USING ALBEDO PROTONS TO SEARCH FOR HYDROGEN IN SHALLOW REGOLITH ON THE MOON.

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Introduction: To understand the history of the sources and losses of the Moon's water ice, it is important to understand how the ice is distributed on large scales. In particular, the location of large-scale maxima in the polar ice can constrain when the ice was emplaced, as suggested by an analysis using data from the Neutron Spectrometer on Lunar Prospector [1]. In both polar regions, the maximum concentrations of hydrogen at a depth of ~50 cm are offset from the Moon's spin axis and yet are antipodal. This suggests the hydrogen, or water ice, was deposited when the Moon had a different spin axis (palaeopoles)—more than ~3.5 Gyr ago. Furthermore, two secondary large-scale maxima are located at the current poles; these suggest that ice has also been deposited more recently.

It is unclear whether this interpretation applies to water ice exposed at the surface. The large-scale distribution of surface ice may be shifted in the direction of the palaeopoles, as shown by an analysis of near-infrared reflectance spectra from the Moon Mineralogy Mapper (M^3) on Chandrayaan-1 [2]. If so, then the surface ice could have the same source as the deeper (~50 cm) deposit.

Albedo Protons: To test further whether the surface and deeper deposits of ice have a common origin, it is necessary to determine the large-scale distribution of ice at mid-range depths. This can be done using albedo protons, which are produced by galactic cosmic rays (GCRs) colliding with nuclei in the regolith (Fig. 1). These collisions release secondary protons and neutrons, and the neutrons can collide with hydrogen nuclei and eject them as albedo protons. In other words, water ice can decrease the flux of albedo neutrons while enhancing the flux of albedo protons [4].

Albedo protons are detected by the Cosmic Ray Telescope for the Effects of Radiation, or CRaTER [3], on the Lunar Reconnaissance Orbiter (LRO). They originate from depths of ~1-10 cm [4]. Consequently, observations of albedo protons can link the surface measurements with the neutron measurements.

A New Technique: Previous analysis using albedo proton observations (~100 MeV) suggested that the abundance of hydrogen in the upper ~10 cm of regolith may increase toward the poles [4]. This result, however, had a low spatial resolution and a large uncertainty. Furthermore, subsequent simulations have shown that more energetic (>1 GeV) albedo protons may be more sensitive to hydrogen in the upper ~10 cm of regolith [6].

It is difficult to isolate these particles, because they can masquerade as GCRs in CRaTER data. Consequently, we plan to combine nadir and horizon observations [e.g., 5] to statistically identify the flux of energetic albedo protons from the Moon. We will use this new technique to revisit the latitudinal trend found in [4]. If we find a trend, then in the future we may be able to use CRaTER data to show whether shallow (~1-10 cm) polar hydrogen is symmetric about either the palaeopoles or the current poles, thus helping to determine whether the surface and deeper (~50 cm) ice deposits have the same origin.

References: [1] Siegler M. A. et al. (2016), *Nature, 531,* 480-484. [2] Li, S. et al. (2018), *PNAS, 115,* 8907-8912. [3] Spence, H. E. et al. (2010), *Space Sci. Rev., 150,* 243-284. [4] Schwadron N. A. et al. (2016), *Icarus, 273*, 25–35. [5] Schwadron N. A. et al. (2018), *Icarus, 162,* 112-132. [6] de Wet et al. (2018), AGU Fall Meeting, abstract #P51E-2934.

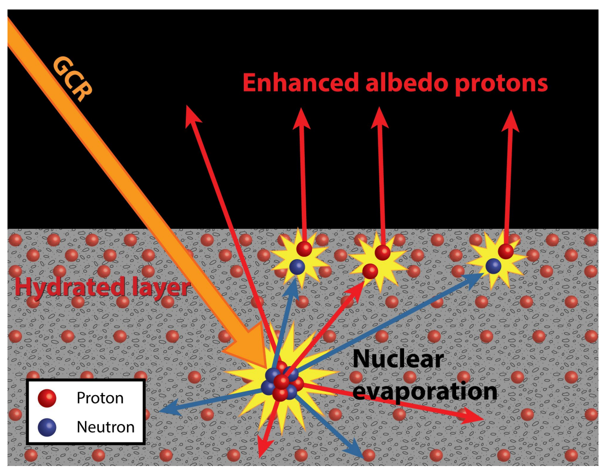

Fig. 1. Cartoon showing how a galactic cosmic ray (GCR) can excite an atomic nucleus in the lunar regolith, causing the nucleus to fragment. The fragments include protons and neutrons. The neutrons can eject hydrogen nuclei, i.e., protons, from the regolith, thus enhancing the yield of albedo protons measured by CRaTER. (Figure from [4].)