The GeMini Plus High-Purity Ge Gamma-Ray Spectrometer: Instrument Overview and Science Applications. David J. Lawrence[1], Morgan T. Burks[2], David H. Do[1], Samuel Fix[1], John O. Goldsten[1], Lena E. Heffern[2], Ramsey S. Hourani[1], Samuel Kerem[1], Patrick N. Peplowski[1]; [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD (David.J.Lawrence@jhuapl.edu), [2]Lawrence Livermore National Laboratory, Livermore, CA.

Introduction: Knowing the elemental composition of a planetary surface is key to understanding its formation and evolution. Planetary gamma-ray spectroscopy is a well-established technique for remotely measuring planetary elemental concentrations for the following elements: H, C, O, Na, Mg, Al, Si, S, Cl, K, Ca, Ti, Fe, Ni, Th, and U. It is unique among the available techniques in that it measures bulk concentrations to depths of tens of cm (in contrast to techniques sensitive only to the top tens of microns), and can quantify compositional layering within this range. Orbital gamma-ray measurements have resulted in significant discoveries from the Moon, Mars, Mercury, and asteroids [1–4]. A Gamma-Ray and Neutron Spectrometer (GRNS) is part of the recently selected Psyche mission, which will orbit the M-class asteroid 16 Psyche [5]. Surface-based, *in situ* gamma-ray spectroscopy has been relatively limited and not fully realized because the laboratory quality spectrometers needed to achieve full elemental sensitivitity require more resources (e.g., mass, power) than are available for landed missions. In addition, orbital missions increasingly require lower resource instruments, and new instruments need to incorporate lessons learned from prior flight instruments.

Here we discuss a new instrument called GeMini Plus, which is a high-purity Ge (HPGe) Gamma-Ray Spectrometer (GRS) that can accomplish laboratory quality, high-precision gamma-ray measurements with the type of low resources needed for landed platforms as well as resource-constrained orbital missions. This abstract provides an overview of the GeMini Plus instrument, including improvements made to prior instruments, as well as future science applications for the use of GeMini-Plus technology. A complementary abstract provides additional information about GeMini Plus, including details of initial performance and expected future tests [6].

GeMini Plus Gamma-Ray Spectrometer: GeMini Plus is based on the MESSENGER GRS [7] and a miniature HPGe instrument known as GeMini (Fig. 1). GeMini was developed by Lawrence Livermore National Laboratory for national security applications [8]. GeMini Plus uses the same HPGe sensor as the MESSENGER GRS and so achieves the same sensitivety. Depending on mission scenario, GeMini Plus may or may not need a plastic scintillator anticoincidence shield (ACS) to reduce background from galactic cosmic rays. An ACS is generally not needed for surface-based measurements, whereas an ACS can significantly increase signal-to-background for many types of orbital measurements [9].

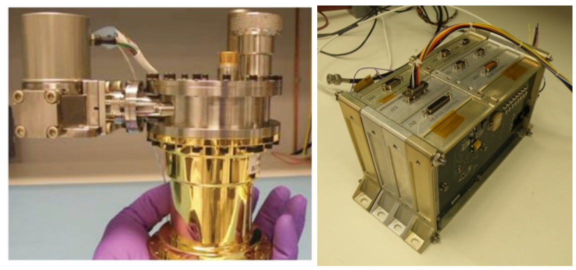

Figure 1. (left) GeMini HPGe GRS [8], which is the basis for GeMini Plus; (right) GeMiniPlus DPU, which includes all capabilities for operating the GRS and reading and processing GRS data.

GeMini Plus includes a newly-developed Data Processing Unit (DPU)(Fig. 1). The GeMini Plus DPU includes capabilities not included with MESSENGER. These capabilities include digital front-end-electronics (FEE) and a new cryocooler controller board. The fully digital FEE (in contrast to the hybrid analog/digital FEE used for MESSENGER) allows increased flexibility for on-board pulse processing, including the implementation of algorithms that can reverse the effects of cosmic-ray-induced radiation damage [10]. The new cryocooler-controller board supports multiple types of pulsed-tube cryocoolers, while retaining the capability to operate the lower cost but shorter life rotary cryocoolers, such as the MESSENGER-heritage Ricor. For the most resource-constrained missions, a non-ACS GeMini Plus can be accomplished with a mass and power usage of <3 kg and <15 W.

GeMini Plus Applications: GeMini Plus can be tailored for a wide variety of planetary science applications. Such applications include missions to asteroids, Mars, the Moon, and outer planetary bodies. Here, we highlight three such applications.

16 Psyche: The NASA Discovery Program recently selected the Psyche mission, which will orbit and characterize the large (211 km diameter) M-class asteroid 16 Psyche [5]. The Psyche mission includes a GRNS that will quantify and characterize the elemental composition of the asteroid. Of particular interest is 16 Psyche's Ni concentration. Measurements of Ni concentration will directly test the hypothesis that Psyche is an exposed core, and if so, how it may have formed and solidified. The Psyche GRNS uses MESSENGER and GeMini-Plus technology along with a borated plastic ACS for background rejection and fast-neutron measurements. Thermal and epithermal neutron measurements are accomplished using ^{3}He sensors. The GRS cryocooler is a miniature (500 g) pulsed-tube cryocooler built by Lockheed Martin [11]. The primary Ni measurements will be accomplished by measuring the 1.454 MeV inelastic Ni line. With the expected energy resolution of 3.6 keV @ 1.454 MeV (equivalent to 3.4 keV @ 1.332 MeV), the Ni line will be clearly distinguished from a nearby K line (Fig. 2).

Titan Exploration: Saturn's moon Titan presents a unique opportunity to explore and investigate solar-system prebiotic chemistry. A key part of such exploration includes making the first in-situ composition measurements of the surface [12]. Elemental composition can be determined via gamma-ray spectroscopy. Titan's atmosphere is sufficiently thick that cosmic-rays cannot reach the surface; therefore gamma-ray measurements at Titan require the use of a pulsed neutron generator (PNG) to generate elemental gamma rays (e.g. [13]). Titan's surface is 90 K, therefore a cryocooler is not needed. High-precision concentration and possibly layering measurements of key elements (H, C, O, N) can be achieved using a HPGe sensor. A few-hour measurement at Titan's surface can strongly discriminate between different types of materials thought to be at Titan's surface (Fig. 3).

Phobos and Deimos: The Mars moons Phobos and Deimos are important targets for future exploration [14]. They are the only moons of terrestrial planets, besides the Earth's moon, and therefore they provide important insights into the evolution of the inner solar system. Additionally, they are attractive targets for future human exploration of the Mars' system. Measurements of the elemental compositions of Phobos and Deimos are required to test the competing hypotheses for the origins of these moons, and to characterize the resource potential for supporting human exploration. A GeMini-Plus-type GRS that acquires measurements from either low altitude (1 body radius; 11 km altitude for Phobos, 6 km altitude for Deimos) or on the surface can make key composition measurements that can test origin hypotheses for both bodies [15].

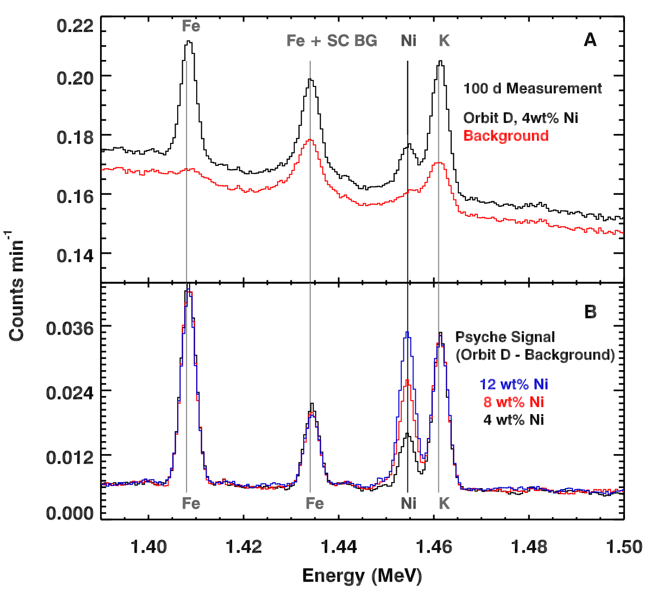

Figure 2. Modeled gamma-ray spectrum in the 1.454-MeV Ni peak region after 100-day accumulation at 16 Psyche for the Psyche mission. A) Gamma-ray spectrum (simulated signal + measured background) at the lowest spacecraft altitude (0.8 times Psyche radius); B) Gamma rays originating from Psyche (lowest altitude minus background) for varying Ni concentrations.

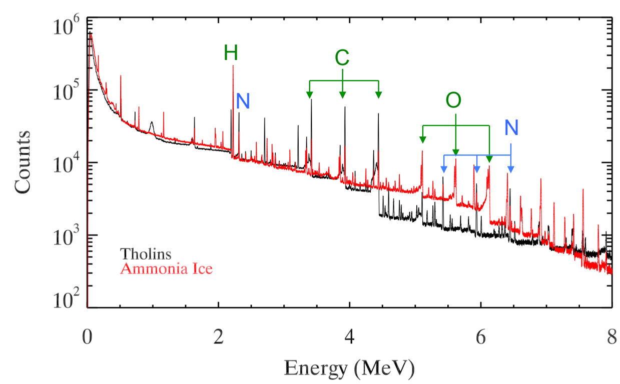

Figure 3. Modeled PNG-induced gamma-ray spectrum for two different types of materials (tholins and ammonia ice) that might be present at the surface of Titan. Gamma-ray lines from H, C, O, and N are labeled.

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