NEW INSIGHTS INTO THE GLOBAL COMPOSITION OF THE LUNAR SURFACE FROM HIGH-ENERGY GAMMA RAYS MEASURED BY LUNAR PROSPECTOR.
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Introduction: An analysis of the gamma-ray albedo of the lunar surface as measured by the Lunar Prospector (LP) Gamma-Ray Spectrometer (GRS) has revealed that 8 to 9 MeV gamma rays contain information about the elemental composition of near-surface materials. These High-Energy Gamma Rays (HEGRs) are found to be primarily sensitive to the total Fe, Mg, and Ti content of the surface, although other elements also contribute. The HEGR measurements offer unique insight into the composition of the lunar surface, particularly the global Mg abundances, which to date have not been determined to high precision from gamma-ray spectroscopy measurements.

Data Reduction: Unlike traditional gamma-ray spectroscopy analyses, which utilize discrete-energy gamma-ray peaks to characterize the elemental composition of a planetary surface, this technique uses the 8 to 9 MeV portion of the gamma-ray continuum. This region was selected due to its lack of contamination by energy-resolved gamma-ray peaks. A comparison of the HEGR region measured during trans-lunar cruise and lunar orbit is shown in Fig. 1.
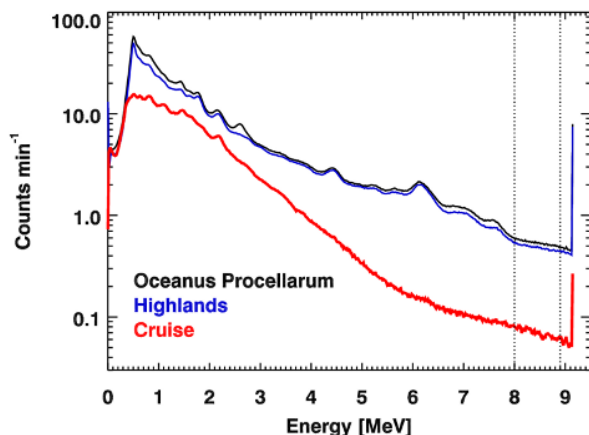

Figure 1. Lunar Prospector gamma-ray spectra measured during trans-lunar cruise and over two compositionally distinct regions of the lunar surface from the 100-km orbit. The HEGR region is denoted by the dashed lines.

The gamma-ray count rate in the HEGR region (C_{HEGR}) is measured over the lunar surface in $0.5^o \times 0.5^o$ equal-area pixels. C_{HEGR} is corrected for detector gain and deadtime, viewing geometry, variations in the spacecraft altitude, and changes in the magnitude of the surface-incident GCR flux over the course of the mission following the formalism of [1]. The 100-km altitude dataset was utilized for this work to enable a com-

parison to the LP GRS derived global elemental abundance maps [2]. C_{HEGR} is then re-binned to $5^o \times 5^o$ pixels, and the resulting map (Fig. 2) clearly shows the ability of HEGRs to discriminate between large, compositionally distinct regions of the lunar surface.
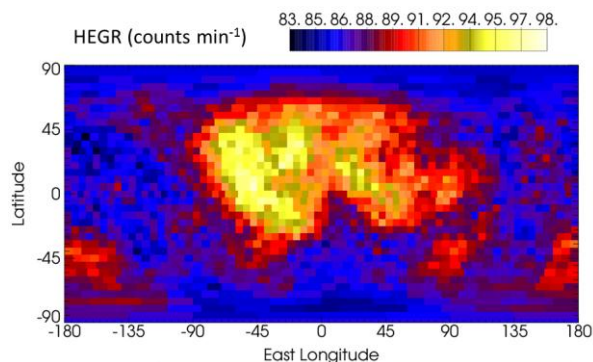

Figure 2. A global map of the HEGR count rate.

HEGR Production: Directly relating HEGR measurements to surface composition requires an understanding of the physics of HEGR production. Monte carlo simulations of the galactic-cosmic-ray (GCR) - induced lunar gamma-ray albedo [e.g., 3,4] indicate that the >8 MeV continuum is dominated by bremsstrahlung gamma rays produced within the lunar surface. A major source of bremsstrahlung-producing particles (electrons and positrons) in the lunar surface is the decay of neutral (π^o) and charged (π^+, π^-) pions. Like neutrons, pions are produced by interactions between surface-incident GCRs, although they result from intra-nuclear cascades [5] as opposed to spallation reactions.

The empirically derived relationship between elemental composition and C_{HEGR} is quantified via a new composition parameter (C_p), where

$$C_p = w(Fe) + 1.14w(Mg) + 0.14w(Ti)$$

where $w(X)$ is the weight fraction abundance of element X as derived from a comparison of Fig 2 to the $5^o \times 5^o$ elemental abundance maps of [2].

The dependence of proton-induced pion production as a function of target composition has been measured in the laboratory [5] and agrees with the empirically derived weighting factors for the contributions of Fe, Mg, and Ti to C_p. Other elements also contribute to C_p, however their variability over the surface is smaller than Fe, Mg, and Ti and therefore they contribute in a near-constant manner to C_p and don't contribute to its variability across the surface.

A comparison of the C_p maps derived from LP HEGR measurements to that calculated directly from the elemental abundance maps of [2] shows excellent agreement (Fig. 3), although there are a few regions with notable differences.
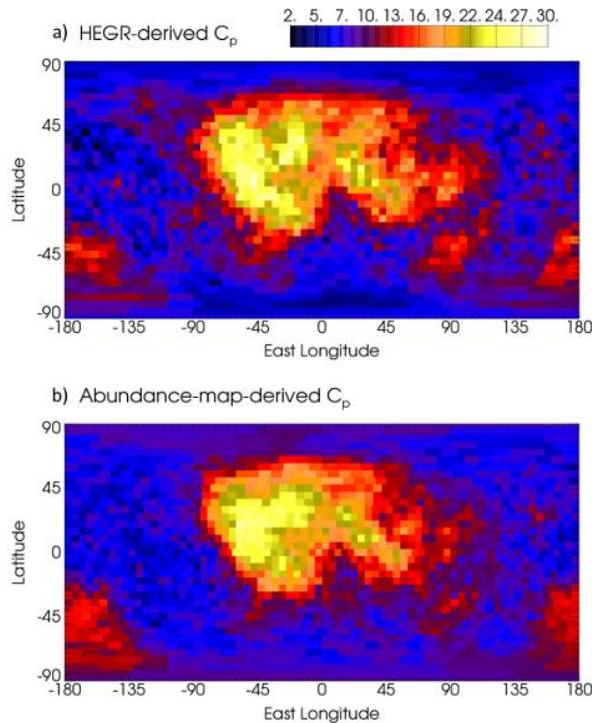

Figure 3. Global maps of C_p derived from a) HEGR measurements and b) the elemental abundance maps of [2]. a) is a scaled version Fig. 2.

Global Mg Abundances: Of the three elements (Fe, Mg, and Ti) that have been identified as contributing the most to HEGR production, Fe and Ti have been mapped globally by LP with low statistical errors and high spatial resolution. The Mg map suffers from lower precision and uncertain spatial resolution as a result of the lack of a strong, energy-resolved Mg gamma ray. Therefore, the HEGR measurements may provide the best LP GRS information available with respect to global abundances of Mg.

The relationship between C_{HEGR} and C_p was empirically derived to be

$$C_{HEGR} = 0.522C_p + 82.249$$

The constant value (82.249) originates from the contribution of other, less variable elements (e.g., Ca, Si, O) to HEGR production. This relationship can be used in conjunction with the definition of C_p to produce a HEGR-derived global map of Mg abundances. The resulting Mg abundance map (Fig. 4) is compared to that of [2], which was created using gamma-ray peak analysis techniques. Note that the Mg map of [2] was used to derive the relationship between surface compo-

sition and C_p, and therefore the HEGR-derived Mg map is not completely independent of that work.

A comparison of the two Mg maps shows general agreement, namely higher (> 4 wt%) Mg abundances in mare basalt regions and lower (< 3 wt%) abundances in the highlands. The two Mg abundance distributions have similar mean values of 4.28 ± 2.05 wt% (HEGRs) and 4.28 ± 1.37 wt% [2], however the HEGR-derived Mg distribution has a larger range.
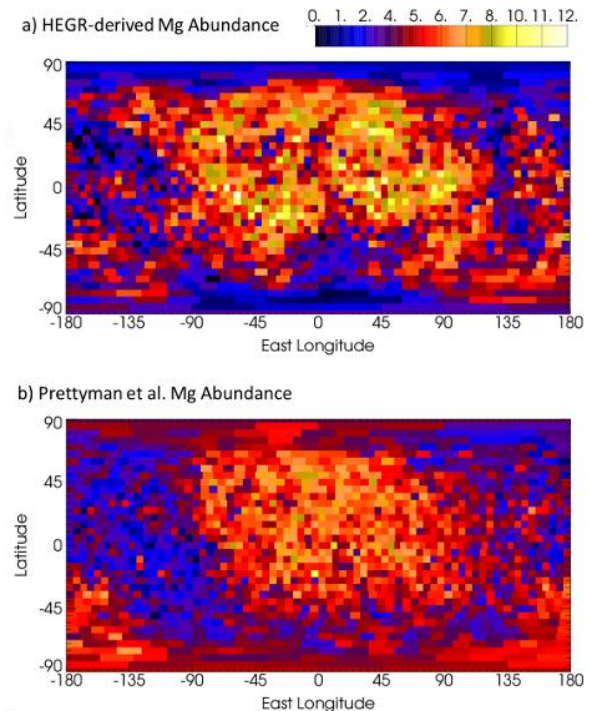

Figure 4. Global Mg abundances from HEGR measurements and [2].

Regional Studies: There are several regions for which there are statistically significant differences in the HEGR- and [2]-derived C_p maps. This includes Mare Australe, Hertzsprung Basin, Mare Nubium, Orientale Basin, and the lunar highlands northwest of Oceanus Procellarum. The Hertzsprung basin HEGR measurements are suggestive of previously unidentified exposures of Ca- or Al-rich material in the western basin rim. The Orientale basin HEGR measurements suggest Mg enhancements in the surrounding lacus. The implications of the HEGR measurements for each of the regions of interest will be presented.

References: [1] Lawrence et al., (2004), *JGR, 109.* [2] Prettyman et al., (2006), *JGR, 111 E12007.* [3] *Thompson et al.,* (1997), *JGR, 102, 14374-14740.* [4] *Moskalendo and Porter* (2007), *ApJ., 670, 1467-1472.* [5] *Cochran et al.,* (1972), *Phys. Rev. D, 6, 3085-3116.*