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Title: CdZnTe GAMMA RAY SPECTROMETER FOR ORBITAL PLANETARY MISSIONS

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CdZnTe GAMMA RAY SPECTROMETER FOR ORBITAL PLANETARY MISSIONS*

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Knowledge of surface elemental composition is needed to understand the formation and evolution of planetary bodies. Gamma rays and neutrons produced by the interaction of galactic cosmic rays with surface materials can be detected from orbit and analyzed to determine composition. Using gamma ray spectroscopy, major rock forming elements such as Fe, Ti, Al, Si, Mg, and Ca can be detected. The addition of neutron spectroscopy enables the mapping of hydrogen and rare earth elements. Thermal and epithermal neutron data are also used to determine the equilibrium density of neutrons in the surface, which is needed to convert gamma ray count rates to relative elemental abundance. Fast neutron spectroscopy can be used to determine the flux of galactic cosmic rays, which is needed for determining absolute elemental abundances from orbit.

The first mission to fly both gamma ray and neutron spectrometers was Lunar Prospector, which gathered data over the entire surface of the moon. The gamma ray spectrometer (GRS) on Lunar Prospector was a BGO detector, which had a pulse height resolution of 13% full width at half maximum (FWHM) at 662 keV. The GRS was deployed on a boom to minimize the detection of background gamma rays produced in the spacecraft. Maps of thorium with 100 km spatial resolution have been constructed using GRS data. Accurate maps of Fe and Ti have been constructed by analyzing the high-energy portion of the pulse height spectrum (above 5 MeV). For BGO, deconvolution is required to determine peak areas for gamma rays from elements other than Fe and Th. Because the background continuum caused by scattering of gamma rays in the surface and by high-energy nuclear reactions is not well defined, accurate estimates of the abundance of some elements are difficult to obtain.

New planetary science missions are being planned to explore Mars, Mercury, the asteroid belt, and the outer planets. Based on the experience obtained by the Lunar Prospector program, most of these missions will include both neutron and gamma ray spectrometers. However, due to the cost and risk associated with boom deployment, spectrometers will be mounted on the deck of the spacecraft for some missions. In addition, scintillation detectors will be favored for gamma ray spectroscopy because their performance is well understood and they are relatively inexpensive to implement.

Significant improvements in the pulse height resolution relative to scintillation detectors can be made through the use of a new room temperature detection technology. CdZnTe, a wide band-gap semiconductor, can be used to make gamma ray spectrometers for planetary science. Coplanar grid CdZnTe detectors have the best peak shape and pulse height resolution (better than 3% FWHM at 662 keV) and can perform gamma ray spectroscopy up to 10 MeV. The size of coplanar grid detectors that can be manufactured routinely is about 1 cm^3. For an orbiting instrument, a CdZnTe detector at least 16 cm^3 in size is needed. Consequently, methods to combine signals from multiple detectors to make a large-volume spectrometer have been developed.

A conceptual design for a multi-element CdZnTe detector for planetary science is shown in Fig. 1. The CdZnTe detector consists of a 4×4 array of 1-cm^3 coplanar grid detectors. Detectors for the array can be manufactured in ~1 year at a cost of $150K. The array is shielded from the spacecraft by a BGO detector. In practice, the CdZnTe and BGO detectors will be surrounded by a boron-loaded plastic anticoincidence shield, which will reject cosmic ray events and acquire fast and epithermal neutron data. Signals from individual CdZnTe detectors and the BGO detector are combined in a field programmable gate array to produce pulse height spectra and list mode data that are transmitted back to Earth.

We have simulated three types of spectra that could be used to determine elemental composition: an accepted spectrum, which is formed by events with interactions that occur only in the CdZnTe array; a pair spectrum, formed by events in which an interaction is detected in the CdZnTe array coincident with an interaction in the BGO that produces a pulse within a window about 511 keV; and a telescope spectrum, in which the sum of the pulse height in the array and BGO detector is recorded for events in which the pulse height in the BGO is larger than the pulse height for the array. Each of these acquisition modes is designed to suppress the response of the spectrometer to gamma rays generated in the spacecraft. The accepted spectrum is the most effective of the three, providing a factor-of-five suppression at 3 MeV for a 6-cm thick BGO crystal.

Simulated pulse height spectra for the three acquisition modes are shown in Fig. 2. An average lunar gamma ray spectrum, including lines and continuum from the lunar surface, was used in the simulation. Acquisition was assumed to take place at low altitude (<100 km). The accepted spectrum shows well-resolved peaks for six major elements at energies below 3 MeV. The double escape peak that appears in the pair spectrum at 5400 keV combines capture gamma rays from Ti and Ca. Ti can be determined independently using the 6761 keV capture gamma ray, which can be extracted from any of the spectra. The process of unfolding BGO planetary spectra above 5 MeV to determine Fe, Ti, Ca, and O has been demonstrated using Lunar Prospector data.

The Monte Carlo simulation shows that the CdZnTe detector with BGO shield will provide ample pulse height resolution and counting efficiency for planetary missions. By improving pulse height resolution by a factor of three at low energy, the CdZnTe detector will be able to make accurate measurements of elements that are currently difficult to measure using scintillation technology. The BGO shield provides adequate suppression of gamma rays originating in the spacecraft, enabling the gamma ray spectrometer to be mounted on the deck of a spacecraft.

We are presently developing a flight qualified, prototype CdZnTe detector array for planetary missions. The prototype consists of a 2 x 2 array of coplanar grid detectors. We will present the design of packaging and electronics, along with the results of mechanical and electronic testing and radiation damage tests, and the performance of the array for gamma ray spectroscopy.

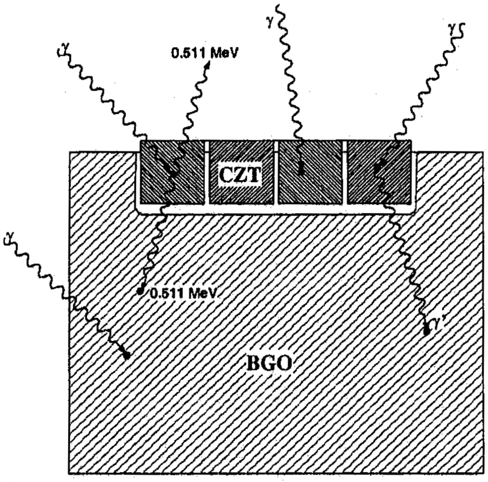

Figure 1. Conceptual design for a multi-element CdZnTe detector for planetary spectroscopy.

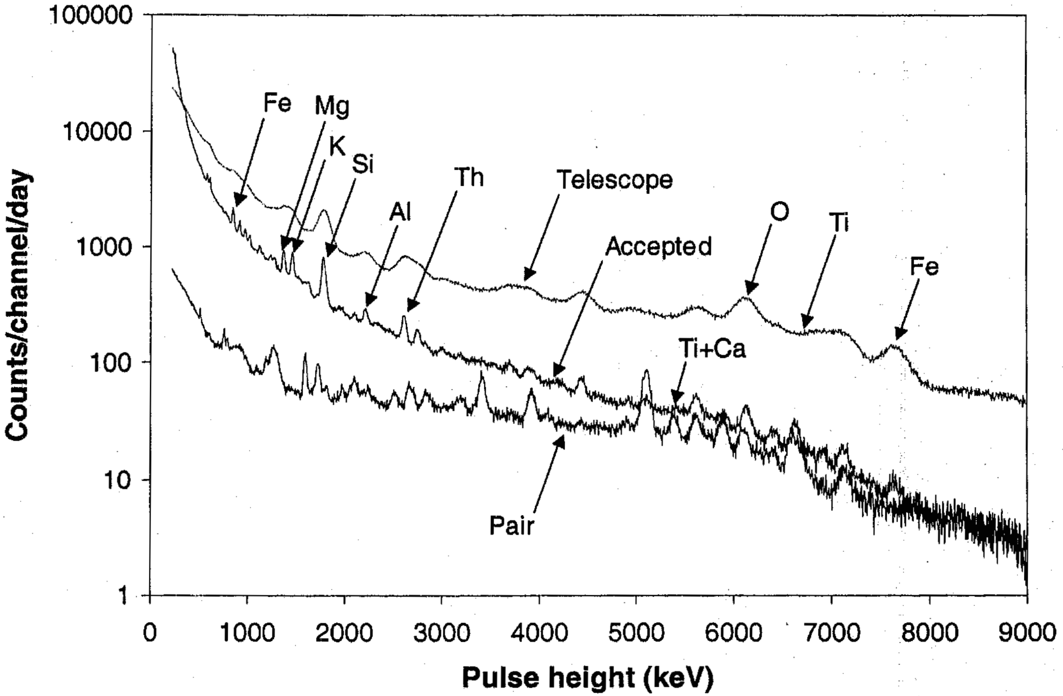

Figure 2. Monte Carlo simulated pulse height spectra for three acquisition modes.

ABSTRACT

Knowledge of surface elemental composition is needed to understand the formation and evolution of planetary bodies. Gamma rays and neutrons produced by the interaction of galactic cosmic rays with surface materials can be detected from orbit and analyzed to determine composition. Using gamma ray spectroscopy, major rock forming elements such as Fe, Ti, Al, Si, Mg, and Ca can be detected. The accuracy of elemental abundance is limited by the resolution of the spectrometer. For space missions, scintillators such as BGO and NaI(Tl) have been used for gamma ray spectroscopy. New planetary science missions are being planned to explore Mars, Mercury, the asteroid belt, and the outer planets. Significant improvements in the pulse height resolution relative to scintillation detectors can be made using CdZnTe, a new room temperature detector technology. For an orbiting instrument, a CdZnTe detector at least 16 cm^3 in size is needed. A 4×4 array of 1-cm^3 coplanar grid detectors can be manufactured that meets requirements for resolution and counting efficiency. The array will shielded from gamma rays produced in the spacecraft by a BGO detector. By improving pulse height resolution by a factor of three at low energy, the CdZnTe detector will be able to make accurate measurements of elements that are currently difficult to measure using scintillation technology. The BGO shield will provide adequate suppression of gamma rays originating in the spacecraft, enabling the gamma ray spectrometer to be mounted on the deck of a spacecraft. To test this concept, we are constructing a flight qualified, prototype CdZnTe detector array. The prototype consists of a 2 x 2 array of coplanar grid detectors. We will present the results of mechanical and electronic testing and radiation damage tests, and the performance of the array for gamma ray spectroscopy.