HIGH-RESOLUTION GAMMA RAY SPECTRA FOR LUNAR GEOCHEMISTRY FROM KAGUYA.

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Introduction: We propose to archive complete, fully-calibrated and corrected, high-resolution gamma-ray spectra of the Moon acquired by the Kaguya mission at Planetary Data System (PDS). The Moon preserves a record of geochemical processes that occurred primarily during the past 3-4 billion years, providing a window to the distant past (e.g. [1]). The elemental compositions of planetary surfaces can be determined uniquely by gamma-ray spectroscopy, essential to explore the origin and evolution of the Moon and to help understand how the Solar System was created [2]. The Kaguya Gamma-Ray Spectrometer (GRS) has up to 20 times better gamma-ray energy resolution [3] than that of Lunar Prospector (LP) [4,5], enabling more accurate determination of the concentration of key rock-forming elements (O, Na, Mg, Al, Si, Ca, Ti, Fe, K, Th, and U) and H (e.g. [6-8], see Figure 1). This project will also enhance the value of the LP-GRS data set by supplementing the high-efficiency measurements of LP-GRS with high-resolution data (Table 1).

Dataset to be used and archived: The level-0/1 (raw) data of the Kaguya GRS time-series spectra will be used. We have a permission to use the data and archive the reduced products at the NASA PDS Geosciences node. We have already begun acquiring the data from the Japan Aerospace Exploration Agency (JAXA) for complete coverage of the Kaguya mission. The SPICE kernels for ephemeris data of the Kaguya satellite are available for public and distributed by Data Archives and Transmission System at JAXA at http://darts.isas.jaxa.jp/pub/spice/SELENE/kernels/.

Fully corrected and calibrated time-series spectra of lunar gamma rays will be archived at PDS as a level 1B product (Reduced Data Records). Each record, accumulated over every 17 s, will contain spacecraft clock, UTC time, high-gain spectrum (<3 MeV, 8192ch), and low-gain spectrum (<12 MeV, 8192ch).

Separately from the spectrum files, we will also archive the ancillary data needed to interpret the spectrum, such as live time, latitudes and longitudes of the spacecraft position, solid angle subtended by the Moon at the spacecraft, pointing information, and correction factors for galactic cosmic rays. We will also generate and document the response function of the detector system needed for the absolute calibration of the counting rates to elemental abundances.

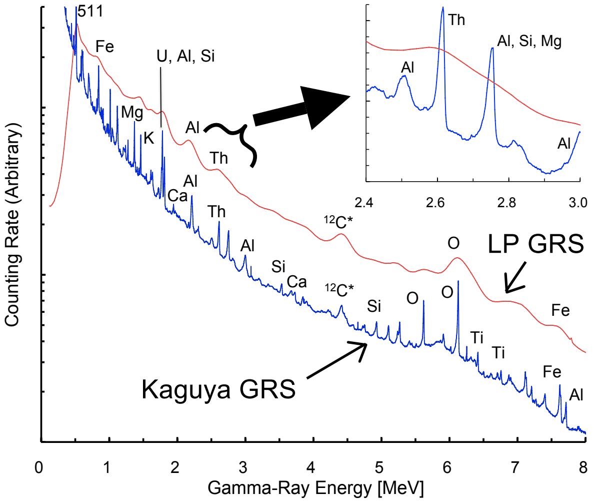

Figure 1 Energy spectra of gamma rays acquired by Kaguya (blue) and Lunar Prospector (LP, red). The inset shows the close-up of the 2.4 to 3.0 MeV region where the Th peak resides.

Methodology: Data reduction processes similar to those for LP, Mars Odyssey, and Dawn missions [9-17] will be applied to the raw time-series spectra of Kaguya GRS to create a complete PDS product, ready to be used by planetary science community at large. The descriptions of the data and methods used to derive the resulting PDS product will be documented. Data reduction steps include the following.

Elimination of invalid events. Each and every time-series spectrum will be evaluated for its ability to be used in the geochemical study of the lunar surface. Invalid spectra include those recorded when the spacecraft was not pointing toward the nadir, during solar energetic particle events, and while the instrument was not configured to the proper settings or was receiving interference from other instruments on board. These contaminated events will be filtered out or flagged so that while we release as much data as possible, users of PDS can easily select which spectrum to process for their own studies.

Correction of analog-to-digital converter differential non-linearity. Each channel of the analog to digital converter (ADC) has variations in the width, such that some channels are slightly more likely to count than others. This effect is known as “differential nonlinearity” (DNL). Systematic distortions caused by DNL can be pronounced and require correction prior to further analysis. We will generate the correction factor for DNL by identifying the pattern of artificial changes in counts at higher frequencies than expected given the resolution of the spectrometer. Since variations in

Table 1 Summary of geochemical observations of the Moon with gamma rays.

Mission	Launch	Detector	Resolution* (keV)	Altitude (km)	Reference
Apollo 15/16	1971/1972	NaI	50	100	[19]
Lunar Prospector	1998	BGO	80	30 and 100	[4,5]
Kaguya	2007	Ge	**4**	30 × 50 and 100	[3,6-8]
Chang'e-1	2007	CsI	60	200	[20]
Chang'e-2	2010	$LaBr_3$	33	100	[21]

*Energy resolution is expressed as the full-width-at-half-maximum of the 662 keV gamma ray from the decay of ^{137}Cs.

width are typically associated with the least significant bits of the ADC [10,11,15,17], DNL artifacts typically occur as a repeating pattern.

Gain correction and energy calibration. Observed variations in gain will lead to lower signal to noise ratio (i.e. higher minimum detectable limit and poorer precision for elemental concentrations). Therefore we will put each and every spectrum on the same pulse height scale. The centroids of high-intensity, isolated Gaussian peaks and known energies of major gamma-ray peaks will be used to determine the gain and offset for each spectrum [9-11,15].

Corrections for variations in satellite altitude and galactic cosmic ray intensity. The gamma ray counting rate varies to first order as the solid angle subtended by the Moon at the spacecraft, which depends on altitude. We will calculate the solid angle for each observation, given spacecraft positions determined by SPICE. A correction factor will be derived to remove solid angle variations in the counting data.

The emission of the lunar gamma rays are induced by neutrons produced in the lunar surface by high-energy galactic cosmic rays (GCR), except for the natural radioelements K, Th, and U. Therefore it is necessary to detrend the variation in GCR intensity in order to properly extract the variations in gamma ray counts solely attributed to changes in the elemental composition.

Deriving instrument response function. In order to convert gamma-ray counting rates into elemental abundances, one needs to know the spectrometer responses to gamma rays. The response function, expressed as an efficiency-area product, depends on the energy of the incident gamma rays, their direction, and pulse-height distribution.

The response function for any selected combination of energy and direction can be calculated using the Monte Carlo code MCNPX, as was similarly done by [5,11-13,18] in modeling response of the LP-GRS, Mars Odyssey Neutron Spectrometer, and Dawn Gamma Ray and Neutron Detector. Full spectrum simulations will be carried out for representative lunar compositions, using an detailed model of the instrument and approximate model of the spacecraft to support the analysis of background sources.

Ancillary data. The reduced data set will include spacecraft ephemerides and pointing needed to create distribution maps of elements.

Perceived Impact: This study will provide complete, fully calibrated and corrected, high-resolution, lunar gamma-ray spectra to the public. The resulting gamma ray data with unprecedented resolution will enable users to identify and quantify elements such as Mg, Al, Si, Ca, Ti, Fe, K, Th, U, and H to explore the origin and evolution of the Moon and help plan future missions. Ancillary data needed to analyze and interpret the data, such as detector response functions will be included in the archive. The derived dataset will be inter-compared with results from Lunar Prospector. The validation process will enhance the scientific value of all nuclear spectroscopy data sets.

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