are performed with LRO riding close to the terminators and the pitch direction is kept for almost half an orbit, and therefore they offer a much narrow range of solar local times and a more direct interpretation of the resonant scattering intensity. The latitudinal profile then represents the combination of the latitude dependence of exospheric helium and the changing altitude of LRO as the spacecraft moves from aposelene at the North Pole (150 km altitude) to the periselene at the South Pole (40 km altitude), and hence of the illuminated path length for LAMP. The latter is plotted against latitude in **Figure 3**.

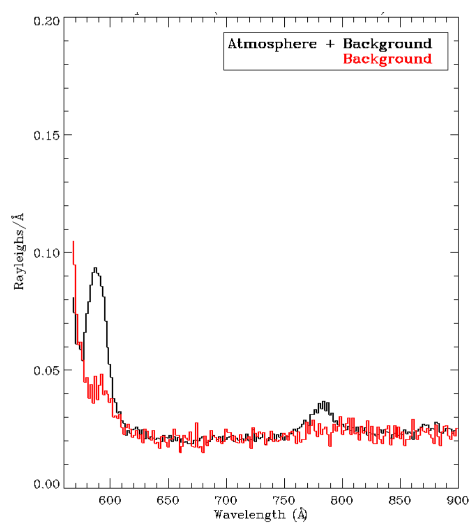

Figure 1 Spectrum of lunar exospheric helium (black), obtained over a total of 400 minutes, and the reference spectrum of the lunar surface (red) taken at similar pitch angle (31°). The feature near 780 Å is a known artifact.

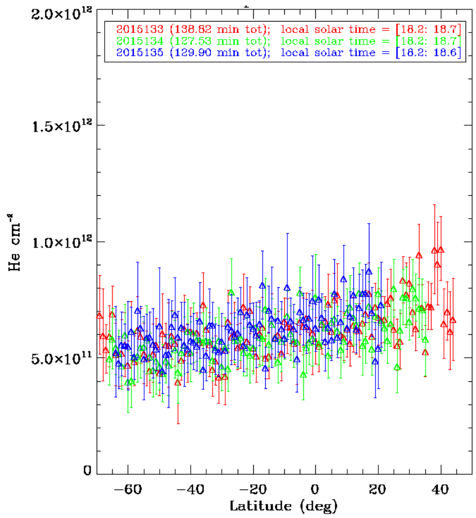

Figure 2 Latitudinal dependence of helium column density along LAMP line of sight. The observations within each day have been binned together as shown in color for three different days.

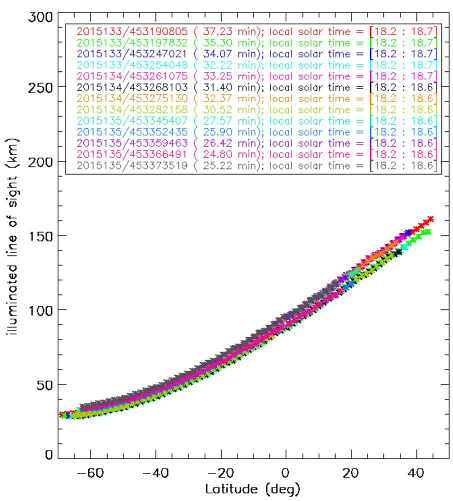

Figure 3 Illuminated line of sight of LAMP (in km) vs. latitude, for each orbit.

We compare such LAMP-derived column densities with the same model used to analyze the lateral rolls [5], and derive additional constraints on the endogenic helium source rate. The unprecedented latitudinal coverage offered by such maneuvers provides a comprehensive picture of abundance and spatial and temporal dependence of the lunar exospheric helium.

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