PRECISE OBSERVATION OF URANIUM, THORIUM, AND POTASSIUM ON THE MOON BY THE SELENE GRS.

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Introduction: The SELENE mission is the first to employ a germanium (Ge) detector to observe lunar gamma rays [1,2]. With a superior energy resolution, the SELENE Gamma-Ray Spectrometer (GRS) has uniquely identified many elements that constitute the lunar surface such as K, Th, U, O, Mg, Al, Si, Ca, Ti, and Fe in the upper layer of ~60 g/cm^2 with high precision [3-5]. With the SELENE GRS, the global distribution of uranium on the lunar surface was revealed for the first time. Together with those of other radioactive nuclides, potassium and thorium, it will provide important information regarding the Moon's thermal history.

Observation: The SELENE satellites were launched on Sep. 14, 2007 [6]. The main orbiter (KAGUYA) has been in the circular polar orbit around the Moon at 100 km altitude for more than one year [7]. The GRS data used in this work were obtained from Dec. 14, 2007 to Feb. 17, 2008 and from Jul. 7, 2008 to Oct. 31, 2008 with an effective measurement time of approximately 2100 hours [8].

The GRS employs an n-type, high purity germanium detector with ~250 cm^3 as a main detector cooled by a Stirling cooler [2]. Surrounding the Ge detector are bismuth germanate (BGO) and plastic scintillators for anticoincidence with background and Compton-scattered gamma rays as well as charged particles [1].

Gamma-Ray Lines: Energy spectra of gamma rays from the Moon with energies from 0.2 to 12 MeV were measured with sufficient statistics. Energy resolution of the Ge detector varied from 8 keV to 19 keV FWHM at 1461 keV, depending on the effect of radiation damage induced in the Ge crystal. The 1765 keV gamma-ray line was used for analysis of ^{238}U, the 2615 keV line for ^{232}Th, and the 1461 keV line for ^{40}K [9].

For comparison with a previous mission, energy spectra containing Th gamma-ray peaks obtained by the SELENE GRS and Lunar Prospector (LP) GRS [10,11] are shown in Fig. 1. Because of its superior energy resolution of the Ge detector, individual peaks were well resolved by the SELENE GRS.

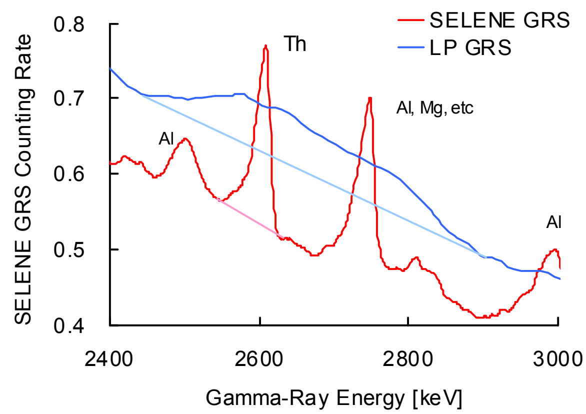

Fig. 1 Comparison of the Th gamma-ray peak at 2615 keV observed by the SELENE GRS and that by the LP GRS [10,11]. The SELENE GRS uniquely resolved individual peaks, contributing precise assessment of elemental abundances. The vertical axis for the LP GRS spectrum is arbitrary.

The U peak observed by the SELENE GRS is shown in Fig. 2 with strong interfering peaks at 1779 and 1809 keV from various interactions of neutrons with ^{28}Si and ^{27}Al [12]. Since the U peak is just 14 keV apart from the interfering peak, the Ge detector and

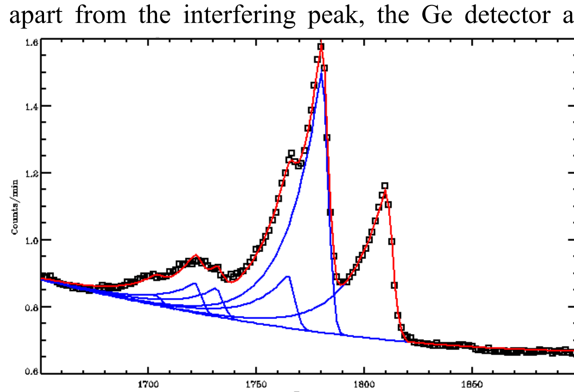

Fig. 2 Example of a peak fitting result of the ^{238}U peak in an energy spectrum observed by the SELENE GRS. Black dots represent the actual observed count rate in each energy bin, the blue lines represent individual peak components, and the red line represents the total fitting result.

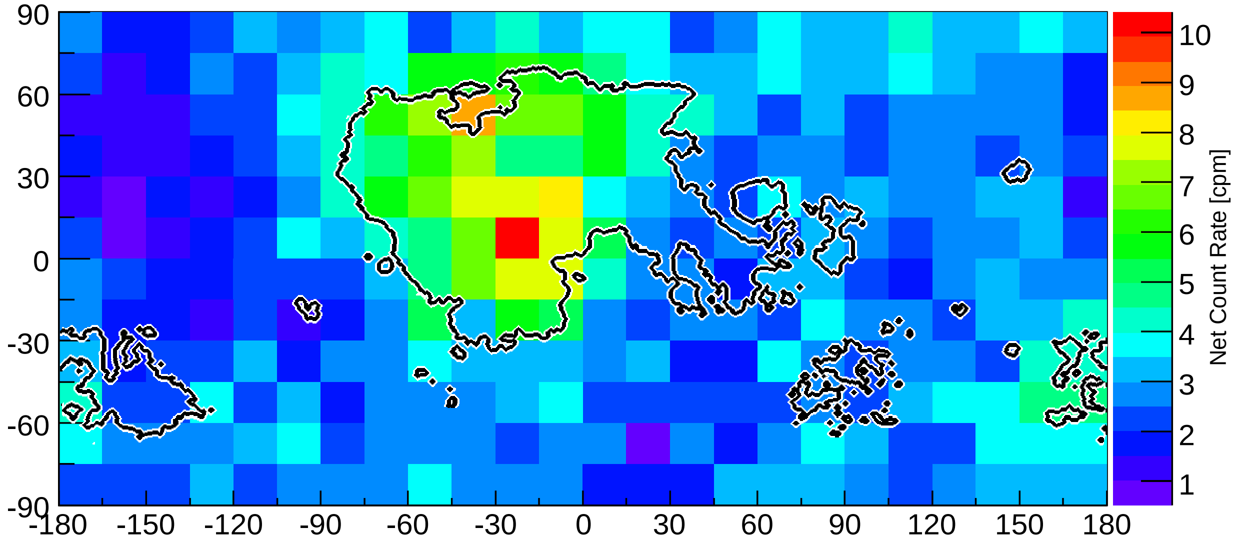

Fig. 3 Color-coded map of the U net counting rate over the entire lunar surface measured by the SELENE GRS. It was drawn using simple cylindrical projection with 15° pixels. The contour shown in the map is based on albedo data by Clementine [13], which roughly shows boundaries between maria and highlands.

peak fitting methods are essential to measure U on the Moon. A net count of a peak, a total number of counts above a continuum, are considered to be proportional to the abundances of natural radioactive elements on the lunar surface such as K, Th, and U [9].

Distribution of U: The lunar surface was divided into 15° latitude by 15° longitude pixels above which each gamma-ray line intensities were accumulated. The distribution of U counting rates of the pixels is shown in Fig. 3. It is obvious from Fig. 3 that U is concentrated in Procellarum KREEP Terrain (PKT) and South Pole Aitken Basin (SPA), while it is depleted in highlands, especially in the western (−180° ~ −120° longitude) highland region just above the equator on the farside. Considering the incompatibility of U and scarcity of water in the equatorial area on the Moon, U distribution can infer the solidification process of the magma ocean, if it existed.

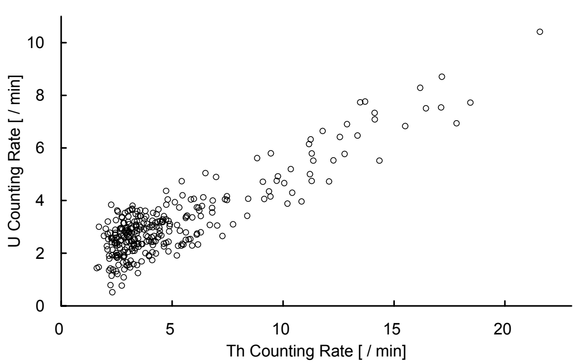

Fig. 4 Variation of U counting rates as a function of Th counting rates measured by the SELENE GRS. Both rates are in unit of count per minute. The data are binned into 15° x 15° pixels.

U-Th Trend: The U counting rates were compared with Th rates, which is also an incompatible element, as shown in Fig. 4. Their variation trend is quite similar, with a linear fit with the correlation coefficient R^2 of ~0.78. Note that this U-Th trend is derived using counting rates, not abundances, and requires careful calibration and background estimation for absolute quantification. However, this result confirms for the first time that the linear relationship of U and Th distribution is global, which has been implied based on limited number of lunar meteorites and returned samples [14,15].

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