Temporal Variability of Lunar Exospheric Helium During January 2012 from LRO/LAMP

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LAMP team

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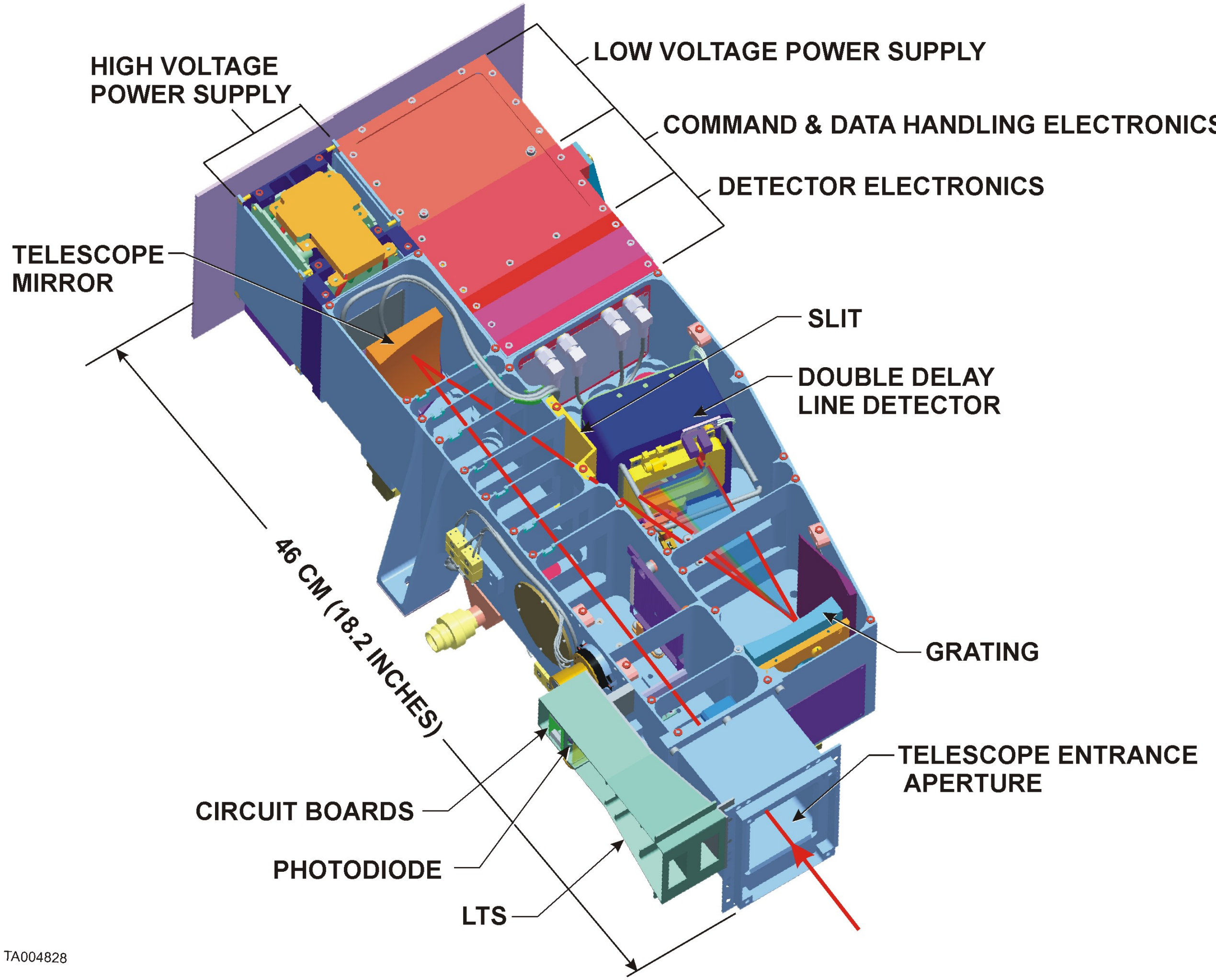
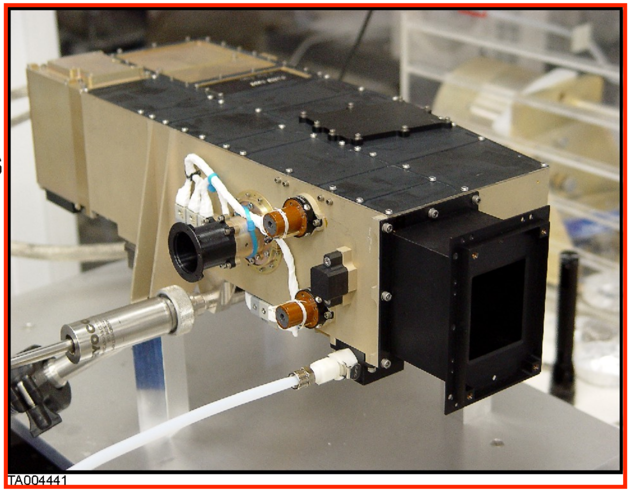
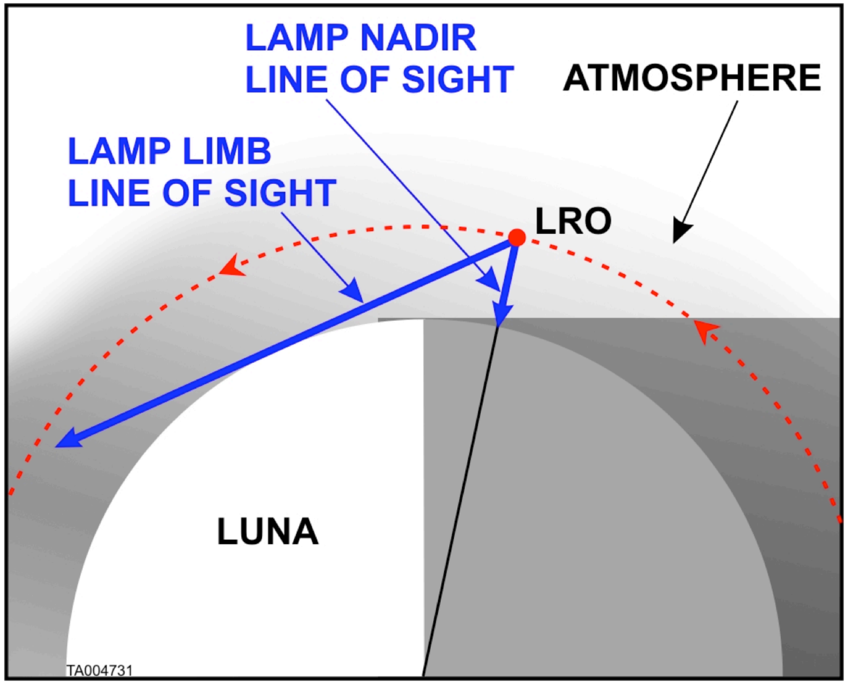
LAMP instrument overview





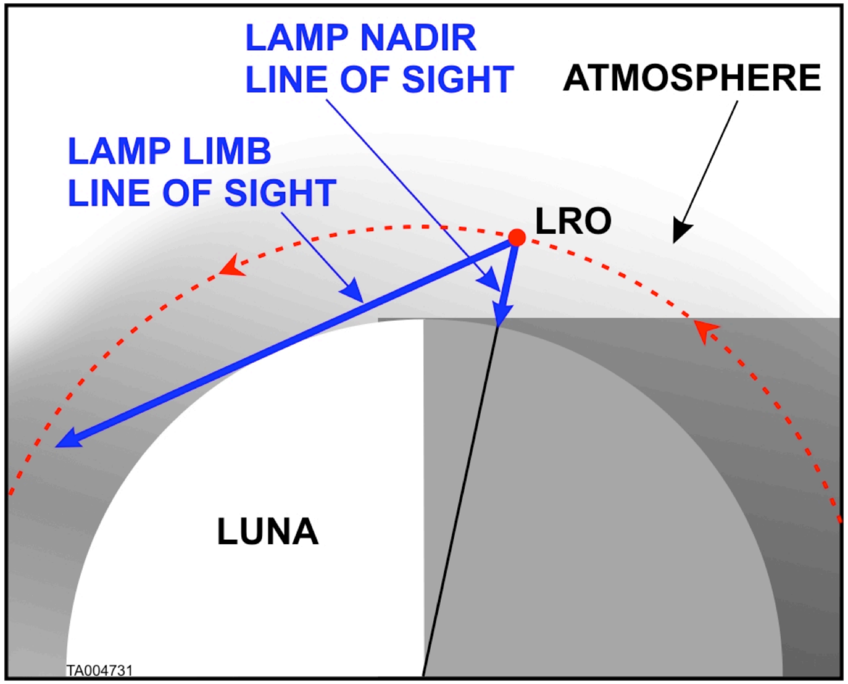
LAMP (with LTS):
5.3 kg, 4.6 W
0.2º×6.0º slit
520-1800 Å passband
20 Å point source spectral resolution

Atmosphere viewing geometry

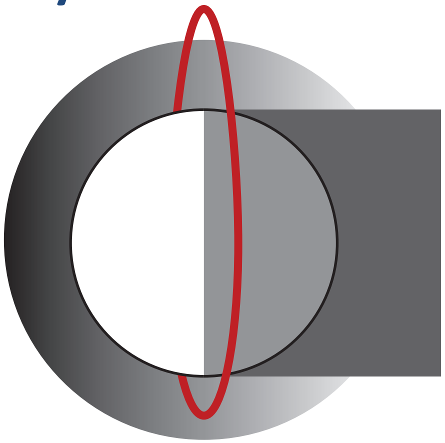


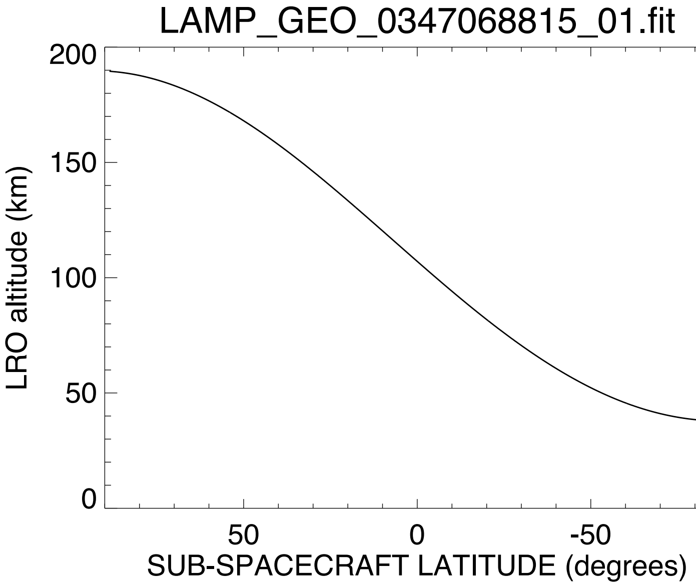
Two modes of atmosphere observation: limb viewing against a bright sky and nadir viewing of illuminated atmosphere against the dark lunar surface.

Atmosphere viewing geometry



“Frozen orbit”



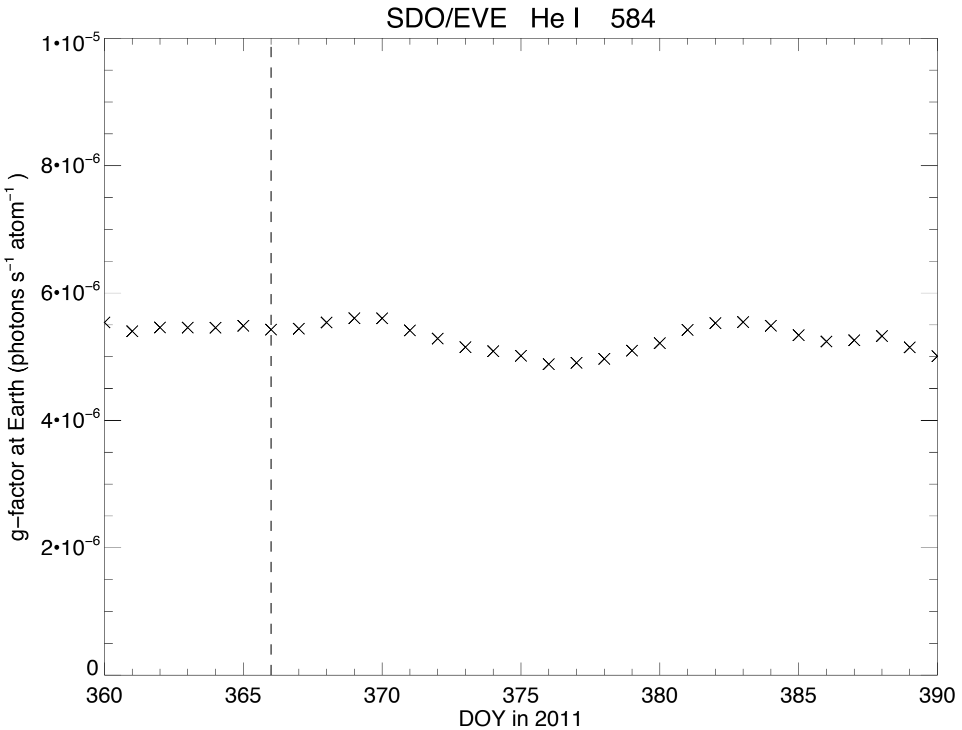


Frozen orbit of 30 km x 200 km enabled long path-lengths through illuminated atmosphere in nadir viewing

Particularly favorable around $\beta=90°$

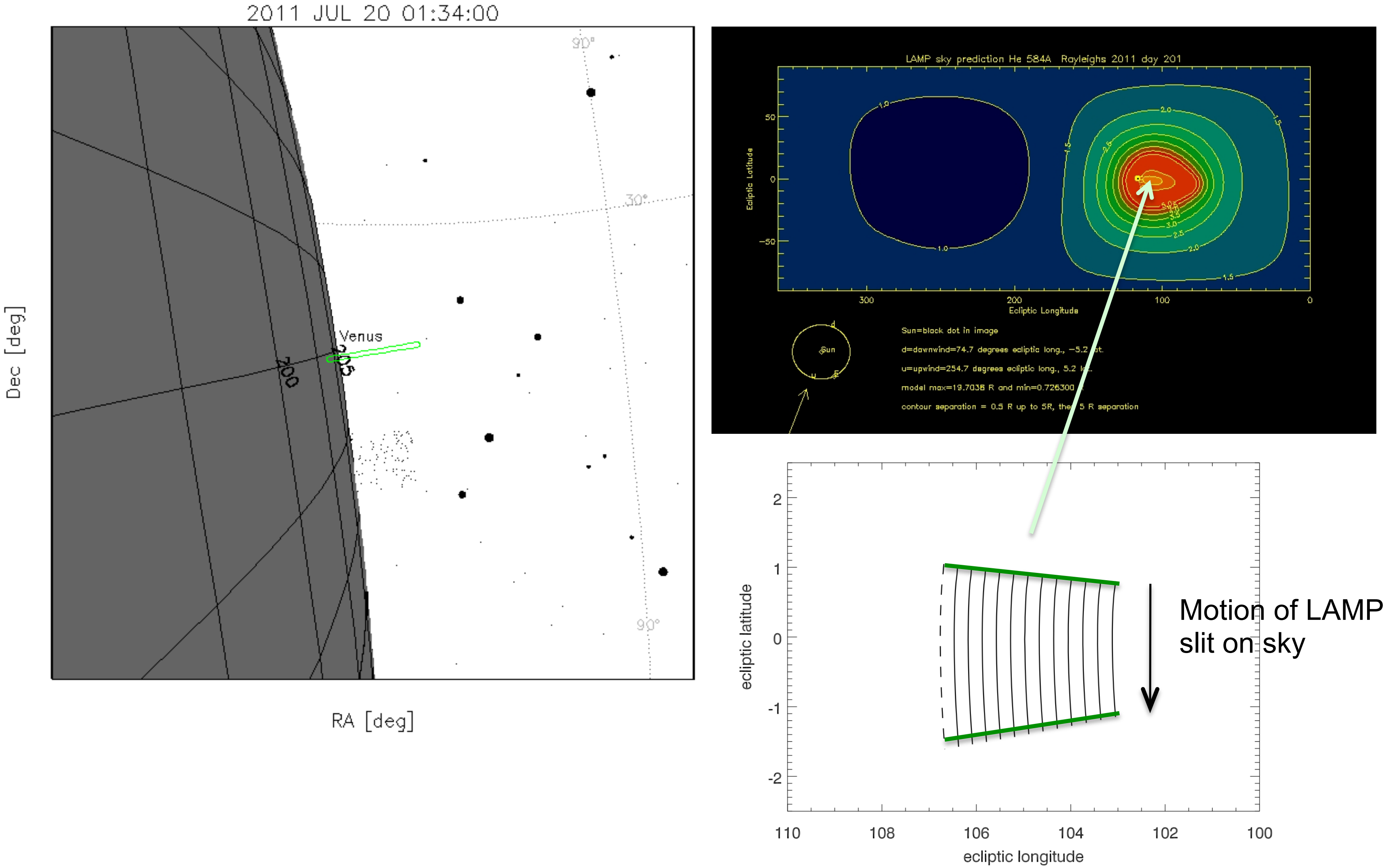
He I λ584 g-factor

EVE measures integrated line flux. Major uncertainty is the FWHM of the solar 584 line. Lallement et al. (A&A 426, 867, 2004) suggest a value of 136 mÅ.
This gives daily values of g of the order of 5 x 10^{-6} photons $atom^{-1}$ s^{-1} for January 2012.
The observed emission is optically thin so that the model He density can be scaled linearly to match the observations.



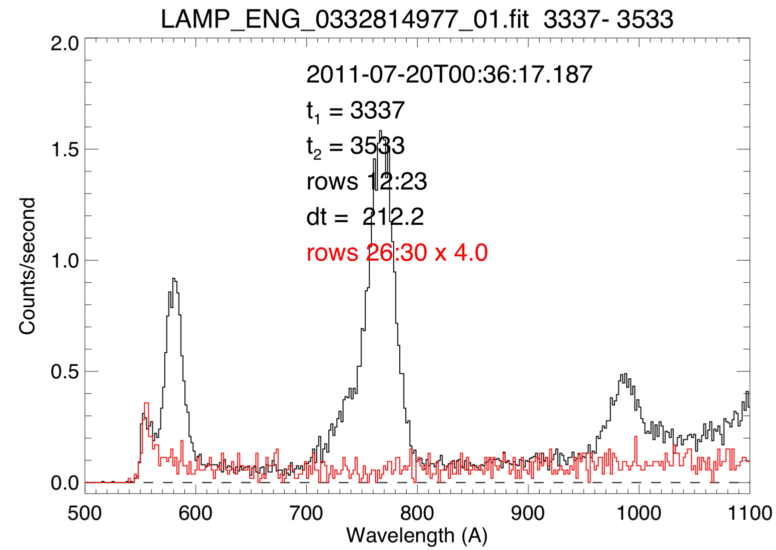
Solar flux from SDO/EVE, http://lasp.colorado.edu/home/eve/data/

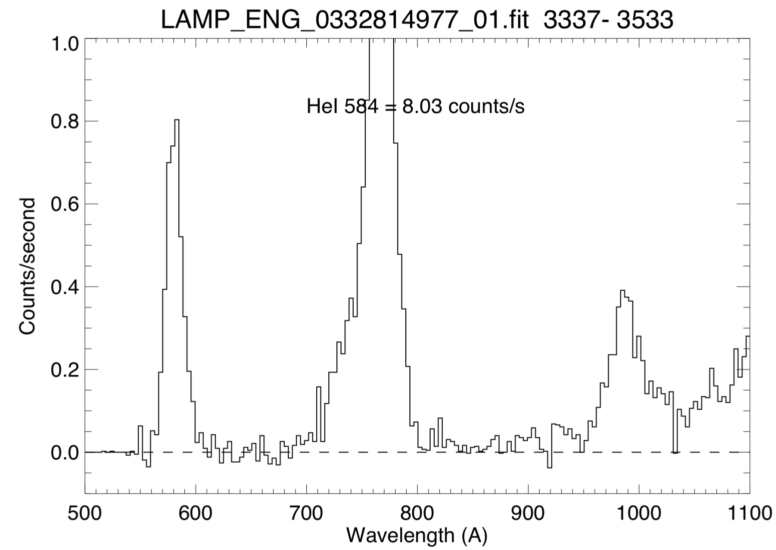
In-flight calibration at 584 Å



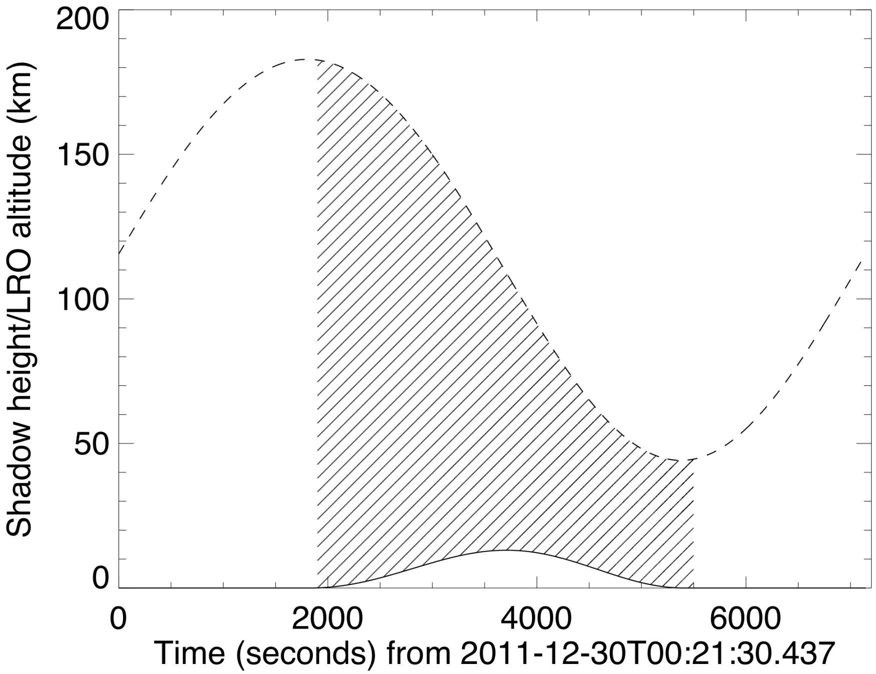
In-flight calibration at 584 Å

In-flight calibration of LAMP at 584 Å is based on the bright He IPM emission observed during a slew on July 20, 2011, when the LAMP slit was placed across the dark lunar limb with the Sun about 10° below the horizon. The measured count rate is compared with IPM models of Wayne Pryor for that date that are integrated over the effective field-of-view of the LAMP slit. To first order, the contribution of atmospheric He along the line-of-sight is ignored. Sky observations (August 8, 2011 and star calibrations) give IPM background count rates that are consistent with this calibration.





Nadir-viewing geometry from "frozen orbit"



December 30, 2011 (β=83.2°)

The shaded area represents the distribution of illuminated atmosphere for a nadir-looking line-of-sight. The shadow height, the solid line, is calculated for a spherical moon and is uncertain to a few km. The dashed line is the LRO altitude.

The initial time in each plot is the equator crossing time on the day side. The orbit crosses the north pole at roughly T+1800 s, descends to the night side equator and crosses the south pole near periapsis at T+5400 s.

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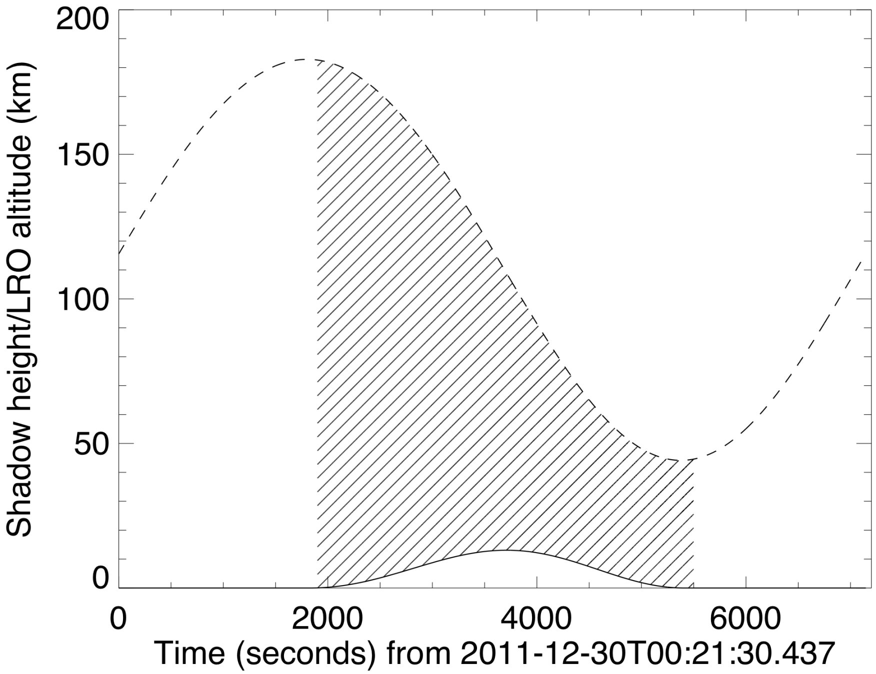

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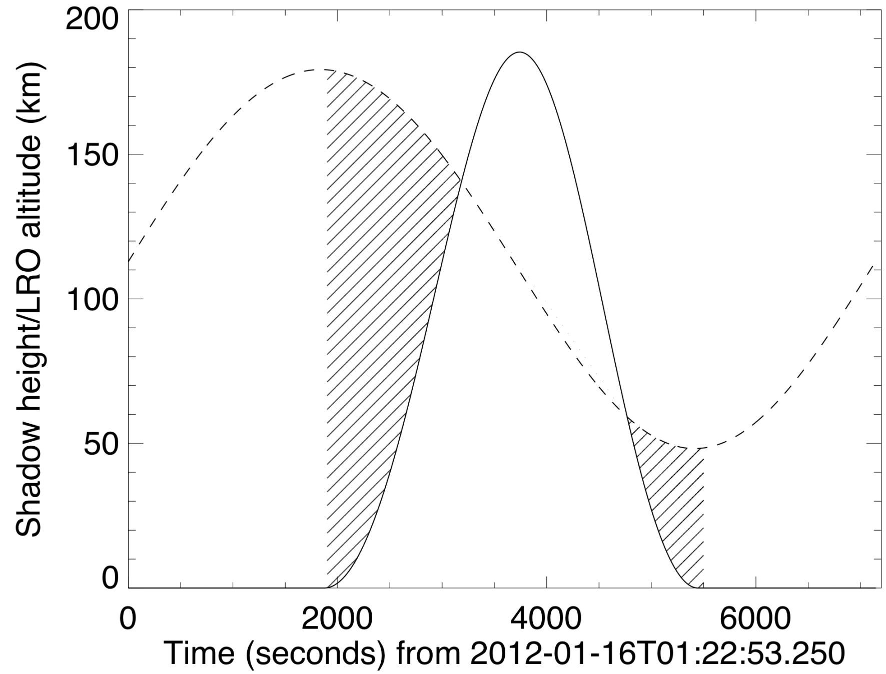
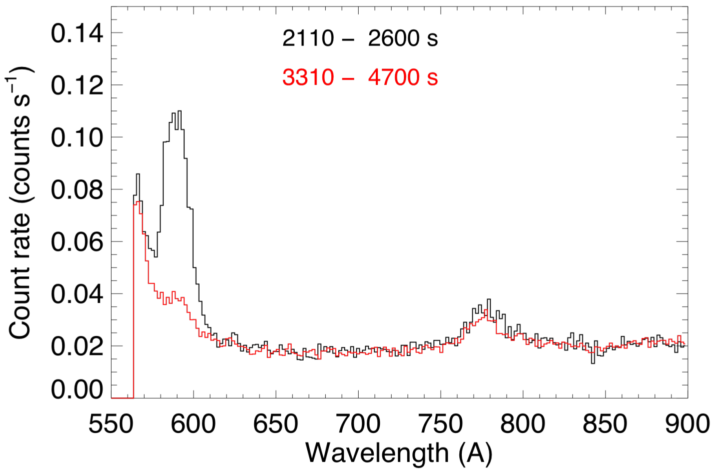


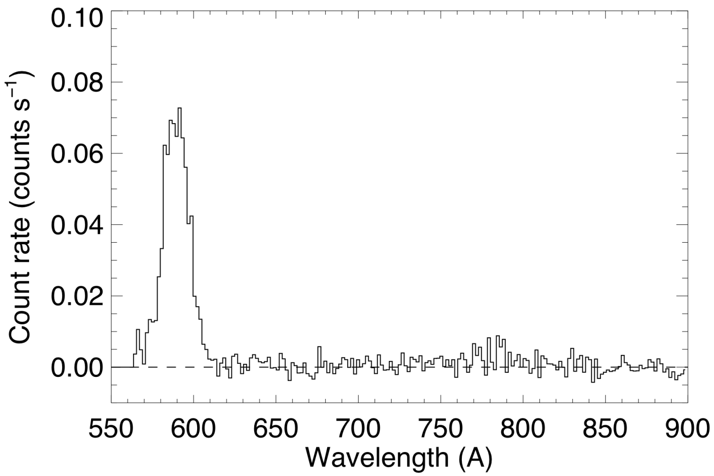
January 16, 2012 (β=64.7°).

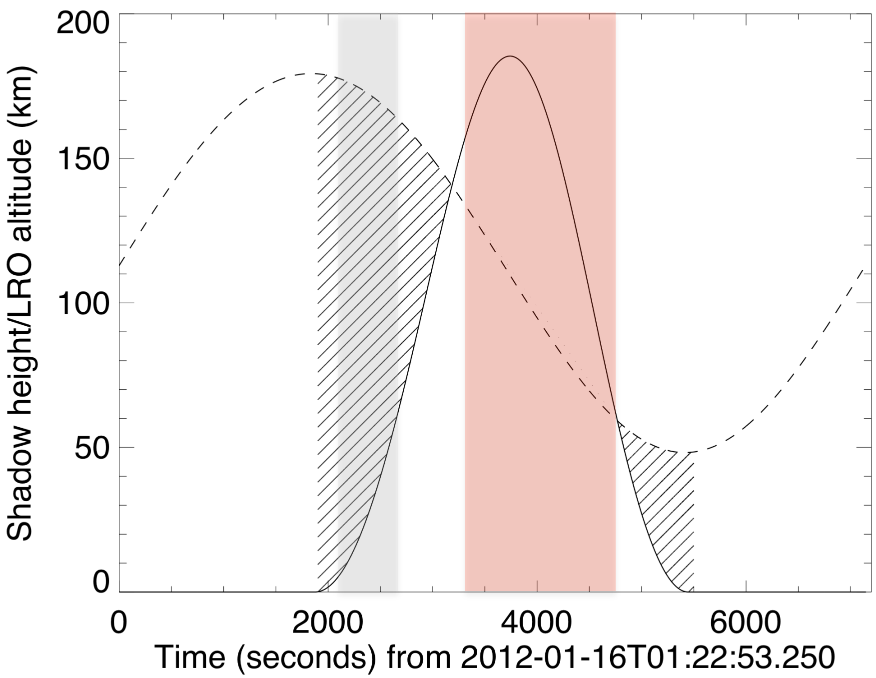
The shaded area represents the distribution of illuminated atmosphere for a nadir-looking line-of-sight. The shadow height, the solid line, is calculated for a spherical moon and is uncertain to a few km. The dashed line is the LRO altitude.

The initial time in each plot is the equator crossing time on the day side. The orbit crosses the north pole at roughly T+1800 s, descends to the night side equator and crosses the south pole near periapsis at T+5400 s.

Nadir-viewing geometry from "frozen orbit"

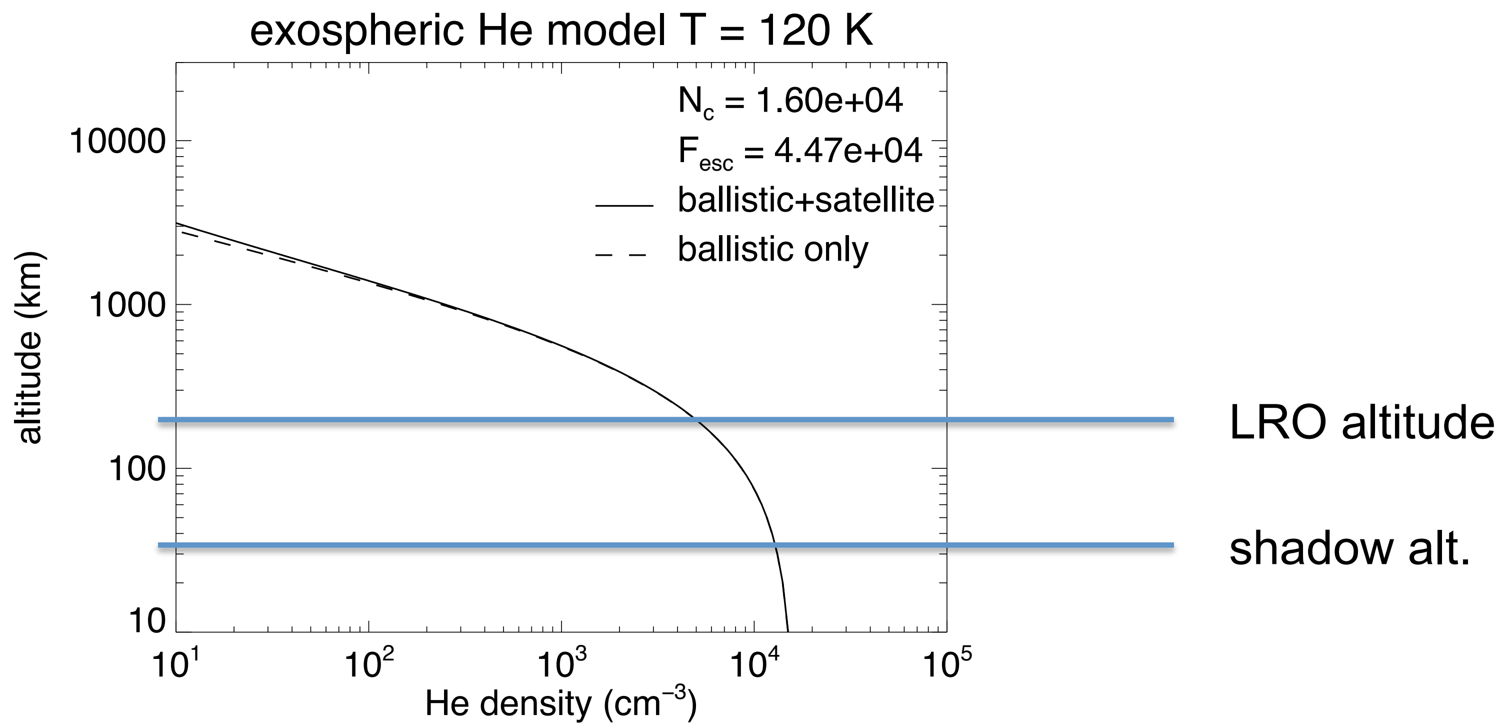






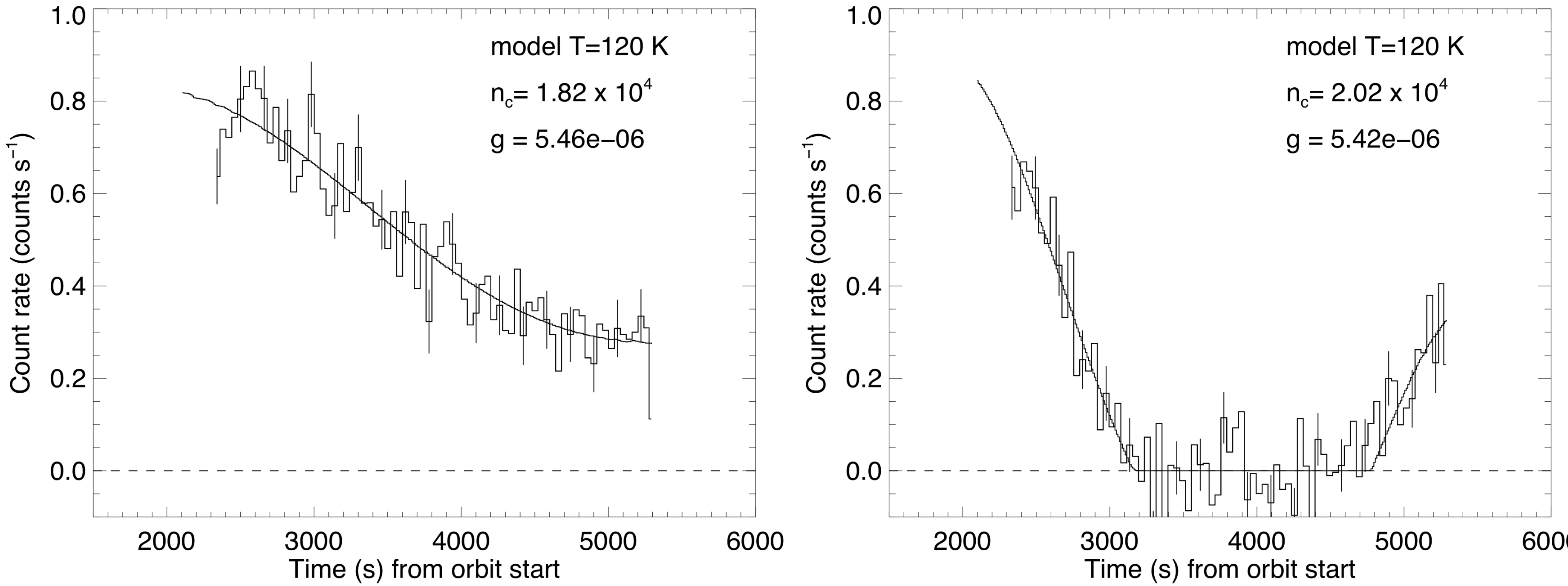
Left: Average of 12 short wavelength LAMP spectra of the illuminated (black) and dark (red) atmosphere on January 16, 2012. The feature centered at 775 Å is another instrumental artifact. The lower panel is the difference, the average atmospheric component of He emission.

Chamberlain exosphere He model



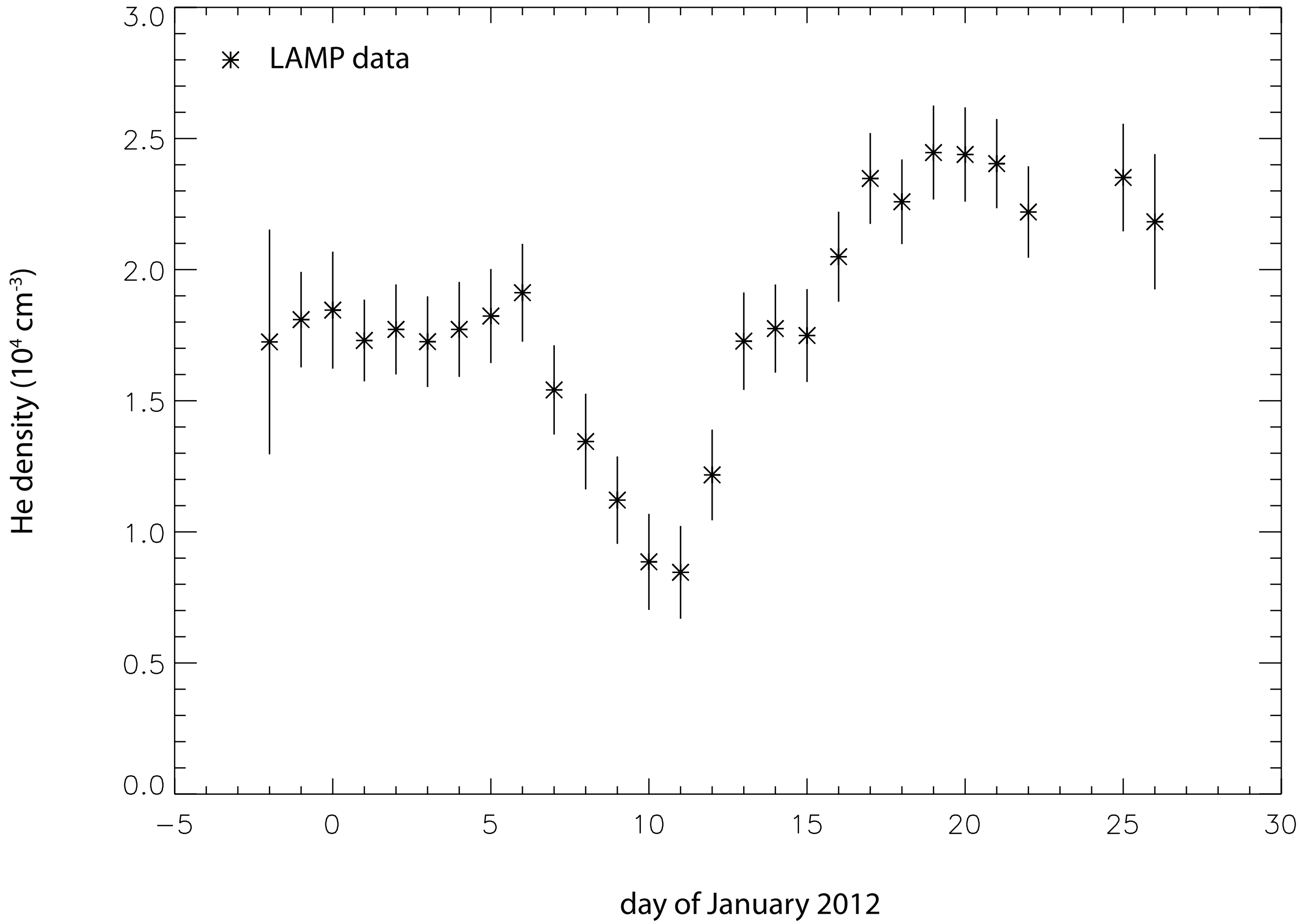
- To fit the data the illuminated He column density was calculated for this viewing geometry using a classical Chamberlain exospheric model.
- Fit gives He density at surface.
- Model dependence is principally on surface density, not temperature.
- Varying He I λ584 g-factor calculated using solar fluxes from SDO/EVE.

Fit of daily co-added He count rates to models



Observed count rates for the atmospheric He I λ584 emission for December 30, 2011 (left) and January 16, 2012 (right). For both dates the data from 12 contiguous orbits have been co-added. The error bars are 1-σ statistical uncertainties. For all of our dates, the fit of the model to the data is excellent, and implies that the He surface density is roughly constant with latitude.

Derived temporal variation in He surface density



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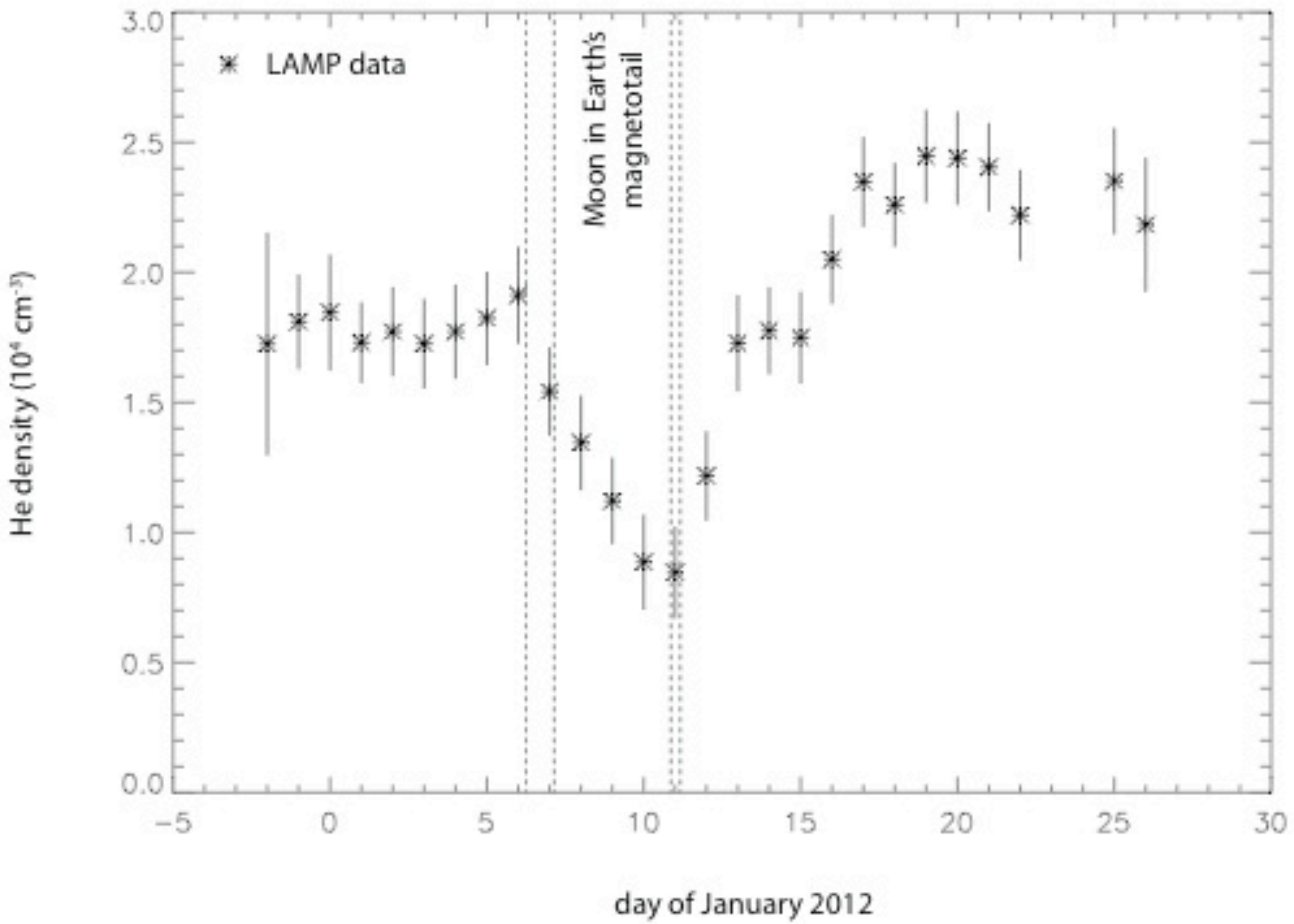

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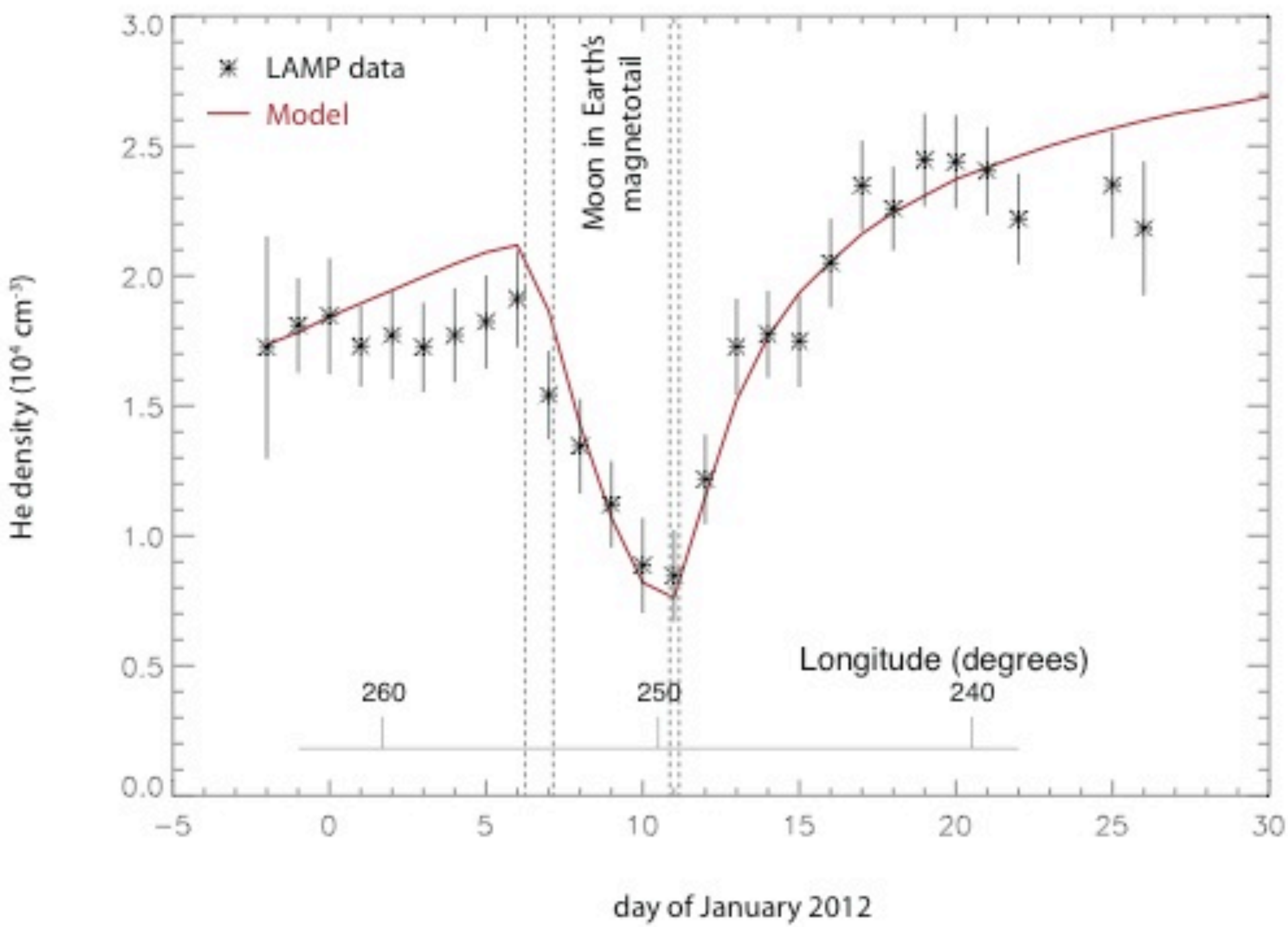
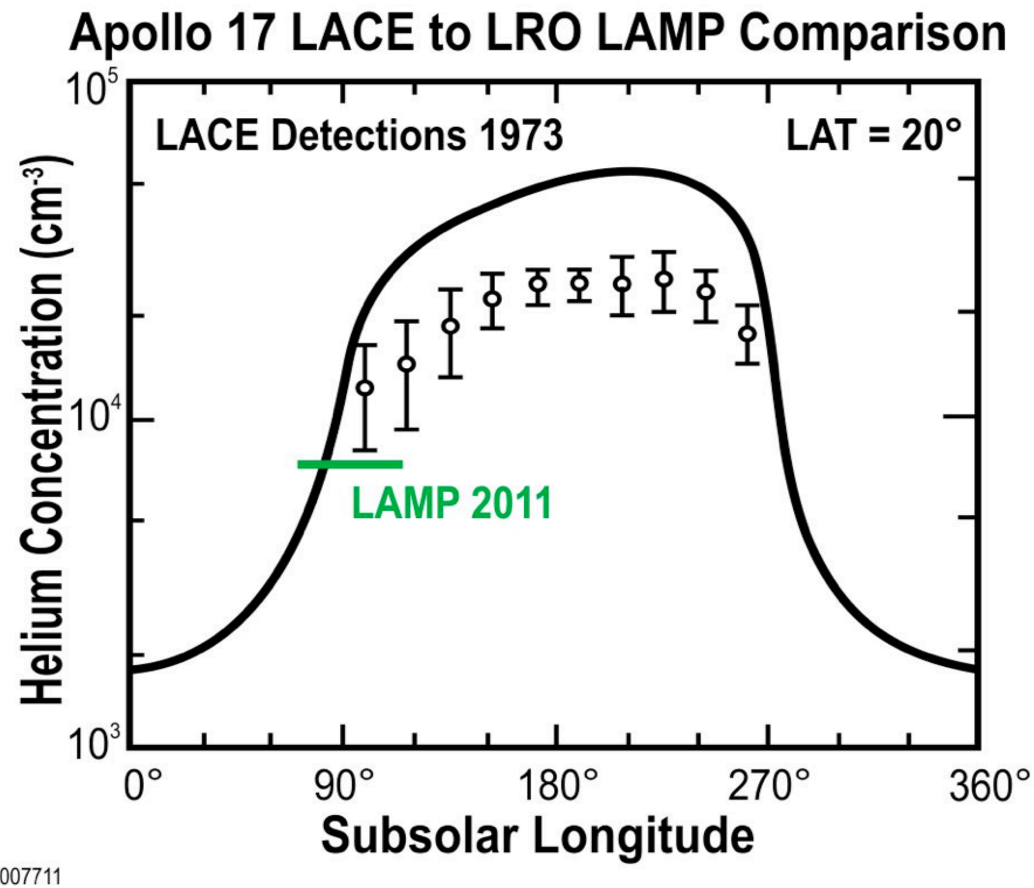


Nightside He distribution

- Limb viewing observation from June 2011 targeted dusk terminator (Stern et al., 2012)
- Further nadir observations were obtained in June and July 2012 (but to date have not been fully analyzed) include data from behind the dusk terminator.
- Initial analysis shows much lower He density at dusk compared to dawn.



Summary

- We have made observations of the lunar helium exosphere made between December 29, 2011, and January 26, 2012, with the Lyman Alpha Mapping Project (LAMP) ultraviolet spectrograph on NASA's Lunar Reconnaissance Orbiter Mission. The observations were made of resonantly scattered He I emission at 584 Å from illuminated atmosphere against the dark lunar surface on the dawn side of the terminator.
- We find no or little variation with latitude.
- The observations support a variation with longitude.
- A decrease to ~35% of the nominal He density occurs due to the passing of the Moon through the Earth's magnetotail.
- Day-to-day variations likely reflect variability in the solar wind alpha flux.
- These results have been submitted for publication in *Icarus.*

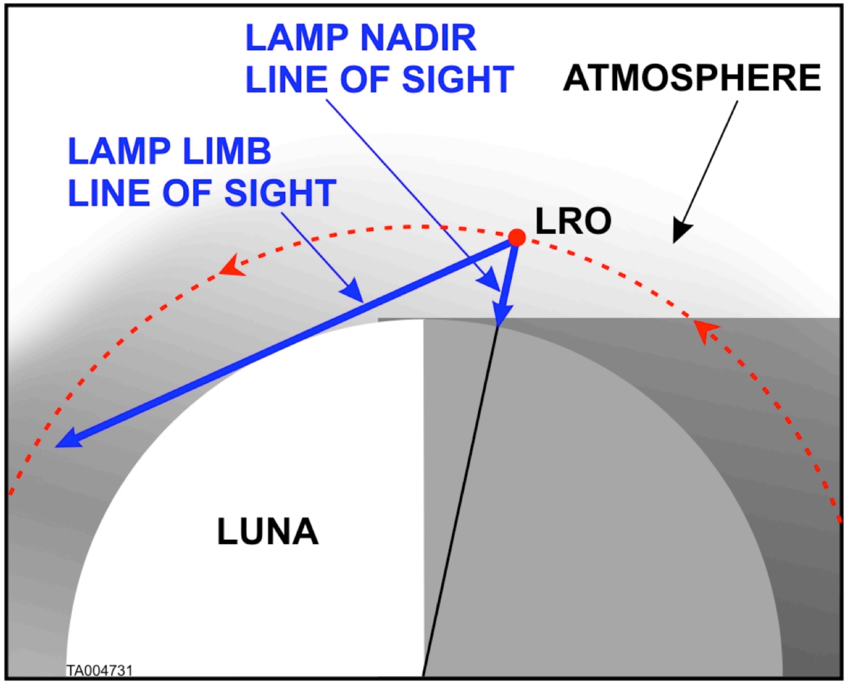
Backup

LAMP Overview

The Lyman Alpha Mapping Project (LAMP) ultraviolet spectrograph on NASA's Lunar Reconnaissance Orbiter Mission (LRO) is a lightweight, low-power, imaging spectrograph optimized for far-ultraviolet (FUV) spectroscopy of the night-side lunar surface and atmosphere. It is designed to obtain spatially resolved spectra in the 570-1960 Å spectral band with a spectral resolution of 34 Å for extended sources that fill its field-of-view. The slit is 6.0° long, with a width of 0.3°. Each spatial pixel along the slit is 0.3° long. From an altitude of 50 km the spatial resolution is 0.26×0.26 km^2. The use of LAMP for the detection of gaseous emission was demonstrated by the observations of the plume produced by the LCROSS impact on October 9, 2009.

A major science objective for the SMD phase of the LRO mission was to measure the composition and variability of the lunar atmosphere.

Atmosphere viewing geometry



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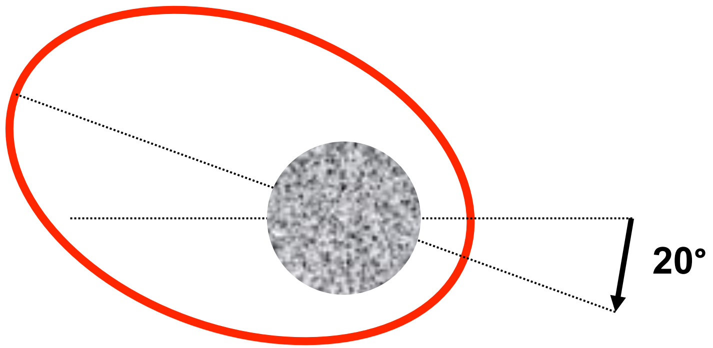
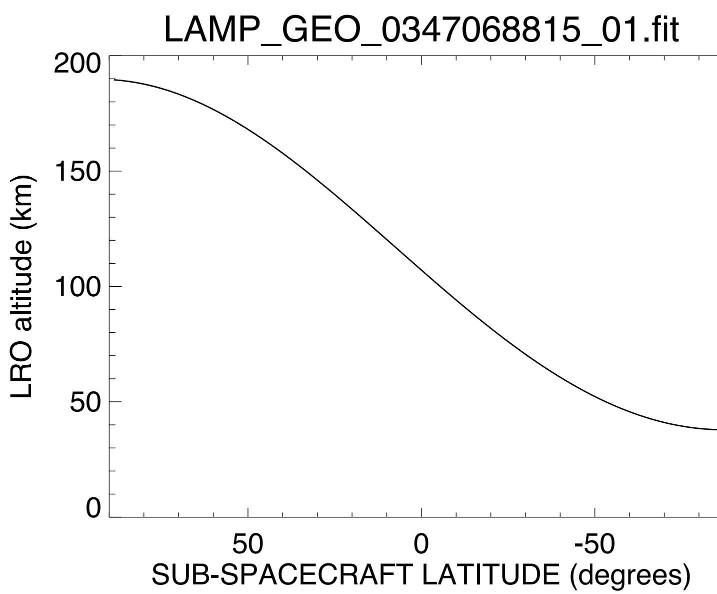




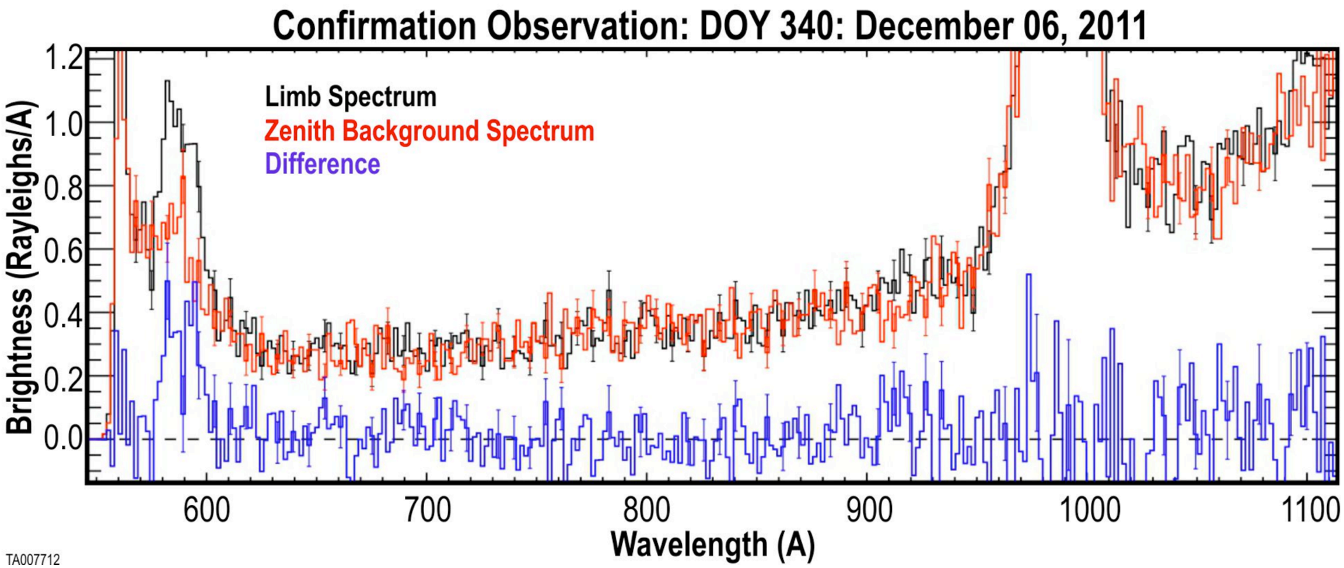
Two modes of atmosphere observation: limb viewing against a bright sky and nadir viewing of illuminated atmosphere against the dark lunar surface.

Nadir observations of He I λ584

- The limb observations provided only a snapshot of the He distribution at just a few specific times, and viewing across the poles.
- On December 14, 2011, the LRO Project altered the spacecraft's polar orbit from a near-circular 50 km altitude to a more stable, fuel efficient elliptical orbit with apoapsis near 200 km and periapsis at 30 km. This change occurred when the orbit was very close to the terminator (at the terminator, the β-angle, defined as the difference between the Sun direction and the spacecraft orbit plane, is 90°).
- As soon as β decreased to the point where it was feasible to observe the dark lunar surface with the full LAMP aperture, we found that the enhanced He column along the line-of-sight from apoapsis (on the night side the He scale height is about 150 km) made detection of He I λ584 fairly straightforward because of the absence of sky background.
- Nadir observations (the nominal LRO mode) also allow continuous monitoring of the He atmosphere until β reaches the point where the spacecraft is totally in shadow, or for roughly a one-month period. Our analysis covers Dec. 29, 2011 to Jan. 26, 2012.
- The technique of observing illuminated atmosphere above the dark lunar surface is the same as that employed by the Apollo 17 Ultraviolet Spectrometer in 1972, except that in that case the near-equatorial orbit permitted only a few minutes of observation at each terminator crossing.

Limb viewing observation of lunar helium

(Stern et al., GRL 39, L12202, 2012)



Black: LAMP spectrum with the spectrograph slit placed 83° from nadir, just above the lunar limb and across the North Pole. In addition to the 584 Å He I emission, a stronger feature appears near 980 Å, caused by an optical ghost reflection of IPM Lyman-α within the spectrograph. Red: sky background spectrum obtained close in time by observing the same location on the sky at the zenith, where any contribution from the lunar atmosphere is minimized. The apparent continuum emission is due to instrument background. Blue: difference spectrum obtained by subtracting the background from the limb spectrum, revealing native lunar atmospheric helium emission.