Shallowly-Buried Hydrogenation in the Lunar Regolith: Using Albedo Protons to Refine Latitude and Local Time Trends

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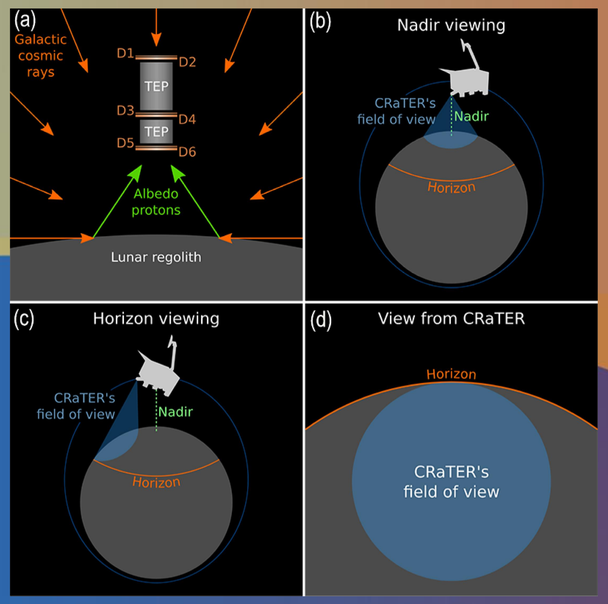
Overview

The CRaTER instrument (Cosmic Ray Telescope for the Effects of Radiation) on LRO has detected the signature of hydrogenated lunar regolith at the local dawn sector of the Moon, using a new type of horizon-viewing observation. The yield of ~100 MeV lunar albedo protons at dawn is ~2 × larger than that of the dusk sector; presumably hydrogen (whether atomic or in a molecule like H_2O) is more abundant on the lunar surface just before sunrise, and galactic cosmic rays (GCRs) scatter the free protons out of the regolith via forward-scattering collisions, thus enhancing the number of albedo protons per incident GCR.



CRaTER's six detectors can discriminate different elements in the galactic cosmic ray (GCR) population above ~10 MeV/nucleon, and can also distinguish between GCRs arriving from deep space and secondary particles traveling up from the lunar surface.

http://crater.sr.unh.edu/

Please see all of the results from this thorough investigation in our paper published in Planetary and Space Science (Schwadron et al., 2017 [1])

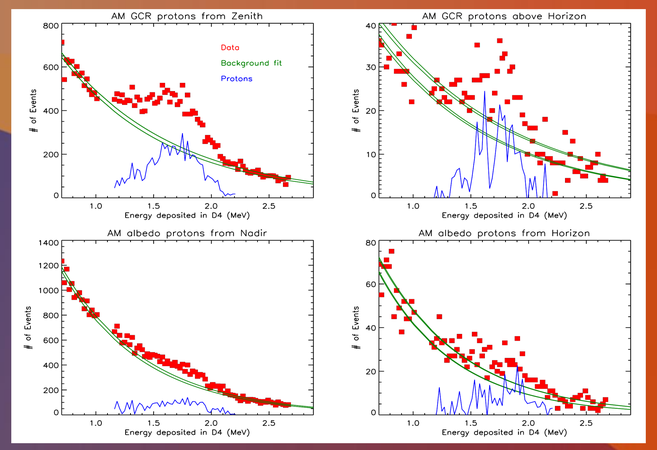
https://doi.org/10.1016/j.pss.2017.09.012

Observations

We use only 36 hours of horizon observations here, all made at the longitudes of Oceanus Procellarum. Each observation was made at either local sunrise or local sunset. We also collected 564 hours of control data (nominal nadir-viewing data) before and after the horizon observations. Two small solar particle events occurred within the control data windows, and we do *not* include that data in the analysis.

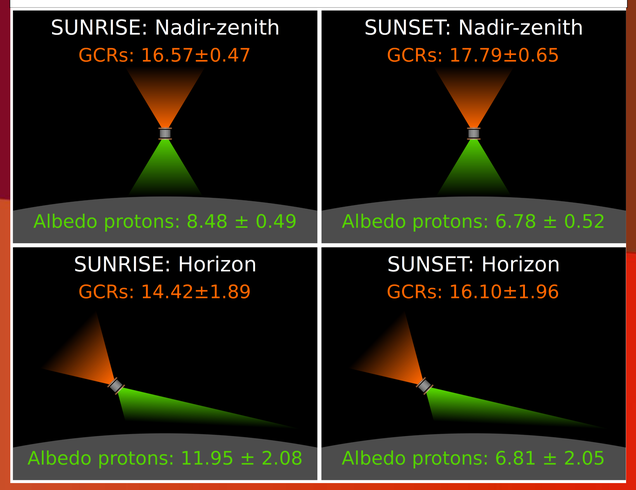
Data Reduction

Rather than assuming fixed lineal energy transfer (LET) proton tracks and fixed background LET spectra as in previous analysis [2,3] we create sparsely-populated cross-plots (below left), cull more than half of the detection events to select for only one direction of arrival (zenith or nadir) and then co-add the cross-plots into one-dimensional LET spectra, resulting in good signal-to-noise ratios, as shown below right (red points below).

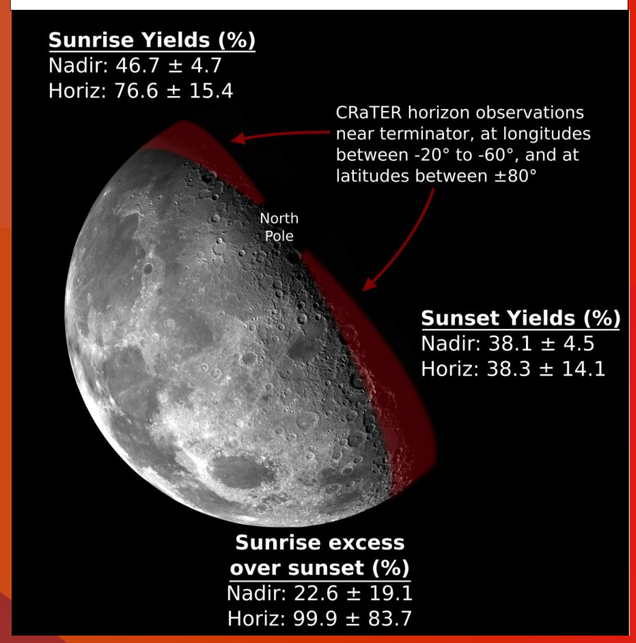


Subtracting the background (green lines above) from the data gives a proton-only LET spectrum (blue lines above), which we co-add to obtain the number of detected protons. We divide the number of albedo protons arriving from the Moon by the number of cosmic ray protons arriving from space to derive a "yield" of albedo protons. As the results in the next column show, the measured yield depends on where CRaTER is pointed (nadir-zenith vs. horizon) and on the time of day (sunrise vs. sunset).

100 MeV Proton *Rates*



Albedo Proton *Yields*



References

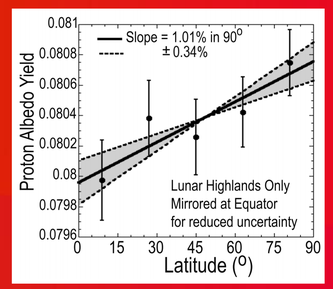
[1] Schwadron N., et al. (2017), PSS
[2] Schwadron, N., et al. (2016), Icarus, 273, 25-35
[3] Wilson, J.K., et al. (2012), JGR, 117, E00H23
[4] de Wet, W. et al. (2018, this meeting)
[5] Jordan, A.P., et al. (2018, this meeting)
[6] Schorghofer, N. (2014), GRL, 41, 4888-4893

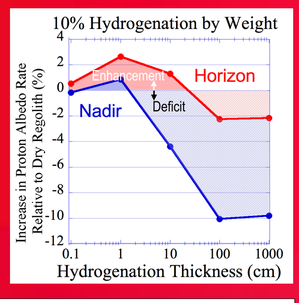
Results and Implications

The lunar albedo proton yield is higher over the dawn terminator than the dusk terminator, and the contrast is particularly high for grazing-angle albedo protons. This is consistent with a population of mobile hydrogen at depths of ~10 cm or less, that is concentrated near the morning terminator. Simulations (de Wet et al. [4] ***this meeting***) confirm that the yield enhancement should be larger for horizon-viewing observations compared to the nadir observations, as seen here.

Other Surface Hydrogen

Schwadron et al. [1] found a 1% high-latitude enhancement in the *nadir-viewing* proton yield compared to lower latitudes (below left) suggesting a high-latitude enhancement of H near the surface. (below right) This may be part of a lunar "polar cap" of ice (Jordan et al. [5] ***this meeting***) that is separate from the mobile H suggested in this study.





Future Work

CRaTER will next conduct horizon observations over all local times on the night-time hemisphere of the Moon to test whether the surface hydrogenation builds up slowly over the night, or whether there is a "standing wave" of hydration near the dawn terminator (i.e., Schorghofer [6]).

We are also developing a new technique for mapping albedo protons that should improve our counting statistics by more than an order of magnitude over all previous studies. ***Stay tuned!***

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