GAMMA RAYS IN SPECTRA MEASURED BY THE KAGUYA GAMMA-RAY SPECTROMETER.

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Summary: About 200 peaks have been observed in spectra measured by the SELENE (KAGUYA) Gamma Ray Spectrometer (GRS) in lunar polar orbit. The sources of 80% of them have been identified. Most peaks are from the Ge detector, structural Al, and other local matter. There are many lunar gamma rays that can be used to determine good elemental abundances, although some have backgrounds.

Introduction: Gamma rays are the best radiations to remotely determine the abundances of many important elements in the Moon [1]. The Kaguya GRS experiment uses a high-energy-resolution germanium (Ge) gamma-ray spectrometer with active anti-coincidence shields to reduce backgrounds [2]. Gamma rays from O, Al, Si, K, Ca, Ti, Fe, Th and U have been observed from Kaguya's 100 km lunar polar orbit. Fig. 1 shows spectra measured by the Kaguya GRS. Preliminary results for several elements from these data have been reported [e.g., 3,4].

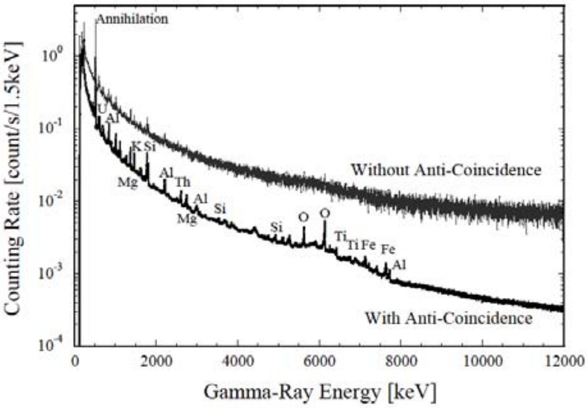

Fig. 1. Energy spectra of gamma rays observed by Kaguya with (for 682 hours) and without (only 1.5 hours) anti-coincidence (A-C). Counts from the continuum but not from peaks are reduced with A-C.

The best elemental results are those obtained by detailed analyses of these measured gamma-ray spectra, as was the case for the Ge GRS on Mars Odyssey [5,6]. Such spectral analyses allow only gamma rays from the elements and nuclear reactions of interest to be used for the accurate determination of abundances and enable the removal of interfering gamma rays and counts in the continuum under the gamma-ray peak [5]. The number of counts in a peak is converted to a flux using the efficiency to detect that gamma ray. The measured gamma-ray flux is compared to a calculated flux to get the abundance. Because the fluxes of cosmic-ray particles, especially the fast (E~1-20 MeV) and thermal (E~0.01-0.4 eV) neutrons that make most gamma rays, vary both with depth and surface bulk composition, the calculation of the fluxes of such gamma rays is complicated [e.g., 1,7,8].

Analysis of Kaguya Gamma-Ray Spectra: A gamma-ray spectrum is the counts as a function of it location (channel) in the spectrum. Two 8192 channel gamma-ray spectra are accumulated every 17 s (or 1° of the surface) with an energy resolution of about 0.4 and 1.5 keV per channel [2]. All individual spectra are adjusted to be on the same energy scale. For a good analysis, many counts are needed, and many individual spectra have to be summed.

A gamma-ray spectrum consist of peaks from gamma rays above a fairly-smooth continuum of counts from many sources, such as scattered gamma rays [5]. A part of a Kaguya spectrum is shown in Fig. 2 for the energy region from 2320 keV to 3130 keV, including the 2615 keV gamma-ray peak used to determine abundances of thorium (Th).

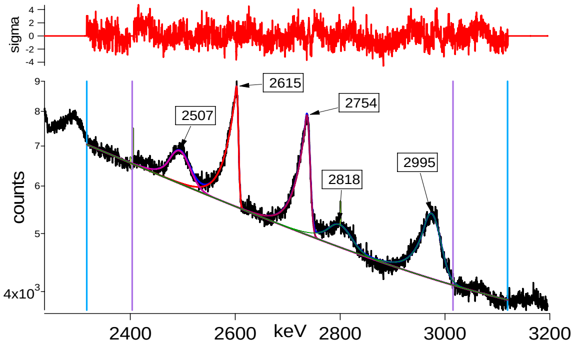

Fig. 2. A measured Kaguya gamma-ray spectrum (black) and fits for 5 peaks and the continuum (brown line, determined between the 2 sets of vertical lines). The red curve (top) shows how many standard deviations the fit is from the measurement.

There are 4 big peaks in this energy region from 2410 to 3100 keV that are from reactions in the Al structure of the gamma-ray spectrometer. The peak-fitting code used for Mars Odyssey gamma-ray spectra [5] was used to fit the continuum and 5 biggest peaks in Fig. 2. The peaks at 2615 and 2754 keV are narrower than those at 2507, 2818, and 2995 (actually 2 Al gamma rays at 2982 and 3004) keV, which are Doppler broadened because those gamma rays were emitted while the excited nuclei was recoiling [5]. Similar fits have been obtained using other codes.

The choice of the continuum location is subjective. In Fig. 2, the continuum was determined for parts of the spectrum where there are no or only weak peaks. The 5 strong peaks inside this energy region were fitted with the parameters that described each peak allowed to be free variables. Besides the continuum below the peaks, there are 4 free variables – the peak location, the peak height, the value of the parameter for the Gaussian width of the peak, and the location below the peak where the fit changes from a Gaussian to an exponential. The fit parameters for each peak are used to get the area, or total counts, for the peak.

The large tail at lower energies is produced by radiation damage induced in the Ge crystal by cosmic-ray particles, which causes some of the electron-hole pairs made in the Ge by a gamma ray not to be collected at the electrodes, resulting in a tail below the peak that is well described by an exponential [5]. The part of the peak near the top of the peak and the high-energy half of the peak is the Gaussian shape expected for a Ge detector with no radiation damage. The peak from Th at 2615 keV and its fit are shown in Fig. 3.

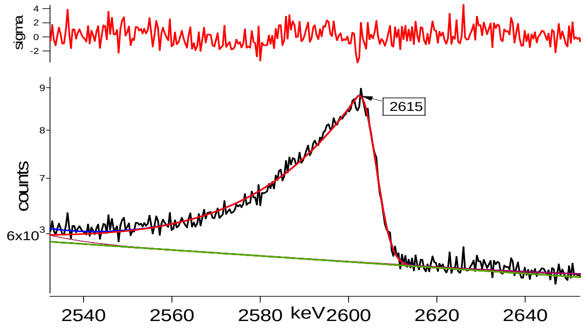

Fig. 3. The fit for the gamma-ray peak at 2615 keV from Th in a Kaguya gamma-ray spectrum. The long, low-energy tail is from radiation damage in the Ge.

Peaks in Kaguya Gamma-Ray Spectra: Preliminary analyses of all the peaks in Kaguya spectra summed over the whole Moon for the first 2 months have been performed. About 200 peaks significantly above the background were found, and the sources of about 160 of those peaks have been tentatively identified from gamma rays in the databases used for Mars Odyssey spectra [5]. There are good peaks from the elements O, Al, Si, K, Ca, Ti, Fe, Th, and U. Preliminary tests among the stronger peaks for Si, Ti, Fe, Th, and U show that the peak areas for the gamma rays from each of these elements are consistent.

Lunar gamma rays. The gamma rays for O, Si, K, Ca, Ti, Fe, Th, and U appear to be mainly from the Moon, although there are probably local backgrounds for many of these peaks [9], as was the case for Mars Odyssey [5,6]. There is some structural Ti in the spacecraft. There are usually some Th and/or U in most structural materials. Some of the peaks for gamma rays from the Moon are very close to some background peaks. A weak peak at 2223 keV for neutron capture by H has been observed but is in the upper edge of a broad peak from Al at 2211 keV.

Background gamma rays. The peaks from Al are almost entirely from the Al structure of the GRS. The large peaks from Al make it unlikely that Kaguya gamma-ray data can be used for studies of lunar Al. Many peaks are from the Ge, including broad “sawtooths” from reactions of fast neutrons with Ge nuclei [5], Ge(n,γ) reactions, and the decay of certain radionuclides made in Ge [10]. The large peaks for gamma rays from Ge nuclei show that the fluxes of neutrons in the Kaguya spacecraft are high, which could be a source of the strong radiation damage observed in the Kaguya gamma-ray spectra.

Background corrections. As was the case for Mars Odyssey [5,6], some of the gamma rays for these elements are both from the Moon and from local matter. Work is needed to accurately determine the local backgrounds to these peaks to correct the measured data. Spectra determined when the Kaguya GRS was pointed away from the Moon [9] had peaks from K, U, Ti, Al and Mg. Spectra for lunar regions with low and high concentrations of an element can also be used to help determine the backgrounds from material in and near the GRS.

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