LRO-LAMP OBSERVATIONS OF LUNAR EXOSPHERIC HELIUM

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Introduction: Lunar exospheric helium

- Observed for the first time by the LACE spectrograph deployed on the lunar surface during the Apollo 17 mission [1].
- Has its main origin in the neutralization, upon impact, of incident solar wind alpha particles [2].
- Helium interacts weakly with the lunar regolith, therefore its density *n* is inversely proportional to the surface temperature *T*: $n \sim T^{-5/2}$ [3], and thus depends on the local time.
- However, a small but non-negligible fraction (between ~15% [4] and ~40% [5,6]) of the lunar helium outgasses from the interior of the Moon, as the radioactive daughter of ^{232}Th and ^{238}U [7].
- Previous LAMP observations detected enhancements in the lunar He density uncorrelated with either local time or solar alpha particle flux [8], which seem to be the result of outgassing.

Goals of the LAMP observations

- What is the fraction of helium that comes from the interior of the Moon, compared to the main source, the solar wind?
- What is the structure of the lunar helium exosphere (i.e. its dependence on local time, latitude, longitude, and altitude)?
- Is the lunar helium exosphere approximated by a Chamberlain profile?
- What is the accommodation coefficient of lunar helium (i.e. how weakly does the solar wind interact with the lunar regolith)?

LAMP: UV spectrograph onboard LRO

- LAMP [9] onboard LRO [10] is uniquely equipped to study the lunar exosphere.
- Very sensitive FUV/EUV spectrograph (57 – 195 nm).
- It studies mainly the lunar surface, looking for signatures of volatiles [12,13] and space weathering [14,15,16,17].
- However, when looking at the lunar night side while the spacecraft (LRO) is illuminated, it can detect emission lines from resonant scattering of solar photons by exospheric constituents [8,5,6,18,19,20,21,22].

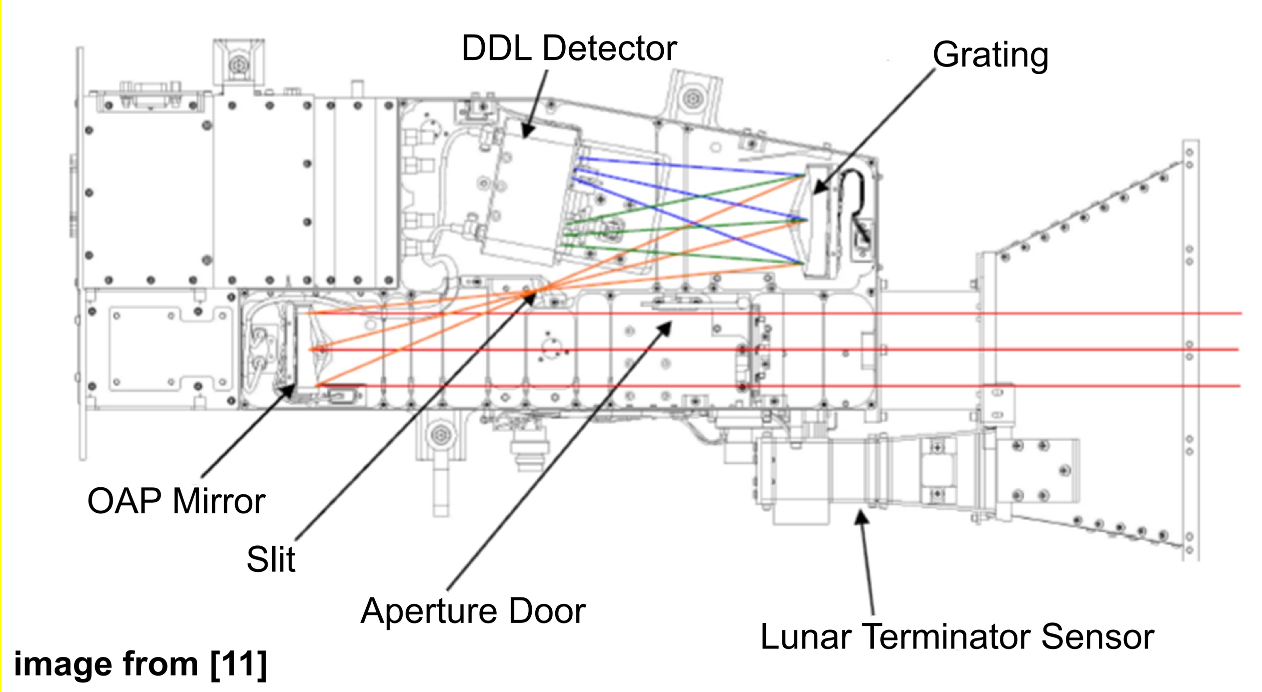
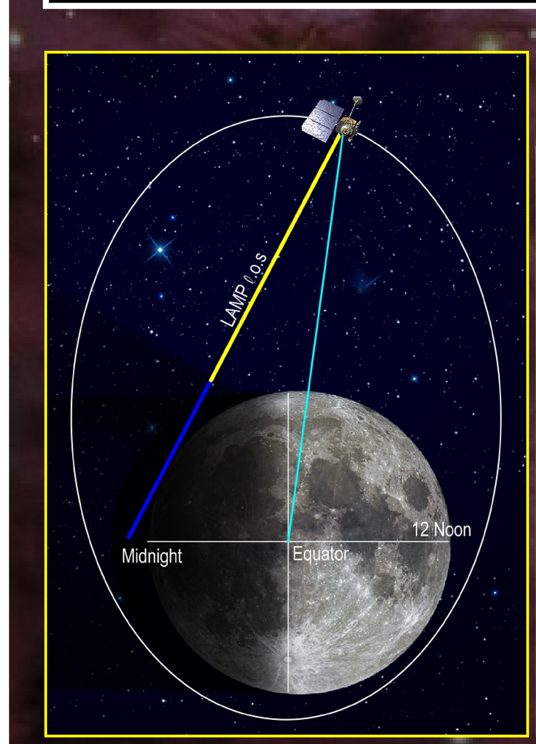
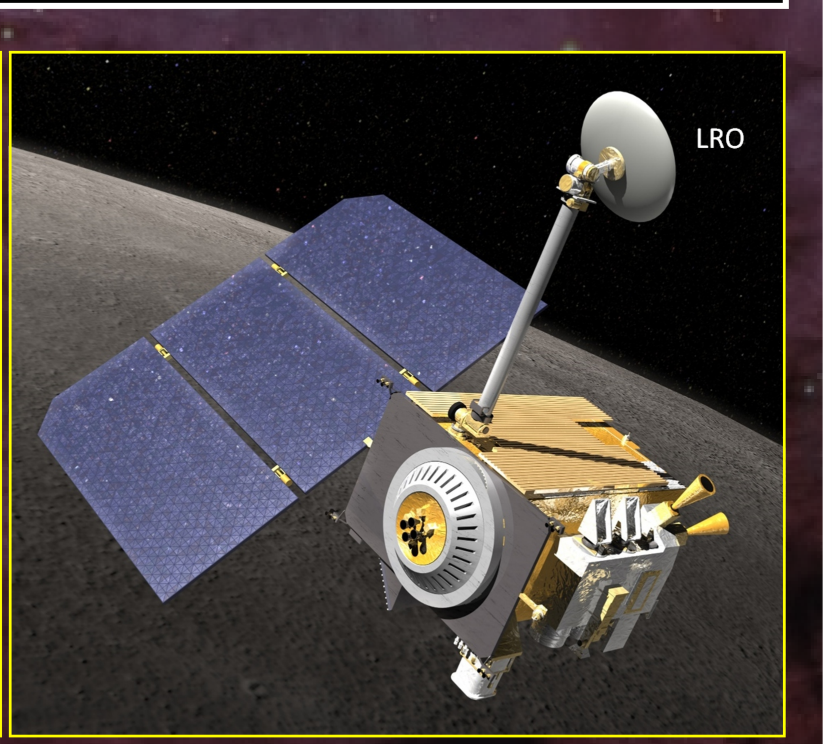


image from [11]

LRO pitch & roll atmospheric campaigns



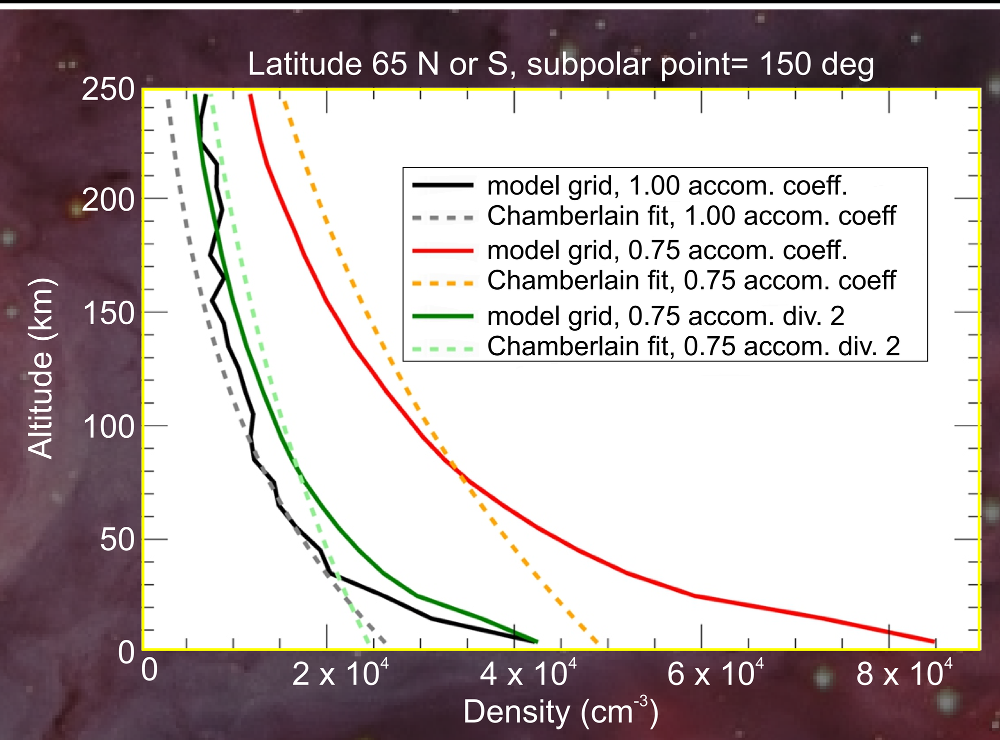


- By tilting LRO along its direction of motion (pitch maneuvers, like in the Figure on the left) and sideways (roll maneuvers), it is possible to considerably increase the illuminated LOS compared to the nominal, nadir mode, and hence to increase the brightness of the helium emission line at 58.4 nm (HeI).
- By repeating these maneuvers over multiple orbits, it is possible to study the dependence of lunar helium density on local time, selenographic longitude, and solar wind conditions (monitored by the ARTEMIS twin spacecraft [23]). Each of these parameters is informative about a specific physical parameter:
  - The dependence of the helium density with local time, and hence on lunar surface temperature, yields the degree of accommodation (and thus the interaction) between helium and the lunar surface temperature.
  - The dependence of the helium density with selenographic longitude yields information on the possible locations of helium outgassing.
  - The dependence of helium density on the solar wind alpha particle flux constrains the source rate and the amount of lunar endogenic helium (compared to the population from the solar wind).

Data reduction and comparison with models

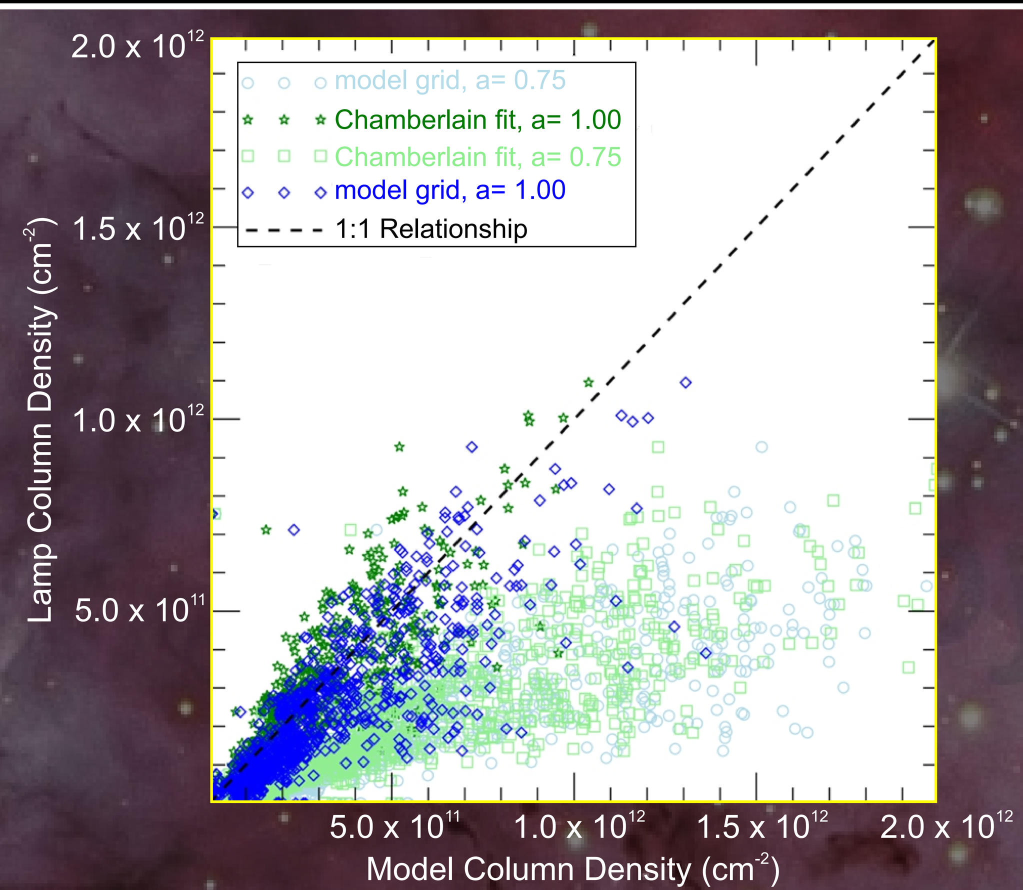
- LAMP count rates are first converted to line-of-sight brightness by applying the instrument calibration factor obtained by looking at interstellar helium [24].
- Line-of-sight brightness is then converted to column density using daily averages of solar irradiance at 58.4 nm measured by the Solar Dynamic Observatory's Extreme ultraviolet Variability Experiment [25].
- Line of sight column densities are finally compared with a series of simulations of the lunar exosphere [6], which predict the density of helium as a function of latitude, solar time, and altitude.
- The models are scaled to the solar wind alpha particles flux measured by ARTEMIS to account for the variability in the solar wind 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 models.
- By comparing the predicted and LAMP-derived illuminated column density, we obtain "weighting factors" to scale the model to match LAMP observations.
- We use 4 sets of models, each with a combination of 2 values of accommodation factor (1.00, or full thermal accommodation) and 0.75 [26] and the assumption of a Chamberlain fit or not.

Effect of the accommodation factor on exospheric density

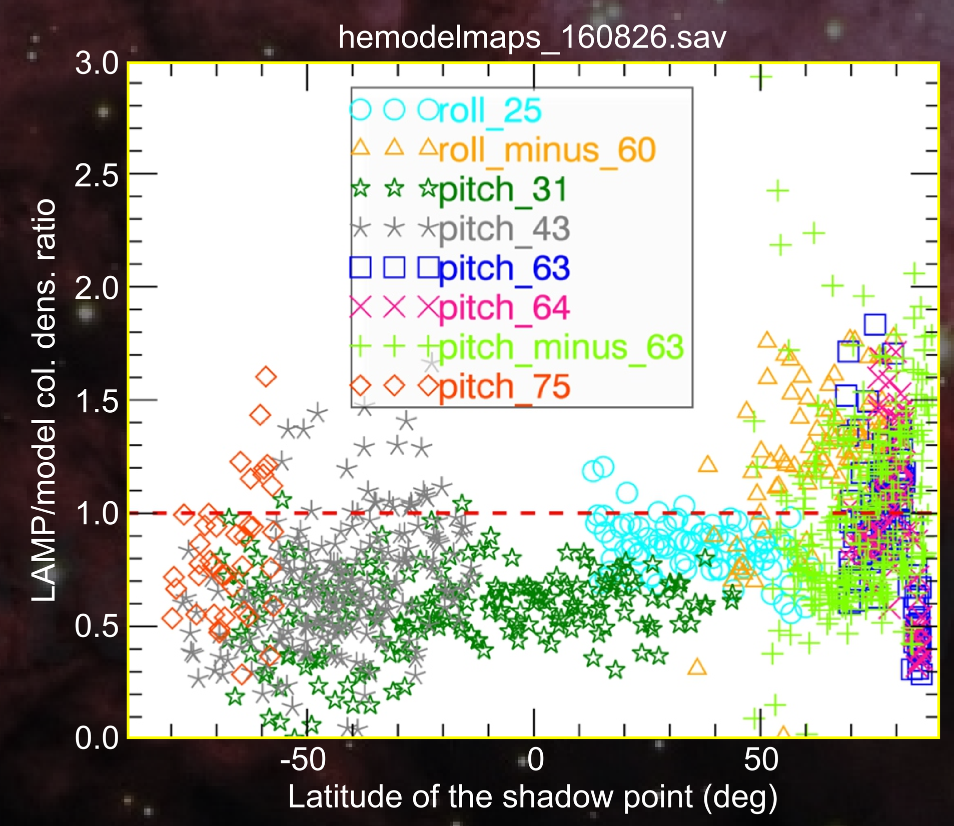


Accommodation factor affects overall exospheric density: a decrease of 25% in the accommodation factor makes the exospheric density double.

Results: thermal accommodation

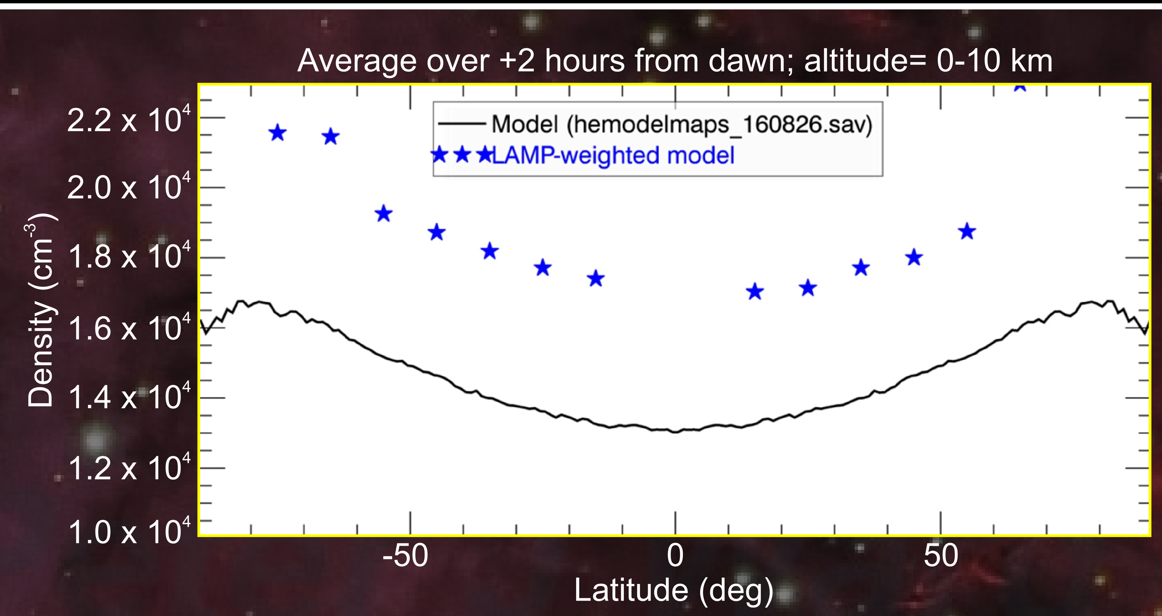


This scatter plot shows that observations are consistent with an accommodation coefficient of 1.00, Meaning that helium atoms are fully accommodated to the temperature of the surface where they last impacted. A Chamberlain profile well approximates the lunar exospheric helium.

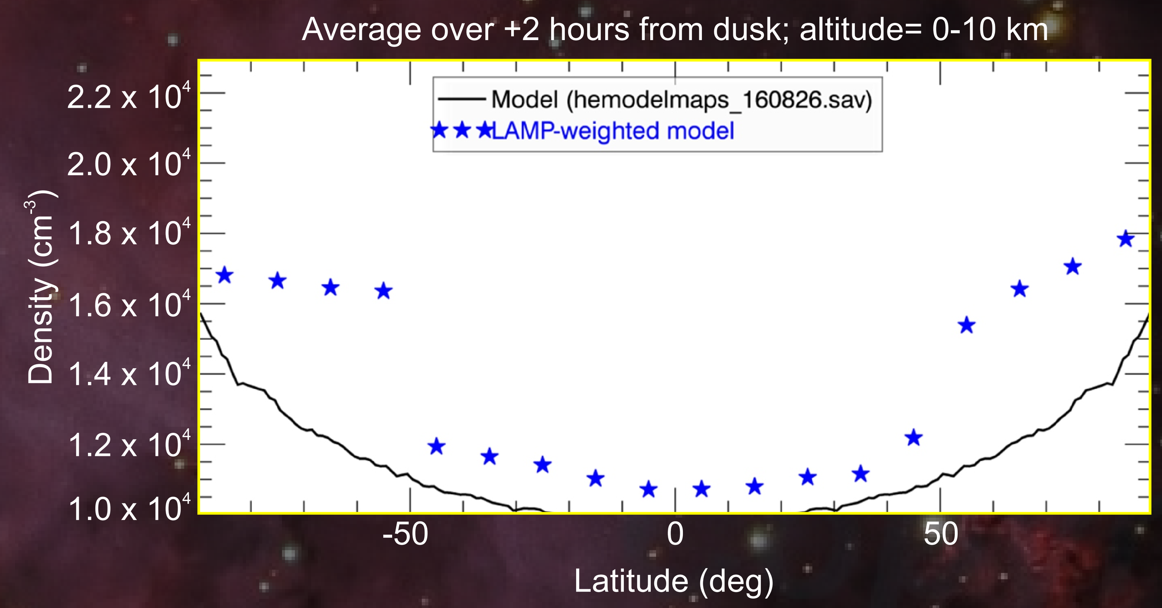


Different observational geometries give different LAMP/model column density ratio.

Results: the structure of the lunar helium exosphere



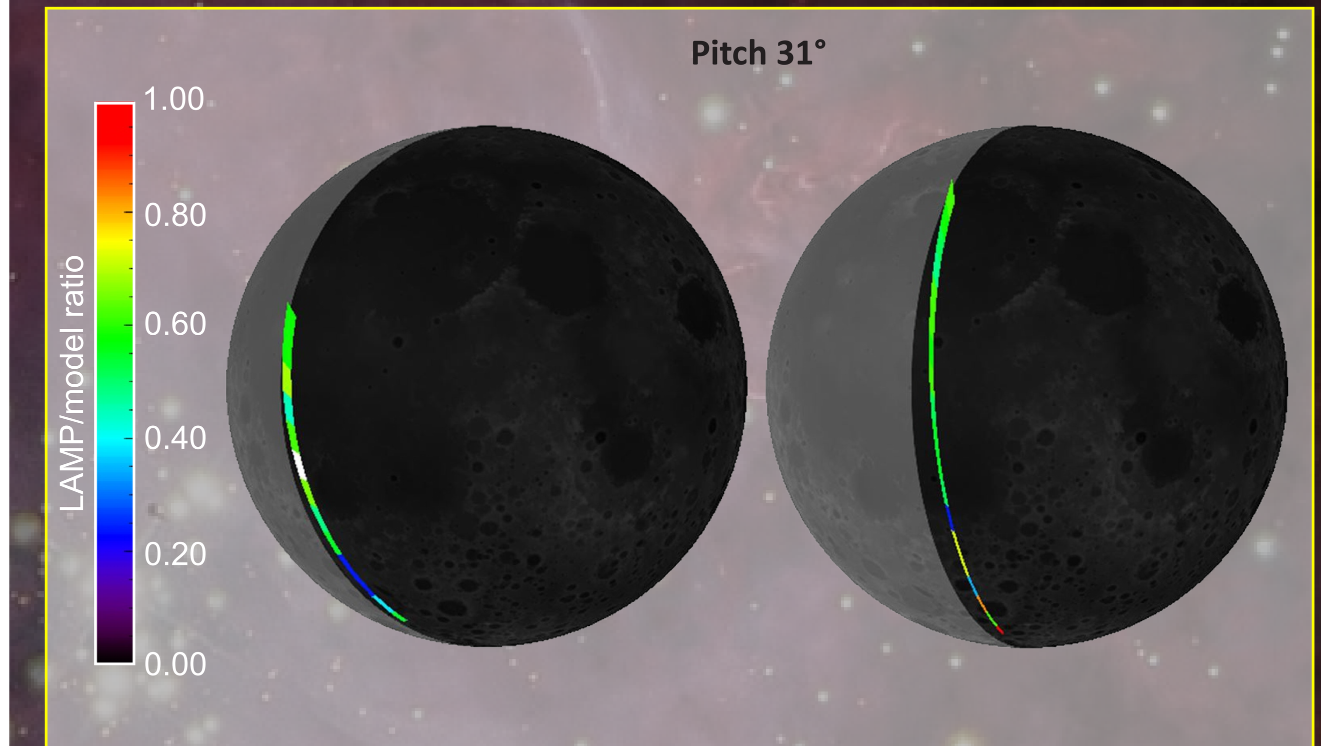
Good overall agreement between model (Chamberlain fit, α = 1.00) and LAMP observations at dawn.



Dusk observations show the greatest discrepancy with the model. Abrupt onset of discrepancy at ~50° latitude (either North or South).

Results: the structure of the lunar helium exosphere

- Observations taken at same local time but different longitudes are sensitive to variations of helium density with longitude (which is not included in the model).
- No clear dependence on longitude (outgassing) so far.



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