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# Potassium and thorium on the surface of Mercury: Early results from the MESSENGER Gamma-Ray Spectrometer

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## Abstract

On 18 March 2011, MESSENGER became the first spacecraft to enter orbit around Mercury, inaugurating a one-year campaign of scientific observation. One of the major mission objectives is to characterize the composition of the surface in order to address fundamental questions regarding the formation and evolution of the innermost planet. To accomplish this task, MESSENGER carries a suite of remote sensing instruments. Here we present results of gamma-ray measurements of potassium and thorium abundances on the surface and their implications for the formation of Mercury.

## 1. Introduction

Mercury is the end-member of the terrestrial planets in terms of solar distance, size, and density [1]. As a result, an increased understanding of the formation of Mercury places constraints on our understanding of planetary accretion and evolution. Currently, a variety of models exist to explain the formation of Mercury [2]. These models were formulated in response to Mariner 10 observations of Mercury's unusually high density and metal/silicate ratio. MESSENGER carries a Gamma-Ray Spectrometer (GRS) [3] capable of measuring the abundances of radioactive elements on the surface of Mercury. These measurements can be compared to predictions of surface composition originating from formational models.

## 2. Gamma-Ray Spectrometry

The MESSENGER GRS measures gamma rays that originate from Mercury's surface both as a result of natural radioactive decay (K, Th, and U) and excitation of stable elements (e.g., Si, O, Fe, Ti) by incident galactic cosmic rays. These gamma rays are isotope-specific, so measurements of the planetary gamma-ray flux contain compositional information about the surface of the planet. With knowledge of applicable nuclear physics processes and the gamma-ray detector response, measured gamma-ray fluxes for specific elements can be used to determine the corresponding surface elemental abundances.

## 3. GRS Data

The gamma-ray flux emanating from a planet is highly altitude-dependent, varying as the inverse of the squared altitude, so GRS data used for this analysis are limited to measurements made at low altitudes (below 2,000 km). Because of MESSENGER's highly elliptical, near-polar orbit, GRS measurements are restricted to regions in the northern hemisphere. This analysis uses the first 30 days of orbital data, which span about half of the northern hemisphere.

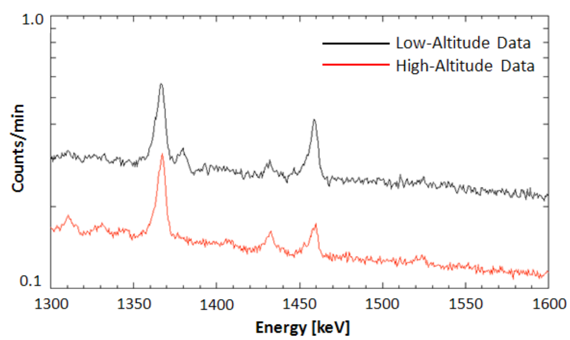


Figure 1. Portions (1300 to 1600 keV) of the high- (red) and low-altitude (black) summed gamma-ray spectra. Note the increase in count rate of the K gamma-ray (1460 keV) line in the low-altitude data, indicating a contribution from the planet.

To calculate the average elemental abundances in the northern hemisphere for K and Th, all low-altitude gamma-ray spectra were summed to create a single low-altitude gamma-ray spectrum with a corresponding total data acquisition time of 3,300 s.

Likewise, a summed high-altitude gamma-ray spectrum was created using all data acquired above 8,000 km, totalling 34,100 s. Figure 1 shows portions of these summed spectra.

The high- and low-altitude spectra are used to determine the gamma-ray flux emanating from the planet for the gamma rays of interest. This procedure requires determining the background-corrected gamma-ray flux for each element, which in the case of radioactive elements consists of trace amounts of K and Th present in the spacecraft, measured with the high-altitude spectrum for which the contribution from the planet is minimal. The difference between the high- and low-altitude count rates, determined by peak fitting, provides the planetary gamma-ray flux. Peaks used for this analysis are at 1460 keV (K) and 2615 keV (Th). Forward models of gamma-ray fluxes from the surface, accounting for the varying spacecraft altitude and attitude as well as the spatially varying detector response, were compared to the measured gamma-ray fluxes to determine the surface K and Th abundances necessary to account for the measured fluxes.

# 4. Results

Preliminary analysis of GRS data acquired during the first month of orbital operations, which covered approximately half of the northern hemisphere, has been used to make quantitative measurements of the average abundances of radioactive elements in the region. These abundances (1078 ± 49 ppm K and 0.173 ± 0.088 ppm Th) correspond to a K/Th value of 6230 ± 3180. Quoted errors are derived from one standard deviation of the background corrected peak area.

# 5. Discussion

Ratios of the volatile incompatible element K to the refractory incompatible element Th provide insights into volatile depletion in planetary bodies. The K/Th ratio for the surface of Mercury is, within uncertainty, similar to the average value for Mars (see Figure 2) [4,5]. Absolute abundances for Mercury are a factor of 3-4 lower than for the surface of Mars, probably reflecting the enhancement of K and Th abundances at the martian surface by aqueous processes. The K/Th ratio, particularly when coupled with the high S abundance of Mercury [6], suggest that evaporation or refractory condensation models [4,5] for the formation of Mercury are not viable. These models should produce volatile-poor compositions, counter to the observations presented here. Other models are less constrained by these data, although chondritic melting models appear to predict higher Th abundances (~1 ppm) than observed [4].

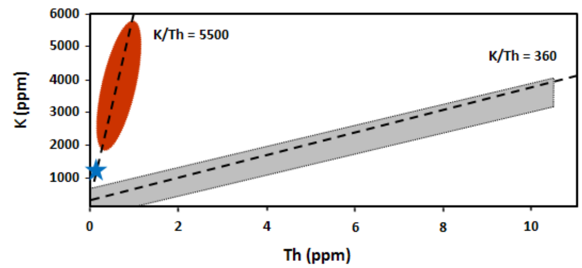


Figure 2. Global K versus Th abundances as measured on Mars and the Moon by Mars Odyssey and Lunar Prospector, respectively [4]. Martian values [4] lie within the red area; lunar values [7] lie within the grey area. The MESSENGER GRS value for Mercury is denoted by the blue star.

# Acknowledgements

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