Lunar atmospheric helium detections by the LAMP UV spectrograph on the Lunar Reconnaissance Orbiter

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[1] The LAMP far ultraviolet spectrograph aboard the NASA Lunar Reconnaissance Orbiter has been used in 2011 to search for helium, the lightest noble gas in the tenuous lunar atmosphere. Based on that search, we report here the first detection of lunar atmospheric He by remote sensing, and point to future observations that can address questions about its source; we also discuss a search for lunar atmospheric argon. Citation: Stern, S. A., K. D. Retherford, C. C. C. Tsang, P. D. Feldman, W. Pryor, and G. R. Gladstone (2012), Lunar atmospheric helium detections by the LAMP UV spectrograph on the Lunar Reconnaissance Orbiter, Geophys. Res. Lett., 39, L12202, doi:10.1029/2012GL051797.

[2] NASA’s Lunar Reconnaissance Orbiter (LRO) spacecraft entered orbit about the Moon in June of 2009. The Lyman Alpha Mapping Project (LAMP) ultraviolet imaging spectrograph aboard LRO is a compact but sensitive far-ultraviolet (FUV) instrument designed primarily to study the lunar surface. As described in detail by Gladstone et al. [2010], the photon-counting LAMP imaging spectrograph is comprised of a telescope and Rowland-circle spectrograph. LAMP has a 40 × 40 mm² entrance aperture that feeds light to the telescope section of the instrument. Light entering this aperture is collected and focused by an f/3 off-axis paraboloidal primary mirror at the back end of LAMP’s telescope section, onto a 0.3 × 6.0” spectrograph entrance slit. After passing through the slit, the light falls onto a toroidal holographic diffraction grating, which disperses the light onto a 2-D (1024 × 32)-pixel double-delay line (DDL) microchannel plate detector. This detector is coated by a CsI solar-blind photocathode, and covers a bandpass of 575–1965 Å.

[3] LAMP conducts its primary observations, which involve surface mapping, by staring at the orbit nadir. However in June and then November–December 2011, LAMP was pointed above the limb of the Moon to search for FUV emissions from the lunar atmosphere [see Stern, 1999].

[4] The first LAMP lunar atmospheric observation campaign, spanning 22–30 June 2011, was comprised of nearly continuous observations on 54 orbits. For these observations, the spectrograph’s line-of-sight was pointed just above the limb at an angle of 83.0° from the nadir in the direction opposite the spacecraft’s forward velocity.

[5] The data collected in this campaign revealed a few Rayleighs of emission from the He I 584 Å resonance line, but no other lunar emissions were detected in LAMP’s bandpass. We then assessed the interplanetary background and its variation using a standard helium “hot” model [Ajello, 1978] that we have tuned by fitting unpublished Galileo EUVS interplanetary cruise observations of interplanetary helium obtained at the same time as published observations of interplanetary hydrogen [Pryor et al., 1996]. Away from the heliospheric downwind focusing cone, where solar gravity concentrates interplanetary helium, the interplanetary background is modest (1–2 R) and slowly varying across the sky. Because there is also background He I 584 Å emission from the interplanetary medium (IPM) at predicted levels of a few Rayleighs, we could not clearly determine how much native lunar He signal was present in the data.

[6] To better determine the native lunar He signal, we designed a subsequent set of observations that included IPM background measurements, which we obtained in November and December of 2011. More specifically, in these observations, the IPM He I background was directly measured by observing at the spacecraft zenith (where the lunar He I signal is minimized), shortly after and before the He I emission was measured just above the lunar limb. This observing geometry was chosen so that LAMP viewed the same Right Ascension and Declination on the sky to measure the IPM He background at zenith, as it viewed at the limb line of sight for native lunar He observations. Although the zenith background potentially contains emission from native lunar He I above the spacecraft altitude, any net excess over the zenith signal seen when observing toward the limb (where there will be a greater column abundance owing to the long path length through the near-surface atmosphere) can be attributed to a detection of native lunar atmospheric helium. Figure 1 schematically depicts these and other observing geometries employed by LAMP in this paper.

[7] Figure 2 depicts the summed data from the limb and zenith observation pairs obtained on 29 November and 6 December 2011. The integration times for each of these limb and zenith times were comparable, 159 and 176 sec, respectively; the signals were converted to fluxes (counts/sec) and then physical units, Rayleighs, for the analysis that follows.

[8] We found that the zenith measurements obtained on these dates well match our He IPM model prediction of 3 R for the observing dates and RA/Dec sky positions we observed, indicating that virtually no native He signal contaminated the zenith IPM background measurements. The blue curves in both panels of Figure 2 represent the net lunar...
Depicted here are atmospheric emission spectra \(L_12202/C_2\) atoms/cm\(^2\) and \(1973/C_6\) atoms/cm\(^2\) photons/cm\(^2\) around local midnight; this increase in Native lunar He I Brightness Detected = 9 0 The limb, zenith, and nadir observing geometries for the assumed \(T = 120\) K atmosphere.

![Diagram](Image 61x283 to 302x487)

**Figure 1.** The limb, zenith, and nadir observing geometries discussed in this paper are depicted schematically here.

He I emission brightness per Angstrom after subtracting the zenith background from the corresponding limb atmospheric measurement. As seen from the two panels in Figure 2, these blue curves clearly demonstrate that emission from native lunar He I was detected on both observing dates. Table 1 quantifies these detections.

![Graph](Image 90x586 to 271x731)

**Figure 2.** Depicted here are atmospheric emission spectra (black) obtained by LAMP, in units of brightness (Rayleighs; one Rayleigh (1 R) is a column emission rate of \(10^6\) photons per square cm per observed column per second.) per angstrom on two dates in late 2011. Each panel’s black line is the spectrum obtained by LAMP when its spectrograph slit was placed 83° from the nadir, just above the lunar limb and across the North Pole. Two strong features are evident in each spectrum: one due to 584 Å He I and a stronger feature near 980 Å caused by an optical ghost reflection within our spectrograph of IPM 1216 Å H I. The red line in each panel is the background spectrum obtained close in time by observing the same patch of sky when it is at the zenith, where any contribution from the lunar atmosphere is minimized. The apparent continuum emission in the red and black data curves is due to instrument background. The blue line in each panel is the difference spectrum obtained by subtracting the background from the limb spectrum, revealing native lunar atmospheric emission from He I at 584 Å. 1-sigma error bars are depicted on each curve every 4th spectral point, for reference.

![Graph](Image 61x283 to 302x487)

**Figure 3.** The observed本地 atmosphere from He I at 584 Å. The exobase temperature is taken to be the nighttime surface temperature near the terminator, itself based on LRO/Diviner measurements [Vasavada et al., 2012]. For this temperature, ballistic orbits constitute almost all of the He concentration within several scale heights of the surface. The density model is then integrated from the spacecraft orbit to infinity along the line-of-sight for a particular observing geometry. This modeling gives a best fit native helium abundance near \(7 \times 10^3\) atoms/cm\(^3\) for the assumed \(T = 120\) K atmosphere.

![Graph](Image 61x283 to 302x487)

**Figure 4.** Our number density determinations, also made near dusk, compare relatively well to the LACE measurements. This gives confidence to our ability to go forward to extend the temporal and spatial range of lunar He measurements over those made by LACE as LAMP maps He across the Moon in future observations. Although our retrieved number densities appear to be somewhat lower than those measured by LACE, which may suggest a difference in the lunar atmospheric He abundance from 1973, such a conclusion requires additional data to accept or refute. The more global view provided by LAMP’s orbital remote sensing observations of He, compared with the single point LACE measurements, enables multiple new areas of investigation.

<table>
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<tr>
<th>Observation Date</th>
<th>Native Lunar He I 584 Å Brightness</th>
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<tbody>
<tr>
<td>29 November 2011</td>
<td>2.8 ± 1.3 R</td>
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<tr>
<td>06 December 2011</td>
<td>3.8 ± 1.3 R</td>
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**Table 1.** Native lunar He I Brightness Detected
helium between the surface and the spacecraft was sunlit and resonantly scattering (see again Figure 1). Such nadir detections are more difficult because the signals are weaker, owing to the reduced column in nadir versus limb viewing geometry. However, the nadir geometry does remove the need for background measurements and makes the inversion of the signal for surface number densities and total column more straightforward.

One important question we plan to revisit with further lunar He observations is the question of the dominant source of the lunar He [Hodges, 1975]. If the source is exogenic, i.e., if it is dominated by solar wind alpha particles that neutralize on the surface to become He I, then there should exist a correlation in lunar He I abundance with changing solar wind conditions measured by ACE and other spacecraft outside of Earth’s magnetosphere. If no such correlation is seen, then a dominantly indigenous source for the atmospheric helium, e.g., radiogenic decay products that diffuse from the lunar interior, could be indicated. Such a finding would open up the enticing future possibility of monitoring internal lunar activity/releases by remote sensing.

Another important area of future investigation will be to determine how the He abundance varies with latitude, and to search for local He source regions which may exist if radiogenic decay is responsible for a significant fraction of the lunar He; neither of these spatial variation investigations have ever previously been addressable.

Finally, despite in situ detections of Ar by LACE, LAMP has not yet detected lunar Ar I emission at Ar I at either of its 1048 Å and 1066 Å resonance lines in our bandpass. Based on Apollo 17 LACE measurements, we calculate that these Ar I lines will be optically thick, with expected column brightnesses that are 10–50 times fainter than the He I 584 Å brightnesses reported here, i.e., of order 0.1 R at the limb. Though challenging, such a detection does appear to be within the capabilities of LAMP.

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References