Emerging Role of High-Purity Germanium Detectors for Planetary Science. Morgan T. Burks[1*], Owen B. Drury[1], John O. Goldsten[2], David J. Lawrence[2], Patrick N. Peplowski[2], Zackary W. Yokley[2]. [1]Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore CA 94550, [2]Johns Hopkins Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723 USA; [*]Burks5@llnl.gov.

Introduction: Gamma-ray spectrometers (GRS) are used on deep space missions to measure the elemental composition of planetary surfaces. Spectrometers based on high-purity germanium detectors offer the highest-resolution of any comparable technology. This resolution translates into superior sensitivity and higher science return. Germanium detectors have been successfully deployed in orbit around the Earth [1], the Moon [2], Mars [3], and Mercury [4]. However, germanium detectors only achieve this high resolution when cryogenically cooled to 100K or below. Cooling schemes have typically been bulky, massive, and/or consumed considerable power [2,3]. This has limited the widespread use of germanium in deep space. However, we have developed a germanium-based gamma-ray spectrometer for NASA's MESSENGER mission to Mercury that utilized innovative infrared shielding and suspension technologies. This allowed for low-power, low-mass operation of the detector and the science results helped shape our understanding of the formation and evolution of Mercury [5]. As a result, gamma-ray spectrometers based on high-purity germanium detectors are emerging as a powerful tool for a range of planetary science applications. Our group will be providing germanium-based spectrometers for two new missions: the first to the asteroid (16) Psyche; and the second to the moons of Mars onboard JAXA's Martian Moons eXploration mission (MMX). In addition, NASA recently announced Phase A funding for the Drgaonfly mission that includes our technology on a dual-quadcopter that will explore Saturn's moon Titan. Although all the detectors for each mission are based on similar technology, each planetary body offers unique and interesting challenges and the instruments must be adapted accordingly. This paper discusses the challenges and technical tradeoffs of each mission.

Mercury MESSENGER: The MESSENGER mission to Mercury carried a 5x5 cm coaxial germanium detector [4]. It was notable for being the first mechanically-cooled germanium in deep space, as well as for overcoming the challenge of deploying a cryogenic detector at one of the hottest places in the Solar System. The instrument was designed to be low-mass and low-power. However, the most important design constraint was the need for infrared shielding that allowed for cryogenic cooling in the harsh thermal environment found at Mercury. Figure 1 shows the IR shields and some of the components that comprised this instrument.

Figure 1. Infrared shielding for the germanium detector on NASA's MESSENGER mission to Mercury. Innovative IR shielding allows for cryogenic cooling in the harsh thermal environment.

The MESSENGER germanium detector also suffered radiation damage from extended exposure to cosmic-ray bombardment. The instrument had the ability to anneal the detector in situ by heating it to 85 ºC, which partially repaired the effects of radiation damage on the crystal. However, one of the lessons learned from this mission was that annealing at higher temperature should result in more complete recovery. This lesson is informing future instrument designs.

(16) Psyche: NASA selected the Psyche mission, which will visit the M-class asteroid (16) Psyche, as one of its next Discovery-class missions [6]. The science payload includes a germanium detector that will be used to determine the elemental composition of that body. This instrument is being designed for optimum energy resolution, ideally achieving laboratory performance in the flight instrument. This will require the complete, or near complete, elimination of the radiation damage accrued during the 3.5 year cruise to the asteroid belt.

Figure 2. The prototype gamma-ray spectrometer for the Psyche mission. Also shown is an iron meteorite of material similar to that expected at (16) Psyche, used for testing and calibration.

Figure 2 shows the prototype gamma-ray spectrometer for the Psyche mission. This prototype is being used to test improved annealing strategies in order to maximize the in-flight resolution achieved during the mission. The detector will be cooled with a long-life, miniature pulsed tube cryocooler built by Lockheed Martin [7].

MMX: The Martian Moons eXploration mission (MMX), sponsored by the Japan Aerospace Exploration Agency (JAXA) will explore the moons of Mars to better understand their composition and origin [8]. This mission is especially notable because it is a sample return mission: it will touch down on Phobos, take a small soil sample, and return it to Earth.

As part of its payload, MMX will carry a gamma-ray and neutron spectrometer (GRNS), which is part of the Mars-moon Exploration with GAmma rays and NEutrons (MEGANE) investigation [9]. MEGANE will measure the elemental composition of Phobos, assist in the sample site selection and provide environmental context for the returned sample. MEGANE contains a germanium detector that derives significant heritage from the MESSENGER GRS .

Because the flight time to Mars is relatively short, radiation damage is less of a concern than for the Psyche mission. Instead, since MMX is a sample return mission, the instrument is being designed for the lowest mass possible. The baseline MEGANE design uses a Ricor K508 cryocooler (Figure 3), which was successfully used for the MESSENGER GRS.

Figure 3. The Ricor k508 cryocooler has a mass of only 450 grams. It also has a very simple control circuit, eliminating a further 100 grams of controller board, as needed by other coolers.

Titan Dragonfly: NASA recently awarded Phase A funding for the Dragonfly mission which would land a rotorcraft on the surface of Titan [10]. Titan has low gravity (1.352 m/s^2) and a dense atmosphere (x4 Earth's at sea level), which makes a rotorcraft a particularly efficient means of transportation. Dragonfly is planning to use a germanium-based gamma-ray spectrometer [7,11] for elemental composition measurements.

Titan offers a unique environment for operating a germanium detector. Titan's atmosphere, primarily nitrogen, has a temperature of around 94 K at the surface, which is similar to the liquid nitrogen baths used to cryogenically cool HPGe detectors in the laboratory. Thus the detector can be directly cooled by the atmosphere, without the need of a mechanical cryocooler.

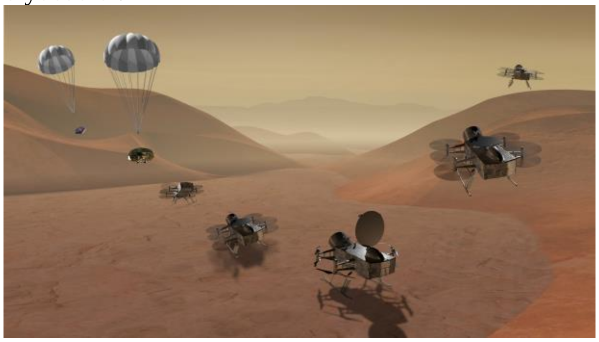

Figure 4. Artist conception of the rotorcraft operating on the surface of Titan. This vehicle would carry a suite of instrumentation for exploring the atmosphere and surface composition, and would include a germanium-based gamma-ray spectrometer.

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